Ground Engineering Using ‘Waste’ Materials

A detailed study in to the potential for steel and iron-working slag to be used in the creation of carbon sinks

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DECLARATION

I hereby certify that this work is my own, except where otherwise acknowledged and that it has not been submitted previously for a degree at this, or any other, university

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"In shadow stained arcadian lanes
the firebird awaits the lick of flames

to mend this broken land of slag & spoil
to conjure an elixir for poisoned soil

if albion's sapling oaks are to mature
the wounded earth demands a cure"

Paul Summers (2008)

ABSTRACT

Carbonation of calcium-rich materials has been proposed as a potentially viable method of CO_2 capture and storage over geological timescales, exploiting high turnover of C through soils to passively fix carbon. This study confirms that soil-mixed iron and steel slag actively promotes CO_2 sequestration, in an *in situ* setting, in temperate U.K. soils. Geophysical modelling and analysis of ground investigation data shows the persistence of slag to significant depth at the former site of Consett Iron and Steel works, of which the upper 300mm were investigated. Calcimeter analysis of 65 soil samples from yields a mean calcium carbonate concentration of 8.5% ± 0.18 throughout the site profile. Isotope data confirms the atmospheric provenance of CO_2 in the calcite, with $\delta^{13}C$ between -11.86‰ and -20.46‰ and $\delta^{18}O$ between -10.00‰ and -12.47‰, demonstrating hydroxylation of atmospheric carbon and organic sequestration pathways. Carbon sequestration modelling for the site, illustrates an idealised carbon capture potential of 1,431,375 tonnes $CO_{2,}$ or 2.40tC/m^2. Collated experimental data confirms the significance of slag as a potentially effective material in carbon sink engineering, as a passive sequestration agent.

Keywords: Geochemical, Calcium carbonate, Slag, Consett, Sequestration, Carbon Sink, Geophysical,

EXECUTIVE SUMMARY

Sequestration through the exploitation of calcium-rich materials has been proposed as a potentially viable method of CO_2 capture and storage over geological timescales. The *in situ* observation of contemporary slag emplacement in this study confirms that soil-mixed calcium-rich iron and steel working slag actively promotes CO_2 sequestration, through a process of organic formation and hydroxylation.

Data from previous Ground Investigation Reports and geophysical surveying, with the use of fixed array resistivity apparatus, confirms the spatial distribution of slag across the study site to significant depth. Calcimeter analysis of 65 soil samples from the former site of Consett Iron and Steel works yields a mean calcium carbonate concentration of 8.5% ± 0.18 by mass, with a third of samples demonstrating a calcium carbonate concentration of ≥10.0% ± 0.18 by mass. Isotopic ratio data illustrates the atmospheric provenance of CO_2 in the samples, confirming the active presence of a carbon sequestration pathway. Optical light microscopy and SEM analysis demonstrated that the nature of weathering and geochemical availability of Ca^+ is dependent upon the physical structure of slag, including particle size and porosity. Carbon sequestration modelling for the site, illustrates an idealised carbon capture potential of 1,431,375 tonnes CO_2.

Collated experimental data confirms the significance of slag as a potentially effective material in carbon sink engineering. Recommendations are made with respect to the implementation of slag in a passive ground engineering context, including future work which would enable further geochemical characterisation.

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ABBREVIATIONS

Abbreviation	**Meaning**
AOD	Above Ordnance Datum
BGL	Below Ground Level
BGS	British Geological Survey
CCS	Carbon Capture and Storage
EDXRF	Energy Dispersive X-Ray Fluorescence
ESEM	Environmental Scanning Electron Microscope
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
IRMS	Isotopic Ratio Mass Spectrometry
NE	North East
NW	North West
PDB	Pee Dee Belemnite
PSD	Particle Size Distribution
SE	South East
SEM	Scanning Electron Microscope
SSSI	Site of Special Scientific Interest
SW	South West
VPDB	Vienna Pee Dee Belemnite
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

CHEMICAL NOTATION

Symbol	**Meaning**
C	Carbon
Ca	Calcium
$CaCO_3$	Calcium Carbonate
CO_2	Carbon Dioxide
(aq)	Aqueous
(g)	Gas
(l)	Liquid
O	Oxygen
Si	Silicon

1. INTRODUCTION

1.0 INTRODUCTION

This project aims to explore the contemporary interest in ‘carbon capture’ technologies, with specific reference to the use of calcium-rich materials, in order to propose a novel method of ground engineering to create carbon sinks. This project will not focus upon the use of commercially extracted silicate minerals in carbon sequestration, as has been proposed by a number of contemporary studies, but will investigate the efficacy of carbon sinks created by the re-use and emplacement of calcium-rich waste materials. Through this investigation, a twofold dilemma imposed upon the engineering industry will be addressed:

1. The persistence of by-product ‘wastes’ from heavy industrial processes and the contemporary sustainability issues commanding the informed disposal or re-use of these materials.
2. Legislation demanding significant reductions in industrial emissions outputs in order to reduce the ‘carbon footprint’ of products. The consideration of this issue is increasingly pressing when coupled with overarching international targets in carbon dioxide emission reduction and offsetting.

It is proposed that both issues may be mitigated in a single action, with the emplacement of suitable calcium-rich waste materials in engineered soils, providing a simple and profitable means of re-using waste products, whilst also creating a means of offsetting the original CO_2 emissions created during the production of the material.

For the purposes of this study, slag has been selected as a typical exemplar of industrial ‘wastes’. Slag is a ubiquitous, glassy by-product of the steel and iron industry. To date, the success of ‘recycling’ slag has been due mainly to its use as a secondary aggregate in construction media. Slag itself is not physically suited to many common engineering applications due to durability concerns related to its high potential for expansion. Until the middle of the 20th Century, slag material was historically extensively dumped or stockpiled in close proximity to the works site, meaning it has been possible for Environmental Scientists to observe the *in situ* weathering behaviour and environmental interactions. The hydrogeochemistry of alkaline leachates, produced as a result of groundwater movement through slag heaps is of particular interest to researchers assessing the contamination risk posed by historic slag heaps in the U.K. During the course of this research it has been observed that these leachates have the potential to form deposits of calcium carbonate when entering surface waters. Geochemical analysis has demonstrated that these deposits may include an assimilative step in their formation, by which dissolved atmospheric carbon dioxide is sequestered by the weathering slag material and fixed as calcium carbonate, which may then be deposited as a solid precipitate in the soil horizons or as an inter-particular coating.

This project will utilise these preliminary field observations in order to assess the potential for calcium carbonate formation and deposition in the terrestrial environment of existing slag heaps and the implications this bears for soil engineering. It aims to verify the geochemical processes at work at an analogue site and to address the frequency and extent of formation of calcium carbonate, in order to quantify this theoretical model of carbon dioxide sequestration and assess its overall significance as a passive carbon capture mechanism. A preliminary assessment of the viability of engineering soils with slag will be completed, with comment made as to most effective means of furthering this research.

1.1 AIM

To critically evaluate the *in situ* geochemical activity of slag material in U.K. soils, with specific empirical focus upon the capacity to attenuate terrestrial-atmospheric carbon exchange by promoting the fixation of sequestered carbon dioxide into geologically stable calcium carbonate horizons.

1.2 OBJECTIVES

- To identify suitable sites at which the long-term behaviour of steel slag in vegetated soil can be studied. A viable, locally situated analogue site was pre-emptively proposed as the focus for this project: the former site of Consett Iron & Steel Works, Consett, County Durham, indicated in the map shown in Figure 1 overleaf. The historic works site was converted to public land and re-landscaped throughout the mid 1980's.
- To conduct surface and geophysical surveys at the selected site in order to catalogue topography, subsurface features and soil horizon depths and to produce suitable figures to illustrate these features. Vegetation cover will also be qualitatively assessed.
- To design and conduct a repeatable soil sampling method to be implemented across the site in order to quantify soil horizon depth and major constituents '*in situ*' and to acquire suitable material for geochemical laboratory analysis.
- To apply suitable laboratory techniques to the analysis of sample material, in order to determine the petrography and habit of the slag and the presence and quantity of calcium carbonate. The isotopic provenance of carbon and oxygen atoms in any calcium carbonate present will be assessed, in order to confirm their chemical

provenance and assess the proportion of atmospheric sequestration contributing to their formation.

- To interpret data acquired during the site survey, sampling and laboratory testing in order to create a conceptual model of the site. Presence and distribution of calcium carbonate ($CaCO_3$) will be determined, to infer sequestration productivity per metre squared of the site. The theoretical maximum quantity of CO_2 which could potentially be sequestered at the site will be calculated.

Figure 1 – Approximate contemporary extent of reclaimed land at former site of Consett Iron and Steel Works, with boundaries illustrated by a black, dashed line (Source: Edina Digimap)

1.3 SIGNIFICANCE

Historically, regulatory attitudes to the production of engineering materials and treatment and disposal of engineering wastes have been laissez-faire. The demand for engineering materials outweighed the consideration of the environmental costs involved in the production process, until recent regulatory reforms on emissions and waste disposal. Heavy engineering industries require a high energy input and produce numerous atmospheric wastes, the most significant being carbon dioxide, as well as solid wastes. The iron and steel industry contributes 1.2 billion tonnes, or 4.23%, of all anthropogenic global CO_2, Park (2004).

Contemporary understanding of the impacts of these wastes has led to the introduction of ‘clean technology’ measures, however, the implementation of these ideas in the iron and steel industry has proven difficult, due to the increasing demand for cheap and rapidly produced construction materials. Changes in the global economy over the last 50 years have seen the bulk of heavy industry move from its historic roots in Western Europe in to rapidly developing global locations such as India and China, the latter of which is now the world’s fastest growing producer of steel. Zeng (2009) notes that ‘there is a tremendous potential for GHG emission reduction in the Chinese I&S industry’, however, the application of offsetting through CCS has not been specifically considered in this manner.

World steel production reached 1,326.5 million tonnes in 2008 and the World Steel Association (2008) estimates that global iron and steel production must increase by 3-5% in the coming years, in order to address the needs of the developing world. 8-10% growth is expected in the iron and steel producers of China, India and Russia.

Direct innovation must be used to ensure that the industrial processes implemented are efficient and clean, producing the minimum amount of waste and atmospheric emissions, however, indirect methods must also be utilised in compensating emissions, past and present and effectively re-using waste materials.

1.3.1 Waste Disposal

The large quantities of solid waste created during iron and steel production (slag, furnace bottom, and ashes) are frequently applied as high-quality secondary aggregates, however, they tend to be routinely stockpiled for want of effective, immediate disposal solutions. Approximately 400 million tonnes of slag are produced every year (GlobalSlag.com), with the global total for iron slag accounting for 240 to 290 million tons, and steel slag around 115 to 170 million tonnes (USGS, Mineral Commodity Summary 2009). Whilst slag production figures for the U.K are relatively low, around 4Mt/yr, Manning (2008) ODPM (2002), historic slag heaps persist across the majority of the northern U.K. The presence of heavy industrial wastes such as steel slag is, indeed, already a ubiquitous historical problem across much of the British Isles and Western Europe. At the peak of the industrial revolution, relatively inefficient blast furnaces produced many tonnes of these wastes, which were emplaced in heaps upon the landscape and are often still visible as steep mounds, clean capped and turf covered.

Previous environmental waste guidelines have advised that steel slag be used in the engineering industry as bulking agents in road building and similar applications (Making Waste Work, 1990) admixed with materials such as bitumen. As engineering media, slag has a generally low durability, and is particularly prone to swelling in the presence of water. Whilst a major recycling pathway for slag is use in road surfaces, this means that it is not ideal in building or foundation applications unless pre-weathered, a long-term tempering process, which has been empirically proven to reduce the tendency of the material to swell in subsequent wetting periods. In recent years, significant work has been carried out in to the study of the behaviour of steel and iron wastes in the environment, with mounting worries that their probable geochemical activity in the environment had been neglected and that there may be the underlying danger of groundwater and soil pollution by heavy metals, extending from the extensive areas over which these wastes had been dumped. Fortunately, little evidence has been found to support the concern that steel slags may encourage heavy metal enrichment of soils or produce leachates which would endanger groundwater above safe environmental guideline levels.

Given the contemporary acceptance of its environmental safety, a novel means of utilising slag, without the need for significant periods of weathering, would be invaluable in the disposal of contemporary wastes. This project aims to study the behaviour of historically processed slag material in soils, to assess the viability of soil engineering in providing an ongoing disposal method which may ultimately yield a significant commercial value.

1.3.2 Carbon Capture

The Intergovernmental Panel on Climate Change (IPCC) notes that the steel industry accounts for between 3-4% of total world greenhouse gas emissions. In June 2009, the World Steel Association published its most recent figures for global iron and steel production. The top five producers of iron and steel are China, Japan, U.S, Russia and India, with China's annual production totals over four times more (by tonnage) than its closest competitor. Despite a recent decrease in production figures for iron and steel as a result of the current economic depression, with output decreasing significantly in Europe, Japan and the U.S., there has been little variation in the production figures for China. In fact a small increase in production has been recorded since 2008. Figure 2 illustrates the relationship between CO_2 emissions and crude steel output in China between 1980 and 1996, one of the most significant periods in the growth of the industry in the country.

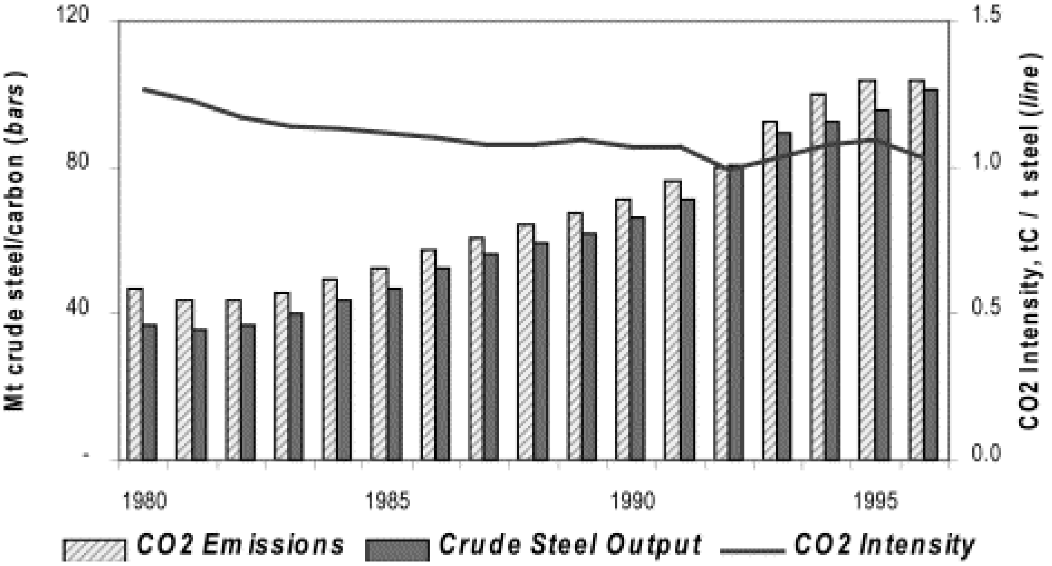


Figure 2 - Carbon dioxide emissions, crude steel output, and carbon dioxide intensity of steel production in China, 1980–1996 (Source: Price, L., *et al.*,)

Table 1 and Figure 3 illustrate the proportional magnitude of CO_2 emissions from the Iron and Steel Industry in the U.S, the world's third largest producer of steel, and compare these emissions with CO_2 derived from other industrial sources. Aside from fossil fuel consumption it can be seen that Iron and Steel production remains a major contributor to anthropogenic CO_2 emissions.

Table 1 – U.S. CO_2 emissions due to industrial processes Tg CO_2 Eq.) (Source: U.S. Environmental Protection Agency)

Gas/Source	**1990**	**1995**	**2000**	**2005**	**2006**	**2007**
CO_2	197.6	198.6	193.2	171.1	175.9	174.9
Iron and Steel Production and Metallurgical Coke Production	109.8	103.1	95.1	73.2	76.1	77.4
Iron and Steel Production	104.3	98.1	90.7	69.3	72.4	73.6
Metallurgical Coke Production	5.5	5.0	4.4	3.8	3.7	3.8

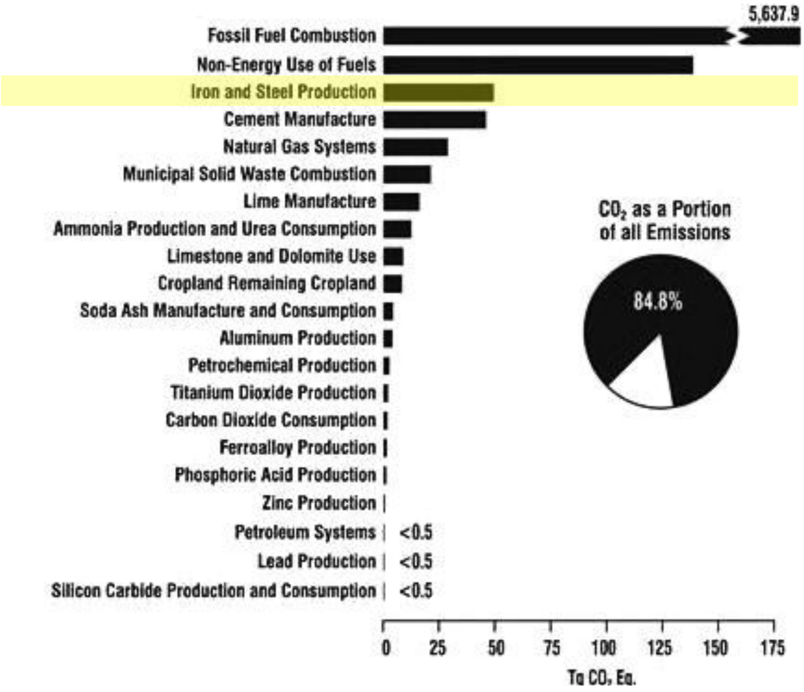


Figure 3 – A comparison of U.S. CO_2 Sources 2006 (Source: U.S. Environmental Protection Agency)

Although the efficiency of the machinery and production processes has continuously improved over the last 50 years of iron and steel production, it is estimated that approximately 90% of the worlds iron and steel is still produced using the relatively archaic blast furnace method, producing large quantities of basic oxygen slag, as opposed to the implementation of more efficient, modern electric arc furnaces.

If iron and steel slag is found to capture significant quantities of carbon dioxide in a passive, *in situ* environment, it is proposed that this mechanism could be used to actively offset the CO_2 produced during the smelting and coke production processes without significant additional energy input. Whilst the concept of ‘carbon neutral’ industry is an ideal, any process which is able to mitigate a significant proportion of the process emissions is valuable as a secondary technology, to be coupled with gas scrubbers and other directly implemented ‘clean’ technologies. Ultimately it may be proven that emissions may be partially offset in this manner without the need for further input to the sequestration process, a methodological advantage over actively engineered carbon sinks.

2. LITERATURE REVIEW

2.0 LITERATURE REVIEW

The success of this project was equally weighted in its reliance upon documentary evidence relating to the experimental efficacy of mineral sequestration and site specific data acquired through desk study and previous site investigation reports, as it was upon the analysis of data attained directly from site survey and laboratory analysis. Each method of data acquisition, therefore, had to be researched in sufficient depth in order to allow an informed, integrated methodology to be developed, with knowledge requirements addressed prior to the inception of the project.

The literature review was split in to four sections in order to effectively address the resource needs of the project:

2.1 Climate Change and Mineral Sequestration

2.2 Slag Properties

2.3 Consett Iron and Steel Works

2.4 Field and Laboratory Methodologies

2.1 Climate Change and Mineral Sequestration

This section presents a brief investigation in to the nature of climate change and the role played by anthropogenic carbon dioxide in the current climate change debate, as well as discussion and brief history of mineral sequestration in academic literature and in experimental practise, covering the types of material proposed to be effective in the engineering of carbon sinks. It aims to assess the advantages, disadvantages and recent progress of this novel method of carbon capture.

2.1.1 Carbon Dioxide and Climate Change

In recent years, scientific and political forces have concluded that climate change, promoted by the increasing presence of anthropogenic greenhouse gas (GHG) emissions in the earth's atmosphere, is irrefutably occurring. Climate change has the potential to affect global climatic patterns, altering global temperatures, causing sea level change through the redistribution of global water stores and rendering significant proportions of the terrestrial environment uninhabitable. Carbon dioxide, produced in large quantities through the burning of fossil fuels and the industrial activities associated with this, presents the most concern as a greenhouse gas, as noted by the Intergovernmental Panel on Climate Change (IPCC). In 2005, it was recorded by the IPCC that atmospheric carbon dioxide concentration had increased by 13ppm since 1998, to a value of 379 ± 0.65ppm, significantly due to anthropogenic forcing.

Whilst governmental focus in the control and mitigation of climate change is presently based heavily upon the regulation of emissions and the development of low carbon power generation and transport technologies, 'carbon capture' has also been proposed as a potentially useful concept in the reduction of global CO_2

concentrations. A ‘carbon sink’ defines a natural or artificial location for capturing and storing atmospheric carbon, over significant time periods. At present, commodities such as young forests and other natural reserves may be legally defined as natural carbon sinks, which are able to ‘offset’ the carbon dioxide emissions of the industrialised nations to which they belong. The potential for the creation of large-scale, artificial carbon sinks is a matter of lengthy debate, with a number of solutions posed over recent years. The use of carbon capture and storage (CCS) has been promoted in research by the Sir Joseph Swan Institute for Energy Research, Newcastle University, which forms part of the UK Carbon Capture and Storage Consortium (UKCCSC), a body which aims to roll out CCS as an industrially feasible method of atmospheric CO_2 reduction. Lackner (2003), effectively summarises the spectrum of contemporarily available CCS technologies:

- Direct injection of carbon dioxide in to the oceans, which has been deemed unsuitable for long-term storage due to significant levels of environmental activity and, therefore, high turnover of CO_2 through the oceanic pool.
- Direct injection of carbon dioxide in to subterranean voids has been proposed as an ‘immediate’ storage option. It has been suggested that this practise be coupled with fossil fuel exploitation, with the injection of CO_2 in to oil and gas reserves to encourage the mobilisation of reserves for extraction. Whilst it is noted that this technique is presently exploited in the oil fields of Texas, U.S., at minimal cost per tonne of CO_2, the gas trapped rather than effectively sequestered and is free to escape via underground wells.
- Mineral ‘neutralisation’ of carbon dioxide to form bicarbonates or carbonates. It is proposed that there are two ‘feasible’ methods of mineral sequestration presently available. Initially it was proposed that CO_2 gas may be injected

directly in to alkaline mineral strata, where high levels of calcium, magnesium, and to a lesser extent sodium and potassium, ions are present. It was proposed that the gas would eventually be dissolved in to the pore water of the formation, where it would have the effect of acidifying pore waters, causing leaching of base ions from the surrounding formations, resulting in the creation of bicarbonate and carbonate compounds. As a safeguard to the possible formation of soluble bicarbonate, it was proposed that the formation of carbonate minerals be forced by an over-ground reaction between carbon dioxide and calcium or magnesium silicates in a ‘production line’ setting. Whilst this method would be energy consumptive, it is noted that it is the only contemporary method, based upon mineral reserve and feasibility studies, which has the potential to sequester all of the anthropogenic CO_2 that could ever be produced from known fossil fuel reserves.

2.1.2 ***A Brief History of Mineral Sequestration***

The theory behind mineral sequestration suggests that many minerals, including metal oxides, hydroxides and silicates are able to sequester atmospheric carbon dioxide by a carbonation reaction, which ultimately forms a mineral carbonate. Whilst this reaction occurs readily in the alkali metals, illustrated in column 1 of Figure 4, the resulting carbonate compounds are not stable over significant timescales due to their high solubility in water. Alkaline earth metals, illustrated in column 2 of Figure 4, have been proposed by Teir *et al.,* (2006) as effective materials for carbonation. Calcium and magnesium are proposed as the most large-scale feasible carbon capture compounds, due to their high availability and the low solubility of their carbonates in water or acidic rainwater. Manning (2001) demonstrates the precipitation of calcite in landfills, as a result of leachate formation, which is stable across a large pH range, 5.9-8. It is noted by Teir *et al.,* (2006) that calcium and magnesium silicates are particularly stable under aqueous conditions, even in the presence of acidity, <2 pH, meaning that they present an effective store for CO_2 even in the presence of acidic ground conditions, without the concern for the re-release of the captured CO_2. Experimental derivations have, in fact, illustrated an increased level of carbon dioxide sequestration in scenarios where raised acidity is present, although the mechanism for this has not been clarified.

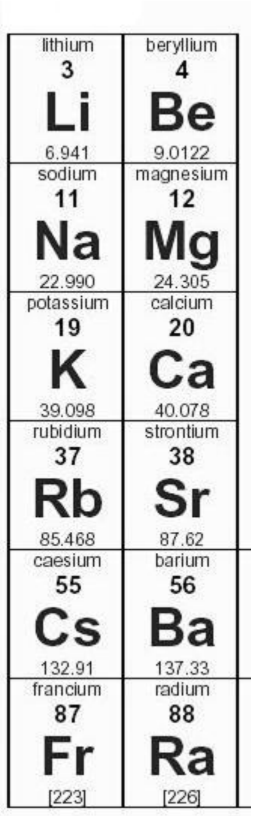


Figure 4 – Alkali metals and alkali earth metals

Lackner (2003) suggests that mineral carbonation is the most effective option for long term carbon capture and storage over geological timescales, it presents a ‘safer and more permanent’ solution to carbon capture than large-scale CO_2 injection in to underground reservoirs. As illustrated in Figure 5, the silicate mineral reserves on earth are estimated to possess the potential to store 10,000-1,000,000Gt of CO_2, which is significantly greater than the potential emissions of the estimated remaining fossil fuel reserves, illustrated by the ‘fossil carbon’ line. From Figure 5, it can also be appreciated that these carbonates will be stable over the order of 1000’s to 10,000’s of years.

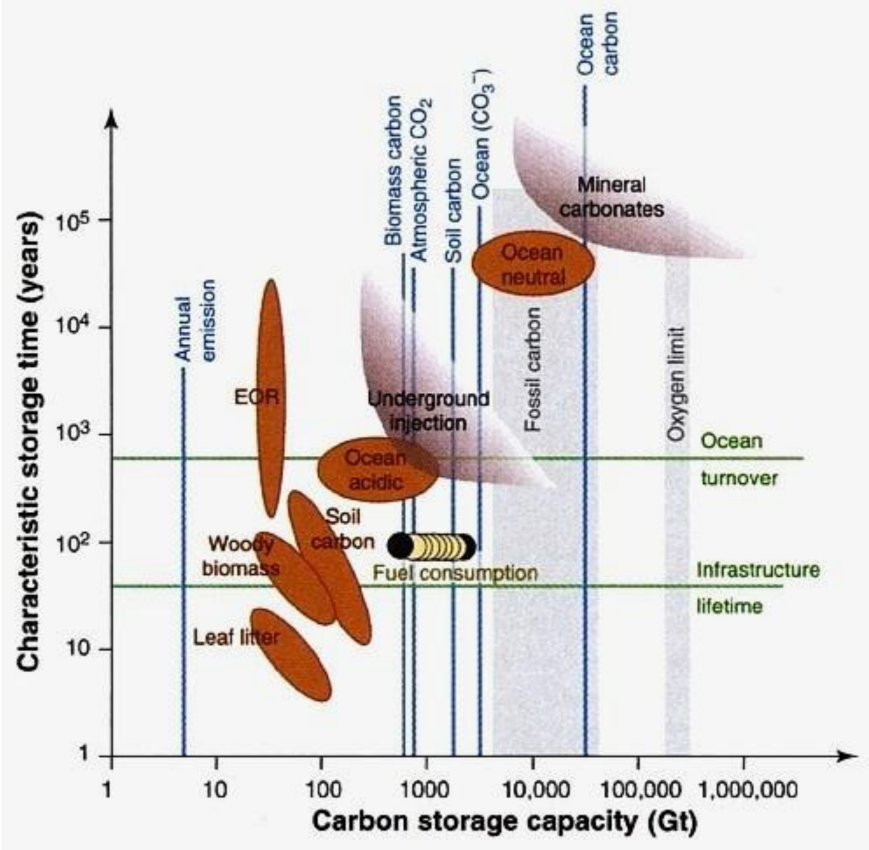


Figure 5 – Estimated storage capacities and times for sequestration methods (Source: Lackner (2003))

Berner (1983, 1985, 2002) proposes that large-scale carbonate formation is part of a global cycle, by which carbon is cycled through sequestration, weathering and atmospheric residence. Figure 6 demonstrates the simplified interaction of global carbon cycling stores and fluxes, as proposed in the amended BLAG model by Berner *et al.*, (1985). This model illustrates the significance of calcite ($CaCO_3$) as a global carbon store, although the magnitude of the flux between these stores is not stressed. The atmosphere-soil carbon flux equates to approximately 120Pg C/yr (Manning (2008)), larger than the flux between all other noted stores.

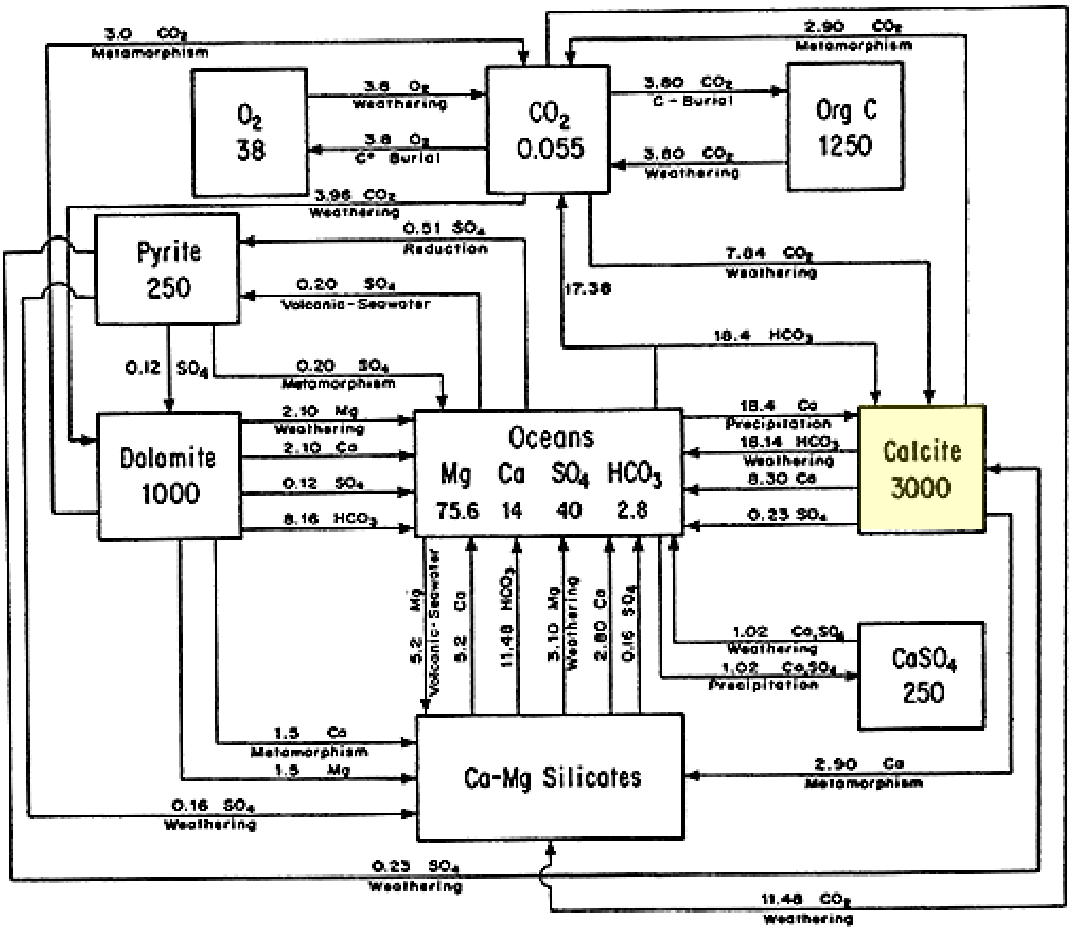


Figure 6 – The BLAG geochemical model. From Lasaga, Berner, and Garrels (1985) in The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present (Source:Parrish, !998)

Lackner (2003) suggests that the most effective means of promoting this storage potential is by directly reacting mined, crushed and milled magnesium and calcium silicates with carbon dioxide at a cost of approximately $10 per tonne of captured CO_2. Huijgen *et al.*, (2005) presents a detailed paper suggesting the mechanical requirements for this process to be commercially achieved, with the use of concentrated CO_2, directed over carbonate minerals in an industrial setting. Lackner (2003) states that ‘currently photosynthesis is the only practical form of air capture’ highlighting the significance of biomass as a carbon store, as part of the 'Organic Carbon' store defined in Figure 6. While biomass is an important short-term carbon store, Ryan (1990), notes that plants respire approximately '50% of the carbon available from photosynthesis', with a significant proportion of this released via the root system.

Whilst industrially coupled carbon capture through the use of integrated carbon sinks, or the injection of CO_2 through silicate mineral strata are large-scale technologies, providing an accelerated solution to carbon sequestration, both would require not only large amounts of initial capital, but the design and construction of specialist equipment and processing methods. Taking this lead, this project aims to investigate the potential for capture of atmospheric carbon dioxide at shallow depth (1-2m) in the ground surface of calcium rich-settings. Manning (2008) stresses the applicability of pedogenic carbonate formation as a carbon sink, using *in situ* techniques to produce a 'low cost – low energy process for the removal of atmospheric CO_2'. With reference to this, this project would look to explore the effectiveness of carbon capture in an *in situ* environment using calcium oxide derived from weathered slag. This process would require minimal technological input, with the sequestration process initiated by the combination of ground slag, or slag fines from aggregate production, with agricultural and engineering soils. Processing of the slag in to fine, granular material in order to provide a larger particulate surface area for reaction and transportation of the material to the desired site are the main active considerations in the application of this theoretical application. These *in situ* sinks could be expanded or renewed as necessary with additional slag, as the calcium oxide derived from the weathering slag is converted to calcium carbonate.

Teir *et al.,* (2006) note that the oxides and hydroxides of earth metals are well suited for carbonation but that their availability is limited in the natural environment, not being common rock-forming minerals. Whilst iron and steel slag (calcium oxide) presents a much smaller mineral reserve by mass than the natural silicates ultimately recommended by the Teir *et al.,* (2006) paper, their application in the creation of carbon sinks through the use of soil engineering has a number of advantages over the extractive use of silicate minerals. As iron and steel slag is a continuous product of the iron and steel industry, its immediate availability is not prohibited by a need for extraction and processing. Iron and steel slag is frequently stockpiled or buried, prior to re-use or as an ultimate disposal method, therefore, ongoing use in carbon sequestration negates the spatial and mechanical need for disposal.

With respect to measuring the efficiency of the sequestration process of mineral carbonation, Montes-Hernandez *et al.,* (2009) claim a sequestration mechanism in the presence of fly-ash from coal combustion, with adsorption of CO_2 on to carbonised material. Laboratory experimentation results in this case have led to the conclusion that '1 ton of fly-ash could sequester up to 26 kg of CO_2'. The empirical nature of the statement posed by Montes-Hernanadez *et al.,*, with respect to soil engineering using iron and steel slag, is the ultimate aim of this project, though determined using *in situ* parameters as opposed to laboratory maximums. The site specific groundwork tied in to this project will enable the development of a more effective picture of sequestration behaviour under true environmental conditions, rather than those assumed in a laboratory, in order to assess that large-scale viability of slag sequestration as a passive engineering measure.

2.2 Slag Properties

This section presents a synopsis of general publications relating to the production and geo-environmental study of steel and iron slag, assessing the common treatment and nature of slag with respect to its use in ground engineering scenarios. This data aims to create familiarity with the general constituents of these materials and understand their mineralogy

2.2.1 Physical Properties

‘Slag’ is the name given to a specific portion of the solid wastes created during the production of iron and steel. Slag is a ubiquitous product of the iron and steel production industry, which may be subdivided in to two major types – blast-furnace slag and steel slag.

- Blast-furnace slag is a relatively porous material with a variable, but generally low bulk density. Significant instability in blast-furnace slag occurs only in relatively rare instances where high lime or iron and sulphur contents are encountered.
- Steel slag is a non-porous material with relatively high bulk density. It is more physically unstable than blast furnace slag. Lee (1974) notes that steel slag is ‘invariably weathered in stock piles’ for up a year, in order to remedy its inherent volumetric instability

Blast-furnace slag is commercially promoted as an effective secondary aggregate material, with a global market for its application in road construction and concrete production. Slag as an untreated material is not inherently ideal in all construction applications, due to durability concerns and a tendency towards damaging levels of physical expansion. This property is usually due to volumetric instability caused by the presence of ‘free oxides’ (CaO, MgO), which are readily hydrated, in the material structure (Thomas Research Services Report, 2008). It is noted in Blast Furnace and Steel Slag (1974) that ‘It [slag] has a relatively high water absorption, due largely to its porosity’, leading to the need for tempering or extensive weathering (up to 18 months) prior to re-use in construction or as an aggregate, especially in relatively sensitive applications such as road construction.

Slag is still often regarded as a chemically ‘harmful’ waste, however, the National Slag Association of America (NSA) produces a great deal of literature to revoke the perpetuation of these negative concepts across the construction sector. As far back as 1980, papers entitled ‘Iron and Steel Slag – Non-Hazard’ attempted to dispel the idea that metal-working slags were truly ‘hazardous’ materials and confirm that they posed no direct threat with respect to environmental health. The NSA claimed that they had been ‘mistakenly’ classified by the Environmental Protection Agency U.S. (EPA), leading to extensive, subsequent legislative correction.

Steel slags have, therefore, with environmental necessity and under legal pressure, been well studied, with contemporary understanding of their mineralogy and defining behaviours enabling the creation of strategies such as those encapsulated in Making Waste Work (1995), regarding realistic re-uses and advice relating to their safe disposal or recycling. For many years it has been suggested that finely ground slag be re-introduced to agricultural land as a low-price fertiliser and liming agent, due to its beneficially high calcium oxide (and phosphorous in the case of basic steel slags) content which is able to effectively neutralise and buffer damagingly acidic soils. The National Slag Association presently market industrial Electric Arc Furnace

(EAF) slag widely in the U.S.A. as an effective agricultural buffer and fertiliser, although the marketed benefits are based very much on the basic activity of the calcium oxide (CaO) in acidic soils rather than upon deeper geochemical interactions. ‘AgSlag’, steel slag dust, is marketed by Tarmac in the U.K as a ‘Green Fertiliser’. A press release documenting the findings of a Tarmac and Newcastle University (2006), notes that AgSlag has the potential to reinstate the mineral balance of arable soils and grassland by supplying a slow-release mechanism for phosphorous. ‘Soil enrichment’ properties provide additional benefits to the *in situ* application of slag to agricultural soils.

2.2.2 Geochemical Properties as a Carbon Sink

The major constituents of iron and steel slag are calcium oxide, silica and aluminium oxides, in varying proportions. They may also contain other metal oxides and sulphur. Tables 2 and 3, below, illustrate the general constituents of Iron and Steel Slag. From these tables it can be seen that calcium oxide is a major constituent of both blast furnace (iron) and steel slag, representing 36-50% of the material by mass. This material is readily weathered to derive Ca^{2+} (aq), required in the proposed sequestration mechanism shown in Figure 7, Page 43. Whilst the actual concentration of calcium oxide in slag heap settings is highly variable, it is likely that calcium ion concentrations will be very high, creating an elevated potential for this reaction to occur.

Table 2 – Chemical constituents of blast furnace slag (Source: Lee (1974))

Constituent	Content by mass (%)
CaO	36-43%
SiO_2	28-35%
Al_2O_3	12-22%
MgO	4-11%
S	1-2%
FeO / Fe_2O_3 (total iron)	0.3-1.7%

Table 3 – Chemical constituents of steel slag (Source: Lee (1974))

Constituent	Content by mass (%)
CaO	40-50%
SiO_2	10-20%
Al_2O_3	3-4%
MgO	2-9%
S	0.2-0.9%
FeO / Fe_2O_3 (total iron)	12-20%

There are a number of contemporary books, discussion forums and papers which strive to directly address slag as a potential accelerator of terrestrial calcium carbonate formation, or directly link it to the construction of terrestrial carbon sinks through the chemical mechanism shown in Figure 7. This simplified mechanism proposes a general geochemical behaviour for any highly calcic soil material, and requires the co-action of vegetation, producing dissolved CO_2 in the subsurface, in order to occur. Like all chemical equilibria this reaction is dependent on temperature and mediated by the availability of the chemical species present. In the case of Consett Works, consideration was made in the context of a temperate soil with varying levels of slag presence, under normal to high pH conditions.

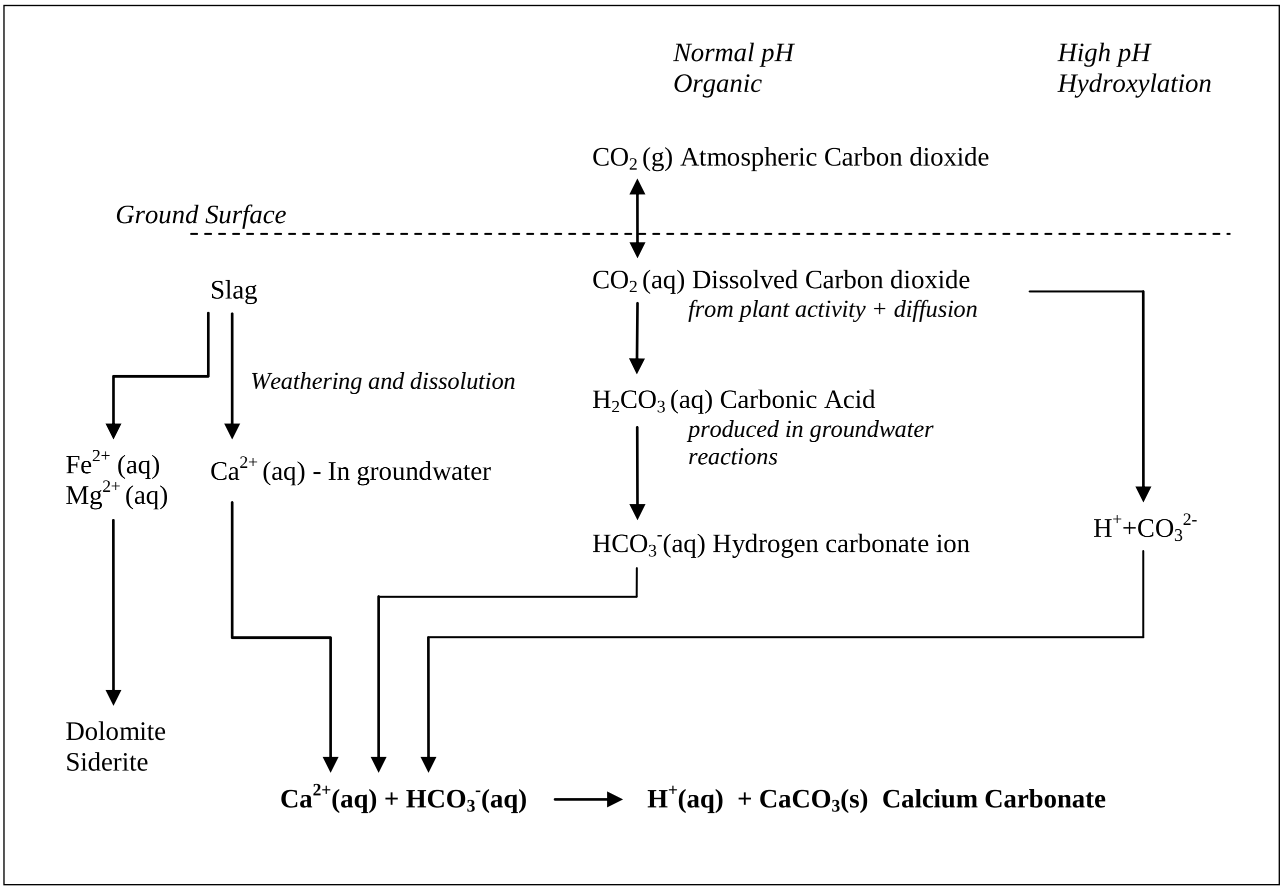


Figure 7 (After Huijen *et al.,*, 2005) Simplified chemical mechanism by which calcium derived from weathered slag is able to sequester atmospheric carbon

Few papers deal directly with the sequestration phenomenon *in situ*, simply assuming that these geochemical mechanisms are actively occurring in the field and opting for a laboratory based, accelerated, bulk analysis of the problem. Huijgen *et al.*, (2005) suggests a number of laboratory derived ‘maximum’ sequestration parameters, as an analogue for a large-scale ‘mineral carbonation’ plant.

Whilst laboratory experimentation in a laboratory context is useful, it gives little indication of the *in situ* geochemical behaviour of slag material within existing soils and is unable to predict the realistic levels of the sequestration which may already be occurring in these instances. A recently published paper by Renforth *et al*., (2009) directly explores the *in situ* behaviour of calcic materials in natural soils, comparing the results attained for the carbonation of construction wastes at a site in Newcastle upon Tyne with those attained in an area of calcium carbonate hard-pan formation at the former Consett Iron and Steel works site. Values of calcium carbonate concentration up to 38.3% were attained through stratigraphic soil sampling methods ~68.6% of which was deemed to have formed by an atmospheric hydroxylation process akin to that illustrated in Figure 7. The remainder of calcium carbonate analysed at the site formed through organic sequestration, due directly to soil-plant root interactions.

2.3 Consett Iron and Steel Works

This section aims to produce an understanding of site specific literature, taken from documentary sources and from previous site investigations. This section aims to characterise the known subsurface environment of the site and to address the most favourable areas for investigation. An understanding of the quantities of slag likely to be present at the Consett works site is also required.

2.3.1 The History of Consett Iron and Steel works

A wealth of information regarding the history and development of Consett Iron and Steel works was published in 1972, in a volume authored by the British Steel Corporation (BSC), the former owners of the site. In lieu of access to this paper, since the migration of British Steel Corporation business to the multinational Corus group in 1999, the details in this section present a synthesis of this data as reproduced by Sheffield (1996). This section also includes further information synthesised by Mayes *et al.,* (2008). These academic sources contain significant amounts of data, from diffuse documentary sources, regarding the historic activity of the site between its opening in the mid 19th century and its eventual closure in the 1980s, which has also been referenced.

Consett Iron and Steel works was founded in 1839, with the identification of productive ironstone deposits in the area south west of the present-day town of Consett, a small post-industrial settlement in north eastern England. By the mid 1840’s production had reached intensive scale, and Consett itself had achieved great size with an influx of industrial workers. The works continued production until 1980, under the remit of the British Steel Corporation, when financial constraints led to the closure and eventual demolition of the site.

It is noted by Mayes *et al.*, (2008) that the closure of the works saw the rapid demolition of the site buildings, and that these composite demolition wastes were added to the historic slag heaps. Although the assumption is that the demolition wastes and slag material are unlikely to be homogenised, there is little documentary evidence available to address the actual constituent nature of the spoil mound as a whole. It is noted in the Derwentside District Council (1989) documents to accompany the reclamation works that approximately 3.5 million m^3 of slag was re-distributed across the works site, during reclamation, and that $350{,}000m^3$ of clean topsoil was imported to be emplaced across the site, prior to grass seeding. It is known that the site has been capped with soil and turf, so an assessment of the capping depth would be necessary before any deeper surveying could occur. If capping depth is negligible, as appears to be the case, then further works upon the site will be simplified, as slag should be present close to the ground surface. Initial plans for site development and drainage in the south western region were produced in the 1960's on behalf of BSC. Whilst extensive drainage works were implemented in the first phase of the reclamation, documented further in the following sections, the presence of artificial drainage in the remainder of the site is not documented. No further intervention has occurred across the majority of the site since its reclamation.

2.3.2 Mapping the development of the works site

The site has been studied using virtual mapping resources, including basic visualising software such as Google Earth, as well as more detailed, tailored software acquired through Edina Digimap, which has allowed a study of the development of the land south of Consett through historic maps of 1867, and 1943-1993 to the present day. From these maps the extent of the former iron & steel works and approximate extent of slag heaps, can be determined as illustrated in the overlay map, Figure 8.

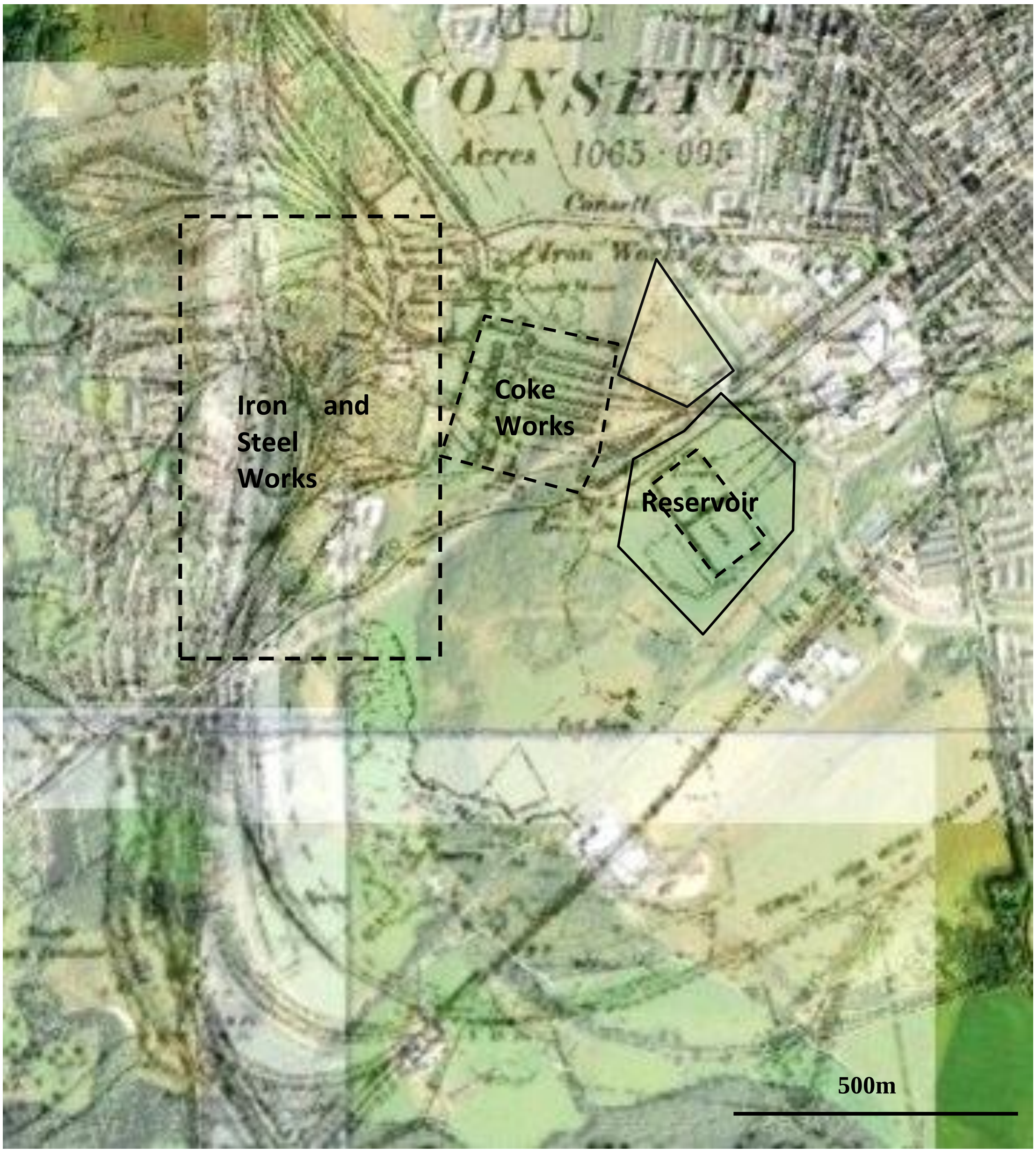


Figure 8 – Overlay map showing former extent of Consett Iron and Steel works (1897) Approximate extent of Previous Site Report coverage indicated by solid black line (Source: Edina Digimap)

Contemporary ordnance survey maps have been utilised in order to determine the likely contemporary extent of post-works land available for study. An approximate boundary for the slag heaps can be seen in a historic National Survey map from 1977, covering a large area extending towards what are now the settlements of Castleside, Moorside and Templetown. From contemporary satellite images it can be seen that a large area, bounded to the south by the Howns Gill Viaduct, consists of the type of rough grassland typical of thinly capped, poor quality Made Ground. An overlain map, shown in Figure 8, was produced as a precursor to the desk study, included in section 3.1 of this report, to illustrate the development of the site surrounding the iron works from the 18th Century to the present day, plotting the known extent of the slag heaps over the present assumed boundary of reclaimed land which will require assessment. It was deemed that site visits would be required to determine which areas within these boundaries would be most amenable for further field study. Further investigation of the site will also be required to determine factors such as detailed site hydrology. Whilst it is known that a number of burns (Dene Burn being predominant in the creation of the alkaline calcic lake studied by Mayes *et al.*, (2008)) have been identified, which drain in the area of the Howns Gill Viaduct, the hillside demarking the former works seems to define a number of potential watersheds, natural and artificial.

The present-day area demarcating the former works is relatively sparse in terms of urban population, having effectively been occupied by extensive industrial works until very recently in to the last century. Much of the land indicated by the black boundaries in Figure 9 is owned by Durham County Council (formerly Derwentside County Council) and a development co-operative known as Project

Genesis, although small sections have been sold in recent years to private developers. There are a number of small settlements which flank the site, Castleside, Moorside and Templetown, as well as a modern business park development to the north, on the outskirts of Consett, with an ongoing construction programme in progress.

Table 4 illustrates the chronology of reclamation works carried out at the Consett works, which are detailed further overleaf. The reclamation of the site was approached in four discrete stages with the Grove Heaps area to the south west being the first to be completed between 1981 and 82 and the 'Howns Gill Plate Mill' to the south east being the last. Table 4 documents further details of these reclamation works post-demolition.

Table 4 – Phases in the reclamation of Consett Works (Source: Sheffield (1996))

Phase	**Name**	**Reclamation works**
1	Grove Heaps	Landscaping, drainage and planting. 1981-84
2	Fell Coke Works	Removal of viscous waste, clean capping
3	Consett Works	Redistribution of works waste. Capping with 3-5m of slag, sub soil and top soil
4	Howns Gill Plate Mill	Re-grading and distribution of slag

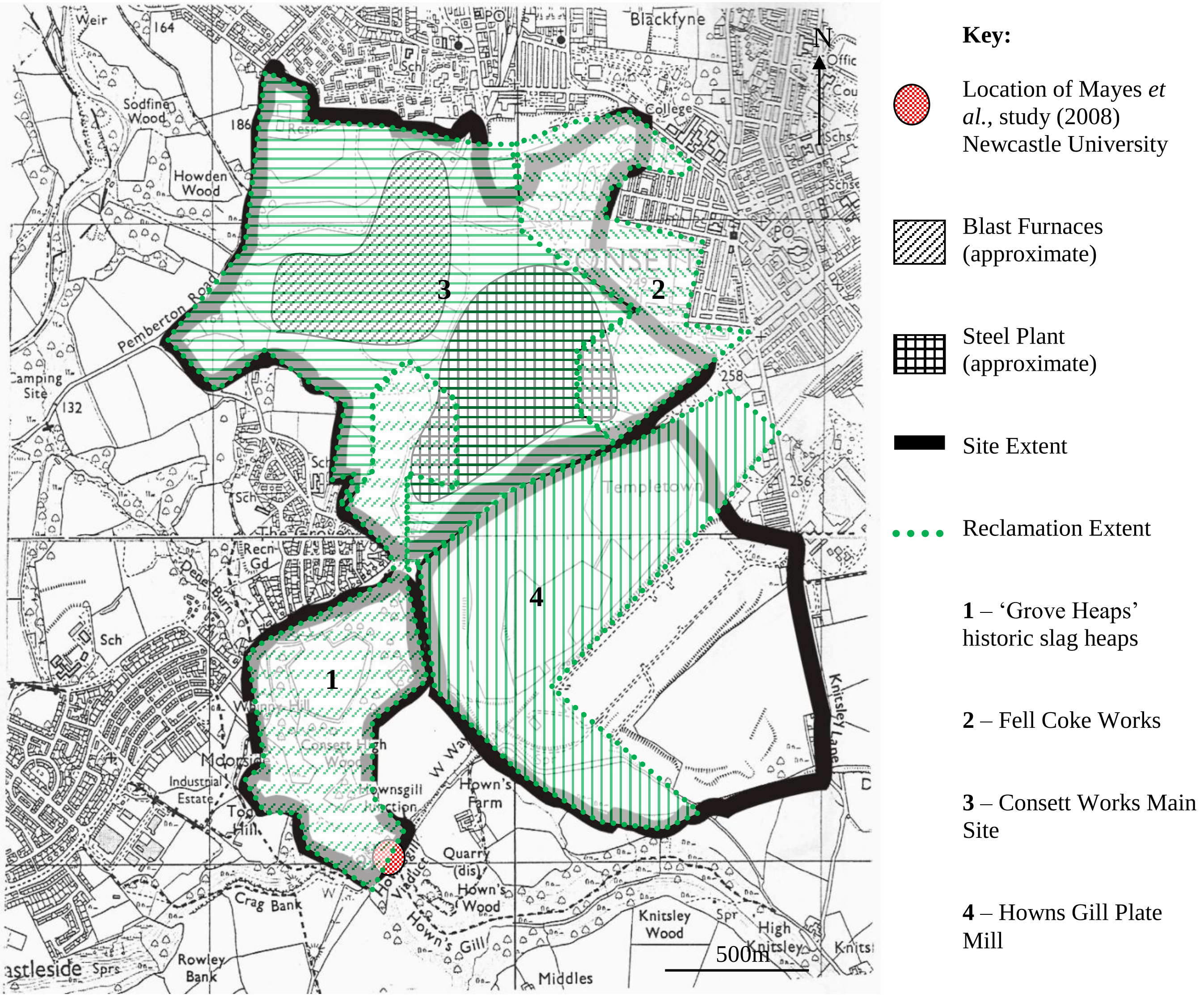


Figure 9 – Area map detailing the extent of the former Consett Iron and Steel works (adapted from OS) and approximate extent of reclamation works (Source: Sheffield (1996))

2.3.3 Previous academic studies

There is a small area in the southern bound of the former works, which has been a site of ongoing study by Newcastle University, marked as ‘area 1’ on Figure 9, page 50, bounded by the A692 to the north west and the Howns Gill Viaduct to the south east, delineated by established woodlands to the east and west. A great deal of literature specific to the alkaline leachates permeating from slag heaps on this site, and their environmental attenuation, has been produced in the form of MSc dissertations in various geochemical and hydrological disciplines. Ongoing research includes a very recently published paper by Mayes *et al.*, (2008), addressing the site as a natural case study in the developing field of wetland attenuation of alkaline leachates. This paper in particular also produces in-depth comment upon the contemporary geological and hydrogeological settings of the site. The presence of calcium carbonate is directly mentioned in this study, as its presence is highly visible in surface waters in the study area, presumed to be a result of mobilisation via the artificial drainage system emplaced. This study did not aim to directly assess the calcium carbonate material as a carbon capture mechanism, though the potential for this is noted.

