# The Analytical Fingerprint (AFP)

Method and Application

Process Manual

Version 1.4

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Editorial: The present document represents a process manual synthesizing key features of the Analytical Fingerprint (AFP) method. It is meant to define a practical guideline for the general AFP management framework when applying the method as an optional tool within an overarching supply chain due diligence scheme. The document shall be considered as work in progress with updates to be integrated as required. The full scientific background of the AFP method is discussed in peer-reviewed publications in international journals as referenced in this document. BGR used its internal funds and research facilities for initial AFP method development and was partly supported by a grant from the German Federal Ministry for Economic Cooperation and Development (BMZ, 2006-2009). In 2011, BMZ commissioned BGR to implement a technical cooperation project with the International Conference on the Great Lakes Region (ICGLR, 2011-2016). This project has recently been extended until end of 2019. Amongst others, the project aims to support the implementation of the Regional Certification Mechanism within the ICGLR Regional Initiative against the illegal exploitation of Natural Resources by furthering the practical application of AFP within the region. The present document was compiled as part of the latter project and builds on AFP experience at BGR since 2006.



Authors: Philip Schütte, Frank Melcher, Hans-Eike Gäbler, Maria Sitnikova, Manuel Hublitz, Simon Goldmann, Wilhelm Schink, Timo Gawronski, Arthémie Ndikumana, Lyne Nziza

AFP Method Development: Frank Melcher, Torsten Graupner, Maria Sitnikova, Hans-Eike Gäbler, Simon Goldmann, Thomas Oberthür, Timo Gawronski, Wilhelm Schink

**Federal Institute for Geosciences and Natural Resources**

Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)

GEOZENTRUM Hannover

Stilleweg 2

30655 Hannover

Germany

Phone: +49 511 643 - 0

E-Mail: info@bgr.de

https://www.bgr.bund.de

https://www.bgr.bund.de/mineral-certification

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## EXECUTIVE SUMMARY

International mineral and metal producers and processors are currently facing reputational risks and increased costs when sourcing "conflict minerals" from the Great Lakes region. This may render minerals from the region internationally less competitive thus depriving the local populations from a significant livelihood base. The International Conference on the Great Lakes Region (ICGLR) has set up the Regional Initiative against the Illegal Exploitation of Natural Resources (RINR) in order to foster good governance in the mining sector of the Great Lakes region and, through the formalized Regional Certification Mechanism (RCM), allow continuous engagement of responsible stakeholders. The success and credibility of ICGLR's RINR scheme and its efficient implementation in ICGLR member states will have a strong impact on facilitating competitive access of "conflict minerals" produced in the Great Lakes region to the international market.

The international credibility of the ICGLR Regional Certification Mechanism will ultimately hinge on the efficient implementation of robust oversight and integrity control measures which will have to succeed in banning illegitimate actors from the mineral supply chains. To this end, the RCM needs to be particularly sensitive to mineral traceability/chain of custody risk assessments and audits in order to be accepted by all local-regional stakeholders while also meeting international due diligence and transparency expectations, in particular of concerned end users. The architects of the ICGLR mineral certification framework have anticipated the need for decisive action on these matters by envisaging regular multi-level audit systems, on-going monitoring activities, as well as by installing a special investigator (the "independent mineral chain auditor") to follow up on any anomalies on his/her own initiative.

The Analytical Fingerprint (AFP) method represents a forensic tool developed by BGR to independently verify the documented origin of minerals without relying on any artificially added traceability information (e.g., tagging). Application of the AFP method as an optional tool to assess mineral origin may substantiate standard supply chain due diligence procedures envisaged in the RINR mineral certification framework thus providing additional credibility for ICGLR oversight at an international scale.

In this context and as part of the German support program to ICGLR[1], the German Federal Ministry for Economic Cooperation and Development (BMZ) commissioned BGR to support ICGLR in adopting the AFP method as an optional forensic tool in order to strengthen ICGLR oversight on the RCM. This process includes the progressive installation of individual AFP modules with regards to sampling, preparation, analysis, and data evaluation/management directly in the Great Lakes region, as well as full ownership of the method and the generated AFP data by ICGLR and its member states.

This manual provides the relevant authorities and international stakeholders with a general introduction to the topic (Chapter 1) and a technical reference overview with regards to scientific (Chapter 2) and practical (Chapter 3) considerations for AFP application.

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[1] The BGR support project to ICGLR's Regional Certification Mechanism, scheduled from 2011-2019, includes two components: (1) AFP application, and (2) implementation of the RINR Regional Certification Mechanism in selected member states. The project correlates with GIZ support to the ICGLR secretariat in the same time period as part of the overarching German support program coordinated by BMZ.

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**List of Acronyms**

| | |
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| 3T | Tin, tungsten and tantalum |
| AFP | Analytical Fingerprint |
| AMU | Analytical Fingerprint management Unit |
| ASM | Artisanal and small-scale mining |
| BGR | Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe) |
| BMZ | Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung) |
| CTC | Certified Trading Chains |
| DRC | Democratic Republic of the Congo |
| GIZ | German International Cooperation (GTZ until 2010) |
| GMD | Rwanda Geology and Mines Department (RNRA as of August 2011), formerly known as OGMR |
| ICGLR | International Conference on the Great Lakes Region |
| iTSCi | ITRI tin supply chain initiative |
| LA-ICP-MS | Laser-ablation inductively coupled mass spectrometry |
| MLA | Mineral liberation analysis (software) |
| OGMR | see GMD |
| QA/QC | Quality Assurance/Quality Control |
| RCM | Regional Certification Mechanism |
| RINR | Regional Initiative against the Illegal Exploitation of Natural Resources |
| RNRA | Rwanda Natural Resources Authority (merger of GMD, the National Land Centre, and the National Forestry Authority) |
| SEM | Scanning electron microscopy |
| U.S. | United States of America |

**Document Version History**

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|---|---|---|
| 1.0 | August 15, 2011 | Initial document draft by BGR |
| 1.1 | October, 2011 | Document version for online publication |
| 1.2 | July, 2012 | Update and extended appendix |
| 1.3 | January, 2013 | General document revision |
| 1.4 | May, 2018 | General document revision |

# 1. INTRODUCTION

## 1.1 Mineral Traceability and Supply Chain Due Diligence

Tin, tungsten, and tantalum (coltan) ore has been mined in Africa's Great Lakes region for more than 100 years, both by artisanal and semi-industrial means. In recent years, mining and trading of these minerals has partly contributed to catalyzing the conflict prevailing in the eastern Democratic Republic of the Congo (DRC) thus coining the term "conflict minerals". Therefore, international mineral supply chain due diligence expectations have emphasized the need to generate robust traceability information for mineral shipments allowing to identify conflict-free supply chains as a prerequisite to facilitate competitive market access of tin, tungsten, and tantalum ("3T") ore mined and traded in the Great Lakes region[2].

Mineral traceability may be achieved by different chain of custody verification systems. Mining and mineral trading companies commonly produce a paper trail which may be used for transport lot-based traceability documentation. More sophisticated systems include the application of tags and additional documentation that may be entered into online databases thus allowing timely mineral tracking. Still more sophisticated mineral traceability schemes involving automatic tagging data integration and online transmission (e.g., based on radio frequency and transponder technology) are currently in development.

These systems provide standard mineral traceability procedures which are practical for everyday usage. However, all these systems share a major weakness in that they seek to generate traceability by attaching additional information, through documentation or tags, to a mineral shipment. The complexity of artisanal mineral sourcing practice in the Great Lakes region makes 100% control of this process practically impossible such that these systems are inherently susceptible to fraud attempts by illegitimate actors aiming to misrepresent mineral origin.

In addition, it is critical to note that mineral traceability should not be considered as a standalone virtue, but forms an integrated part of the five-step supply chain due diligence framework defined by the Organization for Economic Cooperation and Development (OECD). This framework is cited as the reference for the EU regulation (2017) on responsible sourcing of 3Ts and gold from conflict-affected and high risk areas. It is also cited as a possible international reference in section 1502 of the US Dodd-Frank Act. As such, on-going supply chain monitoring, risk assessments and third party auditing form important parts in an integrated supply chain due diligence approach.

While the artisanal "conflict mineral" mining sector in Central Africa represents an important livelihood base for the local population that should be strengthened from a sustainable development perspective[3], responsible companies facing international supply chain due diligence demands require confidence in mineral traceability measures in order to facilitate responsible mineral sourcing in the Great Lakes region. Given the significance of reputational protection for these companies and end user demand for credible claims on a conflict-free mineral origin, an inde-

[2] Gold originating from the Great Lakes region has also been classified as a "conflict mineral" and shall thus be subject to supply chain due diligence. However, traceability measures for gold differ from those for tin, tungsten, and tantalum ore due to the small transport lot volumes. The Analytical Fingerprint (AFP) as presented here cannot be applied to gold.

[3] For example, by supporting responsible artisanal mining practice by means of mineral certification (e.g., the CTC scheme in Rwanda and the DRC, see http://www.bgr.bund.de/mineral-certification).

pendent mechanism is required to support the credibility of standard mineral traceability procedures in a larger due diligence framework.

This is the scenario where the Analytical Fingerprint (AFP) can be applied: AFP is an independent tool for chain of custody risk assessments and supply chain due diligence audits as it just uses the traceability information *contained in the minerals themselves* and information on the supposed origin of a mineral shipment. AFP produces an independent line of evidence with regards to the mineral source. How does this work?

