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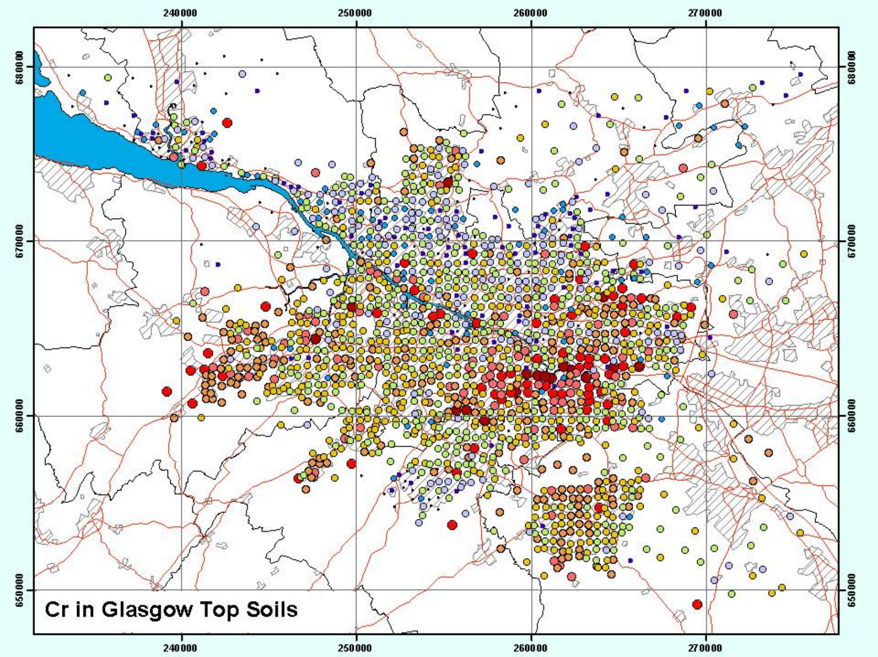
Urban Soil Geochemistry of Glasgow - Main Report

Land Use Planning and Development Programme

Open Report OR/08/002



BRITISH GEOLOGICAL SURVEY

LAND USE PLANNING AND DEVELOPMENT PROGRAMME

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Urban Soil Geochemistry of Glasgow - Main Report

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Front cover

Map showing the distribution of chromium in Glasgow top soils (blue-red symbols = low-high Cr content).

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Maps and diagrams in this book use topography based on Ordnance Survey mapping.

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Foreword

It is estimated that by 2012 more than half the world's population will live in urban areas. Britain was at the heart of the industrial revolution that provided the catalyst for the migration away from a rural lifestyle and as a result many of our large cities have a long legacy of industrial activity and urbanisation. By the late 12th century Glasgow had a population of just 1,500 which grew as the city became a major trading centre through the centuries with particular expansion in the 18th century reflecting growing commerce with America. By the 1770s the environment of the Clyde was being substantially modified to allow ships to sail right into the city allowing for industrial expansion. Manufacturing really grew during the industrial revolution of the 19th century particularly in the areas of textiles, glass-making, soap-making and distilling. Heavy industries such shipbuilding and locomotive engineering were fed by local supplies of coal and iron ore. The twentieth century saw a decline in these heavy industries and a realisation that whilst they brought prosperity to the area they have left a substantially modified and polluted local environment.

The principal controls on our local environment relate to the geology beneath our feet. The rocks - along with superficial materials deposited by rivers or glaciers over long periods of time - dominate the chemical composition of the surface water and soils in our environment. In rural areas less affected by industrialisation, we can establish a near-natural geochemical background of soils. In contrast, by investigating the geochemical composition of soils in built-up urban areas, an assessment of the anthropogenic modification can be made.

This report compares the chemical elements found in soils from the urban area of Glasgow with those from its rural hinterland. This enables an assessment of the anthropogenic pollution present and the areas most affected. This fundamental background information is vital to satisfy the legislatively driven demands for an improved and sustainable urban environment where people can live with a better quality of life.

An endeavour such as this requires a multi-disciplinary approach with geoscientists from many different specialisations working with city planners and authorities. The results presented in this report on the urban soil geochemistry of Glasgow are a testament to the fruitful cooperation between geochemists from the British Geological Survey led by Fiona Fordyce and workers from the Glasgow City Council and other Local Authorities. This work should serve as a model for future cooperation in assessing the extent of anthropogenic pollution in urban centres.

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Guide to Report Layout

This report describes the British Geological Survey (BGS) urban soil geochemical survey of Glasgow and is presented in three volumes as follows:

Urban Soil Geochemistry of Glasgow – Main Report

- Summary of the Glasgow soil geochemical survey
- Project description, results interpretation, conclusions and bibliography

Urban Soil Geochemistry of Glasgow – Appendices 1 and 2 Methods, Tables and Figures

- The data collection, analysis and interpretation methods employed by the survey
- Presentation of the tables and figures referred to in the Main Report.

Urban Soil Geochemistry of Glasgow – Appendices 3-6 Geochemical Maps

- Presentation of geochemical maps of parameter concentrations in Glasgow top and deeper soils referred to in the Main Report

Contents

Glossary

ANOVA	Analysis of Variance
BGS	British Geological Survey
CLEA	Contaminated Land Exposure Assessment
CUSP	Clyde Urban Super-Project
DEFRA	Department for Environment, Food and Rural Affairs
DOE	Department of the Environment
EA	Environment Agency (England and Wales)
EDEN	Environmental Development and Education Network
ED-XRFS	Energy Dispersive X-ray Fluorescence Spectrometry
ESRI	Environmental Systems Research Institute
FOREGS	Forum of European Geological Surveys
G-BASE	Geochemical Baseline Survey of the Environment
GCC	Glasgow City Council
GIS	Geographic Information System
GPS	Global Positioning System
GSNI	Geological Survey of Northern Ireland
HMSO	Her Majesty's Stationery Office
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometry
ICRCL	Interdepartmental Committee for the Redevelopment of Contaminated Land
JHI	James Hutton Institute
LLD	Lower Limits of Detection
LLR	Lower Limits of Reporting
LOI	Loss on Ignition
MAC	Maximum Admissible Concentration
NERC	Natural Environment Research Council
OS	Ordnance Survey
PAH	Polynuclear Aromatic Hydrocarbon
PBET	Physiologically Based Extraction Test
PCB	Polychlorinated Biphenyl
PHE	Potentially Harmful Element
PHS	Potentially Harmful Substance
RM	Reference Material
SEPA	Scottish Environment Protection Agency
SGV	Soil Guideline Value

SSL	Soil Screening Level
SSV	Soil Screening Value
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
UBM	Unified Bioaccessibility Method
UK	United Kingdom
ULR	Upper Limits of Reporting
US-EPA	United States Environmental Protection Agency
VROM	Dutch Ministry of Housing, Spatial Planning and Environment
WD-XRFS	Wavelength Dispersive X-ray Fluorescence Spectrometry
WHO	World Health Organisation
XRFS	X-ray Fluorescence Spectrometry

Summary

This report presents the results of a geochemical survey carried out by the British Geological Survey (BGS) between 2001 and 2002. The survey collected 1381 urban soil samples at a density of 1 per 0.25 km^2 and 241 rural samples at a density of 1 per 2 km^2 on a systematic grid across the Glasgow conurbation. The study was carried out as part of the BGS Geochemical Baseline Survey of the Environment (G-BASE) project.

Top (5 - 20 cm) and deeper (35 - 50 cm) soil samples underwent analysis for approximately 46 chemical elements including contaminants such as As, Al, Cd, Cu, Cr, Ni, Pb, Se, V and Zn according to standard G-BASE procedures. In addition, pH and loss on ignition (LOI) as an indicator of organic matter content were determined in the samples.

The aim of the project was to provide an overview of the urban soil geochemistry of Glasgow and the immediate rural hinterland as an aid to planning and development. This report presents the initial findings of the Glasgow soil survey. The data have a wide range of applications and will be interpreted in more detail as part of a wider BGS Clyde Urban Super-Project (CUSP), to be reported elsewhere.

This report documents the G-BASE soil survey and analytical methods and presents the distribution of soil parameters as a series of geographic information system (GIS)-generated graduated symbol geochemical maps.

The Glasgow conurbation is the largest built-up area in Scotland and has a long history of urban and heavy industrial development including coal and other mineral mining; ship building; steel and iron making; railway engineering; car manufacture and - until the 1960s - was home to the world's largest chromium ore processing plant based in Rutherglen in the south-east of the city. As with all cities, urban land quality in Glasgow is the result of complex interactions between these man-made inputs and the natural concentrations of substances in soil, which are influenced by the geology and soil forming processes. Therefore, comparisons with rural soils can help elucidate the level of anthropogenic input to soils in urban areas.

As an indication of anthropogenic (man-made) pollution, the results of the present study reveal that on the basis of median values, Cd, Cr, Ni and Zn concentrations are 2-3 times and Cu and Pb 5-7 times higher in Glasgow than the national average in Scottish soils. However, these results should be treated with caution due to the difference in analytical methods between the current G-BASE project and the national data for Scotland. Nevertheless, Ag (x 3.5), As, Co, Ge, Mo and P_2O_5 (~ x2) are also enhanced in Glasgow urban soils relative to world averages. Similarly, Pb (x 7.5), Cu, Ni, Sb, Sn and Zn (~ x2) and Se (x3) are enriched in Glasgow urban soils relative to world averages and are higher than BGS regional geochemical median values for the Humber-Trent area of England. This may in part reflect anthropogenic pollution and in the case of As, Co, Mo, Ni, and Se the presence of coals and volcanic bedrock in the Glasgow area.

Comparisons between median values in the Glasgow dataset and other urban areas surveyed by the G-BASE project in the UK show that Cr and Ni are higher in Glasgow soils than most other cities. This is attributed to the history of Cr-processing and heavy industry in Glasgow and the presence

of coals underlying the city and volcanic bedrock on the outskirts of Glasgow. In contrast, As, Cd and Pb are lower in Glasgow soils than most other urban areas.

The results of the present study demonstrate that regardless of parent material type, concentrations of As, Bi, Ba, CaO, Ce, Co, Cr, Cu, Ge, Mo, Ni, Pb, Sb, Se, Sn, Sr, Th, Y, Zn and pH are generally higher in urban than rural soils in the Glasgow area. Elements that are rare in nature in most environments but commonly associated with anthropogenic pollution such as Pb, Sb and Sn show greatest levels of enrichment (2.6 – 3.3 times, based on median values) in the urban soils. Calcium is also enhanced significantly (x2.1, based on median values) in deeper urban than rural soils probably as a result of buildings, coal and industrial waste in the urban environment, which tend to be calcareous in nature and commonly used as fill materials. Indeed, high Ba, CaO, Sr and pH soils are closely associated with made ground, industrial and derelict land in the city probably reflecting the presence of fill materials.

The elements that show greatest enhancement in the Glasgow urban environment, namely CaO, Cu, Mo, Ni, Pb, Sb, Sn and Zn are a typical indicator 'suite' of urban anthropogenic pollution commonly identified in studies of urban areas under the G-BASE project.

Conversely, levels of organic matter are lower in urban than rural soils and several elements that are closely associated with organic matter show the same relationship including Br, I, U and W. Concentrations of Hf, SiO_2, TiO_2 and Zr are also lower in urban than rural soils as these elements are more closely associated with the detrital mineral composition of natural soils.

Despite the over-riding influence of urban anthropogenic pollution on the soil geochemistry of many elements, geology and geogenic processes still exert a fundamental control on soil composition. Results in rural and urban Glasgow soils demonstrate that, for example, many elements such as Al_2O_3, Co, Cr, Cu, Ga, Ni, Pb, Se, Sn, Th, TiO_2, U, V and Zn are relatively lower in concentration over Devonian sandstones present in the Dumbarton area as a result of natural geological processes including the lower clay content of these rock types. Similarly, many elements associated with alkali basaltic lavas (for example, CaO, Fe_2O_3, MgO, Na_2O, Nb, Ni, P_2O_5, Sr, TiO_2 and V) are relatively higher in soils over the Clyde Plateau Volcanic Formation, to the north and south of the city than other rock types in the area. Superficial peat deposits also have an effect on the geochemistry of the soils due to the importance of organic matter on the distribution of many elements such as As, Br, Cd, Co, Cs, Ga, Ge, I, Mo, Pb, Sb, Se, Sn and U in the environment. As might be anticipated, pH is also lower in these soils due to the presence of humic acids.

The G-BASE Glasgow dataset is one of the first collected by the project to have geochemical information for top and deeper soils sieved to the same <2 mm size fraction, allowing direct comparisons of soil chemistry down-profile. Results demonstrate that organic matter (LOI) is 1.4-1.6 times higher in top than deeper soils as expected. As a consequence, Br (x1.3 rural; x1.5 urban) and I (x2.0 rural; x 1.5 urban) are elevated in top relative to deeper soils. The main source of these elements in the environment is atmospheric deposition of marine aerosols and this study demonstrates the close relationship between the westerly weather pattern, and distribution of these elements in the peaty upland soils formed over the Renfrew Hills to the southwest of Glasgow and the Kilpatrick and Campsie Hills to the north of Glasgow. Sodium is also higher in soils on the western periphery of Glasgow, which again may indicate the influence of marine aerosols. However, in this case, the results could also reflect the underlying Clyde Plateau Volcanic bedrock and raised beach and marine superficial deposits.

Similarly, elements such as Sn (x2.3); Bi, Pb (x2.0); Cs, Ge (x1.5) and As, Cu, Se, Zn (x1.3) are enhanced in top versus deeper rural soils probably reflecting the greater organic matter content of top soils. Although no obvious enhancement of element concentrations is observable in the geochemical maps of top soils located down-wind of the Glasgow urban area, comparisons between top and deeper soils suggest that the rural top soils on the periphery of Glasgow may also be enriched by the atmospheric deposition of these elements.

The distribution of Cs is also closely associated with the upland soils of the Kilpatrick and Campsie Hills to the north of Glasgow and the Renfrew Hills in the south. It is possible that the element is naturally enhanced over the Clyde Plateau Volcanic Formation. However, another major source of the element in the UK environment is fallout from the nuclear weapons testing programme during the 1950s and 1960s and the Chernobyl accident in 1986. The main control on deposition following the accident was the rainfall pattern, which tended to be higher in upland areas. The fact that concentrations are higher in top rather than deeper soils may also indicate that the element is from an airborne depositional rather than a bedrock source. Further investigations into isotopic compositions would be required to determine whether the Cs is from a nuclear fallout source.

On the basis of median values, Pb, Sb, W and Zn are enhanced c. 1.3 times in urban top soils and concentrations of As, Ba, Cd, Cu, Ge, Mo, Ni and Se are also generally higher in urban top soils than deeper soils. Whilst this may relate to the greater organic matter content of urban top soils, these results probably also reflect the addition of these elements from: atmospheric deposition; urban surface run off and/or waste disposal.

Phosphorus median contents in top soils are higher than deeper soils in urban (x1.3) and rural (1.9) Glasgow soils probably as a result of fertiliser use.

Urban soils show a greater variability compared with rural soils in the concentrations of As, Ba, Cd, Cr, Cu, Ga, Ge, Mo, Ni, Pb, Sb, Se, Sn, W, Y and Zn down the soil profile probably as a result of anthropogenic activity. This evidence of the much greater heterogeneity of urban soils (both laterally and vertically) has implications for the presentation of urban geochemical data. For example, care should be taken to quantify the levels of variability before attempting to interpolate data between sample points.

Within the urban environment, concentrations of many of the metal elements such as Ag, As, Cd, Co, Cr, Cu, Ge, Mo, Ni, Pb, Sb, Se, Sn, W and Zn are higher in soils over made ground and/or industrial and derelict land because of anthropogenic pollution. High concentrations of all these parameters are distributed in the East End and Rutherglen areas of the city. This was the industrial heartland, which was the focus of metal processing such as iron foundries, Cr-chemical works, railway and other heavy industrial works. Cr-processing waste from the chemical works was subsequently used as fill material throughout south and east Glasgow and this is reflected in the distribution of Cr, CaO, Fe_2O_3, Ni and other metal elements in the soils. Indeed, extremely high concentrations of up to 4363 mg kg^{-1} Cr are reported in soils from the Rutherglen area. Other clusters of high metal values are associated with the shipbuilding corridor on the north bank of the River Clyde and the industrial and traffic impacted areas of north-west Paisley and Johnstone. Higher CaO, MgO, Ba, Sr and pH over made ground probably reflect the nature of fill materials, which tend to contain a lot of concrete and building materials, furnace slag and coal waste all of which are calcareous. Indeed concentrations of CaO are markedly higher over made ground than non made ground indicative of the presence of fill materials.

Interestingly, despite the fact that a significant number of the Glasgow samples were collected on road and railway verges (323) no relationships with higher Ba, Pb or Zn concentrations as indicators of traffic pollution are evident; with the exception of a cluster of higher Pb values in the city centre. The results of this study suggest that the G-BASE sampling methodology is not particularly appropriate to investigate road-based vehicular anthropogenic pollution, which is often more readily detected by sampling roadside depositional sediments.

The elements As, Cu, Ge, Pb, Sb, Sn and Zn are also marginally enhanced in residential garden soils relative to some other land use types and this may reflect the historic dumping and use as a soil conditioner of domestic coal ash and the presence of household debris such as fragments of glass, ceramics, bricks and paint in domestic garden soils. Lead is also marginally higher in the vicinity of schools than some other land use categories.

Current UK environmental legislation considers soil quality in terms of potential concern for human health from exposure to contaminated soils. The UK contaminated land soil guideline values (SGVs) are being revised at the time of completing this report. It should be emphasised that concentrations above the SGV do not indicate that land is contaminated or that there is a risk to human health; rather that further investigations should be implemented. As a general indication of soil quality, only 2% of Glasgow top soils exceed the As residential SGVs of 32 mg kg^{-1}. However, the guidelines are land use specific and only two of these soils were collected from residential gardens. Soils exceeded the former Ni residential SGV of 50 mg kg^{-1} at 40% of sites across the city but only 2% exceed the new 130 mg kg^{-1} SGV highlighting the impact of the new soil quality guidelines on land quality assessments in a city like Glasgow. Again only two of these soils were collected from gardens. Similarly only 2% of top soils exceed the Cd allotment SGV of 1.8 mg kg^{-1} but none of the soils were collected from allotments. Only one top soil exceeds the new residential Cd SGV of 10 mg kg^{-1} and this is not a garden soil. No soil Se concentrations above the 120 mg kg^{-1} residential SGV are reported. New guidelines are awaited for Cr and Pb but approximately 20% and 5% of soils exceed the existing residential garden/allotment SGVs of 130 and 450 mg kg^{-1} respectively. Of these, only five (Pb) and 13 (Cr) are garden soils. The number of soils exceeding the SGVs for Cr is likely to decrease once the new guidelines are available. It should be noted that the legislation is primarily concerned with residential garden and allotment soils and only 69 garden and one allotment soils were sampled during the survey.

It is recommended that further studies are carried out in conjunction with the Local Authorities concerned to determine whether source-pathway-receptor linkages are likely, and the bioaccessibility of these elements as a further step to risk assessment.

It was beyond the scope of the present study to examine the urban geochemical data as an indictor of land quality in the context of the detailed historical and current land use information held by Glasgow City Council. **It is recommended** that land quality - land use investigations form part of future integrated geo-environmental studies of the Clyde Basin to aid urban planning and land quality assessment.

1 Introduction

This study presents the results of a British Geological Survey (BGS) project comprising a systematic urban soil geochemical survey across the Glasgow conurbation between 2001 and 2002. The aim of the project was to provide an overview of soil quality in the urban environment and immediate rural hinterland as an aid to planning and development.

The geochemical data are presented as a series of graduated symbol maps in the appendices of this report.

The project forms part of a larger joint initiative between Glasgow City Council (GCC) and BGS, which aims to characterise the geo-environment of the Clyde Basin. In this context, this report presents the initial findings of the Glasgow soils geochemical survey but it is anticipated that further interpretation of the data will take place under the ongoing Clyde Urban Super-Project (CUSP).

1.1 GEOCHEMISTRY AND ENVIRONMENTAL CONCERNS

The 92 naturally occurring elements on Earth that form the different rocks, soils, waters and gases that are the building blocks of the planet are not distributed evenly across the globe. Concentrations at any location are often controlled by factors such as geology, vegetation, soil forming processes and climate. In addition to natural sources of these elements, environmental concentrations can be enhanced by anthropogenic (man-made) activities such as mining, industrialisation, urbanisation and waste disposal. The distribution of the elements is of concern because although many are essential to life, at least 26 of the naturally occurring elements are potentially harmful to plants and animals in high doses (Table 1.1). The toxicity and mobility of these potentially harmful substances (PHSs) are often controlled by the amount of other elements present so it is important to understand as fully as possible, the chemical composition of the environment.

Of further concern are the quantities of potentially harmful organic compounds mainly of man-made origin and many of which are detrimental to health. These include the polynuclear aromatic hydrocarbons (PAHs), which have been linked to cancer, the polychlorinated biphenyls (PCBs), and toxins such as cyanide. Whilst these substances were not measured as part of the current study, other parameters such as soil pH, organic matter content and major element chemistry could be used to predict their likely mobility in future investigations.

Many UK city environments have a long history of urbanisation resulting in elevated concentrations of PHSs including organic contaminants (for example, PAHs and PCBs), radioactive materials and potentially harmful elements (PHEs) such as As, Cd, Cr, Cu, Ni, Pb, V and Zn derived from industrial and mineral processing and the atmospheric deposition of Pb and other toxins from vehicular exhausts. Whether or not these substances constitute a hazard depends on a variety of factors. These include their chemical form, concentration, mobility and behaviour in the environment, the extent to which they are taken up by living organisms (bioaccessibility), the properties of the substrate in which they occur (for example, the acidity of waters or soils and the soil texture and mineral composition), the level of exposure and the dose received. Water is unlikely to pose a risk to human health due to the high standard of public water quality in the UK and the minimal use of private wells in city areas; however, the protection of water resources is a major ecological issue in the urban environment.

Physical hazards such as flooding subsidence and storm damage are more readily understood by the public than chemical hazards, which are generally unseen and more difficult to comprehend. The concern here is to produce systematic geochemical baseline information rather than site specific data so that potential chemical hazards in the environment can be identified and assessed, and mitigated where they are thought to be a potential risk to human or ecosystem health.

1.2 UK LEGISLATIVE FRAMEWORK

Prompted by concerns about land and water quality, national governments and international agencies are developing policies to limit the amount and impacts of PHSs in the environment. Although links between long term human health effects and PHSs are often difficult to prove, the majority of regulatory authorities adopt a precautionary principal approach to legislate against high environmental concentrations of PHSs for ecosystem as well as human health protection.

In the UK, one of the main legislative drivers relating to PHSs is the Government target for sustainable development, which focuses on the re-use of brownfield sites for 60% of new residential homes. Whilst this policy protects green belts around urban environments, brownfield sites include land that may or may not be polluted with PHSs.

The Environmental Protection Act, Part IIa (1990) was implemented on 1st April 2000 in England, 14th July 2000 in Scotland and 1st July 2001 in Wales. The Act places the responsibility for the identification, assessment, remediation and monitoring of contaminated land with Local Authorities as follows:

Environmental Protection Act, Part IIa (1990)
Definitions:

Contaminated land is defined 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:

Significant harm is being caused or there is a significant possibility of such harm being caused or
Pollution of controlled water is being or likely to be caused"

Harm is defined as:
"harm to the health of living organisms, or other interference with the ecological systems of which they form a part, and in the case of man, harm to his property"

The Act addresses the pollution of waters and threats to ecosystems and buildings in addition to human health risks and operates a 'polluter pays' principle in terms of remediation. However, it is important to point out that Part IIa only applies to a sub-set of land that is chemically contaminated. The identification of contaminated land relies on the concept of risk assessment, based on a pollutant linkage whereby the presence or source of anthropogenic pollution has the potential to impact on a receptor by means of a pathway (Figure 1.1). If the linkage does not exist then, in terms of the Act, the land is not contaminated. Thus, for example, an area of ground could contain high concentrations of As but if this is not affecting water resources, property, living organisms or ecosystems then it will not be classified as contaminated.

Several guidelines exist to aid the identification, assessment and management of contaminated land. Until 2002, the UK Government Interdepartmental Committee for the Redevelopment of Contaminated Land (ICRCL, 1987) guidelines provided maximum recommended thresholds or trigger values for contaminants in soil depending on the land use (Table 1.2). However, the Government has since developed a new risk assessment tool for human exposure known as the Contaminated Land Exposure Assessment (CLEA) model. Initially conceived by Nottingham University, the model was subsequently developed by the Environment Agency (EA) and Department for Environment, Food and Rural Affairs (DEFRA) and includes risk assessment information for the metal elements As, Cd, Cr, Pb, Ni, and Se. On this basis 'typical' soil guideline values (SGVs) for As, Cd, Cr, Pb, Ni and Se were defined taking account of likely human exposure to soil associated with various land uses (EA, 2008a) (Table 1.2). However, revisions to the contaminated land guidance and SGVs are in the process of being carried out. To date, revised SGVs have been prepared for As, Cd, Ni and Se but new guidelines are awaited for Cr and Pb (EA, 2011). A similar risk assessment model compatible with CLEA has been developed for the Scottish Environment Protection Agency (SEPA) (SNIFFER, 2003). The EA and DEFRA have also devised a set of soil screening values (SSVs) to aid the assessment of potential risks to ecological receptors (Table 1.2). However, the framework for these guidelines is still being formulated (EA, 2008b).

It should be emphasised that exceedence of the guidelines *per se* does not mean that there is a threat to human or ecosystem health, just that further investigations, such as establishing source-pathway-receptor linkages and assessing the bioaccessibility of contaminants, need to be carried out.

In order to aid the assessment of environmental quality in urban environments, the BGS is providing systematic information on the concentrations of PHSs across British cities (Section 1.3).

1.3 GEOCHEMICAL BASELINE SURVEY OF THE ENVIRONMENT (G-BASE)

The BGS is responsible for carrying out the national strategic geochemical survey of Great Britain, known as the Geochemical Baseline Survey of the Environment (G-BASE), which defines the spatial distribution of chemical elements in the British surface environment.

The mapping programme is based primarily on the collection of fine fraction (<150 µm) rural stream sediments and stream waters from first and second order streams at a sampling density of 1 per 1.5 km^2. The programme, which began in the late 1960s in the north of Scotland and working southwards, will eventually provide information for the whole country (Johnson et al., 2005). In more recent years, soil sampling has been incorporated into the programme; hence soil data are available from Mid-England southwards. Soil sampling is based on the <2 mm fraction of rural top soils (5 - 20 cm) at a density of 1 per 2 km^2. Deeper soils (35 - 50 cm) are also collected from each site but are currently stored and not analysed. Initially, the programme focussed on rural areas; however, in response to concerns about PHSs in the urban environment and the new statutory requirements on Local Authorities (Environmental Protection Act Part IIa, 1990), urban mapping commenced in 1992.

Urban geochemical mapping, developed from preliminary studies carried out in collaboration with Imperial College, London in Wolverhampton and Richmond-on-Thames (Kelly et al., 1996; Bridge et al., 1997; Kelly, 1997) and has been described by (Fordyce et al., 2005). To date, 27 urban areas have been sampled (Figure 1.2). Urban surveying is based primarily upon the collection of soil samples at a sampling density of 4 per km^2 and is designed to give an overview of the city's geochemical signature or urban geochemical baseline.

The soils are analysed for a range of total element concentrations including elements that are of concern in terms of environmental pollution such as As, Cd and Pb. In addition, the project includes analysis of the major elements (for example, CaO, K_2O, Fe_2O_3 and MnO), soil pH and loss on ignition (LOI) as an indicator of organic matter content as these parameters can influence the mobility of PHS in soils. The concentrations of many contaminants are enhanced in the urban environment as a result of the contribution from both atmospheric and terrestrial sources. The characteristics of urban ground, which is often disturbed and in-filled with little relation to the surrounding rural hinterland, also have a major influence on urban soil chemistry. Hence it is necessary to establish the urban geochemical baseline so that areas of concern within a city can be identified. It should be noted that systematic urban surveys do not replace the need for site-specific investigations; rather the data provide the citywide framework and context for more detailed assessments. The BGS is the only organisation providing systematic geochemical information on urban environments in the UK.

