



# Application of Multi-Element Soil Geochemistry and Particulate Gold Exploration in the Kambele Plain, Batouri Gold District, Southeast Cameroon

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## Abstract

Soil geochemistry remains an essential tool in mineral exploration, especially in areas where the scarcity of outcrops and a thick lateritic overburden undermine the understanding of subsurface ore deposits. Thirty-five soil samples collected from six profiles within a 40 km<sup>2</sup> block around the Batouri gold district, southeast Cameroon were analyzed for major elements (Fe, K) and trace elements (Au, As, Ba, Hg, Sb, W, Cd, Cu, Mo, Mn, Ni, Pb, Zn, Ga, Ge, Se, Ta, Cs, Ti, Bi) using both inductively coupled plasma mass spectrometry (ICP-MS) and instrumental neutron activation analysis (INAA). Furthermore, a heavy mineral concentrate from the sampling point with the highest Au concentration (64 mg Kg<sup>-1</sup> Au) was examined for the presence of particulate gold. The element concentrations obtained were plotted on element distribution maps and contoured to show the distribution patterns of the various elements in the soil. The results show that anomalous gold concentrations are found in the northeastern part of the study area. The data were analyzed using multivariate statistics and results from the principal component analysis (PCA) shows six components with components 2 (Au-As-Sb-W) and 3 (Cu-Ni-Zn-S) pointing to hydrothermal sulphide-related mineralization in the underlying rocks. As, Sb, W and S are identified in this study as potential pathfinder elements

for gold mineralization in the Batouri gold district. Gold grains were recovered from the concentrate and this point to gold dispersal in the solid-state within the weathering cycle.

## Keywords

Soil • Geochemistry • Principal component analysis (PCA) • Pathfinder elements • Particulate gold • Cameroon

## 1 Introduction

The search for ore deposits in recent times makes use of soil geochemistry, especially in areas of scarce outcrops and thick overburden which undermines the understanding of subsurface ore deposits (Nforba et al. 2011; Vishiti et al. 2015). Secondary dispersion is vital in exploring geochemistry as it results in the various elements present in an ore body being dispersed over a much wider target area, enabling the presence of mineralization to be detected as anomalous metal content in soils.

Soils derived from the weathering of underlying rocks with primary Au mineralization in savannah and rainforest areas are commonly enriched in gold, often with gold fragments that can even be extracted at a profit. Understanding the element composition, distribution and associations within a lateritic geochemical anomaly provides a better understanding of source rock geology and helps pinpoint favourable locations for drilling, especially where surface indications are lacking. Minimal studies have seen the use of soils as a tool in exploration and baseline studies, especially in the Central African Sub-region and Cameroon in particular (Nforba et al. 2011; Vishiti et al. 2015; Butt et al. 2000; Craig 2001). In this study, soil samples were collected from deep pits of between 2 and 4 m. The pits were placed over a wide Au-in-soil anomaly derived from a previous survey of

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shallow (<65 cm deep) 100 m spacing grid controlled soil programme carried out by African Aura Resources (AAR) Ltd (2009). Unlike the AAR survey, the samples were analyzed for a range of elements and the heavy mineral concentrate tested for the presence of particulate gold in the weathering profile.

The objective of this present study is to decipher through the use of soil geochemical anomalies, areas of high-gold potential as targets for further and more detailed exploration.

## 2 Geological Setting and Methodology

The Batouri gold district is situated in the equatorial rain-forest belt of Cameroon and forms part of the Adamawa-Yade lithostructural unit (Vishiti et al. 2015) that constitutes the Pan African Fold Belt north of the Congo Craton (Fig. 1a). This fold belt is characterized mainly by metasedimentary and metaplutonic (metagabbros, meta-granites, metadiorites, metasyenites) rocks (Fig. 1b). The location of the study area is shown in Fig. 1c.

