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Ultra-low density geochemical mapping in Zimbabwe

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ABSTRACT

On the basis of the topographical and landscape features in Zimbabwe, an ultra-low density regional geochemical survey was conducted over all of Zimbabwe using stream sediment sampling of catchment basins. Sampling methods, elements to be determined and analytical methods for the ultra-low density survey of Zimbabwe are discussed. Regional geochemical maps were compiled based on the sample data and the features of the catchment basins, and the characteristic parameters of the geochemical background throughout Zimbabwe were calculated and are presented. The result of the nationwide geochemical mapping in Zimbabwe was evaluated. A summary of the features of the nationwide ultra-low density geochemical background in Zimbabwe is presented, a preliminary analysis was performed on the distribution of mineral resources and the geochemical provinces in Zimbabwe, and regional prospecting problems are discussed.

1. Introduction

The success of applied geochemistry, especially geochemical mapping, has revealed a whole hierarchy of geochemical patterns from the local, regional, provincial, megaprovincial to global levels, which serve different purposes (Xie and Yin, 1993). The effectiveness of regional geochemical mapping at the basic scales (1:50 000 and 1:250 000) in the exploration for mineral resources is universally acknowledged and widely applied. The role of geochemical mapping goes far beyond the complementary role to geological or geophysical prospecting in the pioneering period of the 1940s (Garrett et al., 2008; Hawkes and Webb, 1962). However, strategic issues, such as quickly understanding the distribution features and regularity of both known and potential mineral resources over large areas, and answering questions, such as in which area, what type of minerals and what methods should be used in prospecting, are vital in mineral exploration and prediction. National geochemical mapping has been conducted, or is in the process of implementation, in many countries, including the EU (FOREGS Geochemical Baseline Programme, 1998–present, FOREGS), the USA (National Geochemical Project 2004–present, USGS); the UK (McGrath and Loveland, 1992), Finland (Elo et al., 1992), China (Xie and Cheng, 2001), Mexico (unpublished) and Canada (Friske and Hornbrook, 1991; Garrett et al., 2008; Hornbrook, 1989). At the sample densities traditionally used for local and regional anomalies (1 sample per 1–25 km^2), the geochemical mapping of a country, continent or the entire earth is logistically extremely demanding and tremendously expensive (Smith, 2008; Xie and Cheng, 1997). Therefore, the method of geochemical mapping at low-density over a large area is worthy of exploration and research, with selected sampling media, scientifically arranged sampling positions and effectively controlled areas, the regional geochemical characteristics could be truly and effectively revealed with limited samples. The first examples of such surveys were undertaken in Africa, in Sierra Leone, Zambia and Uganda (Garrett et al., 2008). Although sample densities ranging from 1 sample per 100 km^2 to 1 sample per 18 000 km^2 are much lower than the traditional density (1 sample per 1–25 km^2), many studies have obtained strikingly similar geochemical patterns among the different density levels (Xie and Cheng, 1997). The ranges from soils and stream sediments, apart from the distorting effect of a few outliers, are reported by Ferreira et al. (2001) as quite similar.

As early as the 1980s, a program of regional geological mapping and geochemical exploration was carried out by the British Geological Survey in collaboration with the Zimbabwe Geological Survey under a Technical Co-operation agreement supported by the UK Department for International Development (DFID). Three regions of Zimbabwe were mapped and the results of the stream sediment geochemical surveys were presented as three reports by P.N. Dunkley (1987a,b,c).

In collaboration with the Zimbabwe Geological Survey, the China Geological Survey conducted a regional geochemical survey at a scale of 1:250 000 in a jointly selected area in the province of Mutare between 2008 and 2010. Meanwhile, the ultra-low-density geochemical background investigation and research were conducted over the whole Zimbabwe, a total of 41 elements were determined, and a preliminary analysis of regional geochemical background characteristics was made.

