

Origin of Gold

Geoforensic Passport

Presented at the LBMA's Assaying & Refining Digital Conference 2021
March 16th 2021

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Background

- Refiners receive thousands of doré lots every year – all have a declared origin

Our goal

To reliably confirm the supplier's declared origin for every doré

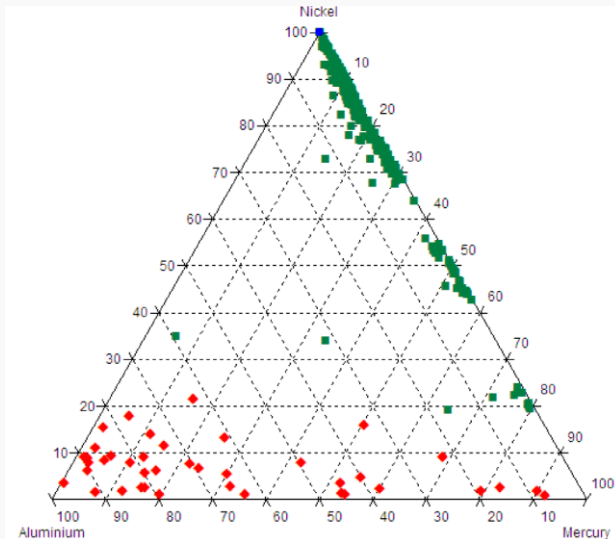
Our challenges

- Technical & practical feasibility
- Impossibility to collect reference samples from all existing mines in an area/country/continent
- Routine implementation at Metalor Technologies

Our approach

- Geoforensic Passport – the DNA of doré

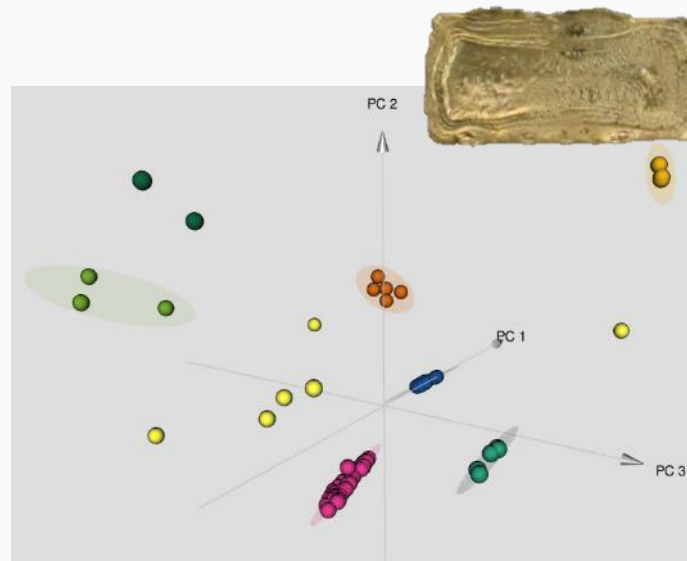
State of the Art



Geoforensic Passport

Creation

Validation



Applications

Mine collector's case study

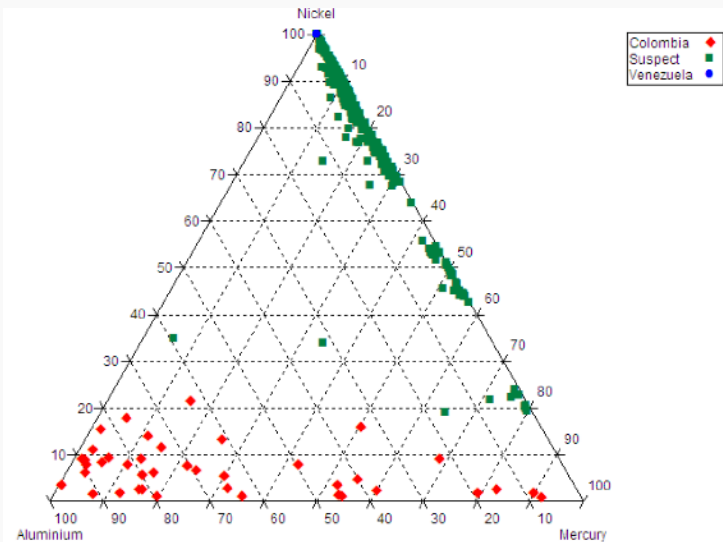
Complex case study

La Rinconada



Roger Dixon (Univ. of Pretoria), LBMA A&R 2013

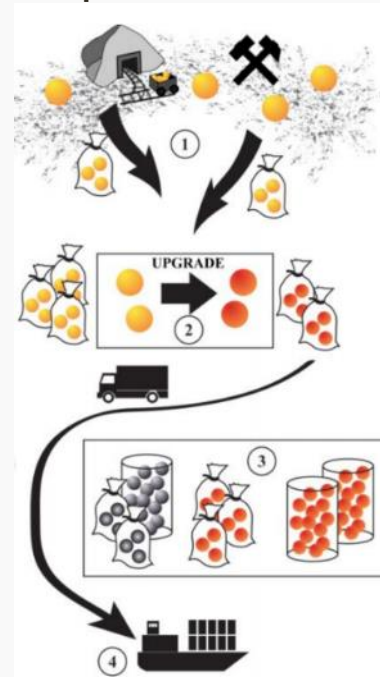
- Determination of the origin of gold in criminal cases
- Project based on PhD studies & for police inquiries