The Renforth *et al.*, (2009) study, cited in the previous section, also concentrates in part upon the Howns Gill area of the former works, collecting a portion of data from calcium carbonate hard pans found in the location of the previously mentioned alkaline lake. This study utilises Howns Gill as an analogue site, identifying pedogenic calcium carbonate formation, presumably as a direct result of leachates exuded from the artificial drainage system serving the Howns Gill region.

A large number of BGS boreholes are recorded across the region, as noted in Figure 2 on Page 3 of the appendix to this document, taken from the BGS GeoIndex service. Four of these borehole records were requested, carried out at the site in 1905, 1961, 1924 and 1975. These boreholes illustrate the presence of boulder clay, to a depth of approximately 0.3-1m, with sandstone bedrock at approximately 1-3m. It is noted that ‘fill’ persists across the site at a depth of 3-5m although in some areas it may be significantly thicker. There are also a large number of ‘confidential’ investigations recorded by GeoIndex, which are likely to have been carried out prior to the decision to commercially and residentially develop the site. It is known that commercial site investigations have been carried out across the former steel works site, the details of which are held by contractors employed by the site guardians, Shadbolt Environmental. These previous investigations are discussed further in the Desk Study and Results sections of this report, as it is deemed that the findings, collated as recently as 2008, are able to contribute directly to the results of the project.

2.4 Field and Laboratory Methodologies

This section aims to provide a critical analysis of information relating to potentially applicable field work and laboratory methodologies which have been used in similar investigations, in order to create an informed and effective methodology.

2.4.1 Field Methodology

The methodology which was employed on-site, and in the analysis of site material, needed to be multi-disciplinary in its approach in order to sufficiently consider all of the process at work in a system complex enough to favour the sequestration mechanism described. The validity of this project depended upon the co-assessment of climatic, biological and geochemical interactions, therefore it is fitting that all of these aspects were clearly understood, investigated and addressed prior to the creation of the methodology.

The site methodology was designed to address the need to investigate the overall subsurface of the site in knowledge of the limited intrusive works which were physically and temporally feasible. The most practical means of satisfying this objective are discussed in this section of the literature review.

2.4.1.1 Initial Surveying

GPS is deemed to be an effective method of location fixing, for both engineering and geological problems. As noted by Barnes (2004) GPS instruments ‘pick up radio signals from orbiting satellites that continuously transmit the exact time and their position’. ‘By simultaneously using signals from several satellites, the position of the receiver on the ground can be determined’. For the purposes of this study, it was deemed that GPS would be used to fix points of interest.

GPS data is frequently collated with geophysical data in order to produce composite sections, from which topographical variation in the study transect can be seen. It was proposed that GPS be used to fix the data points used in any geophysical surveys carried out during the completion of works at the site in order to enable an ongoing comparison between data points and site topography and to ensure agreement with GPS records from previous site investigations.

2.4.1.2 Vegetation and Ecological Surveying

A vegetation survey must be carried out in order to determine the percentage coverage of the site to ensure that this does not act as a variable in determining soil activity. A count will also be carried out to build up a crude picture of the biodiversity in order to ensure that activities at the chosen site will not have a negative impact upon indigenous wildlife.

A Phase 1 Habitat Survey and Protected Species Risk Assessment was carried out in November 2008, in the north eastern part of the site, by Penn Associates with reference to guidelines stipulated by the Joint Nature Conservation Committee (2003). This survey notes that there are three major types of habitat present at the site; semi-improved neutral grassland, broadleaved woodland of native species (10-20 years old) and mixed, decorative planting of native and non native tree species. For the purposes of this study, it is deemed that areas in which woodland and ornamental planting are established are unlikely to be suitable areas for soil sampling, therefore, areas in which grassland predominates are to be favoured during site selection. Though it has been experimentally suggested that the precise species of vegetation growing in soils treated with calcium rich material, such as slag, has little effect on the rate of calcium carbonate deposition, as long as they operate the same metabolic pathway (C_3 or C_4), they are able to affect the isotopic signature of calcite material causing analytical disparities (Stevenson *et al.,* 2005). The overall percentage of ground covered by vegetation will inevitably have a marked effect on this rate, therefore, a quadrat survey was deemed to be suitable to determine the relative ground cover present at the site. Significant variation in species type will also be noted.

The Habitat survey did not identify the presence of any protected plant or animal species. Foraging bats, reptiles and ground nesting birds are noted as potential exploiters of the habitats present. It was noted that care must, therefore, be taken whilst any works were carried out onsite, in order to ensure that ground dwelling species were not disturbed.

Table 5 summarises the main objectives of the vegetation survey, with reference to the documentary evidence which supports the need for this data to be collected.

Table 5 – A summary of methodological objectives for the implementation of a vegetation and ecological survey

	Objective	**Justification**
1.	To determine percentage groundcover of vegetation and significant vegetation changes across the study site	It is known that carbon dioxide fixation occurs to an elevated extent in the presence of vegetation, as dissolved organic C from plant root respiration provides a substrate for sequestration. Variations in ground cover have the potential to alter the levels of sequestration occurring. Variations in vegetation type may also affect this process, but are known to have to potential to alter isotopic ratios recorded for pedogenic carbonates.
2.	To assess the presence of prevalent or protected plant and animal species	An understanding of the local environment is required in order to ensure that further site works are carried out with due care and in accordance within necessary ecological guidelines

2.4.1.3 Geophysical Surveying

Vernon *et al.,* (1999) discuss the survey of post-industrial sites using magnetometer survey and resistivity meters, claiming that ‘Slag can produce a wide range of responses, which may be attributed to changes in iron-content, depth of burial and thickness of the slag deposit’. They agree that the use of either geophysical technique is likely to produce complex but interpretable results for sites underlain by slag, although ideally a combination of the two geophysical techniques is most effective in producing a definitive site image and discriminating between more transient features.

It is thought that a resistivity survey is likely to be the most viable form of geophysical survey for the Consett works site, as magnetometer surveys are susceptible to anomalies caused by metallic inclusions in the subsurface, which is a high possibility at a historic iron works. Resistivity surveys operate by determining the difference in resistance though a ‘squared’ unit of the ground (Milsom, 1996). They utilise metal electrodes, which are connected to a cable and assigned a ‘current’ or ‘potential’ role, by which they either deliver an electrical current to the ground, or measure the current reaching them over a short period of time in order to infer the apparent resistivity properties of the ground between the survey points. Numerous arrays are possible in resistivity survey, however, the equally spaced Wenner arrangement, illustrated in Figure 10, is still the most popular due to its long history of use, meaning that the majority of interpretational packages are best suited to its application.

Other array types may also be suited to a post-industrial site, including the double dipole array shown in Figure 11 which is often used to produce 2-dimensional pseudo-sections of the subsurface. This array type is created by the ‘complete seperation of current and voltage circuits' allowing information from varying depths to be determined by internally varying the length of the horizontal array.

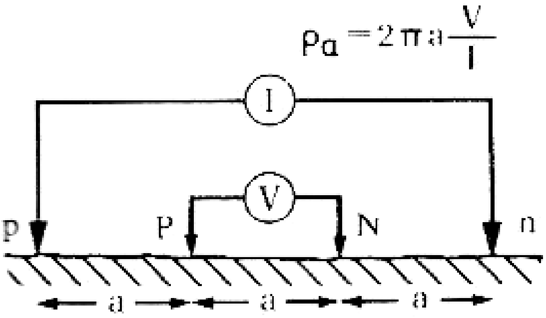


Figure 10 – A typical Wenner Array l resistivity survey (Source: Milsom (1996))

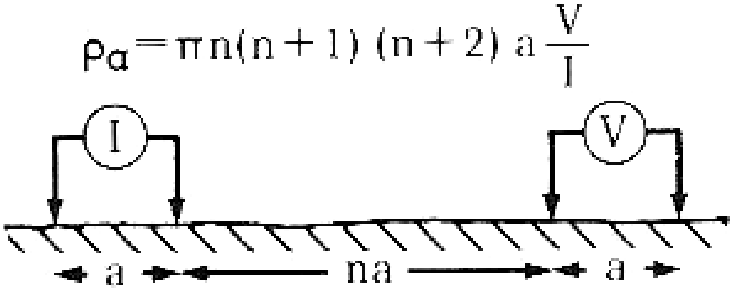


Figure 11 – Schematic representation of Double Dipole resistivity configuration (Source: Milsom (1996))

A summary of the objectives of the geophysical survey is illustrated in Table 6. This summary defines the most significant objectives informing the selection of this method of site survey.

Table 6 – A summary of methodological objectives for the implementation of a geophysical survey

	Objective	**Justification**
1.	To confirm the stratigraphic results of previous ground investigations	A geophysical survey should differentiate subsurface levels to significant depth, depending upon the size of the array implemented, which should allow correlation with boreholes, trial pits and cone penetration tests completed during previous investigations.
2.	To investigate the geophysical properties of iron and steel slag	There are no readily available geophysical results for post industrial sites such as Consett works. The geophysical response of slag will be assessed in comparison to other known substrates.
3.	To determine the presence of calcium carbonate horizons as a geophysical anomaly	Calcium carbonate, if present in discrete horizons within the soil matrix, should be detectable as a distinctively high resistivity anomaly of 500 – 10,000Ωm (Milsom (1996))

2.4.1.4 Sampling

The implementation of an effective soil sampling methodology at the Consett works site was seen as central in enabling a relevant, ongoing laboratory investigation. The sampling strategy required the acquisition of representative soil samples from across the site.

With respect to the 'depth' resolution, soil sampling methods are highly variable dependent upon the nature of the study site. It is noted by Mayes *et al.*, (2008) and Renforth *et al.*, (2009) that in some areas of the works at Howns Gill, calcium carbonate is present in 'hard pans' at the site surface, however, this is not the case for the site in general. Processed slag material covers the site area defined in Figure 9, page 47, to significant depth and whilst in some areas, large fragments have been exposed at the surface, illustrating a thin carbonate crust, the majority of the site consists of levelled and capped ground. It is, therefore, proposed that if calcium carbonate formation is occurring across the site, the evidence will be found in the soil matrix, as carbonate deposits forming around the fine grains and large cobbles of slag which constitute the superficial layers of the site. Figure 13 shows that whilst calcium carbonate is predicted to persist in soil horizons to a depth of 1.75m, with a regression value of 1.40m, evidence of formation should be present within the shallow subsurface, at a depth of 100-500mm.

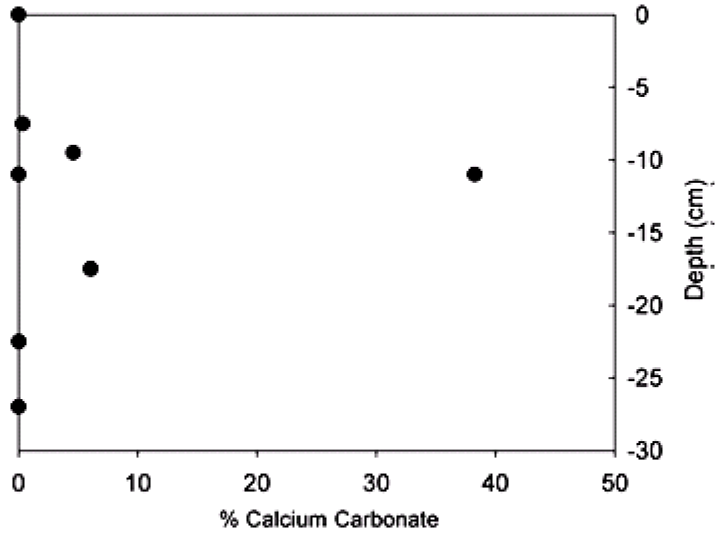


Figure 12 – Variation of calcium carbonate concentration with depth at Consett Iron and Steel works (Source: Renforth et al., (2009))

The data collected during the Renforth *et al*., (2009) study suggests that the percentage of calcium carbonate forming at the Howns Gill site varies to a significant and unpredictable extent with spatial variation and does not vary in a predicable manner with depth, as illustrated in Figure 12. This study would aim to determine, through a process of stratigraphic sample collection, whether other areas within the Consett works site also demonstrate a diffuse concentration-depth relationship of this manner, or whether variation with depth can be quantified. In order to achieve this, samples will need to be taken with a significant amount of spatial variation and to a variety of depths. A systematic sampling method would be effective in ensuring coverage of the site.

With respect to the ‘spatial’ resolution of soil sampling method, it has been commented in previous sections that the Consett works site was landscaped in the 1980s, after the closure of the plant and that the slag and demolition materials were distributed across the site. Whilst there is anecdotal evidence that specific classes of material were utilised in different areas of the site, it was assumed that the ground conditions across the extent of the former works are

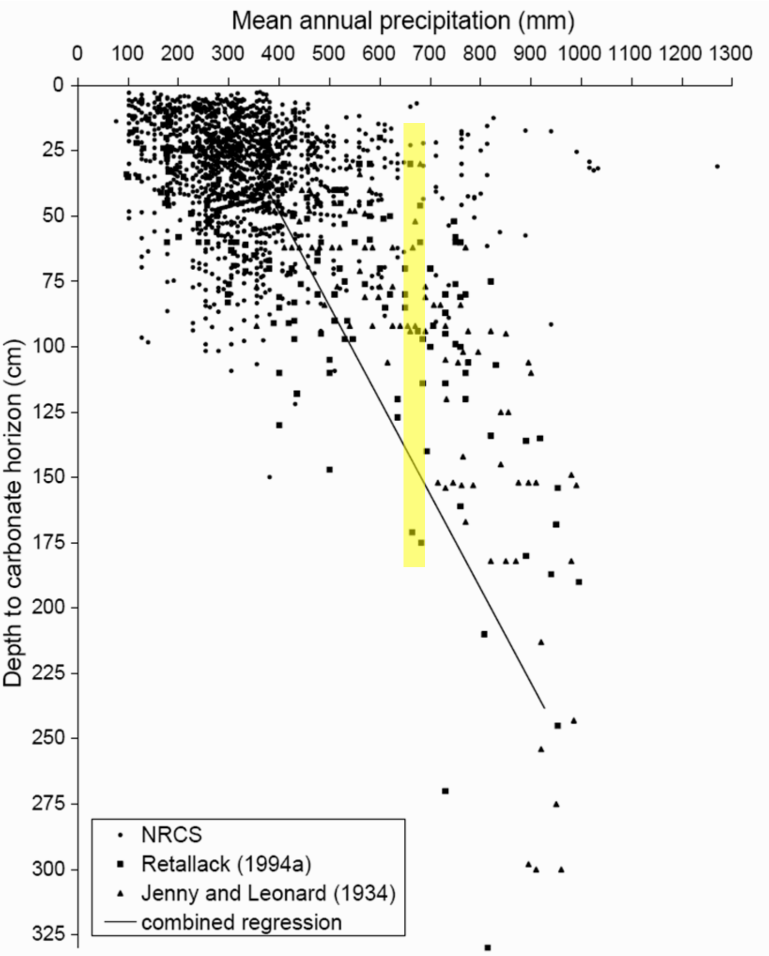


Figure 13 – Variation of calcium carbonate concentration with depth with reference to annual rainfall. Average rainfall for Consett is highlighted
(Source: Royer, (1999) After Jenny, NRCS and Reatallack)

likely to be relatively heterogeneous. It was decided that the soil sampling strategy should be designed in a manner which would address this heterogeneity and attempt to analyse any patterns of calcium carbonate formation which may be present across the study site. It was concluded that a systematic sampling method would be the most effective means of addressing the phenomenon of spatial variation in ground conditions, by selecting a small number of equally spaced sampling points in order to determine the presence of any underlying patterns in spatial variation.

With reference to the likely ground conditions present at the Consett Site, fine grained Made Ground with larger inclusions to significant depth, and the required depth of excavation, the most effective sampling methods were deemed to be hand auger or window pit, as utilised at Howns Gill by Renforth *et al*., (2009). This methodology would allow the quantitative comparison of spatial data, as well as the definition of patterns of variation with depth.

In summation, the main objectives of the sampling strategy employed at the site were seen to be threefold, as documented in Table 7 below.

Table 7 – A summary of methodological objectives for the implementation of soil sampling

	Objective	**Justification**
1.	To confirm the presence of calcium carbonate at the study site	To determine whether, and to what extent, calcium carbonate formation is occurring across the Consett works site
2.	To address the nature of variation in calcium carbonate content at increasing depth below the soil surface	It is noted by Renforth *et al.*, (2009) that there is no discernable pattern with respect to calcium carbonate formation with depth at Howns Gill. This study aims to determine whether this is also the case across other parts of the Consett works.
3.	To determine the level of spatial variation in calcium carbonate across the site	It is thought that slag and demolition material was spread heterogeneously across the site during landscaping. Spatial variation in sequestration potential is likely to occur depending upon the concentration and physical nature of slag

2.4.2 Laboratory Methodology

The methodology which was to be employed in the laboratory work, required the implementation of numerous, complimentary analysis methods which could be applied to the variable types of material available from the site.

2.4.2.1 Calcimeter Testing

Calcimeter testing is a technique used to quantify the presence of calcium carbonate ($CaCO_3$) in soils and other loose deposits, usually in order to determine relative fertility levels. A calcimeter operates by estimating the amount of calcium carbonate present in a sample, from the measured quantity of carbon dioxide that is evolved when the sample is combined with a strong acid (usually hydrochloric acid). From these measurements, a bulk calcium carbonate content for the sample as a whole can be estimated.

Eijelkamp Calcimeters, utilised in the Renforth *et al.,* (2009) study, are designed to determine carbonate content in small, aqueous samples, making them particularly suited to the analysis of fine grained soils. These calcimeters utilise approximately 1-2g of material (Eijelkamp Agrisearch Equipment. 2006) and are able to accurately determine calcium carbonate concentration by a simple reaction with hydrochloric acid. Gas (CO_2) evolved during this reaction is collected in burettes. The amount of CO_2 produced during the reaction is then measured against a standard calibration in order to determine the percentage of calcium carbonate, by mass, contained in the original sample.

In summation, the main objectives of calcimeter testing on samples collected at the site are documented in Table 8, overleaf.

Table 8 – A summary of methodological objectives for the implementation of calcimeter testing

	Objective	**Justification**
1.	To confirm and quantify the presence of calcium carbonate in soil samples	A calcimeter is the simplest means of assessing soil samples of the type expected from the Consett works site. Calcimeter results will be presented as a percentage presence of calcium carbonate, by mass, of each tested sample.

2.4.2.2 Petrographic Microscopy

Petrographic microscopy may be carried out utilising prepared sample slides created by the production of a thin section from a lager mass of material or from a prepared resinous matrix of granular materials, like the soils which were likely to be encountered at the study site, mounted on a glass slide. Petrographic microscopy can be used to analyse the mineral speciation and to identify and describe the constituent minerals of a sample. Slides needed to be prepared to suitable dimensions from slag collected in the field, which would then allow the material to be observed in normal light conditions in the same manner as a rock or mineral thin section as prescribed in Optical Mineralogy (1959). The presence of common minerals such a calcium carbonate should be recognisable through light microscopy, as should large opaque inclusions such as iron.

As well as optical mineralogy, carried out in a traditional manner with the use of a light microscope, scanning electron microscopy (SEM) may be effectively applied to slag samples in thin section. SEM utilises high energy electrons to investigate the surface topography of samples. The most common method of analysis using SEM is the detection of ‘back-scattered’ electrons, reflected from the sub-surface of the sample under analysis. Scanning electron microscopy provides an opportunity to view samples at magnifications of approximately 200x to 5000x, whilst light microscopes are generally limited to magnifications up to 400x. Scanning electron microscopy may also be coupled with energy dispersive or characteristic X-ray analysis, which is able to provide a qualitative analysis of the elements present in the sample.

As well a qualitative analysis of minerals present in the slag material, petrographic microscopy would also enable the observation of calcium carbonate formation on the outer surfaces of slag, and should allow a quantitative analysis of the surface depth to which this reaction occurs. The persistence of calcium carbonate formation at a microscopic scale may allow insight in to the factors limiting formation, such as the surface area availability of slag at the Consett works and evidence of calcium carbonate formation within the mineral structure of weathering slag.

Table 9 below summarises the main objectives related to the application of microscopy to the samples collected at Consett works.

Table 9 – A summary of methodological objectives for the implementation of petrographic microscopy

	Objective	**Justification**
1.	To investigate the mineralogical constituents of weathered slag	Petrography is a useful tool in qualitatively investigating the mineral constituents of rocks, and has been effectively applied to the analysis of slag
2.	To qualify the findings of previous petrographic site investigations	Petrographic investigations have been carried out on slag attained at the Consett works. There are no images available to record this, however, detailed descriptions exit, which may be qualified by further investigation

2.4.2.3 Isotopic Ratio Mass Spectrometry

As discussed previously, the matter of addressing isotopic fractionation within the samples to assess the provenance of carbon and oxygen atoms in any calcium carbonate ($CaCO_3$) deposits is necessary in proving confirmation of the mechanism by which these horizons have formed (pedogenic or lithogenic). Isotopic Ratio Mass Spectrometry may be used in order to determine these values for comparison with known standards. Pedogenic carbonates, derived from biomass related soil activity and hydroxylation, tend to have much higher fractionation values for the depletion of $\delta^{13}C$ and $\delta^{18}O$ than their lithogenic counterparts. Biomass activity renders them isotopically 'lighter' due to the relatively higher concentration of $\delta^{12}C$ present. The mechanism of this discussed in detail in Hoefs' Stable Isotope Geochemistry (1997) and illustrated in Figure 14, where it is commented that kinetic isotopic effects are the main determiner in this fractionation.

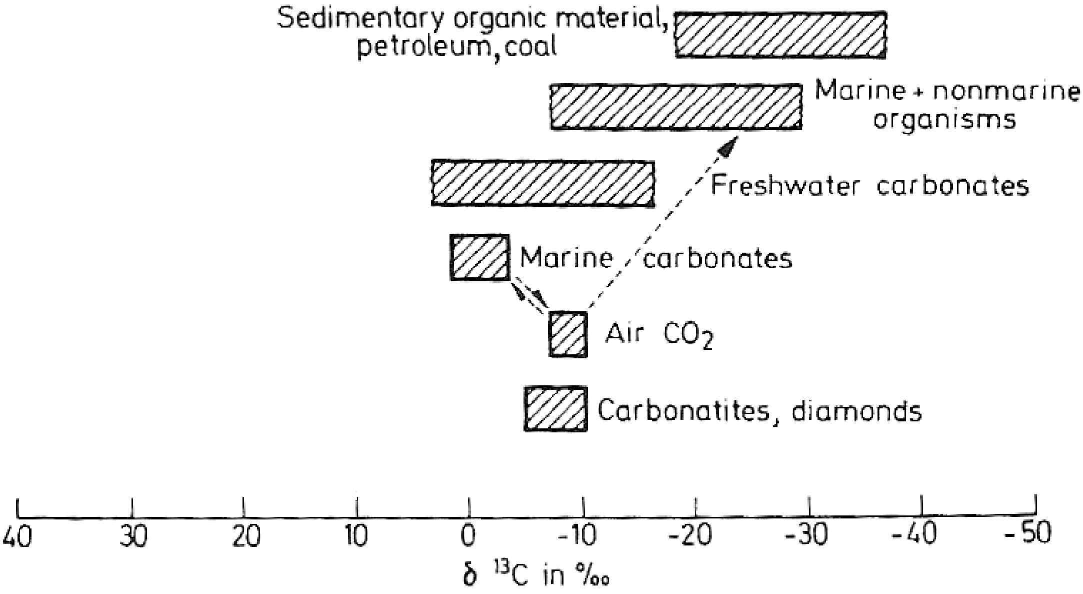


Figure 14 – $\delta^{13}C$ of selected, significant carbon reservoirs (Source: Hoefs (1997))

As discussed by Dietzel *et al.*, (1992), the analysis of the fractionation values of Carbon isotopes within the site samples will allow the assessment of the material with respect to known documentary ranges of fractionation in carbonates produced through soil sequestration reactions. All values are recorded against international standards for carbon isotopes, Vienna Pee Dee Belemnite (VPDB) or Pee Dee Belemnite (PDB), USGS (2006). Fractionation figures for depletion of $\delta\ ^{13}C$ in pedogenic carbonates are always higher than those in the lithogenic counterparts, with pedogenic carbonates generally quoted around the values of $^{12}C/^{13}C$ -13-25‰, though values of up to -27.8±2.2‰ have been quoted for C_3 grasses in the Deccan Traps of India (Das *et al.*,, 2005), and lithogenic carbonates generally around 0-2‰. The fractionation values for the samples found at the Consett works site would be expected to be depleted, exhibiting $\delta^{18}O$ and $\delta\ ^{13}C$ values of around -6.75‰ and -8‰ respectively for organic carbonates and $\delta^{18}O$ and $\delta\ ^{13}C$ values of around -17.6‰ and -25.3‰ respectively for hydroxylated carbonates (Renforth *et al.*, (2009)).

Table 10 summarises the main objectives related to the application of IRMS to the samples collected at Consett works.

Table 10 – A summary of methodological objectives for the implementation of IRMS

	Objective	**Justification**
1.	To determine the provenance of carbon and oxygen isotopes found in soil formed calcium carbonate	To determine the major means by which calcium carbonate formation at the site occurs. To estimate the overall proportion of calcium carbonate forming due to atmospheric carbon dioxide sequestration and to determine the predominant method by which this occurs (organic / hydroxylation)

3. METHODOLOGY

3.0 METHODOLOGY

The programme of work for this project consisted of three distinct phases:

3.1 Preliminary Survey and Desk Study

Between December 2008 and May 2009 a Desk Study was completed and preliminary site surveys carried out. These preliminary works aided in site selection, defined the ground situation at the site, and assisted in the identification of any areas which may have presented hazards or posed difficulty to the project.

3.2 Site Investigation and Sampling

Site investigation, mapping, geophysical surveying and sample acquisition were carried out throughout May, June and July 2009, when weather conditions permitted close investigation of the site and allowed a closer analysis of vegetation-soil interaction. All fieldwork was carried out before the middle of July 2009, due to a notable increase in public usage of the study site over the summer months, which was deemed likely to delay or interrupt sampling.

3.3 Laboratory Testing

Calcimeter testing of samples was carried out in the Newcastle University geochemical laboratories. Petrographic slides were prepared by Durham University and analysed using light microscopy and SEM analysis at Newcastle University. Isotopic analysis samples were sent for external analysis by Iso-Analysis, Crewe.

Pages 2 -42 of the appendix to this document present the data used in the construction of the methodologies presented.

3.1 Preliminary Survey and Desk Study

3.1.1 Desk Study

A Desk Study was completed using data acquired during previous site investigations completed by commercial bodies, at the former Consett works site. Precise document references can be viewed in the appropriate section of the references to this document. The most widely available reports for the Consett works concerned two sites in the north east of the former works, the Upper Plateau and Derwent View sites illustrated in Figures 15 and 23 respectively, which were selected for further consideration as study sites on this merit. Advice regarding preferable ground conditions at the sites was offered by Project Genesis and ACE Civil Engineering.

The majority of the information included in this report was collated from the desk studies carried out by Shadbolt Environmental, on behalf of Project Genesis, in May and June 2008. These desk studies, along with Phase 2 site investigation documents, aimed to explore the geological, geotechnical and contamination conditions of the study site with respect to their suitability for construction and development.

Primary data sources for the desk top studies are noted as:

- GroundSure
- Coal Authority
- British Geological Survey
- Geological Survey Sheets
- Ordnance Survey
- Environment Agency

3.1.2 Upper Plateau Retail Site (NZ10400, 50450)

Location and Description:

The site is triangular, covering approximately 7 hectares, located between Genesis way to the east and the A692 to the south. Site topography varies significantly, with aOD 255m in the south east dropping to aOD 240m in the north west. The site is surrounded by fencing, and vehicular access is limited. The site is jointly owned by Project Genesis and overseen by Durham County Council, formerly Derwentside County Council.

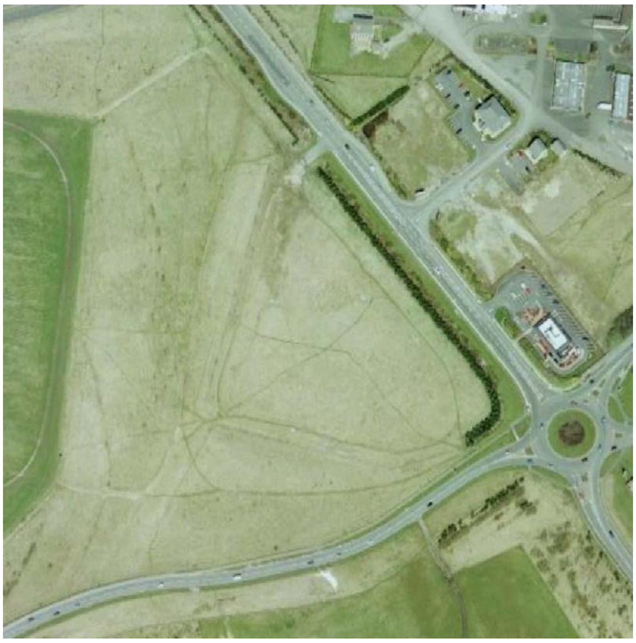


Figure 15 – Aerial view of the Upper Plateau site (Source: Shadbolt Environmental)

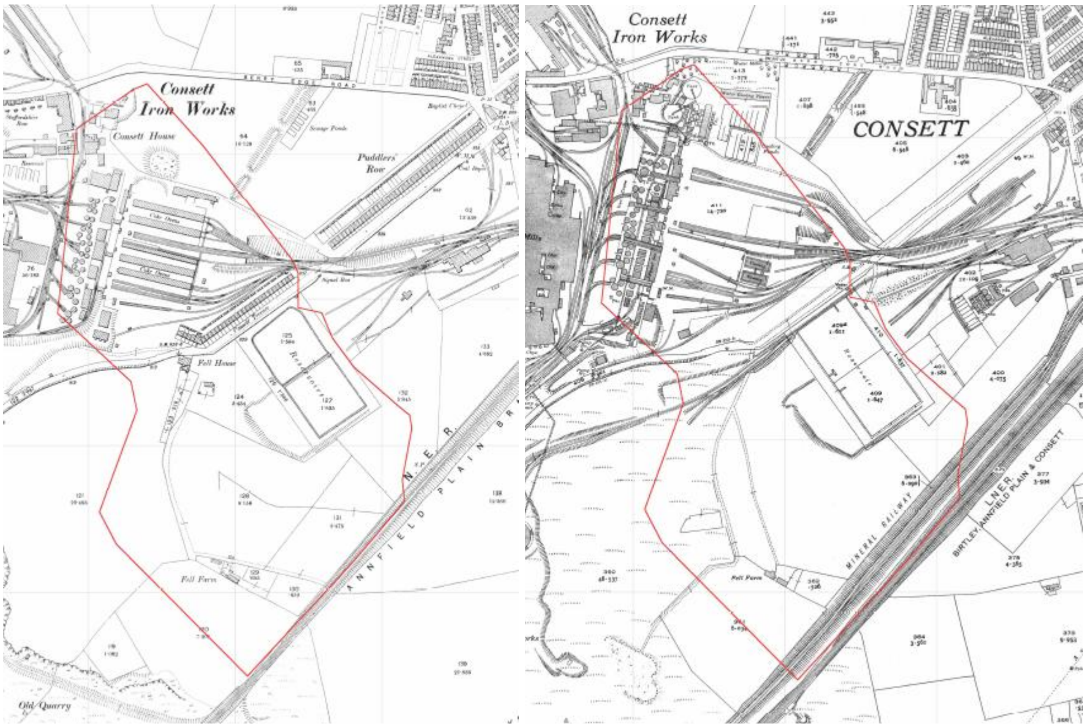
Geographical Setting and Climatic Conditions:

The site is elevated with respect to the surrounding land area and the former site of the ‘Grove Heaps’ at Howns Gill, focus of the aforementioned geochemical studies. It acts as a frost-pocket during cold weather, where vegetation may be fully covered by snow and any standing water can become frozen. The climate of the site is generally temperate, with average summer temperatures of 19˚C and average winter temperatures dropping to 6.2˚C. Average rainfall is around 643.3 mm/yr, a moderate level for the site’s latitude and elevation (period 1971-2000 Met Office).

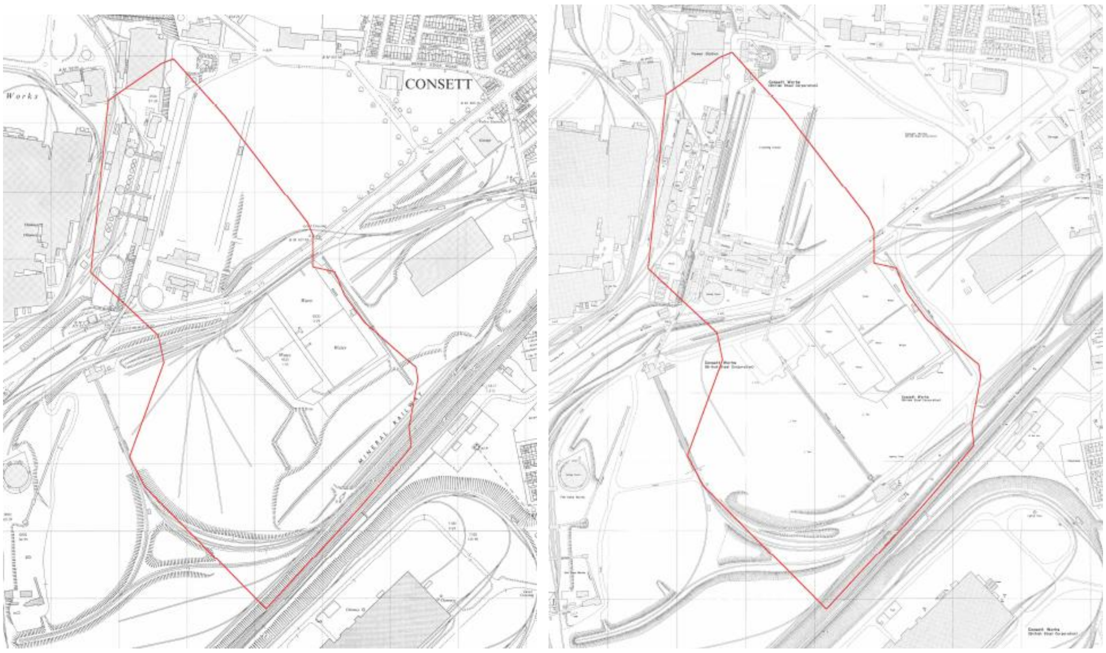
History:

As seen in Figures 16-18, and Figure 1, Page 2 of the appendix to this document, buildings and structures related to the Consett Iron and Steel works occupied the site from the 1850s to 1980s, when the works were demolished. Over this period, the site saw the progressive development of the coke ovens in the Upper Plateau Retail Site and progressive movement of the main works operations to the north west boundary of the site. In Figure 16a, it can be seen that a row of residential dwellings were located along the south eastern boundary of the site, forming the southern extremity of the settlement of Consett. These buildings and the houses which formed ‘Puddlers Row’ had been demolished shortly in to the 20th century.

No notable archaeological or historic activity aside from coal mining, which is discussed further in the following sections, is noted prior to the construction of the works. Prior to the opening of the iron and steel works, the area was farmed or forested. Since the demolition of the works, the site has been extensively re-landscaped.



Figures 16a and b – Area maps circa. 1896 and 1939 illustrating the approximate location of the study site (Source: GroundSure, 2008) (Source: Shadbolt Environmental)



Figures 17a and b – Area maps circa. 1961 and 1977-78 illustrating the approximate location of the study site (Source: GroundSure, 2008) (Source: Shadbolt Environmental)

Figures 18a and b – Area maps circa. 2002 and 2005 illustrating the approximate location of the study site (Source: GroundSure, 2008) (Source: Shadbolt Environmental)

With respect to variations in historic landscape, point heights were assessed for the Consett Works over the period of National Grid and Ordnance Survey mapping. Figure 19 illustrates variations in point heights between surveys in 1923 and 2005. These measurements illustrate variations in point heights across the east of the former works site in the order of 5-

10m, which is concurrent with the expected depth to which slag material was utilised as fill in the reclamation of the former works.

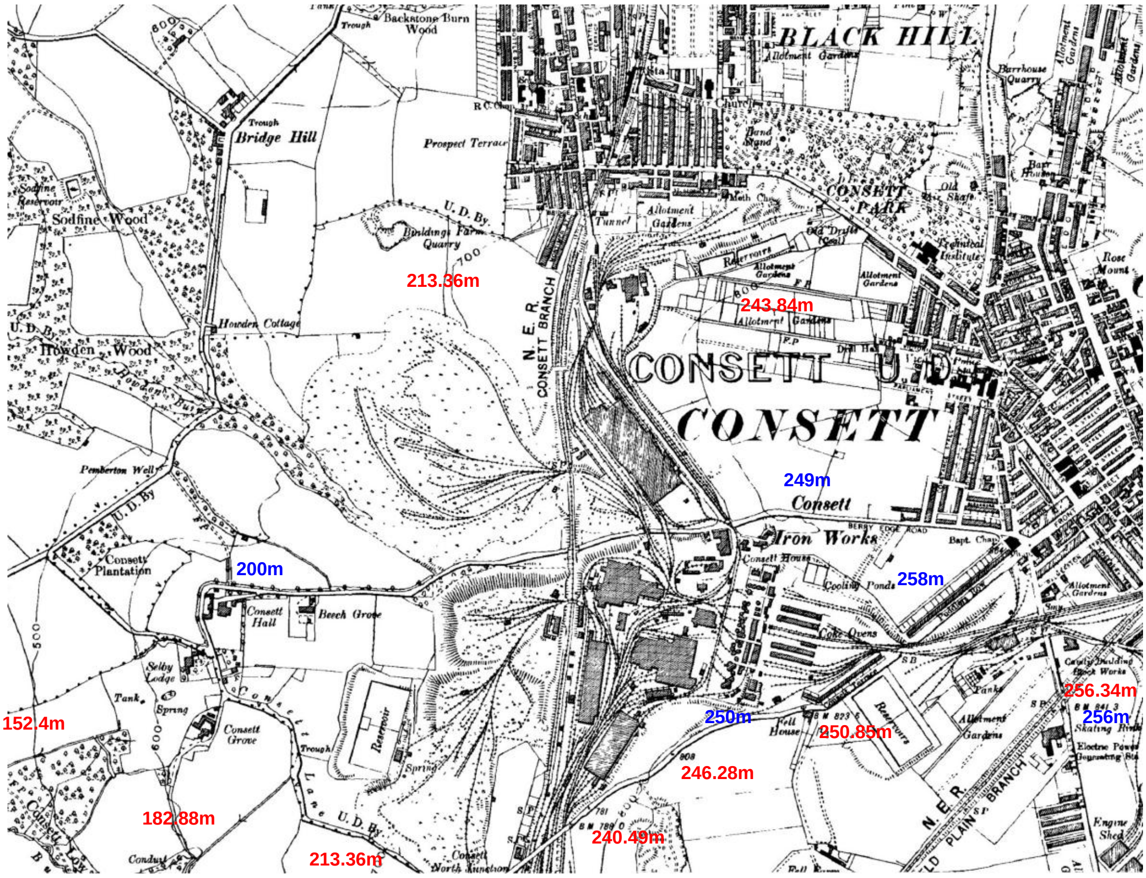


Figure 19 – Comparison between historic and contemporary spot heights. Red figures illustrate historic spot heights and contours (National Grid 1923) Blue figures illustrate contemporary spot height and contours (Source: Ordnance Survey (2005))

Geology:

Previous Site Reports and Drift maps (BGS 1:50,000, mapped extent: 406400, 548000 - 414020, 555620, as seen in Figure 20), show that the superficial deposits of the study area consists almost entirely of made-ground, superimposed to considerable depth upon superficial glacial deposits of sandy, gravelly clay. The overwhelming depth and spread of made ground across the study area is assumed to significantly reduce the impact that the underlying solid geology will have upon surface geochemical processes.

The bedrock underlying the site comprises of interbedded mudstone, siltstone, sandstone and coal seams, which make up the Carboniferous Coal Measures, Lower Coal

Measure geology of Westphalian age, familiar to much of north east England, overlying Millstone Grit. This stratigraphy is confirmed by BGS boreholes, locations of which can be seen in Figure 2, Page 3 of the appendix to this document. The orientation of the bedrock strata varies across the study site.

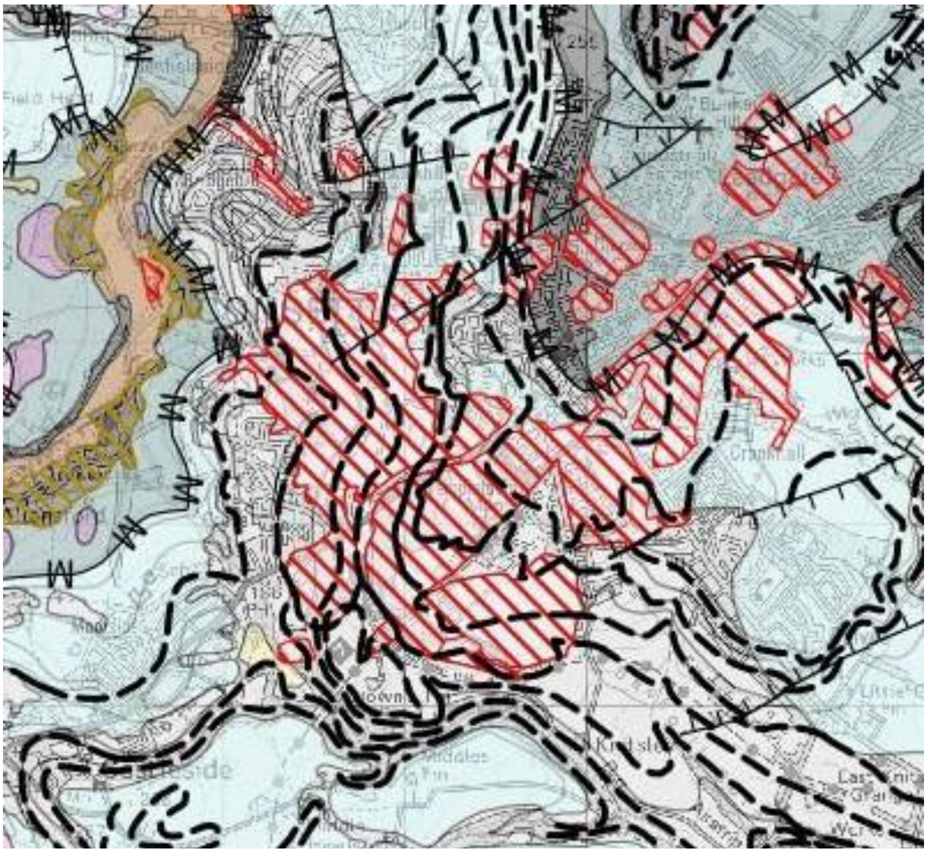


Figure 20 – Geological map of the area illustrating 'made ground' in red hatching, superimposed upon the underlying geology (coal seams (inferred) are indicated by black dashes) (Source: Edina Digimap)

Mining:

Geological maps indicate that four coal seams outcrop in the vicinity of the site, with potential, shallow mine workings associated with each. Mine works abandonment plans record the mining of the Busty, Three Quarter and Brockwell seams in the area of the works. Old workings may exist to the east and south of the Upper Plateau site, while the Coal Authority Mining Report illustrates the presence of a historic shaft to the east of the site, beneath Genesis Way as seen in Figure 21.

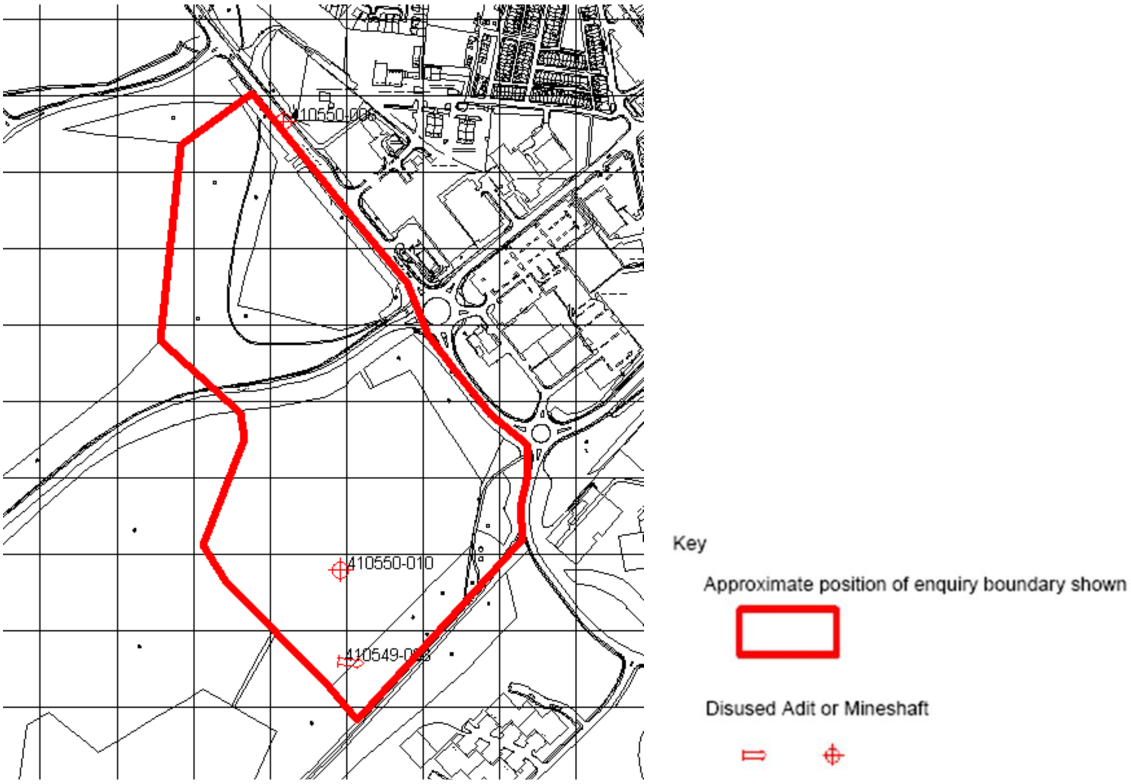


Figure 21 – Area map illustrating the approximate location of the study site and associated mine workings (Source: Coal Authority Report, 2008)

Unexploded Ordnance:

There is no specific reference made to the presence of unexploded ordnance at the site. Whilst there is the potential for many sites across the NE of England to have experienced air dropping of ordnance during the Second World War, the previous investigations carried out at the site, with respect to BGS activities, commercial works and deep trial pitting, would suggest that the area has already been surveyed and found to be safe for surface works.

Hydrogeology:

The Made Ground overlying the site is thought to be highly permeable, both in a primary and secondary nature. Coal Measures, as the solid deposits underlying the site, are classified as a minor aquifer, which is variably permeable due to the secondary nature of its permeability, through fractures. This is deemed to be important in local supply and contributes significantly to river base flow in the area. No Groundwater Protection Zones exist in the locality.

The patterns of groundwater drainage through the site are difficult to estimate. The Upper Plateau study area comprises of an upland region to the north, dipping steeply towards the Howns Gill Viaduct in the south, defining a strongly demarked watershed. The site is elevated with respect to the land to the south and east, therefore it should be assumed that the site will act as a watershed, with the direction of groundwater movement dominantly occurring to the south and east. It is noted in the Ground Investigation Report carried out by Shadbolt Environmental that ‘No water was encountered within any of the trial pits or boreholes and all of the investigation positions remained dry throughout the period of the ground investigation works’, suggesting that the water table at this point is very low.

Hydrology:

The nearest surface water is found in the form of a spring, 400m to the south west of the site. The Dene Burn is located 1km to the south west, and Howden Burn, approximately 1km to the west. It is thought that drainage from the site, via surface water drains, discharges in to the Howden Burn. No discharge consents exist within 500m of the site. Met Office records, up to 1990, record the mean annual rainfall for the area as 651mm. The Environment Agency Floodplain maps note that the site is not located in any area which may be at risk from flooding from rivers or the sea.

Contamination:

From Table 11 it can be seen that a number of site specific contamination parameters have been formulated. It may be noted that in this context calcite is included as a ‘contaminant’ source. Contaminant analysis is carried out with an understanding of present and future land-use at a study site, in order to assess the likelihood of pathway availability in the contamination conceptual model, Figure 22. The site has, therefore, been assessed with respect to possible residential (relatively sensitive) and commercial (relatively insensitive) land-use proposals. Contaminant analysis at the Upper Plateau site demonstrates the presence of one analytical value in excess of Shadbolts Contamination Tier One Screening Values (TSVs) recommended maximum values for a commercial development, the value for lead determined at Trial Pit 19 in the south west of the site.

Table 11 – A summary of contamination elements assumed for the site (Source: Shadbolt Environmental)

Sources	**Pathways**	**Receptors**
• Acids from steel finishing works • Metals and hydrocarbons from the railway sidings • *Calcite ($CaCO3$) – a white substance which can cause discolouring and harden waters* • Potential mineral oil and PCB contamination from historical electrical switchgear • Possible contamination from drums, storage tanks on site • Asbestos from construction material and demolition materials • Potential from any activities that may have been undertaken on the site, prior to the development of the site which have not been identified during this desk top study • Mine workings and Made Ground could be a source of land fill type gases	• Inhalation of dust and volatile contaminants • Direct contact (ingestion and dermal contact) • Leaching of contaminants and migration through permeable soils • Groundwater migration • Migration through service conduits • Migration through the local drainage network • Leakage from site drainage • Surface water run-off • Ground gas migration • Plant root uptake	***Human Health*** • Current site users • Future site users (assuming residential use) • Site development workers ***Environmental*** • Local aquifers • Local surface waters • Flora and fauna • Buildings and underground services

A moderate risk of contamination, with respect to the analysis of a source-pathway-receptor model, is advised under Part IIA of the Environmental Protection Act 1990. No pollution incidents, BGS recorded landfill sites or radioactive sites are present in the area. No environmentally protected sites or sites of special scientific interest are present in close proximity to the study area.

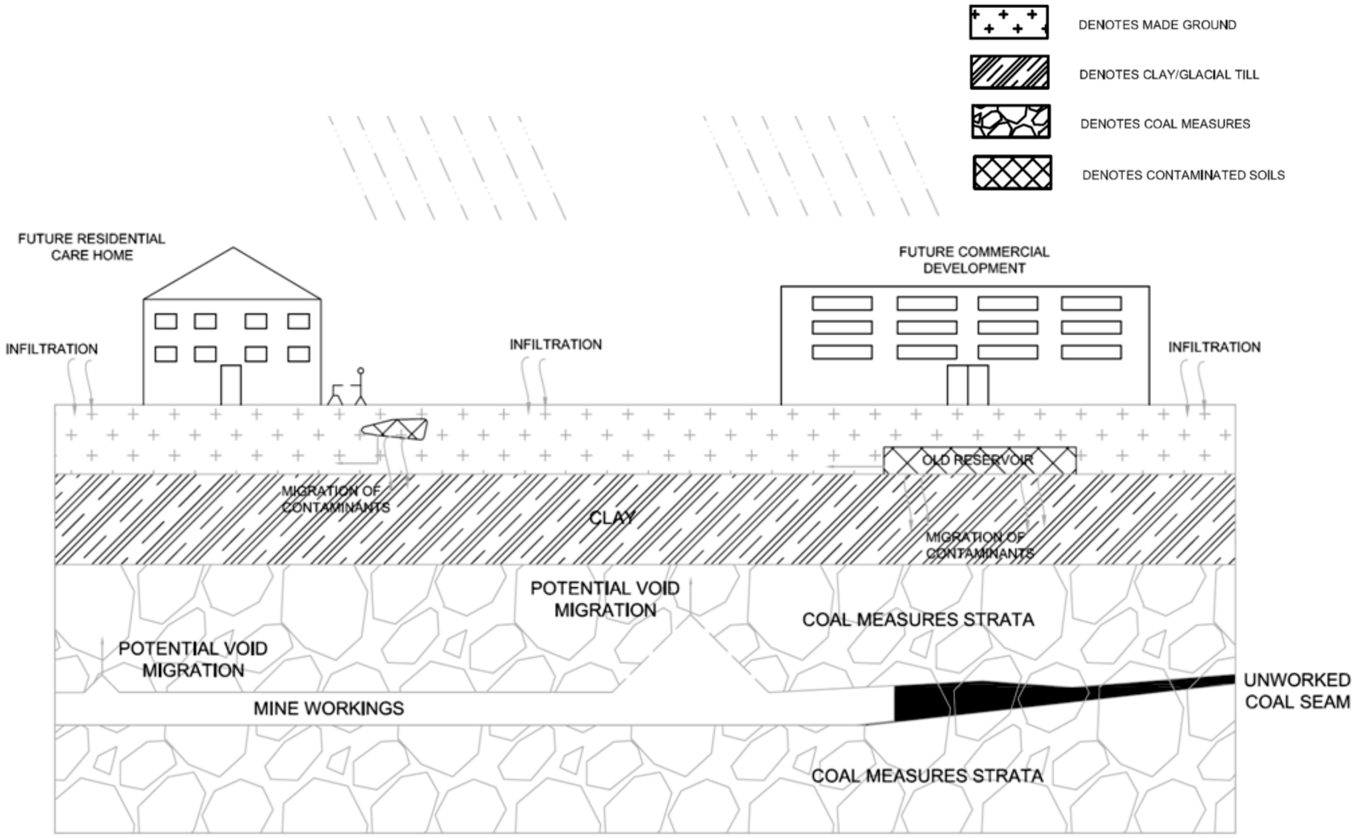


Figure 22 – Conceptual model of potential contamination processes at the Upper Plateau and Derwent View Sites (Source: Shadbolt Environmental)

Environmental:

As noted by the Penn Associates Ecological Survey (2008), environmental considerations at the study site are limited. The Upper Plateau area consists of rough, open ‘self-improved neutral grassland’, consisting of typical ‘restoration’ grasses and common shrubs, which is not put aside as a reserve. Larger vegetation species are infrequent within the site, with trees confined to protective / ornamental planting at the boundaries of the site.

It is noted that a number of potential habitats exist at the Upper Plateau, including foraging location for bats, reptiles and other small mammals. The semi-managed grassland of the Upper Plateau site provides an ideal habitat for a wealth of insect species. The presence of ground-nesting birds is also considered likely, with the confirmed presence of meadow pipits, which are assigned an ‘amber’ conservation status by the RSPB due to their recent population decline and ‘unfavourable European conservation status.’ There are no recorded sightings of protected animal species. None of the areas surrounding the site are designated as SSSIs or wildlife reserves (local or national) within a 2.5km radius.

Geotechnical:

Geotechnical issues identified onsite consist of shallow mine workings and associated remains, the presence of buried concrete foundations and expansive steel slag. Expansive steel slag is considered to be a more significant issue in basic steel slag, which is deposited over the Derwent View site, than the basic oxygen slag deposited across the Upper Plateau site, due to the higher proportions of ‘free oxides’ (CaO and MgO) present in this material. It is noted that evidence of ‘fused slag’ is found at numerous points across the site. Fused slag is thought to be the result of improperly cooled slag during the operation of the works. Anecdotal sources suggest that slag was frequently deposited on to the heaps in a molten state, leading to the fusing of the material in to large, impenetrable blocks, which were subsequently remobilised across the site during the landscaping processes of the 1980s.

Urban Services:

Urban services are present in the area directly surrounding the site. The surrounding area is not associated directly with large conurbations, but a number of smaller settlements and commercial buildings are located within the study area, with ongoing developments to the north. The Upper Plateau site is set away from neighbouring residential areas. A sewage main is known to run below the site, at a depth of approximately 7m bGL (Mark Short, ACE Civil Engineering). Electricity cables supplying street lighting are present around the perimeter of the site, however, the implementation of CAT (cable avoidance tool) surveying at the site was advised to illustrate the presence of any electrical services directly beneath the site.

Future Site Development

The Upper Plateau site will be developed to house a commercial development, in the form of a large retail buildings and hard standing parking areas. Outline remediation measures have been proposed for this development with respect to the geotechnical engineering which is likely to be required to ensure foundation stability on the heterogeneous and potentially expansive site.

3.1.3 Derwent View (NZ10400, 50100)

According to the data included in previous desk studies, the Derwent View site is comparable to the Upper Plateau retail site in all respects, aside from those listed below:

Location and Description:

The site is roughly rectangular, covering approximately 9 hectares, bounded by the A692 to the north east. Site topography varies slightly, with aOD 258m in the north east dropping to aOD 250m. The site is relatively flat, with a steep slope adjacent to the A692 accounting for the majority of the noted topographical variation.

Figure 23 – Aerial photograph of Derwent View Site (Source: Shadbolt Environmental)

History

Derwent View marks the location of the historic reservoirs associated with the Consett Works. These reservoirs were present throughout the history of the works and are likely to have supplied the coke works and furnaces. The reservoirs are likely to have been capped at their base with an impermeable material, such as concrete, in order to prevent leakage of water in to the relatively permeable surrounding ground. No notable archaeological or historic activity aside from coal mining, which is discussed further in the following sections, is noted prior to the construction of the works. Prior to the opening of the iron and steel works, the area was farmed or forested. Since the demolition of the works, the site has been extensively re-landscaped.

Mining:

Geological maps indicate that four seams outcrop in the vicinity of the site, with potential, shallow mine workings associated. Mine works abandonment plans record the mining of the Busty, Three Quarter and Brockwell seams in the area. Old workings may exist to the east and south of the site, as illustrated in Figure 21, page 71, while the Coal Authority Mining Report illustrates the presence of two historic features within the site boundaries, a disused adit and a disused shaft. No evidence of these features or associated works has been noted at the ground surface.

