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Geochemical fingerprinting methods identify the origin of raw materials in conflict regions: the example of TTT (Ta, Sn, W) ores in Central Africa

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Summary

The principle aims and methods of the geochemical fingerprint for tantalum, tin and tungsten ores are illustrated based on the relationships of ongoing armed conflicts and mineral production in the eastern Democratic Republic of Congo. The fingerprinting method is placed as an analytical proof of origin within the framework of the Certified Trading Chains (CTC) concept, developed at BGR and presently implemented in the region (Rwanda, DR Congo).

A proof of origin is conducted in three consecutive steps: after preparation of a polished section from an ore concentrate, two analytical steps are applied to fully characterize the sample: first, the mineralogical composition is determined using automated scanning electron microscopy techniques (e.g., Mineral Liberation Analysis), followed by major and trace element measurements on a representative number of single mineral grains using laser ablation-ICP-MS. This step also includes determination of U-Pb isotope ratios that are used to calculate mineral formation model ages. Comparison with a comprehensive data base enables to distinguish the origin of a concentrate from a geological province down to the scale of a deposit.

Political and economic background

Natural Resources often play a key role in triggering, prolonging, and financing resource-related conflicts, especially in African countries: three of the worst wars of recent years were related to natural resources - Sierra Leone, Liberia and the Democratic Republic of Congo

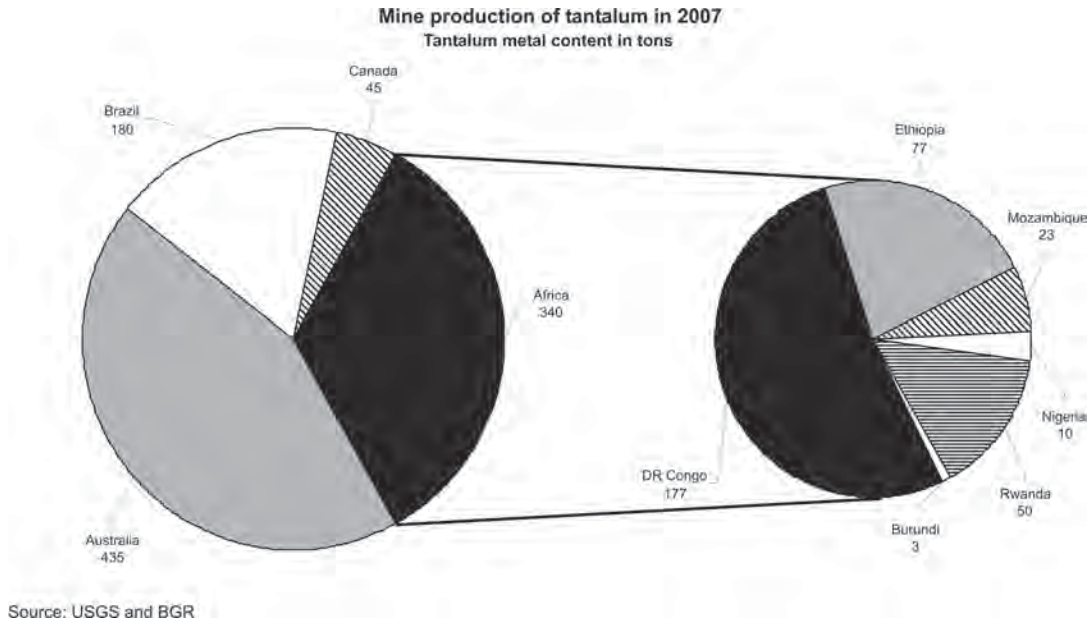

Fig. 1: World mine production (metal contents) and African production of tantalum in 2007 according to the USGS (2009) and the BGR (2009b).

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(DRC). The eastern part of the DRC has been suffering under armed conflicts for more than 12 years. In the provinces North and South Kivu, armed groups partly control the extraction and trade of cassiterite (tin ore), gold, columbite-tantalite ("coltan", tantalum ore), wolframite (tungsten ore) and other minerals. Lucrative business networks exist due to a lack of state control and the unregulated nature of the mining sector.