## 1.2 What is the Analytical Fingerprint (AFP)?

The term Analytical Fingerprint[4] (AFP) refers to a combination of scientific techniques which might be used as a traceability tool to check whether or not the alleged origin of 3T concentrates as declared in accompanying documents can be verified. AFP compares a sample from a shipment in question (control sample) to samples of the documented origin stored in a database (reference samples). This is done by analyzing characteristic geochemical features preserved in mineral concentrates which reflect the source-specific mineralogical and geochemical features related to the unique geological context of each deposit. The final comparison of these features between control and reference sample is achieved by applied statistics and evaluates whether or not the declared origin given in the documents of a shipment in question is plausible.

Applying AFP generates geochemical mineral traceability information which is widely independent of shipping documentation and tagging procedures thus allowing the robust verification of the integrity of these standard traceability measures. However, AFP is designed as an optional proof of origin within the certification framework of 3Ts and does not represent an alternative to everyday mineral traceability techniques (e.g., tagging). Instead, AFP shall be used on a spot check base to verify the integrity, and thus credibility, of the applied traceability scheme.

AFP may be applied proactively by a mining company or their customers wishing to demonstrate a conflict-free origin of their minerals, or as a forensic tool in the frame of chain of custody risk assessments and supply chain due diligence audits (e.g., as part of the RCM). In the latter case, it may be applied as a regular or optional (i.e., reserved for special investigations) spot check procedure to verify supply chain integrity and standard mineral traceability measures.

## 1.3 AFP Management Unit (AMU)

The AFP Management Unit is integrated within ICGLR's Natural Resources Unit established at the ICGLR headquarters in Bujumbura, Burundi, and is the key entity overseeing all AFP processes. It facilitates the link to apply AFP in the frame of supply chain due diligence measures and provides recommendations for the relevant ICGLR Member state authorities in specific questions of mineral traceability (e.g., within a mineral certification scheme).

The AFP Management Unit has the following functions:

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[4] AFP is a method situated in an environment with many different actors. According to the specific focus and insight into the mining business, usage of a homogeneous terminology concerning all aspects of 3T mining activities is difficult to achieve. The definitions of relevant terms (e.g., mine site) used in relation with AFP might therefore vary from those of others stakeholders or institutions. The most significant terms and definitions are presented in the appendix.

(1) coordinate and provide support to AFP reference sampling activities, in cooperation with national authorities (e.g., the geological surveys of ICGLR member states); ensure that reference sampling activities are done according to accepted AFP procedures; arrange shipment of the sampled ore concentrate to a local sample preparation laboratory; training and accreditation of qualified personnel for sampling;

(2) organize and verify documentation of AFP reference sampling activities; provide updated maps of sampled mine sites to inform stakeholders;

(3) maintain and update the AFP reference sample database based on data provided by AFP laboratories and partners (national authorities); the reference sample database shall include details on sample origin locations and sampling procedures, documentation of sample handling and preparation steps, mineralogical, geochemical, and geochronological data of the samples;

(4) support the organizational planning and implementation of AFP supply chain control sampling by accredited stakeholders (e.g., auditors) in the frame of regular risk assessments, audits, or special investigations;

(5) based on the previous steps, scientifically evaluate the analytical results of AFP supply chain control sampling with respect to the contents of the AFP reference database; inform the relevant authorities (or their delegates, such as auditors in a mineral certification framework) whether the claimed mineral origin could be verified and provide recommendations with regards to the integrity of the respective supply chain;

(6) public relations and transparency management of AFP activities including the disclosure of relevant documents; reporting to the relevant authorities (e.g., within a mineral certification framework).

# 2. THE AFP METHOD – SCIENTIFIC BACKGROUND

**Explanatory Note**: This chapter outlines the scientific background of the AFP method, established through on-going collaborative BGR research since 2006. Research comprised (1) demonstrating the scientific validity of identifying source-specific features of tin, tungsten, and tantalum deposits; and (2) developing the analytical and statistical procedures to efficiently measure and evaluate these unique features. The AFP method follows a modular setup with individual preparation, analysis, and data evaluation steps thus allowing for flexibility in its practical application as outlined in chapter 3. Research details have been published in international scientific journals as indicated in the reference list.

## 2.1 Source-characteristic Features of Tin, Tungsten, and Tantalum Deposits

Tin, tungsten, and tantalum mineralization in Central Africa commonly comprises cassiterite (tin ore), wolframite (tungsten ore), and columbite-tantalite also known as “coltan” (tantalum ore). Coltan, cassiterite, and minor wolframite mineralization is frequently associated with *pegmatites* (e.g., Pohl 1994). These pegmatites represent highly evolved, coarse-grained, granitic intrusions of relatively small volume[5] (typically few tens to hundreds of meters in the longest dimension; Figure 1). The small size of the pegmatite bodies is a key for the high spatial resolution of the AFP method. The majority of the cassiterite and wolframite mineralization in Central Africa is hosted by *hydrothermal*[6] *quartz veins,* lacking coltan, and usually unrelated to pegmatites or granites. Individual quartz veins may continue over kilometers of strike length and hundreds of meters in the vertical dimension at a thickness ranging from few decimeters to meters. They are commonly arranged parallel to each other in mineralized vein systems either carrying cassiterite or wolframite (rarely both).

On-going BGR research since 2006 has shown that the pegmatite bodies, as the product of the crystallization and cooling of small magma batches, are characterized by a unique combination of mineralogical and geochemical source-specific features which are reflected in the compositions of crystallizing ore minerals (coltan, cassiterite) (Melcher et al. 2015; Melcher at al. 2017). Their geochemical compositions result from internal (parental magma composition and differentiation, crystallization) as well as external (host rock composition, magma emplacement depth) control factors. At the same time, certain minerals acquire a specific isotopic composition upon crystallization and subsequent cooling, which may be used to constrain the geological timing of the mineralization. In a similar manner, mineralized quartz vein systems acquire specific geochemical compositions from their source fluids, their parental rocks, and the way of rock-fluid interaction. Therefore, AFP analysis combines mineralogical and geochemical features of major and accessory minerals (like ore minerals) to derive a characteristic composition of each mineral deposit which is inherently recorded by its mineral concentrates.

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[5] Pegmatites may be genetically associated with precursor granite plutons of larger dimensions. Mineralization is mainly related to the pegmatites; to a lesser extent, disseminated ore minerals may also occur within the granitic plutons. Also note that mineralized pegmatites elsewhere in the world may be larger (up to several km in the longest dimension).

[6] In hydrothermal vein systems, minerals precipitate from hydrous fluids (hot water, usually of high salinity) during water-rock interaction processes. The fluids may be generated by magmatic processes (e.g., from granite emplacement) or by dehydration of hydrous minerals at deeper levels in the crust.

**Figure 1:** *Top* – Pegmatite-related cassiterite-coltan mine site in the Great Lakes region (Gatumba, Rwanda) of typical size (few dozens of meters in diameter; note artisanal miners for scale); the commonly small spatial dimension of individual mine sites is one of the key factors for the high spatial resolution of the AFP method. *Lower left* – mineral pre-concentrate produced on site by artisanal miners through panning; this type of concentrate represents the ideal AFP sampling material (for reference database construction). *Lower right* – Joint BGR-GMD AFP sampling in Rwanda (note that most persons on the photograph are artisanal miners/mining company employees; a single person is generally sufficient to carry out sampling).

## 2.2 Overview Principal Procedures

Based on initial methodological trials by BGR in the 2006-2009 period, a streamlined AFP protocol was established to efficiently analyze source-specific features of 3T mineral concentrates. The AFP protocol comprises four steps: (1) sampling and sample preparation, (2) determination of the modal mineralogy of mineral pre-concentrates or concentrates, (3) geochemical analysis of a representative number of individual 3T ore grains (major and trace elements, isotope abundances) and (4) statistical data evaluation. The analytical accuracy of the obtained results, as well as their reproducibility is verified by repeated tests over time including duplicates, blanks, and standard measurements[7].

### 2.2.1 AFP Sample Preparation

AFP samples represent mineral pre-concentrates or concentrates sampled at mine sites, storage sites, processing centers, and along the mineral supply chain. A statistically representative sample size should correspond to 50-100 g of the

[7] e.g., BGR (2009) Herkunftsnachweis von Columbit-Tantalit-Erzen – Status-quo-Bericht. BGR open file report no. 11082/09, 154 p.

<2 mm fraction[8] which is reduced to about 5 g by representative sample splitting in the laboratory. These grains are then embedded into epoxy resin on a sample mount (1 inch in diameter) and polished such that their grain interiors are exposed for subsequent analysis (Figure 2).


**Figure 2:** Left – Typical AFP mineral concentrate sample (ca. 50 g; diameter of flask = 4 cm); Center – Grinding machine used to prepare mounted AFP sample for polishing. Right – Polished section of sample for AFP analysis.

### 2.2.2 Mineralogical Analysis

The mineralogical composition of an AFP sample is assessed by scanning electron microscopy (SEM)[9] with attached automated mineralogy analysis software. Directed by the software, the polished surface of the sample is scanned by an electron beam and the resulting back-scatter electrons are collected to generate electronic image information. All mineral grains exposed on the sample surface are then automatically analyzed using energy-dispersive X-ray spectrometry (EDX) producing a characteristic X-ray spectrum for each particle. This information is compared to a calibrated standard mineral reference database. The software automatically identifies individual minerals at a high spatial resolution (0.005 mm) and quantifies their respective proportions. By calibrating against minerals of known composition, individual ore mineral end member compositions may be identified as a base for subsequent geochemical analysis (Figure 3).