Important concepts in geochemistry are the geochemical baseline and the geochemical background. The importance of these terms in urban geochemical mapping is explained by Johnson and Ander (2008).

The following definition of a geochemical baseline is that used by the Forum of European Geological Surveys (FOREGS) Geochemistry Working Group:

"A geochemical baseline is the concentration at a specific point in time of a chemical parameter (element, species or compound) in a sample of geological material. It is a fluctuating surface rather than a given value".

A geochemical baseline is a function of many different parameters used to determine it including the sample medium and the analytical methodology. A geochemical baseline simply reports the chemical state of the surface environment exactly as it is with no interpretation or partitioning of the data. The G-BASE geochemical data provide information on the urban baseline.

Another frequently used term is the geochemical background. In the context of the urban environment the geochemical background can be defined as:

"A relative measure to distinguish between natural element or compound concentrations and anthropogenically-influenced concentrations in real sample collectives" (Matschullat et al., 2000).

The relationship between the urban geochemical baseline and background can be expressed in a basic equation:

URBAN BASELINE = BACKGROUND + Anthropogenic Contribution

This is a simplification because the background may be made up of many contributing geochemical populations (caused by variations in underlying parent material, for example) and the anthropogenic contribution can also be from multiple sources. Definition of the background enables us to quantify the urban anthropogenic pollution by subtracting the background (determined from rural area to represent the “natural” background) from the urban baseline. Background, unlike a baseline, is determined by interpreting or modelling the data.

An important aspect of the G-BASE project is that the rigorous sampling and analytical methodology for soils is consistent in both urban and rural areas so that the geochemical baselines of different urban areas and their surrounding rural backgrounds can be directly compared (Kelly et al., 1996; Bridge et al., 1997; Fordyce and Ander, 2003; Rawlins and O’Donnell, 2004; Fordyce et al., 2005).

2 Environmental Data for Glasgow

The collection, analytical and data presentation methods employed during the soil geochemical survey of Glasgow are outlined in Appendix 1 of this report. For interpretation and presentation purposes, the geochemical data were incorporated into a geographic information system (GIS) for the urban area. As background to the present study and to aid the geochemical interpretation; environmental data for Glasgow were also included in the GIS. Many of these datasets were derived from the environmental geological mapping of the Glasgow area carried out by the BGS during the 1980s (Forsyth et al., 1984a, b, c; Forsyth et al. 1985; Browne et al., 1986 and Hall et al., 1998). A summary of the information pertinent to the current project is presented here as an introduction to the study area.

2.1 THE GLASGOW STUDY AREA

The study area comprises approximately 825 km^2 of the Glasgow conurbation and surrounding rural environment (Figure 2.1). The area includes the entire City of Glasgow administered by Glasgow City Council and extends along the River Clyde corridor to the north-west of the city to the town of Dumbarton in West Dunbartonshire. The area extends north-east into rural East Dunbartonshire around Kirkintilloch and east to include the North Lanarkshire conurbation of Coatbridge. The urban areas of Rutherglen and Cambuslang and new town of East Kilbride in South Lanarkshire also formed part of the survey. To the west, the study area covers the conurbations of Paisley, Johnstone and Renfrew in East Renfrewshire and Renfrewshire districts.

The settlement of Glasgow has existed since the Bronze Age and developed on high ground close to the most reliable seaward ford of the River Clyde. The City and Burgh were decreed by Royal Charter during the 12th century, but up until the establishment of the university in 1451 the city was essentially a small ecclesiastical centre (population 4500) based around the Cathedral (Figure 2.2). By the end of the 16th century, coal was being exported in flat-bottomed barges but development of the River Clyde was necessary to allow safe passage for larger vessels. In the 19th century a dredged channel was cut to allow ocean-going ships access to the city centre. The development of the area was based largely on the combination of transport via the River Clyde and mineral extraction related to the local geology. The numerous and easily accessible coal and ironstone seams of the Coal Measures provided the fuel and raw materials to support a thriving industrial centre. From 1732 onwards the establishment of ironworks and forges increased the local demand for coal and ironstone at the expense of the export trade and by 1800 the population had grown to 84 000, reflecting the gathering momentum of the industrial revolution.

The trend of increasing population and commercial success continued through the 19th century with the advent of stream trains and iron ships which made further demands on the coal and iron resources. The mining of ironstone peaked around 1880 but declined rapidly as the ore proved unsuitable for steel production and it finally ended after the First World War (1914-1918). In contrast, the subsurface mining of coal was at its height in the early 20th century and continued until 1983. Mining waste was used as stowing in the workings. Domestic coal ash was dumped and used as a soil conditioner in gardens/allotments and industrial coal ash was used as a fill material across the city. Several other materials were extracted in the area including limestone, seatclay, sandstone, sand and gravel, and dolerite. Several of the quarries have been infilled and used for waste disposal such as at Greenoakhill, which was Scotland's largest recipient of liquid waste (Figure 2.2).

In addition to mining, Glasgow became the third most important port in the UK after London and Liverpool during the 18th and 19th centuries with imports of tobacco, cotton, coffee, rum and sugar. In the last years of the 18th and the early years of the 19th centuries, Glasgow became the centre of a cotton spinning region; the number of cotton-mills within a radius of twenty-five miles of the city rose from 19 to 134 between 1787 and 1834. The flourishing cotton industry stimulated the development of related industries such as bleaching, dyeing and fabric printing. Cotton spinning, weaving, calico printing and bleaching were centred in the Gallowgate in 1779 and moved to Thornliebank in Renfrewshire, as business expanded (Figure 2.2). Paisley and the Vale of Leven in Dunbartonshire attracted textile printworks partly because of the suitability of the water.

Heavy industry, particularly shipbuilding which was focussed at Clydebank, developed along the Clyde during the 19th and first half of the 20th centuries and Glasgow was renowned for iron and steel manufacture including the Clydebridge, Westburn, Camlachie and Cathcart Holm works and centres in Coatbridge. Heavy engineering was centred at complexes such as Shieldhall, Pollockshaws, Provanmill and Swinton and the railway yards at St Rollox in Royston and Cowlairs (Figure 2.2). Numerous gas works were located throughout the city including Provanmill, Maryhill and Hurlet. Glasgow was also a centre of mineral processing, the company of JJ Whites in Rutherglen (Figure 2.2), was the world's largest chrome producer, during the 19th century and operated until 1967. Chromite-ore processing residues were extensively used as landfill material around south-east Glasgow and between 1960 and 1966 it is estimated that 60 – 70 tonnes of chromite waste were dumped daily.

The city, and in particular Clydebank, sustained heavy bombing during the 2nd World War (1939-1945) and large tracts of the 19th century tenement housing were cleared between the 1950s and 1970s as part of the city's post-war regeneration programme. Much of the inner city population moved out to satellite developments such as Drumchapel, Easterhouse and East Kilbride at this time. This, coupled with a decline in heavy industry over the same period, left the city with a legacy of derelict land, which has subsequently been the subject of regeneration schemes, which continue to the present day. Glasgow today is a thriving business, retail, cultural and tourism centre with a modern mixed economy including biosciences, optoelectronics, contact centre management, software development, creative industries, construction and communication technologies.

2.2 ENVIRONMENTAL DATASETS FOR GLASGOW

2.2.1 Ordnance Survey Topographic Information

All data derived from the Ordnance Survey (OS) are covered by the corporate BGS licensing agreements, which allow data to be used for internal BGS projects. Figure 2.2 shows the main roads, railways, drainage and built-up areas derived from OS Meridian data across the region.

2.2.2 Land Use Information

Information on the land use at each site recorded during the soil survey of Glasgow by the sampling teams is presented in Figure 2.3 and is used in the interpretation of the geochemical data in this report.

Detailed historical and current digital polygonised land use information is available for Glasgow and has been developed in the Environmental Services Department as part of the Council's contaminated land prioritisation strategy under Part IIa of the Environmental Protection Act (1990). It was beyond the scope of the present study to incorporate this information. However, it is anticipated that detailed assessments including land use will form part of future integrated geo-environmental studies of the Clyde Basin (CUSP).

2.2.3 Solid Geology and Superficial Deposits

The 1: 50 000 and 1: 250 000 scale digital solid geology line work and 1: 50 000 and 1: 625 000 scale digital superficial deposit linework for the study area were incorporated into the GIS from the BGS DigMap® database. The solid geology information was rationalised into the main lithology groups for the area for comparison with the geochemical data (Figure 2.4). The main coal seams in the Glasgow area are also shown on Figure 2.5. Table 2.1 outlines how the rationalised geology key relates to BGS lexicon code and 1:50 000 scale solid geology information. Comparisons were also made between the geochemical data and the 1: 625 000 superficial deposit map of the area (Figure 2.6).

The oldest rocks in the Glasgow area are metamorphosed Dalradian psammites, pelites and greywackes, which occur to the west of Dumbarton. These are overlain unconformably by Lower and Upper Devonian sandstones and Lower Carboniferous Inverclyde Group sediments. These sediments comprise sandstones, calcareous sandstones; carbonate cornstones, and mudstones (Figure 2.4).

Uplift occurred after the deposition of the Inverclyde sediments and was followed by a major period of subaerial volcanic activity. This produced the lavas and volcaniclastic rocks of the Clyde Plateau Volcanic Formation, which form the Kilpatrick and Campsie Hills to the north of Glasgow and the Renfrew Hills to the south and are generally alkali basalt in composition (Figure 2.4). The overlying Strathclyde Group of sediments comprise sandstones, siltstones, mudstones and conglomerates derived from the upstanding volcanic terrain formed by the Clyde Plateau Volcanic Formation and underlie areas to the west and south of Glasgow (Figure 2.4). Although coals, sandstones and marine bands are present in this sequence, they are poorly developed. The Hurlet Limestone at the base of the overlying Lower Limestone Formation marks a significant change in the sequence indicating that the area was slowly subsiding at this time allowing more extensive marine transgression.

The Carboniferous age Lower Limestone Formation comprises interbedded dark grey mudstones, clayband ironstones, siltstones, sandstones and marine limestones laid down in quiet conditions, with deposition occurring westwards from a large delta that is thought to have occupied most of the central Midland Valley. This is overlain by the Limestone Coal Formation, which was laid down in quiet conditions similar to the Lower Limestone period but with stronger currents bearing sediment from the delta to the east preventing fully marine conditions. The land surface periodically emerged and vegetation colonised the alluvial plain leading to the development of thin coals. The sequence comprises bedded dark grey mudstones, siltstones, sandstones, clayband ironstones and coals near the top. Despite its name, the Limestone Coal Formation contains only a few argillaceous shelly limestones.

The overlying Upper Limestone Formation marks a contrast in the palaeogeography of the area. The district was inundated by a shallow sea at least four times. The sequence comprises thin marine limestones, sandstones and thin coals indicating that deltaic and swampy vegetative conditions prevailed periodically, but not to the same extent as the earlier Limestone Coal Formation.

The overlying Passage Formation marks a change to fluvially dominated conditions and comprises sandstones, some of which are coarse-grained with large pebbles and unbedded mudstones. The depositional basin probably contracted at this time, almost completely excluding the sea, and subsidence was reduced so that the basin was repeatedly filled with fluvial sands minimising the opportunities for coal formation. The fluvially-dominated conditions of the Passage Formation gradually gave way to a broad flat coastal deltaic plain where coal-swamp conditions occurred frequently and persistently giving rise to the Upper Carboniferous Coal Measures at the top of the solid geological sequence in the study area. Cyclical sequences of marine bands, mudstones, siltstones, sandstones, seatearths and coals predominate. These rocks underlie most of eastern and southern Glasgow (Figure 2.4) and the coals have been extensively mined across the area. The locations of the major coal seams in the Glasgow area are outlined in Figure 2.5.

Superficial (drift) deposits occur extensively throughout the area mainly comprising glacial tills and morainic material (Figure 2.6). These deposits underlie much of southern and northern Glasgow and in places can be in excess of 100 m thick. Much of this material has been moulded into drumlins but elsewhere forms a gently undulating plain and commonly rests directly on the bedrock. With the exception of the northern outskirts of the city, glaciofluvial sand and gravel deposits normally overlie the tills and have been extensively extracted as bulk resources in south-east Glasgow. Raised beach and marine deposits comprising muds and sands dominate the centre of the city to the south and north of the River Clyde (Figure 2.6) and were formed during periglacial marine incursions into the Clyde Valley. Peat is generally the uppermost natural superficial deposit and is developed in hollows and low-lying areas to the east of the city (Figure 2.6). Recent coarse-grained sand and gravel alluvial deposits occupy the Clyde Valley in the centre of the city (Figure 2.6).

2.2.4 Made and Infilled Ground

Extensive areas of man-made deposits are present in and around the urban areas of Glasgow (Figure 2.7). In many areas, the natural ground surface has been covered by redistributed natural and man-made materials that have highly variable geotechnical properties. Typically made ground of this nature is only a few meters thick but in areas close to former excavations, thicker deposits up to tens of meters may be expected. These deposits, where known, are indicated as fill on Figure 2.7. Examples of major ground disturbance include the motorway network, former coal pit bings, slag tips and dredged material from the River Clyde and the Clyde Road Tunnel.

2.2.5 Quarries

As indicated in the preceding sections of this report, the district has been extensively quarried for minerals including sand and gravel, brick clay, hardrock aggregate fireclay, shale, sandstone and coal. The locations of known quarries derived from BGS data are outlined in Figure 2.8. Many former quarries have been infilled with variably compacted materials and built over. Furthermore, early landfill in Glasgow took place in the numerous sand, gravel and brick pits and in building stone quarries in and around the city. The existence of some of these quarries and landfills has only been revealed by drilling over the last 15 years. The Wilderness Landfill at Buchley (Figure 2.8) was formerly a sand and gravel pit and suffered leachate loss into the River Kelvin during the 1970s. The problem was subsequently rectified via engineering works. Another problematic site was at Balmuildy where sand and gravel lenses on the floodplain of the River Kelvin allowed leachate to access the river (Figure 2.8). The adjacent Blackhill Brickworks site was engineered in the early 1980s to allow leachate to access the Upper Limestone Formation via the sands and gravels. However, by the mid-1980s techniques had progressed and the nearby Summerston site was constructed for containment of the leachate using an impermeable liner. The former Greenoakhill Quarry was Scotland’s largest recipient of liquid waste whereas domestic waste has also been disposed of at Summerston, Wilderness and Mavis Valley (Figure 2.8).

3 Urban Soil Geochemistry

3.1 INTRODUCTION

This chapter outlines the various methods used to interpret the Glasgow soils geochemistry and considers the results of the survey with particular reference to pollutants in the urban environment.

3.2 POTENTIAL SOURCES OF ANTHROPOGENIC POLLUTION IN URBAN ENVIRONMENTS

The likely sources of inorganic pollutants in urban environments have been well documented in the literature and useful synopses are provided by Fergusson (1990); Bridge et al. (1997); Appleton (1995), Hooker et al., (2000); D'Arcy et al. (2001) DEFRA-EA (2002a) and DOE (1996-1997). Possible sources include building, waste disposal, transport, industrial and manufacturing activities and the use of fossil fuels. The types of pollutants commonly associated with these activities are summarised as follows.

3.2.1 Buildings, Households and Waste Disposal

Metal accumulation in the environment is well documented and is often associated with the disposal of fossil fuel residues (ash and soot), household refuse, bonfires and the application of phosphate fertilizers (Cd and P_2O_5). Soils are also affected by atmospheric anthropogenic pollution from the burning of fossil fuels, vehicle emissions and industrial processes. Metal contaminants are often present in variable concentrations in domestic and industrial wastes. Over 90% of refuse in the UK is now deposited in landfill sites from which there is usually little dispersion of metals into the neighbouring environment. However, the disposal of waste materials was often undocumented and uncontrolled in the past. In addition to solid refuse, waste-waters from a host of urban activities such as food processing, laundries and breweries often contain high concentrations of metal and metalloid elements; arsenic is present in household detergents, for example. Although the majority of building materials are relatively inert, the demolition of properties, particularly older buildings may lead to anthropogenic pollution with metals such as Pb from paint and substances such as asbestos. Fragments of brick, concrete and mortar, debris from demolition and construction, also commonly form significant constituents of urban soils.

3.2.2 Urban Surface Run-off and Transport

Urban surface run-off waters often contain high concentrations of Cu, Pb, Zn and other compounds derived from road traffic and industrial sources. Until recently, traffic fumes have also been a major source of Pb in the surface environment and, for example, Kelly et al. (1996), Davies (1995) and Ward (1990) have demonstrated the effects of proximity to roads on urban soil quality. Although there is evidence to suggest that Pb levels in urban environments are falling due to removal of this element from petrol, studies have shown a coincident increase in Pt concentrations as a result of usage in catalytic converters (Farago et al., 1996). Due to the fall in Pb levels, Monaci and Bargagli (1997) and Monaci et al. (1999) have suggested that Ba is a good indicator of traffic fume anthropogenic pollution as it is added to diesel to reduce soot emissions (for example, Petkov et al.,1999). Elements such as Zn (used in tyres) are also enhanced in the urban environment as a result of road vehicle usage. In addition to road transport, areas of railway land often contain scrap metal, oil and debris from rolling stock in the soil whereas canal sediments are commonly contaminated with spillage from cargo, motor fuel and paint. More recently, Ce has been used as a fuel-borne catalyst to aid the regeneration of diesel particulate filters (for example, Wakefield et al., 2008) and this may lead to increased environmental levels of Ce in the future.

3.2.3 Metal Smelting

Metal smelting activities can result in the anthropogenic pollution of land and drainage via stack and fugitive emissions, liquid effluent and the dumping and erosion of slag materials and the transport and spillage of metal concentrates. Historically, atmospheric emissions were large, but today depend on the technology employed in the plant, the composition of the raw materials and the pollution control system. Elevated levels of Ag, As, Cd, Cr, Cu, Fe_2O_3, Hg, Ni, Pb, Sb, Se and Zn are often recorded in the vicinity of smelters and other elements such as Au, Bi, F, Mo, Sn, Tl and W may also be enhanced in the local environment depending on the type of smelter.

3.2.4 Extraction and Combustion of Fossil Fuels

Coal mining and the waste products derived from it (ash and slag) can contain elevated concentrations of potentially harmful substances (PHSs). Drainage waters from old coal mines and leachates and run-off from coal and waste piles may be extremely acid due to the oxidation of sulphides. These fluids can contain high levels of Cu, Fe_2O_3, MnO, Ni and Zn and appreciable amounts of other elements such as As and Pb which can contaminate soils. Sites of disused and demolished power stations often contain soluble salts such as B, residues of coal and pulverised fuel ash (which is highly alkaline pH 11 – 12). Atmospheric pollutants associated with power stations include Ag, Cd, Cu, Ga, Ge, Hg, Pb, Sb, Se, and Zn and environments around coal power stations can be enhanced in Cd, Co, Cr, Cu, Fe_2O_3, Hg, Ni, TiO_2 and Zn. Fly ash from power stations, which was often used historically to condition land, contains concentrated levels of As, B, Be, Cd, Cu, MnO, Mo, Ni, Sb, Se, Te, V and Zn and may result in anthropogenic pollution if application was not regulated correctly.

3.2.5 Manufacturing Industries

Many industrial processes can give rise to anthropogenic pollution; as a general rule, the older the industry, the more likely it is to have produced substantial anthropogenic pollution of the local environment and nearby drainage systems. Chemical works, gas works and oil refineries give rise to a wide range of contaminants in air, soil, sediment and waters. Potential pollutants from chemical works include Cd, Cr, Cu, Hg, Pb, Sn and Zn. Agricultural-chemical and fertiliser industries may be associated with a wide range of contaminants (trace metals, metalloid elements, P_2O_5 and N) whilst explosive works residues may contain As, Cu, Hg and Pb. Oil refineries and the manufacture of oil-based products are potential sources of As, Cd, Co, Cr, Cu, Mo, Ni, Pb, V and Zn, whereas petroleum cracking catalysts have been traced as the source of light rare-earth element anomalies. Old gas works may be polluted with coal and coal residues, spent iron oxides, cyanides, sulphates and a range of organic compounds.

Many metals may be present in high concentrations around steelworks, foundries, electroplating and finishing works. The cleaning and etching of bare metal surfaces in metal finishing and plating processes are major sources of Cd, Cr, Cu, Ni and Zn in drainage systems. Battery manufacture may generate waste rich in Cd, Hg, Ni, P_2O_5, Sb and Zn. The processing of scrap metals results in site anthropogenic pollution with metal and metalloid elements in addition to organic substances. Waste-waters derived from paint and dye-stuff producers often contain elevated levels of Cd, Cr, Cu, Hg, Pb and Se from the pigments and raw materials of these industries. Electrical and electronic industry waste can contain Cd, Cu, Pb, Se and Zn, whereas Cd, Pb, Sn and Zn are used in the manufacture of synthetic rubber and plastics as stabilisers and pigments. The leather and textile industries use chromates and dichromates to condition cloth, which can be sources of Cr enhancement in drainage systems. The glass and ceramic industries use Co, Cr, Cu, Fe_2O_3, Mo, Pb, Se, TiO_2 among other elements as pigments, glazes and conditioning agents. Finally, new technologies such as mobile phones and integrated circuits are adding new trace element contaminants to the environment such as tantalum (Ta). For example, a mobile phone contains 39 mined and processed inorganic chemical elements (Nokia, 2009).

In summary, an extensive array of activities in urban environments form potential sources of anthropogenic pollution and urban soils often act as sinks for these contaminants. Some of these contaminants are considered in more detail with reference to Glasgow in this chapter.

A review of the natural behaviour of elements in the surface environment around Glasgow is provided by the BGS Regional Geochemical Atlas for the area (BGS, 1993).

3.3 GLASGOW SOILS DATA INTERPRETATION

A variety of visual and statistical methods were used to aid the interpretation of the Glasgow soils geochemical data and these are outlined in the following sections of this report.

The locations of the 1622 urban and rural soil sampling sites across the Glasgow study area are shown in Figure 3.1. The spatial distributions of the individual geochemical parameters determined during the study are shown as graduated symbol maps, generated from the project GIS, in Appendices 3 and 4 of this report for top and deeper soils respectively. It was not possible to display all the site locations referred to in this chapter on the maps presented in this report. Grid references are provided for the individual soil samples referred to in the text, should the reader wish to locate these either on hard copy maps or in a GIS.

3.4 GLASGOW SOILS NATIONAL COMPARISONS

Summary statistics for parameter concentrations in Glasgow top and deeper urban and rural soils are outlined in Table 3.1. Comparisons between the Glasgow data and urban areas elsewhere as well as regional and national soil datasets provide an overview of the Glasgow geochemistry in the wider context.

Several datasets are available for comparison with the Glasgow soils including rural top soil data collected at a sample density of 1 per 2 km^2 over the Humber-Trent region of England by the BGS G-BASE project (BGS, 2009). This dataset provides a more extensive regional background than the limited number of rural samples collected around the Glasgow conurbation for the present project as it is underlain by similar Carboniferous rock types to Glasgow (with the exception of the

Clyde Plateau Volcanic Formation). Available for comparison also are urban top soil data collected at a sample density of 4 per km^2 in other UK urban centres by the BGS G-BASE project (Fordyce et al., 2005); national top soil data generated by the Soil Survey of England and Wales Inventory (McGrath and Loveland, 1992) and national top soil data held by the James Hutton Institute (JHI) Inventory for Scotland (SEPA, 2001; Paterson et al., 2003). Where no other UK data existed for comparison at the time of writing, the Glasgow results were assessed relative to world top soil averages taken from Reimann and Caritat (1998).

Data from the national inventories of England and Wales and of Scotland provide overviews of top soil pseudo-total element concentrations (<2 mm fraction) based on collection at a sample density of 1 per 25 km^2 (5 x 5 km grid) and 1 per 100 km^2 (10 x 10 km grid) respectively. However, it should be noted that although, in England and Wales, the sampling depth (15 cm) was similar to that of G-BASE top soils; in Scotland samples were collected from the midpoint of the upper-most genetic horizon and not from a uniform depth. It should also be noted that the analysis of the England and Wales and Scottish national samples was carried out by an extraction (aqua-regia 4:1 HCl: HNO3 vol/vol followed by inductively coupled plasma atomic emission spectrometry (ICP-AES)) rather than a true total technique. These differences in methodology are likely to lead to some bias when comparing one dataset to the other as values will be inherently lower in the National datasets. Data from the National Inventory of Scotland are split into organic and mineral soils, and data from mineral soils only are compared to Glasgow as these most closely match soils in the city environment. Although a range of elements were analysed for the National Inventory of Scotland, data for six elements were selected for comparison with the present study (SEPA, 2001; Paterson et al., 2003).

Comparisons with G-BASE regional top soil and urban data can be made directly as the sampling and analytical methods are the same as Glasgow. However, regional deeper soils from Humber-Trent were sieved to <150 µm, a finer size fraction than the Glasgow deeper soils. Comparisons between these two datasets should be treated with caution as many metal elements are preferentially concentrated in the fine material in soils; hence are often elevated in the <150 µm relative to the <2 mm size fraction purely as a result of the sampling methodology.

Since Glasgow is underlain primarily by the Coal Measures, the G-BASE Humber-Trent dataset was sub-sampled to give an indication of regional background element concentrations in soils developed over this lithology.

Summary statistics for these datasets are shown in Table 3.2. The median value of a geochemical dataset provides an indication of the ‘average’ concentration and is less influenced by outlying data values than the mean concentration. Comparisons between median element concentrations in the Glasgow soils and the UK national and regional datasets and world soils are shown in the bar charts in Figure 3.2. It is also useful to compare the ratios of median values between Glasgow and the other datasets to assess the levels of enhancement in the urban environment and these are outlined in Table 3.3.

3.4.1 Cd, Cr, Cu, Ni, Pb and Zn Comparisons with the National Soils Inventory of Scotland

Data for six elements in top soil were selected from the National Soil Inventory of Scotland for comparison with the Glasgow soils; these were Cd, Cr, Cu, Ni, Pb and Zn (Table 3.2 and Figure 3.2). Median ratios for the Glasgow urban and rural top soils versus the National Inventory of

Scotland are outlined in Table 3.3. Results demonstrate that these elements are elevated in Glasgow relative to national averages ranging from approximately 2-3 times in the cases of Cd (x1.7 rural and urban), Cr (x2.4 rural; x 2.6 urban), Ni (x1.9 rural; x2.7 urban) and Zn (x2.2 rural; x3.2 urban) to even greater levels of enhancement for Cu (x4.2 rural; x6.9 urban) and Pb (x3.4 rural; x5.5 urban). Whilst this could result from the presence of volcanic rocks and coals in the Glasgow area, such large enrichments of Cu and Pb in the urban environment are unlikely to relate to the local geological conditions alone and almost certainly reflect anthropogenic pollution. However, these ratios should be treated with caution as the difference in analytical method between the two datasets means that element values in the Scotland dataset will be inherently lower than the Glasgow dataset.

3.4.1.1 Cd, Cr, Cu, Ni, Pb and Zn COMPARISONS WITH OTHER DATASETS

Cd

Cadmium median concentrations in Glasgow top soils are much lower (less than half) than those from England and Wales (x0.4 rural and urban) and the Humber-Trent region (x0.3 rural and urban) but are similar to world averages (x0.8 rural and urban) (Table 3.3). Median Cd values in the Glasgow deeper soils are approximately half those in the Humber-Trent region (x0.6).

Cr

Chromium medians in Glasgow top soils show 2-3 times the level of enhancement relative to England and Wales soils (x2.5 rural; x2.7 urban). However, levels of enrichment are less when compared to the Humber-Trent (x1.4 rural; 1.5 urban); Humber-Trent Coal Measures (x1.3 rural; x1.4 urban) datasets and world averages (x1.2 rural; x1.4 urban). The former result could be influenced by the different analytical method of the National datasets for England and Wales. Therefore, comparisons with Humber-Trent soils probably give more realistic indications of how little Cr is enhanced in the Glasgow environment relative to regional backgrounds. The marginal enrichment in the rural soils probably reflects the presence of volcanic rocks on the periphery of the city, whereas results for the urban environment may also be influenced by anthropogenic pollution. Median concentrations of Cr in Glasgow urban deeper soils are marginally enhanced (x1.3) compared to soils in the Humber-Trent region despite the fact that in Humber-Trent a finer size fraction was analysed (Table 3.3).