Detailed chemical composition
(LA-ICP-MS)

BGR (Federal Institute for Geosciences and Natural Resources, Germany)

- Scientific tool to check the origin of Sn, W & Ta (3T) ore mineral shipments from the African Great Lakes region
- Project at UN request

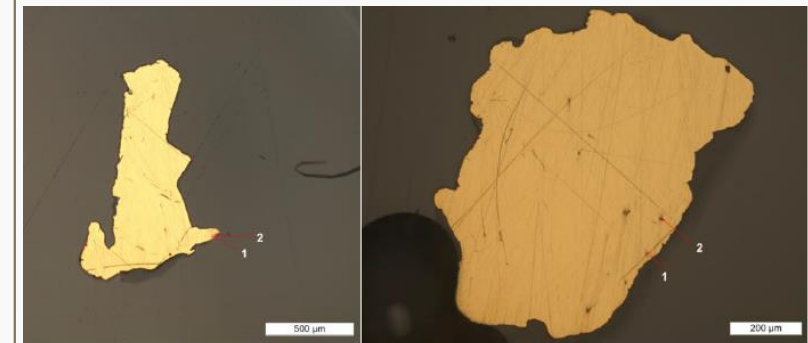


Complex
mineralogical
analyses
(since 2006)

Schütte, Certified Trading Chains, BGR 2013

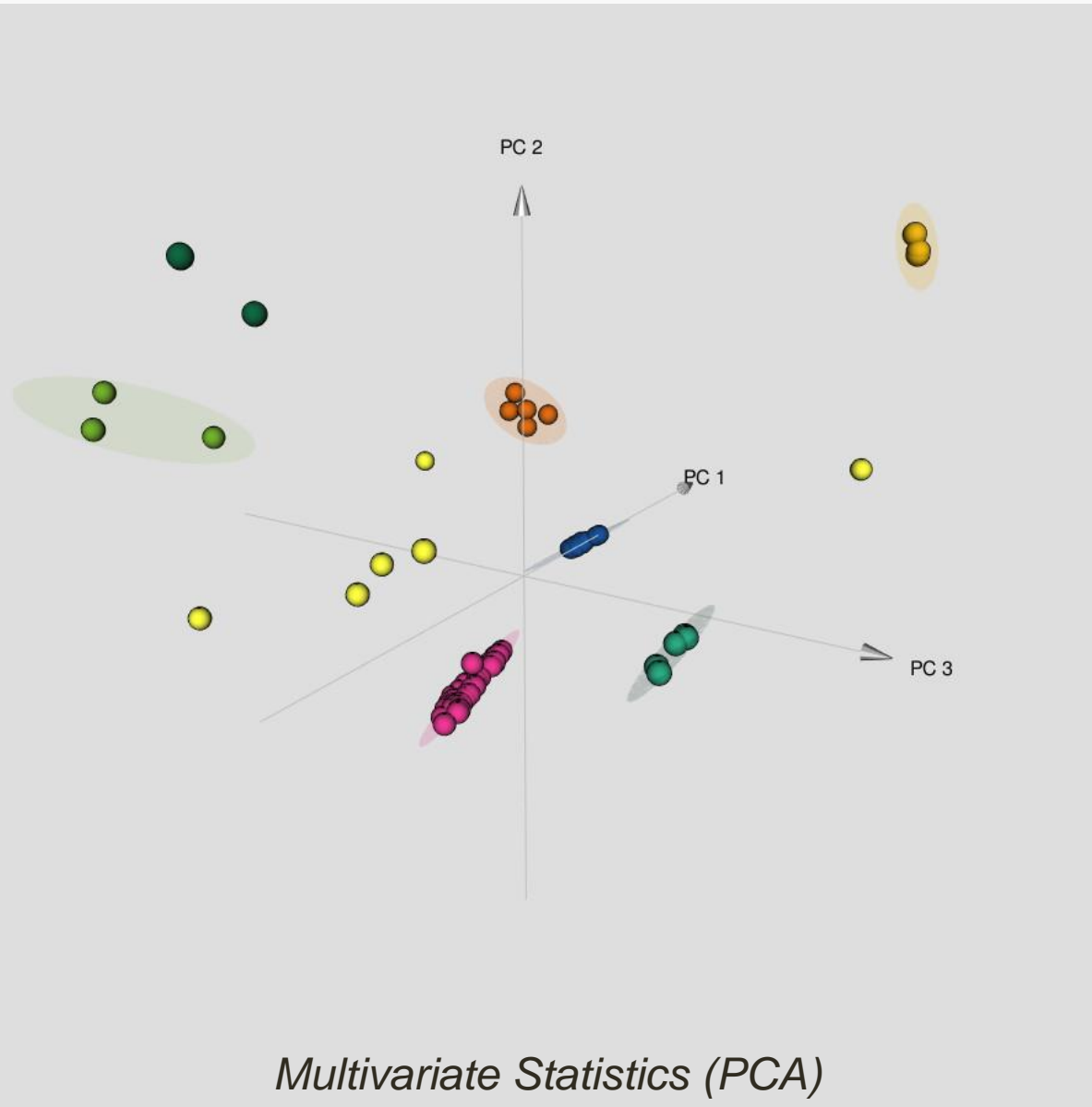
BRGM (French Geological Survey)