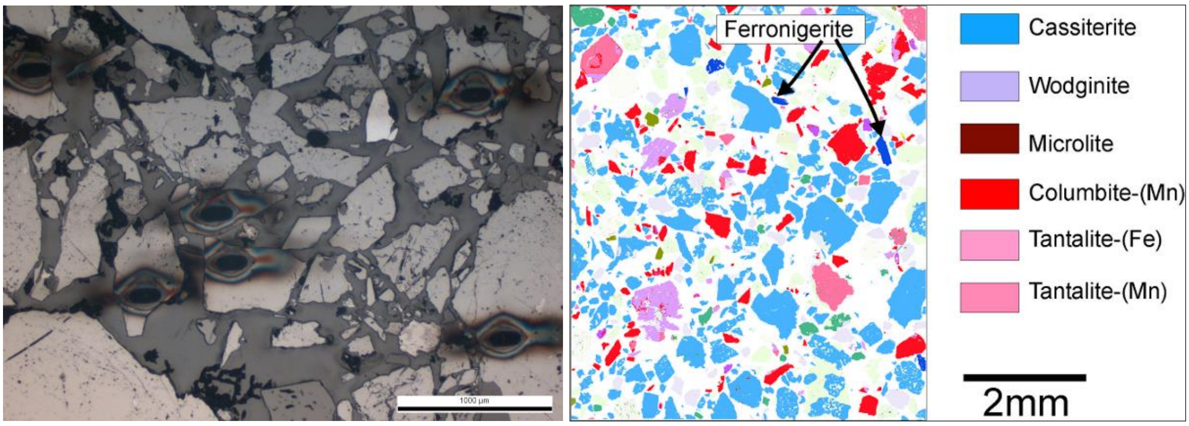


**Figure 3:** Left –reflected light image of polished sample showing mainly cassiterite grains (light grey); the groundmass (dark grey) represents epoxy resin; black pits represent laser ablation measurement spots where minerals have been “drilled” by the laser in order to determine their individual major and trace element compositions. Right – image showing characteristic mineralogy of a given cassiterite-coltan concentrate obtained through automated SEM-coupled automated mineralogy analysis (the

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[8] Slightly different considerations may apply in case the typical mineralization style of a given deposit is coarse-grained. A typical sample weight for coarse-grained mineralization is 100-200 g. It is important to sample the typical original grain size range of the mineralization – ore minerals shall not be artificially fragmented for the AFP sampling process.

[9] At BGR, a FEI Quanta 600 machine is used for SEM.

software assigns artificial colors (blue, red, brown, etc) to visually discern different minerals on this image; epoxy resin is colored in white).

The mineralogical information gained from reference samples has the potential for beneficial use beyond certification schemes by governmental institutions, mining companies and exporters in the Great Lakes region. An overview of these benefits has been compiled as a handout and can be found in the appendix.

### 2.2.3 Mineral Geochemistry and Geochronological Analysis

Analysis of the geochemical composition of about 50 individual grains per sample by laser-ablation inductively coupled mass spectrometry (LA-ICP-MS) is conducted for both major and trace elements[10]. Individual grains are selected based on automated SEM screening of the whole polished section and 30, 42, or 50 elements are analyzed in cassiterite, coltan, or wolframite, respectively. The measurement includes uranium and lead isotopic analysis in order to calculate U-Pb model ages to constrain the geological timing of mineralization. In-house standards are used for internal standardization of measurements.

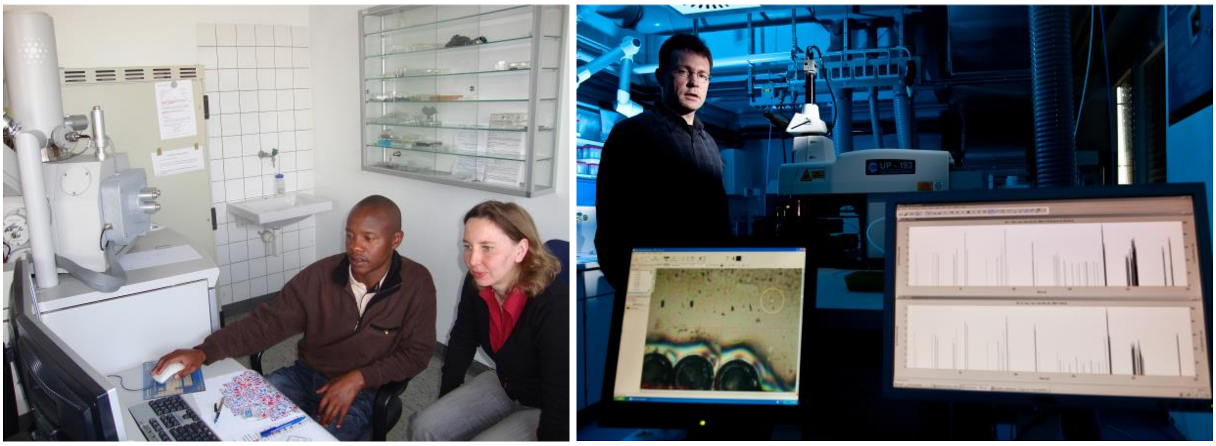

**Figure 4:** AFP measurements at BGR (Hannover, Germany). *Left* – Scanning electron microscopy (SEM) to obtain quantitative mineralogical information on mineral concentrates. *Right* – Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to obtain mineral-specific compositional data (geochemistry and isotopes). Thus obtained data are unique for each mineral deposit.

[10] A Thermo Scientific ELEMENT XR machine coupled to a 193 nm New Wave UP193-FX laser used at BGR.

## 2.2.4 AFP Data Evaluation

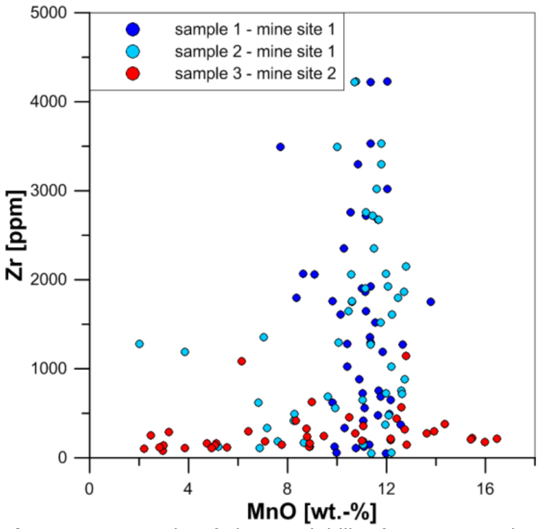


**Figure 5:** Example of data variability for two samples with common origin (blue) and one sample with different origin (red) for MnO and Zr.

AFP data evaluation aims to check the integrity of mineral traceability measures along a given supply chain by verifying the documented origin of a mineral shipment. This is done by comparing geochemical data from a mineral shipment in question to data from a reference sample of the supposed origin stored in the AFP reference sample database. A degree of statistical similarity in the geochemical composition of the two samples has to be established and evaluated bearing in mind the special nature of ore concentrate data like huge variability, not normal distribution of the data, and others. A detailed description of this procedure is given in Gäbler et al. (2017) for wolframite and can be applied for coltan and cassiterite as well.

The nature of the AFP data evaluation process is best illustrated by considering the following example: Figure 5 shows the concentrations of manganese (Mn) and zirconium (Zr) in three coltan concentrates. Mn as a major element in coltan is traditionally given as the oxide MnO in weight-%; Zr as a trace element is usually given in mg/kg also known as part-per-million (ppm). Each data point represents the analysis of one coltan grain. In this example, two samples were taken on the same mine site (mine site 1) and a third sample was taken on a different mine site (mine site 2).

As shown in Figure 5, sample 1 and 2 share a similar distribution field with the majority of the grains plotting between 6 and 13 weight-% MnO and between 10 and about 5000 ppm of Zr. In contrast, the values of sample 3 display a wider MnO spread between 2 to 16 weight-% and significantly lower Zr concentrations between 10 and 1000 ppm.

Cumulative frequency diagrams can be used to uncover similarities and differences between data sets. Fig. 6 presents such diagrams for the three samples using the parameters MnO and Zr. Similarities and differences between the samples are now expressed by calculating the Kolmogorov-Smirnov statistic (often called “Kolmogorov-Smirnov distance”, KS-d) which is defined as the maximum vertical distance between two cumulative frequency curves. As two samples with a common origin are supposed to be geochemically similar to each other they should yield a small KS-d whereas two samples with different origin will most likely be geochemically different to each other and show a large KS-d. This can also be observed in the given example where the maximum vertical distance between the blue curves (same mine site) is smaller than the distance between any blue and the red curve (different mine sites).

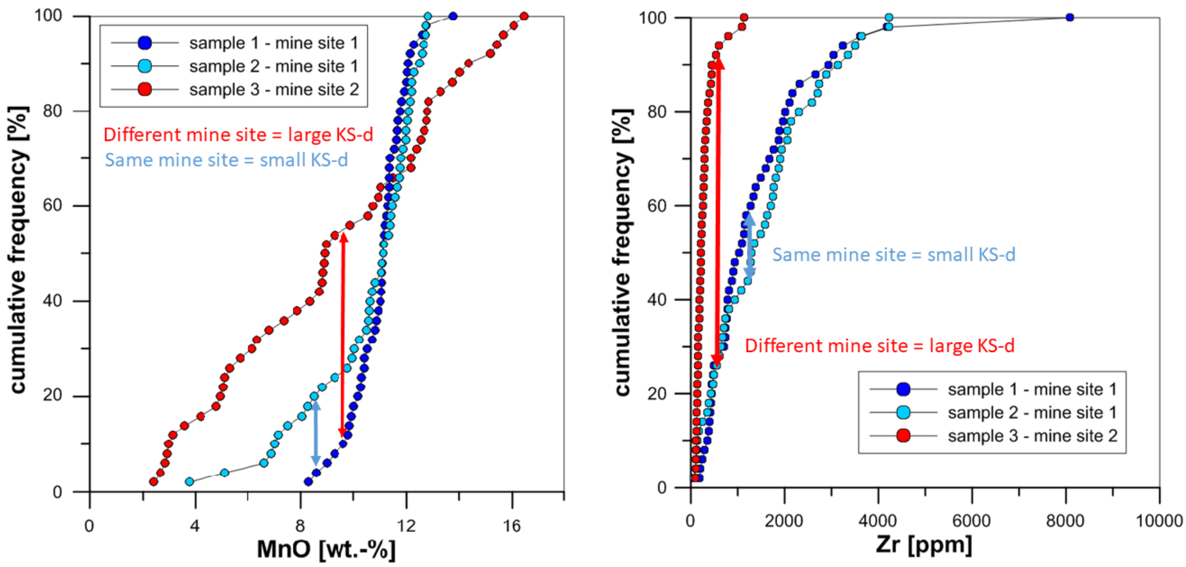


**Figure 6:** Example of data variability for two samples with common origin (blue) and one sample with different origin (red) for MnO (left) and Zr (right).