A total of 35 bulk sediment samples were collected from six soil profiles across a 40km<sup>2</sup> block. Ten litres (~20 kg) of each sample were collected in a calibrated plastic bucket and subsequently quartered down to a 200 g fraction that was sent for analysis. The soil samples were analyzed at Activation Laboratories Canada (Actlabs) using combined Inductively Coupled Plasma/Mass Spectrometry (ICP-MS) and Instrumental Neutron Activation Analysis (INAA) techniques. In order to evaluate if particulate gold exists in the soil profiles, a heavy mineral concentrate was prepared for the soil sample that returned the highest gold concentration. This concentrate was examined under a binocular microscope and recovered gold grains by handpicking were further studied under a scanning electron microscope to elucidate their morphology and evolution within the weathering cover.

## 3 Results

### 3.1 Concentration of Elements in the Soil Samples

A total of 35 samples were analyzed for a suite of elements and 23 elements with concentrations (mg Kg<sup>-1</sup>) above the detection limit are presented on element distribution maps (Fig. 2). The distribution shows two anomalous areas for Au with relatively high concentrations (>80 mg Kg<sup>-1</sup>) around the northeastern part of the study area, which decreases to <5 mg Kg<sup>-1</sup> towards the south. Other elements such as As, Sb, W, also have high concentrations around the