- Origin of gold from Guyana and Surinam. Transparency in the local supply chain
- Initiative of the WWF



Metallographic (shape, inclusions),
chemical & isotopic analyses
(2014 / 2015)

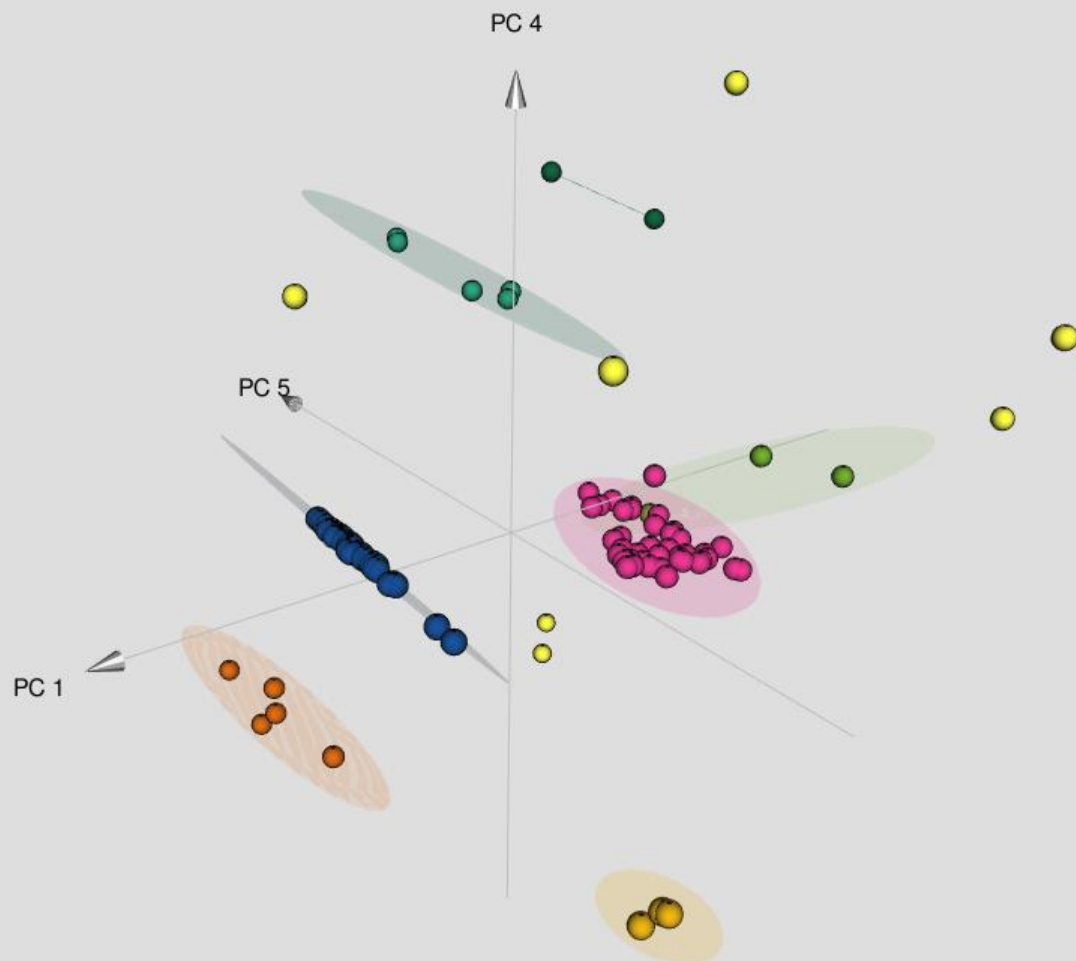
Augé, Report BRGM/RP-64880-FR 2015



A new paradigm in gold origin determination

Geoforensic passport

- A complex signature of a given customer
- Segregated in several subgroups (a mine, a pit, a geological sub-area)