Cu

Median Cu values in Glasgow top soils show a 2-3 times enhancement relative to England and Wales and Humber-Trent (x1.7 rural; x2.9 urban) soils, but the enrichment factors are less than comparisons with Scottish soils. These differences could reflect geological conditions as Cu concentrations over most of Scotland are generally low compared to England and Wales. Taking geological setting into account, median concentrations in Glasgow top soils much more closely match those for the portion of the Humber-Trent region underlain by the Coal Measures (x0.8 rural; x1.4 urban) (Table 3.3). In deeper Glasgow urban soils, Cu is enhanced x2.4 relative to the Humber-Trent region.

Ni

Nickel median values in the Glasgow datasets are enhanced 1.5 – 2.0 times relative to England and Wales and Humber-Trent (x1.5 rural; x2.1 urban) top soil averages. Median ratios for the Humber-Trent Coal Measure top soils (x1.4 rural; x1.9 urban) and Humber-Trent deeper soils (x1.2 rural;

x1.8 urban) are of a similar order. These top soil ratios are smaller than those reported between the Glasgow datasets and Scottish soils, as again soils in Scotland tend to contain lower concentrations of the element than those in England and Wales.

Pb

The ratios of Pb median values in Glasgow demonstrate a 2-times enhancement in rural and 3-times enhancement in urban top soils compared to England and Wales (x1.9 rural; x3.2 urban) and Humber-Trent (x1.8 rural; x3.0 urban). However, taking geological conditions into account, values in Glasgow much more closely match those over the Humber-Trent Coal Measure top soils (x0.7 rural; x1.2 urban). Urban deeper soils from Glasgow are enhanced relative to the Humber-Trent soils despite the fact that a finer size fraction was analysed in Humber-Trent (x1.0 rural; x2.7 urban). These levels of enhancement are much lower than those reported between the urban top soils and Scottish averages as Scottish soils tend to contain less Pb than those in England and Wales. Interestingly, comparison with world averages indicates a 4-fold and 7-fold enhancement of Pb in the Glasgow rural and urban top soils respectively, probably as a result of anthropogenic pollution.

Zn

Zinc median value ratios in Glasgow show a 1-2 times enhancement of the element relative to England and Wales (x1.3 rural; x1.9 urban) and Humber-Trent (x1.5 rural; x2.1 urban) top soils and Humber-Trent deeper soils (x1.1 rural; x1.7 urban). However a better comparison with background values is provided by the Humber-Trent Coal Measure averages, which are similar to median values in rural Glasgow soils (x0.9) and show marginal enhancement in urban Glasgow soils (x1.3), the latter probably as a result of atmospheric anthropogenic pollution in the urban environment. None of these results are as high as the enrichment reported between Glasgow urban top soils and the Scottish average (x3.2) probably due to the generally lower levels of Zn in Scotland than England and Wales as a result of different geological conditions and the different methods of analysis of the Scottish survey.

3.4.2 Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, P_2O_5, Ba, Co, pH and LOI Comparisons with the National Soil Inventory of England and Wales

Eleven further parameters are available from the National Soil Inventory of England and Wales for comparison with the Glasgow top soils; these are Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, P_2O_5, Ba, Co, pH and LOI. On the basis of median ratio comparisons (Table 3.3), these elements are enhanced in rural and urban Glasgow top soils in the order of x1.3 – 2.5 for CaO, Fe_2O_3, K_2O, MgO, MnO, P_2O_5 and Co. Aluminium and Ba show marginally greater levels of enrichment (x2.7 rural; x2.8 urban) and (x3.2 rural; x3.7 urban) respectively. These differences may again reflect the variations in analytical method between the two datasets whereby values in England and Wales will be inherently lower than those for Glasgow. Median values for soil pH are rather similar between the two datasets (x0.8 rural and x0.9 urban) whereas LOI as an indicator of organic matter is higher in the Glasgow top soils (x2.8 rural; x2.5 urban) than England and Wales averages probably as a result of the greater proportion of peaty soils and presence of coals in the Glasgow area.

3.4.2.1 Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, P_2O_5, Ba, Co, pH AND LOI COMPARISONS WITH OTHER DATASETS

Al_2O_3

Median values for Al_2O_3 in Glasgow rural and urban top soils show only marginal enhancement relative to the Humber-Trent region (x1.2 - 1.3) and are close to world averages (Table 3.3).

CaO

On the basis of median ratios, although less marked than the results for England and Wales, CaO shows some level of enhancement in Glasgow urban relative to Humber-Trent (x1.4) and Humber-Trent Coal Measure (x1.4) top soils and Humber-Trent deeper soils (x1.3), probably as a result of anthropogenic pollution from furnace slag, coal, building and Cr processing waste in the urban environment. In contrast, values in rural Glasgow soils are similar to or marginally lower than those in Humber-Trent (x0.7 Humber-Trent top soils; x0.9 Humber-Trent Coal Measures top soils; x0.6 Humber-Trent deeper soils). Interestingly, the top soils in Glasgow contain on average lower concentrations of the element than world soils (x0.3 rural; x0.5 urban) (Table 3.3).

Fe_2O_3

The ratios of Fe_2O_3 median values in Glasgow rural and urban to Humber-Trent (x1.4) and world (x1.3) top soils and Humber-Trent deep soils (x1.4 rural; x1.3 urban) are all similar and lower than those quoted for comparisons with the England and Wales dataset. Values for the area of the Humber-Trent region underlain by the Coal Measures indicate little enhancement (x1.1) in the Glasgow urban and rural environment relative to regional data from a similar geological setting.

K_2O

Comparisons of median K_2O values with world top soils and Humber-Trent deeper soils indicate levels are marginally lower in the Glasgow environment, in contrast to comparisons with England and Wales soils (Table 3.3). This again may reflect differences in the analytical method of the England and Wales dataset.

MgO

Median ratio comparisons between MgO in Glasgow top and deeper soils and the Humber-Trent region show lesser levels of enhancement in the Glasgow soils (x1.1-1.8) than those reported for England and Wales, and values in the Glasgow rural and urban top soils are marginally lower (x0.7) than world averages.

MnO

The levels of enhancement of MnO in Glasgow relative to world top soils (x1.3 rural; x1.5 urban) are the same as those quoted for comparisons with England and Wales and similar to the Humber-Trent region (x1.2 rural; x1.3 urban). However, comparisons between the deeper soil median values for Glasgow and Humber-Trent (x0.9 rural; x1.0 urban) and between Glasgow and Humber-Trent Coal Measure top soils (x0.7) show little evidence of element enrichment in the Glasgow environment.

P_2O_5

On the basis of median ratios, P_2O_5 is enriched in Glasgow top soils relative to world averages (x2.2 rural; x1.9 urban) to a similar degree (c. double) as reported for soils in England and Wales (x2.5 rural; x2.1 urban). Comparisons with the Humber-Trent region show lesser levels of enhancement in the Glasgow soils relative to these regional background datasets with similar lithological background as the Glasgow area (x1.1-1.4).

Ba

In contrast to the 3-4 times levels of enhancement in Glasgow relative to England and Wales top soils quoted above, comparisons with median values in the Humber-Trent region and world soils indicate no enrichment of Ba in the Glasgow area (Table 3.3). Again the results for England and Wales my reflect differences in analytical methodology between the datasets.

Co

Median comparisons between Glasgow top soils and England and Wales (x2.1 rural; x2.6 urban) and world averages (x2.1 rural; x2.5 urban) show c. 2-times level of enhancement of Co in the Glasgow environment. However, comparisons with the top and deeper soil medians from the Humber-Trent datasets indicate little enrichment in the Glasgow soils relative to this lithologically similar regional background (x0.9-1.4).

pH

The similarities in pH medians between Glasgow top soils and England and Wales soils noted above are also evident with the Humber-Trent datasets (Table 3.3).

LOI

On the basis of the median value ratios (Table 3.3), the levels of enhancement of LOI (as an indicator of organic matter) in Glasgow relative to Humber-Trent top soils (x2.8 rural; x2.6 urban) are very similar to those reported for England and Wales. However, compared to top soils developed over the Coal Measures in the Humber-Trent region Glasgow rural (x0.8) and urban (x0.7) samples are marginally lower in organic matter than these soils from a similar geological setting.

3.4.3 TiO_2, Ag, As, Ce, Ga, La, Mo, Nb, Rb, Sb, Se, Sn, Sr, Th, U, V, Y and Z Comparisons with BGS Humber-Trent Regional Soils

Data for 12 additional elements in both top and deeper soils (TiO_2, Ag, As, Mo, Rb, Sb, Se, Sn, Sr, U, V and Zr) and a further six elements in deeper soils only (Ce, Ga, La, Nb, Th and Y) are available from the BGS Humber-Trent regional dataset for comparison with the Glasgow soils.

TiO_2

Based on a comparison of TiO_2 median values, Glasgow soils are marginally enhanced in the element (x1.8 rural; x1.5 urban) relative to Humber-Trent; Humber-Trent Coal Measure and world top soils probably reflecting volcanic parent materials in the Glasgow area.

Ag and As

On the basis of median comparisons (Table 3.3), Ag and As concentrations in Glasgow rural and urban top soils are generally lower than those for Humber-Trent but enhanced relative to world averages (Ag x3.6; As x1.8) probably due to anthropogenic pollution and the presence of coals in the Glasgow environment.

Mo

Glasgow rural (x1.2) and urban (x1.8) soils show marginal enhancement in Mo compared to world soils based on median ratios (Table 3.3). The slightly higher values in urban soils probably reflect anthropogenic pollution compared to the world dataset. However, Glasgow urban soils show no enrichment in the element relative to the Humber-Trent values (x1.0 top; x1.1 deeper) and averages in Glasgow are lower in both rural (x0.5) and urban (x0.7) top soils than those developed over the Coal Measures in the Humber-Trent region.

Rb

Rubidium median values in the Glasgow rural and urban datasets are approximately half those of the Humber-Trent region and of world soils, probably due to the predominance of alkali volcanic rocks in the Glasgow area, which tend to be low in the element (BGS, 1993) (Table 3.3).

Sb and Sn

Antimony and Sn in Glasgow urban top soils both show the same level of enhancement (x.2.6) relative to the Humber-Trent and world soil datasets on the basis of median ratios (Table 3.3). However, taking geological conditions into account, both elements are elevated to a lesser degree (x1.3) in Glasgow urban versus Humber-Trent Coal Measure top soils. These results indicate a small degree of anthropogenic pollution in the city environment. In contrast, rural soils from Glasgow show no enhancement (x1.0) of Sb relative to Humber-Trent and world top soil averages. However, Sn is elevated (x1.5) in the rural environment around Glasgow relative to these datasets, again indicating anthropogenic pollution on the urban periphery. In deeper soils, Sb is much lower in the Glasgow than Humber-Trent soils (x0.2 rural; x0.3 urban), probably reflecting the finer size fraction analysed in Humber-Trent, which tends to concentrate Sb. In contrast, despite the finer size fraction analysed in Humber-Trent, Sn is elevated (x2.3) in deeper urban soils from Glasgow relative to this dataset.

Se

Selenium median concentrations are significantly enhanced in the Glasgow urban and rural top and deeper soils relative to the Humber-Trent region and world soils (x3.0 – 4.5) (Table 3.3). Compared to soils developed over Coal Measures geology in Humber-Trent, the levels of enhancement in Glasgow datasets are still approximately two-fold probably reflecting anthropogenic pollution and the presence of peaty soils in the Glasgow area.

Sr

Median Sr ratios (Table 3.3) show enhancement of the element in Glasgow top and deeper soils relative to the Humber-Trent datasets, which may result from the estuarine location and presence of marine deposits and volcanic rocks in Glasgow as well as anthropogenic pollution from building waste, but values in Glasgow are less than half those reported for world soils.

U

Comparisons of U median values (Table 3.3) show that Glasgow rural top soils are marginally enhanced in the element relative to soils in the Humber-Trent region (x1.1 Humber; x1.4 Humber Coal Measures) whereas urban top soils are not (x0.8 Humber; x0.9 Humber Coal Measures) probably due to the presence of peaty soils in the area around Glasgow which tend to concentrate elements like U. Values in Glasgow rural and urban environments are lower in top soils relative to world averages and in deeper soils compared to the Humber-Trent region.

V

Vanadium median concentrations are enhanced x1.3-1.6 in Glasgow rural and urban top and deeper soils relative to the Humber-Trent and world soil averages reflecting the coal and volcanic geology of the Glasgow area.

Zr

Median levels of Zr in Glasgow soils are the same as those reported for Humber-Trent and world top soils but are lower than the Humber-Trent deeper soils (Table 3.3). However, this finding is due to the finer size fraction analysed in Humber-Trent deeper soils, which tends to enhance the Zr concentration. Hence the Glasgow soils appear low in the element relative to these results.

Deeper Soils Only

Ce and Ga

In deeper soils, Ce medians closely match those in Humber-Trent but Ga is marginally enhanced in Glasgow relative to Humber-Trent soils (x1.3) probably due to the presence of coals and alkali volcanics in the Glasgow area (Table 3.3). Cerium and Ga median concentrations in Glasgow top soils are similar to those reported for world soils.

La and Y

Lanthanum and Y median concentrations in Humber-Trent deeper soils and world top soils are similar to those reported for Glasgow rural and urban soils; although values of Y in rural deeper soils are marginally lower in Glasgow (x0.7) than the Humber-Trent region, again probably as a result of the different size fractions of the two datasets (Table 3.3).

Nb and Th

Niobium concentrations are marginally enhanced in Glasgow rural and urban soils relative to world top soils and Humber-Trent deeper soils (x1.2-1.4) probably as a result of volcanic parent materials in the Glasgow area. In contrast, Th concentrations are lower in Glasgow soils than world top soils and Humber-Trent deeper soils (x0.6 – 0.9) on the basis of median comparisons.

3.4.4 Na_2O, SiO_2, Bi, Br, Cs, Ge, Hf, I, Sc, Ta, Te, Tl and W Comparisons with World Soils

For 13 of the elements, Na_2O, SiO_2, Bi, Br, Cs, Ge, Hf, I, Sc, Ta, Te, Tl and W, there were no regional UK datasets for comparison with the Glasgow soils at the time of writing and medians are evaluated relative to world top soil averages (Table 3.3).

Na_2O, SiO_2 and Ta

Sodium and Ta median concentrations in Glasgow top toils are half those reported for world soils in both the rural and urban environment whereas SiO_2, concentrations in Glasgow match those of world soils (Table 3.3).

Br, Bi, Cs, Hf, I and W

Bromine, Hf and I show a greater level of enhancement in Glasgow rural (x1.9 Br; x1.3 Hf; x 2.5 I) than urban (x1.7 Br; x1.1 Hf; x1.5 I) top soils relative to world averages (Table 3.3). Bismuth shows a similar relationship but values in urban soils are lower than those for world soils (x0.8). Caesium (x1.0) and W (x0.9) show no enhancement in rural relative to world top soils and values in urban soils are below world averages (x0.3 Cs; x0.7 W). In the case of Hf these relationships may reflect the presence of alkali volcanic parent materials in the rural area around Glasgow and in terms of Bi, Br and I are indicative of the peaty organic rich soils in the hinterland of the city, which tend to trap these elements.

Ge, Sc and Tl

Germanium, Sc (both x1.5 rural; x1.9 urban) and Tl (x1.1 rural; x1.2 urban) median values in Glasgow top soils are marginally enhanced relative to world soil averages but show a greater level of enhancement in the urban environment reflecting anthropogenic pollution.

Te

Median ratios for Te should be ignored as the majority of Te values are below the detection limit.

Comparisons with regional, national and international datasets are interesting and help to place the Glasgow data in context. Median values for many elements in Glasgow, Humber-Trent Coal Measures and Humber-Trent soils are similar and are all elevated compared to the national datasets (Table 3.3). Whilst this could be due in large part to the difference in analytical methods for the national datasets, it also suggests that because of the presence of the Coal Measures, the rural background for Glasgow is significantly higher than the national averages as the national data are collected over a very large range of parent materials, many of which contain low concentrations of metal and metalloid elements. It should be noted, however, that because of the very close relationship between the outcrop of the Coal Measures and industrialisation in the UK it is difficult to distinguish a truly natural geochemical background for this lithology and even over the large rural area of Humber-Trent, the Coal Measure soils demonstrate a mixed natural and man-made geochemical signal. None-the-less, for some elements, elevated concentrations over the Coal Measures are likely to be naturally rather than anthropogenically controlled. These issues and the specific geological and rural-urban setting of Glasgow are explored in more detail in subsequent sections of this report.

3.4.5 Comparisons with Other Urban Datasets

In order to compare the geochemical environment of Glasgow with other UK urban areas surveyed by the BGS G-BASE project, the median values of six selected elements (As, Cd, Cr, Ni, Pb and Se) in top soils are shown in Figure 3.3. These are the six PHS for which there are soil guideline values (SGV) in the UK (EA, 2009a). Median As levels in Glasgow are similar to those in Coventry, Lincoln, Telford and York but are lower than those for most of the other urban centres.

Similarly, Cd concentrations in Glasgow are lower than most of the other urban centres but are comparable to median values in Corby, Coventry, Northampton and Peterborough. However, these results should be treated with caution as concentrations reported in many of the urban centres are close to or below the detection limit. Median Cr and Ni concentrations in Glasgow are higher than any of the urban centres as expected given the history of Cr ore processing in the city and the presence of volcanics and coals in the Glasgow area. Lead concentrations in Glasgow are on average similar to those in Hull but noticeably lower than other major industrial conurbations including Derby, Manchester, Sheffield, Swansea and Wolverhampton. Selenium median values in Glasgow are similar to those in Wolverhampton but are higher than the other urban centres for which data are available; however, these results should be treated with caution as many of the values are close to the detection limit. Evidence from the G-BASE urban datasets suggests that Ca is often enhanced in urban soils as a result of various industrial and urban processes (Fordyce et al., 2005). The median value in Glasgow top soils (0.92 wt%) is lower than that of Mansfield but is higher than other cities underlain by the Coal Measures such as Doncaster (0.73 wt%) and Sheffield (0.77 wt%).

Urban studies elsewhere have demonstrated analogous enhancements of specific contaminants associated with urban and industrial activities including relationships between city environments and rural background, for example in Edinburgh (Purves and MacKenzie, 1969), Richmond-on-Thames (Kelly et al., 1996) and Aberdeen (Paterson et al., 1996). However, many of the published studies on urban soil geochemistry in Britain are for restricted analytical suites of elements limiting comparisons with the G-BASE data.

Similar systematic urban soil geochemical sampling has been carried out in Norway based on the collection of the top 2 – 3 cm of the soil profile at a sample density of 1 km rather than 500 m across the urban area (Tijhuis et al., 2002). Soils were analysed by a pseudo-total nitric acid ICP-AES technique and results presented as proportional symbol maps analogous to those for Glasgow. Although the results are not directly comparable due to the differences in analytical techniques, with the exception of Cd, median metal concentrations in Glasgow surface soils are 2 – 4 times those reported for Oslo reflecting the differences in geological setting and industrial history of the two urban areas.

Hence it can be concluded that Glasgow soils show a significant urban industrial geochemical signature for several metal elements (Ag, As, Ge, Mo, Sb and Sn) relative to national/regional averages. However, the concentrations of these pollutants are similar to those of other urban centres in the UK whereas Cr and Ni are higher in Glasgow soils than most other cities.

3.5 TOP AND DEEPER SOIL COMPARISONS

As outlined in Appendix 1 of this report, top (5 – 20 cm) and deeper (35 – 50 cm) soil samples were collected at each site across Glasgow to provide information on the chemistry of near-surface soils, which may be influenced by atmospheric anthropogenic pollution, and of deeper soils, which should more closely represent parent materials (whether natural or anthropogenic). In order to assess differences in geochemistry down the soil profile, graphs of parameter concentrations in top versus deeper urban soils are shown in Figure 3.4 and rural soils in Figure 3.5.

Summary statistics for element, pH and LOI concentrations in Glasgow top and deeper urban and rural soils are also outlined in Table 3.1. Another useful way to compare the relationships between top and deeper samples is to assess the ratios between median values in the two sample media (Table 3.4). Inter-element relationships in both top and deeper soils were also examined using correlation coefficients. Spearman Rank non-parametric correlation coefficients were calculated for statistical analysis, as these are less sensitive to outlying values than product moment (Pearson) correlations (Tables 3.5 – 3.8).

Ag, Bi, Cs, Ta, Te and Tl

The results outlined in Figures 3.4 and 3.5 demonstrate that for some elements it is difficult to define the relationships between top and deeper soils as the values are very close to the detection limit, these include Ag, Bi, Cs, Ta, Te and Tl.

Cs: However, a comparison of element median values in Table 3.4 indicates that Cs is enhanced in rural top soils (x1.5). This may reflect the fact that the element is associated with alkaline igneous rocks such as those present on the periphery of Glasgow. Indeed the distributions of Cs shown in Appendices 3 and 4 demonstrate higher values over the Clyde Plateau Volcanics to the north and south of the city. However, Cs can also enter the environment as a result of nuclear leaks and it is probable that these findings are a result of fallout out from the Chernobyl accident in 1986 and the atmospheric nuclear weapons' testing programmes of the 1950s and 1960s. Deposition of Cs from the atmosphere is to a large extent controlled by weather and rainfall patterns. The Clyde Plateau Volcanics form the upland areas around Glasgow and higher rainfall over regions of greater relief mean that Cs is more likely to be washed out of the atmosphere in such areas. Atmospheric Cs fallout has been identified in other similar environments in Scotland (For example, Eades et al., 1998; MacKenzie et al., 1997). Caesium shows a strong (>0.600, p-value <0.01) negative correlation with Fe_2O_3 in urban top and deeper soils and with Fe_2O_3, MnO, TiO_2 and Co in rural top toils (Tables 3.5 – 3.8) indicating that it is not held within Fe-Ti-Mn oxides in the soils. Further investigations into isotopic compositions would be required to confirm whether the Cs in the environs of Glasgow is from a nuclear fallout source.

Bi: Bismuth is also enhanced in rural top versus deeper soils (x2.0) based on a comparison of median values (Table 3.4). Bismuth is rare in nature but tends to be associated with shales, schists and pegmatites (BGS, 1993). It is also released to the environment via the smelting of other metals. The element is commonly associated with organic matter in soils and this may in part explain the greater concentration in the rural top soils as top soils generally contain more organic matter than deeper soil layers. Indeed, in both the Glasgow urban (x1.4) and rural (x1.6) datasets, LOI (an indicator of organic matter) is greater in top than deeper soils (Table 3.4). However, no statistically significant correlation between Bi and LOI in rural soils is evident in Tables 3.7 and 3.8. The higher concentrations of the element in rural top than deeper soils shown on the maps in Appendices 3 and 4 may also reflect atmospheric deposition from smelting and other processes.

Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, SiO_2, TiO_2, Ce, Co, Ga, Nb, Rb, Sc, Sr, Th, V, Zr and pH

Many of the parameters with a strong geological/natural control on their distribution, show a close relationship between top and deeper soils in both urban and rural environments, such as Al_2O_3, CaO (in urban soils), Fe_2O_3, K_2O, MgO (in urban soils), MnO, Na_2O, SiO_2, TiO_2, Ce (in urban soils), Co (in urban soils), Ga, Nb, Rb, Sc, Sr, Th, V, Zr and pH (Figures 3.4 and 3.5). Cerium and Co would show a similar relationship in rural soils but for one anomalous high value in each of these datasets (Figures 3.4 and 3.5). Indeed, comparisons of median values in Table 3.4 show that the average concentrations of each of these parameters in top and deeper soils are very similar.

However, the graphs of element distributions in top and deeper soils in Figures 3.4 and 3.5 also demonstrate that the majority of these parameters including Al_2O_3, Fe_2O_3, K_2O, MgO (particularly), MnO, Na_2O, SiO_2, Co, Nb, Rb, Sr, Th, V, and Zr are marginally enhanced in rural deeper relative to top soils. This is probably due to the greater mineral content and lower organic matter content of deeper soils in rural environments. This relationship is exemplified by the strong (>0.600, p-value <0.01) negative correlation between SiO_2, the main constituent of silicate minerals, which are the most abundant mineral types in most soils; and LOI in both urban and rural top soils (Tables 3.5 and 3.7).

CaO and Sr: In addition to the rural environment, Sr is marginally enhanced in urban deeper soils, which could again relate to the higher mineral content of deeper soils or could reflect anthropogenic pollution from buried buildings waste. In contrast, CaO is x1.2 higher in rural top than deeper soils based on average values (Table 3.4) despite a number of higher CaO values in rural deep soils (Figure 3.5).

pH: Soil pH shows the same association in both rural and urban environments, namely lower in top soils and higher in the deeper soils. The lower values in top soils reflect more acidic conditions due to the greater organic matter content and associated humic acids. In the urban environment, pH correlates strongly (>0.600, p-value <0.01) with CaO in top and deeper soils (Tables 3.5 and 3.6).

V: Vanadium is marginally enhanced in top rather than deeper rural and urban soils probably reflecting the affinity of the element for organic matter as exemplified by the strong (>0.600, p-value <0.01) correlations with LOI in urban top and deeper soils (Tables 3.5 and 3.6).

Hf, La, Sc and U

Several elements with a strong geogenic control on their distribution, show more complex relationships between the top and deeper soils. At low concentration, values of Hf, La, Sc (in urban soils) and U are higher in deeper soils. At greater concentration, levels of these elements are higher in top soils (Figures 3.4 and 3.5). This could in part be due to the step-wise analytical reporting of some of these elements but may also reflect the complex interaction between binding to organic matter in the top soil layer and a greater proportion of clay and resistate minerals, which contain these elements at depth. The association with resistate phases is exemplified by the strong (>0.600, p-value <0.01) correlations between Hf and Zr in rural and urban soils (Tables 3.5 – 3.8) as these elements are commonly held within the resistate mineral zircon (BGS, 1993). With the exception of U, which is x1.2 higher in rural top than deeper soils, these elements show similar average contents in top and deeper soils based on median values (Table 3.4). These elements also show strong (>0.600, p-value <0.01) statistical correlations with each other and with other elements such as Ce, Nb, Th and Y that are commonly held in the same minerals and are associated with igneous source rocks (Tables 3.5 – 3.8).

P_2O_5

In the case of P_2O_5, the greater concentrations in top soils in both urban and rural areas as shown in Figures 3.4 and 3.5 and comparing median values in Table 3.4 (x1.9 rural; x1.3 urban) almost certainly reflect fertiliser application, with greater use in the agricultural areas around Glasgow.

Br and I

On the basis of Figures 3.4 and 3.5 and the median values in Table 3.4 higher concentrations of Br (x1.3 rural; 1.5 urban) and I (x2.0 rural; x1.5 urban) are evident in top versus deeper soils. The main source of these elements in the environment is atmospheric deposition of marine aerosols and they are strongly associated with organic matter in soils. Indeed Br shows a strong (>0.600, p-value <0.011) correlation with LOI (as an indicator of organic matter) in urban and rural top and deeper soils and with I in urban deeper and rural top and deeper soils (Tables 3.5 – 3.8).

As, Ba, Cd, Cr, Cu, Ga, Ge, Mo, Ni, Pb, Sb, Se, Sn, Y, W and Zn

Many of these metal and metalloid elements show strong statistical correlations (> 0.600, p-value < 0.01) with each other, which in some cases almost certainly indicate the presence of anthropogenic pollution. For example, Sn shows strong correlations with Cu, Ge, Pb, Sb and Zn in both rural and urban soils whereas As shows no strong correlations with other elements in the natural rural environment but correlates strongly with Cu, Ge, Pb and Zn in urban soils (Tables 3.5 – 3.8). In other cases, relationships reflect natural associations between elements. For example, Cr correlates strongly with Ni in both urban and rural soils and with Al_2O_3, Ce, Co, Ga, La, Sc, V and Y variously in urban deep and rural top and deeper soils reflecting the presence of the Clyde Plateau Volcanic Formation in the Glasgow area.

Several of these elements show a linear relationship in their distributions between top and deeper soils in the rural environment but much greater variability between top and deeper samples in the urban environment as a result of anthropogenic pollution (Figures 3.4 and 3.5). These include Ba, Cd, Cr, Cu, Ga, Mo, Ni, Pb, W, Y and Zn. This category also includes As, Ge and Se, which all would, with the exception of one anomalously high value in deeper soils, show a strong linear relationship in rural soils (Figures 3.4 and 3.5).