Contamination:

From Table 11, in the Upper Plateau desk study, it can be seen that a number of site specific contamination parameters have been formulated. A number of sampling sites across the Derwent View site illustrate contaminant values in excess of Shadbolts Contamination Tier One Screening Values (TSVs), as illustrated in Table 1, Page 19 of the appendix to this document. A number of values were also in excess of the recommended maximum values for a commercial development. Whilst it is iterated that this does not necessarily illustrate a contamination risk to the surrounding environment or human health, the conduct of further works at the site must be informed by this data. A moderate risk of contamination, with respect to the analysis of a source-pathway-receptor model for the site as a whole, is advised under Part IIA of the Environmental Protection Act 1990. No pollution incidents, BGS recorded landfill sites or radioactive sites are present in the area. No environmentally protected sites or sites of special scientific interest are present in close proximity to the study area.

Urban Services

The presence of sewage main at depth of approximately 7m should be assumed for this site. CAT (cable avoidance tool) surveying of the site would illustrate the presence of any electrical services directly beneath the site.

Future Site Development

Commercial and residential developments have been proposed for the Derwent View site. Plans for future site development are mixed commercial, residential and leisure, with significant geotechnical remediation recommended prior to construction. Outline remediation measures have been proposed for this development with respect to the geotechnical engineering which is likely to be required to ensure foundation stability on the heterogeneous and potentially expansive site.

3.1.4 Desk Study Conclusions

From the information collected in the Desk Study, a number of conclusions were drawn with respect to the completion of further study at the site:

- *History:* Historically, both the Upper Plateau and Derwent View sites have served active roles in the operation of Consett works. The Upper Plateau site was not a historic site for slag disposal, but marks the location of the coke ovens, meaning that the present cover of slag material is likely to have been almost entirely emplaced during landscaping in the 1980's. The Derwent View site presents a more complex ground condition, as it was previously the location of the works reservoir. It is noted that this reservoir may have been concrete lined, and its historic extent is indefinite. The overburden at Derwent View is also likely to have been emplaced during the 1980's, therefore, ground conditions at both sites are likely to be recent.
- *Geology:* The sites are geologically similar, with overlying deposits of Made Ground superimposed upon superficial clays and gravels, or directly emplaced upon the mudstone or sandstone bedrock of the coal measures formation. The Derwent View site exhibits a much smaller variation in thickness of Made Ground, with few localities exhibiting presence to a depth >5m. A number of testing locations at the Derwent View site do not exhibit the presence of overburden, therefore, it was deemed that the Upper Plateau site was likely to prove more reliable in soil sampling.
- *Mining:* Mining reports suggest that whilst both sites are likely to be underlain at depth by coal workings, the Derwent View site possesses two locations at which shafts / adits have been identified, which were deemed to have the potential to interrupt geophysical surveying. No specific evidence of mining is noted at the Upper Plateau site.

- *Hydrogeology:* The hydrogeology of the sites is relatively similar, with groundwater draining to the south and west. Both sites are elevated in respect to their surroundings, therefore, the pattern of groundwater drainage is thought to follow the slope to the south west. Neither site is known to possess specific variations in hydrogeological setting.
- *Contamination:* Whilst minor contamination issues are possible for both sites, little of the investigation data for the Upper Plateau site breaches the Contamination Tier One Screening Values Version (TSVs), derived from Contaminated Land Exposure Assessment (CLEA) Soil Guideline Values (SGVs). A number of testing locations at the Derwent View site exceed the recommended TSV values, therefore, it was proposed that these sampling areas be avoided for the purposes of this study.
- *Environmental Considerations:* Neither the Upper Plateau or Derwent View sites present sensitive environments or protected habitats. Both sites primarily consist of semi-managed grassland, therefore, soil sampling should be relatively simply implemented. The Upper Plateau site was deemed likely to possess a number of wildlife habitats, with birds nesting in the long grass and other small mammals exploiting the site, which should be avoided during site works.
- *Geotechnical:* Fused slag may be present at some points across both sites, which had the potential to disrupt soil sampling. It was also deemed that shallow concrete and fused material at both sites posed potential problems for geophysical surveying, however, the comparatively low persistence of these materials during ground investigation at the Upper Plateau site was favourable.
- *Urban Services:* The presence of urban services at both sites was deemed to be highly unlikely. Comments from ACE Civil Engineering suggest the potential for the presence of a sewage main at approximately 7m depth, which is significantly deeper than the necessary soil sampling depth. There are a number of land drains present at the site,

which have been installed at various historical points, in order to divert surface runoff from roads and developments to the north and east of the site, however, these were not thought to pose any concern for the study.

- *Future Site Development:* Neither site was at risk of being imminently developed over the period of study, therefore this was not considered to be a determining factor in selection for this study.

3.1.5 Preliminary Site Investigations

Preliminary investigations were carried out throughout the period between December 2008 and May 2009. It was decided that the former works area identified in Figure 1, page 16 of this report, is too large to be fully surveyed to a satisfactory extent, therefore, it was decided that walkovers and initial sampling be conducted to define a more suitable area of focus. These field visits were mainly intended to investigate the Upper Plateau and Derwent View sites in order to identify the areas which would be most suitable for further study.

December 2008

In December 2008, an initial visit to the site was carried out in order to observe the site referenced by Mayes *et al.*, (2008), the location of which is illustrated in Figure 8, page 41. Hard pans of calcium carbonate, illustrated in Figures 24a and b, were observed as a deposit of the shores of the calcic, alkali lake at the Dene Burn. This lake sits at the south eastern extremity of the former works; water draining to the lake passes through an artificial drainage system within the notably steep banks of the historic ‘Grove Heaps’.

Figure 24a and b – Calcium carbonate on the shore of the alkali lake and ‘hard pans’ visible on the ground surface close to Howns Gill Viaduct (Carla Washbourne, December 2008)

March 2009

Field investigations carried out in March 2009, using dilute hydrochloric acid, found that calcium carbonate was actively forming on large fragments of slag at the soil surface and below the surface, as illustrated in Figures 26a and b. Four areas along a SW-NE transect of part of the works site, indicated in Figure 25, were sampled with the use of a hand auger and a spit, seen in Figure 26b. It was noted that the area had been capped to a shallow depth with clayey topsoil. The area was deemed unsuitable for further investigation due to the high proportion of large fragments of slag within the Made Ground which would hinder sampling efforts.

Figure 25 – Location of sampling traverse, with auger sampling points indicated (Source: Google Earth)

Figure 26 a and b – Calcium carbonate at ground surface (Carla Washbourne, March 2009)

May-June 2009

Two regions in the north of the site, illustrated in Figure 27, were selected as the main focus of this report due to a wealth of previous site reports and recommendations. The Upper Plateau site has been subject to substantial previous geotechnical and environmental surveys and consists of rough grassland with freely excavatable soils. A CAT survey was undertaken which confirmed the lack of buried electrical services across the site. Derwent View is located to the south of the Plateau site, and consists of rough grazing, with cropped grass.

Figure 27 – Location of 1: Upper Plateau, 2: Derwent View (Source: Google Earth)

Plates 28 a and b – a, Apparatus for preliminary fieldwork with capped borehole in foreground, b, Excavations at the Upper Plateau site (Carla Washbourne, May 2009)

3.2 Site Survey and Sampling

It was decided that field work would be concentrated upon the Upper Plateau site due to factors discussed in the desk study conclusions and accessibility issues when compared to the Derwent View site. The Derwent View site is frequently utilised for sheep grazing, therefore would not be ideal for geophysical surveys due to the potential for interference with livestock.

3.2.1 Initial Surveying

A topographic survey was carried out in order to catalogue surface features at the site, such as capped boreholes and evidence of previous excavations. These points were then compared with figures acquired during previous site reports, in order to tally further survey and sampling information with known reference points.

The Upper Plateau site was electronically surveyed, in order to ensure that intrusive works would not cause disruption to existing features or services. A CAT (cable avoidance tool) survey of the site was completed in order to determine the presence of any shallow, electrical services which may have interfered with sampling at the site, or created anomalies on geophysical surveys.

Assessment of capping depth was carried out by test pitting. Trial pits were hand-dug with the use of pick-axe and spit, in order to enable surveying of the upper soil profile of the site. It was determined that ‘clean cover’ capping at the site was negligible, in the order of 0-50mm, therefore sampling of the full soil profile should be carried out.

3.2.2 ***Vegetation and Ecological Surveying***

A vegetation density survey was carried out, with the implementation of a randomly distributed quadrat survey. A randomised sampling method was used to cover the study site without biasing the results to any particular region, as it was noted that variation in the ground cover species such as clover occurred unpredictably across the site. It was decided that at least one quadrat survey would completed in proximity to each proposed sampling location.

Percentage cover, notable changes in species distribution and overall vegetation diversity were noted as significant knowledge requirements in the design of a vegetation survey methodology, determining the selection of a quadrat survey as an effective method of data acquisition. A $1m^2$ quadrat grid was utilised, with vegetation density assessed for ground cover and under-storey, equating to a percentage ground cover in some regions which exceeds 100%. These have been normalised to within 100% for the purposes of this study.

With respect to species identification, the vegetation survey methodology employed in this survey took significant reference from the Penn Associates Ecological Survey, November 2008. This commercial survey was carried out in November 2008, whilst the survey utilised in this report was carried out over summer 2009, therefore, small seasonal differences in vegetation species were visible.

The presence and number of animal species was noted by means of a tally of common species sighted during site visits, in order to qualitatively assess the population size and assure that breeding habitats were not disturbed during field work. Existing habitats, noted in the Penn Associates Survey were assessed in reference to the present site conditions. No evidence of protected species was noted during site visits.

Vegetation and Ecological Survey Methodology

1. A 1m^2 quadrat was randomly thrown to select two survey sites within a 50m radius of each sampling location illustrated in Figure 29
2. The ground cover, as a percentage of the quadrat area, was calculated at each of the sample locations
3. Prevalent vegetation species were recorded with reference to Penn Associates Ecological Survey, November 2008
4. The evidence of bird and animal habitats within each quadrat was noted, including the presence of burrows and spoor.
5. Sightings of birds and animals were recorded as a tally throughout fieldwork

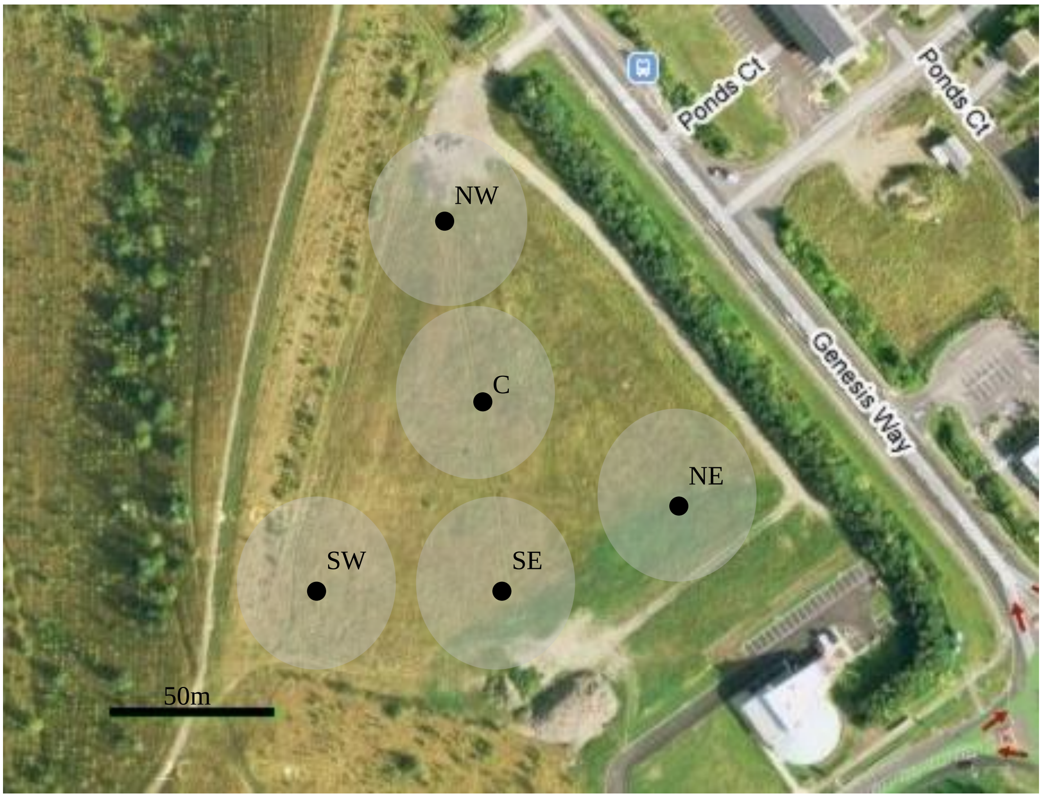


Figure 29 – Upper Plateau Sampling Locations (Source: Google Earth)

3.2.3 Geophysical Surveying

Depth profiles and sub-surface material distribution were assessed with the use of a Syscal Pro Switch 72 fixed array resistivity system. The use of resistivity equipment was deemed to be the most potentially effective method of differentiating layers within a ground profile where fused slag, concrete and ferro-metallic remains were likely.

The original transect model proposed the use of three transects, as illustrated diagrammatically in Figure 30, in order to attain the maximum potential for site coverage and correlation of data with points utilised in previous investigations. The central transect, running N-S across the site, a second transect running E-W across the site and a third transect following the eastern boundary of the site, in order to correlate findings with known locations of borehole and trial pits associated with previous investigations. The field model of the transects ran much to this plan, with the three transects implemented during a single days work at the study site.

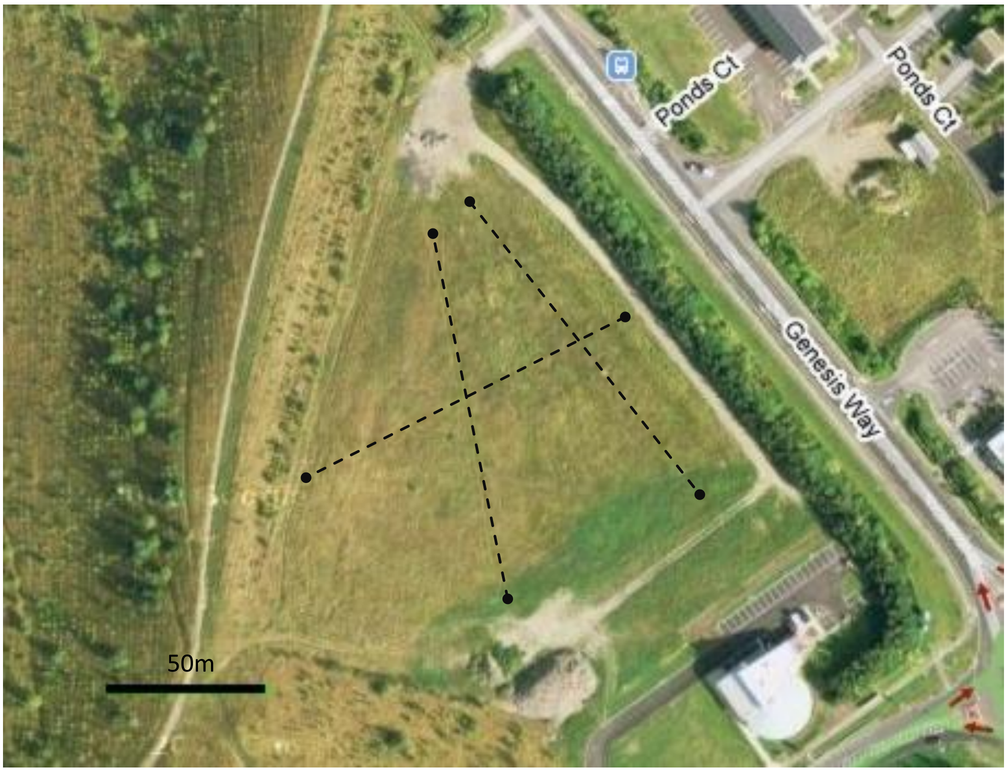


Figure 30 – Aerial view of retail site, with proposed geophysical transect locations (Source: Google Earth)

Resistivity Survey Methodology:

The full methodology employed during the geophysical survey of the Upper Plateau site is included in below, modified from the original operating procedures supplied by Iris Instruments, the makers of the Syscal range. The methodology above documents the significant procedural points within the completion of the survey and subsequent data analysis.

1. 'Virtual models' of the desired transects were created using ElectrePro software, which were then downloaded on to the Syscal Pro Switch 72 apparatus. A double dipole array was selected.
2. Cables were progressively laid across the survey area as illustrated in Figure 30, with new cable positions laid once a transect had been completed
3. Metal electrodes were hammered in to the ground at 5m intervals along the survey section and connected to nodes on the cables using crocodile clips
4. GPS apparatus was used to fix the transect points covered by the resistivity survey, in order to allow a more accurate correlation of subsurface features between the transects
5. The Syscal Pro apparatus was connected to the flying end of the cable and the virtual array activated, with power supplied via an external car battery. Data collection programme continued for approximately 20 minutes
6. Data was downloaded on to a laptop for further analysis
7. Data was analysed and filtered using Prosys software
8. Data was manipulated using RES2D inv software
9. 2D pseudo sections of the site were created

3.2.4 ***Sample Collection***

Desiccated ‘pans’ of calcium carbonate were noted at the soil surface during early site walks at Howns Gill, however, these are not present across the majority of the site, where calcium carbonate in present within the soil matrix, but visually undetectable at the soil surface. It was decided that an effective sample collection methodology would need to take this in to account, as well as the potential for unfavourable or fused ground conditions to be encountered.

As noted in the literature review to this document, the objectives of the sampling strategy employed at the site were seen to be threefold:

1. To confirm the elevated presence of calcium carbonate at the study site – soil samples from the works site were tested for reaction in the field with dilute HCl (0.3M), qualitatively suggesting the presence of calcium carbonate. A control sample was collected from an area of gassed, public land close to Jesmond Dene, Newcastle upon Tyne, a site with similar solid geology and no record of made ground presence, to allow the comparison between calcium carbonate concentrations in naturally derived soils and the soils at Consett works
2. To determine the level of spatial variation in calcium carbonate across the site – a suite of five sample locations were selected, with even geographical distribution across the Upper Plateau site. Samples were also collected to the north of the Derwent View site and at the Howns Gill site to the south, in order to determine variation in calcium carbonate content in the larger-scale geographical context of the site.
3. To address the nature of variation in calcium carbonate content at increasing depth below the soil surface - soil samples were collected at varying depth at each of the

geographical sample locations, in order to identify patterns of calcium carbonate formation with depth

Window samples, recommended by the results of the initial survey and test pits, were carried out in order to confirm the presence of calcium carbonate within the soil horizons and determine the depth of occurrence, thickness, extent and habit. In order to address documentary concerns that calcium horizons are often found below BS soil survey depths, sampling would ideally reach a maximum range of approximately 1–2 metres below the vegetated surface. Given the compacted nature of the site, it was decided that a sample depth of approximately 300mm would be sufficient to investigate the formation of calcium carbonate within the range recommended by Roger (1999) and Jenny (1980) without the use of mechanical excavators. Samples were taken systematically across the site in order to determine the spatial variation of these horizons.

It was necessary that the soil sample material be preserved for further laboratory testing, therefore was bagged and labelled onsite. Samples of fine soil containing calcium carbonate and slag were to be assessed by calcimeter testing and petrographic analysis respectively, therefore *in situ* soil samples had to be collected. Window pits were stratigraphically sampled in order to plot the occurrence of vertical variations in calcium carbonate within the soil horizon. A methodology can be seen overleaf, documenting notable points adhered to in sample collection.

Sample Collection Methodology:

1. Geographical sample location were determined as illustrated in Figures 31-33, in order to attain maximum coverage of the site
2. At each site the turfs were cut back and a small window pit, measuring 200-300mm in diameter was cut, with the use of a spit and pick axe
3. The section was cut back and cleaned with trowel
4. A tape measure and markers were used to separate the soil profile exposed in to 40mm sections
5. Pre-marked sample bags were prepared, documenting location and depth of sample
6. Samples of approximately 20g were taken across each marked section, with the use of metal and plastic spatulas. Samples were taken from the base of the excavation upwards, in order to reduce the risk of contamination from descending material
7. Sample bags were sealed and stored in a secure location
8. All excavations were re-instated to original level with soil infill and turf
9. Samples were dried for laboratory investigation. 15-20g were air dried in labelled, silicone containers
10. Samples were returned to labelled bags
11. A 'control' soil was collected from a location separate from the Consett works, illustrated in Figure 33. This sample was processed in the same manner as the Consett works samples, using steps 1-10.

Fieldwork and sample collection sessions took place on a number of separate occasions and represented a number of full days work onsite. Field assistants were utilised during these works, aiding in the collection of samples and in addressing potential 'lone worker' issues with respect to the project risk assessment, discussed in the following sections.

Figure 31 – Upper Plateau Sampling Locations (Source: Google Earth)

Figure 32 – Additional sample locations, with limit of Upper Plateau and Derwent View sites illustrated (Source: Google Earth)

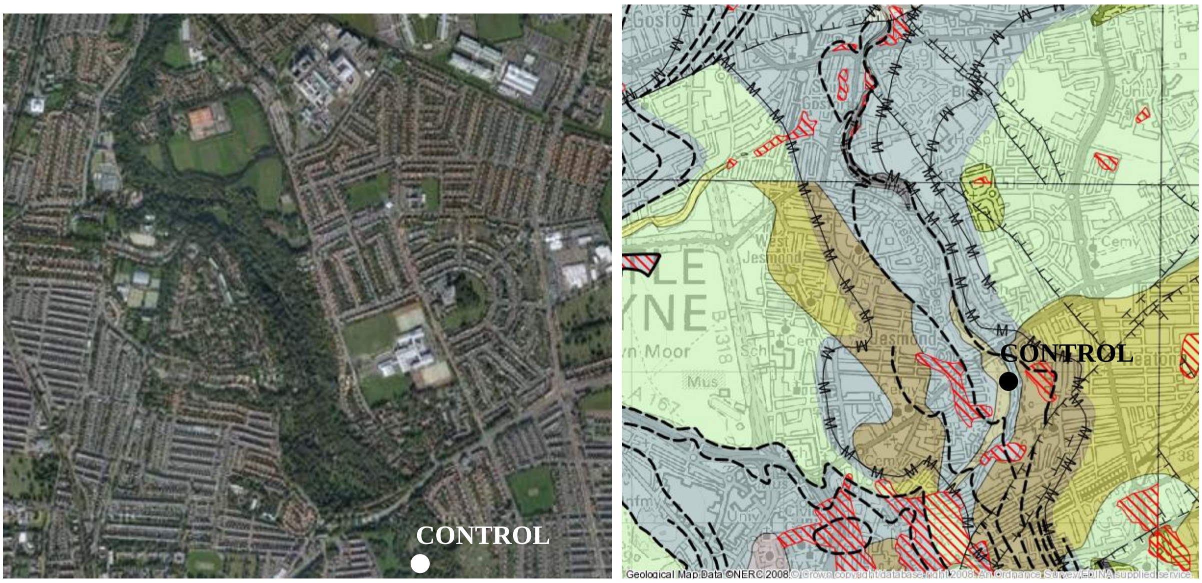


Figure 33 – Location of Control Site, Jesmond Dene Newcastle upon Tyne (Source: Google Earth / Edina Digimap)

Table 12 – Soil sample catalogue

Sample Location	**Sampling Frequency (mm)**	**Maximum Sampling Depth (mm)**	**Total Samples Collected**
NW	40	280	7
NE	40	320	8
CENTRE	40	280	7
SW	40	320	8
SE	40	340	9
SURFACE	-	-	6
DERWENT VIEW	40	200	5
HOWNS GILL	40	200	5
CONTROL	40	280	5

Total Samples	60

3.2.5 Method Statements and Risk Assessment

The selected study areas, Upper Plateau and Derwent View, are managed by Project Genesis, a co-operative who oversee the management, retention and sale of the former Consett works land. All Methodologies were, therefore, constructed with respect to the requirements and advice of this overseeing body, in order to ensure that the safety and applicability of all site methods.

Method Statements, including Risk Assessments, were completed prior to the start of investigative works at the Project Genesis sites. These documents were provided to the School of Civil Engineering and Geosciences, ACE Civil Engineering and Project Genesis and can be seen attached in pages 28-42 of the appendix to this document.

A Civil Engineering and Geosciences Departmental Risk Assessment was also completed. A number of specific Risk Assessments were completed, which can be seen in pages 23-27 of the appendix to this document. These risk assessments illustrate the contemplation of potential risks, by project section, and include mitigation measures.

3.3 Laboratory Analysis

It was decided that a smaller suite of complimentary procedures recommended in the literature review be carried out to fulfil the most pressing project objectives.

- Calcimeter testing would be carried out on all fine grained (<2mm) samples taken from the site, in order to determine their calcium carbonate content by percentage mass.

- Petrographic microscopy would be carried out on a limited number of large slag samples, taken from the surface of the site, in order to determine the variation in the nature of the slag and calcium carbonate formation trends which occurred. A qualitative analysis of slag constituents would also be undertaken. Scanning electron microscopy would be applied to the samples, in order to view the structure of the slag and its associated formations.

- Isotopic Ratio Mass Spectrometry (IRMS) would be carried out on a maximum of ten fine grained (<2mm) samples, which had illustrated high calcium carbonate contents in calcimeter testing, in order to determine whether the calcium carbonate they contained had been derived through organic, hydroxylation or lithogenic sources.

3.3.1 Calcimeter

Calcium carbonate presence and its quantitative content in sample material were assessed using Eijkelkamp calcimeter equipment available within Newcastle University geotechnical laboratories. 49 samples in total were assessed from excavations at the Upper Plateau and Derwent View sites, with a further 5 from Howns Gill and 6 samples analysed from surface features. 5 samples were analysed from the control site, a glacially derived soil outside of the suspected margins of influence of the Consett works. A full calcimeter methodology can be seen below.

Calcimeter Methodology:

1. Calcimeter equipment is calibrated, with the use of two suites of blank samples, containing known volumes of and water, 20ml and 80ml, reacting with 7ml of hydrochloric acid and two suites of control samples containing a known mass of calcium carbonate, 0.2g and 0.4g, reacting with 7ml of hydrochloric acid.
2. Soil samples were prepared by hand crushing, with the use of a pestle and mortar
3. Samples were sieved to a maximum particle size of 2mm
4. Samples were returned to dry, labelled containers
5. Approximately 2g of sample were weighed in to a weighing boat
6. The sample was poured in to a clean conical flask, and mixed with 20ml of de-ionised water
7. 7ml of 4mol/l hydrochloric acid was measured in to a reaction vessel, which was lowered in to the conical flask with the use of tweezers, taking care to avoid premature mixing of solutions
8. Steps 5-7 were repeated with four further samples

9. With the measuring burette taps open, the bungs connected to the inlet tubes of the calcimeter were wetted and fitted securely to the necks of the conical flasks
10. The measuring burette was set to a value of 3ml, and the taps set to the closed ‘measuring’ position.
11. In turn, each flask was tipped and agitated so that hydrochloric acid from the reaction vessel entered the sample solution.
12. The buffer vessel was moved in response to any gas emitted, so that the water level in the measuring burette and buffer vessel did not differ by more than 3ml at any point
13. Readings were taken from the burette at 10 minutes, 20 minute and 30 minutes from the initiation of the reaction
14. All waste solutions were disposed to a designated waste bottle. Equipment was cleaned using de-ionised water and dried in heated drying cabinets.
15. Steps 2-14 were repeated for additional samples.
16. Sample data was manipulated to determine the presence of calcium carbonate as a percentage of the bulk weight of each sample
17. Reproducibility was determined experimentally by the analysis of five identical samples, in order to assess the homogeneity of the sample
18. Equipment error was calculated by the comparison of blank calibration runs

3.3.2 Petrographic Microscopy

Petrographic slides were externally prepared by Durham University from slag samples collected at, and below, the surface of the Upper Plateau site. Six thin section slides in total were prepared. These slides were studied with the use of a light microscope and scanning electron microscope in order to determine the crystallographic nature of the slag material.

Petrography Methodology:

1. Petrographic analysis was carried out using a James Swift Microscope at 10x magnification. 6 samples in total were assessed
2. Samples were analysed using transmitted light, transmitted light with crossed polars and direct light
3. Samples were described with reference to mineral descriptions recommended by MacKenzie (2003):
    - Shape and habit
    - Colour
    - Colour change in plane polarised light
    - Presence of cleavage
    - Refractive index
    - Interference colours with crossed polars
    - Extinction position
    - Twinning and zoning
4. Areas of interest for SEM analysis were identified, including regions in which calcium carbonate was detected to a significant extent and regions in which open vesicles were present within the mineral structure

SEM Methodology:

1. SEM analysis was carried using an FEI XL30 Environmental Scanning Electron Microscope (ESEM) – with Field Emission Gun (FEG)
2. Analysis was carried out using a Rontec system
3. The application of an Environmental SEM allowed the direct analysis of thin sections without the need for sample coating
4. Three slides were selected for SEM analysis
5. Samples were mounted in sample chamber and equipment was activated
6. Samples were analysed using a 20kV electron beam, under low vacuum
7. All samples were analysed using back-scattered electrons, an analysis technique which allows investigation of the subsurface of a sample as illustrated in Figure 34 below
8. Qualitative elemental analysis was carried out with the use of characteristic X-ray detection from the deep sub-surface of the sample as illustrated in Figure 30
9. Scanning analysis was carried out where large, homogeneous areas were detected

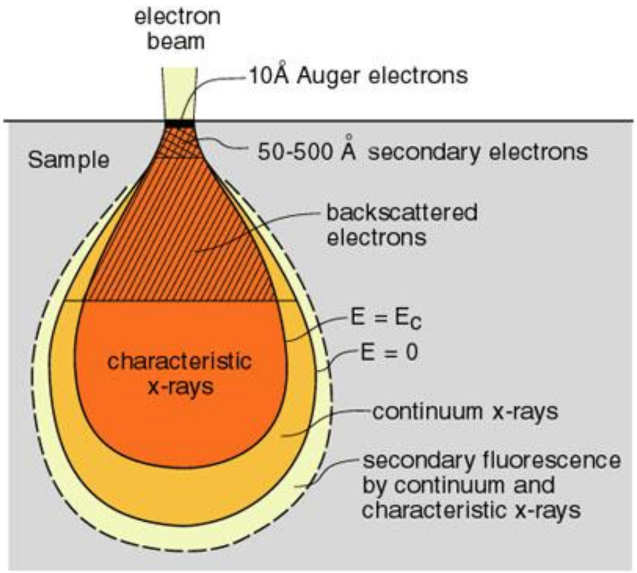


Figure 34 – Diagram of emission zones used in SEM analysis (1 angstrom (Å) = 0.0001 microns (µm)) (Source: Northern Arizona University College of Engineering and Natural Sciences)

3.3.3 Isotopic Ratio Mass Spectrometry

Isotopic analysis of selected soil samples was carried out in order to determine critical fractionation values of carbon and oxygen isotopes in any calcium carbonate present. This fractionation procedure was carried out using specialised IRMS apparatus and was carried out externally by a commercial laboratory Iso-Analytical Ltd., Crewe. 10 samples in total were assessed. The samples were subject to Carbon-13 and Oxygen-18 analysis, with 20% duplication during analysis, in order to determine the methodological repeatability. Table 13 illustrates the location, depth and mass of samples sent for IRMS analysis. Calcium carbonate content (% by mass) is also documented, derived from the results of calcimeter analysis.

A full IRMS methodology, provided by Iso-Analytical, Crewe, can be seen on pages 21-22 of the appendix to this document.

Isotopic Ratio Mass Spectrometry Methodology:

1. 10 samples were selected from those prepared for calcimeter testing (dried and sieved to 2mm)
2. Samples with a variety of calcium carbonate contents were selected for this analysis
3. Samples were weighed to approximately 1g, and sealed in labelled plastic vials. Exact analysis values can be seen in Table 13, page 110.
4. Samples were externally tested by Iso-Analytical using standard IRMS equipment, in accordance with the operating procedures detailed in pages 21-22 of the appendix to this document.
5. Results were returned in tabulated form and analysed using Microsoft Excel.

Table 13 – IRMS sample details and references for analysis

Sample Name	**Depth (mm)**	**Mass (g)**	**$CaCO_3$ (%)**
NW 1-4	10-40	1.56440	2.42
NW 12-16	120-160	1.52430	5.01
NW 20-24	200-240	1.52640	11.70
NW 24-28	240-280	1.60440	11.42
SW 1-4	10-40	1.53000	2.77
SW 16-20	160-200	1.57970	3.43
SW 28-32	280-320	1.52540	3.34
SE 1-4	10-40	1.56400	2.59
SE 16-20	160-200	1.57230	3.69
SE 32-34	320-340	1.65850	2.97

4. RESULTS

4.0 RESULTS

4.1 Field Results

Field results were acquired during works completed onsite during the preliminary site investigation, carried out in March, and throughout the site works which were carried out throughout May and June.

4.1.1 Field Testing

Acid testing in the field, using 0.3M Hydrochloric acid, illustrated the presence of reactive alkaline material, of which calcium carbonate is a typical example. This basic procedure was used to infer the presence of calcium carbonate across the site, from shallow depth. A number of large surface samples were also tested for reaction with dilute HCl, from which a reaction evolved in all cases.

A soil description was carried out for the material present at the site, the BS5930:1999 version of which can be seen below. The soil to shallow depth (≤350mm) at the site was not subjected to any laboratory classification tests as part of this investigation, however, classification and geotechnical testing was carried out as part of the previous site investigations implemented at the Upper Plateau site. A Particle Size Distribution (PSD) curve for a typical sample from the Upper Plateau site can be seen in Figure 12, Page 44 of the appendix to this document. In general, soil samples from the Upper Plateau Site range in description from clays to gravelly sands.

Soil Description: Light grey to light brown, dense, medium, MADE GROUND

During initial surveying of the site, a number of features were identified, which were catalogued for further reference. GPS locations and a brief description of features in included in Table 14. TP refers to a suspected trial pit location, BH refers to a suspected borehole location, or presence of metal borehole cap. These features have been correlated with ground investigations carried out at the site in summer 2008, discussed further in section 4.3 of this report. Surface samples were taken at a number of these locations, as referenced in section 4.2.1 of this report, in order to determine the presence of calcium carbonate in the suspected spoil material.

Table 14 – Observed site features and GPS Locations

Reference	**Shadbolt Env. Ref.**	**Easting**	**Northing**	**Height**
BH1	Rotary Open Hole 1	410411.849	550473.197	253.925
BH2	Unknown	410354.299	550512.269	251.999
TP1	Unknown	410372.129	550512.061	252.349
TP2	Trial Pit 10	410316.475	550524.836	251.711
TP3	Trial Pit 16	410290.226	550494.043	252.658
TP4	Trial Pit 18 (?)	410285.793	550436.634	252.574
TP5	Trial Pit 18 (?)	410305.242	550427.791	252.791
TP6	Trial Pit 8	410365.167	550432.675	252.944

4.1.2 ***Vegetation Survey Results***

A summary of the vegetation survey data can be seen in Table 15 below, which documents the ground cover and vegetation types encountered at each survey point, taking in to account only major transitions in vegetation type. A detailed species count has not been implemented for the means of this report, as significant spatial disparities were not noted in the area sampled. Reference with respect to vegetation type is taken from the Penn Associates ecological survey detailed in the literature review of this report.

Table 15 – Percentage ground cover and vegetation species finings made across the Upper Plateau site

Location	Percentage Cover (%)	Dominant Vegetation Type
NW 1	95	Grass (mixed)
NW 2	100	Grass (mixed)
NE 1	100	Grass (mixed)
NE 2	100	Grass (mixed)
CENTRE 1	100	Grass (mixed)
CENTRE 2	100	Grass (mixed)
SW 1	90	Grass (mixed), clover, thistles
SW 2	100	Grass (mixed), clover, thistles
SE 1	100	Grass (mixed)
SE 2	100	Grass (mixed)

The survey has not indicated any areas in which animal activity is elevated or in which it was deemed that field work was likely to pose a risk to habitats. Ground nesting birds were encountered on a number of occasions, therefore, care was taken whilst working onsite, that frequently used public paths were adhered to in order to avoid unnecessary disturbance. No areas of ground disturbance related to animal activity were noted.

4.1.3 ***Geophysical Results***

An interpretation of geophysical survey data, taken from the fixed array resistivity survey completed on 1st July 2009, can be seen in Figure 13, page 45 of the appendix to this document. Three transects were laid as illustrated in Figure 35, however due to poor readings caused by inclement weather, all data presented below is taken from the eastern boundary survey, running N-S across suspected previous survey features, illustrated by the solid black line in Figure 35. Dashed black lines represent unsuccessful readings.

2D Rho pseudo-sections, relating to the apparent resistivity acquired during the survey are attached as Figures 36 and 38. The pseudo-section data illustrated in Figures 36 and 38 have been created with the use of 'filtered' data, from which extreme values have been removed as suspected sampling anomalies. The filtering parameters applied to this data are listed in Table 16 and are taken from the recommended parameters suggested in data provided by Iris Instruments. With the application of these filtering parameters, 79% of the original survey data was put forward for further analysis (266 records out of 336).

Table 16 – Filtering values applied to resistivity data

Parameter	Minimum Value	Maximum Value
Vp	-2500	0
ln	0	500
Rho	0	1000
Dev	0	2
M	0	0

The filtered data has been analysed with the use of several proprietary software packages. The pseudo-section presented in Figure 38, was created directly from the apparent resistivity data collated in ElectraPro. Figure 36 has been created using RES2Dinv software, with false colour parameters applied to the surface anomalies and ‘fine mesh’ parameters applied to refine the apparent spatial variation in resistivity readings. Figure 37 has also been created with RES2Dinv software, but has been processed using least-squares inversion, in order to identify ‘bad’ data points. In all cases, topographical data from the field investigation data has been flattened relative to the sampling horizon.

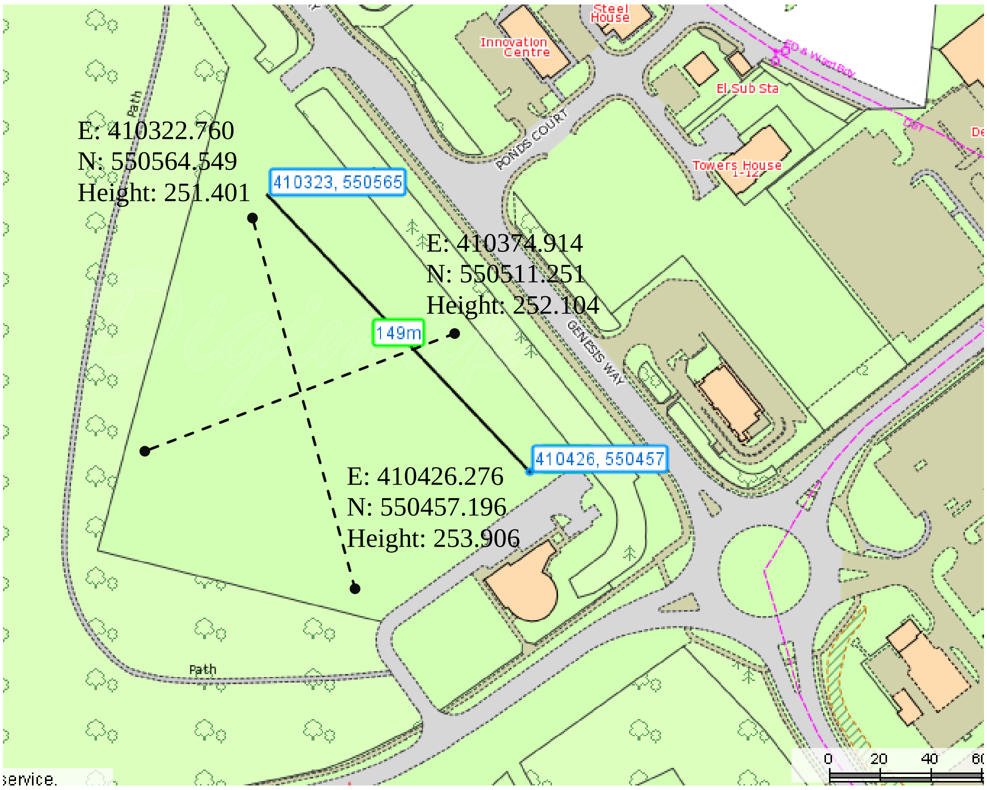


Figure 35 – Aerial view of retail site, with proposed geophysical transect locations with GPS Location noted (Source: Edina Carto)

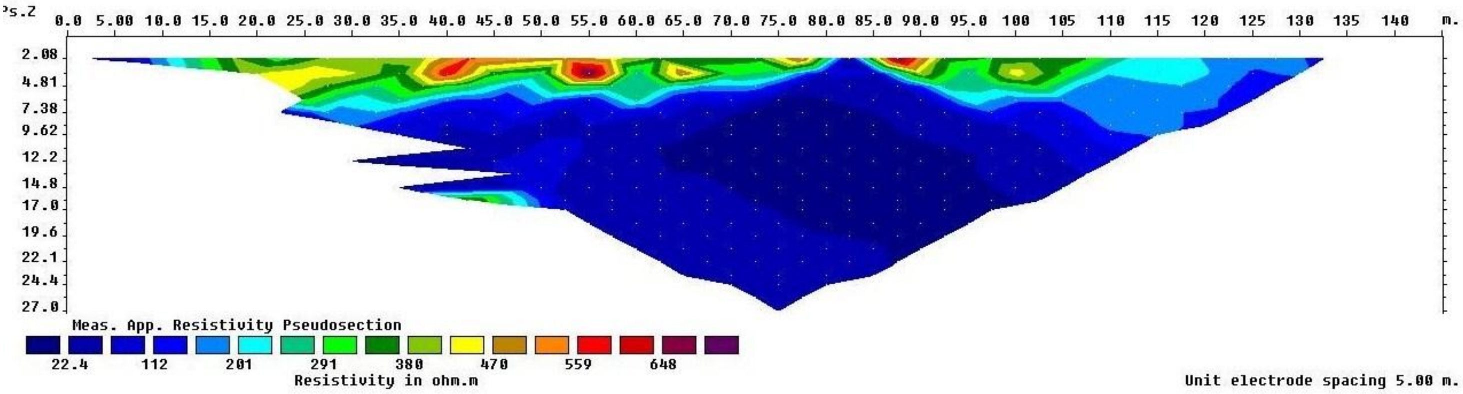


Figure 36 – Normalised North-South Pseudo section created using RES2Dinv software, illustrating high resistivity values close to the surface of the site

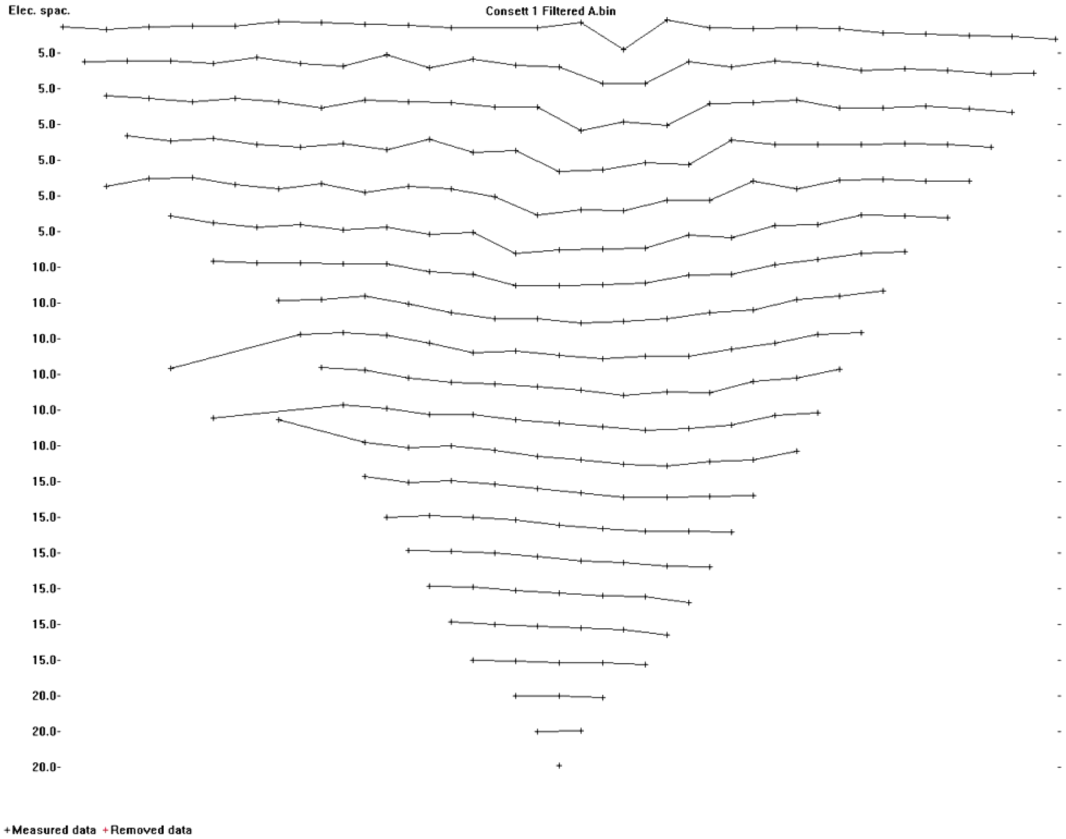


Figure 37 – Linear data view illustrating the raw data after removal of ‘bad’ data points

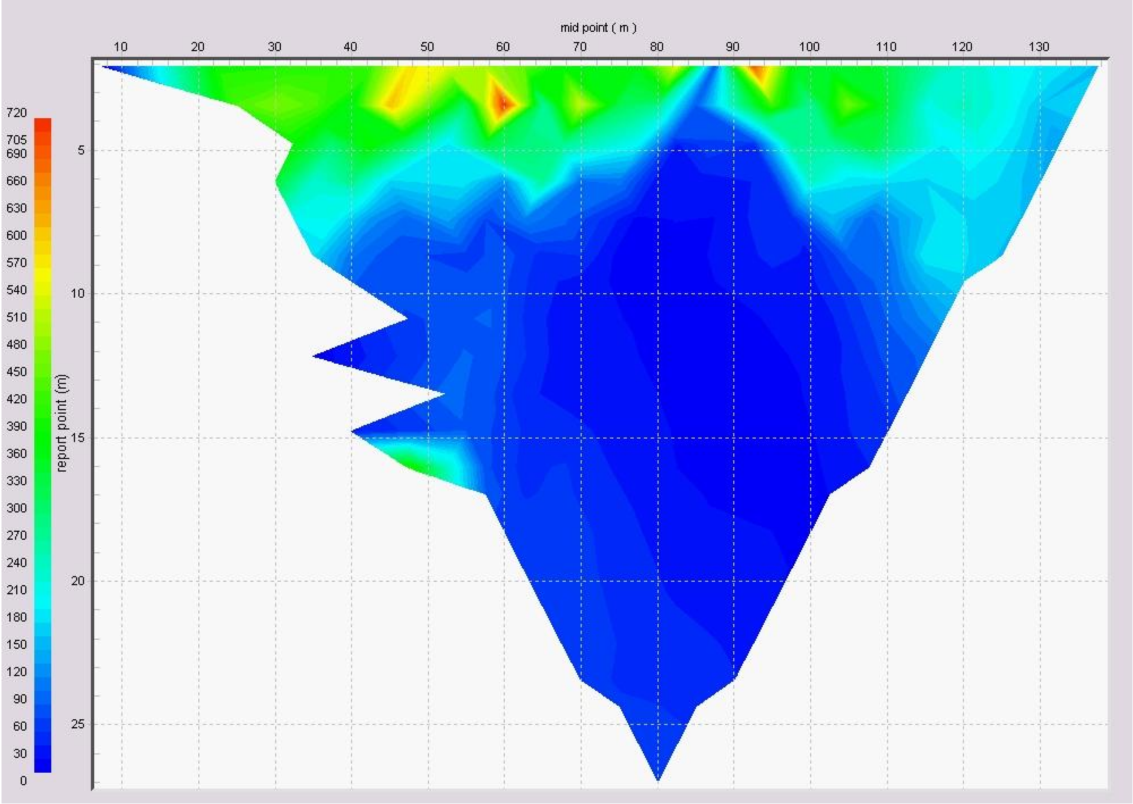


Figure 38 – North-South Pseudo section of the site creating using ElectraPro Software

4.2 **Laboratory Results**

Laboratory results acquired from soil samples collected during site works are presented in the following pages, divided by analysis type and chronological completion.

4.2.1 Calcimeter

Full calcimeter data and experimental values for each of the data sets included can be seen in pages 46 to 49 of the appendix to this document. These tables also include calculations for sample and apparatus error, which take in to account the measured variability of the experimental equipment in addition to the inherent variation achieved when a single sample is subjected to 5 simultaneous analyses. Eijkelkamp advise that carbonate contents of 0-50g/kg of sample have an acceptable repeatability error of 3g/kg, therefore, the repeatability values calculated in Table 17 are well within the acceptable range. Horizontal error bars have been added to all graphical calcimeter data analysis to represent this uncertainty. These error bars demonstrate equal error with respect to the measured 'mean'.

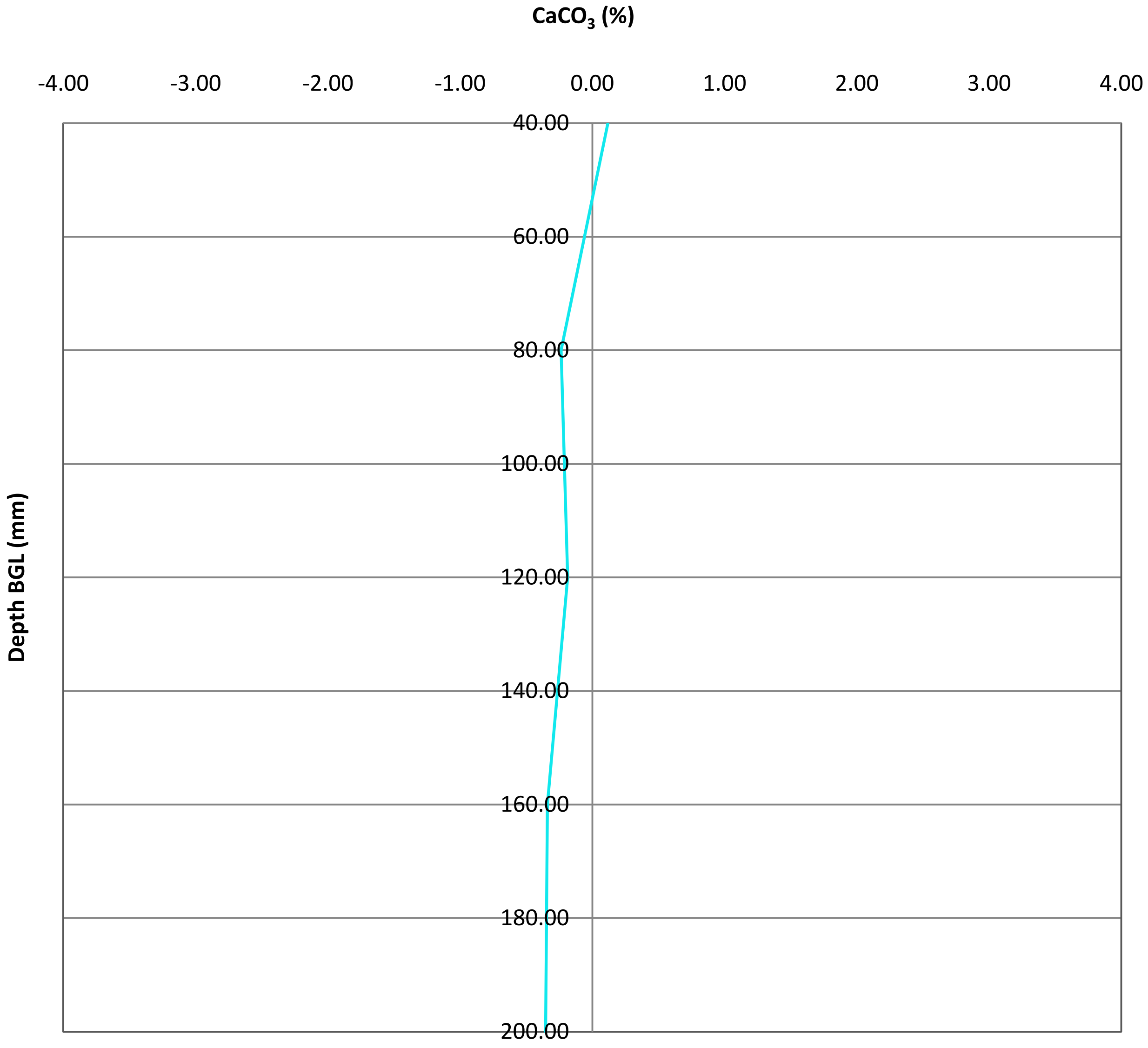
Table 17 – Calcimeter error calculations

Source of Error	**Magnitude of Error (%)**
Equipment Error	0.00272331
Repeatability (Sample Error)	0.36
TOTAL ERROR	0.36272331

The results detailed in the Figures on pages 119 to 125 document the percentage concentrations of calcium carbonate found at various points and depths across the sample site. These results are divided in to geographical areas covered by the survey. The associated graphs represent the spread of this data in order to investigate the presence of any spatial patterns, or consistent variation in concentration with depth. In terms of graphical output, the control, preliminary, Derwent view and Howns Gill readings are separately plotted, whilst the Upper Plateau results have been combined to provide a geographical-depth comparison.

4.2.1.1 Control Sample Results

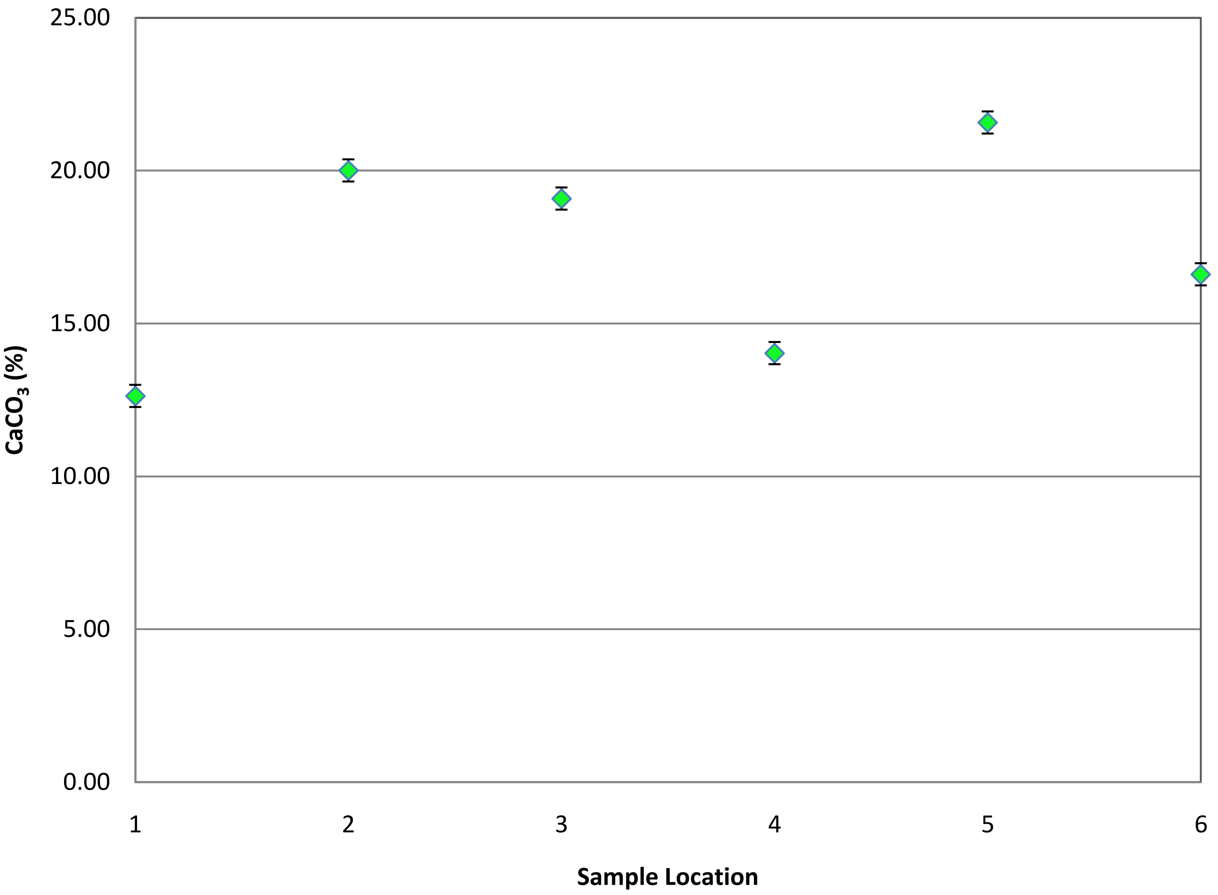
Calcium carbonate contents presented were acquired from samples taken at a control site in the North East of England. Calcium carbonate concentrations attained for the sample are included in Table 18. Graph 1 demonstrates calcium carbonate variation with depth at the control site.



