

THE FORMER SSI STEELWORKS, REDCAR: PRIORITY AREAS WITHIN SSI LANDHOLDINGS CONTRACT 1 AND 2A

Contract 1 and 2A Site Condition Report

South Tees Site Company Limited

REPORT NO. Redcar Steelworks-AUK-XX-XX-RP-GE-0001-02-SSI1_SSI2A_GI_SCR

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The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract
Contract 3: Site Condition Report

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This report dated August 2018 has been prepared for South Tees Site Company (the "Client") in accordance with the terms and conditions of appointment dated 14 September 2017(the "Appointment") between the Client and **Arcadis (UK) Limited** ("Arcadis") for the purposes specified in the Appointment. For avoidance of doubt, no other person(s) may use or rely upon this report or its contents, and Arcadis accepts no responsibility for any such use or reliance thereon by any other third party.

CONTENTS

1	INTRODUCTION	1
1.1	Project Background.....	1
1.2	Contract Details	1
1.3	Project Aims and Objectives	1
1.4	Report Aims.....	2
1.5	Scope of Works.....	2
1.6	Reliability / Limitations of Information	2
2	SITE CONCEPTUALISATION.....	3
2.1	Site Location	3
2.2	Site Description	4
2.2.1	SSI1	4
2.2.2	SSI2 Area A.....	5
2.3	Site History.....	6
2.4	Geology.....	6
2.5	Obstructions	13
2.6	Hydrogeology.....	13
2.7	Hydrology	15
2.8	Historical Data Review	16
2.9	Magnetic Anomaly.....	18
3	CONCEPTUAL SITE MODEL AND ENVIRONMENTAL SITE CONDITION	
	ASSESSMENT	19
3.1	Introduction.....	19
3.2	Contamination Sources	19
3.2.1	On-Site.....	19
3.2.2	Off-Site.....	20
3.3	Contamination Sources Assessment.....	20
3.3.1	Made Ground	20
3.3.2	Natural Deposits and Hydraulic Fill	25
3.3.3	Groundwater	25
3.4	Pathways	27
3.4.1	Airborne Migration Pathways.....	27
3.4.2	Direct Contact Exposure Pathways	27

3.4.3	Aqueous Migration Pathways	27
3.5	Ground Gas Assessment.....	27
3.6	Receptors	28
3.6.1	Human Health	28
3.6.2	Property (buildings, etc.).....	28
3.6.3	Controlled Water.....	28
3.6.4	Ecological.....	28
3.7	Slag Testing Data.....	28
3.8	Conceptual Site Model	29
5 SUMMARY OF RESULTS.....		31

APPENDICES

APPENDIX A

Legislative Context and Regulatory Guidance

APPENDIX B

Study Limitations

APPENDIX C

Figures

APPENDIX D

Trial Pit Investigation Summary

APPENDIX E

Summary of PAOC

APPENDIX F

Statistical Analysis Results

APPENDIX G

Slag Analysis Reports

APPENDIX D

Trial Pit Investigation Summary

APPENDIX E

Summary of PAOC

APPENDIX F

Statistical Analysis

APPENDIX G

Slag Analysis Reports

1 INTRODUCTION

1.1 Project Background

The former SSI landholdings are made up of eleven discrete, sizeable land parcels situated in the Redcar, Lackenby, Grangetown and South Bank conurbations of the Borough of Redcar & Cleveland, within the industrial area generally known as 'South Tees'.

Desk study work has been ongoing since November 2016, and in two of the SSI areas at Redcar (SSI1 and part of SSI2), this work has already been augmented by an advance programme of ground investigation works, comprising close to 300 trial pit excavations (SSI1) and 67 trial pit excavations (part of SSI2), together with laboratory analysis. The desk studies and advance programme of ground investigation works was undertaken by CH2M Hill (CH2M). A package of investigations was subsequently designed for the SSI land, namely SSI1, SSI2 and SSI3.

1.2 Contract Details

Arcadis (UK) Limited (Arcadis) were appointed by South Tees Site Company Limited (STSC) to oversee and manage a ground investigation undertaken by Allied Exploration and Geotechnics Limited (AEG) and to provide consultancy advice with respect to redevelopment of the site. The work was carried out in accordance with the "Ground investigation consultancy services former Iron and Steel Works Site, South Tees" contract (Ref: STSC-JN-0007) dated 14 September 2017.

The scope of works (for all three priority contract areas) was defined by CH2M, on behalf of STSC, and presented in:

- South Tees Site Company Limited, Ground Investigation Consultancy Services, Former Iron and Steel Works Sites, South Tees, Invitation to Tender (STSC Reference Number: STSC-JN-0007, dated July 2017).

The scope of works being undertaken by AEG was developed by CH2M and is presented in:

- STSC - SS - 0028 - Ground Investigation – Contract 1 – Invitation to Tender – The Former SSI Steelworks, Redcar – Ground investigation: Priority Areas within SSI Landholdings Contract 1. CH2M., August 2017.
- STSC - SS - 0029 - Ground Investigation – Contract 2 – Invitation to Tender – The Former SSI Steelworks, Redcar – Ground investigation: Priority Areas within SSI Landholdings Contract 2. CH2M., August 2017.

1.3 Project Aims and Objectives

The overarching aim of the works was to deliver a sustainable ground remediation strategy for the contract sites which is compliant with regulatory needs and has their approval in principle. As technical consultant, the specific objectives of this phase of works were to:

- Manage and technically supervise the site works, undertaken by AEG, on behalf of STSC;
- Direct the site works to ensure compliance by the ground investigation contractors with existing site management protocols and procedures;
- Specify the requirements for laboratory analysis;
- Analyse the results of ground investigations;
- Prepare interpretative technical reports, namely;
 - Site Condition Report
 - Environmental Risk Assessment
 - Geotechnical Risk Assessment
 - Remediation Options Appraisal

- Consult with regulators to ensure compliance with all relevant regulatory requirements;
- Develop cost-effective, value-engineered outline remediation strategies.

1.4 Report Aims

The aim of this site condition reports is to use the available information to develop a conceptual site model for the contract area, which will form the base of the subsequent risk assessments.

1.5 Scope of Works

The scope for this investigation was developed by CH2M, who undertook the advanced works. Arcadis were subsequently appointed to act as Principal Designer, and Allied Exploration and Geotechnics (AEG) as Principal Contractor. Whilst the scope was broadly that designed by CH2M, there were some variations to scope based on site findings.

- Site service and utilities clearance of exploratory locations by STSC operatives;
- 15no trial pits excavated by a 20 tonne 360 excavator, to a target depth of 4.5m or refusal, or until natural material is encountered;
- 26no boreholes drilled by a Dando 2000 cable-percussive rig, with target depths of between 15m and 20m, or refusal on bedrock;
- UXO clearance using down-hole magnetometer at each borehole location upon encounter of natural material;
- Soil sampling for in-field assessment and submission to Derwentside Environmental Testing Services (DETS), AEG in-house Geotechnical Laboratory and Thomas Research Services laboratories for chemical and geotechnical testing;
- Installation of 26no groundwater monitoring wells with subsequent purge development;
- Ground gas monitoring of all newly installed monitoring wells;
- Groundwater sampling of all newly installed monitoring wells;
- Review of data from CH2M advance works for SSI1 and SSI2A excluding Areas C and D of SSI1;
- GPS elevation survey of all new exploratory locations; and
- Groundwater elevation survey of all newly installed monitoring wells.

The legislative context and regulatory guidance for the management of potentially contaminated land is presented as Appendix A.

1.6 Reliability / Limitations of Information

A complete list of Arcadis Study Limitations is presented in Appendix B.

It should be noted that ground conditions between exploratory holes may vary from those identified during this ground investigation; any design should take this into consideration. It should also be noted that groundwater levels may be subject to diurnal, tidal, seasonal, climatic variations and those recorded in this report are solely dependent on the time the ground investigation was carried out and the weather before and during the investigation.

Arcadis have incorporated and utilised data from recent CH2M investigations of SSI1 and SSI2A in this report. Arcadis can provide no reliance as to the accuracy of this data.

2 Site Conceptualisation

The following Environmental Site Assessments (ESA) for the site prepared by CH2M and Enviros were made available to Arcadis:

- CH2M, SSI1 Redcar Works – Phase 1 Geo-environmental Desk Study, ref. 678079_SSI1_001, dated August 2017; and,
- CH2M, SSI1 Redcar Works – Phase 1 Geo-environmental Desk Study, ref. 678079_SSI2_001, dated August 2017;
- Enviros, Corus UK Ltd. – Soil and Groundwater Baseline Characterisation Study Teesside Works – Interpretative Report Volume 1, 2 and 3 of 3, June 2004
- CH2M, Factual Report – Initial Trial Pitting - SSI Redcar – SSI1, dated November 2017; and,
- CH2M, Factual Report – Initial Trial Pitting - SSI Redcar – SSI2, dated November 2017

This section incorporates a review of the above documents and publicly available records incorporating data collected as part of the site investigation works by AEG and reported in the Factual Report “The Former SSI Steelworks, Redcar – Ground Investigation Contract – Priority Areas Within SSI Landholdings Contract 1 and Contract 2 (Area A)”, Final Issue dated June 2018.

2.1 Site Location

The area identified as SSI1 (Contract 1) is a rectangular patch of land, comprising approximately 116 hectares, in the northwest part of the larger Former SSI Steelworks Facility. During the advance work programme conducted by CH2M, SSI1 was subdivided into eight sub-areas (Areas A-F, H and I), the findings in Areas C and D have been reported separately by CH2M. SSI2 Area A is located immediately to the north of SSI1 and covers a rectangular area of land comprising 84 hectares. While the desk study covered the entire footprint of SSI2 Area A, (SSI2A) the investigation only covered two easily accessed sections that were not currently developed. These are known as the Coke Ovens Area (as it is located immediately to the north of the coke ovens) and the RTL Area. The former blast furnace, power plant and coke processing plant, while located within SSI2A are not covered by this report. Within SSI1 no intrusive works were conducted in the immediate vicinity of the Sinter, Ore Blending, and Coke Crushing Plants. The Ordnance Survey (OS) National Grid Reference for the centre SSI1 is 456187E 525126N and for SSI2A is 456604E 525666N.

SSI2A is bordered to the north by coastline including dunes of the South Gare and Coatham Sands Site of Special Scientific Interest (SSSI), and the Teesmouth and Cleveland Coast Special protection Area (SPA). The Former SSI Steelworks Facility extends to the west where it meets the River Tees. A historical landfill and the Bran Sands Northumbrian Water Sewage Treatment Works border the site to the south west, and Coatham Marsh is located to the east.

A site location plan is presented as Figure 1 below and within Appendix C.



Figure 1: Site Location Plan

2.2 Site Description

2.2.1 SSI1

The contract location is dominated by large expanses of relatively flat artificial topography that gradually slopes from north to south, reducing in elevation. The region is divided by roads, steelworks structures; including the Teesside Management Office (TMO), Sinter Plant, D. Jones Construction and Haulage Limited compound (former Tube City) and Redcar Bulk Terminal (RBT) offices located centrally, and the north-eastern and south-western corners of the site respectively. Railway lines bisect the site approximately east to west before connecting into the off-site Redcar Bulk Terminal to the west to the wider rail network. Tunnels associated with the former Pellet Plant may also be present on site.

In general, the roadways are level with the surrounding land, however, there are a number of exceptions, in particular:

- The roads running around the square plot of land north of the sinter plant are all approximately 3-4m higher, with steep slopes leading onto SSI1.
- The road that bisects the site is approximately 2 m higher than the plots of land to the south, and level with those to the north. The land to the south gently slopes away from the road leaving the road at a higher level.

The ground around the TMO and north of the sinter building is primarily of soft landscaping with areas of gravel. The southern, central and western portions of the site are comprised of compacted gravel comprising sinter where the former coal, ore and sinter stocks were located, these stocking yards are traversed by covered conveyor belts which transported the materials northwards to the blast furnace and coke ovens located within the adjacent SSI2 site. Old stockpiles are still present in these areas and form an east to west mound across the central stock area.

For the purposes of the advance works investigation CH2M split SSI1 into eight sections A-F, and H-I; sections C and D located south of the railway lines which cross SSI1 are not covered by this report and have been investigated by CH2M under a different cover.

CATS Pipeline - The Central Area Transmission System pipeline, a 36" (91cm) diameter gas pipeline running from the North Sea and making landfall northeast of the site. The pipeline runs in a south-southwest direction, parallel to and within 50 metres of the SSI1 eastern boundary. The pipeline started operating in 1993. While unlikely to be contaminative, it's an extremely sensitive asset and poses a significant constraint to be considered during the development of SSI1.

2.2.2 SSI2 Area A

This site condition report relates to Contract 2 (Area A), comprising two portions of land within the original rectangular SSI2 (CH2M) contract area. The portion of land to the north-west of Area A (Redcar Coke Ovens (RCO)) covers approximately 12.3ha and contains the old coke stocking area, plus the liquid nitrogen and fuel oil storage plant. The portion of land to the south-east of Contract 2 Area A (RDL Stores) covers approximately 29.1ha and contains the ponding/disposal area, and Redcar stores.

Site layout – The RCO area contains above ground buildings and infrastructure with surrounding expanses of open land originally used for the mass storage of coke. The liquid nitrogen and fuel oil storage plant, and auxiliary buildings are located centrally within the area, with the by-products processing plant bordering the south of it. The primary road extends on a north-west to south-east tangent through the centre of Area A1, with occasional secondary roads extending north and southwards from it.

The RDL Area is dominated by shallowly undulating scrubland in the southern portion and the disposal/ponding areas to the north which contain pits and mounds of by-product materials. The Redcar stores building, and associated parking area are located in the south-east corner of the RDL, with the blast furnace stock house bordering the south-west corner. The coke oven gas main runs along the southern border on a north-west to south-east tangent. The primary access road through the area runs from the south-east corner of site, next to Redcar stores, to the western side above the maintenance workshop, and travels adjacent to the hot metal transport rail track. The disposal/ponding area comprises a network of "rough" undulating access roads.

Site access – access to the RCO Area is achieved by following the main trunk road which runs parallel to the Contract 1 area. Roads of hardstanding surrounding the coke ovens can be used to travel from the trunk road to the RCO area. Access to the RDL area is via the old access road for freight trucks to the disposal / ponding areas, passing the Redcar stores building.

Topography – The site at ground level is relatively flat throughout with localised but large areas of undulating ground (mainly in the RDL area) attributed to excavation of pits for by-product disposal, and historic location of factory buildings. Ground elevation can drop 2-3 metres in the north-east of Area A2 (disposal / ponding area), and by 1-2 metres in the south (historic buildings). There are occasional increases in elevation from general ground level, of 1-2 metres in the RDL area. The RCO area is significantly less undulating, although does contain land bund features and an access ramp in the south-east corner.

Vegetation – The RCO area contains sporadic areas of grassland as the surfacing generally comprises made ground materials. The RDL area contains areas of scrubland in the south-western half, and to the west of Redcar stores. No trees are present within the site.

Infrastructure – The RCO area contains the nitrogen and fuel oil storage plant, which is supplied by an underground industrial water main, and outputs via an underground nitrogen supply pipeline. A potable water supply and telecommunications line connects with adjacent buildings.

The overhead coke oven gas main runs from the by-products plant south to the trunk road and continues eastwards parallel with the road to border the south of the RDL area. A potable water supply and telecommunication line connects with buildings in the area. A dis-used railway, originally used for transporting "hot metal" from the blast furnace, runs on an east-west tangent through the RDL area.

Building Condition – Buildings present on site appear to be generally in good condition and show few external signs of ground movement (e.g. ground heave indicated by vertical / sub-vertical cracks in brickwork). The Redcar stores building is the largest structure present on site and comprises a brick base with pre-fabricated shell (containing asbestos), and ancillary brick buildings.

Tunnels - During trial pitting works in the RDL Stores section of Contract SSI2A, CH2M identified a number of brick built sub surface tunnels. Based on photographs taken by CH2M the tunnels appear to be approximately 1m wide and 1.7m high with the crown of the tunnel located less than 0.5m below the current ground surface; the extent and layout of the tunnels is unknown. The features are potentially associated with

the former Redcar Iron and Steel Works steel processing building shown as PAOC4b on Figure 7. The presence of these tunnels limited subsequent investigation works in the vicinity.

2.3 Site History

A full discussion of the site history is presented in the desk study reports and summarised below:

SSI1 - The majority of the site is shown as a tidal mudflat and sand on the earliest historical mapping. The Redcar iron and steel works with associated railway lines were developed in the north east corner of the site in the late 18th century. The majority of the site was reclaimed from the estuary in the 1970 to facilitate the construction of the current site structures. This reclamation is thought to have included end tipping of slag from railway sidings and the placement of hydraulic fill dredged from the River Tees and pumped to the site which closely resembles natural deposits. The 1970 layout remains largely unchanged except for the demolition of the Pellet Plant in the 1980s.

A British Steel Corporation drawing from 1973 (R/Gen 144), shows areas of land beneath the proposed blended ore stockyard which would require removal of silty clay and loose sand material. Cross section drawings appear to suggest that the loose sand may have included hydraulic fill.

SSI2A- The site was originally part of the Bran Sands intertidal zone. In the mid-18th century the South Gare Breakwater was built, transecting the site in a broadly northeast/southwest alignment. Following land reclamation, the Redcar Iron and Steel works and small tar works were constructed within the north eastern area of SSI2 by 1930; north of South Gare Breakwater, and evidence of tipping, most likely of slag was apparent within the area. Development of the current Blast Furnace, Coke Ovens, By Products Plant and Power Plant began during the 1970's.

2.4 Geology

The previous investigations have identified that Made Ground is likely to be present across the whole of the site typically in the order of 4 to 6m but noted to be up to 10m thick in some areas. The Made Ground predominantly comprised slag deposits with fragments of slag ranging from gravel to boulder size and occasionally layers of fused slag, locally mixed with reworked natural sands, demolition rubble etc. Other Made Ground materials were also identified including possible 'hydraulic fill' which is anticipated to comprise material dredged from sand banks in the estuary mouth and as such is likely to appear similar in nature to natural ground.

Review of the British Geological Survey (BGS) and previous investigation data suggests that the majority of the site is underlain by the following sequence of superficial deposits:

- **Tidal Flat Deposits** predominantly comprising sand and silt with layers of gravel and clay; and
- **Glacial Till** predominantly comprising slightly gravelly clay.

In some areas the following superficial deposits are anticipated:

- **Blown Sand Deposits** are shown to be present beneath the eastern boundary of the site comprising pale brown, fine grained sand;
- **Glaciolacustrine Deposits** predominantly comprising laminated clays and silt may be present overlying, or potentially within, the Glacial Till.

Historical investigations and the Desk Study information indicates variable superficial deposits; comprising unconsolidated alluvium, estuarine clay and sand.

Bedrock beneath the majority of the site is anticipated to comprise Redcar Mudstone Formation, part of the Lias Group. The north western section is anticipated to be underlain by the Mercia Mudstone Group with a thin band of Penarth Group indicated to be present between the two main units. The geological sequence of units comprises:

- **Redcar Mudstone Formation** (up to 250m thick but only basal part of unit likely to be present beneath the site) comprising grey fossiliferous, fissile mudstones and siltstones with subordinate thin beds of shelly limestone in lower part and argillaceous limestone concretions throughout;
- **Penarth Group** (approximately 15m in thickness) comprising grey to black mudstones with subordinate limestones and sandstones;

- **Mercia Mudstone Group** (approximately 200m in thickness) comprising predominantly red mudstones and subordinate siltstones with thick halite-bearing units.

The desk study suggests that bedrock is dipping approximately 14 degrees to the north-northwest. However, it is considered more likely that the bedrock is dipping to the east, possibly with a northerly component.

Excerpts from the BGS mapping data are presented as Figure 2 below and in Appendix C.

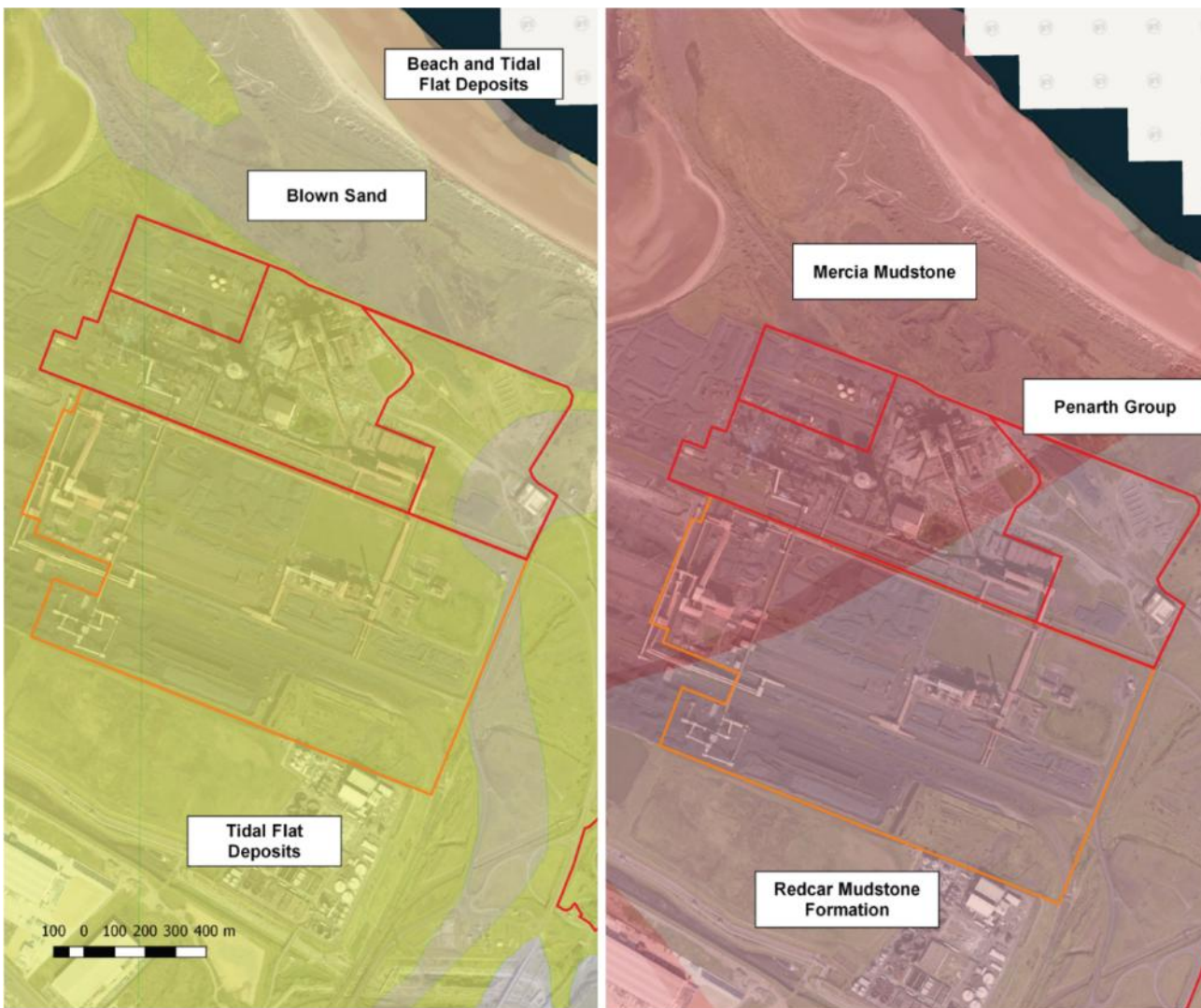


Figure 2: Extracts from BGS Mapping

The following table provides an overview of the site-specific geology encountered during the investigation across the site. The full geology encountered is provided on the trial pit and borehole logs within the AEG and CH2M Factual Reports.

Unit	Minimum Basal Depth (m bgl)	Maximum Basal Depth (m bgl)	Comment
Made Ground (excluding Hydraulic Fill)	1.9	8.9	<p>The made ground encountered during the investigation predominantly comprised granular material with a fine-grained component and low to high cobble/boulder content which included fused slag, refractory brick, concrete and occasionally clinker, coke, coal and/or metal. Several of the trial pits recorded slag with a white mineralised outer crust, suggesting that some expansion may have occurred. The majority of the trial pits excavated at the site terminated in this material.</p> <p>However, variably sandy, variably gravelly clay with low to medium cobble/boulder content was also encountered. The depth of made ground was noted to be thicker in areas understood to have been reclaimed from the Tees Estuary.</p>
Made Ground-Hydraulic Fill	4	5	<p>According to the desk study, historic plans suggest a large portion of the site was reclaimed using Hydraulic Fill. Although the exact composition of this material is unknown it is likely to closely resemble natural sand with rounded gravels and cobbles.</p> <p>Material matching this description was identified in relatively few locations across the site, but was noted in CH2M trial pits excavated in SS11 Area F. This is coincident with areas of possible hydraulic fill recorded in BSC Drawing R/Gen 144.</p>
Wind Blown Sand (Secondary A Aquifer)	N/A	10	<p>The geological map indicates that Blown Sand Deposits are present beneath the eastern part of SS12A (RDL Area) and north eastern corner of SS11. Blown Sand comprises fine to coarse silty sand or clayey sand and may be difficult to differentiate from the Tidal Flat Deposits covering much of the remainder of the site. Possible Blown Sand was encountered in borehole S2-BHA02.</p>
Tidal Flat Deposits (Secondary A Aquifer)	4.5	18	<p>The Tidal Flat Deposits (TFD) were predominantly medium dense comprising silty variably gravelly sand with layers/bands of gravel and shell beds. In several of the exploratory holes a more gravelly layer was encountered at the base of the deposits and in some exploratory holes (e.g. BH14 and BH20B) beds and layers of soft or loose clay and/or silt were identified.</p> <p>The Tidal Flat Deposits generally increase in depth towards the northwest and northeast and become shallower towards the southeast. The overall thickness of the Tidal Flat Deposits is governed by depth to rockhead, and so TFD were thin or absent where shallow rock was encountered (e.g. central/western area SS11).</p>
Glacial Till (non-Aquifer)	10.8	27	<p>Predominantly comprising firm becoming stiff and very stiff slightly sandy slightly gravelly clay with gravel composed of mixed lithologies, including sandstone, limestone and rare coal.</p>
Glaciolacustrine Deposits (non-Aquifer)	7.3	21	<p>Glaciolacustrine Deposits were observed in a limited number of boreholes and comprised brown laminated clay interlaminated with silt partings. Locally these deposits were noted to be organic. This was consistent with the findings of historic investigations which encountered discontinuous, generally thin laminated clays at depth</p>

Trial pits were not advanced to natural deposits in approximately 90% of cases, reasons for shallow termination included encountering groundwater, hard strata, or the pit stability; a summary of the trial pit investigation conducted by Arcadis and AEG is presented in Appendix D.

Made Ground was encountered in all intrusive locations and proven to a thickness of at least 8.9m. The base of the Made Ground was not proven in the majority of the CH2M and AEG trial pits, therefore, greater thickness of material may exist across the site. These findings are broadly in line with previous investigations which identified a maximum thickness of 9m of Made Ground (BH17BB1 Enviro 2004).

A figure showing the distribution of the thickness of Made Ground is presented as Figure 3 below and in Appendix C, this illustrates that the greatest depths of Made Ground were identified in the east of the site around the SSI2A Redcar Coke Ovens Area and around section F and the northern half of section E of SSI1. This is broadly consistent with areas previously part of the Tees Estuary, recorded Made Ground thicknesses were slightly shallower in the south of Area E potentially due to the difficulties differentiating between hydraulic fill and natural deposits.



SSI3A Figure 3 – Depth of Made Ground Encountered

Two main types of Made Ground were noted:

- **Slag-dominant material:** Generally ranging from gravel to boulder size fragments and intermixed with other types of manmade fragments including brick, concrete, coal, sandstone, and clinker. The slag material generally ranged from light grey to dark grey/black in colour, but a wide range of other colours were also noted including grey brown, red brown and orange brown. Discolouration of the slag surface was also noted with white crystallisation/discolouration often noted on the outer surface.
- **Granular Made Ground:** Generally described as a sandy gravel with varying amounts of clay, cobbles and gravel. Gravel and cobbles include brick, concrete and other demolition materials, slag was not the dominant constituent although often still present within the soil matrix.

In addition, the following Made Ground Types were encountered

- **Cohesive Made Ground:** Generally described as soft to very stiff clay containing minor constituents of sand, gravel and cobbles. Gravel and cobbles include brick, concrete and other demolition materials, slag was not the dominant constituent although often still present within the soil matrix.
- **Hydraulic Fill Material:** Generally described as yellow gravelly fine to coarse sand with shell fragments.
- **Sinter:** Widely identified as a surfacing material across SSI1 by CH2M and generally described as black fine gravel.
- **Lime:** Infrequently identified and described as very soft white clay; and
- **Waste:** Comprised significant amounts waste materials including metal, wood, and plastic in addition to the Made Ground deposits.

Where rotary coring was carried out, a continuous core of material was obtained and described. Cable percussion drilling provides disturbed samples of weathered rock only and is not capable of penetrating significant thicknesses of rock, but can be used to identify depth to rock. The rockhead elevation was noted to vary by approximately 17m across the site ranging from -2.48 m AOD (S1-BH15) to -19.47 m AOD (S2-BHA04), the following table provides an overview of the site-specific geology encountered during the investigation. The full geology encountered is provided on the borehole logs within the AEG Factual Reports.

Bedrock Unit	Comment
Redcar Mudstone Formation and	<p>The Redcar Mudstone Formation was recovered as an extremely weak or weak grey MUDSTONE which was locally noted to be fossiliferous. Some horizons were noted to be heavily fractured, or recovered as non-intact rock, but Solid Core Recovery (SCR), and Rock Quality Designation (RQD) were generally higher than for the other formations encountered.</p> <p>The sub crop of the Redcar Mudstone was found be similar to that recorded on the regional geological map and was encountered beneath the SSI2A (RDL Stores) and much of the SSI 1 areas of the site.</p>
Penarth Group (Secondary (Undifferentiated) Aquifer)	Rocks of the Penarth Group were recovered in one location only (S2 BHA4). The rock was found to be a weak weathered sequence of interbedded mudstones and siltstones and was encountered from 27 to 33m bgl.
Mercia Mudstone (Secondary B Aquifer)	Mercia Mudstone was encountered in all rotary holes drilled in the western area of the site and was found to include distinctly weathered extremely weak or weak red brown mudstone. In several of the holes, the mudstone was noted to include significant gypsum veins. No evidence of solution features was noted. TCR and RQD were notably lower than the Redcar Mudstone, indicating the weaker nature of this material.

Data collected during this site investigation together with selected historical borehole information has been used to develop a model of the bedrock surface. The profile indicates that across SSI1 and SSI2A there are several former valleys which crossed the site infilled with the Glacial Till deposits predominantly resting within

these depressions. Generally, where the glacial deposits were found to be absent corresponds with locations with high bedrock elevations (i.e. former hills). An east to west trending valley appears to be present within the north western part of SSI1 and southwestern part of SSI2A with a second east to west trending valley located in the southern part of SSI1. Another valley (orientation unclear) appears to be located beneath the RDL Stores Area of SSI2A.

It should be noted that this model has been constructed with a limited number of data points and that further investigation will be required to understand the profile of the bedrock beneath each building. In addition, a limitation with the model is that it will suggest that there will be smooth elevation changes. However, as the underlying bedrock has been eroded by glacial activity it is possible that there could be more dramatic changes in the bedrock profile which is not evident from the model presented here. This model should be used for indicative purposes only and not used to enable detailed design.