Antimony and Sn concentrations are not only variable between top and deeper soils collected at the same sites in the urban environment but show inconsistencies in rural top and deeper soils also indicating the influence of anthropogenic pollution on the urban periphery of Glasgow (Figures 3.4 and 3.5).

A*s, Ba, Cd, Cu, Ge, Mo, Ni, Se and Zn*: Figure 3.5 shows that Ni values are marginally higher in rural deeper soils than top soils, probably due to greater mineral versus organic matter content of the deeper soils. However, in general terms, concentrations of As, Ba, Cd, Cu, Ge, Mo, Ni, Se and Zn are broadly similar in rural top and deeper soils. In contrast, values in urban top soils are generally higher than deeper soils collected at the same sites (Figure 3.4). Interestingly, based on median values, many of these elements show similar concentrations in urban top and deeper soils (Table 3.4). However, several are enhanced on average in rural top versus deeper soils As (x1.3), Cu (x1.3), Ge (x1.6) and Se (x1.3). These results are perhaps an indication of the more pervasive, general and multi-source nature of anthropogenic pollution in the urban environment, which affects both top and deeper soils. Whereas in the rural environment elevated median concentrations of the elements in top soils are more apparent as a result of diffuse atmospheric and surface anthropogenic pollution. Many of these elements are associated with organic matter in soil and this could also account for the higher concentrations in top soils. Although not evident on the graph in Figure 3.5, on the basis of median values, Zn is enhanced in rural (x1.3) as well as urban (x1.2) top relative to deeper soils.

Pb, Sb, Sn and W: Figures 3.4 and 3.5 show that Pb (only marginally in rural soils), Sb, Sn and W are higher in top than deeper soils in both urban and rural environments. These elements tend to be rare in nature in most circumstances and associated more specifically with atmospheric pollution and surface anthropogenic pollution. In addition, they have a strong affinity for organic matter in soils and these two factors account for the higher values in top soils. Interestingly, the comparison of median values (Table 3.4) confirms that Pb (x2.0 rural; x1.3 urban) is enhanced in top soils in both environments whereas Sb (x1.0 rural; x1.3 urban) and W (x1.1 rural; x1.3 urban) show enrichment in the urban top soils only and Sn is particularly enhanced in rural top soils (x2.3 rural; x 1.1 urban).

Cr: Although Cr concentrations in top and deeper rural soils are generally similar (Figure 3.5), values are higher in deeper urban soils than top soils probably reflecting the presence of buried Cr-waste in the Glasgow area (Figure 3.4).

As indicated in Appendix 1 of this report, the sampling design in the rural environment was restricted by funds; therefore it extends much further to the north-east of Glasgow than the south and west to give coverage over similar lithologies to those underlying the Glasgow conurbation. However, the area to the north-east lies down-wind from the city, and although no obvious enhancement of element concentrations is evident in top soils from this area in the spatial distributions presented in the maps in Appendices 3 and 4, the comparisons between top and deeper soils shown in Figures 3.4 and 3.5 and Table 3.4 suggest that rural top soils in the Glasgow area may be affected by the atmospheric deposition of pollutants.

3.5.1 Highest Parameter Concentrations in the Glasgow Dataset

From the plots of top versus deeper urban and rural soils outlined in Figures 3.4 and 3.5, some parameters demonstrate high concentrations relative to the rest of the Glasgow dataset. In some cases, high values occur in both top and deeper soils at the same location, whereas in other cases, values in top soils are far greater than results from deeper soils collected at the same site or *visa versa*. These highest concentrations are discussed in the following sections of this report. It was not possible to show the locations referred to in the text on the maps in Appendices 3 and 4. Grid references and sample location details are provided should the reader wish to locate these on hard copy maps or in a GIS. It should be noted that the presence of high parameter concentrations relative to the rest of the Glasgow dataset at any location does not in itself imply any potential threat to ecosystems, water resources or humans; indeed several of the elements discussed are essential for ecosystem and animal health.

3.5.1.1 URBAN SOILS

Highest concentrations of major and trace elements, pH and LOI in the urban soils are summarised in alphabetical order in the following paragraphs. However, at some sites more than one element concentration is high; therefore, elements are not always discussed in strict alphabetical order. In the discussion, the Glasgow dataset refers to both urban and rural soils, whereas the Glasgow urban dataset refers to urban soils only.

CaO (MgO, Cr, Co, pH; Fe_2O_3, Ni)

This sample - on the site of the former J J White's Cr chemical works - contains the highest CaO in deeper soil; highest top and deeper soil concentrations of MgO, Cr, Co and highest pH in the Glasgow dataset. Iron and Ni values are also elevated. These geochemical signatures are indicative of Cr-ore processing waste known to be present at the site and these samples lie within an area of elevated CaO and Cr values in soils associated with the Cr-waste that stretches from Carmyle in the east to Oatlands and Polmadie in the west, on former industrial land along the River Clyde in the East End of Glasgow (Appendices 3 and 4; note: named locations are not given in Appendices 3 and 4 please refer to an OS map or to a GIS):

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611469	260390	662300	CaO	15.8	wt%	20.3	wt%	Derelict land, site of former J J White's Cr chemical works, Southcroft Road, Shawfield Industrial Estate, Rutherglen
			MgO	19.5	wt%	21.2	wt%	
			Co	560	mg kg^{-1}	478	mg kg^{-1}	
			Cr	4286	mg kg^{-1}	4363	mg kg^{-1}	
			pH	8.79		8.88		
			Fe_2O_3	18.95	wt%	15.27	wt%	
			Ni	960	mg kg^{-1}	807	mg kg^{-1}	

CaO (Ba, Cr)

High CaO, Ba and Cr soil contents are reported from this site within the Cr-waste affected area in Rutherglen:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611322	262600	661760	CaO	17.8	wt%	18.6	wt%	Grass verge, Ballochmill Road Industrial Business Park, Rutherglen
			Ba	1049	mg kg^{-1}	3733	mg kg^{-1}	
			Cr	161	mg kg^{-1}	286	mg kg^{-1}	

Fe_2O_3

The highest Fe_2O_3 soil concentrations in the Glasgow dataset are reported in the heart of the shipbuilding industrial estate in Scotstoun on the River Clyde:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611015	253340	667190	Fe_2O_3	20.18	wt%	20.23	wt%	Derelict land, Methil Street, Scotstoun

Higher Fe_2O_3 content is reported in deeper soil than top soil at this derelict site. Coal waste and tarmac are noted in the deeper soil. The difference in element concentration between top and deeper soil almost certainly reflects made ground:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610956	261870	664260	Fe_2O_3	6.53	wt%	16.40	wt%	Derelict land, Janefield Street, north of Parkhead football stadium, Glasgow East End

Fe_2O_3 (Ag, Ba)

Higher Fe_2O_3, Ag and Ba contents are reported in deeper soils than top soils from this site. China, glass, plastics, rubber and industrial waste are noted in the soils. The presence or these anthropogenic materials probably accounts for the difference in element concentrations between top and deeper samples:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610113	252270	661310	Fe_2O_3	8.18	wt%	18.91	wt%	Househill Park south of B762, Priesthill
			Ag	1.4	mg kg^{-1}	9.0	mg kg^{-1}	
			Ba	797	mg kg^{-1}	7038	mg kg^{-1}	

MgO

The higher MgO content reported in deeper soil than top soil at this site probably reflects the presence of made ground at this site:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611485	251220	668100	MgO	1.9	wt%	11.3	wt%	Made ground, industrial estate, Clyde Port Authority, Renfrew

MnO

The highest MnO soil content in the Glasgow dataset is reported in this deeper soil. The MnO concentration in top soil is much lower. This may reflect coal waste noted in the soils. However, the differences in MnO values between the top and deeper samples may also result from soil forming processes:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610583	266200	662790	MnO	0.544	wt%	1.089	wt%	A74 London Road verge, Mount Vernon

Two further samples show higher MnO contents in deeper soil than top soil and a third sample has higher MnO concentrations in top soil than the deeper soil. The differences between top and deeper soils may reflect coal waste noted in the soils but could also result from soil forming processes:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611214	264380	659680	MnO	0.623	wt%	1.164	wt%	Holmhill Avenue road verge, adjacent to Borgie Glen recreational walk, Cambuslang
611150	264700	651720	MnO	0.216	wt%	0.878	wt%	Grass field adjacent to A726 and Calder Water, south-east East Kilbride
610269	242810	663660	MnO	0.752	wt%	0.330	wt%	Open ground adjacent to cycle track on former railway, Barbush, Johnstone

Ag (W)

Silver generally occurs in very trace amounts in nature and within the urban environment its presence above detection limit is a good indicator of anthropogenic pollution. The highest Ag and W concentrations in the Glasgow dataset are reported in this top soil. However, Ag and W values in deeper soil at the same site are much lower. This difference in concentrations between top and deeper soils may reflect atmospheric pollution or coal waste noted in the samples. With the exception of the sample immediately to the west of this site (see 610671 in following paragraphs), surrounding Ag results are below the detection limit indicating the pollution is limited in spatial extent (Appendix 3):

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610634	251660	665830	Ag	23.50	mg kg^{-1}	0.25	mg kg^{-1}	Grass verge Dalziel Road, Hillington Industrial Estate, Renfrew
			W	155.0	mg kg^{-1}	2.7	mg kg^{-1}	

Ag

Higher Ag contents in deeper soil than top soil are reported in two samples. In the first (610178), from a site 1 km south of the previous Dalziel Road location (610634), bricks, china and hardcore are noted in the samples. In the second (611296), coal waste is noted in the deeper sample. The difference in Ag values between top and deeper soils almost certainly reflect this anthropogenic material. Surrounding Ag results are below the detection limit indicating the pollution is limited in spatial extent (Appendix 3):

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610178	252170	660210	Ag	0.25	mg kg^{-1}	16.90	mg kg^{-1}	Derelict land between railway and A726, Nitshill
611296	263220	654270	Ag	0.25	mg kg^{-1}	11.10	mg kg^{-1}	Adjacent to swimming pool, Town Centre Park, East Kilbride

As (Bi, Sb, Se; Tl)

The highest concentrations of As, Bi, Sb and Se in the Glasgow dataset are reported in a deeper soil from a railway verge in the former railway works in the old industrial heartland of Royston. The Tl content is also high in the soil. Corresponding values for these elements in the top soil are much lower; although As is none-the-less elevated. Coal waste is noted in the samples and higher metal/metalloid contents in the deeper soils probably reflect buried anthropogenic pollution and fill materials:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611479	261290	666670	As	72	mg kg^{-1}	1001	mg kg^{-1}	Former industrial railway works, adjacent to railway, Royston
			Bi	2.6	mg kg^{-1}	25.8	mg kg^{-1}	
			Sb	16	mg kg^{-1}	207	mg kg^{-1}	
			Se	3.3	mg kg^{-1}	15.1	mg kg^{-1}	
			Tl	1.9	mg kg^{-1}	11.6	mg kg^{-1}	

As

High As contents are reported in two further deeper soil samples immediately to the south-west of the previous railway works site (611479). The first (611422) is over made ground and the second (611467), is from a school sports ground. Industrial and coal waste are noted in the deeper soil and copper metal in the top soil at this site. These results may reflect the presence of made ground or buried pollution dispersed from the former industrial heartland of Royston:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611422	260780	666200	As	21	mg kg^{-1}	70	mg kg^{-1}	Grassy area on made ground Tharsis Street residential district, Royston
611467	260400	666200	As	15	mg kg^{-1}	49	mg kg^{-1}	School sports ground, Baird Street, Royston

Very high As content is reported in a deeper soil whereas the value in the top soil is much lower from a grassy area in Possil Park. This suggests buried contaminants or made ground; brick and coal waste are noted in the deeper sample:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611108	258780	668330	As	11	mg kg^{-1}	320	mg kg^{-1}	Grassy area residential flats, B808 Bilsland Drive, Possil Park

High values of As are also recorded in the Shawfield Industrial Estate, Rutherglen in the heart of the former Cr and other metal processing centre in the East End of Glasgow:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611429	260800	662240	As	122	mg kg^{-1}	128	mg kg^{-1}	Grass verge, A730 Glasgow Road, Shawfield Industrial Estate

Ba

The highest Ba concentration in the Glasgow dataset is reported in a top soil from a recreational park in East Kilbride. This may reflect fill material as brick is noted in the soil sample or it could result from atmospheric particulate deposition from the road and rail networks proximal to the site:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611264	263220	654740	Ba	10978	mg kg^{-1}	1679	mg kg^{-1}	Kirktonholme Park, East Kilbride

Higher Ba values are reported in a cemetery deeper soil than top soil. Coal waste and bricks are noted in the samples and the differences in element concentrations between top and deeper soils probably reflect this anthropogenic material:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610952	262230	664290	Ba	1235	mg kg^{-1}	3596	mg kg^{-1}	Eastern Necropolis cemetery, Parkhead

Bi (Cr)

High Bi and Cr concentrations in soils from this area in Renfrew, may indicate the presence of fill materials as coal waste and bricks are noted in the soils:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611307	249790	666220	Bi	10.7	mg kg^{-1}	9.1	mg kg^{-1}	Tended road verge, B791, Cockles Loan, Victory Gardens residential area, Renfrew
			Cr	1812	mg kg^{-1}	1321	mg kg^{-1}	

Bi

Higher Bi concentration in top soil than deeper soil at this site may reflect industrial emissions:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610992	262800	663360	Bi	15.9	mg kg^{-1}	1.9	mg kg^{-1}	Industrial estate, A74 London Road, Westhorn

Br

The highest Br concentrations reported in urban soils occur in adjacent samples collected on the northern edge of Glasgow in Milngavie. Both these samples have high organic matter contents explaining the elevated concentrations of Br:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610038	253280	675290	Br	88	mg kg^{-1}	77	mg kg^{-1}	Woodland, Craigton Road, Milngavie
610091	253690	675300	Br	69	mg kg^{-1}	77	mg kg^{-1}	Grassy wasteland, Douglas Academy, Milngavie

Cd (As, Bi)

The highest Cd content in the Glasgow dataset is recorded in this top soil. The As and Bi concentrations are also high, whereas values in the deeper soil are much lower. Industrial emissions and/or proximity to the road and rail network may account for pollution in the surface soil:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610482	247700	664350	Cd	16	mg kg^{-1}	2	mg kg^{-1}	Outside office complex, verge of Underwood Road, Paisley
			As	283	mg kg^{-1}	46	mg kg^{-1}	
			Bi	9.3	mg kg^{-1}	1.6	mg kg^{-1}	

Ce (La, Y)

By far the highest Ce, La and Y soil concentrations in the Glasgow dataset are reported from this derelict land site, probably as a result of coloured glass, tarmac and industrial waste present in the samples:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610480	240850	675390	Ce	1181	mg kg^{-1}	1183	mg kg^{-1}	Derelict land, Milburn Crescent, Silverton, Dumbarton
			La	507	mg kg^{-1}	408	mg kg^{-1}	
			Y	75	mg kg^{-1}	99	mg kg^{-1}	

Cr

In addition to the former J J White's Cr chemical works site, Rutherglen (see 611469 paragraph previously), equal highest Cr contents in the Glasgow dataset are reported in a deeper soil from an industrial estate within the same area of Rutherglen. The concentration in top soil is also high. These samples lie within an area of elevated CaO and Cr values in soils associated with the Cr-waste that stretches from Carmyle in the east to Oatlands and Polmadie in the west, on former industrial land along the River Clyde in the East End of Glasgow (Appendices 3 and 4; note: named locations are not given in Appendices 3 and 4 please refer to an OS map or to a GIS):

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611394	261140	662130	Cr	949	mg kg^{-1}	4363	mg kg^{-1}	Road verge, Ashton Road industrial estate, Rutherglen

Very high Cr values in soils collected over made ground from playing fields in the Braidholm Sports Ground also reflect an area of known Cr-waste pollution:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611261	257370	659680	Cr	1092	mg kg^{-1}	2740	mg kg^{-1}	Made ground, playing fields, Braidholm Sports Ground, Muirend

Cu (Ni; Ag, Sn)

The highest Cu and Ni concentrations in soils in the Glasgow dataset are recorded from this industrial site. Tin concentrations are also high. Bricks, plastics and coal waste are noted in the soils and these results probably reflect industrial pollution. However, concentrations in surrounding samples are lower; therefore, the pollution is not spatially extensive (Appendices 3 and 4):

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610671	251150	665850	Cu	3680	mg kg^{-1}	3182	mg kg^{-1}	Grass verge, Abercorn Avenue, Hillington Industrial Estate, Renfrew
			Ni	1038	mg kg^{-1}	859	mg kg^{-1}	
			Ag	1.00	mg kg^{-1}	0.90	mg kg^{-1}	
			Sn	647	mg kg^{-1}	652	mg kg^{-1}	

Cu (Pb, W)

Higher Cu, Pb and W contents in deeper soil than top soil are reported from this industrial site. These results probably indicate buried anthropogenic materials including coal waste noted in both soils and pottery and bricks noted in the deeper soil:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611432	249790	667750	Cu	263	mg kg^{-1}	2986	mg kg^{-1}	Shopping centre verge, Inchinnan Road, Argyll Avenue Industrial Estate, Renfrew
			Pb	344	mg kg^{-1}	3889	mg kg^{-1}	
			W	3.3	mg kg^{-1}	38.9	mg kg^{-1}	

Cu

Higher Cu contents in deeper soils than top soils probably indicate buried anthropogenic contaminants including coal waste, bricks and hardcore noted in the samples:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610955	263160	664290	Cu	1228	mg kg^{-1}	2232	mg kg^{-1}	Grass verge outside works, Westmuir Street, Parkhead

Ga (Ge; Sc, Se, Tl, V)

Highest Ga soil contents in the Glasgow dataset and highest soil Ge in the Glasgow urban dataset are reported in this sample. Scandium, Se, Tl and V values are also high. Contents are higher in top soils than deeper soils. This may reflect the presence of coal waste in the sample. Surrounding samples contain lower concentrations of these elements; hence the pollution is likely to be localised (Appendix 3):

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611011	252730	668740	Ga	54	mg kg^{-1}	13.8	mg kg^{-1}	Road verge outside library, Foxbar Drive, Knightswood residential area
			Ge	91	mg kg^{-1}	9.5	mg kg^{-1}	
			Sc	34	mg kg^{-1}	12	mg kg^{-1}	
			Se	14.0	mg kg^{-1}	1.3	mg kg^{-1}	
			Tl	10	mg kg^{-1}	1	mg kg^{-1}	
			V	581	mg kg^{-1}	123	mg kg^{-1}	

Ga

Higher Ga content is reported in deeper soil than top soil from this site probably reflecting coal ash noted in the soils:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611119	258340	668750	Ga	16	mg kg^{-1}	47	mg kg^{-1}	Derelict land adjacent to railway and building site north of Parkbrae Gardens, Ruchill

Ga (Ge)

Higher Ga and Ge contents in deeper soils than top soils at this site are probably a result of coal waste, bricks, tarmac and industrial materials noted in the deeper soil:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610011	257940	656380	Ga	18	mg kg^{-1}	43	mg kg^{-1}	Woodland adjacent to River White Cart, Field Road, Busby
			Ge	7	mg kg^{-1}	67	mg kg^{-1}	

Ga (Ge, Sc, Y)

Higher Ga, Ge, Sc and Y concentrations are reported in this deeper soil sample collected from the verge of the M8 in Renfrew than in the top soil. This may reflect made ground and the coal, pottery, glass and brick materials in the soil:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610444	247280	665760	Ga	28	mg kg^{-1}	40	mg kg^{-1}	Made ground, M8 verge, St James' Park, Renfrew
			Ge	43	mg kg^{-1}	76	mg kg^{-1}	
			Sc	31	mg kg^{-1}	42	mg kg^{-1}	
			Y	55	mg kg^{-1}	79	mg kg^{-1}	

Hf

The highest Hf value reported in the Glasgow dataset is in a deeper soil sample collected from playing fields in Carmyle in the former industrial heartland of the East End of Glasgow. Concentrations in top soil are also high. High values may be a result of metal wire and furnace slag noted in the samples:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611094	265380	662250	Hf	14	mg kg^{-1}	23	mg kg^{-1}	Playing fields east of school, Montrose Avenue, Carmyle, south of M74.

I

The highest I content in the Glasgow urban dataset is reported in deeper soil at this site and may reflect coal waste and plastic noted in deeper soil:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611413	258240	667356	I	4	mg kg^{-1}	36	mg kg^{-1}	Made ground, Forth and Clyde canal bank, Firhill

Higher I contents in top soil than deeper soil at this site may reflect atmospheric deposition.

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611124	264720	653660	I	26	mg kg^{-1}	2	mg kg^{-1}	Park, Blacklaw Drive, East Kilbride

Mo

The highest Mo contents in the Glasgow dataset are reported in deeper soil from the industrial heartland of Polmadie. Furnace slag and industrial waste are noted in the soils:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611383	259740	662360	Mo	10	mg kg^{-1}	37	mg kg^{-1}	Derelict land, made ground, Polmadie works site

Higher Mo values in top soil than deeper soil probably reflect furnace slag and coal waste noted in the soils at this site:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611050	264710	662730	Mo	33	mg kg^{-1}	13	mg kg^{-1}	Park, Falside Road, Fullerton

Nb

Highest Nb contents in the Glasgow soils dataset probably reflect basic volcanic bedrock clasts noted in these soils:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611273	261760	655750	Nb	61	mg kg^{-1}	87	mg kg^{-1}	Grass verge, Maclean Crescent residential area, East Kilbride

Pb (Tl; Cr, Th)

Highest Pb and Tl soil contents in the Glasgow dataset are reported at this site over made ground. Chromium and Th values are also high, all of which indicate the probable presence of fill materials in this otherwise residential location:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610040	255240	673350	Pb	5001	mg kg^{-1}	5001	mg kg^{-1}	Tended area, made ground, Craigdhu Burn north of Rowan Drive residential area, Milngavie
			Tl	8.4	mg kg^{-1}	16.2	mg kg^{-1}	
			Cr	725	mg kg^{-1}	1190	mg kg^{-1}	
			Th	16	mg kg^{-1}	25	mg kg^{-1}	

Pb (Zn)

Higher Pb and Zn contents in deeper soils than top soils probably reflect coal waste noted in the deeper soil from this site:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611083	256190	666280	Pb	332	mg kg^{-1}	3770	mg kg^{-1}	Road verge, offices, Old Dumbarton Road
			Zn	204	mg kg^{-1}	1774	mg kg^{-1}	

Sb

High Sb values are reported in top and deeper soils in this industrial site, associated with metal working activities:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610110	250260	659740	Sb	174	mg kg^{-1}	121	mg kg^{-1}	Vehicle repair yard adjacent to railway, Shanks Industrial Park, Barrhead

Sc (Sr, Th, U)

Highest Sc, Sr, Th and U soil values reported in the Glasgow dataset are from this site. Cerium and Y contents are also high. Element concentrations are higher in deeper soil than top soil probably as a result of coal ash noted in the deeper soil. Surrounding samples contain lower concentrations of these elements hence the presence of anthropogenic materials is likely to be localised (Appendix 4):

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610569	266740	663610	Sc	12	mg kg^{-1}	57	mg kg^{-1}	Residential garden, Gargrave Avenue, Baillieston
			Sr	92	mg kg^{-1}	1766	mg kg^{-1}	
			Th	8	mg kg^{-1}	28	mg kg^{-1}	
			U	2.4	mg kg^{-1}	11.8	mg kg^{-1}	
			Ce	81	mg kg^{-1}	436	mg kg^{-1}	
			Y	22	mg kg^{-1}	83	mg kg^{-1}	

Sn

Tin generally occurs in very trace amounts in nature and within the urban environment its presence above detection limit is a good indicator of anthropogenic pollution. Highest Sn concentrations in the Glasgow dataset reported at these sites may reflect coal waste, industrial waste and plastics noted in the soils:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611291	264230	654680	Sn	12	mg kg^{-1}	1394	mg kg^{-1}	Woodland, adjacent A725 dual carriage-way, Whitemoss Grove, East Kilbride
610034	254720	675760	Sn	312	mg kg^{-1}	765	mg kg^{-1}	Recreational grass area adjacent to Allander Water, north of Cloberfield works, Milngavie

Higher Sn in top soils than deeper soils reported at this site may indicate atmospheric pollution. However, bricks and coal waste were also noted in the soils:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610452	245900	664110	Sn	659	mg kg^{-1}	107	mg kg^{-1}	Grass area, Barskiven Road, Paisley

V

Highest soil V concentrations in the Glasgow dataset are reported at this site. Bricks and coal waste are noted in the soils, but V contents are generally high in this area, reflecting volcanic bedrock:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610184	242370	662250	V	737	mg kg^{-1}	969	mg kg^{-1}	Adjacent to running track, Thomas Shanks Park, Beith Road, Johnstone

W

Higher W contents in deeper soil than top soil may reflect ceramics, brick and plastic noted in both soils and coloured glass in the deeper soil:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610632	249770	671720	W	9.9	mg kg^{-1}	47.8	mg kg^{-1}	Open ground end of Morar Drive adjacent to A8014, Kilbowie

Zn

The highest Zn values in the Glasgow dataset are reported at this site. Contents are higher in top soil than deeper soil, which may reflect coal waste noted in the soils or atmospheric pollution:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610844	265240	666670	Zn	1781	mg kg^{-1}	151	mg kg^{-1}	Grass area, Jerviston Road, Craigend

Zr

Highest Zr values in the Glasgow soils dataset may reflect the presence of bricks and fill materials noted in the Carmyle sample and a higher detrital mineral content in the relatively undisturbed soils of Moor Park in Renfrew:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
611094	265380	662250	Zr	668	mg kg^{-1}	1112	mg kg^{-1}	Sports ground, Carmyle Junction
611397	250160	666720	Zr	816	mg kg^{-1}	974	mg kg^{-1}	Grass verge, High Mair, Moor Park, Renfrew

LOI

Highest LOI (organic matter) values in the Glasgow urban dataset are reported in peaty soils in this low-lying area:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
610317	262630	671650	LOI	36	%	50	%	Grass area, industrial estate, Low Moss, Bishopbriggs

3.5.1.2 RURAL SOILS

High values of major and trace elements, pH and LOI in the rural soils are summarised in alphabetical order in the following paragraphs. However, at some sites more than one element concentration is high; therefore, elements are not always discussed in strict alphabetical order. In the discussion, the Glasgow dataset refers to both urban and rural soils, whereas the Glasgow rural dataset refers to rural soils only. In general, highest rural element concentrations are lower than those reported in the urban dataset.

