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DAVID R. LENTZ
KATHLEEN G. THORNE
KRISTY-LEE BEAL

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GEOCHEMICAL SURVEYS IN GOVERNMENT - NEW DEVELOPMENTS AND USES

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Presentation of regional geochemical data via Internet Earth browsers

Stephen W. Adcock[1], Wendy A. Spirito[1], & Eric C. Grunsky[1]
[1]*Geological Survey of Canada, 601 Booth Street, Ottawa, ON, K1A 0E8, CANADA*
(e-mail: adcock@nrcan.gc.ca)

ABSTRACT: The Geological Survey of Canada (GSC) has large amounts of regional geochemical data which are under-utilised both within and outside the organisation. The situation is being rectified by three overlapping activities: (1) cataloguing of the data holdings, to international metadata standards; (2) downloading of the data in a standardised spreadsheet format; (3) simple visualisation of the analytical data using Internet Earth browsers. Regional geochemical surveys have undergone a continuous evolution in sampling and analytical procedures. The resultant multitude of sample media and analytical methods poses several data management challenges, which are being mitigated by developing XML-based data transformation procedures. The GSC geochemical data management system has provisions for detailed metadata describing every aspect of a sample's history. In order to avoid inappropriate merging of disparate data, the analytical data are separated into many distinct datasets. The recent emergence of free, XML-based Earth browser software makes it much easier to visualise and compare the different datasets, without resorting to sophisticated GIS software.

KEYWORDS: *regional geochemistry, geochemical mapping, web mapping, Canada, New Brunswick*

INTRODUCTION

Many government geoscience organisations have accumulated large quantities of regional geochemical data over the past half-century. Systematic management of the data has posed many problems, due primarily to the continuous evolution in sampling and analytical procedures. Regional geochemical data are typically presented in a spreadsheet format, with each row representing an analysed sample, and each column representing an analytical measurement. This approach works well for individual surveys, but becomes unmanageable for a large collection of disparate surveys. Hence, most organisations have opted to store the data in relational database management systems, and to "normalise" the data to varying degrees. Whilst this makes centralised management of the data much easier, it puts a major obstacle in the way of end-users easily accessing the data.

In the past, accessing these data has usually involved the creation of complex, specialised computer programs, either in-house or via external contracts. Both approaches are expensive and hard to sustain. The recent emergence of XML-based technologies, coupled with the decreasing costs of computers makes it possible to create much simpler data extraction and manipulation procedures.

This paper outlines one approach that is being developed at the Geological Survey of Canada (GSC), where data are extracted from the database and re-cast as KML files that can be displayed in Google Earth or any other KML-aware application. Examples are presented for a recently-completed compilation of till geochemical data from New Brunswick (Adcock *et al.* 2009).

MANAGEMENT AND PUBLICATION OF REGIONAL GEOCHEMICAL DATA AT THE GSC

Geochemical surveys at the GSC are generally conceived and executed as individual entities, optimised for the local geography and for the scientific objectives of the funding project. The only major exception to this approach is the National Geochemical Reconnaissance (NGR) program, which has been collecting and analysing lake and stream sediment samples across Canada since the early 1970s according to a well-defined protocol (Friske & Hornbrook 1991).

Individual surveys are usually published as GSC Open Files, which can be downloaded over the Internet at no cost. Most Open Files include maps of the analytical data, and raw data in the form of a spreadsheet. The maps are typically presented using proportional dot symbology (Bjorklund & Gustavsson 1987), but other approaches, such as contouring, are sometimes used.

The exact format of each Open File is left to the discretion of the authors. This has resulted in a tremendous variability in content and format over the years, which in turn makes it frustrating and time-consuming for end-users to incorporate the data into their own projects. [For a comprehensive listing of GSC geochemical Open Files, see http://gdr.nrcan.gc.ca/geochem/metadata_pub_gsc_e.php] Even within the GSC, it is hard to get an accurate idea of what data are available. A further complication arises from the close working relationships between GSC scientists and their colleagues in Provincial agencies (projects are co-managed, samples are shared, publications emanate from different organisations).

The unsatisfactory nature of the current situation has been recognised for many years, but efforts to rectify it have encountered many technical challenges which could not be overcome with the available personnel and financial resources. Recent advances in computing hardware and software have led to new approaches and the development of cost-effective solutions.

A long-term project commenced in 2004 to catalogue GSC and Provincial geochemical surveys. The catalogue conforms to ‘Federal Geographic Data Committee’ metadata standards (FGDC, 1998) and is publicly accessible over the Internet (Spirito & Adcock 2009). Attention is now focussing on managing the analytical data. Several demonstration projects have been completed as a test of the data management system, most notably two collections of till geochemistry (Adcock 2009a; Adcock *et al.* 2009).

DEVELOPMENT OF A STANDARDISED DATA MODEL FOR REGIONAL GEOCHEMICAL SURVEYS

Any generalised approach to managing regional geochemical data must be built on top of a well-designed data model. If the model is well-designed, it should be able to adapt easily to ongoing changes in how geochemical surveys are carried out. Poorly constructed models will be harder to adapt, and will become steadily more difficult to maintain. Prior to the late 1980s, geochemical data modelling at the GSC was not consciously undertaken. The emergence of desktop relational database software in the late 1980s led to a serious effort to construct data models, based on methodologies designed specifically for use with relational database software (Halpin 1995). The current data model (Adcock 2009b) has been used successfully in a variety of projects. The most complex of these projects involved the compilation of till geochemical data from across New Brunswick (grouped into 39 surveys, collected and analysed between 1985 and 2006). The final database contains data for 13846 samples, collected from 11841 distinct sites. The database, in MS Access 2003 format, is available as a DVD (or free download) from the GSC or NBDNR (Adcock *et al.* 2009).

The data model is highly normalised, which suits data integrity and manipulation via the SQL language, but creates difficulties for the end-user in terms of accessing the data. Straightforward queries may involve numerous tables which have to be joined together. As a practical work-around, the database includes several very large denormalized tables.

XML-BASED TECHNOLOGIES

Extensible Markup Language (XML), in its various forms, is rapidly emerging as the dominant data format across all computer systems. Coupled with Unicode (UTF-8), it promises to greatly reduce the problems of interoperability between operating systems and software packages. XHTML is being adopted by all large organisations as the preferred “dialect” of HTML, for use on web sites (W3C 2006). Office productivity software developers are switching to XML as the default file format for word processing and spreadsheets (ISO, 2006; ISO, 2008). KML is becoming a very popular XML syntax for geographic data, partly because of the popularity of Google Maps and Google Earth, but also because it is a relatively easy file format for programmers to work with (in contrast to the SHAPE file format, for example (ESRI 1998)). KML was recently endorsed by the Open Geospatial Consortium as a recognised standard for geographic data visualisation (OGC 2008).

The different dialects of XML (XHTML, KML) are constrained by XML schemas (W3C, 2004). These schemas are critical to the success of XML. They are used to ensure that an XML file adheres to a well-defined structure. Schemas are themselves XML files, which must conform to the XSD specification. Schema designers are free to develop constraints to varying degrees. Forcing an XML file to be compatible with a tightly-constrained schema frees developers from having to write their own data validation procedures. This leads to a great simplification of data manipulation software.

XML files can be manipulated programmatically by a number of different techniques. One of the most powerful and elegant techniques involves yet another XML-based technology – the XSLT programming language (W3C 2007). An XSLT program is itself an XML file. XSLT was designed for the express purpose of transforming XML files into alternative formats. The language includes many constructs to allow efficient restructuring of the data. This leads to programs which are much smaller and easier to write than equivalent programs in more generic languages.

XSD and XSLT working together provide a very powerful technique to take output from one software package and transform it through intermediate formats, each of which is constrained by its own XSD schema, into a format suitable for end-user display.

XML TRANSFORMATION IN PRACTICE

All modern relational databases include the ability to export tables as XML files. It is usually possible to apply an XSLT transformation to the data as part of the export procedure. In the interest of simplicity and compatibility across different databases, no special transformation was applied to the tables extracted from the New Brunswick till database. Therefore, after exporting data out of MS Access in a generic XML format, the first XSLT transformation involves restructuring the data to conform to a “Geochemical Survey” XML schema, developed at the GSC (Adcock 2009b). The second transformation produces a set of files which conform to the GML schema (OGC, 2007). KML shares many features with GML, and hence the third and final GML-to-KML transformation is very simple.

Separating the data transformation into three distinct steps enforces a completely modular software design. In practice, the data transformation is executed via command shell scripts, using freely available software for both the XSLT transformation and XSD validation. The raw data contained in the 39 surveys in the New Brunswick compilation are exported into 7,000 individual KML files, which can be viewed online at http://gdr.nrcan.gc.ca/geochem.

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The National Geochemical Survey of Australia: 2009 update on progress

Patrice de Caritat[1], Michelle Cooper[1] & Paul Morris[2]
[1]Geoscience Australia, GPO Box 378, Canberra, ACT 2601 AUSTRALIA (email: Patrice.deCaritat@ga.gov.au)
[2]Geological Survey of Western Australia, Mineral House, 100 Plain Street, East Perth, WA 6004 AUSTRALIA

ABSTRACT: Building on method developments achieved during a series of precursor pilot projects, the National Geochemical Survey of Australia (NGSA) project targets catchment outlet (overbank) sediments as a uniform sampling medium. These transported, fine-grained materials are collected (from a shallow and a deeper level) near the lowest point of 1390 catchments, which cover 91% of Australia. Dry and moist Munsell® colour, soil pH and electrical conductivity and pH of 1:5 (soil:water) slurries are recorded and laser particle size analysis and infrared spectroscopy analysis are determined on bulk splits. The dried samples are sieved into two grain-size fractions (<2 mm and <75 µm) that are analysed by x-ray fluorescence (XRF) and inductively-coupled mass spectrometry (ICP-MS) (multi-element, total analyses), by ICP-MS after aqua regia digestion (multi-element, including low level gold), and specialised methods for platinum group elements, fluorine and selenium. At the time of writing, 78% of the samples have been collected and most analyses are completed for the first 25% of samples. The project is due for completion in June 2011.

KEYWORDS: *geochemical mapping, overbank sediment, mineral exploration,* energy

INTRODUCTION

The National Geochemical Survey of Australia (NGSA) project was initiated in late 2006 as part of the Federal Government's Energy Security Initiative (Johnson 2006). It aims to provide pre-competitive data and knowledge to support exploration for energy resources in Australia. In particular, it will improve the existing knowledge of the concentrations and distributions of energy-related elements such as uranium (U) and thorium (Th) at the national scale.

The project is underpinned by a series of pilot surveys recently carried out by Geoscience Australia and the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC-LEME) to test robust and cost-effective protocols for sample collection, preparation and analysis. Examples of these are the Riverina (Caritat *et al*. 2005 2007), Gawler (Caritat *et al*. 2008a) and Thomson (Caritat & Lech 2007; Lech & Caritat 2007) projects. Selected results from these geochemical surveys have been presented by Caritat *et al*. (2008b).

The current national project, described below, is being conducted in collaboration with the State and the Northern Territory geoscience agencies.

BACKGROUND

The nation-wide geochemical survey was initiated because there is no complete geochemical coverage available for Australia. Experience elsewhere shows that such a data layer is an important complement to other national-scale geological and geophysical datasets.

The current distribution of geochemical data available through the national repository (OZCHEM database) is shown in Figure 1. The map shows that there are vast areas of the country (>60%) that lack any geochemical information. Also, where geochemical data are available, they are often not comparable as a result of incompatible sampling media, inconsistent sample preparation and analysis methods, incomplete quality assessment metadata and/or different analyte suites being reported.

Similarly, the current airborne gamma-ray spectrometric (radiometric) survey coverage available at a resolution deemed appropriate for exploration does not provide a complete national picture of the

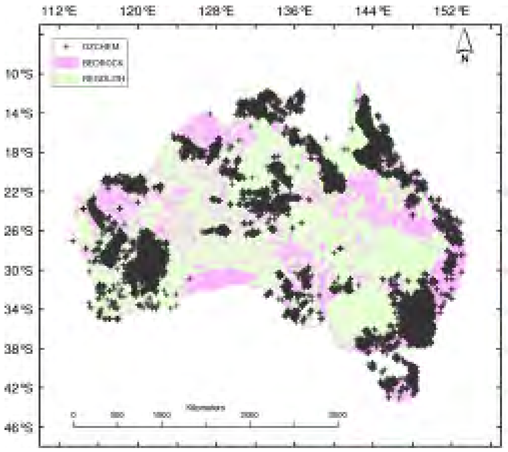

Fig. 1. Distribution of whole rock geochemical data in Australia (plus signs) extracted from the OZCHEM national database as at June 2006, overlain on bedrock (pink) and regolith (green) coverages.

distribution of radiogenic elements potassium (K), uranium (U) or thorium (Th). This situation is being remedied by the new airborne geophysics project, which, together with the NGSA, will result in a significantly improved understanding of the distribution of K, U and Th in Australia.

Some regional geochemical surveys have been carried out in parts of Australia, but no national coverage exists. Since the inception of the concept of regional geochemical surveys in the 1960s, they have proven to be a reliable tool for mineral exploration.

OBJECTIVES

The objectives of the NGSA project are to:

- Collect catchment outlet (overbank) sediment samples from ~1400 large catchments covering >90% of Australia using an ultra low sampling density approach to keep costs down;
- Prepare and analyse the samples to extract the maximum amount of geochemical information (60+ elements) using internally consistent, state-of-the-art techniques;
- Populate the national geochemical database with the resulting new data;
- Compile an atlas of geochemical maps for use by the mineral exploration industry to identify areas of interest in terms of energy-related resources and other mineral commodities, which can then be the focus of targeted exploration efforts.

STRATEGY

Sampling Media

Catchment outlet sediments (similar to floodplain sediments in most cases) are sampled at two depths (0-10 cm below the surface as well as a 10 cm interval at a depth of between around 60 and 90 cm).

Sampling Sites

1390 catchments covering 91% (or about seven million km^2) of Australia across all States and Territories have been targeted for sampling. Catchments are sampled as close as possible to their lowest point (usually their outlet). Small coastal catchments and small islands are not included in the survey. The resulting distribution of sites targeted for sampling is shown in Figure 2 and translates to an average sampling density of around 1 site/5500 km^2.

Sample Collection

A detailed Field Manual was compiled (Lech *et al*. 2007) and all sampling equipment and consumables were centrally purchased to ensure a standard approach. Sample collection is being undertaken by all State and Northern Territory geoscience agencies following a hands-on, in-field training period. At each locality, a detailed site description, field pH, dry and moist soil Munsell® colours and GPS coordinates are recorded and several digital photographs are taken. All information is recorded digitally to facilitate subsequent uploading into databases.

Sample Preparation

Samples are dried, split and sieved to <2 mm and <75 µm fractions. The <2 mm fractions is mechanically ground for some analyses, while the finer fraction is not. A bulk split of each dried sample is archived for future investigations.

Sample Analysis

Bulk parameters routinely recorded at

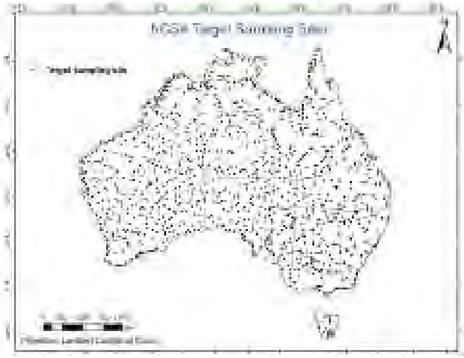

Fig. 2. Distribution of target sampling sites for the National Geochemical Survey of Australia.

Geoscience Australia are pH and electrical conductivity of 1:5 (soil:water) slurries, and laser particle size distribution. Sample analysis has started for 60+ elements using mainly XRF and collision cell ICP-MS at Geoscience Australia. Special analyses not available at Geoscience Australia (e.g., low-level gold and multi-element analysis after aqua regia digestion, fluorine, selenium, platinum group elements, infrared spectroscopy) are obtained externally.

Quality Assessment/Quality Control

Sample numbers have been randomised to minimise regional bias, help separate false from true anomalies and obtain meaningful estimates of the variance of duplicates. Field duplicates, analytical duplicates, in-house standards and certified reference materials are introduced at regular intervals in the analytical streams.

Data Analysis

Graphical and statistical data analysis will be carried out at various scales (regional, States/Northern Territory, and National). Non-parametric univariate and multi-variate analysis along with the production of geochemical maps will be carried out.

Timeline

Following planning in the first half of 2007, fieldwork, including initial training, began in mid-2007 and is expected to continue until mid-2009 (allowing for the wet season prohibiting field work in northern Australia for six months each year, and for time to obtain access permissions for some areas). Figure 3 shows the catchments sampled to 31 December 2008. Sample preparation started in early 2008 and will continue until late 2009. Sample analysis started mid-2008 and will continue until mid-2010. Data analysis and reporting are planned to take place in 2010 and early 2011. The project concludes on 30 June 2011.

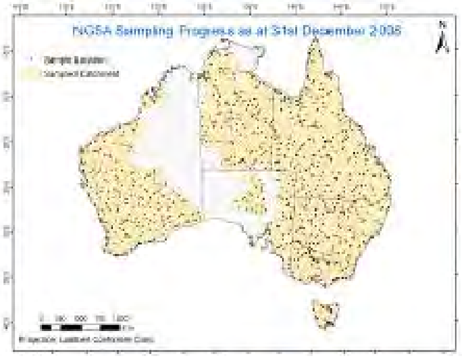

Fig. 3. Distribution of catchments sampled for the National Geochemical Survey of Australia, as at 31 December 2008 (1078 catchments, or 78%, completed).

DATA DELIVERY

By 2011, the NGSA project will deliver a National Geochemical Atlas of Australia, which will be available online. In addition, reports on the geochemistry of all States and the Northern Territory will be released, as will separate reports on energy related commodities, on implications for geothermal resources, on comparison with airborne radiometric surveys, and for regions that are the focus of other energy security projects. The national geochemical database OZCHEM will be populated with the new data.

The NGSA will lead to increased knowledge on the concentrations and distributions of geochemical elements in the near-surface environment at the national scale. Further, NGSA results should support increased exploration activity for energy related resources in Australia, particularly using national geochemical survey data to select specific areas for further exploration investment. Finally, it is hoped that the NGSA will be one of several contributors to success in mineral exploration in Australia. Spin-off benefits in environmental management, land use policy development and geohealth assessment are also expected.

CONCLUSIONS

A national-scale geochemical survey of Australia is under way. It applies ultra low sampling density to transported and well-mixed outlet sediments, which are expected to represent the average composition of large catchments. The NGSA will provide the first complete, internally consistent geochemical data layer for Australia and is expected to find applications in energy and mineral resources exploration.

ACKNOWLEDGEMENTS

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Multi-element geochemical mapping in Southwest China

Zhizhong Cheng[1] **& Xuejing Xie**[1]
[1]*Institute of Geophysical and Geochemical Exploration, Jinguang Road, Langfang, Hebei, 065000 CHINA*
(e-mail: zhizhong9@yahoo.com.cn)

ABSTRACT: Southwest China's geochemical mapping project to measure 76 elements was initiated in 2000. 2700 composite samples were analysed by ICP-MS, XRF and ICP-AES, along with other techniques where necessary. The resulting geochemical maps shows the distribution of majority of the elements in the periodic table.