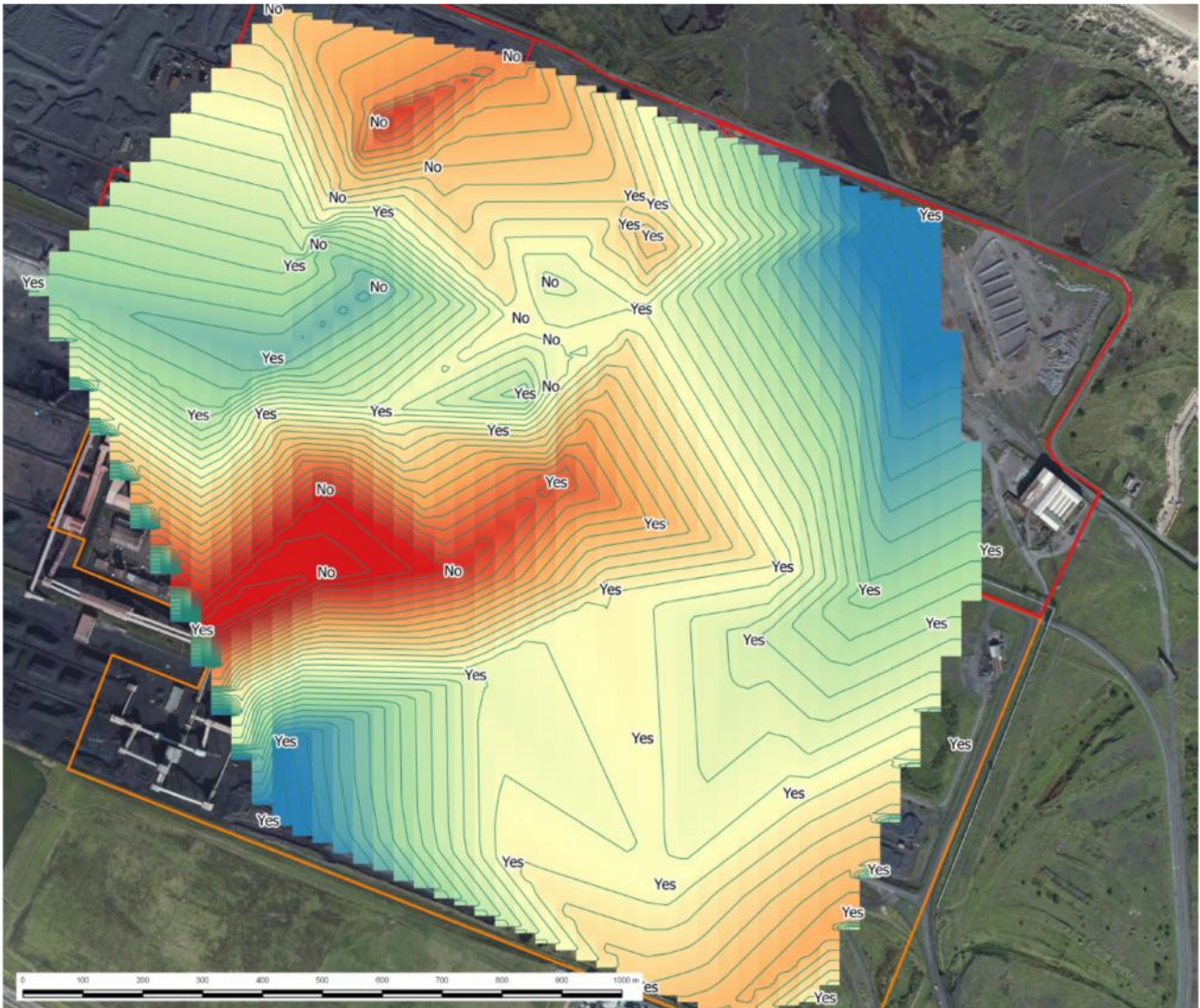


Figure 4: Rockhead Elevation and Distribution of Glacial Till Deposits

The bedrock surface also assists in understanding the distribution of the Glacial Till with the deposits primarily confined to the former valleys cut into the bedrock. Within areas of higher bedrock elevation granular rather than clay rich superficial deposits are present immediately overlying the bedrock. The clay rich deposits where present may act as an aquiclude, or lower permeability layer for the vertical movement of groundwater.

Bedrock beneath the majority of the site was generally found to comprise Redcar Mudstone Formation, part of the Lias Group with the north western section (approximately 20% of the site) underlain by the Mercia Mudstone Group. A thin band of Penarth Group was indicated to be present between the two main units.

The change in geological units across the site appears to generally coincide with the boundary as indicated on the geological map. It should be noted that this follows the orientation of one of the former glacial valleys.

Bedrock appears to be dipping to the southeast.

2.5 Obstructions

In addition to the large boulders of slag and fused slag deposits which presented issues with progression of a number of the exploratory holes further buried obstructions including walls, foundations, metal, and wooden railway sleepers were identified during the course of the investigation. A summary of the non-slag related obstructions is presented on Figure 5 below and in Appendix C, full details are presented on the trial pit logs. It should be noted that further obstructions may be encountered in areas not investigated. Of particular note were frequent concrete slab obstructions in the vicinity of the former Pellet Plant and tunnels identified by CH2M in the RDL Stores Area

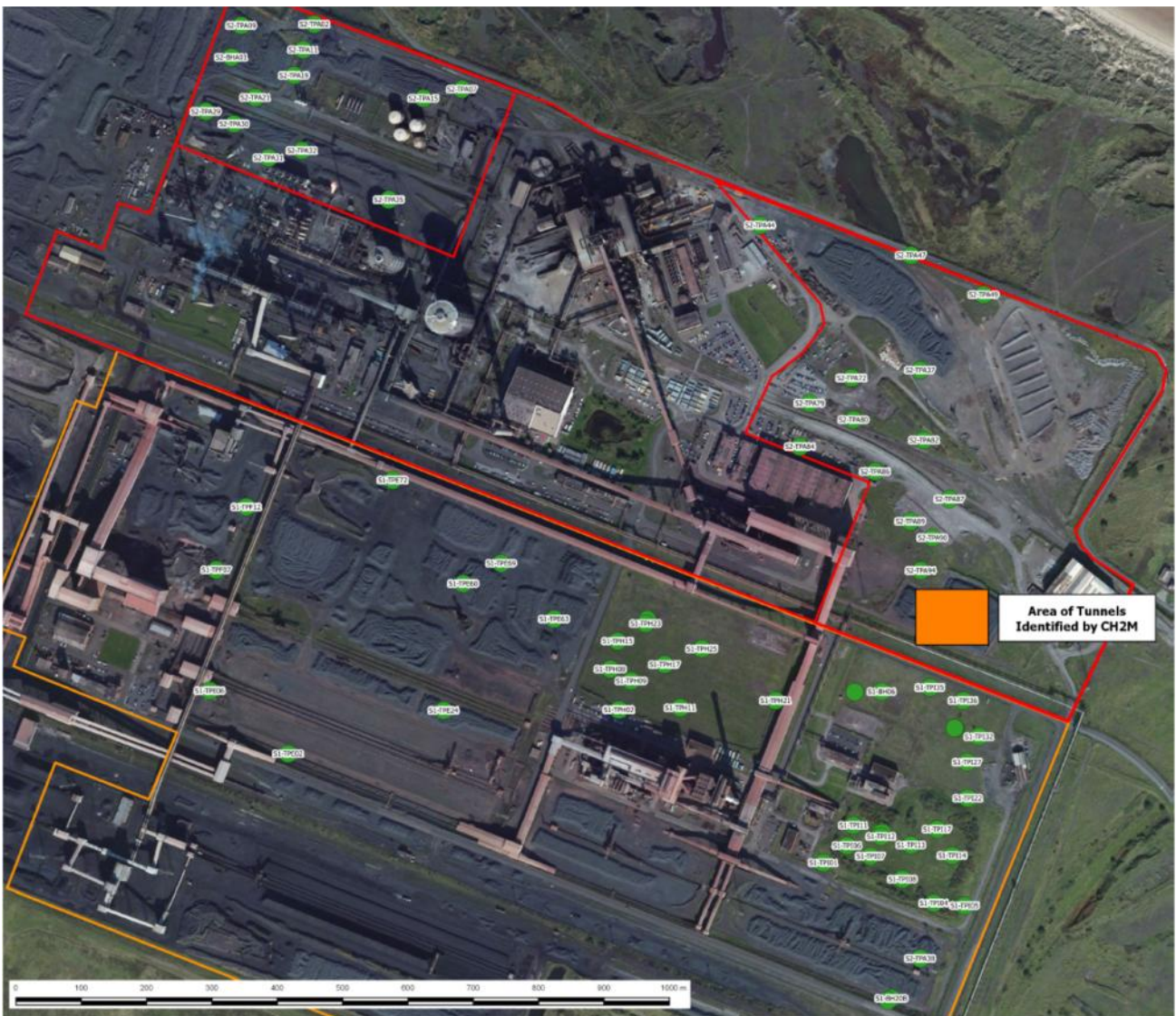


Figure 5: Non-Slag Related Obstructions in Trial Pits

2.6 Hydrogeology

Previous investigations have indicated that groundwater is present at elevations of between 4.5 and 1.5m AOD. The site is not located within a Groundwater Source Protection Zone. Groundwater levels recorded during the site investigation are consistent with historical data and are shown in the table below:

Monitoring well Screen	Range in Depth to Groundwater Visit 1 (m bgl)	Range in Depth to Groundwater Visit 2 (m bgl)	Range in Groundwater Elevation Visit 2 (m AOD)	Range in Groundwater Elevation Visit 2 (m AOD)
Made Ground Only	4.90 – 1.80	4.85 – 1.80	4.12 – 2.32	4.22 – 2.37
Made Ground and Superficial Deposits	4.50 – 1.6	4.59 – 1.64	5.466 – 2.32	5.476 - 2.29
Alluvium	4.60 – 3.10	4.60 – 3.52	4.12 – 2.92	3.7 - 2.93
Mercia Mudstone	5.00 - 4.80	5.20 – 4.40	2.42 – 1.55	2.42 – 1.35

Groundwater in wells screened across the Made Ground alone, the Made Ground and Superficial Deposits, and the Alluvium were all broadly consistent with elevations generally higher in the south east of the site and indicating a flow direction towards the north west. The elevation data from twin installations, where monitoring wells are screened separately across both the Made Ground and the Alluvium shows the same or very similar levels in both wells indicating that groundwater within these two geologies are in continuity; this is expected given the granular nature of these deposits. Groundwater was encountered in 148 of 294 trial pits and was more frequently observed in trial pits in the west of the site.

A groundwater elevation plan for wells partially or fully screened across the Made Ground is presented as Figure 6 below and in Appendix C.

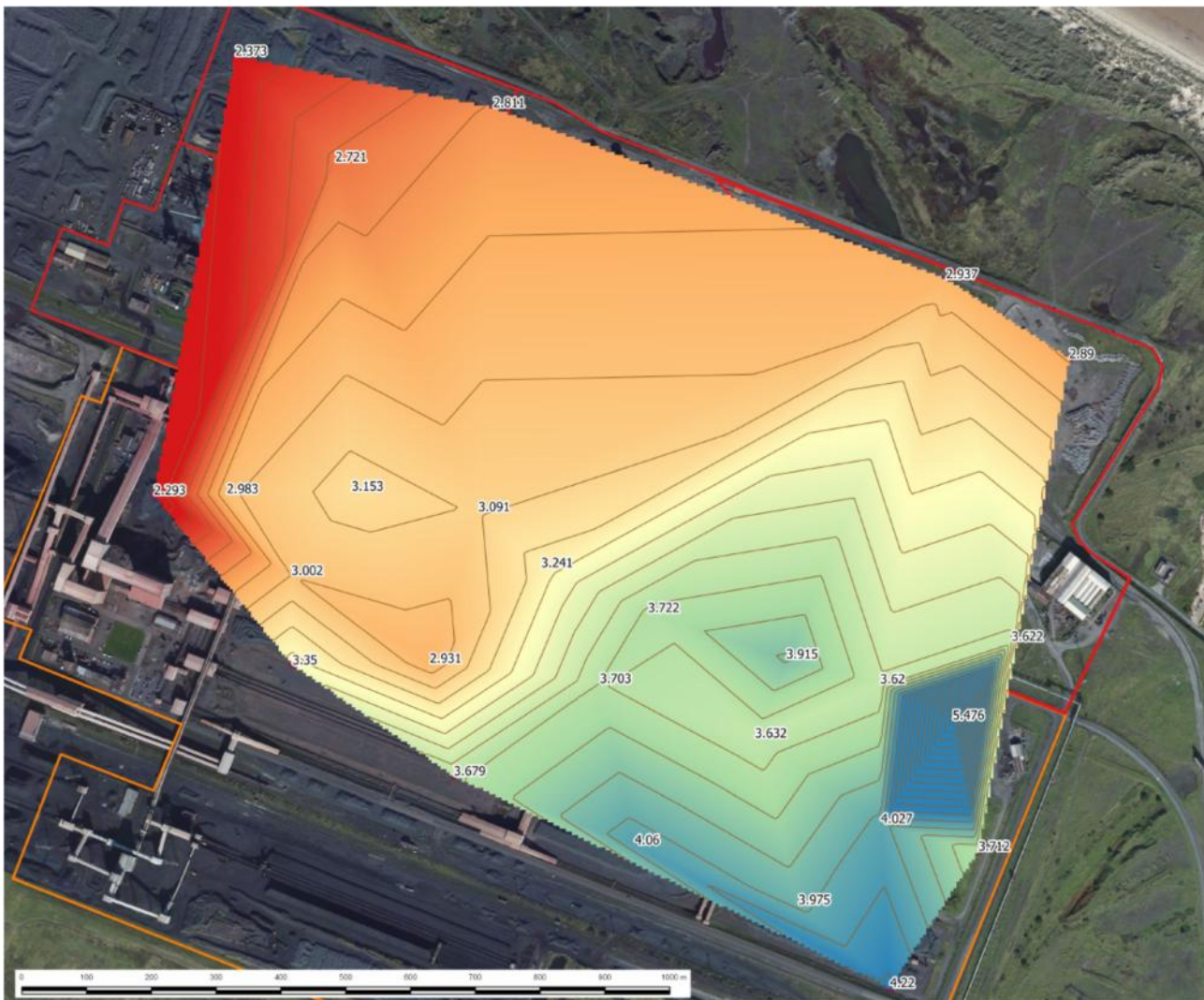


Figure 6: Groundwater Elevation Interpolation – Made Ground Deposits

Groundwater within the Mercia Mudstone is indicated to be flowing to the south east, however this assessment should be treated with caution given it is based on three monitoring wells over a short monitoring period. The data from twin installations indicates in S1-BH09 the elevation within the Mercia Mudstone are the same as that within the Made Ground / Alluvium, and in S2-BHA01 groundwater sits approximately 5cm higher in the Made Ground than the bedrock. No Glacial Till which is capable of acting as an aquitard was noted in S2-BH01, and only a limited thickness was present in S1-BH09. These data indicate the Superficial Deposits and Mercia Mudstone are likely in hydraulic continuity.

No tidal influence was noted at the site.

2.7 Hydrology

The River Tees is approximately 0.50 to 1.0km to the west of the site boundary and is classified by the Environment Agency as a Main River. This section of the river is intertidal. The Teesmouth & Cleveland Sands SPA & RAMSAR, and the South Gare & Coatham Sands border SSI2A to the north. The Fleet Drain runs past the south eastern corner of the site.

There is a small manmade pond adjacent to the site Power Station, and a surface water pond is shown just north of the SSI2A Area site boundary.

2.8 Historical Data Review

The desk study reports identified a number of potential areas of concern associated with SS11 and SS12A, these are presented as Appendix E and summarised on Figure 7 below and in Appendix C.

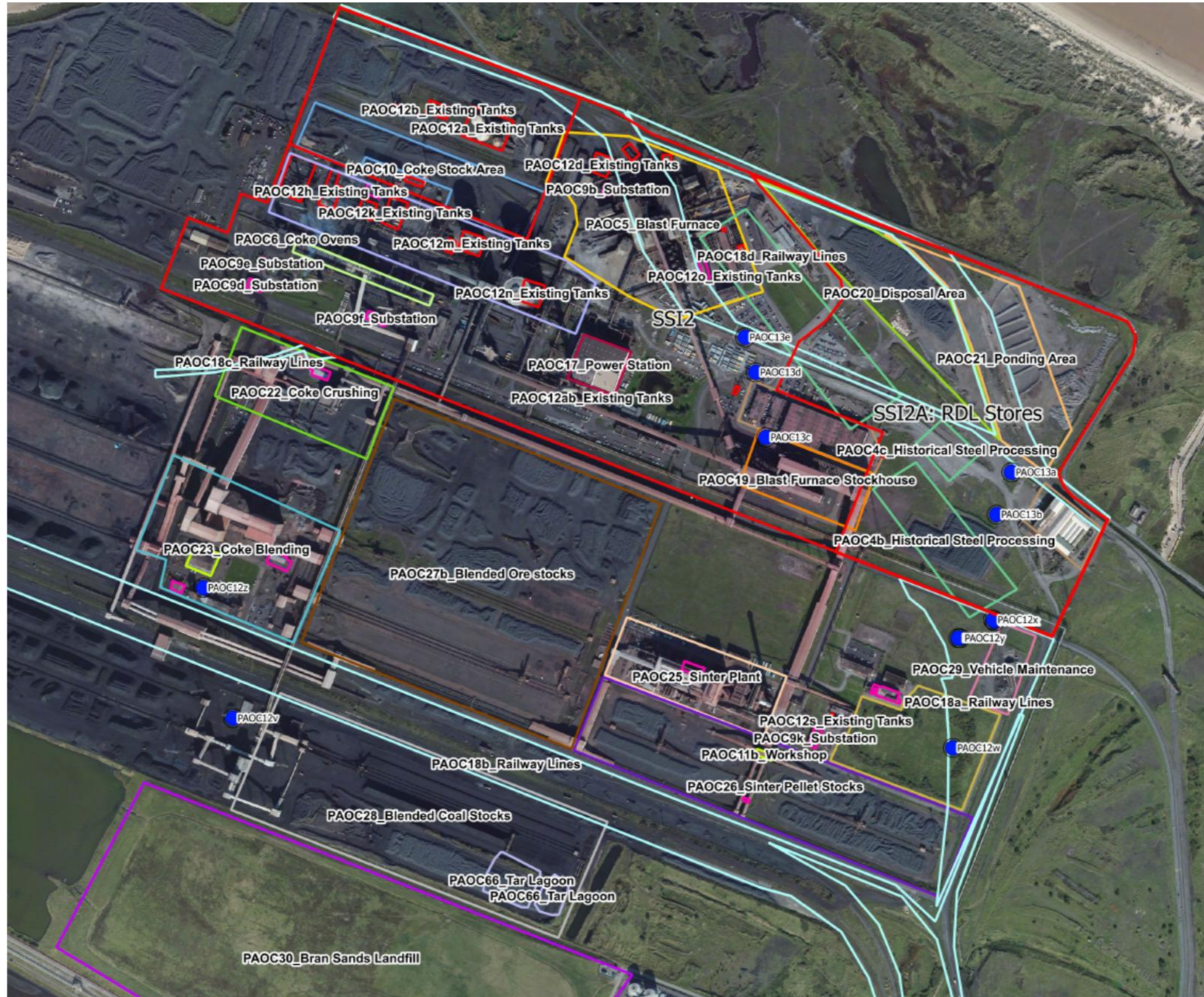


Figure 7: PAOC SSI1 and SSI2A (PAOC1 – Made Ground, PAOC2 Waste Materials, and PAOC3 Tidal Flats Glaciolacustrine Deposits not shown)

2.9 Magnetic Anomaly

Due to the perceived risk of encountering unexploded ordnance (UXO) on site, a down hole magnetometer was used at all exploratory locations which involved drilling into natural superficial deposits. An explosive ordnance engineer reviewed the magnetometer readings as drilling progressed to identify any magnetic anomalies which might indicate the presence of buried ordnance. Within SSI2A a magnetic anomaly was identified in S2-BHA05 at a depth of approximately 11m bgl. Given the depth of the anomaly, further inspection was not possible, and on the advice of the ordnance engineer, the borehole was terminated at this depth.

While this magnetic anomaly cannot categorically be identified as UXO (for example it could be caused by the base of a metal pile from former development), the presence of UXO is one possibility and as such the anomaly needs to be treated as if ordnance was present.

3 CONCEPTUAL SITE MODEL AND ENVIRONMENTAL SITE CONDITION ASSESSMENT

3.1 Introduction

This section summarises the findings of Section 2 in the form of a geo-environmental conceptual site model (CSM) which is presented as Figure 8 in Appendix C.

The CSM provides a qualitative evaluation of potentially active “pollutant linkages” at the site; these being plausible scenarios whereby a contamination source is connected to a possible receptor by one or more pathways:

- Potential sources of contamination: these include any actual or potentially contaminating materials and activities, located either on or in the vicinity of the site;
- Potential pathways for contamination migration: these comprise the routes or mechanisms by which contaminants may migrate from the source to the receptor including environmental migration pathways and human health exposure pathways; and
- Potential receptors of contamination: these include present and/or future land users, ecological systems, water resources and property.

The significance of these source-pathway-receptor linkages will be assessed in the Environmental Risk Assessment Report.

3.2 Contamination Sources

Based on the information reviewed in this report the following potential contamination sources have been identified:

3.2.1 On-Site

On-site sources have been identified associated with Made Ground and potential contaminants of concern (CoC) associated with former site uses. The table below summarises the main potential on-site sources and the primary contaminants associated with these sources which are outlined in further detail in the Desk Study report and Appendix D.

Potential On-Site sources	Primary Contaminants
Made Ground including slag deposits	Metals (including heavy metals), polyaromatic hydrocarbons (PAHs), cyanide, thiocyanate, sulphate, sulphide, pH, ammonia, and asbestos. Potential source of ground gas if found to have a high organic content. Coal and coke deposits – combustible fill
Sub Stations	Asbestos, total petroleum hydrocarbons (TPH), polychlorinated biphenyls (PCB).
Current SSI Steelworks and former Redcar Iron and Steel Works including: <ul style="list-style-type: none"> • Former Pellet Plant • Coke Oven Gas Main • Garages and workshops • Stockyards • Fuel tanks 	Metals, asbestos, TPH, PAH, VOC, SVOC, cyanide, thiocyanate, sulphate, sulphide, carbonates, pH, ammonia
Railway lines and sidings	Metals, asbestos, TPH, PAH, sulphate, sulphide, and pH

Potential On-Site sources	Primary Contaminants
Tar and Macadam Works	TPH, PAH, ammonia, phenols, pH

3.2.2 Off-Site

Potentially contaminative land uses have been identified in the vicinity of the site including parts of SSI1 and SSI2A not subject to investigation as part of Contracts 1 or 2, the most pertinent of which are presented in the table with potentially associated contaminants:

Potential Off-Site sources	Primary Contaminants
Surrounding landfills	Metals, asbestos, TPH, PAH, VOCs, SVOCs, chloride, ammonia, sulphate, pH
SSI Steelworks including: <ul style="list-style-type: none"> • Coking Plant • Biproducts Plant • Blast Furnace • Sinter Plant • Power Station • Crushing and Blending Plant 	Metals, asbestos, TPH, PAH, cyanides, thiocyanate, VOCs, SVOCs, chloride, ammonia, sulphates, sulphides, pH
Sub Stations	Asbestos, TPH, PCB
Bran Sands Water Treatment Works	Metals, TPH, PAH, VOCs, SVOCs, chloride, ammonia, sulphate, pH

Contaminants of concern in green are of low mobility and have therefore been discounted for some sources in question based on the distance from the site, for others they have been retained due to the unknown composition of surface Made Ground adjacent to the site and the consequential potential for dust generation.

3.3 Contamination Sources Assessment

The contamination assessment will be undertaken in two ways – contaminants that are dependent upon the material composition (e.g. metals, inorganics, asbestos and PAHs) will be assessed separately for each material type and contaminants that are associated with a particular point source (e.g. hydrocarbons) will be assessed based on the likely source.

A summary of the analytical data and statistical analysis is presented as Appendix F.

3.3.1 Made Ground

Asbestos

Asbestos was identified as loose fibres in approximately 10% of samples associated with the Made Ground, the distribution was noted to be primarily across the south eastern quarter of SSI1 in the vicinity of the former Pellet Plant, with further detections across the wider contract area. Within SSI2A asbestos was identified in the north west corner of the contract and along the northern and eastern boundary. The distribution of asbestos presented on Figure 8 below and in Appendix C.

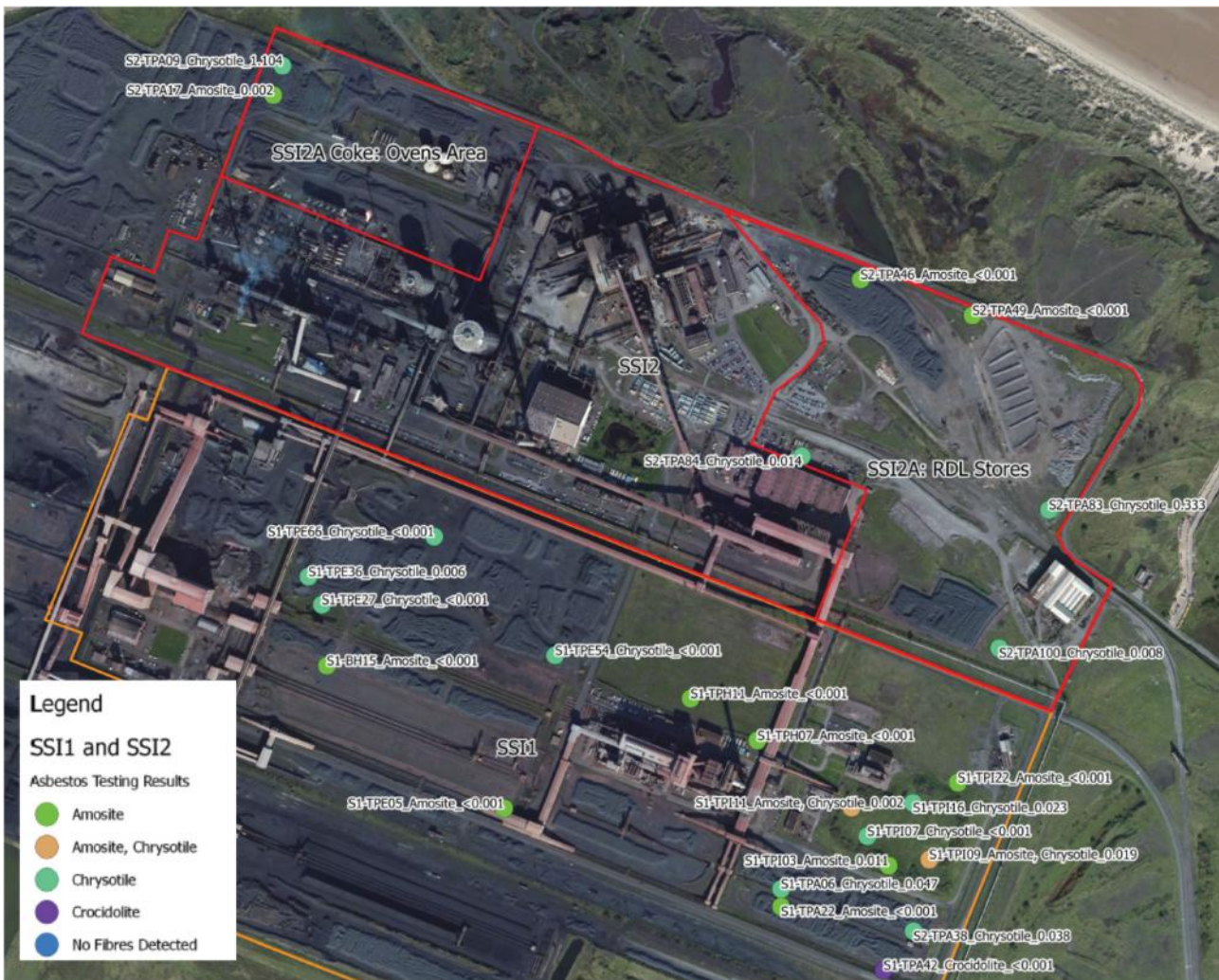


Figure 9: Asbestos Testing Results

Metals and Inorganics

With the exception of hexavalent chromium which was not measured above the method detection limit (MDL) and mercury the metals analysed were detected in the majority of the soil samples taken from the Made Ground. Statistical analysis indicates that the metal and inorganic ion distribution across the site within the two main types of Made Ground deposit (slag dominant deposits, granular Made Ground) are relatively consistent within the same order of magnitude, concentrations in cohesive Made Ground were noted on average to be an order of magnitude lower.

Statistical analysis showed that the highest average (mean) metal concentrations were identified in the slag dominant materials, particularly for copper, chromium, iron, and vanadium, however the copper result is affected by a hotspot in one trial pit and is consistent if this is removed. Nickel was noted to be higher in granular made ground than slag. A distribution plot for chromium is presented as Figure 10 below and in Appendix C; further plots for lead, and vanadium are presented as Figures 11 and 12 in Appendix C.



Figure 10: Chromium in Made Ground

Levels of cyanide and thiocyanate were generally low across the site, where cyanide was detected it was generally complexed. Sulphate concentrations were noted to be elevated with higher levels noted in slag dominant and cohesive Made Ground. Soil samples were on average strongly alkaline with mean pH values of 10.9, 10.6, and 11.1 for slag dominant, granular, and cohesive Made Ground respectively.

A limited number of samples were classified as waste where a range of waste materials including metal, plastic and wood had been identified in the trial pits; samples from these locations showed levels of metals and inorganic ions comparable to the other Made Ground Deposits with the exception of lead which was notably higher.

Leachability testing was conducted on slag dominant, granular Made Ground, waste materials and hydraulic fill. Barium, copper and selenium were the most commonly detected metals in leachate from slag dominant and granular Made Ground. Barium and copper were also most frequently detected in leachate from hydraulic fill, along with Manganese and lead. Levels of metals in leachate from waste materials was generally comparable or lower than those in other made ground types

A summary of the analytical data is presented as Appendix F.

Polyaromatic Hydrocarbons

Concentrations of PAH were measured in the almost all the samples of slag dominant material and granular made ground tested as well as the majority of samples of cohesive Made Ground. Statistical analysis indicates that average concentrations in slag dominant material were comparable with those in granular Made Ground and approximately twice those in cohesive Made Ground.

A limited number of samples were classified as waste where a range of waste materials including metal, plastic and wood had been identified in the trial pits; samples from these locations showed levels of PAH notably higher than to the other Made Ground Deposits.

Leached concentrations of PAH were measured all three samples tested and comprised a broad range of light to heavy end compounds. Based on the small dataset total leached concentrations were higher from samples of slag dominant material than granular Made Ground.

Total Petroleum Hydrocarbons

Concentrations of TPH were detected above the MDL in approximately two thirds of soil samples, the following samples reported concentrations of above 500mg/kg:

- Elevated concentrations of TPH (630mg/kg and 3,800mg/kg respectively) were measured in samples from S1-TPH06 (0.5m bgl), and S1-TPH07 (2m bgl) located north-east of the Sinter Plant chimney., concentrations of PAH within the same samples were low. A black clayey material was noted in S1-TPH06 and a non-aqueous phase liquid (NAPL) on the arisings from S1-TP07. Analysis indicated the contamination was primarily heavy end hydrocarbons in the C21-C35 range. A concentration of 92µg/l TPH and 19 µg/l PAH was measured in groundwater from monitoring well S1-BH12 which is screened across the depth from which the soil sample was recovered in S1-TPH07. This suggest a relatively low leaching potential for the soil impact. Given the location and similar chemical signature of these detections the impact in the two trail pits is considered the same source
- An elevated concentration of TPH (2,600mg/kg) was measured in S1-TPH24 (2.3m bgl), and a concentration of 330mg/kg PAH was measured in S1-TPH23 (3.4m bgl), located in the centre of Zone H between the Sinter Plant and the Ore Blending Plant. A hydrocarbon odour had been noted on arisings from the trial pit. Analysis indicated the contamination was primarily mid to heavy end hydrocarbons in the C16-C35 range in S1-TPH24 and middle molecular weight PAH in S1-TPH23. A concentration of 8.8µg/l TPH and 2.9µg/l PAH were measured in groundwater from monitoring well S1-BH04 which is screened across the depth from which the soil sample was recovered in S1-TPH23. This suggest a relatively low leaching potential for the soil impact. Given the location and similar chemical signature of these detections the impact in the two trial pits is considered the same source.
- An elevated concentration of TPH and PAH (25,000mg/kg and 230mg/kg respectively) was measured in S2-TPA08 (4m bgl) located close to the railway lines north of the blast furnace. A tar like odour was noted on the arisings from the trial pit. Analysis indicated the contamination was primarily heavy end

hydrocarbons in the C21-C35 range. The impact is noted to be to the north west of the former tar and macadam works shown on 1929 plans.

- An elevated concentration of TPH (730mg/kg) was measured in S2-TPA17 (4m bgl) located in the northern corner of the RCO area, the concentration of PAH within the same sample was 570mg/kg. A very strong creosote odour was noted on the Made Ground during excavation of the trial pit and a reading of 15ppm recorded on the photo-ionisation detector during field screening. Analysis indicated the contamination was mid-range to heavy end hydrocarbons in the C16-C35 range. A concentration 120µg/l TPH and 130µg/l PAH was measured following leaching tests on the sample, the PAH primarily comprised naphthalene, the results suggest a leaching potential for the soil impact.
- Elevated concentrations of TPH (6,900mg/kg, 1,100-19,000mg/kg, and 650mg/kg respectively) was measured in S2-TPA48 (0.8m bgl), S2-TPA58 (1.2-3.6m bgl), and S2-TPA59 (3m bgl) located in the north-east of SSI2, concentrations of PAH within the same samples were low in comparison to the TPH data. A slight to strong hydrocarbon odour was noted on arisings from the trial pits during field screening and tar was noted in S2-TPA59. Analysis indicated the contamination was primarily heavy end hydrocarbons in the C21-C35 range. The distribution and chemical signature of these impacts suggests they are the same source.
 - The impacts are noted to be in the vicinity of the former tar and macadam works shown on 1929 plans, however the depth of some of the samples within the shallow Made Ground suggest it may be associated with later phases of development. An additional source identified in S2-TPA53 (2.2m bgl) located further to the east may also comprise the same or a very similar CoC; a TPH concentration of 51,000mg/kg and the presence of tar was noted in the sample from this location.
- Elevated concentrations of TPH (690mg/kg and 3,800mg/kg respectively) were measured in S2-TPA78 (1.2m bgl) and S2-TPA79 (1m bgl) located east of the railway lines to the blast furnace close to the main workshops and stores. An elevated concentration of PAH (150mg/kg) was also in a sample from the ground surface in S2-TPA79. An oily residue had been noted on the Made Ground during excavation of trial pit S2-TPA79. Chemical analysis indicated the contamination was primarily heavy end hydrocarbons in the C21-C35 range. Based on the distribution and chemical signature these impacts are considered to represent a single source.
- An elevated concentration of TPH (620mg/kg) was measured in S2-TPA83 (3m bgl) located on the south eastern boundary of SSI2, the concentration of PAH within the same sample was 670mg/kg. A solid tar like substance had been noted on the Made Ground during excavation of trial pit. Analysis indicated the contamination was primarily heavy end hydrocarbons in the C21-C35 range.