In the above example only two elements have been used to illustrate what AFP data evaluation is based on. In practice, AFP combines statistical evaluations of up to 42 different elements (for each of the ~50 grains to be analyzed) and evaluates the results based on the knowledge of the typical behavior of ore concentrates originating from the same or different mine sites. If the documented origin of a sample (e.g., from the supply chain) is in doubt, the statistical comparison of geochemical data between this sample in question and the reference sample (related to the documented origin) must result in small Kolmogorov-Smirnov distances or the doubt on the origin is persisting.

Additional geochronological and to a minor extent mineralogical data evaluation is carried out for AFP to check whether the sample in question and the related reference sample share the same geological age and mineralogical features typical for a given mining region and the processing steps along the associated supply chains.

With the support of BGR, AFP data evaluation is carried out by the AFP Management Unit (AMU) established at ICGLR headquarters in Bujumbura. AMU thus provides the link between the compositional data generated through AFP measurements and the practical application of AFP in a supply chain due diligence/mineral certification framework.

# 3. AFP IN PRACTICE

**Explanatory Note:** AFP serves as an optional tool to supplement standard mineral traceability measures in cases where additional credibility is required. Making practical use of the AFP method to check the integrity of mineral supply chains with regards to mineral origin requires progressive and continuous extending of the AFP reference sample database. This chapter provides a practical guidance with regards to AFP sampling and sample preparation procedures (section 3.1), mineralogical and geochemical sample analysis (section 3.2), and data evaluation (section 3.3). These processes are to be conducted in cooperation with various partners and are steered by AMU.

## 3.1 Sampling and sample preparation procedures

Two principal types of AFP sampling exist; (i) “AFP reference sampling” (section 3.1.1), that is, sampling to integrate a specific mine site into the AFP reference sample database and (ii) supply chain “AFP control sampling” (section 3.1.2) to verify the supposed origin of a mineral shipment. AFP reference and control sampling activities are done in parallel to on-going mining and mineral trading activities and do not cause any significant interruptions of these processes. Considerations concerning AFP sample preparation are provided under section 3.1.3.

**AFP Sampling Entities**

As a general rule, AFP reference sampling may only be carried out by AMU staff, by accredited partner institutions (national authorities; e.g., geological surveys) or BGR representatives following the established sampling protocols[11]. In detail, individual persons are authorized to perform AFP reference sampling by receiving renewable accreditation for a period of one year. The applicable accreditation standards as well as AFP reference sampling standards are enclosed in the Appendix of the present document. For partner institutions in the Great Lakes region interested in becoming accredited for AFP reference sampling BGR may provide training in both AFP sampling and analysis, and may also provide sampling equipment as well as logistic support.

Supply chain control sampling may additionally be performed by other affected stakeholders (e.g., auditors, industry clients, mineral certification authorities and their delegates) provided they are mandated to do so in the frame of specific mineral supply chain due diligence measures. The sampling person is therefore responsible for the accuracy and precision of sampling documentation, as well as the physical integrity of the sample until it has been delivered to an AFP sample preparation/storage facility.

**AFP Sample Features**

AFP sampling targets multi-mineral pre-concentrates or concentrates integrating the range of geological features associated with the mineralization at a given mine site.

*Mineral pre-concentrate* is defined as ore that has been subject to an initial non-standardized upgrading process (usually washing done by artisanal miners: panning, ground sluicing). *Mineral concentrate* is defined as ore or mineral pre-concentrate that has been subject to a standardized ore dressing/beneficiation process (usually done at a mechanized processing plant) in order to obtain a mineral product of export quality (i.e., of a pre-defined homogenous grade).

[11] Sampling practice may be subject to spot checks or regular reviews by BGR/AMU staff.

A sample representing the actual grain size range of the mined ore should be obtained; sample material should not be additionally fragmented during the AFP sampling process. Particular attention should be paid to sample weight: a minimum of 50-100 g of mineral pre-concentrate or concentrate is required for samples where the typical grain diameter is up to <2 mm; 100-200 g should be obtained for larger grain diameters. The ideal sample container is a 50 ml or 100 ml plastic flask. Sampling flasks should be labeled with a sample number as defined below. In order to prevent the sample number on the flask from being obliterated, it should be covered by a strip of transparent adhesive tape. In case the sampled material is dry, a note with the sample number shall additionally be inserted into the flask (together with the sample); in case the sampled material is wet, this might be skipped or water-proof material shall be used. Further handling of thus obtained samples is described in section 3.1.3 below. It should be noted that AFP reference samples may optionally be split (provided the sample is of sufficient size) and part of the sample may be used for other purposes by involved national authorities.

### 3.1.1 Reference Sampling

**Mining and Geology – Implications for Sampling**

Artisanal and small-scale mining concessions in the Great Lakes region are typically made up of several individual mine production sites (open pit or underground). The ore-bearing rocks may either be hard rock or unconsolidated (alluvial or eluvial) material. Mining of hard rock is done by rock fragmentation (manual drilling and blasting) and selective mining of mineralized zones (jackhammer, hammer and chisel). A basic processing step commonly takes place close to the mine sites where mineral pre-concentrates are obtained through panning, ground sluicing, and hand cobbing. Further formalized processing in order to produce a mineral concentrate of export quality (i.e., of a specific, homogenous grade) may then take place at a central upgrading plant.

Due to the high spatial resolution of geological features associated with the mineralization, AFP may differentiate source-specific signatures of individual mine sites on a given mining concession[12]. Therefore, in addition to the upgraded mineral product processed at a plant, each mine site should be sampled individually in order to integrate a given mining concession into the AFP reference sample database. In case a large number of mine sites (>10) with strongly variable production parameters are present, a limited number of mine sites may be selected for sampling according to their respective production significance.

Throughout the mine life, mineral production and processing procedures may be modified, and on-going exploration and exploitation activities may result in additional parts of the mineralization being targeted for mining. Such changes should be reported in a timely manner to the AFP Management Unit (e.g., via the relevant national authorities) in order to allow updating of the AFP signature of a specific deposit.

[12] Care must be taken when applying consistent terminology for “mine sites”. In context with AFP, a mine site is defined as a location of mineral extraction of limited spatial extent. For large or more complex mine sites with several separated spots of ore extraction and apparent and reasonable spatial relation to each other (which allows to assign them to originate from a mutual ore body) sub-mine sites are defined which refer to individual tunnels or small open pits (in the dimension of a few meters) from which ore is extracted. In contrast, ICGLR defines “mine sites” for certification purposes as concession areas (that is, related to a mining or exploration license). A “mine site” (or concession area) according to ICGLR classification typically has several dedicated tagging sites and still more individual production sites. The iTSCi tagging scheme in Rwanda and the DRC uses dedicated mineral tagging sites which are partly associated with individual production sites and, on other occasions, simply represent offices where minerals from various production sites are collected. AFP reference sampling mainly targets those individual production sites (that is, tunnels and pits).

**Implementation of Sampling Activities**

AFP reference sampling shall be authorized by and performed in close coordination with the mine site operator. Ideally, the sampling mission is accompanied by a mine site operator representative who is familiar with mining concession infrastructure, geology, safety, and security issues. In cooperation with the mine site operator the sampling entity (AMU, BGR or accredited partner) should set up a schedule for selecting individual sampling sites taking into account impact factors such as geology, logistics, site production relevance, or specific risks.

Total time requirements for mine site reference sampling depend on the scope of the agreed sampling plan and mine site access conditions; it may typically range from less than one day (well-organized mining operation with a number of major production sites) to one week (poorly organized mining operation with a widely disseminated range of small- to medium-scale individual production sites and difficult access conditions). In any case, sampling at mine sites can be performed without causing any significant interference with on-going mining and processing activities.

AFP reference sampling shall collect accurate and precise information as indicated in the sampling form provided in the Appendix of this manual. The person carrying out the sampling shall record these data either directly on a printout of the sampling form or in a field book (or similar) on site; data shall be digitized as soon as possible and forwarded to the AFP Management Unit via the relevant national authority. Sampling equipment (flasks) can be provided by BGR and can be made freely available to accredited partner institutions.

### 3.1.2 Supply Chain Control Sampling

AFP control samples can be taken along the upstream segments of the mineral supply chain in order to verify the claimed origin of these minerals[13] and to monitor incremental mineral aggregation processes along the supply chain. It is critical to note that, unlike standard mineral traceability measures (e.g., tagging), supply chain control sampling for AFP is generally envisaged through spot checks on specific mineral shipments only if doubt on the documented origin arises. An appropriate number of sampling locations along the supply chain as well as sampling frequency shall be consulted among the relevant stakeholders (mainly national authorities and AMU), ideally taking into account the factual circumstances of the respective supply chain due diligence measures (e.g., weighted by risk). Sampling of every single mineral transport lot (unit), on the other hand, would not represent an appropriate AFP sampling approach. Potential applications for supply chain control sampling are discussed in section 4.

