Geochemical Mapping in Europe.

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Abstract

The Forum of European Geological Surveys (FOREGS) includes Geological Surveys from 34 European countries and is responsible for co-ordinating Geological Survey activities in Europe. The FOREGS Geochemistry Task Group was established in 1994 to supervise European geochemical mapping policy for environmental, legislative, resource-management and scientific purposes. The task group comprises representatives from five countries, charged initially with the compilation of an inventory of geochemical data within FOREGS countries. The preparation of European Geochemical Baseline maps will involve the integration of different national datasets following the recommendations of the International Geological Correlation Programme (IGCP) Project 259 "International Geochemical Mapping". Results of the inventory show that most geochemical surveys in Europe conform to the IGCP 259 recommendations. Stream sediment (26% coverage), surface water (19% coverage), soil/till (21% coverage) and radiometric data (19% coverage) are the most extensive sample types, and the majority of surveys (81%) have been carried out at sampling densities of ≤ 1 sample per 100 km^2. Most filtered-water surveys are based on a filter size of 0.45µm, and 83% of stream sediment surveys collect samples sieved at 100-200 µm. The collection of the Global Reference Network (GRN) samples recommended by IGCP 259 to provide internationally standardised geochemical data and the careful use of statistical and map-generation techniques should facilitate the levelling of different national datasets and preparation of a European Geochemical Baseline.

Keywords: Europe, international geochemical mapping standards, inventory environmental geochemical baselines

INTRODUCTION

Public concern about the environment is growing throughout the world and especially in

the industrialised countries of North America and Europe. These regions of the world, Europe in particular, have had a long history of mining, industrialisation, intensive agriculture, forestry and urbanisation, leading in some areas to contamination and/or land degradation. These problems are increasingly being extended over the rest of the world as a
result of economic growth and population pressure.

In response, national governments and international organisations such as the European Union are attempting to develop policies, legislation and infrastructure such as the European Environment Agency to deal with environmental issues, and attempts are also being made to establish ‘safe’, ‘trigger’ and ‘action’ levels of potentially harmful chemical elements and species (PHES). These measures are often based on inadequate information, as systematic chemical data are available for only 20% of the continental land area of the globe [3, 10].

Geochemical mapping began in Europe and other areas of the world 50 years ago, and for several reasons a variety of methods developed in different countries. Data are often inconsistent between and within countries, and the current situation makes comparison between datasets at an international level difficult. Systematic environmental geochemical baseline data are urgently required to inform policy-makers and provide a sound basis for environmental legislation and resource management.

A standardised World Geochemical Atlas is being prepared by the International Geochemical Mapping Programme lead by Dr A.G. Darnley of Canada and Prof J. A. Plant of the UK. During the first stage of the project entitled ‘International Geochemical Mapping’ (International Geological Correlation Programme (IGCP) Project 259), standard geochemical mapping, analysis and data management methodologies were developed for national survey organisations. In addition, the project recommended the establishment of a Global Reference Network (GRN) of 5000 sampling sites as an essential first step towards international correlation and the standardisation of present and future national geochemical surveys [3]. The current phase of the project, ‘Global Geochemical Baselines’ (IGCP Project 360) is concerned with the implementation of the IGCP 259 recommendations and the collection of GRN samples. IGCP 360 will terminate in 1997 and the project will be carried forward by an International Union of Geological Scientists (IUGS)/ International Association of Geochemistry and Cosmochemistry (IAGC) Working Group on Global Geochemical Baselines.

The Forum of European Geological Surveys (FOREGS) is an informal body of 34 Geological Survey directors and is responsible for co-ordinating geological policy on a Europe-wide basis. In 1994, the FOREGS Geochemistry Task Group was established to develop a strategy for the preparation of a European Geochemical Baseline following the recommendations of IGCP 259 and the IUGS/IAGC Working Group. The initial group was chaired by Prof J.A. Plant of the UK, and included representatives from Finland, The Netherlands, Slovakia and Spain. It was charged with compiling an inventory of geochemical data based on the results of a questionnaire completed by Geological Surveys and related organisations throughout the FOREGS community. Results of the inventory and recommendations for the preparation of European Geochemical Maps are detailed in the report of the Task Group [11]. This paper discusses the results of the inventory in relation to the recommendations of IGCP 259/360 and the IUGS/IAGC Working Group.