KEYWORDS: *76 elements, geochemical mapping, analytical scheme,*

INTRODUCTION

In 1973, J.S. Webb (Webb *et al*. 1973, 1978) published the first geochemical atlas "Provisional Geochemical Atlas of Northern Ireland". From 1973 to now, more than 40 regional and national geochemical mapping projects have been carried out (Reedman 1973; Bowie & Plant 1978a,b; Bolivar 1980; Geological Survey of Canada 1981; Stephenson *et al*. 1982; Weaver *et al*. 1983; Fauth *et al*. 1985; Bolviken 1986; Koljonen *et al.* 1989; Simpson 1993; Varna *et al*. 1997; Laszlo *et al*. 1997; Reimann *et al*. 1998; Salminen 2005; De Vos & Tarvainen 2006).

China's national geochemical mapping project (Regional Geochemistry-National Reconnaissance (RGNR) Project) was initiated in 1978 (Xie 1977, 1978, 1989), involving analysis of 39 elements by a variety of methods. Environmental geochemical monitoring networks (EGMON) Project, (Xie & Cheng 1997) were established in 1993, in which 54 elements were analyzed. In 2000, a project to produce geochemical maps for 76 elements was carried in Southwest China (Xie *et al*. 2008).

SAMPLE TYPE AND COLLECTION

The RGNR project in Yunan, Guizhou Sichuan and Guangxi provinces were commenced in 1980, and finished in 1995. For the Southwest China regional geochemical mapping program, about 100 RGNR samples from each 1:50000 map sheet were composited into a single sample. The resulting 2700 composite samples were subsequently analysed.

MULTI-ELEMENT ANALYTICAL SCHEME

The 76 elements analyzed include 39 elements originally analyzed in the RGNR Projects, and 37 new elements. The analytical scheme is based largely on ICPMS, ICPAES and XRF, supplemented with other techniques (Table 1). The lower levels of detection of all elements are less than their crustal abundances (Table 2). The log deviation are logC≤0.1, standard deviation (SD) is between 5%~30%. (majority element's standard deviation less than 10%, only that of S and Os are less than 30%)

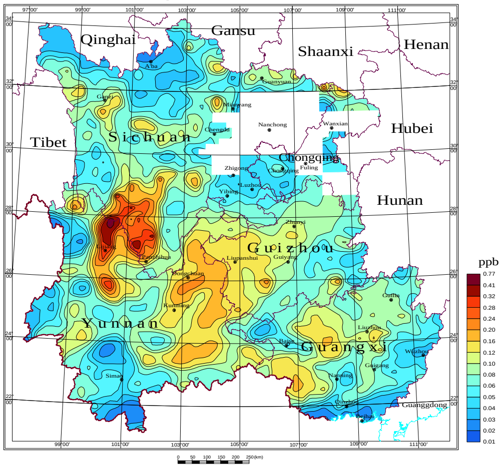

Fig.1. Geochemical map of osmium Os in southwest China.

Table 1. Analytical Scheme

Analytical method	Elements
XRF	Si, Al, Fe, Mg, Ca, Na, K, Ba, Ce, Co, Cr, Cu, Ga, La, Mn, Nb, Ni, P, Pb, Rb, S, Sc, Sr, Th, Ti, V, Y, Zn, Zr, Cl, Br
ICP-MS	Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu
	Be, Bi, Ce, Co, Cs, Cu, Ga, In, La, Mo, Nb, Ni, Pb, Rb, Sb, Th, U, W, Y, Zn, Tl, Ta, Hf, Re Te
ICP-AES	Na, Mg, Al, K, Ca, Fe, Ba, Be, Co, Cr, Cu, Li, Mn, Ni, P, Sr, Ti, V, Zn
GF-AAS	Ag, Au
HG-AFS	As, Sb, Se, Ge
CV-AFS	Hg
SIE	F
ES	Ag, B, Sn,
VOL	C, N,
CF-COL	I
FA-POL	Ir,Rh
FA-ES	Pt, Pd
FA-COL	Os, Ru

GEOCHEMICAL MAPS FOR 76 ELEMENTS

All of the geochemical data are loaded into the GeoMDIS system, The data were gridded using the data-gridding function of GeoMDIS, and geochemical maps for each of the 76 elements were generated .

Fig.1 shows a large Os anomaly distributed over and area of approximately 60 000km^2 in north Yunnan and southwest Sichuan possibly indicating widespread platinum group element mineralization. The distribution of In (Fig. 2) shows three large and two small geochemical anomalies .A strong Hf anomaly delineated near Lincang in Yunnan province(Fig. 3), coincides with an extensive area of granitic rocks.

CONCLUSIONS

Using samples collected from a more detailed geochemical mapping exercise, the multi-element geochemical mapping exercise carried out in southwest China has indicated regional anomalies which may be related to economic areas of mineralization. Such regional programs illustrate the importance or low-density

Table 2. Required lower level of detection

element	D_L	element	D_L
Ag	0.02	Mo	0.2
Al_2O_3	0.05*	N	20
As	1	Na_2O	0.1*
Au	0.2	Nb	2
B	2	Nd	0.1
Ba	5	Ni	1
Be	0.2	Os	0.02
Bi	0.05	P	10
Br	1	Pb	2
C	0.1*	Pd	0.2
CaO	0.05*	Pt	0.2
Cd	0.02	Pr	0.1
Ce	2	Rb	1
Cl	20	Re	0.2
Co	1	Rh	0.02
Cr	5	Ru	0.02
Cs	0.5	S	50
Cu	1	Sb	0.05
Dy	0.1	Sc	1
Er	0.1	Se	0.01
Eu	0.1	SiO_2	0.1*
F	100	Sm	0.1
Fe_2O_3	0.05*	Sn	1
Ga	2	Sr	5
Gd	0.1	Ta	0.2
Ge	0.1	Tb	0.1
Hf	1	Te	5
Hg	0.5	Th	2
Ho	0.1	Ti	50
I	0.5	Tl	0.1
In	0.01	Tm	0.1
Ir	0.01	U	0.2
K_2O	0.05*	V	5
La	1	W	0.3
Li	1	Y	1
Lu	0.1	Yb	0.1
MgO	0.05*	Zn	5
Mn	10	Zr	5

D_L : detect limit , * in % , Au, Hg, Ir, Os, Pd, Pt, Re, Rh, Ru in ppb , others in ppm

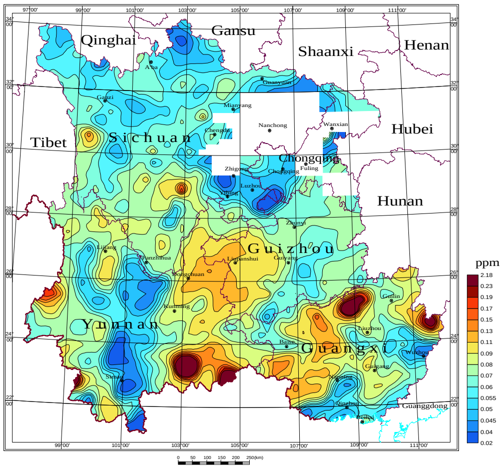

Fig. 2. Geochemical map of Indium (In) in southwest China.

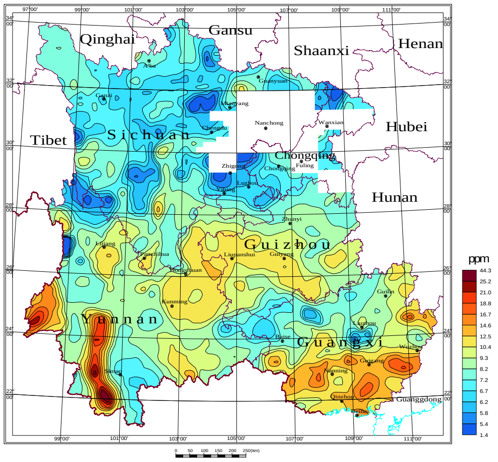

Fig. 3. Geochemical map of hafnium (Hf) in Southwest China.

geochemistry as an exploration tool. Furthermore, the analysis of a wide variety of elements to low levels means the data are also suited to environmental management as well as mineral exploration.

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Exploration geochemical surveys of the Taupo Volcanic Region, New Zealand

Anthony B. Christie[1] & Richard Carver[2]
[1]GNS Science, P O Box 30-368, Lower Hutt NEW ZEALAND (e-mail: t.christie@gns.cri.nz)
[2]GCXplore Pty Ltd, 67 Chelmsford Road, Mt Lawley, WA 6050 AUSTRALIA

ABSTRACT: Open file mining company exploration geochemical survey data in New Zealand are compiled in the REGCHEM (Regional Exploration Geochemistry) database managed by GNS Science (see http://maps.gns.cri.nz/website/minmap). Data for the Taupo Volcanic Region includes 1350 stream sediment (including 163 BLEG analyses), 960 pan concentrate, 2241 rock chip and 510 soil samples from 16 surveys completed between 1983 and 2007. The main exploration target was epithermal gold deposits hosted by volcanic rocks. The usefulness of the conventional stream sediment data is limited by the large number (>90%) of samples with Au and Ag values below the detection limit, and the narrow geographic coverage of the BLEG samples. Pan concentrate stream sediment and rock chip surveys have yielded the best results for reconnaissance exploration.

KEYWORDS: *stream sediment, BLEG, rock chip, soil, geochemical survey, epithermal, gold, silver, Taupo Volcanic Region*

INTRODUCTION

In New Zealand, there have been no systematic stream sediment geochemical surveys by Government agencies and the only comprehensive data sets are from mining company surveys carried out during mineral exploration activities. These are reported to government as a condition of prospecting and exploration permits. Much of the publicly available archived data has been compiled in digital form in the REGCHEM (Regional Geochemistry) database (Warnes & Christie 1995) and is publicly accessible via the MinMap interface at http://maps.gns.cri.nz/website/minmap/.

This study describes the REGCHEM data for the Taupo Volcanic Region (Fig. 1), an area highly prospective for epithermal Au-Ag deposits (Crown Minerals 2003).

REGIONAL GEOLOGY AND MINERAL DEPOSITS

The Taupo Volcanic Region consists of the Taupo Volcanic Zone (TVZ) and large flanking areas of plateau-forming ignimbrite sheets that are up to several hundred metres thick (Fig. 1). The TVZ occupies a 250 km long, 30-50 km wide, 2-4 km deep volcano-tectonic depression striking northeast and filled with Quaternary volcanic rocks overlying a basement of Mesozoic greywacke. The volcanic rocks consist mostly of rhyolite, lesser andesite and dacite, and minor basalt, that form domes, cones, and vents with surrounding and intervening pyroclastic flows (ignimbrite) and airfall deposits, and volcaniclastic sediments. The andesite volcanoes of White Island, Ngauruhoe and Ruapehu are currently active, basalt was erupted at Tarawera in 1886, and the most recent plinian rhyolitic eruption (Taupo Pumice) was deposited in c. AD 233.

Early discoveries of gold in the region included alluvial gold in Onaia Stream, several gold-bearing quartz veins in basement greywacke west of Lake Taupo (e.g. December Reef and Hades Reef in Mangatu Stream), and gold-bearing quartz veins in volcanic rocks at Puhipuhi. Gold-silver mineralisation has also been reported in several of the active geothermal fields, including Kawerau, Waiotapu, Ohaaki and Rotokawa. Mineral exploration from the 1970s discovered several new epithermal Au-Ag prospects including Horohoro, Matahana, Thomsons, Ohakuri, Wharepapa, Pukemoremore, Umukuri and Forest Road (Fig. 1). These were mostly found by mapping occurrences of hydrothermal breccias, sinters and hydrothermal alteration.

EXPLORATION GEOCHEMICAL DATA

Data have been compiled from 15 exploration campaigns between 1982 and 1988 (MR reports 628, 629, 630, 631, 632, 641, 647, 649, 654, 657, 665, 669, 682, 2270, 2532), and one in 2007 (MR report 4307). These included stream sediment, pan concentrate, rock chip and soil sample media (Table 1).

Most of the 1187 stream sediment samples were analysed for Au, Ag, As and Sb, but high detection limits (e.g., Au mostly 0.01, 0.02 and 0.05 ppm, but some 0.0002 and 0.002 ppm) result in most samples having concentrations of these elements below their detection limits (Table 1), thus limiting their usefulness.

The 510 soil samples were collected in four small grids over known gold prospects at Ohakuri, Wharepapa, Wharepapa NE and Pukemoremore North.

Weak gold anomalies and trends are present, typically associated with areas of hydrothermal breccias and alteration. Of the other elements analysed, As shows the best contrast with values ranging from 2-2800 ppm.

Rock Chip Samples

The 2241 rock chip samples were collected mainly from sinters, veins, hydrothermal breccias or altered rocks. Most were analysed for Au, Ag, As and Sb, and about half were analysed for Hg, Cu, Pb and Zn. About 25% of the Au and Ag assays are below their detection limits. The high values for Au and Ag are in the areas of known prospects (Fig. 2).

BLEG Samples

The 2007 survey collected 163 stream sediment samples and analysed them for Au using a bulk leach extratable gold (BLEG) cyanide digestion. The survey extended beyond the TVZ, north into the older Coromandel Volcanic Zone. Despite the low sample density, (1 sample per 9 km^2), the data outline one anomalous

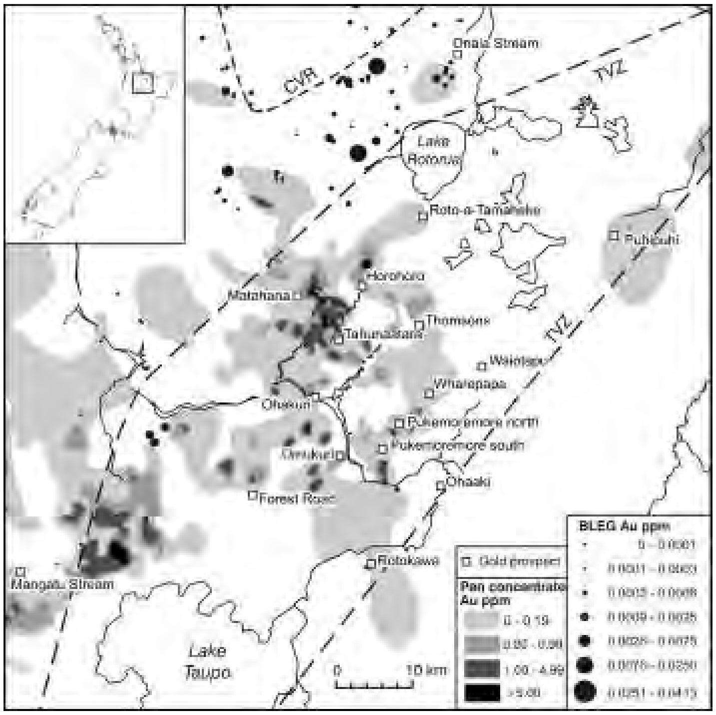

Fig. 1. Au concentrations in pan concentrate and BLEG stream sediment samples. (CVR = Coromandel Volcanic Region; TVZ = Taupo Volcanic Zone).

Table 1. Percentile statistics for exploration samples.

Element	n	P 25	P 50	P 75	P 97.5	BLD %
			Stream sediment			
Ag ppm	1100	BLD	BLD	BLD	1.50	91
As ppm	947	BLD	BLD	BLD	22	79
Au ppm	924	BLD	BLD	BLD	0.05	94
Cu ppm	33	BLD	8	10	21	24
Pb ppm	101	BLD	BLD	BLD	10	94
Sb ppm	877	BLD	BLD	BLD	BLD	98
Zn ppm	19	30	40	60	80	0
			BLEG			
Au ppb	163	0.10	0.20	0.50	1.70	7
			Pan concentrate			
Ag ppm	950	BLD	BLD	0.27	5.00	61
Au ppm	960	BLD	0.03	0.74	20.50	46
			Rock chips			
Ag ppm	2235	BLD	BLD	BLD	5.50	84
As ppm	2124	BLD	20	80	510	35
Au ppm	2241	BLD	BLD	BLD	0.38	75
Cu ppm	927	BLD	2	3	8	27
Hg ppm	1257	BLD	BLD	1	11	62
Pb ppm	963	BLD	5	9	29	36
Sb ppm	1908	BLD	BLD	3	48	69
Zn ppm	1003	4	12	25	63	18

n = number; BLD = below detection; BLD % = percent of samples below the detection limit
BLEG = bulk leach extractable gold stream sediment

catchment (25-75 ppb Au), one probably anomalous catchment (8-25 ppb Au) and two other catchments of interest (2-8 ppb Au) (Fig. 1).

Pan concentrates

More than 900 pan concentrate samples were analysed for Au and Ag. About 50% of the assays are below the detection limits (Table 1). The contrast 97.5/50% ratio for Au is very high (500-683).

DISCUSSION AND CONCLUSIONS

The young volcanism of the TVZ creates several challenges for geochemical exploration. A thick mantle of young ash and pumice deposits over large areas limits the use of soil geochemical surveys. Exploration in the early 1980s recognised that conventional stream sediment surveys were not effective because target sediments were overwhelmingly diluted by young post-mineral pyroclastics and volcaniclastics. BLEG and other proprietary stream sediment bulk sampling and analysis techniques appeared more effective, but most explorers concluded that pan concentrate sampling was the most effective reconnaissance geochemical exploration method. Large areas of the region are planted in exotic commercial forests, and clear felling forestry operations have added another complication with the extensive reworking of the erodible surface cover resulting in a very high proportion of young volcaniclastic material in active stream sediments.

Unsuccessful follow-up of some anomalies suggests that erosion and exposure of some deposits may have been temporary and they are now buried beneath younger volcanic rocks.

Work to date has highlighted the Matahana area and two main parallel NE trends of anomalies and prospects, inside

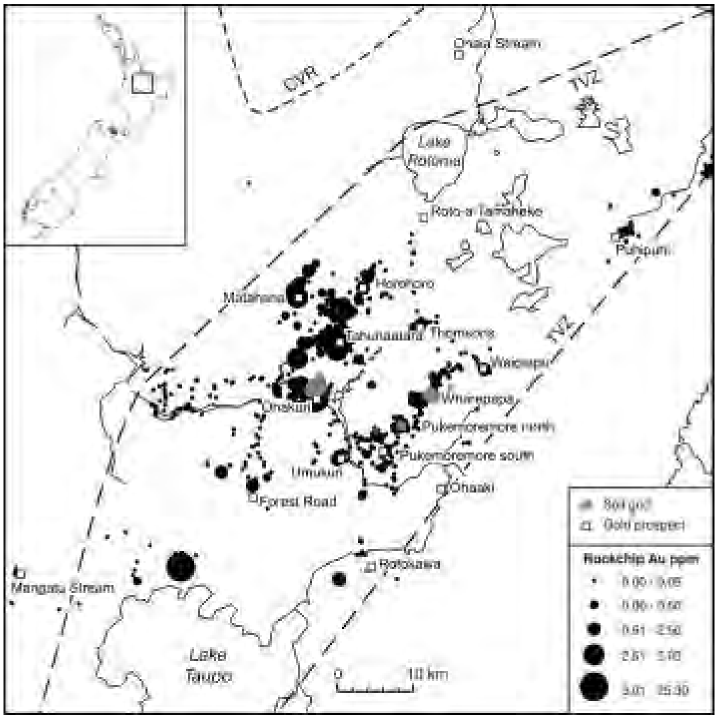

Fig. 2. Au concentration in rock chip samples and location of four soil sampling grids. (CVR = Coromandel Volcanic Region; TVZ = Taupo Volcanic Zone).

the margins of the TVZ (Fig. 2), along with several anomalies in other areas with no known cause.