northeastern part of the study area similar to S and Pb. Cu and Ni have a more-or-less uniform distribution.

### 3.2 Element Association

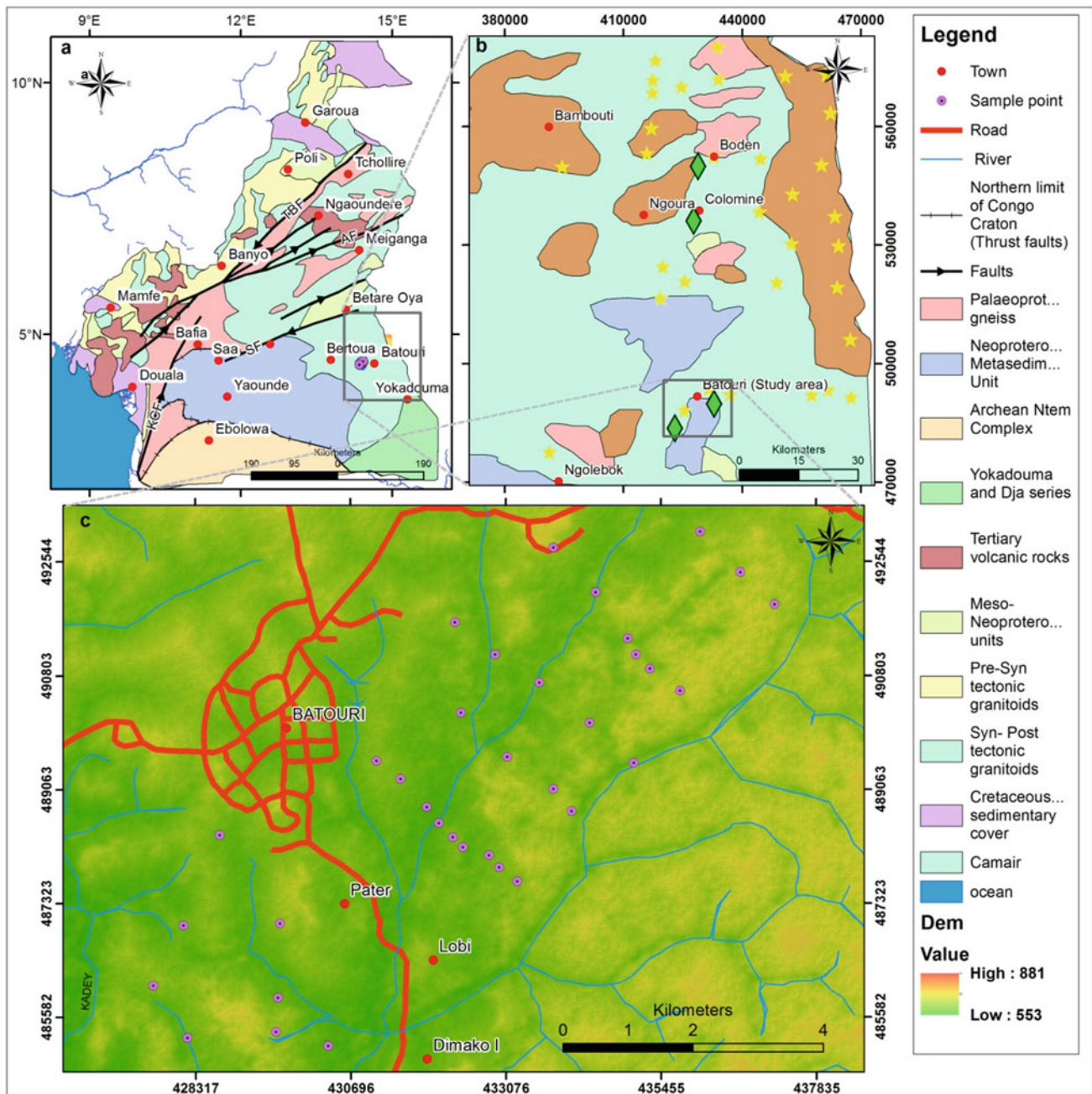
The raw data were log-transformed, and a Pearson's correlation matrix was computed for the elements in order to investigate their inter-element relationship. It is noticed that Au has a relatively high-correlation coefficient  $r$  of 0.64, 0.52 and 0.55 with As, Sb and S, respectively. Other element pairs with relatively high-positive  $r$  values include As-Sb ( $r = 0.77$ ), As-W ( $r = 1.00$ ), Sb-W ( $r = 0.89$ ), W-Cd ( $r = 0.89$ ), W-Ni ( $r = 0.71$ ). A few other elements such as W-Ge ( $r = -0.76$ ) and Se-Cs ( $r = -0.61$ ) are negatively correlated. The data were further subjected to principal component analysis (PCA) in order to investigate their elemental associations. Six components were generated. Each of these components represent a cluster of interrelated elements within the data set as follows: Component 1: As-Sb-Mn-Ga-Ge-Se-Ta-Fe, Component 2: Au-As-Sb-W, Component 3: Cu-Ni-Zn-S Component 4: Ge-Bi, Component 5: Mo, Component 6: Ni-Pb.