THE FOREGS INVENTORY

Information for inclusion in the inventory was collected using a standard form comprising nine sections, each for a particular sample type (Table 1). Detailed information on collection, preparation, analysis and data availability were requested for all sample types, with the exception of rock and biological surveys where information on availability only was required. The form was distributed to 57 Geological Survey and related organisations in FOREGS countries [11]. Mining and exploration companies and universities were generally not included because the surveys which they carry out tend to cover relatively small areas of less than 5000 km^2, the lower limit considered relevant for the purpose of the inventory. Completed forms were received from 30 of 34 countries (Fig. 1). Croatia, Iceland, Latvia and Switzerland have not conducted regional geochemical surveys over the minimum area required for the survey.

Table 1. Sample types included in the FOREGS geochemical inventory.

Form Section	Sample Type	Information Required
A	Drainage Sediment	Full survey procedure
B	Lake Sediment	Full survey procedure
C	Overbank Sediment	Full survey procedure
D	Soil and Regolith	Full survey procedure
E	Heavy Mineral	Full survey procedure
F	Surface Water	Full survey procedure
G	Rock Sample	Information available Yes/No
H	Biological Sample	Information available Yes/No
I	Radiometric	Full survey procedure

RECOMMENDATIONS FOR EUROPEAN GEOCHEMICAL MAPS

The FOREGS Geochemistry Task Group recommend that high-resolution national geochemical survey information available for many European countries should be incorporated into geochemical maps of Europe and the globe. The use of existing geochemical data will involve integrating the results of surveys based on different sample- collection, preparation and analytical methods. In order to obtain compatibility between the results of these different surveys, IGCP 259/360 recommends the collection of a Global Reference Network (GRN) of samples, using standard techniques for collection, preparation and analysis [3, 11]. The data for these samples will be directly comparable between different countries and different survey areas, and will be used to level existing national datasets. During the process of data integration, several aspects of data acquisition such as sample type, sampling density and analytical techniques will require careful consideration, and these are discussed in the following sections.

Figure 1. Countries included in the FOREGS Geochemical Inventory 1994-1996. Greenland is also included in the inventory but is not shown on the map.

SAMPLE TYPES

In Europe, as in other areas of the world, a variety of geochemical sample types have been collected by different survey organisations depending on the purpose of the survey and the physical conditions in the survey area. The sample types collected in the FOREGS region are detailed in Figure 2 and Table 2 and include stream sediments, surface waters (including shallow groundwaters), soils, till, overbank sediments, biological samples, heavy-mineral concentrates and rocks. Radiometric data are also included. Figures indicating the percentage of coverage of each sample type are based on the total area of the 34 FOREGS countries which extend to 8 417 427 km^2.

IGCP 259 recommendations for GRN collection

The IGCP 259 recommendations for GRN sample collection recognise that a variety of sample types have been collected in different regions of the world. A sampling scheme which includes the collection, where possible, of stream sediment, surface water, residual soil, overbank regolith, floodplain regolith and humus at each GRN site has been devised in order to relate different national datasets based on any one of these sample media (Fig. 3). Other sample types, such as rock and biological samples, are not included in the sampling scheme as surveys of these types generally cover areas that are too small for inclusion in regional and global scale geochemical surveys [3].

Figure 2. Area of FOREGS countries covered by each sample type. (Percentage cover of the total area of FOREGS countries is indicated at the top of each column)

Most of the sample types collected in Europe are included in the GRN scheme with the exception of rock, biological, heavy-mineral and stream organic samples. Most FOREGS countries collect more than one geochemical sample type, and only Bulgaria (area 110911 km^2 , 1% of the FOREGS region) has survey information based on rock geochemistry alone (Table 3). Significant datasets based on rock geochemistry (3% of the FOREGS region) in Cyprus, Czech Republic, Estonia, Finland, Germany, Lithuania, The Netherlands and Slovakia and on biological samples (5% of the FOREGS region) in Finland, Lithuania, Norway, Slovakia and Sweden will not be included in the preparation of European and world geochemical maps. However, these countries conduct geochemical mapping programmes based on stream sediment, soil, till or overbank samples for the same areas (Table 3). Similarly it will not be possible to incorporate datasets based on the collection of stream organic matter in Finland and Sweden (amounting to 6% of the FOREGS region) in the global and European mapping scheme but geochemical data derived from alternative sample types are available for these areas (Table 3). Heavy-mineral data are excluded from the IGCP 259 GRN mapping strategy, since samples of this type have traditionally undergone quantitative rather than qualitative analysis.