While reference sampling may be logistically challenging for the sampling entity (e.g., AMU, accredited partner or BGR), supply chain control sampling is typically straightforward such that sampling time requirements are minimal (commonly few minutes per sample). Basic sampling procedural requirements correspond to the respective requirements listed above. Standard sampling equipment may be provided by BGR upon request. Sampling does not interfere with mineral production or trading activities. The small AFP sample size (50-100g; up to 200g for coarse-grained samples) mostly falls below the typical precision of balances commonly used to weigh the minerals for production and trade purposes such that AFP sampling does not have any measurable impact on recorded mineral weights.

[13] Provided that the claimed sites of origin have been subject to AFP reference sampling and have been integrated into the AFP reference sample database. Supply chain control sampling is also formalized through CTC standard 1.1 (e.g., in Rwanda and the DRC).

Precise and accurate information to be collected in the frame of supply chain control sampling shall include a detailed sampling documentation (see Appendix 2 for an exemplary data sheet).

### 3.1.3 AFP Sample Preparation

Once an AFP reference or control sample has been taken by a mandated entity (e.g., an accredited sampler), the sample is due to be sent for preparation to an AFP sample preparation laboratory. Local sample preparation laboratories have been set up in Rwanda (Kigali), the DRC (Bukavu), and Burundi (Bujumbura). Alternatively, an AFP sample obtained in the frame of reference or supply chain control sampling may be stored for a specific time period at an appropriate location[14] for *optional* AFP analysis should the need arise. For example, AFP samples may be selected for AFP analysis in retrospect in the frame of a regular risk assessment or supply chain audit over a given time period (to be defined by the relevant authorities). In line with regulations on standard chain of custody procedures, AFP samples for optional analysis should be stored for a minimum period of 5 years. Further details on risk assessment time scales are provided in section 4.2.

It is possible to split individual AFP sample preparation and analysis steps, and delegate the respective tasks to more than one laboratory. It is important to note that any laboratory is solely tasked to perform the preparatory and/or analytical work itself including AFP raw data evaluation (see below) according to international QA/QC procedures in a verifiable and transparent way.

**Logistical Considerations for Sample Handling and Preparation**

Due to an increased content in radioactive elements, columbite-tantalite may show slightly elevated radiation (generally low for cassiterite and wolframite) and imposes some health and safety precautions. Three categories regarding the radiation dose of primary AFP samples can be differentiated:

1. category I (harmless) < 0.5µS/h
2. category II (attention) 0.5µS/h to 3µS/h
3. category III (critical) >3µS/h

If the sample is harmless and classified as category I (the radiation of cassiterite and wolframite is generally low, but columbite-tantalite may show slightly elevated radiation), all relevant information of the sample is collected (see sampling form) and digitized. Samples classified as category II are generally acceptable, but the elevated radiation has to be taken into account. Category III is regarded as critical and the sample has to be split into smaller aliquots to reduce radiation exposure for lab users.

Processed samples (polished sections) are exported as part of a sample consignment (typically 10-30 samples at once) from the local AFP sample preparation laboratories to the AMU office in Burundi and then to the analytical AFP laboratory at the African Minerals and Geosciences Centre (AMGC, former SEAMIC), Dar es Salaam, Tanzania using standard air freight shipping.

Shipping of unprocessed AFP samples might thus largely be handled at the domestic/national level in the Great Lakes region. Following the procedures set forth in section 2.2.1, AFP sample preparation laboratories process primary AFP samples and create polished sections as a base for subsequent AFP analytical procedures. At the same time, these laboratories might serve as

[14] A secure, accredited location where AFP sample flux is monitored and documented as defined in the respective AFP application framework – e.g., a preparation laboratory.

storage facilities for samples awaiting optional AFP analysis at a later stage (cf. sections 3.2 and 4.4).

Thus, only shipping of processed AFP samples (polished sections) is required at an international level in order to send AFP samples to the analytical AFP laboratory in Dar es Salaam. The samples do not possess any commercial value[15].

All processed sample material shall be stored for a minimum time period of 5 years. The leftovers of the polished section preparation shall be stored at the sample preparation laboratories and the analyzed polished sections shall be sent to the AFP Management Unit for storage.

## 3.2 Sample Analysis

The analytical tasks of the AFP laboratory at AMGC are independent from evaluating AFP results with regards to supply chain due diligence-relevant implications for mineral production and trade – the latter process is done by the AFP Management Unit in cooperation with the relevant authorities within a given application framework as further discussed in section 4.2.

### 3.2.1 Time requirements for mineralogical and geochemical analysis

In practice, the analytical laboratory has to process a variable influx of samples resulting from both reference as well as supply chain control sampling. In order to obtain a balanced workload for the laboratory, reference samples due for analysis (for integration into the AFP reference database) may be stockpiled during peak periods of sample influx, such that supply chain control samples will be prioritized for analysis.

The time required for AFP sample preparation and analysis may be estimated according to the following schedule:

- International shipping time (air freight) varies from ca. 1 day up to 1 week. In case preparation and analytical facilities are set up individually, domestic shipping and verification of associated documentation may take an additional 1-2 days.
- The preparation procedure to obtain a polished section from a primary AFP sample takes up to 3 days in total (drying, representative sample splitting, embedding the sample in epoxy resin, grinding and polishing). Several samples can be treated in parallel such that the processing capacity for a preparation laboratory to produce polished sections from primary AFP samples is ca. 12 samples per week.
- The analytical run time for SEM-coupled automated mineralogy sample screening is 1-2 hours per sample; mineralogical data evaluation is an additional hour. The total capacity for the analytical AFP laboratory to perform SEM-coupled automated mineralogy measurements is ca. 20 samples per week on average.
- The analytical run time for LA-ICP-MS measurements (≥50 grains per sample) is about 4 hours; subsequent data reduction takes an additional 0.5 hours. The capacity for the AFP laboratory to perform LA-ICP-MS measurements is ca. 20 samples per week on average.

[15] This has been attested by the Rwanda Geology and Mines Authority (OGMR) and the DRC Ministry of Mines for recent AFP sampling activities in Rwanda and DRC, respectively.

- Statistical data evaluation by the AFP Management Unit is streamlined using special software generating rapid results per individual sample (<0.5 h/sample) once LA-ICP-MS data have been properly reduced.

Thus, the minimum total time for samples from posting the primary AFP sample to obtaining laboratory output data and, subsequently, AFP data evaluation through the AFP Management Unit is approximately 1 week. Using routine analytical procedures (with parallel sample treatment; 12 prepared samples per week) the typical minimum batch processing capacity of the AFP procedure (including preparation facilities, analytical laboratory, AFP Management Unit) is 36 samples for a time period of 3 weeks. This time range fits well into the risk evaluation framework as relevant for the Great Lakes region (cf. section 4.2).

### 3.2.2 Costs of Sample Analysis

In the framework of the BGR-ICGLR project partnership (2011-2019), AFP reference sampling analysis as well as control sample analysis is performed under the overall framework of the ICGLR's Regional Certification Mechanism and is funded directly through the project[16].

## 3.3 AFP Data Evaluation

### 3.3.1 Raw Data Evaluation

AFP raw data evaluation, obtained by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) analysis, is based on the application of laboratory QA/QC procedures to assess accuracy and precision of the generated geochemical data. The analytical laboratory is responsible for raw data evaluation in the above context as part of the analytical protocol, prior to clearing the data for statistical assessment. BGR will provide guidance in this context.

### 3.3.2 Statistical Data Evaluation

The aim of statistical data evaluation is (1) to identify deposit-specific AFP signatures (i.e., unique mineralogical, geochemical, and geochronological data defining a given deposit to be included in the AFP reference database), and (2) to assess the reliability of the documented origin of an AFP sample in question. The latter is done by comparison of data from a sample in question to data of a corresponding reference sample from the AFP reference sample database. Data evaluation is carried out by the AFP Management Unit who is also responsible to manage ownership of the data as well as ensuring verifiable transparency of the data flow.

Statistical data processing at the AFP Management Unit is streamlined by special software allowing rapid and straightforward data handling. The results of this data evaluation shall form the base for recommendations of the AFP Management Unit to the relevant authorities (e.g., within a mineral certification framework). All AFP results are to be presented in a transparent and verifiable manner. It is important to note that the results of AFP data evaluation are meant to be considered in concert with other due diligence processes and investigations in the frame of a given risk assessment or audit; they are not supposed to represent stand-alone evidence as a base for potential sanctions for a given supply chain.

[16] That is, through funds made available by the German Federal Ministry for Economic Cooperation and Development, BMZ.

### 3.3.3 Data ownership

Mineralogical and geochemical data are fully owned by ICGLR and co-owned by BGR. Member states own the mineralogical and geochemical data of samples taken within their respective countries. AFP Management Unit provides the mineralogical data to the national institutions in charge of AFP reference sampling and preparation who would access the data through the ICGLR regional mineral database which is about to be developed. As co-owner, BGR cannot provide companies, e.g. concession holders, with data; instead, they would have to approach the relevant member states' authorities.

