Geochemical examination of gold mining waste at Nzunguni in central Tanzania

Hiroaki Ishiga*, Paschal Justin Magai* and Miguta Faustine Ngulimi*

Abstract

Waste of gold mining at Nzunguni, central Tanzania was analyzed by X-ray fluorescence analysis (XRF) using the press powder method to evaluate environmental impact to the surrounding area. Gold (Aurum) occurred within quartz vein (reef) in the host granitic rock, which was separated by crushing the quartz vein and concentrated by gravity separation process on the slope. Mercury (Hg) was used for more concentration, but this process was not common in this site. Samples were collected at the gravity separation site, which were light yellowish gray silt. Aurum was detected in all 11 samples, even though only by qualitative analysis. This is because Au bearing standard powder was not obtained yet. Mercury was not detected for two samples which were treated with Hg at the site. Copper concentrations show variation from 500 to 1200 ppm suggesting relation of Au or Au bearing minerals. High Fe$_2$O$_3$ concentrations (10-19 wt%) in waste materials may be mainly derived from secondary formed iron oxide in cracks of quartz veins. Zn, Pb, Cr, Ni and V did not show high concentrations indicating absence of heavy minerals in the veins. Stream sediments did not show deviation of both Cu and Hg, suggesting negligible effects of contamination from the smelting process.

Keywords: geochemistry, gold mining, waste, mercury, Tanzania

Introduction

Mining industries are important economic factors that contribute to the level of livelihood, however, they also have significant environmental effects (Ikingura et al., 1997). Human exposure to mercury (Hg) in artisanal gold mining of the world can harm human health condition and its risk is well known (Kristensen et al., 2014). Emission of Hg into the air has become a global issue even though the activities are small-scale gold mining industries in developing countries (Lacerda, 2003). The Minamata convention in 2013 stipulated action for reduction and feasible elimination of Hg use in artisanal gold mining (Spiegel et al., 2015). In Tanzania, 0.5-1.5 million small-scale artisanal gold minings have been operated and gold-extracting chemicals and their waste disposal were reported to have caused severe hazard to humans and surrounding areas (Bose-O’Reilly et al., 2010; Taylor et al., 2005; Van Straaten, 2000; Charles et al., 2014). The present study described geochemical compositions of waste materials of the mining site to evaluate their potential environmental impact. In addition soil, stream sediments and host rock compositions were analyzed for comparison and evaluation of back ground level of heavy metals.

Study Area

Small-scale artisanal gold mining is common in Tanzania, especially in southwest of Lake Victoria (Fig. 1). Other activities are scattered in western and central Tanzania (Fig. 1). This study focused on the Nzunguni artisanal mining site located 12 km east of Dodoma, central Tanzania (Fig. 1). The central part of Tanzania is mainly characterized by a flat geography with some rocky hills. Dodoman area forms smooth hills and ridges. Geologically the area belongs to the Tanzania shield composed of migmatites and granitic complexes of Archaean age (Williams, 1936; Wade et al., 1938; Fozzard, 1962a, b). The Dodoman gneisses (2500 Ma) and the post-Nyanzian intrusive granites (1870 Ma) have been described (Wendt, 1972; Bell and Dodson, 1981). Barth et al. (1996) has reported the geology of the Nzunguni mining and described the geology and mineralogy of the site...
as follows: Beginning of Madengi Hill artisanal gold mining (Fig. 2) was recorded in 1932 after the discovery of eluvial and alluvial placers. The “gold rush” came to Madengi Hill, where 10,000 people inhabited in early 1990th. After decline of production of gold, the local name “Nzunguni” was settled at this hill. According to Barth et al. (1996), 6,000 people were living.

The geology of the gold prospect comprised mainly of granite and “schistose quartz-sericite schist” (mylonitic schists), accompanied by some roof pendant of green metadolerite. The granite shows gray color and is coarse-grained with dark clots consisting of hornblende, biotite, sillimanite and sphene. Rocks bearing gold mineralization were sheared, crushed and saucerization with trend of NE-SW dipping 60˚NW. The shear zone was stained with iron and manganese oxides. Gold and auriferous rocks occurred within quartz veins (reef). For this small-scale artisanal mining, shafts were commonly constructed to approach to underground ore materials (Fig. 3).