CaO (Ce, Co, Ga, Ge, La, Mo, Ni, Pb, Sc, Sn, Sr, Tl, W, Y, Zn; Ag, Ba, Bi, Cu, Sb)

Highest soil CaO, Ce, Co, Ga, La, Mo, Ni, Pb, Sc, Sn, Sr, Tl, W, Y and Zn contents in the Glasgow rural dataset are reported at this site. This site also contains the highest soil Ge reported in the Glasgow dataset. Silver, Ba, Bi, Cu and Sb concentrations are also high. Ceramics were noted in the soils and made ground and mine spoil occur in the immediate area:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620245	271590	665760	CaO	15.1	wt%	5.0	wt%	Playing fields edge, Drumpellier Country Park, Coatbridge
			Ce	208	mg kg^{-1}	482	mg kg^{-1}	
			Co	75	mg kg^{-1}	123	mg kg^{-1}	
			Ga	36	mg kg^{-1}	53	mg kg^{-1}	
			Ge	68	mg kg^{-1}	111	mg kg^{-1}	
			La	113	mg kg^{-1}	204	mg kg^{-1}	
			Mo	5	mg kg^{-1}	7	mg kg^{-1}	
			Ni	227	mg kg^{-1}	343	mg kg^{-1}	
			Pb	956	mg kg^{-1}	1150	mg kg^{-1}	
			Sc	32	mg kg^{-1}	42	mg kg^{-1}	
			Sn	176	mg kg^{-1}	129	mg kg^{-1}	
			Sr	462	mg kg^{-1}	620	mg kg^{-1}	
			Tl	2.2	mg kg^{-1}	3.3	mg kg^{-1}	
			W	6.6	mg kg^{-1}	8.0	mg kg^{-1}	
			Y	62	mg kg^{-1}	86	mg kg^{-1}	
			Zn	918	mg kg^{-1}	1132	mg kg^{-1}	
			Ag	1.3	mg kg^{-1}	1.3	mg kg^{-1}	
			Ba	1249	mg kg^{-1}	1502	mg kg^{-1}	
			Bi	2.1	mg kg^{-1}	1.8	mg kg^{-1}	
			Cu	349	mg kg^{-1}	423	mg kg^{-1}	
			Sb	14	mg kg^{-1}	18	mg kg^{-1}	

P_2O_5 (Pb, Sb, Sn)

The highest P_2O_5 soil concentrations in the Glasgow dataset are reported in this field. Lead, Sb and Sn values are also high in top soil. These results may reflect fertiliser use; however, coal waste is also noted in the samples:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620184	244830	666220	P_2O_5	1.81	wt%	1.31	wt%	Rhubarb field, Blackstoun, north-east of Linwood
			Pb	652	mg kg^{-1}	422	mg kg^{-1}	
			Sb	28	mg kg^{-1}	3	mg kg^{-1}	
			Sn	85	mg kg^{-1}	20	mg kg^{-1}	

Ag

The highest Ag soil concentration in the Glasgow rural dataset is reported at this site. The value in top soil is higher than in deeper soil, which may reflect atmospheric pollution:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620111	271560	657470	Ag	2.60	mg kg^{-1}	0.25	mg kg^{-1}	Grass field between race course and M74, Hamilton

As (Bi, Sb, Se)

The highest As, Bi, Sb and Se concentrations in the Glasgow rural dataset are reported in deeper soils from this location. Values are higher in deeper soil than top soil, which may reflect coal waste noted in the samples or industrial pollution:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620094	271060	677880	As	55	mg kg^{-1}	400	mg kg^{-1}	Grass area, industrial estate, Victoria Park, Kilsyth
			Bi	0.25	mg kg^{-1}	4.1	mg kg^{-1}	
			Sb	3	mg kg^{-1}	53	mg kg^{-1}	
			Se	6.6	mg kg^{-1}	12.3	mg kg^{-1}	

Ba (Cu; Pb, Sn)

The highest Ba and Cu values in the Glasgow rural dataset are reported over made ground at the Hamilton Mausoleum. Lead and Sn contents are also high. Furnace slag is noted in the soils:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620024	272670	656220	Ba	591	mg kg^{-1}	1544	mg kg^{-1}	Made ground, parkland, Hamilton Mausoleum
			Cu	96	mg kg^{-1}	474	mg kg^{-1}	
			Pb	147	mg kg^{-1}	558	mg kg^{-1}	
			Sn	15	mg kg^{-1}	65	mg kg^{-1}	

Br (I)

Highest Br and I contents in the Glasgow soils dataset are associated with organic rich peaty upland soils. Organic matter in the soil trapping Br and I brought in on sea spray via the westerly winds and atmospheric deposition probably account for the high values reported at this location:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620175	244340	678630	Br	209	mg kg^{-1}	268	mg kg^{-1}	Peaty moorland, Meikle White Hill, north-east of Dumbarton
			I	53	mg kg^{-1}	41	mg kg^{-1}	

Cd

The highest Cd content in the Glasgow rural dataset is reported in deeper soil over made ground. The concentration in top soil is much lower. Bricks, clear glass and plastic are noted in the soils indicating pollution:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620183	243400	665300	Cd	1	mg kg^{-1}	12	mg kg^{-1}	Playing fields on made ground north of Linwood

Cr

The highest Cr concentration in the Glasgow rural dataset is reported in clay-rich soil in an area of generally elevated Cr values over volcanic bedrock:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620157	239190	661360	Cr	285	mg kg^{-1}	283	mg kg^{-1}	Rough grazing, Drygate Hill, north of Howwood, Renfrewshire

High Cr contents in these soils probably also reflect the underlying volcanic bedrock in this location but may also be influenced by coal waste noted in the samples and proximity to the railway line:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620141	249710	657200	Cr	280	mg kg^{-1}	145	mg kg^{-1}	Pasture field adjacent to railway, south-west of Netherton, Barrhead

Cs

Highest Cs concentrations reported in the Glasgow dataset are from two top soils, both from peaty heather moorland locations to the north of the city. Corresponding Cs concentrations in the deeper soils are much lower suggesting an atmospheric depositional source of the element in top soils. Concentrations of the element are generally elevated over the upland moorlands to the north of Glasgow (Appendices 3 and 4) compared to the rest of the Glasgow dataset:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620199	245460	679570	Cs	20	mg kg^{-1}	1	mg kg^{-1}	Peaty moorland, Knockupple Hill at Dumbarton Muir
620001	258230	676460	Cs	18	mg kg^{-1}	1	mg kg^{-1}	Peaty moorland, west of Craigmaddie Muir, east of Mugdock

Ni (Pb, Zn)

High concentrations of Ni, Pb and Zn in soils relative to the rest of the Glasgow rural dataset are associated with made ground at this location:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620061	266170	674690	Ni	164	mg kg^{-1}	251	mg kg^{-1}	Made ground, former Birdston Hospital, Kirkintilloch
			Pb	256	mg kg^{-1}	580	mg kg^{-1}	
			Zn	245	mg kg^{-1}	456	mg kg^{-1}	

Sn

Higher Sn content is reported in top soil than deeper soil from this location, which may reflect coal waste noted in the soils or atmospheric pollution:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620219	275570	669240	Sn	89	mg kg^{-1}	21	mg kg^{-1}	Pasture south-west of Rigghead Wood, Lanarkshire

V

Highest V contents in the Glasgow rural dataset occur in an area of generally high values underlain by the Clyde Plateau Volcanic Formation. However, the high values could also reflect coal waste noted in the samples or pollution from an adjacent disused railway line:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620151	240520	662590	V	753	mg kg^{-1}	649	mg kg^{-1}	Pasture field adjacent to railway, Abbanoy south of Kilbarchan

LOI

Highest LOI (organic matter contents) in the Glasgow dataset are reported in two peaty upland soils to the north of Glasgow:

Sample Number	Easting	Northing	Parameter	Top Soil	Units	Deeper Soil	Units	Location
620090	259140	677690	LOI	94	%	97	%	Rough grazing, Craigend Muir, east of Mugdock
620112	244590	680350	LOI	95	%	96	%	Peat bog north-east Auchenreoch Muir, north-east of Bonhill

In summary, the relationships between top and deeper samples highlight the highly heterogeneous nature of urban as opposed to rural soils as a result of localised anthropogenic pollution in the urban environment. The rural soils show far less variability in values between top and deeper soils and for many elements the highest values reported in the rural dataset occur in samples that are on the periphery of urban development or have been impacted by urban anthropogenic pollution or made ground.

3.6 RURAL-URBAN COMPARISONS

As indicated in the previous chapters of this report, in addition to the samples collected from the urban area of Glasgow, soils were sampled from the surrounding environment to provide information on the rural geochemical background around the city. A comparison of these two datasets reveals the levels of contaminant enhancement in the urban versus the rural environment. Summary statistics for the two datasets are outlined in Table 3.1 and the ranges of element concentrations are compared in the box and whisker plots presented in Figures 3.6 and 3.7 for top and deeper soils respectively. Another useful way to evaluate the relationships between urban and rural samples is to assess the ratios between median values in the two media (Table 3.9 and Figures 3.8 and 3.9). It was not possible to show the locations referred to in the discussion on the maps in Appendices 3 and 4. Some of the locations are given in Figure 2.2 or the reader should refer to hard copy maps or a GIS.

3.6.1 Urban Soil Parameter Enrichments Relative to Rural Soils

Ag, Cd and Te

As the box and whisker plots in Figures 3.6 and 3.7 demonstrate, for some elements (Ag, Cd and Te) the relationships between rural and urban soils are difficult to determine due to the limited data distribution close to the detection limit. However, the spatial distributions of these elements show a greater proportion of sites above the detection limit in the urban than the rural environment (Appendices 3 and 4). These elements occur rarely in nature other than in trace amounts; hence the values above the detection limit in urban environments and their scattered distributions are indicative of anthropogenic pollution. Although high Cd values are dispersed throughout the Glasgow conurbation, there is a cluster of high values in the East-End of Glasgow in the former heavily industrialised areas of Rutherglen, Carmyle and Shettleston (Appendices 3 and 4).

As, Bi and Se

The concentrations of As, Bi and Se reported in urban and rural top soils are similar (Figure 3.6) although values are higher in urban than rural deeper soils (Figure 3.7) probably as a result of anthropogenic pollution and particularly the presence of coal waste/ash in the urban environment. Interestingly only As median values in deeper soils are elevated in the urban versus the rural environment (x1.2) (Table 3.9). In the urban environment, higher As, Bi and Se values in both top and deeper soils are clustered in the East End of Glasgow along the former industrial corridor of the River Clyde where heavy industry, metal smelting and coal mining were present in the past. High As and Se values are also clustered along the north bank of the Clyde in the shipbuilding areas of Scotstoun and Yoker (Appendices 3 and 4).

Ba, CaO, Ce, Co, Cr, Cu, Ge, Mo, Ni, Pb, Sb, Sn, Sr, Th, Y, Zn and pH

Ba, CaO, Ce, Co, Cr, Cu, Ge, Mo, Ni, Pb, Sb, Sn, Sr, Th, Y, Zn and pH values are generally higher in urban than rural soils (Figures 3.6 and 3.7) for both top and deeper samples.

Ce, Sr, Th and Y: Comparing the median values of parameters with a likely geological control on their distribution indicates enhancements in urban soils of Ce (x1.2 deeper); Sr (x1.3 top; x1.4 deeper); Th (x1.2 top and deeper) and Y (x1.2 top and deeper) (Table 3.9), which may relate in part to the marine deposits underlying much of Glasgow. Cerium and Y contents are likely to be higher over shales and ironstones whereas Sr is likely to be associated with limestones. However, as the maps in Appendices 3 and 4 show, although high Ce, Sr and Y values are dispersed throughout the urban and rural environment, there is evidence of the influence of anthropogenic pollution on the distributions. Clusters of high values occur in the former industrial heartland of the East-End of Glasgow in the Rutherglen-Shettleston area; in the shipbuilding centre on the north bank of the River Clyde at Yoker and along the A737 and M8 corridors through Johnstone, Linwood and north-west Paisley. These areas correspond to made ground, which could account for the high values of these elements, particularly Sr, which tends to be a component of building rubble and other fill materials. In addition, Ce is used as an automotive catalyst and the latter cluster associated with the road network may reflect deposition from traffic fumes. However, Th also demonstrates a cluster of high values in the Johnstone-Linwood area as well as in East Kilbride (Appendices 3 and 4). Aluminium shows a similar distribution. Both these elements indicate greater clay contents in these soils, which could also account for the higher Ce and Y in the Johnstone area.

Ba, CaO, Co, Cu, Ge, Mo, Ni, Pb, Sb, Sn and Zn: Anthropogenic pollution is likely to contribute significantly to the enhancements of Ba, CaO, Co, Cu, Ge, Mo, Ni, Pb, Sb, Sn and Zn in urban soils (see Table 3.9 for median ratios). Elements whose main source in the Glasgow environment is likely to be anthropogenic pollution such as Pb, Sb and Sn show greatest levels of enrichment in the urban soils (Figures 3.6 and 3.7). As the maps in Appendices 3 and 4 demonstrate, several of these elements including Ba, CaO, Co, Cu, Ge, Mo, Ni and Zn are high in concentration in the East-End and Rutherglen-Shettleston former industrial area and the shipbuilding centre on the north bank of the River Clyde at Yoker indicating anthropogenic pollution and the presence of made ground and Cr-waste in the case of the East End and Rutherglen.

Elevated concentrations of Co, Cu, Ge, Mo, Ni, Pb and Zn are also evident in the north-west of Paisley and Johnstone again in areas of made ground, industrial and traffic impacts. These elements could also be associated with the clay and organic matter rich soils of the area. High Pb values are also found in the city centre reflecting traffic influences (Appendices 3 and 4). In contrast, high Sb and Sn soils are dispersed sporadically throughout the city.

Cr: On the basis of median comparisons (Table 3.9), Cr values are not particularly enhanced in urban versus rural soils (x1.1 in top and deeper soils) but the concentrations ranges in Figures 3.6 and 3.7 demonstrate that levels are generally higher in the urban environment. High values are clustered in the south and east of the city in the Mansewood – Muirend – Cathcart – Rutherglen – Carmyle – Shettleston areas concurrent with the former Cr processing site and other heavy industries and areas of known Cr-waste dispersal. High values also occur on the periphery of Paisley-Johnstone probably as a result of volcanic bedrock in the area.

3.6.2 Similar Parameter Concentrations in Rural and Urban Soils

Al_2O_3, Fe_2O_3, Ga, K_2O, La, MgO, MnO, Na_2O, Nb, Rb, Sc, Ta, Tl and V

Several elements with a strong geological control on their distribution show a similar range in concentration in urban versus rural top and deeper soils (Figures 3.6 and 3.7). These are Al_2O_3, Fe_2O_3, Ga, K_2O, La, MgO, MnO, Na_2O, Nb, Rb, Sc, Ta, Tl and V. The majority of these elements also show a similarity in median values; however, Rb (top) and Tl (deeper) are marginally enhanced (x1.2) in urban soils (Table 3.9).

Al_2O_3: As indicated above, Al_2O_3 values are higher in East Kilbride and the Johnstone areas indicating a higher clay content of these soils.

Fe_2O_3, MgO, Ga, Nb and Ta: A few high Fe_2O_3 and MgO values are found in the former industrial heartland of the East End - Rutherglen area of the city reflecting metal smelting influences. However, clusters of high Fe_2O_3, MgO, Ga, Nb and Ta values located in the north-west of East Kilbride, around the southern fringe of Glasgow and in the Johnstone area are a result of the underlying volcanic bedrock (Appendices 3 and 4). The north-west of East Kilbride is underlain by the Clyde Plateau Volcanic Formation unlike the rest of the town (Figure 2.4).

K_2O and Rb: Potassium and Rb concentrations are higher over the Devonian Sandstones of the Dumbarton area and glaciofluvial sand and gravel deposits in Bothwell to the south-east of the city

reflecting the higher feldspar and resistate mineral phase content of sandier soils developed over these parent materials (Appendices 3 and 4).

La and Sc: Lanthanum and Sc show a similar distribution to Ce and Y; namely clusters of high values in the East End – Rutherglen area probably as a result of anthropogenic pollution. Higher values in the Paisley – Johnstone area perhaps reflect anthropogenic pollution or the greater clay content of these soils.

MnO: Manganese also demonstrates a cluster of high values in the East End – Rutherglen – Cambuslang area of the city perhaps as a result of metal pollution. Generally higher values in East Kilbride and around the southern and western fringes of the city are associated with the Clyde Plateau Volcanic Formation (Appendices 3 and 4).

Na_2O: High Na_2O values are concentrated to the west of Glasgow, which may also reflect the underlying Clyde Plateau Volcanic Formation bedrock and marine superficial deposits, but may also indicate the deposition of marine aerosols from westerly winds.

P_2O_5: Phosphorus, which may be influenced by fertiliser use, shows a greater range of concentration in rural than urban top soils and broadly similar concentration in deeper soils (Figures 3.6 and 3.7). On the basis of median values the element is enhanced in urban versus rural deeper soils (x1.2) (Table 3.9). The distribution maps in Appendices 3 and 4 indicate that high values in the rural environment to the south and west of Glasgow may also be associated with the Clyde Plateau Volcanic Formation (Figure 2.4).

Tl: The very few high Tl values in the Glasgow soils dataset are sporadically dispersed throughout the built environment indicating anthropogenic pollution.

V: Vanadium shows a cluster of high values in the Paisley-Johnstone area of Glasgow, which may be due to the presence of both coals and volcanic bedrock in the area and higher organic matter contents of these soils (Appendices 3 and 4).

3.6.3 Urban Soil Parameter Depletions Relative to Rural Soil

LOI

Levels of organic matter in soils (as shown by LOI) are generally lower in the urban environment than the rural environment (Figures 3.6 and 3.7); although these relationships are not reflected in the median values presented in Table 3.9. The geochemical maps in Appendices 3 and 4 clearly show that organic matter is higher in the peaty upland soils developed over the Clyde Plateau Volcanic Formation of the Renfrew Hills to the south and Kilpatrick and Campsie Hills to the north of Glasgow (Figures 2.2 and 2.4).

Br, I, U and W

Several elements that are closely associated with organic matter in soil show the same relationship. These are: Br (x0.9 top; x0.8 deeper); I (x0.6 top; x0.8 deeper), U (x0.7 top; x0.9 deeper) and W (x0.8 top; x0.7 deeper) (Table 3.9). Indeed, the maps in Appendices 3 and 4 demonstrate the very close spatial relationship between organic matter and Br and I in soils. Both these elements are higher to the west than the east of Glasgow, which probably reflects the main westerly wind direction and deposition of marine aerosols containing these elements.

Cs

Caesium is also lower in urban than rural soils (median ratios: x0.3 top; x0.5 deeper) (Table 3.9). As discussed in Section 3.5 of this report, this may reflect nuclear fallout on the upland areas surrounding Glasgow or higher Cs concentrations over the Clyde Plateau Volcanic bedrock in these locations.

Hf, SiO_2, TiO_2 and Zr

Concentrations of Hf, SiO_2, TiO_2 and Zr are also lower in urban than rural soils reflecting differences in soil mineralogy. As outlined in Section 3.5 of this report, Hf and Zr are associated with resistate minerals in soils whereas SiO_2 and TiO_2 indicate a greater proportion of silicate minerals and titanium oxides in the natural rural soils. Indeed, even within the urban environment, higher Hf and Zr values are associated with the least disturbed and ‘most similar to natural’ soils in parkland areas such as Pollock Park in southern Glasgow (Appendices 3 and 4).

3.6.4 Urban Enhancement

The rural-urban median comparisons presented in terms of the relative enhancement of parameters in urban as opposed to rural soils and *visa versa* are shown in Figures 3.8 and 3.9 for top and deeper soils respectively. On the basis of median values, parameters that are enhanced in the urban environment plot on the positive scale, whereas those that are higher in the rural environment plot on the negative scale. Calcium, Cu, Pb, Sb and Sn show the greatest levels of enhancement in urban soils although the order of enhancement varies between top and deeper soils. This suite is fairly typical of contaminant indicators in urban environments; CaO is interesting as concentrations in urban areas reflect the presence of building materials, coal and foundry waste, which tend to be CaO-rich. Conversely, many elements with a strong geogenic control on their distribution are higher in rural than urban soils including Br, Cs, Hf, I, Nb, SiO_2, TiO_2, U, W and Zr as expected.

Comparisons between rural and urban environments taking account of the differences in the geological background of soils developed over the various rock types in the Glasgow area are examined in more detail in the following sections of this report.

3.7 GEOLOGICAL COMPARISONS

In order to investigate the effects of the underlying geological parent materials on the geochemistry of the Glasgow area, the concentration ranges of soil parameters in rural and urban environments over the different rock types are shown in Figures 3.10 and 3.11 and superficial deposits in Figures 3.12 and 3.13. In this context, the rural values are taken as an indication of natural geological conditions in the soils and the urban results as the influence of city environments on this natural geochemical signature.

Due to proximity to the detection limit, it is not possible to evaluate geological associations in soils for Ag and Te (Figures 3.10 – 3.13).

3.7.1 Solid Geology

3.7.1.1 GENERAL RELATIONSHIPS

As Figures 3.10 and 3.11 demonstrate, several parameters are elevated in urban top and deeper soils relative to rural soils regardless of the bedrock over which the soils are developed. These include Ba, Bi (deeper soils), CaO, Ce, Co, Cr, Cu, Ge, K_2O, Mo, Ni, Pb, Sb, Sc, Sn, Sr, Th, Y, Zn and pH indicative of anthropogenic pollution in the urban environment.

Conversely, some parameters are generally higher in concentration in rural as opposed to urban soils in spite of different parent materials and these include Bi (top soils) Br, Cs (top soils), Hf, I (top soils), Nb (not over the Devonian; see Section 3.7.1.2), SiO_2, TiO_2 (not over the Devonian; see Section 3.7.1.2), U, W, Zr (deeper soils) and LOI as an indicator of organic matter. As discussed in the previous section of this report, these relationships reflect the association of these parameters with natural soil forming processes.

The majority of parameters (Al_2O_3, Ba, Bi, CaO, Ce, Co, Cr, Cu, Fe_2O_3, Ga, Ge, Hf, La, MgO, MnO, Mo, Nb, Ni, P_2O_5, Sc, Se, Sn, Sr, Ta, Th, TiO_2, Tl, U, V, Y, Zn, Zr and pH) are lower in top and deeper soils over the Devonian Sandstones of the Dumbarton area (Figure 2.4). This is to be expected as many of the metal elements are associated with the clay fraction in rocks and soils rather than the sand fraction and these are predominantly coarser siliciclastic rocks. The lesser clay content of soils over this rock type is evidenced by the lower concentrations of elements such as Al_2O_3, TiO_2, Ga and Th.

In contrast, K_2O, Na_2O, Rb and SiO_2 in top and deeper soils demonstrate higher concentrations over the Devonian sandstones of Dumbarton than other rock types in the area reflecting the quartz and feldspar dominated mineral content of this rock type.

3.7.1.2 PARAMETER DISTRIBUTIONS OVER VARIOUS ROCK TYPES

Al_2O_3

With the exception of the lower values over the Devonian Sandstones, Al_2O_3, top and deeper soil values are rather similar over the other rock types present in the Glasgow area. Aluminium values are higher in urban than rural soils over the Clyde Plateau Volcanic Formation, Strathclyde Group and Devonian Sandstones (Figures 3.10 and 3.11).

CaO

Calcium contents are lower in soils developed over the Devonian Sandstones relative to other rock types in the Glasgow area but values are higher in rural over the Clyde Plateau Volcanic Formation. The higher values over the volcanics reflect expected geological associations with this rock type (BGS, 1993). Concentrations in rural soils developed over the other rock types in the Glasgow area are rather similar (Figures 3.10 and 3.11). Concentrations in urban soils are markedly higher than rural soils over the Coal Measures. Since these urban soils lie in the former industrial heartland of east Glasgow, these results give a good indication of the degree of anthropogenic pollution from metal processing and other industrial activities in the urban as opposed to rural soils.

Fe_2O_3

Iron contents are also lower in soils developed over the Devonian Sandstones and higher over the Clyde Plateau Volcanic Formation. Again, the higher values over the volcanic rocks reflect expected geological associations (BGS, 1993). Concentrations in soils developed over the other rock types in the Glasgow area are similar (Figures 3.10 and 3.11). Values in urban soils over the Strathclyde Group and Devonian are higher than in rural soils developed over these rock types, which probably reflect anthropogenic pollution.

K_2O and SiO_2

With the exception of the higher values associated with the Devonian, K_2O and SiO_2 ranges in soils over the other parent materials in the Glasgow area are rather similar. However, K_2O shows a broad range of concentrations in rural Strathclyde Group soils (Figures 3.10 and 3.11).

MgO

Magnesium contents are lower in soils developed over the Devonian Sandstones relative to other rock types in the Glasgow area but values are higher over the Clyde Plateau Volcanic Formation and Strathclyde Group. The higher values over these lithologies reflect expected geological associations (BGS, 1993). Contents in urban and rural soils are similar over the Clyde Plateau Volcanics and Strathclyde Group as a result of the higher natural background of the element. In contrast, MgO is higher in urban than rural soils over all the other rock types reflecting anthropogenic pollution (Figures 3.10 and 3.11).

MnO

Manganese contents are also lower in soils developed over the Devonian Sandstones and higher over the Clyde Plateau Volcanic Formation (Figures 3.10 and 3.11). The higher values over the volcanics probably reflect the presence of Mn-oxides in the upland peaty environments associated with the Formation as well as expected geological associations with this rock type (BGS, 1993). Manganese shows broad ranges in concentrations in rural soils underlain by the Coal Measures and Limestone Coal Formation, which may reflect varying organic matter content as the element is closely associated with organic matter in soils (McBride, 1994). Manganese concentrations are higher in urban soils than in rural soils over the Strathclyde Group and Devonian, which probably reflect anthropogenic pollution.

Na_2O

Sodium is elevated in soils over the Devonian, Clyde Plateau Volcanic Formation and the Strathclyde Group relative to other rock types. In general, Na_2O shows broader concentration ranges in rural than urban top and deeper soils over all rock types (Figures 3.10 and 3.11). However, the element is elevated in urban versus rural soils over the Coal Measures. Since these urban soils lie within the former industrial heartland of east Glasgow, these results probably reflect made ground pollution. In deeper soils, rural values exceed those of urban soils over the Clyde Plateau Volcanic Formation indicating a greater influence of this Na_2O-rich bedrock in the natural soils.

P_2O_5

Phosphorus contents are lower in soils developed over the Devonian Sandstones but values are higher over the Clyde Plateau Volcanic Formation, reflecting expected geological associations. Concentrations in soils developed over the other rock types in the Glasgow area are similar (Figures 3.10 and 3.11). Phosphorus is higher in rural than urban top soils over the Clyde Plateau Volcanic and Limestone Coal Formations. In contrast, urban deeper soil values exceed those in the rural environment over all rock types with the exception of the Clyde Plateau Volcanic Formation.

TiO_2

Titanium contents are also lower in soils developed over the Devonian Sandstones but higher over the Clyde Plateau Volcanic Formation and Strathclyde Group. The higher values over these rock types reflect expected geological associations (BGS, 1993). Titanium concentrations are higher in rural than urban soils over all rock types except the Devonian where the opposite is the case (Figures 3.10 and 3.11). This is to be expected as the element is commonly associated with clay minerals in natural soils whereas the Devonian Sandstones comprise coarser lithologies. The higher values over urban Devonian soils probably reflect the presence of other material such as fill in the urban soils.

As

Arsenic concentrations in top soils are rather similar between rural and urban environments over the various rock types in the Glasgow environment with the exception that values are elevated over urban Devonian soils and rural Limestone Coal Formation soils. The former probably reflects anthropogenic pollution, or as in the case of the latter, an association with organic-rich soils developed over these strata. In deeper soils, urban values exceed rural soils over all lithologies with the exception of the Limestone Coal Formation (Figures 3.10 and 3.11).

Ba, Cu and pH

With the exception of lower values over the Devonian Sandstones, Ba, Cu and pH top and deeper soil values are rather similar over the other rock types present in the Glasgow area (Figures 3.10 and 3.11).

Bi

The graphs of Bi distributions in soils over the various rock types presented in Figures 3.10 and 3.11 are interesting. The element is lower over Devonian Sandstones but concentrations vary little over the other rock types in the Glasgow area. In top soils, rural concentrations in general exceed urban values over most rock types indicating that atmospheric deposition and the control of organic matter on soil chemistry may be important determinants in the distribution of the element in surface soils. In contrast, in deeper soils, the highest values in rural areas are recorded over the Clyde Plateau Volcanic Formation as expected over this lithology (BGS, 1993). However, in all cases urban concentrations exceed those of rural soils probably indicating anthropogenic pollution.

Br

The distribution of Br in soils closely follows that of the organic matter content and is higher in rural than urban soils of the Devonian as well as the Clyde Plateau Volcanic Formation and

Strathclyde Group as these areas are underlain by peaty soils rather than a relationship with bedrock (Figures 3.10 and 3.11).

Cd, Pb and Sb

Cadmium, Pb and Sb contents in rural top and deeper soils are higher over the Coal Measures than other lithologies in the area reflecting the association of these elements with this rock type and anthropogenic pollution associated with the extraction and use of this mineral resource (Figures 3.10 and 3.11).

Ce, Hf, Y and Zr

Cerium, Hf, Y and Zr values in top and deeper soils are lower over the Devonian Sandstones and Strathclyde Group than other rock types as these elements are more commonly concentrated by clay minerals or in resistate minerals that are not significant components of these particular sandstones (Figures 3.10 and 3.11).

Co

Cobalt contents are lower in soils developed over the Devonian Sandstones but values are higher over the Clyde Plateau Volcanic Formation. The higher values over the volcanics reflect expected geological associations with this rock type and the presence of Mn-oxides in the upland peaty areas formed by this Formation (BGS, 1993). Concentrations in soils developed over the other rock types in the Glasgow area are rather similar (Figures 3.10 and 3.11).