ACKNOWLEDGEMENTS

Data were compiled as part of the GNS Science REGCHEM project, and by Crown Minerals (2003), utilising an earlier compilation by Delta Gold. Bob Brathwaite and Paul Morris are thanked for their reviews of the manuscript.

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The effect of geology on lake geochemical trends in Sudbury, Ontario, viewed through Google Earth

Richard Dyer[1]

[1]*Ontario Geological Survey, 933 Ramsey Lake Road, Sudbury, ON CANADA(e-mail: richard.dyer@ontario.ca)*

ABSTRACT: The Ontario Geological Survey (OGS) lake geochemical sampling program was designed to obtain high quality natural geochemical signals from both greenfield and brownfield regions. An excellent example of this is in the Sudbury area where, despite significant mining activity and disturbance, OGS lake sediment sampling was successful in obtaining relatively uncontaminated deep sediments. The Sudbury area survey is one of many that the OGS has undertaken in the past 22 years. Recent development of 'OGS-Earth', a prototype add-on to Google Earth has allowed very fast and easy visual display of the entire (>60,000 samples) dataset at any scale and viewing angle. Google Earth allows the visualization of geological, topographic and cultural information with overlain geochemistry in virtual 3-D through all scales and view angles. Profound geochemical trends and relationships between geochemistry and geology can be immediately apparent. When viewed in Google Earth, the close association of the lake sediment geochemistry with mineralization and Sudbury Igneous Complex rocks is immediately apparent. Future geochemical data releases by the OGS will include Google Earth (kml) files to allow much easier and quicker viewing of geochemical data than has traditionally been the case.

KEYWORDS: *Lake Sediment, Geochemistry,Sudbury Igneous Complex, GIS, OGSEarth*

INTRODUCTION

The high density (approximately 1 sample per 3 km^2) lake sediment geochemical program at the Ontario Geological Survey takes advantage of the greater than 250,000 lakes covering almost 1/5th of Ontario's 1,000,000 km^2 surface area. The program mandate has always been twofold: 1) to support mineral exploration by sampling in areas of high mineral potential; 2) provide high quality baseline geochemical data of the Province., over 60,000 samples have now been collected across Ontario, covering an area of more than 200,000 km^2 (Fig. 1).

The OGS lake sediment is so large and at such high density that displaying significant portions of the data using conventional geographic information systems (GIS) is sometimes very slow – even with fast computers. To address this problem, the OGS has developed "OGS-Earth", an in-house add-on to Google Earth for the purpose of rapid integration of multiple geochemical datasets. Many of the Province–wide geological layers, including lake sediment data, are now available on the Geology Ontario website for easy downloading and viewing in Google Earth (http://www.mndm.gov.on.ca/mines/data/google/default_e.asp). Google Earth allows the visualization of geological, topographic and cultural information with overlain geochemistry in virtual 3-D through all scales and view angles. Even to novice users, profound geochemical trends and relationships between geochemistry and geology can be immediately apparent – and the platform is considerably easier to operate than a typical GIS.

SAMPLING METHODS

From the outset of the high density lake sampling program in 1987, the application of a robust and consistent sampling protocol was considered paramount and this is still the case. Lake sediment and water sampling is performed by 2-person teams primarily from float-equipped Bell 206B helicopters.

Intact lake cores are retrieved from the lake bottom in a polycarbonate tube. Bottom-up extrusion of the sediment

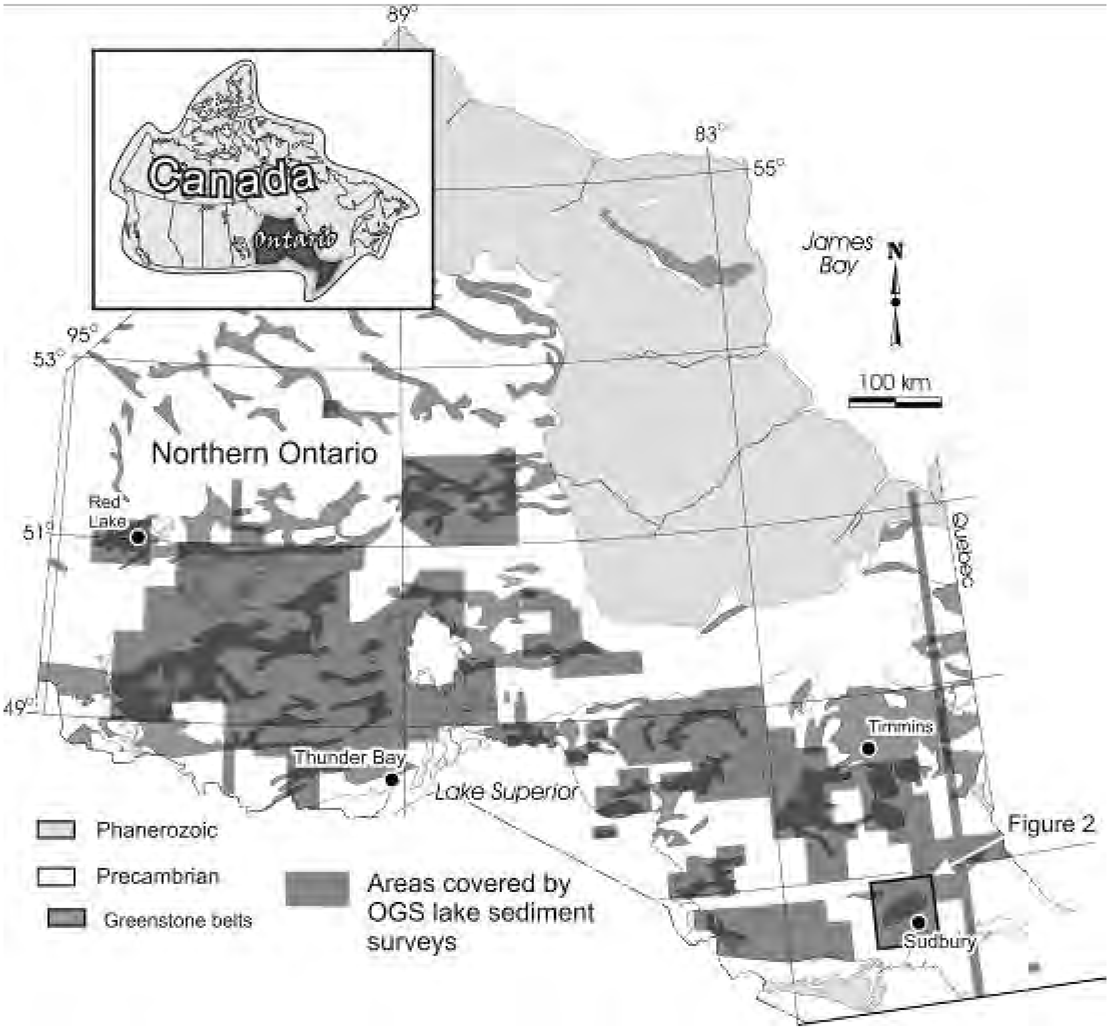

Fig. 4. High density lake sediment coverage of northern Ontario.

allows for discrimination between shallow (0-15 cm) sediment and deeper sediment (e.g. >20 cm). All samples are taken from depths >20 cm below the sediment–water interface (SWI) in order to avoid anthropogenic influences and near surface diagenetic effects. Therefore, these deeper sediments more accurately reflect the natural geochemical inputs, which may be traced back to local bedrock geology. If required, the upper (shallow) sediment can also be kept as a separate sample to characterize potential anthropogenic inputs, for example, near industrial areas or existing mines.

THE USE OF DEEP LAKE SEDIMENT

The sampling of deep lake sediment has always been considered an essential part of the OGS lake sediment sampling program. The practice of consistently sampling deep (>20 cm) lake sediment was initially based on studies by Dickman & Fortescue (1984) on the increase/appearance of *Ambrosia* (ragweed) pollen at a sediment depth of 10 to 15 cm within 8 test lakes in the Sudbury and Wawa regions. This increase in the *Ambrosia* pollen corresponds to the onset of extensive deforestation associated with agricultural development during the post-industrial period of the past 100 years. Data from a more recent study in the Sudbury area confirm that a sample depth of >20 cm is adequate to avoid contamination (Hunt 2003). Hunt's

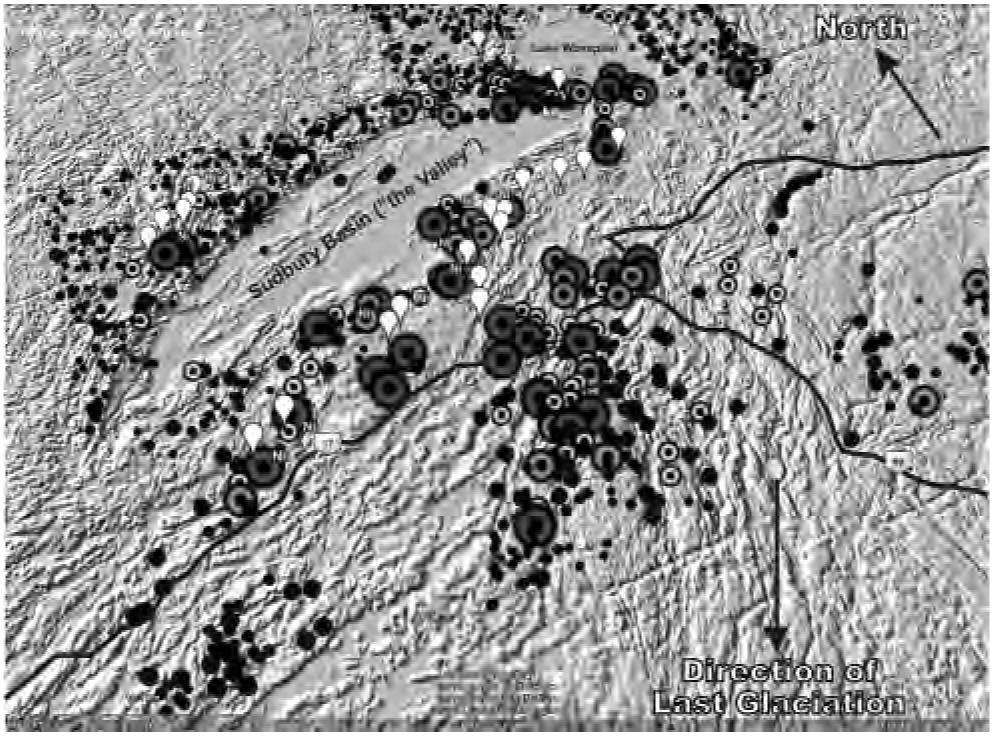

Fig. 5. The distribution of nickel in the Sudbury area shown by lake sediment sampling, draped over a regional DEM viewed through Google Earth. Circle size is proportional to concentration, with the largest circle representing >200 ppm Ni. Tear-drop symbols are locations of major Ni deposits. View aspect is northeast toward the direction of last glacial advance.

study involved Pb^{210} age dating of lake sediment cores obtained with a KB gravity corer from 14 lakes. The sedimentation rate averaged 1.6 cm per decade, therefore a 20 cm depth in lake sediment corresponds to approximately 125 years ago. Eleven of the lakes cored by Hunt (2003) were also sampled by the OGS with the coring torpedo. The geochemical results are very similar indicating that the OGS sampling methodology is successful at obtaining and discriminating between recent and pre-industrial sedimentation (Dyer *et al*. 2004).

DISTINGUISHING BETWEEN NATURAL & ANTHROPOGENIC SIGNALS AT SUDBURY

Environmental Disturbance in the Sudbury Area

A significant mining and smelting "footprint" exists in the Sudbury basin which hosts numerous world-class Ni-Cu-PGE deposits. This footprint poses a challenge for the use of lake sediment geochemistry in the region. Whether the objective is baseline geochemical mapping or mineral exploration, it is difficult to "see" through the ecological disturbance of the past 100 years to understand background geochemical conditions as they would have existed prior to industrial activity.

Environmental impact in Sudbury and the surrounding area is mainly due to smelter emissions. By the early 1970s, these had resulted in vegetation loss or damage over approximately 720 km^2. This disturbance is manifest as acidified lakes, metal-contaminated lake sediments and indirect effects resulting from damage to vegetation in the lake basins. These disturbances have been amplified due to the presence of Precambrian bedrock that offers very little buffering capacity and the presence of carbonate-poor drift materials over the region, which cannot neutralize the acidity formed in the by-products of Sudbury's mining industry.

The Lake Sediment Geochemical Response in the Sudbury Area

The distribution of Ni in lake sediment for the Sudbury area is displayed in Figure 2. Most of the regional distribution of Ni is spatially associated with Sudbury Igneous Complex (SIC) rocks, which host most of the Ni mineralization in the Sudbury basin. Anomalies from lakes in close proximity to tailings/slag/waste rock may have, in part, an anthropogenic component due to much higher than average sedimentation rates (resulting in more than 20 cm of young sediments). The pattern of elevated Ni concentrations south of the basin is probably due to the effect of glacial and hydromorphic contributions into the lake basins. The elevated Ni pattern that extends further to the south may be in response to the presence of the Ni-mineralized Copper Cliff offset dike and Nipissing gabbro rocks, in addition to glacial dispersal southward from the Ni deposits contained with the south range of the SIC.

The close association of the lake sediment geochemistry with SIC rocks and Ni mineralization indicates that the OGS protocol of sampling a discrete depth interval of deeper sediments is successful in obtaining relatively undisturbed and uncontaminated sediments in the vast majority of cases.

CONCLUSIONS

The OGS lake geochemical sampling program was designed to obtain a high density, high quality natural geochemical signal from both pristine and disturbed landscapes. It is intended both as a record of natural baseline conditions in pre-industrial sediments and a mineral exploration tool. An excellent example of this is the high density survey over the Sudbury region, where, despite the significant mining activity and significant ecological disturbance, the OGS lake sediment sampling methodology was successful in obtaining relatively undisturbed and uncontaminated deep sediments in the vast majority of cases. When viewed in Google Earth, the close association of the lake sediment geochemistry and SIC rocks is immediately apparent, as are other geochemical trends that are directly related to the effects of geology.

The ease with which geochemical data can be visualized in Google Earth has important implications to geochemistry beyond the display of OGS data. This platform is not hindered by the size of the geochemical dataset, and it can reach a worldwide audience. As such, Google Earth could be the platform for the integration of other provincial or continental scale geochemical mapping efforts, ultimately leading to a widely and easily accessible geochemical map of the Earth.

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Developing an exploration/environmental geochemical database on a shoestring budget

Ronald R. McDowell[1], Katharine L. Avary[1], David L. Matchen[2],
James Q. Britton[1], J. Eric Lewis[1], & Paula J. Hunt[1]
[1]West Virginia Geological and Economic Survey, 1 Mont Chateau Road, Morgantown, WV 26508 USA
(e-mail: mcdowell@geosrv.wvnet.edu)
[2]Department of Physical Science, Concord University, Box 1000, Athens, WV 24712 USA

ABSTRACT: The West Virginia Geological and Economic Survey (WVGES) has been building a stratigraphic, geochemical database since 1997. Piggybacking geochemical sampling together with field work undertaken for other ongoing Survey research projects, it has been possible to assemble a suite of nearly one thousand rock samples representing approximately 90% of the State's stratigraphic units exclusive of coal-bearing strata (represented geochemically in a separate database). Analytical costs have been kept to a minimum by utilizing a commercial laboratory which caters to the mineral exploration industry. Although data were initially stored in spreadsheet format, the inclusion of geographic coordinates allowed the database to be converted to a form that can be queried, analyzed statistically, and displayed using readily available, GIS software. Since its release to the public in 2001, the geochemical database has been utilized by other State agencies and by the mineral industry to answer specific questions regarding the metal content of the State's bedrock.

KEYWORDS: *database, geochemistry, West Virginia, bedrock, metals*

INTRODUCTION

Since 1997, staff members of the West Virginia Geological and Economic Survey (WVGES) have been building a geochemical database for the State's bedrock units to be used for the dual purposes of mineral exploration and environmental quality assessment. The results of these efforts were first released to the public in 2001 when the number of sample analyses in the database reached approximately five hundred (McDowell, 2001). Prior to the initiation of this project, bedrock geochemical data for West Virginia was only available in print, scattered throughout a variety of WVGES publications. Extant information was limited to geochemical analyses (done principally by *wet chemistry*) of economic materials and minerals such as iron and manganese ore, salt, aggregate, limestone, sandstone, shale, and coal. The only other comprehensive set of geochemical data currently available electronically for West Virginia is data on trace elements in the State's coals (Grady 2002).

Funding for this project has been and continues to be limited by fiscal constraints on State Government spending. Nevertheless, by combining sample collection with geological reconnaissance being done for the United States Geological Survey's (USGS) STATEMAP bedrock mapping program and utilizing commercial laboratories for geochemical analyses, we have been able to create a publicly accessible database containing nearly a thousand samples and representative of a large portion of the State's igneous, metamorphic, and sedimentary rocks. The database comprises a multisheet Excel® workbook. Individual samples within the database are segregated by stratigraphic unit – each worksheet contains all analyses available for samples from a single formation. Because a geographic location is recorded for each sample, it has been possible to migrate all of the information from the database into ARCGIS® allowing the data to be queried, analyzed statistically, and displayed in ways not possible with a simple spreadsheet. The database continues to grow as samples collected during each year's field work are analyzed and the results added.

SAMPLING AND ANALYSIS

Sampling is done concurrently or as an adjunct to geological reconnaissance; each sample is taken opportunistically during outcrop examination. The standard information recorded at an outcrop in preparation for later making a geologic map is recorded for each sample. This includes a location generated and recorded in the field by GPS unit. Generally, 2 kg samples are collected at each site to insure that enough material is available for repeated geochemical analysis if necessary and thin section preparation if desired. All team members have been trained to collect the freshest possible rock samples, free of debris and organic matter and to assign a unique sample number to each; samples are turned over to the team leader (McDowell) when everyone returns to the office from the field. The team leader is responsible for transcribing field information into the electronic database. This is the most time-consuming step in the entire process because initial data are recorded with pencil and notebook and must be typed into spreadsheet format.