This paper addresses the sampling methods, elements determined, analytical methods and the results of nationwide ultra-low density geochemical mapping in Zimbabwe. In addition, a preliminary analysis of the distribution of mineral resources and geochemical provinces in

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Zimbabwe is given, and the regional geochemical background and prospecting matters are discussed.

2. Outline of the regional geology and mineral resources in Zimbabwe

2.1. Regional geotectonic background

The following description is based on the work of the Zimbabwe Geological Survey (Mugumbate et al., 2001; Stagman, 1978). Zimbabwe occupies more than 390 000 km^2 of Central Southern Africa. Tectonically, Zimbabwe can be divided into two parts: the Zimbabwe craton and three marginal mobile belts. The central part of Zimbabwe consists mainly of the Archean craton; accounting for 3/5 of the land area of Zimbabwe, the craton is bordered to the northwest by the Zambezi Belt, the east by the Mozambique Belt, and the south by the Limpopo Belt. In the northwest, the Archean craton is overlain by Proterozoic–Cenozoic sediments, and thus the boundary is obscured.

The strata in Zimbabwe consist of an Archean greenstone belt, Precambrian metamorphosed rocks and Permian, Triassic, Jurassic and Quaternary strata. The Archean granite–greenstone belts occupy the central and south-central Zimbabwe craton. The lithology consists mainly of komatiites, tholeiitic volcanic rocks and felsic volcanic rocks intercalated with clastic rocks and banded iron-formations, being the main host of gold deposits. Proterozoic metamorphosed rocks are present in the western and eastern parts of Zimbabwe, consisting of calcareous phyllite, siltstone, carbonate, shale and intercalated basic volcanic rocks. These rocks are important for the occurrence of mineral resources such as copper, lead, zinc, cobalt and iron. Permian and Triassic to Jurassic terrigenous clastic rocks comprise the so-called Karoo group, distributed mainly in the western part of Zimbabwe, with a small area occurring in the south of the Limpopo Belt; among the Karoo group components the Permian terrigenous sediments are the important coal-bearing strata, the Jurassic fine clastic rocks contain volcanic rocks, and the lithology consists mainly of basic dolerite. The Kalahari Basin in the west also contains some late Cretaceous alkaline volcanic rocks and Neogene eolian accumulation strata of the Kalahari formation. Quaternary deluvium, alluvium and diluvium are ubiquitous in the mountain valleys of different sizes in various parts of Zimbabwe.

Granite, diorite, tonalite, diorite and basic–ultrabasic intrusive rocks are extensively developed in the Zimbabwe craton. The best developed basic intrusion is the Great Dyke, which trends NNE, extends over 530 km, is 8–10 km wide and consists mainly of serpentized pyroxenite, peridotite, harzburgite and norite, as well as many chromitite layers. Parallel to the Great Dyke, many small intrusions and dykes of diorite and quartz diorite are distributed on both sides. Karoo dolerites are widely distributed. Fig. 1 shows the simplified geology of Zimbabwe.

2.2. Distribution of regional mineral resources

Zimbabwe is endowed with abundant mineral resources, including gold, chromite, nickel, iron, copper, cobalt, platinum group metals and coal.

(1) Gold deposits: The majority of gold mines occur in greenstone belts or quartz veins related to greenstone belts. Gold deposits can be roughly divided into the following types: quartz vein type and ductile shearing belt type, altered rock type related to iron formations and pyroclastic rocks (Foster, 1982). The distribution of main gold deposits in Zimbabwe is shown in Fig. 2.

(2) Chromite deposits: Mainly occurred in the Great Dyke and ultrabasic intrusive bodies in greenstone belts on both sides of the south end of the Dyke. The former are stratigraphically controlled orebodies, occurring in multilayers in the Great Dyke, the latter is an irregularly shaped orebody, in small quantities but at a large scale (Vallieres, 1993).