Mineral production in the DRC depends to a large degree on the artisanal and small-scale mining sector. It is estimated that about 2 million people are working in this sector and about 10 million people depend on the earnings generated – this is equivalent to 15% of the total Congolese population. In the early years of this decade, the artisanal mining sector in the DRC produced between 80-100% of the total Congolese mineral production (Garrett & Mitchell 2009), due to difficult operating environments for industrial mining operations und lack of infrastructure. The two main warring parties in eastern DRC, the Forces Démocratiques de Libération du Rwanda (FDLR) and the Forces Armées de la République du Congo (FARDC, Congolese national army), control highly mineralised areas in North and South Kivu. The analysis of export data suggests that under-declaration and smuggling are also major problems. The trade starts at remote sites, from where the minerals are transported by foot, car, truck, and by plane to the main export centres, Goma and Bukavu.

In 2002, the United Nations' Panel of Experts on the Illegal Exploitation of Natural Resources and Other Forms of Wealth of the Democratic Republic of the Congo presented their findings to the Security Council (United Nations Security Council 2002). The Panel had found that the plunder of natural resources and other forms of wealth of the DRC was fuelling conflict in the region. In 2005, the Panel of Experts proposed that enhanced traceability systems should be developed for all important natural resources of the Democratic Republic of the Congo (United Nations Security Council 2006).

Taking up the call for more transparency in mineral production, the Federal Institute for Geosciences and Natural Resources (BGR) started two pilot projects in 2006. The first project was a feasibility study of 'fingerprinting' coltan samples based on the mineralogical and chemical characteristics of specific ore concentrates. In the second project, a chain of custody assurance systems was developed, based on the establishment of transparent, traceable and ethical trading chains. This concept of Certified Trading Chains (CTC) found entry into the G8 summit in Heiligendamm in 2007 (G8 Summit 2007).

Economics of TTT

High-commodity value metals such as gold and the 3 T´s (tantalum, tin and tungsten and) are especially linked to financing armed conflicts in eastern DRC. Deposits of tantalum, tin and tungsten are abundant in the Kibaran orogenic belt of central-east Africa, where they are extracted exclusively by artisanal mining methods.

Within the past ten years, tantalum production (ca. 1900 t in 2008) mainly focused on Western Australia, Brazil, Asia and Africa (Fig. 1). The economic crisis in 2009 has led to mine closures in Australia and Canada, with Africa, Brazil and China remaining as the principal producers. Major African producers are the DRC, Ethiopia, Rwanda and Mozambique, followed by Nigeria, Zimbabwe and others (Fig. 1).

The global tin production strongly increased from 1990 until today, with 350000 tons of metal content mined in 2007. Major producers are China and Indonesia, accounting for more than 70% of the production, followed by Peru. Africa's mine production was estimated to approximately 20000 tons, representing a 6% share of the world production. Tin exports as cassiterite concentrates from central Africa have strongly increased from 2001 to 2008; especially in 2008, about 17000 tons metal content were produced in the DRC and 2400 tons in Rwanda.

With 52000 tons of tungsten and 81% of the market share, China is by far the largest producer of this commodity, followed by Canada, Russia and Rwanda. Austria and Portugal have a 3.2% market share (BGR, 2009a). About 3% (3155 tons tungsten metal content) originated from Africa in 2007. The tungsten production in Africa is restricted to deposits in the Kibaran Province, with Rwanda (61%), the DRC (31%), Burundi (4%) and Uganda (4%) as the major producers.

Tantalum, tin and tungsten and play a crucial role for our modern society. Tantalum is an important electronic metal, widely used for the production of small capacitors that make up about 60% of the current tantalum demand. Such capacitors are used in consumer electronics, e.g. in cars, laptops, cell phones, digital cameras and pagers. In many products of daily use, tantalum may be substituted by cheaper metals such as niobium and aluminium. However, increasing demand is expected mainly due to its use in aerospace and aviation industries. Tin is mainly used as a solder material in the electronics industry (53%), as corrosion-resistant tinplates (16%), in chemicals and in the manufacturing of bronze. The major use for tungsten is in the production of heat- and corrosion-resistant hard metals that consumes about 60 percent of the global tungsten consumption.