IGCP 259 recommendations for national surveys

IGCP 259 recommends the preparation of national geochemical surveys based on the collection of stream sediment, stream water, soil and radiometric data wherever possible[3]. In areas where drainage networks are poorly developed, such as the Canadian shield and Scandinavia, lake sediment or till samples should be collected in place of stream sediment samples. The IGCP 259 recommendations for national surveys relate very closely to the situation in Europe, where stream sediment surveys are by far the most extensive and have been carried out in 22 of the 34 countries covering 26% of the FOREGS region (Fig. 2, Table 2). Surface water surveys cover nearly one fifth of the FOREGS region and soils have been collected in 16 of the 34 countries (Fig. 2 and Table 2). Radiometric data are available for 19% of the FOREGS region (Table 2) but data have not been collected systematically, a situation which compares unfavourably with other regions of the world such as Australia, North America and the former Soviet Union [3].

Table 2. Sample types collected in FOREGS countries

Figure 3. Sample types required for the IGCP 259 Global Reference Network. From Darnley et al. [3].

Table 3. FOREGS geochemical datasets based on sample types excluded from the IGCP 259 GRN sampling scheme.

Country	Sample Type	Area of survey km^2	Alternative sample type for the same area
Bulgaria	Rock	110911	None
Cyprus	Rock	Unknown	Soil
Czech	Rock	78000	Stream sediment, overbank sediment, lake sediment, soil

Estonia	Rock	12000	Soil
Finland	Rock	7000	Till
Finland	Stream organic	337000	Till
Fin/Nor/Swe	Biological	250000	Stream sediment, till
Germany	Rock	34000	Stream sediment, soil
Lithuania	Rock	64000	Stream sediment, soil
Lithuania	Biological	64000	Stream sediment, soil
Netherlands	Rock	10000	Overbank sediment
Norway	Biological	68600	Stream sediment, overbank sediment
Slovakia	Rock	49104	Stream sediment, soil
Slovakia	Biological	49104	Stream sediment, soil
Sweden	Stream organic	201000	Till

In Scandinavian countries, till sampling from depths of 60-200 cm has been carried out in preference to soil sampling. The IGCP 259 report recommends the collection of C horizon soils from the deepest accessible depth and in many areas of Europe the depth of C horizon soil sampling will be similar to that of till sampling in Scandinavia. Studies by Appleton [1] and Flight et al. [4] have shown that it is possible to integrate data for approximately 50% of the elements routinely determined in stream sediments and soils using percentile-percentile plots, despite the different geochemical processes controlling element levels in the two sample media. The geochemical differences between soils and stream sediments are greater than between soil and till therefore it should be possible to integrate geochemical determinations based on till sampling and those derived from C horizon soils to obtain maps which detail element levels in deep regolith samples.

SAMPLING DENSITY

A wide range of sampling densities have been employed across the FOREGS region, reflecting different survey objectives. Stream sediment survey densities range from 1 sample per <0.5 km^2 in France, Greece, Italy, Portugal and Spain for mineral exploration to 1 sample per 2000 km^2 in Romania for rapid reconnaissance mapping (Table 4). Most surveys, however, have been carried out in the range of 1 sample per 1 km^2 to 1 sample per 5 km^2 (Table 4). Surface water surveys range from relatively high densities (< 1 sample per 2.5 km^2 in Albania, Germany and the UK) to very low densities in Finland and Romania (1 sample per 290 km^2 and 1 sample per 2000 km^2 respectively). In general, soil survey sampling densities follow similar trends to those of stream sediments ranging from 1 sample per < 1 km^2 in France and Portugal to 1 sample per 3500 km^2 in Estonia. Most soil surveys have been conducted in the range 1 sample per 5 km^2 to 1 sample per 25 km^2.

Table 4. Sampling densities employed for stream sediment, surface water and soil surveys in FOREGS countries.