### 3.3 Particulate Gold

Samples of gold grains recovered from Sample number 28 with Au concentration of 90.5 mg Kg<sup>-1</sup> are provided in Fig. 3. The gold grains vary from dendritic irregular to sub-rounded. Delicate structures on the surface of some of the grains such as dendrites are still well preserved, whilst the sub-rounded ones have blunt edges. The grains also have pitted surfaces. The aspect ratios of these gold grains are also plotted in Fig. 3 compared to grains from other parts of the world. The long measured axes and perpendicular short axes of the gold grains under study ranged between 480 and 750  $\mu\text{m}$  and 240 and 700  $\mu\text{m}$ , respectively. More than half of the gold grain population (80%) had long to short axes ratios between 1:0.5 and 1:0.98.

## 4 Discussion

The concentration of gold in the analyzed samples varies considerably ranging from 2.7 to 90.5 mg Kg<sup>-1</sup>. According to Suh et al. (2006), considerable variations in gold concentration suggest the existence of high-grade ore shoots within a mainly low-grade gold system. Visible gold grains observed from panned samples imply that the gold occurs freely and is likely released by the oxidation of sulphides. This process usually leads to the release of gold that is held

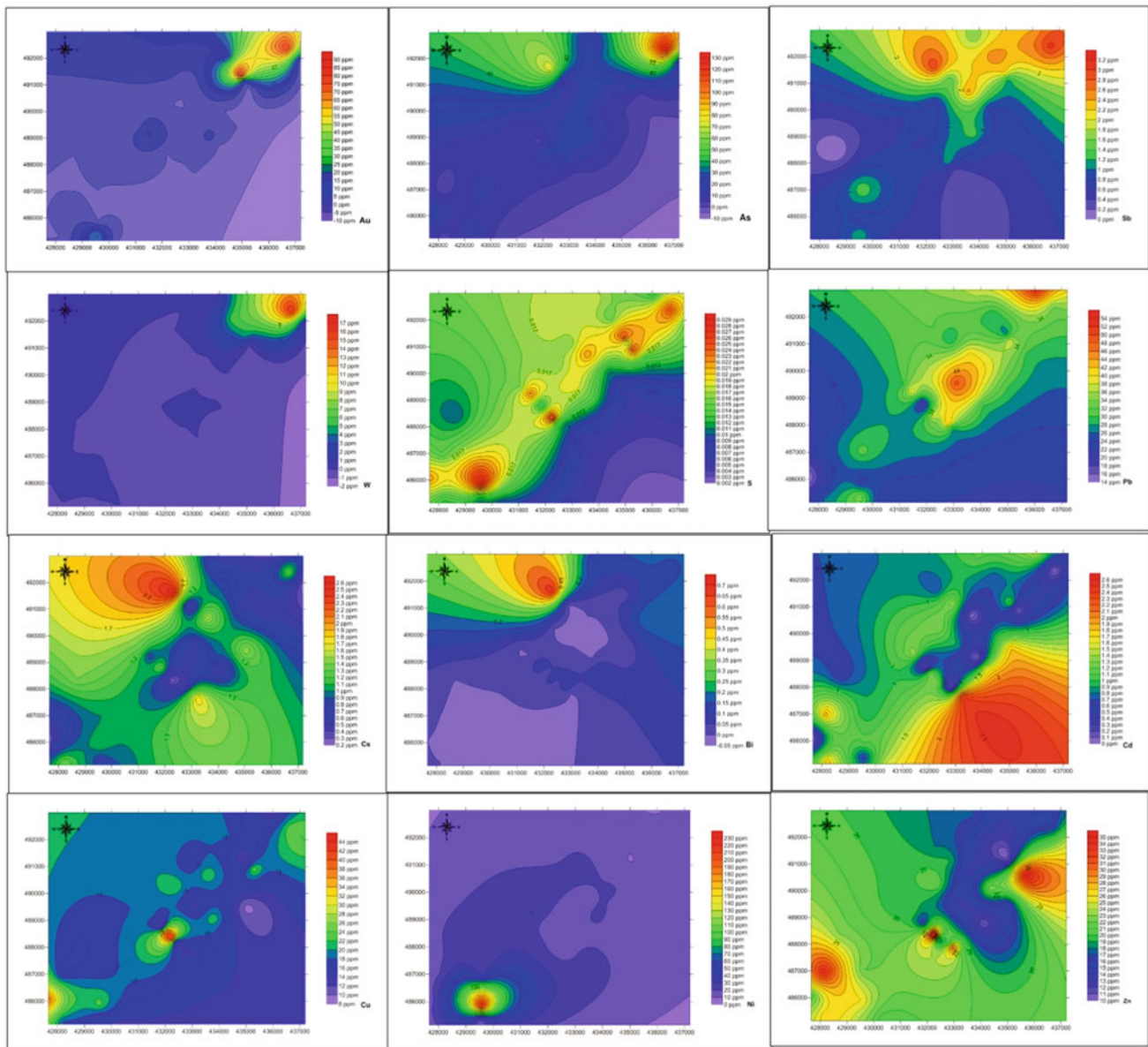


**Fig. 1** Location of study area. **a** Geological map of Cameroon (modified after Vishiti et al. 2015) **b** Regional geological map of south eastern Cameroon showing artisanal gold mining sites (modified after

Vishiti et al. 2015). **c** Topographic map of the study area showing sample collection points

in the sulphides as free gold and is attributed to deep weathering (Radtko 1985). The element distribution map for Au (Fig. 2) shows two anomalous areas with a promising prospect for gold occurrence in the northeastern part of the investigated block. The distribution pattern of gold in soils of the Batouri gold district shows a more extensive dispersion halo of about 2 km wide, with such distribution halo attributed to the extensive supergene lateral distribution of

gold. The distribution pattern of Au in the investigated block also follows a NE-SW trend, and according to Suh et al. (2006), gold deposits in Cameroon are confined to a NE-SW trending shear zone. Principal components extraction method was applied, and the analysis indicated six components in the data accounting for 76.93% of the total variability. The geology of the area under study, particularly the rock formations can be associated with component 1