The geochemical fingerprint for TTT

Economic deposits of tantalum, commonly associated with niobium and other rare elements (e.g., lithium, beryllium, tin, tungsten, rare-earth elements), are related to rare-metal granites, associated pegmatites, and to alkaline igneous rocks. In the DRC, tantalum, cassiterite and wolframite are produced by artisanal methods in the Kivu provinces, Ituri, Maniema and Katanga (Fig. 2). In neighbouring Rwanda, Burundi, and Uganda, artisanal production is smaller, but also significant. Heavy mineral concentrates are usually produced by panning and sieving, and may undergo limited additional processing steps (e.g., magnetic separation) before they are exported. The mines operate on eluvial and alluvial deposits associated with lenses of pegmatite rocks and quartz veins. Meta-sediments and igneous rocks make up the principal host rocks within the Kibaran Province, a Mesoproterozoic to Neoproterozoic

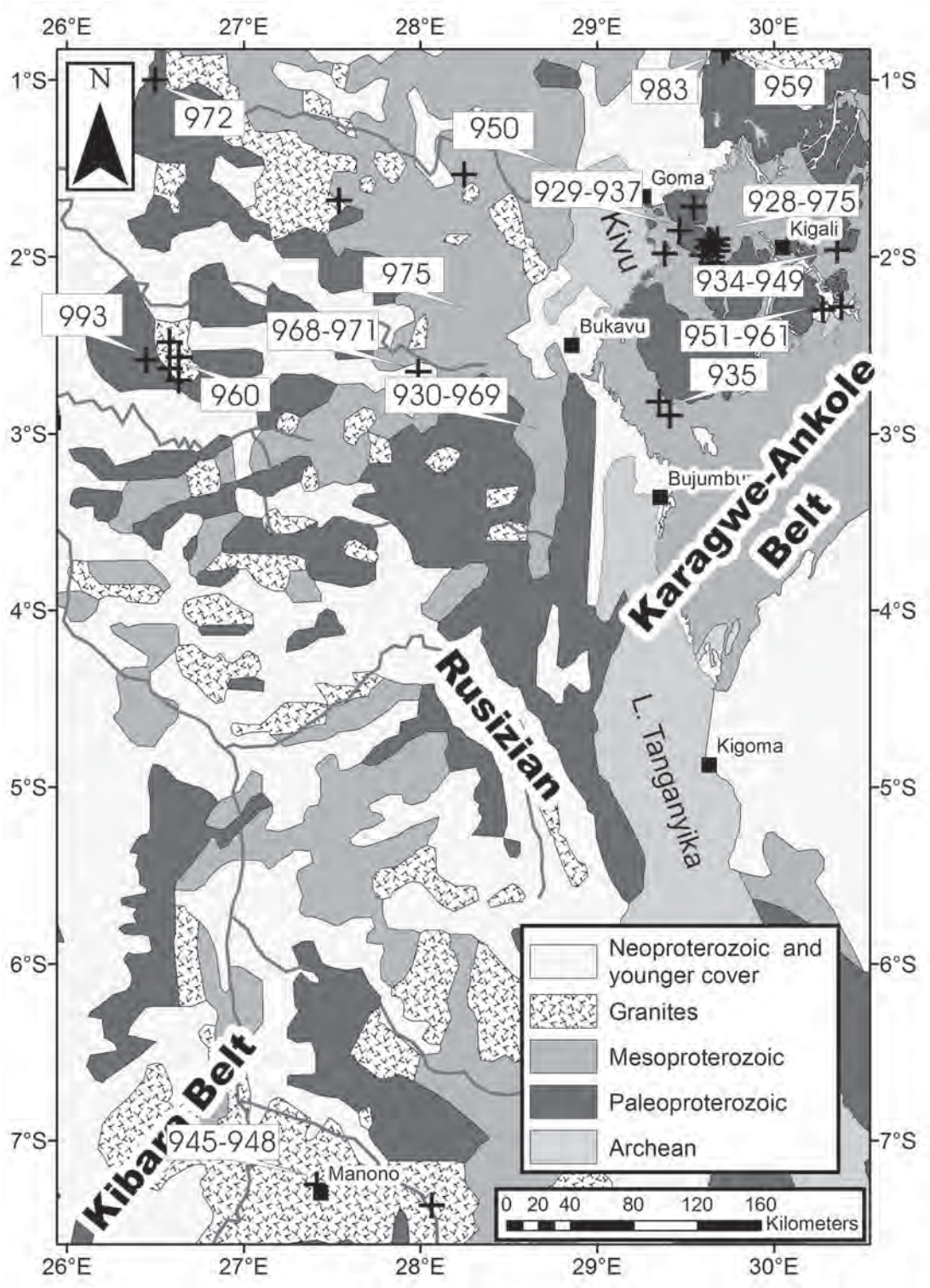

Fig. 2: Geological map of the Great Lakes Region in Central Africa with sample locations (crosses), and U-Pb ages of columbite-tantalite mineralization in million years (numbers in yellow fields). BU, Burundi; TZ, Tanzania. Modified from G. Rantitsch (MU Leoben).

major orogenic structure extending from Uganda in the NE to Katanga in the SW (Fig. 2). In addition, cassiterite and wolframite are mined from quartz veins probably related to post-orogenic, highly fractionated tin granites and pegmatites. Less significant production of tantalum, tin and tungsten takes place in the Ituri Province north of the Kivu Provinces; this mineralization is probably associated with Archean to Paleoproterozoic pegmatites (MELCHER et al. 2009).

On behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), BGR carried out comprehensive investigations from 2006 to 2009 to develop

analytical methods for a "coltan fingerprint". Based on an evaluation of geological and mineralogical factors, the following measurable properties were identified as critical parameters (Fig. 3) to verify the origin of tantalum ore concentrates

- Mineralogical composition and variability of ore concentrates
- Geochemical composition of single tantalum mineral grains in the concentrates
- Radiometric age of tantalum minerals

Several methodological approaches were tested. A three-stage analytical protocol is proposed taking into account the time available in routine work (Fig. 3):

- Preparation of polished sections
- Quantification of the mineralogy of ore concentrates using automated scanning electron-microscopic techniques (SEM/MLA)
- Determination of the chemical composition of single tantalum mineral grains, including uranium and lead isotopic composition for radiometric dating, using laser ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS).

The results are entered into a relational database and these samples are classified using statistical methods, e.g., by machine learning techniques.

The combined mineralogical and geochemical signatures allow for the definition of nine large tantalum provinces in Africa. These range in age from the Archean (>2500 million years) to the Mesozoic (younger than 225 million years) (Melcher et al. 2008a, b, 2009). The accuracy of allocating a sample to a province or sub-province is calculated by applying error-validated classification methods. Blind experiments revealed excellent hit rates.

Within the Kibaran province, uranium-lead model ages are similar for all pegmatite-derived ores (between 920 and 980 million years; Fig. 2). However, distinct differences in the mineralogy of concentrates and in the geochemical composition of single tantalum mineral grains enable discrimination down to the scale of an ore district such as the Gatumba district in Rwanda (Lehmann et al. 2008). Automated scanning-electron microscope-based methods such as Mineral Liberation Analysis (MLA) allow for a rapid quantitative measurement of a polished section prepared from an ore concentrate. Even rare phases are detected with a high probability. Once identified by MLA,