Cr

Chromium contents are also lower in soils over the Devonian Sandstones and higher over the Clyde Plateau Volcanic Formation. Again, the higher values over the volcanics reflect expected geological associations (BGS, 1993). Concentrations in soils developed over the other rock types in the Glasgow area are similar (Figures 3.10 and 3.11). However, it should be noted that Cr shows a broad range of high values in urban soils developed over the Coal Measures. Since these urban soils lie in the former industrial heartland of east Glasgow, comparison of the urban versus rural geochemical signatures gives a good indication of the degree of anthropogenic pollution from metal processing and other industrial activities.

Cs

Caesium contents in rural top soils are higher over the Devonian than other rock types. However, this relationship is not evident in the deeper soils indicating the probable influence of atmospheric deposition on top soil geochemistry rather than a geological association. Indeed, Cs is higher in rural than urban top soils over all lithologies (Figures 3.10 and 3.11). In deeper soils, urban and rural concentrations are similar over the Coal Measures, Limestone Coal Formation and Lower and Upper Limestone Formations and urban values exceed those of the rural environment over the Devonian.

Ga

Gallium contents are lower in soils developed over the Devonian Sandstones relative to other rock types in the Glasgow area but values are higher over the Clyde Plateau Volcanic Formation. The higher values over this formation reflect expected geological associations (BGS, 1993).

Concentrations in soils developed over the other rock types in the Glasgow area are rather similar (Figures 3.10 and 3.11). Values in urban soils over the Strathclyde Group and Devonian Sandstones are higher than in rural soils developed over these rock types, which may reflect anthropogenic pollution.

Ge and U

Germanium and U soil concentrations are lower over the Devonian and higher over the Coal Measures and Limestone Coal Formation relative to other lithologies, which may reflect the association of these elements with shales.

I

The distribution of I in soils closely follows that of the organic matter content and in top soils is higher in rural than urban soils over all rock types (Figure 3.10). Iodine is also higher in rural than urban deeper soils over the Clyde Plateau Volcanics (Figure 3.11). Concentrations in top and deeper soils over the Coal Measures show a smaller range than over the other rock types in the area. In deeper soils, urban concentrations exceed rural values over the Devonian of Dumbarton, which may reflect coal waste/ash in soils in the urban environment.

La

Lanthanum soil contents are lower over the Devonian Sandstones but higher over the Coal Measures and Limestone Coal Formation relative to other lithologies, which may reflect the association of La with shales. Lanthanum top soil concentrations are similar between rural and urban environments over all parent material types with the exception of lower rural values over the Clyde Plateau Volcanic Formation. In contrast, rural deeper soil contents are higher than urban soils over the Limestone Coal Formation (Figures 3.10 and 3.11). Urban values are higher than rural contents in deeper soils developed over the Devonian reflecting the low natural abundance of the element in these rural soils.

Mo

Concentrations of Mo in top and deeper soils are lower over the Devonian Sandstone relative to other rock types in the Glasgow area. Molybdenum shows a broader range in concentration over the Limestone Coal Formation than other rock types, which may reflect the association of the element with coals and shales.

Nb

Niobium contents are also lower in soils developed over the Devonian Sandstones but values are higher over the Clyde Plateau Volcanic Formation. The higher values over the volcanics reflect expected geological associations with this rock type. Concentrations in soils developed over the other rock types in the Glasgow area are rather similar (Figures 3.10 and 3.11). Niobium is generally higher in rural than urban soils over all rock types with the exception of the Devonian.

Ni, Sc and Sr

Nickel, Sc and Sr contents are lower in soils developed over the Devonian Sandstones but are higher over the Clyde Plateau Volcanic Formation. The higher values over the volcanics reflect expected geological associations with this rock type (BGS, 1993). Concentrations in soils developed over the other rock types in the Glasgow area are similar (Figures 3.10 and 3.11).

Rb

Soil Rb values show greater ranges in concentration over the Strathclyde Group and Devonian Sandstones than over other rock types in the area (Figures 3.10 and 3.11). Values are marginally higher in soils over the Devonian and marginally lower over the Clyde Plateau Volcanic Formation. These results reflect natural geological processes with low Rb associated with the volcanic rocks (BGS, 1993). Concentrations of Rb are rather similar between rural and urban environments over the various rock types with the exception of higher urban than rural values over the Clyde Plateau Volcanics in top and deeper soils and the Devonian in top soils.

Se

Selenium contents are lower in soils developed over the Devonian Sandstones but values are higher over both the Clyde Plateau Volcanic and Limestone Coal Formations (Figures 3.10 and 3.11). In deeper soils, Se concentrations in the urban environment are greater than rural soils over all rock types with the exception of the Clyde Plateau Volcanic Formation, indicating anthropogenic pollution. In contrast, top soil Se contents are higher in rural than urban areas over the Clyde Plateau Volcanic Formation and show a broad range in composition over the Devonian. This probably reflects the dominance of peaty organic rich soils over these rock types rather than a relationship with the composition of the underlying bedrock.

Sn and Th

Tin and Th are present at lower concentrations in soils developed over the Devonian Sandstones relative to other rock types in the area. However, Sn and Th contents in top and deeper soils are higher over the Coal Measures relative to other rock types, which may represent natural associations with the coal bearing strata or the effect of anthropogenic pollution from the extraction and use of this mineral resource (Figures 3.10 and 3.11).

Ta

Tantalum contents are lower in soils developed over the Devonian Sandstones but values are higher over the Clyde Plateau Volcanic Formation, Strathclyde Group and Limestone Coal Formation. These results probably reflect geological associations of the element with volcanic rocks, shales and sandstones. However, these results should be treated with caution due to proximity to the detection limit (Figures 3.10 and 3.11).

Tl

With the exception of lower values over the Devonian Sandstones, Tl top and deeper soil values are rather similar over the other rock types present in the Glasgow area (Figures 3.10 and 3.11). Thallium shows a broader range of concentration in urban than rural soils over several rock types probably reflecting anthropogenic pollution.

V

Vanadium contents are lower in soils developed over the Devonian Sandstones but values are higher over the Clyde Plateau Volcanic Formation and Limestone Coal Formation. Rural soils contain more of the element than urban soils over these latter two rock types, which may reflect a combination of geological associations (BGS, 1993) and organic-rich soils developed over these lithologies. In contrast, V concentrations are greater in urban than rural soils over the Coal Measures, Strathclyde Group, Devonian and Lower and Upper Limestone Formations, reflecting anthropogenic influences.

W

Tungsten contents in top and deeper soils are lower over the Clyde Plateau Volcanic Formation and higher over the Coal Measures relative to other rock types reflecting natural geological associations (Figures 3.10 and 3.11). In general, values in rural soils exceed those in urban soils over all lithologies, particularly over the Coal Measures and Devonian. This may reflect the importance of atmospheric deposition, organic matter content and Mn-oxides in natural soils as a control on the distribution of the element rather than a geological relationship.

Zn

With the exception of the lower values over the Devonian Sandstones, Zn top and deeper soil values are rather similar over the other rock types present in the Glasgow area (Figures 3.10 and 3.11). Zinc shows a greater range of values in urban soils underlain by the Coal Measures, indicative of anthropogenic pollution.

LOI

LOI as a measure of organic matter content is markedly higher over rural than urban soils of the Devonian as well as the Clyde Plateau Volcanic Formation and Strathclyde Group reflecting organic rich overburden overlying these lithologies (Figures 3.10 and 3.11).

3.7.2 Superficial Deposits

3.7.2.1 GENERAL RELATIONSHIPS

Figures 3.12 and 3.13 demonstrate that several parameters are elevated in urban top and deeper soils relative to rural soils regardless of the superficial deposits over which the soils are developed. These include CaO, Co, Cu, Ge, Mo, Ni, Pb, Sb, Sn, Sr, Zn and pH, indicative of anthropogenic pollution in the urban environment.

Conversely, several parameters are higher in rural than urban top and deeper soils over all superficial deposit types including Br, Hf, I, Nb, TiO_2, U, W and LOI indicating the importance of pedogenic and geogenic processes on the distribution of these parameters in soils.

The most noticeable feature of the box and whisker plots in Figures 3.12 and 3.13 is the large number of parameters that display a broad range of concentrations in soils developed over rural peat deposits, which are discussed in more detail in Section 3.7.2.2. This in part reflects the influence of the high organic matter content of these soils on element geochemistry but is also a consequence of the diverse geochemistry of the bedrock types underlying peat in the rural environment around Glasgow (Figures 2.4 and 2.6).

3.7.2.2 PARAMETER DISTRIBUTIONS OVER VARIOUS SUPERFICIAL DEPOSIT TYPES

Al_2O_3

Although showing a broad range in concentration, Al_2O_3 values are lower over rural peat deposits than other superficial types in the area. The element is commonly associated with the mineral rather than the organic phase in soils; hence is lower over peat deposits than the other superficial drift types. Aluminium values in top and deeper soils are also lower over glaciofluvial sand and gravel deposits as expected as these tend to contain coarser material rather than the clays with which Al_2O_3 is often associated in soils. Soil Al_2O_3 concentrations are similar between rural and urban environments over all superficial deposit types with the exception of higher rural values over alluvial deposits (Figures 3.12 and 3.13).

CaO and P_2O_5

Concentrations of CaO and P_2O_5 in rural soils show broad ranges in concentration over peat whereas contents in rural soils over other superficial deposit types are similar (Figures 3.12 and 3.13). These results reflect the diverse geochemistry of the bedrock types underlying the peat in the rural environment around Glasgow, which range from volcanic rocks to marine sediments (Figures 2.4 and 2.6). Calcium concentrations are higher in urban than rural soils regardless of drift deposit type, indicating anthropogenic pollution.

Fe_2O_3, MgO, TiO_2, Nb and Ta

Several parameters, although showing a broad range in concentration, demonstrate lower values over rural peat deposits. These include Fe_2O_3, MgO, TiO_2, Nb and Ta (in deeper soils only) (Figures 3.12 and 3.13). Again, these elements are commonly associated with the mineral rather than the organic phases in soils; hence are lower over peat deposits than the other superficial drift types. Concentrations of these elements are higher in top and deeper soils over areas of no drift than other superficial types in the area. In rural environments this probably reflects the underlying Clyde Plateau Volcanic Formation geology in these particular locations (Figures 2.4 and 2.6). In urban environments results for areas of no drift should be treated with caution as several of these locations correspond to areas of made ground (Figures 2.6 and 2.7); hence soil concentrations may be elevated as a consequence of anthropogenic pollution.

K_2O and Rb

Potassium and Rb rural soil contents are also lower over peat due to the lesser mineral content of these superficial deposits (Figures 3.12 and 3.13). Potassium and Rb values are rather similar in rural and urban environments over the other superficial deposit types with the exception of higher rural concentrations over raised beach and marine deposits. This may reflect a greater feldspathic content in these deposits.

MnO

Manganese demonstrates large concentration ranges in top and deeper soils developed over peat reflecting the diverse bedrock underlying these deposits and secondary sorbtion-precipitation mechanisms in these peaty acid environments. Manganese values in top and deeper soils are lower over raised beach and marine deposits than the other drift types probably indicative of lesser clay and Mn-oxide content of these deposits (Figures 3.12 and 3.13).

Na_2O

Sodium soil contents are lower over peat due to the lower mineral content of these superficial deposits (Figures 3.12 and 3.13). Concentrations are marginally lower over till and morainic deposits than other superficial deposit types in the area. This may reflect the fact that till/moraine cover is less extensive over the Na_2O-rich Clyde Plateau Volcanic Formation than other rock types in the area (Figures 2.4 and 2.6).

SiO_2

Top and deeper soil SiO_2 values are higher over glaciofluvial sands and gravels reflecting the greater content of coarser siliciclastic materials such as quartz in these deposits. Concentrations in top and deeper soils developed over peat and areas of no drift are lower. In the case of the former, this reflects the lower mineral content of the peaty soils and in the case of the latter probably reflects the underlying SiO_2-poor Clyde Plateau Volcanic bedrock that predominates in these locations in rural soils (Figures 2.4 and 2.6). Values in rural soils generally exceed those in urban soils (Figures 3.12 and 3.13).

As, Bi, Cs, Cu, Mo, Ni, Pb, U and W

Arsenic, Bi, Cs, Cu, Mo, Ni, Pb, U and W show very broad ranges in composition in rural top and deeper soils over peat and, with the exception of Bi and Cs in deeper soils, are higher over raised beach and marine deposits than over other superficial deposit types (Figures 3.12 and 3.13). The higher organic matter content of the peat and of soils developed on the raised beach and marine deposits to the west of Glasgow, almost certainly influences the distribution of these elements, which may be present in the environment as a result of atmospheric deposition. However, the broad ranges of concentration over rural peat deposits also reflect the diverse geochemistry of the bedrock types underlying peat in the rural environment around Glasgow (Figures 2.4 and 2.6). The raised beach and marine deposits mainly overlie the Clyde Plateau Volcanic Formation and Limestone Coal Group in rural areas, which may account for the higher concentrations of these elements over this drift type. Anthropogenic pollution in the peri-urban environment may also influence soil element concentrations over these deposits. In deeper soils, urban Bi values exceed rural concentrations over most drift types, indicative of anthropogenic pollution.

Ba

Barium also shows broad ranges in concentrations in top and deeper soils developed over rural peat reflecting the diverse bedrock underlying these superficial deposit types (Figures 2.4 and 2.6). Concentrations of Ba are marginally higher in soils over alluvium, which may reflect natural processes or the presence of made ground on the banks of the River Clyde where the majority of alluvial deposits are located in the study area (Figures 2.6 and 2.7). Soil Ba is also higher over raised beach and marine deposits and than other superficial deposit types (Figures 3.12 and 3.13).

Br, Co, I and LOI

Bromine, Co, I and LOI values are markedly higher in rural top and deeper soils developed over peat deposits and areas of no drift reflecting the high organic matter content of soils in these areas as expected. Areas of no drift tend to occur in the moorland areas to the north, west and south of Glasgow; hence the higher organic matter in these soils (Figure 2.6). Cobalt shows similar relationships; however, in this case, the higher values over areas of no drift probably also reflect the underlying geology as the majority of these locations occur over the Clyde Plateau Volcanic Formation (Figure 2.4).

Cd, Ce, Ge, Se and Tl

With the exception of broad ranges in composition in soils developed over rural peat deposits, concentrations of Cd, Ce, Ge and Tl are rather similar between rural and urban environments in soils over the other drift types in the area (Figures 3.12 and 3.13). Selenium shows a similar distribution but values in urban soils are higher than in rural soils over raised beach and marine deposits, indicating anthropogenic pollution. The broad range in concentrations over rural peat deposits are a consequence of the greater organic matter content of these soils and diversity of bedrock underlying these deposits (Figures 2.4 and 2.6).

Cr

Chromium shows the broadest range in concentration in soils over rural peat deposits, again reflecting the diverse nature of the bedrock underlying this drift type (Figures 3.12 and 3.13). In urban environments, top and deeper soils also show higher ranges of Cr over peat deposits. However, these results should be treated with caution as there is only one area of peat cover within the urban environment, in the Cathcart region of the city (Figures 2.2 and 2.6). Three samples only were collected over this superficial deposit type. The area of peat corresponds to a major railway junction and anthropogenic pollution, rather than the presence of peat, probably accounts for the high values over these urban deposits. Concentrations over the other superficial deposit types in the area are rather similar.

Ga, La and Sc

In contrast to the broad ranges of Ga, La and Sc soil values reported over peat, concentrations of these elements are lower in top and deeper soils developed over glaciofluvial sands and gravels as expected as these deposit types tend to have a lesser clay content and may also contain less heavy or resistate mineral phases than other drift types (Figures 3.12 and 3.13). Lanthanum is also lower in soils over areas of no drift probably due to the underlying volcanic bedrock in these locations.

Hf, Th, Y, Zr and pH

Several other parameters although showing broad ranges in concentrations, demonstrate lower values over rural peat deposits than other superficial types in the area. These include Hf, Th, Y, Zr and pH. The elements are commonly associated with the mineral rather than the organic phases in soils; hence are lower over peat deposits than the other drift types. Soil pH is also lower in these soils due to the presence of humic and other organic acids. Soil Th values are lower over glaciofluvial sand and gravel deposits probably reflecting the lower clay content of these deposits. Thorium and Y soil contents are also lower in areas of no drift cover, which may reflect the predominance of organic-rich soils and Clyde Plateau Volcanic Formation bedrock in these areas.

Sb and Sn

Antimony and Sn show broadest ranges in composition in rural top and deeper soils over peat and are marginally higher in soils developed over raised beach and marine deposits than over other drift types (Figures 3.12 and 3.13). The higher organic matter content of the peat and of soils developed over the raised beach and marine deposits to the west of Glasgow almost certainly influences the distribution of these elements, which can be associated with organic matter in soils and may be present in the environment as a result of atmospheric deposition. Anthropogenic pollution in the peri-urban environment probably also influence these results. In urban deeper soils, Sb and Sn also show broad ranges of concentrations over peat deposits. However, these results should be treated with caution as there is only one area of peat cover within the urban environment, from which only three samples were collected. The peat lies within the Cathcart region of the city in an area that corresponds to a major railway junction (Figures 2.2 and 2.6). Therefore, anthropogenic pollution, rather than the presence of peat, probably accounts for the high values of these elements over these urban deposits.

Sr and Zn

Strontium and Zn show broad ranges in composition over rural peat deposits reflecting the diversity of bedrock underlying these deposits and, in the case of Zn, the greater organic matter content of these soils (Figures 2.4 and 2.6). Values in urban soils are higher than in rural soils over all superficial deposit types, indicating anthropogenic pollution (Figures 3.12 and 3.13).

V

Vanadium concentrations are higher in top and deeper rural soils developed over peat, raised beach and marine deposits and areas of no drift (Figures 3.12 and 3.13). This probably reflects the organic-rich nature of these soils, which tend to occur in the moorland areas to the south, west and north of Glasgow and the predominance of volcanic bedrock underlying these superficial deposit types and areas of no drift.

In summary, the relationships with the solid geology and superficial deposits demonstrate the influence that the underlying substrate has on the geochemistry of Glasgow urban and rural soils. Many elements are lower in concentration in soils developed over Devonian Sandstones in both rural and urban environments as a result of natural geological compositions. Similarly many elements associated with lavas are higher in soils over the Clyde Plateau Volcanic Formation in both rural and urban environments. Superficial peat deposits also have an effect on the geochemistry of many soils due to the importance of organic matter on the distribution of many elements in the environment.

Imprinted over this natural geological variability is the impact of anthropogenic pollution and the majority of elements are elevated in the urban versus the rural environment over all the rock and superficial deposit types present in the area. Therefore, as outlined in Section 1.3 of this report, the geochemical baseline in Glasgow urban soils is the result of complex interactions between the geological background and anthropogenic pollution.

Evidence from the present study suggests that with the exception of peat deposits, underlying bedrock has a greater influence on the background geochemistry of the soils in the Glasgow area than the superficial deposits but urban anthropogenic pollution is the dominant control on the distribution of most elements in the city environment. Relationships with anthropogenic influences are examined in more detail in the following two sections of this report in terms of made ground and land use.

3.8 COMPARISONS WITH MADE GROUND

In order to examine the relationships between made ground and soil geochemistry, parameter ranges collected over made ground versus non made ground are compared in Figures 3.14 and 3.15 for top and deeper soils respectively. It should also be noted that the majority of made ground occurs in the urban as opposed to the rural environment (Figure 2.7).

Several parameters with a strong geological control on their distribution show similar concentration ranges in top and deeper soils collected over made ground and non made ground, including Al_2O_3, Fe_2O_3, MnO, Na_2O, SiO_2, Ga, La, Ta, Tl, U, V and LOI. Bismuth shows a similar distribution in top soils but in deeper soils, Bi is higher over made ground, indicative of anthropogenic pollution (Figures 3.14 and 3.15).

Similarly, several elements with a strong geological or natural soil forming process control on their distribution are higher in top and deeper soils over areas of non made ground than areas of made ground. These include TiO_2, Br, Cs, Hf, I, Nb and Zr. In the case of Br, Cs and I this probably reflects the greater organic matter content and influence of upland soils developed over non made ground. Phosphorus shows a similar pattern and this may reflect greater fertiliser use in soils developed in non made ground areas, or the dominance of the Clyde Plateau Volcanic Formation bedrock in non made ground areas (Figures 2.4 and 2.7).

The majority of parameters are higher in top and deeper soils over areas of made ground than non made ground reflecting the influence of anthropogenic pollution and the nature of made ground materials. Higher concentrations of K_2O, Ce, Rb, Sc, Th and Y in made ground soils may indicate the presence of clays or ceramic materials in the fill. Higher CaO, MgO, Ba, Sr and pH over made ground probably reflect the nature of fill materials, which tend to contain a lot of concrete and building materials, furnace slag and coal waste all of which are calcareous. Indeed concentrations of CaO are markedly higher over made ground than non made ground indicative of the presence of fill materials. Higher Ag, As, Cd, Co, Cr, Cu, Ge, Mo, Ni, Sb, Se, Sn, W and Zn in made ground soils are highly indicative of gross and diffuse metal pollution associated with this land type.

3.9 COMPARISONS WITH LAND USE

Information on the land use of each of the sampling sites was recorded at the time of collection (Figure 2.3). The relationships between soil geochemistry and land use are presented in Figures 3.16 and 3.17.

Al_2O_3, Na_2O, La, Nb, Sc, Se, Tl, V and Zr

Several elements with a strong geological control on their distribution show similar ranges in concentration in top and deeper soils over all land use types. These are Al_2O_3, Na_2O, La, Nb, Sc, Se, Tl, V and Zr. Niobium shows a broader range in concentration in agricultural soils reflecting the diversity of rock types and presence of volcanic rocks in particular, in the rural hinterland surrounding Glasgow.

CaO, Ag, As, Ba, Cd, Ce, Co, Cr, Cu, Ge, Mo, Ni, Pb, Sb, Sn, Sr, Th, Y, Zn and pH

Several parameters are lower in agricultural top and deeper soils than the other land uses that predominate in the urban environment. These are CaO, Ag, As, Ba, Cd, Ce, Co, Cr, Cu, Ge, Mo, Ni, Pb, Sb, Sn, Sr, Th, Y, Zn and pH. Of these, Ba and Sr are higher over derelict land as are CaO and pH, which are also higher over industrial and commercial land but lower over parkland. These results are indicative of the presence of calcareous building rubble, coal waste and other such materials in industrial and derelict areas. Cerium, Co and Cr are also higher over industrial land and Ag over derelict land indicating anthropogenic pollution.

Indeed, several of the metal elements As, Cd, Cu, Mo, Ni, Sb, Sn and Zn are higher over derelict and industrial land and, in deeper soils only, over commercial land as well. Interestingly, As, Cu, Ge, Sb, Sn and Zn are also marginally enhanced in residential garden soils relative to other land use types and this may reflect the historic dumping and use as a soil conditioner of domestic coal ash and the presence of household debris such as fragments of glass, ceramics, bricks and paint in domestic garden soils. Germanium is also higher in park and recreational soils relative to other land use types.

Lead ranges over the different land use types are also interesting. In top soils, values are higher in residential gardens, parkland and derelict land and show a broad concentration range over industrial land. In deeper soils values are higher in commercial and derelict land and show a broad range over schools and playgrounds. The higher values in garden soils and in the proximity of schools may reflect anthropogenic pollution from the former use of lead-based paints and lead piping whereas higher values over derelict land may be associated with former industrial processes. It is notable that road networks show little enhancement of Pb relative to the other land use types despite the widespread use of leaded petrol in the UK for several decades. Indeed no enhancement of other elements associated with traffic pollution such as Ba and Zn is evident from the results of the present study. This suggests that although the G-BASE sampling methodology has successfully identified traffic pollution in Richmond-upon-Thames in earlier studies (Kelly et al., 1996); it is not as diagnostic as roadside depositional sediments, which are more commonly used in traffic pollution studies.

Fe_2O_3, MnO and Ga

Iron, MnO and Ga show broadest ranges in concentration in agricultural soils as a result of the diversity of bedrock underlying rural areas around Glasgow, but are elevated over industrial land uses relative to other types due to anthropogenic pollution.

K_2O and MgO

Similarly, K_2O and MgO have broadest concentration ranges in agricultural soils reflecting the influence of volcanic bedrock, but are higher over industrial and derelict land probably indicating the presence of building materials, fill and rubble.

P_2O_5, SiO_2, TiO_2, Bi, Br, Cs, Hf, I, U and LOI

Several parameters with a strong geological or soil forming process control on their distributions are higher in top and deeper soils from agricultural areas than other land use types. These are P_2O_5, SiO_2, TiO_2, Bi, Br, Cs, Hf, I, U and LOI. Phosphorus is also higher in residential gardens reflecting greater fertiliser use in agricultural and domestic soils.

Bismuth concentrations in top soils are higher in agricultural areas and lower over commercial land uses. However, values in deeper soils are lower in agricultural soils and higher over industrial land uses probably as a result of anthropogenic pollution in the urban environment.

Loss on ignition (as a measure of organic matter content) is also higher in parkland soils reflecting more natural conditions in these relatively undisturbed urban soils. As a result, Br and I concentrations, which are strongly associated with organic matter in soils, are also marginally higher over parkland and in residential areas where again many grassy open spaces sampled during the present project represent relatively undisturbed soils. Similarly, Cs values show a broad range in agricultural and parkland soils reflecting soil organic matter content. Loss on ignition values in deeper soils show a broad range over derelict land and industrial soils probably reflecting a variety of fill materials.

Rb, Ta and W

Rubidium and W are also marginally elevated over industrial land uses, whereas Ta concentrations are lower over derelict land and residential gardens than the other land use types (Figures 3.16 and 3.17).

The ranges in concentration of top soil Cr, Cu, Ni and Pb collected from parks and recreational areas are greater than those reported previously in Glasgow top soils by Madrid et al. (2006) based on 27 samples collected in Glasgow Green and Alexandria Park (Table 3.10). This is expected given the greater number of parkland sites surveyed during the present project (350).

Hence, some interesting relationships with land use are evident from the Glasgow soils dataset. Whether these are of interest in terms of soil quality guidelines is examined in the following section of this report.

3.10 COMPARISONS WITH SOIL QUALITY GUIDELINES

As an indictor of soil quality across Glasgow it is useful to compare parameter concentrations in the Glasgow soils dataset to soil guideline values from the UK and elsewhere.

As outlined in Section 3.5 of this report, element concentrations are often variable between top and deeper samples collected in the same location. Therefore, for all the elements under consideration, whilst there is some concurrence between concentrations exceeding the guideline values in both top and deeper soils, equally, there is disparity in some locations whereby top soils exceed the guidelines and deeper soils do not and *visa versa*. In terms of human interaction, top soils are of greater importance. However, information for deeper soils is also included in this report as future land use changes could disturb soils at depth.

3.10.1 UK CLEA Soil Guideline Values

As outlined in Chapter 1 of this report, the UK human CLEA contaminated land soil guideline values (SGVs) provide information on the concentrations of As, Cd, Cr, Ni, Pb and Se that, if exceeded in soils over various land use types, may warrant further investigation to establish whether a source-pathway-receptor linkage exists and subsequent action should be taken (EA, 2011). The SGVs are being revised at the time of completing this report; providing the first opportunity to assess the impact of the new guidelines on land quality assessments at the city-wide scale. The old and new UK SGVs applied to the Glasgow soils dataset are detailed in Tables 1.2; 3.11 and 3.12.

To provide an overview of soil quality across the city, the most protective SGVs for either allotment or residential garden land use types were applied to the whole Glasgow soils dataset for each element. The number of samples that exceed these SGVs expressed as a percentage of the total dataset for each of the elements is outlined in Tables 3.11 and 3.12 and Figure 3.18. Maps of all the locations where the current UK residential or allotment SGVs are exceeded across Glasgow in top and deeper soils are shown in Appendices 5 and 6 respectively. The locations are grouped according to the land use noted at the site to reflect land types where human interaction is more likely (Table 3.13). It was not possible to show the place names referred to in the discussion on the maps in Appendices 5 and 6. Some of these are shown in Figure 2.2 or the reader should refer to hard copy maps or a GIS.

It is useful to apply the guidelines to the whole dataset in-case land use changes in the future. However, it should be emphasised that the UK SGVs are land use specific and so do not apply to all soils across Glasgow. Therefore, relationships between soil quality and the land uses considered under the guidelines are discussed in more detail. It should be stressed that exceedence of the SGV in itself does not imply any risk to human health, simply that further investigations should be carried out.