Graph 1 – Variation in $CaCO_3$ content with depth at control site

4.2.1.2 Upper Plateau Surface Results

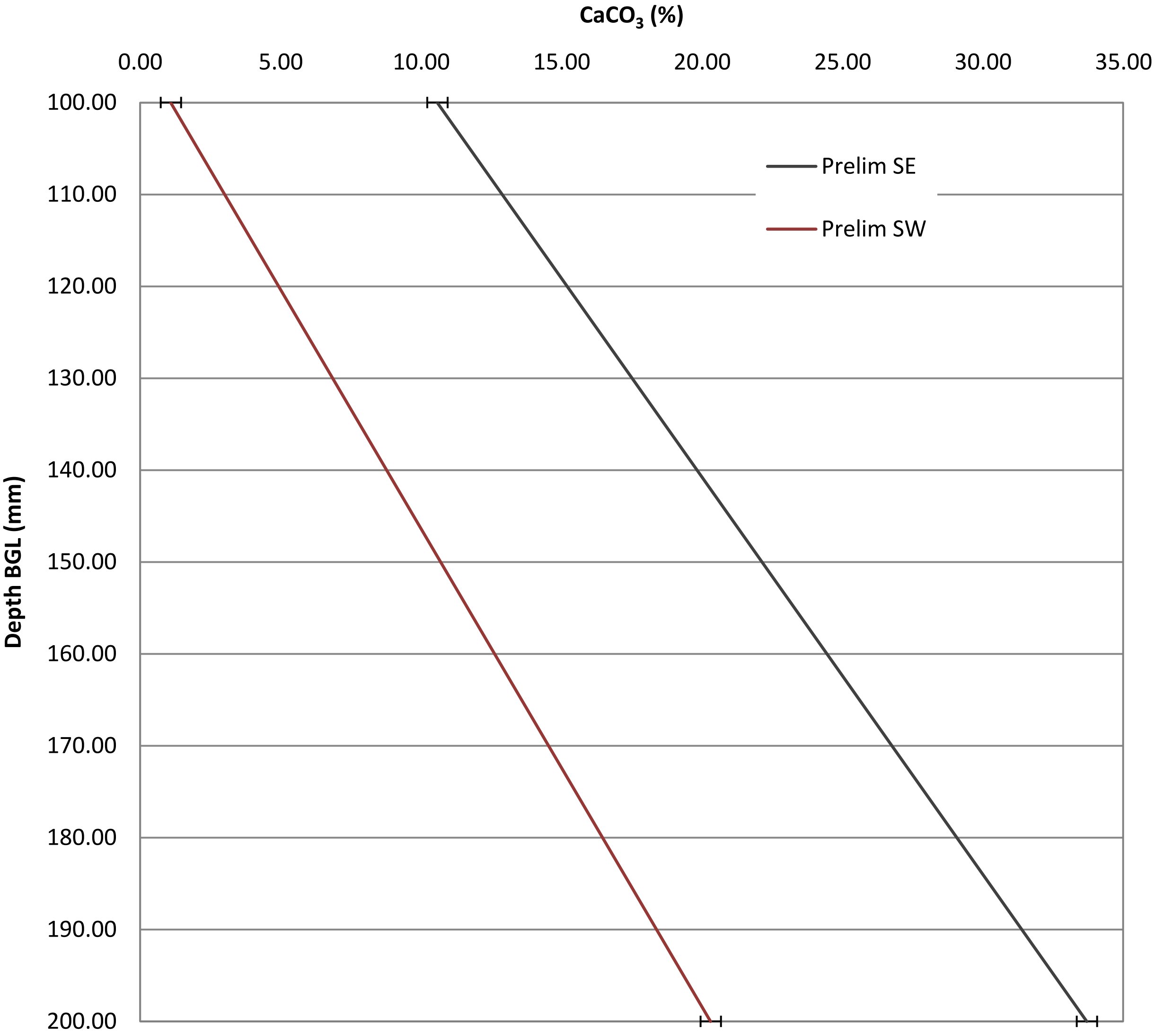
Calcium carbonate contents presented were acquired from four samples taken at disturbed surface features across the site, thought to represent the location of trial pits (TP) or borehole spoil (BH).



Graph 2 – Percentage $CaCO_3$ at disturbed surface locations

4.2.1.3 Preliminary Upper Plateau Results

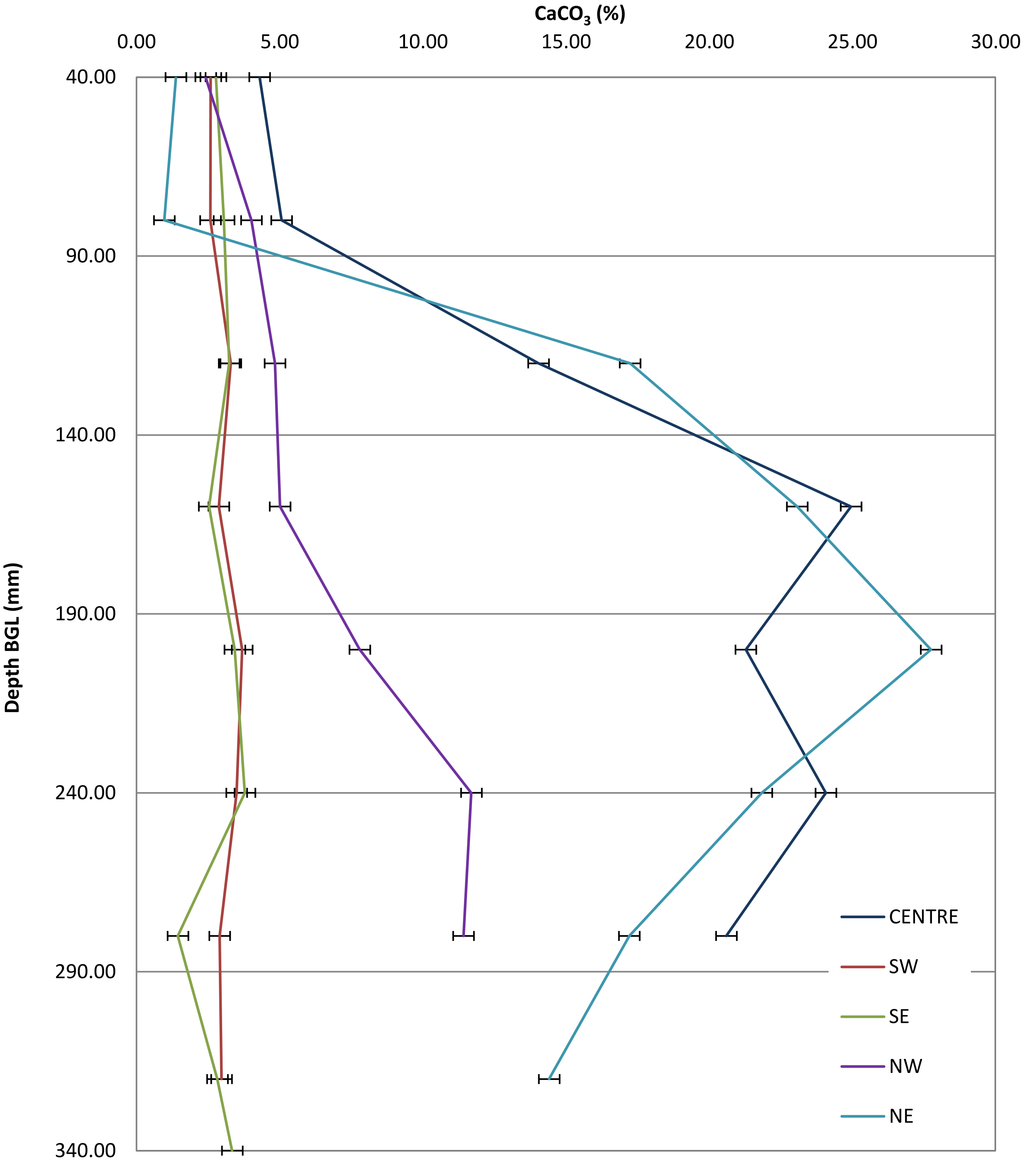
Calcium carbonate contents presented were acquired from four samples taken at two depths, at the southern corners of the Upper Plateau Retail Site.



Graph 3 – Variation in $CaCO_3$ content with depth in preliminary samples

4.2.1.4 Upper Plateau Sample Results

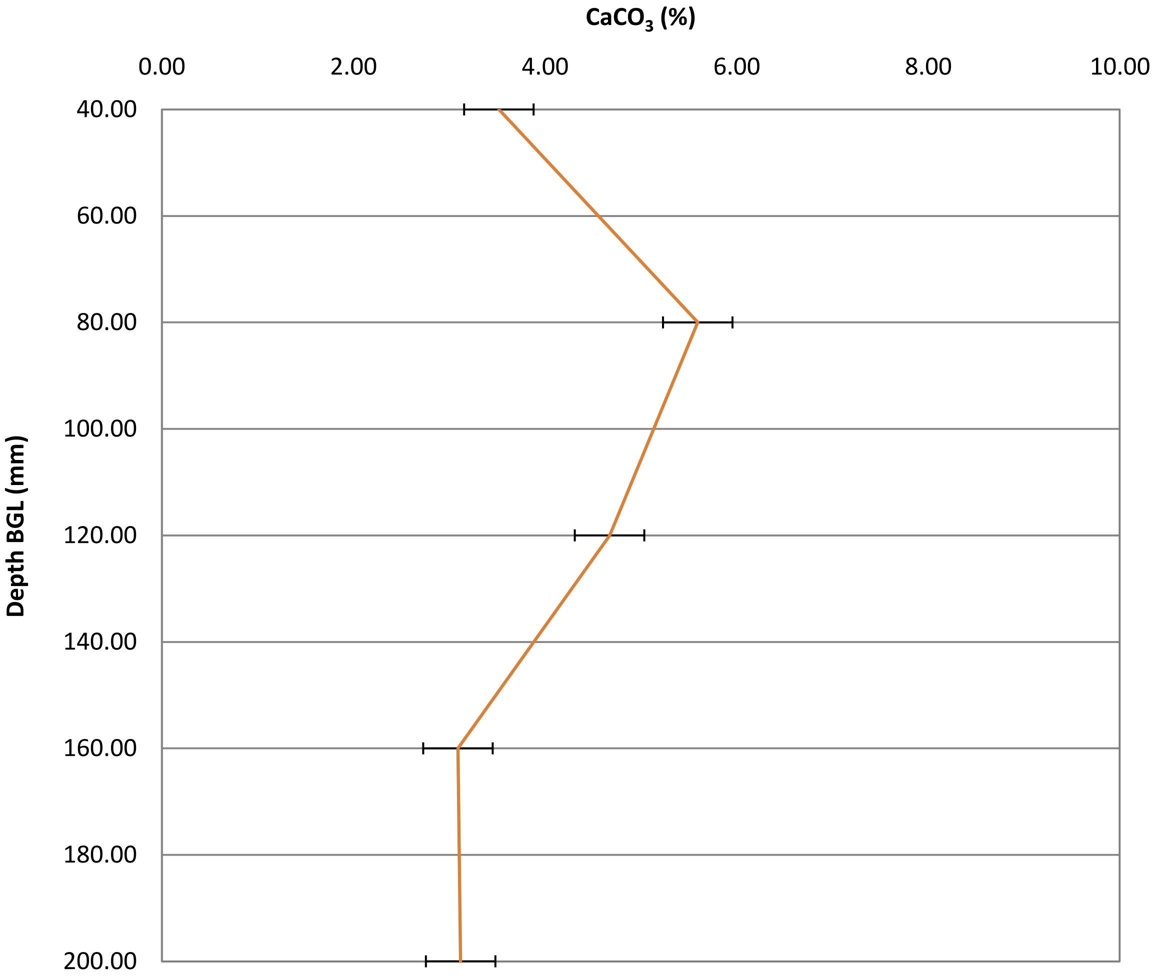
Calcium carbonate contents presented were acquired from samples taken, at varying depths, at five locations across the Upper Plateau site. Graph 4 represents spatial and depth variation.



Graph 4 – Variations in CaCO$_3$ content with depth across the Upper Plateau Site

4.2.1.5 Derwent View Sample Results

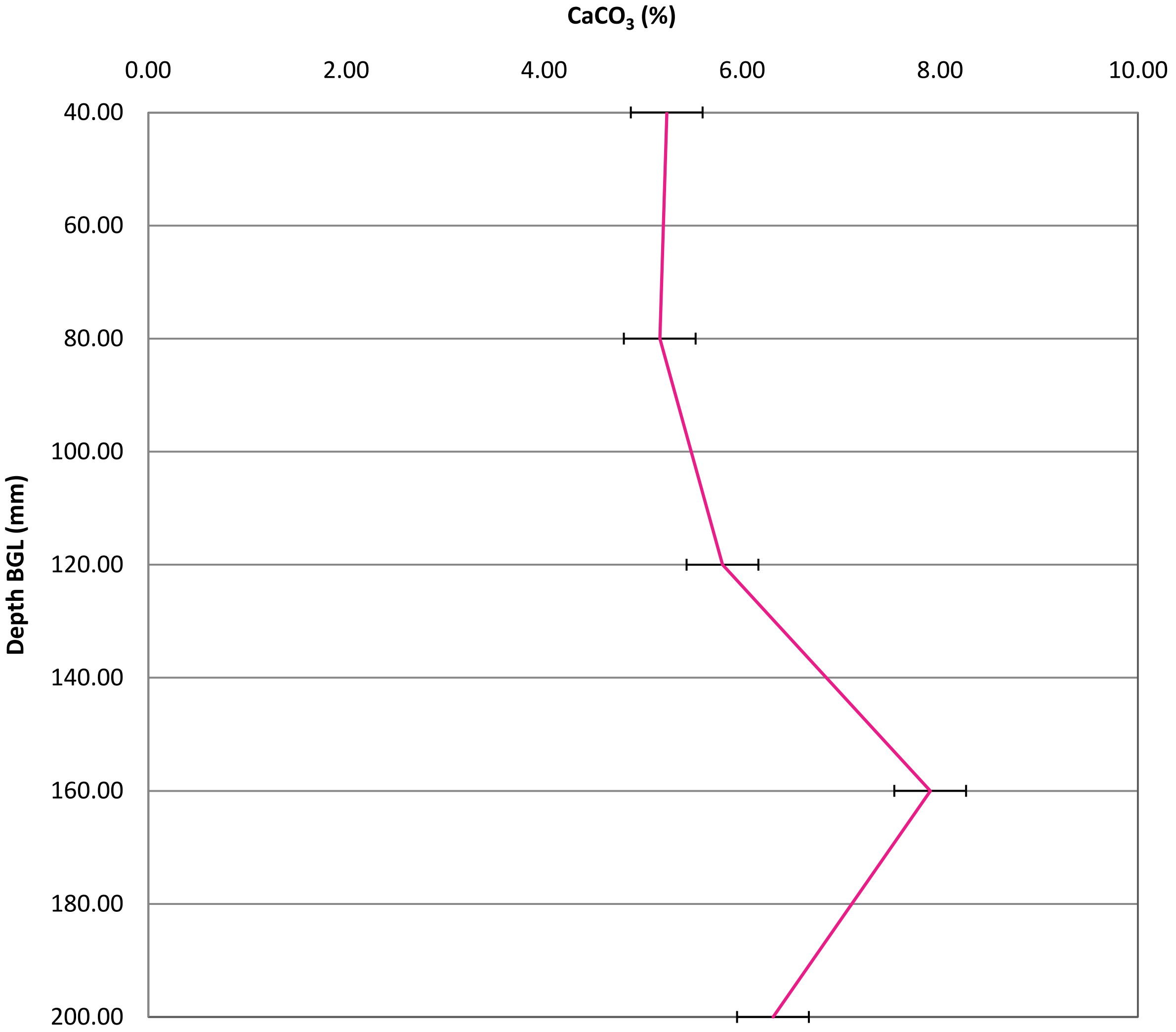
Calcium carbonate contents presented were acquired from samples taken, at varying depths, at a central location of the Derwent View site.



Graph 5 – Variations in $CaCO_3$ content with depth, Derwent View Site

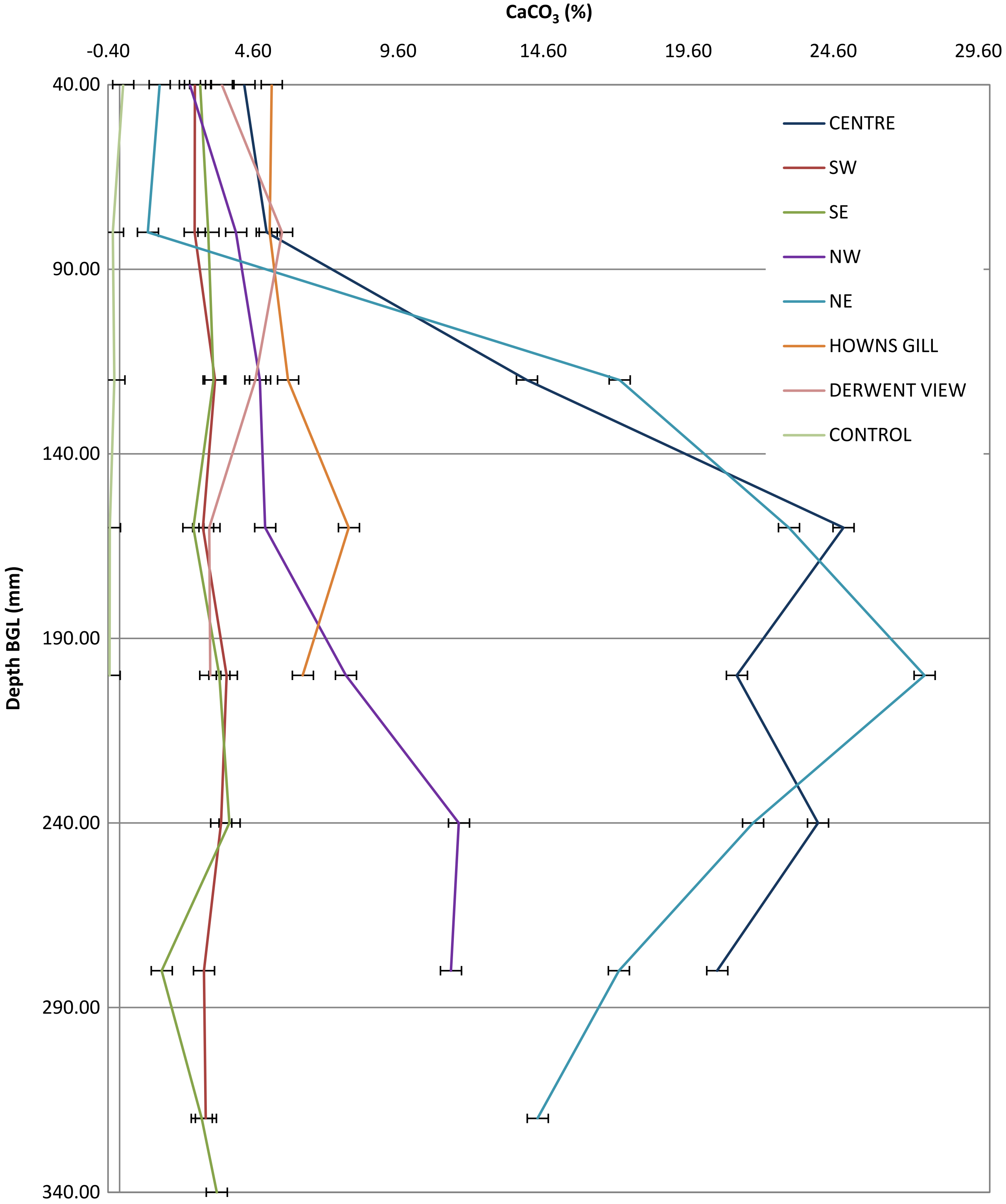
4.2.1.6 Howns Gill Sample Results

Calcium carbonate contents presented were acquired from samples taken, at varying depths, at a southern location of the Howns Gill site.



Graph 6 – Variations in $CaCO_3$ content with depth, Howns Gil Site

4.2.1.7 Combined Results



Graph 7 – Combined variations in CaCO$_3$ content with depth

4.2.2 Petrographic Microscopy

4.2.2.1 Light Microscopy Results

Observations collated during petrographic analysis of slag samples in thin section are presented in Table 18. These observations relate to the analysis of thin sections using a polarised light microscope, using direct light, transmitted plane polarised light and transmitted light with crossed polarisation.

An analysis of the habit of the materials forming the slag was made, as well as observations regarding the habit of the slag itself. It was noted that whilst some samples consisted of relatively homogeneous, prismatic crystals set within a glassy matrix, others possessed inclusions, including metallic iron. The presence of calcium carbonate was noted in all sections analysed, as shown in Table 18. It was noted that this material tended to form in association with vesicles and tubules in the slag structure, as a thin coating on the surface of these structures. All slides analysed were seen to exhibit the presence of circular or oval shaped inclusions which appeared at low relief with respect to the body of the thin section, with a lower refractive index. These inclusions were deemed to indicate the presence of voids in the mineral structure, as their optical properties were identical to those exhibited by the glass mounting medium – demonstrating pink to black vesicular dichroism in plane polarised light and grey to black dichroism in cross polarised light, with alteration of stage height. This property was useful in determining the persistence of deep voids and channels in the slag structure. Slides with high persistence of vesicles and tubules were also selected for SEM analysis in due to the associated persistence of calcium carbonate formation.

Figures 39-42 illustrate samples as viewed using a light microscope, these images have been false-coloured to facilitate observation. Figures 39 and 40 illustrate the presence of a calcium carbonate coating around the surface of a vesicle. Figure 39 demonstrates calcium carbonate as a pale coating, set in a darker glassy matrix. Figure 40 illustrates the same observation area under cross polarised light, demonstrating a double diffraction pattern in the calcium carbonate regions, with the glassy matrix of the slag in dark contrast. Figures 41a and b illustrate the appearance of the matrix of the slag, close to an outer margin. These were viewed under transmitted and cross polarised light, demonstrating a mixture of prismatic crystals, calcium carbonate and vesicles within an anisotropic glassy matrix.

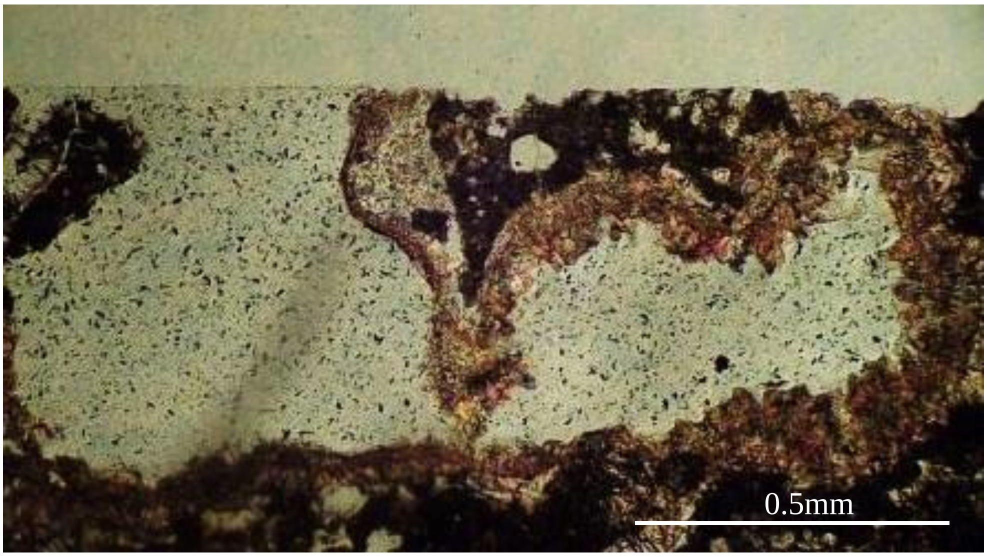


Figure 39 – Petrographic thin section of sample edge – plane polarised light (Magnification 10x)

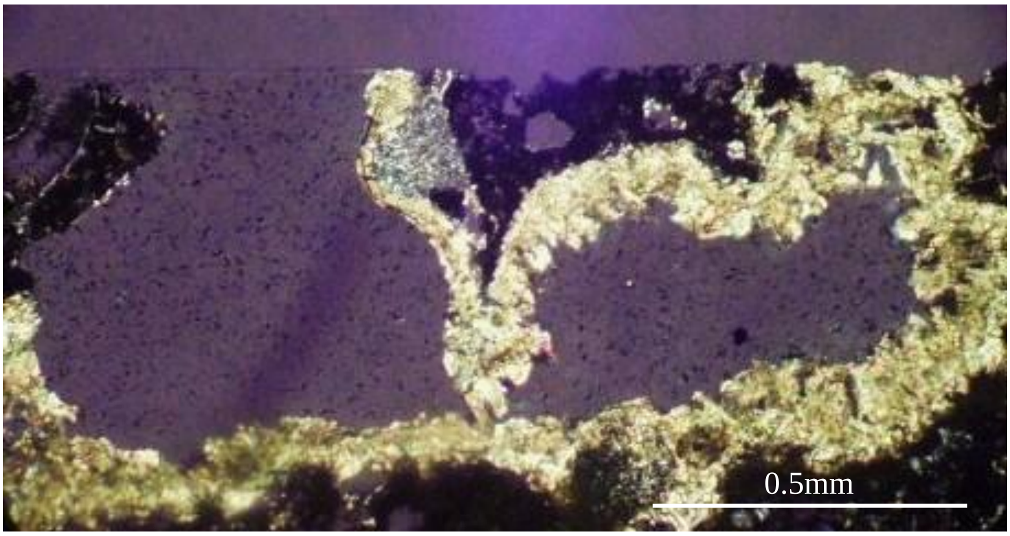


Figure 40 – Petrographic thin section of sample edge – cross polarised light (Magnification 10x)

Figure 42a demonstrates an enlarged image of a vesicle with calcium carbonate coating under cross polarised light, illustrating the strong visibility of the mounting media through the thin section, in light pink, which was used in identifying vesicles for analysis. Figure 42b illustrates the appearance of an iron inclusion in the glassy slag matrix.

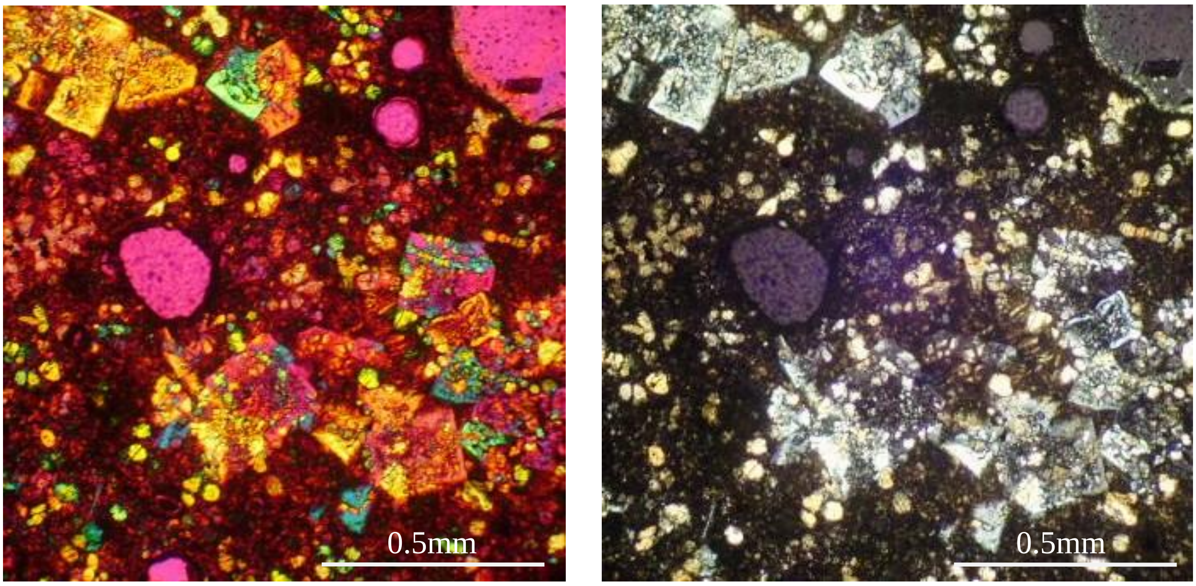


Figure 41a and b – Petrographic thin section – crystals set in glassy matrix, false colour under cross polarised light and in normally cross polarised light (Magnification 10x)

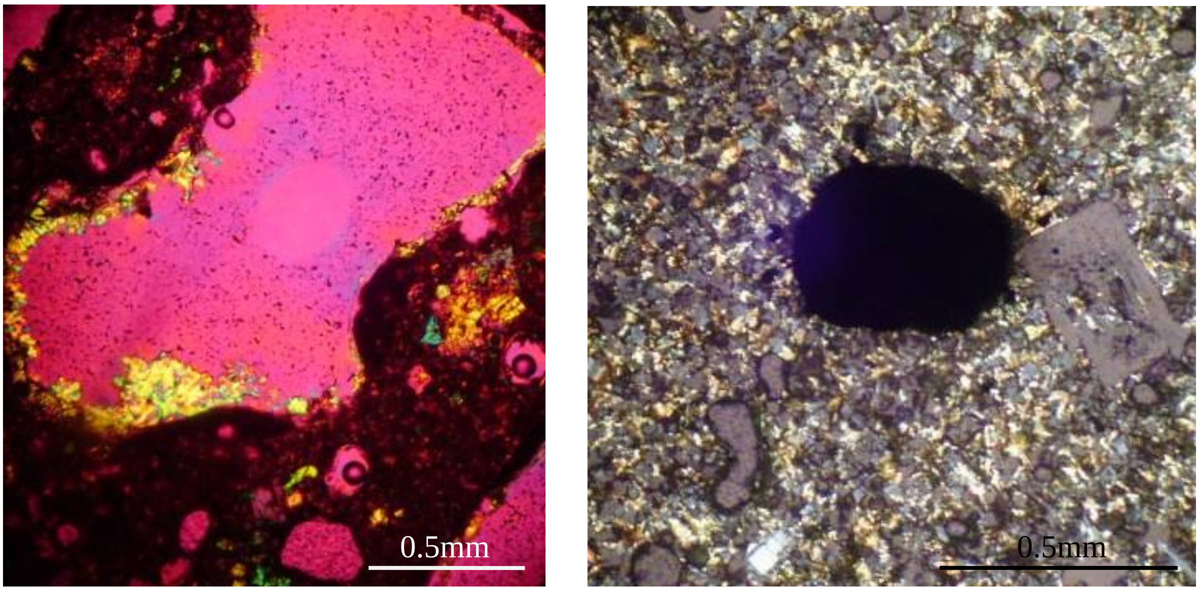


Figure 42a and b – Petrographic thin section –vesicle surrounded by calcium carbonate, cross polarised light with false colour, and iron inclusion under cross polarised light (Magnification 10x)

Table 18 – Optical microscope analysis - all samples analysed at 10x magnification, James Swift microscope

Slide Reference	Direct Light	Transmitted Light (Plane Polarised)	Transmitted Light (Cross Polar)
CLW – 1	Surface appearance – dark, fine texture, vesicles Light grey matrix with mid-grey, amorphous inclusions	Acicular crystals, pale brown, persisting around the perimeter of colourless vesicles. No colour change noted on rotation.	Glassy matrix, anisotropic, appearing black Calcite present as a bright white, corona –like coating around vesicles and within mineral structures – strong birefringence 'twinkling'
CLW – 2	Surface appearance – dark, fine texture, vesicles Dark grey / brown matrix with mid-grey to black amorphous inclusions	Amorphous, dark brown crystals forming matrix Prismatic crystals, possibly calcite, with brown-orange alteration at margins	Glassy matrix, anisotropic, appearing black Calcite present as a bright white, corona –like coating around vesicles and within mineral structures – strong birefringence 'twinkling'
CLW – 3	Surface appearance – pale, fine texture, vesicles Light yellow matrix with light grey, amorphous inclusions.	Predominantly pale matrix, amorphous regions with dark, needle-shaped inclusions.	Calcite present as a bright white, corona –like coating around vesicles and within mineral structures – strong birefringence 'twinkling'
CLW – 4	Surface appearance – pale, fine texture, no vesicles Very dark grey matrix with black inclusions	Predominantly pale matrix, amorphous regions with dark, needle-shaped inclusions Colourless, striated, amorphous crystals set in matrix Pale brown, prismatic crystals set in matrix	Prismatic crystals appear colourless to pale blue Brown tabular crystals show strong termination at 45˚, with blue / green interference colours. Calcite present as a bright white, corona –like coating around vesicles and within mineral structures – strong birefringence 'twinkling'
CLW – 5	Surface appearance – black / dark grey, coarse texture, many vesicles Pale grey matrix with large, amorphous, colourless vesicles, mid-grey to dark grey inclusions	Predominantly dark brown matrix with red-brown staining Colourless, prismatic crystals set in to matrix	Calcite present as a bright white, corona –like coating around vesicles and within mineral structures – strong birefringence 'twinkling'
CLW – 6	Surface appearance – black / brown, many vesicles, coarse, reflective metallic inclusions Dark grey – not visible	Predominantly dark brown matrix with red-brown staining Colourless, prismatic crystals set in to matrix Large dark inclusions with dendritic surface pattern	Calcite present as a bright white, corona –like coating around vesicles and within mineral structures – strong birefringence 'twinkling'

4.2.2.2 SEM Results

Results collected during SEM analysis of petrographic slides are presented below. Detailed results are presented in pages 50 to 58 of the appendix to this document. Numerous SEM images have been produced though the analysis of backscatter electrons from the samples, with spectral analysis of characteristic X-rays from the sample taken at margins, and other points of interest where calcium carbonate was observed using light microscopy.

Figures 43 and 47a and b illustrate the type of images acquired during backscatter electron analysis of the slag samples. Figure 43 illustrates three location points at which analysis of characteristic X-rays emitted from the sample was conducted; these locations relate to the spectra in Figures 44 to 46.

- Figure 44 was taken at Point 0, in the mid-grey, homogenous coating of a vesicle. Spectral analysis indicates notable peaks for calcium, carbon and oxygen, strongly suggesting the presence of calcium carbonate.
- Figure 45 was taken at Point 1, in a heterogeneous region of the mineral structure of the slag. Spectral analysis indicates peaks for oxygen and calcium, but a lower peak for carbon. Strong peaks for magnesium, aluminium and silicone are also present. Elemental analysis suggests the presence of silicate minerals.
- Figure 46 was taken at Point 2, a dark grey, heterogeneous region of the sample, located between the calcium carbonate crust and glassy mineral matrix. Spectral analysis indicates moderate peaks for oxygen, calcium, magnesium, aluminium and silicone. Elemental analysis suggests the presence of silicate and carbonate minerals.

Similar results were determined across samples CLW – 2 and CLW – 6, with calcium carbonate presence indicated on the outermost surface of surface features and vesicles, silicate minerals forming the bulk of the slag matrix and a combination of carbonate minerals and silicate minerals in the interface between these bodies.

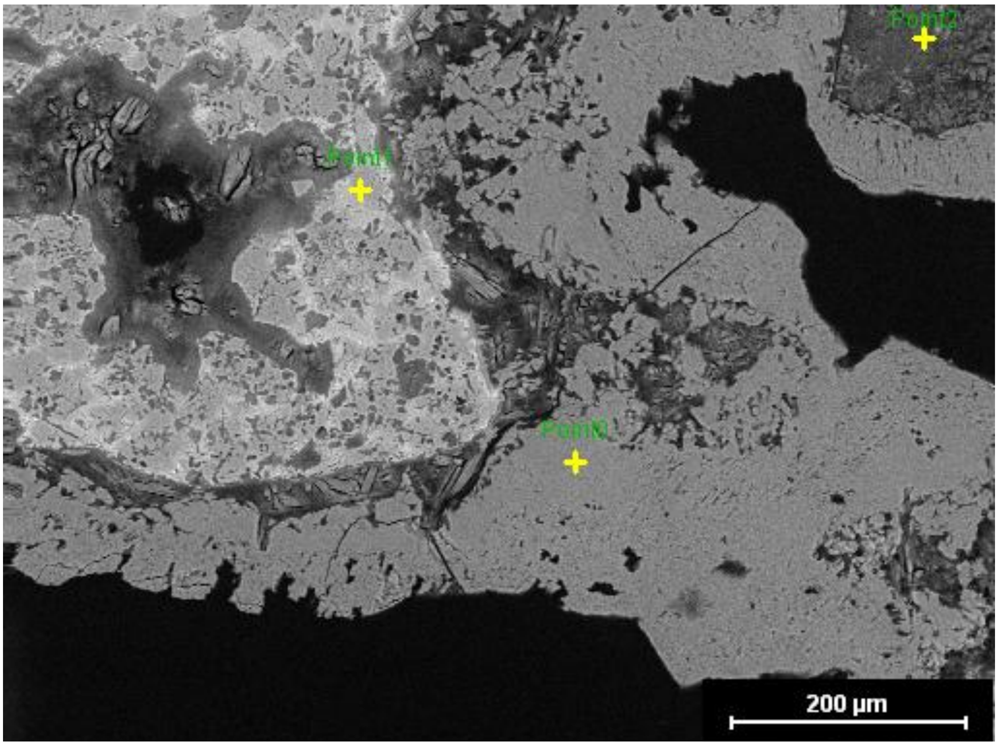


Figure 43 – SEM image – CLW – 2, Observation Area 1 (Magnification 25x)

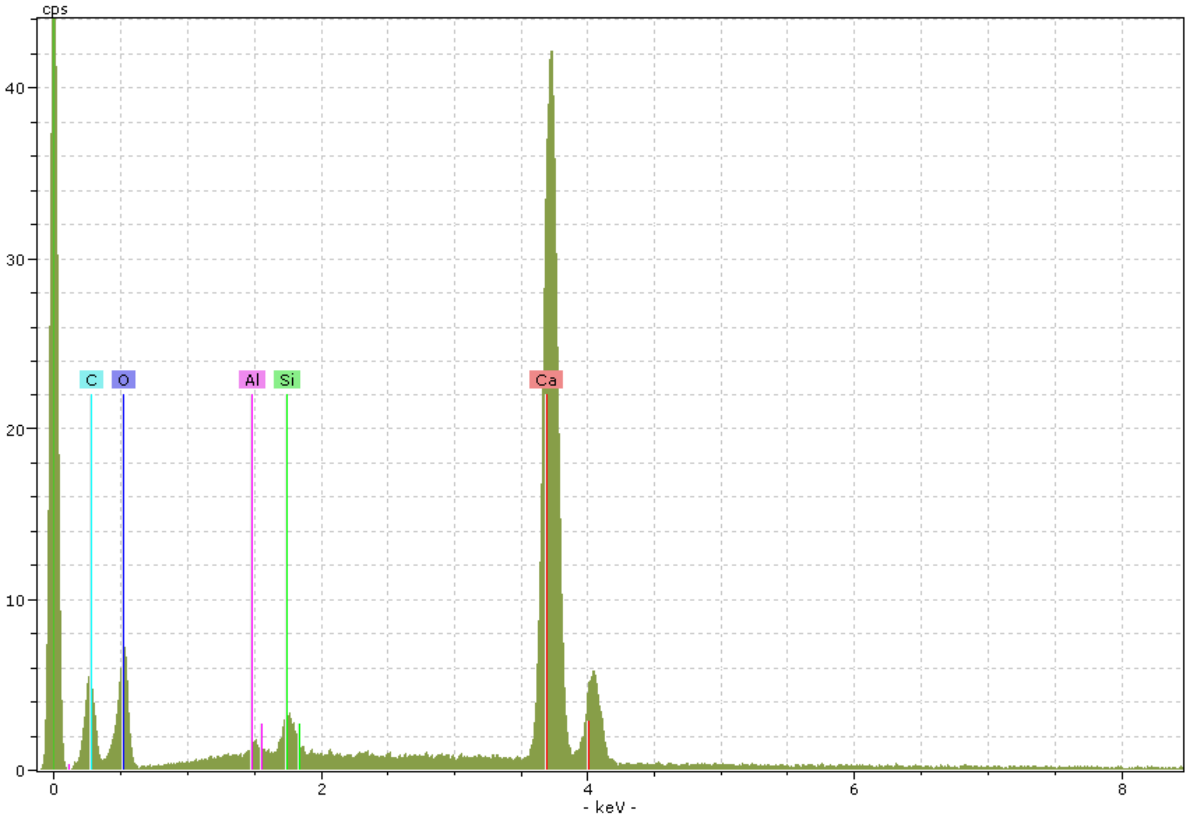


Figure 44 - Sample 2-1 Analysis Point 0

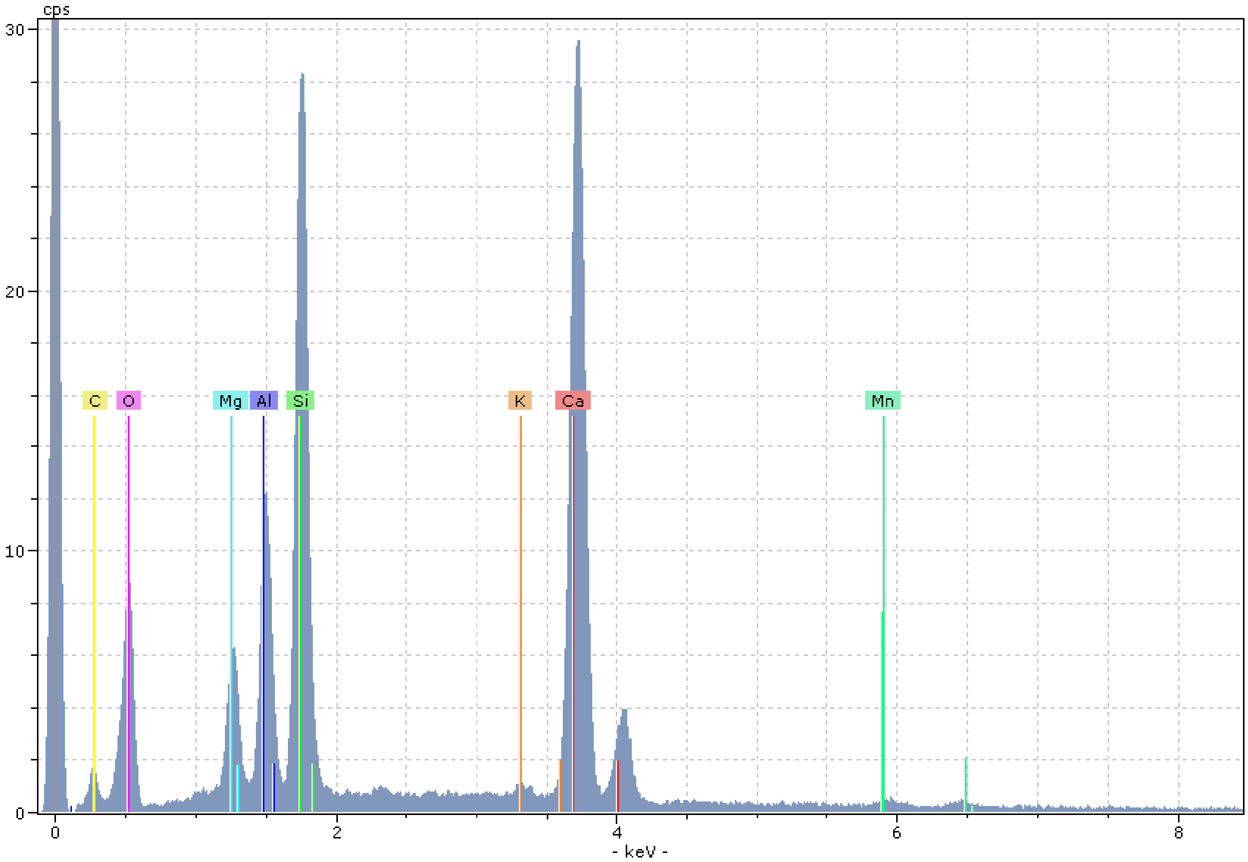


Figure 45 - Sample 2-1 Analysis Point 1

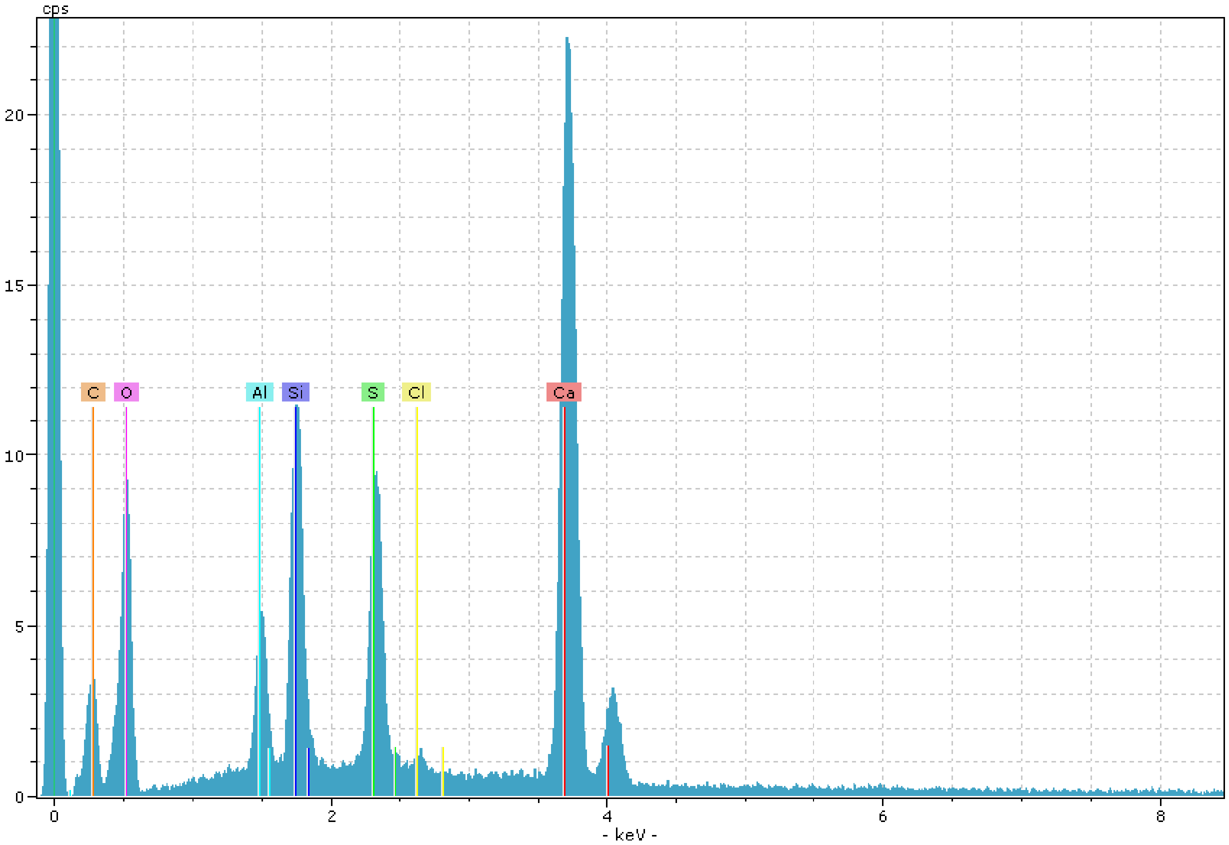


Figure 46 - Sample 2-1 Analysis Point 2

Figures 43a and b clearly illustrate the presence of a calcium carbonate 'crust' forming around the perimeter of vesicles and tubules. In these cases the crust is approximately 33-133µm thick. Spectral analysis demonstrates the persistence of this crust throughout the mineral structure, in association with vesicles and at the margins of the mounted samples.

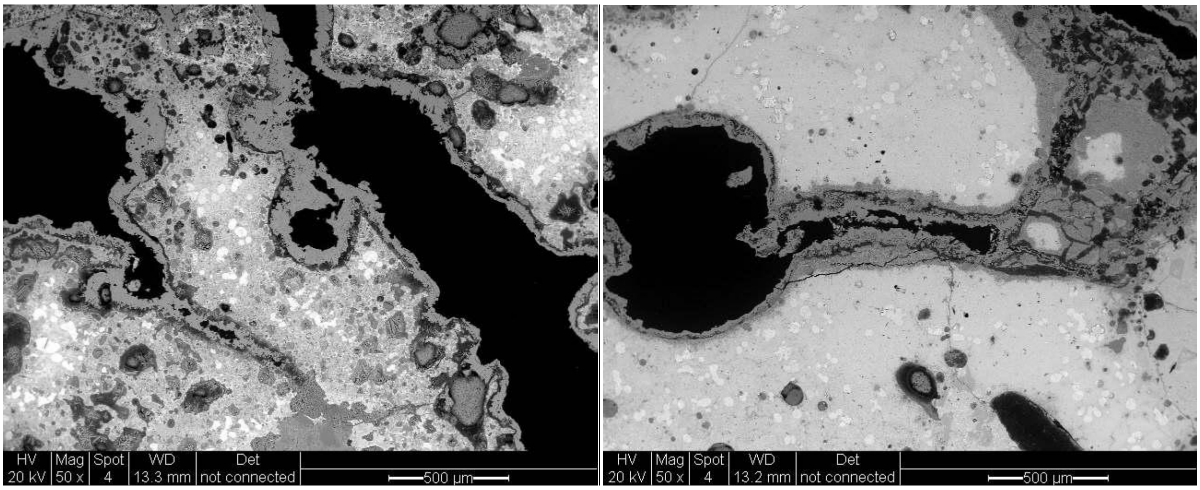


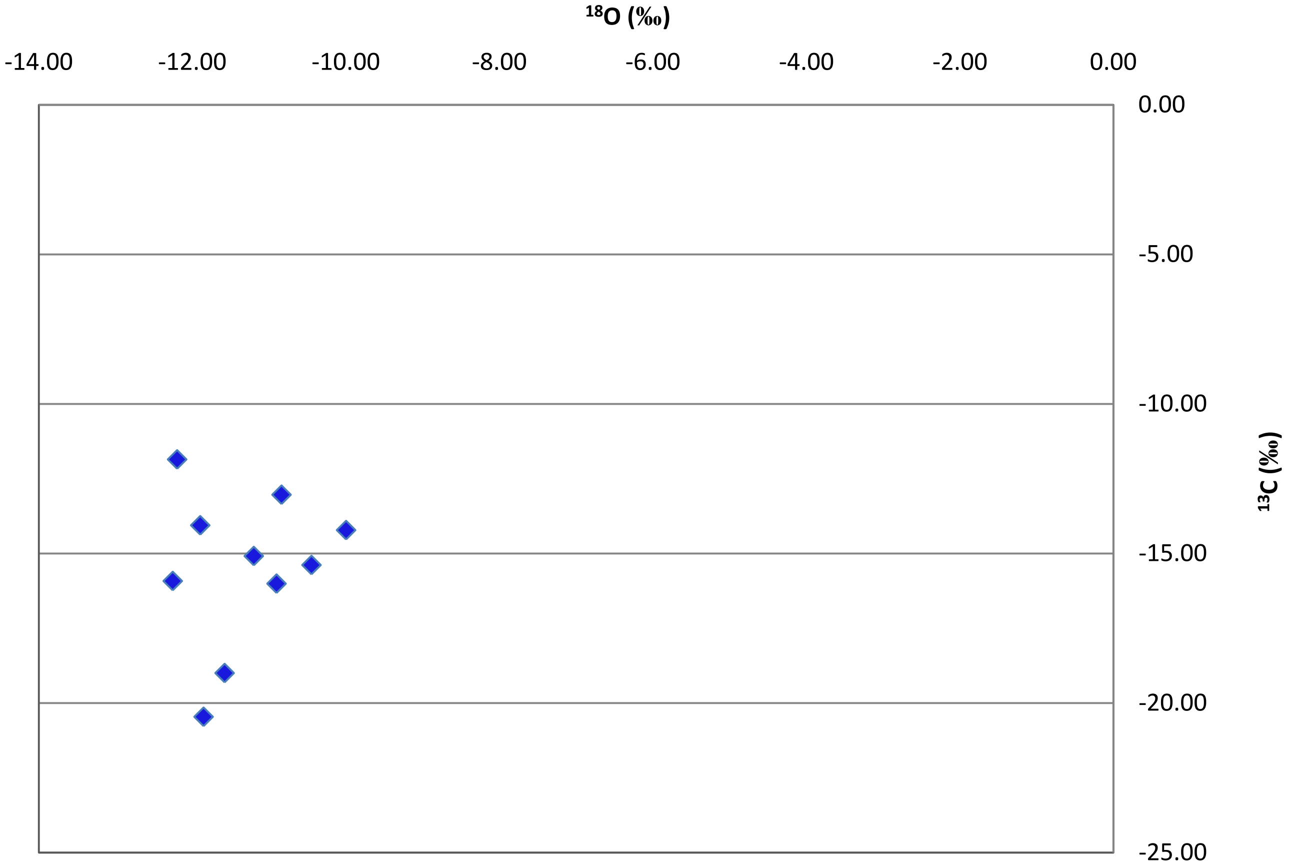
Figure 47a and b – CLW – 2, Observation Area 2 (Magnification 50x), CLW – 5, Observation Area 6 (Magnification 50x)

Bulk areas of the slag matrix were mapped using elemental mapping techniques, which illustrated an even spread and intensity of silicone and calcium across the material surface, as illustrated in pages 54 to 57 of the appendix to this document. Carbon demonstrated high intensity in the mounting medium, which created difficulty in discerning variations in concentration around vesicle margins.

Elements with high Relative Atom Mass (RAM) appear in high contrast as bright-white anomalies. Metallic iron was also identified during back scatter electron and characteristic X-ray analysis, as illustrated in pages 57 to 58 of the appendix to this document. Spectral analysis of the metallic inclusions indicated the presence of iron, as well as traces of lead, magnesium and aluminium, as would be expected.

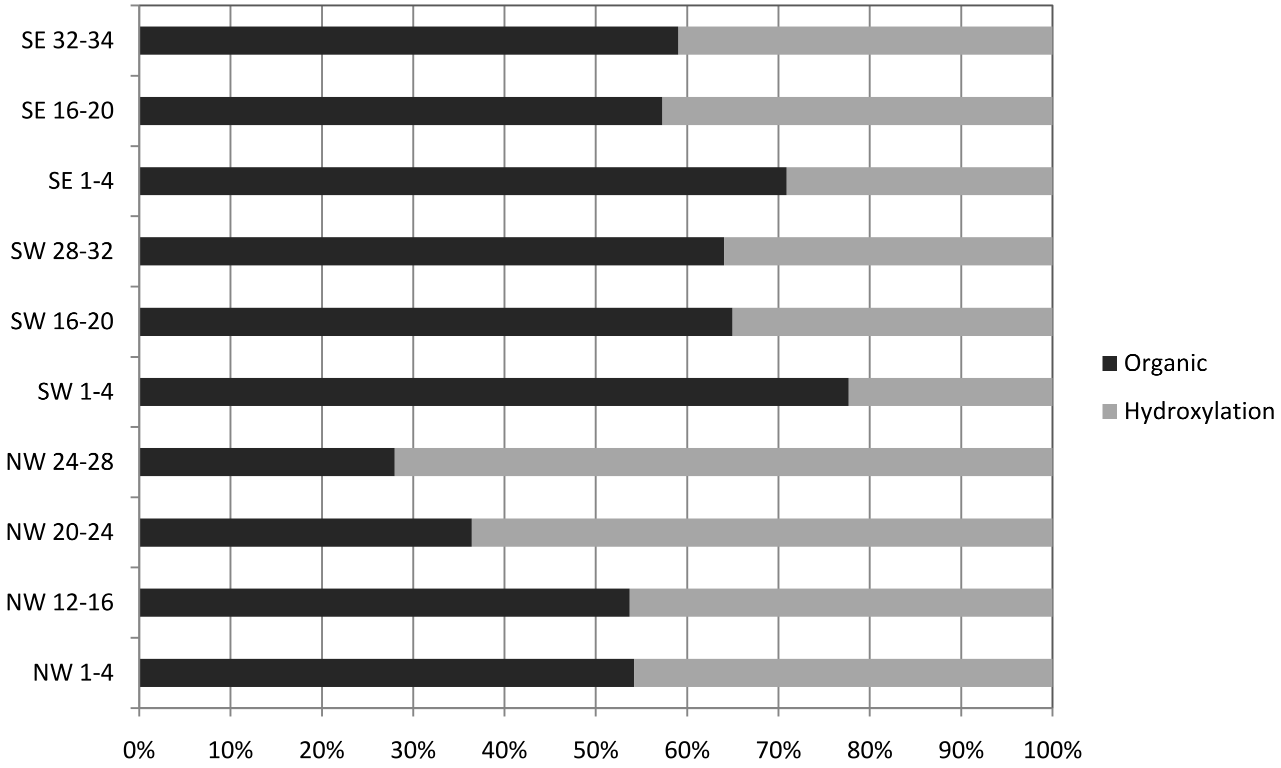
4.2.3 Isotopic Ratio Mass Spectrometry

Data provided by Iso-Analytical is included in page 59 of the appendix to this document, including error calculations and repeatability analysis. Results collected during IRMS analysis of samples taken from the Upper Plateau site are presented below and overleaf. Graph 8 presents the correlation between oxygen and carbon isotope data, illustrating clustering of results around -11‰ to -21‰ for ^{13}C and -9‰ to -13‰ for ^{18}O. These values correlate closely with values from the literature, determined for hydroxylated and organically derived carbonates and have been grouped thus.



Graph 8 – Isotopic Ratio Mass Spectrometry values. ^{13}C plotted against ^{18}O.

Graph 9 presents an interpretation of ^{13}C carbon isotope data as a continuum of 'mixing' values between the significantly depleted hydroxylation carbonates and less significantly depleted organic carbonates. The end-members of this analysis were assumed from data collated by Renforth *et al.*, (2009), with ^{13}C values of -25.3‰ for Hydroxylation and -8.0‰ for Organic carbonates, with the variability between these end members taken to represent 100% concentration towards either pole, as illustrated in Figure 48. Sample references in Graph 9 relate to sample locations illustrated in Figure 31, page 94, with depth values in cm also indicated.



Graph 9 - Isotopic Ratio Mass Spectrometry values. Interpolation of ^{13}C values to determine proportions of calcium carbonate produced through hydroxylation and through organic reactions

Figure 48 – Diagrammatic representation of ^{13}C interpolation values

4.3 Results from Previous Site Investigations

4.3.1 Slag Analysis results

The slag analysis results produced by Thomas Research Services (TRS) consist of seven, petrographic examinations of 'bulk samples' from the Upper Plateau. These samples were crushed to approximately 5mm. The resultant material was set in to resin, and used to create petrographic slides for analysis using light microscopy.

Table 19 – Locations and descriptions of materials used in TRS slag analysis (Source: Thomas Research Services)

TRS Ref	**Site Ref**	**Mass/kg**
GI8E01	TP3 0.80m-1.00m	19.9
GI8E02	TP4 3.20m	25.3
GI8E03	TP5 1.40m	23.9
GI8E04	TP6 2.20m	20.7
GI8E05	TP9 0.70m	25.2
GI8E06	TP10 4.00m	28.6
GI8E07	TP12 3.30m	24.9

It is noted in the report that 'The samples comprised predominantly of blast furnace slag and basic steel slag, with the blast furnace slag being slightly more predominant'. This would suggest that their major constituents are within the range of the figures in Table 20 with the primary constituent being calcium oxide, which may constitute up to 50% of the material by mass.