WVGES has not had analytical laboratory facilities since the 1970's so contract geochemical analyses are a necessity. After considering a variety of sources for analytical work including both university and government laboratories, we decided to use a commercial lab, located in Ontario, which specializes in analyses for the mineral exploration industry (they have since expanded into the environmental field as well). For the sake of consistency, each sample is analyzed using the same set of techniques, a combination of Instrumental Neutron Activation Analysis (INAA) and Selective Extraction-Ignition Coupled Plasma spectroscopy that yield results for 49 elements - Au, Ag, As, Ba, Br, Ca, Co, Cr, Cs, Fe, Hf, Hg, Ir, Mo, Na, Ni, Rb, Sb, Sc, Se, Sn, Sr, Ta, Th, U, W, Zn, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Cu, Pb, Mn, Cd, Bi, V, P, Mg, Ti, Al, K, Y, Be, and S.

We have been well pleased with the commercial lab's low cost-per-sample, reliable and consistent turnaround time for analyses, and continuing diligence in maintaining ISO standards of quality control on analytical procedures. Addressing these issues (especially, cost and turnaround time) seems to be a problem for academic and government laboratories. For example, we estimate that the cost-per-sample would double or triple if we used a non-commercial laboratory, assuming we could find one capable of performing comparable analyses. By the same token, turnaround times from non-commercial labs might be as much as five or six times longer than for commercial facilities.

COVERAGE AND UTILITY

Because geochemical sampling was originally conducted exclusively along with bedrock mapping, the initial geographic distribution of samples within the State was limited to Pendleton County, West Virginia (Figure 1). It should be noted that this study area was specifically chosen because of its geologic complexity. Although small in size (approximately 700 ha), it contains rock units ranging in age from Ordovician through Tertiary, excluding only the coal measures. As such nearly 90% of West Virginia's stratigraphic units are found in the initial study area.

As the database has increased in size, interest in expanding its geographic scope to a truly Statewide enterprise (the original intent) has also increased. In 2008, the State's Mapping Advisory Committee recommended just such an expansion. Fortunately, this undertaking can be readily accomplished because the only real requirements for adding samples taken elsewhere in the State are the necessities of identifying the stratigraphic unit being sampled, maintaining consistency in sample description, recording the sample's geographic location, and, of course, collecting the sample. To date, workers from WVGES' Oil and Gas and Coal programs have

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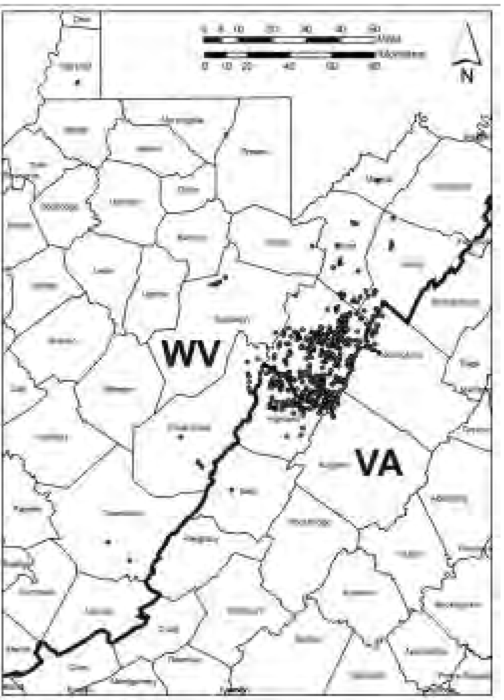

Fig. 1. Location of geochemical samples taken during STATEMAP reconnaissance and as part of other WVGES projects, 1997-2008. Initial sampling centered on Pendleton County, West Virginia (indicated by the heavy concentration of sample points) but geographic distribution has been slowly increasing over the past five years due to increased interest in the project and changing focus of bedrock mapping efforts. Notice that a number of geochemical samples were also collected in neighbouring Virginia during cooperative mapping efforts. The results of analyses for those samples have been shared with the Virginia Division of Geology and Mineral Resources (VDGMR).

contributed samples from other parts of the State to the program.

In 2002, the West Virginia Department of Environmental Protection (WVDEP) used analytical data for the Silurian Tuscarora Sandstone in assessing the potential environmental impact of proposed new quarrying operations in that unit. In 2006, the West Virginia Department of Highways (WVDOH), used analytical data for the Devonian Mahantango Formation to evaluate a legal dispute over the valuation of property containing a quarry in that unit. In 2008, a controversy arose over the levels of selenium in water draining from coal mine spoils in southern West Virginia. Thus far, WVGES has utilized geochemical data on the selenium content in West Virginia coals (Grady 2002) and bedrock (McDowell 2001) to help pinpoint the exact source of the contamination. In addition, one example of a mineral exploration use of the database was a recent industry inquiry as to which rock units in the State were a potential source of both potassium and aluminum for use in making ceramics.

CONCLUSIONS

By piggybacking sample collection with existing bedrock mapping projects and utilizing the services of commercial analytical laboratories, it has been possible to build a publicly accessible database of geochemical data that has grown over the past eleven years to include the results of analyses for nearly 1,000 samples from 38 of West Virginia's bedrock units. The database is sufficiently populated for each of these units to allow the establishment of elemental background levels in the majority of these stratigraphic units and to perform comparative and discriminatory statistics between units. Consequently, it is now possible to assess new rock samples to determine if their elemental content should be considered anomalous (useful for mineral exploration purposes). By the same token, it is possible to evaluate potential sources of contamination in light of typical concentrations of metals that can be expected in the local bedrock.

ACKNOWLEDGEMENTS

Partial funding was provided by various USGS STATEMAP contracts. Consultation with the geologists of the Virginia Division of Geology and Mineral Resources is gratefully acknowledged. We would also like to thank numerous private landowners of eastern West Virginia and western Virginia for granting permission to cross property boundaries and collect samples.

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The value of government-generated geochemical data, and an example of its delivery

Paul Morris[1]
[1]*Geological Survey of Western Australia, Department of Mines and Petroleum, 100 Plain Street, East Perth 6004 AUSTRALIA*
(email: paul.morris@dmp.wa.gov.au)

ABSTRACT: Regional scale (i.e., sample density of 10^n km^{-2}, n > 1) geochemistry are routinely used in mineral exploration, yet the cost and time required to generate do not fit well into company exploration strategies in terms of cost and time. In this context, there is clear role for government to both generate and disseminate geochemical data. The benefit of government involvement is demonstrated by a three-fold increase in exploration activity following release of government geochemistry in Western Australia. Delivery of geochemical data via the web in a standard format using a limited number of queries has been developed by the Western Australian government. The approach combines rigorous data standards for incoming data, the ability to store QAQC information, and coupling the data with validated information for sample location and lithology. The database contains > 24 000 analyses derived from > 300 individual batches generated by eleven government, university and commercial laboratories.

KEYWORDS: *Geochemistry, database, government, exploration, world wide web*

INTRODUCTION

Despite the increased use in mineral exploration of remotely-sensed data (e.g. airborne geophysics, Aster™, Landsat™, Hymap™), there is a continuing demand for regional-scale geochemical datasets, especially those composed of multi-element analyses accompanied by quality control and quality assurance (QA-QC) data, which can be used in the exploration of a variety of commodities. Government organisations have provided these data in Australia (de Caritat *et al.* 2008), the United States and Canada (Kettles *et al.*, 2008), and Europe (Smith & Reimann 2008). In many jurisdictions (including Western Australia), the alternative provider is the mineral exploration industry, where geochemical data form part of exploration reporting requirements, with data subsequently released to the public release after a set time period. Even though these data compare favourably with government-sourced data in some respects (sample media, analytical techniques), there is often some disparity in terms of sample density or extent (i.e. scale), scope, data quality, metadata quality, availability, and QA-QC (Table 1).

Aside from these issues, several factors can influence whether exploration companies are willing to consider generating their won regional geochemistry datasets. For example, mineral exploration over an area of 1000 km^2 in Western Australia involves costs in the first year of > $370 000 in terms of an application fee, rent, security, and minimum expenditure requirements, with legislation requiring relinquishment of 50% of the tenanted ground each year. Apart from the additional costs of sample collection and analysis incurred by geochemical programs, surveys must be completed to the stage of data interpretation within a 12 month period following ground acquisition.

In response to the need for regional geochemical coverage, GSWA generated multi-element regolith geochemical datasets based on a one sample/16 km^2 and covering an area > 300 000 km^2 over the period 1994 - 2001 (e.g. Morris and Verren, 2001). As part of its regional mapping program, GSWA routinely generates > 500 multi-element analyses of rocks and regolith. GSWA has embarked on joint ventures with federal agencies (CSIRO and Geoscience Australia), and the success of these projects can be gauged by a low-density (1 sample/70km^2) multi-element laterite geochemistry program for 3150 samples over the southwest of Western Australia, which resulted in a three-fold increase in tenement uptake from 5136 km^2 month prior to data release, to 15 102 km^2 in the month following (Cornelius *et al.* 2007).

In addition to generating these data, it is also necessary to ensure that they are disseminated via an easily accessible interface, along with appropriate metadata. A major initiative, undertaken in 2004 by GSWA, was to design and populate a corporate geochemical database of all GSWA geochemical data, and to serve these data to the public via a web interface, in a standard format, free of charge. The resulting corporate database (WACHEM) is accessed by GSWA's web interface, GeoChem Extract (www.dmp.wa.gov.au/geochem).

STRUCTURE OF WACHEM AND GEOCHEM EXTRACT

WACHEM is a fully relational database on a SQL (structured query language) platform that uses the DataShed™ data management system software model for loading and storage of data. The DataShed™ base model has been customised to GSWA's needs, including the content of various look-up tables to ensure that incoming data are 'clean' in terms of data type (e.g. text versus numeric) and batches contain the minimum requisite amount and type of data. A modification allows the storage of information on pre-analysis sample preparation (i.e. screening, crushing, milling), recognising that results from increasingly sophisticated analytical techniques can be influenced by contamination during sample preparation. To maintain data quality, each analytical batch must list a recognised element or oxide name, unit of measurement, laboratory technique (as a laboratory-specific acronym), and lower level of detection (LLD). The database can also store related QAQC data for duplicates (i.e. a second analysis of the parent pulp) and reference materials.

GSWA's GeoChem Extract application draws together data from the WACHEM and WAROX databases. The latter is the repository of all field-based point data generated by GSWA, and is used throughout the organisation to automatically create various layers for GSWA maps (e.g. structural symbology), geochronology compilations (sample location, rock, type), and will eventually underlie an online version of map-related explanatory notes.

To date, the WACHEM database contains 24,200 analyses made up of 323 separate analytical batches sourced from eleven laboratories. In order to maintain a dynamic database, the contents of available data are updated daily using a series of stored procedures, with each data download appropriately time stamped.

DATA ACCESSIBILITY

To achieve a simple user interface, GeoChem Extract relies on a either downloading the whole database, or extracting data according to a limited number of spatial queries (Fig. 1). All selected data are presented as a comma-separated (.csv) file of locational and lithological data (WAROX) and geochemical data (WACHEM), for easy manipulation in third-party software. Embedded in the file is a hyperlink to the batch for each sample. Batch data can be accessed and downloaded, providing information on analytical techniques, detection levels etc and any available QAQC data.

CONCLUSIONS

Government organisations are well placed to generate regional geochemical datasets, in that they are not subject to the time and cost constraints which form part of mineral exploration legislation. These data are usually multi-element and include QA-QC data which mean the data are well suited to multi-commodity exploration and evaluation in terms of data quality. The

Table 1. Comparison Of Government And Exploration Company Geochemical Datasets.

	Government	**Exploration Company**
Scale (10^n km^{-2})	$1 < n < 4$	n typically < 1
Number of elements	Broad (multi-commodity)	Narrow (commodity-focused)
Sample media	Usually limited	Usually limited
Analytical techniques	Varied	Varied
Data quality	Usually good	Variable
Metadata quality	Usually good	Variable
Availability	Good (often digital)	Limited (usually hardcopy)
QAQC	Usually tabulated	Occasionally tabulated

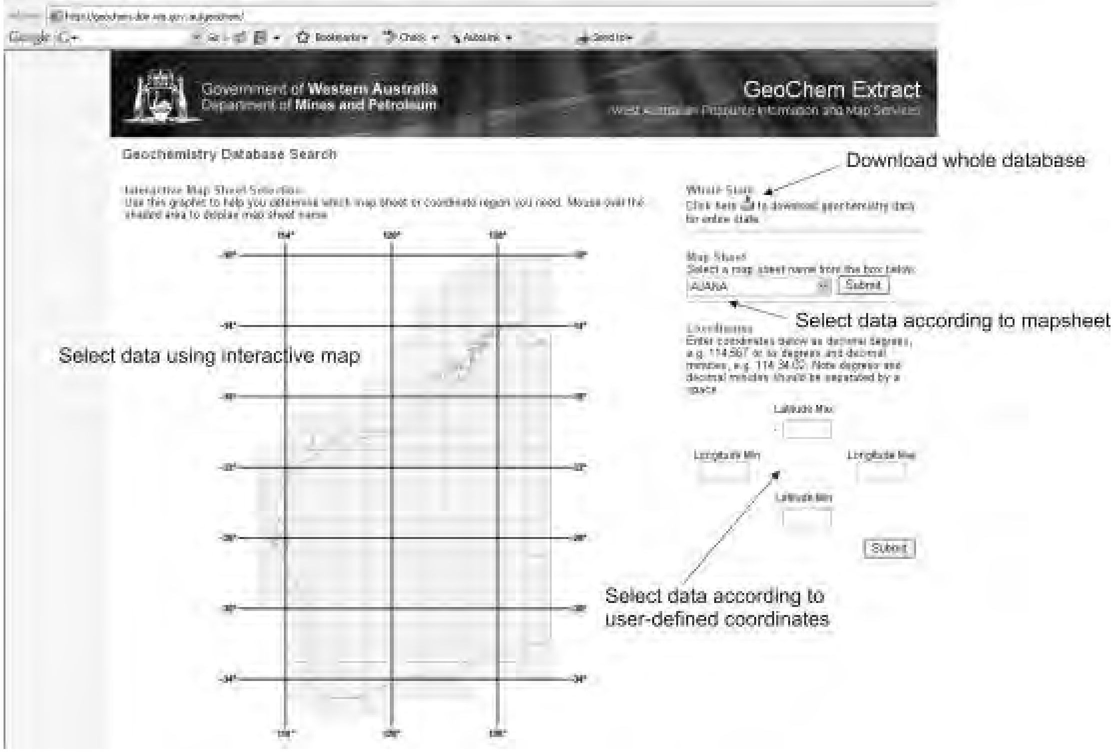

Fig. 1. GeoChem Extract introductory screen showing the four options for accessing data.

Geological Survey of Western Australia has combined its regional geochemical data with other lithogeochemical information in a corporate database, and delivered the data via a customised web application which combines validatedlocational, lithological, and geochemical data. A series of simple, largely spatially-attributed search tools result in generic file formats that are easily imported into third party software for further manipulation. Hyperlinks in these data provide information on individual batch conditions. At present, the available data comprise > 24 000 analyses from > 300 analytical batches generated by eleven laboratories.

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Using stream sediments for environmental geochemistry in Austria

Sebastian Pfleiderer[1], Albert Schedl[1], & Herbert Pirkl[2]
[1]*Geological Survey of Austria, Neulinggasse 38, 1030 Wien AUSTRIA (e-mail: pflseb@geologie.ac.at)*

ABSTRACT: The dataset of stream sediment analyses in Austria consists of 36,136 samples analyzed for 34 chemical elements. Formerly used for mineral exploration, the data now serve for environmental geochemistry studies. These include the derivation of natural background levels of different rock units, the investigation of chemical fluxes between soil, rock and groundwater and the evaluation of emission risks of historical mine waste. Natural background levels are derived in lithologically homogeneous areas away from mining sites or mineralization. Homogeneity is defined on the basis of catchment areas. Chemical fluxes between soil, rock and groundwater are traced by studying regional distribution patterns as well as temporal dependencies. While most of the major elements in soils and groundwater are lithology-controlled, Cl, NO_3, SO_4, Pb, and Cd are strongly affected by precipitation. Within areas of historic mining, univariate and multivariate statistics serve to identify areas with elevated heavy metal concentrations. Lead and zinc mineralizations are easily identified by factor analysis. Detailed mineralogical phase analysis is used to distinguish between natural and anthropogenic sources and to determine the origin and transport of industrial particles in the environment.

KEYWORDS: *stream sediment, natural background levels, chemical fluxes, phase analysis, historical mine waste*

INTRODUCTION

The country-wide dataset of stream sediment analyses in Austria consists of 36,136 samples analyzed for 34 chemical elements (Fig. 1), (Thalmann *et al*. 1989). Complemented by local surveys of hydrochemistry, whole rock geochemistry, soil chemistry and mineralogical phase analyses, these data are used to derive natural background levels of different rock units, investigate chemical fluxes between soil, rock and groundwater, and evaluate the emission risks of historical mine waste.

NATURAL BACKGROUND LEVELS

Natural background levels of different rock units can be derived by either correlating element concentrations of stream sediment analyses with geological maps, or morphological catchment areas (Fig. 2). When using geological maps, statistics for a given unit are calculated using all sample points contained within all the polygons of that unit, whereas when using catchments, the lithologies within all catchment areas are derived automatically and only point samples in homogeneous areas are used to define natural background levels.

While the first method gives a quick visual overview of ranges, the second, more sophisticated method leads to a more detailed correlation. In both cases, the correspondence between stream sediment and whole rock geochemistry is not perfect since sediments represent only the weathered product of rocks (Pfleiderer *et al*. 2008). Lithologically homogeneous areas away from mining sites or mineralization are used to derive natural background levels.

CHEMICAL FLUXES BETWEEN SOIL ROCK AND GROUNDWATER

For long-term quality assurance of drinking water reserves in large karst areas, the chemical characteristics of different soils, rocks, stream sediments and aquifers are analyzed with respect to the exchange of chemical substances between media (Fig. 3). The origin and mobility of heavy metals are traced and egional as well as seasonal dependencies are studied.

Regional distribution patterns in the data show that lithology is responsible for the amounts of Ca, Mg, K, Na, Al, Si, and SO_4 in soils and groundwater. Cr, Ni and Cu pass from rocks into groundwater, and show up in stream sediments, but do not affectsoils. Concentrations of Cl, NO_3 and SO_4 show a temporal dependence on precipitation suggesting rain as the source of input into soil and groundwater. Equally, Pb and Cd originate from emission. (Pirkl 2005). These two elements pass through all media and end up in the groundwater, their concentrations occasionally exceeding the limits of drinking water standards.

MINE WASTE EMISSIONS

Combining data from stream sediment analyses with data on historic mining areas, the emission risks of old mine waste sites are evaluated systematically throughout Austria. Univariate and multivariate statistics serve to identify areas with naturally, or anthropogenically, elevated heavy metal concentrations (Fig. 4). Lead and zinc mineralization for example are easily identified by factor analysis (high factor loadings for Ba, Cd, F, Pb, S, and Zn). Natural background levels in the vicinity of historic mining areas, potential risks of emission and maximum possible propagation of pollutants are then estimated.

However, factor analysis cannot always distinguish between naturally elevated heavy metal concentrations and anthropogenic pollution. In specific areas, detailed mineralogical phase analysis is used to make this distinction and to determine the origin and transport distance of industrial particles in the environment (Neinavaie *et al.* 2000).