# 4. POTENTIAL APPLICATIONS OF AFP FOR CHAIN OF CUSTODY VERIFICATION AND SUPPLY CHAIN RISK ASSESSMENTS

## 4.1 General Considerations

Identifying and mitigating the risks of potential conflict associations for a given mineral supply chain includes, amongst others, mapping, and tracking the supply chain and verifying the origin of the minerals. As such, mineral traceability forms one component (among several) of supply chain due diligence efforts aimed at keeping these supply chains conflict-free, as laid out in international due diligence guidelines[17].

Its inherent advantage of making use of the traceability information contained in the minerals themselves, rather than relying on the addition of external traceability information, makes AFP a particularly attractive tool in the context of the rather poorly formalized and regulated artisanal mining sector at the upper end of supply chains originating in the Great Lakes region. AFP is not meant to represent a stand-alone mechanism in the frame of supply chain due diligence measures on mineral origin; instead, it supports and complements related mineral traceability efforts with a view to maximizing their credibility for responsible end users demanding a conflict-free origin for the products they purchase, and the associated supply chains.

## 4.2 Supply Chain Risk Evaluation Time Scales

Supply chain due diligence requires stakeholders to identify and respond to risks through risk mitigation strategies, with the ultimate option of temporary or permanent disengagement from a given supplier. In order to facilitate efficient risk responses, the time scale of supply chain due diligence measures must correlate with the respective risk evaluation framework.

The U.S. State Department is required to provide an updated map of conflict mines in the DRC every 6 months in the frame of the Dodd-Frank Act (Section 1502). The typical risk evaluation time period of the ICGLR mineral certification scheme is envisaged to be 3 months (updating of ICGLR and member state mineral databases) or longer (e.g., annual regular audits). Routine time requirements for AFP supply chain control sampling, sample preparation, sample analysis, and data evaluation (1-2 weeks; cf. section 3.2.1) fit well into this time range such that AFP results have the potential to directly contribute to risk evaluation schemes in the above context. Alternatively, AFP supply chain control samples may be stored to be analyzed at a later time, thus allowing independent integrity control of chain of custody verification schemes through variable reference time periods.

## 4.3 Confirming Plausibility of Mineral Origin (Voluntary)

International stakeholders (mining companies, mineral processors, or their clients) sourcing tin, tantalum, and tungsten ore from specific mines inside or outside of the Great Lakes region may opt to have these mines sampled for integration into the AFP reference database. Subsequently, the origin of these minerals may be positively verified by AFP supply chain control sampling, e.g., as part of company-internal risk assessments or independent audits aimed at demonstrating due diligence.

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[17] In particular, the OECD (2011) Due Diligence Guidance on responsible supply chains of minerals from conflict-affected and high-risk areas, as well as its supplement on tin, tantalum, and tungsten, as well as gold.

For mines located within the Great Lakes region, sampling may take place in the frame of the BGR support project (2011-2019) to the ICGLR mineral certification scheme and, as such, would not implicate additional costs for the involved stakeholders other than logistic support.

## 4.4 Investigation of Chain of Custody Integrity

Supply chain due diligence efforts may be formalized through a mineral certification framework with specific elements such as a chain of custody verification system and regular evaluations of its efficiency and integrity. As part of the regular evaluation process, supply chain anomalies and risks (e.g., fraud attempts) may be investigated through a combination of measures.

In this context, AFP supply chain sampling and analysis may be performed within the frame of other risk assessment measures (such as an audit investigation)[18]. The combined findings of the investigation might then inform a decision on potential responses by the relevant authorities to actual or perceived risks. The advantage of employing AFP in this context is that AFP findings are particularly robust against fraud attempts, as the deposit-specific AFP signature, i.e., the traceability information contained in the minerals themselves, cannot be altered. Therefore, AFP findings from supply chain control sampling may be used to verify the integrity of standard mineral traceability measures such as tagging procedures and shipping documentation within an overarching supply chain due diligence framework.

AFP application may either form part of regular risk assessments (e.g., supply chain control sampling for audit purposes) or may be reserved for special investigations (e.g., in response to specific reports received through a whistle blowing platform triggering a larger in-depth investigation). In both cases, AFP supply chain control sampling may take place as spot checks integrated into an overarching due diligence process (e.g., selection of samples for analysis by an auditor). Samples may either be sent directly for AFP analysis or may be stored for optional AFP analysis at a later stage (e.g., to trace mineral flows through time in order to monitor anomalies such as the potential influx of foreign minerals). The latter process may be particularly valuable as a monitoring tool for poorly controlled artisanal mining operations at the upper end of the mineral supply chain.

[18] Provided prior AFP reference sampling has taken place. Various complementary mineral certification (e.g., CTC, ICGLR-RINR) and traceability (e.g., iTSCi) schemes are currently in development in the Great Lakes region. BGR aims to support the sampling of relevant “conflict mineral” mine sites across the Great Lakes region for integration into the AFP reference sample database as a base for subsequent optional AFP supply chain control sampling. Reference sampling is envisaged as a progressive and continuous process. Therefore, a production- and risk-weighted sampling approach is envisaged, where either high-volume producers or/and high-risk areas may be prioritized for integration into the AFP reference sample database.

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## Geological Background

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## Appendix 1 – definitions related to AFP

In alphabetical order

AFP reference sample data base

The AFP reference sample data base contains information on 3T ore concentrate samples taken during AFP reference sampling activities. The data comprise general information like mine site name, concession, type of 3T commodity present, GPS coordinates, etc as well as mineralogical, geochronological and geochemical data. In case that the documented origin of an ore concentrate sample is in doubt, these data are used to confirm or dispel this doubt.

Mine site and sub-mine site

In context with AFP, a mine site is defined as a location of mineral extraction of limited spatial extent. For large or more complex mine sites with several separated spots of ore extraction and apparent and reasonable spatial relation to each other (which allows to assign them to originate from a mutual ore body) sub-mine sites are defined which refer to individual tunnels or small open pits (in the dimension of a few meters) from which ore is extracted.

Mineral pre-concentrates and mineral concentrates

Mineral pre-concentrate is defined as ore that has been subject to an initial non-standardized upgrading process (usually washing done by artisanal miners: panning, ground sluicing). Mineral concentrate is defined as ore or mineral pre-concentrate that has been subject to a standardized ore dressing/beneficiation process (usually done at a mechanized processing plant) in order to obtain a mineral product of export quality (i.e., of a pre-defined homogenous grade).

Reference sample

A reference sample is a 3T ore concentrate sample which was taken on the mine site by qualified AMU/BGR personnel or by trained and accredited samplers according to the AFP sampling protocol. To be categorized as reference sample, several prerequisites have to be fulfilled in order to facilitate their analytical results to be included into the AFP reference data base. Once AFP is implemented, reference samples shall then serve as the reference for comparisons with other samples (which e.g. have been taken from the supply chain).

Sample in question

A sample in question is any ore concentrate sample whose origin is doubted or has to be verified by comparison with a reference sample (see “Reference sample data base”). As a prerequisite for AFP testing, a reference sample from the mine site where the sample in question is supposed to come from has to be already integrated in the AFP reference sample data base or must be provided.

**Appendix 2 - Benefits of the AFP mineralogical data beyond certification schemes**

The Analytical Fingerprint (AFP) method is a traceability/forensic tool to verify the documented origin of tin, tungsten and tantalum (3T) ore concentrates. AFP is based on a comparison of chemical properties of a sample in question with those from a reference sample of the supposed origin stored in a reference sample data base. In the course of this method, samples are taken from ore concentrates by accredited samplers and prepared as polished sections (Fig. 7) in laboratories established in Kigali (Rwanda), Bukavu (DRC) and Bujumbura (Burundi). The polished sections are then subject to mineralogical and chemical analyses and thus obtained data are evaluated to constrain the origin of a sample in question.

The mineralogical information gained from reference samples has the potential for beneficial use by governmental institutions, mining companies and exporters in the Great Lakes region.

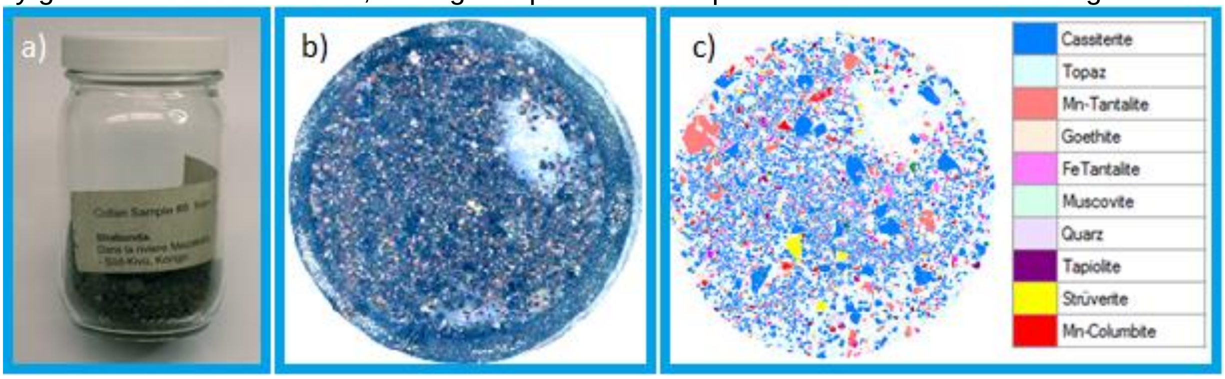


**Fig. 7:** a) typical AFP mineral concentrate sample; b) polished section obtained from the sample; c) image showing the mineralogy of individual grains of a given cassiterite-coltan concentrate.

### How is it done?

Identification of minerals and quantification of mineral proportions in ore concentrates is achieved by using scanning electron microscopy (SEM) combined with automated mineralogy analysis in the AFP laboratory at the premises of the African Minerals and Geosciences Center (AMGC) in Dar es Salaam, Tanzania. The surface of a polished section is analyzed and the mineralogy of each grain is identified. A special software assigns a pre-defined color to each grain according to its mineralogy.