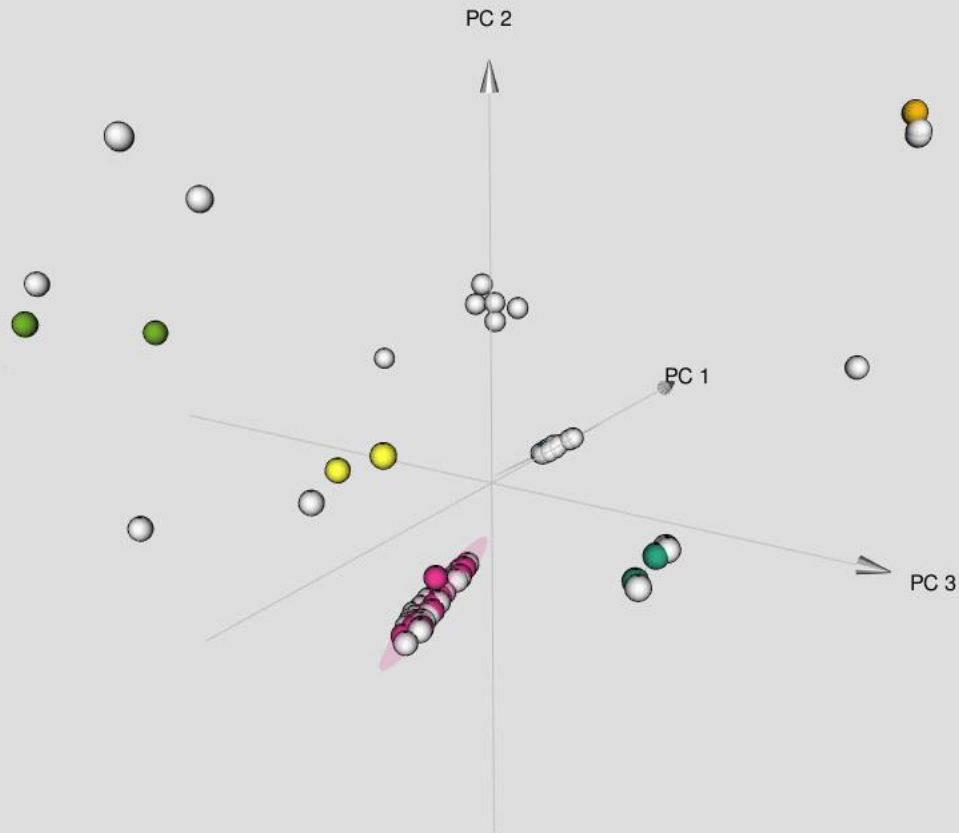


*only 3 dimensions represented
geoforensic passport has typically 9-15 dimensions*