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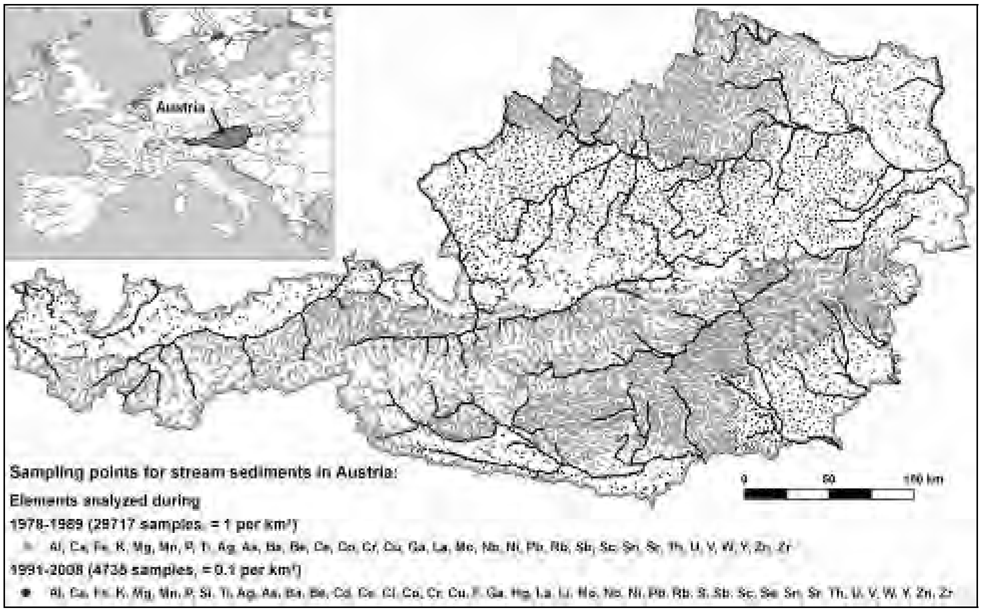

Fig. 1. Location of sampling points for stream sediments, Austria.

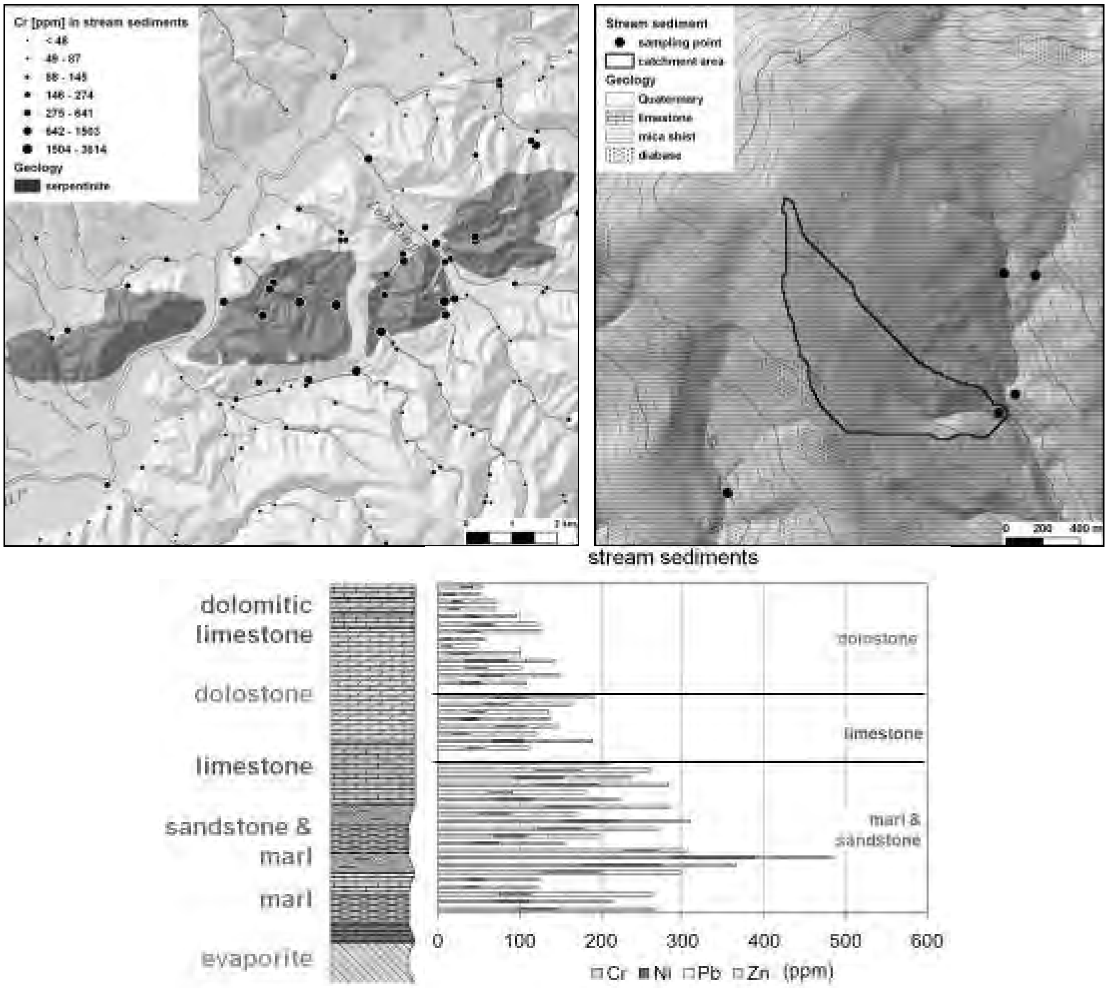

Fig. 2. Derivation of natural background levels by (a) superimposing sample points on geological units (left) and by (b) relating sample points to catchment areas (right).

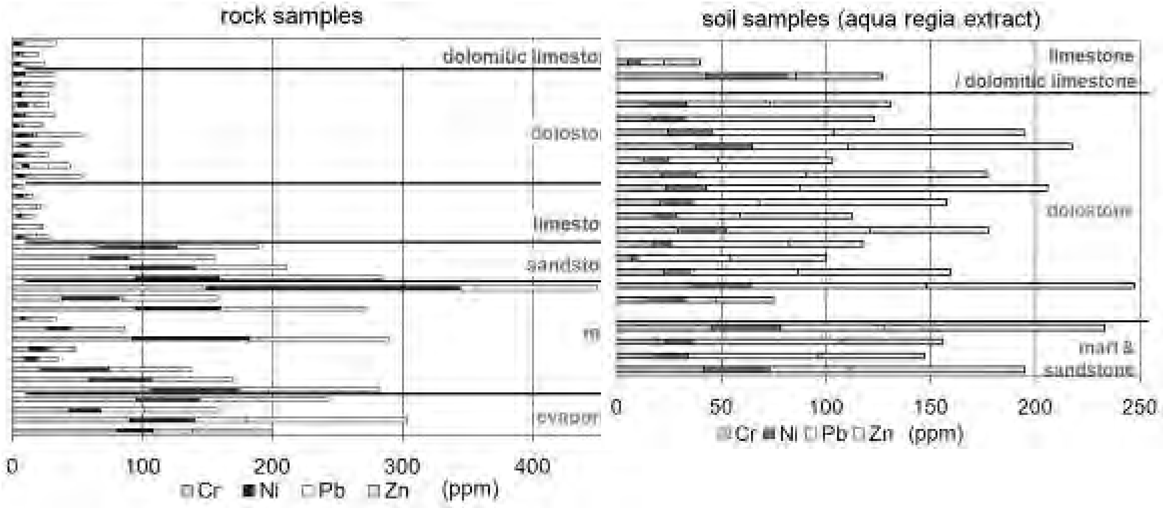

Fig. 3. Chemical analyses of Cr, Ni, Pb and Zn in rocks, soils and stream sediments.

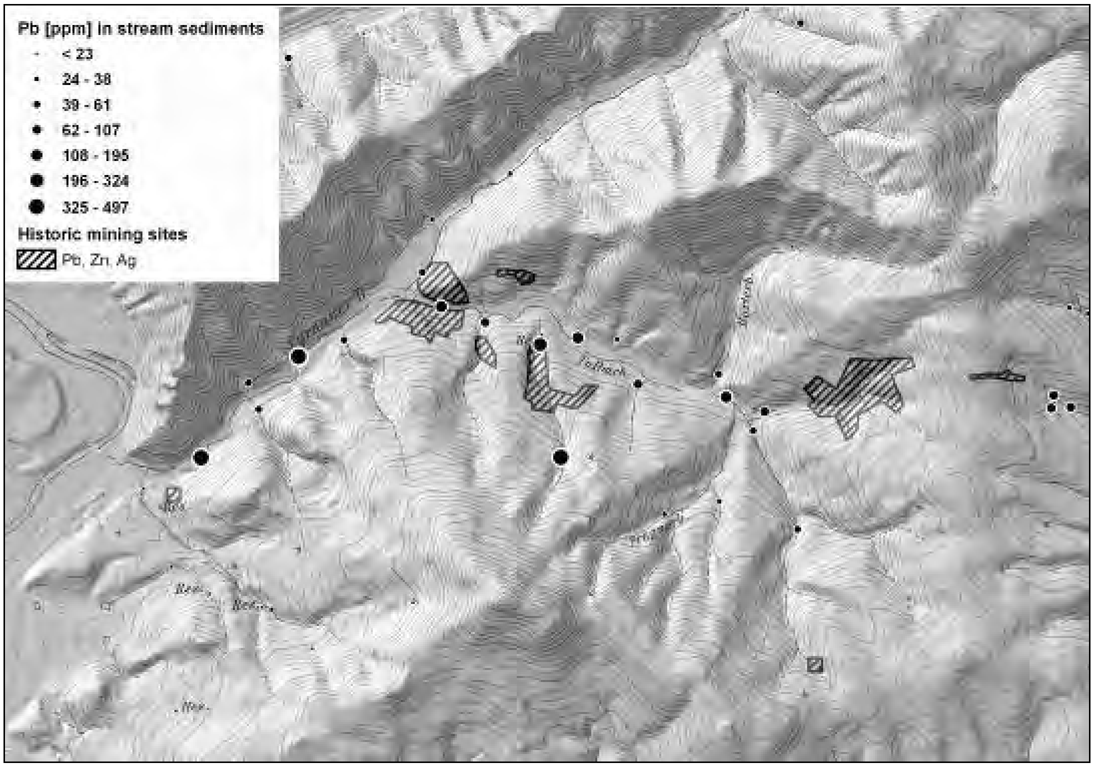

Fig. 4. Elevated Pb concentrations in stream sediments of an historic mining area.

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Surficial geochemical studies in support of non-renewable mineral resource assessments, Northwest Territories, Canada

Toon Pronk[1], Roger C. Paulen[2], Andrea Mills[3], & Adrian Hickin[4]
[1]New Brunswick Department of Natural Resources, P.O.Box 6000, Fredericton, NB, E3B 5H1 CANADA
(email: toon.pronk@gnb.ca)
[2]Geological Survey of Canada, 601 Booth Street, Ottawa, ON, K1A 0E8 CANADA
[3]Newfoundland Geological Survey,Natural Resources Building,P.O. Box 8700,St. John's, NL, A1B 4J6 CANADA
[4]Development and Geoscience Branch, British Colombia Ministry of Energy, Mines & Petroleum Resources, 6th Floor, 1810 Blanshard Street (PO 9333 Stn Prov Gov't), Victoria, BC, V8W 9N3 CANADA

ABSTRACT: The Non-renewable Resource Assessment is a legislated requirement in the Northwest Territories' Protected Area Strategy and is used to facilitate informed decision making on land use issues, special management areas, protected areas, and the establishment of territorial parks. Two Resource Assessments detailing the Mineral and Petroleum potential of the proposed protected area are completed for each area. If these protected areas are granted as such, it is possible that this study may be last geochemical/mineralogical survey conducted within the boundaries of any area that is a candidate for protection. The NRA process is designed to provide as much information as possible on the mineral potential of the proposed protected area and it covers a multitude of potential mineral deposit targets. Thus, an extensive suite analysis is carried out on tills including geochemical analysis of the -63 micron fraction of the indicator minerals. Indicator minerals from a wide variety of deposit types, e.g. kimberlite, base and precious metals and other pathfinder minerals are being evaluated from bulk glacial sediment samples as well. In areas of low relief, basal till is the targeted sample medium whereas in areas with higher relief, stream sediments, and waters as well as pre-concentrated and screened bulk stream sediments are the target media. Since some of the proposed protected areas are composed of low-relief as well as mountainous areas, sometimes a hybrid approach has been employed. The objective is to provide detailed and pertinent information in support of balanced decision-making.

KEYWORDS: *Resource assessment, Northwest Territories, geochemistry, indicator minerals, land use*

INTRODUCTION

The goal of the Northwest Territories (NWT) Protected Areas Strategy (PAS) is to protect culturally and ecologically important areas within the NWT. The PAS attempts to balance the needs of the present with the needs of the future by providing a process by which communities can identify and protect significant cultural and ecological areas prior to future development (NWT PAS, 2007). It is to be a comprehensive and inclusive process. The NWT's PAS is set with the Mackenzie Valley Action Plan and is sensitive to First Nations land claims. One major issue for both territorial and federal government, as well as communities, is balancing the level of development and/or protection for an area.

The Non-renewable Resource Assessments (NRAs) are part of step 5 in an 8-step process that may ultimately result in (partial or limited) protection of certain areas from development. Phase 1 of an NRA is a desktop exercise that evaluates all existing mineral deposit and survey data for an area from all sources, determines knowledge gaps of the mineral potential, and suggests an approach for Phase 2 follow-up work. Phase 2 of the NRA typically involves field and analytical work designed to lead to a better understanding of the resource potential for a candidate protected area.

Each proposed protected area (PPA) is represented by a Working Group comprising a sponsoring agency, federal, territorial, and band council

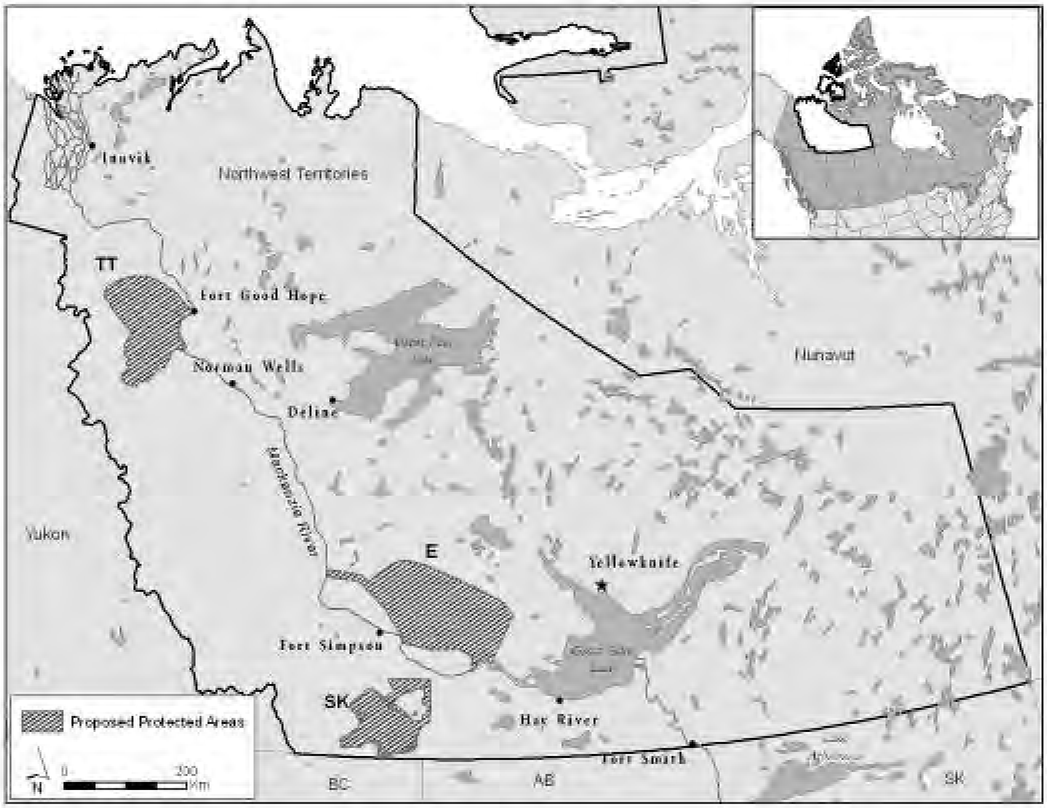

Fig. 1. Location of the three Proposed Protected areas in the Northwest Territories: TT = Ts'ude niline Tu'eyeta (Ramparts River wetlands), E = Edehzhie (Horn Plateau), and SK = Sambaa K'e (Trout Lake).

representatives and interested members of neighbouring communities.

Cooperation is imperative in this process, and education and outreach go hand-in-hand with consensus building. Community meetings are part of the process and an understanding of the First Nations cultural landscape is an importantasset. Some of the proposed protected areas also play in land claim settlements between the federal government and First Nations people.

This paper deals with three different proposed protected areas that are in different stages with respect to their NRAs; Edehzhie (Horn Plateau), Ts'ude niline Tu'eyeta (Ramparts), Sambaa K'e (Trout Lake). Thus for the three areas different issues and/or stages will be highlighted. All three areas lie (at least partly) within the Western Canada Sedimentary Basin.

GEOLOGICAL SETTING

The three proposed protected areas lie within the Western Canada Sedimentary Basin (WCSB). This basin is wedged between the Canadian Shield and the Rocky Mountains and consists of largely near-horizontal lying sedimentary rocks of Devonian to Cretaceous aged limestone, dolostone, anhydrite, shale, siltstone, and sandstone (Gal 2007). The Quaternary geology of the Sambaa K'e area was most recently described in Huntley *et al*. (2008) as part of Geological Survey of Canada mapping of the Mackenzie Valley corridor. The late Wiconsinan glacial history of the area is relatively simple as the Laurentide Ice Sheet (LIS) moved across the area from the northeast. Ice thickness in excess of 1000m is implied by the presence of granitic erratic boulders at 1588m elevation in the eastern Foothills

(Bednarksi & Smith 2007). The LIS advanced into the WCSB in the Late Wisconsinan. A wood fragment recovered from a till exposure in a riverbank within the Sambaa K'e area dated 35,570 +/- 330BP (AMS date Beta Analytic Inc. - 249392) South of the Sambaa K'e area, Late Wisconsinan Laurentide glaciations is bounded by a younger date of 24,400 +/- 150 BP (Levson *et al.* 2004). During de-glaciation, meltwater and meteoritic drainage was temporarily routed to the south and many outwash channels are present in the landscape around Trout Lake. Huntley *et al.* (2008) provides more detail in regard to the (de-)glacial history and landform assemblages of the area.

The Phase I NRA (Pronk 2008) made an initial assessment of the mineral potential of the area and makes recommendations for the type of survey that should be carried out for further mineral resource assessment (strategy for Phase II).

METHODOLOGY

Field work methodology follows Paulen (2009) and was closely adhered to for the till survey component of the work, while National Geochemical Reconnaissance protocols (Friske & Hornbrook 1991) were followed in the more mountainous areas of Ts'ude niline Tu'eyeta. These methodologies have both been successfully used throughout the WCSB, in some instances as a single method, or in combination with other methods (Prior *et al*. 2009).