Native gold appears as sharp-edged to elongated grains, usually 50-400 mm in size (Barth et al., 1996). Following description was given by Barth et al. (1996). Assay of samples yielded gold of 2.3 g/t in average (the highest values ranging 23-55 g/t). Paragenetic ore mineral is galena embedded in a quartz matrix. Microprobe analysis showed silver contents of 3-20 % (average of 42 grains) and an outlier value of 59 % Ag, copper values were constant at about 0.2 %. The grade of the crude ore is 150 g/t (average of 3 bulk samples); 33 g/t were produced from single mineral aggregates of hematite; a sample of metadolerite from the waste dump yielded 27 g/t.

**Extraction and Processing in mining site**

The Nzunguni gold mining is a typical small-scale mining, for the hoisting system at shaft has been adopted for taking out of ore material. Two people were holding hands on rotating by applying a force (Fig. 3). Due to the manual operation of the shaft, the potential depth of safety was limited within 30 m. After removing wood fragments and roots, quartz veins (Fig. 4A) were packed into bags for temporary storage (Fig. 4B). Crushing ore material on the hard rocks by steel made hammers was usually done by women (Fig. 4B). Crushing was observed at three sites where it was engaged in same manner in 2015. After crushing and drying, materials are fed into ball mill grinder using tungsten carbide balls (Fig. 4B) to process them into finer powder (Fig. 4C). The next stage was gravity separation carried out by hydraulic washing on wood made slope about 45 degrees and followed by more gentle slope, both of which were covered by straw mat (Fig. 4D). Heavy material presumably yielding gold was retained on the mat (Fig. 4E). Aurum amalgamation using mercury and panning to refine gold was partly conducted at the site C in Fig. 2. For sluicing process, demand of water is significant due to scarcity on the hill sites and the related dry climate. For this reason, grit chamber system was settled for separation of water and solid material (waste) (Fig. 4F). The wall of the grit chamber was coated by clay material for protection from water leakage (Fig. 4F).
Sampling Methods

Samples of soil, stream sediment and waste of about 100 g each were collected at the Nzunguni area (Fig. 2). Two soil samples were taken close to the mining pit (Fig. 2). The soil samples may represent the background geochemical compositions of the area. In addition three stream sediment samples were taken directly from river that runs out of Nzunguni mine site (Fig. 2). Eleven samples were taken from waste materials left behind at the site after extraction of gold and auriferous minerals (Fig. 2). Among them seven samples were collected at the site C (Fig. 2), and the locality of each was indicated in Fig. 5. This figure indicates system of gravity separation and grit chambers from right to left. Granite samples were taken as a representative of the host rock.

Samples were imported with permission of Soil Plant Protection, the Ministry of Agriculture, Forestry and Fisheries, Japan on 20th August, 2015.

Sample Preparation and Analytical procedure

Approximately one-third of each sample was transferred to Pyrex beakers, covered with aluminum foil to protect from contamination, and dried in an oven at 160˚C for 48 hours. Once
dried, sub-samples of the soil were crushed in an Automatic Agate Mortar and Pestle grinder to produce a powder sample. Then, the pressed powder pellets were prepared by pressing the powdered sample into 30 mm diameter vinyl chloride rings, using a force of 200 kN for about 60 s in an automatic pellet press (E-30.M Maekawa Co., Ltd.).

Abundances of selected major elements (TiO$_2$, Fe$_2$O$_3$* (total iron expressed as Fe$_2$O$_3$), MnO, CaO and P$_2$O$_5$ wt%) and the trace elements As, Pb, Zn, Cu, Ni, Cr, V, Sr, Y, Nb, Zr, Th, Sc, TS (total sulfur), F, Br, I in ppm were determined by using X-ray fluorescence analysis (XRF; Rigaku RIX-2000) in the Department of Geoscience, Shimane University. Gold (Au) was analyzed and detected by the XRF but was not quantified. The XRF analyses were performed following the method of Ogasawara (1987). Average errors for all elements are less than ±10% relative. Analytical results for GSJ standard JSL-1 were acceptable compared to the proposed values by Imai et al. (1996). Analytical results of samples are given in Table 1.