In addition, a sample from S2-TPA29 (4.9m bgl) was reported by CH2M to contain a PAH concentration of 227,300mg/kg; although tar was noted in this trial pit the concentrations reported do not correspond to the soil descriptions and Arcadis have concluded the samples was of the tar material only not the wider Made Ground and therefore is not fully representative of the trial pit.

The locations of elevated TPH and PAH are shown on Figure 13 below and in Appendix C.

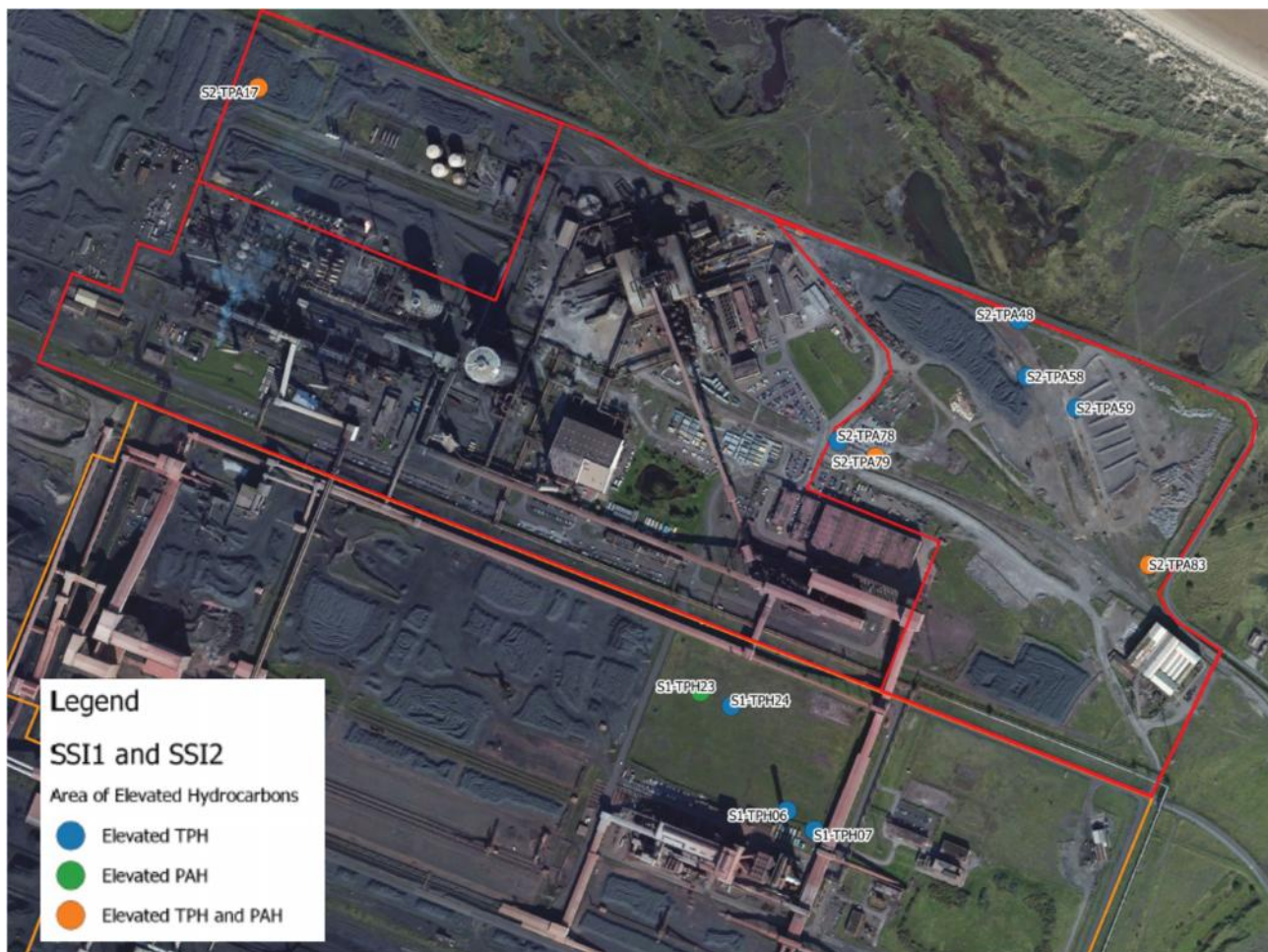


Figure 13: Areas of Elevated Hydrocarbons

Other Contaminants

No elevated concentrations of VOC, SVOC, or PCBs were measured in any of the soil samples.

Additional sources were identified by Environ in 2004, these are detailed in the relevant report and will be considered as part of the risk assessment.

3.3.2 Natural Deposits and Hydraulic Fill

Concentrations of metals within the natural Blown Sands, Alluvium, and Tidal Flat Deposits were generally consistent within the same order of magnitude with each other and with the Hydraulic Fill. Statistical analysis indicates metals concentrations were generally lower than those observed in slag and granular Made Ground particularly for barium, chromium, lead, and zinc.

3.3.3 Groundwater

Metals and Inorganic Ions

Metals and inorganic ions were measured in groundwater samples from all monitoring wells, concentrations were broadly similar within the same order of magnitude both between monitoring visits. Antimony, arsenic, barium, iron, selenium and vanadium were detected in all groundwater samples across both visits

Elevated concentrations of boron were in S1-BH01 during the initial monitoring visit, compared to other monitoring well, as were elevated concentrations of iron in S2-BHA01 and S2-BHA04, and elevated levels of manganese in S1-BH17, S2-BHA05, and S2-BHA06.

No elevated concentrations of boron were noted in soil or leachate from the corresponding trial pit (S2-TPA17), elevated concentrations of iron were noted in Made Ground from S2-TPA48 the trial pit through which monitoring well S2-BHA04.

Levels of sulphate were measured above the MDL in all wells during both visits and were noted to range over two orders of magnitude, chloride was detected over a similar range of concentrations but less frequently in approximately 75% of samples. Elevated cyanide was noted in S2-BHA01, and S2-BHA04, the cyanide was primarily complexed. Groundwater pH ranged between neutral (7.5) and strongly alkaline (12.4). A plan showing the distribution of sulphate in groundwater is shown as Figure 14 below and in Appendix C.



Figure 14: Sulphate in Groundwater

Organics

Concentrations of TPH were, if detected generally below 100µg/l with the exception of S1-BH09D (170µg/l), S1-BH20S (230µg/l), and S2-BHA01S (2,300-4,000µg/l), no TPH was measured in S1-BH09D during the second monitoring visit. Monitoring wells S1-BH20, and S2-BHA01 are screened across Made Ground deposits, S1-BH09D is screened across the Marl. In all samples the TPH was primarily heavy end compounds in the C21-C35 range.

Monitoring well S2-BHA01 is installed in S2-TPA17 from which as discussed in section 4.3.3 soils and leachate containing similarly elevated TPH were identified. Concentrations of TPH were present in soil from S1-BH09, S1-TPF08 (the trial pit through which S1-BH09 was installed), and from S1-BH20 but were not elevated over other samples within the area.

No significant sources of VOC, SVOC, or phenols were detected.

3.4 Pathways

Potential migration pathways based on a proposed commercial / industrial end use are discussed below.

3.4.1 Airborne Migration Pathways

- The majority of the site is currently covered in soft landscaping, as such, particulate inhalation due to dust generation is a potentially active pathway.
- Vapour inhalation pathways in relation to soil are potentially active, vapour inhalation pathways in relation to groundwater are considered potentially active due to the identified depth of groundwater (approximately 1.5-5.0m bgl).
- During potential re-development works, sub-surface soils could be exposed at the surface due to trenching and or re-profiling requirements and therefore dust has the potential to be generated. Notwithstanding this, typical dust suppression techniques should be employed so that exposures would be minimised.
- Migration and accumulation of permanent ground gases originating from the Made Ground on site in confined spaces leading to asphyxiation and/or explosion is considered potentially active.

3.4.2 Direct Contact Exposure Pathways

- The proposed site surfacing under any potential re-development scenario is unknown, should a significant portion of the site area be covered in some form soft landscaping direct contact pathways in relation to soil would be considered active. Given the identified depth to groundwater, direct contact pathways in relation to groundwater are not considered active.
- Direct contact pathways would be active throughout a potential redevelopment. The contractor will need to develop a suitable safe system of work however, typical mitigation measures such as personal protective equipment as defined by the contractor (PPE; overalls, gloves etc.) should be used to mitigate this risk. Where significant levels of contamination (such as NAPL) are present additional PPE should be used as required as mitigation.
- Direct contact between made ground and gypsum bearing rock may present a risk to future subsurface concrete (foundations, floor slabs, drains, piles etc.). Detailed design will need to specify appropriate concrete for any future construction.

3.4.3 Aqueous Migration Pathways

- Leaching of contaminants in the Made Ground to groundwater within the Superficial Deposits is considered potentially active
- Based the incomplete coverage of Glacial Till between the Tidal Flat Deposits and the bedrock (Redcar Mudstone Formation, Penarth Group and Mercia Mudstone) identified in on-site boreholes the potential for vertical migration of contaminants to the underlying bedrock aquifers is considered active
- Given the granular nature and thickness of the Made Ground and the permeability of the superficial deposits lateral migration of off-site impacts on to the site from nearby PAOC is considered active. The most likely sources would be the British Steel facility to the east. Under the same logic the migration of on-site contaminants off site is considered potentially active.
- Lateral migration of on-site impacts towards the off-site surface water features within the SSSI and also the River Tees is considered potentially active given the likely thickness and nature of the Made Ground and the permeability of the Tidal Flat Deposits and Blown Sand.
- Migration of contaminants of concern into surface water runoff from the Made Ground is considered active.
- The vertical migration of impacts down piled foundations is considered potentially active.
- The presence of sulphate and other aggressive compounds in water (from made ground and natural deposits) is considered active.

3.5 Ground Gas Assessment

Ground gas monitoring was conducted on 3 occasions across a range of weather and atmospheric conditions. In monitoring wells S1-BH17, and the deep wells of the five twin installations the groundwater was resting above the top of the well slotted section indicating the data recorded is not representative if the sub surface

ground gas condition, this is expected as the monitoring well was designed to assess groundwater conditions within the deeper deposits.

In the remaining wells which are wholly or partially screened across the Made Ground, and Tidal Flat Deposits methane levels were below the detection limit of the instrument and carbon dioxide levels were below 1% across all the visits. Flow rates were observed to be at or below the detection limit of the instrument. Note the number of wells was limited and it is possible that conditions may vary from those observed.

3.6 Receptors

With reference to Part 2a of the Environmental Protection Act (1990), the potential receptors to be considered in any contaminated land scenario can be summarised as follows:

3.6.1 Human Health

For the purposes of this assessment it is assumed that the proposed development will comprise a commercial or industrial end use, and as such commercial and industrial workers are the primary receptor of concern for any contamination risk. The risk would be influenced by the duration and location of the staff work regimes.

Construction workers/contractors could also be exposed to contaminants during any construction processes (i.e. during any ground reprofiling or utility/foundation trenching).

Users of the adjacent buildings could also be at risk. However, for exposure to occur, active cross-boundary migration pathways would be required.

3.6.2 Property (buildings, etc.)

The proposed development will include new structures and associated infrastructure, which could be subject to potential attack from sulphate or other contaminants of concern in relation to buried concrete and utilities. Given the presence of slag deposits within the Made Ground the potential for expansive slag to impact structures and utilities is considered active.

The Mercia Mudstone present in the north of the site contains gypsum a source of sulphate, this has the potential to attack concrete within foundation piles.

3.6.3 Controlled Water

Groundwater is a Controlled Water; therefore, the groundwater beneath the site requires consideration and protection. At this site, the underlying geology comprises Tidal Flat Deposits classified as a Secondary A Aquifer and three bedrock units, the Redcar Mudstone Formation and Penarth Group which are both classified as a Secondary (Undifferentiated) Aquifers, and the Mercia Mudstone a Secondary A Aquifer. At this CSM stage all the above water bearing bodies are considered groundwater receptors at the site.

The pond beyond the eastern boundary of SSI2A, and the Fleet Drain adjacent to SSI1 are also considered Controlled Water receptors as is the Tees Estuary. The small pond adjacent to the power station is unlikely to be considered a Controlled water by the Environment Agency.

3.6.4 Ecological

The Teesmouth & Cleveland Sands SPA & RAMSAR, and the South Gare & Coatham Sands site of special scientific interest border SSI2A to the north and are considered ecological receptors.

3.7 Slag Testing Data

A total of 34 samples of slag recovered from trial pits were submitted for examination by CH2M, and a further 12 samples were submitted by Arcadis, the results are presented in Appendix G and summarised below.

- The majority of the samples contained mixed slag deposits with blast furnace slag predominating in all but 6 samples within which basic steel slags dominated.
- Small amounts of basic refractory materials were noted in 4 slag samples, these materials are particularly susceptible to expansion.

- Samples containing medium or higher proportions of basic steel slag were tested for free calcium and magnesium oxides. Free calcium oxide compositions ranged from 0.3% to 1.8% and free magnesium oxides ranged between 0.0% and 2.8%.
- All samples were subject to 14 day expansion tests, two slags did not expand during the tests, the remaining 44 samples showed expansions between 0.01% and 1.46% with slags high in basic steel slag generally showing the greater expansion.
- Samples from CH2M containing medium or higher proportions of basic steel slag and all Arcadis samples were subject to 28 day accelerated expansion tests. The results showed expansion in all seventeen samples ranging between 0.06 and 2.05%.
- Approximately half the samples tested contained Ettringite indicating expansion has occurred in the past, however this does not mean the expansion is necessarily complete.

3.8 Conceptual Site Model

The above data has been used to produce a geo-environmental CSM for the site, this is presented as Figure 7 below and in Appendix C.

Potential Human Health SPR Linkages

- A = Dust inhalation from Made Ground from site and adjacent land
 - B = Vapour inhalation of indoor or outdoor air from contaminated soil and or groundwater
 - C = Direct contact and ingestion
 - D = Accumulation of ground gas in confined spaces
- SPR linkages for construction workers during redevelopment not shown

Potential Water Resource SPR Linkages

- E = Leaching of contaminants from Made Ground and other sources to groundwater in superficial deposits
- F = Migration of contaminated groundwater to Secondary Aquifers in bedrock
- G = Migration of contaminated groundwater onto site in Made Ground and Superficial Deposits
- H = Migration of contaminated groundwater into off site surface water features and Tees Estuary via Made Ground and Superficial Deposits

Other SRP Linkages

- J = Attack by contaminants of concern on foundations

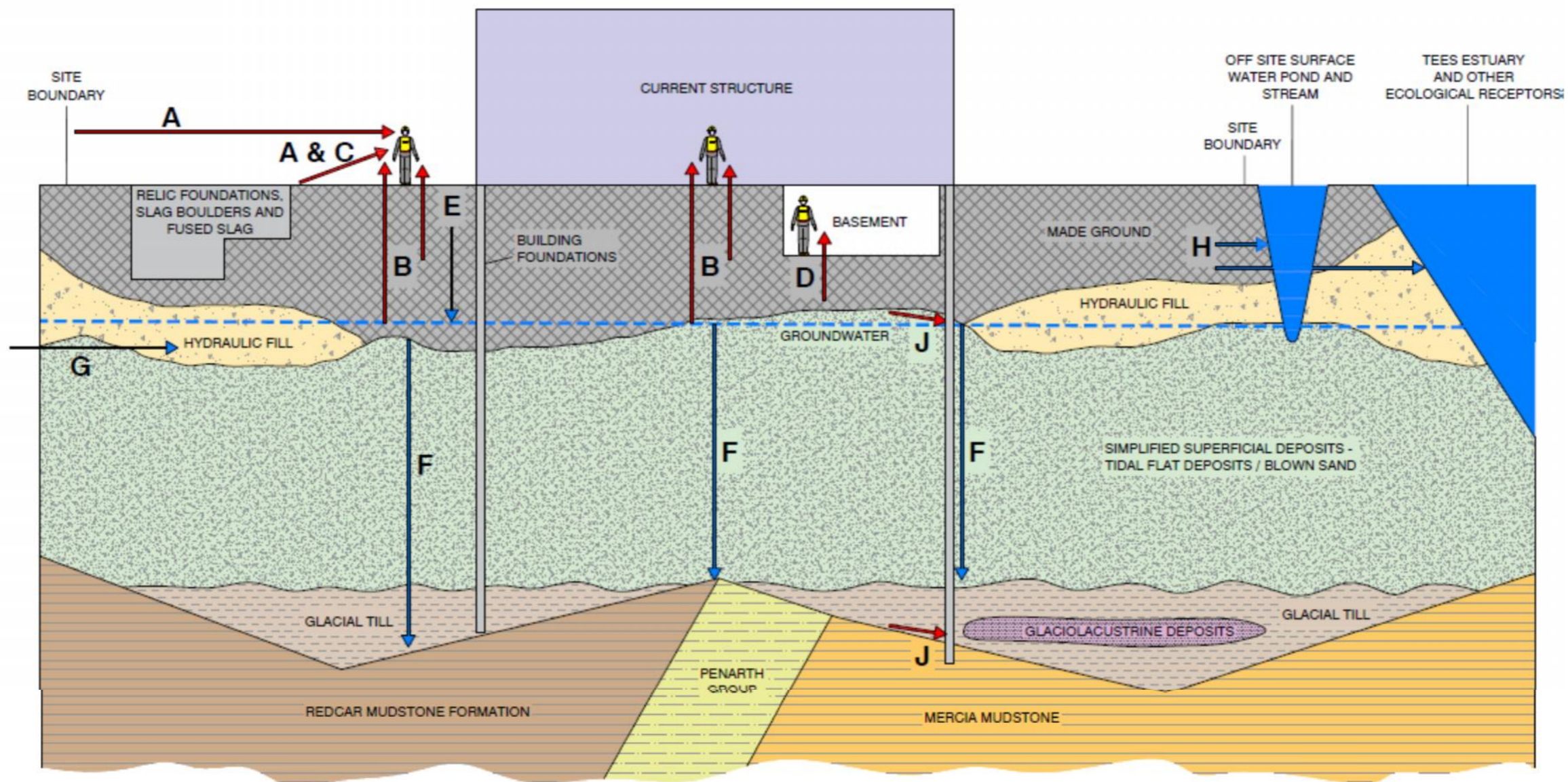


Figure 8: CSM

5 SUMMARY OF RESULTS

Based on a review of historic documentation and the results of the intrusive investigation a CSM has been developed for SSI1 and SSI2A. The main findings of the investigation were:

- Made Ground was encountered across both sites including sands and gravel with varying amounts of slag, concrete, and brick and other materials; slag deposits ranged from gravel to boulder sized and were locally fused. The maximum thickness of Made Ground was approximately 9 m however the base of the made ground was not identified in 90% of locations and greater thickness of material may exist elsewhere.
- Within SSI1 and SSI2A the majority of the deposits were classed as either slag dominant or granular Made Ground. A small amount of cohesive Made Ground, potential hydraulic fill, and waste rich deposits were also identified.
- Relic foundations and underground structures were identified in SSI1 and SSI2A, these are likely to impact and redevelopment of the site and will be further considered in the Geotechnical Risk Assessment.
- Asbestos fibres have been identified in approximately 10% of Made Ground in both SSI1 and SSI2. Detections were most frequent around the former Pellet Plant in SSI1.
- The Made Ground deposits were noted to be highly alkaline with a pH of between 10 and 12.5, the pH of leachate from the Made Ground was strongly alkaline to neutral as was groundwater.
- Elevated sulphate levels were noted in Made Ground, bedrock, and groundwater;
- Leaching of sulphate from gypsum in the Mercia Mudstone presents a potential dissolution hazard to piled foundations;
- Based on a statistical analysis the highest concentrations of metals were generally identified in slag dominant Made Ground, and the highest concentrations of PAH in granular Made Ground Concentrations in natural deposits were generally an order of magnitude lower.
- A number of point sources of petroleum hydrocarbon have been identified associated with the Made Ground;
- Tests identified that metals readily leached from Made Ground deposits, TPH and PAH were also noted to leach in some samples. Metals, TPH and PAH were also detected in groundwater.
- Based on the slag testing conducted the majority of the slag deposits are of mixed blast furnace and basic steel slag, with the latter comprising the minor fraction in most cases. The testing indicated approximately half the slags tested showed signs of past expansion and that there is the potential for further expansion in the future. The basic steel slags are indicated to have the highest expansion potential.

The significance of the identified ground conditions will be assessed in the Environmental and Geotechnical Risk Assessment Reports.

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

APPENDIX A

Legislative Context and Regulatory Guidance

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

Land contamination is generally dealt with by the following types of regulation:

- Acts of Parliament to investigate and remedy harm caused by land contamination;
- Conditions placed upon Planning Permissions for the redevelopment of land; and,
- Acts of Parliament and Regulations for the control of waste.

In England land contamination is identified and dealt with through Acts / Regulations including:

- The Contaminated Land (England) (Amended) Regulations (2012);
- Part IIA of the Environmental Protection Act (1990);
- The Environment Act 1995;
- The Town and Country Planning Act (1990);
- The Environmental Permitting (England and Wales) (Amended) Regulations (2011);
- The Water Resources Act (1991);
- The Water Act (2003); and
- The Environmental Damage (Prevention and Remediation) Regulations 2009.

Part IIA of the Environmental Protection Act 1990

Part IIA of the Environmental Protection Act 1990 (which was inserted by Section 57 of the Environment Act 1995) created a regime for the identification and remediation of contaminated land. Section 78A (2) of the Environmental Protection Act 1990 defines contaminated land for the purposes of Part IIA as:

'any land which appears to the local authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land, that;

(a) Significant harm is being caused or there is a significant possibility of such harm being caused; or

*(b) significant pollution of controlled waters is being caused or there is a significant possibility of such pollution being caused.'*¹

Harm is defined under section 78A of the Environmental Protection Act as meaning 'harm to the health of living organisms or other interference with the ecological systems of which they form part and, in the case of man, includes harm to his property'. Types of harm are related to specific receptors in order to determine whether they can be regarded as "significant", as defined in the DEFRA (2012)² statutory guidance.

Part IIA sets the definition of contaminated land within the context of the 'suitable for use' approach. The 'suitable for use' approach underlies these objectives, and is based on the principles of risk assessment, including the concept of the 'pollutant linkage'.

In the event that there are unacceptable levels of risk posed by a site, a remediation notice can be served under the contaminated land regime introduced under Part IIA of the Environmental Protection Act 1990.

Regulation of Development on Land Affected by Contamination

Management of risks from contamination in development of land is also regulated in the England under the Town and Country Planning Act 1990. Land contamination is a material planning consideration within this planning regime.

The Local Planning Authority may impose conditions on the development during planning that include preliminary risk assessment, site investigation, risk assessment and remediation. The Environment Agency may use its role as a statutory consultee to provide the Local Planning Authority with advice.

¹ Definition amended by the Water Act 2003, and came into force on 6th April 2012

² Contaminated Land Statutory Guidance. DEFRA 2012, which came into force on 6th April 2012

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

Assessment of risk is again based on the pollutant linkage concept. The aim of risk management in the development should be to render the land suitable for the proposed use and, therefore, to prevent consideration of the site under Part IIA.

The National Planning Policy Framework (NPPF) (2012) provides high level guidance on the relationship between development and the management of risks from land contamination caused by historical use. The interpretation of the NPPF is left to local decision-makers, but with the expectation that good practice developed using the pre-existing Planning Policy Statements will be maintained. The Building Regulations 2000, made under the Building Act 1984, also require measures to be taken to protect new buildings and their occupants from the effects of contamination. Guidance on the requirements is provided in Approved Document C - Site preparation and resistance to contaminants and moisture, published by ODPM in 2004.

Voluntary Remediation Action

Voluntary remediation action on contamination resulting from historical activities can often anticipate future remediation requirements, such as through the Planning regime, and is encouraged, especially where the site is not being assessed under Part IIA.

Environmental Damage

The Environmental Damage (Prevention and Remediation) Regulations 2009 came into force on 1st March 2009 to implement EC Directive 2004/35 on environmental liability with regard to the prevention and remedying of environmental damage.

These Regulations do not apply retrospectively; environmental damage that took place before the Regulations came into force (1st March 2009), or damage that takes place (or is likely to take place) after that date but is caused by an incident, event or emission that occurred before that date are exempt from the requirements of the Regulations.

The Regulation is concerned with preventing environmental damage. It requires that all operators of activities that cause an imminent threat of environmental damage to take all reasonably practical steps to prevent the damage. Where damage has already been caused, the operator must take all reasonably practical steps to prevent further damage from occurring.

Non-Statutory Regulatory Technical Guidance Documents

The non-statutory regulatory technical guidance for England on the assessment of land contamination, primarily released as part of the Contaminated Land Exposure Assessment (CLEA) methodology (DEFRA and EA) has recently been updated. The following documents currently present guiding principles in investigating and assessing potentially contaminated land, which are generally adopted in considering sites within any of the legal frameworks discussed above, or when considering voluntary remediation action:

- Investigation of potentially contaminated sites – Code of Practice (British Standard 10175: 2011).
- Contaminated Land Report CLR11 Model Procedures for the Management of Land Contamination. (DEFRA and EA, 2004).
- Human health toxicological assessment of contaminants in soil Environment Agency Science Report SC050021/SR2 (EA, 2009).
- Updated technical background to the CLEA model Environment Agency Science Report SC050021/SR3 (EA, 2009).
- Compilation of Data for Priority Organic Pollutants for Derivation of Soil Guideline Values Environment Agency Science Report SC050021/SR7 (EA, 2008).
- An ecological risk assessment framework for contaminants in soil. Environment Agency Science Report SC070009/SR1 and related reports S2a-e.
- Groundwater Protection: Policy and Practice, Environment Agency GP3 Parts 1-4.

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

- Remedial Targets Methodology: Hydrogeological Risk Assessment for Land Contamination (EA of England and Wales, 2006) developed in consultation with the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Heritage and Environment Service.
- Assessing risks posed by hazardous ground gases to buildings Report C665 (CIRIA, 2007).
- BS 8485:2007 Code of practice for the characterization and remediation from ground gas in affected developments (British Standards Institution, 2007).
- Risk Based Corrective Action (RBCA) Methodology (ASTM designation E1739-95, E2081-00).
- DoE Industry Profiles.

APPENDIX B

Study Limitations

IMPORTANT: This section should be read before reliance is placed on any of the information, opinions, advice, recommendations or conclusions contained in this report.

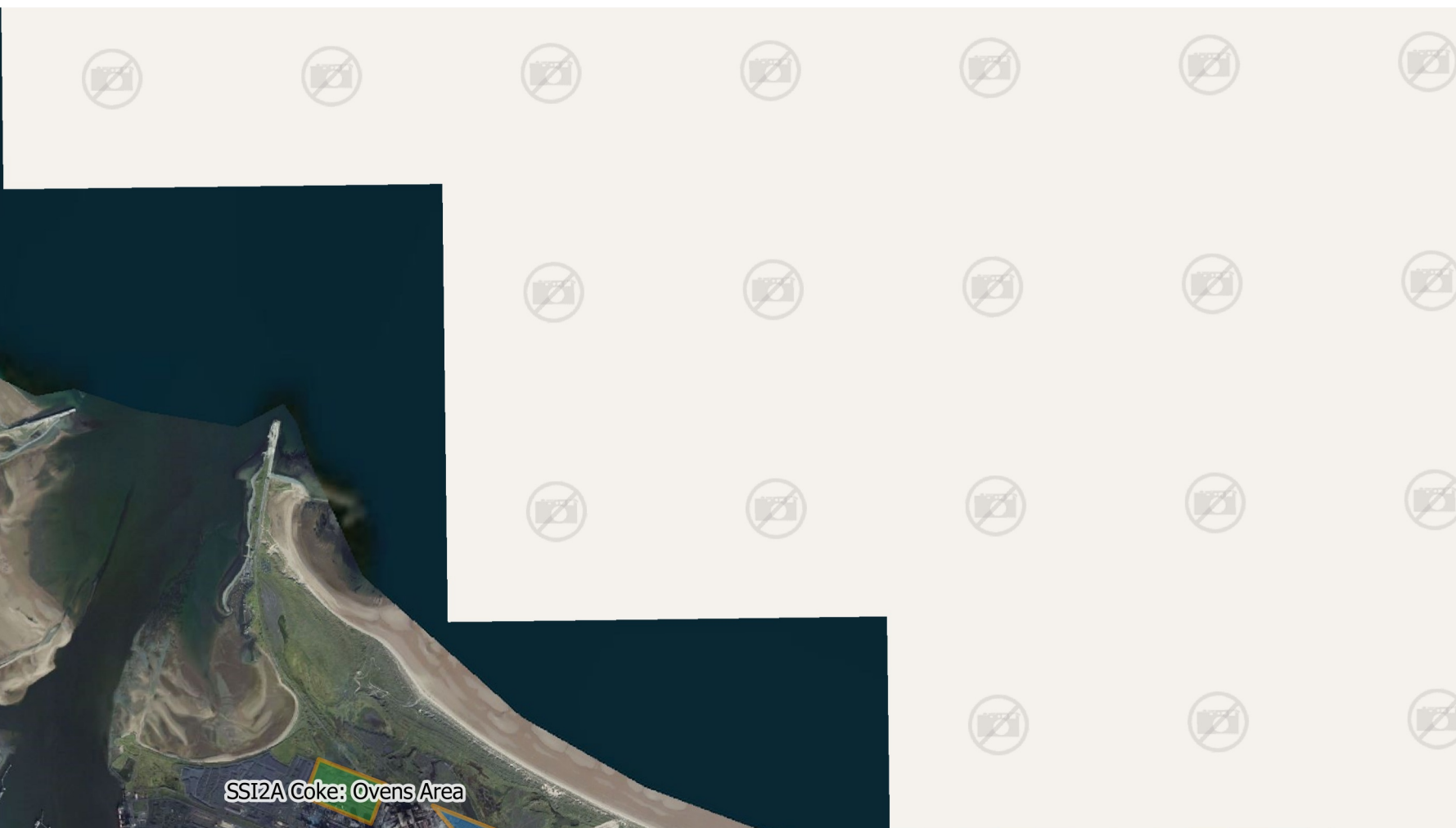
1. This report has been prepared by Arcadis UK Ltd (Arcadis), with all reasonable skill, care and diligence within the terms of the Appointment and with the resources and manpower agreed with **STSC** (the 'Client'). Arcadis does not accept responsibility for any matters outside the agreed scope.
2. This report has been prepared for the sole benefit of the Client unless agreed otherwise in writing.
3. Unless stated otherwise, no consultations with authorities or funders or other interested third parties have been carried out. Arcadis are unable to give categorical assurance that the findings will be accepted by these third parties as such bodies may have unpublished, more stringent objectives. Further work may be required by these parties.
4. All work carried out in preparing this report has used, and is based on, Arcadis' professional knowledge and understanding of current relevant legislation. Changes in legislation or regulatory guidance may cause the opinion or advice contained in this report to become inappropriate or incorrect. In giving opinions and advice, pending changes in legislation, of which Arcadis is aware, have been considered. Following delivery of the report, Arcadis have no obligation to advise the Client or any other party of such changes or their repercussions.
5. This report is only valid when used in its entirety. Any information or advice included in the report should not be relied upon until considered in the context of the whole report.
6. Whilst this report and the opinions made are correct to the best of Arcadis' belief, Arcadis cannot guarantee the accuracy or completeness of any information provided by third parties.
7. This report has been prepared based on the information reasonably available during the project programme. All information relevant to the scope may not have been received.
8. This report refers, within the limitations stated, to the condition of the Site at the time of the inspections. No warranty is given as to the possibility of changes in the condition of the Site since the time of the investigation.
9. The content of this report represents the professional opinion of experienced environmental consultants. Arcadis does not provide specialist legal or other professional advice. The advice of other professionals may be required.
10. Where intrusive investigation techniques have been employed they have been designed to provide a reasonable level of assurance on the conditions. Given the discrete nature of sampling, no investigation technique is capable of identifying all conditions present in all areas. In some cases, the investigation is further limited by site operations, underground obstructions and above ground structures. Unless otherwise stated, areas beyond the boundary of the site have not been investigated.
11. If below ground intrusive investigations have been conducted as part of the scope, service tracing for safe location of exploratory holes has been carried out. The location of underground services shown on any drawing in this report has been determined by visual observations and electromagnetic techniques. No guarantee can be given that all services have been identified. Additional services, structures or other below ground obstructions, not indicated on the drawing, may be present on Site.
12. Unless otherwise stated the report provides no comment on the nature of building materials,

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

operational integrity of the facility or on any
regulatory compliance issue

APPENDIX C

Figures



Notes:
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Title:
SS1 & SS12A Site Location Plan

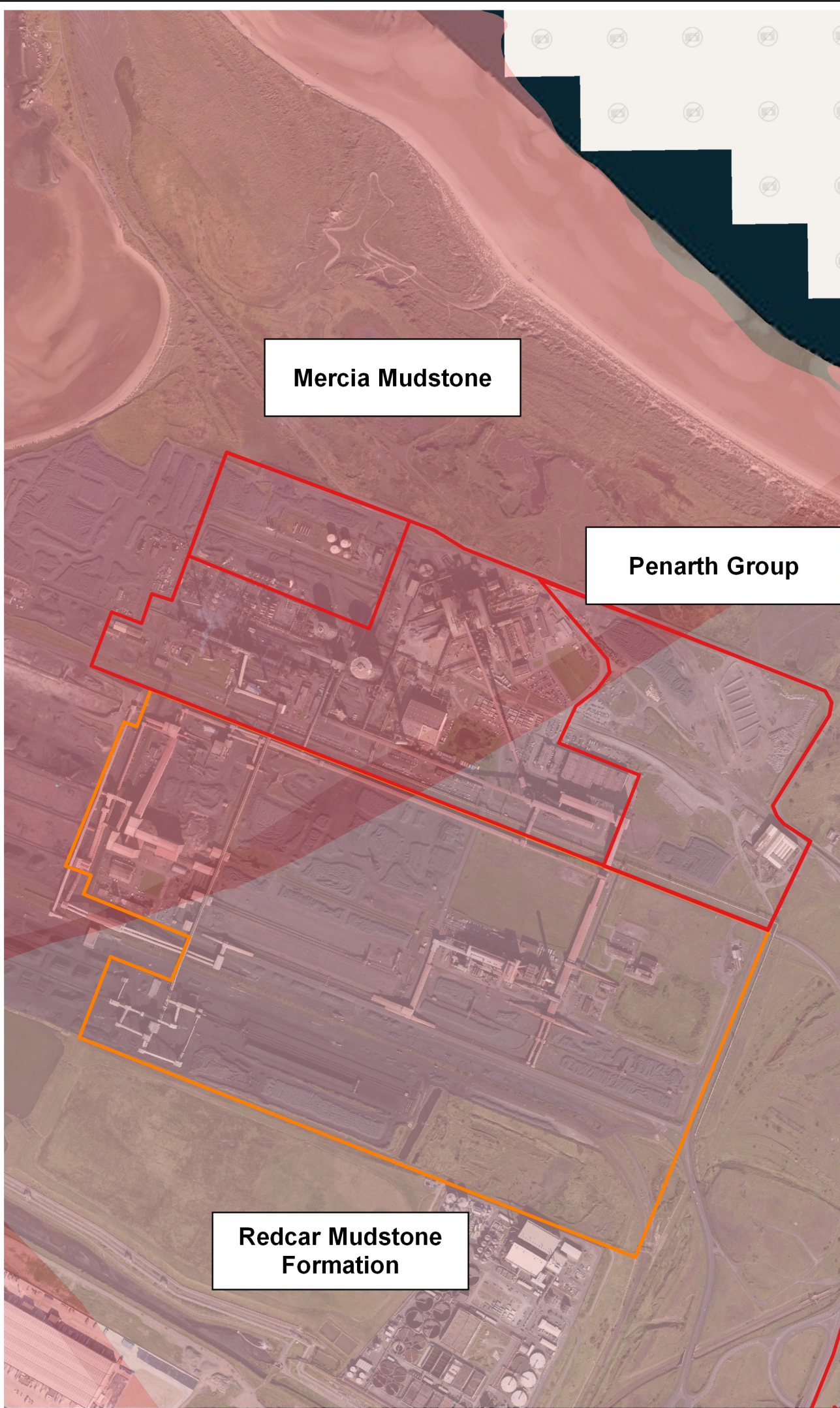
Site:
Redcar Steelworks

Client:
South Tees Site Company

Project: 37774100	Figure 1
----------------------	----------

Date: 02/05/2018
 Drawn By: JALM
 DRG No: 37774100_01_SS1_2A_Figure 1





Legend

Site Areas

- Contract 1
- Contract 2

Notes:

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CONTACT ARCADIS IN CASE OF ANY QUERIES.