In the till surveys the targeted sample density was one sample/100km^2. This density was not attained in Ts'ude niline Tu'eyeta; largely because of the presence of unsuitable sample material at the surface (glacio-lacustrine sediments and organic deposits as well as the added caveat of permafrost in some areas). The sample density target was slightly surpassed in the Sambaa K'e PPA (1 sample/92km^2). Samples were taken at depths between 40 and 110cm in hand-dug pits and in river cuts, below the oxidized soil zones where possible. Sample depth at Sambaa K'e was considerably more than in Ts'ude niline Tu'eyeta, where permafrost often limited the sampling depth, although frost boils were alternatively used to access relatively unoxidized sample medium. These were especially recognizable in 'recent' areas razed by forest fires where the organic cover was removed.

SOME RESULTS AND CONCLUSIONS

Results of the Edehzhie survey (a hybrid survey) have been used to adjust suggested protected area boundaries and make compromises in light of mineral potential. There is a high kimberlite potential on the Horne Plateau, as suggested by the presence of indicator minerals and a small diamond recovered from a bulk stream sediment sample (Day *et al.,* 2007).

Potential for diamond-bearing kimberlites is also present Sambaa K'e area. There are basement and structural similarities with the Buffalo Head Hills kimberlite field, Alberta (Prior *et al*. 2007) and there is ongoing diamond exploration within the WCSB to the north as well. Further discussion has altered the potential boundaries for the proposed protected area on the Horn Plateau and discussions are ongoing before any permanent decisions are made by all parties involved. Analytical results for the remaining two areas are pending.

ACKNOWLEDGEMENTS

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Abundances of chemical elements in rocks, sediments, and the continental crust of China

Chi Qinghua[1] & Yan Mingcai[2]

[1]Institute of Geophysical and Geochemical Exploration, CAGS, Langfang 065000 CHINA
(e-mail: chiqinghua@igge.cn)
[2]Key Laboratory of Applied Geochemistry, CAGS, Langfang 065000 CHINA

ABSTRACT: This paper provides concise data sets of elemental abundances for various kinds of geological media of rocks, soils, stream sediments, and sea sediments in China. The data sets include the abundances of 39-76 elements in igneous rocks, sedimentary rocks, metamorphic rocks, soils, stream sediments, sea sediments, and the continental crust of China. The samples have a good representativity for various media and elements were analyzed by sensitive and accurate analytical methods under strict quality control using geochemical certified reference materials (CRMs). The abundances of many trace and ultra-trace elements such as Au, Hg, PGEs etc. are greatly improved. These data can be widely used for geology, geochemistry, environment and agriculture.

KEYWORDS: *Elemental abundance, rocks, sediments, continental crust, China*

INTRODUCTION

Elemental abundances in various types of geological media such as rocks, sediments and soils of China have been studied since 1980s. These data were published in many literatures (Chi & Yan 2007; Yan & Chi 1997, 2005; Ren *et al*. 1998; Zhao & Yan 1994; Zhu *et al*. 2006). To provide readers with a general overview and convenient use, the authors collected these published data and compiled a concise data set in this paper.

ABUNDANCES OF 76 ELEMENTS IN ROCKS

2,718 composite rock samples systematically were collected in China. The contents of 76 elements were determined by 15 analytical methods under quality monitoring with CRMs. The arithmetic mean is taken as the elemental abundances by rejecting the data beyond the range of X±2s. Abundances of 76 elements in igneous rocks of China, sedimentary rocks, metamorphic rocks of the eastern part of China were listed in Table 1 (Chi & Yan 2007; Yan & Chi 1997, 2005).

The estimated abundances of 76 elements in the continental crust based on a 36 km thickness crustal structure model, rock composition model and contents of elements in the eastern part of China was given in Table 1 (Yan & Chi 1997, 2005).

ABUNDANCES OF 39 ELEMENTS IN STREAM SEDIMENTS

The systematically representative stream sediments were collected by the regional geochemistry-national reconnaissance (RGNR) project in all over China. 39 elements were determined by 8 analytical methods (Xie & Ren, 1993). An average value is calculated from original data within each 1:25,000 map sheet (about 100 km^2, with about 25 original data for each element). There are 44,422 1:25,000 map sheets used for this calculation. The arithmetic mean is taken as the elemental abundance by repeatedly rejecting the data beyond the range of X±3s. The abundances of 39 elements in stream sediments of China are given in Table 1 (Ren *et al*. 1998).

ABUNDANCES OF 76 ELEMENTS IN SOILS

154 composite soil samples were collected in China. The contents of 76 elements were determined using 15

analytical methods. The arithmetic mean is taken as the elemental abundance by rejecting the data beyond the range of X±2*s*. The abundances of 76 elements in soils of China is given in Table 1 (Yan & Chi 1997, 2007).

517 composite soil samples were collected from alluvial plains in the eastern part of China. The contents of 70 elements were determined using 13 analytical methods. The arithmetic mean is directly taken as the elemental abundance for all analytical data with no rejection. The abundances of 76 elements in soils of alluvial plains of the eastern part of China are given in Table 1 (Zhu *et al*. 2006).

ABUNDANCES OF 62 ELEMENTS IN CHINA SEA SHELF SEDIMENTS

286 sediments of China Shelf Sea were collected under a seawater depth -200 m. The contents of 62 elements were determined using 10 analytical methods. The arithmetic mean is taken as the elemental abundance by rejecting the data beyond the range of X±2*s*. Abundances of 62 elements in sediments of China Shelf Sea are given in Table 1 (Zhao & Yan, 1994).

CONCLUSIONS

The data listed in Table 1 factually reflect abundances of chemical elements in various kinds of geological media of rocks, soils, sediments and in the continental crust of China, because the samples have a good representativity for various media and elements analyzed by high-quality analytical methods under strict quality control. These data can be widely used for geology, geochemistry, environment and agriculture.

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Table 1. Elemental abundances of rocks, soils, sediments, and the continental crust in China

Elements	Detection limits	Whole China				Eastern part of China										Whole China		
		Rocks												Conti-nental crust	Soils		Sediments	
		Acidic rock	Inter-mediate rock	Basic rock	Ultra-mafic rock	Sand-stone	Shale	Carbo-nate	Gneiss	Leptite	Amphi-bolite	Meta-pelite	Marble		Alluvial plain soils	Soils	Stream Sedi-ments	Shallow sea Sed-ments
Literatures	A	B, C	A	B, C	B, C	B, C	B, C	B, C	B, C	B, C	B, C	A	B, C	B, C	D	B, C	E	F
N		1249 (693)	198 (130)	184 (128)	91 (73)	425	210	207	201	82	77	149	38	2718	517	154	44422	286
n		10458 (6665)	1523 (1287)	1756 (1060)	503 (387)	5720	2027	2708	1786	901	628	1571	400	28253				
SiO_2	0.05	70.85	57.79	48.68	45.11	72.63	60.63	6.49	65.63	66.89	49.72	63.22	8.09	60.62	66.00	65.0	64.74	62.23
TiO_2		0.295	0.868	1.578	0.385	0.485	0.761	0.053	0.510	0.507	1.238	0.688	0.044	0.667	0.72	0.72	0.74	0.58
Al_2O_3	0.05	14.20	16.42	15.54	4.69	10.91	16.35	1.14	14.84	14.47	13.72	16.11	0.96	14.83	13.51	12.6	12.73	10.67
TFe_2O_3	0.01	2.98	7.58	11.26	10.41	3.66	5.89	0.70	5.03	4.56	12.74	6.09	0.62	6.53	4.70			4.4
Fe_2O_3		1.22	2.98	4.18	3.85	2.46	4.33	0.35	2.03	2.23	4.38	3.06	0.26	2.45	3.89			
FeO	0.1	1.60	4.18	6.44	5.96	1.09	1.42	0.32	2.73	2.12	7.60	2.75	0.33	3.71	0.74	1.2		
MnO		0.049	0.124	0.167	0.119	0.057	0.059	0.044	0.075	0.068	0.207	0.067	0.045	0.105	0.09	0.08	0.09	0.07
MgO	0.05	0.94	3.60	7.50	26.98	1.26	1.86	6.53	2.15	1.94	7.35	2.08	10.56	3.16	1.57	1.8	1.56	1.81
CaO	0.01	1.83	5.81	9.02	7.40	2.52	2.66	42.84	3.26	2.70	9.11	1.59	39.14	5.41	2.91	3.2	2.87	5.19
Na_2O	0.1	3.52	3.77	2.80	0.62	1.41	0.80	0.10	3.64	3.19	2.48	1.30	0.11	3.45	1.63	1.6	1.37	2.18
K_2O	0.02	4.00	2.09	1.18	0.26	2.40	3.45	0.34	2.87	2.88	1.00	3.90	0.23	2.31	2.47	2.5	2.40	2.23
P_2O_5		0.099	0.275	0.343	0.069	0.094	0.124	0.037	0.163	0.124	0.190	0.110	0.034	0.172	0.10	0.12	0.15	0.12
H_2O^+	0.2	1.07	1.49	1.70	3.25	2.56	4.56	0.74	1.34	1.88	2.10	3.26	1.02	1.50	3.9	4.2		
CO_2	0.01	0.32	0.38	0.45	0.55	1.72	2.15	40.45	0.31	0.38	0.40	1.02	38.72	1.15	2.0	2.7		4.00
Corg	0.01					(0.20)	0.38	0.20				0.38			0.34	(0.35)		0.62
Ag	0.02	0.060	0.053	0.056	0.046	0.052	0.050	0.056	0.057	0.060	0.053	0.054	0.042	0.055	0.072	0.080	0.094	0.063
As	0.1	1.7	1.7	1.8	1.1	5.0	7.8	3.2	1.3	1.8	1.6	7.2	2.5	2.4	10	10	13.3	7.7
Au	0.05	0.53	0.85	0.80	0.80	1.0	1.4	0.47	0.65	0.88	1.2	1.1	0.42	0.90	1.6	1.4	2.0	1.1
B	1	6.2	5.7	7.5	7.0	38	76	13	5.5	15	10	72	6.0	11	48	40	51	58
Ba	20	700	775	460	90	525	590	63	850	740	260	665	155	620	565	500	520	410
Be	0.1	2.7	0.91	0.50	0.15	1.6	2.3	0.60	1.4	1.9	0.4	2.3	0.54	1.4	2.3	1.8	2.3	2.0
Bi	0.05	0.24	0.090	0.085	0.090	0.18	0.34	0.070	0.090	0.14	0.11	0.29	0.064	0.15	0.31	0.30	0.50	0.33
Br	0.2	(0.2)	(0.3)	(0.4)	(0.4)	(0.3)	(0.4)	(0.5)	(0.2)	(0.2)		(0.3)	(1.0)	(0.25)	2.6	(3.5)		15
Cd	0.01	0.060	0.092	0.10	0.080	0.081	0.11	0.13	0.070	0.090	0.12	0.080	0.096	0.082	0.118	0.090	0.26	0.065
Cl	20	58	140	112	120	51	52	124	107	80	164	54	68	112	136	68		3400
Co	0.2	4.8	22	46	88	8.0	14	1.5	13	11	49	13	1.6	19	13	13	13	12
Cr	0.5	12	83	190	1630	39	72	7.5	53	48	240	70	5.5	76	65	65	68	60

Continued

Elements	Detection limits	Whole China				Eastern part of China											Whole China	
		Rocks												Continental crust	Soils		Sediments	
		Acidic rock	Intermediate rock	Basic rock	Ultramafic rock	Sandstone	Shale	Carbonate	Gneiss	Leptite	Amphibolite	Metapelite	Marble		Alluvial plain soil	Soil	Stream sediment	Shallow sea sediment
Cs	0.3	3.5	1.9	1.4	0.45	4.3	8.2	0.5	1.8	3.0	1.0	7.2	0.46	2.0	7.5	7.0		6.3
Cu	1	8.0	30	55	27	15	29	4.0	22	22	58	26	4.0	26	23	24	26	15
F	50	490	650	485	385	405	775	275	570	510	740	705	310	540	510	480	530	480
Ga	1	18.0	20.0	19.9	8.9	13.6	20.5	1.7	18.7	18.4	18.7	21.2	1.6	19	15.7	17.0		14
Ge	0.1	1.2	1.1	1.1	0.90	1.4	1.6	0.35	1.0	1.2	1.4	1.7	0.3	1.2	1.4	1.3		
Hf	0.2	5.0	4.6	3.5	1.0	5.5	5.8	0.34	4.8	5.2	2.6	5.6	0.29	4.5	8.5	7.4		6.0
Hg	2	6.6	6.9	7.8	6.0	15	27	18	6.0	6.7	8.5	11	9.0	7.0	25	40	69	25
I	0.1	(0.05)	(0.13)	(0.1)	(0.15)	(0.1)	(0.4)	(0.2)	(0.05)	(0.05)		(0.1)	(0.14)	(0.1)	2.2	(2.2)		18
In	0.01	(0.05)	(0.06)	(0.07)	(0.03)	(0.035)	(0.07)	(0.02)	(0.05)	(0.045)	(0.07)	(0.07)		(0.045)	0.054	(0.055)		0.09
Ir	3	(3)	(17)	40	(1350)	18	20	7	(30)	22	(85)	(28)	(6)	(20)		22		
Li	1	19	13	11	4	25	38	9	14	19	11	34	9	17	36	30	34	38
Mn	5	380	960	1310	920	440	460	340	580	530	1600	520	350	810	705	600	730	530
Mo	0.1	0.70	0.58	0.63	0.21	0.54	0.93	0.57	0.49	0.50	0.28	0.52	0.36	0.50	0.57	0.80	1.1	0.50
N	10	28	72	80	(50)	170	460	120	37	55	20	222	55	60	440	640		620
Nb	1	15	10.4	19	5.2	12	18	(2)	10	12	9	15	(3.4)	10	15.5	16	17	14
Ni	1	7.7	34	100	960	17	34	4.8	24	20	96	29	3.8	31	30	26	29	24
Os	6	(15)	(36)	60	(1300)	32	140	50	35	34	(140)	(50)	27	(40)		40		
P	5	430	1200	1570	310	410	540	160	710	540	830	480	150	750	475	520	655	500
Pb	2	24	15.5	13	8	18	23	8	16	18	12.3	19	8.6	15	23	23	29	20
Pd	0.1	(0.08)	0.42	0.63	2.6	0.30	0.78	(0.16)	0.42	0.50	2.2	0.58	(0.16)	0.75	0.52	0.65		
Pt	0.1	(0.06)	0.42	0.72	5.2	0.26	0.50	(0.12)	0.44	0.50	2.6	0.44	(0.15)	0.80	0.48	0.50		
Rb	2	140	58	31	7	78	130	9	82	95	29	140	7	70	107	100		96
Re	0.1	(0.25)					(1.4)		(0.4)					(0.1)		(0.1)		
Rh	3	(4)	(45)	60	(800)	12	25	4	28	26	150	25	(4)	(40)		17		
Ru	4	(7)	(12)	65	(3500)	28	58	15	30	27	(230)	45	(15)	(35)		60		
S	20	120	180	280	210	220	300	240	200	150	270	210	160	250	160	150		510
Sb	0.05	0.16	0.17	0.18	0.14	0.43	0.58	0.24	0.12	0.22	0.14	0.45	0.23	0.18	0.79	0.80	1.42	0.5
Sc	0.1	5.3	19	29	24	8.3	15	1.3	11	9.7	39	16	1.1	17	11	11		10
Se	0.01	0.033	0.058	0.085	0.050	0.073	0.17	0.070	0.060	0.065	0.11	0.12	0.040	0.070	0.10	0.20		0.15
Sn	0.2	2.0	1.3	(1.0)	(0.5)	1.6	3.0	0.5	1.2	1.9	1.1	3.1	0.5	1.4	3.1	2.5	4.1	3.0

Continued

Elements	Detection limits	Whole China				Eastern part of China										Whole China		
		Rocks												Conti-nental crust	Soils		Sediments	
		Acidic rock	Inter-mediate rock	Basic rock	Ultra-mafic rock	Sand-stone	Shale	Carbo-nate	Gneiss	Leptite	Amphi-bolite	Meta-pelite	Marble		Alluvial plain soil	Soil	Stream sediment	Shallow sea sediment
Sr	2	250	565	510	115	120	110	320	390	265	240	95	225	350	175	170	165	230
Ta	0.2	1.2	0.56	1.1	0.26	0.76	1.2	(0.1)	0.54	0.7	0.47	1.0	0.080	0.65	1.17	1.1		1.0
Te	10	(5)	(15)	(10)		(10)	(15)	(5)	(10)			(15)		(6)		40		40
Th	0.2	14.5	4.9	2.8	0.70	9.2	14	1.1	7.0	8.6	1.5	12.5	0.90	6.0	12	12.5	13.5	11.5
Ti	10	1770	5200	9470	2650	2910	4560	320	3060	3040	7420	4125	265	4000	4175	4300	4460	3500
Tl	0.1	0.73	0.36	0.24	0.15	0.51	0.68	0.14	0.47	0.54	0.23	0.76	0.16	0.42	0.66	0.60		0.30
U	0.2	2.5	1.15	0.70	0.35	2.1	3.1	1.2	1.05	1.45	0.50	2.5	0.77	1.3	2.3	2.7	3.1	1.9
V	5	33	135	210	110	60	115	13	70	71	260	103	12	112	87	82	87	70
W	0.2	0.85	0.47	0.50	0.3	1.1	1.7	0.27	0.41	0.72	0.44	1.8	0.56	0.6	1.7	1.8	2.7	1.5
Zn	2	45	90	110	78	51	80	18	65	65	120	88	18	76	64	68	77	65
Zr	2	160	180	150	50	195	210	16	175	185	110	200	13	160	250	250	295	210
Y	0.5	22	18	17	7.0	18	27	4.8	16.5	20	17	26	3.1	17	26	23	26	22
La	0.2	40	35	24	6.7	34	50	5.5	38.5	37	14	43	5.4	29	37	38	41	33
Ce	0.5	75	68	47	15.0	63	88	10.3	75	68	28	78	10	57	58	72		67
Pr	0.2	7.8	7.8	5.3	2.0	6.9	9.8	1.2	8.2	7.6	3.7	8.7	1.2	6.5	7.0	8.2		
Nd	3	30	34	24	7.2	28	40	4.6	32	31	16	37	4.5	26	27	32		29
Sm	0.1	5.3	6.1	5.1	2.0	5.0	7.2	0.95	5.3	5.4	3.9	6.8	0.80	4.9	5.2	5.8		5.6
Eu	0.05	0.90	1.7	1.8	0.67	1.05	1.4	0.21	1.3	1.2	1.4	1.4	0.20	1.3	1.1	1.2		1.0
Gd	0.1	4.9	5.4	4.7	1.7	4.5	6.2	0.88	4.4	4.6	4.3	6.0	0.70	4.3	4.5	5.1		
Tb	0.1	0.72	0.82	0.80	0.39	0.72	1.0	0.13	0.67	0.70	0.71	0.96	0.11	0.69	0.73	0.80		0.73
Dy	0.1	4.4	4.5	4.3	1.8	3.9	5.8	0.69	3.7	3.7	4.4	5.4	0.55	3.7	3.9	4.7		
Ho	0.03	0.90	0.90	0.85	0.35	0.77	1.2	0.15	0.77	0.77	0.85	1.1	0.11	0.77	0.92	1.0		
Er	0.05	2.6	2.4	2.2	1.0	2.2	3.2	0.42	2.1	2.3	2.6	3.2	0.28	2.2	2.4	2.8		
Tm	0.02	0.39	0.35	0.32	0.16	0.35	0.49	0.065	0.31	0.34	0.90	0.50	0.038	0.34	0.42	0.42		
Yb	0.2	2.4	2.2	1.9	0.99	2.1	3.0	0.42	1.9	2.1	2.4	3.1	0.25	2.2	2.4	2.6		2.2
Lu	0.02	0.38	0.34	0.31	0.16	0.33	0.47	0.065	0.30	0.33	0.37	0.48	0.035	0.33	0.39	0.40		0.34

EC: the eastern part of China. Concentration units: major components: %; Au, Hg, Pd, Pt, Re and Te: ppb; Ir, Os, Rh, and Ru: ppt; other elements: ppm.