A new paradigm in gold origin determination

Geoforensic passport

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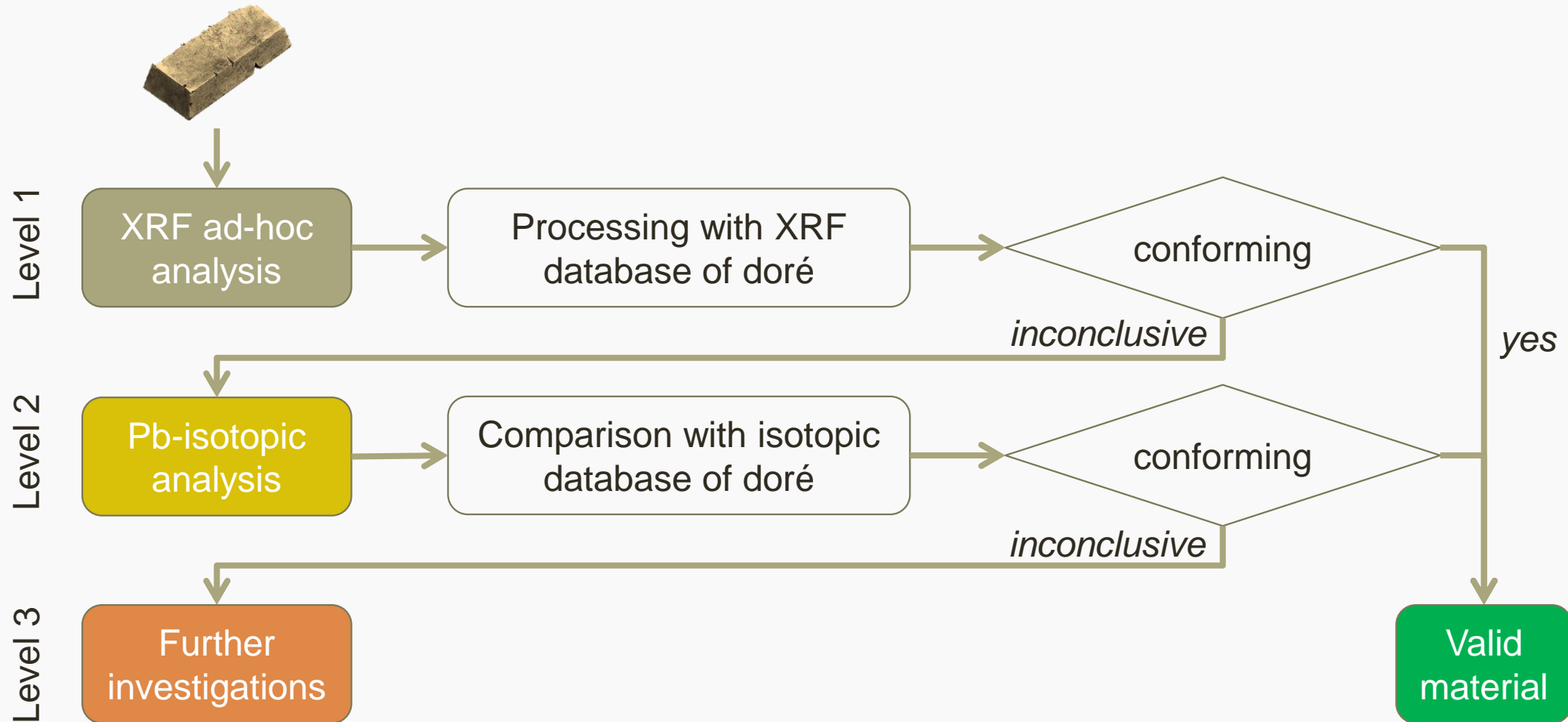
Time adaptation

- Adapting overtime to take into account natural & process variations

Geoforensic Passport – the DNA of doré

3 levels of investigation:

- First level based on **ED-XRF analysis**
- Second level using **isotopic analyses** – performed only if needed
- Further investigations available



Level 1 : ED-XRF (Energy dispersive XRF)

- Relatively inexpensive
- No specific infrastructure required
- Zero sample preparation time



Ad-hoc calibration

- 20 elements (major, minor, traces)
- 120 standards



Level 2 : MC-ICP-MS (Multi-collector ICP-MS)

- Very expensive equipment
- Extensive infrastructure (to limit contaminations)
- Long sample preparation time
- Highly advanced technical knowledge required
- Very specific standards needed for calibration



Scientific
Research

Routine
Analyses

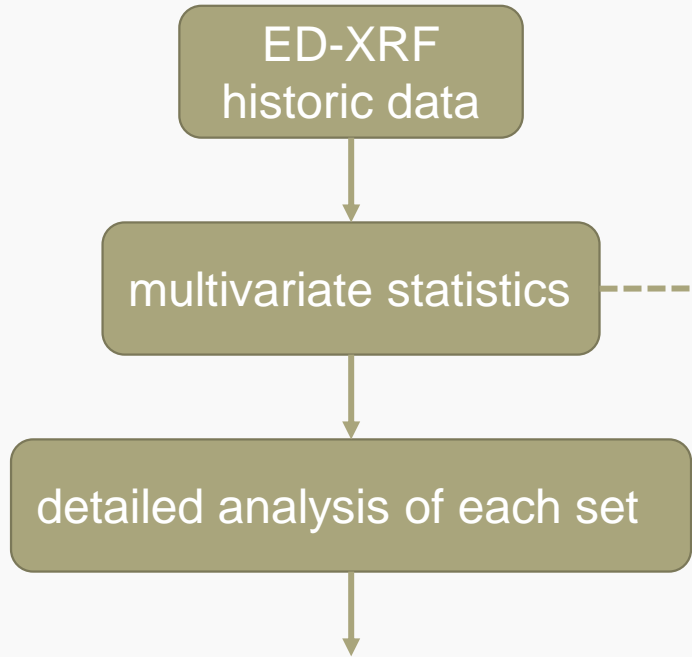
ED-XRF
historic data

- **Data preparation**
- Data set definition (client, groups of clients, countries, continent)