(3) PGE (platinum group element) deposits: PGE deposits occur mainly in the central and southern sections of the Great Dyke with limited distribution. PGE orebodies of economic importance are found in Selous, Ngezi, Mhondoro, Mimosa and other locations. PGE mineralization is also found in the north.

(4) Nickel (Cu) deposits: Mainly occur with minor copper sulfides in basic–ultrabasic intrusions distributed along Archean greenstone belts, which are magmatic liquation deposits.

(5) Base metal (Cu–Pb–Zn–Co) polymetallic deposits: Polymetallic deposits are mainly distributed in the Proterozoic Mugandi tectonic belt in the west of Zimbabwe, where several Archean granite domes, trending NE–SW, occur in a beaded distribution, parallel to the regional tectonic belt. Cu–Co polymetallic deposits circle around the Archean granite gneiss dome (see Fig. 3).

3. Methods for ultra-low density geochemical mapping in Zimbabwe

3.1. Sampling principle of regional geochemical mapping

Regional geochemical mapping attempts to obtain useful information reflecting geological targets at different scales through the collection of limited samples; the key is to collect representative geochemical samples, which reasonably reflect the regional geochemical variation at a certain spatial scale. The samples and data of the geochemical mapping at different scales should be different.

In the case of m samples collected in the region, if the sampling control area of each sample in the geochemical survey is $S_{\mathrm{i}}(\mathrm{i}=1,2,\ldots,\mathrm{m})$, where n evenly distributed geologic bodies occur, the concentration distribution of a given element in each geologic body is denoted as $\mu_{\mathrm{ij}}(\mathrm{i}=1,2,\ldots,\mathrm{m};\ \mathrm{j}=1,2,\ldots,n)$, the area of the geologic bodies denoted as $S_{\mathrm{ij}}(\mathrm{i}=1,2,\ldots,\mathrm{m};\ \mathrm{j}=1,2,\ldots,n)$ (as shown in Fig. 4), and then, the sampling model for the sample analyzed (X_{i}) of the ith sampling control area (S_{i}) can be expressed as

$$X_{\mathrm{i}}=\frac{1}{S_{\mathrm{i}}}\left(\mu_{\mathrm{i}1}s_{\mathrm{i}1}+\mu_{\mathrm{i}2}s_{\mathrm{i}2}+\cdots+\mu_{\mathrm{i}n}s_{\mathrm{i}n}\right)=\frac{1}{S_{\mathrm{i}}}\sum_{\mathrm{j}=1}^{n}\mu_{\mathrm{ij}}s_{\mathrm{ij}} \tag{1}$$

where S_{i} is the spatial scale related to the resolution of the sampling distribution. Obviously, the size of a single sample control area, components in the controlled area and representativeness of the element distribution are the most important factors; they have a close relationship with the geomorphology and landscape. The weathering products of rocks would definitely enter into drainage systems under the action of denudation and be homogenized at the same time. Avoiding contamination of other objects (e.g., eolian sediments) outside of the sampling control area and the effect of geochemical barriers, stream sediments can be regarded as a natural assemblage of materials in the catchment basin of upper streams, the content of the elements in the assemblage is approximately the estimation of the weighted average of the content of the elements in various geological bodies in the sampling control area.

The components of stream sediment samples are usually changed under supergenesis, especially under acid conditions, and fine-grained materials are susceptible to alteration and exchange of elements, causing the representativeness of components in the rock formation in the denudation area to be modified. To ensure that the data of the geochemical survey satisfy the above model, detailed attention needs to be paid to the influence of geochemical barriers, such as the loss of the components of rock and minerals in fine-grained materials, adsorption on clay or organic materials, sedimentation and concentration of iron and manganese oxide and the concentration of colloids.

A preliminary assessment was made using stream sediment and soil samples taken from the Trojan nickel and Shamwa gold mines, to determine the sample size fraction that can be fully representative of the region. A total of 27 samples were analyzed. We made the conclusion from