Literatures: A: Chi & Yan (2007); B: Yan & Chi (1997); C: Yan & Chi (2005); D: Zhu et al. (2006); E: Ren et al. (1998); F: Zhao & Yan (1994)

The number of composite samples for analysis is indicated as “N” and the number of collected individual rock samples is indicated as “n”. The number of data without brackets is for major elements, while that with brackets is for trace elements; and those without brackets for the both mean that they are the same. The data of element abundance with brackets in the table are for reference.

Elemental bundance of intermediate rocks in China is average of dioritoids and andesitoids; Elemental bundance of metapelite in the eastern part of China is average of slate, phylite and micaceous schist.

CSIRO Exploration and Mining: the challenge of being pure, applied and relevant

John L. Walshe[1]
1CSIRO Exploration and Mining, PO Box 1130, Bentley, WA 6102 AUSTRALIA
(e-mail: john.walshe@csiro.au)

ABSTRACT: CSIRO Exploration and Mining is addressing practical challenges of mineral exploration in the modern era, particularly in Australia. This paper documents some of the scientific opportunities provided by these challenges and some of the progress made. A fundamental problem is to understand “Why the deposit is there and not there?” CSIRO has partnered with Geoscience Australia, state government surveys, universities and industry to develop a mineral systems approach (termed the “Five Questions”) to understanding what controls the location of major resources. The Embedded Researcher is one concept trialled in the Eastern Goldfields, WA, as a mechanism to promote the real-time transfer of concepts, data and promote the uptake of R and D in exploration.

KEYWORDS: *exploration, mineral systems, embedded researchers*

INTRODUCTION

Established as the Council for Scientific and Industrial Research (CSIR) in 1926, CSIRO is Australia's national science agency. CSIRO’s goals are the pursuit of innovative science and application for industry, society and the environment.

The roots of CSIRO’s Division of Exploration and Mining can be traced to the mineragraphic work of Stillwell and Edwards in the 1930s. They provided services directly to exploration, mining and processing companies. Research and development activities spread across the fields of mineralogy, geochemistry and geophysics through the 1960s and 1970s as CSIRO engaged with Australia’s expanding minerals industry. A focus on practical outcomes and a willingness to collaborate with industry from the detail of the early exploration stage through to the mining of resources continues with the Minerals Down Under (MDU) initiative. Launched in 2007, MDU is a cross-divisional national flagship enterprise that aims to help sustain and transform the Australian minerals industry with new technologies and ideas through the 21st Century.

THE CULTURAL DRIVERS

The close engagement with and direct funding from industry means CSIRO Exploration and Mining operates differently from Geoscience Australia (GA), the national geoscience agency, state government surveys and most, if not all, equivalent agencies around the globe. Engagement with industry has focused on development of new exploration technologies and methodologies, rather than as a provider of pre-competitive data. CSIRO Exploration and Mining has evolved a scientific culture that aims to balance short term practical goals with long terms research goals. Arguably, the most significant catalyst of cultural change within CSIRO was the external earning targets introduced in the early to mid 1980s. The MDU flagship has a projected life through to 2025 and an external earnings target of about 40% of revenue.

The challenge of sustaining long term scientific development while contributing practical outcomes in the near term, in tandem with aggressive external earnings targets, is not only driving internal collaboration between a diverse range of scientific disciplines but also external partnerships with other government agencies, the university sector and industry. Numerous competitive funding vehicles have been developed over the last two decades by both state and commonwealth governments to encourage cross - institutional R and D. The most significant of these has been the Cooperative Research Centres (CRC) program established by the Australian Commonwealth Government in 1990 to encourage collaboration in R and D between the public and private sector, as well as support world-class research teams and prepare PhD students for non-academic careers.

THE PRACTICAL CHALLENGES OF MINERAL EXPLORATION IN THE MODERN ERA

The challenges of mineral exploration have been widely commented upon in recent times: falling rates of discovery despite increased exploration expenditure, application of a wide range of new science and technology, and unparalleled access to most parts of the globe (Etheridge 2004). In the Australian context, the problems are compounded by perceptions of maturity of mineral fields and the difficulties of exploration under cover. Neil Williams, Director of Geoscience Australia and SEG President for 2008, commented that over the last century we have become very skilled at describing mineral deposits and their genesis, but there is a growing need for research on why known ore deposits occur where they do, and where they do not (Williams 2008). Explorers targeting to depth will be focusing on large high-grade deposits. The research emphasis needs to be the elucidation of the controls on the size and grade of deposits and importantly, their distribution with depth.

The CRC program provided the R and D vehicle to bring together the multi-disciplinary teams across academe and industry to address the fundamental science issues underpinning the question of “Why is the deposit there and not there?” (Jon Hronsky, circa 1998). Inspired by work in the oil industry in the 1980s, the *AGCRC* (Australian Geodynamics CRC) followed closely by the *pmd*CRC* (Predictive Mineral Deposits CRC) worked on developing mineral systems concepts with genuine predictive capacity at any scale. Concurrently, *CRC LEME* (CRC for Landscape Evolution (later, Environments) and Mineral Exploration) set out to determine the influence of regolith - landscape evolution on mineral exploration; a particularly pertinent problem for explorers in Australia that complemented efforts to better understand the workings of the primary mineral systems. CSIRO Exploration and Mining partnered with Geoscience Australia, state government surveys, universities and industry in developing the cutting-edge science programs to underwrite these endeavours for over a decade and a half.

GETTING MORE SCIENCE INTO EXPLORATION: THE MINERAL SYSTEMS PERSPECTIVE

Traditional exploration strategies focus on finding a proxy for the deposit. The aim is to find geological, geochemical or geophysical anomalies that allow the deposit “to be seen” at a scale somewhat larger than the deposit. The mineral systems methodology aims to focus less on finding proxies for the deposit and more on understanding the critical parts of mineral systems, such as sources of fluids and flow paths, learning to read the rock record for their presence and using that knowledge to direct exploration. From the R and D perspective, in addition to having a robust geological description of the mineral system, there needs to a numerical view of the system for the purposes of testing and quantifying geological thinking and an exploration view of the system that distils the exploration implications from the geological and numerical descriptions. The geological, numerical and exploration descriptions could be thought of as different but equivalent views of the mineral system.

The ‘Five Questions’ geological description of a mineral system adopted by the AGCRC and the *pmd**CRC (Price & Stoker 2002; Walshe *et al*. 2005) explicitly highlights the problem of understanding the system in space and the temporal evolution of the system at all scales. Questions 1 and 2 'What is the geodynamic/thermal history of the system' and 'What is the architecture and size of the system?' ensure the issues of 'source(s) of fluids (melts)', 'transport' and 'depositional sites' are addressed within the context of an understanding of the architectural and geodynamic history of the whole system, taking account of information from the deposit to the terrane scale. For systems in which the metal is transported in solution (melt), the mathematical description highlights the importance of physico-chemical gradients to sustain metal transport and promote deposition. From work on Archean gold deposits in the Yilgarn Craton, WA, it seems that understanding the system at the deposit to district scale is mostly a problem in mapping critical fluid pathways and recognising where in the architecture (2 or 3D) fluids have interacted to maximize the key physico-chemical gradients determining Au precipitation. Some judicious combination of geochemical, geophysical, and mineralogical data sets is required to map fluid pathways. Hyperspectral logging is proving a powerful tool for the rapid acquisition of data on mineral distribution.

POST SCRIPT

It transpires that getting more science into exploration will require a bit more than a few enthusiastic researchers working with some equally enthusiastic explorers. Technology and concept transfer across the academe – industry interface is a complex, two-way process that is at least as challenging as the science itself. One of the more novel approaches to bridging the divide has been the embedding of researchers within companies to promote the real-time transfer of concepts, data and promote the uptake of R and D in exploration. The health of the interface is as dependent on supportive and informed managements as it is on those ever-green enthusiastic practitioners. The re-emergence of the bust phase of the boom-bust resources cycle means a testing time for both.

It is the wisdom of the modern era that government funding from "special pots" comes with sunset clauses. Sunset for *pmd**CRC and CRC LEME came in 2008. Was sufficient progress made in the allotted time to really make a difference? Will the messages from these CRC programs have a lasting impact on exploration practice? Will the mineral exploration R and D cycle be reinvigorated? The business of being pure, applied and relevant remains a challenge.

ACKNOWLEDGEMENTS

In preparing this paper comments by Drs. Charles Butt and Graham Carr, two colleagues with much experience of the various guises of CSIRO Exploration and Mining, were much appreciated.

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Determination of platinum and palladium for geochemical mapping

Yao Wensheng[1,2], Yan Hongling[3], Sun Aiqin[3], & Wang Xueqiu[1,2]

[1]Institute for Geophysical and Geochemical Exploration (China), 84 Jinguang Road, Langfang,Hebei Province 065000 CHINA (e-mail: Yaows68@yahoo.com.cn)

[2]Key Laboratory of Applied Geochemistry, Chinese Academy of Geological Sciences, 84 Jinguang Road, Langfang, Hebei Province, 065000 CHINA

[3]Geoanalysis Laboratory of Henan Province, 28 Jinshui Road, Zhengzhou, 450012 CHINA

ABSTRACT: A procedure including chemical pre-concentration, determination by emission spectrometry or inductively coupled plasma-mass spectrometry, and quality control was developed for platinum and palladium analysis for geochemical mapping samples. Application in multi-scale geochemical mapping projects indicates that: (1) the detection limits, data accuracy and precision can meet the analytical requirements; (2) a sub-sample weight of 10 g is suitable for national- and global-scale geochemical mapping; and (3) sub-sampling errors caused by "nugget effects" could be effectively controlled by the quality control system through the duplicate or triplicate determinations of doubtful samples with relatively high PGE contents.

KEYWORDS: *Analysis, Nugget effects, ICP-MS, Sub-sampling, Quality Control*

INTRODUCTION

Geochemists have a fascinating dream for mapping the whole earth with all elements in periodic table (Wang *et al*. 2006). However many ultra-trace elements such as Platinum Group Elements (PGE) are difficult to determine accurately and precisely. The average concentration of Pt and Pd in most geochemical mapping samples is extremely low, at less than 1 ppb. The detection limits should be below their crustal abundance in order to produce informative geochemical maps (Xie 1995; Xie, Wang *et al*. 2008). The "nugget effect" is another obstacle for the accurate determination of Pt and Pd. Consequently, the complicated chemical pre-concentration steps and sub-sampling are two major sources of error. A procedure of chemical pre-concentration, emission spectrometry (ES) or inductively coupled plasma-mass spectrometry (ICP-MS), and analytical quality control system has been developed for geochemical mapping projects (Wilhelm *et al*. 1997; Yao *et al*. 2003) and more than 50,000 samples have now been analysed using this approach. In this paper, the procedure and its application in multi-scale geochemical mapping projects are discussed.

ANALYTICAL METHOD

A 10 g sample is roasted at 650°C and decomposed with hydrochloric acid/hydrogen peroxide. The Pt and Pd in the solution is pre-concentrated using adsorbent materials which are composed of active charcoal and anion resin. The adsorbent materials are washed sequentially with 2% ammonium bifluoride, 5% hydrochloric acid and distilled water, and subsequently ashed in a muffle furnace at 650°C. The total residue of ca. 0.25 mg is dissolved with 2 ml fresh aqua regia, then diluted to 5ml using 10% hydrochloric solution, and determined using ICP-MS, which has a detection limit of 0.2 ppb for Pt and Pd. The residue can also be mixed with a spectral buffer, and determined by DC-arc ES, which has detection limits of 0.3 ppb for Pt and 0.2 ppb for Pd.

QUALITY CONTROL

Reference Materials

The certified reference materials (GPt CRMs) are used for quality control (Yan *et al*. 1998; Gu *et al*. 2007). GPt-1, GPt-2, GPt-7 and GPt-8 are suitable for analytical quality control in national and global geochemical mapping projects. For local geochemical exploration, use of the GPt CRMs depends on the style of mineralization and PGE contents (Table 1).

Quality Control Method

A set of CRMs, approximately equal to 5% of the samples, are inserted in each batch of 100 samples during routine analysis.

The relative error (RE%) is used to monitor the between-batch or between-map bias:

$$RE\% = [(C_d - C_s) / C_s] \times 100\%$$

where C_d is the determined value, C_s is the standard reference value.

The tolerance of RE% is listed in Table 2. If the RE% results are beyond these limits, analysis of the batch should be repeated.

5-10% samples are randomly selected and coded for duplicate analysis.

The relative deviation (RD%) is used for monitoring sub-sampling error:

$$RD\% = [(C_{d1} - C_{d2}) / C_{d1,2}] \times 100\%$$

where C_{d1} is the determined value, C_{d2} is duplicate analysis value, and $C_{d1,2}$ is the mean of C_{d1} and C_{d2}.

The tolerance in RD% is listed in Table 2. If the RD% is beyond these limits, duplicate or triplicate determinations should be undertaken for the doubtful samples.

For local exploration, samples with relative higher PGE contents, about 5% of the total, are selected for the duplicate determination to monitor sub-sampling error.

RESULTS AND DISCUSSION

Applications in Geochemical Mapping

The analytical approach and quality control system has been successfully applied in geochemical mapping projects. During the past 15 years, approximately 50,000 samples have been analysed for Pt and Pd. Some examples of applications are as follows:

Table 1. PGE reference materials

RM	10^{-9}		Sample type
	Pt	Pd	
GPt-1	0.26	0.26	Soil
GPt-2	1.6	2.3	Stream sediment
GPt-3	6.4	4.6	Peridotite
GPt-4	58	60	Pyroxene peridotite
GPt-5	20	11.3	Chromite
GPt-6	440	570	Low grade ore
GPt-7	14.7	15.2	Soil
GPt-8	0.66	0.66	Soil

Table 2. Tolerance of accuracy

Content (ppb)	RE(%)	RD (%)
<1.0	100	100
1~30	66.6	66.6
>30	50.0	50.0

Regional-scale: Pt and Pd mapping of the Bushveld Complex, South Africa (density 1 sample per 1 km^2) (Wilhelm *et al*. 1997, Lombard *et al*. 1999, Yao *et al*. 2003).

National-scale: The 76-element geochemical mapping pilot project in southwestern China (1 composite sample per 400 km^2) (Xie, Cheng *et al*. 2008).

Global-Scale: The EGMON project as pilot global geochemical mapping (1 sample per approx. 15 000 km^2) (Cheng *et al*. 1998; Xie *et al*. 2001).

Sub-Sampling Errors

The “nugget effect” causes sub-sampling errors in PGE determinations. Previously, large sub-samples (30 g) of all samples were analyzed to decrease sub-sampling errors. This is not cost-effective. Our new approach is: *firstly*, a 10 g sub-sample is used for the routine analysis of all samples; *secondly*, samples with anomalous values are selected for duplicate or triplicate determinations, and the average value of these determinations is considered trustworthy. The selection of these samples is mainly based on the Pt/Pd ratio, statistics of RD% of coded duplicate analyses and total batch data distributions.

Results of the analysis of 105 samples determined from a 10 g sub-sample by the authors’ methods and from a 30 g sub-sample by fire assay ICP-MS in another laboratory are compared in Figure 1. This shows that analysis of a 10 g sub-sample by our analytical and quality control procedure can give as good results as methods using a 30 g sub-sample.

Accuracy of CRM Analyses

240 CRMs were inserted into the approximately 3000 samples in the 76-element geochemical mapping pilot project in southwestern China. The RSD% of these determinations and the certified values are listed in Table 3. All the RSD are less than 25% and the analytical data are considered accurate. Data accuracy had also been subsequently justified from the mapping results.

CONCLUSIONS

(1) The detection limits for Pt and Pd can meet the analytical requirements for geochemical mapping.
(2) A sub-sample weight of 10 g is suitable for national- and global-scale geochemical mapping.
(3) Sub-sampling errors caused by the PGE "nugget effect" is effectively controlled by duplicate or triplicate determinations of samples with relatively high PGE contents.

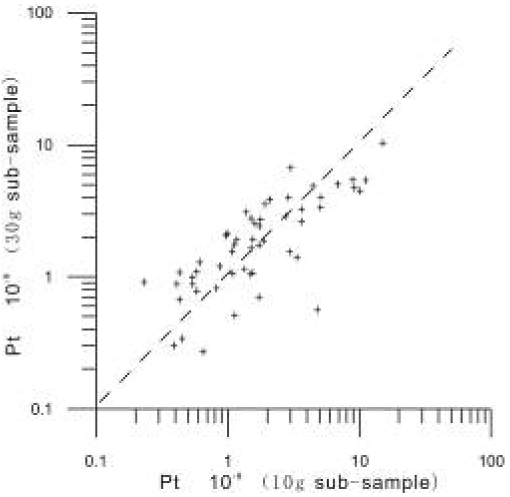

Fig. 1. Comparison of analyses using 10 g and 30 g sub-samples

Table 3. RSD (%) of CRMs

RM	Pt	Pd
GPt-1	14.58	18.30
GPt-8	21.41	15.03
GPt-2	14.90	13.29
GPt-7	7.03	6.83

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76 elements geochemical mapping in Southwest China

Zhizhong Cheng[1] **& Xuejing Xie**[1]
[1]*Institute of Geophysical and Geochemical Exploration,Jinguang Road, Langfang, Hebei, 065000 CHINA*
(e-mail: zhizhong9@yahoo.com.cn)

ABSTRACT: Southwest China's 76 elements geochemical mapping project was initiated in 2000. 2700 composite samples from the 1000,000 RGNR supplement samples were prepared. The 76 elements analytical system using modern analytical instruments such as ICP-MS, XRF, ICP-AES as backbone, supplemented with other techniques was estabished. The geochemical maps provided the distribution of all the elements in the periodic table.