The outcome of the gained data is an image of the polished section with systematically colored particles and information on the mineralogical composition of the ore concentrate (Fig. 8). This holds a large quantity of useful information which can be used apart from the AFP application.

### What information can be drawn from automated mineralogy images?

Automated mineralogy images give information on the

- Mineralogy, size and shape of individual grains
- Mineralogical composition of the sample
- Grain size distribution
- Mineral intergrowth

and can be used for various purposes.

a) Governmental institutions
   - Distribution of valuable minerals in the country can be gained and updated by combining the information about origin and mineralogical composition of reference samples.

b) Mining companies, exporters

- With regards to 3Ts; the existence/absence of valuable minerals at a specific mining site or in a shipment can be revealed.
- Concerning coltan, the occurrence of other valuable tantalum-containing minerals (e.g. microlite, often called "white coltan") is noticed.
- Concerning coltan, information on compositional differences can be detected as coltan comprises tantalum-rich or niobium-rich species.
- Information on minor minerals can be used to constrain the deposit type. For example, cassiterite from pegmatites is usually accompanied by a variety of minor minerals while cassiterite from veins is usually accompanied only by quartz.
- Knowledge on the content of accompanying minerals may also directly affect the value as some accompanying minerals can be easier separated by processing than others (e.g. quartz vs. zircon).
- The grade of mineral phase liberation affects separation strategies and can be used for the alignment of concentration procedures resulting in enhanced recovery rates.

| Name | Area % |
|---|---|
| Mn-Columbite | 21.64% |
| Cassiterite | 14.38% |
| Almandine-Spess... | 13.58% |
| Albite | 13.33% |
| Fe-Columbite | 10.04% |
| Mn-Tantalite | 5.29% |
| Pyrite | 5.01% |
| Goethite | 4.60% |
| Quarz | 3.71% |

**Fig. 8:** Left - Automated mineralogy image of a polished section prepared from a cassiterite-coltan ore concentrate; Right – Legend and mineralogical composition

## Appendix 3 – AFP Reference Sampling Form

See next page

| | |
|---|---|
| ▪ **Sample number** | a code specifying the sample by a one-digit abbreviation for the country combined with the two-digit abbreviation for the initials of the accredited sampler, and a three-digit running number (format XYY-000) |
| ▪ **Sampling Date** | date of sampling |
| ▪ **Name / affiliation of sampling person** | full name of the accredited sampler |
| ▪ Accompanying persons / affiliation | e.g., company officials; also serves as documentation for training of partner organization employees |
| ▪ **Coordinates and elevation of original sample site** | shall be specified in international format (degrees – minutes – seconds) using a GPS device. Collect additional coordinates in case the actual sampling site differs from the original mine site (e.g., a concentrate washing place at significant distance to the mine site) |
| ▪ Country / province / district | |
| ▪ **Name of concession** | |
| ▪ **Owner / operator of concession** | specify in case the operator is different from the owner (e.g., legal mining rights belong to a company, but mining is done informally or illegally by artisanal miners) |
| ▪ Name of individual mine site | |
| ▪ Type of mining / Sample treatment | note basic processing steps of pre-concentrates (e.g., ground sluicing, panning, hand cobbing) |
| ▪ Typical production of mine site (per day or month) | information from miners and/or the mining company and production/traceability records |
| ▪ **Type of sample** | specify mineral pre-concentrate vs. mineral concentrate[19]; also specify type of source rock (e.g., alluvial, eluvial, weathered rock), if possible |
| ▪ Economic minerals | specify main commodity (cassiterite, coltan, wolframite; combinations are possible) |
| ▪ **Sample weight [g]** | may be measured in a laboratory at a later stage; the target weight for a representative AFP pre-concentrate or concentrate sample of up to <2 mm typical grain diameter is 50-100 g; 100-200 g for larger grain diameters |
| ▪ Grain size range | specify typical range; aim to sample representative range of grain sizes included in pre-concentrate or concentrate; samples are not to be artificially fragmented during the AFP sampling process (!) |
| ▪ Additional information | e.g., note special circumstances of sampling such as audit or risk assessment; age of mining structures such as a newly constructed tunnel |

[19] In case a new type of mineralization is sampled, grab samples might additionally be taken for scientific study. However, these grab samples are supplementary and do not substitute for mineral pre-concentrate or concentrate samples which are required for the AFP reference database.

| AFP Reference Sampling (Mine Site/Concession) | | | |
|---|---|---|---|
| Sample number | | | |
| Sampling date | | | |
| Name / affiliation of sampling person | | | |
| Accompanying persons / affiliation | | | |
| Coordinates and elevation of original sample site (GPS) | | | |
| Country / province / district | | | |
| Name of concession | | | |
| Owner / operator of concession | | | |
| Name of individual mine site | | | |
| Type of mining / sample treatment | | | |
| Typical production of mine site (kg per day or month) and/or number of miners | | | |
| Type of sample (tick) | grab sample | | |
| | pre-concentrate | | |
| | concentrate | | |
| Geology (tick) | Pegmatite | | |
| | Quartz vein | | |
| | Alluvial | | |
| Economic minerals | | | |
| Sample weight [g] (to be added after sampling) | | | |
| Estimated grain size range | | | |
| Additional observations | | | |

## Appendix 4 – AFP Supply Chain Control Sampling Form

See next page

| | |
|---|---|
| ▪ **<u>Sample number</u>** | a code specifying the sample by a one-digit abbreviation for the country combined with two-digit abbreviation for the initials of the auditor/accredited sampler, and a three-digit running number (e.g., RJS001 for a sample from Rwanda collected by John Smith); see Appendix 3 for details |
| ▪ **<u>Sampling Date</u>** | date of sampling |
| ▪ **<u>Name / affiliation of sampler</u>** | |
| ▪ Accompanying persons / affiliation | e.g., company officials; also serves as documentation for training of partner organization employees |
| ▪ **<u>Name / address of sampled entity</u>** | e.g., mineral processor, trader, or exporter |
| ▪ **<u>Origin of sampled minerals</u>** | claimed mineral origin, e.g., according to traceability documentation; record all potential sites of origin and, if available, their respective weight proportions (in case mineral shipments have been blended) |
| ▪ Sampling reference | e.g., tag or delivery number linking mineral shipment to standard traceability procedure |
| ▪ **<u>Sampling details</u>** | specify plant feed, plant run-off, (tagged) transport bag, export drum, etc. |
| ▪ **<u>Type of sample</u>** | specify mineral pre-concentrate vs. mineral concentrate |
| ▪ Type of sample processing | specify what kind of equipment has been used, e.g., shaking table, jigs, magnetic separation |
| ▪ Economic minerals | specify main commodity (cassiterite, coltan, wolframite; combinations are possible) |
| ▪ Grain size range | specify typical range; aim to sample a representative range of grain sizes included in the mineral pre-concentrate or mineral concentrate; do not fragment the minerals during sampling; |
| ▪ Processing step | specify primary processing vs. re-processing (e.g., re-processing of fine grain size fraction) |
| ▪ Grade analysis | if available; concentration of the commodity in the shipment |
| ▪ **<u>Sample weight</u>** | may be measured in a laboratory at a later stage; the target weight for a representative AFP pre-concentrate or concentrate sample of up to <2 mm typical grain diameter is 50-100 g; 100-200 g for larger grain diameters |
| ▪ **<u>Additional information</u>** | note special circumstances of sampling such as audit or risk assessment; also note specific questions to investigate |

| **AFP Supply Chain Control Sampling** | | | |
|---|---|---|---|
| Sample number | | | |
| Sampling date | | | |
| Name / affiliation of sampling person | | | |
| Accompanying persons / affiliation | | | |
| Name / address of sampled entity (e.g., trader, processor) | | | |
| Origin of sampled minerals; indicate the respective individual proportions of blended shipments (attach packing list, if applicable) | | | |
| Sampling reference (e.g., tag number) | | | |
| Sampling details (tick) | plant feed | | |
| | plant run-off | | |
| | tagged bag | | |
| | export drum | | |
| | other (specify) | | |
| Type of sample (tick) | pre-concentrate | | |
| | concentrate | | |
| Type of sample processing (tick) | shaking table | | |
| | jigs | | |
| | magnetic sep. | | |
| | other (specify) | | |
| Economic minerals | | | |
| Grain size range | | | |
| Processing step (primary/re-processed) | | | |
| Grade analysis (if available) | | | |
| Sample weight | | | |
| Additional information | | | |

## Appendix 5 – AFP Sample Codes

A formal AFP sample code system shall be applied in order to avoid potential inconsistencies at a later stage (e.g., duplication of sample codes by different sampling teams).

The code specifies the sample by a one-digit abbreviation for the country combined with the two-digit abbreviation for the initials of the accredited sampler or auditor and a three-digit running number (starting with 001), according to the format XYY000.

The following country codes shall be applied in the Great Lakes region for countries where coltan, cassiterite, and wolframite concentrates are mined and traded, and AFP application is potentially relevant (the list may be extended, if applicable):

B – Burundi

C – Democratic Republic of the Congo

E – Ethiopia

K – Kenya

M – Mozambique

R – Rwanda

T – Tanzania

U – Uganda

Z – Zambia

Based on AFP experience so far, a three-digit running number is sufficient to differentiate the number of samples taken by a single sampler. In case a larger number of samples are taken, a four-digit running number may be assigned.