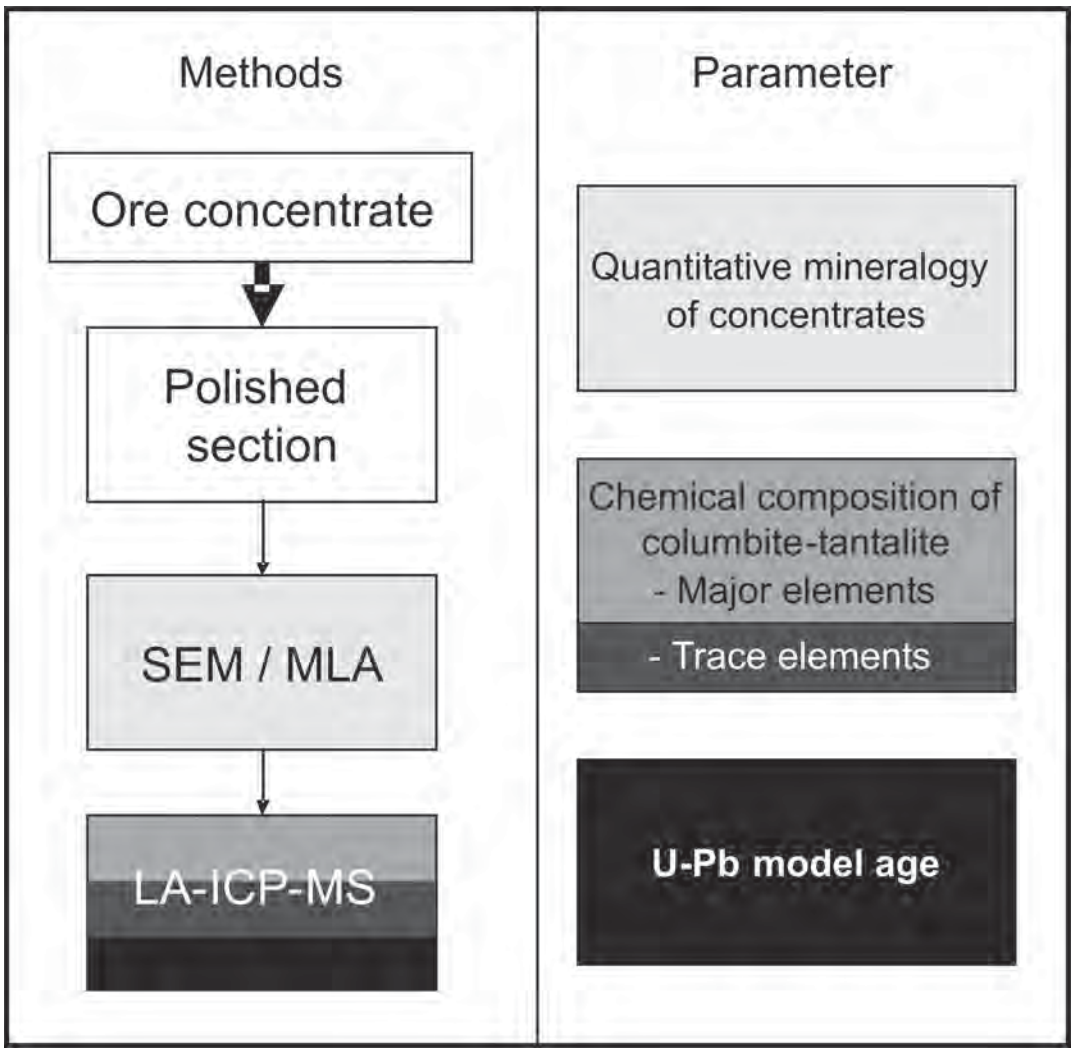

Fig. 3: Parameters and analytical methods used to fingerprint the origin of coltan; for abbreviations see text.

the compositions of single tantalum mineral grains are subsequently determined by laser ablation-ICP-MS, resulting in a comprehensive data set for each concentrate. In columbite-tantalite minerals, the concentrations of the major elements Fe, Mn, Nb, Ta, and of the minor to trace elements (Li, Sc, Ti, Zr, Y, Sn, Hf, W, U, rare earth elements) vary systematically within a given ore body (MELCHER et al. 2008a, b, 2009). In combination with textural attributes such as intergrowths, inclusions and zoning, chemical data are used to identify the host pegmatite and to discriminate it from neighbouring occurrences.

Thus, for the first time, an analytical method is available to fingerprint the origin of tantalum ore concentrates. The method may be applied as a forensic instrument, or in conjunction with certified trading chains in mineral production.

Following the same analytical protocols, fingerprints for tin (cassiterite) and tungsten ores (wolframite, scheelite) are developed at present. If necessary, this would allow for the control of a significant portion of mineral exports from Central Africa's conflict region.

Certified Trading Chains (CTC) in mineral production

Export bans on high quality and low volume commodities are costly and difficult to enforce. Certification can be oriented at the same goals, whilst allowing companies to continue mining or buying minerals from the region on the basis of demonstrated social and environmental responsibilities, as required by the certification system. CTC is an instrument to implement ethical standards and transparency in mineral production, and thereby to improve responsibility in the minerals sector by introducing a concept of voluntary self-commitment among the partners within the value chain. A principal flowchart of CTC is presented in Fig. 4.

CTC serves as an instrument

- to ensure that the trade of certain mineral resources is conducted legally and does not support belligerent groups in the region and
- to assure that process and production methods at the mine site adhere to minimum social and ecological standards.

CTC aims to increase the contribution of the minerals sector to poverty reduction and the political stabilisation of developing nations. On the other hand, it aims to improve supply security for the processing industry and fosters responsibility in industrialised economies. The proper implementation of certification will support areas of good governance, where mineral resources are produced and traded legally and transparently and in ways, which protect workers, communities, and the environment. Certification will also progressively transform and formalise informal mining. Formalisation is a precondition for achieving transparent records of production and trade,