[w‰]	As	Co	Au	Te	Pt	Bi	Fe	Ni	Ag	Pb	Zn	Pd	Cu
A	nd	nd	728.7	nd	nd	nd	nd	5.5	186.6	nd	nd	2.5	72.3
B	nd	nd	493.4	nd	nd	nd	nd	nd	497.0	nd	nd	nd	8.0
C	7.4	nd	842.8	nd	nd	nd	8.7	8.2	71.7	nd	nd	3.4	55.7
D	nd	nd	728.7	nd	nd	nd	nd	5.5	186.6	nd	nd	2.5	72.3
E	6.6	nd	605.4	1.0	nd	5.2	nd	nd	176.1	13.6	0.6	2.3	187.1
F	nd	nd	188.8	nd	nd	nd	nd	0.1	797.0	2.9	4.9	nd	5.9

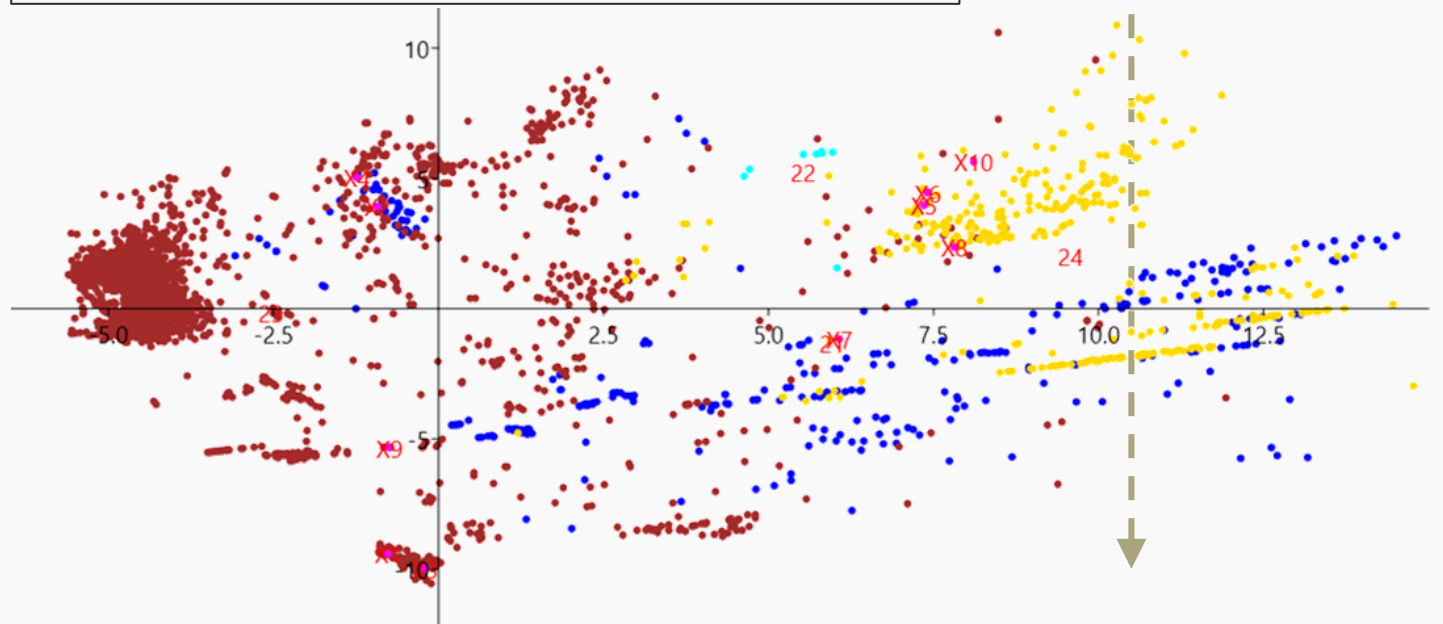
Geoforensic Passport – Creation

Scientific Research Routine Analyses

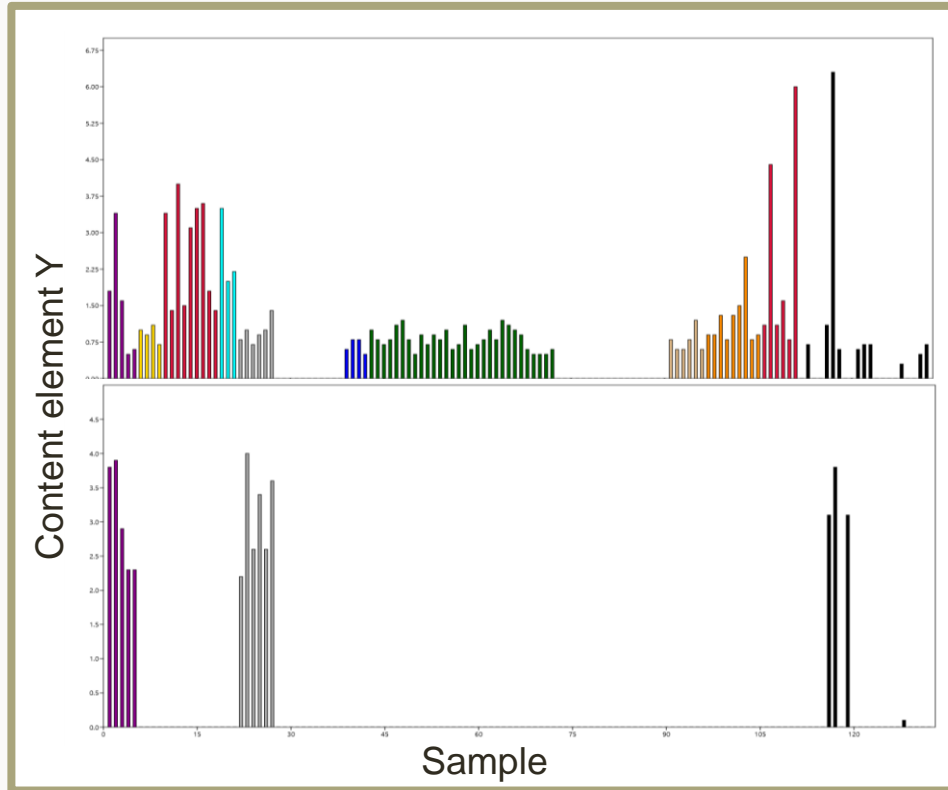
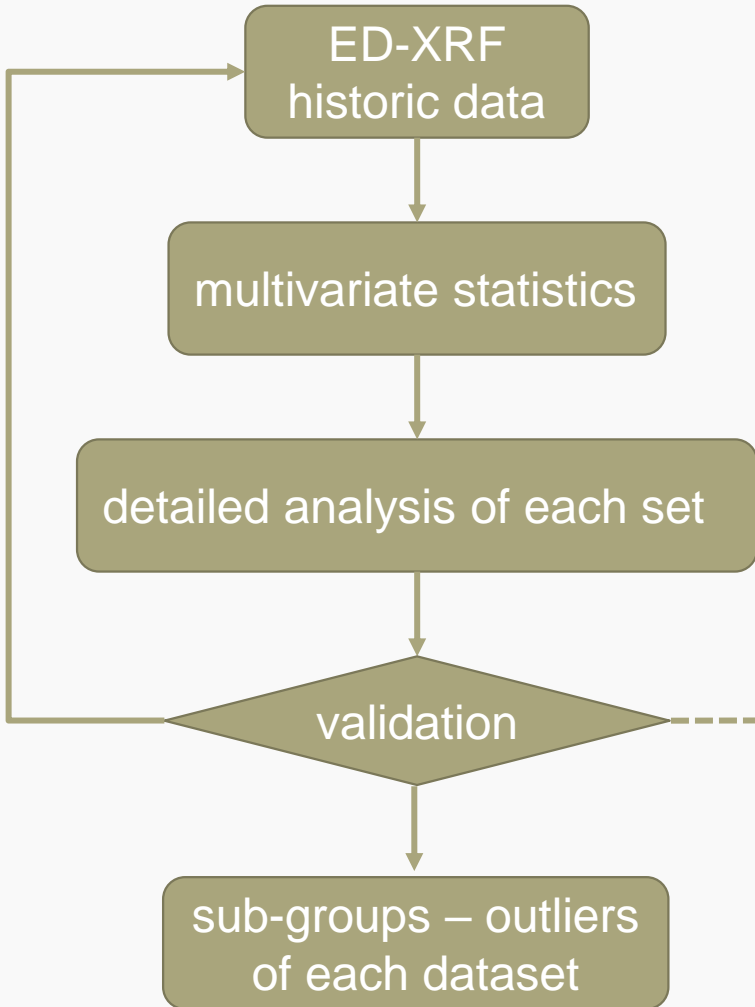


Unsupervised learning (machine learning)

