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How robust are geochemical patterns? A comparison of low and high sample density geochemical mapping in Germany

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ABSTRACT

Regional geochemical mapping projects have been carried out for mineral exploration in Germany since 1954. In the early days, geochemical prospecting methods were mainly used for exploration of ore and non-metal deposits in Germany. Mapping for the first geochemical atlas of Germany was conducted in the 1980s by the Federal Institute of Geosciences and Natural Resources (BGR) with a sample density of one sample per 3 km^2. Parts of eastern Germany (Flechtingen Ridge, Harz Mountains, Thuringian Forest, Slate Mountains, Ore Mountains, Granulite Mountains, the Lausitz region, and along the Elbe River) were mapped by the former Central Geological Institute Berlin (ZGI) during the same period at a density of 1.3 samples per km^2. Stream sediment and surface water were sampled in all of these high-density geochemical mapping projects. The first low sample density geochemical survey (one site per 380 km^2) was carried out for the latest geochemical atlas of Germany, which presents comprehensive information about the regional distribution of hazardous inorganic and organic substances. A density of one sample per 5000 km^2 was also used in Germany for the FOREGS Geochemical Mapping Project of Europe. Geochemical stream sediment and surface water data obtained at these three different scales in different geochemical mapping projects have been compared in this study for the elements Ba, Cu, Cr, Pb and U in stream sediment as well as pH, EC and U in stream water. Comparison of overlapping high and low sample density surveys conducted in the same study areas, demonstrates that the geochemical patterns produced from low sample density surveys are very nearly the same as those from the high sample density surveys, and that they can be related to natural processes. The low sample density geochemical surveys in Germany provide element background values very similar to those obtained by high sample density mapping of the same region. In unmapped terrain, low-density geochemical mapping provides a cost-effective reconnaissance technique to establish element background values.

1. Introduction

For the past eighty years geochemical prospecting methods have involved trace-element analysis of bedrock, soil, stream sediment, stream water, plants and soil air (Hg exploration), with the aim of using elevated concentrations of certain elements to detect mineralised zones, ore deposits or contaminated areas. Since the 1950's geochemical exploration in both parts of Germany has usually been confined to analysis of a few elements of interest in small study areas. In western Germany, the Institute for Geosciences and Natural Resources (BGR) commenced studies of the application of geochemical prospecting in 1958 (Fauth, 1960, 1962a, 1962b, 1964, 1966, 1968a, 1968b, 1969, 1971, 1973, 1975, 1976a, 1976b, 1978a, 1978b; Fauth and Hindel, 1973, 1975, 1978; Fauth et al., 1975, 1978; Hindel, 1975, 1977, 1978; Schneider, 1978). In western Germany, geochemical exploration has been carried out mainly for U, Pb, Cu, Zn, baryte and fluorite. These and other types of mineralisation were also the targets of geochemical prospecting in eastern Germany (Bernstein, 1960; Dahm et al., 1968; Leutwein, 1957; Leutwein and Pfeiffer, 1954; Michael and Schön, 1964; Rösler, 1962, 1963), e.g., tin ores, polymetallic skarn deposits, fluorite, baryte and non-ferrous metals.

At sampling densities traditionally used for geochemical exploration (1–4 samples per km^2 and 1 sample per 1–25 km^2), geochemical mapping of countries or continents is logistically extremely demanding and tremendously expensive. One of the first relatively low-density surveys in northern Europe was the Nordkalott Project (Bølviken et al., 1986), based on a sample density of one site per 30 km^2. The Geochemical Atlas of Finland based on till sampling (Koljonen, 1992), and the geochemical mapping programme in north-eastern Europe, the Kola Project (Reimann et al., 1998), were based on a similar low sample density of one site per 300 km^2.

Low-density geochemical surveys provide a cost-effective means to assess the composition of near-surface materials over large areas. Many countries have compiled geochemical atlases based on such data. In the last fifteen years, large land areas in northern Europe, and

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more recently all of Europe, except some Eastern European and Balkan countries, have been mapped at ever decreasing sample densities: one site per 1000 km^2 (Barents Project, Salminen et al., 2004); one site per 2500 km^2 (Baltic Soil Survey, Reimann et al., 2003); one site per 5000 km^2 (Geochemical Atlas of Europe, Salminen et al., 2005; De Vos et al., 2006), and finally one site per 2500 km^2 (GEMAS Project, Reimann et al., 2014a, 2014b). In the Environmental Geochemical Monitoring Network (EGMON) project of China an extremely low sample density survey of one site per 18,000 km^2 was conducted (Wang, 2005, 2012; Xie, 2008; Xie and Cheng, 1997, 2001). The soil geochemical survey of North America (North American Soil Geochemical Landscapes Project, NASGLP) used a sample density of one site per 1600 km^2 in the USA (4857 sites in conterminous U.S.; Smith and Reimann, 2008; Smith et al., 2013, 2014; Woodruff et al., in this issue). In preparation for this American low-density soil survey, the USGS conducted a pilot study on a regional-scale in northern California (Goldhaber et al., 2009; Morrison et al., 2008), and a continental-scale study along two transects across the United States and Canada (Smith and Reimann, 2008; Smith et al., 2005, 2009, 2012, 2013). In the first Australia-wide geochemical survey (National Geochemical Survey of Australia, NGSA, Caritat and Cooper, 2011a, 2011b, 2011c, 2011d) an average sample density of around one site per 550 km^2 was used.

The geochemical mapping in Germany has been conducted at two quite different scales. The Regional Geochemistry Reconnaissance Project (Birke and Rauch, 1993; Birke et al., 1995a; Fauth et al., 1985; Röllig et al., 1990) collected samples of stream sediment and stream water from about 75,600 sites throughout western Germany (one sample per 3 km^2), and 18,000 stream sediment and surface water samples in eastern Germany (one sample per 1.3 km^2). A low-density geochemical survey (one sample per 380 km^2) was conducted in 2002–2006 as part of a new geochemical mapping project (Geochemical Atlas of Germany, Birke et al., 2006).