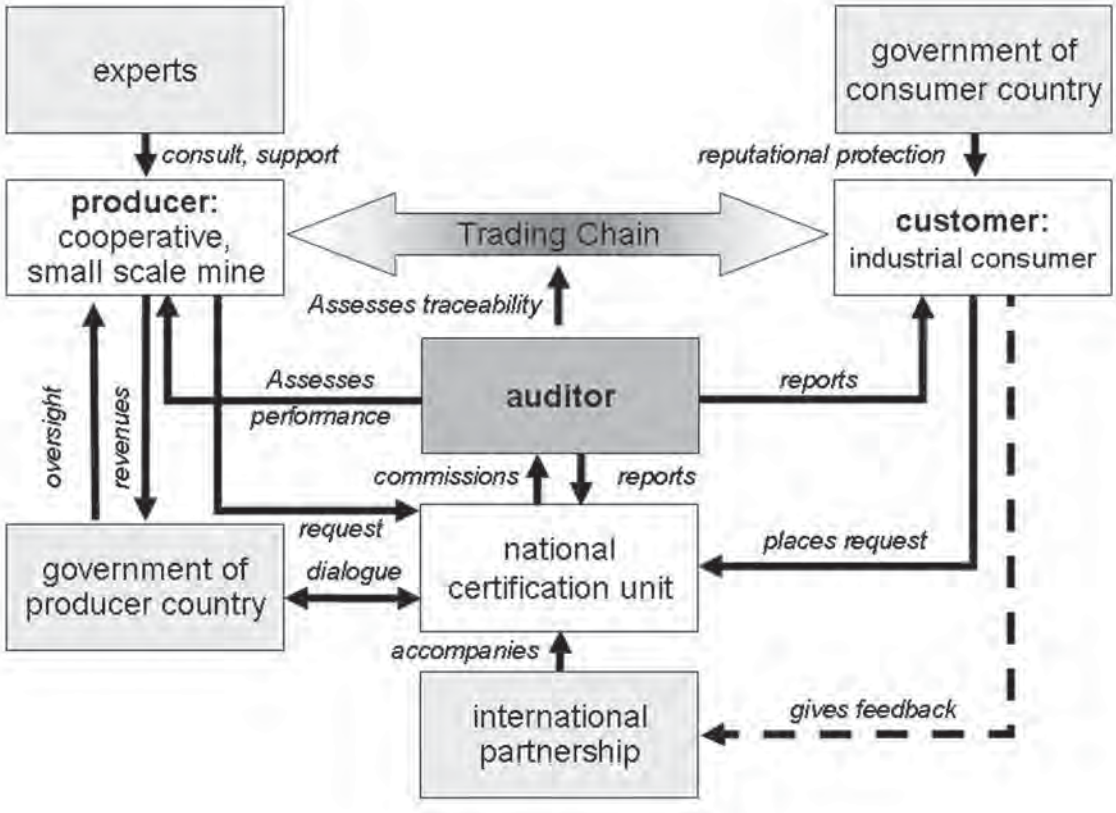

Fig. 4: Conceptual Flowchart of a Certified Trading Chain.

to improve governance and to reduce conflicts associated with the mining sector.
On the basis of company audits at different mining sites in Rwanda, a set of principles and standards was drafted based on a number of international 'integrity instruments' as well as national law, with the focus on transparency along the trading chain. The first principle includes "Origin and production volume of minerals from the pilot mine site throughout the trading chain are traceable" as standard 1.1. Other principles and standards relate to assuring corporate social and environmental responsibility. The traceability of origin and production volume is based on documentation and plausibility checks related to production, trade and export. In case of doubt, the instrument of the geochemical fingerprint can be used. The origin of a concentrate from a company joining the CTC can be verified based on comparison with the existing data set from the mine or concession in the standard data base. Mixtures from several sources can be identified, as well as material admixed from outside sources.

Outlook

In November 2006, the eleven member states of the International Conference on the Great Lakes Region (ICGLR) signed the Protocol against the Illegal Exploitation of Natural Resources, which includes the aim of implementing a mechanism for the certification of natural resources in its Article 11. In 2008 BGR has started the CTC pilot project in Rwanda and, in 2009, commenced with the implementation of a national certification scheme in DR Congo. Besides supporting transparency and control in the mining sector, CTC aims for regional stability and peace building. The bilateral projects in Rwanda and DRC may also support the intergovernmental body of the ICGLR in initiating regional certification of natural resources.
Certification of mineral production and trade can be relevant as a tool for development especially in artisanal and small-scale mining communities. The role of the fingerprinting method in creating traceability and strengthening transparency in the region has not yet been clearly addressed or enforced by the parties involved. However, the analytical fingerprint is a suitable way to identify the origin of traded TTT-ores, and, if conducted, to protect customers and consumers from being accused of supporting conflicts. Hence, it is recommended that a legal framework is established to integrate analytical methods into the certification of mineral production and trade in the Great Lakes Region of central Africa.

Acknowledgments

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