Title:
SSI2B BGS Mapping

Site:
Redcar Steelworks

Client:
South Tees Site Company

Project:
37774100

Figure 2

Date: 30/04/2018
 Drawn By: JALM
 DRG No: 37774100_01_SSI1and 2A_Figure 2



Legend

Base of Made Ground Identified

- No (at depth m bgl)
- Yes (at depth m bgl)

Site Areas

- Contract 1
- Contract 2

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Note: Where boreholes have been installed through trial pits the top of the natural deposits (if identified) is taken from the trial pit log.



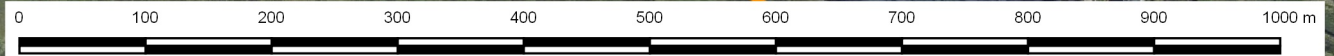
Title:
 SS11 & SS12A Made Ground Elevations (m AOD)

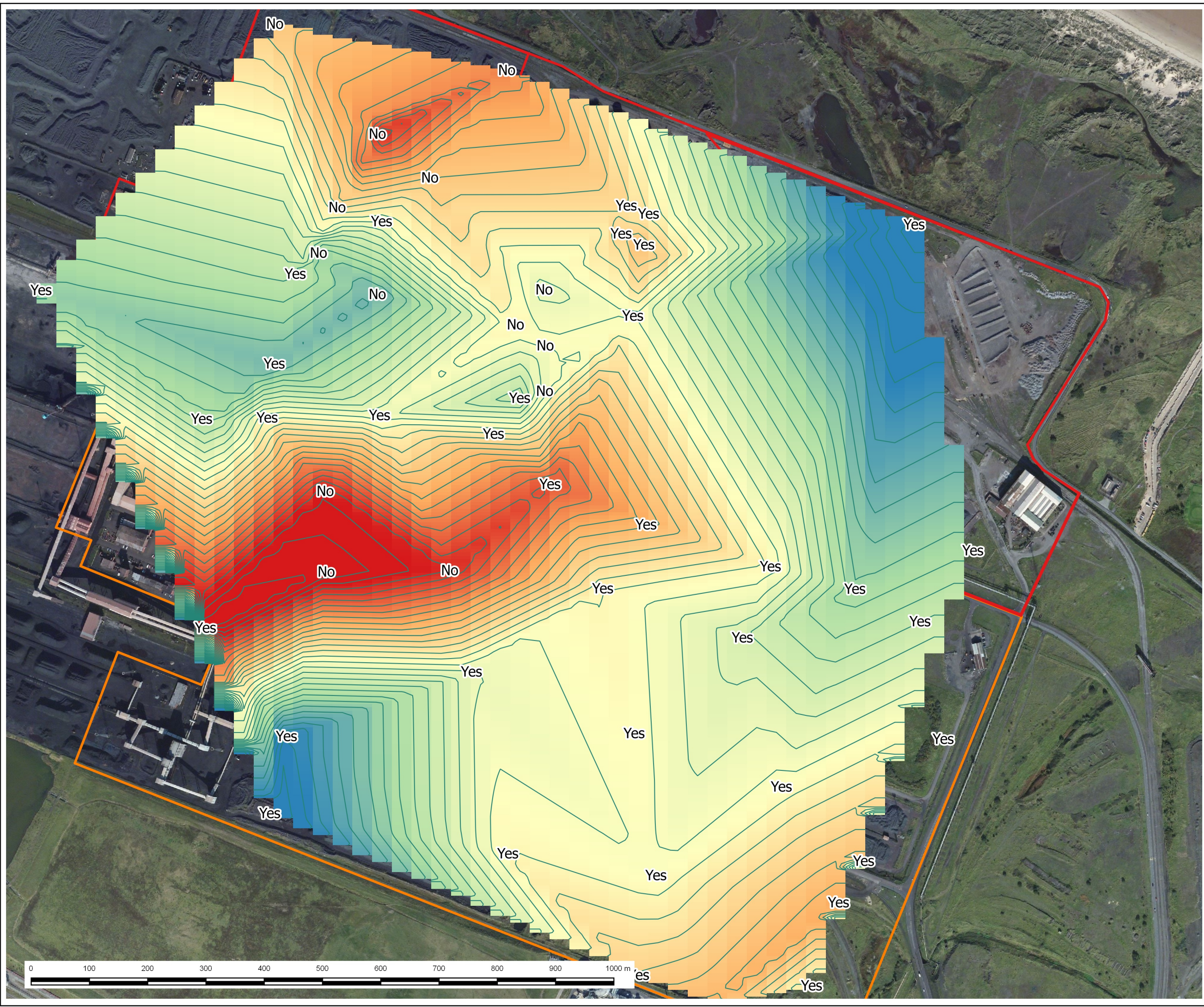
Site:
 Redcar Steelworks

Client:
 South Tees Site Company

Project: 37774100	Figure 3
----------------------	----------

Date: 02/05/2018
 Drawn By: JALM
 DRG No: 37774100_01_SS11_2A_Figure 3





Legend

SSI1 and SSI2

- Contour (0.5m Interval)

Rock Elev

- 17
- 13.7
- 10.3
- 6.94
- 3.59

Glacial Till Yes / No

Site Areas

- Contract 1
- Contract 2

Notes:

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CONTACT ARCADIS IN CASE OF ANY QUERIES.

Title:
SSI1 & SSI2A Rockhead and Glacial Till Deposits

Site:
Redcar Steelworks

Client:
South Tees Site Company

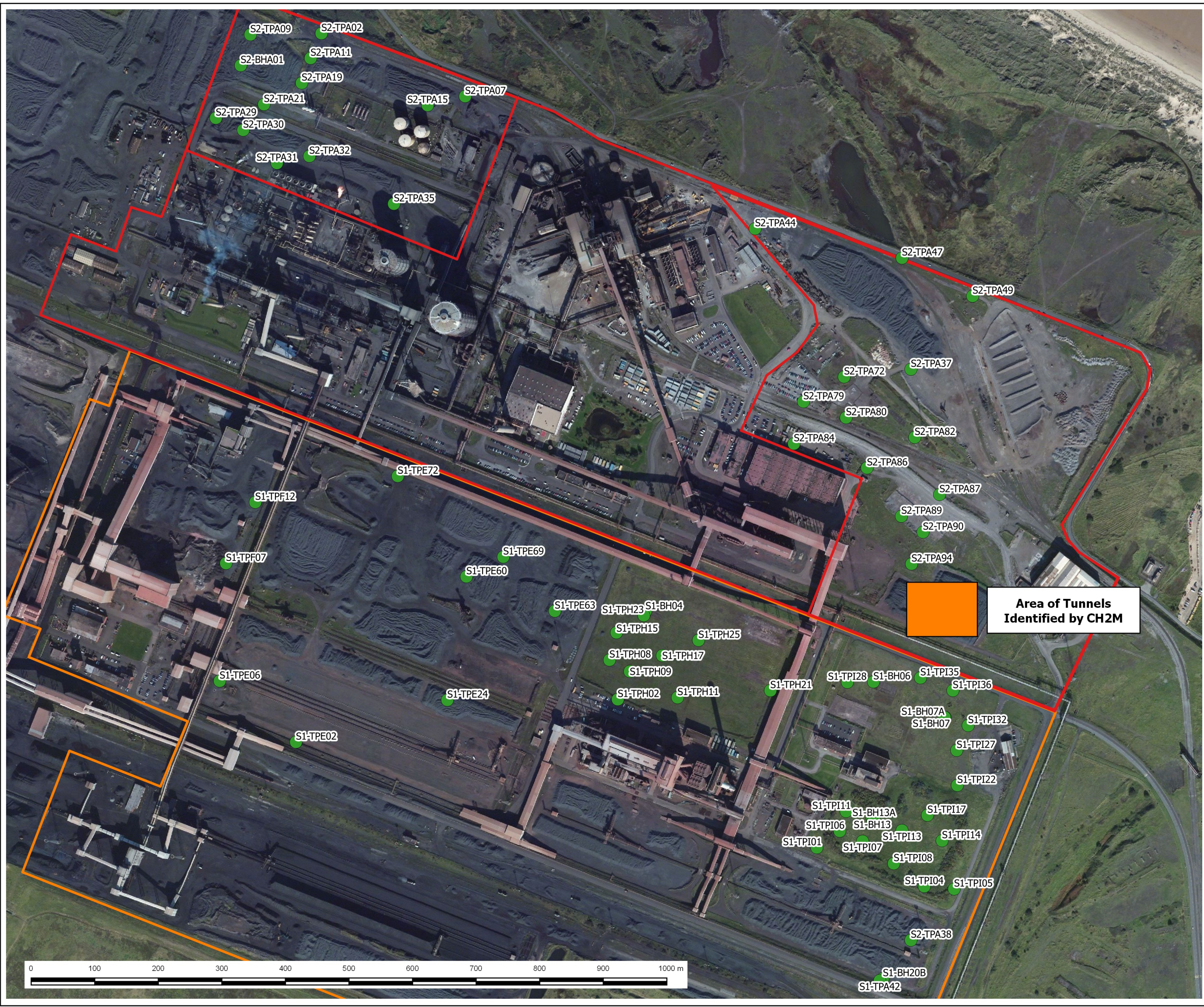
Project:
37774100

Figure 4

Date: 03/05/2018
 Drawn By: JALM
 DRG No: 37774100_01_SSI1_2A_Figure 4

ARCADIS Design & Consultancy for natural and built assets





Legend

Non-slag related obstruction

● Yes

Site Areas

▭ Contract 1

▭ Contract 2

Notes:

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CONTACT ARCADIS IN CASE OF ANY QUERIES.

Area of Tunnels Identified by CH2M



Title:
SS11 & SS12A Non-Slag Based Obstructions Identified In Trial Pits

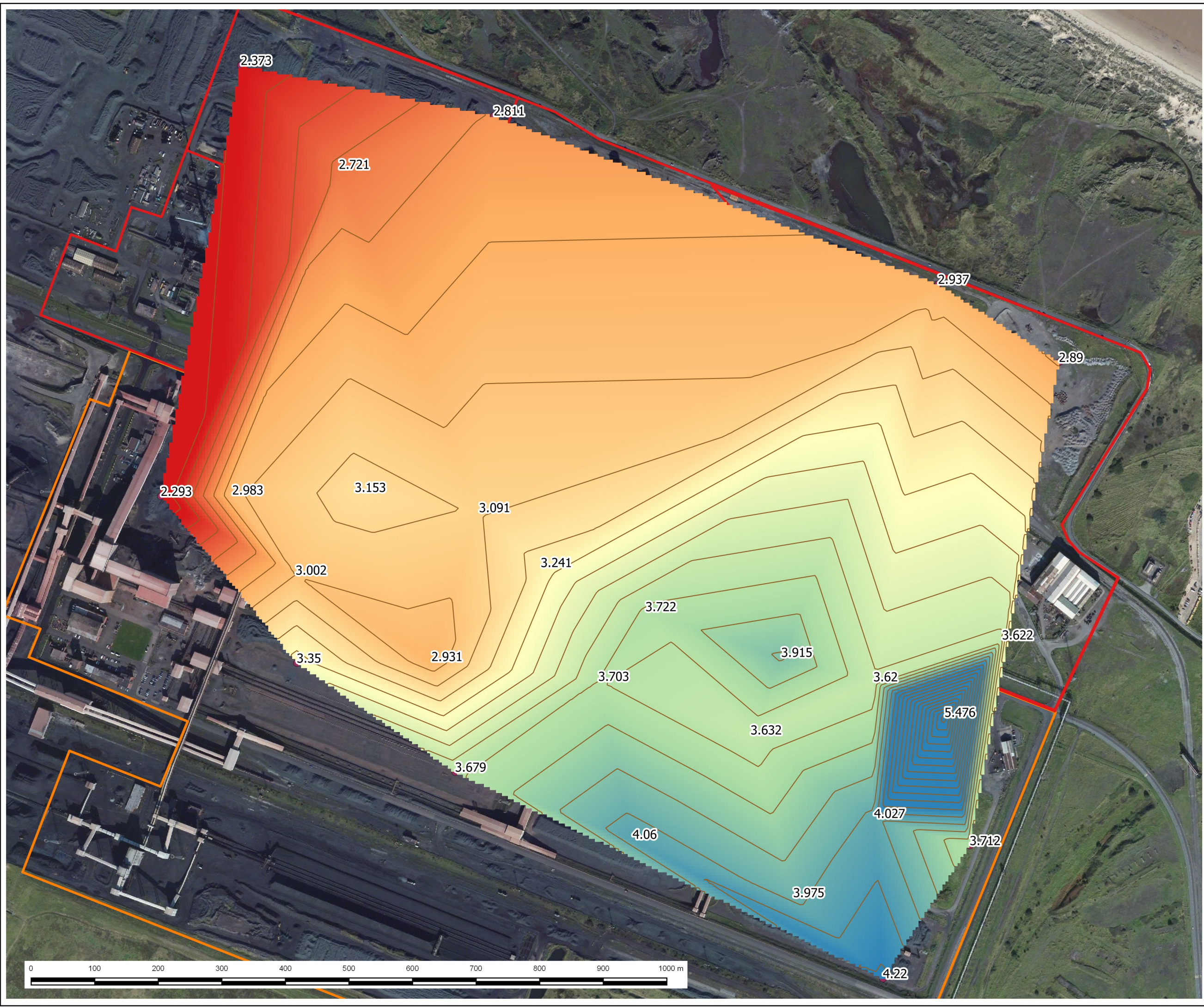
Site:
Redcar Steelworks

Client:
South Tees Site Company

Project:
37774100

Figure 5

Date: 02/05/2018
 Drawn By: JALM
 DRG No: 37774100_01_SS11_2A_Figure 14



Legend

SSI1 and SS12

— Interpolated Contour (0.10m)

Groundwater Elevation

- 2.44
- 2.88
- 3.32
- 3.77
- 4.21

Site Areas

- Contract 1
- Contract 2

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CONTACT ARCADIS IN CASE OF ANY QUERIES.

Note: Includes all wells screened fully or partially across the Made Ground, data collected during the second groundwater monitoring event.

Title:
SS11 & SS12A Groundwater Elevations and Flow Interpolation Made Ground Deposits (m AOD)

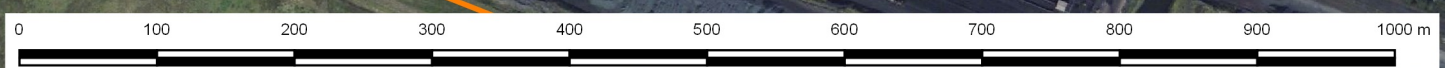
Site:
Redcar Steelworks

Client:
South Tees Site Company

Project: 37774100	Figure 6
-----------------------------	-----------------

Date: 03/05/2018
 Drawn By: JALM
 DRG No: 37774100_01_SSI1_2A_Figure 5

ARCADIS Design & Consultancy for natural and built assets





Legend

Site Areas

- Contract 1
- Contract 2

Notes:

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CONTACT ARCADIS IN CASE OF ANY QUERIES.

Not Shown:
 PAOC1 - Made Ground
 PAOC - Waste Materials
 PAOC3 - Ground gas from Tidal Flat and Glaciolacustrine Deposits



Title:
 SS1 & SS1A Potential Areas of Concern

Site:
 Redcar Steelworks

Client:
 South Tees Site Company

Project: 37774100	Figure 7
----------------------	----------

Date: 1/05/2018
 Drawn By: JALM
 DRG No: 37774100_01_SS1_2A_Figure 7



PAOC67a Embankment

Potential Human Health SPR Linkages

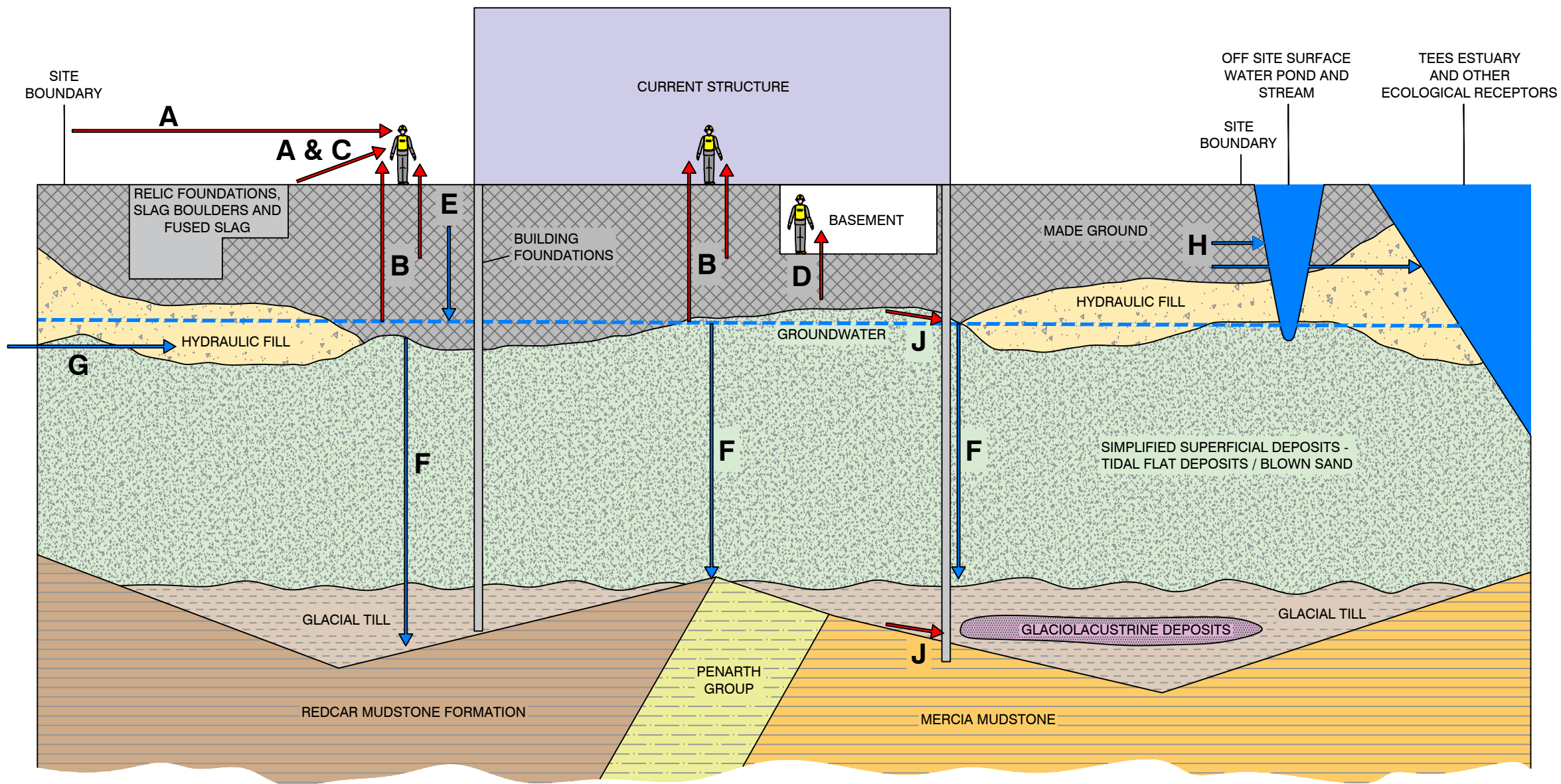
- A = Dust inhalation from Made Ground from site and adjacent land
- B = Vapour inhalation of indoor or outdoor air from contaminated soil and or groundwater
- C = Direct contact and ingestion
- D = Accumulation of ground gas in confined spaces
- SPR linkages for construction workers during redevelopment not shown

Potential Water Resource SPR Linkages

- E = Leaching of contaminants from Made Ground and other sources to groundwater in superficial deposits
- F = Migration of contaminated groundwater to Secondary Aquifers in bedrock
- G = Migration of contaminated groundwater onto site in Made Ground and Superficial Deposits
- H = Migration of contaminated groundwater into off site surface water features and Tees Estuary via Made Ground and Superficial Deposits

Other SRP Linkages

- J = Attack by contaminants of concern on foundations



KEY

NOTES

SCHEMATIC DRAWING ONLY - NOT TO SCALE

REV	DATE	COMMENT	CAD

TITLE: CONCEPTUAL SITE MODEL - SS1 AND SS2A

SITE: REDCAR

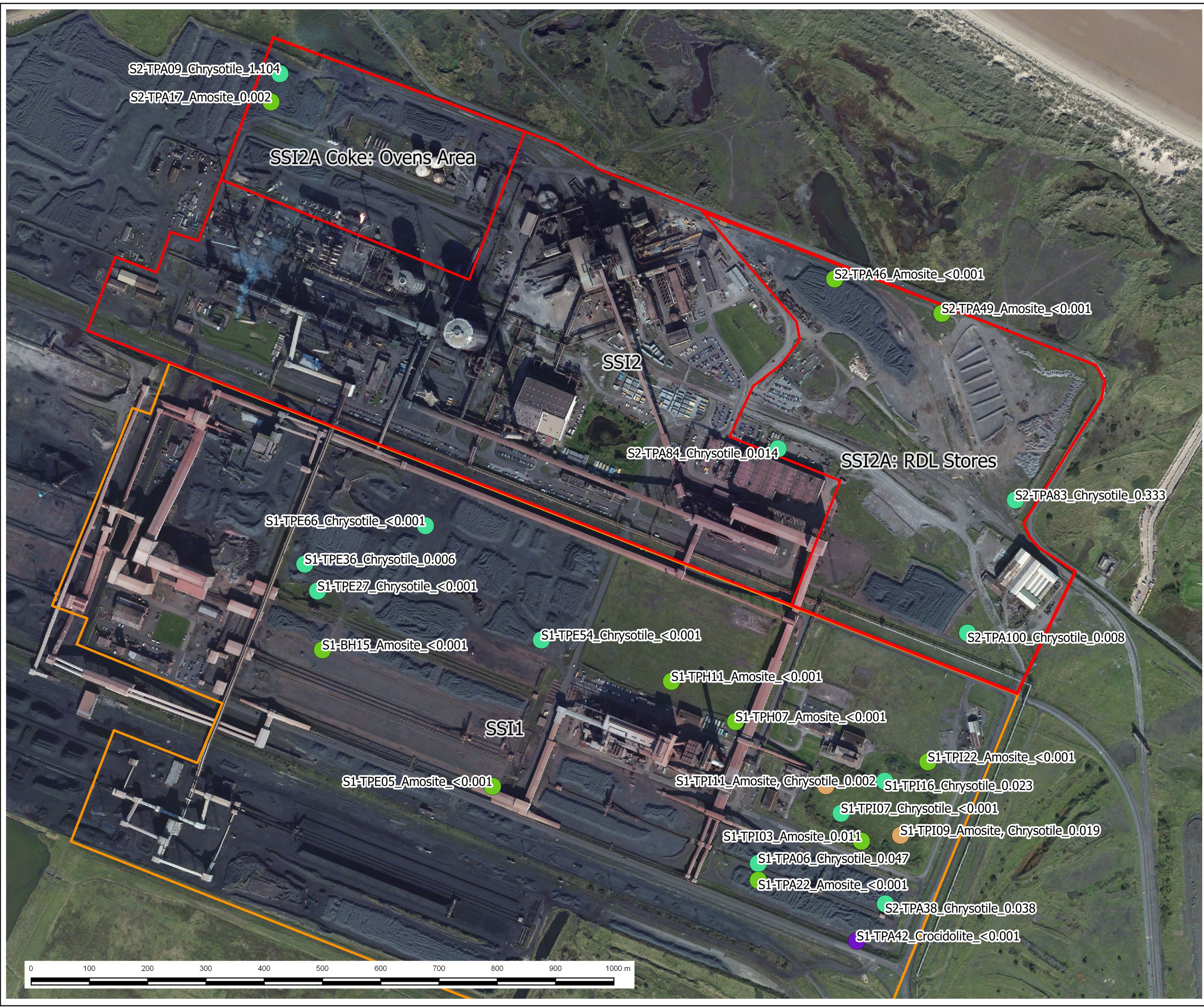
CLIENT: STSC

PROJECT: 10013655 FIGURE 8

DATE: 19/04/18 DRAWN: BNB REV: -

DRG.No.: 10013655_CSM_4 PRINT: A3





- ### Legend
- #### SSI1 and SSI2
- Asbestos Testing Results
- Amosite
 - Amosite, Chrysotile
 - Chrysotile
 - Crocidolite
 - No Fibres Detected
- Site Areas
- Contract 1
 - Contract 2

Notes:

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CONTACT ARCADIS IN CASE OF ANY QUERIES.

Format: Location_ID_Asbestos Type_% Composition



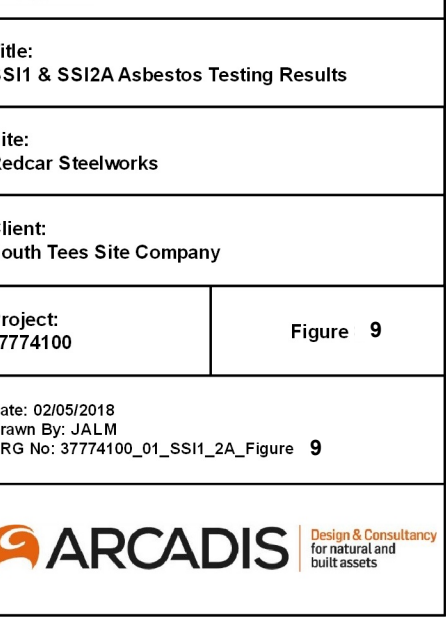
Title:
SSI1 & SSI2A Asbestos Testing Results

Site:
Redcar Steelworks

Client:
South Tees Site Company

Project: 37774100	Figure 9
-----------------------------	-----------------

Date: 02/05/2018
 Drawn By: JALM
 DRG No: 37774100_01_SSI1_2A_Figure 9



Slag Dominant Made Ground

Granular Made Ground

Legend

SSI1 and SSI2

Chromium in Made Ground

- Chromium (MDL - <100 mg/kg)
- Chromium (100 - <500 mg/kg)
- Chromium (>500 mg/kg)

Site Areas

- Contract 1
- Contract 2

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CONTACT ARCADIS IN CASE OF ANY QUERIES.

Note: Two data points from different depth in the same location are linked by grey circles.



Title:
Chromium Levels in Made Ground Soils SSI1 and 2A

Site:
Redcar Steelworks

Client:
South Tees Site Company

Project:
37774100

Figure 10

Date: 02/05/2018
Drawn By: JALM
DRG No: 37774100_01_SSI1_2A_Figure_10



Slag Dominant Made Ground

Granular Made Ground

Legend

SSI1 and SSI2

Lead in Made Ground

- Lead (MDL - <100 mg/kg)
- Lead (100 - <500 mg/kg)
- Lead (>500 mg/kg)

Site Areas

- Contract 1
- Contract 2

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CONTACT ARCADIS IN CASE OF ANY QUERIES.

Note: Two data points from different depth in the same location are linked by grey circles.



Title:
Lead Levels in Made Ground Soils SSI1 and 2A

Site:
Redcar Steelworks

Client:
South Tees Site Company

Project:
37774100

Figure 11

Date: 02/05/2018
Drawn By: JALM
DRG No: 37774100_01_SSI1_2A_Figure_11



Slag Dominant Made Ground

Granular Made Ground

Legend

SSI1 and SSI2

Vanadium in Made Ground

- Vanadium (MDL - <100 mg/kg)
- Vanadium (100 - <500 mg/kg)
- Vanadium (>500 mg/kg)

Site Areas

- Contract 1
- Contract 2

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CONTACT ARCADIS IN CASE OF ANY QUERIES.

Note: Two data points from different depth in the same location are linked by grey circles.