In 1977, a systematic multi-element geochemical survey of western Germany was begun to support mineral exploration and to establish environmental baselines (Fauth et al., 1985, Table 1). A geochemical survey of the Variscan basement was conducted with the same aims in an area of about 14,000 km^2 in the southern part of eastern Germany from 1977 to 1985 (Birke et al., 1995a, 1995b; Röllig et al., 1990).

After reunification in 1990, several German Geological Surveys (Saxony, Thuringia, Brandenburg) resumed regional geochemical mapping of their areas (Barth et al., 1996; Kardel et al., 1996; Müller and Scheps, 1997; Pälchen et al., 1996, 2004; Rank et al., 1999, 2009; Schramm et al., 1997). They used old geochemical data sets and supplemented these partly by recent high-density sampling. Especially in Saxony new geochemical atlases were produced for topsoil, stream sediment and rock formations. In 2010, selected geochemical maps of the distribution of As, Cd and Pb in topsoil in Saxony were published at a scale of 1:4.000.000 (Kardel and Rank, 2010a, 2010b, 2010c).

In 2002, sampling for the first relatively low-density Geochemical Atlas of Germany, based on surface water and stream sediment, was started (Birke et al., 2006, Table 1). An extremely low-density sampling project had begun in 2000 (stream water, stream sediment, topsoil, subsoil, humus, and floodplain sediment) throughout Germany for the FOREGS Atlas of Europe (De Vos et al., 2006; Salminen et al., 1998, 2005) and completed in 2002. The FOREGS programme was initiated to provide high-quality environmental baseline data for Europe. The FOREGS Atlas is the product of the European input to the Global Geochemical Baselines project of the International Union of Geological Sciences (IUGS) and International Association of GeoChemistry (IAGC). It represents the first multi-purpose, multi-media, and multi-method geochemical atlas on a European scale, but also globally.

Geochemical exploration methods are based on the established principle that a stream sediment sample and a floodplain sediment sample represent the average composition of the investigated part of catchment upstream of the sample site, including any anthropogenic contamination. Stream water reflects the interplay between geosphere/hydrosphere and anthropogenic pollution. The selected sampling media stream water and stream and floodplain sediments are considered to be the most representative of the surface environment, and they are the most commonly used media in past and current environmental geochemical mapping programmes.

From the beginning of the various mapping surveys, the environmental aspects of the surface geochemistry were taken into account by including one of the most important factors of the landscapes – land use – in the statistical treatment of the geochemical data.

In this paper, the original data for some trace elements from three different German geochemical surveys and the FOREGS Project in surface water and stream sediment samples are compared. The study demonstrates that comparable analytical data of certain elements in different surveys with reduced sampling densities can produce the same patterns. Finally, the geochemical mapping of all Germany with high- and low-density surveys shows that the geochemical patterns produced from lower density surveys are very nearly the same as those from high-density surveys.

Table 1
Geochemical mapping projects in Germany.

Mapping project	Time period	Number of samples	Sample density	Analysed determinants
Geochemical Atlas of FRG Fauth et al. (1985)	1977–1985	76,665 stream water 66,750 stream sediment	1 sample per 3 km^2	10 parameters: pH, EC, Cd, Co, Cu, F, Ni, Pb, U, Zn 15 elements: Ba, Cd, Co, Cr, Cu, F, Li, Ni, Pb, Sn, Sr, U, V, W, Zn
Geochemical survey of eastern Germany Röllig et al. (1990); Birke and Rauch (1993); Birke et al. (1995a, 1995b)	1977–1985	17,443 stream water 17,395 stream sediment	1.3 samples per km^2	3 parameters: pH, EC, F 31 elements: Ag, As, B, Ba, Be, Bi, Co, Cr, Cu, F, Fe, Ga, Hg, La, Li, Mn, Mo, Nb, Ni, Pb, Rb, Sc, Sn, Sr, Ti, V, W, Y, Yb, Zn, Zr
FOREGS Atlas (German part) Salminen et al. (2005); De Vos et al. (2006)	2000–2001	75 stream water	1 sample per 5,000 km^2	67 parameters: Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Ho, I, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Pb, Pr, Rb, Sb, Se, Sm, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr, pH, EC, Br^-, Cl^-, F^-, HCO_3^-, NO_3^-, SO_4^{2-}, SiO_2, DOC
		75 stream sediment		55 parameters: Al, As, Ba, Be, CaO, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Hg, Ho, K_2O, La, Li, Lu, MgO, MnO, Mo, Na_2O, Nb, Nd, Ni, P_2O_5, Pb, Pr, Rb, S, Sb, SiO_2, Sm, Sn, Sr, Ta, Tb, Th, TiO_2, Tl, Tm, U, V, W, Y, Yb, Zn, Zr, TOC
Geochemical Atlas of Germany Birke et al. (2006)	2002–2006	944 stream water	1 sample per 380 km^2	75 parameters: Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, Ho, I, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Pb, Pr, Rb, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr, BO_2^-, Br^-, HCO_3^-, Cl^-, F^-, NO_2^-, NO_3^-, NH_4^-, PO_4^{3-}, SO_4^{2-}, SiO_2, pH, EC, AOX, DOC
		945 stream sediment		61 parameters: Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, F, Fe, Ga, Ge, Hf, Hg, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, SO_3, Sb, Sc, Se, Si, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn, Zr, LOI, TC, TOC, AOX, PAH, PCB, HC, PCDD, PCDF