IGCP 259 GRN recommendations

The IGCP 259 report [3] recommends the collection of a minimum of 5000 samples around the globe from predefined 160x160 km sampling grid squares to form a Global Reference Network (GRN) of samples. The very low sampling density (1 sample per 25600 km^2) was chosen to facilitate global coverage in a reasonable time-scale and is considerably lower resolution than surveys carried out in Europe. However, the primary purpose of the GRN samples is to provide reference materials for laboratory standardisation and data integration and not for the preparation of geochemical maps. The 5000 samples will each comprise a composite of 5 sub-samples collected from every 160x160 grid-square. The sub-samples should be collected by sub-dividing the square into 4 sub-squares of 80x80 km, one sub-sample should be collected from each subsquare and the fifth sample from any one of the 4 sub-squares chosen at random (Fig.4). The IGCP 259 report recommends that where possible the 5 sub-samples should be analysed in addition to the 1 composite sample for each 160x160 km grid square. In order to gain the greatest amount of information from the GRN samples, the 5 sub-samples will be analysed in Europe thus the GRN sampling density will be increased to 1 sample per 5120 km^2.

Figure 4. Schematic outline of drainage basin sampling pattern for the GRN. Site distribution A is preferable to B. Modified from Darnley et al. [3].

IGCP 259 recommendations for national surveys

The wide-spaced GRN samples will provide useful geochemical information in many inaccessible areas of the world where national surveys are not currently active. For most European countries, however, surveys based on much greater sampling densities are available and this data should be incorporated into European and global geochemical maps. The IGCP 259 report recommends a minimum sampling density of 1 sample per 100 km^2 for national programmes. Several stream sediment, soil and surface water surveys carried out in Estonia, Finland, Norway, Portugal, Romania, Slovenia and Sweden are based on sampling densities of greater than 1 sample per 100 km^2 (Table 5). In Estonia, Finland, Slovenia and Sweden more detailed information is available for stream sediment and soil/till samples for the same areas. However, stream sediment and soil survey programmes in Portugal (0.6% of the FOREGS region), Romania (1.4% of the FOREGS region) surface water surveys in Slovenia (0.2% of the FOREGS region) should be encouraged to provide more detailed information than is currently available if possible (Table 5).

The majority of modern geochemical maps are produced using geographical information systems (GIS) and image-generating software packages which interpolate a regular gridded surface from the randomly distributed point data [2, 7, 8]. The appearance and ‘smoothness’ of the final maps is dependant on the original sampling density, the

interpolating parameters selected and the grid-size of the generated surface. Investigations into methods of combining datasets of differing sampling densities have centred on reducing the density of high resolution surveys prior to interpolation to improve compatibility with low density sampling. Studies by Garrett et al. [6], Ridgway et al. [12] and Fordyce et al. [5] have shown that it is possible to simulate low density survey maps from high density geochemical data using averaging techniques. These methods
result in a loss of detailed information from high density surveys as local variations are 'smoothed out' by the averaging process. If the averaging method of data integration was applied to stream sediment datasets in Europe, for example, all datasets would be reduced to the level of the lowest density survey in Romania at 1 sample per 2000 km^2 with the loss of much valuable information in other countries.

Table 5. Surveys based on a sampling density < 1 sample per 100 km^2 in FOREGS countries.

Country	Survey Type	Sampling Density 1 per x km^2	Alternative survey for the same area	
			Survey Type	Sampling Density 1 per x km^2
Estonia	Soil	450-3500	Soil	16
Finland	Stream sediment	200	Till	4
Norway	Stream sediment	200	Till	40
Portugal	Soil	225	None	
Portugal	Stream sediment	225	None	
Romania	Stream sediment	2000	None	
Romania	Surface water	2000	None	
Slovenia	Stream sediment	200	Soil	25
Slovenia	Soil	180	Soil	25
Slovenia	Surface water	200	None	
Sweden	Stream sediment	200	Till	7, 15

Alternatively, a surface grid-size greater than the resolution of the raw data can be selected during interpolation. If a grid-size of 5x5 km is applied to raw data collected at a sampling density of 1 per km^2, for example, an interpolating function based on inverse distance weighting and selection of nearest neighbour points will select the raw data points with most influence at a given grid point and calculate a 5x5 km grid surface. The calculation of a reduced number of gridded values from more detailed raw data will also result in a loss of resolution of high sampling density information. In order to maintain the resolution of high sampling density surveys ($\geq$ 1 sample per 3 km^2), a high density interpolating grid of 1 km or less could be selected. However, application of a detailed grid of this size to the whole of Europe would generate a huge data-file and the level of detail available in low density areas would be falsely presented.