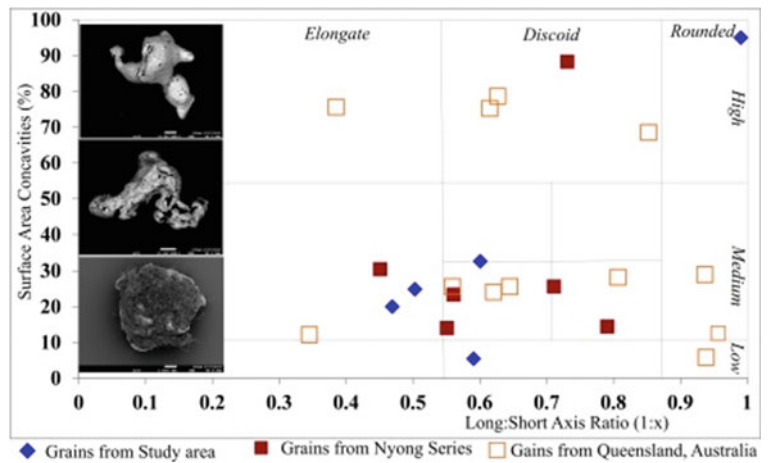


**Fig. 2** Element distribution maps for Au, As, Sb, W, S, Pb, Cs, Bi, Cd, Cu, Ni and Zn concentrations determined by combined ICP-MS and INAA

(As-Sb-Mn-Ga-Ge-Se-Ta-Fe). The study area is known to be underlain by metagranites which are particularly rich in K-feldspars minerals. These granitic plutons have high-magnetic susceptibility values (Suh et al. 2006; Asaah et al. 2014) and belong to the magnetite series. This accounts for elevated Fe values and associated elements in the soil samples. The association of Au, As, Sb and W can be attributed to hydrothermal alteration of the wall rock resulting in the formation of arsenopyrite, stibnite and scheelite giving rise to this metal association. This sulphidation event may prove a greater possibility of finding primary gold mineralization in the region. It indicates that the primary gold mineralization is a product of wall rock

sulphidation. The metal association of component 3 which is comprised of Cu, Ni, Zn and S is also a product of a possibly late and barren sulphidation event related to the formation of chalcopyrite. This late hydrothermal process might not be responsible for Au mineralization in the area. Weathering of rocks and oxidation of their sulphide minerals may have permitted As, Sb, S and W to be introduced within the soil profile in solution; thus these elements can assume the role of pathfinder elements for potentially economic deposits during a geochemical exploration using soil samples. The gold distribution pattern in this study shows a lateral SW extension. Where gold remobilization occurs from a quartz vein or stockwork system, secondary gold distribution is

**Fig. 3** A plot of long to short axis ratio of each grain and the percentages of surface area occurring as concavities. SEM images of some recovered gold grains in insert



primarily lateral at or near the palaeowater table with a characteristic T-shape. The gold grains recovered from sample number 28 possess delicate secondary gold structures such as dendrites which are common in authigenic gold. The presence of particulate gold with dendrites in the soil indicates proximity to the primary source. A predominance of dendritic shaped grains to circular grains indicates a short distance of transport as grains will be more circular with an increase in distance of transport (Townley et al. 2003). The elongated, discoid and rounded morphologies of the grains exhibit pitted surfaces which are corrosion features showing evidence of gold dissolution probably as a result of exposure to weathering solutions (Larizzatti et al. 2008). Au is usually dissolved from the higher horizons and reprecipitated from stable complexes to form mottled zone and saprolite haloes at depth especially in soil profiles where Au remobilization and chemical precipitation of authigenic gold is evident (Vishiti et al. 2015; Suh and Lehmann 2003).

## 5 Conclusions

This study shows that soil geochemical survey serves as a very effective method for gold exploration in this area as it is made up mainly of weathered overburden. Gold distribution in the area presents the potential of economic primary gold mineralization. Gold anomalies show an NW-SW trending direction. The application of factor analysis to multi-element soil geochemical data from the Batouri gold district showed that gold is associated with arsenic, antimony and sulphur and thus can be considered as pathfinder elements. The morphologies and surface features on the particulate gold grains indicate proximity to the primary source.

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