**Results and Discussion**

Waste samples show lower concentrations of As, Pb, Zn and Ni (Table 1). Contents of Cu show higher values than other heavy metals ranging from 500 ppm to 1200 ppm (Table 1). This indicates the existence of Cu bearing minerals and their relation to auriferous minerals. Arsenopyrite (FeAsS) is often accompanied in the auriferous mineral matrix (Keshavarzi et al., 2012), and this chemical species may also become a toxic matter for human (Charles et al., 2014). However, present results show quite low contents of As of less than 5 ppm (Table 1). This indicates absence of As bearing minerals in Nzunguni mining site. Thus hazard by arsenite reported from other mining sites in Tanzania (Charles et al., 2014; Kassenga and Mato, 2008) may not be the case. Contents of V and Cr show some variation (Table 1), and may occur as heavy minerals. Yttrium, Nb, Zr and Th have lower contents excluding two samples with higher Zr contents (C-2 = 270 ppm and C-5 = 117 ppm in Table 1). Fluorine contents vary among samples, but TS contents show quite lower levels. TiO$_2$, MnO and CaO contents vary among samples but do not show considerable deviation. Fe$_2$O$_3$ concentrations show quite high values ranging from 7.99 wt% to 19.84 wt% in Table 1, suggesting derivation from iron oxide stained quartz veins (indicated in Fig. 4a and b) and additional contamination from crushing hammer and ball mill machine (Fig. 4b).

Concerning to results of stream sediments, significant high values of Cu, Zn and Pb were not observed. Sample E-3 has considerably high Zr content (1042 ppm) and relatively high Th (217 ppm), Cr (228 ppm) and V (244 ppm) contents compared to other samples. This may be related to sorting effects within the stream during wet season. Granite sample does not show peculiar results (Table 1), but lower Nb (2 ppm) for continental granite may reflect subduction related magmatism. Looking at Nb contents of waste, soil and stream sediments in Table 1, all values are below 10 ppm which can support this consideration. Although material derived from the source rocks do not always show the same concentrations of Nb, considerable low Nb contents could suggest depletion at the source.

Qualitative analysis of XRF, aurum peak was detected at 2θ=36.96˚ for waste sample (A-1) from Nzunguni gold mining (Madengi Hill) in central Tanzania (Charles et al., 2014; Kassenga and Mato, 2008) may not be the case. Contents of V and Cr show some variation (Table 1), and may occur as heavy minerals. Yttrium, Nb, Zr and Th have lower contents excluding two samples with higher Zr contents (C-2 = 270 ppm and C-5 = 117 ppm in Table 1). Fluorine contents vary among samples, but TS contents show quite lower levels. TiO$_2$, MnO and CaO contents vary among samples but do not show considerable deviation. Fe$_2$O$_3$ concentrations show quite high values ranging from 7.99 wt% to 19.84 wt% in Table 1, suggesting derivation from iron oxide stained quartz veins (indicated in Fig. 4a and b) and additional contamination from crushing hammer and ball mill machine (Fig. 4b).

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was mostly completed and if any, quite lower level of Hg might be included in the waste.

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タンザニア中央部のズグニにおける金鉱山の周辺環境への影響を評価するため、廃棄物について、XRF による粉末プレス法により分析した。金および金を含む鉱物は母岩に含まれる石英脈中に産出し、この石英脈を粉砕し、斜面において比重選鉱により分離される。さらに金を濃縮するために水銀が用いられるが、この鉱山ではこの作業はまれであった。試料は比重選鉱場で採取したが、それは淡黄色色シルトであった。定性分析ではあるが、10 試料で金が検出された。この分析を行ったのは、金の標準試料がまだ準備されていないためである。水銀による処理が行われた。2 試料について検討したが、水銀は検出されなかった。銅の含有量は、500 から 1200 ppm と変化に富むが、これらは金を含む鉱物に伴われると考えられる。高い Fe₂O₃ 含有量（10-19 wt%）は、主に石英脈の割れ目に 2 次的に生じた酸化鉄による。亜鉛、銅、クロム、ニッケルとパナジウムは低濃度であり、これらを含む重鉱物が石英脈に伴わないことを示す。鉱山流域の堆積物の鉛と水銀については異常値を示さず、精錬による影響が低いことを示す。