3.10.1.1 ARSENIC

Whilst there is some evidence that As may be required for certain animal species, an essential role for the element in humans has yet to be established. Conversely at high doses, As is a human carcinogen and is one of the oldest poisons known to man. The toxicity of As depends on its chemical form. Inorganic As^{3+} is more toxic than As^{5+} whereas organic or methylated As compounds are considered to be less toxic than the inorganic compounds. However, since all these types of As can exist in nature there is no distinction between a natural or anthropogenic form of the element. Arsenic toxicity can lead to severe gastrointestinal damage and haemorrhaging, with resultant vomiting and diarrhoea; muscular cramps; cardiac abnormalities; skin lesions and skin cancer; neurological effects; lung cancer and reproductive disorders (EA, 2009a).

Five percent of top and deeper soils in Glasgow exceeded the former UK CLEA SGV of 20 mg kg^{-1} for residential gardens and allotments (Table 3.11) but only 2% exceed the current residential SGV of 32 mg kg^{-1} (Table 3.12 and Figure 3.18). The majority of these soils occur within the built environment (Appendices 5 and 6). A cluster of high values in top soils is located in Paisley associated with made ground, road and rail networks (Appendix 5). Similarly, a cluster of high values in deeper soils is associated with the former heavy railway engineering works in Royston to the north-east of the city centre (Appendix 6). Several high values occur along the north bank of the River Clyde between Whiteinch and Whitecrook and in Dumbarton probably as a result of anthropogenic pollution from ship building. However, these guidelines only apply to garden soils and of the 69 garden soils collected during the survey, only one exceeds the As SGV (Table 3.12). Seventeen top soil and 21 deeper soil samples exceed the 43 mg kg^{-1} As SGV for allotment soils but none of these samples were collected from allotments. Similarly, only one deeper soil sample in the Glasgow dataset exceeds the 640 mg kg^{-1} As SGV for commercial land. This was collected from a railway verge; not from a commercial land use where human interaction with soil is a consideration.

A BGS - Edinburgh University - Environmental Development and Education Network (EDEN)/ URS Ltd. sponsored PhD has recently been completed to assess the bioaccessibility of As, Cr and Pb in Glasgow soils. The study was based on 21 of the G-BASE top soil samples from land uses with most potential for human contact (category 1 Table 3.13) that exceeded the CLEA residential/allotment SGVs for these elements (Broadway, 2008). In the case of As, laboratory tests were carried out to determine the human As bioaccessibility in the samples simulating oral soil ingestion. Oral bioaccessible As was present in nine soil samples only and was on average only 36% of the total As concentration. Oral bioaccessible As concentrations were below the 32 mg kg^{-1} As residential garden SGV in all the samples (Broadway, 2008).

3.10.1.2 CADMIUM

Cadmium may be essential to some animals but is generally considered a toxic element and is a known human carcinogen. High intakes can cause nausea, vomiting, diarrhoea, muscle cramps, and damage to the liver, kidneys, bone and cardiovascular systems, neurotoxicity, renal failure and lung cancer if inhaled (EA, 2009b).

Cadmium concentrations exceeded the former 1 mg kg^{-1} (pH 6) UK CLEA SGV for allotments in 5% and 4% of Glasgow top and deeper soils respectively (Table 3.11) but only 2% exceed the current 1.8 mg kg^{-1} SGV for allotment soils (Table 3.12 and Figure 3.18). The majority of sites are in the urban environment indicating the influence of anthropogenic pollution (Appendices 5 and 6). A cluster of higher values occurs in the East End and Rutherglen area of the city associated with the former River Clyde industrial corridor. However, none of these samples were collected from allotments to which the guideline applies. Only one top soil and one deep soil exceed the new residential Cd SGV of 10 mg kg^{-1} and these are not garden soils. None of the soils exceed the 230 mg kg^{-1} Cd SGV for commercial land.

3.10.1.3 CHROMIUM

The health outcomes related to Cr exposure depend on the chemical form of the element. Chromium^{3+}, which is the most common form found in nature, is an essential element for human health and is involved in insulin regulation (WHO, 1996a). In contrast, Cr^{6+}, which occurs rarely in nature and is normally the product of industrial processes, is toxic and a known human carcinogen. In addition to cancer, Cr toxicity can cause growth inhibition, liver and kidney damage and dermal irritation (DEFRA-EA, 2002b).

New guideline values for Cr are awaited but Cr concentrations exceed the existing UK CLEA residential garden and allotments SGV of 130 mg kg^{-1} for 22% and 17% of top and deeper Glasgow soils respectively (Tables 3.11 and 3.12 and Figure 3.18). High concentrations are not restricted to the urban environment but extend into agricultural soils around the north, west and south of Glasgow underlain by the Clyde Plateau Volcanic Formation, which is relatively enhanced in the element. Indeed the clusters of high values in the north-west of East Kilbride and the south-west urban fringes of Johnstone may well reflect natural geological conditions rather than anthropogenic pollution. However, there is a demonstrable cluster of high values in the East End of Glasgow and in the south-east around Rutherglen that are associated with former industrial processing and the dispersal of Cr-waste in the environment (Appendices 5 and 6). Of the 69 garden soils collected during the survey, 13 top and nine deeper soils exceed the Cr SGV (Table 3.12).

Only one top and three deeper soil samples exceed the commercial land Cr SGV of 2000 mg kg^{-1} and all of these are from known Cr-waste impacted sites. However, only the top soil and two of the deeper soil samples sites are located on commercial land to which the guideline applies.

In the same Edinburgh University – BGS PhD study outlined in Section 3.10.1.1 of this report (Broadway, 2008), speciation tests demonstrated that Cr^{6+} was present in appreciable quantities in soils collected from known Cr-waste impacted sites only. Laboratory tests were carried out to determine the human bioaccessibility in the samples simulating oral soil ingestion and soil particle inhalation. The bioaccessibility of soil Cr was related to the amount of Cr^{6+} present in the samples. Oral (via soil ingestion) bioaccessible Cr was present in 10 of the samples ranging from 0.08 – 18% of the total Cr present. However, Cr^{6+} was reduced to Cr^{3+} during ingestion, which is of lesser concern in terms of human exposure. In none of the cases did the bioaccessible concentration of Cr exceed the SGV. Only two of the G-BASE soil samples underwent inhalation bioaccessibility testing (on <10 µm material) and this demonstrated that approximately 7% of Cr in the samples was inhalation-bioaccessible. One soil contained inhalation-bioaccessible Cr^{6+} amounting to 56% of the overall bioaccessible Cr in the sample (Broadway et al., 2010).

Although the number of soils exceeding the Cr SGVs is likely to decrease once the new guidelines are available, not all of the garden and commercial soils that exceed the Cr SGVs were examined in this study. Therefore, it is recommended that Cr bioaccessibility and source-pathway-receptor linkages are examined in more detail.

3.10.1.4 LEAD

Lead is a non-essential element for health and is generally considered toxic. The main concern is the association of high Pb exposure with impaired mental development and intellectual performance in children. Therefore, exposure is most critical during pregnancy and in infants (DEFRA-EA, 2002c).

New guideline values are awaited for Pb, but concentrations exceed the existing UK CLEA SGV for residential gardens and allotments of 450 mg kg^{-1} in 5% of Glasgow top and deeper soils (Tables 3.11 and 3.12 and Figure 3.18). As the maps in Appendices 5 and 6 show these soils are almost exclusively located within the urban environment indicating anthropogenic pollution. There is a clustering of high values, particularly in deeper soils, in the former industrial corridor of the River Clyde in the East End and Rutherglen areas of the city. Another cluster in top soils occurs in the West End of the city on the north back of the Clyde between the M8 and Broomhill and a further grouping on the south side of the River in the Craigton area proximal to the M8. Of the 69 garden soils sampled during the survey, five top and three deeper soils exceed the Pb SGV, as does one allotment top soil. Only 2% of soils exceed the commercial land use Pb SGV of 750 mg kg^{-1}; the majority of these are from recreational and grassy open spaces within the urban environment but two top and seven deeper soils are from commercial land uses (Table 3.12).

As part of the joint Edinburgh University – BGS PhD study outlined in Section 3.10.1.1 of this report, the oral (by ingestion) bioaccessibility of Pb in 21 of the G-BASE Glasgow top soils was determined (Broadway, 2008). Results demonstrated that 23 – 77% of Pb in the soils was bioaccessible. The oral bioaccessible Pb concentration in the soils exceeded the 450 mg kg^{-1} residential SGV in nine samples, two of which were garden soils. Lead isotope studies were also used to determine the source of Pb in the urban soils. Results revealed that the Pb was from mixed, coal, petrol and paint sources. Oral bioaccessible Pb was closely related to the total Pb content in the soil rather than to the source of Pb. However, Pb from petrol was marginally more bioaccessible than Pb from other sources (Farmer et al., 2011).

Not all of the garden and commercial soils that exceed the Pb SGVs were examined in this study. Therefore, it is recommended that Pb bioaccessibility and source-pathway-receptor linkages are examined in more detail in the Glasgow soils.

3.10.1.5 NICKEL

Although Ni is readily taken up by vegetation and is essential for plant metabolism, there is still some debate as to whether it is an essential element for human health. Conversely, Ni is a known human toxin. Inhalation of the element can lead to chronic bronchitis, emphysema, asthma and lung cancer whereas ingestion has been associated with reduced body weight and reproductive disorders. Dermal exposure can cause allergic contact dermatitis (EA, 2009c).

In Glasgow, Ni concentrations exceeded the former 50 mg kg^{-1} UK CLEA SGV for residential gardens and allotments in 40% and 42% of top and deeper soils respectively (Table 3.11). Whilst Ni has been shown to be higher in Glasgow soils than other UK cities as a result of the coal and volcanic bedrock and history of metal processing in the area (see Section 3.4.5 of this report); the high proportion of soils exceeding the former SGV reflects the fact that the old guideline was low relative to the natural abundance of the element.

In contrast, only 2% of top soils and 4% of deeper soils exceed the revised residential SGV of 130 mg kg^{-1} (EA, 2009d) highlighting the significant impact of the revised SGVs on soil quality assessments across the Glasgow conurbation (Tables 3.11 and 3.12 and Figure 3.18). The majority of samples exceeding the guidelines are located within the urban environment, with a cluster of high values in the former industrial heartland of the East End of Glasgow and Rutherglen and the shipbuilding corridor of the north bank of the River Clyde (Appendices 5 and 6). However, a few high values in rural deeper soils around Johnstone and Dumbarton may reflect volcanic bedrock in these areas (Appendix 6). Of the 69 garden soils collected during the survey, only two and four top and deeper soils respectively exceed the new Ni SGV. Less than 1% of soils in Glasgow exceed the Ni allotment SGV of 230 mg kg^{-1} and none of these were collected from allotments (Table 3.12). None of the soils exceed the commercial Ni SGV of 1800 mg kg^{-1}.

3.10.1.6 SELENIUM

Selenium is an essential element for human and animal health involved in a number of key enzymes and selenoproteins in the body. Selenium deficiency has been implicated in heart disease, growth and development disorders, cancer and HIV/Aids (Fordyce, 2005; Johnson et al., 2010). Conversely, excess Se exposure can result in hair and nail loss, skin lesions, neurological disorders, convulsions and paralysis (EA, 2009d).

Selenium concentrations in soils in Glasgow do not exceed the former 35 mg kg^{-1} or the new 120 mg kg^{-1} UK CLEA allotment SGV at any location (EA, 2009d) (Tables 3.11 and 3.12 and Figure 3.18).

3.10.2 Selected International Soil Guideline Values

In addition to the CLEA list of elements, Ba, Co, Cu, Mo, Tl, Sb, Sn, U, V, Zn and pH in the Glasgow soils dataset are compared to soil guideline values from various countries (Tables 1.2 and 3.14 and Figure 3.19) to provide a general indication of soil quality. However, it must be stressed that these guidelines do not apply in the UK as these soil parameters are not considered to be of importance in terms of human exposure (EA, 2011).

3.10.2.1 ANTIMONY

Antimony concentrations exceeding the Dutch Soil Intervention Value of 22 mg kg^{-1} (VROM, 2009) are reported in 1% of top and deeper Glasgow soils all of which occur in the urban environment indicating anthropogenic pollution (Table 3.14 and Figure 3.19). Antimony is considered a non-essential element for health and is more toxic than As or Pb at high doses. Antimony^{3+} is more toxic than Sb^{5+}; however, both these forms can occur in nature so there is no distinction between a natural or anthropogenic form of the element. It is a potential human carcinogen and high intakes can cause nausea, vomiting, diarrhoea, eye disorders such as conjunctivitis, skin rashes known as antimony spots, effects on the respiratory, cardiovascular, kidney, liver, reproductive and nervous systems function (US-EPA, 2000a). The majority of high exposures occur during occupational contact and are less likely through interaction with soils; therefore, comparisons with the Dutch guidelines are included in this report for information only as human exposure to soil Sb is not considered an issue under the current UK CLEA guidelines.

3.10.2.2 BARIUM

Barium concentrations exceed the United States Environmental Protection Agency (US-EPA) 5500 mg kg^{-1} Soil Screening Level (SSL) (US-EPA, 1996) in one Glasgow top and one deeper soil (Table 3.14 and Figure 3.19). Both of these samples were collected from parks but were proximal to major roads or car parks and underlying fill material may account for the high Ba concentrations in these soils.

Barium may be essential to some organisms, although a requirement in human health has yet to be established. However, in high doses, soluble Ba compounds are toxic and as such are used as a rat poison. They can cause gastrointestinal problems, muscle weakness, high blood pressure, hypertension, cardiotoxicity and kidney failure (US-EPA, 1997). However, exposure to high doses is unlikely through contact with soils; therefore, comparisons with the US-EPA SSL are included in this report for information only as human exposure to Ba in soil is not considered an issue under the current UK CLEA guidelines.

3.10.2.3 COBALT

Cobalt concentrations above the Dutch Soil Intervention Value of 190 mg kg^{-1} (VROM, 2009) are reported in one Glasgow soil from the former Cr chemical works in the East End of Glasgow (Table 3.14 and Figure 3.19). Cobalt is an essential element for human health and is a constituent of vitamin B12. It is also used to treat anaemia as it stimulates the production of red blood cells. However, exposure to high doses of the element can lead to respiratory irritation, wheezing, asthma, decreased lung function, pneumonia, fibrosis, heart enlargement, impaired heart function, congestion of the liver, kidneys, and conjunctiva, immunological effects, nausea, vomiting, and diarrhoea (US-EPA, 2002b). However, high levels of exposure are unlikely from soils. Comparisons with the Dutch intervention guidelines are included in this report for information only as human exposure to soil Co is not considered an issue under the current UK CLEA guidelines.

3.10.2.4 COPPER

Copper concentrations above the Dutch Soil Intervention Value of 190 mg kg^{-1} (VROM, 2009) are reported in 4 and 5% of Glasgow top and deeper soils respectively (Table 3.14 and Figure 3.19). These sites are almost entirely located within the urban environment indicating the influence of anthropogenic pollution. Although sites are dispersed throughout the city, there are clusters of high values in the East End of Glasgow and along the former industrial corridor of the River Clyde.

Copper is an essential element for human health and is involved in a large number of enzymes within the body that carry out a variety of fundamental metabolic reactions including the utilisation of oxygen during cell respiration and functioning of the nervous system. Copper deficiency can lead to anaemia, neutropenia, hypopigmentation of the skin, bone and vascular abnormalities and brittle hair. Conversely, Cu poisoning causes gastric pain, vomiting, diarrhoea, jaundice, hypotension, vascular collapse, acute renal failure and liver damage (WHO, 1996a). However, exposure to high Cu doses is rare and unlikely to occur via contact with soils. Therefore, comparisons with the Dutch guidelines are included in this report for information only as human exposure to soil Cu is not considered an issue under the current UK CLEA guidelines.

3.10.2.5 MOLYBDENUM

No soil Mo concentrations exceed the 190 mg kg^{-1} Dutch intervention guideline (VROM, 2009) in the Glasgow dataset (Table 3.14 and Figure 3.19). Molybdenum is an essential element for health and is a constituent of several enzymes in mammals. Deficiency can lead to irritability, coma, tachycardia and night blindness. Excess Mo can cause gout-like symptoms including pain, swelling, inflammation and deformities of the joints and increase in the uric acid content of the blood. Molybdenum also adversely affects the homeostasis of Cu leading to excess Cu excretion (WHO, 1996a; US-EPA, 1992). However, high levels of exposure are unlikely from soils and comparisons with the Dutch guidelines are included in this report for information only as human exposure to soil Mo is not considered an issue under the current UK CLEA guidelines.

3.10.2.6 THALLIUM

Eleven top and deeper agricultural soil samples exceed the German agricultural soil maximum admissible concentration (MAC) of 1 mg kg^{-1} for Tl (Reimann and Caritat, 1998) (Table 3.14). Thallium is toxic to many plants and to animals and is used as a rat poison. Excessive human exposure is rare but can result in hair loss, nervous disorders, gastrointestinal irritation, liver and kidney damage (WHO, 1996b). Comparisons with the German agricultural MAC are included in this report for information only as there are no Tl soil quality guidelines for the UK.

3.10.2.7 TIN

Tin concentrations exceed the German agricultural soil MAC of 50 mg kg^{-1} (Reimann and Caritat, 1998) in three Glasgow top and one deeper agricultural soil. These are located on the periphery of the urban environment indicating anthropogenic pollution (Table 3.14). Tin may be an essential element for rats, but there is no evidence of a requirement for other animal species or humans. Rather the element is toxic at high doses and can cause vomiting, diarrhoea, stomach cramps, fatigue, and headache and a pneumoconiosis known as stannosis (WHO, 1980). However, high levels of exposure are unlikely from soils and comparisons with the German agricultural MAC are included in this report for information only as human exposure to soil Sn is not considered an issue under the current UK CLEA guidelines.

3.10.2.8 VANADIUM

The results demonstrate that V exceeds the US-EPA SSL of 550 mg kg^{-1} (US-EPA, 1996) in <1% of Glasgow soils (Table 3.14 and Figure 3.19). Vanadium is an essential element for health that may play a role in the regulation of Na^+/K^+ in the body and may be linked to thyroid function, growth and reproduction. However, the element is also toxic at high doses and can cause reduced growth, diarrhoea, reduced appetite, gastrointestinal disturbances and green tongue. However, toxic effects as a result of large intakes in the diet or environmental exposure are unlikely. Toxicity is usually associated with industrial exposure (WHO, 1996a). As such, comparisons with the US-EPA guidelines are included in this report for information only as human exposure to soil V is not considered an issue under the current UK CLEA guidelines.

3.10.2.9 URANIUM

No U concentrations in Glasgow agricultural soils exceed the German agricultural MAC of 5 mg kg^{-1} (Reimann and Caritat, 1998) (Table 3.14). Uranium is considered a non-essential element for health but is toxic at high doses in heavy metal terms as well as radiologically. High doses may cause inflammation of the nasal passages, lung disease and kidney damage. Some studies suggest that U may also cause lung cancer and tumours of the lymphatic and hematopoietic tissues and there is also suggestion of reproductive disorders in animal studies (US-EPA, 2000c). However, high levels of exposure are unlikely from soils and comparisons with the German agricultural MAC are included in this report for information only as there are no U soil quality guidelines for the UK.

3.10.2.10 ZINC

Zinc concentrations exceed the Dutch Soil Intervention Value of 750 mg kg^{-1} (VROM, 2009) at 2% of sites in top and deeper soils in Glasgow (Table 3.14 and Figure 3.19). These are almost exclusively located in the urban environment indicating anthropogenic pollution. Although the high values are dispersed through the built-up areas, there are concentrations of high values in the East End of Glasgow and along the former heavy industrial corridor of the River Clyde.

Zinc is an essential element for human and other animal health and is found in all body tissues. It is involved in a large number of enzymes and the stabilisation of cells and membranes as well as genetic expression and as such it is an element fundamental to life. Zinc deficiency can lead to growth retardation, reproductive disorders, dermatitis, diarrhoea, hair loss, loss of appetite, behavioural changes and suppressed immune system. In contrast, at high doses the element is toxic and can cause vomiting, diarrhoea, lethargy and interference with the metabolism of other trace elements particularly Cu (WHO, 1996a). However, high exposures from contact with soils are unlikely and comparisons with the former UK guideline value are included in this report for information only as human exposure to soil Zn is not considered an issue under the current UK CLEA guidelines.

3.10.3 Proposed UK Ecological Soil Screening Values

As outlined in Chapter 1 of this report, the UK EA and DEFRA have proposed a set of Soil Screening Values (SSVs) to help assess threats to ecosystem health from pollutants in soil (EA, 2008b). Although the framework for these guidelines is still being formulated and these guidelines only refer to nature conservation land use types; it is interesting to apply them to the whole Glasgow soils dataset as an indicator of soil quality. The SSVs are outlined in Tables 1.2 and 3.15 and the number of top and deeper soils in Glasgow exceeding the SSVs is given in Table 3.15. It should be emphasised that concentrations of a substance in soil above the SSV does not imply a threat to ecosystem health; rather that further investigations should be carried out.

Chromium, Ni and Zn exceed the proposed SSVs in top and deeper soils in 100%, 94% (top)/ 91% (deeper) and 86% (top)/ 73% (deeper) of cases respectively (Table 3.15). However, that fact that most Glasgow soils exceed the guidelines is because the SSVs for these elements are low compared to their natural abundance in soils. Therefore, most world soils would exceed these guidelines. The framework for use of the SSVs states that if it can be demonstrated that element concentrations on a site are no higher than the natural background in an area, no action need be taken (EA, 2008b). This is likely to be the case for Cr and Ni in Glasgow soils with the presence of coals and volcanic bedrock resulting in a higher natural background in the area. Lead and Cu exceed the guidelines in 30% (top)/ 24% (deeper) and 17% of soils respectively whereas only 4% (top)/ 3% (deeper) of soils exceed the Cd SSV (Table 3.15). However, only 11 soils in the case of Pb and Cu and three in the case of Cd are within nature conservation areas.

3.10.4 Summary and Future Follow-up

Application of both the old and current UK CLEA SGVs to the whole Glasgow dataset demonstrates the impact of the revised SGVs on assessments of soil quality across an urban area such as Glasgow. As Tables 3.11 and 3.12 and Figure 3.18, show in all cases the SGVs have been revised upwards resulting in far fewer soils exceeding the guidelines. The results are most significant for Ni with a decrease from 40% to 2% exceedences across the city. The fact that most Glasgow soils exceed the proposed ecological SSVs for Cr, Ni and Zn is a consequence of the low guideline values for these elements relative to their natural abundance rather than particularly poor soil quality in Glasgow compared to other places. As Tables 3.12 and 3.14 and

Figure 3.19 show, with the exception of Cr, low proportions (2 - 5%) of soils across Glasgow exceed current soil guidelines from the UK and other countries. The UK CLEA SGV for Cr is currently under revision and the number of Glasgow soils exceeding the SGV is likely to fall once the new guidelines are issued. Soil guideline values are revised periodically by national governments and regulators and are based on the best evidence of exposure risk to a given receptor available at the time. It is important that soil guideline values are reviewed regularly and are evidence based because of their impact on assessments of soil quality and costs of further site investigation and follow-up during development. For example, from the results of the present study it can be surmised that the new higher UK Ni SGVs have resulted in a notable reduction in the number of locations earmarked for site investigation and a concordant reduction in the costs of development in Glasgow.

It is recommended that soil element concentrations that exceed the current UK CLEA SGVs for As, Cd, Cr, Ni and Pb identified during the present study be investigated further with the Local Authorities concerned to assess whether source-pathway-receptor linkages are present. Although the total concentration of PHSs in soils may exceed the SGVs, these only constitute a risk if they are mobile and available for uptake to ecosystems and humans.

The BGS is the main organisation in the UK developing laboratory tests to assess the availability of PHSs from human exposure to soils. These investigations are founded upon physiologically based extraction tests (PBET) originally developed in the United States (Ruby et al., 1996) and have been refined for use in the UK into the Unified Bioaccessibility Method (UBM) (Cave et al., 2006). These *in vitro* tests attempt to mimic conditions during soil ingestion in the human gut to give an indication of likely element uptake from eating soil, the main exposure route of concern in urban areas. The methods have been validated against animal models for As and Pb and have been optimised for Cr in conjunction with Edinburgh University (Broadway, 2008). The tests give a valuable refinement of likely human exposure risk from soils exceeding the UK CLEA SGVs so that sites of concern can be identified, and conversely, sites of no concern can be eliminated.

4 Conclusions and Recommendations

1. As a result of legislative drivers such as the UK Environmental Protection Act, it is increasingly important to understand the quality of urban environments. Concerns have grown in recent years about the distribution of potentially harmful substances (PHS) and the need for environmental protection and sustainable development, which minimise the impacts of anthropogenic pollution on key receptors such as humans, animals, ecosystems, water resources and buildings. Systematic urban soil surveys such as those carried out by the BGS G-BASE project are a useful tool to establish the city-wide urban geochemical baseline to aid the assessment of land quality for planning and development.

2. 1381 urban and 241 rural top (5-20 cm) and deeper (35-50 cm) soil samples were collected across the Glasgow conurbation for the present study. In city environments, land quality and soil geochemistry are the result of complex interactions between the natural concentrations of substances in soil, which are influenced by the geology and soil forming processes plus anthropogenic inputs and the impact of man's activities on the environment:

   Urban geochemical baseline = natural geochemical background + anthropogenic pollution

   Therefore, in this study, the geochemical background was established by sampling soils in the rural area around Glasgow in order to assess the extent of man-made pollution in the urban environment.

3. In the wider context, comparisons between over 40 median soil parameter concentrations determined in the Glasgow urban dataset and national, regional and international datasets demonstrate that Cd, Cr, Ni and Zn are elevated 2-3 times and Cu and Pb 5-7 times the national average in Scottish soils as an indication of contaminant levels in the urban environment. However, these results should be treated with caution due to the difference in analytical methods between the current G-BASE project and the national data for Scotland. Nonetheless, Pb is enhanced in Glasgow urban soils 7-fold compared to world averages indicating the influence of anthropogenic pollution. Similarly, Ag (x3.5), As, Co, Ge, Mo, P_2O_5 (x2) are all enhanced in Glasgow urban soils relative to world averages. Copper, Ni, Sb, Sn and Zn (~ x2) and Se (x3) are enriched in Glasgow urban soils relative to world averages and are higher than BGS regional geochemical median values for the Humber-Trent area of England. This may in part reflect anthropogenic pollution and in the case of As, Co, Mo, Ni, and Se the presence of coals and volcanic bedrock in the Glasgow area. Conversely, Rb concentrations are on average lower than soils from the Humber-Trent region and world averages due to dominance of alkali basalts in the Glasgow area, which are low in the element.

4. Comparisons between median values in the Glasgow dataset and other urban areas surveyed by the G-BASE project in the UK show that Cr and Ni are higher in Glasgow soils than most other cities due to the presence of volcanic and coal parent materials and the history of Cr-processing and heavy industry in Glasgow. Selenium in Glasgow soils is higher than most other urban centres which may reflect coals and peaty soils in the

Glasgow area. However, these results should be treated with caution as they may also reflect differences in analytical detection limits. In contrast, As, Cd and Pb are lower in Glasgow soils than most other urban areas

5. These general comparisons are interesting to place the Glasgow soils in context. However, of greater significance is the link between the urban environment and the immediate rural hinterland where relationships with the 'natural' environment can be established in a similar geogenic setting. This allows anthropogenic impacts in the urban environment to be assessed relative to the regional geochemical background for the area. Results in rural and urban Glasgow soils demonstrate that the underlying parent materials have a major influence on the geochemistry. Many elements such as Al_2O_3, Co, Cr, Cu, Ga, Ni, Pb, Se, Sn, Th, TiO_2, U, V and Zn are relatively lower in concentration in soils developed over Devonian sandstones present in the Dumbarton area as a result of natural geological processes including the lower clay content of these rock types. Conversely, elements held in the coarse quartz and feldspar mineral fraction which dominate these sandstones, such as K_2O, Na_2O, Rb and SiO_2, are higher over this rock type. Similarly, many elements associated with alkali basaltic lavas (for example, CaO, Cr, Fe_2O_3, MgO, Na_2O, Nb, Ni, P_2O_5, Sr, TiO_2 and V) are relatively higher in soils over the Clyde Plateau Volcanic Formation, which crops out to the north and south of the city than other rock types in the area. Superficial peat deposits also have an effect on the geochemistry of the soils due to the importance of organic matter on the distribution of many elements such as As, Br, Cd, Co, Cs, Ga, Ge, I, Mo, Pb, Sb, Se, Sn and U in the environment. In contrast, concentrations of elements associated with the mineral fraction in soils are lower over these organic-rich deposits (for example, Al_2O_3, Fe_2O_3, Hf, K_2O, MgO, SiO_2, Rb, Y and Zr). As expected, pH is also lower in these soils due to the presence of humic acids. Evidence from the present study suggests that with the exception of peat deposits, underlying bedrock has a greater influence on the background geochemistry of the soils in the Glasgow area. Relationships with superficial deposits are more difficult to determine, and this may be because much of the superficial material is locally derived.