Table 20 – Chemical constituents of blast furnace and basic steel slag (Source: Lee (1974))

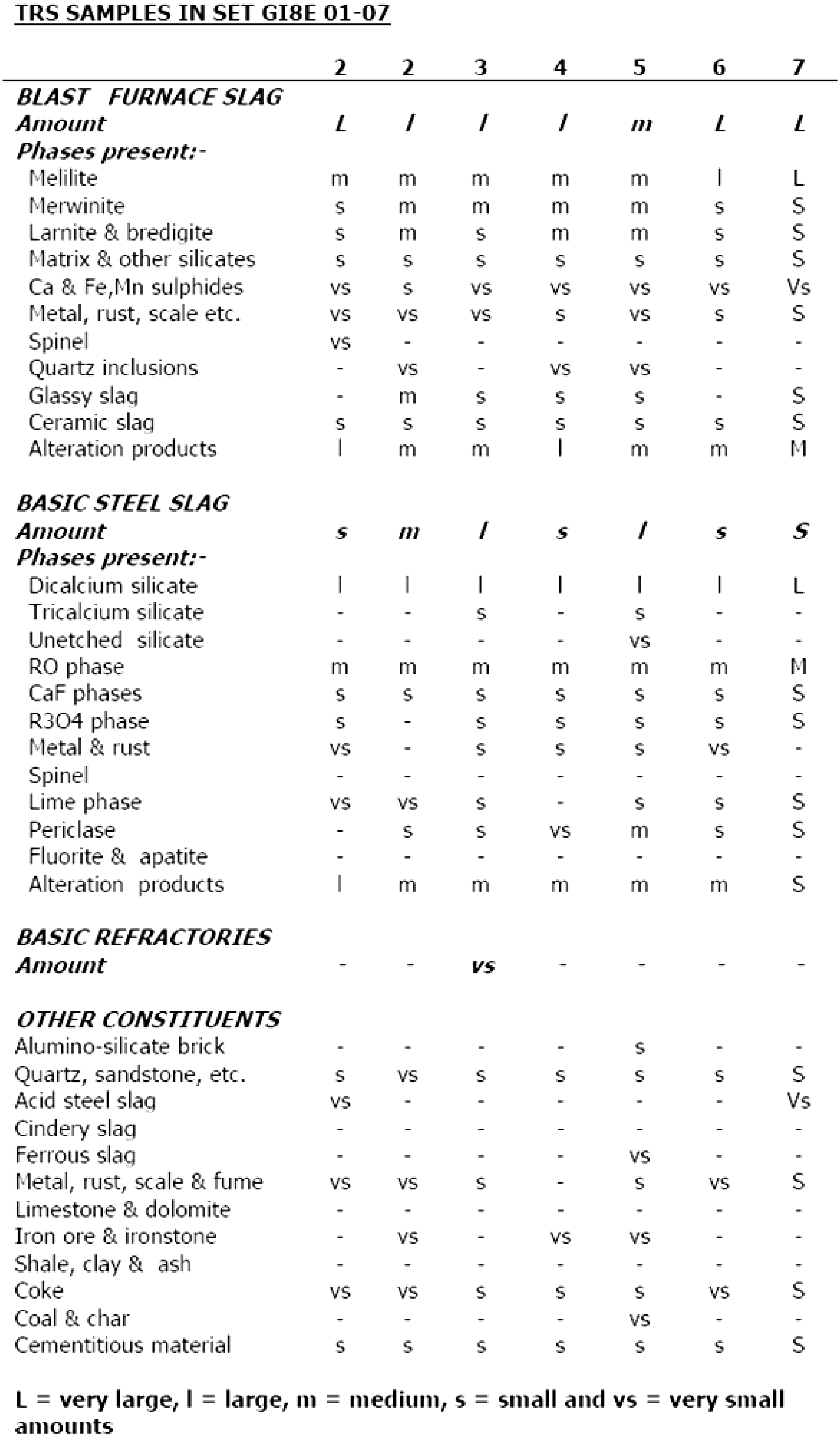
Constituent	**Content by mass (%)**
CaO	36-50%
SiO_2	10-35%
Al_2O_3	3-22%
MgO	2-11%
S	0.2-2%
FeO / Fe_2O_3 (total iron)	12-20%

Petrographic microscopy conducted on the samples listed in Table 19 confirmed the presence of large to very large amounts of Blast Furnace Slag; ‘predominantly crystalline, with relatively minor amounts of glassy and ceramic material recorded’. Significant quantities of melilite ‘a volumetrically stable mineral’ were identified along with more minor amounts of merwinite, larnite and wollastonite. Calcite was identified as a major weathering product. Basic Steel Slag occurred to a lesser extent in all samples, consisting mainly of dicalcium silicate, tricalcium silicate, CaF, metal, lime phase and periclase. Portlandite and calcium carbonate were noted as significant weathering products; TRS note that the Basic Steel Slag present was ‘significantly altered’ to these materials. Basic Refractory Material was also present in very small quantities.

Minor Constituents identified in the Thomas Research Services slag analysis included:

- Alumino-silicate refractories
- Quartz sand
- Sandstone
- Acid steel slag
- Ferrous slag
- Rusted metal
- Iron ore
- Iron ore sinter
- Coke and coal

The presence of calcium carbonate is noted at several points in the report. Unfortunately, as calcium carbonate has been noted as an ‘alteration product’, its presence and proportionality is not differentiated from all other alteration products in Figure 49. ‘The slag is much affected by secondary alteration. The products are difficult to identify specifically and are probably, mainly hydrated silicates. They do include some portlandite ($Ca(OH)_2$) and calcite (CaCO3)’. It is noted that ‘The finer particles were often bound by a cementitious material similar in nature to the alteration products of the slags’, though the nature of this ‘cementitious’ material is not discussed further.



TRS SAMPLES IN SET GI8E 01-07

	2	2	3	4	5	6	7
BLAST FURNACE SLAG							
Amount	***L***	***l***	***l***	***l***	***m***	***L***	***L***
Phases present:-							
Melilite	m	m	m	m	m	l	L
Merwinite	s	m	m	m	m	s	S
Larnite & bredigite	s	m	s	m	m	s	S
Matrix & other silicates	s	s	s	s	s	s	S
Ca & Fe,Mn sulphides	vs	s	vs	vs	vs	vs	Vs
Metal, rust, scale etc.	vs	vs	vs	s	vs	s	S
Spinel	vs	-	-	-	-	-	-
Quartz inclusions	-	vs	-	vs	vs	-	-
Glassy slag	-	m	s	s	s	-	S
Ceramic slag	s	s	s	s	s	s	S
Alteration products	l	m	m	l	m	m	M
BASIC STEEL SLAG							
Amount	***s***	***m***	***l***	***s***	***l***	***s***	***S***
Phases present:-							
Dicalcium silicate	l	l	l	l	l	l	L
Tricalcium silicate	-	-	s	-	s	-	-
Unetched silicate	-	-	-	-	vs	-	-
RO phase	m	m	m	m	m	m	M
CaF phases	s	s	s	s	s	s	S
R3O4 phase	s	-	s	s	s	s	S
Metal & rust	vs	-	s	s	s	vs	-
Spinel	-	-	-	-	-	-	-
Lime phase	vs	vs	s	-	s	s	S
Periclase	-	s	s	vs	m	s	S
Fluorite & apatite	-	-	-	-	-	-	-
Alteration products	l	m	m	m	m	m	S
BASIC REFRACTORIES							
Amount	-	-	***vs***	-	-	-	-
OTHER CONSTITUENTS							
Alumino-silicate brick	-	-	-	-	s	-	-
Quartz, sandstone, etc.	s	vs	s	s	s	s	S
Acid steel slag	vs	-	-	-	-	-	Vs
Cindery slag	-	-	-	-	-	-	-
Ferrous slag	-	-	-	-	vs	-	-
Metal, rust, scale & fume	vs	vs	s	-	s	vs	S
Limestone & dolomite	-	-	-	-	-	-	-
Iron ore & ironstone	-	vs	-	vs	vs	-	-
Shale, clay & ash	-	-	-	-	-	-	-
Coke	vs	vs	s	s	s	vs	S
Coal & char	-	-	-	-	vs	-	-
Cementitious material	s	s	s	s	s	s	S

L = very large, l = large, m = medium, s = small and vs = very small amounts

Figure 49 – Slag Analysis Results (Thomas Research Services (2008))

4.3 Results from Previous Site Investigations

4.3.2 Geological / Geotechnical Survey Results

A summary of the Geotechnical Survey results from the Upper Plateau site can be seen in the desk study information, presented on pages 7 to 18 of the appendix to this document. These tables have been produced from data collated from cone penetration tests, boreholes and trial pits completed by Shadbolt Environmental in July 2008. The Ground Investigation report illustrates high levels of variation in the sub-surface stratigraphy at the Upper Plateau site, with the depth to rock head varying from 5-6m in the south of the site to over 20m in the north. As previously noted, the site itself is relatively level, varying in height by approximately 15m with aOD 255m in the south east, dropping to aOD 240 in the north west, therefore these depth variations and the spatial properties which they possess are a consequence of infilling during reclamation.

The Ground Investigation Report aimed to determine the stratigraphy of the site, as well as identifying any areas in which geotechnical hazards may be encountered. For the requirements of this report, only the data pertaining to the depth and nature of Made Ground has been collated, with specific geotechnical properties not included. Whilst buried concrete and other geotechnical obstacles are recorded across the site, these are not likely to significantly alter the calculation of Made Ground presence across the site. Figure 50 on page 140 illustrates the location of ground investigation points utilised in the creation of the Ground Investigation Report. The points at which depth of Made Ground is known have been annotated in red. This data will be utilised in the construction of a conceptual ground model for the site, from which an estimate of the quantity of Made Ground at the Upper Plateau site can be made, in order to ultimately estimate the likely availability of slag for carbonation across the site as a whole.

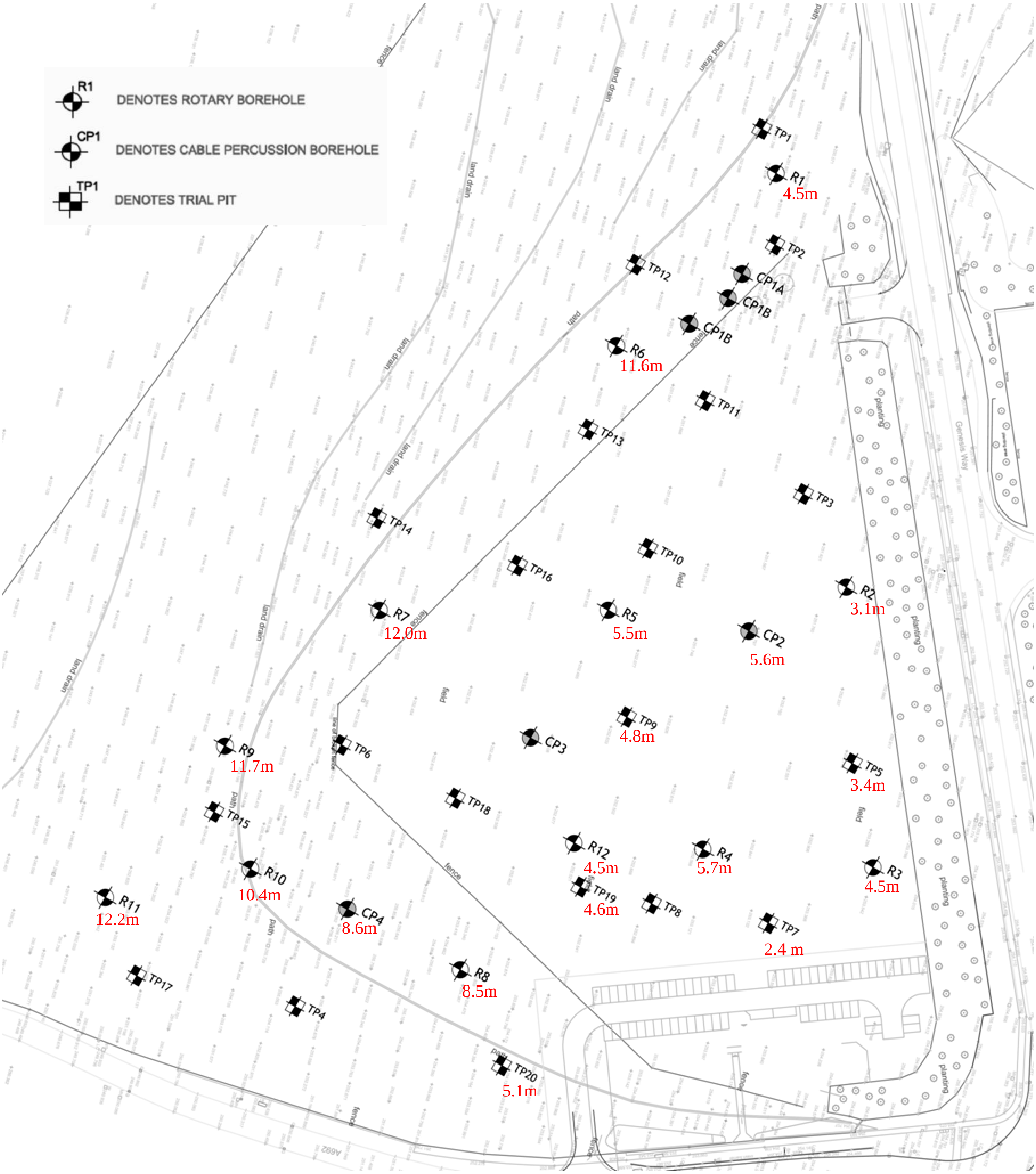


Figure 50 - Location of Trial Pits, Cone Penetration Tests and Rotary Boreholes across the Upper Plateau site. Figures in red denote thickness of Made Ground (where known). (Source: Shadbolt Environmental)

5. DISCUSSION

5.0 DISCUSSION

5.1 Field Work

5.1.1 Field Testing

Acid testing in the field illustrated numerous locations, and sample depths, at which reactions supporting the presence of calcium carbonate visibly occurred. This data supported the validity of soil sampling measures carried out across the site, in order to determine the comparative presence of calcium carbonate present. The visible reaction of samples with dilute acid also supported the supposition that high levels of calcium carbonate presence were likely to be encountered.

The preliminary findings regarding the nature of the soil were significant in informing the procedure implemented in soil sampling at the site. During the completion of fieldwork it was decided that a number of alterations be made to the initial soil sampling method. From preliminary site works, it was noted that the ground conditions present at the site were particularly unfavourable for hand excavation. It was found that at shallow depth the soil was fine grained, with the majority being under a particle size of 2mm. This soil frequently contained small pebbles at greater depth and was compacted to a significant extent, making excavation problematic. Whilst augering was suggested as a potential method for acquiring soil samples at increasing depth, it was noted during preliminary surveying that whilst a hand auger was effective in sampling the topsoil and immediate subsurface present at the site, samples of made ground could not be taken in this manner. Large inclusions of slag persisted through the deeper levels of the site, as illustrated by the PSD curve in Figure 12, page 44 of the appendix representative of samples taken at 1.4m. From the results of these works, it was decided that hand dug profile samples, proposed as an alternative methodology, would be most effectively employed in representative soil sample collection.

5.1.2 Vegetation Survey Results

The vegetation survey results have illustrated that the site in general has significant vegetation cover, which does not seem to seasonally vary in density, with observations of ground cover carried out in spring and summer, compared to winter data in the Penn Associates study (2008). These results suggest that the maximum potential amount of dissolved carbon dioxide, produced by plant root activity, with respect to the prevailing climax vegetation type (grassland) is being provided to the soil. As mentioned in the literature review to this document, this 'maximum potential' with respect to the presence of dissolved carbon dioxide is likely to depend upon the vegetation type present at the site, however, the vegetation survey results have shown little variation in vegetation types across the site, meaning that this phenomenon is unlikely to influence variations between sample locations in this instance.

Table 21 – Fulfilment of objectives

	Objective	**Comments**
1.	To determine percentage groundcover of vegetation across the study site	The percentage ground cover for the site was found to range from 90 to 100%. Percentage ground covers of this order are indicative of relatively productive vegetation turnover, therefore, meaning that variation in vegetation density is unlikely to spatially affect the rate of carbon dioxide supply to the soil, which in turn determines calcium carbonate formation.
2.	To assess the presence of prevalent or protected plant and animal species	The variation in plant species across the site was noted. Little variation occurred over the majority of the Upper Plateau site, which consisted mainly of rough, reclamation grassland. No known protected plant or animal species were encountered during works at the site.

5.1.3 Geophysical Results

The pseudo-sections produced during the geophysical survey of the Upper Plateau site illustrate the presence of a highly variable resistivity signal with increasing depth. Resistivity values of over 210Ω.m persist to a depth of 5-8m, with significantly lower values of resistivity persisting below this depth. Close to the ground surface a number of high resistivity anomalies can be noted, of approximately 470-648Ω.m. As noted by Milsom (1996) calcium carbonate has a distinctively high resistivity of 500 – 10,000Ωm. Whilst the surface anomalies detected in the resistivity survey are concurrent with this value, it is unlikely that calcium carbonate persists in the dimensions noted in the pseudo-section images. It is also known that small metallic formations exist across the site, due to their persistence in initial surveying works, therefore, it is interesting to note that the presence of low resistivity anomalies, which would be typified by metals such as iron and steel, has not been recorded during this survey. These metallic inclusions do, however, often seen to form part of a larger, conglomerate structure, some elements of which have been identified as furnace bottom, which may explain their lack of detection in this survey, due to shielding by associated materials of low resistivity.

Figure 51 illustrates an interpretation of the 2D pseudo-section produced during the geophysical survey, correlated with the formation depths identified by boreholes and trial pits in previous site investigations. From this figure it can be seen that the ground conditions indicated during direct survey correlate relatively well with the geophysical results attained for the site. The low resistivity anomaly at a survey length of 80m is through to demark the point at which a break in survey was created by the addition of non-signalling switch boxes to the array. This area is defined by a length of approximately 5m in which no resistivity readings are available, appearing as a break in the resistivity boundary. The geophysical boundaries included in Figure 51 have been stylised and oriented with respect to simplified site topography, but represent the true depth responses recorded during the resistivity survey. Slag resistivity, in the context of slag cements, is quoted at 300-500Ωm (Ferreira *et al.*, (2004)). It can be seen that the resistivity boundary at and above 350Ωm correlates relatively closely with the lower surface of the made ground detected at the site, proving the effectiveness of this survey method in determining sub-surface stratigraphy. The resolution of the method, however, is not entirely correct, as the survey passed close to Rotary Borehole 3, indicated in Figure 51, at which the resistivity readings do not directly correlate with the known ground strata. The provenance of low resistivity anomalies within 1-3m of the ground surface has not been quantified by this survey, but these are thought to have been caused by heterogeneity of material distribution within the site. The heterogeneity represented by the immediate surface response was noted by George Tuckwell of RSK STATS Geoconsult Ltd.

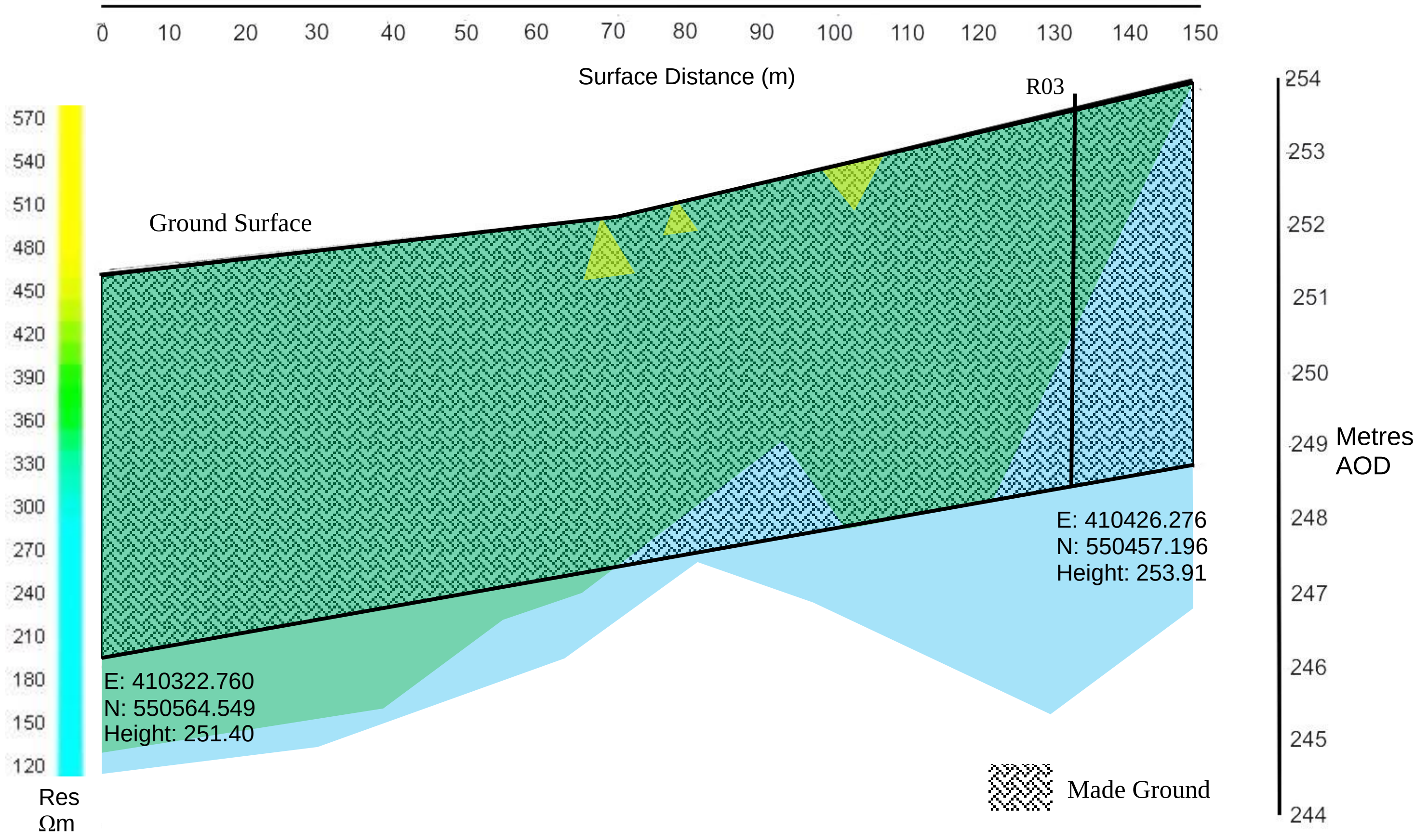


Figure 51 – Comparison between ground formation data from previous site investigation and resistivity data. Vertical exaggeration 10x

Table 22 – Fulfilment of objectives

	Objective	**Comments**
1.	To confirm the stratigraphic results of previous ground investigations	The resistivity survey has confirmed the presence of large-scale, heterogeneous formations immediately below the ground surface at the Upper Plateau site. A comparison between actual ground investigation results for the immediate area has illustrated the presence of heterogeneous variation in ground substrate, which matches with the horizontal depths attained during ground investigation works.
2.	To investigate the geophysical properties of iron and steel slag	Iron and steel slag would appear to present a geophysical anomaly of relatively low resistivity, concurrent with the resistivity values assumed for mixed slag, 300-500Ωm.
3.	To determine the presence of calcium carbonate horizons as a geophysical anomaly	The survey has not been able to quantify the presence of discrete calcium carbonate horizons within the soil. Whilst a number of resistivity values fall within the range expected for bulk calcium carbonate formations, these results cannot be qualified by ground investigation observations.

5.2 Laboratory Testing

5.2.1 Calcimeter

The calcimeter data illustrates the presence of calcium carbonate in all tested samples, with the exception of the control samples, proving the formation of calcium carbonate in soils in the region is not a wide-ranging phenomenon. The presence of calcium carbonate in glacially derived soils, such as those present across the areas bounding Consett works, is generally low, in the order of ≤1%. The control sample results are concurrent with this proposed data, demonstrating no significant sequestration potential, registering values of 0.1% or lower. The negative calcium carbonate readings produced are thought to be an artefact of the analysis process as opposed to a significant geochemical signature. When error bars are applied to this data, all falls within the range of 0-0.1% $CaCO_3$.

The Upper Plateau site produced a significant number of high calcium carbonate readings, with over 35% of results in excess of 10% calcium carbonate by mass. The variability in the calcimeter results attained at the Upper Plateau site is, however, exceptionally high at 26.8%. It was noted that the highest readings at the site were experienced at sampling points where it had been observed that large fragments of slag material were directly weathering, with a calcium carbonate crust visible. This situation was recorded at the central and north eastern sampling points, where it is demonstrated that calcium carbonate concentration increased with depth to a maximum depth concurrent with the persistence of the weathering slag formation.

The preliminary laboratory data illustrated in Table 26, page 113 matches closely with data acquired during studies by Renforth *et al.*, (2009), which attained a mean value of 29.6% calcium carbonate by mass at the Howns Gill site, to the south of the Upper Plateau site. A summary of the results attained for calcium carbonate concentration across the Consett works site are summarised in Table 32 below. Renforth *et al.*, (2009) also note significant variability of 38.3% in calcimeter results acquired at the Consett works site. It must be concluded that the presence of calcium carbonate across the Upper Plateau is heterogeneous, relating directly to the heterogeneous distribution of slag across the site. Whilst it is impossible to directly measure the variation in calcium carbonate presence throughout the likely formation depth of the entire site, it may be assumed that the minimum concentrations identified are likely to be 'worst case' values. Table 23 illustrates the probability of calcium carbonate concentrations encountered at the site between various concentration boundaries. These figures demonstrate that the probability of any tested sample possessing a calcium carbonate concentration (by percentage mass) of over 2% is 92%. A third of samples tested are, by the same deduction, likely to possess a calcium carbonate concentration (by percentage mass) in excess of 10%, which is deemed to be a significant proportion, unusual for natural soils.

Table 23 – Calcium carbonate concentration probabilities

$CaCO_3$ concentration $CaCO_3$ = x (%)	**Experimental Values EV > x**	**Probability (when EV > x)**
1	38	0.974
2	35	0.923
3	27	0.692
5	16	0.410
10	13	0.333
15	9	0.230
20	7	0.180

Spatially the calcimeter data illustrates a wide range of calcium carbonate values across the site. As fewer samples were collected at the Derwent View and Hown's Gill it is difficult to draw direct comparison between the study areas, however the results produced in the two datasets do not appear incompatible as illustrated in Graph 7, page 125. Derwent

View exhibits a lower mean calcium carbonate content, by percentage mass, than the Upper Plateau samples however, these samples show a significantly lower level of variability than the Upper Plateau results of 2.5%. The Howns Gill site represents a similar ground situation, with calcium carbonate concentrations ranging from 5.17-7.90% throughout the profile, which falls within the range of mean values calculated at the Upper Plateau site. The soils sampled at the Derwent View and Howns Gill had a different texture and appearance from the samples collected at the Upper Plateau site, with an elevated organic content indicated by dark colouration and peaty texture. The capping depth at Derwent View and Howns Gill appears to be significantly deeper than the Upper Plateau site, with the potential for calcium carbonate formation to be occurring at greater depth than observed at the neighbouring site. Derwent View has also been utilised as grazing land for a number of years, meaning that turnover of organic matter is likely to occur to a different extent than the semi-managed grassland of the Upper Plateau site, which may explain increased topsoil depth. These additional sites have demonstrated the presence of comparable mean calcium carbonate concentrations persisting in soils across the site between 0 and 240mm below ground level.

Table 24 – Calcium carbonate concentration and variability in tested samples

Site Location	Mean Calcium Carbonate (%)	Variability in Calcium Carbonate (%)
Control	-0.198	0.47
Upper Plateau (Preliminary)	16.42	32.61
Upper Plateau	8.53	26.8
Upper Plateau (Surface)	17.3	8.94
Derwent View	4.0	2.5
Howns Gill	6.1	2.73

Table 25 – Fulfilment of objectives

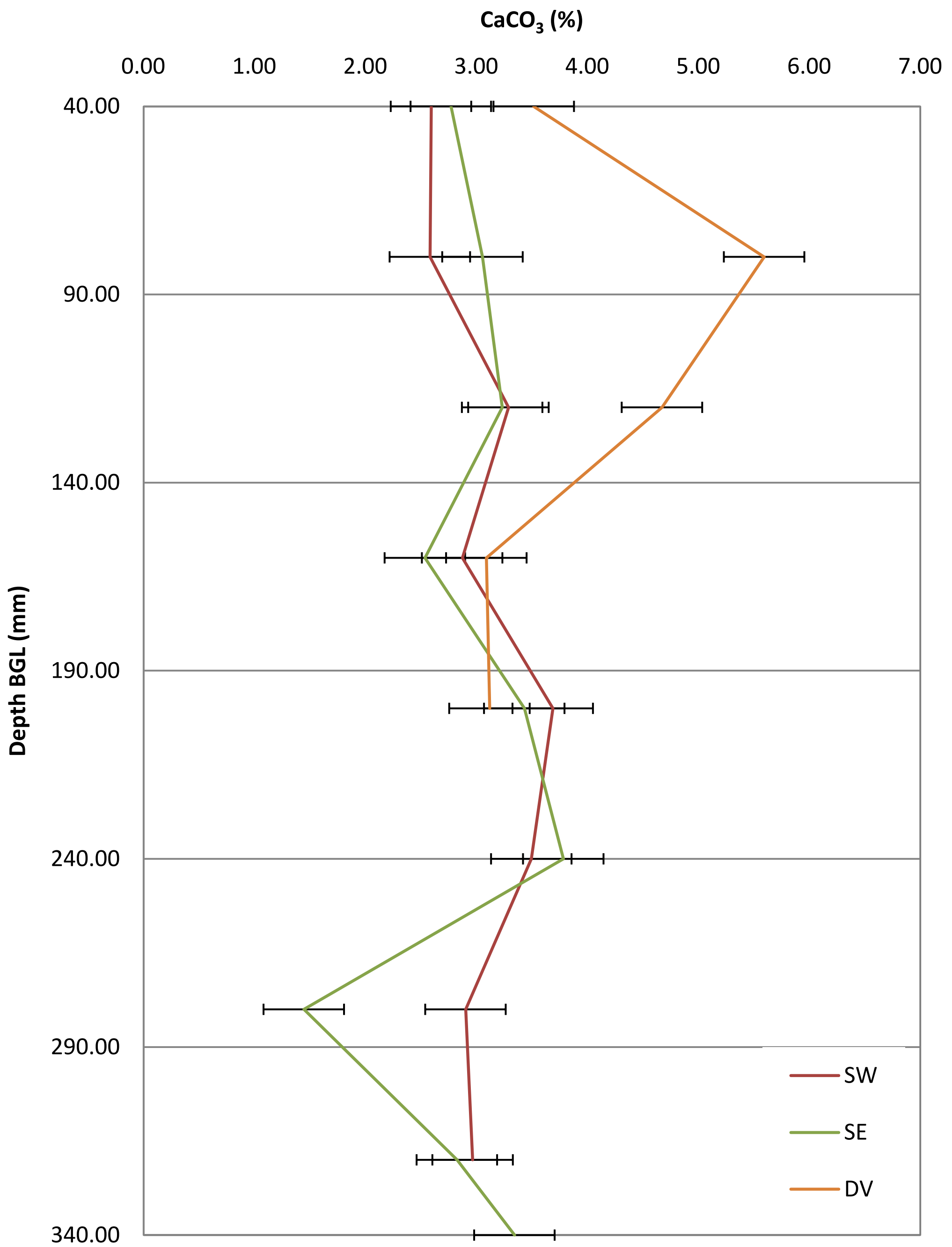
	Objective	**Justification**
1.	To confirm and quantify the presence of calcium carbonate in soil samples	The presence of calcium carbonate has been quantified across the Upper Plateau site, with concentration variation between 1% and 27%. Comparison with a control sample has confirmed the promotion of this reaction by slag.

Observations and Trends

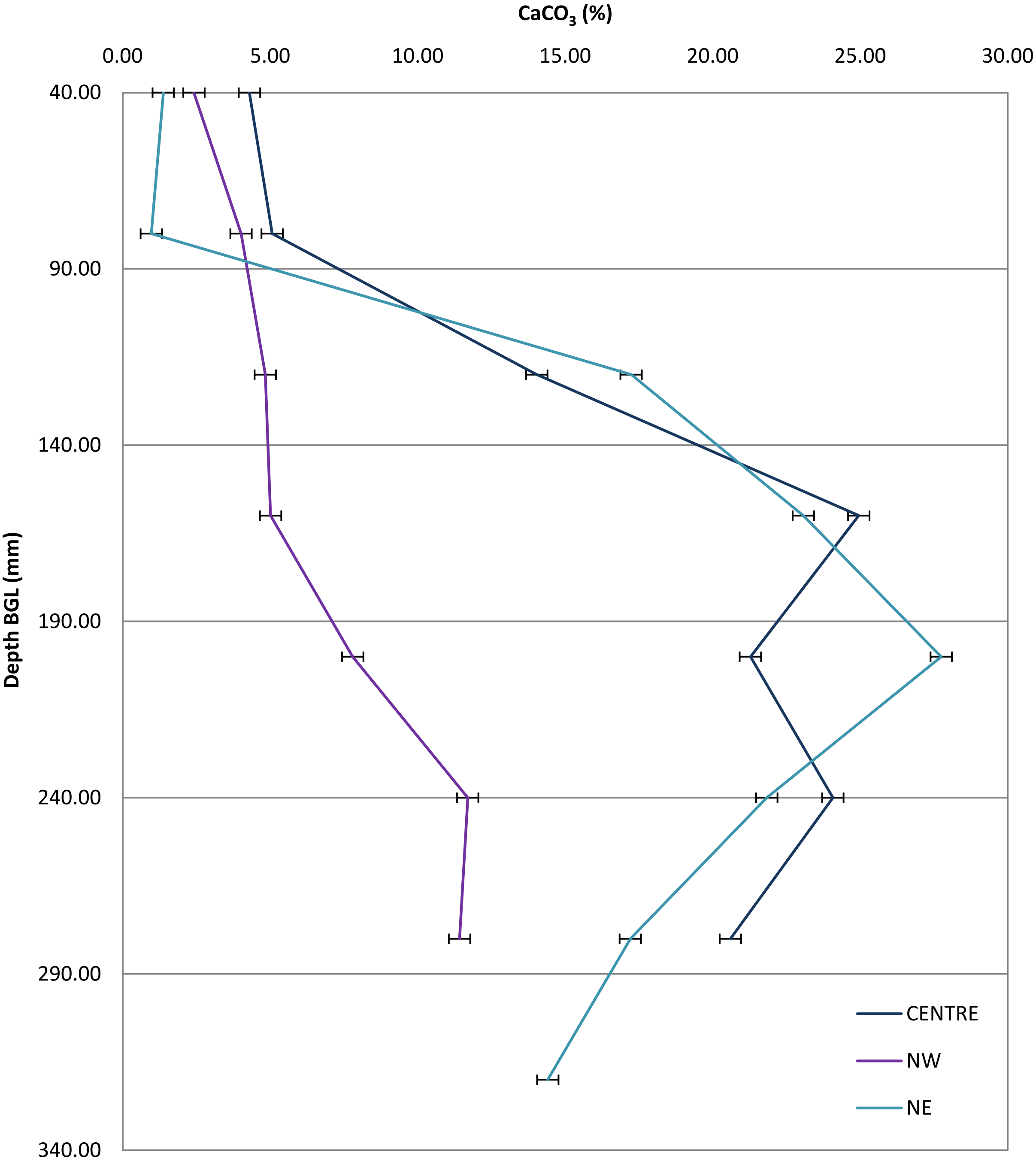
Graph 7, page 125 illustrates the spatial and depth-related variability of calcium carbonate concentration in all tested samples. This graph illustrates that a number of the Upper Plateau samples tested demonstrate significant variation in calcium carbonate concentration with depth (Centre, NW, NE), as well as the Howns Gill data. All of these data sets demonstrate an increase in calcium carbonate presence with increasing depth, up to 200-240mm, which appears to level or decrease slightly after this point.

- The first trend, Graph 10, is shared by the samples analysed from the south east and south west of the site (as well as the samples taken at the neighbouring Derwent View site), showing calcium carbonate contents of below 5%, which varies little with change in depth.
- The second trend, Graph 11, is shared by the samples collected in the north east and north west of the site, which illustrate an increase in calcium carbonate concentration with depth, to approximately 20-24cm, after which concentration values begin to decrease.

Royer (1999) notes that the rate and extent of calcium carbonate formation can be altered by variations in rainfall. Whilst it is impossible to confirm this as a major contributing factor, it must be noted that all of the samples which adhere to the second graphical trend were collected after a period of warm, dry weather. The samples collected in the south east and south west of the site were collected during a period of wet weather, and after a sustained period of stormy conditions. This hypothesis is reinforced by the preliminary data collected at location in the south east and south west of the Upper Plateau site (within 5m of the final data collection points), which was collected after a period of sustained dry weather and both exhibit a trend towards increased calcium carbonate concentration with increased depth.



Graph 10 – Trend 1 – calcium carbonate content does not significantly vary with depth



Graph 11 – Trend 2 – calcium carbonate concentration varies significantly with depth

5.2.2 Petrographic Microscopy

5.2.2.1 Light Microscopy

Analysis of sample material under a light microscope using optical mineralogical techniques has illustrated high levels of mineralogical variability present in slag at the Consett works site. Table 18 records the sample notes collected during analysis of the sample slides, which illustrates major variations in both mineral matrix and inclusions. As expected for slag, the mineral matrix is glassy, with fine crystals inset. Larger crystals persist in smaller quantities, thought to have formed due to differential cooling in the molten slag material. Metallic inclusions were also observed in a number of the samples, as circular to oval black, opaque bodies.

Figure 52 – Photomicrograph of a typical blast furnace slag in thin section (Magnification x300) Source: Lee (1974))

The identity of all of the mineral phases observed is difficult to assess, as many uncommon, stable and meta-stable calcium minerals persist within weathering slag. Lee (1974) notes the presence of akermanite $2CaO.MgO.2SiO_2$, gehlenite $2CaO.Al_2O_3.SiO_2$, anorthite $CaO.Al_2O_3.2SiO_2$ and dicalcium silicate $2CaO.SiO_2$ in common blast-furnace slags.

The image illustrated in Figure 52 demonstrates the microscopic appearance of an ‘idealised’ blast furnace slag, taken from Lee’s 1974 publication ‘Blastfurnace and Steel Slag’. Figure 52 illustrates blast furnace slag in thin section, at relatively high magnification of 300x. The dark, striated inclusions indicate the presence of dicalcium silicate ($2CaO.SiO_2$) which frequently forms in slag with high lime content. This mineral phase has a similar appearance in polarised light to calcium carbonate, with striations which manifest in a similar manner to the cleavage patterns encountered in well-formed calcium carbonate crystals. The direct identification of this important, meta-stable weathering product of slag, which may be critical in determining the availability of CaO, was not possible using light microscopy, however some progress was made using SEM techniques, as discussed in section 5.2.2.2.

The ‘target’ mineral, calcium carbonate, is distinctive when viewed in thin section, under transmitted light with crossed polars, as it produces a characteristic ‘twinkling’ effect due to its high birefringence (double diffraction) MacKenzie (2003), producing strong, pastel interference colours on rotation of the microscope stage. The presence of calcium carbonate was confirmed within all six of the thin sections analysed, utilising this optical property. High concentrations of calcium carbonate were noticed at the margins of the sample and in association with low relief features, thought to be ‘holes’ in the sample, through which the mounting medium can be clearly viewed. Section 4.2.2.1 notes the presence of vesicles, thought to have been formed by air escaping during the cooling of the slag, is a notable feature of all of the sample slides. As well as the limited presence of calcium carbonate within the mineral matrix, a white corona of calcium carbonate, with an average thickness of 100-300μm, is present around all vesicles in the thin sections. CLW – 4 and CLW – 5 clearly exhibit the presence of ‘channels’ in the slag, with calcium carbonate formations also persisting on all available outer surfaces. The presence of these channels is attributed to the orientation in which the samples have been prepared; the vesicles observed in samples 1-3 and 6 may represent the cross section of a tubular feature. At a microscopic level it can be proposed that the reaction surface available for conversion of calcium oxide to calcium carbonate would be significantly increased if the slag possessed tubular vesicles, presenting access to the external environment.

5.2.2.2 Scanning Electon Microscopy

With respect to the determination of bulk mineralogies, the photomicrographs acquired during SEM analysis of slag samples collected at the Consett works site have demonstrated a number of discernable patterns in elemental spread throughout the samples. Both calcium and silica produce strong spectra when characteristic X-ray analysis is applied to the samples. Crystals set within the glassy matrix were also analysed in this manner and found to contain, as well as significant proportions of calcium and silicone, iron, magnesium and aluminium. The identification of magnesium and aluminium within the heterogeneous matrix of the slag suggests the presence of the ‘typical’ blast-furnance silicate minerals proposed by Lee (1974), akermanite $2CaO.MgO.2SiO_2$, gehlenite $2CaO.Al_2O_3.SiO_2$, anorthite $CaO.Al_2O_3.2SiO_2$ and dicalcium silicate $2CaO.SiO_2$. Few other elemental spectra were identified with certainty within the samples.

The presence of silicate minerals and carbonate minerals in zonation throughout the sample has been noted in a number of areas, with calcium carbonate presence strongly suggested during optical microscopy, confirmed by the spectral analsyses conducted around the margins of vesicles and tubules within the slag struture. As noted in section 4.2.2.2, a coating of calcium carbonate approximately 33-133μm thick was noted on tubules and vesicles throughout the slag structure. In these slides, ‘cross sections’ of vesicle features persist for a distance of ≥500μm, presenting the appearance of a large potential surface area for weathering. Whilst a third dimension is not calculable from the appearance of the thin section, due to unpredictability of orientation of the sample and persistence of the vesicular features, it is possible to predict that the available surface area for sequestration reaction to occur would be significantly greater than the area presented by the surface of slag fragments alone.

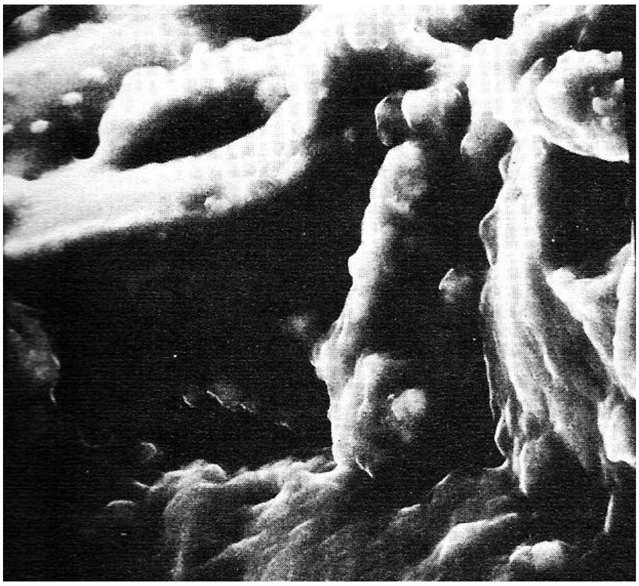


Figure 53 – Scanning electron photomicrograph of a typical blast furnace slag as an untreated aggregate (Magnification x1000) (Source: Lee (1974))

Figure 53 illustrates an SEM image, depicting the surface appearance of an untreated slag aggregate under magnification of 1000x, demonstrating the rough surface topography of the porous sample. The SEM images illustrated in section 4.2.2.2 and the appendix to this document demonstrate the appearance of slag in polished thin section, which has created a virtual topography of cross-sections through variations in the mineral structure. This image is useful in comprehending the microstructure of the material, as it suggests a significant potential for ‘rough’ surface topography to provide a preferential site for weathering and geochemical reaction, increasing the surface area of the material.

The presence of calcium carbonate forming in association with persistent physical features of the slag provides a useful microscopic understanding of the manner in which the material preferentially weathers and the geochemical limitations which are imposed by these physical properties. It would appear that calcium carbonate formation does not occur uniformly through the material as would be expected, its concentration does not appear to decline in a liner manner towards the interior of the specimen, nor is its formation limited to the outer surfaces of the material. SEM and light microscope analysis has proven the persistence of calcium carbonate formation in vesicles throughout the slag fragments analysed, therefore, it is proposed that as well as calcium carbonate formation being controlled by chemical properties, such as the type of slag and chemical species present, it is also directly controlled by physical properties, such as the porosity of the slag. This factor may be especially significant in the weathering and sequestration behaviour of larger slag fragments, which have an inherently smaller surface area to volume ratio than the finer material encountered in surface excavations at the site. It is difficult to predict, in this context, the level of calcium carbonate formation occurring in vesicles throughout the slag structure. Recommendations for further study include the SEM analysis of slag fragments, in order to assess surface topography and vesicle persistence, combined with thin section analysis, to determine the proportion of calcium carbonate forming for each ‘slice’ of the material.

Table 26 - Fulfilment of objectives

	Objective	**Comments**
1.	To investigate the mineralogical constituents of weathered slag	Whilst it was difficult to identify all mineral phases within the slag, significant features thought to relate to its physical habit and weathering processes were noted. Calcium carbonate was detected under polarised light and through the use of SEM coupled with characteristic X-ray analysis. The presence or absence of the deduced X-ray spectra for calcium carbonate was used to map notable formation sites.
2.	To qualify the findings of previous petrographic site investigations	The presence of silicate and carbonate minerals was suggested by SEM coupled with characteristic X-ray analysis. The potential for hydroxide minerals was also noted, as well as the potential for aluminium inclusive phases such as gehlenite and anorthite.

5.2.3 Isotopic Ratio Mass Spectrometry

Isotopic ratio readings, presented in Graphs 8 and 9 pages 134-135, have demonstrated the provenance of carbon and oxygen isotopes with respect to known experimental values. These figures have illustrated, through comparison with documentary evidence, that the calcium carbonate present in the tested samples has been formed through both organic and hydroxylation reactions, producing ^{13}C values of -11‰ to -21‰. No evidence of lithogenic carbonates, which tend to demonstrate less depleted isotopic values of -0‰ to -10‰ for ^{13}C, were detected in the samples, proving the hypothesis that carbonate formation at the Consett works site is not mediated by geological factors.

Analysis of IRMS data has demonstrated a sequestration provenance of the carbon and oxygen present in carbonate formations. Figure 54 presents a proportional comparison between organic and hydroxylation data determined in this study and in the Renforth *et al.*, (2009) study carried out at the Consett works site. These graphical representations demonstrate a higher organic provenance of calcium carbonate in the samples collected at the Upper Plateau site than the Howns Gill site. Hydroxylation, which occurs as the predominant sequestration process in high pH environments appears to be a less significant source of calcium carbonate at the Upper Plateau site, suggesting a lack of strongly alkaline conditions, such as those noted by Mayes *et al.*, (2008) at the Howns Gill site, across the Consett works site. The high proportion of organic carbonate present at the Upper Plateau site may be explained by the high levels of vegetation cover, leading to a higher turnover of carbon in the soil than at the less densely vegetated Howns Gill site. In general, the proportion of carbonate forming through hydroxylation is higher in the North of the Upper Plateau site, potentially suggesting the persistence of higher alkalinity in this region, a it is proposed that the spatial disparity in hydroxylation at Howns Gill is mediated by proximity to artificial drainage features, presenting an alkaline environment in which this reaction is favoured.

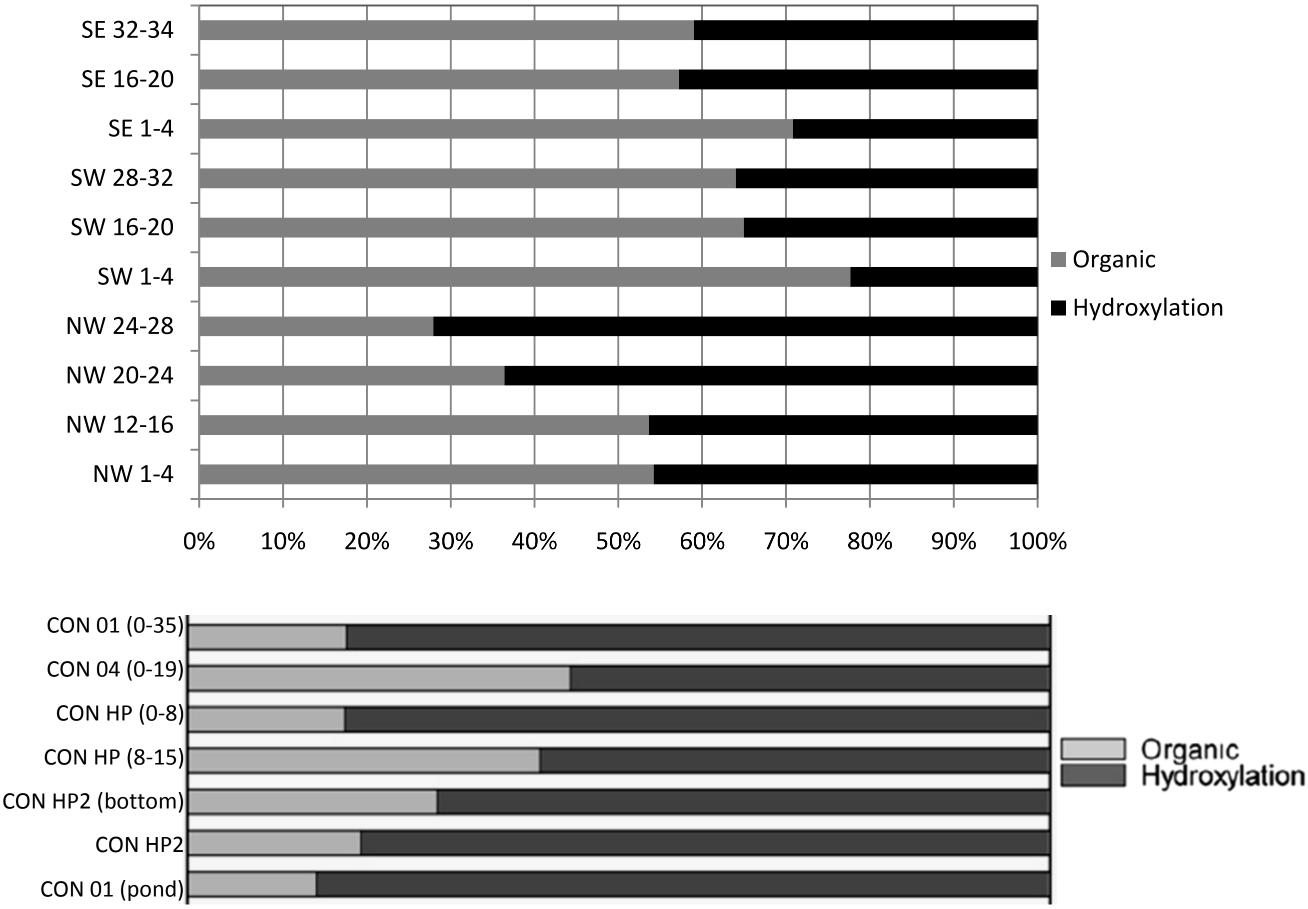


Figure 54 – Comparison between site data and isotopic ratio results acquired during the Renforth *et al*., (2009) study at Consett works

Figure 55 illustrates a comparison between $\delta^{13}C$ and $\delta^{18}O$ IRMS data acquired in this study and data collated from the literary sources. The data presented by Renforth *et al*., from Consett works shows a trend toward heavier isotopic signatures than the data presented in this report, created by a higher proportion of calcium carbonate produced through hydroxylation. A significant overlap of data is still observable. Andrews *et al*., (1997) reports comparable isotopic figures for IRMS analysis of carbonate formations in high calcium regions surrounding a former lime quarry, created significantly by hydroxylation in the presence of high pH waters from the dissolution of lime spoil. Krishnamurthy *et al*., (2003) present data from analysis of carbonate formations on concrete structures, mediated almost exclusively by hydroxylation, which form a characteristic cluster of more significantly depleted values.

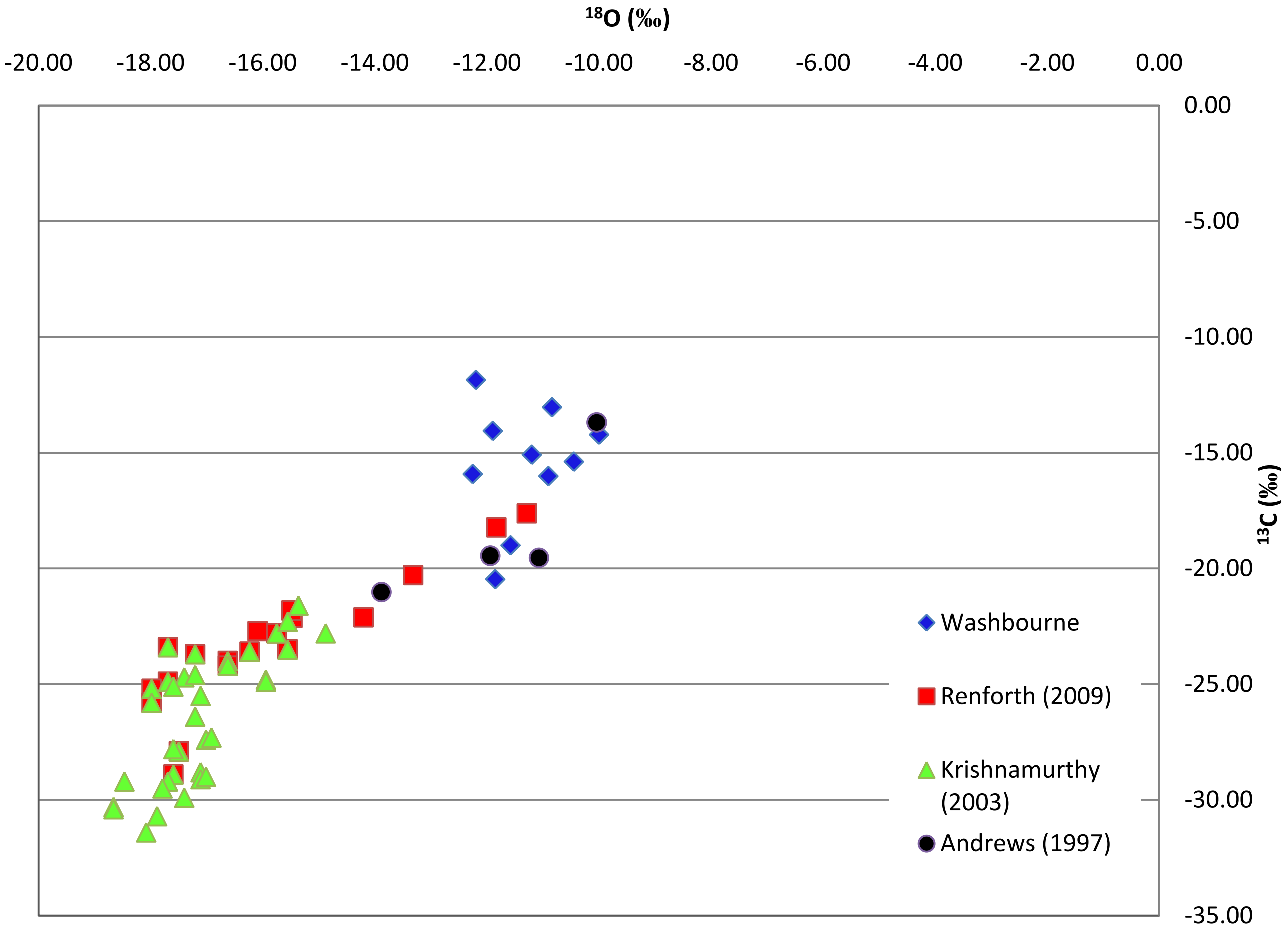


Figure 55 – Comparison between soil carbonate data values – Renforth *et al*., (2009), Krishnamurthy *et al*., (2003) Andrews at el (1997)

Table 27 - Fulfilment of objectives

	Objective	**Comments**
1.	To determine the provenance of carbon and oxygen isotopes found in soil formed calcium carbonate	IRMS analysis has proven that calcium carbonate at the Upper Plateau site was produced through a combination of organically mediated sequestration and hydroxylation. Comparison with documentary evidence has illustrated the favourable context of the attained data, as illustrated in Figure 55, demonstrating its comparability with other site data and IRMS analysis for natural carbonates.

5.3 Previous Site Investigations

5.3.1 Slag Analysis

The slag analysis carried out by Thomas Research Services on samples taken from the Upper Plateau site have been useful in providing a comparison with data acquired during petrographic microscopy and SEM analysis. The objectives of this analysis, as stated in the report by TRS, were of a geotechnical nature:

- To determine the range and relative concentrations of any iron and steelmaking slags present in the samples
- To investigate whether there was any potential for volumetric instability in the slag

This limited the information presented in the report by relevance to aims of the project, meaning that no quantitative data was provided with respect to relative proportions of slag types or mineral constituents. Whilst it is difficult to qualify the presence of all minerals noted in the TRS report, through optical microscopy and SEM analysis, without a considerable level of expertise in the petrography of slag, the presence of calcium carbonate in the petrographic samples studied has been qualified in optical microscopy and SEM analysis carried out on the petrographic samples taken from the Consett works site. The analysis figures have allowed an investigation in to the nature of the slag material present at the site, with respect to bulk mineralogy and inclusions, although quantitative data cannot be acquired in this manner. SEM analysis of characteristic X-rays has confirmed the presence of a suite of silicate and carbonate minerals in the samples, which correlates closely with the findings of the TRS report. As previously stated, the TRS report notes that finer particles in samples were often bound together with ‘cementatious material similar in nature to the alteration products of the slag’. This has been qualified by the presence of inclusions observed within the glassy matrix of the slag, bound together by a heterogeneous matrix containing both silicate minerals and calcium carbonate as illustrated in Figures 47a and b.

5.3 Previous Site Investigations

5.3.2 Geological / Geotechnical Survey

The completion of a conceptual ground model required an analysis of the findings of boreholes and trials pits completed as part of the 2008 site investigation at the Upper Plateau site to create a map of known stratigraphic points across the survey site. This enabled the prediction of Made Ground quantities across the site, by interpolation of depths from the ground surface elevation at known sampling points. Whilst the images created in this instance, illustrated on page 60-62 of the appendix to this document, address the variation in cross sections, a three dimensional image of the site can also be constructed in this manner by connecting the topographic ‘slices’ using an average persistence of slag across delineated surface sections.