The generation of European Geochemical Maps will therefore require careful consideration. The grid-size to be used in data interpolation should be determined by the scale at which the maps will be presented. Studies [7, 8] have demonstrated that is it possible to combine geochemical surveys of variable density in Finland (1 sample per 4 km^2) and Sweden (1 sample per 16 km^2) and in Brazil (average sampling density of 1 sample per 1 km^2). However, the variation in sample densities across Europe is considerable (1 sample per 0.01 - 1 sample per 3500 km^2) and in order to show both high and low density data in a representative manner it may be necessary to interpolate the raw data at two or more grid-sizes. This method of data presentation has been used successfully to combine datasets of differing resolution to demonstrate potentially harmful element concentrations in stream sediments in the UK [1].

SAMPLE SIZE FRACTIONS

In Europe, the size fractions analysed for the different stream sediment surveys range from < 63 µm (BSI 240 mesh) in the Czech Republic, Romania and Slovenia to < 1000 µm
(BSI 16 mesh) in Lithuania (Table 6). Most stream sediment surveys have, however, been based on the collection and analysis of < 177 to < 200 µm (BSI 80 to 76 mesh) fractions (Table 6). All the filtered surface water analyses carried out in the FOREGS region have been based on a filter size of 0.45 µm with the exception of Poland where a hard filter was used (Table 6). The range of grain-size fractions collected for soil surveys is bimodal. Some countries collect < 100 to < 180 µm (BSI 150 to 85 mesh) fractions to integrate with stream sediment surveys, while others follow traditional soil survey practice and use < 1000 or < 2000 µm (BSI 16 or 8 mesh) fractions (Table 6).

IGCP 259 recommendations
IGCP 259 recommendations for sample size fractions are similar for both GRN and national survey programmes. Collection of < 150 µm size fraction stream sediment samples is preferred whereas < 2000 µm regolith samples should be collected to conform to the International Standard Organisation (ISO) recommendations. The < 150 µm fraction in soils should also be collected whenever possible for comparison with stream sediment data. A filter size of 0.45 µm is recommended for filtered water surveys.

The majority of stream sediment surveys in Europe conform to the IGCP 259 recommendations with the exception of surveys in the Czech Republic, Lithuania,
Romania and Slovenia (Table 6). Alternative geochemical data based on the collection of 1000 µm - 2000 µm soils are available in Lithuania and Slovenia but in the Czech Republic (0.6% of the FOREGS region) and Romania (1.4% of the FOREGS region) no additional datasets are available. Similarly, soil and till surveys based on the collection of 63-180 µm size fractions in Albania, Cyprus, Denmark, Finland, France, Norway, Portugal, Slovakia, Sweden and the UK (in total 11% of the FOREGS region) do not conform to the recommendations.

In these cases it may be possible to estimate the concentration in the coarse < 2000 µm fraction from the fine fraction concentrations. Tarvainen [13] has shown that the concentration of certain elements (trace elements in particular) in < 2000 µm Finnish till samples can be estimated from the concentration in the < 63 µm size fraction tills. Linear relationship functions can be calculated between the two datasets if the concentration in both size fractions is known for a proportion of each dataset. Analyses of both fine fraction and < 2000 µm fraction soil and till GRN samples will be required to provide the necessary overlap of information between datasets if these methods of data levelling are to be incorporated into the preparation of European Geochemical Maps .

Table 6. Stream sediment, surface water and soil sample size fractions collected in FOREGS countries.

ANALYTICAL TECHNIQUES

A range of techniques have been employed to analyse geochemical samples in FOREGS countries, largely reflecting the years during which the survey was conducted. The main analytical methods available include XRF, ICP-AES, ICP-MS, DC-Arc ES, Flame AAS and NAA (Table 7). Surveys in Ireland, Italy and Luxembourg do not have the facilities to analyse regional geochemical samples and geochemical analyses are carried out in commercial and survey laboratories in other countries in these cases.