6. Imprinted over this natural geogenic variability is the impact of anthropogenic pollution and concentrations of the majority of substances are elevated in urban versus rural soils over all the rock types present in the area. However, the fundamental geological control is still apparent. Where the geogenic background is lower such as in the Dumbarton area, the resultant combination of natural concentration and anthropogenic pollution is lower in urban soils.

7. Soil quality is also influenced by factors such as natural and anthropogenic atmospheric deposition, urban surface run-off, waste dispersal and burial of fill materials. In order to examine these impacts, the G-BASE Glasgow dataset is one of the first collected by the project to have geochemical information for the top (5 - 20 cm) and deeper (35 - 50 cm) soils sieved to the same <2 mm size fraction, allowing direct comparisons of soil chemistry down-profile. Linear regression plots and comparisons of median values between the two datasets demonstrate:

   - The majority of parameters with a strong geogenic control on their distribution in the environment show a close relationship between concentrations in rural and urban top and deeper soils collected at the same site. These include Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, SiO_2, TiO_2, Ce, Co, Ga, Nb, Rb, Sc, Sr, Th, V, Zr and pH.

Hafnium, La, Sc and U also have a strong geogenic control on their distribution and show a close but more complex relationship between concentrations in top and deeper soils reflecting soil forming processes.

- LOI as an indicator of organic matter content is higher in both urban (x1.4) and rural (x1.6) top versus deeper soils in the Glasgow area as expected. As a result, elements such as Sn (x2.3); Bi, Pb (x2.0); Cs, Ge (x1.5) and As, Cu, Se Zn (x1.3) are enhanced in rural top versus deeper soils reflecting the greater organic matter content of top soils. However, the higher values in top soils may also reflect atmospheric deposition of these elements.
- Hence, although no obvious enhancement of element concentrations is evident in the spatial distribution maps of top soils collected down-wind of the Glasgow conurbation during the present project, comparisons between top and deeper soils suggest that the rural top soils on the periphery of Glasgow may be affected by atmospheric pollution.
- Similarly, Br (x1.3 rural; x1.5 urban) and I (x2.0 rural; x 1.5 urban) are elevated in top relative to deeper soils. The main source of these elements in the environment is atmospheric deposition of marine aerosols and they are strongly associated with organic matter in soils. The results of this study demonstrate the close relationship between the westerly weather pattern, and distribution of these elements in the peaty upland soils formed over the Renfrew Hills to the southwest of Glasgow and the Kilpatrick and Campsie Hills to the north of Glasgow. Sodium is also higher in soils on the western periphery of Glasgow, which again indicate the influence of marine aerosols; however, in this case, results could also reflect the underlying Clyde Plateau Volcanic Formation bedrock.
- The distribution of Cs is also closely associated with the upland soils of the Kilpatrick and Campsie Hills to the north of Glasgow and the Renfrew Hills in the south. It is possible that the element is naturally enhanced over the Clyde Plateau Volcanic Formation. However, another significant source of the element in the UK environment is fallout from the nuclear weapons testing programme during the 1950s and 1960s and the Chernobyl accident in 1986. The main control on deposition following the accident was the rainfall pattern, which tended to be higher in upland areas. The fact that concentrations are higher in top rather than deeper soils may also indicate that the element is from an airborne depositional rather than a bedrock source. Further investigations into isotopic compositions would be required to determine the source of Cs.
- Top relative to deeper soil median values are enhanced c 1.3 times for Pb, Sb, W and Zn in urban environments. Concentrations of As, Ba, Cd, Cu, Ge, Mo, Ni, Se and Zn are also generally higher in urban top soils than urban deeper soils. Whilst this may, in part, be a consequence of the greater organic matter content of the top soils; these results also reflect atmospheric pollution, urban surface run off and waste disposal.
- In contrast, Cr concentrations are higher in deeper urban soils perhaps due to the presence of buried Cr-waste in the Glasgow area.
- Furthermore, As, Ba, Cd, Cr, Cu, Ga, Ge, Mo, Ni, Pb, Sb, Se, Sn, W, Y and Zn all show much greater variability between element concentrations in top and deeper samples collected from the same site in urban than rural environments as a result of anthropogenic pollution. Antimony and Sn values also show marked variability between top and deep soils from the same location in the rural environment as these elements are rare in nature in most environments and their presence is very often an indication of anthropogenic pollution, particularly of atmospheric deposition from smelting and other processes and gross surface anthropogenic pollution.

- This evidence of the much greater heterogeneity of urban soils has implications for the presentation of urban geochemical data. For example, care should be taken to quantify the levels of variability before attempting to interpolate data between sample points.

8. As a consequence of these complex interactions between geology, soil forming processes, atmospheric and man-made inputs, the results of the present study demonstrate that concentrations of Ba, CaO, Ce, Co, Cr, Cu, Ge, Mo, Ni, Pb, Sb, Sn, Sr, Th, Y, Zn and pH are all generally higher in urban than rural soils regardless of parent material type. Arsenic, Bi and Se are also higher in deeper urban than rural soils probably reflecting buried anthropogenic pollution. Elements that are rare in nature in most circumstances but commonly associated with anthropogenic pollution such as Pb, Sb and Sn show greatest levels of enrichment (2.6 – 3.3 times, based on median values) in the urban soils. Calcium is also enhanced significantly (x2.1, based on median values) in deeper urban than rural soils as a result of buildings, coal and industrial waste in the urban environment, which tend to be calcareous in nature and commonly used as fill materials. Indeed, high CaO, Ba, Sr and pH soils are closely associated with made ground, industrial and derelict land in the city reflecting the presence of fill materials.

9. The elements that show greatest enhancement in the Glasgow urban environment, namely CaO, Cu, Mo, Ni, Pb, Sb, Sn and Zn, are a typical indicator ‘suite’ of urban anthropogenic pollution commonly identified in studies of urban areas under the G-BASE project.

10. Conversely, as indicated above, levels of organic matter are lower in urban than rural soils and several elements that are closely associated with organic matter show the same relationship including Br, I, U and W. Concentrations of Hf, SiO_2, TiO_2 and Zr are also lower in urban than rural soils as these elements are more closely associated with the detrital mineral composition of natural soils.

11. Within the urban environment, many of the metal elements such as Ag, As, Cd, Co, Cr, Cu, Ge, Mo, Ni, Pb, Sb, Se, Sn, W and Zn are higher in soils over made ground and/or industrial and derelict land reflecting the influence of anthropogenic pollution. High concentrations of all these parameters are distributed in the East End and Rutherglen areas of the city; in the former industrial heartland, which was the focus of metal processing such as iron foundries, railway and other heavy industrial works and what was until the 1960s the world’s largest chromium ore processing plant located in Rutherglen. Cr-processing waste from this site was us as fill material throughout south and east Glasgow and this is reflected in the distribution of Cr, CaO, Fe_2O_3, Ni and other metal elements in soils. Extremely high concentrations of up to 4363 mg kg^{-1} Cr are reported in soils from the Rutherglen area. Other clusters of high values are associated with the shipbuilding corridor on the north bank of the River Clyde and the industrial and traffic impacted areas of north-west Paisley and Johnstone.

12. Interestingly, despite the fact that a significant number of the Glasgow samples were collected on road and railway verges (323) no relationship with higher Ba, Pb or Zn concentrations as indicators of traffic pollution is evident; with the exception of a cluster of higher Pb values in the city centre. The results of this study suggest that the G-BASE sampling methodology is not particularly appropriate to investigate specific

vehicular anthropogenic pollution, which is often more readily detected by sampling roadside depositional sediments.

13. Arsenic, Cu, Ge, Pb, Sb, Sn and Zn are also marginally enhanced in residential garden soils relative to some other land use types and this may reflect the historic dumping and use as a soil conditioner of domestic coal ash and the presence of household debris such as fragments of glass, ceramics, bricks and paint in domestic garden soils. Lead is also marginally higher in the vicinity of schools than other land use categories.

14. In terms of potential human exposure to urban soils, comparisons with the current UK contaminated land soil guideline values (SGV) for residential gardens or allotments for As, Cd, Cr, Ni, Pb and Se indicate that Cr is the most spatially extensive PHS in the Glasgow environment, exceeding the existing 130 mg kg^{-1} guideline at 22% of the sites surveyed. These results are due in part to the presence of naturally elevated concentrations of these elements in the Glasgow environment as a result of volcanic rocks and coals in the area. However, the results also reflect the Cr-ore processing history of Glasgow and resultant dispersal of Cr-rich waste around the city. Of the 69 garden soils sampled during the survey, 13 exceed the Cr SGV. The UK Cr SGV is currently under review and the number of sites exceeding the guideline is likely to decrease once the new SGV is available. Arsenic, Cd and Pb concentrations exceed the guideline values (32, 1.8 and 450 mg kg^{-1} respectively) at only 2-5% of sites whereas no Se concentrations above the 120 mg kg^{-1} SGV are reported. Soils exceeded the former Ni residential SGV of 50 mg kg^{-1} at 40% of sites but only 2% exceed the new 130 mg kg^{-1} SGV highlighting the impact of the new soil quality guidelines on land quality assessments in a city like Glasgow. Concentrations above the SGVs do not indicate that land is contaminated or that there is a risk to human health; rather that further investigations should be carried out. **It is recommended** that further studies are carried out with the Local Authorities concerned to determine whether source-pathway-receptor linkages are likely and the bioaccessibility of these PHSs as a further step to risk assessment.

15. The Glasgow soils geochemical survey was carried out within the wider context of the BGS Clyde Urban Super-Project and it is anticipated that further interpretation and use of the data, will be carried out particularly to investigate:
    (i) the risk to groundwater resources from surface contaminants
    (ii) the relationships between soil quality and land use to aid urban planning and contaminated land assessments
    (iii) contaminant inputs to the River Clyde, in conjunction with data generated from the Clyde Tributaries and Clyde Estuary Geochemical Survey projects, both co-funded with Glasgow City Council.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

APPLETON, JD. 1995. *Potentially Harmful Elements from Natural Sources and Mining Areas: Characteristics, Extent and Relevance to Planning and Development in Great Britain.* Technical Report WP/95/3. (Keyworth: British Geological Survey)

BRIDGE, DM, BROWN, MJ AND HOOKER, PJ. 1997. *Wolverhampton Urban Environmental Survey: An Integrated Geoscientific Case Study.* Technical Report WE/95/49. (Keyworth: British Geological Survey)

BGS. 1993. *Regional Geochemistry of Southern Scotland and Part of Northern England.* (Keyworth: British Geological Survey).

BGS. 2009. *Geochemical Baseline Survey of the Environment Project,* http://www.bgs.ac.uk/gbase. Access Date: December 2009.

BROADWAY, A. 2008. *Development of Methodologies for Determination of the Human Bioaccessibility of Chromium and Other Elements in Glasgow Soil.* PhD Thesis. University of Edinburgh

BROADWAY, A, CAVE, MR, WRAGG, J, FORDYCE, FM, BEWLEY, RJF, GRAHAM, MC, NGWENYA, BT AND FARMER, JG. 2010. Determination of the bioaccessibility of chromium in Glasgow soil and the implications for human health risk assessment. *Science of the Total Environment*, Vol. 409(2), 267-277.

BROWN, MJ AND MARCHANT, A. 2000. Providing GIS solutions for Local Authorities. *Earthwise,* Vol. 16, 22-23.

BROWNE, MAE, FORSYTH, IH AND MCMILLAN, AA. 1986. Glasgow, a case study in urban geology. *Journal of the Geological Society of London,* Vol. 143, 509-520.

CAVE, M, WRAGG, J, KLINCK, B, GRON, C, OOMEN, A, VAN DE WIELE, T, OLLSON, C, KOCH, I, REIMER, K, BASTA, N AND TACK, K. 2006. Preliminary assessment of a unified bioaccessibility method for potentially harmful elements in soils. *Epidemiology*, Vol. 17(6), S39-S39.

DAVIES, BE. 1995. Lead. In: ALLOWAY, BJ. (editor). *Heavy Metals in Soils*. (London: Blackie Academic & Professional) 206-223.

D'Arcy, BJ, Ellis, JB, Ferrier, RC, Jenkins, A and Dils, R. (eds). 2001. *Diffuse Pollution Impacts*. (Lavenham, Surrey: CIWEM, Terence Dalton Publishers)

DEFRA-EA. 2002a. *Priority Contaminants for the Assessment of Land*. R& D Report CLR 8. (Bristol: Environment Agency)

DEFRA-EA. 2002b. *Soil Guideline Values for Chromium Anthropogenic Contamination*. R & D Report SGV 4. (Bristol: Environment Agency)

DEFRA-EA. 2002c. *Soil Guideline Values for Lead Anthropogenic Contamination*. R & D Report SGV 10. (Bristol: Environment Agency)

DOE. 1996-1997. *Industry Profiles*. Reports for 47 different industrial activities. Department of the Environment (London: HMSO)

EA. 2008a. *Contaminated Land Exposure Assessment Soil Guideline Values,* Environment Agency. http://www.environment-agency.gov.uk/research/planning/33714.aspx

EA. 2008b. *Guidance on the Use of Soil Screening Values in Ecological Risk Assessment*. Science Report SC070009/SR2b. (Bristol: Environment Agency)

EA. 2009a. *Soil Guideline Values for Arsenic in Soil*. Science Report SC050021/Arsenic SGV. (Bristol: Environment Agency)

EA. 2009b. *Soil Guideline Values for Cadmium in Soil*. Science Report SC050021/Cadmium SGV. (Bristol: Environment Agency)

EA. 2009c. *Soil Guideline Values for Nickel in Soil*. Science Report SC050021/Nickel SGV. (Bristol: Environment Agency)

EA. 2009d. *Soil Guideline Values for Selenium in Soil*. Science Report SC050021/Selenium SGV. (Bristol: Environment Agency)

EA. 2011. *Contaminated Land Exposure Assessment Soil Guideline Values*, Environment Agency, http://www.environment-agency.gov.uk/research/planning/33714.aspx. Access Date: November 2011.

Eades, LJ, Farmer, JG, MacKenzie, AB, Kirika, A and Bailey-Watts AE. 1998. High-resolution profile of radiocaesium deposition in Loch Lomond sediments. *Journal of Environmental Radioactivity*, Vol. 39(2), 107-115.

ELLISON, RA, ARRICK, A, STRANGE, PJ AND HENNESSEY, C. 1998. *Earth Science Information in Support of Major Development Initiatives.* Technical Report WA/97/84. (Keyworth: British Geological Survey)

ELLISON, RA, HOUGH, E AND KESSLER, H. 2002. Applied geological maps: presenting earth science information for planning and development. *Earthwise,* Vol. 18, 4-5.

ENVIRONMENTAL PROTECTION ACT PART IIA. 1990. *Contaminated Land* (London: HSMO)

FARAGO, ME, KAVANAGH, P, BLANKS, R, KELLY, J, KAZANTIS, G, THORNTON, I, SIMPSON, PR, COOK, JM, PARRY, S AND HALL, GEM. 1996. Platinum metal concentrations in urban road dust and soil in the United Kingdom. Fresenius *Journal of Analytical Chemistry,* Vol. 354(5-6), 660-663.

FARMER, JG, BROADWAY, A, CAVE, MR, WRAGG, J, FORDYCE, FM, GRAHAM, MC, NGWENYA, BT AND BEWLEY, RJF. 2011. A lead isotopic study of the human bioaccessibility of lead in urban soils from Glasgow, Scotland. *Science of the Total Environment*, Vol. 409(23), 4958–4965.

FERGUSSON, JE. 1990. *The Heavy Metals: Chemistry, Environmental Impacts and Health Effects.* (Oxford: Pergamon Press)

FORDYCE, FM AND ANDER, EL. 2003. *Urban Soils Geochemistry and GIS-aided Interpretation – A Case Study from Stoke-on-Trent.* Research Report IR/01/35/R. (Keyworth: British Geological Survey)

FORDYCE F M. 2005. Chapter 15: Selenium Deficiency and Toxicity in the Environment. In: SELINUS, O. (editor). *Essentials of Medical Geology.* (Amsterdam: Elsevier) 373-415.

FORDYCE, FM, BROWN, SE, ANDER, EL, RAWLINS, BG, O'DONNELL, KE, LISTER, TR, BREWARD, N AND JOHNSON, CC. 2005. GSUE: Urban geochemical mapping in Great Britain. *Geochemistry: Exploration, Environment, Analysis,* Vol. 5 (4) 325-336.

FORSYTH, IH, MCMILLAN, AA, BROWNE, MAE AND BALL, DF. 1984a. *Account Accompanying Environmental Geology Maps of Glasgow (National Grid Sheet NS66).* Central Scotland Research Programme Technical Report WA/LS/84/2 (Edinburgh: British Geological Survey).

FORSYTH, IH, MCMILLAN, AA, BROWNE, MAE AND BALL, DF. 1984b. *Account Accompanying Environmental Geology Maps of Glasgow (National Grid Sheet NS56).* Central Scotland Research Programme Technical Report WA/LS/84/3 (Edinburgh: British Geological Survey)

FORSYTH, IH, PATERSON, IB, AND HALL, IHS. 1984c. *Account Accompanying Environmental Geology Maps of Glasgow Phase 2 Parts of National Grid Sheets NS 55, 57 and 65.* Central Scotland Research Programme Technical Report WA/LS/84/2 (Edinburgh: British Geological Survey)

FORSYTH, IH, PATERSON, IB, AND HALL, IHS. 1985. *Account Accompanying Environmental Geology Maps of Glasgow Phase 3 Parts of National Grid Sheets NS 55, 57 and 65.* Central Scotland Research Programme Technical Report WA/LS/85/2 (Edinburgh: British Geological Survey)

HALL, IHS, BROWNE, MAE AND FORSYTH, IH. 1998. *Geology of Glasgow District.* British Geological Survey Memoir for 1:50 000 Geological Sheet 30E (Scotland). (London: HMSO)

HARRIS, JR, AND COATS, JS. 1992. *Geochemistry Database: Data Analysis and Proposed Design.* Technical Report, WF/92/5. (Keyworth: British Geological Survey)

HOOKER, PJ, ELLISON, RA, MARCHANT, AP, SHAW, RP, LEADER, RU, NEWSHAM, R, BROWN, MJ, WARD, RS, VEITCH, N, HART, AJ AND MORRIS JL. 2000. *Some Guidance on the Use of Digital Environmental Data.* Technical Report WE/99/14. (Keyworth: British Geological Survey)

ICRCL. 1987. *Guidance on the Assessment and Redevelopment of Contaminated Land.* Interdepartmental Committee for the Redevelopment of Contaminated Land Guidance Note No. 59/83 (2nd Edition). (London: Department of the Environment)

INGHAM, MN AND VREBOS, BAR. 1994. High Productivity Geochemical XRF Analysis. *Advances in X-ray Analysis*, Vol.37, 717-724.

JOHNSON, CC. 2005. *2005 G-BASE Field Procedures Manual.* Internal Report IR/05/097. (Keyworth: British Geological Survey)

JOHNSON, CC AND ANDER EL. 2008. Urban geochemical mapping studies: how and why we do them. *Environmental Geochemistry and Health*, Vol. 30 (6), 511-540.

JOHNSON, CC, BREWARD, N, ANDER, EL AND AULT, L. 2005. G-BASE: baseline geochemical mapping of Great Britain and Northern Ireland. *Geochemistry: Exploration, Environment, Analysis*, Vol. 5. 347–357.

JOHNSON, CC, FORDYCE, FM AND RAYMAN, MP. 2010. Factors controlling the distribution of selenium in the environment and their impact on health and nutrition. *Proceedings of the Nutrition Society*, Vol. 69(1), 119-132.

KELLY, JJP. 1997. *Influence of Geology and Anthropogenic Activity on the Geochemistry of Urban Soils.* Unpublished Thesis, Imperial College Centre for Environmental Technology, London.

KELLY, JJP, THORNTON, I AND SIMPSON PR. 1996. Urban geochemistry: a study of the influence of anthropogenic activity on the heavy metal content of soils in traditionally industrial and non-industrial areas of Britain. *Applied Geochemistry*, Vol. 11, 363-370.

KOCH, GS AND LINK, RF. 1970. *Statistical Analysis of Geological Data*. (New York: John Wiley and Sons)

LISTER, TR AND JOHNSON, CC. 2005. *G-BASE Data Conditioning Procedures for Stream Sediment and Soil Chemical Analyses*. Internal Report IR/05/150. (Keyworth: British Geological Survey)

MACKENZIE, AB, FARMER, JG AND SUGDEN, CL. 1997. Isotopic evidence of the relative retention and mobility of lead and radiocaesium in Scottish ombrotrophic peats. *Science of the Total Environment*, Vol. 203(2), 115-127.

MADRID, L, DIAZ-BARRIENTOS, E, RUIZ-CORTES, E, REINOSO, R, BIASIOLI, M, DAVIDSON, CM, DUARTE, AC, GRCMAN H, HOSSACK, I, HURSTHOUSE, AS, KRALJ, T, LJUNG, K, OTABBONG, E, RODRIGUES S, URQUHART, GJ AND AJMONE-MARSAN, F. 2006. Variability in concentrations of potentially toxic elements in urban parks from six European cities. *Journal of Environmental Monitoring*, Vol. 8, 1158-1165.

MATSCHULLAT, J, OTTENSTIEN, R AND REIMANN, C. 2000. Geochemical background – can we calculate it? *Environmental Geology*, Vol. 39, 990-1000.

MCBRIDE, M B. 1994. *Environmental Chemistry of Soils* (Oxford: Oxford University Press.)

MCGRATH, SP AND LOVELAND, PJ. 1992. *Soil Geochemical Atlas of England and Wales*. (Glasgow: Blackie Academic and Professional)

MERRITT, JW AND WHITBREAD K. 2008. Combining ArcGIS maps and attributed 3D geological models to provide geoscience solutions in the urban environment: examples from the City of Glasgow and North-East England. In: COORS V, RUMOR M, FENDEL E AND ZLATANOVA S (editors). *Urban and Regional Data Management. Proceedings and Monographs in Engineering, Water and Earth Sciences.* (London: Taylor and Francis) 185-192.

MONACI, F AND BARGAGLI, R. 1997. Barium and other trace metals as indicators of vehicle emissions. *Water, Air and Soil Pollution*, Vol. 100 (1-2), 89-98.

MONACI, F, MONI, F, LANCIOTTI, E, GRECHI, D AND BARGAGLI, R. 1999. Biomonitoring of airborne metals in urban environments: new tracers of vehicle emission, in place of lead. *Environmental Pollution* Vol. 107, 321-327.

NOKIA. 2009. Nokia/Corporate Responsibility/Substance Management/ What's in a Phone. http://www.nokia.com/A4197012. Access Date: December 2009.

PATERSON, E, SANKA, M. & CLARK, L. 1996. Urban soils as pollutant sinks – a case study from Aberdeen, Scotland. *Applied Geochemistry*, Vol. 11 (1-2), 129-131.

PATERSON, E, TOWERS, W, BACON, JR, AND JONES, M. 2003. *Background Levels of Contaminants in Scottish Soils.* Scottish Environment Protection Agency Commissioned Report. (Aberdeen: MLURI)

PETKOV, P, PALICHEV, T AND DIMITROV, A. 1999. A study of the mechanism of action of antismoke additives for diesel fuels. *Oxidation Communications* Vol. 22 (2), 194-206.

PLANT, JA. 1973. A random numbering system for geochemical samples. *Transactions of the Institute of Mining and Metallurgy*, Vol. B82, 63-66.

PLANT, JA JEFFREY, K GILL, E AND FAGE C. 1975. The systematic determination of accuracy and precision in geochemical exploration data. *Journal of Geochemical Exploration*. Vol. 4 (4), 467-486.

PURVES, D AND MACKENZIE, E J. 1969. Trace element anthropogenic contamination of parklands in urban areas. *Journal of Soil Science*, Vol. 20, 288-20.

RAWLINS, BG AND O'DONNELL, KE. 2004. *Presentation of Lead and Zinc Data from Soil Geochemical Surveys of the Urban Area of Corby and Surrounding Rural Land.* Internal Report IR/04/095. (Keyworth: British Geological Survey)

RAWLINS, BG, WEBSTER, R AND LISTER, TR. 2003. The influence of parent material on top-soil geochemistry. *Earth Surface Processes and Landforms*, Vol. 28 (13), 1389-1409.

REIMANN, C AND CARITAT, P. 1998. *Chemical Elements in the Environment.* (Berlin: Springer)

ROWELL, DL. 1994. *Soil Science: Methods and Applications.* (UK: Longman Scientific and Technical)

RUBY, MV, DAVIS, A, SCHOOF, R, EBERLE, S. AND SELLSTONE, CM. 1996. Estimation of lead and arsenic bioavailability using a physiological based extraction test. *Environmental Science and Technology*, Vol. 30, 422-430.

SAS INSTITUTE INC. 1989. *SAS Language and Procedures; Usage.* (Cary, NC: SAS Institute Inc.)

SEPA. 2001. *State of the Environment Soil Quality Report.* (Stirling: Scottish Environment Protection Agency)

SNEDECOR, GW AND COCHRAN, WG. 1989. *Statistical Methods.* (Ames, IA: Iowa State University Press)

SNIFFER. 2003. *Method for Deriving Site-Specific Human Health Assessment Criteria for Contaminants in Soil*. SNIFFER Report LQ1. (Stirling: Scottish Environment Protection Agency)

TIJHUIS, L, BRATTLI, B AND SAETHER, OM. 2002. A geochemical survey of top soil in the city of Oslo, Norway. *Environmental Geochemistry and Health*, Vol. 24 (1), 67-94.

US-EPA. 1992. *Integrated Risk Information System (IRIS) Toxicological Review: Molybdenum (CASRN 7439-98-7)*. (Washington: US-EPA)

US-EPA. 1996. *Soil Screening Guidance: Technical Background Document.* US-EPA Document Number EPA/540/R-95/128. (Washington: US-EPA)

US-EPA. 1997. *Barium Compounds; Toxic Chemical Release Reporting; Community Right-to-Know*. Federal Register: January 3, 1997. Vol. 62 (2). (Washington: US-EPA).

US-EPA. 2000a. *Hazard Summary: Antimony Compounds*. (Washington: US-EPA)

US-EPA. 2000b. *Hazard Summary: Cobalt Compounds*. (Washington: US-EPA)

US-EPA. 2000c. *Hazard Summary: Radionuclides (including Radon, Radium and Uranium)*. (Washington: US-EPA)

VAN ZYL, C. 1982. Rapid preparation of robust pressed powder briquettes containing a styrene and wax mixture as a binder. *X-ray Spectrometry*, Vol. 11, 29-31.

VROM. 2009. *Circular on Target Values and Intervention Values for Soil Remediation*. (The Hague: The Ministry of Housing, Spatial Planning and Environment (VROM)).

WAKEFIELD, G, WU, XP, GARDENER M, PARK, B AND ANDERSON, S. 2008. Envirox fuel-borne catalyst: Developing and launching a nano-fuel additive. *Technology Analysis and Strategic Management*, Vol. 20 (1), 127-136.

WARD, NI. 1990. Multielement anthropogenic contamination of British motorway environments. *Science of the Total Environment*, Vol. 93, 393-441.

WHO. 1980. *Environmental Health Criteria 15: Tin and Organotin Compounds.* (Geneva: World Health Organisation)

WHO. 1996a. *Trace Elements in Human Nutrition and Health.* (Geneva: World Health Organisation).

WHO. 1996b. *Environmental Health Criteria 182: Thallium.* (Geneva: World Health Organisation)