The Ground Investigation Report produced by Shadbolt Environmental includes a number of conceptual ground sections which were used to inform the production of the conceptual sections created in this project. These basic models can be seen reproduced, with amendments, illustrated in the desk study section of the appendix to this document, pages 4-6. It must be noted that the majority of subsurface data collected during the Ground Investigation Report was focussed around the southern half of the site, meaning that whilst the ground situation in this area appears more complex in conceptual models, this is mainly due to the higher resolution of the data in this region.

The geological cross sections produced in this report, illustrate similar ground conditions to those presented by the Ground Investigation Report. These sections illustrate the relatively large variations in Made Ground depth across the site, from 12.2m in the south west to 3.1m in the mid-east.

5.4 Conceptual Modelling

5.4.1 Conceptual Modelling - Upper Plateau

The conceptual site model combines the ground model produced from the previous site investigation reports with laboratory findings in order to predict the likely presence of calcium carbonate across the Upper Plateau site. The conceptual ground model has been created by the interpolation of points across the site at which depth of Made Ground is known, combined with recorded ground elevation levels and mapped surface areas.

In order to estimate the quantity of made ground present at the site, the area was divided in to surface area sections in which thickness of made ground was within agreement of ±2m. Using a combination of site area data acquired from EDINA Digimap Carto and average thicknesses of made ground within each of the sections shown in Figures 56-57, the quantity of made ground present at the Upper Plateau site was estimated. These calculations are included in Table 28. These conceptual calculations of made ground presence at the Upper Plateau site have been used to estimate the potential for carbon sequestration at the site, by assuming a relative quantity of slag material present in the made ground across the site.

Table 28 – Quantity of Made Ground present in conceptual sections across the Upper Plateau site

Region	**Area (m^2)**	**Average Depth of Made Ground (m)**	**Quantity of Slag (m^3)**
1	4429.5	4.68	20707.91
2	9758.0	4.56	44496.48
3	6378.0	7.84	50003.52
4	2122.0	8.40	17824.80
		Total	133,032.71

There are a number of assumptions and limitations presented with respect to this model:

Assumptions:

- Variations in depth of Made Ground occur in a linear manner between points at which depth in known – this may not be the case, but as a conceptual model, a straight line plot is an acceptable assumption
- That undulation in the upper ground profile improves the overall accuracy of average thickness calculations
- Made Ground material is relatively homogenous, at a larger scale, and contains a uniform distribution of slag material
- That the made ground consists (almost) entirely of slag
- That sequestration is able to occur through the full depth of made ground
- That the average thickness of Made Ground assumed across the surface areas in Figures 56 and 57 are representative of the ground conditions

Limitations:

- The model is unable to predict variations in calcium carbonate concentration with depth across the site and is based upon minimum, mean and maximum experimental figures illustrated in Table 28 and the following sections.
- The model is unable to realistically apply stratigraphic variations in sequestration

Figure 56a and b – Approximate area divisions of Upper Plateau site (Source: EDINA Carto)

Figure 57a and b – Approximate area divisions of Upper Plateau site (Source: EDINA Carto)

Quantity of Slag Available

As this project aims to address slag as an engineering commodity, its carbon capture properties need to be assessed as a bulk material, with a relevant commercial value. If this ground model is, therefore, approached as an economic geology assessment, in the same manner as a commercial mineral deposit would be viewed, something approaching a minimum, mean and maximum ‘reserve estimate’ for the slag material can be created.

The quantity of slag present at the Upper Plateau site has been estimated using a conceptual ground model, the details of which are illustrated in section 5.3.2, produced using information collated from previous Ground Investigation reports. The site boundaries were calculated using the EDINA Digimap Carto service, where known depths of made ground were used to calculate a stratigraphic map of the slag ‘reserve’, interpolating data between points using average thickness values.

In these calculations, the availability of slag in m^3 has been converted to a mass in tonnes using an assumed unit density taken from BS648:1964. Whilst fresh blast furnace slag has a unit weight of approximately 1150–1440 kg/m^3 (Lee, 1974), as a coarse aggregate slag is assigned a unit weight of 320.4–800.9 kg/m^3 which may increase to 1 041 kg/m^3 in the case of fine slag aggregates (BS648:1964). These figures have, therefore, been applied in minimum, mean and maximum sequestration calculations.

Quantity of Calcium Carbonate forming

Calculations are illustrated on pages 158-161. In the first instance a simple molar relationship has been assumed between CaO and CO_2, with the sequestration of the site estimated as a maximum potential with respect to the equilibrium balance of the reacting materials. In the second instance, a known average concentration of calcium carbonate, informed by experimental data, is applied to the site, with the relevant quantity of CO_2 back-calculated to estimate the likely quantity of CO_2 which has been captured, to date, by sequestration at the site.

It has been proven that pedogenic calcium carbonate formation occurs at high levels (from 1-27% with a mean value of 8.5% ± 0.18) across the Upper Plateau site. In the calculation of sequestration potential, this mean value will be used to represent the average quantity of calcium carbonate forming, with the minimum and maximum figures attained through calcimeter testing used to produce minimum and maximum estimates of calcium carbonate presence across the site.

In the calculation of maximum sequestration potential, the rate of calcium carbonate formation is, of course, likely to affect this estimate, due to the fact that the observed presence of calcium carbonate across the site may not be representative of an ‘advanced’ stage in the ultimate sequestration potential of the material present at the site. For the purposes of this report, the time dependent nature of the formation is negated, with the average percentage concentrations of calcium carbonate in the soil samples studied being taken as the maximum possible values, using stoichiometric assumptions.

Calculations

The calculations presented on pages 172-176, demonstrate the relationships between the predicted sequestration potential of the site and the estimated quantity of calcium carbonate currently present due to sequestration reactions were investigated.

In the first instance, the maximum sequestration potential of the Upper Plateau site, with respect to the simple equilibrium reaction shown, was found to be 54,405.63tonnes CO_2. This calculation assumes the maximum possible bulk density value and maximum proportion of CaO by mass in the slag. The sequestration figure denotes the maximum potential capacity for carbon capture if all of the CaO material present at the Upper Plateau site were to react to form $CaCO_3$. This calculation also assumed the maximum estimated quantity of slag present at the site through conceptual modelling. No time-dependency is assumed.

The second set of calculations illustrate the minimum, mean and maximum values of CO_2 currently sequestered at the Upper Plateau site, assuming minimum, mean and maximum figures for bulk density of slag and observed calcium carbonate concentration by mass from experimental data. These figures demonstrate a minimum presence of 468.80 tonnes CO_2 and a maximum presence of 16,452.26 tonnes CO_2, a difference of 15,983.46 tonnes. These calculations have assumed minimum, mean and maximum estimated figures for slag quantities at the Upper Plateau site, taken from the conceptual model included in section 5.4.1.

These calculations have demonstrated the difficulty in estimating the sequestration potential of the Upper Plateau site, due to the high variability imposed by multiple site parameters. The quantity of slag present at the site significantly affects the output of these calculations as well as factors including slag density, mass of CaO and the maximum attainable *in situ* calcium carbonate concentration. The maximum estimated value of sequestered carbon dioxide presently at the site is approximately 3 times lower than the maximum estimated sequestration potential (assuming geochemical equilibrium), demonstrating the remaining potential for the capture of 37,953.37 tonnes CO_2.

5.4.1.1 Maximum Sequestration Potential of Upper Plateau

Table 29 – Calculation of parameters

Parameter	**Source**	**Value**
Slag Quantity	Sheffield (1996)	133,032.71m^3
Bulk Density (av.)	BS648:1964 (max. value between medium-fine aggregate)	1041.0kg/m^3
Mass Slag	Calculated	138,487,051.10kg 138,487.05tonnes
Mass CaO (max. 50% by mass)	Lee (1974) (average value of CaO content for blast furnace slag)	69,243,525.56kg 69,243.53tonnes
Molar Mass CaO	Calculated	56g
Molar Mass CO_2	Calculated	44g
Molar Mass $CaCO_3$	Calculated	100g

Molar Balance, $1 \text{ mol } CaO + 1 \text{ mol } CO_2 \rightarrow 1 \text{ mol } CaCO_3$

Therefore, $56g\ CaO + 44g\ CO_2 \rightarrow 100g\ CaCO_3$

If,

69,243,525,560.00g CaO / 56g = 1,236,491,528.00mol CaO

Then,

123,649.15tonnes $CaCO_3 \rightarrow$ 69,243.53tonnes CaO + 54,405.63tonnes CO_2

54,405.63tonnes CO_2 is the maximum sequestration potential under the given parameters

Estimated potential per site area = 2.40tC/m^2

5.4.1.2 Minimum Quantity of Carbon Dioxide Presently Captured at Upper Plateau

Table 30 – Calculation of parameters

Parameter	**Source**	**Value**
Slag Quantity	Sheffield (1996)	133,032.71m^3
Bulk Density (av.)	BS648:1964 (min. value between medium-fine aggregate)	800.9kg/m^3
Mass Slag:	Calculated	106,545,897.40kg 106,545.90tonnes
Observed $CaCO_3$ (% by mass)	Experimental	1.0%
Molar Mass CaO	Calculated	56g
Molar Mass CO_2	Calculated	44g
Molar Mass $CaCO_3$	Calculated	100g

Molar Balance, $1 \text{ mol CaO} + 1 \text{ mol } CO_2 \rightarrow 1 \text{ mol } CaCO_3$

Therefore, $56\text{g CaO} + 44\text{g } CO_2 \rightarrow 100\text{g } CaCO_3$

If,

$1\text{kg slag} \rightarrow 0.01\text{kg } CaCO_3$

$106{,}545{,}897.40\text{kg slag} \rightarrow 1{,}065{,}458.97\text{kg } CaCO_3 = 10{,}654{,}589.74\text{mol } CaCO_3$

Then,

$10{,}654{,}589.74\text{mol } CO_2 \rightarrow 468{,}801.95\text{kg } CO_2 = 468.80\text{tonnes } CO_2$

468.80tonnes CO_2 is the minimum projected quantity of CO_2 presently sequestered at the Consett Works Site.

Estimated potential per site area = 0.02tC/m^2

5.4.1.3 Mean Quantity of Carbon Dioxide Presently Captured at Upper Plateau

Table 31– Calculation of parameters

Parameter	**Source**	**Value**
Slag Quantity	Sheffield (1996)	133,032.71m^3
Bulk Density (av.)	BS648:1964 (average value between medium-fine aggregate)	920.95kg/m^3
Mass Slag:	Calculated	122,516,474.30kg 125,516.47tonnes
Observed $CaCO_3$ (% by mass)	Experimental	8.5%
Molar Mass CaO	Calculated	56g
Molar Mass CO_2	Calculated	44g
Molar Mass $CaCO_3$	Calculated	100g

Molar Balance, $1 \text{ mol CaO} + 1 \text{ mol } CO_2 \rightarrow 1 \text{ mol } CaCO_3$

Therefore, $56\text{g CaO} + 44\text{g } CO_2 \rightarrow 100\text{g } CaCO_3$

If,

$1\text{kg slag} \rightarrow 0.085\text{kg } CaCO_3$

$122{,}516{,}474.30\text{kg slag} \rightarrow 10{,}413{,}900.31\text{kg } CaCO_3 = 104{,}139{,}003.10\text{mol } CaCO_3$

Then,

$104{,}139{,}003.10\text{mol } CO_2 \rightarrow 4{,}582{,}116.14\text{kg } CO_2 = 4{,}582.12\text{tonnes } CO_2$

4,582.12tonnes CO_2 is the average projected quantity of CO_2 presently sequestered at the Consett Works Site.

Estimated potential per site area = 0.20tC/m^2

5.4.1.4 Maximum Quantity of Carbon Dioxide Presently Captured at Upper Plateau

Table 32 – Calculation of parameters

Parameter	**Source**	**Value**
Slag Quantity	Sheffield (1996)	133,032.71m^3
Bulk Density (av.)	BS648:1964 (max. value between medium-fine aggregate)	1041.0kg/m^3
Mass Slag:	Calculated	138,487,051.10kg 138,487.05tonnes
Observed $CaCO_3$ (% by mass)	Experimental	27%
Molar Mass CaO	Calculated	56g
Molar Mass CO_2	Calculated	44g
Molar Mass $CaCO_3$	Calculated	100g

Molar Balance, $1 \text{ mol } CaO + 1 \text{ mol } CO_2 \rightarrow 1 \text{ mol } CaCO_3$

Therefore, $56g\ CaO + 44g\ CO_2 \rightarrow 100g\ CaCO_3$

If,

$1kg \text{ slag} \rightarrow 0.27kg\ CaCO_3$

$138{,}487{,}051.10kg \text{ slag} \rightarrow 37{,}391{,}503.80kg\ CaCO_3 = 373{,}915{,}038.00mol\ CaCO_3$

Then,

$373{,}915{,}038.00mol\ CO_2 \rightarrow 16{,}452{,}261.67kg\ CO_2 = 16{,}452.26tonnes\ CO_2$

16,452.26tonnes CO_2 is the maximum projected quantity of CO_2 presently sequestered t the Consett Works Site.

Estimated potential per site area = 0.73tC/m^2

Table 33 – Maximum CO_2 sequestration potential

Estimate	Quantity of Slag (m^3)	Mass of Slag (tonnes)	Quantity of calcium carbonate (%)	Mass of calcium carbonate (tonnes)	Quantity of CO_2 sequestered (tonnes)
Maximum	133,032.71	138,487.05	-	69,243.53	54,405.63

Table 34 – Quantity of CO_2 sequestered using variable slag quantity, slag bulk density and calcium carbonate concentration

Estimate	Quantity of Slag (m^3)	Mass of Slag (tonnes)	Quantity of calcium carbonate (%)	Mass of calcium carbonate (tonnes)	Quantity of CO_2 sequestered (tonnes)
Low	133,032.71	106,545.90	1.0	1,065.46	468.80
Moderate	133,032.71	125,516.47	8.5	10,413.90	4,582.12
High	133,032.71	138,487.05	27	37,391.50	16,452.26

5.4.2 Conceptual Modelling – Consett Works

From the data collected at the Upper Plateau site, a rough estimation of the persistence of calcium carbonate across the Consett works site in general can be made. This model utilises the same assumptions as the Upper Plateau model and is limited by the same conditions.

Quantity of Slag Available

It is noted in the literature review of this document that approximately 3.5 million m^3 of slag is thought to have been mobilised at the site during reclamation works. In the estimation of maximum sequestration capacity, this figure has been taken as the absolute maximum availability of slag at the Consett works site. It must be noted that it this case ‘availability’ is used to denote geochemical availability, however, it is likely that calcium carbonate formation is limited to slag available close to the ground surface, immediately below the root zone and to $\leq$1.75m. By this deduction, a large quantity of slag present across the site is unlikely to be geochemically ‘available’, due to its depth of burial. This study has also illustrated that in a number of locations across the Upper Plateau site, calcium carbonate concentration varies with soil depth, however, the depth limitations of the survey have only allowed this phenomenon to be studied to an order of hundreds of millimetres as opposed to metres. In this instance, formation is assumed to be uniform throughout the profile.

Quantity of Calcium Carbonate forming

It has been proven that pedogenic calcium carbonate formation occurs at high levels (from 1-27% with a mean value of 8.5% ± 0.18) across the Upper Plateau site. It is proposed that these values may be utilised across the Consett works site in order to estimate the potential for carbon capture and storage that it presents, due to general agreement with calcium carbonate concentration values for the Howns Gill and Derwent View sites. Whilst some level of heterogeneity is still assumed, these values should be sufficient in providing preliminary estimates for site storage potential.

Calculations

Calculations are illustrated on pages 180-184. In the first instance a simple molar relationship has been assumed between CaO and CO_2, with the sequestration of the site estimated as a maximum potential with respect to the equilibrium balance of the reacting materials. In the second instance, a known average concentration of calcium carbonate, informed by experimental data, is applied to the site, with the relevant quantity of CO_2 back-calculated to estimate the likely quantity of CO_2 which has been captured, to date, by sequestration at the site.

In the first instance, the maximum sequestration potential of the Consett Works was found to be 1,431,375tonnes $CO_{2.}$ This calculation assumes the maximum possible bulk density value and maximum proportion of CaO by mass in the slag. The sequestration figure denotes the maximum potential capacity for carbon capture if all of the CaO material present at the Consett Works site were to react to form $CaCO_3$.

The second set of examples illustrate the minimum, mean and maximum values of CO_2 sequestration, assuming minimum, mean and maximum figures for bulk density of slag and observed calcium carbonate concentration by mass. These figures demonstrate a minimum presence of 12,334tonnes CO_2 and a maximum presence of 432,488tonnes CO_2, and a difference of 420,154tonnes.

These calculations have demonstrated the difficulty in estimating the sequestration potential of the Consett Works site, due to the high variability imposed by the site parameters such as slag density, mass of CaO and the maximum attainable *in situ* calcium carbonate concentration. The maximum estimated value of sequestered carbon dioxide at the site is approximately 3.4 times lower than the maximum estimated sequestration potential, demonstrating the remaining potential (assuming geochemical equilibrium) for the capture of 1,011,221tonnes CO_2.

5.4.2.1 Maximum Sequestration Potential of Consett Works

Table 35 – Calculation of parameters

Parameter	**Source**	**Value**
Slag Quantity	Sheffield (1996)	3,500,000m^3
Bulk Density (av.)	BS648:1964 (average value between medium-fine aggregate)	1041.0kg/m^3
Mass Slag:	Calculated	3,643,500,000kg 3,643,500tonnes
Mass CaO (max. 50% by mass):	Lee (1974) (average value of CaO content for blast furnace slag)	1,821,750,000kg 1,821,750tonnes
Molar Mass CaO	Calculated	56g
Molar Mass CO_2	Calculated	44g
Molar Mass $CaCO_3$	Calculated	100g

Molar Balance, 1 mol CaO + 1 mol $CO_2 \rightarrow$ 1 mol $CaCO_3$

Therefore, 56g CaO + 44g $CO_2 \rightarrow$ 100g $CaCO_3$

If,

1,821,750,000,000g CaO / 56g = 32,531,250,000mol CaO

Then,

3,253,125tonnes $CaCO_3 \rightarrow$ 1,821,750tonnes CaO + 1,431,375tonnes CO_2

1,431,375tonnes CO_2 is the maximum sequestration potential, under the given parameters, at the Consett Works Site.

5.4.2.2 Minimum Quantity of Carbon Dioxide Presently Captured at Consett Works

Table 36 – Calculation of parameters

Parameter	**Source**	**Value**
Slag Quantity	Sheffield (1996)	3,500,000m^3
Bulk Density (av.)	BS648:1964 (average value between medium-fine aggregate)	800.9kg/m^3
Mass Slag:	Calculated	2,803,150,000kg 2,803,150tonnes
Observed $CaCO_3$ (% by mass)	Experimental	1.0%
Molar Mass CaO	Calculated	56g
Molar Mass CO_2	Calculated	44g
Molar Mass $CaCO_3$	Calculated	100g

Molar Balance, $1 \text{ mol CaO} + 1 \text{ mol } CO_2 \rightarrow 1 \text{ mol } CaCO_3$

Therefore, $56\text{g CaO} + 44\text{g } CO_2 \rightarrow 100\text{g } CaCO_3$

If,

$1\text{kg slag} \rightarrow 0.01\text{kg } CaCO_3$

$2{,}803{,}150{,}000\text{kg slag} \rightarrow 28{,}031{,}500\text{kg } CaCO_3 = 280{,}315{,}000\text{mol } CaCO_3$

Then,

$280{,}315{,}000\text{mol } CO_2 \rightarrow 12{,}333{,}860{,}000\text{kg } CO_2 = 12{,}333.86 \text{ tonnes } CO_2$

12,334tonnes CO_2 is the minimum projected quantity of CO_2 presently sequestered at the Consett Works Site.

5.4.2.3 Mean Quantity of Carbon Dioxide Presently Captured at Consett Works

Table 37 – Calculation of parameters

Parameter	**Source**	**Value**
Slag Quantity	Sheffield (1996)	3,500,000m^3
Bulk Density (av.)	BS648:1964 (average value between medium-fine aggregate)	920.95kg/m^3
Mass Slag:	Calculated	3,223,325,000kg 3,223,325 tonnes
Observed $CaCO_3$ (% by mass)	Experimental	8.5%
Molar Mass CaO	Calculated	56g
Molar Mass CO_2	Calculated	44g
Molar Mass $CaCO_3$	Calculated	100g

Molar Balance, $1 \text{ mol CaO} + 1 \text{ mol } CO_2 \rightarrow 1 \text{ mol } CaCO_3$

Therefore, $56g \text{ CaO} + 44g \text{ } CO_2 \rightarrow 100g \text{ } CaCO_3$

If,

1kg slag → 0.085kg $CaCO_3$

3,223,325,000kg slag → 273,982,625kg $CaCO_3$ = 2,739,826,250mol $CaCO_3$

Then,

2,739,826,250mol CO_2 → 120,552,355kg CO_2 = 120,552.355tonnes CO_2

120,552tonnes CO_2 is the average projected quantity of CO_2 presently sequestered at the Consett Works Site.

5.4.2.4 Maximum Quantity of Carbon Dioxide Presently Captured at Consett Works

Table 38 – Calculation of parameters

Parameter	**Source**	**Value**
Slag Quantity	Sheffield (1996)	3,500,000m^3
Bulk Density (av.)	BS648:1964 (average value between medium-fine aggregate)	1041.0kg/m^3
Mass Slag:	Calculated	3,643,500,000kg 3,643,500tonnes
Observed $CaCO_3$ (% by mass)	Experimental	27%
Molar Mass CaO	Calculated	56g
Molar Mass CO_2	Calculated	44g
Molar Mass $CaCO_3$	Calculated	100g

Molar Balance, $1 \text{ mol } CaO + 1 \text{ mol } CO_2 \rightarrow 1 \text{ mol } CaCO_3$

Therefore, $56g\ CaO + 44g\ CO_2 \rightarrow 100g\ CaCO_3$

If,

$1kg \text{ slag} \rightarrow 0.27kg\ CaCO_3$

$3{,}643{,}500{,}000kg \text{ slag} \rightarrow 983{,}745{,}000kg\ CaCO_3 = 9{,}837{,}450{,}000mol\ CaCO_3$

Then,

$9{,}837{,}450{,}000mol\ CO_2 \rightarrow 432{,}847{,}800kg\ CO_2 = 432{,}847.8tonnes\ CO_2$

432,488tonnes CO_2 is the maximum projected quantity of CO_2 presently sequestered t the Consett Works Site.

Table 39 – Maximum CO_2 sequestration potential

Estimate	Quantity of Slag (m^3)	Mass of Slag (tonnes)	Quantity of calcium carbonate (%)	Mass of calcium carbonate (tonnes)	Quantity of CO_2 sequestered (tonnes)
Maximum	3,500,000	3,223,325	-	2,475,053.125	1,089,023.375

Table 40 – Quantity of CO_2 sequestered using variable slag bulk density and calcium carbonate concentration

Estimate	Quantity of Slag (m^3)	Mass of Slag (tonnes)	Quantity of calcium carbonate (%)	Mass of calcium carbonate (tonnes)	Quantity of CO_2 sequestered (tonnes)
Low	3,500,000	2,803,150	1.0	28,031.5	12,333.86
Moderate	3,500,000	3,223,325	8.5	273,982.625	120,552.355
High	3,500,000	3,643,500	27	983,745	432,847.8

6. CONCLUSIONS

6.0 SCOPE

This project acted as a precursor for ongoing study at the Consett works site and post-industrial locations of a similar nature, investigating the properties of historic slag to apply to contemporary wastes. A small region of a large former industrial site was surveyed using physical and geophysical methods, in order to describe the bulk sub-surface stratigraphy and geochemical properties were assessed using a combination of laboratory techniques. Conclusions drawn from detailed study of a small area of the Consett works were assumed to be approximately representative of the site as a whole, verified by geochemical analyses from across the site, including data taken from literary sources.

Sampling and geochemical analysis has confirmed that calcium derived from weathered slag is behaving as an active sink for atmospheric CO_2. The project critically demonstrates, though a comparison with documentary evidence, that calcium carbonate formation occurs at a significant level in soils containing steel slag. Confirmation of this fact was achieved through the analysis of ‘control’ soils, collected from a geographically similar site with no history of industrial activity.

The project relied upon the design and implementation of a programme of soil sampling to define and describe existing calcium carbonate horizons and determine variations in concentration. Laboratory methods applied to these samples included calcimeter testing to illustrate bulk calcium carbonate content and, critically, isotopic ratio mass spectrometry. Fractionation values for carbon and oxygen, within a sub-set of samples, were acquired and compared with values determined in similar studies to confirm that all carbon present as calcite had been sequestered from atmospheric carbon dioxide sources.

6.1 CONCLUSION

6.1.1 Fulfilment of aim

The former site of Consett Iron and Steel works provided an effective study site, where the geochemical activity of slag over a period of 20+ years was able to be studied. The Upper Plateau region of the former works was identified as a representative sub-section of the site area and utilised as the analogue for this study. Limited samples were also analysed from the Derwent View and Howns Gill areas of the Consett works site, which were used to assess the extent to which the Upper Plateau analyses were representative of the behaviour of slag across the entire site. Calcium carbonate concentrations and ground conditions for the site in general were found to fall within the average values of the Upper Plateau analyses, illustrating the persistence of sequestration in association with slag. The sequestration potential of the Consett works site has been determined through the combined analysis of Desk Studies, Ground Investigation Reports, site surveying, geophysical surveying, soil sampling and laboratory analysis.

The findings of this project hold considerable onus on the use of slag in ground engineering to create carbon sinks. The calcium carbonate contents determined through calcimeter testing, up to 27% ± 0.18, are promising with respect to the effectiveness of slag as a sequestration medium. Whilst a number of lower calcium carbonate concentrations were determined during calcimeter testing, it is noted that these results often occurred in locations which were visibly devoid of slag material. Concentrations in excess of the mean value, 8.5%, were generally encountered where slag was visibly weathering within the soil. These results suggest that calcium carbonate concentration within soil horizons is strongly determined by proximity to weathering slag material, as would be expected. Homogenisation of the soil-slag mixture would be expected to normalise calcium carbonate production across the site, bringing all analytical results within closer agreement of the high mean value. IRMS analysis illustrated the organic and hydroxylation provenance of calcium carbonate present at the Consett works site, exhibiting values between -11.86 and -20.46 for $\delta^{13}C$ and -10.0 and -12.25 for $\delta^{18}O$. The high proportion of organic carbonate present at the site suggests a significant proportion of interaction in plant root – soil C turnover.

Conceptual modelling of the Upper Plateau site, using data acquired during geophysical survey and from Ground Investigation Reports, has allowed a determination of the maximum quantity of atmospheric carbon dioxide presently sequestered in the form of calcium carbonate, 16,452tonnes. This model has been assumed to represent the maximum productivity of the site given the residence period of the slag since reclamation, approximately 20 years. An extrapolated conceptual model also allowed the evaluation of sequestration potential at the site, under 'ideal' geochemical conditions, of 1,431,375 tonnes CO_2. Whilst there are a number of limitations involved in this extrapolation, conceptual modelling has enabled a closer understanding of the potential for sequestration that slag presents and the factors which promote or inhibit this behaviour.

Whilst the Consett works site was not reclaimed in the knowledge of its sequestration potential, therefore, has not been engineered in a manner which would favour this property, the site provides a useful analogue for the intentional engineering of carbon sinks, with the use of contemporarily produced slag. This report has illustrated a number of requirements for the informed use of slag in this manner:

- Ensure homogeneity of the soil material – calcium carbonate production in the terrestrial environment is mediated by the availability of and proximity to slag material.

Homogeneous mixing of the material should ensure maximum sequestration potential for the site.

- Ensure grading of the slag material and utilisation of small granules or powder in ground engineering – calcium carbonate formation exploits the outer surfaces and vesicular features of porous slag, therefore a large surface area to volume ratio is preferable. Fines from aggregate production are therefore assumed to be ideal for this application.
- Investigate maximum deposition depth – Royer (1999) demonstrates the likely formation depth for calcium carbonate, given the climatic conditions of Consett, to be 0.1-1.75m, therefore effectively engineered soils would look to cover this depth range. Calcium carbonate concentration in the upper 0.3m of the Consett works can be very high, therefore, renewal or mobilisation of the upper strata of an engineered soil may be considered to ensure maximum sequestration potential over larger time spans.
- Investigate the effects of vegetation cover and type. IRMS analysis has illustrated a significant proportion of calcite formation occurring due to organic sequestration. As mentioned, this is tied in closely to the turnover of organic soil carbon, promoted by high vegetation cover. Slag emplacement in agricultural soils is likely, therefore, to be highly beneficial in carbon sink creation, promoting significant quantities of C turnover.

The processes which have coincidentally occurred as a consequence of the reclamation of Consett works have proven significant in the portrayal of slag as a carbon sequestration media. The potential for further investigations to be carried out at this site is far from exhausted. The focus of ongoing works is to further investigate the novel and intentional implementation of slag-mediated sequestration in agricultural and engineering soils, in order to assign a globally significant role to this multifarious ‘waste’ material.

7. LIMITATIONS, RECOMMENDATIONS AND FUTURE WORK

7.0 LIMITATIONS, RECOMMENDATIONS AND FUTURE WORK

In this section, the major limitations to this project are documented, with recommendations given to their rectification. The potential for future work, based upon these recommendations, is also discussed.

In assessing the overall success of the project, a critical evaluation of the manner in which the initial project objectives were addressed and satisfied has been completed. In this context, conclusions were drawn regarding the success with which each facet of the project was implemented, in order to determine site related, methodological and analytical limitations and the opportunities for further study that each of these presents.

7.1 LIMITATIONS

7.1.1 Site Limitations

The main limitation to the project and its conclusions is the heterogeneity of the Consett works site, meaning that where assumptions are made regarding the representativeness of individual findings with respect to the site in general, these cannot be guaranteed to any level of accuracy. A large number of samples, 65 in total, were collected and tested for calcium carbonate presence, however, the high level of variation between the minimum and maximum carbonate concentrations in these samples is discouraging, as they impart a significant uncertainty on the applicability of project findings.

It is noted that the survey area around the Upper Plateau site is situated on a watershed area. It can, therefore, be assumed that groundwater flow will occur in all directions away from the summit of the site. It is known from the nearby Howns Gill site that calcium carbonate can be mobilised in alkali leachates, therefore, it can be concluded that the calcium carbonate concentrations found in the terrestrial deposits may be affected by directional groundwater flows.

7.1.2 Methodological Limitations

Sub-surface and geophysical surveys allowed data to be correlated with previous site reports and confirmed the presence of both weathering slag and its associated geochemical products, including calcium carbonate. Geophysical surveying and analysis of previous site investigation data has enabled the creation of pseudo-sections for the site, investigating variability in made ground distribution. Whilst a fixed array resistivity survey was able to approximately determine the base of made ground at the site, it was unable to determine variations in stratigraphy to higher resolution, or differentiate between high resistivity anomalies.

The soil sampling method implemented allowed the observation of the ground conditions close to the surface of the site, however, deeper stratigraphic formation of calcium carbonate within the made ground horizon was unable to be determined. Whilst care was taken during the collection of soil samples not to cause contamination between different stratigraphic levels, this could not be guaranteed using the sampling techniques implemented on the working scale utilised. A quantitative analysis of the maximum depth of carbonate formation would be of significance in the construction of a geochemical model of the site, enabling a more accurate prediction of the productive depth of ground over which sequestration is able to occur.

7.1.3 Analytical Limitations

Laboratory analysis found that the sample material contained variable, but consistently high quantities of calcium carbonate. Whilst the implementation of calcimeter analysis was effective, additional analysis methods may be implemented to further characterise the bulk mineralogy of the samples collected. SEM analysis was effective in analysing slag from the Consett works site in thin section, however, further SEM analysis of surface conditions would be required to quantify a number of predictions made with respect to this property.

Limitations regarding the construction and implementation of the conceptual model are documented in section 5.4.1. The majority of these limitations are related to the applicability of a conceptual model to a highly variable site, however, variation in the physical properties of material onsite, such as porosity and bulk density, is also able to affect the predicted sequestration potential.

7.2 RECOMMENDATIONS

Recommendations for the improvement and expansion of this project are noted below. Recommendations have been divided with respect to methodological section, in order to address the relative effectiveness of each element.

7.2.1 Site Recommendations

The collection of samples from across the site, Upper Plateau, Derwent View and Howns Gill has allowed the conclusion that whilst carbonate concentrations across the site are variable, they tend to fall within close range of the mean value for the Upper Plateau site. Further sampling across the site area would be recommended to investigate the heterogeneity of the site, in order to determine variations in geographical and stratigraphic carbonate concentration over a larger study area.

Further spatial data would enable a better assessment of site features and their discrete impacts upon calcium carbonate formation, in order to assess the influence of site topography, depth of made ground and small-scale climatic variations as well as vegetation cover, land use and hydrogeochemical settings.

7.2.2 Methodological Recommendations

The geophysical survey may have been improved by further use, across larger areas of the survey site, in order to determine its sensitivity to variations in ground condition using known profiles. The use of alternative or additional survey types may also have been effective. Electrical conductivity and gravity surveys have the potential to further discerning between the sub-surface layers of the site. Gravity Surveys are able to determine between different sub-surface layers, by differentiating between their gravitational field signals. This data can then be compared to standard density values for known strata types. The main limitation with this method is that the resolution may not be sufficient to horizontally differentiate between variations in very thin strata.

Soil sampling coupled with calcimeter testing may be further used in the determination of horizontal resolution of calcium carbonate formation. In order for deeper soil sampling to be carried out at the site, mechanical digging apparatus such as a JCB is likely to be required. By implementing machinery of this type, samples could be taken to ~2.0m, in concurrence with calcium carbonate formation depths proposed by Royer (1999) Jenny (1980). This type of sampling would allow the analysis of calcium carbonate presence and concentration throughout the profile, to maximum expected formation depth, when coupled with 40-80mm sampling resolution and calcimeter testing. Creation of larger excavations at the site would also allow the preparation and collection of discrete samples from a larger surface area and enable blinding of the excavation surfaces to reduce cross-contamination of samples.

7.2.3 Analytical Recommendations

Further application of microscopy in the determination of the relationship between the large-scale, physical properties of slag and the small-scale, geochemical properties would be useful. As described in section 5.2.2.2, surface and thin section SEM analysis could be used in combination to construct a three-dimensional image of calcium carbonate formation throughout a slag fragment and to determine whether the formation of calcium carbonate is significantly controlled by the physical structure of the slag and weathering properties.

Other analysis methods may be useful in qualitatively characterising the constituents of samples, including X-ray Diffraction (XRD) and X-ray Fluorescence (XRF). XRF utilises the traceable behaviour of materials under irradiation to determine the chemical components of complex samples. Energy Dispersive X-Ray fluorescence (EDXRF) is the most commonly used method, and relies upon the detection of characteristic releases of photon energy (detection of secondary X-rays) from the surfaces of samples undergoing X-Ray bombardment. It is a useful, wide-spectrum technique, frequently utilised in geochemical testing, and can be applied to determine the presence of calcium oxide (CaO) as discussed in a number of papers including B.D., Wheeler's (1983) publication regarding the analysis of Portland Cement using this technique with 'excellent precision' to produce results accurate to '0.6% for alumina and silicon oxide to 1.0% for calcium oxide' (from least-square linear regression). XRD is an effective technique in ascertaining bulk mineralogy. It also utilises X-rays, but maps their diffraction or 'scattering' by a sample, which is ultimate able to provide data regarding the electron density of crystals and hence aim to identify them by graphical tallying of known specimens. It is frequently applied in industrial archaeology settings, due to its strength in discriminating between numerous mineral constituents, and has widely applicable benefits in industrial 'whole mineral' analysis as described in Chung and Smiths' 'Industrial Applications of XRD. Some man-made wastes such as slag, cements and clinker may produce analysis errors in this technique, which must be overcome during the automated analysis phase, by utilising a 'whole-pattern' (Rietveld) method of analysis, by which the full diffraction spectrum of a material is simultaneously analysed. The application of these analysis methods would allow quantitative conclusions to be drawn regarding slag constituents. This small-scale analysis has the potential to affect the understanding of large-scale processes occurring at the site, though a more detailed knowledge of mineral presence.

7.3 FUTURE WORK

The evidence presented in this report is intended to form part of an ongoing project to address the rate of calcium carbonate formation in the presence of calcium rich materials such as steel working slag. The completed project provides a point of reference upon which further investigation of the site may be based, and with which earlier site investigations may be easily cross-referenced.

This project aimed to provide an in-depth initial study of the Consett Iron & Steel works as an example of a CO_2 sequestration site. A comprehensive picture of the site was produced through integrated survey techniques, with subsurface features being profiled and some estimate of the true ground profile being made, with some conclusions as to the extent of material distribution being drawn. This project was unable to directly comment upon the long-term carbon capture behaviour promoted by presence of slag material at the Consett site, which requires empirical determination over realistic timescales, ranging to a number of years after this initial assessment. Any time-dependent developments on the site would need to be reassessed using similar sampling methods to those implemented in this study after a period several years from the initial survey. In this manner, change in calcium carbonate concentration at original sample points could be reassessed, with the assumption that any significant variation is likely to be attributable to additional sequestration since the last assessment period.

The conceptual models constructed for the Upper Plateau site were useful in characterising the conditions encountered at the Consett works site and in determining the *in situ* processes occurring at a site in which slag had been emplaced in the topsoil. Ultimately the project aims to comment upon the realistic application of contemporarily produced slag in commercial carbon sequestration applications, and estimate the likely quantities required to sequester the maximum potential amount of carbon dioxide (CO_2) per land area. The data collated in this project is useful in characterising the geochemical activity in slag-emplaced soils, which have not been created for the means of sequestration. The results are promising, as they illustrate significant levels of sequestration occurring under these conditions, which would be expected to be accelerated by an informed and intentional admixing of slag to create carbon sinks. Although Manning (2008) notes that soil formed carbon sinks are ‘low cost’ passive agents with ‘no additional energy inputs’, consideration must be made of the methods of creation such as transportation measures and processing. Schlesinger (2000), recommends that care must always be taken when suggesting viable means of carbon sequestration by soils, that the energy input and carbon expenditure involved in the creation of the carbon sink do not outweigh the sequestration potential that it will ultimately bring. The practicalities of this will need to be considered further, in order to determine the economic applicability of slag in carbon sink engineering.

8. REFERENCES

8.0 REFERENCES

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Shadbolt Environmental Ground Investigation Interpretative Report, for Project Genesis Limited (July 2008)

Shadbolt Environmental Outline Remediation Strategy, for Project Genesis Limited (June 2008)

Thomas Research Services Report – Petrological examination of eight bulk samples from Derwent View development, Consett (June 2008)

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Derwent View Site

Shadbolt Environmental Geotechnical and Ground Contamination Desk Top Review, for Project Genesis Limited (June 2008)

Shadbolt Environmental Ground Investigation Interpretative Report, for Project Genesis Limited (July 2008)

Shadbolt Environmental Outline Remediation Strategy, for Project Genesis Limited (June 2008)

Thomas Research Services Report – Petrological examination of eight bulk samples from Derwent View development, Consett (June 2008)

APPENDICES

APPENDIX 1

Methodology

1.0 Methodologies

1.1 DESK STUDY

1.1.1Historical Images

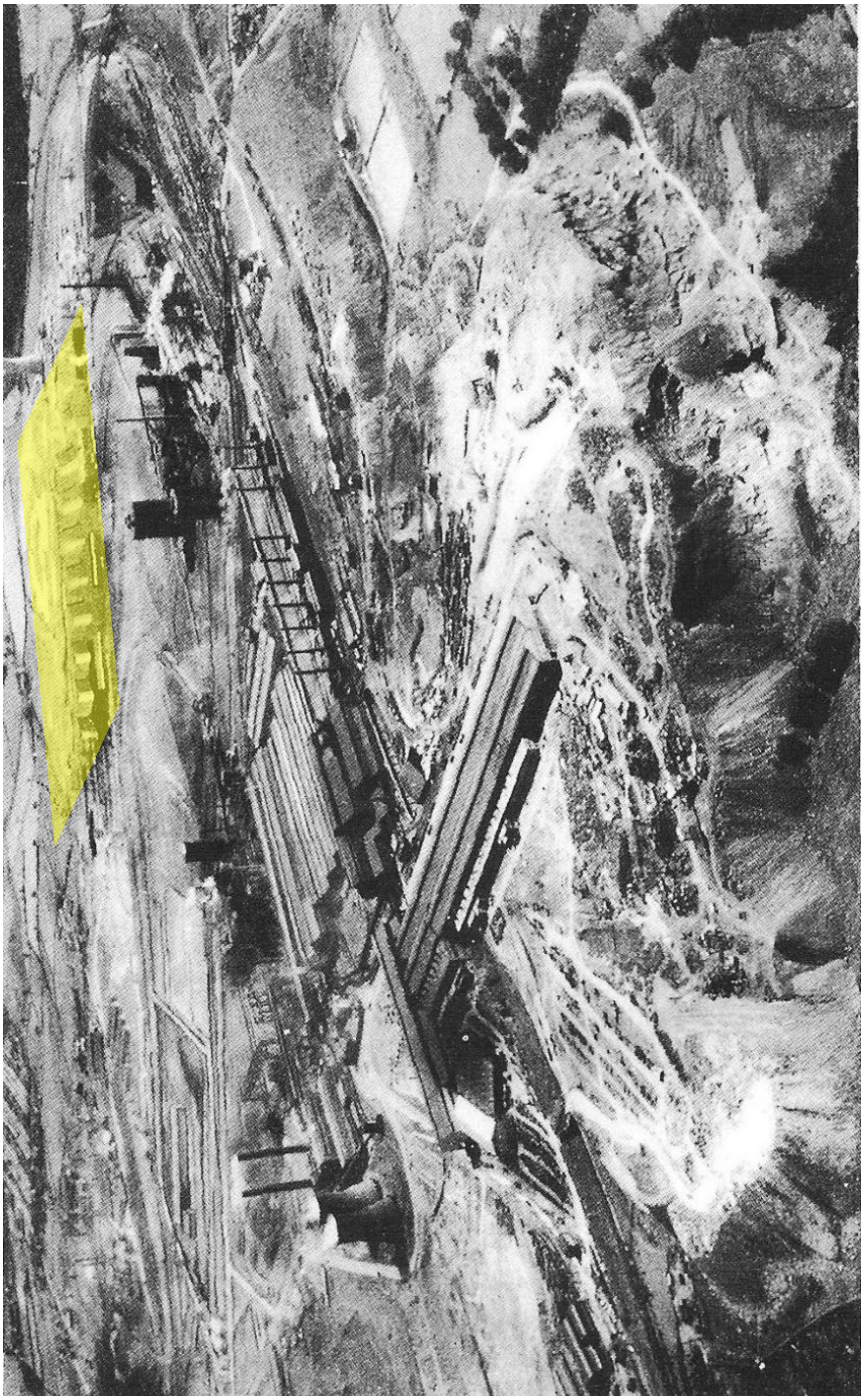

Figure 1 – Historic image of Consett Iron and Steel Works, circa 1960. Approximate location of Upper Plateau site indicated in yellow (Source: Warren, K., 1990).

1.1.2 Geology

1.1.2.1 BGS Borehole Locations

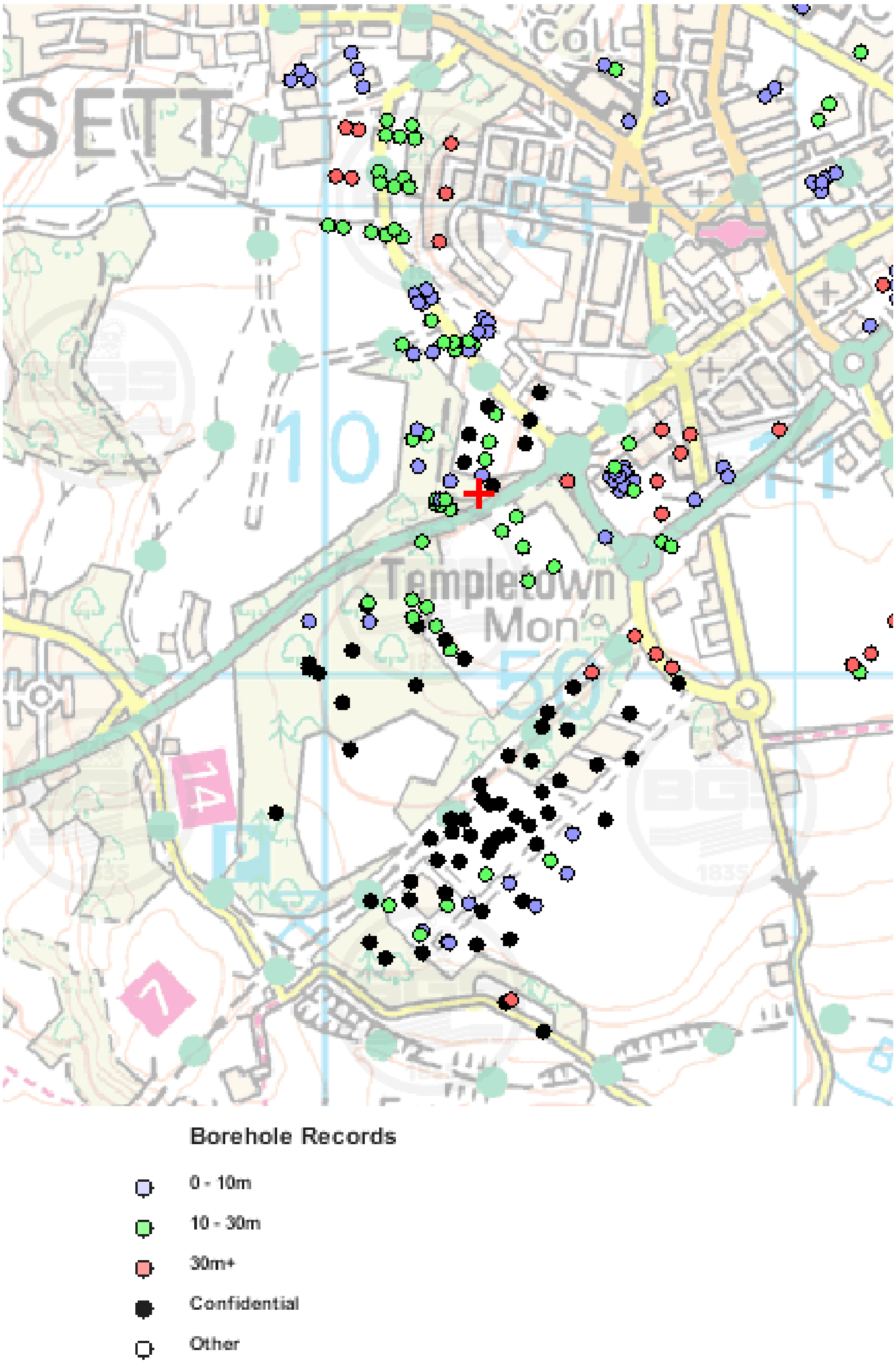

Figure 2 – BGS Borehole locations (Source: BGS Geoindex)

1.1.2.2 Ground Sections

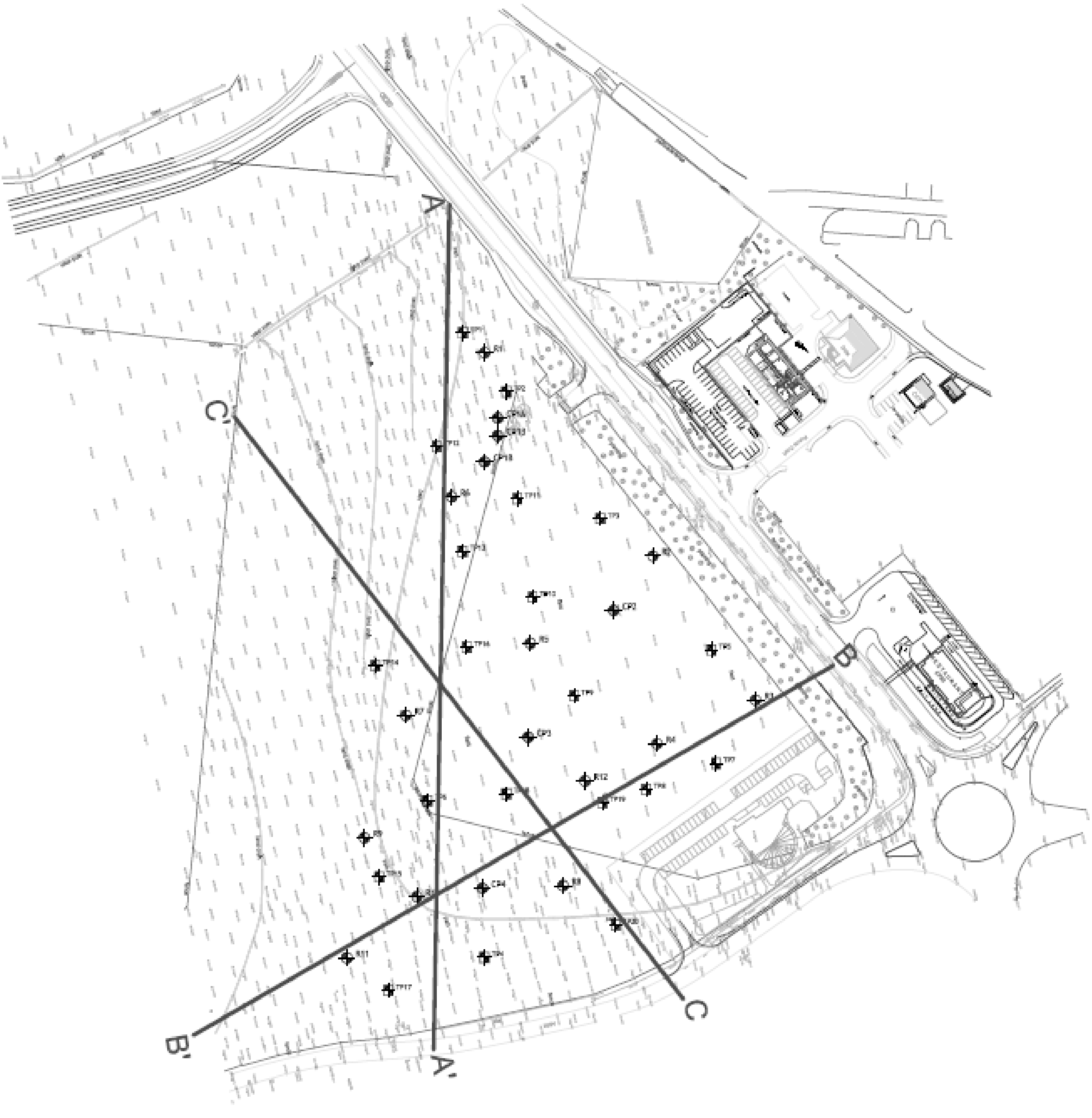

Figure 3 – Site Plan with Ground Sections Indicated (Source: Shadbolt Environmental Ground Investigation Report 2008)

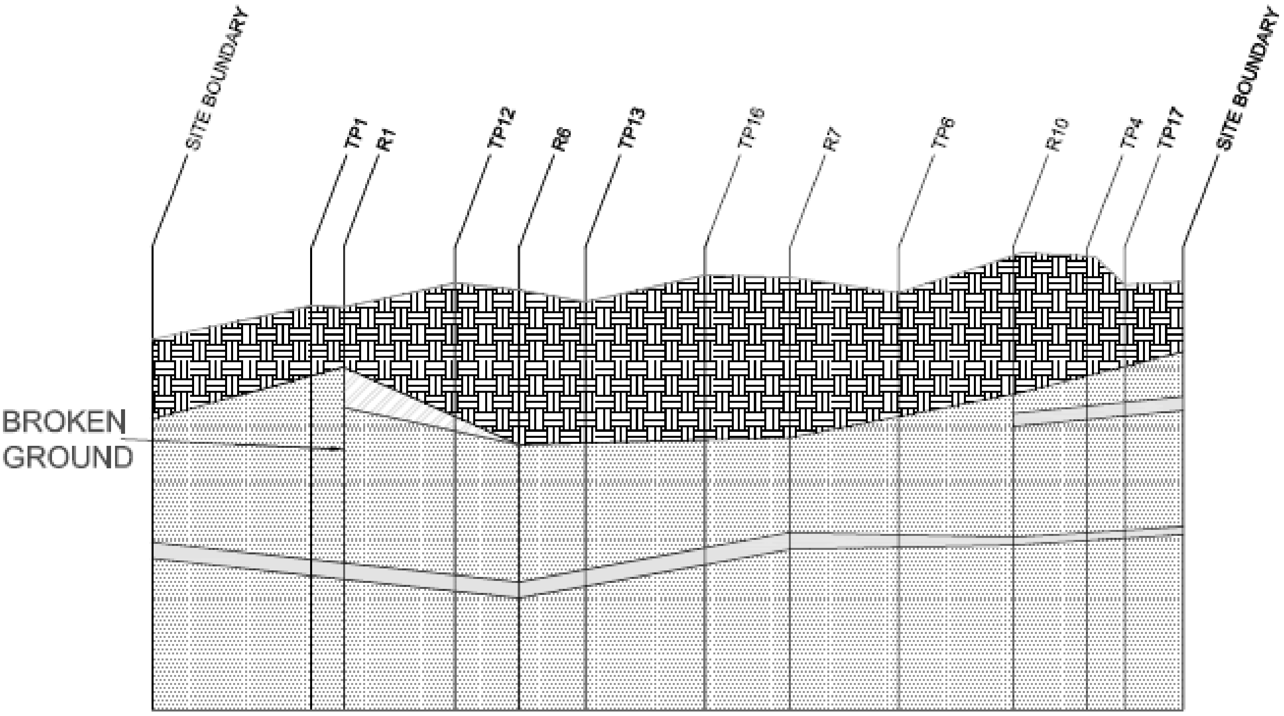

Figure 4 – Ground Section A (Source: Shadbolt Environmental Ground Investigation Report 2008)

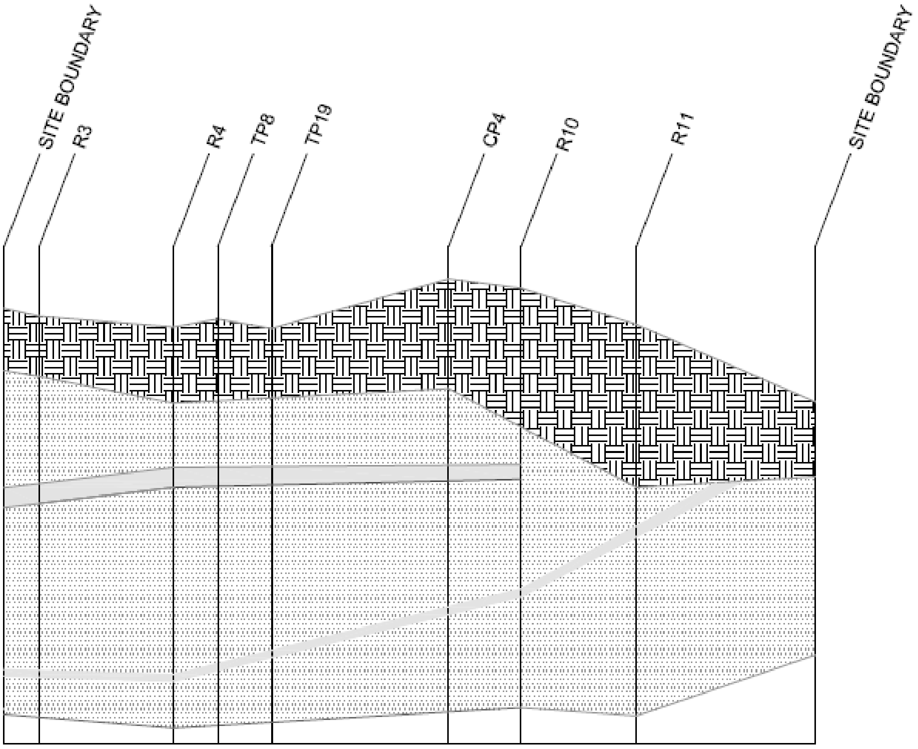

Figure 5 - Ground Section B (Source: Shadbolt Environmental Ground Investigation Report 2008)

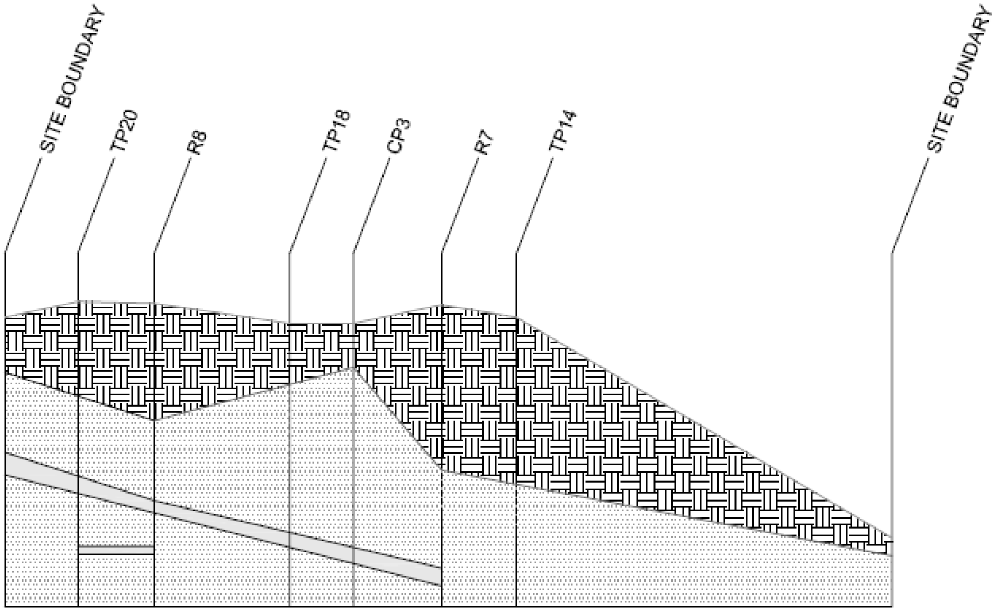

Figure 6 – Ground Section C (Source: Shadbolt Environmental Ground Investigation Report)

LEGEND:

- ▦ DENOTES MADE GROUND
- ⬡ DENOTES SAND & GRAVEL
- ☰ DENOTES CLAY
- ▨ DENOTES CLAY & GRAVEL
- ⁘ DENOTES COAL MEASURES STRATA (SANDSTONE/MUDSTONE/SOLID GROUND
- ✚ DENOTES BROKEN GROUND
- ▩ DENOTES COAL