Title:
Vanadium Levels in Made Ground Soils SSI1 and 2A

Site:
Redcar Steelworks

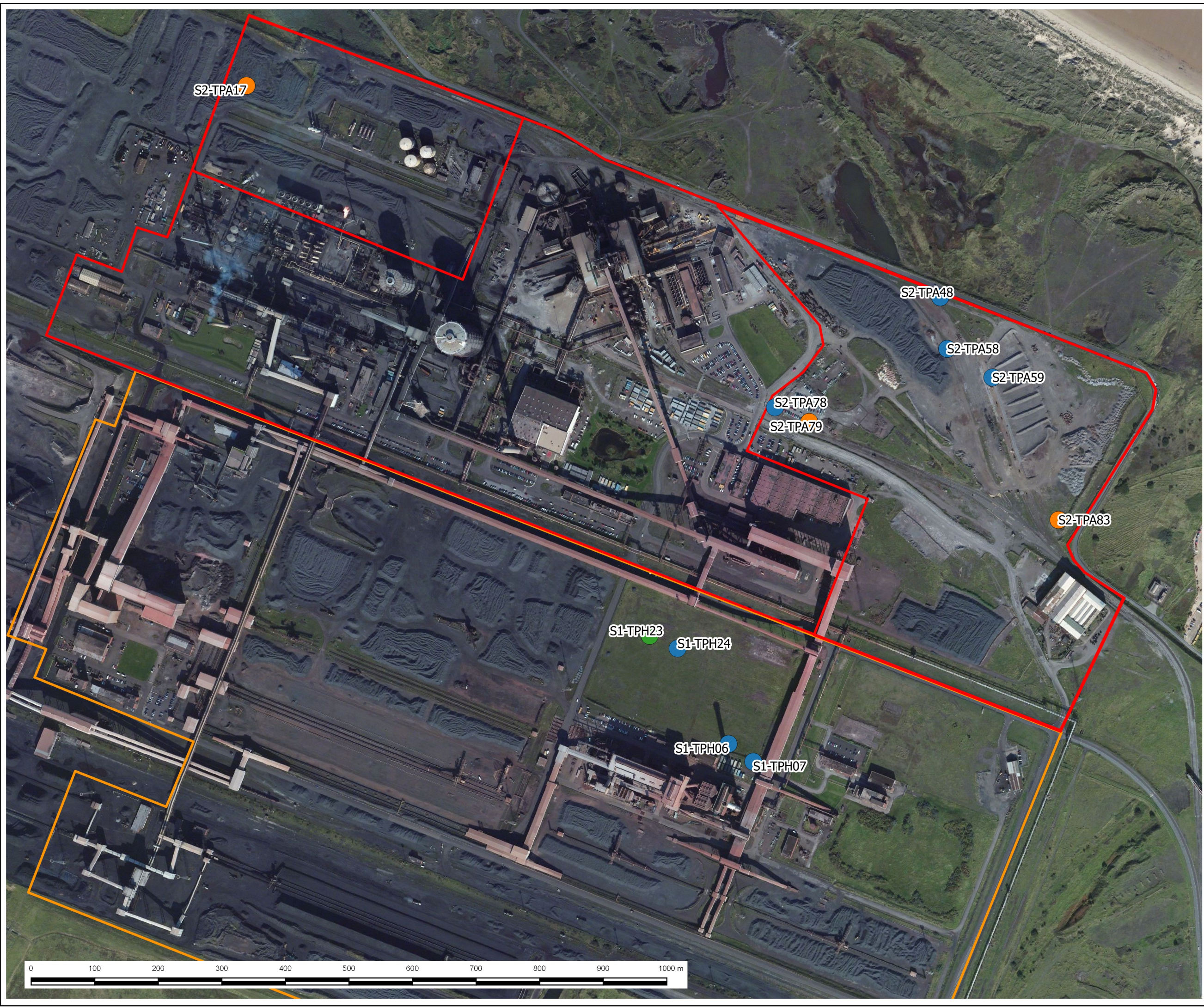
Client:
South Tees Site Company

Project:
37774100

Figure 12

Date: 02/05/2018
Drawn By: JALM
DRG No: 37774100_01_SSI1_2A_Figure_12





Legend

SSI1 and SSI2

Area of Elevated Hydrocarbons

- Elevated TPH
- Elevated PAH
- Elevated TPH and PAH

Site Areas

- Contract 1
- Contract 2

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Title:
SSI1 & SSI2A Areas of Elevated Hydrocarbons

Site:
Redcar Steelworks

Client:
South Tees Site Company

Project:
37774100

Figure 13

Date: 02/05/2018
Drawn By: JALM
DRG No: 37774100_01_SSI1_2A_Figure_ 13



Legend

SSI1 and SSI2

Sulphate in Groundwater

- Sulphate (MDL - <math>< 500 \text{ mg/l}</math>)
- Sulphate (<math>500 - < 1000 \text{ mg/l}</math>)
- Sulphate ($> 1000 \text{ mg/l}$)

Site Areas

- Contract 1
- Contract 2

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CONTACT ARCADIS IN CASE OF ANY QUERIES.



Title:
SSI1 & SSI2A Sulphate Concentrations in Groundwater

Site:
Redcar Steelworks

Client:
South Tees Site Company

Project: 37774100	Figure 14
----------------------	-----------

Date: 02/05/2018
 Drawn By: JALM
 DRG No: 37774100_01_SSI1_2A_Figure 14



APPENDIX D

Trial Pit Investigation Summary

Excavation Summary - Taken from the AEG Factual report

Exploratory Hole Number	Excavation Method	Completion Depth (m BGL)	Remarks
S2-TPA09	Machine excavated	4.50	Advanced to required depth.
S2-TPA10	Machine excavated	4.50	Advanced to required depth.
S2-TPA17	Machine excavated	4.50	Advanced to required depth.
S2-TPA18	Machine excavated	4.50	Advanced to required depth.
S2-TPA21	Machine excavated	4.50	Advanced to required depth.
S2-TPA31	Machine excavated	3.20	Terminated due to encountering flat concrete surface.
S2-TPA32	Machine excavated	3.10	Terminated due to encountering flat concrete surface.
S2-TPA33	Machine excavated	2.50	Terminated due to sides collapsing.
S2-TPA34	Machine excavated	4.00	Terminated due to sides collapsing.
S2-TPA35	Machine excavated	2.20	Terminated due to encountering an obstruction.
S2-TPA36	Machine excavated	4.50	Advanced to required depth.
S2-TPA37	Machine excavated	2.40	Terminated due to encountering an obstruction.
S2-TPA38	Machine excavated	1.80	Terminated due to encountering an obstruction.
S2-TPA39	Machine excavated	4.20	Unable to progress due to reach of bucket.
S2-TPA40	Machine excavated	4.30	Advanced to required depth.

Field Screening Summary - Taken from the AEG Factual Report

Exploratory Hole Number	Occurrence (in-situ/surface/laboratory sample)	Visual / Olfactory / Laboratory Testing	Depth (m BGL)	Occurrence Type	Additional Remarks
S1-BH12	<i>In-situ</i>	Olfactory	0.00-4.80	Slight hydrocarbon odour noted	None
S1-BH14	<i>In-situ</i>	Olfactory	4.00-8.00	Slight hydrocarbon odour noted	None
S2-BHA1	<i>In-situ</i>	Olfactory	0.00-5.90	Hydrocarbon/creosote odour noted	None
S2-TPA09	<i>In-situ</i>	Olfactory	1.40-2.00	Strong creosote odour	None
S2-TPA17	<i>In-situ</i>	Olfactory	0.30-1.50	Strong creosote odour	None
S2-TPA17	<i>In-situ</i>	Visual and olfactory	3.30	Tar noted in gravels. Strong creosote odour	None
S2-TPA33	<i>In-situ</i>	Olfactory	0.00-0.30	Ammonia odour noted	None
S2-TPA34	<i>In-situ</i>	Olfactory	0.00-2.70	Ammonia odour noted	None
S2-TPA35	<i>In-situ</i>	Olfactory	0.30-1.80	Ammonia odour noted	None
S2-TPA38	<i>In-situ</i>	Olfactory	0.00-1.80	Sulphurous odour noted throughout and possible ammonia odour noted	None
S2-TPA39	<i>In-situ</i>	Olfactory	2.80	Sulphurous odour noted throughout and possible ammonia odour noted	None
S2-TPA40	<i>In-situ</i>	Olfactory	0.00-0.10	Ammonia odour noted	None
S2-TPA40	<i>In-situ</i>	Olfactory	0.10-4.30	Sulphurous odour noted	None

Field Screening Summary - Taken from the CH2M Trial Pit Logs

Location	Evidence
S1-TPA06	Slight hydrocarbon odour
S1-TPA42	Hydrocarbon odour
S1-TPC10	Tar deposits
S1-TPA14	Highly plastic odour
S1-TPE06	Oily residue inside service
S1-TPE32	Hydrocarbon odour
S1-TPE37	Oil coming in at base of pit
S1-TPE60	Oil odour
S1-TPE75	Hydrocarbon odour
S1-TPH07	Waste materials, oil contamination.
S1-TPH11	Slight hydrocarbon odour, waste materials
S1-TPH23	Hydrocarbon odour
S1-TPH24	Slight hydrocarbon odour
S1-TPH25	Hydrocarbon odour
S1-TPI03	Hydrocarbon odour
S1-TPI12	Creosote and hydrocarbon odour
S2-TPA08	Tar odour
S2-TPA09	Tar in pit/strong creosote odour
S2-TPA17	Creosote odour and tar in gravel from 3.3m bgl.
S2-TPA45	Slight hydrocarbon odour
S2-TPA48	Slight hydrocarbon odour
S2-TPA53	Possible tar pockets
S2-TPA58	Hydrocarbon odour at 1m
S2-TPA59	Strong hydrocarbon odour
S2-TPA61	Slight hydrocarbon sheen
S2-TPA62	Slight oil sheen at water level
S2-TPA68	Hydrocarbon odour

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

Location	Evidence
S2-TPA69	Slight hydrocarbon odour
S2-TPB24	Strong hydrocarbon odour in natural

APPENDIX E

Summary of PAOC

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

PAOC ID	Source ID	Site	Type	Location	General Description	Specific Details	Data Source / Dates	Risk Level	Point or Material Source	On- / off-site	CoC
PAOC1	n/a	All areas	Made Ground	Site Wide	Likely to be several metres thick due to land raising and to comprise variety of materials including slag waste.	-	CH2M Desk Study, Industry profiles, Arcadis site observations	High	Material	On-site	Various metals, PAHs, asbestos, sulphates, pH, carbon dioxide, methane and hydrogen sulphide.
PAOC2	n/a	All areas	Waste materials	Site Wide	Authorised and historic landfills in close proximity to the site.	-	CH2M Desk Study, Industry profiles, Arcadis site observations	High	Material	Off-site	Carbon dioxide, methane and hydrogen sulphide
PAOC3	n/a	Most areas	Tidal Flat / Glaciolacustrine Deposits	Site Wide	Potential source of permanent ground gas	-	CH2M Desk Study, Industry profiles, Arcadis site observations	High	Material	On-site	Carbon dioxide, methane and hydrogen sulphide
PAOC4	4a	SSI2A	Historic steel plant and coil processing plant	Between blast furnace and ponding area	Pre-1970s was cleared from site, however, there is evidence that below ground structures associated with this former development are still present. In addition, contamination associated with these processes could also still be present. Potentially contaminative activities could include refractory wastes, coking wastes, fuels and oils, slag wastes and asbestos. A small tar and macadam works is shown associated with these structures on historical maps.	The former Ironworks/Steel works (pre 1970s) have been cleared from the site however, the potential for contamination associated with these processes cannot be discounted. Many of the activities were potentially contaminative and which could include, refractory wastes, coking wastes, fuels and oils, slag wastes and asbestos.	CH2M desk study, historical maps, Industry profiles	Very high risk	Point / Material	On-site	Diesel/petrol/oil/coal tar PCBs from transform oil Metals, asbestos, PAHs, phenols, sulphates Ammoniacal liquor
	4b	SSI2A									
	4c	SSI2A									

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

PAOC ID	Source ID	Site	Type	Location	General Description	Specific Details	Data Source / Dates	Risk Level	Point or Material Source	On- / off-site	CoC
PAOC5	n/a	SSI2	Blast furnace	To the east of coke ovens area	The iron was processed together with coke and fluxes (typically limestone). The high operating temperature of the blast furnace (1,500°C) decomposes the limestone to calcium oxide which reacts with the ore to form a liquid slag that subsequently solidified. Flue dusts (containing cyanide compounds and heavy metals) were also another waste product.	The Blast Furnace is to the east of the stocking areas. On its western side is the waste water Clarifier, with Bag Filter Plants located either side. The Hot Metal (railway) Track runs through the centre of the Blast Furnace, connecting it with the Basic Oxygen Steel (BOS) Plant in the SSI3 site area. The track also connects to tracks and siding running along the northern and eastern perimeters of SSI2. Railway ballast is of slag, with ketch (a waste product of the iron making process); scattered around the area of the Blast Furnace. The Slag Quencher Pump House and associated water pits and tanks are located north of the Blast Furnace, with Slag Pits to the northeast and southwest sides. Stores, workshops, garages and Cooling Plant are located east of the Blast Furnace, as well as a concrete bunded Fuel Oil Tank Farm and fuel loading area. Intermediate bulk containers for waste oil were noted within a former car parking area.	CH2M Desk Study, Industry profiles, Arcadis site observations	Very high risk	Point	Off-site	Organic/inorganic compounds, asbestos, metals, sulphates, sulphides, PCBs, flue dust, coal dust.
PAOC6	n/a	SSI2	Coke ovens	To the south of coke ovens area and to the north of SSI1	The manufacturing of coke from coal involves the carbonisation of coal at high temperatures in an oxygen-deficient atmosphere in order to concentrate the carbon. The process removed tar, ammonia, phenol, naphthalene, light oil and sulphur.	-	CH2M Desk Study, Industry profiles, Arcadis site observations	Very high risk	Point	Off-site	Organic/inorganic compounds, asbestos, PCBs, coal tar

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

PAOC ID	Source ID	Site	Type	Location	General Description	Specific Details	Data Source / Dates	Risk Level	Point or Material Source	On- / off-site	CoC
PAOC7	n/a	SSI2	By-products processing plant	South of by-products plant and coke stocking area	A by-product of the coal carbonisation process is off gas which was collected and sent to the by-products plant.	"Gas produced by the process was cleaned and treated in the By-Products Plant located adjacent to the north. Access to this area was restricted at the time of inspection. The resulting clean gas was stored within two large gas holders, east of the By-Products Plant and use in the Blast Furnace, Power Station, or as fuel elsewhere within the wider SSI site. The gas was transported via the elevated Coke Oven Gas Main, a section of which runs parallel to the southern boundary of SSI2. Condensate pits are periodically located along its length."	CH2M Desk Study, Industry profiles, Arcadis site observations	Very high risk	Point	Off-site	Organic/inorganic compounds, asbestos
PAOC8	n/a	SSI2	Coke oven gas main	Runs along the north and eastern boundaries of SSI1, with a spur of pipe running along the access road between the TMO and Sinter Plant, the pipe provides gas to the sinter plant.	High energy gas was a by-product of the coke oven process which after quenching and treatment to remove impurities was recycled and used to fuel boilers and furnaces elsewhere on site. Coke oven gas is toxic in its unburnt state consisting mainly of hydrogen (52%) and methane (32%) and approximately 5.5% of carbon monoxide.	Coke Oven gas is also a pyrophoric substance i.e. it will ignite spontaneously in air at or below 55°C without an ignition source being required. This did not pose a risk during service as there was no air present within the pipework. However, during periods of maintenance, there were reported numerous occasions where the COG mains have been opened, allowing air to enter, resulting in fires. The pyrophoric materials are caused when internal corrosion takes place within the steel constructed gas mains caused by corrosive products in the gas. This results in the formation of iron sulphide, the pyrophoric material. Other products, such as naphthalene, are not pyrophoric but are flammable. Therefore, the self-ignition source of the iron sulphide will then ignite the naphthalene, resulting in an internal gas mains fire. SSI UK RCO 2016 reports that the gas distribution systems on the entire site contain many hundreds of tonnes of flammable deposits, along with pyrophoric materials. If left unmanaged, there is a risk of air ingress resulting in spontaneous fires across the site. In addition, the condensate pits located along the route of the gas main may represent areas of potential spillage/leakage.	SSI UK RCO 2016	High	Point	off-site	tar vapours, BTEX, Iron sulphide (pyrophoric material), naphthalene, ammonia gas, hydrogen sulfide gas, hydrogen cyanide gas
PAOC9	9a	SSI2	Substation	By-products plant	PCBs were routinely used as in insulator in electricity substation	11kV		Moderate	Point	On-site	PCBs, Metals, Asbestos

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

PAOC ID	Source ID	Site	Type	Location	General Description	Specific Details	Data Source / Dates	Risk Level	Point or Material Source	On- / off-site	CoC	
	9b	SSI2		Blast Furnace	prior to the 1980s. The PCBs were generally of high viscosity and low leaching potential, and therefore contamination is expected to be localised.	11kV	CH2M Desk Study, Industry profiles, Arcadis site observations					
	9c	SSI2		Blast Furnace		11kV						
	9d	SSI2		Coke ovens		66kV						
	9e	SSI2		Coke ovens		11kV						
	9f	SSI2		Coke ovens		11kV						
	9g	SSI1		NW corner		HV						
	9h	SSI1		W end		HV						
	9i	SSI1		W end		HV						
	9j	SSI1		E end		HV						
	9k	SSI1		E end		HV						
	9l	SSI1		E end		HV						
	9m	SSI2		Redcar stores		11kV						
	9n	SSI1		Within PAOC26		HV						
	PAOC10	n/a		SSI2		Coke stocking area						North of coke ovens and by-products plant
PAOC11	11a and 11b	SSI1	Workshop	Within PAOC23 and 26	Use of chemicals and materials in equipment/facility maintenance at workshops		CH2M Desk Study, Industry profiles, Arcadis site observations	Moderate	Point	On-site	Organic/inorganic compounds, SVOC's, VOC's and asbestos	
PAOC12	12a	SSI2	Existing Tanks/Storage	Fuel oil tank farm	Various fuel storage areas are present within the site area. The main fuel tanks were removed from service prior to SSI purchase of the site but the tanks were not fully emptied.	Fuel storage area for use in blast furnace (x3 5,000,000L tanks and x1 2,000,000L waste oil tank)	SSI SR 2016	Very high	Point	on-site	Organic/inorganic compounds, hydrocarbons	
	12b			CRYOS butane plant		Liquid nitrogen storage area	CH2M Desk Study, Industry profiles, Arcadis site observations	High	Point	on-site	organic/inorganic compounds	
	12c											
	12d											
	12e			Blast Furnace		SEE HISTORIC PLANS	CH2M Desk Study, Industry profiles, Arcadis site observations	High	Point	off-site	Assumed hydrocarbons, inorganic compounds, VOCs, SVOC	
	12f					SEE HISTORIC PLANS						
	12g					SEE HISTORIC PLANS						
	12h					SEE HISTORIC PLANS						
	12i			By-products plant		SEE HISTORIC PLANS	CH2M Desk Study, Industry profiles, Arcadis site observations	High	Point	off-site	Assumed hydrocarbons, inorganic compounds, VOCs, SVOC	
	12j					SEE HISTORIC PLANS						
	12k					SEE HISTORIC PLANS						
12l		SEE HISTORIC PLANS										

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

PAOC ID	Source ID	Site	Type	Location	General Description	Specific Details	Data Source / Dates	Risk Level	Point or Material Source	On- / off-site	CoC
	12m			Blast Furnace		SEE HISTORIC PLANS	CH2M Desk Study, Industry profiles, Arcadis site observations	High	Point	off-site	Assumed hydrocarbons, inorganic compounds, VOCs, SVOC
	12n					Blast furnace gas storage tank					
	12o					SEE HISTORIC PLANS					
	12p					SEE HISTORIC PLANS					
	12q					SEE HISTORIC PLANS					
	12r					SEE HISTORIC PLANS					
	12s	SSI1	Existing Tanks	Sinter plant (E end)	Various fuel storage areas are present within the site area. The main fuel tanks were removed from service prior to SSI purchase of the site but the tanks were not fully emptied.	Diesel tank - 200 tonnes of diesel stored in concrete bund in 2012.	Envirocheck 1986-2012	High	Point	on-site	Hydrocarbons
	12t				1 smaller tank	-	-	High	Point	on-site	Unknown
	12u			PAOC22 pellet plant	2 tanks	-	-	High	Point	on-site	Unknown
	12v		Historical Tanks		West of PAOC28	-	-	Envirocheck 1982	High	Point	on-site
12w				Within PAOC24	-	-	Envirocheck 1986	High	Point	on-site	Unknown
12x				North West of PAOC29	-	-	Envirocheck 1954	High	Point	on-site	Unknown
12y				West of PAOC29	-	-	Envirocheck 1954	High	Point	on-site	Unknown
12z	Historical Tanks			within PAOC23	-	Diesel tank 25 tonnes	Envirocheck 2012	High	Point	on-site	Hydrocarbons
12ab	SSI2		Existing tanks		Diesel	65 tonnes	Site Plans	High	Point	on-site	Hydrocarbons
12ac	SSI2	Existing tanks		Propane	1.75 tonnes	Site Plans	Low	Point	on-site	Hydrocarbon residues	
12ad	SSI2	Existing tanks		Diesel	5 tonnes	Site Plans	High	Point	on-site	Hydrocarbons	
PAOC13	13a	SSI2	Historical Tanks	Redcar Stores	SEE site constraints plan	Contents unknown	CH2M Desk Study, Industry profiles, Arcadis site observations	Moderate	Point	on-site	Assumed hydrocarbons, inorganic compounds, VOCs, SVOC
	13b					Contents unknown		Moderate			
	13c			Maintenance workshop and stores		Contents unknown		Moderate	Point	off-site	Assumed hydrocarbons, inorganic compounds, VOCs, SVOC
	13d					Contents unknown		Moderate			
	13e					Contents unknown		Moderate			

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

PAOC ID	Source ID	Site	Type	Location	General Description	Specific Details	Data Source / Dates	Risk Level	Point or Material Source	On- / off-site	CoC
PAOC14	n/a	All	Site roads / car parks	Site wide	These routes represent a potential source of contamination as a result of spillages.	-	n/a	Low	Point	on-site	Metals, asbestos, hydrocarbons, inorganics
PAOC15	n/a	SSI2	Ramming Paste	Waste ground close to fitting workshop	Report of a material called 'Ramming Paste' (33 tonnes), a reported carcinogen. The status of this material remains to be confirmed.	Anecdotal evidence is that this was stored in barrels and has since been removed from site.	SSI UK RBF 2016 (appendix C3 to desk study)	-	Material	off-site	-
PAOC16	16a	SSI2	Redcar Stores	SE corner SSI2 A, south of ponding area	The site included numerous offices and stores that could have contained contaminative materials such as asbestos, organic materials and chemicals.	Also included associated historic / current storage tanks	CH2M Desk Study, Industry profiles, Arcadis site observations	Moderate	Point	on-site	Organic/inorganic compounds, solvents/chemicals, asbestos
	16b	SSI2	Maintenance Workshop	SE of blast furnace				Moderate	Point	off-site	
PAOC17	n/a	SSI2	Power station	South of blast furnace	<p>The Power Station construction started in March 1975 and was fully constructed ready for the Blast Furnace commissioning in the summer of 1979. The station included associated outlying systems and an Estuary Cooling Water Pump house situated approximately one mile from the Station on the Tees bay. The Station was shut down by October 2015 (SSI UK RPS 2016). The Power Station was a fully integrated facility that used Blast Furnace Gas (BFG) and Coke Oven Gas (COG) arising from the Iron making process.</p> <p>The site comprised:</p> <ul style="list-style-type: none"> • 3 Traditional Water Tube Boilers • 2 Steam Turbine driven Axial Compressors • 2 x 30MW Steam Condensing Turbo Alternators • 2 Back Pressure Turbo Alternators • 200m3/hr Water Treatment Plant • Estuary Water Pumphouse with 3 Cooling Water Pump 	A 200m3/hr Water Treatment Plant was necessary to provide make up water for steam lost during the steelmaking process. The demineralised plant consisted of a filtration section, followed by ion exchange units and then a final mixed bed polishing stage. The plant also housed chemical regeneration equipment and large underground storage tanks.	SSI UK RPS 2016 CH2M desk study	High risk	Point	off-site	Organics/inorganics, asbestos, PCBs, metals

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

PAOC ID	Source ID	Site	Type	Location	General Description	Specific Details	Data Source / Dates	Risk Level	Point or Material Source	On- / off-site	CoC
PAOC18	18a	n/a	Railway lines	Site wide	Various rail/tramways cross or crossed the site. These could be a potential source of contamination as a result of spillages / loss of materials. Asbestos also CoC.	The Hot Metal Route railway line links to the site via the TS2 site area. This line was used to transport the liquid metal in the Torpedo ladles to the Basic Oxygen Steelmaking plant located approximately 7km to the south within the SSI3 site. In addition to this route numerous other rail lines link the various processes on site.	CH2M Desk Study	Moderate	Point/material	on-site	Hydrocarbons, metals, phenols, sulphates and PAHs.
	18b					East corner of site over PAOC24	CH2M Desk Study				
	18c					Centre of site running north east to south west	CH2M Desk Study				
	18d	SSI2				Norther corner of Site	CH2M Desk Study				
PAOC19	n/a	SSI2	Blast Furnace Stockhouse	SE corner SSI2 A, south of workshop			CH2M Desk Study, Industry profiles, Arcadis site observations	High risk	Point/material	off-site	Metals, asbestos, Coal dust
PAOC20	n/a	SSI2	Disposal Area	NE corner of SSI2 A	North of the stores and east of the Blast Furnace. Used. Used for the storage of materials during works operation.		CH2M Desk Study, Industry profiles, Arcadis site observations	High risk		on-site	Metals, sulphates/sulphides, pH, asbestos, organic/inorganic compounds
PAOC21	n/a	SSI2	Ponding area	NE corner of SSI2 A	Located on the eastern perimeter of the site north of the rail routes are a series of nine ponds that were used for the disposal of waste products from the Blast Furnace, or for excess molten iron that was unable to be processed by the BOS plant. The ponds covered an area of 8,000m2 with a capacity to hold 60,000t of iron.	The status of the disposal of waste and iron ore into the ponding areas is not known, however, excavation of the pond area is understood to have commenced.	SSI UK RBF 2016	High risk	Material	on-site	Metals, sulphates/sulphides, pH, asbestos, organic/inorganic compounds
PAOC22		SSI1	Coke crushing and blending plant	Approx. 1.5 ha in northwest of SSI1	The coke crushing plant prepared material for firing. A typical system used a sequence of toothed rollers to reduce grain size and screen materials for intended usage. Dust suppression was likely to have been		CH2M Desk Study, Industry profiles, Arcadis site observations	High risk	Material	on-site	Asbestos, hydrocarbons, metals, flue dust, coke/coal

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

PAOC ID	Source ID	Site	Type	Location	General Description	Specific Details	Data Source / Dates	Risk Level	Point or Material Source	On- / off-site	CoC
					required and therefore drainage system likely to be in place.						
PAOC23		SSI1	Ore blending plant	Approx. 2.4 ha at west end of SSI1	The process of ore blending was carried out to standardise, improve and tailor ingredients to specific iron products. A number of methods were used, such as blending low quality ore with high-iron-content flue dust from the Basic Oxygen Steel (BOS) plant to raise the iron content. The specific process is unclear at the time of reporting, but it is believed that a number of conveyor belts and junction houses mix material from the raw ore stocks, with some additions made through a number of hoppers on site, before they are deposited by the 'stacker' in to the blended yards. Dust suppression was likely to have been required and therefore drainage system likely to be in place.		CH2M Desk Study, Industry profiles, Arcadis site observations	High risk	Material	on-site	Asbestos, metals, flue dust, coke/coal
PAOC24		SSI1	Pellet Plant	Approx. 4 ha to east of Sinter Plant.	Demolished in late 1980s		CH2M Desk Study, Industry profiles, Arcadis site observations	High risk	Point	on-site	Asbestos, metals, flue dust, coke/coal
PAOC25		SSI1	Sinter Plant	Approx. 3.5 ha in the east of SSI1	Built around mid 1970s. Sinter comprises small, irregular nodule-shaped agglomerate of iron ore fines, limestone and coke, used as a feedstock for the blast furnace. It is produced by mixing and blowing hot air through very fine grained material until liquefied and fused.		CH2M Desk Study, Industry profiles, Arcadis site observations	High risk	Point	off-site	Asbestos, metals, flue dust, coke/coal
PAOC26		SSI1	Sinter/Pellet Stocks	Approx. 8.7 ha to south of sinter plant.	Stockyards have been emptied since the ironworks closure, with some residual material remaining on the surface. Sinter and pellets production built up a surplus of material to support the continuous running of the blast furnace. When both plants were operational, sinter was stored in the west and pellets in the east. Following closure of the pellet plant in the late 1980s both stocking areas were used for sinter.		CH2M Desk Study, Industry profiles, Arcadis site observations	High risk	Material	on-site	Asbestos, metals, flue dust, coke/coal
PAOC27	27a	SSI1	Blended Ore	Approx. 20 ha in central and western SSI1	Ore blending was carried out to standardise, improve and tailor ingredients to specific iron products. A number of methods were used, such as blending low quality ore with high-iron-content flue dust from the Basic Oxygen Steel (BOS) plant to raise the iron content.	Blended Ore Handling	CH2M Desk Study, Industry profiles, Arcadis site observations	High risk	Material	on-site	Metals, flue dust
	27b	SSI1				Blended Ore Stocks			Material	on-site	

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

PAOC ID	Source ID	Site	Type	Location	General Description	Specific Details	Data Source / Dates	Risk Level	Point or Material Source	On- / off-site	CoC
PAOC28		SSI1	Blended Coal Stocks	Extends to west into RBT land. Approx. 17.5ha in west of SSI1	Shown on site plans as Raw (west) and Blended (east) coal stocks. Coal is blended to achieve the optimal mix for its end application. While the materials will differ slightly, potential contaminants are not expected to differ between raw and blended coal stocks. In some cases, condensed volatile residues from the coke ovens were blended with inferior coal stocks to increase the calorific value and usability.	-	CH2M Desk Study, Industry profiles, Arcadis site observations	High risk	Material	on-site	Metals, flue dust, coke/coal
PAOC29		SSI1	Vehicle Maintenance	NE corner of SSI1	Warehouse used by D Jones Haulage and Construction for vehicle storage and maintenance. Previously used by Tube City IMS, an on-site service provider (probably industrial cleaning) that ceased operating in 2015.	-	CH2M Desk Study, Industry profiles, Arcadis site observations	High risk	Point	on-site	Heavy fuel oils, grease, hydraulic oil and associated hydrocarbons
PAOC30		SSI1	Bran Sands Landfill	Immediately to south of SSI1	Landfill accepting Special Waste. Permit issued to ICI Chemicals and Polymers Ltd.	-	Permit Ref No. EAEPR\EA\EPR\MP3790ZW/V002	High risk	Point	Off-site	Metals, VOC, SVOC, TPH
PAOC66		SSI1	Tar lagoons	Southern area of SSI1	No longer in use and have been backfilled.	-	CH2M desk study	High risk	Point	on-site	Unknown backfill and tar
PAOC 067		SSI2	Slag of Tar and Macadam works	Northern area of SSI2 RDL area. Two small sites	Shown on 1929 historical mapping	Potentially processing biproducts from coke manufacture. Structures are relatively small suggesting not a large scale operation	Historical Mapping	Medium risk	Point	On-site	TPH, PAH, ammonia, phenols, tar

APPENDIX F

Statistical Analysis Results

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

Granular Made Ground Analysis Summary						
Analyte	Tests	Detections	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Mean Concentration (mg/kg)	Standard Deviation
Aluminium	0	NA	NA	NA	NA	NA
Antimony	84	74	13	1.1	4.33	3.46
Arsenic	137	137	350	2.3	27.6	51.1
Barium	84	84	1200	31	312	210
Beryllium	84	84	7.4	0.3	2.41	1.82
Boron, Water Soluble	137	136	21	0.1	3.83	3.07
Cadmium	137	131	31	0.1	1.33	3.26
Chromium	138	138	1200	3.7	166	245
Chromium, Hexavalent	84	N/A	N/A	N/A	N/A	N/A
Copper	137	137	1200	5.2	54	118
Iron	29	26	110000	20	14,569	26,414
Lead	121	121	1000	4.9	96	152
Magnesium	0	NA	NA	NA	NA	NA
Manganese	0	NA	NA	NA	NA	NA
Mercury	138	45	5	0.05	0.141	0.489
Molybdenum	83	82	15	0.6	3.48	2.96
Nickel	138	138	730	1.8	28.2	67.1
Silicon	0	NA	NA	NA	NA	NA
Vanadium	83	83	3600	11	510	702
Zinc	137	137	7200	14	383	788
pH	154	154	12.7	1.3	10.6	1.347
Cyanide, Total	137	109	160	0.1	3.8	16.463
Cyanide, Free	87	12	0.5	0.1	0.1	0.079
Cyanide, Complex	84	54	60	0.2	2.5	8.359
Thiocyanate	88	14	2	0.6	0.4	0.328
Sulphate Aqueous Extract as SO4	154	150	1900	11	664.6	545.259
Naphthalene	139	75	2.5	0.02	0.159	0.371
Acenaphthylene	138	49	3	0.03	0.094	0.309
Acenaphthene	138	51	11	0.04	0.295	1.248
Fluorene	138	62	8.4	0.03	0.252	0.882
Phenanthrene	138	128	110	0.03	2.060	9.775
Anthracene	138	90	26	0.03	0.530	2.334
Fluoranthene	138	131	130	0.04	2.580	11.447
Pyrene	138	132	97	0.03	2.115	8.629
Benzo(a)anthracene	138	122	62	0.03	1.179	5.424
Chrysene	138	123	55	0.03	1.128	4.830
Benzo(b)fluoranthene	138	117	60	0.03	1.282	5.302
Benzo(k)fluoranthene	138	106	22	0.03	0.568	2.092
Benzo(a)pyrene	138	110	45	0.03	0.946	4.027
Indeno(1,2,3-c,d)pyrene	138	108	19	0.03	0.490	1.771
Dibenzo(a,h)anthracene	138	64	6.1	0.03	0.160	0.558