IGCP 259 recommendations

The IGCP 259/360 recommendations for GRN samples are similar to those for national survey programmes. The determination of total concentrations based on XRF, NAA or total acid digestion (HF + HNO_3 + $HClO_4$) followed by ICP-AES and ICP-MS analysis are recommended. Determinations based on partial extraction methods are not encouraged as these are less reproducible than total methods [3, 15]. The majority of FOREGS countries employ analytical methods included in the IGCP 259/360 scheme with the exception of Bulgaria, Cyprus, Ireland, Italy, Turkey and Ukraine. It should therefore be possible to standardise geochemical techniques among the majority of countries. The analysis of GRN samples provides an excellent opportunity for standardisation and calibration between laboratories as each suite of GRN samples, for example GRN stream sediments or GRN soils, will be analysed by one laboratory. The GRN samples will also be analysed by each national laboratory allowing comparison between the standard laboratory results and the national laboratory. Standardisation of analytical methods will be enhanced by the inclusion of the international standard reference materials recommended by the IGCP 259/360 analytical committee (Canadian STSD and Chinese GSD and GSS
standards) in GRN and national analytical programmes [3].

Table 7. Main analytical techniques employed by FOREGS countries.

XRF	DC-Arc ES	ICP-AES	ICP-MS	Flame AAS	NAA
Albania	Albania	Albania	Finland	Austria	Czech
Austria	Austria	Austria	Romania	Belgium	Finland
Belgium	Germany	Belgium	Slovenia	Cyprus	Greece
Czech	Greenland	Czech	UK	Czech	Greenland
Estonia	Lithuania	Finland		Denmark	Ireland
Finland	Ukraine	France		Estonia	Norway
Germany	UK	Germany		Finland	Sweden
Greece		Greece		Germany	UK
Greenland		Hungary		Greece	
Lithuania		Norway		Greenland	
Luxembourg		Poland		Hungary	
Italy		Portugal		Ireland	
Netherlands		Slovakia		Italy	
Norway		Slovenia		Luxembourg	
Romania		Spain		Norway	
Sweden		Sweden		Spain	
UK		UK		Sweden	
				Turkey	
				UK	

Recent work in Brazil [8] has shown that is possible to integrate datasets analysed in different laboratories without inter-laboratory calibration provided the laboratories use the same form of analysis and employ rigorous quality control procedures. However, several European surveys such as those in Albania have been carried out without the analysis of international reference materials or documented quality control procedures

(Table 8) and retrospective standardisation of datasets analysed by different laboratories may only be possible if sub-sets of archive material are analysed using the standardised IGCP 259/360 techniques.

The reanalysis of archive material may also be necessary to complete coverage for elements of environmental importance which are not routinely analysed by national sampling programmes. Iodine has been determined on only one water survey, for example, and only Greenland, Norway, Slovakia and the UK have data for Se concentrations in stream sediments, surface waters or soils [11].

Several elements such Al, Fe, Ca and Ni will be determined by more than one analytical method in the analytical structure proposed by the IGCP 259/360 analytical committee (Fig 4). Overlapping datasets generated by two or more analytical methods are essential when integrating data determined by different techniques. In the UK, for example, determinations of element concentrations in stream sediments by both XRF and DC-Arc ES techniques have been used successfully to 'level' older data based on DC-Arc ES methods and new XRF generated data to produce 'seamless' geochemical maps (T R Lister pers. commun.).

Table 8. Analysis of international reference standard materials in FOREGS countries.

International Standards Analysed		No Response to Inventory
Yes	No	Question
Austria	Albania	Belgium
Cyprus	Germany (seds)	Denmark
Czech	Greece	Italy
Estonia	Poland	Portugal (some surveys)
Finland	Spain (some surveys)	Romania
France	Ukraine	Turkey
Germany (soil)	UK (some surveys)	
Greenland		
Hungary		
Ireland		
Lithuania		
Netherlands		
Norway		
Portugal		
Slovakia		
Slovenia		
Spain		
Sweden		
UK		

XRF: glass beads:	Special elements:

Si, Al, Fe, Ca, Mg, K, Na, Mn, Ti, P, LOI
pressed powder:
Cu, Pb, Zn, Cr, Ni, Co, Sr, Ba, Rb, Cs, Sc, Y, La, Zr, V, Nb, Th, Ce, S, As

DIGESTION:
total decomposition, high pressure,
$HF- HNO_3 -HClO_4$

ICP-AES:
Al, Ba, Be, Ca, (Cd), Co, Cr, Cu, Fe, K, La, Li, Mg, Mn, Mo, Na, Ni, P, (Pb), Sc, Sr, Ti, V, Y, Zn, (Zr)

ICP-MS:
Ag, Ba, Cd, Pb, U, (Ta), Th, (Hf), Tl, Ce, Pr, Nd, Pm, Sm, Eu, (Yb)

INAA: (Au to 5 ppb)
Ag, As, Au, B, Ba, Br, Ca, Co, Cr, Cs, Fe, Hf, Ir, Mo, Na, Ni, Rb, Sb, Se, Sr, Ta, W, Zn, Sc, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, U, Th, Dy, Gd

Hydride ICP-MS: Hg, Se, Te, Bi

IC + fusion: I, F, Cl, Br

DC-Arc ES: B

Fire-assay: Au, Pt, Pd

Leco: C, N, S

Figure 4. The IGCP 259/360 analytical sampling scheme. Modified after Vermeulen [15].