1.1.2 Geotechnical data

All data presented in this section is taken from Shadbolt Environmental Ground Investigation Report 2008

Borehole Ref.	**Type**	**East.**	**North.**	**Elevation (m)**
CP1A	Cone Penetration Test	410298.00	550603.00	251.01
CP1B	Cone Penetration Test	410292.00	550583.00	251.52
CP1C	Cone Penetration Test	410298.00	550595.00	251.75
CP2	Cone Penetration Test	410351.00	550515.00	251.80
CP3	Cone Penetration Test	410312.00	550457.00	252.51
CP4	Cone Penetration Test	410291.00	550388.00	256.26
R01	Rotary Open Hole	410292.00	550633.00	251.40
R01a	Rotary Open Hole	410292.00	550633.00	251.40
R02	Rotary Open Hole	410369.00	550540.00	251.70
R03	Rotary Open Hole	410416.00	550474.00	253.40
R03a	Rotary Open Hole	410416.00	550474.00	253.40
R04	Rotary Open Hole	410371.00	550454.00	252.57
R05	Rotary Open Hole	410313.00	550500.00	251.84
R06	Rotary Open Hole	410277.00	550567.00	252.77
R07	Rotary Open Hole	410256.00	550467.00	253.90
R07a	Rotary Open Hole	410256.00	550467.00	253.90
R08	Rotary Open Hole	410327.00	550389.00	254.00
R09	Rotary Open Hole	410237.00	550411.00	253.20
R10	Rotary Open Hole	419261.00	550384.00	255.50
R11	Rotary Open Hole	410229.00	550356.00	252.84
R11a	Rotary Open Hole	410229.00	550356.00	252.84
R12	Rotary Open Hole	410338.00	550437.00	252.52
TP1	Trial Pit	410282.00	550642.00	251.44
TP2	Trial Pit	410302.00	550615.00	250.62
TP3	Trial Pit	410345.00	550557.00	251.50
TP4	Trial Pit	410292.00	550356.00	255.05
TP5	Trial Pit	410396.00	550497.00	252.74
TP6	Trial Pit	410266.00	550428.00	253.22
TP7	Trial Pit	410398.00	550445.00	253.13
TP8	Trial Pit	410366.00	550433.00	252.89
TP9	Trial Pit	410333.00	550476.00	252.63
TP10	Trial Pit	410314.00	550521.00	251.51
TP11	Trial Pit	410307.00	550566.00	251.69
TP12	Trial Pit	410270.00	550590.00	253.30

TP13	Trial Pit	410282.00	550542.00	251.99
Borehole Ref.	**Type**	**East.**	**North.**	**Elevation (m)**
TP14	Trial Pit	410242.00	550489.00	253.61
TP15	Trial Pit	410244.00	550393.00	254.06
TP16	Trial Pit	410284.00	550498.00	525.27
TP17	Trial Pit	410248.00	550341.00	253.10
TP18	Trial Pit	410302.00	550431.00	252.44
TP19	Trial Pit	410346.00	550427.00	252.52
TP20	Trial Pit	410352.00	550371.00	254.13

Name	**To Depth (m)**	**Total Depth (m)**		**Description to BS5930:1999**
CP1A	0.10		MADE GROUND	Grass overlaying brown sandy clayey soil
	2.30		MADE GROUND	Very dense, grey brown fused slag recovered as gravel and cobbles
		2.30		
CP1B	0.10		MADE GROUND	Grass overlaying brown sandy clayey soil
	2.50		MADE GROUND	Very dense, grey brown fused slag recovered as gravel and cobbles
		2.50		
CP1C	0.10		MADE GROUND	Grass overlaying brown sandy clayey soil
	2.40		MADE GROUND	Very dense, grey brown fused slag recovered as gravel and cobbles
		2.40		
CP2	0.10		MADE GROUND	Grass overlaying brown sandy clayey soil
	5.60		MADE GROUND	Very dense, grey brown fused slag recovered as gravel and cobbles
	6.00		SANDSTONE	Red brown SANDSTONE
		6.00		
CP3	0.40		MADE GROUND	Grass overlaying brown sandy clayey soil with gravels of slag and sandstone
	3.20		MADE GROUND	Very dense, grey brown fused slag recovered as gravel and cobbles
		3.20		
CP4	0.60		MADE GROUND	Grass overlaying brown sandy clayey soil
				with gravels of slag and sandstone
	3.20		MADE GROUND	Very dense, grey brown fused slag
				recovered as gravel and cobbles
	5.30		MADE GROUND	Very dense, blue grey fused slag
				recovered as gravel and cobbles
	6.00		MADE GROUND	Brown yellow grey gravelly clay with gravels
				of slag
	8.20		MADE GROUND	Very dense, grey brown fused slag
				recovered as gravel and cobbles
	8.60		MADE GROUND	Brick and concrete
	8.80		SANDSTONE	Brown SANDSTONE
		8.80		

Name	To Depth (m)	Total Depth (m)		Description to BS5930:1999
R01	4.50		MADE GROUND	Fill
	7.50		CLAY and GRAVEL	Grey CLAY and GRAVEL
	8.10		SANDSTONE	Brown SANDSTONE
	9.40			BROKEN GROUND
	12.00			SOLID
		12.00		

R01a	4.50		MADE GROUND	Fill
	7.50		CLAY and GRAVEL	Grey CLAY and GRAVEL
	8.10		SANDSTONE	Brown SANDSTONE
	9.10			BROKEN GROUND
	10.00			SOLID
		10.00		

R02	3.10		MADE GROUND	Fill
	5.70		CLAY and GRAVEL	Sandy CLAY and GRAVEL
	9.80		SANDSTONE	Brown SANDSTONE
	10.40		SANDSTONE	Grey SANDSTONE
	11.80		COAL	COAL
	23.80		MUDSTONE	MUDSTONE
	24.20		COAL	COAL
	30.00		MUDSTONE	MUDSTONE
		30.00		

R03	4.50		MADE GROUND	Fill
	5.20		SANDSTONE	Brown SANDSTONE
	7.00		SANDSTONE	Grey SANDSTONE
	12.50		SANDSTONE	Brown SANDSTONE
	14.00		COAL	COAL
	26.50		MUDSTONE	MUDSTONE
	27.00		COAL	COAL
	30.00		MUDSTONE	MUDSTONE
		30.00		

R03a	4.50		MADE GROUND	Fill
	5.20		SANDSTONE	Brown SANDSTONE
	7.00		SANDSTONE	Grey SANDSTONE
	10.00		SANDSTONE	Brown SANDSTONE
		10.00		

R04	5.70		MADE GROUND	Fill
	10.50		SANDSTONE	Brown SANDSTONE
	12.00		COAL	COAL
	26.00		MUDSTONE	Grey SANDSTONE
	26.50		COAL	COAL
	30.00		MUDSTONE	MUDSTONE
		30.00		

R05	5.50		MADE GROUND	Fill
	8.50		CLAY and GRAVEL	Sandy CLAY and GRAVEL
	9.60		SANDSTONE	Brown SANDSTONE
	10.50		SANDSTONE	Grey SANDSTONE
	12.20			BROKEN GROUND
	15.00			SOLID
		15.00		

R06	11.60		MADE GROUND	Fill
	21.90		SANDSTONE	Brown SANDSTONE
	23.10		COAL	COAL
	30.00		SANDSTONE	Grey SANDSTONE
		30.00		

R07	12.00		MADE GROUND	Fill
	15.20		MUDSTONE	Grey MUDSTONE
	17.10		SANDSTONE	Grey SANDSTONE
	19.10		MUDSTONE	Grey MUDSTONE
	20.40		COAL	COAL
	26.80		MUDSTONE	Grey MUDSTONE
	30.00		SANDSTONE	Grey SANDSTONE
		30.00		

R07a	10.00		MADE GROUND	Fill
		10.00		

R08	8.50		MADE GROUND	Fill
	9.60		SANDSTONE	Brown SANDSTONE
	14.30		SANDSTONE	Grey SANDSTONE
	15.20		COAL	COAL
	17.50		MUDSTONE	Grey MUDSTONE
	19.90		SANDSTONE	Grey SANDSTONE
	24.10		MUDSTONE	Grey MUDSTONE
	24.70		COAL	COAL
	30.00		MUDSTONE	Grey MUDSTONE

		30.00		

R09	11.70		MADE GROUND	Fill
	13.10		SANDSTONE	Grey SANDSTONE
	14.00		MUDSTONE	Grey MUDSTONE
	18.30		SANDSTONE	Grey SANDSTONE
	19.10		COAL	COAL
	26.90		MUDSTONE	Grey MUDSTONE
	30.00		SANDSTONE	Grey SANDSTONE
		30.00		

R10	10.40		MADE GROUND	Fill
	11.80		SANDSTONE	Brown SANDSTONE
	12.90		COAL	COAL
	21.10		MUDSTONE	Grey MUDSTONE
	21.70		COAL	COAL
	30.00		MUDSTONE	Grey MUDSTONE
		30.00		

R11	12.20		MADE GROUND	Fill
	15.20		MUDSTONE	Grey MUDSTONE
	15.80		SANDSTONE	Grey SANDSTONE
	16.60		COAL	COAL
	26.70		MUDSTONE	Grey MUDSTONE
	30.00		SANDSTONE	Grey SANDSTONE
		30.00		

R11a	10.00		MADE GROUND	Fill
		10.00		

R12	4.50		MADE GROUND	Fill
	6.20		CLAY and GRAVEL	Brown sandy CLAY and GRAVEL
	8.50		SANDSTONE	Brown SANDSTONE
	11.00		SANDSTONE	Grey SANDSTONE
	12.40		COAL	COAL
	23.00		MUDSTONE	Grey MUDSTONE
	23.50		COAL	COAL
	30.00		MUDSTONE	MUDSTONE
		30.00		

Trial Pits

Name	To Depth (m)	Total Depth (m)		Description to BS5930:1999
TP1	0.30		MADE GROUND	Grass overlying brown sandy clayey soil.
	4.00		MADE GROUND	Very dense grey fused slag. Recovered as fine to coarse gravels and cobbles. Occasional pieces of metal and concrete fragments.
	5.10		MADE GROUND	Red brown flue dust, recovered as a sandy gravelly clay, with refractory brick and fine to coarse gravels of slag.
	5.50		MADE GROUND	Light brown slightly clayey gravelly sand.
		5.50		
TP2	0.45		MADE GROUND	Grass overlying brown sandy clayey soil.
	3.30		MADE GROUND	Dense grey brown fused slag, recovered as fine to coarse gravels and cobbles.
	3.45		MADE GROUND	Red brown flue dust, recovered as a sandy gravelly clay, with fine to coarse gravels of slag.
	3.50		MADE GROUND	Concrete slab.
		3.50		
TP3	0.20		MADE GROUND	Grass overlying brown sandy clayey soil.
	3.50		MADE GROUND	Very dense light grey, occasionally blue grey, fused slag, recovered as fine to coarse gravels and cobbles.
	5.00		MADE GROUND	Loose grey slag, recovered as fine to coarse gravels.
	5.20		MADE GROUND	Soft black silt (possible sinter dust).
	5.50		MADE GROUND	Extremely heavy brown iron slag.
		5.50		

TP4	0.40		MADE GROUND	Grass overlying brown sandy clayey soil.
	5.00		MADE GROUND	Dense grey brown fused slag, recovered as fine to coarse gravels and cobbles.
		5.00		

TP5	0.20		MADE GROUND	Grass overlying brown sandy clayey soil.
	3.40		MADE GROUND	Dense grey brown fused slag, recovered as fine to coarse gravels and cobbles.
	4.30		CLAY	Dark brown mottled grey orange sandy gravelly CLAY with occasional coal fragments.
	4.50		SANDSTONE	Brown completely weathered SANDSTONE, recovered as a sandy very gravelly clay with angular fragments of sandstone.
		4.50		

TP6	0.20		MADE GROUND	Grass overlying brown sandy clayey soil.
	4.20		MADE GROUND	Dense grey brown fused slag, recovered as fine to coarse gravels and cobbles. Becoming extremely fused from c.1.5m bgl.
		4.20		

TP7	0.30		MADE GROUND	Grass overlying brown sandy clayey soil.
	1.50		MADE GROUND	Dense dark brown black fused slag, recovered as fine to coarse gravels and cobbles.
	2.20		MADE GROUND	Dense dark grey fused slag, recovered as fine to coarse gravels and cobbles.
	2.40		MADE GROUND	Dark grey sandy clayey soil (Relic Topsoil).
	3.70		CLAY	Light brown mottled grey orange sandy gravelly CLAY with occasional sandstone gravels.
	3.80		SANDSTONE	SANDSTONE.
		3.80		

TP8	0.70		MADE GROUND	Grass overlying brown sandy clayey soil.
	3.80		MADE GROUND	Dense grey fused slag, recovered as fine to coarse gravels and cobbles.
	4.20		MADE GROUND	Dense red brown flue dust with fine to coarse gravels of slag, frequent refractory brick and sandstone fragments. Large piece of iron slag c.2m x c.1m noted at c.1.3m bgl.
		4.20		

TP9	0.25		MADE GROUND	Grass overlying brown sandy clayey soil.
	0.90		MADE GROUND	Very dense dark grey blue slag, recovered as fine to coarse gravels and cobbles.
	4.10		MADE GROUND	Dense alternating bands of grey and brown slag, recovered as fine to coarse gravels and cobbles.
	4.40		MADE GROUND	Black sandy clay.
	4.80		MADE GROUND	Disturbed brown orange grey mottled sandy gravelly CLAY.
	5.00		CLAY	Brown grey mottled sandy gravelly CLAY.
		5.00		

TP10	0.10		MADE GROUND	Grass overlying brown sandy clayey soil.
	3.30		MADE GROUND	Dense alternating bands of grey and brown slag, recovered as fine to coarse gravels and cobbles.
	5.00		MADE GROUND	Loose grey slag, recovered as fine to coarse gravels.
		5.00		

TP11	0.15		MADE GROUND	Grass overlying brown sandy clayey soil.
	5.00		MADE GROUND	Dense alternating bands of grey and brown slag, recovered as fine to coarse gravels and cobbles.
	5.50		MADE GROUND	Loose grey slag, recovered as fine to coarse gravels.
		5.50		

TP12	0.20		MADE GROUND	Grass overlying brown sandy clayey soil.
	5.60		MADE GROUND	Dense alternating bands of grey and brown slag, recovered as fine to coarse gravels and cobbles. Large piece of fused slag recovered c.1.5m x c.1.3m.
		5.60		

TP13	0.40		MADE GROUND	Grass overlying brown sandy clayey soil.
	2.80		MADE GROUND	Dense grey fused slag, recovered as fine to coarse gravels and cobbles.
	2.90		MADE GROUND	Concrete slab.
		2.90		

TP14	0.30		MADE GROUND	Grass overlying brown sandy clayey soil.
	2.80		MADE GROUND	Dense grey fused slag, recovered as fine to coarse gravels and cobbles. Large piece of slag recovered c.2.6m x c.1.8m x c.1.0m.
	3.30		MADE GROUND	Brown sandy slightly gravelly clay with frequent clinker.
	5.30		MADE GROUND	Very dense dark grey slag, recovered as fine to coarse gravels and cobbles.
		5.30		

TP15	0.70		MADE GROUND	Grass overlying brown sandy clayey soil.
	1.60		MADE GROUND	Dense grey fused slag, recovered as fine to coarse gravels and cobbles.
	2.70		MADE GROUND	Red brown clayey gravel of clinker and slag with flue dust.
	3.90		MADE GROUND	Grey sandy gravelly clay with sandstone fragments and a thin band of grey slag.
	6.00		MADE GROUND	Red brown clayey gravel of ash, clinker and slag.
		6.00		

TP16	0.20		MADE GROUND	Grass overlying brown sandy clayey soil.
	4.50		MADE GROUND	Dense black light grey fused slag, recovered as fine to coarse gravels and cobbles. Large piece of slag recovered c.2.6m x c.1.8m x c.1.0m.
	5.00		MADE GROUND	Black silt/fine grained sand of ash/sinter dust with frequent gravels of slag and cinder.
		5.00		

TP17	0.40		MADE GROUND	Grass overlying brown sandy clayey soil.
	4.60		MADE GROUND	Dense grey fused slag, recovered as fine to coarse gravels and cobbles.
	5.30		MADE GROUND	Grey slag, concrete, recovered as fine to coarse gravels. Sandstone fragments, pieces of rebar and timber fragments.
		5.30		

TP18	0.20		MADE GROUND	Grass overlying brown sandy clayey soil.
	3.10		MADE GROUND	Dense grey fused slag, recovered as fine to coarse gravels and cobbles.
	3.60		MADE GROUND	Red brown flue dust, recovered as gravelly silt, with fine to coarse gravels of slag.
	5.00		MADE GROUND	Black silt/fine grained sand of ash/sinter dust with frequent gravels of slag and cinder. Boulder of concrete recovered.
		5.00		

TP19	0.30		MADE GROUND	Grass overlying brown sandy clayey soil.
	2.90		MADE GROUND	Dense grey fused slag, recovered as fine to coarse gravels and cobbles.
	3.40		MADE GROUND	Red brown flue dust, recovered as gravelly silt, with fine to coarse gravels of slag.
	3.80		MADE GROUND	Black silt/fine grained sand of ash/sinter dust with frequent gravels of slag, cinder and refractory brick.
	4.00		MADE GROUND	Red brown flue dust, recovered as gravelly silt, with fine to coarse gravels of slag.
	4.60		MADE GROUND	Red brown sandy gravelly clay.
	5.00		SANDSTONE	SANDSTONE
		5.00		

TP20	0.40		Soil	Grass overlying brown sandy clayey soil.
	2.30		MADE GROUND	Dense grey fused slag, recovered as fine to coarse gravels and cobbles.
	5.10		MADE GROUND	Red brown flue dust, recovered as gravelly silt, with fine to coarse gravels of slag. Large piece of iron slag c.1.9m x c.1.1m recovered at c.3.50m bgl.
	5.80		CLAY	Brown sandy very gravelly CLAY with frequent sandstone fragments.
		5.80		

1.1.3 Contamination data

Table 1 – Contaminant screening values for Derwent View

Sample Reference	Indicators Over Tier One Screening Values	Shadbolt's TSV land-use indicator, in excess of
CP4	Naphthalene Fluorine Benzo(a)pyrene Dibenz(ah)anthracene TPH (C5-C35)	Residential development Residential development Residential development Residential development Residential development
CP5	Lead	Commercial development
TP2	Lead	Commercial development
2	Arsenic Chromium Lead TPH (C21-C35)	Residential development Residential development Commercial development Residential development
3	Lead	Commercial development
9	Lead	Commercial development
12	Arsenic Lead TPH (C21-C35)	Residential development Residential development Residential development
22	Arsenic Lead	Residential development Commercial development
25	Arsenic Lead	Residential development Residential development
30	Arsenic Lead Benzo(a)pyrene Dibenz(ah)anthracene	Residential development Residential development Residential development Residential development
31	Arsenic Chromium Lead TPH (C21-C35)	Residential development Residential development Commercial development Residential development
32	Arsenic Lead Benzo(a)pyrene Dibenz(ah)anthracene TPH (C16-C44)	Residential development Commercial development Residential development Residential development Residential development

1.1.4 Site Photographs

Figure 7 – Upper Plateau site looking south. June 2009 (Source: Renforth, P., 2009)

Figure 8 – Upper Plateau site looking west. June 2009 (Source: Renforth, P., 2009)

1.2 METHOD

1.2.1 Methodologies

1.2.1.1 Isotopic Ratio Mass Spectrometry (Source: Iso-Analytical Report 090709)

1. For analysis, sample powder was placed in clean glass septum capped vials. The vials were then placed in a drying oven for 4 hours prior to the caps being fitted to ensure no moisture is present. The vials then had their headspaces flushed with pure helium (99.995%). After flushing, pure phosphoric acid* was injected into the vials and mixed with the sample powder. The samples were left to react with the acid for 24 hours at ambient temperatures then heated for 25 minutes to 90° C to ensure complete conversion to carbon dioxide.
2. *Phosphoric acid suitable for isotopic analysis of carbonate samples is prepared according to the procedure published by Coplen et al (1983) Nature, vol. 302, pp. 236-238.
3. The CO_2 gas was then analysed by continuous flow isotope ratio mass spectrometry. In brief, the CO_2 is flushed from the septum vial using a double holed needle and resolved on a packed column gas chromatograph. The carbon dioxide then enters the ion source of a Europa Scientific 20-20 IRMS and is ionised and accelerated. Here, gas species of different mass are separated in a magnetic field then simultaneously measured using a Faraday cup collector array at m/z 44, 45, and 46.he reference material used for this analysis was our laboratory calcium carbonate standard IA-R022 ($\delta^{13}C_{V\text{-}PDB}$ -28.63 ‰ and $\delta^{18}O_{V\text{-}PDB}$ -22.69 ‰), which is traceable to NBS-19 (Limestone, $\delta^{13}C_{V\text{-}PDB}$ +1.95 ‰ and $\delta^{18}O_{V\text{-}PDB}$ -2.2 ‰).
4. During analysis NBS-19, IA-R022 and NBS-18 ($\delta^{13}C_{V\text{-}PDB}$ -5.01 ‰ and $\delta^{18}O_{V\text{-}PDB}$ -23.20 ‰) were analysed as check samples. The results of these analyses are included in the attached results table.

5. The International Atomic Energy Agency, Vienna distributes NBS-18 and NBS-19 as international reference standards.

1.2.1.7 Risk Assessment

A risk assessment has been produced for the project and is divided in to three main areas in which risks may be encountered:

1. Literature Review and Desk Study
2. Fieldwork
3. Laboratory
4. Project Risk Assessment

Risk assessments for all areas have been produced in tabulated form, with the likelihood and severity of the risks associated with each project stage represented numerically and multiplied together the produce an overall ‘total’ risk. In this manner, the relative summative effect of each risk category can be assessed

1 Literature Review and Desk Study

The risk assessment for the initial literature review and desk study considers any risk related to the sourcing and analysis of existing documentary resources relating to the project.

Key: 1 = Low Risk, 2 = Medium Risk, 3 = High Risk

Risk	**Hazard Severity**	**Potential for Occurrence**	**Risk (H x P)**	**Mitigation**
Lack of contemporary papers	1	1	1	Ensure research is carried out throughout the dissertation period in order to identify contemporary developments Contact relevant peer researchers
Unattainable literature	2	3	6	Ensure sufficient time for inter-library loans, or the attainment of specific literature from external bodies
Referencing issues	3	3	9	Catalogue all research materials using Microsoft Endnote.
Gaps in literature	2	2	4	Expand the scope of the project in order to address research needs
Lack of focus	2	2	4	Reduce the scope of the project or implement less diffuse subject searches

Table 2 – A Risk assessment for initial research and the desk study

2 Fieldwork Risk Assessment

This risk assessment details any specific risks identified during the preliminary visit, including any general risks encountered during preliminary fieldwork. This visit entailed a site walk and prior assessment of the study area and was carried out on Thursday 11th December 2008.

Key: 1 = Low Risk, 2 = Medium Risk, 3 = High Risk

Risk	**Hazard Severity**	**Potential for Occurrence**	**Risk (H x P)**	**Mitigation**
Inclement weather	1	3	3	Check weather forecasts and avoid sampling during likely periods of severe weather
Incorrect clothing and footwear	2	1	2	Ensure correct, weather applicable clothing is worn / taken to site
Misuse of equipment	3	1	3	Complete any necessary training. Work alongside individuals familiar with more complex equipment
Equipment malfunction	2	3	6	Ensure spare parts / repair kits are present on site. Bring multiples of equipment if possible
Working in isolated areas	3	3	9	Assign field assistant to assure no fieldwork is carried out alone
Working with the public / on public land	3	3	9	Assure any landowners have been notified of any intrusive works in advance Take care not to disrupt access to public rights of way

Table 3 – A Risk assessment for fieldwork

3 Laboratory Risk Assessment

A laboratory risk assessment has been completed in order to detail the risks specifically involved directly in laboratory work and in sending samples to external laboratories for testing.

Key: 1 = Low Risk, 2 = Medium Risk, 3 = High Risk

Risk	**Hazard Severity**	**Potential for Occurrence**	**Risk (H x P)**	**Mitigation**
Improper laboratory practise	2	1	2	Complete any necessary training on unfamiliar equipment Ensure proper laboratory practise is noted and adhered to Check qualifications of any external handlers
Insufficient COSHH assessment	2	1	2	Complete a full assessment of any potentially hazardous chemicals which need to be handled during laboratory work
Loss of samples	3	2	6	Ensure that samples are clearly labelled and correctly stored, and that technicians are notified of their presence.
Insufficient results	2	2	4	Ensure that sufficient samples have been collected in order to allow for testing repetitions if required
Anomalous results	3	2	6	Ensure that sufficient sample has been retained in order to carry out repetitions in the case of anomalous results

Table 4 – A Risk assessment for laboratory work

4 Project Risk Assessment

A risk assessment for the project as a whole has also been completed in order to address any problems which may arise in the completion of the written dissertation.

Key: 1 = Low Risk, 2 = Medium Risk, 3 = High Risk

Risk	**Hazard Severity**	**Potential for Occurrence**	**Risk (H x P)**	**Mitigation**
Data loss	3	3	9	Ensure that any paper copies of results and field notes are retained Regularly backup electronic copies of report and results in several different locations
Referencing issues	2	2	6	Ensure that materials are logged as read in order to prevent lost or incorrect references
Illness	2	2	6	Ensure that all personal deadlines are set significantly before the actual deadlines required for the project, in order to allow for down-time due to illness
Delays	2	2	6	As above – ensure that all deadlines are set sufficiently early. Ensure that delays in printing and binding are avoided by carrying out early.

Table 5 – A Risk assessment for the project completion

1.2.2 Method Statements

1.2.2.1 Sampling – Upper Plateau

Method statement and Risk Assessment: Soil Sampling
Upper Plateau Retail Site, Project Genesis, Consett, County Durham

Date / period of sampling: 12th – 19th June 2009

This document has 5 pages.

Staff involved:
University of Newcastle: David Manning (Project Supervisor), Carla Washbourne

No lone working is permitted.

Project Supervisor Contact information:
Contact office: Devonshire Building, Newcastle University, Newcastle upon Tyne
Contact person: Professor David Manning
Office telephone: 0191 246 4808
Mobile telephone: 07857 478 697

Contact information:
Contact office: Project Genesis, Management Centre, Ponds Court, Genesis Way, Consett
Contact person: Ian Sparks
Site office telephone: 0120 758 1119

Contact for emergency at the University of Newcastle:
Mrs Pam Moderate (Safety Officer): 0191 222 5912 / 0191 222 7607

Required equipment:
You will wear the following items onsite:
Hard hat
Hi-visibility jacket
Safety boots (walking boots are acceptable)
You are ADVISED to wear warm, waterproof clothing

The following equipment will be used onsite:
CAT (cable avoidance tool) locator
Hand operated sampling equipment – hand auger, spade, trowel
Sampling equipment – sample bags

First aid:
A first aid kit must be carried in the University's vehicle.
This MUST include eyewash and water fit for drinking.
In the event of any accident or near miss the project supervisor and safety officer must be contacted. Contact Ian Sparks of Project Genesis.

Communications:
There is no land line at the site. Mobile phones work due to proximity to residential areas (Orange). A land line can be used if necessary at the Project Genesis Office, Ponds Court Business Park.

Procedures: Soil Sampling

Spatial resolution:
Representative samples of the site area will be collected spatially as illustrated in Figure 1 at approx. 50m intervals at Upper Plateau Retail.

Before sampling, the proposed points will be surveyed to determine the presence of underground services with the use of a CAT locator. Any points at which shallow services are located will be marked with plastic pegs. Sample locations will be reconsidered to avoid buried services as necessary.

Auger cores will be collected in order to determine the stratigraphy of the made ground. These will be implemented by hand, depressing the apparatus in to the ground and collecting narrow diameter samples as they are extruded.

Once works have been completed any areas in which the ground has been disturbed returned to a state which renders the site safe for public use.

Sample Collection:
Samples will initially be taken at locations as illustrated in Figure 1.
2 auger cores will be taken at each location indicated, to a depth of 500mm, or to the point where sampling is restricted by ground conditions.
Samples will be taken at 100mm intervals throughout the auger core.
Samples of soil from each location will be tested for carbonates by acid reaction.

Sample Handling:
Samples will be of small volume, contained in polythene sample bags, and will be transported from the site with the use of vehicular transport. Sampling apparatus will be cleaned offsite – care will be taken to reduce potential contamination due to sample handling.

All material including waste must be removed from site on completion of sampling

No powered sampling equipment will be used on site.
Chemicals utilised onsite will be restricted to <50ml of dilute Hydrochloric acid.

Procedure prepared by:

Carla Washbourne
June 2009

Risk assessment: On-Site Hazards Only

The site is level and grassed over and cuttings from the well. It is fenced off, and approached via a minor, tarmac road.

On arrival, inspect the site and assess any hazards not identified below prior to starting work.

Hazard	**Cause**	**Risk**	**Avoidance**
Tripping	Rabbit holes. uneven ground, dense vegetation	Moderate	Work in a level area, be observant to any changes in ground level
Inclement weather	Rain, cold weather	High	Ensure suitable, waterproof clothing is worn Cease works if weather hinders sampling operations
Slipping / Tripping	Incorrect clothing and footwear	Moderate	Ensure suitable, durable, waterproof clothing applicable to the site is worn
Injury caused by misuse of equipment	Misuse of equipment	Moderate	Ensure that correct operation procedures for equipment are observed Do not operate equipment beyond personal physical capabilities
Delays to work	Equipment malfunction	High	Ensure spare parts or multiples of equipment are taken if possible
Lone working	Working in isolated areas	High	Ensure no lone working Ensure emergency contact is designated
Contact with members of public	Working with the public / on public land	Moderate	Ensure that works cause no restriction to public rights of way Ensure that effective public facing manner is maintained
Injury caused by lifting	Carrying equipment and samples	Moderate	Carry no more than 15kg at once
Incidents involving motor vehicles	Movement of vehicles; getting stuck on site	Low	Park on the lay by from the public road at the entrance from Genesis Way

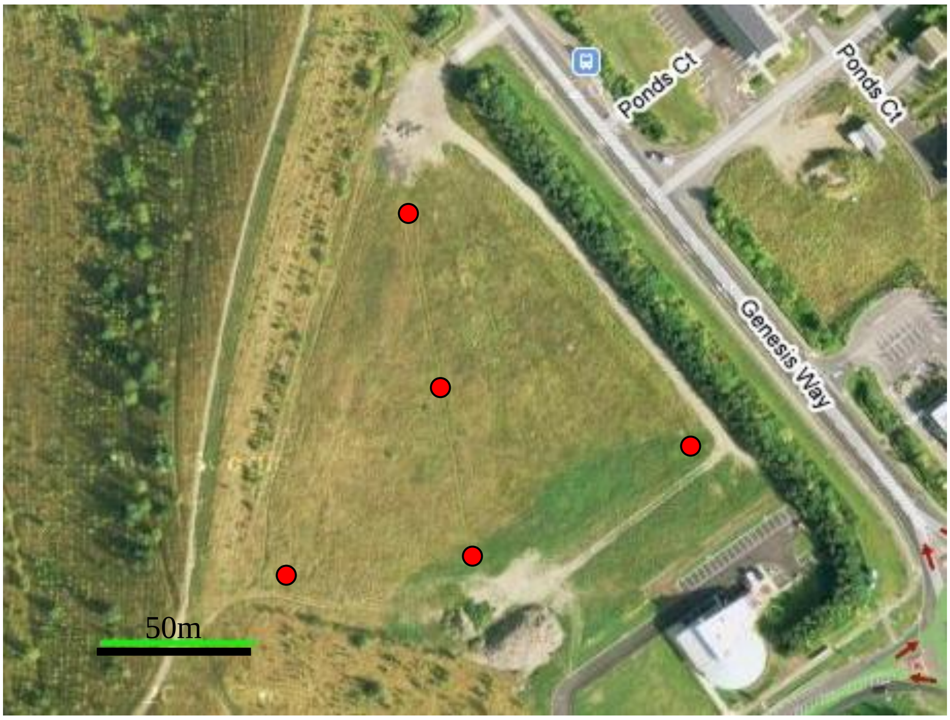

Figure 9 – Aerial view of retail site, with proposed preliminary sampling locations

<u>Site Contacts:</u>

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1.2.2.2 Sampling – Derwent View

Method statement and Risk Assessment: Soil Sampling
Derwent View Site, Project Genesis, Consett, County Durham

Date/ period of sampling: 12th – 19th June 2009

This document has 5 pages.

Staff involved:
University of Newcastle: David Manning (Project Supervisor), Carla Washbourne

No lone working is permitted.

Project Supervisor Contact information:
Contact office: Devonshire Building, Newcastle University, Newcastle upon Tyne
Contact person: Professor David Manning
Office telephone: 0191 246 4808
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Contact person: Ian Sparks
Site office telephone: 0120 758 1119

Contact for emergency at the University of Newcastle:
Mrs Pam Moderate (Safety Officer): 0191 222 5912 / 0191 222 7607

Required equipment:
You will wear the following items onsite:
Hard hat
Hi-visibility jacket
Safety boots (walking boots are acceptable)
You are ADVISED to wear warm, waterproof clothing

The following equipment will be used onsite:
CAT (cable avoidance tool) locator
Hand operated sampling equipment – hand auger, spade, trowel
Sampling equipment – sample bags

First aid:
A first aid kit must be carried in the University's vehicle.
This MUST include eyewash and water fit for drinking.
In the event of any accident or near miss the project supervisor and safety officer must be contacted. Contact Ian Sparks of Project Genesis.

Communications:
There is no land line at the site. Mobile phones work due to proximity to residential areas (Orange). A land line can be used if necessary at the Project Genesis Office, Ponds Court Business Park.

Procedures: Soil Sampling

Spatial resolution:

Representative samples of the site area will be collected spatially as illustrated in Figure 1 at approx. 100m intervals at the Derwent View site.

Before sampling, the proposed points will be surveyed to determine the presence of underground services with the use of a CAT locator. Any points at which shallow services are located will be marked with plastic pegs. Sample locations will be reconsidered to avoid buried services as necessary.

Auger cores will be collected in order to determine the stratigraphy of the made ground. These will be implemented by hand, depressing the apparatus in to the ground and collecting narrow diameter samples as they are extruded.

Once works have been completed any areas in which the ground has been disturbed returned to a state which renders the site safe for public use.

Sample Collection:
Samples will initially be taken at locations as illustrated in Figure 1.
2 auger cores will be taken at each location indicated, to a depth of 500mm, or to the point where sampling is restricted by ground conditions.
Samples will be taken at 100mm intervals throughout the auger core.
Samples of soil from each location will be tested for carbonates by acid reaction.

Sample Handling:
Samples will be of small volume, contained in polythene sample bags, and will be transported from the site with the use of vehicular transport. Sampling apparatus will be cleaned offsite – care will be taken to reduce potential contamination due to sample handling.

All material including waste must be removed from site on completion of sampling

No powered sampling equipment will be used on site.
Chemicals utilised onsite will be restricted to <50ml of dilute Hydrochloric acid.

Procedure prepared by:

Carla Washbourne
June 2009

Risk assessment: On-Site Hazards Only
The site is level and grassed over and cuttings from the well. It is fenced off, and approached via a minor, tarmac road.

On arrival, inspect the site and assess any hazards not identified below prior to starting work.

Hazard	**Cause**	**Risk**	**Avoidance**
Tripping	Rabbit holes. uneven ground, dense vegetation	Moderate	Work in a level area, be observant to any changes in ground level
Inclement weather	Rain, cold weather	High	Ensure suitable, waterproof clothing is worn Cease works if weather hinders sampling operations
Slipping / Tripping	Incorrect clothing and footwear	Moderate	Ensure suitable, durable, waterproof clothing applicable to the site is worn
Injury caused by misuse of equipment	Misuse of equipment	Moderate	Ensure that correct operation procedures for equipment are observed Do not operate equipment beyond personal physical capabilities
Delays to work	Equipment malfunction	High	Ensure spare parts or multiples of equipment are taken if possible
Lone working	Working in isolated areas	High	Ensure no lone working Ensure emergency contact is designated
Contact with members of public	Working with the public / on public land	Moderate	Ensure that works cause no restriction to public rights of way Ensure that effective public facing manner is maintained
Injury caused by lifting	Carrying equipment and samples	Moderate	Carry no more than 15kg at once
Incidents involving motor vehicles	Movement of vehicles; getting stuck on site	Low	Park on the lay by from the public road at the entrance from Genesis Way

Figure 10 – Aerial view of retail site, with proposed preliminary sampling locations

Site Contacts:

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1.2.2.3 Geophysics – Upper Plateau

Method statement and Risk Assessment: Geophysical Survey
Upper Plateau Retail Site, Project Genesis, Consett, County Durham

Date / period of works: 1st July 2009

This document has 5 pages.

Staff involved:
University of Newcastle: David Manning (Project Supervisor), Carla Washbourne

No lone working is permitted.

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Office telephone: 0191 246 4808
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Contact information:
Contact office: Project Genesis, Management Centre, Ponds Court, Genesis Way, Consett
Contact person: Ian Sparks
Site office telephone: 0120 758 1119

Contact for emergency at the University of Newcastle:
Mrs Pam Moderate (Safety Officer): 0191 222 5912 / 0191 222 7607

Required equipment:
You will wear the following items onsite:

Hi-visibility jacket
Safety boots (walking boots are acceptable)
You are ADVISED to wear warm, waterproof clothing

The following equipment will be used onsite:

"Syscal Pro" Fixed Array Resistivity System -

- Electrodes
- Electrode Clips
- Resistivity Cables
- Silicon Spray
- Junction Boxes
- Laptop
- Tape Measures
- Car Battery + Charger
- Lump Hammer(s)
- Salt
- Large Containers Filled With Water
- Jugs and small bottles
- GPS apparatus

First aid:
A first aid kit must be carried in the University's vehicle.
This MUST include eyewash and water fit for drinking.
In the event of any accident or near miss the project supervisor and safety officer must be contacted. Contact Ian Sparks of Project Genesis.

Communications:
There is no land line at the site. Mobile phones work due to proximity to residential areas (Orange). A land line can be used if necessary at the Project Genesis Office, Ponds Court Business Park.

Procedures: Geophysical Survey
Geophysical apparatus will be delivered to the site using a Land Rover via the access road from the A692 (Consett Road)

Electrodes and resistivity cables will be laid out in transects across the survey site as illustrated in Figure 1. Electrodes will be inserted using physical force and small hammers where required. Small quantities of saltwater may be applied to the electrodes in order to ensure connectivity.

Readings will be taken along the defined transects with the use of a console, transferring the data to a laptop in the field. Power will be supplied by a 12V car battery.

Data points will be logged using GPS.

All material including waste must be removed from site on completion of sampling

Powered Equipment
Powered equipment will be used onsite – care will be taken to ensure the safe usage of all equipment within recommended operating procedures.
Public access to the site will be controlled during the data acquisition phase of the survey, due to high risk of electric shock posed by the electrode arrays.

Chemicals
Chemicals utilised onsite will be restricted to saltwater dilutions in small quantities.

Procedure prepared by:

Carla Washbourne
June 2009

Risk assessment: On-Site Hazards Only

The site is level and grassed over and cuttings from the well. It is fenced off, and approached via a minor, tarmac road.

On arrival, inspect the site and assess any hazards not identified below prior to starting work.

Hazard	**Cause**	**Risk**	**Avoidance**
Tripping	Rabbit holes. uneven ground, dense vegetation	Moderate	Work in a level area, be observant to any changes in ground level
Inclement weather	Rain, cold weather	High	Ensure suitable, waterproof clothing is worn Cease works if weather hinders sampling operations
Slipping / Tripping	Incorrect clothing and footwear	Moderate	Ensure suitable, durable, waterproof clothing applicable to the site is worn
Injury caused by misuse of equipment	Misuse of equipment	Moderate	Ensure that correct operation procedures for equipment are observed Do not operate equipment beyond personal physical capabilities
Delays to work	Equipment malfunction	High	Ensure spare parts or multiples of equipment are taken if possible
Lone working	Working in isolated areas	High	Ensure no lone working Ensure emergency contact is designated
Contact with members of public	Working with the public / on public land	Moderate	Ensure that works cause no restriction to public rights of way Ensure that effective public facing manner is maintained
Injury caused by lifting	Carrying equipment	Moderate	Carry no more than 15kg at once
Electric Shock	Resistivity apparatus	Moderate	Do not approach cable array when recording is being carried out. Limit public access to the site.
Incidents involving motor vehicles	Movement of vehicles; getting stuck on site	Low	Use the accessible entrance from the A692 (Consett Road) Ensure parking is on areas of hard-standing

Figure 11 – Aerial view of retail site, with proposed geophysical transects

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APPENDIX 2

Results

2.0 Results

2.1 PREVIOUS INVESTIGATIONS

2.3.1 Previous studies – ground investigation data

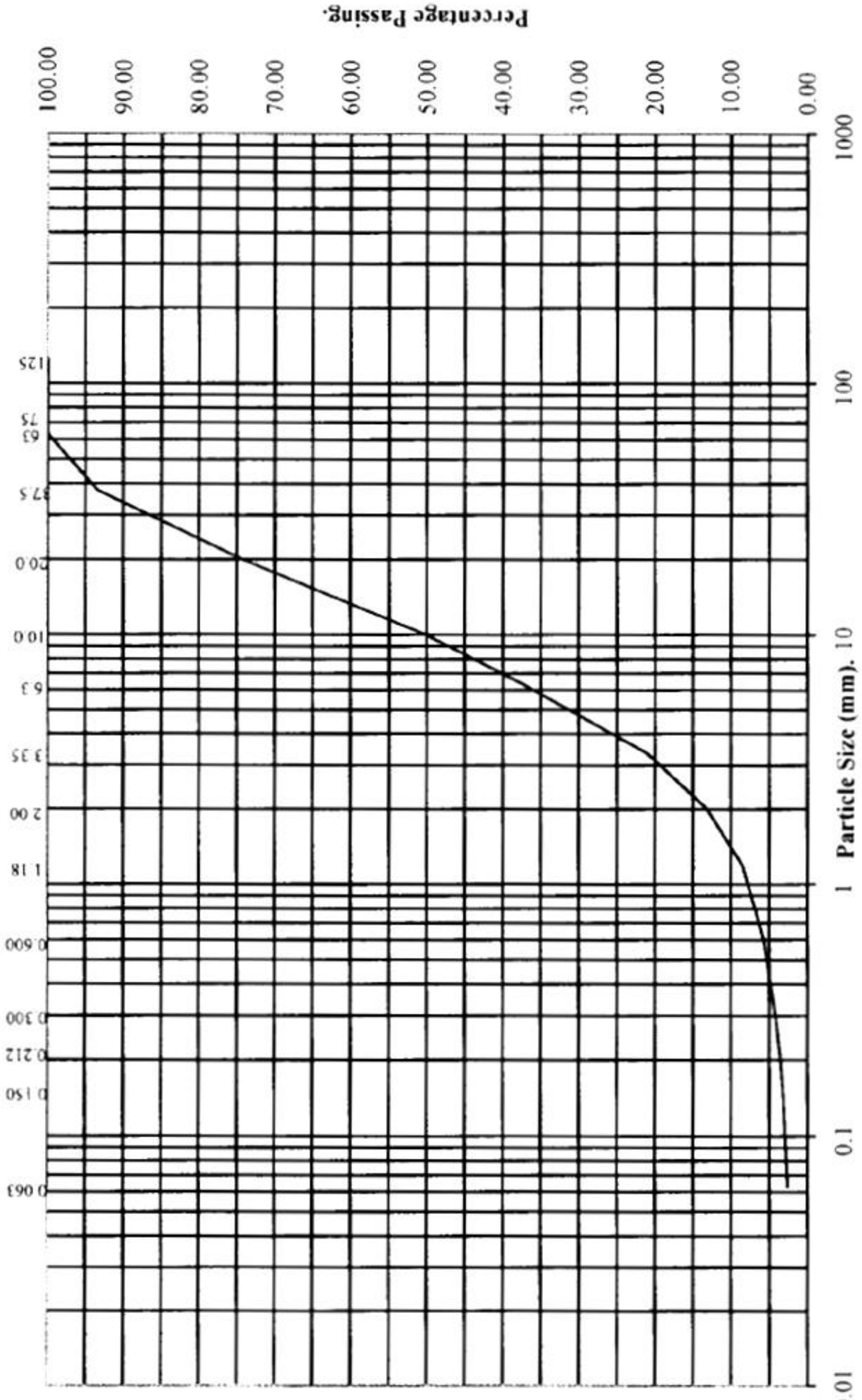


Figure 12 – Particle Size Distribution Chart for Trial Pit 7 (see Figure XX), Upper Plateau Site, at 1.4m depth

(Source: Shadbolt Environmental Ground Investigation Report 2008)

2.2 FIELD REULTS

2.2.1 Resistivity Figures

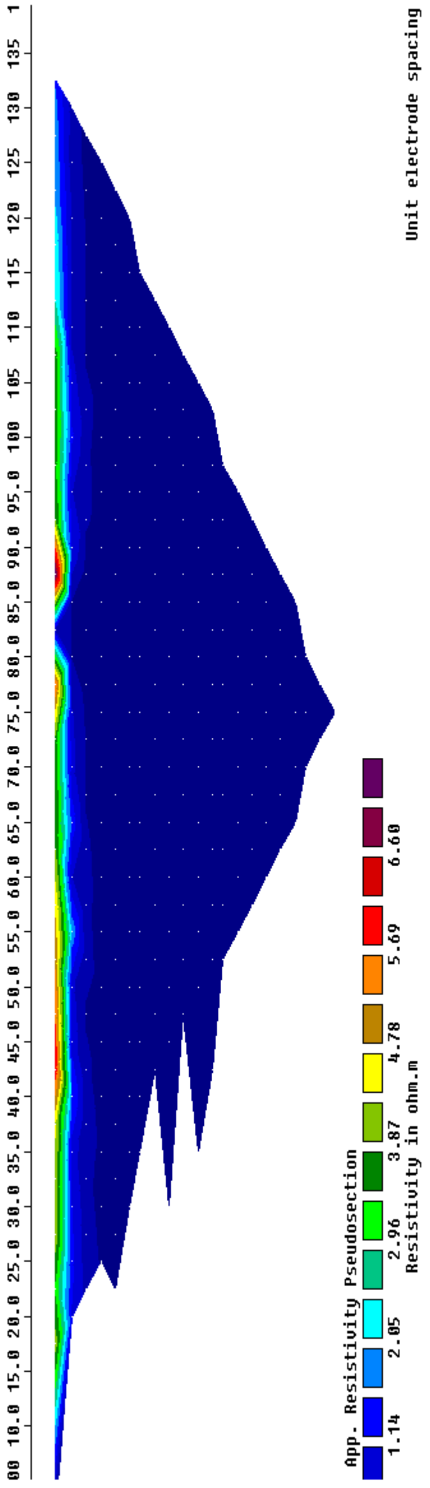


Figure 13 – Filtered IV Section (Source: Authors Own – Res2DInv)

2.3 LAB RESULTS

2.3.1 Calcimeter

Control Sample Results

Table 6 – Percentage of calcium carbonate at depth

Sample Depth (mm)	**$CaCO_3$ (%)**
10-40	0.12
40-80	-0.23
80-120	-0.19
120-160	-0.34
160-200	-0.35

Upper Plateau Surface Sample Results

Table 7 - Percentage of calcium carbonate present in soil samples

Sample Location Ref.	**Shadbolt Env. Ref.**	**Sample Depth (mm)**	**$CaCO_3$ (%)**
1	Unknown	0	12.63
2	Unknown	0	20.01
3	Unknown	0	19.08
4	Unknown	0	14.03
5	Unknown	0	21.57
6	HEAP (North)	0	16.61

Preliminary Calcimeter Results

Table 8 - Percentage of calcium carbonate at depth

Sample Location	**Sample Depth (mm)**	**$CaCO_3$ (%)**
SE	100	10.58
SE	200	33.70
SW	100	1.09
SW	200	20.31

Upper Plateau Sample Results

Calcium carbonate contents were acquired from samples taken, at varying depths, at five locations across the Upper Plateau site.

Table 9 - Percentage of calcium carbonate at depth

Sample Location	**Sample Depth (mm)**	**$CaCO_3$ (%)**
SE	10-40	2.77
SE	40-80	3.06
SE	80-120	3.23
SE	120-160	2.54
SE	160-200	3.43
SE	200-240	3.78
SE	240-280	1.45
SE	280-320	2.83
SE	320-340	3.34

Table 10 - Percentage of calcium carbonate at depth

Sample Location	**Sample Depth (mm)**	**$CaCO_3$**
SW	10-40	2.59
SW	40-80	2.58
SW	80-120	3.29
SW	120-160	2.87
SW	160-200	3.69
SW	200-240	3.50
SW	240-280	2.90
SW	280-320	2.97

Table 11 - Percentage of calcium carbonate at depth

Sample Location	**Sample Depth (mm)**	**$CaCO_3$**
NE	10-40	1.37
NE	40-80	0.97
NE	80-120	17.24
NE	120-160	23.08
NE	160-200	27.75
NE	200-240	21.84
NE	240-280	17.21
NE	280-320	14.41

Table 12 - Percentage of calcium carbonate at depth

Sample Location	**Sample Depth (mm)**	**$CaCO_3$**
NW	10-40	2.42
NW	40-80	4.01
NW	80-120	4.84
NW	120-160	5.01
NW	160-200	7.80
NW	200-240	11.70
NW	240-280	11.42

Table 13 - Percentage of calcium carbonate at depth

Sample Location	**Sample Depth (mm)**	**$CaCO_3$**
CENTRAL	10-40	4.30
CENTRAL	40-80	5.07
CENTRAL	80-120	14.04
CENTRAL	120-160	24.96
CENTRAL	160-200	21.28
CENTRAL	200-240	24.08
CENTRAL	240-280	20.60

Derwent View Sample Results

Table 14 - Percentage of calcium carbonate at depth

Sample Location	**Sample Depth (mm)**	**$CaCO_3$**
DERWENT VIEW	10-40	3.52
DERWENT VIEW	40-80	5.59
DERWENT VIEW	80-120	4.67
DERWENT VIEW	120-160	3.09
DERWENT VIEW	160-200	3.12

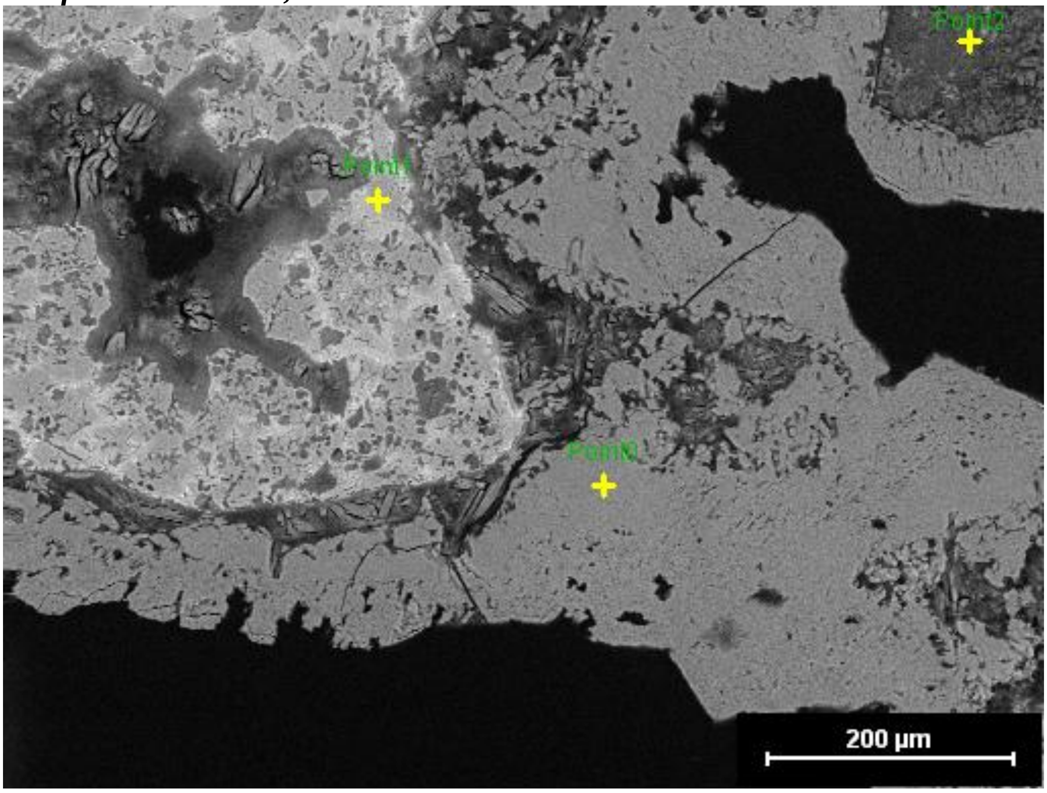
Howns Gill Sample Results

Table 15 - Percentage of calcium carbonate at depth

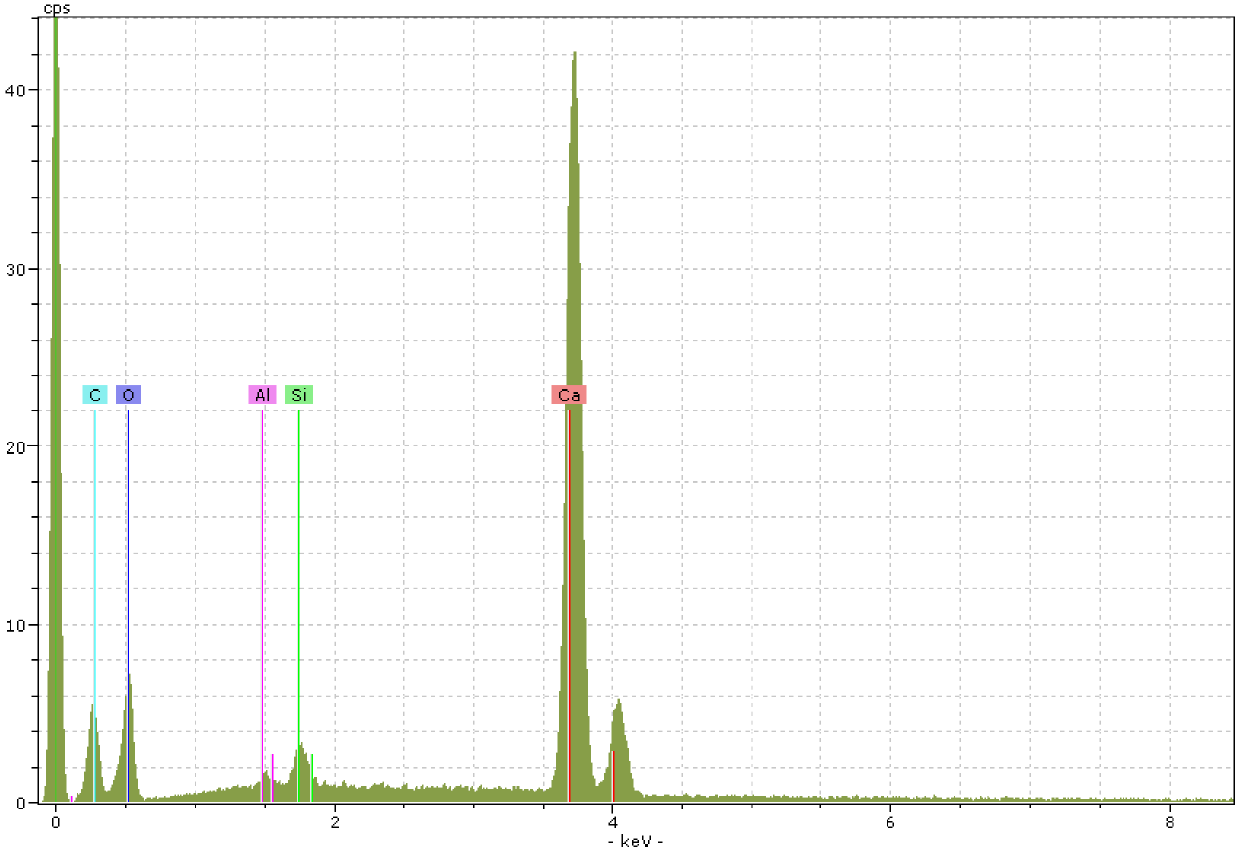
Sample Location	**Sample Depth (mm)**	**$CaCO_3$**
HOWNS GILL	10-40	5.24
HOWNS GILL	40-80	5.17
HOWNS GILL	80-120	5.80
HOWNS GILL	120-160	7.90
HOWNS GILL	160-200	6.31

2.3.2 SEM Data

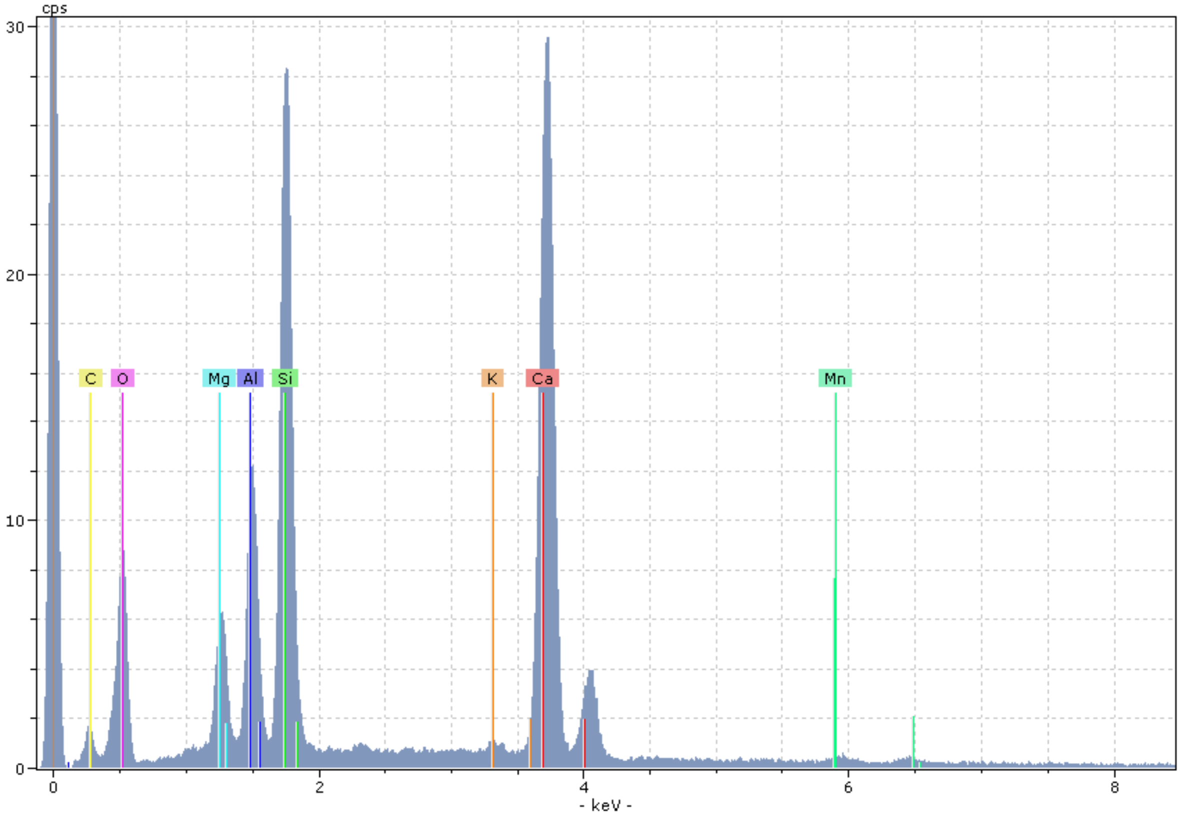
Sample Reference CLW – 2, Observation Area 1