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

Granular Made Ground Analysis Summary						
Analyte	Tests	Detections	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Mean Concentration (mg/kg)	Standard Deviation
Benzo(g,h,i)perylene	138	106	21	0.03	0.550	1.939
PAH - USEPA 16, Total	138	137	670	0.05	14.293	59.377

Slag Dominant Materials Analysis Summary						
Analyte	Tests	Detections	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Mean Concentration (mg/kg)	Standard Deviation
Aluminium	14	14	65000	8000	36,750	19,796
Antimony	75	49	16	1	3.97	4.43
Arsenic	106	106	270	0.3	21.3	39.9
Barium	75	75	2100	13	356	336
Beryllium	75	73	8.2	0.1	3.46	2.32
Boron, Water Soluble	106	106	21	0.3	4.43	2.81
Cadmium	106	90	29	0.1	1.02	2.95
Chromium	106	106	1300	1.1	244	329
Chromium, Hexavalent	78	0	N/A	N/A	N/A	N/A
Copper	106	106	23000	0.5	262	2,220
Iron	29	26	250000	22	50,306	57,972
Lead	99	98	600	2	73	108
Magnesium	14	14	170000	17000	35,143	37,770
Manganese	14	14	32000	1300	9,664	9,537
Mercury	106	31	1.3	0.05	0.083	0.189
Molybdenum	75	72	36	0.5	3.91	5.77
Nickel	106	104	220	1.1	18.0	26.9
Silicon	14	14	120000	12000	60,000	25,475
Vanadium	75	75	3300	12	662	906
Zinc	106	106	3600	1.6	280	495
pH	125	125	13	7.5	11.0	0.996
Cyanide, Total	106	86	59	0.1	1.5	6.203
Cyanide, Free	74	7	0.3	0.1	0.1	0.035
Cyanide, Complex	74	46	59	0.2	1.5	6.877
Thiocyanate	74	30	3.7	0.6	0.8	0.763
Sulphate Aqueous Extract as SO ₄	125	122	2600	11	1,060.6	643.003
Naphthalene	109	30	38	0.015	0.474	3.673
Acenaphthylene	109	26	16	0.03	0.258	1.580
Acenaphthene	109	31	20	0.03	0.374	2.076
Fluorene	109	33	33	0.04	0.483	3.225
Phenanthrene	109	82	100	0.03	2.033	10.281
Anthracene	109	46	29	0.03	0.541	2.933
Fluoranthene	109	94	100	0.03	2.296	10.657
Pyrene	109	92	74	0.03	1.863	8.231

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

Slag Dominant Materials Analysis Summary						
Analyte	Tests	Detections	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Mean Concentration (mg/kg)	Standard Deviation
Benzo(a)anthracene	109	85	35	0.03	0.927	3.900
Chrysene	109	83	32	0.03	0.897	3.750
Benzo(b)fluoranthene	109	82	28	0.03	0.903	3.443
Benzo(k)fluoranthene	109	63	10	0.03	0.348	1.253
Benzo(a)pyrene	109	65	19	0.03	0.629	2.471
Indeno(1,2,3-c,d)pyrene	109	63	11	0.03	0.375	1.387
Dibenzo(a,h)anthracene	109	35	3.5	0.03	0.130	0.450
Benzo(g,h,i)perylene	109	63	13	0.03	0.430	1.618
Total PAH	106	86	570	0.05	11.487	60.331

Cohesive Made Ground Materials Analysis Summary						
Analyte	Tests	Detections	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Mean Concentration (mg/kg)	Standard Deviation
Aluminium	0	NA	NA	NA	NA	NA
Antimony	5	1	2.9	2.9	0.98	0.96
Arsenic	9	9	22	3.2	8.9	5.1
Barium	5	5	340	93	193	81
Beryllium	5	4	1.7	0.1	1.04	0.58
Boron, Water Soluble	9	9	5.2	1.1	2.66	1.41
Cadmium	9	9	0.8	0.1	0.37	0.22
Chromium	9	9	770	18	123	230
Chromium, Hexavalent	6	NA	NA	NA	NA	NA
Copper	9	9	92	5	30	23
Iron	2	1	31	19	25	6
Lead	7	7	120	6.7	39	35
Magnesium	0	NA	NA	NA	NA	NA
Manganese	0	NA	NA	NA	NA	NA
Mercury	9	3	0.24	0.09	0.069	0.072
Molybdenum	5	5	1.8	0.6	1.08	0.43
Nickel	9	9	30	4.7	18.1	8.2
Silicon	0	NA	NA	NA	NA	NA
Vanadium	5	5	350	40	110	120
Zinc	9	9	280	22	102	72
pH	10	10	12.6	8.4	10.5	1.220
Cyanide, Total	9	6	1.8	0.2	0.5	0.549
Cyanide, Free	6	1	0.1	0.1	0.1	0.019
Cyanide, Complex	5	2	0.7	0.3	0.3	0.233
Thiocyanate	6	2	2.8	1.3	0.9	0.932
Sulphate Aqueous Extract as SO ₄	10	10	1400	15	332.1	387.854
Naphthalene	9	5	0.07	0.03	0.033	0.019
Acenaphthylene	9	3	0.3	0.05	0.058	0.088

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

Cohesive Made Ground Materials Analysis Summary						
Analyte	Tests	Detections	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Mean Concentration (mg/kg)	Standard Deviation
Acenaphthene	9	3	12	0.05	1.381	3.755
Fluorene	9	3	18	0.05	2.059	5.637
Phenanthrene	9	7	71	0.08	8.198	22.208
Anthracene	9	4	20	0.22	2.313	6.254
Fluoranthene	9	7	67	0.06	8.099	20.861
Pyrene	9	7	50	0.05	6.319	15.537
Benzo(a)anthracene	9	5	21	0.05	2.598	6.535
Chrysene	9	5	18	0.04	2.242	5.598
Benzo(b)fluoranthene	9	4	13	0.05	2.013	4.158
Benzo(k)fluoranthene	9	4	8.2	0.05	1.169	2.568
Benzo(a)pyrene	9	4	17	0.05	2.272	5.300
Indeno(1,2,3-c,d)pyrene	9	4	10	0.05	1.378	3.123
Dibenzo(a,h)anthracene	9	3	1.9	0.05	0.269	0.588
Benzo(g,h,i)perylene	9	4	7.6	0.05	1.112	2.392
Total PAH	9	9	330	0.05	40.760	102.641

The Former SSI Steelworks, Redcar: Priority Areas within SSI Landholdings Contract 1 and 2A: Site Condition Report

Granular Made Ground Leachate Analysis Summary						
Analyte	Tests	Detections	Minimum Concentration (µg/l)	Maximum Concentration (µg/l)	Mean Concentration (µg/l)	Standard Deviation
Arsenic, Dissolved	42	39	0.23	55	3.157	8.379
Barium, Dissolved	52	51	0.49	200	20.1	31.1
Beryllium, Dissolved	50	17	0.2	140	7.82	22.6
Boron	56	18	50	400	91.3	78.2
Cadmium, Dissolved	56	11	0.03	0.56	0.042	0.091
Chromium, Dissolved	56	38	0.25	21	2.247	4.132
Copper, Dissolved	56	43	0.4	9.2	1.545	1.842
Iron	44	28	5.9	370	35.0	63.1
Lead, Dissolved	56	31	0.1	2	0.317	0.415
Manganese, Dissolved	50	46	0.11	68	7.406	11.8
Mercury, Dissolved	55	18	0.01	0.06	0.010	0.012
Nickel, Dissolved	56	16	0.5	2.5	0.498	0.516
Selenium, Dissolved	56	46	0.26	9	1.446	1.823
Vanadium, Dissolved	50	46	0.6	51	8.858	10.0
Zinc, Dissolved	56	34	1.6	32	4.018	5.939
pH	56	56	6.6	12.2	8.689	1.515

Slag Dominant Made Ground Leachate Analysis Summary						
Analyte	Tests	Detections	Minimum Concentration (µg/l)	Maximum Concentration (µg/l)	Mean Concentration (µg/l)	Standard Deviation
Arsenic, Dissolved	36	31	0.25	17	2.18	3.70
Barium, Dissolved	51	48	0.35	120	23.0	30.8
Beryllium, Dissolved	47	21	5.2	200	13.2	31.5
Boron	54	15	50	280	80.9	63.9
Cadmium, Dissolved	54	15	0.03	1.3	0.090	0.237
Chromium, Dissolved	54	31	0.25	36	2.531	6.027
Copper, Dissolved	54	45	0.4	16	1.874	2.712
Iron	41	24	5.8	4400	132	685
Lead, Dissolved	54	24	0.1	3.2	0.334	0.683
Manganese, Dissolved	47	42	0.27	190	12.8	28.8
Mercury, Dissolved	54	17	0.01	0.17	0.015	0.027
Nickel, Dissolved	54	12	0.5	5.7	0.680	1.282
Selenium, Dissolved	54	51	0.26	14	1.818	2.702
Vanadium, Dissolved	47	37	0.6	52	7.53	11.6
Zinc, Dissolved	54	31	1.5	450	14.4	61.3
pH	54	54	6.6	12	8.7	1.7

APPENDIX G

Slag Analysis Reports

TRS REPORT

Report Ref: BG8A/AEG/4154A/TRS/05/18/RP2
Date Issued: 03 May 2018
TRS Sample Refs: BG8A32-43
Order No: LA1958

EXAMINATION OF 12 SAMPLES
FROM
JOB 4154A, FORMER SSI STEELWORKS, REDCAR
(PRIORITY AREAS WITHIN SSI LANDHOLDING CONTRACT 2, AREA A)
FOR
ALLIED EXPLORATION & GEOTECHNICS LTD



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A Limited Company registered in England. Company Registration No: 2518421

EXAMINATION OF 12 SAMPLES
FROM
JOB 4154A, FORMER SSI STEELWORKS, REDCAR
(PRIORITY AREAS WITHIN SSI LANDHOLDING CONTRACT 2, AREA A)
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1. BACKGROUND

Twelve bulk samples were received from the above site on 18th January 2018. Each sample was weighed and allocated a unique TRS reference number, the details of which are recorded below:-

<u>TRS REF</u>	<u>Site Ref</u>	<u>Depth/m</u>	<u>Mass/kg</u>
BG8A32	S2 TPA09	2.2	16.0
BG8A33	S2 TPA17	2.5	19.8
BG8A34	S2 TPA18	2.0	16.6
BG8A35	S2 TPA21	1.2	10.4
BG8A36	S2 TPA31	1.2	16.2
BG8A37	S2 TPA33	1.2	16.1
BG8A38	S2 TPA34	1.3	11.3+12.3
BG8A39	S2 TPA35	1.2	12.00
BG8A40	S2 TPA36	1.7	18.8
BG8A41	S2 TPA37	2.2	14.1
BG8A42	S2 TPA39	3.2	12.4
BG8A43	S2 TPA40	0.5	11.9

The purpose of the exercise was to identify the range and relative concentrations of any iron and steelmaking slags present in the samples, and whether there was any potential for volumetric instability from the materials.

2. SAMPLE PREPARATION & PROGRAMME OF ANALYSIS

The samples were primary crushed to reduce particle size down to <50mm, portions then being selected and dried at low temperature to constant weight. The dried material was subjected to a regime of stage crushing and quartering to further reduce particle size down to <5mm. Portions of this <5mm material were made up into resin bound blocks, one face of which was ground flat and polished using diamond pastes. Further portions of the <5mm material were milled to a fine powder. Fractions of material were extraction throughout the preparation procedure to provide the materials necessary for the tests and analyses required in the programme.

A petrological examination was made of the polished blocks using reflected light microscopy, the complete findings of which are recorded in appendix A. The results of this examination were recorded and discussed in our report of 7th February 2018. On the basis of that report, further work was authorised on the samples on 28th March 2018 as follows:-

Samples BG8A 36 & 38-43 were subjected to the following tests & analyses to assess the potential for expansion of the blast furnace slag.

- Water soluble sulphate (table 1)
- Acid soluble sulphate (table 1)
- Total sulphur (table 1)
- Thermal analysis (table 3)
- TRS accelerated expansion test (table 4)

Samples BG8A 32-34 were subjected to the following tests & analyses to assess the potential for expansion of the mixed slag.

- Water soluble sulphate (table 1)
- Acid soluble sulphate (table 1)
- Total sulphur (table 1)
- Free CaO (table 2)
- Free MgO (table 2)

- Thermal analysis (table 3)
- TRS accelerated expansion test (table 4)

3. DISCUSSION OF RESULTS

3.1 Petrology

A petrological examination was made of the 12 samples using reflected light microscopy. The complete findings of this examination are recorded in appendix A.

Blast furnace slag was present in significant quantities in all but samples BG8A 35 & 37. The blast furnace slag was mostly vesicular and crystalline, with vesicular infill and particle coatings from secondary materials (products of weathering). The unaltered slag consisted predominantly of melilite, along with more minor amounts of merwinite, larnite, bredigite, monticellite, wollastonite, anorthite, Ca, Mn & Fe sulphides, graphitic iron and Ca titano-silicate. Some glassy and finely ceramic material was present in minor amounts. Secondary alteration was moderate, consisting mainly of pore infill and surface rinds. Products of alteration included calcite, gypsum and possibly ettringite. Old weathered blast furnace slag may occasionally contain pockets of potentially expansive material. This potential can only be assessed by direct expansion testing (see sections 3.2-3.5).

Basic steel slag was present in all but four of the samples. Most samples contained fairly moderate amounts (very small), but samples 32, 33 & 34 contained much more significant concentrations. The unaltered basic steel slag consisted mainly of dicalcium silicate, along with more minor amounts of RO & R₃O₄ phase, CaF phase, Fe₂O₃ phase, lime phase and periclase. The slag was extensively altered due to weathering, the secondary phases being difficult to identify specifically under the microscope. The mineralogy of the basic steel slag

would suggest that it may have significant potential for expansion. This potential can only be assessed by direct expansion testing (see sections 3.2-3.5).

Minor amounts (small) of basic refractory material were seen in two of the samples. This material, even in minor amounts, can have significant potential for expansion.

Other constituents seen in the samples, in varying concentrations, included alumino-silicate refractories (firebrick and common brick), quartz (mainly as sand but also silt and sandstone), cinder and clinker (from heating furnaces), iron ore, fume, metallic iron with associated iron oxide scale, rust, clay, limestone, shale, coal and coke. Some of the particles were bonded together by a cementitious material similar in nature to the slag alteration products.

3.2 Sulphur Species

The following range of analyses were performed on samples BG8A 32-34, 36, & 38-43 (These samples contained medium or more amounts of blast furnace slag). The results are recorded in table 1:-

- Water soluble sulphate
- Acid soluble sulphate
- Total sulphur

Total sulphur values were in the range 0.20 to 1.81 percent. Acid soluble sulphates were in the range 0.18 to 2.73 percent, with corresponding water soluble sulphates of 0.07 to 1.70 g/l. These sulphate and sulphur values were variable, commensurate with the variable amounts of blast furnace slag present. However, some values were very high, and consequently, care should be taken when specifying concrete that may come into contact with the slag. Calculations show that between 18 and 98 percent of the available sulphur is present as sulphate.

3.3 Thermal Analysis

Simultaneous differential thermal analysis (DTA) and thermo-gravimetric analysis (TGA) were performed on samples BG8A 32-34, 36, & 38-43. The results are recorded in table three.

Ettringite was seen in five of the samples examined, at trace levels up to 1.1 percent. Gypsum was seen in all of the samples, at between trace and 4.5 percent. On comparing the gypsum values with the acid soluble sulphates, some of the gypsum values were overstated. This is common in old weathered blast furnace slag, and is usually an indicator of the presence of thaumasite. The presence of ettringite and possibly thaumasite would suggest some past expansion has occurred in the blast furnace slag.

No calcium hydroxide was seen in the samples. Magnesium hydroxide was seen in two of the samples, at 0.2 and 0.6 percent. These values were used to correct the free CaO and free MgO analyses recorded in table 2.

Calcite was present in all of the samples examined at between trace and 4.3 percent. This product is an indicator as to the weathered state of the slag, although some may have come from other components present in the samples.

3.4 Free CaO & Free MgO

Free CaO & free MgO analyses were carried out on samples BG8A 32-34 (These samples contained medium or more mounts of basic steel slag). The results are recorded in table 2. Both original and corrected values are recorded. The original values include both the oxide (CaO and MgO) and the hydroxide ((Ca(OH)₂ and Mg(OH)₂)) contents. The corrected values report only the oxide content (CaO and MgO) after correction using the hydroxide values from the

thermal analyses. These corrected values are the more significant, as it is only the oxides that are still free to hydrate, i.e. expand.

Free lime was recorded in the samples at between 0.7 and 1.5 percent. Free magnesia was recorded at between 0.0 and 0.3 percent. These corrected free lime and free magnesia levels record oxides that are potentially still free to hydrate (i.e. expand).

3.5 TRS Accelerated Expansion Test

The TRS accelerated expansion test was performed on samples BG8A 32-34, 36, & 38-43. The results are recorded in table four. The samples were subjected to the test for a period of 14 days unless basic steel slag was present in medium or more amounts, where the test duration was extended to 28 days. Note that the test measures potential for future expansion, and is not a measure of expansion that may have taken place in the past.

Samples consisting predominantly of blast furnace slag, with only minor amounts of basic steel slag recorded expansion results of between 0.06 and 0.15 percent. Samples containing medium or more concentrations of basic steel slag recorded expansion results of between 0.13 and 1.27 percent.

4. CONCLUSIONS & RECOMMENDATIONS

The following conclusions can be drawn:-

- Blast furnace slag was a dominant constituent in all but two of the twelve samples examined. The slag was mainly crystalline although minor amounts of glassy and ceramic material were seen. The slag showed some alteration due to weathering. Old weathered blast furnace slag may occasionally contain pockets of potentially expansive material.
- Further testing of samples consisting predominantly of blast furnace slag (with only minor amounts of basic steel slag) recorded expansion results of between 0.05 and 0.15 percent. Thermal analysis indicated some evidence of past expansion of the blast furnace slag (presence of ettringite and possibly thaumasite). Some of the sulphate values were high and should be taken into consideration when specifying concrete that may come into contact with the slag.
- Minor amounts of basic steel slag were seen in most of the samples. However, more dominant amounts were present in samples 32, 33 & 34. This material may present a significant risk of expansion.
- Expansion testing of these three samples recorded expansion results of between 0.13 and 1.27 percent.
- Minor amounts of basic refractory material were seen in two of the twelve samples examined. This product can be a significant source of expansion.
- Other products seen in the samples, in varying amounts, included alumino-silicate refractories (firebrick and common brick), quartz (mainly as sand but also silt and sandstone), cinder and clinker (from heating furnaces), iron ore, fume, metallic iron with associated iron oxide scale, rust, clay, limestone, shale, coal and coke.

The following recommendations are made:-

The site contains significant proportions of iron and steel industry slag. To date, only 12 samples have been examined from this part of the site. A more significant site investigation, commensurate with the volume of material, should be undertaken. This should aim to determine the distribution of slag types across the site, and further assess the expansive properties of the slag.

Note

These conclusions apply only to the samples tested and may not represent the bulk of the material on the site from which they were taken.

Ian D. Thomas

Ian D Thomas BSc(Hons)

03 May 2018

TABLE 1**SULPHUR SPECIES ANALYSES**

TRS Ref	Site Ref	Water Sol.	Acid Sol.	Total S
		SO ₃ (g/l)	SO ₃ (%)	(%)
BG8A32	S2 TPA09	0.49	0.18	0.37
BG8A33	S2 TPA17	0.07	0.49	0.20
BG8A34	S2 TPA18	0.40	0.64	0.45
BG8A36	S2 TPA31	0.79	0.49	0.98
BG8A38	S2 TPA34	0.53	0.39	0.83
BG8A39	S2 TPA35	1.00	0.56	1.23
BG8A40	S2 TPA36	1.70	1.22	1.06
BG8A41	S2 TPA37	1.28	1.05	0.95
BG8A42	S2 TPA39	1.16	2.73	1.81
BG8A43	S2 TPA40	0.28	0.38	0.59

TABLE 2**ANALYSIS FOR FREE CaO AND FREE MgO**

TRS Ref	Site Ref	Free CaO	Free CaO	Free MgO	Free MgO
		Original (%)	Corrected (%)	Original (%)	Corrected (%)
BG8A32	S2 TPA09	0.7	0.7	0.3	0.3
BG8A33	S2 TPA17	1.1	1.1	0.1	0.0
BG8A34	S2 TPA18	1.5	1.5	0.4	0.1
BG8A36	S2 TPA31	-	-	-	-
BG8A38	S2 TPA34	-	-	-	-
BG8A39	S2 TPA35	-	-	-	-
BG8A40	S2 TPA36	-	-	-	-
BG8A41	S2 TPA37	-	-	-	-
BG8A42	S2 TPA39	-	-	-	-
BG8A43	S2 TPA40	-	-	-	-

TABLE 3**RESULTS FROM THERMAL ANALYSIS**

TRS Ref	Site Ref	Mass % by Thermal Analysis						
		L.O.I.	Ettringite	Gypsum	Calcite	Ca(OH) ₂	Mg(OH) ₂	Others
BG8A32	S2 TPA09	5.94	0.0	3.4	4.0	0.0	0.0	quartz
BG8A33	S2 TPA17	5.30	0.0	trace	3.8	0.0	0.2	-
BG8A34	S2 TPA18	6.16	trace	1.6	4.3	0.0	0.6	quartz
BG8A36	S2 TPA31	4.76	0.0	2.7	2.0	0.0	0.0	-
BG8A38	S2 TPA34	1.85	0.0	1.6	trace	0.0	0.0	-
BG8A39	S2 TPA35	2.78	trace	0.9	trace	0.0	0.0	-
BG8A40	S2 TPA36	3.09	trace	1.6	0.4	0.0	0.0	-
BG8A41	S2 TPA37	3.16	1.1	1.5	0.5	0.0	0.0	-
BG8A42	S2 TPA39	6.09	trace	4.5	0.7	0.0	0.0	-
BG8A43	S2 TPA40	4.33	0.0	0.4	3.1	0.0	0.0	quartz

TABLE 4**TRS ACCELERATED EXPANSION TEST**

TRS Ref	Site Ref	7 day	14 day	21 day	28 day
		(%)	(%)	(%)	(%)
BG8A32	S2 TPA09	0.11	0.18	0.22	0.22
BG8A33	S2 TPA17	0.08	0.08	0.11	0.13
BG8A34	S2 TPA18	0.51	0.79	1.09	1.27
BG8A36	S2 TPA31	0.08	0.12	0.14	0.15
BG8A38	S2 TPA34	0.05	0.06	0.06	0.08
BG8A39	S2 TPA35	0.10	0.13	0.14	0.14
BG8A40	S2 TPA36	0.12	0.12	0.14	0.15
BG8A41	S2 TPA37	0.07	0.07	0.08	0.08
BG8A42	S2 TPA39	0.05	0.06	0.08	0.09
BG8A43	S2 TPA40	0.06	0.06	0.06	0.06

APPENDIX A

PETROLOGICAL REPORT ON SAMPLES BG8A 32-43

A petrological examination has been carried out of twelve samples, BG8A 32 to 43.

Polished blocks were prepared using particulate material crushed to a nominal size of -5mm . Representative material was made up into resin-bonded blocks. One face of each of these was ground flat and polished using diamond pastes. In addition, when appropriate, the surfaces were selectively etched with water and 0.1%N HCl in order to help with the phase identification.

The detailed results are given in the accompanying Table.

Blast furnace slag occurs in medium, large or very large amounts in most of the samples.

Basic steel slag occurs in medium to large amounts in samples 32, 33 and 34.

Basic refractory material is present in samples 33 and 34.

Very little fume is reported; spherical particles chiefly of iron oxides typically less than 0.01mm in size.

The blast furnace slag is mostly vesicular and crystalline with vesicular infill and particle coatings of secondary material.

The unaltered slag consists mainly of melilite (Ca,Mg,Al silicate) with minor amounts of spinel (MgAl_2O_4) as a second principle phase. Minor amounts of merwinite (Ca,Mg silicate) and dicalcium silicate (e.g. larnite ($\beta\text{-Ca}_2\text{SiO}_4$) and bredigite (Ca_2SiO_4 with some Mg in solid solution)) are present and also, monticellite (Ca,Mg silicate), tentatively identified, other silicates such as wollastonite (Ca silicate), anorthite (Ca,Al silicate, alkali silicates and Ca titanosilicate. These form a matrix to the melilite crystals. Some glassy slag is present, again mostly as a matrix phase. There is also some finely crystalline ceramic slag. Very small amounts of Ca, Mn and Fe sulphides are present and graphitic iron occurs as minute spherules and occasional larger prills. Secondary alteration is moderate in amount mainly infilling pores and occurring as surface rinds. Some has replaced the original phases especially the calcium-rich silicates. It consists mainly of calcite (CaCO_3) together with granular material and aggregates of needle shaped crystals that are probably silicate and sulpho-

aluminate hydrates such as ettringite. A few samples have well-crystallised gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).

The unaltered basic steel slag is very variable in composition from particle to particle and even within individual particles. It consists mainly of dicalcium silicate, RO and R_3O_4 phases (FeO and Fe_3O_4 with some Al, Mn, Mg and Ca in solid solution), a Fe_2O_3 type phase and CaF phases (complex Ca aluminoferrites). The iron oxides vary considerably in composition as shown by the reflectance of individual crystals that is related to their content of minor elements, especially Mg and Mn, and their state of oxidation. There are small or very small amounts of lime phase (CaO with some Fe, Mn and Mg in solid solution) and, more common, periclase (MgO with some Fe in solid solution). The lime phase mostly forms spongy grains up to about 0.3 mm in size or is finely crystalline, well dispersed at other phase boundaries. The periclase occurs mostly as rounded grains up to about 0.1 mm in size that are sometimes encapsulated in RO phase. The slag is extensively altered with the formation of secondary phases difficult to identify specifically under the microscope but are probably silicate hydrates.

Small or very small amounts of basic refractory material are present in most samples. This consists mainly of used burnt magnesia consisting mainly of periclase. This occurs mostly as rounded grains up to about 0.1 mm in size that are sometimes encapsulated in RO phase.

The fume is made up of particles ranging in size from less than 1 to about 100 microns of iron oxides, glass, coke, etc. embedded in an extremely fine-grained matrix.

Other constituents include alumino-silicate refractories (firebrick and common brick), quartz (mainly as sand but also silt and sandstone), cinder and clinker from heating furnaces, iron ore, metallic iron with associated iron oxide scale, rust, clay, limestone, shale, coal and coke. There are small to medium amounts of cementitious material binding the smaller and adherent to the larger particles. This appears to be similar to the slag alteration products including calcite but probably is also partly clay.

TRS SAMPLES BG8A 32-43												
	32	33	34	35	36	37	38	39	40	41	42	43
BLAST FURNACE SLAG												
Amount	<i>m</i>	<i>l</i>	<i>m</i>	<i>s</i>	<i>L</i>	<i>s</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>L</i>	<i>m</i>
Phases present:-												
Melilite	L	L	L	L	L	L	L	L	L	L	L	L
Merwinite	-	-	vs	-	vs	-	-	-	-	-	-	-
Larnite & bredigite	-	-	vs	-	s	-	-	-	-	-	-	-
Matrix & other silicates	s	s	s	s	s*	s	s*	s	s*	s*	s	s
Ca & Fe,Mn sulphides	-	vs	vs	vs	vs	-	vs	vs	vs	vs	vs	vs
Metal, rust, scale etc.	vs	vs	vs	vs	s	vs	s	s	s	vs	s	s
Spinel	-	vs	vs	s	s	s	vs	-	s	s	s	s
Glassy slag	-	s	s	-	s	-	vs	s	-	-	-	s
Alteration products	s	s	m	vs	s	vs	vs	s	s	s	m	s
Calcite	-	-	-	-	s	-	-	-	-	-	-	-
Gypsum	-	-	-	-	s	vs	-	s	m	s	m	-
BASIC STEEL SLAG												
Amount	<i>m</i>	<i>m</i>	<i>l</i>	-	<i>vs</i>	<i>vs</i>	-	<i>vs</i>	<i>vs</i>	-	<i>vs</i>	-
Phases present:-												
Dicalcium silicate	l	l	l	-	l	l	-	l	l	-	l	-
Unetched silicates	-	-	vs	-	-	-	-	vs	-	-	-	-
RO phase	m	m	m	-	m	m	-	m	m	-	-	-
CaF phase	s	s	vs	-	-	-	-	-	s	-	-	-
R3O4 phase	s	s	s	-	-	-	-	s	-	-	l	-
R2O3 phase	vs	-	-	-	-	-	-	-	-	-	-	-
Metal & rust	s	vs	s	-	-	vs	-	-	-	-	-	-
Lime phase	vs	-	-	-	-	-	-	-	-	-	-	-
Periclase	s	s	s	-	-	-	-	-	-	-	l	-
Alteration products	l	m	m	-	s	m	-	vs	m	-	s	-
BASIC REFRACTORIES												
Amount	-	<i>s</i>	<i>s</i>	-	-	-	-	-	-	-	-	-
OTHER CONSTITUENTS												
Alumino-silicate brick	-	-	-	vs	-	-	-	-	-	-	-	vs
Quartz, sandstone, etc.	l	m	m	l	s	l	vs	s	s	vs	s	l
Cindery slag	vs	-	vs	-	-	-	-	-	-	-	-	s
Siliceous clinker	-	-	-	-	-	-	-	-	-	-	s	-
Metal, rust & scale	s	s	s	-	vs	-	vs	-	vs	vs	s	vs
Fume	vs	-	-	-	-	-	-	-	-	-	-	-
Limestone & dolomite	-	-	-	s	-	vs	-	-	-	-	-	-
Iron ore, ironstone, sinter, etc.	vs	vs	vs	vs	vs	vs	-	vs	vs	vs	-	-
Shale, clay & ash	m	s	s	-	-	-	-	-	-	-	-	s
Coke	s	s	s	vs	vs	vs	vs	vs	vs	vs	s	vs
Coal & char	s	vs	vs	-	-	vs	-	-	-	-	-	-
Cementitious material & clay	l	l	m	-	s	-	-	-	vs	vs	s	-
L = very large, l = large, m = medium, s = small and vs = very small amounts												
* ? Momticellite (Ca,Mg silicate)												

GENERAL EXPLANATION

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

Blast furnace slag. When present this consists mainly of melilite (Ca,Mg,Al silicate ranging in composition between $\text{Ca}_2\text{Al}_2\text{SiO}_7$ and $\text{Ca}_2\text{MgSi}_2\text{O}_7$). Other common phases are merwinite ($\text{Ca}_3\text{MgSi}_2\text{O}_8$), larnite ($\beta\text{-Ca}_2\text{SiO}_4$) and bredigite (Ca_2SiO_4 with some Mg in solid solution). The matrix often consists of some of the above phases, especially melilite, but may also contain other phases such as wollastonite (CaSiO_3), anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) and pyroxene ($(\text{CaMg})\text{SiO}_3$). Spinel (MgAl_2O_4) may be present. Sulphides and metal usually occur and are mostly finely dispersed, but the metal sometimes occurs as prills and may contain some graphite and Ti carbo-nitride (TiCN). Material reported as ceramic in appearance is very finely crystalline. The alteration products often include calcite and gypsum but are mostly silicate and/or sulpho-aluminate hydrates that are difficult to identify specifically under the microscope.

Basic steel slag. When present this consists mainly of dicalcium silicate, mostly the β -form (larnite) but sometimes the alpha form. Phosphoric slags may contain nagelschmidtite (Ca_2SiO_4 with $\text{Ca}_3\text{P}_2\text{O}_8$ in solid solution). Other silicate often present in small amounts, unetched by dilute HCl, is probably melilite. RO, R_3O_4 and RF phases are typically present and are mainly FeO and Fe_3O_4 with some Mg, Mn, Ca, etc. in solid solution and complex Ca aluminoferrites. There may also be some Fe_2O_3 and spinel ($(\text{Mg,Fe})\text{Al}_2\text{O}_4$). The slag typically carries minor amounts of periclase (MgO with some Fe in solid solution) and lime phase (CaO with some Fe, Mn & Mg in solid solution). Other possible minor constituents include fluorite (CaF_2) and apatite (Ca fluoro-phosphate), the last present in phosphoric slags. The alteration products are, again, difficult to identify specifically but are probably, mainly, hydrated silicates. Portlandite ($\text{Ca}(\text{OH})_2$) may be present.