Total and extractable analytical methods

Both total and extractable analytical methods have been employed in FOREGS countries (Table 9). Methods of partial extraction vary between surveys making comparisons between total and extractable surveys difficult and it is unlikely that extractable surveys can be used to estimate the total element concentration in various sample types [11].

Investigations into the total and extractable element concentrations in till samples in Finland, for example, proved that it was not possible to estimate the total concentration on the basis of the extractable concentration [9,14]. Significant extractable stream sediment and soil survey datasets from Germany (3% of the FOREGS region), Greece (0.7% of the FOREGS region) Hungary (0.2% of the FOREGS region) and Poland (4% of the FOREGS region) may be excluded from the preparation of European Geochemical Maps on this basis unless methods of integrating and levelling total and extractable datasets are investigated further (Table 9). Alternatively, the preparation of geochemical maps in these areas may require the reanalysis of sample archive material using standardised IGCP 259/360 analytical techniques.

Table 9. Surveys based on extractable analytical methods in FOREGS countries.

Country	Extractable Survey Type	Total Survey Type (for the same area)
Belgium	Soil	Overbank and stream sediment
Czech Republic	Soil	Stream and lake sediment
Finland	Till	Till
Germany	Soil	None

Germany	Stream sediment	None
Greece	Stream sediment	None
Hungary	Stream sediment	None
Norway	Till and stream sediment	Till
Poland	Soil and stream sediment	None
Poland	Soil and stream sediment	None
Portugal	Soil and stream sediment	None
Sweden	Till	None

CONCLUSIONS

Modern standardised, high-resolution, multi-element international geochemical databases, prepared to the standards agreed by IGCP 259/360 and the FOREGS Geochemistry Task Group, are urgently required to inform policy-makers and provide a sound basis for environmental legislation and resource management.

The preparation of European Geochemical Maps will incorporate existing geochemical data, and the integration of existing datasets will be greatly aided by collection and analysis of the Global Reference Network (GRN) of samples recommended by IGCP 259/360.

Results of an inventory of geochemical data in FOREGS countries show that most countries in Europe conduct geochemical surveys based on the sample types recommended by IGCP 259/360. Countries that do not currently base their national programmes on stream sediment, stream water, soil and radiometric sampling as recommended by IGCP 259/360 should be encouraged to alter their programmes to include these sample media as soon as possible.

Most surveys carried out in FOREGS countries are based on sampling densities of 1 per 100 km^2 or more and conform to the recommendations of IGCP 259/360. For areas where information from lower-density surveys only is available, national programmes should be encouraged to increase the sampling density where possible. Careful consideration should be given to the preparation of European Geochemical Maps. In particular, the parameters involved in computerised map generation should be chosen to reflect the differing resolutions of national datasets (1 sample per 0.05-3500 km^2) and maintain detailed survey information wherever possible.

Many geochemical datasets available in Europe conform to the IGCP 259/360 recommended sample size fractions (< 150 µm for stream sediment; < 2000 µm for regolith and < 0.45 µm for filtered water). In areas where information is currently unavailable at the recommended size fraction, linear relationship functions may be applied to estimate element concentrations in the desired size fraction from the existing size fraction, providing data for both size fractions are collected during GRN sampling.

Most FOREGS countries employ analytical methods such as XRF, ICP-AES, ICP-MS and NAA, as recommended by IGCP 259/360 for determination of element concentrations in GRN samples and national survey samples. The collection and analysis of the GRN samples provides an excellent means of standardising laboratory methods across Europe. National surveys should also be encouraged to include the Canadian STSD and Chinese GSD and GSS reference materials recommended by IGCP 259/360 in their analytical programmes as soon as possible to aid standardisation between countries. Some reanalysis of sample archive material may be required in areas where no data suitable for inclusion in European Geochemical Baseline maps currently exists.

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