KEYWORDS: *76 elements, geochemical mapping, analytical Scheme,*

INTRODUCTION

In 1973, J.S. Webb (Webb *et al*. 1973, 1978) published the first geochemical atlas "Provisional Geochemical Atlas of Northern Ireland". From 1973 to now, more than 40 regional and national geochemical mapping projects (Reedman 1973; Bowie & Plant 1978a,b; Bolivar 1980; Geological Survey of Canada 1981; Stephenson *et al*. 1982; Weaver *et al*. 1983; Freeman *et al*. 1983; Fauth *et al*. 1985; Bolviken 1986; Koljonen *et al.* 1989; Simpson 1993; Varna *et al*. 1997; Laszlo *et al*. 1997; Reimann *et al*. 1998; Salminen 2005; De Vos & Tarvainen 2006) were carried out.

China's national geochemical mapping project, the "Regional geochemistry-National Reconnaissance (RGNR) Project" was initiated in 1978 (Xie 1977, 1978, 1989). 39 elements were determined by multi-method analytical system. Environmental geochemical monitoring networks (EGMON Project) (Xie & Cheng 1997) was carried out in 1993, 54 elements were analyzed 54 by the new analytical system. In 2000, the 76 elements geochemical mapping was carried in Southwest China.

SAMPLE COLLECTION AND COMPOSITION

The RGNR project in Yunan, Guizhou Sichuan and Guangxi provinces were started in 1980, and finished in 1995. All the supplement ones of stream sediment samples for the project were kept in very good condition. About 100 RGNR supplement samples within each 1:50000 map sheet were mixed and composite into 1 samples. 2700 composite samples were submitted for analysis.

MULTI-ELEMENT ANALYTICAL SCHEME

The 76 elements are analyzed, including the 39 elements originally analyzed in analyzed in RGNR Projects and 37 elements newly added. The 76 elements analytical system were established using ICPMS, ICPAES and XRF as backbone, supplemented with other techniques (Table 1). The Detection limits of all trace and subtrace elements are lowered below their crustal abundance (Table 2). The log deviation are $\triangle \log C \leq 0.1$, standard deviation (SD) is between 10%~30%.

GEOCHEMICAL MAPS FOR 76 ELEMENTS

All of geochemical analytical data for the reasearch area are loaded in GeoMDIS system with Excel format. The geochemical maps are generated by data which are gridded by using data-gridding function of GeoMDIS. 76 elements geochemical maps were generated by GeoMDIS.

The 76 elements geochemical maps show the distribution of all elements in the periodic table, especial for rare and dispersive and precious metals elements.

Table 1. The analytical system for 76 elements.

analytical method	elements
XRF	Si, Al, Fe, Mg, Ca, Na, K, Ba, Ce, Co, Cr, Cu, Ga, La, Mn, Nb, Ni, P, Pb, Rb, S, Sc, Sr, Th, Ti, V, Y, Zn, Zr, Cl, Br
ICP-MS	Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu Be, Bi, Ce, Co, Cs, Cu, Ga, In, La, Mo, Nb, Ni, Pb, Rb, Sb, Th, U, W, Y, Zn, Tl, Ta, Hf, Re Te
ICP-AES	Na, Mg, Al, K, Ca, Fe, Ba, Be, Co, Cr, Cu, Li, Mn, Ni, P, Sr, Ti, V, Zn
GF-AAS	Ag, Au
HG-AFS	As, Sb, Se, Ge
CV-AFS	Hg
SIE	F
ES	Ag, B, Sn,
VOL	C, N,
CF-COL	I
FA-POL	Ir,Rh
FA-ES	Pt, Pd
FA-COL	Os, Ru

Fig.1 show that a Giant Pt geochemical anomaly is distributed over north Yunnanand southwest Sichuan about 60000km^2. Three large and 2 small In geochemical anomaly areas are delineated in the researched region (Fig. 2). The In anomaly area is of great ore-finding potentialities. A strong Hf anomaly was delineated in Lincang of Yunnan provice(Fig. 3). The Hf anomaly zone coincides with the Lincang granitoids area.

CONCLUSIONS

The earth is constructed by all elements in the periodic table. Mapping of the spatial distribution of nearly all the elements in the periodic table will get a new overview of the earth surface construction for better stewarship of sustainable environmental management with sustainable mineral resources development.

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Table 2. The requirement of method detect limit.

element	D_L	element	D_L
Ag	0.02	Mo	0.2
Al_2O_3	0.05*	N	20
As	1	Na_2O	0.1*
Au	0.2	Nb	2
B	2	Nd	0.1
Ba	5	Ni	1
Be	0.2	Os	0.02
Bi	0.05	P	10
Br	1	Pb	2
C	0.1*	Pd	0.2
CaO	0.05*	Pt	0.2
Cd	0.02	Pr	0.1
Ce	2	Rb	1
Cl	20	Re	0.2
Co	1	Rh	0.02
Cr	5	Ru	0.02
Cs	0.5	S	50
Cu	1	Sb	0.05
Dy	0.1	Sc	1
Er	0.1	Se	0.01
Eu	0.1	SiO_2	0.1*
F	100	Sm	0.1
Fe_2O_3	0.05*	Sn	1
Ga	2	Sr	5
Gd	0.1	Ta	0.2
Ge	0.1	Tb	0.1
Hf	1	Te	5
Hg	0.5	Th	2
Ho	0.1	Ti	50
I	0.5	Tl	0.1
In	0.01	Tm	0.1
Ir	0.01	U	0.2
K_2O	0.05*	V	5
La	1	W	0.3
Li	1	Y	1
Lu	0.1	Yb	0.1
MgO	0.05*	Zn	5
Mn	10	Zr	5

D_L : detect limit , * in % , Au, Hg, Ir, Os, Pd, Pt, Re, Rh, Ru in ppb , others in ppm

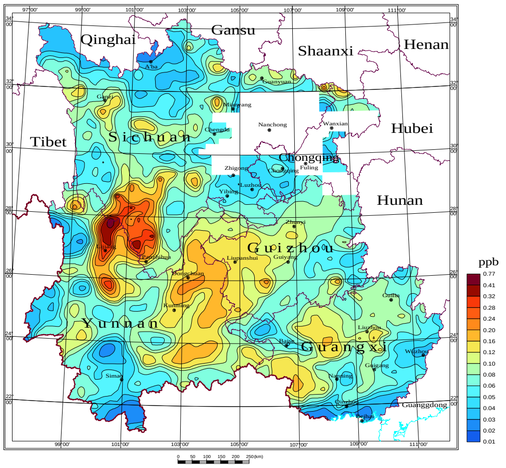

Fig.1. Geochemical map of osmium Os in southwest China.

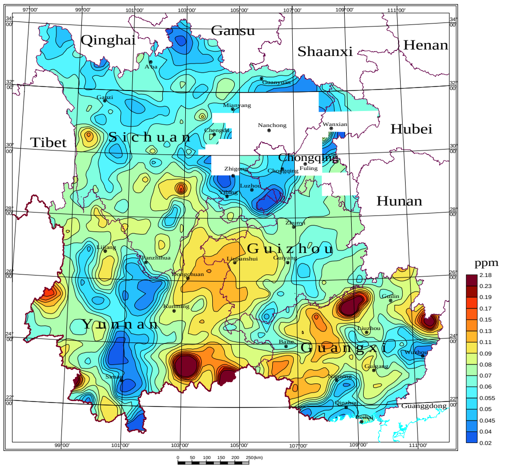

Fig. 2. Geochemical map of Indium (In) in southwest China.

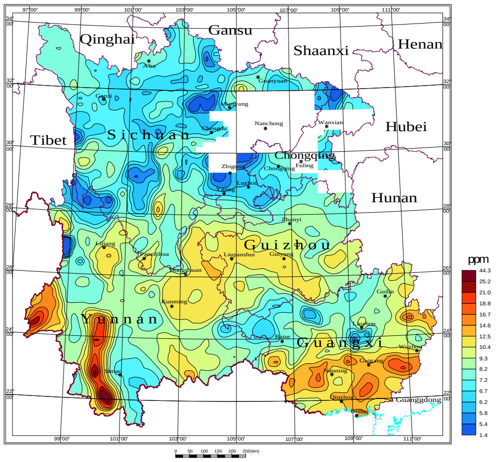

Fig. 3. Geochemical map of hafnium (Hf)in southwest China.

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A Methodology of source tracking of cadmium anomalies and their quantitative estimation along the Yangtze River Basin, China

Chuandong Zhao[1] & Hangxin Cheng[1]
[1]Institute of Geophysical and Geochemical Exploration, CAGS, Langfang, Hebei, 065000, China
(e-mail: zhaochuandong@igge.cn)

ABSTRACT: Cd anomalies spreading along almost the whole Yangtze River basin, discovered by the multi-purpose geochemical investigation being carried out in China, have been of the major ecological environmental issue. By taking the Anhui section of the Yangtze River basin as its object, a systematical study on methodology of the source tracking and quantitative estimation of the Cd anomalies has been made in the paper. Tt is shown that the suspended matters are the main carriers of heavy metals for long distance migrations; the concentration of Cd in the suspended matters is much higher than those of other heavy metals, this may be the main reason for forming the Cd anomalies spreading along the whole Yangtze River basin; The endogenetic mineral deposits, especially Pb-Zn deposits, are the largest suppliers of Cd in the suspended matters. With techniques of layer sampling of sediments on alluvial beds and isotopic age-determination, the geochemical history of sedimentation of Cd and other heavy metals and so resulted pollutions has been primarily reconstructed, with prediction and early warning of evolution of anomalies of Cd and other heavy metals made.

KEYWORDS: *Yangtze River basin, source tracking of Cd anomaly, quantitative estimation, suspended matter, sediments on alluvial bed*

INTRODUCTION

The multi-purpose geochemical investigation on a scale of 1:250,000 has been performed in 7 provinces and 2 cities along the Yangtze River basin since 1999 in China, up to now covering a total of 360,000 km^2, with a sampling density of 1 sample per 1 km adopted. Results show that element Cd has been anomalously enriched in soils on either bank of Yangtze River, forming Cd geochemical anomalies spreading in a belt of several thousands of kilometres long and tens of kilometres wide. Carrying out systematical studies on the origin, migration course and ecological effects of the Cd geochemical anomalies and predicting their developments in future are not only of scientific significance but also of immediate significance for blocking migrations of Cd in various ecological systems and protecting environments.

SURVEY OF STUDY AREA

The Anhui section of the Yangtze River basin is located on the middle and lower reaches of Yangtze River and on the central and southern part of Anhui province, totalling 416 km long and covering 66,000 km^2, including 10 large basins. It is an important part of the Fe-Cu-S-Au metallogenic belt on the middle and lower reaches of Yang-tze River.

SAMPLE COLLECTION

A batch of research works indicates that aqueous suspended matters (suspended matters in water) and their sediments-alluvial bad sediments/flood plain sediments could be adopted to quantitatively inverse average chemical compositions for every catchment basin in the studied area. It is thus concluded that aqueous suspended matters and their sediments could be selected as the best sampling media for source tracking of geochemical anomalies along river basins. By determining the element contents in the suspended matters, the output flows of the elements could roughly calculated for corresponding rivers; while with ^{137}Cs and ^{210}Pb age-determinations, the rates of sedimentations of alluvial bed sediments/flood plain sediments could estimated, and combining with content determinations of element in samples, the variations of the elements contents with time could therefore be studied.

DISTRIBUTIVE FEATURE OF HEAVY METALS IN THE SUSPENDED MATTERS

Contents of Heavy Metals in Different Media

It is seen from the contents of heavy metals in stream sediments, soils and suspended matters for the main basins of the Anhui section of the Yangtze River that the contents of heavy metals in suspended matters are obviously higher than those in stream sediments and soils, indicating that the suspended matters are the main carriers for long distance migrations of heavy metals in the Yangtze River basin.

However obvious differences in enrichment degrees among heavy metals in suspended matters can be observed, the average enrichment degrees of heavy metals in suspended matters are listed in Table 1. It is seen from the table that enrichment degree of Cd in the suspension, averagely 32.9 times, is obviously higher than those of the other heavy metals.

OUTPUT FLOW OF HEAVY METALS ALONG THE ANHUI SECTION THE YANGTZE RIVER BASIN

Table 2 lists the year-output flows of heavy metals for the main tributaries of the Anhui section of Yangtze River.

The data in the table 2 show that the year-discharge of Cd from the main tributaries to Yangtz River in the form of suspended matters is about 1.212 t. The calculations of output flows of Cd for the sections of just getting into and out of Anhui province indicate that the input of Cd into Anhui province from the upper reaches of Yangtze River is about 316.85 t per year, while the output of Cd to the lower reaches of Yangtz River is 313.60 t. The difference between the two is 3.25 t. Considering that the total discharge of Cd to Yangtze River from the tributaries of the Anhui section is 1.21 t, the amount of 4.45 t of Cd is settled in the Anhui section.

Table. 1. Average enrichment degrees of heavy metals in suspended matters for the main tributary basins of the Anhui section of the Yangtze River basin.

	Cd	Cu	Hg	Zn	Pb	Ni
Suspension/stream sediment	31.2	9.8	6.2	5.7	2.8	2.4
Suspension/soil	34.5	7.7	5.9	6.1	2.4	2.1
Average	32.9	8.8	6.0	5.9	2.6	2.2

Table2. Year-output flow of heavy metals for the main tributaries of the Anhui section of Yangtze River (t/a).

Basin of	Cd	Cu	Pb	Zn	As	Hg
Bo Lake	0.092	36.157	8.040	37.978	3.168	0.0384
Wan River	0.069	37.275	3.273	16.570	0.661	0.0081
Caizi Lake	0.007	4.537	0.649	2.654	0.249	0.0045
Qiupu River	0.282	331.382	91.883	23.651	2.368	0.0122
Qingtong River	0.098	19.548	2.117	16.753	0.581	0.0026
Shun'an River	0.144	27.116	0.260	2.135	0.057	0.0004
Yuxi River	0.312	130.325	6.033	23.527	1.805	0.0175
Qingyi River	0.143	67.003	5.156	27.646	2.187	0.0132
Shuiyang River	0.065	47.724	4.009	19.823	1.533	0.0124
Total	1.212	701.067	121.421	170.737	12.609	0.1094

SOURCE TRACKING OF CD GEOCHEMICAL ANOMALIES

To track the sources of the geochemical anomalies of heavy metals in suspended matters along the Shun'an River basin (one of the main tributary basins of the Anhui section of the Yangtze River basin), a rock survey was conducted on typical ore deposits and outcrops of main strata and geological bodies along the Shun'an River basin. The results shown in Table 3 indicate the largest source of Cd in suspended matters on the Shun'an River basin is endogenetic deposits, especially Pb-Zn deposits.

PRELIMINARY RECONSTRUCTION OF POLLUTION BY HEAVY METALS

Figure 1 shows the results of age-determination for the sedimentary columns of alluvial beds for the upper reach of the Anhui section of Yangtze River by using 210Pb and 137 Cs. It could be seen from the figure above that: After1949, the content of Cd was continuously going up; especially it went up rapidly after 1977 when the policy of reformation and opening was put into effect. The content of Cd came up to 1,037ng/g around 1990, exceeded the

Table 3. Contents of heavy metals based on the rock survey along the Shun'an River (μg/g).

Ore deposit	Number of samples	Cd	Cu	Pb	Zn	As	Hg	Ni
Yejichong Pb-Zn Deposit	3	826.9	260.5	37266.7	100201.8	115.4	7.77	27.0
Fenghuangshan Cu Deposit	5	16.8	99188.1	19.9	4589.2	34.5	0.05	16.7
Xinqiao FeS Deposit	5	14.3	1581.5	505.7	820.3	1834.6	0.28	29.1
Tailing storehouse of Fenghuangshan Cu Deposit	5	2.2	1501.1	76.4	705.5	90.6	0.06	11.0
Lixin coal Mine	3	0.3	34.7	23.4	49.4	8.4	0.15	19.0
Shengchonghe Coal Mine	5	0.5	31.0	54.9	58.1	17.6	0.13	9.4
Fenghuangshan rock bodyock	4	0.24	185.96	24.95	92.58	15.1	0.01	13.38
strata	16	0.38	53.59	90.37	127.92	15.84	0.05	19.04

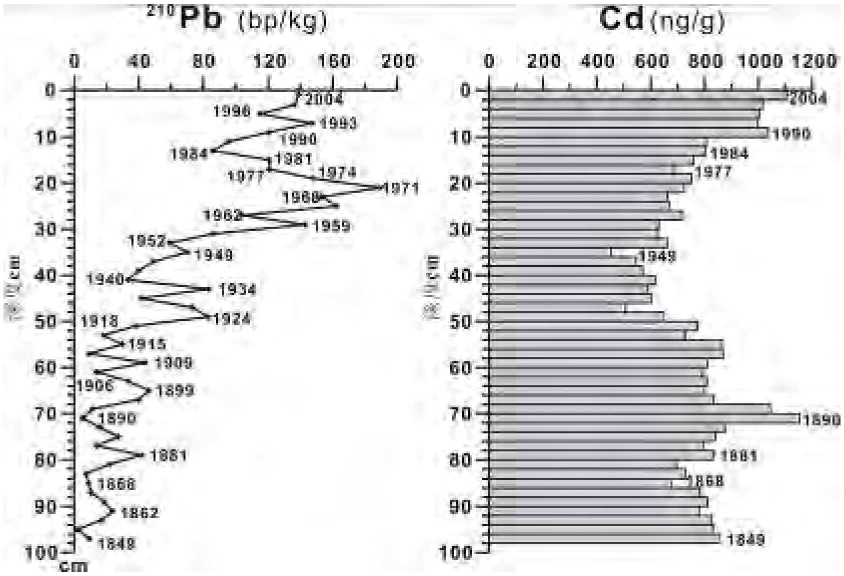

Fig.1. The variation of Cd content versus time on the sedimentary column of alluvial beds for the upper reach of the Anhui section of Yangtze River.

state limitation of the third class of soil environment. It even came up to 1,107ng/g in 2004.

If the content of Cd is continuously increasing at the current rate, the content of Cd would be up to 1,574 ng/g for the period of 2040 ~ 2049 at the upper reach of the Anhui section of Yangtze River, and would exceed 2,000 ng/g for the period of 2070 ~ 2079.

PRELIMINARY CONCLUSION

The measured results of the contents of heavy metals in suspended matters for the Anhui section of the trunk stream and main tributaries of Yangtze River show that the suspended matters have been the main carrier for long distance migration of the heavy metals, the enrichment degree of Cd in the suspended matters has been much higher than those of the other heavy metals. Perhaps it is just the reason for the forming of Cd geochemical anomalies along the basin of Yangtze River. The calculation results of output flow of heavy metals for the Anhui section of the trunk stream and main tributaries of Yangtze River indicate that the largest output flow of heavy metals has been from Qiupu River, with 4.45 t of Cd per year sedimented along the Anhui section of Yangtze River.

The results of source tracking show that the endogenic deposits, especially Pb-Zn deposits, have been the largest supplier of Cd.

The age-determination results by using ^{210}Pb and ^{137}Cs for the sedimentary columns of the alluvia beds along the trunk stream and main tributaries of the Anhui section of Yangtze River show that the variations of the contents of Cd and other heavy metals were basically corresponding closely to major historical events, say the establishment of PRC, the exercise of the policy of reformation and opening and the course of extensive industrialization, etc.

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