Basic refractory material. When present, this is mainly magnesian and consists of granular periclase (MgO) with interstitial silicates. Sometimes samples contain chrome-magnesia material with chromite present in addition to the other phases. Hot face material (from close to the furnace) may also occur. The periclase and interstitial silicates show secondary alteration similar to that of the basic steel slag. Brucite ($\text{Mg}(\text{OH})_2$) is likely.

Acid steel slag. When present this consists mainly of fayalite ($(\text{Fe,Mn})_2\text{SiO}_4$), Fe,Mn oxides and cristobalite (high temperature SiO_2).

Other slags. The 'intermediate slag' (probably primary flush slags from steel furnaces) has a variable phase assemblage, being mainly formed of silicates, particularly dicalcium silicate, melilite, merwinite and a complex olivine phase together with spinel and wustite (FeO). Sometimes it contains significant amounts of periclase, well embedded in the slag. The 'ferrous slag' (probably from foundry operations) has similar silicates but much more substantial content of iron oxides, usually wustite. It is often associated with scale (iron oxides formed on the surface of steel during reheating/cooling). When present, the 'cindery slag' consists of various silicates and silicate glass with Fe oxides, hercynite (FeAl_2O_4) and, sometimes, corundum (Al_2O_3). It is usually derived from heating furnaces and is often associated with burnt shale. When present, the 'siliceous clinker' is similar but devoid of iron oxides.

Other constituents The aluminosilicate brick includes a range of refractory firebrick, common brick and alumina-rich refractories. The 'quartz, sandstone, etc.' may include used silica refractory material consisting of quartz and its high temperature forms. Sometimes there is a distinct granular texture and it is derived from silcrete, a kind of chert. Cementitious material may bond the finer particles together. It is similar to the other alteration products consisting mostly of complex hydrates difficult to identify under the microscope. Sometimes some is used Portland cement recognised by the relict textures of the clinker and the embedded quartz sand.

APPENDIX B

MECHANISMS OF VOLUMETRIC INSTABILITY IN IRON AND STEEL INDUSTRY SLAGS

Volumetric change with time can occur in some types of iron and steel industry slags. These mechanisms are briefly described in this section.

Blast Furnace Slags

Fresh-make air-cooled, i.e. crystalline, blast furnace slags are almost always volumetrically stable after cooling. The two mechanisms for volumetric instability listed in BS1047:1983 – “Air Cooled Blast furnace Slag for use in Construction” are:-

- a) Beta to gamma inversion of dicalcium silicate.**
- b) Iron unsoundness.**

a) Research by G H Thomas on this phase transformation has shown the transformation to be athermal rather than isothermal. In practical terms this means that inversion, and the expansion associated with it, can only occur during the cooling cycle. In fully cooled material there would appear to be no further risk of instability from this mechanism.

b) Iron unsoundness is a very rare form of instability frequently associated with operating problems in the blast furnace. TRS know of only one instance in over 40 years. The mechanism, which is a hydrolysis reaction, is immediately triggered off by the presence of water. Once water has initiated the reaction, the mechanism proceeds to completion. It is impossible to arrest the process once started; at least by methods operating in normal ambient conditions.

It follows that the risk of late expansion from either of these mechanisms in blast furnace slag is remote.

c) Sulphoaluminate Type Activity

Some years ago, G. H. Thomas discovered a third mechanism that may give rise to volumetric instability. The process is possible only in some old blast furnace slag altered by weathering. When the sulphide sulphur in the blast furnace slags is oxidised during

weathering to sulphate, under some circumstances reactions can take place within the slag to produce an 'ettringite' type product. The process is somewhat analogous to sulphatic attack on concrete and has a similar result - expansion of the mass and associated disruption.

For the mechanism to have any significance, the slag needs to have residual potential for this reaction. Evidence of past activity does not necessarily indicate further reaction is possible.

The TRS accelerated expansion test is, we believe, uniquely capable of identifying such slags, as well as instability attributable to free CaO and free MgO in steel slag & etc.

Basic Steel Slags

Basic steel slags commonly contain significant quantities of free CaO and free MgO. These free oxides are well known for the massive expansion associated with their hydration. In practical terms, it is impossible to forecast when hydration will take place, but it can be up to decades after the material was cooled – or placed. The reasons are complex, but include the varying density of the oxides, due to the variation in temperatures at which the products have been held in the furnace. Other factors influencing rate of hydration include:-

- the protection of slags by a reaction product at the oxide interface with the slag.
- the presence of the oxides as lime or magnesia rich solid solutions instead of the pure oxide.

The result is potential future volumetric instability but at an unforeseeable date. Periclase, i.e. free MgO, is relatively much slower than free CaO to hydrate.

Scrap High Magnesia Refractories

These are particularly undesirable components in fill as they commonly result in high concentrations of free MgO. The problems associated with these concentrations are similar to those where periclase is found in basic steel slag.

TRS REPORT

Report Ref: BG7F/AEG/RED/TRS/07/17/RP1
Date Issued: 21 July 2017
TRS Sample Refs: BG7F01-14
Order No: LA1855

**EXAMINATION OF FOURTEEN BULK SAMPLES
FROM REDCAR SLS1015
FOR
ALLIED EXPLORATION & GEOTECHNICS LTD**



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**EXAMINATION OF FOURTEEN BULK SAMPLES
FROM REDCAR SLS1015
FOR
ALLIED EXPLORATION & GEOTECHNICS LTD**

1. BACKGROUND

Fourteen bulk samples were received from the above site on 6th June 2017. Each sample was weighed and allocated a unique TRS reference number, the details of which are recorded below:-

<u>TRS Ref</u>	<u>Site Ref</u>	<u>Depth/m</u>	<u>Mass/kg</u>
BG7F01	TP22 LB4	1.5	14.2
BG7F02	TP26 LB3	2.0	24.7
BG7F03	TP41 LB1	0.2	30.0
BG7F04	TPC23 LB2	0.3	13.9
BG7F05	TPD10 LB1	0.5	20.0
BG7F06	TPD32 LB2	1.3	13.5
BG7F07	TPD33 LB2	1.0	15.1
BG7F08	TPD44 LB1	0.5	14.4
BG7F09	TPE09 LB1	1.0	19.9
BG7F10	TPE11 LB2	1.7	16.1
BG7F11	TPE31 LB3	3.6	16.3
BG7F12	TPE46 LB1	0.3	16.7
BG7F13	TPE76 LB2	2.1	26.5
BG7F14	TPI36 LB2	2.0	21.0

The purpose of the exercise was to identify the range and relative concentrations of any iron and steelmaking slags present in the samples, and whether there was any potential for volumetric instability from the materials.

2. SAMPLE PREPARATION & PROGRAMME OF ANALYSIS

The fourteen samples were primary crushed to reduce particle size down to <50mm, portions then being selected and dried at low temperature to constant weight. The dried material was subjected to a regime of stage crushing and quartering to further reduce particle size down to <5mm. Portions of this <5mm material were made up into resin bound blocks, one face of which was ground flat and polished using diamond pastes. Further portions of the <5mm material were milled to a fine powder. Fractions of material were extraction throughout the preparation procedure to provide the materials necessary for the tests and analyses required in the programme.

A petrological examination was made of the polished blocks using reflected light microscopy, the complete findings of which are recorded in appendix A. On the basis of these results, and after discussions with the client, the following tests were carried out on samples BG7F 01, 06, 10, 11, 12, 13 & 14:-

- Water & acid soluble sulphates (table 1)
- Total sulphur (table 1)
- Free CaO & free MgO (samples BG7F 13 & 14 only) (table 2)
- Thermal analysis (DTA & TGA) (table 3)
- TRS accelerated expansion test (table 4)

3. DISCUSSION OF RESULTS

3.1 Petrology

A petrological examination was made of the fourteen samples using reflected light microscopy. The complete findings of this examination are recorded in appendix A.

All of the samples except BG7F13 contained large or very large amounts of blast furnace slag. Basic steel slag was the dominant constituent in sample BG7F13, as was present in medium amounts in sample 14, and small amounts in samples 3 and 4. Very small amounts of basic refractory material were seen in samples 8 and 14.

Some of the samples, especially sample 4, contained loosely compacted fume/dust. Other constituents seen, generally in minor amounts, included quartz, iron ore, ooidal (local) ironstone, metallic iron, clay, coal, coke and used Portland cement.

The blast furnace slag was predominantly crystalline with a mineralogy dominated by melilite, although some glassy or ceramic material was seen. The slag was moderately altered due to weathering. Old weathered blast furnace slag may contain pockets of potentially expansive material. Potential for expansion can only be assessed with direct expansion testing (see sections 3.2 to 3.5).

The basic steel slag was fairly significantly altered due to weathering. The mineralogy of the material would suggest that there may be significant potential for expansion. Potential for expansion can only be assessed with direct expansion testing (see sections 3.2 to 3.5).

The basic refractory material, if present in greater concentrations on the site, could have significant potential for expansion.

3.2 Sulphur Species

The following range of analyses were performed on samples BG7F 01, 06, 10, 11, 12, 13 & 14. The results are recorded in table 1:-

- Water soluble sulphate
- Acid soluble sulphate
- Total sulphur

Total sulphur values were in the range 0.19 to 1.13 percent. Acid soluble sulphates were in the range 0.10 to 2.21 percent, with corresponding water soluble sulphates of 0.03 to 1.70 g/l. The lower sulphate and sulphur values were generally in samples with lower blast furnace slag contents. However,

some values were very high, and consequently, care should be taken when specifying concrete that may come into contact with the slag. Calculations show that between 4 and 78 percent of the available sulphur is present as sulphate.

3.3 Thermal Analysis

Simultaneous differential thermal analysis (DTA) and thermo-gravimetric analysis (TGA) were performed on samples BG7F 01, 06, 10, 11, 12, 13 & 14. The results are recorded in table three.

Ettringite was seen in all but two of the samples examined, at levels between 0.6 and 1.6 percent. Gypsum was seen in all but one of the samples, at between 0.3 and 3.3 percent. The presence of ettringite would suggest past expansion has occurred in the blast furnace slag.

Both calcium hydroxide and magnesium hydroxide were measured in sample BG7F13 at 0.6 and 0.5 percent. These values were used to correct the free CaO and free MgO analyses recorded in table 2.

Calcite was present in all of the samples examined at between 0.1 and 1.6 percent.

3.4 Free CaO & Free MgO

Free CaO & free MgO analyses were carried out on samples BG7F 13 & 14. The results are recorded in table 2. Both original and corrected values are recorded. The original values include both the oxide (CaO and MgO) and the hydroxide ((Ca(OH)₂ and Mg(OH)₂) contents. The corrected values report only the oxide content (CaO and MgO) after correction using the hydroxide values from the thermal analyses. These corrected values are the more significant, as it is only the oxides that are still free to hydrate, i.e. expand.

Free lime was recorded in the samples at 1.8 and 0.4 percent. Free magnesia was recorded at 0.3 and 0.3 percent. These corrected free lime and free magnesia levels record oxides that are potentially still free to hydrate (i.e. expand).

3.5 TRS Accelerated Expansion Test

The TRS accelerated expansion test was performed on samples BG7F 01, 06, 10, 11, 12, 13 & 14. The results are recorded in table four. The samples were subjected to the test for a period of 14 days, this being extended to 28 days for samples 13 & 14 due to the presence of basic steel slag. Note that the test measures potential for future expansion, and is not a measure of expansion that may have taken place in the past.

Most of the blast furnace slag samples recorded modest expansions, the exception being sample 1 that recorded 0.34% at 14 days. Sample 13, which was predominantly basic steel slag, recorded 1.55 % at 28 days. Sample 14, which was mixed slag, reached 0.36 % at 28 days.

4. CONCLUSIONS & RECOMMENDATIONS

The following conclusions can be drawn:-

- All but one of the samples contained significant amounts of blast furnace slag. The blast furnace slag was mainly crystalline and showed some alteration due to weathering. Old weathered blast furnace slag may contain pockets of potentially expansive material. Potential for expansion can only be assessed with direct expansion testing.
- Basic steel slag was the dominant constituent of one sample, and a more minor constituent of three. The basic steel slag, which was substantially altered due to weathering, could be a significant source of expansion. Potential for expansion can only be assessed with direct expansion testing.
- Minor amounts of basic refractory material were seen in two of the samples. If pockets of this material were to be present on the site, there could be significant risk of expansion.
- Other materials present, generally in minor concentrations, included quartz, iron ore, ooidal (local) ironstone, metallic iron, clay, coal, coke and used Portland cement.
- Some of the samples, especially sample 4, contained loosely compacted fume/dust.
- Further testing of the blast furnace slag indicated some high sulphate levels which should be taken into account when specifying concrete that may come into contact with the slag. There was also some evidence of past expansion with the presence of ettringite. Expansion testing recorded some potential for expansion, with one sample recording 0.34 percent

- Significant potential for expansion was recorded for the sample that was predominantly basic steel slag, with 1.55 percent recorded. Again, there was also evidence of past expansion with this material.

The following recommendations are made:-

The site from which these samples were taken is of significant size, potentially containing huge amounts of iron and steel industry slag. To date, only 14 samples have been examined, with expansion testing carried out on only 7. A much more significant site investigation, commensurate with the volume of material on site, should now be undertaken. This should aim to determine the distribution of slag types across the site, and further assess the expansive properties of the slag.

It is highly likely that material will be present on the site with far greater potential for expansion than that recorded in this small batch of samples.

Note

These conclusions apply only to the samples tested and may not represent the bulk of the material on the site from which they were taken.

Ian D. Thomas

Ian D Thomas BSc(Hons)

21 July 2017

TABLE 1 **SULPHUR SPECIES ANALYSES**

TRS Ref	Site Ref	Water Sol. SO ₃ (g/l)	Acid Sol. SO ₃ (%)	Total S (%)
BG7F01	TP22 - 1.5m	0.97	2.21	1.13
BG7F06	TPD32 - 1.3m	1.00	0.96	0.94
BG7F10	TPE11 - 1.7m	1.70	1.22	1.13
BG7F11	TPE31 - 3.6m	1.33	1.15	0.89
BG7F12	TPE46 - 0.3m	0.49	0.49	0.80
BG7F13	TPE76 - 2.1m	0.03	0.12	0.19
BG7F14	TPI36 - 2.0m	0.28	0.1	0.95

TABLE 2 **ANALYSIS FOR FREE CaO AND FREE MgO**

TRS Ref	Site Ref	Free CaO Original (%)	Free CaO Corrected (%)	Free MgO Original (%)	Free MgO Corrected (%)
BG7F13	TPE76 - 2.1m	2.3	1.8	0.6	0.3
BG7F14	TPI36 - 2.0m	0.4	0.4	0.3	0.3

TABLE 3 **RESULTS FROM THERMAL ANALYSIS**

TRS Ref	Site Ref	Mass % by Thermal Analysis						
		L.O.I.	Ettringite	Gypsum	Calcite	Ca(OH) ₂	Mg(OH) ₂	Others
BG7F01	TP22 - 1.5m	3.42	1.4	3.3	0.1	0.0	0.0	-
BG7F06	TPD32 - 1.3m	2.93	1.6	1.0	0.4	0.0	0.0	-
BG7F10	TPE11 - 1.7m	2.87	1.0	1.5	0.3	0.0	0.0	-
BG7F11	TPE31 - 3.6m	2.40	0.9	1.3	0.1	0.0	0.0	quartz
BG7F12	TPE46 - 0.3m	2.21	0.6	0.6	0.5	0.0	0.0	-
BG7F13	TPE76 - 2.1m	2.74	0.0	0.0	1.6	0.6	0.5	-
BG7F14	TPI36 - 2.0m	1.66	0.0	0.3	0.5	0.0	0.0	-

TABLE 4 **TRS ACCELERATED EXPANSION TEST**

TRS Ref	Site Ref	7 day (%)	14 day (%)	21 day (%)	28 day (%)
BG7F01	TP22 - 1.5m	0.22	0.34	-	-
BG7F06	TPD32 - 1.3m	0.01	0.03	-	-
BG7F10	TPE11 - 1.7m	0.00	0.00	-	-
BG7F11	TPE31 - 3.6m	0.00	0.00	-	-
BG7F12	TPE46 - 0.3m	0.01	0.02	-	-
BG7F13	TPE76 - 2.1m	0.72	1.05	1.39	1.55
BG7F14	TPI36 - 2.0m	0.22	0.31	0.34	0.36

APPENDIX A

PETROLOGICAL REPORT ON SAMPLES BG7F 01-14

A petrological examination has been carried out of fourteen samples, BG7F 01 to 14.

Polished blocks were prepared using particulate material crushed to a nominal size of –5mm. Representative material was made up into resin-bonded blocks. One face of each of these was ground flat and polished using diamond pastes. In addition, when appropriate, the surfaces were selectively etched with water, 10% MgSO₄ solution and 0.1%N HCl in order to help with the phase identification.

The detailed results are given in the accompanying Table.

Blast furnace slag occurs in large to very large amounts in all the samples except no. 13. Basic steel slag occurs in small amounts in samples 03 and 04 and in medium to large amounts in samples 13 and 14. A little basic refractory material (dolomet) was seen in samples 08 and 14. Several samples contain small amounts of particles consisting of loosely compacted fume/dust. Sample 04 has a medium amount of this material.

The blast furnace slag is mostly vesicular and crystalline with vesicles infilled by secondary material. It is mostly dark grey or greenish in colour.

The unaltered slag consists mainly of melilite (Ca,Mg,Al silicate) with spinel (MgAl₂O₄) as a second principle phase. Minor amounts of merwinite (Ca,Mg silicate) and dicalcium silicate (e.g. larnite (β-Ca₂SiO₄) and bredigite (Ca₂SiO₄ with some Mg in solid solution)) are present and other silicates such as wollastonite (Ca silicate). These form a matrix to the melilite crystals. Some glassy slag is present, again mostly as a matrix phase. There is also some finely crystalline ceramic slag. Very small amounts of Ca, Mn and Fe sulphides are present and graphitic iron occurs as minute spherules and occasional larger prills. Secondary alteration is moderate in amount mainly infilling pores and occurring as surface rinds. Some has replaced the original phases especially the calcium-rich silicates. It consists mainly of granular material and aggregates of needle shaped crystals that are probably silicate and sulpho-aluminate hydrates such as ettringite. Calcite (CaCO₃) occurs in some samples and most samples have copious amounts of well-crystallised gypsum (CaSO₄.2H₂O).

The unaltered basic steel slag consists mainly of dicalcium silicate, RO and R₃O₄ phases (FeO and Fe₃O₄ with some Al, Mn, Mg and Ca in solid solution) and CaF phases (complex Ca alumino-ferrites). There are minor amounts of another

silicate, probably melilite (Ca,Mg,Al silicate). There are small amounts of lime phase (CaO with some Fe, Mn and Mg in solid solution) and periclase (MgO with some Fe in solid solution). The lime phase mostly forms spongy grains up to about 0.3 mm in size or is finely crystalline, well dispersed at other phase boundaries. The periclase occurs mostly as rounded grains up to about 0.1 mm in size that are often encapsulated in RO phase. The slag is extensively altered with the formation of secondary phases difficult to identify specifically under the microscope.

A little basic refractory material is present. This consists of partly hydrated dolomet (originally finely crystalline periclase and lime phase bonded by minor amounts of silicates).

The compacted fume/dust is made up of particles ranging in size from less than 1 to about 100 microns of iron oxides, glass, coke, etc. embedded in an extremely fine-grained matrix.

Other constituents include quartz (as sand, sandstone and silt), iron ore, ooidal (local) ironstone, metallic iron with associated rust, clay, coal, coke and used Portland cement. There are small to medium amounts of cementitious material binding the smaller and adherent to the larger particles. This appears to be similar to the slag alteration products but may also include clay.

TRS SAMPLES BG7F 01-14 (Sheet 1 of 2)

	1	2	3	4	5	6	7	8	9	10
BLAST FURNACE SLAG										
Amount	L	L	L	I	L	L	I	L	L	L
Phases present:-										
Melilite	L	L	L	L	L	L	L	L	L	L
Merwinite	-	-	-	-	vs	vs	-	-	-	-
Larnite & bredigite	-	vs	-	-	vs	-	vs	-	-	vs
Matrix & other silicates	s	s	s	s	s	s	s	s	s	s
Ca & Fe,Mn sulphides	vs	vs	vs	vs	vs	vs	vs	vs	vs	vs
Metal, rust, scale etc.	vs	vs	vs	vs	s	vs	s	s	vs	vs
Spinel	s	s	s	s	s	s	s	s	s	s
RO phase (R mainly Fe)	-	-	-	-	s	-	-	-	-	-
Glassy slag	s	vs	vs	s	vs	vs	vs	vs	vs	vs
Ceramic slag	vs	vs	vs	vs	vs	vs	vs	vs	vs	vs
Alteration products	m	m	m	m	m	m	m	m	m	m
Calcite	-	-	-	-	-	-	-	s	-	-
Gypsum	s	s	m	m	m	s	s	s	m	s
BASIC STEEL SLAG										
Amount	-	-	s	s	-	-	-	-	-	-
Phases present:-										
Dicalcium silicate	-	-		s	-	-	-	-	-	-
Unetched silicates	-	-	s	-	-	-	-	-	-	-
RO phase	-	-	m	m	-	-	-	-	-	-
CaF phase	-	-	vs	s	-	-	-	-	-	-
R3O4 phase	-	-	s	s	-	-	-	-	-	-
Metal & rust	-	-	-	-	-	-	-	-	-	-
Spinel	-	-	vs	-	-	-	-	-	-	-
Lime phase	-	-	vs	-	-	-	-	-	-	-
Periclase	-	-	vs	-	-	-	-	-	-	-
Fluorite	-	-	vs	-	-	-	-	-	-	-
Alteration products	-	-	m		-	-	-	-	-	-
BASIC REFRACTORIES										
Amount	-	-	-	-	-	-	-	vs	-	-
OTHER CONSTITUENTS										
Quartz, sandstone, etc.	s	vs	vs	vs	-	vs	s	vs	-	s
Acid steel slag	-	-	-	-	-	-	s	-	-	-
Metal, rust & scale	vs	vs	vs	vs	vs	-	vs	vs	vs	vs
Fume	-	-	-	m	vs	-	-	-	-	-
Iron ore, ironstone, sinter, etc.	vs	-	-	-	-	vs	-	vs	-	s
Shale, clay & ash	-	-	-	-	vs	vs	s	vs	-	s
Coke	s	vs	vs	s	vs	vs	s	vs	vs	s
Coal & char	vs	-	-	-	-	-	vs	vs	-	vs
Cementitious material & clay	s	s	s	s	s	s	s	s	s	s
Used Portland cement	vs	-	-	-	-	-	vs	-	-	-

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

TRS SAMPLES BG7F 01-14 (Sheet 2 of 2)

	11	12	13	14
BLAST FURNACE SLAG				
Amount	L	L	s	I
Phases present:-				
Melilite	L	L	L	L
Merwinite	-	vs	-	-
Larnite & bredigite	-	vs	-	-
Matrix & other silicates	s	s	s	s
Ca & Fe,Mn sulphides	vs	vs	vs	s
Metal, rust, scale etc.	vs	vs	vs	vs
Spinel	s	s	s	vs
RO phase (R mainly Fe)	vs	-	-	s
Glassy slag	vs	vs	-	-
Ceramic slag	vs	vs	-	-
Alteration products	m	m	s	s
Calcite	-	s	-	s
Gypsum	s	s	-	s
BASIC STEEL SLAG				
Amount	-	-	L	m
Phases present:-				
Dicalcium silicate	-	-	l	l
Unetched silicates	-	-	s	s
RO phase	-	-	m	m
CaF phase	-	-	s	s
R3O4 phase	-	-	s	s
Metal & rust	-	-	s	vs
Spinel	-	-	-	-
Lime phase	-	-	s	s
Periclase	-	-	s	s
Fluorite	-	-	-	-
Alteration products	-	-	m	m
BASIC REFRACTORIES				
Amount	-	-	-	vs
OTHER CONSTITUENTS				
Quartz, sandstone, etc.	m	vs	s	-
Acid steel slag	-	-	-	m
Metal, rust & scale	vs	vs	vs	s
Fume	-	-	s	-
Iron ore, ironstone, sinter, etc.	vs	-	vs	vs
Shale, clay & ash	s	-	-	-
Coke	vs	vs	s	vs
Coal & char	-	-	vs	vs
Cementitious material & clay	s	s	s	s
Used Portland cement	-	-	-	-

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

GENERAL EXPLANATION

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

Blast furnace slag. When present this consists mainly of melilite (Ca,Mg,Al silicate ranging in composition between $\text{Ca}_2\text{Al}_2\text{SiO}_7$ and $\text{Ca}_2\text{MgSi}_2\text{O}_7$). Other common phases are merwinite ($\text{Ca}_3\text{MgSi}_2\text{O}_8$), larnite ($\beta\text{-Ca}_2\text{SiO}_4$) and bredigite (Ca_2SiO_4 with some Mg in solid solution). The matrix often consists of some of the above phases, especially melilite, but may also contain other phases such as wollastonite (CaSiO_3), anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) and pyroxene ($(\text{CaMg})\text{SiO}_3$). Spinel (MgAl_2O_4) may be present. Sulphides and metal usually occur and are mostly finely dispersed, but the metal sometimes occurs as prills and may contain some graphite and Ti carbo-nitride (TiCN). Material reported as ceramic in appearance is very finely crystalline. The alteration products often include calcite and gypsum but are mostly silicate and/or sulpho-aluminate hydrates that are difficult to identify specifically under the microscope.

Basic steel slag. When present this consists mainly of dicalcium silicate, mostly the β -form (larnite) but sometimes the alpha form. Phosphoric slags may contain nagelschmidtite (Ca_2SiO_4 with $\text{Ca}_3\text{P}_2\text{O}_8$ in solid solution). Other silicate often present in small amounts, unetched by dilute HCl, is probably melilite. RO, R_3O_4 and RF phases are typically present and are mainly FeO and Fe_3O_4 with some Mg, Mn, Ca, etc. in solid solution and complex Ca alumino-ferrites. There may also be some Fe_2O_3 and spinel ($(\text{Mg,Fe})\text{Al}_2\text{O}_4$). The slag typically carries minor amounts of periclase (MgO with some Fe in solid solution) and lime phase (CaO with some Fe, Mn & Mg in solid solution). Other possible minor constituents include fluorite (CaF_2) and apatite (Ca fluoro-phosphate), the last present in phosphoric slags. The alteration products are, again, difficult to identify specifically but are probably, mainly, hydrated silicates. Portlandite ($\text{Ca}(\text{OH})_2$) may be present.

Basic refractory material. When present, this is mainly magnesian and consists of granular periclase (MgO) with interstitial silicates. Sometimes samples contain chrome-magnesia material with chromite present in addition to the other phases. Hot face material (from close to the furnace) may also occur. The periclase and interstitial silicates show secondary alteration similar to that of the basic steel slag. Brucite ($\text{Mg}(\text{OH})_2$) is likely.

Acid steel slag. When present this consists mainly of fayalite ($(\text{Fe,Mn})_2\text{SiO}_4$), Fe,Mn oxides and cristobalite (high temperature SiO_2).

Other slags. The 'intermediate slag' (probably primary flush slags from steel furnaces) has a variable phase assemblage, being mainly formed of silicates, particularly dicalcium silicate, melilite, merwinite and a complex olivine phase together with spinel and wustite (FeO). Sometimes it contains significant amounts of periclase, well embedded in the slag. The 'ferrous slag' (probably from foundry operations) has similar silicates but much more substantial content of iron oxides, usually wustite. It is often associated with scale (iron oxides formed on the surface of steel during reheating/cooling). When present, the 'cindery slag' consists of various silicates and silicate glass with Fe oxides, hercynite (FeAl_2O_4) and, sometimes, corundum (Al_2O_3). It is usually derived from heating furnaces and is often associated with burnt shale. When present, the 'siliceous clinker' is similar but devoid of iron oxides.

Other constituents The alumino-silicate brick includes a range of refractory firebrick, common brick and alumina-rich refractories. The 'quartz, sandstone, etc.' may include used silica refractory material consisting of quartz and its high temperature forms. Sometimes there is a distinct granular texture and it is derived from silcrete, a kind of chert. Cementitious material may bond the finer particles together. It is similar to the other alteration products consisting mostly of complex hydrates difficult to identify under the microscope. Sometimes some is used Portland cement recognised by the relict textures of the clinker and the embedded quartz sand.

APPENDIX B

MECHANISMS OF VOLUMETRIC INSTABILITY IN IRON AND STEEL INDUSTRY SLAGS

Volumetric change with time can occur in some types of iron and steel industry slags. These mechanisms are briefly described in this section.

Blast Furnace Slags

Fresh-make air-cooled, i.e. crystalline, blast furnace slags are almost always volumetrically stable after cooling. The two mechanisms for volumetric instability listed in BS1047:1983 – "Air Cooled Blast furnace Slag for use in Construction" are:-

- a) Beta to gamma inversion of dicalcium silicate.**
- b) Iron unsoundness.**

a) Research by G H Thomas on this phase transformation has shown the transformation to be athermal rather than isothermal. In practical terms this means that inversion, and the expansion associated with it, can only occur during the cooling cycle. In fully cooled material there would appear to be no further risk of instability from this mechanism.

b) Iron unsoundness is a very rare form of instability frequently associated with operating problems in the blast furnace. TRS know of only one instance in over 40 years. The mechanism, which is a hydrolysis reaction, is immediately triggered off by the presence of water. Once water has initiated the reaction, the mechanism proceeds to completion. It is impossible to arrest the process once started; at least by methods operating in normal ambient conditions.

It follows that the risk of late expansion from either of these mechanisms in blast furnace slag is remote.

c) Sulphoaluminate Type Activity

Some years ago, G. H. Thomas discovered a third mechanism that may give rise to volumetric instability. The process is possible only in some old blast furnace slag altered by weathering. When the sulphide sulphur in the blast furnace slags is oxidised during

weathering to sulphate, under some circumstances reactions can take place within the slag to produce an 'ettringite' type product. The process is somewhat analogous to sulphatic attack on concrete and has a similar result - expansion of the mass and associated disruption.

For the mechanism to have any significance, the slag needs to have residual potential for this reaction. Evidence of past activity does not necessarily indicate further reaction is possible.

The TRS accelerated expansion test is, we believe, uniquely capable of identifying such slags, as well as instability attributable to free CaO and free MgO in steel slag & etc.

Basic Steel Slags

Basic steel slags commonly contain significant quantities of free CaO and free MgO. These free oxides are well known for the massive expansion associated with their hydration. In practical terms, it is impossible to forecast when hydration will take place, but it can be up to decades after the material was cooled – or placed. The reasons are complex, but include the varying density of the oxides, due to the variation in temperatures at which the products have been held in the furnace. Other factors influencing rate of hydration include:-

- the protection of slags by a reaction product at the oxide interface with the slag.
- the presence of the oxides as lime or magnesia rich solid solutions instead of the pure oxide.

The result is potential future volumetric instability but at an unforeseeable date. Periclase, i.e. free MgO, is relatively much slower than free CaO to hydrate.

Scrap High Magnesia Refractories

These are particularly undesirable components in fill as they commonly result in high concentrations of free MgO. The problems associated with these concentrations are similar to those where periclase is found in basic steel slag.

TRS REPORT

Report Ref: BG8B/AEG/SLS1015/TRS/04/18/RP2
Date Issued: 25 April 2018
TRS Sample Refs: BG8B01-24
Order No: LA1970

**EXAMINATION OF 24 SAMPLES
FROM
CONTRACT SLS1015,
FORMER SSI STEELWORKS, REDCAR
FOR
ALLIED EXPLORATION & GEOTECHNICS LTD**



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**EXAMINATION OF 24 SAMPLES
FROM
CONTRACT SLS1015,
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FOR
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1. BACKGROUND

Twenty four bulk samples were received from the above site on 13th February 2018. Each sample was weighed and allocated a unique TRS reference number, the details of which are recorded below:-

TRS Ref	Site Ref	Depth/m	Mass/kg	TRS Ref	Site Ref	Depth/m	Mass/kg
BG8B01	S2TPA15	1.5-2.0	16.7	BG8B13	TPE05	0.5	9.5
BG8B02	S2TPA43	0.2-0.3	15.4	BG8B14	TPE20	0.5-0.8	4.0
BG8B03	S2TPA51	1.9-2.3	14.1	BG8B15	TPE59	3.5-4.0	6.1
BG8B04	S2TPA55	0.5	15.8	BG8B16	TPF04	0.7	15.3
BG8B05	S2TPA57	4.0-4.3	14.1	BG8B17	TPH08	1.2-1.5	23.9
BG8B06	S2TPA74	1.0-1.5	9.7	BG8B18	TPH12	1.0-1.3	19.2
BG8B07	S2TPA96	3.0-4.0	20.5	BG8B19	TPH27	1.8	19.7
BG8B08	TP13	2.4	20.8	BG8B20	TPH30	1.8-2.1	20.4
BG8B09	TPB02	0.3-0.6	2.3	BG8B21	TPI03	3.4-3.7	19.4
BG8B10	TPB03	2.8-3.1	20.4	BG8B22	TPI19	3.4-3.7	9.7
BG8B11	TPB08	1.7-2.0	21.4	BG8B23	TPI25	2.7-3.0	16.6
BG8B12	TPD34	0.2-0.8	20.0	BG8B24	TPI33	3.3-3.6	16.4

The purpose of the exercise was to identify the range and relative concentrations of any iron and steelmaking slags present in the samples, and whether there was any potential for volumetric instability from the materials.