## Appendix 6 – AFP Sampling Declaration

Every batch of AFP samples taken by an authorized party, that is, an accredited sampler, has to be accompanied by appropriate sampling documentation (cf. Appendices 1-3) and an AFP Sampling Declaration as shown on the following page. These Declarations are stored at the authorized AFP preparation laboratory where the AFP samples have been submitted to, or at the AFP Management Unit.

**AFP Sampling Declaration**

Name of sampling person:

Organization:

Position:

DECLARATION

I hereby certify that I have either personally taken the submitted AFP sample batch or directly supervised taking these samples at the indicated coordinates according to the instructions provided in the AFP manual. I take full responsibility for the accuracy of submitted sample locations and sampling procedures.

Place and date: ______________________________

Signature: ______________________________

## Appendix 7 – AFP Reference Sampling Accreditation Standards

The Analytical Fingerprint (AFP) method represents a forensic tool used to constrain the origin of certain minerals (cassiterite, coltan, and wolframite). To this end, method application relies on a statistic comparison of the chemical and mineralogical composition of *reference sampling* and *control sampling*. Details of the method are defined in the AFP Manual of BGR and the International Conference on the Great Lakes Region (ICGLR), available at "http://www.bgr.bund.de/mineral-certification".

The activity of obtaining AFP *reference samples* in the above context falls under the responsibility of ICGLR member state authorities, supported by BGR. Any person undertaking formal AFP *reference sampling* activities has to meet the accreditation standards as defined below; the accreditation procedure can be performed by the following AMU and BGR officials:

- Arthémie Ndikumana (AMU Bujumbura), arndikumana@yahoo.fr
- Dr. Rudolf Mauer (BGR Bujumbura), rudolf.mauer@bgr.de
- Uwe Näher (BGR Kinshasa), uwe.naeher@bgr.de

These AMU and BGR officials will provide written documentation for any accredited person. This documentation will be available at BGR and at the AFP Management Unit at ICGLR, Bujumbura.

AFP *reference sampling* accreditation shall be valid for a period of one year and may be renewed, subject to approval by a BGR official.

Standards for a person to be accredited as being eligible for AFP *reference sampling* are as follows:

1) University degree in mining, geology, chemistry, or a related discipline; OR: relevant work experience (on a scientific or technical level) at an institution defined under (§2) of at least one year;
2) Being affiliated with an official ICGLR member state government authority in charge of the mining sector of the respective member state; OR: being affiliated with an official ICGLR member state institution (e.g., a university) with equal expertise and credibility as the member state authority in charge of the mining sector; OR: being affiliated with an international organization with similar tasks and credibility as BGR;
3) Demonstrably being in good standing at the authority or institution defined under (§2);
4) Accurate and diligent work standards (work performance record);
5) Technical understanding of GPS measurements and computer-literate (office software: Word, Excel; report writing; electronic data entry;
6) Understanding of the contents of the AFP Manual, in particular as far as technical sampling protocols are concerned;
7) Verified ability to obtain AFP samples according to the technical sampling protocols in the field.

**Appendix 8 – AFP Reference Sampling Procedures/Protocols to be Observed**

1) AFP *Reference Sampling* should be carried out by an accredited person or a BGR official (as listed in the accreditation form) in coordination with the respective ICGLR member state authority (as defined in the accreditation form) as well as ICGLR (AFP Management Unit);

2) Prior to sampling activities and under consultation with ICGLR (AFP Management Unit) seek confirmation from the local AFP liaison office where AFP *reference samples* are to be submitted

    a. either an official AFP preparatory laboratory (Bujumbura, Bukavu, Kigali) or the AFP Management Unit (Bujumbura);

3) AFP *reference sampling* plans (contact local AFP *reference sampling* liaison office or AFP Management Unit) for a given country/region shall be respected;

    a. ideally, this considers production-representative AFP *reference sampling* activities at regional-local (concession) levels;

4) The permit holder and/or mine site operator of the mine site / concession where AFP *reference sampling* is to take place shall be notified and permission (written or oral) be obtained for planned sampling activities;

    a. note that mine sites / concessions of permit holders / operators who do not agree to AFP *reference sampling* on their concession area are to be yellow- flagged under the ICGLR Regional Certification Mechanism; if applicable, the national certification authority and ICGLR shall be notified to update the respective mine site status in response to denied AFP *reference sampling*;

5) Clarify logistic requirements for AFP *reference sampling* (access to/security at sampling sites, access to sampling material, and sampling documentation tools) with ICGLR (AFP Management Unit) as well as the permit holder / mine site operator;

    a. sampling may logistically be supported by the local AFP liaison office (e.g., making available/renting a vehicle); this should be clarified at least one week prior to planned AFP *reference sampling*;

6) Respect technical sampling protocols (including sampling procedures, adequate sampling documentation and the AFP Sampling Declaration) as defined in the AFP Manual;

    a. use the sampling form provided in the AFP Manual for each sample, or collect the information contained therein (or more sophisticated information) in an appropriate manner, e.g., a field book; thus compiled information is to be submitted in an acceptable format to the AFP liaison office;

b. AFP *reference sampling* targets multi-mineral pre-concentrates or concentrates integrating the range of geologic features associated with the mineralization at a given mine site and causing the site-specific AFP signature. *Mineral pre-concentrate* is defined as ore that has been subject to an initial non-standardized upgrading process (usually washing done by artisanal miners: panning, ground sluicing). *Mineral concentrate* is defined as ore or mineral pre-concentrate that has been subject to a standardized ore dressing/beneficiation process (usually done at a mechanized processing plant) in order to obtain a mineral product of export quality (i.e., of a pre- defined homogenous grade);

c. a sample representative of the actual grain size range of the mined ore should be obtained; sample material should not be additionally fragmented during the AFP sampling process;

d. particular attention should be paid to sample weight: a minimum of 50-100 g of mineral pre-concentrate or concentrate is required for samples where the typical grain diameter is up to <2 mm; 100-200 g should be obtained for larger grain diameters;

e. check the grade of a pre-concentrate to be sampled: if it is of very low grade (e.g., rich in quartz, feldspar and other minerals), further washing should be performed; as a rough reference guide, pre-concentrates to be sampled should be black in bulk color appearance, rather than other colors (e.g., white or brown);

f. the ideal sample container is a 50 ml or 100 ml plastic flask (to be provided by the AFP liaison office). Sampling flasks should be labeled with a sample number as defined below. In order to prevent the sample number on the flask from being obliterated, it should be covered by a strip of transparent adhesive tape. In case the sampled material is dry, a note with the sample number shall additionally be inserted into the flask (together with the sample); in case the sampled material is wet, this might be skipped or water-proof material shall be used;

g. measure the GPS coordinates directly at the source of the mined minerals, i.e., a tunnel entrance or pit (also in case the minerals are panned/washed at another location); in case panning/washing takes place at a distance of >200m to the source of the mined minerals, provide additional GPS coordinates for this location;

h. always undertake best efforts to obtain an AFP reference sample directly from the original mining location;

i. in some situations, a sample might be taken at a certain location, e.g., a washing site, but the original mine site (the claimed origin) of the sample is not directly accessible;

i. this situation might occur, for example, when mining activities are not all day long and daily activities at the mine site have stopped at the time of AFP *reference sampling,* but a sample is available from an associated washing/panning or storage location and local miners claim the sample originates from the mine site;

ii. in that case, discuss in detail (in the sampling notes) the plausibility and probability of the claim that the sample originates from a given mine location (e.g., verify the presence of mine workings at the claimed mine site); samples taken under these circumstances cannot be categorized as reference samples.

j. GPS coordinates should always be saved as a GPS waypoint; saved waypoint information should be stored on the GPS device for a period of at least 6 months following sampling; stored waypoint data must be made available to staff of the AFP liaison office upon request;

7) At all times, ensure the integrity of AFP *reference samples* and the associated sampling documentation (during sampling and while taken samples are in the accredited sampling person's custody);

a. refers to undertaking maximum efforts to constrain and adequately document the origin of AFP *reference samples* at the highest possible precision and accuracy (including correct documentation of any constraints / uncertainties encountered during sampling);

b. includes ensuring the physical integrity of samples and associated documentation while in the custody of the accredited sampler;

c. personal responsibility for the above is acknowledged by signing the AFP Sampling Declaration;

8) Collect information (while on site) and compile this information into an AFP sampling report, to be submitted to the official AFP liaison office;

a. the report should be in English or French language;

b. the report shall include basic information on the AFP *reference sampling* framework at the sampled location including information on the geological setting as well as mining activities; examples and guidance for elaborating AFP sampling reports are available from AFP Management Unit;

9) Submit AFP *reference samples* and the associated sampling documentation (including the AFP sampling report) as well as the AFP sampling declaration to the local AFP liaison office noted under (§3)

a. personal responsibility of the accredited person for ensuring the integrity of AFP *reference samples* and associated documentation ends once the local liaison office takes custody of these items;

b. the accredited person submitting the AFP *reference samples* agrees to provide additional clarifications on AFP *reference samples* and the associated documentation in case of later inquiries by the AFP liaison office;

c. accredited persons of an ICGLR member state authority or institution are eligible for reimbursement of AFP *reference sampling*-associated mission costs according to established regulations[1]; reimbursing these costs falls under the responsibility of the local AFP liaison office / BGR unless the respective ICGLR member state authority or institution provides such mission cost reimbursement itself (in which case the liaison office reserves to not, or only partly providing mission cost reimbursement);

d. the AFP liaison office will verify whether submitted AFP *reference samples* comply with technical sampling requirements and whether submitted documentation is adequate and accurate; the liaison office reserves the right to deny acceptance of AFP *reference samples* in case of insufficient adequacy/accuracy of samples and/or associated documentation;