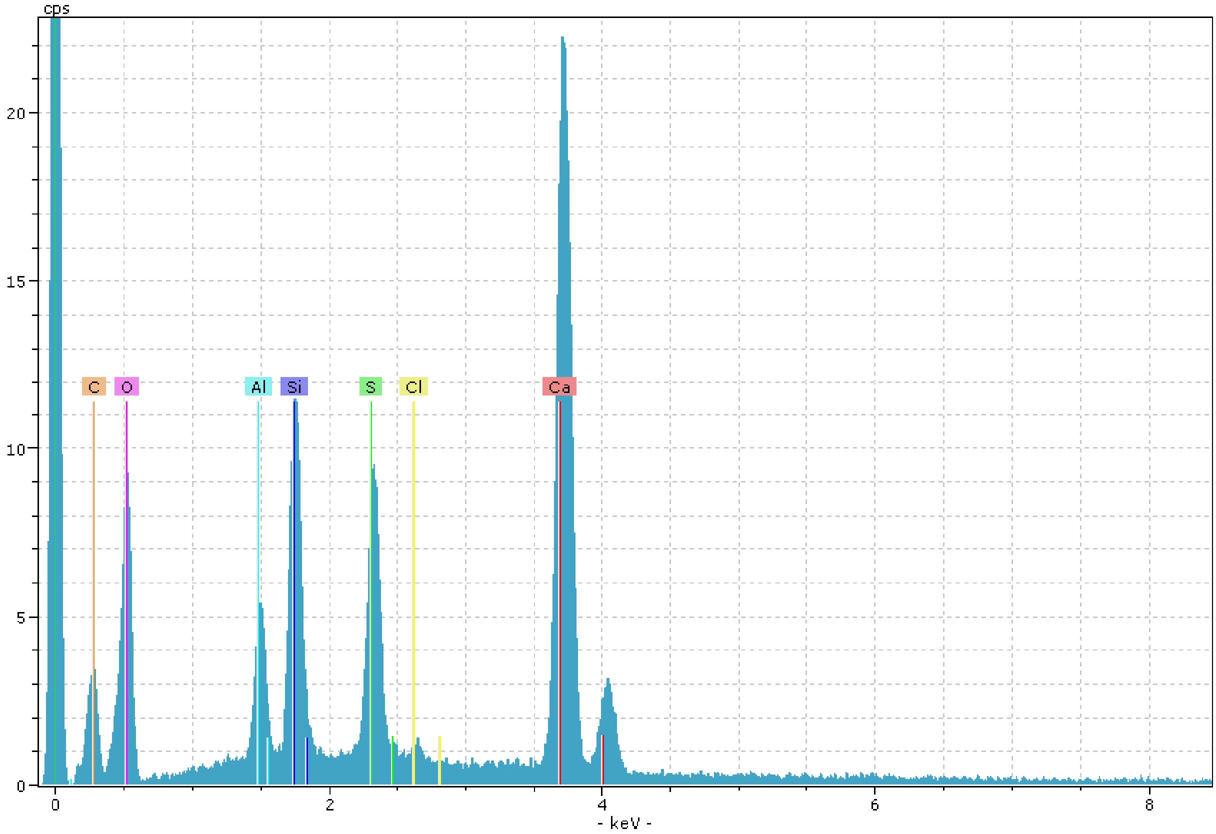
Sample 2-1 250x Magnification



Sample 2-1 Analysis Point 0

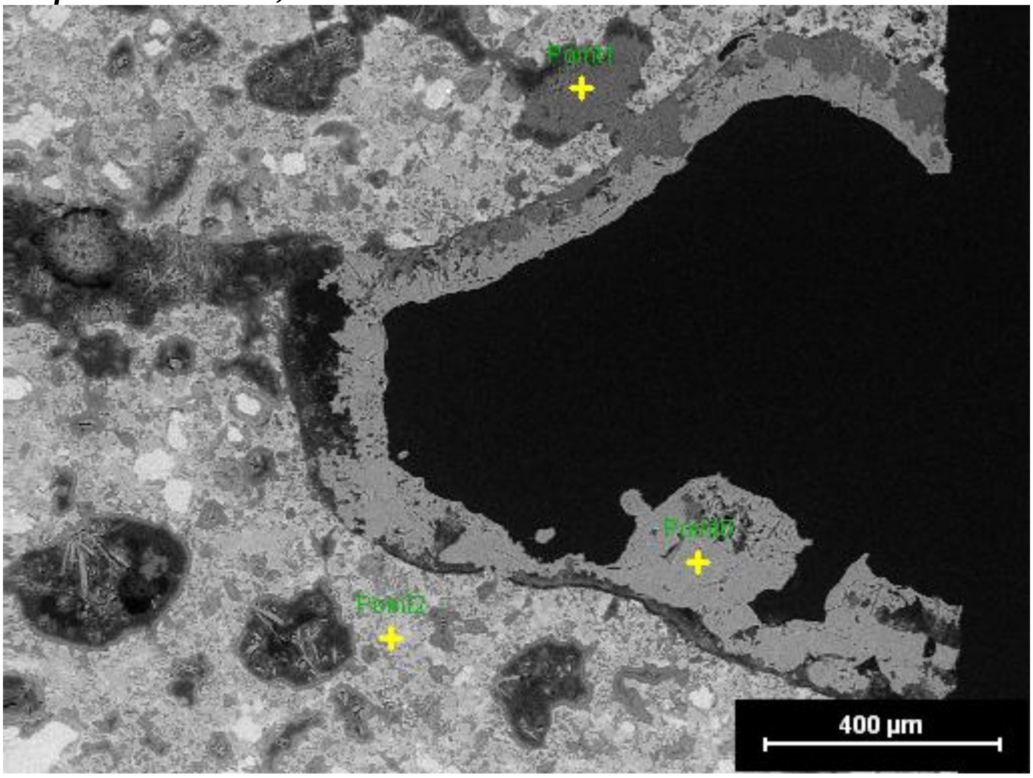


Sample 2-1 Analysis Point 1

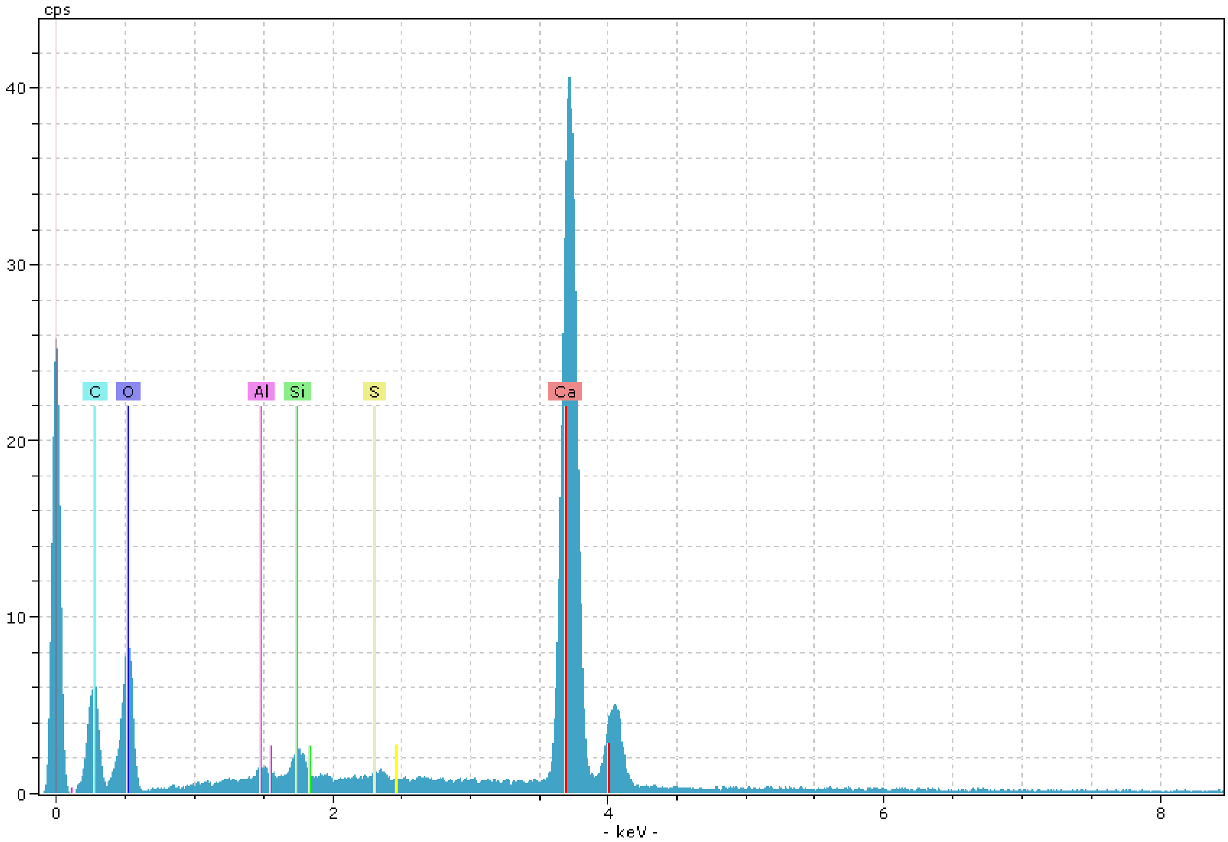


Sample 2-1 Analysis Point 2

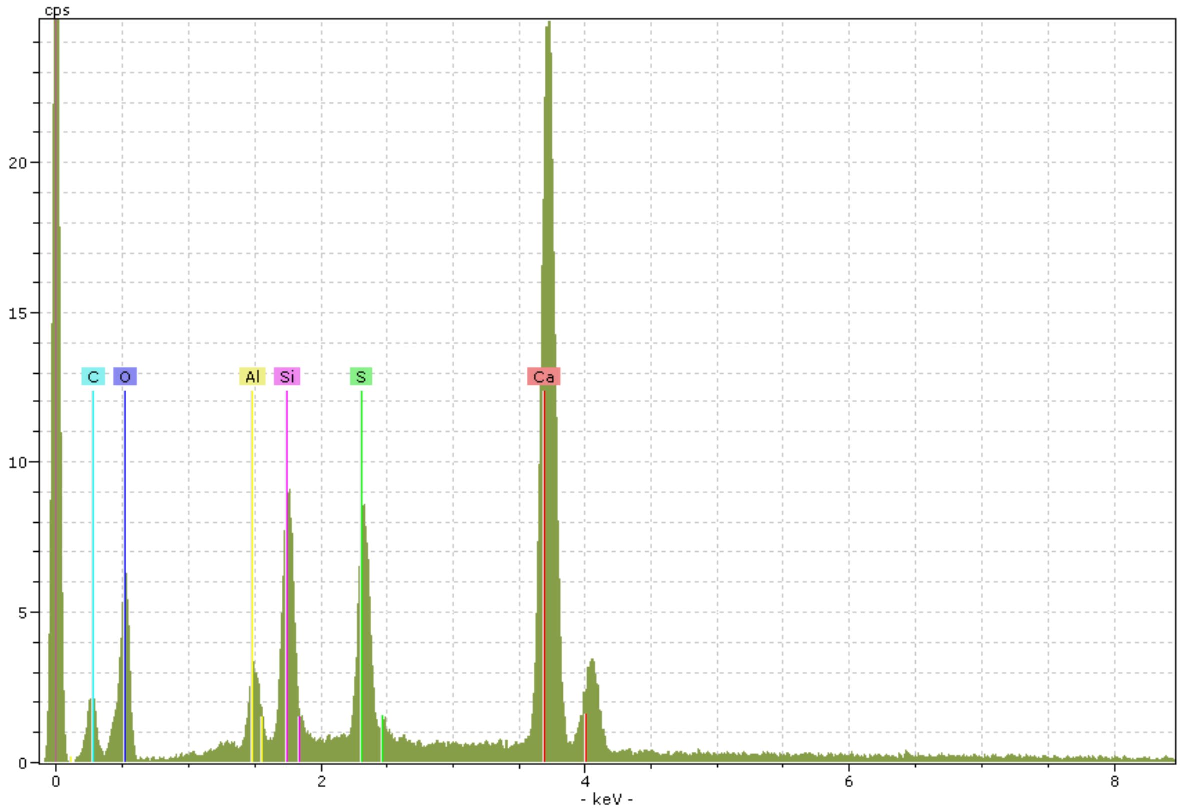
Sample Reference CLW – 2, Observation Area 3



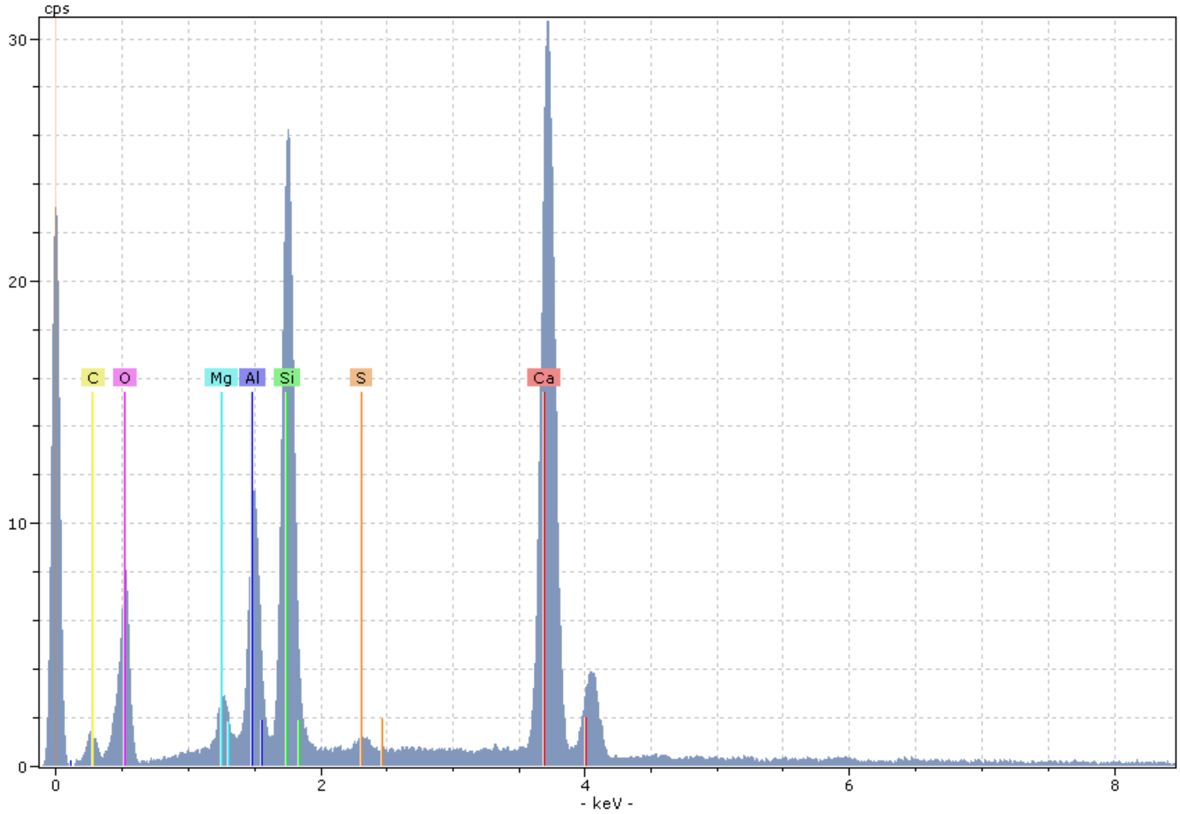
Sample 2-3 120x Magnification



Sample 2-3 point 0

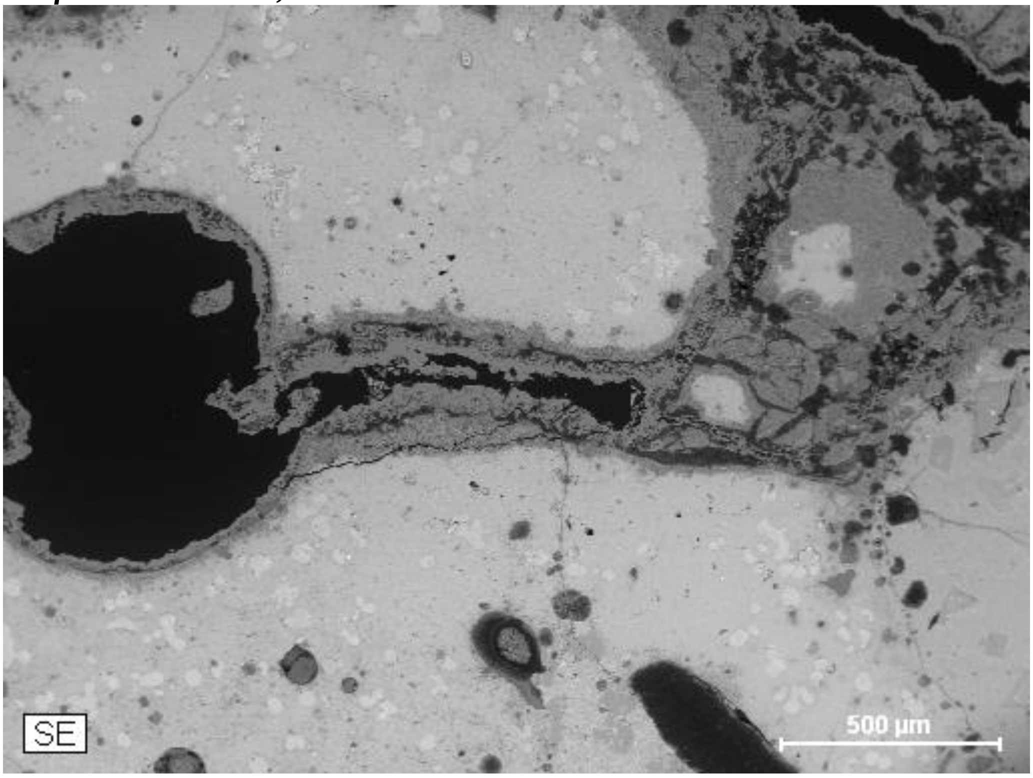


Sample 2-3 point 1

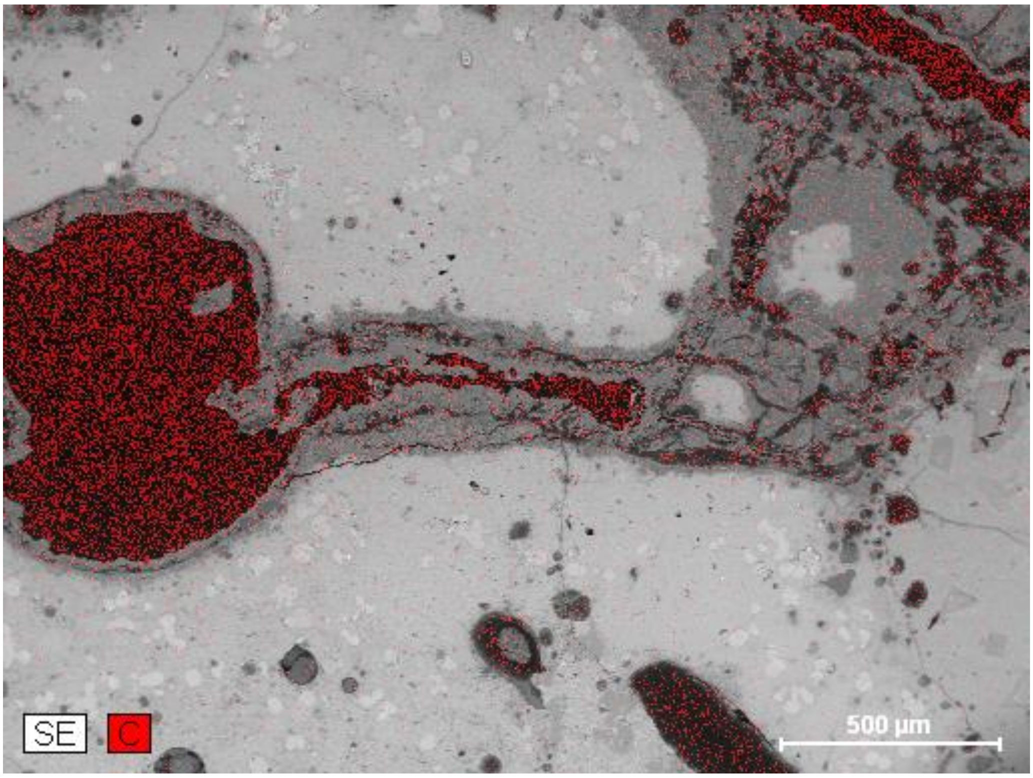


Sample 2-3 point 2

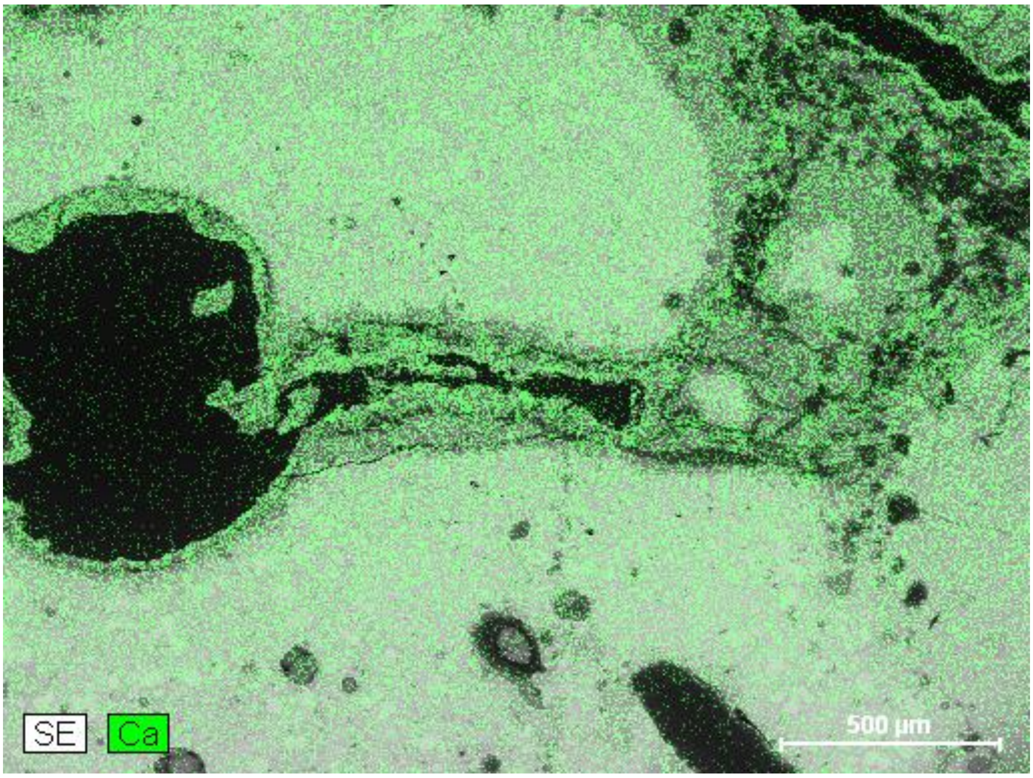
Sample Reference CLW – 5, Observation Area 6



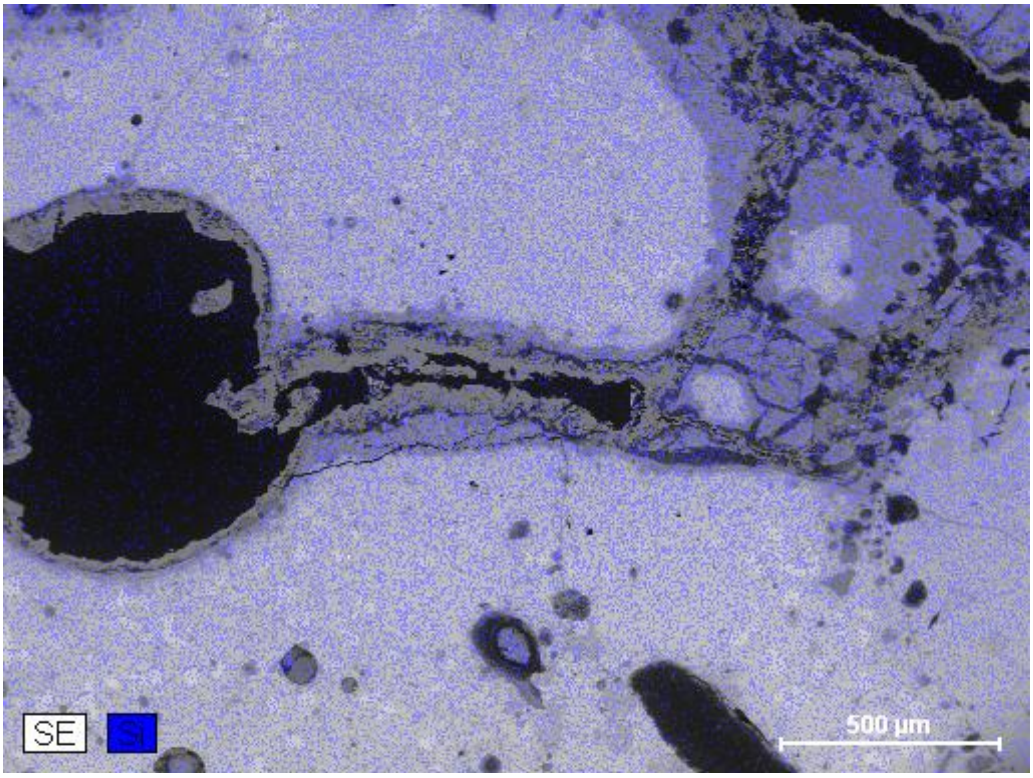
Sample 5-6 50x Magnification



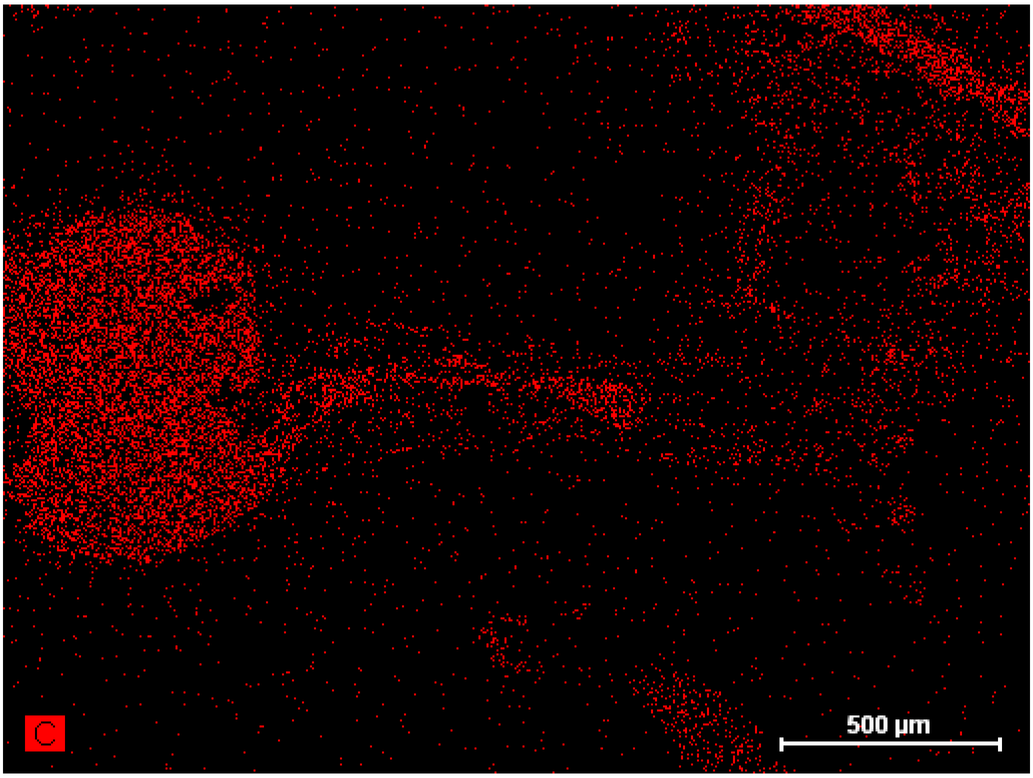
Sample 5-6 50x Magnification
Plot of Elemental Carbon Presence



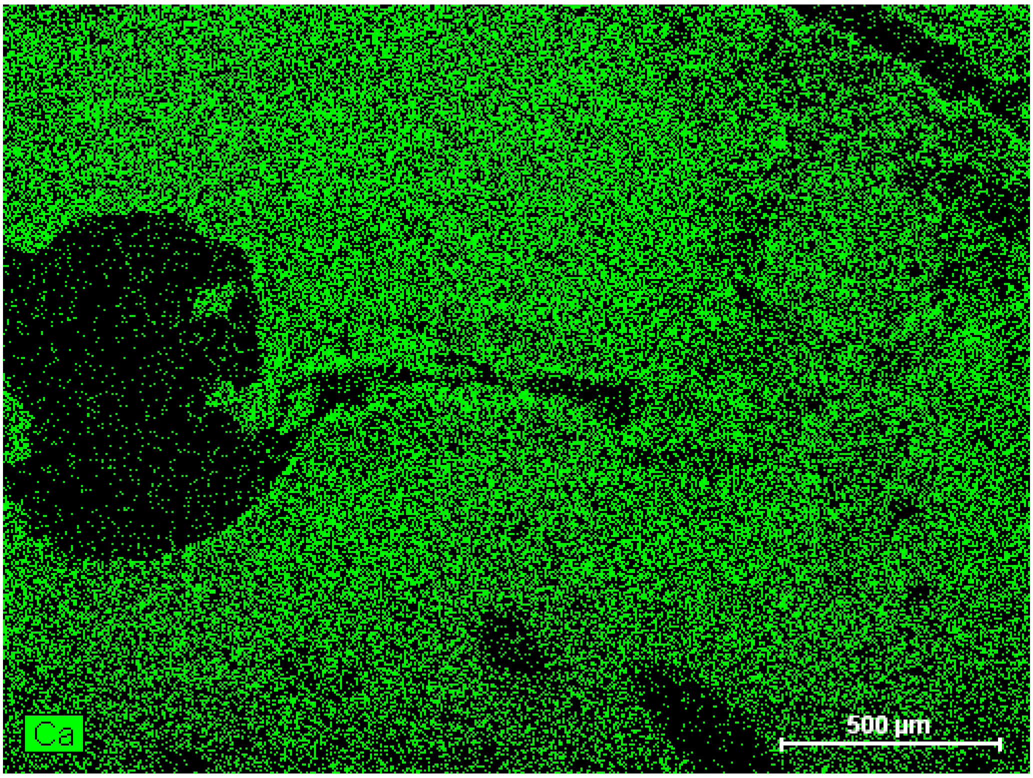
Sample 5-6 50x Magnification
Plot of Elemental Calcium Presence



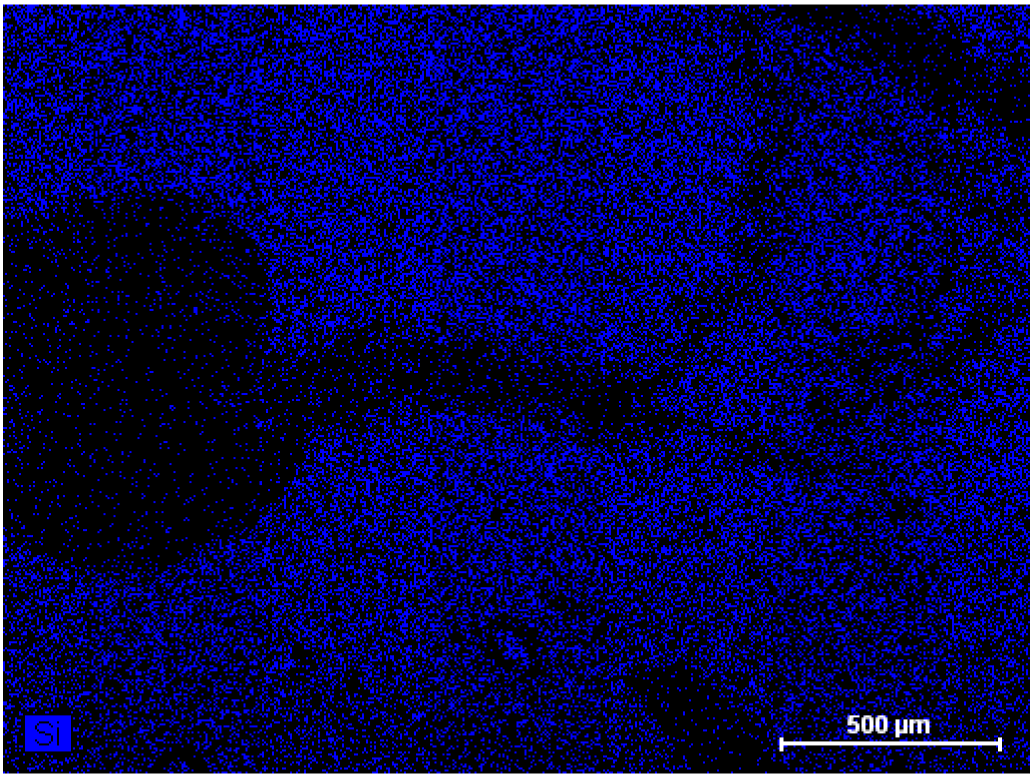
Sample 5-6 50x Magnification
Plot of Elemental Silicon Presence



Sample 5-6 50x Magnification
Plot of Elemental Carbon Presence

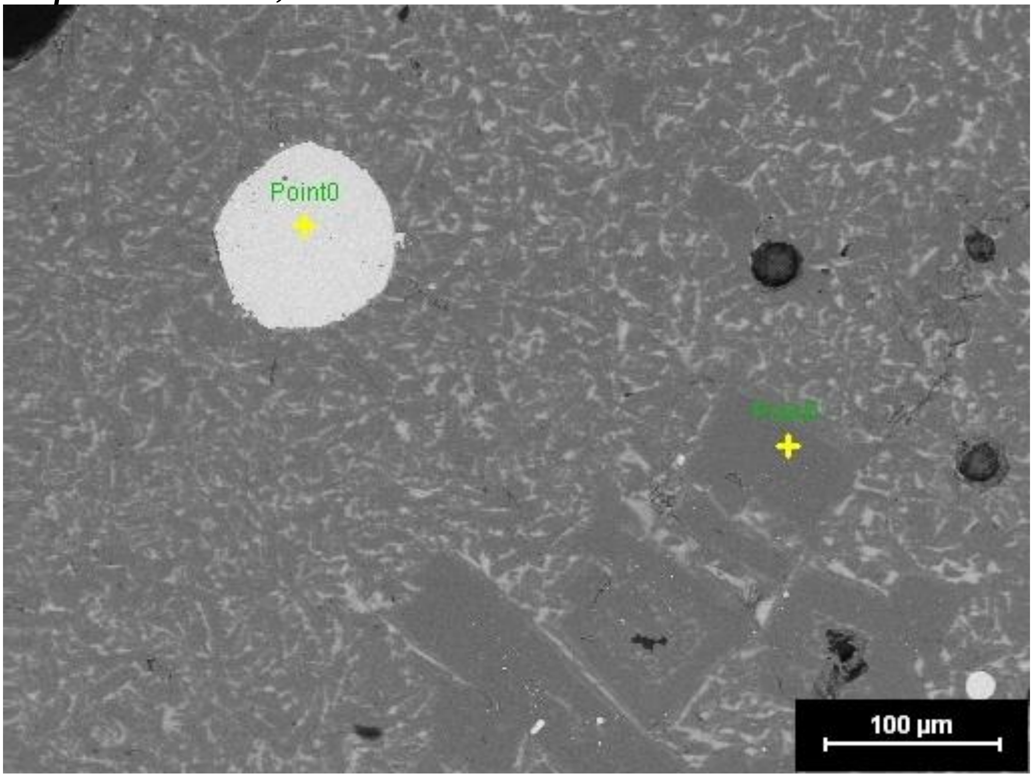


Sample 5-6 50x Magnification
Plot of Elemental Calcium Presence

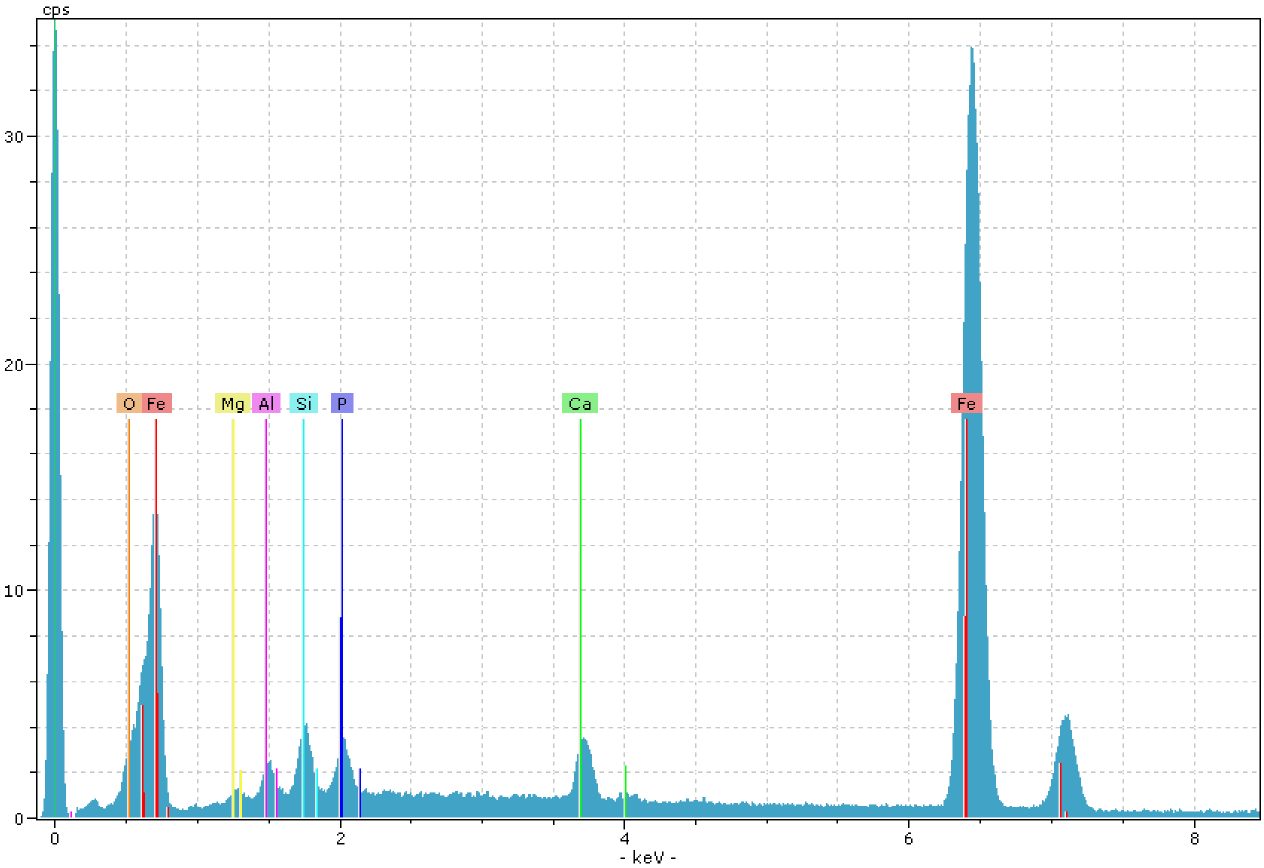


Sample 5-6 50x Magnification
Plot of Elemental Silicon Presence

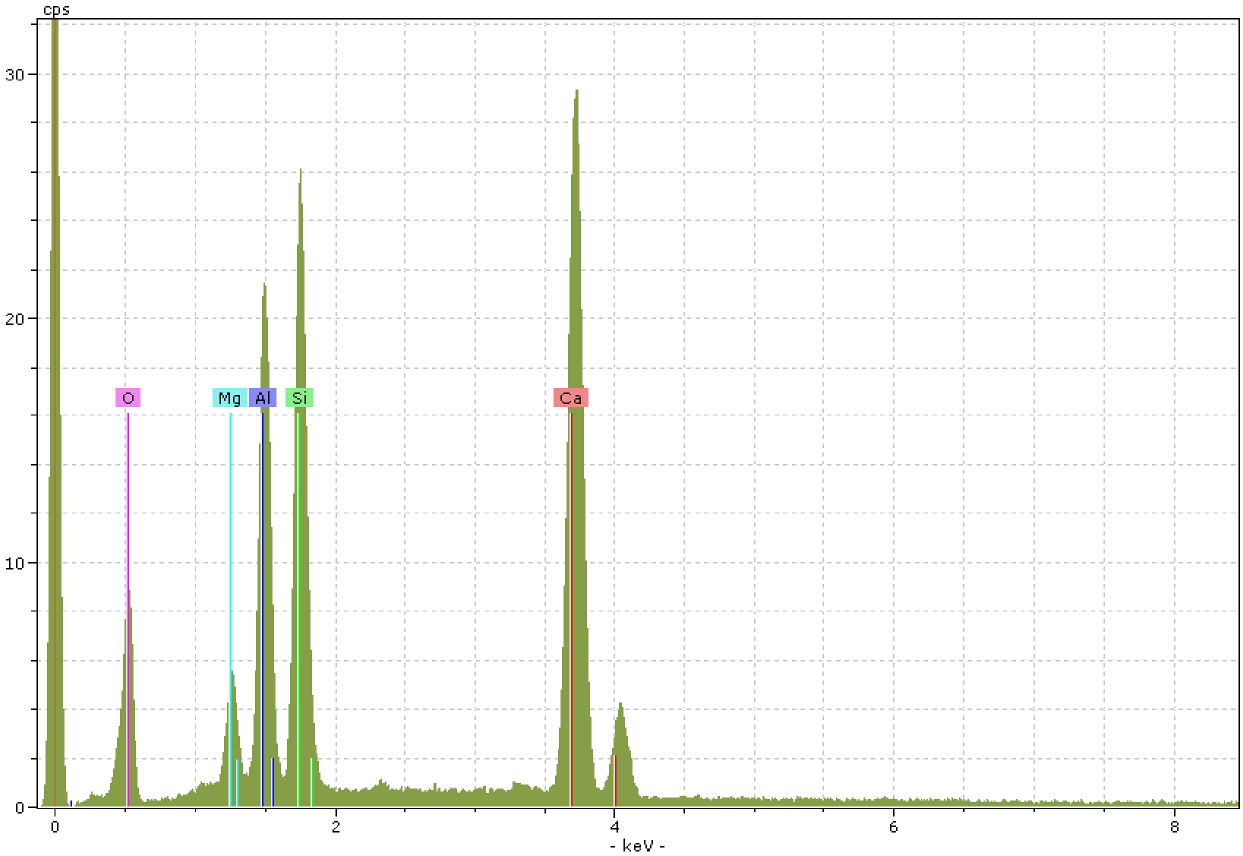
Sample Reference CLW – 6, Observation Area 3



Sample 6-3 120x Magnification

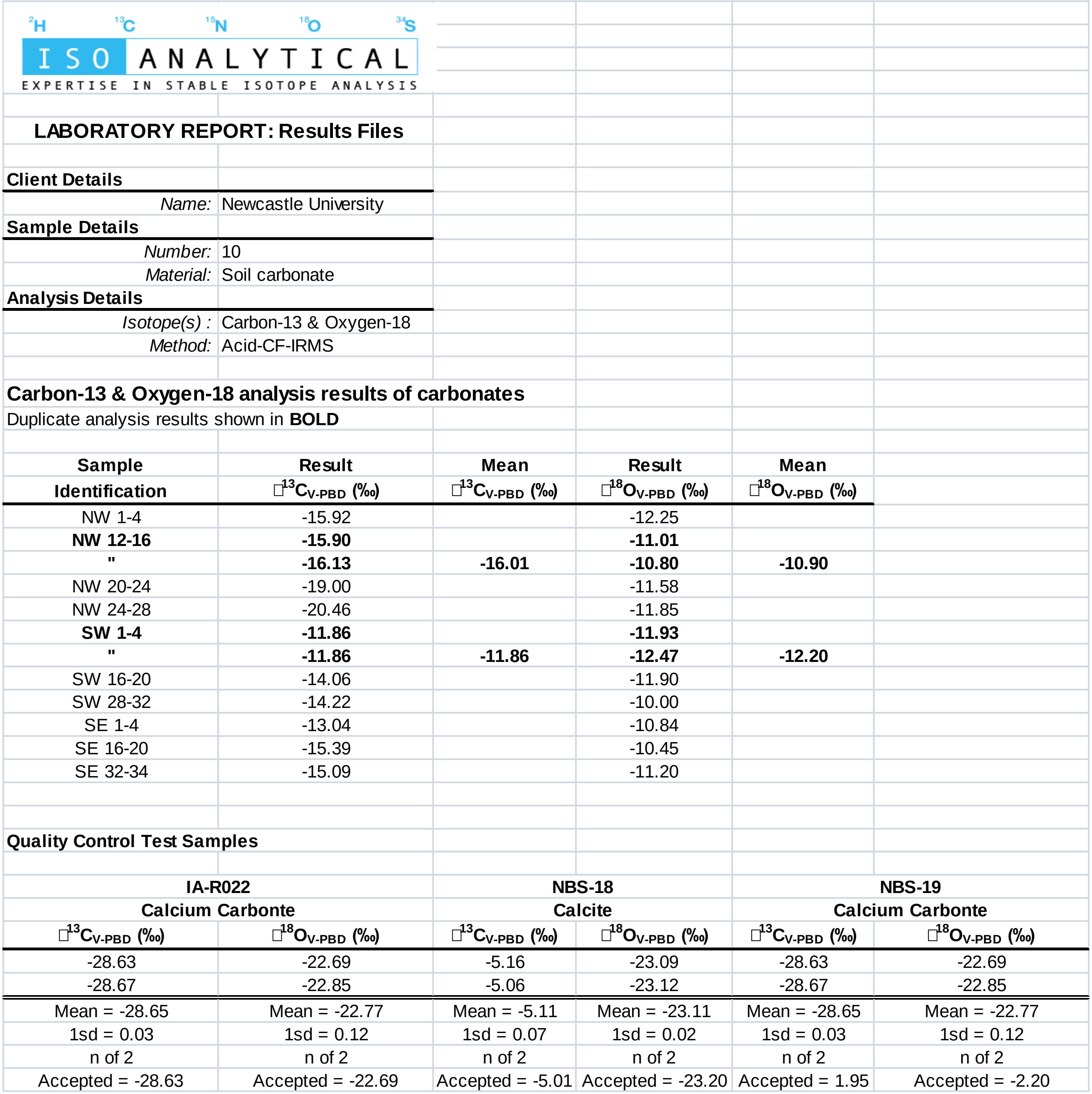


Sample 6-3 Analysis Point 0



Sample 6-3 Analysis Point 1

2.3.3 IRMS Data



^{2}H ^{13}C ^{15}N ^{18}O ^{34}S

ISO ANALYTICAL

EXPERTISE IN STABLE ISOTOPE ANALYSIS

LABORATORY REPORT: Results Files

Client Details

Name:	Newcastle University

Sample Details

Number:	10
Material:	Soil carbonate

Analysis Details

Isotope(s) :	Carbon-13 & Oxygen-18
Method:	Acid-CF-IRMS

Carbon-13 & Oxygen-18 analysis results of carbonates

Duplicate analysis results shown in **BOLD**

Sample Identification	**Result $\delta^{13}C_{V-PBD}$ (‰)**	**Mean $\delta^{13}C_{V-PBD}$ (‰)**	**Result $\delta^{18}O_{V-PBD}$ (‰)**	**Mean $\delta^{18}O_{V-PBD}$ (‰)**
NW 1-4	-15.92		-12.25	
NW 12-16	**-15.90**		**-11.01**	
"	**-16.13**	**-16.01**	**-10.80**	**-10.90**
NW 20-24	-19.00		-11.58	
NW 24-28	-20.46		-11.85	
SW 1-4	**-11.86**		**-11.93**	
"	**-11.86**	**-11.86**	**-12.47**	**-12.20**
SW 16-20	-14.06		-11.90	
SW 28-32	-14.22		-10.00	
SE 1-4	-13.04		-10.84	
SE 16-20	-15.39		-10.45	
SE 32-34	-15.09		-11.20	

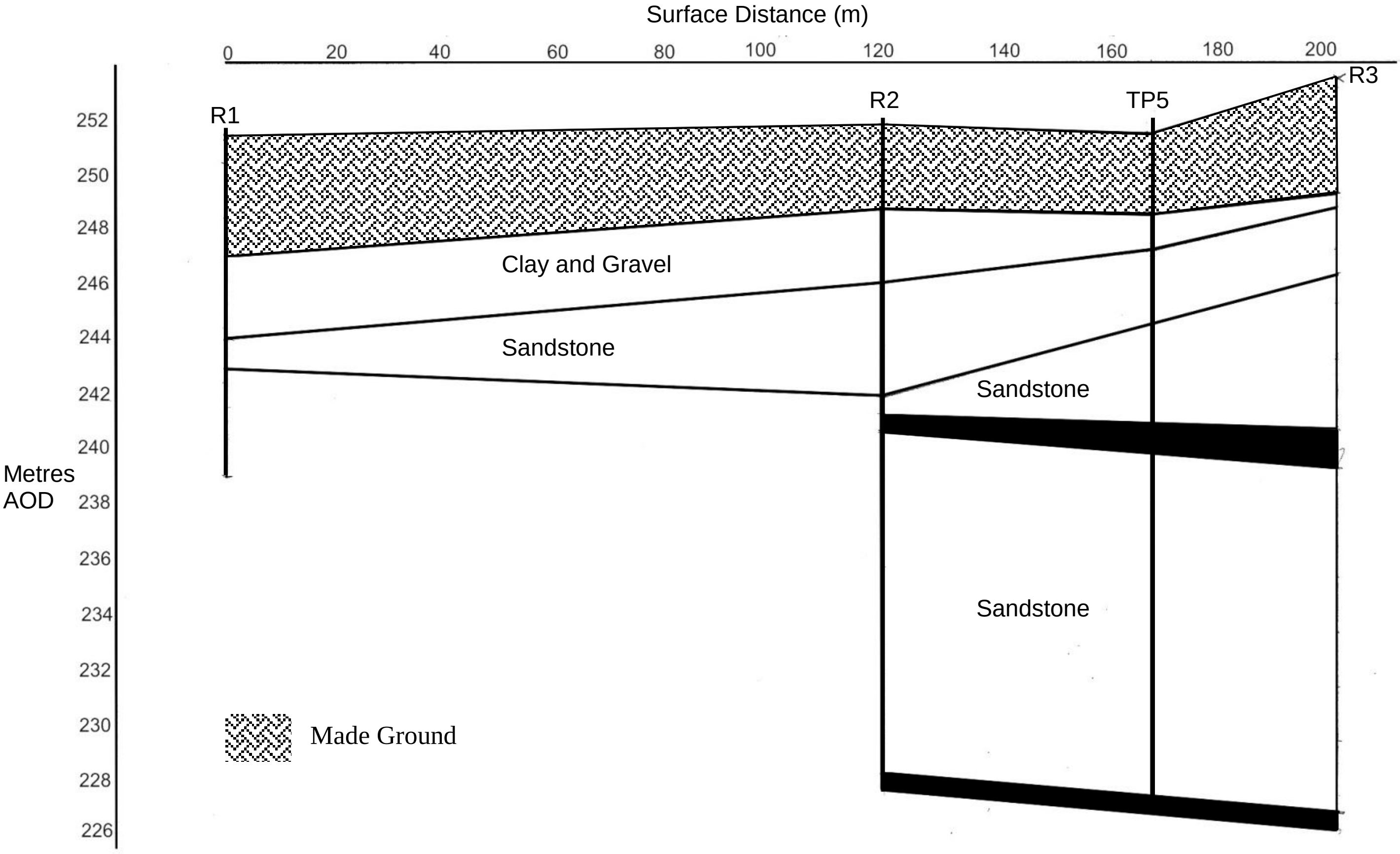
Quality Control Test Samples

IA-R022		**NBS-18**		**NBS-19**	
Calcium Carbonte		**Calcite**		**Calcium Carbonte**	
$\delta^{13}C_{V-PBD}$ (‰)	**$\delta^{18}O_{V-PBD}$ (‰)**	**$\delta^{13}C_{V-PBD}$ (‰)**	**$\delta^{18}O_{V-PBD}$ (‰)**	**$\delta^{13}C_{V-PBD}$ (‰)**	**$\delta^{18}O_{V-PBD}$ (‰)**
-28.63	-22.69	-5.16	-23.09	-28.63	-22.69
-28.67	-22.85	-5.06	-23.12	-28.67	-22.85
Mean = -28.65	Mean = -22.77	Mean = -5.11	Mean = -23.11	Mean = -28.65	Mean = -22.77
1sd = 0.03	1sd = 0.12	1sd = 0.07	1sd = 0.02	1sd = 0.03	1sd = 0.12
n of 2	n of 2	n of 2	n of 2	n of 2	n of 2
Accepted = -28.63	Accepted = -22.69	Accepted = -5.01	Accepted = -23.20	Accepted = 1.95	Accepted = -2.20

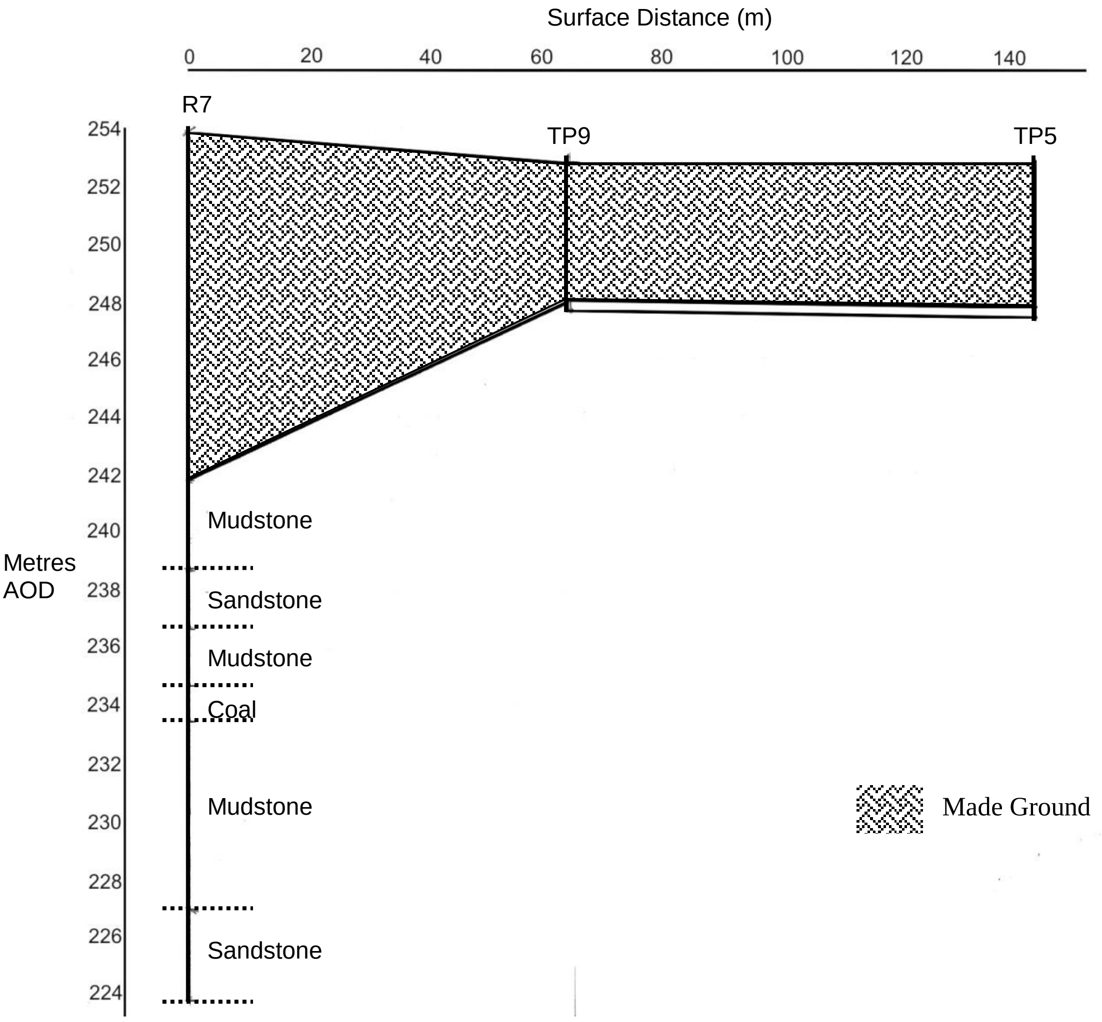
IRMS Results – Iso-Analytical (Source: Iso-Analytical)

2.3.4 Conceptual Model

Section 1 – North West – South East section (Source: EDINA Carto)



Section 2 – East – West section (Source: EDINA Carto)



Section 3 – South West - North East (Source: EDINA Carto)