2. SAMPLE PREPARATION & PROGRAMME OF ANALYSIS

The samples were primary crushed to reduce particle size down to <50mm, portions then being selected and dried at low temperature to constant weight. The dried material was subjected to a regime of stage crushing and quartering to further reduce particle size down to <5mm. Portions of this <5mm material were made up into resin bound blocks, one face of which was ground flat and polished using diamond pastes. Further portions of the <5mm material were milled to a fine powder. Fractions of material were extraction throughout the preparation procedure to provide the materials necessary for the tests and analyses required in the programme.

A petrological examination was made of the polished blocks using reflected light microscopy, the complete findings of which are recorded in appendix A. The results of this examination were recorded and discussed in our report of 27th February 2018. On the basis of that report, further work was authorised on the samples on 15th March 2018 as follows:-

Mixed slag expansion testing on samples BG8B 01-03, 05-09, 11-13, 15, 17-19 & 22-24. (**Note:-** Sulphur and sulphate analyses were only carried out on samples containing medium or more amounts of blast furnace slag. Free CaO & free MgO analyses were only carried out on samples containing medium or more amounts of basic steel slag.)

The results of the analyses are recorded as follows:-

- Water & acid soluble sulphates (table 1)
- Total sulphur (table 1)
- Free CaO & free MgO (table 2)
- Thermal analysis (DTA & TGA) (table 3)
- TRS accelerated expansion test (table 4)

3. DISCUSSION OF RESULTS

3.1 Petrology

A petrological examination was made of the 24 samples using reflected light microscopy. The complete findings of this examination are recorded in appendix A.

Blast furnace slag was present in all but one of the samples, with significant quantities present in all but samples 16, 18, 19, 20 and 21. The blast furnace slag was mostly vesicular and crystalline, with vesicular infill and particle coatings from secondary materials (products of weathering). The unaltered slag consisted predominantly of melilite, along with more minor amounts of merwinite, larnite, bredigite, wollastonite, monticellite, Ca, Mn & Fe sulphides and graphitic iron. Some glassy and finely ceramic material was also present. Secondary alteration was moderate, consisting mainly of pore infill and surface rinds. Products of alteration included calcite, gypsum and possibly ettringite. Old weathered blast furnace slag may occasionally contain pockets of potentially expansive material. This potential can only be assessed by direct expansion testing (see sections 3.2-3.5).

Basic steel slag was present in all but seven of the samples. Most of these samples contained fairly moderate amounts (small / very small), but samples 07, 15, 17, 18 & 19 contained much more significant concentrations. The unaltered basic steel slag consisted mainly of dicalcium silicate, along with more minor amounts of RO & R₃O₄ phase, CaF phase, possibly melilite, lime phase and periclase. The slag was extensively altered due to weathering, the secondary phases being difficult to identify specifically under the microscope. The mineralogy of the basic steel slag would suggest that it may have significant potential for expansion. This potential can only be assessed by direct expansion testing (see sections 3.2-3.5).

Minor amounts (small / very small) of basic refractory material were seen in samples 15 and 18. This material, even in minor amounts, can have significant potential for expansion.

Other constituents seen in the samples, in varying concentrations, included alumino-silicate refractories, quartz (mainly as sand but also silt and sandstone), iron ore, ooidal (local) ironstone, fume, metallic iron, rust, shale, coal and coke. A cementitious material often bound the smaller particles together. This material appeared similar to the slag alteration products.

3.2 Sulphur Species

The following range of analyses were performed on samples BG8B 01-03, 05-06, 08-09, 11-13, 15, 17 & 22-24 (These samples contained medium or more amounts of blast furnace slag). The results are recorded in table 1:-

- Water soluble sulphate
- Acid soluble sulphate
- Total sulphur

Total sulphur values were in the range 0.27 to 1.73 percent. Acid soluble sulphates were in the range 0.27 to 2.86 percent, with corresponding water soluble sulphates of 0.32 to 1.62 g/l. These sulphate and sulphur values were variable, commensurate with the variable amounts of blast furnace slag present. However, some values were very high, and consequently, care should be taken when specifying concrete that may come into contact with the slag. Calculations show that between 23 and 80 percent of the available sulphur is present as sulphate.

3.3 Thermal Analysis

Simultaneous differential thermal analysis (DTA) and thermo-gravimetric analysis (TGA) were performed on samples BG8B 01-03, 05-09, 11-13, 15, 17-19 & 22-24. The results are recorded in table three.

Ettringite was seen in eight of the samples examined, at levels between trace and 0.8 percent. Gypsum was seen in all but one of the samples, at between trace and 7.2 percent. On comparing the gypsum values with the acid soluble sulphates, some of the gypsum values were overstated. This is common in old weathered blast furnace slag, and is usually an indicator of the presence of thaumasite. The presence of ettringite and possibly thaumasite would suggest some past expansion has occurred in the blast furnace slag.

Calcium hydroxide was recorded in two of the samples, at trace and 0.5 percent. Magnesium hydroxide was measured in eight of the samples, at between trace and 1.2 percent. These values were used to correct the free CaO and free MgO analyses recorded in table 2.

Calcite was present in all of the samples examined at between trace and 20.6 percent. This product is an indicator as to the weathered state of the slag, although some may have come from other components present in the samples.

3.4 Free CaO & Free MgO

Free CaO & free MgO analyses were carried out on samples BG8B 07, 15 & 17-19 (These samples contained medium or more mounts of basic steel slag). The results are recorded in table 2. Both original and corrected values are recorded. The original values include both the oxide (CaO and MgO) and the hydroxide ((Ca(OH)₂ and Mg(OH)₂) contents. The corrected values report only the oxide content (CaO and MgO) after correction using the hydroxide values from the thermal analyses. These corrected values are the more significant, as it is only the oxides that are still free to hydrate, i.e. expand.

Free lime was recorded in the samples at between 0.3 and 1.1 percent. Free magnesia was recorded at between 1.1 and 2.8 percent. These corrected free lime and free magnesia levels record oxides that are potentially still free to hydrate (i.e. expand).

3.5 TRS Accelerated Expansion Test

The TRS accelerated expansion test was performed on samples BG8B 01-03, 05-09, 11-13, 15, 17-19 & 22-24. The results are recorded in table four. The samples were subjected to the test for a period of 14 days unless basic steel slag was present in medium or more amounts, where the test duration was extended to 28 days. Note that the test measures potential for future expansion, and is not a measure of expansion that may have taken place in the past.

Samples consisting predominantly of blast furnace slag, with only minor amounts of basic steel slag recorded 14 day expansion results of between 0.01 and 0.30 percent. Samples containing medium or more concentrations of basic steel slag recorded 28 day expansion results of between 0.80 and 2.05 percent.

4. CONCLUSIONS & RECOMMENDATIONS

The following conclusions can be drawn:-

- Blast furnace slag present in all but one of the 24 samples examined, and was a dominant constituent in 18 of them. The slag was mainly crystalline although minor amounts of glassy and ceramic material were seen. The slag showed some alteration due to weathering. Old weathered blast furnace slag may occasionally contain pockets of potentially expansive material.
- Further testing of samples consisting predominantly of blast furnace slag (with only minor amounts of basic steel slag) recorded expansion results of between 0.01 and 0.30 percent. Thermal analysis indicated some evidence of past expansion of the blast furnace slag (presence of ettringite and possibly thaumasite). Some of the sulphate values were very high and should be taken into consideration when specifying concrete that may come into contact with the slag.
- Basic steel slag was seen in all but 7 of the samples, with significant amounts present in five.
- Expansion testing of these five samples recorded expansion results of between 0.80 and 2.05 percent.
- Minor amounts of basic refractory material were seen in two of the 24 samples examined. This product can be a significant source of expansion.
- Other products seen in the samples, in varying amounts, included alumino-silicate refractories, quartz, iron ore, ooidal ironstone, fume, metallic iron, rust, shale, coal and coke. A cementitious material often bound the smaller particles together. This material appeared similar to the slag alteration products.

The following recommendations are made:-

The site contains significant proportions of iron and steel industry slag. To date, only 24 samples have been examined from this part of the site. A more significant site investigation, commensurate with the volume of material, should be undertaken. This should aim to determine the distribution of slag types across the site, and further assess the expansive properties of the slag.

Note

These conclusions apply only to the samples tested and may not represent the bulk of the material on the site from which they were taken.

Ian D. Thomas

Ian D Thomas BSc(Hons)

25 April 2018

TABLE 1 **SULPHUR SPECIES ANALYSES**

TRS Ref	Site Ref	Water Sol. SO ₃ (g/l)	Acid Sol. SO ₃ (%)	Total S (%)
BG8B01	S2TPA15	1.20	0.81	1.21
BG8B02	S2TPA43	0.32	0.43	0.63
BG8B03	S2TPA51	1.55	1.02	0.79
BG8B05	S2TPA57	1.24	0.80	0.73
BG8B06	S2TPA74	0.74	0.27	0.47
BG8B07	S2TPA96	-	-	-
BG8B08	TP13	1.62	2.86	1.73
BG8B09	TPB02	1.62	0.91	0.75
BG8B11	TPB08	1.38	1.40	1.13
BG8B12	TPD34	1.13	0.81	0.69
BG8B13	TPE05	0.83	0.33	0.27
BG8B15	TPE59	1.43	1.46	0.73
BG8B17	TPH08	0.45	0.64	0.56
BG8B18	TPH12	-	-	-
BG8B19	TPH27	-	-	-
BG8B22	TPI09	0.48	1.20	0.69
BG8B23	TPI25	1.24	0.99	0.83
BG8B24	TPI33	1.33	1.06	0.96

TABLE 2 **ANALYSIS FOR FREE CaO AND FREE MgO**

TRS Ref	Site Ref	Free CaO Original (%)	Free CaO Corrected (%)	Free MgO Original (%)	Free MgO Corrected (%)
BG8B01	S2TPA15	-	-	-	-
BG8B02	S2TPA43	-	-	-	-
BG8B03	S2TPA51	-	-	-	-
BG8B05	S2TPA57	-	-	-	-
BG8B06	S2TPA74	-	-	-	-
BG8B07	S2TPA96	0.3	0.3	1.1	1.1
BG8B08	TP13	-	-	-	-
BG8B09	TPB02	-	-	-	-
BG8B11	TPB08	-	-	-	-
BG8B12	TPD34	-	-	-	-
BG8B13	TPE05	-	-	-	-
BG8B15	TPE59	1.1	1.1	1.7	1.3
BG8B17	TPH08	0.9	0.9	1.8	1.3
BG8B18	TPH12	0.5	0.5	1.8	1.3
BG8B19	TPH27	0.9	0.9	3.1	2.8
BG8B22	TPI09	-	-	-	-
BG8B23	TPI25	-	-	-	-
BG8B24	TPI33	-	-	-	-

**RESULTS FROM THERMAL
ANALYSIS**

TABLE 3

TRS Ref	Site Ref	Mass % by Thermal Analysis						
		L.O.I.	Ettringite	Gypsum	Calcite	Ca(OH) ₂	Mg(OH) ₂	Others
BG8B01	S2TPA15	2.87	0.8	0.8	trace	0.0	0.0	clay?
BG8B02	S2TPA43	9.09	trace	trace	8.3	0.0	0.0	-
BG8B03	S2TPA51	2.27	0.0	1.5	0.4	0.0	0.0	-
BG8B05	S2TPA57	2.34	0.7	0.8	0.4	0.0	0.0	-
BG8B06	S2TPA74	5.07	0.0	0.2	trace	0.0	0.0	clay?
BG8B07	S2TPA96	0.91	0.0	0.0	0.2	trace	0.0	-
BG8B08	TP13	7.34	0.0	7.2	1.3	0.0	0.0	-
BG8B09	TPB02	6.29	0.0	1.9	3.9	0.0	0.1	-
BG8B11	TPB08	4.69	0.0	6.0	1.1	0.0	0.0	-
BG8B12	TPD34	2.21	0.0	1.2	0.6	0.0	trace	-
BG8B13	TPE05	15.83	0.0	0.5	20.6	0.0	0.0	quartz
BG8B15	TPE59	9.43	0.0	4.7	4.1	0.0	0.6	-
BG8B17	TPH08	6.46	trace	1.4	3.3	0.0	0.7	quartz
BG8B18	TPH12	4.56	trace	1.0	1.6	0.0	0.7	-
BG8B19	TPH27	2.28	trace	trace	0.9	0.0	0.4	-
BG8B22	TPI09	9.42	trace	2.5	3.7	0.5	1.2	-
BG8B23	TPI25	4.13	0.0	3.5	1.5	0.0	0.0	-
BG8B24	TPI33	5.03	trace	4.2	1.5	0.0	trace	-

**TRS ACCELERATED EXPANSION
TEST**

TABLE 4

TRS Ref	Site Ref	7 day (%)	14 day (%)	21 day (%)	28 day (%)
BG8B01	S2TPA15	0.06	0.10	-	-
BG8B02	S2TPA43	0.05	0.06	-	-
BG8B03	S2TPA51	0.05	0.06	-	-
BG8B05	S2TPA57	0.03	0.04	-	-
BG8B06	S2TPA74	0.06	0.06	-	-
BG8B07	S2TPA96	0.80	1.05	1.18	1.21
BG8B08	TP13	0.10	0.13	-	-
BG8B09	TPB02	0.17	0.30	-	-
BG8B11	TPB08	0.08	0.11	-	-
BG8B12	TPD34	0.00	0.01	-	-
BG8B13	TPE05	0.05	0.07	-	-
BG8B15	TPE59	0.56	0.75	0.90	1.01
BG8B17	TPH08	0.49	0.84	1.03	1.13
BG8B18	TPH12	0.96	1.46	1.84	2.05
BG8B19	TPH27	0.22	0.41	0.61	0.80
BG8B22	TPI09	0.15	0.18	-	-
BG8B23	TPI25	0.08	0.11	-	-
BG8B24	TPI33	0.04	0.04	-	-

APPENDIX A

PETROLOGICAL REPORT ON SAMPLES BG8B 01-24

A petrological examination has been carried out of twenty-four samples, BG8B 01 to 24.

Polished blocks were prepared using particulate material crushed to a nominal size of –5mm. Representative material was made up into resin-bonded blocks. One face of each of these was ground flat and polished using diamond pastes. In addition, when appropriate, the surfaces were selectively etched with water, 10% MgSO₄ solution and 0.1%N HCl in order to help with the phase identification.

The detailed results are given in the accompanying Table.

Blast furnace slag occurs in large or very large amounts in the majority of the samples (1-6, 8-12, 23 and 24). Basic steel slag occurs in large or very large amounts in several samples (7, 15, 17 and 18) and in medium amounts in some others. Very little basic (magnesian) refractory material was seen. Several samples contain medium or larger amounts of other materials such as quartz sand (9-22 and 24), iron ore and iron ore sinter (1, 9, 10, 13 and 16) and coal and coke (6 and 16). Most samples contain aggregates consisting of loosely compacted 'dust' (particles less than about 100µm in size) that sometimes includes fume (less than 20µm).

The blast furnace slag is mostly vesicular and crystalline with vesicles infilled by secondary material. It is mostly dark grey or greenish in colour.

The unaltered slag consists mainly of melilite (Ca,Mg,Al silicate) with spinel (MgAl₂O₄) as a second principle phase. Minor amounts of merwinite (Ca,Mg silicate) and dicalcium silicate (e.g. larnite (β-Ca₂SiO₄) and bredigite (Ca₂SiO₄ with some Mg in solid solution)) are occasionally present and other silicates such as wollastonite (Ca silicate) and monticellite (Ca,Mg silicate) also occur forming a matrix to the melilite crystals. However, it's believed that the calcium-rich silicates have been partly removed as a result of weathering. Some glassy slag is present, again mostly as a matrix phase. There is also some finely crystalline ceramic slag. Very small amounts of Ca, Mn and Fe sulphides are present and graphitic iron occurs as minute spherules and occasional larger prills. Secondary alteration is mainly moderate in amount, mainly infilling pores and occurring as surface rinds. Some has replaced the original phases especially the calcium-rich silicates as noted above. It consists mainly of granular material and aggregates of needle shaped crystals that are probably silicate and sulpho-aluminate

hydrates such as ettringite. Calcite (CaCO_3) occurs in some samples and some samples have well-crystallised gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).

The unaltered basic steel slag consists mainly of dicalcium silicate, RO and R_3O_4 phases (FeO and Fe_3O_4 with some Al, Mn, Mg and Ca in solid solution) and CaF phases (complex Ca alumino-ferrites). In some samples there are amounts of another silicate, probably melilite (Ca,Mg,Al silicate). This is sometimes associated with small prismatic crystals probably identified as apatite (Ca fluoro-phosphate). There are small amounts of lime phase (CaO with some Fe, Mn and Mg in solid solution) and periclase (MgO with some Fe in solid solution). The lime phase mostly forms rounded grains up to about 0.3 mm in size or is finely crystalline, well dispersed at other phase boundaries. The periclase occurs mostly as rounded grains up to about 0.1 mm in size that are often encapsulated in RO phase. These two oxide phases are distributed sporadically being often absent and concentrated in some particles. The slag is extensively altered with the formation of secondary phases difficult to identify specifically under the microscope.

A little basic refractory material is present. This consists of partly hydrated periclase.

The compacted dust is made up of particles ranging in size from less than 1 to about 100 microns of iron oxides, glass, coke, etc. embedded in an extremely fine-grained matrix. It sometimes includes spheroidal particles of fume, mostly iron oxide or slag glass.

Other constituents include quartz (as sand, sandstone and silt), iron ore, ooidal (local) ironstone, metallic iron with associated rust, shale, coal and coke. There are small to medium amounts of cementitious material binding the smaller and adherent to the larger particles. This appears to be similar to the slag alteration products but may also include clay.

TRS SAMPLES BG8B 01-24 (Page 1 of 2)												
	1	2	3	4	5	6	7	8	9	10	11	12
BLAST FURNACE SLAG												
Amount	L	L	L	L	L	I	-	I	I	I	I	L
Phases present:-												
Melilite	L	L	L	L	L	L	-	L	L	L	L	L
Merwinite	-	-	-	-	-	-	-	-	-	-	vs	-
Larnite & bredigite	-	-	-	-	-	-	-	-	-	vs	-	-
Matrix & other silicates	s	s	s	s	s	s	-	s	s	s	s	s
Ca & Fe,Mn sulphides	vs	vs	vs	vs	vs	vs	-	vs	vs	vs	vs	vs
Metal, rust, scale etc.	vs	s	vs	vs	vs	s	-	vs	vs	vs	s	vs
Spinel	vs	-	s	s	s	s	-	s	s	s	s	s
Glassy slag	s	m	s	vs	-	s	-	s	s	m	s	s
Alteration products	s	s	s	s	s	s	-	m	m	m	m	s
Calcite	s	-	s	-	-	s	-	s	-	s	-	s
Gypsum	-	-	vs	s	s	s	-	-	-	-	-	s
BASIC STEEL SLAG												
Amount	-	vs	-	-	-	-	L	s	s	s	vs	-
Phases present:-												
Dicalcium silicate	-	l	-	-	-	-	l	l	l	l	l	-
Tricalcium silicate	-	-	-	-	-	-	-	-	-	-	-	-
Unetched silicates	-	-	-	-	-	-	m	s	s	s	s	-
RO phase	-	m	-	-	-	-	m	m	m	m	m	-
CaF phase	-	s	-	-	-	-	s	s	s	s	vs	-
R3O4 phase	-	s	-	-	-	-	-	s	-	-	-	-
R2O3 phase	-	-	-	-	-	-	-	-	-	-	-	-
Metal & rust	-	vs	-	-	-	-	vs	s	-	s	-	-
Spinel	-	-	-	-	-	-	-	-	-	s	-	-
Lime phase	-	vs	-	-	-	-	-	-	s	s	-	-
Periclase	-	-	-	-	-	-	-	-	s	s	-	-
Apatite	-	-	-	-	-	-	vs	-	vs	-	-	-
Alteration products	-	m	-	-	-	-	s	m	m	m	m	-
BASIC REFRACTORIES												
Amount	-	-	-	-	-	-	-	-	-	-	-	-
OTHER CONSTITUENTS												
Alumino-silicate brick	-	-	-	-	-	-	-	-	-	-	-	-
Quartz, sandstone, etc.	vs	s	vs	vs	vs	m	vs	s	m	s	s	vs
Acid steel slag	-	-	-	-	-	-	-	vs	-	vs	vs	-
Cindery slag	-	-	-	-	-	s	-	-	-	-	-	-
Siliceous clinker	-	-	-	-	-	m	-	s	-	s	s	vs
Metal, rust & scale	vs	vs	s	vs	-	s	vs	s	s	s	s	vs
Fume	-	vs	-	-	-	-	-	vs	vs	vs	vs	-
Limestone & dolomite	-	-	-	-	-	-	-	-	-	-	-	-
Iron ore, ironstone, sinter, etc.	m	vs	vs	vs	-	vs	vs	s	m	m	s	vs
Shale, clay & ash	-	-	-	vs	-	s	-	s	s	s	s	vs
Coke	vs	s	s	vs	vs	m	-	s	vs	s	s	vs
Coal & char	-	-	-	-	-	m	-	vs	-	-	-	-
Cementitious material & clay	s	s	s	s	s	m	-	m	m	m	m	s
Used Portland cement	-	-	-	-	-	-	-	-	-	-	-	-
L = very large, l = large, m = medium, s = small and vs = very small amounts												

TRS SAMPLES BG8B 01-24 (Page 2 of 2)

	13	14	15	16	17	18	19	20	21	22	23	24
BLAST FURNACE SLAG												
Amount	<i>m</i>	<i>m</i>	<i>m</i>	<i>s</i>	<i>m</i>	<i>s</i>	<i>s</i>	<i>vs</i>	<i>s</i>	<i>m</i>	<i>l</i>	<i>L</i>
Phases present:-												
Melilite	L	l	l	l	l	l	l	L	L	L	L	L
Merwinite	-	-	-	-	-	s	-	-	-	-	-	-
Larnite & bredigite	-	vs	-	-	-	-	-	-	-	-	-	-
Matrix & other silicates	s	s	s	s	s	s	s	vs	s	s	s	s
Ca & Fe,Mn sulphides	vs	vs	vs	vs	vs	s	vs	-	-	vs	vs	vs
Metal, rust, scale etc.	vs	vs	vs	vs	vs	vs	vs	-	-	vs	s	s
Spinel	s	s	s	s	s	s	vs	-	vs	s	s	s
Glassy slag	s	m	s	s	s	m	s	-	-	s	s	s
Alteration products	s	s	m	m	m	m	m	vs	s	s	m	m
Calcite	-	-	-	-	-	-	-	-	-	-	-	-
Gypsum	-	-	-	-	-	-	-	-	-	-	-	-
BASIC STEEL SLAG												
Amount	-	<i>s</i>	<i>l</i>	<i>vs</i>	<i>l</i>	<i>l</i>	<i>m</i>	<i>s</i>	<i>s</i>	<i>s</i>	<i>vs</i>	<i>s</i>
Phases present:-												
Dicalcium silicate	-	l	l	s	l	m	l	l	l	l	-	l
Tricalcium silicate	-	-	-	-	-	-	-	-	-	vs	-	-
Unetched silicates	-	m	vs	-	-	s	s	-	s	-	-	-
RO phase	-	m	m	-	m	l	m	m	m	m	s	m
CaF phase	-	vs	vs	-	vs	s	s	s	s	s	s	s
R3O4 phase	-	-	vs	-	vs	s	s	s	-	s	-	s
R2O3 phase	-	-	-	-	vs	s	-	-	-	-	-	-
Metal & rust	-	-	vs	-	-	-	vs	-	-	s	-	s
Spinel	-	-	-	-	-	-	-	-	-	-	-	-
Lime phase	-	-	-	-	vs	-	s	s	-	vs	-	-
Periclase	-	vs	s	-	s	m	s	s	vs	vs	-	-
Apatite	-	s	-	-	-	-	-	-	-	-	s	-
Alteration products	-	m	m	L	m	m	m	m	m	m	l	m
BASIC REFRACTORIES												
Amount	-	-	<i>vs</i>	-	-	<i>s</i>	-	-	-	-	-	-
OTHER CONSTITUENTS												
Alumino-silicate brick	s	-	-	-	-	-	s	-	s	s	-	s
Quartz, sandstone, etc.	m	m	m	m	m	m	m	L	l	m	s	m
Acid steel slag	-	-	s	-	-	-	-	-	-	-	-	-
Cindery slag	-	-	-	-	-	-	-	-	-	-	-	vs
Siliceous clinker	s	s	s	-	-	-	-	-	-	-	s	-
Metal, rust & scale	-	-	-	-	-	-	-	-	-	-	-	-
Fume	vs	vs	-	-	-	m	vs	-	vs	vs	-	-
Limestone & dolomite	m	s	-	s	-	vs	-	-	-	-	-	-
Iron ore, ironstone, sinter, etc.	l	s	s	m	s	s	s	vs	vs	s	s	s
Shale, clay & ash	s	s	-	s	s	m	s	vs	l	m	m	-
Coke	s	s	s	l	s	s	s	vs	vs	s	s	s
Coal & char	-	s	-	s	s	-	-	vs	vs	s	vs	-
Cementitious material & clay	s	s	m	m	s	m	m	s	s	m	s	s
Used Portland cement	-	-	-	-	-	-	-	-	-	-	-	-
L = very large, l = large, m = medium, s = small and vs = very small amounts												

GENERAL EXPLANATION

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

Blast furnace slag. When present this consists mainly of melilite (Ca,Mg,Al silicate ranging in composition between $\text{Ca}_2\text{Al}_2\text{SiO}_7$ and $\text{Ca}_2\text{MgSi}_2\text{O}_7$). Other common phases are merwinite ($\text{Ca}_3\text{MgSi}_2\text{O}_8$), larnite ($\beta\text{-Ca}_2\text{SiO}_4$) and bredigite (Ca_2SiO_4 with some Mg in solid solution). The matrix often consists of some of the above phases, especially melilite, but may also contain other phases such as wollastonite (CaSiO_3), anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) and pyroxene ($(\text{CaMg})\text{SiO}_3$). Spinel (MgAl_2O_4) may be present. Sulphides and metal usually occur and are mostly finely dispersed, but the metal sometimes occurs as prills and may contain some graphite and Ti carbo-nitride (TiCN). Material reported as ceramic in appearance is very finely crystalline. The alteration products often include calcite and gypsum but are mostly silicate and/or sulpho-aluminate hydrates that are difficult to identify specifically under the microscope.

Basic steel slag. When present this consists mainly of dicalcium silicate, mostly the β -form (larnite) but sometimes the alpha form. Phosphoric slags may contain nagelschmidtite (Ca_2SiO_4 with $\text{Ca}_3\text{P}_2\text{O}_8$ in solid solution). Other silicate often present in small amounts, unetched by dilute HCl, is probably melilite. RO, R_3O_4 and RF phases are typically present and are mainly FeO and Fe_3O_4 with some Mg, Mn, Ca, etc. in solid solution and complex Ca aluminoferrites. There may also be some Fe_2O_3 and spinel ($(\text{Mg,Fe})\text{Al}_2\text{O}_4$). The slag typically carries minor amounts of periclase (MgO with some Fe in solid solution) and lime phase (CaO with some Fe, Mn & Mg in solid solution). Other possible minor constituents include fluorite (CaF_2) and apatite (Ca fluoro-phosphate), the last present in phosphoric slags. The alteration products are, again, difficult to identify specifically but are probably, mainly, hydrated silicates. Portlandite ($\text{Ca}(\text{OH})_2$) may be present.

Basic refractory material. When present, this is mainly magnesian and consists of granular periclase (MgO) with interstitial silicates. Sometimes samples contain chrome-magnesia material with chromite present in addition to the other phases. Hot face material (from close to the furnace) may also occur. The periclase and interstitial silicates show secondary alteration similar to that of the basic steel slag. Brucite ($\text{Mg}(\text{OH})_2$) is likely.

Acid steel slag. When present this consists mainly of fayalite ($(\text{Fe,Mn})_2\text{SiO}_4$), Fe,Mn oxides and cristobalite (high temperature SiO_2).

Other slags. The 'intermediate slag' (probably primary flush slags from steel furnaces) has a variable phase assemblage, being mainly formed of silicates, particularly dicalcium silicate, melilite, merwinite and a complex olivine phase together with spinel and wustite (FeO). Sometimes it contains significant amounts of periclase, well embedded in the slag. The 'ferrous slag' (probably from foundry operations) has similar silicates but much more substantial content of iron oxides, usually wustite. It is often associated with scale (iron oxides formed on the surface of steel during reheating/cooling). When present, the 'cindery slag' consists of various silicates and silicate glass with Fe oxides, hercynite (FeAl_2O_4) and, sometimes, corundum (Al_2O_3). It is usually derived from heating furnaces and is often associated with burnt shale. When present, the 'siliceous clinker' is similar but devoid of iron oxides.

Other constituents The aluminosilicate brick includes a range of refractory firebrick, common brick and alumina-rich refractories. The 'quartz, sandstone, etc.' may include used silica refractory material consisting of quartz and its high temperature forms. Sometimes there is a distinct granular texture and it is derived from silcrete, a kind of chert. Cementitious material may bond the finer particles together. It is similar to the other alteration products consisting mostly of complex hydrates difficult to identify under the microscope. Sometimes some is used Portland cement recognised by the relict textures of the clinker and the embedded quartz sand.

APPENDIX B

MECHANISMS OF VOLUMETRIC INSTABILITY IN IRON AND STEEL INDUSTRY SLAGS

Volumetric change with time can occur in some types of iron and steel industry slags. These mechanisms are briefly described in this section.

Blast Furnace Slags

Fresh-make air-cooled, i.e. crystalline, blast furnace slags are almost always volumetrically stable after cooling. The two mechanisms for volumetric instability listed in BS1047:1983 – “Air Cooled Blast furnace Slag for use in Construction” are:-

- a) Beta to gamma inversion of dicalcium silicate.**
- b) Iron unsoundness.**

a) Research by G H Thomas on this phase transformation has shown the transformation to be athermal rather than isothermal. In practical terms this means that inversion, and the expansion associated with it, can only occur during the cooling cycle. In fully cooled material there would appear to be no further risk of instability from this mechanism.

b) Iron unsoundness is a very rare form of instability frequently associated with operating problems in the blast furnace. TRS know of only one instance in over 40 years. The mechanism, which is a hydrolysis reaction, is immediately triggered off by the presence of water. Once water has initiated the reaction, the mechanism proceeds to completion. It is impossible to arrest the process once started; at least by methods operating in normal ambient conditions.

It follows that the risk of late expansion from either of these mechanisms in blast furnace slag is remote.

c) Sulphoaluminate Type Activity

Some years ago, G. H. Thomas discovered a third mechanism that may give rise to volumetric instability. The process is possible only in some old blast furnace slag altered by weathering. When the sulphide sulphur in the blast furnace slags is oxidised during

weathering to sulphate, under some circumstances reactions can take place within the slag to produce an 'ettringite' type product. The process is somewhat analogous to sulphatic attack on concrete and has a similar result - expansion of the mass and associated disruption.

For the mechanism to have any significance, the slag needs to have residual potential for this reaction. Evidence of past activity does not necessarily indicate further reaction is possible.

The TRS accelerated expansion test is, we believe, uniquely capable of identifying such slags, as well as instability attributable to free CaO and free MgO in steel slag & etc.

Basic Steel Slags

Basic steel slags commonly contain significant quantities of free CaO and free MgO. These free oxides are well known for the massive expansion associated with their hydration. In practical terms, it is impossible to forecast when hydration will take place, but it can be up to decades after the material was cooled – or placed. The reasons are complex, but include the varying density of the oxides, due to the variation in temperatures at which the products have been held in the furnace. Other factors influencing rate of hydration include:-

- the protection of slags by a reaction product at the oxide interface with the slag.
- the presence of the oxides as lime or magnesia rich solid solutions instead of the pure oxide.

The result is potential future volumetric instability but at an unforeseeable date. Periclase, i.e. free MgO, is relatively much slower than free CaO to hydrate.

Scrap High Magnesia Refractories

These are particularly undesirable components in fill as they commonly result in high concentrations of free MgO. The problems associated with these concentrations are similar to those where periclase is found in basic steel slag.

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