- Hierarchical classifications
- **Principal component analysis (PCA)**



Geoforensic Passport – Creation



- **Graphical reports**
- Histograms
- Correlations and dependences

Scientific
Research

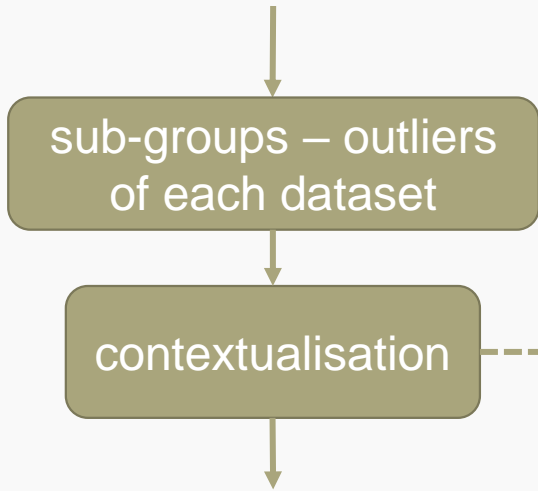
Routine
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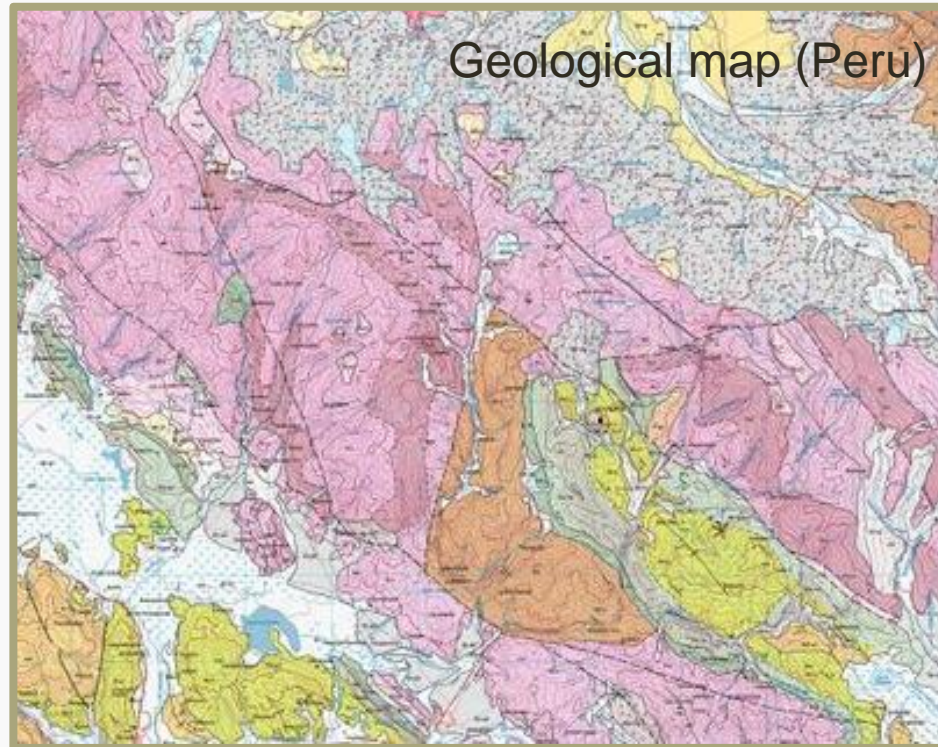
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Scientific
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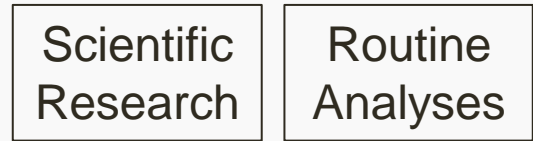
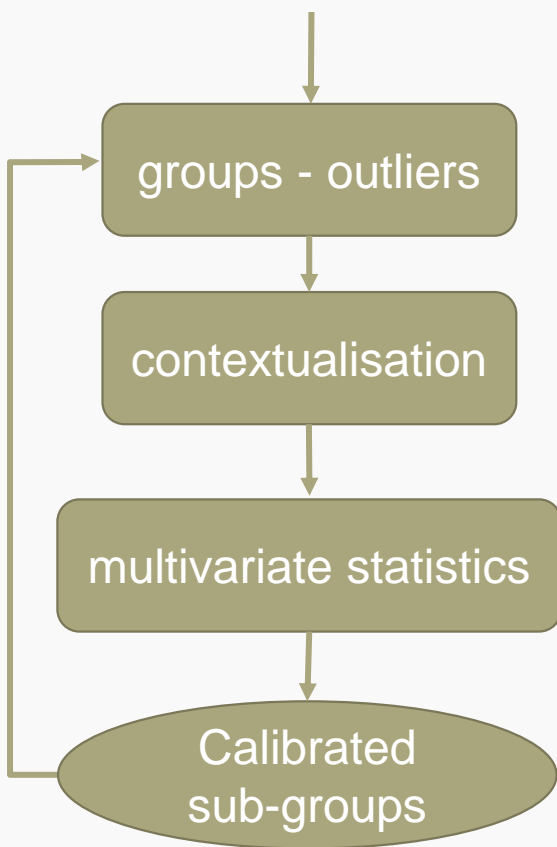
Routine
Analyses



- Similarity tests (SIMPER) with other suppliers
- **Geological information**
- Supply chain information



Geoforensic Passport – Creation



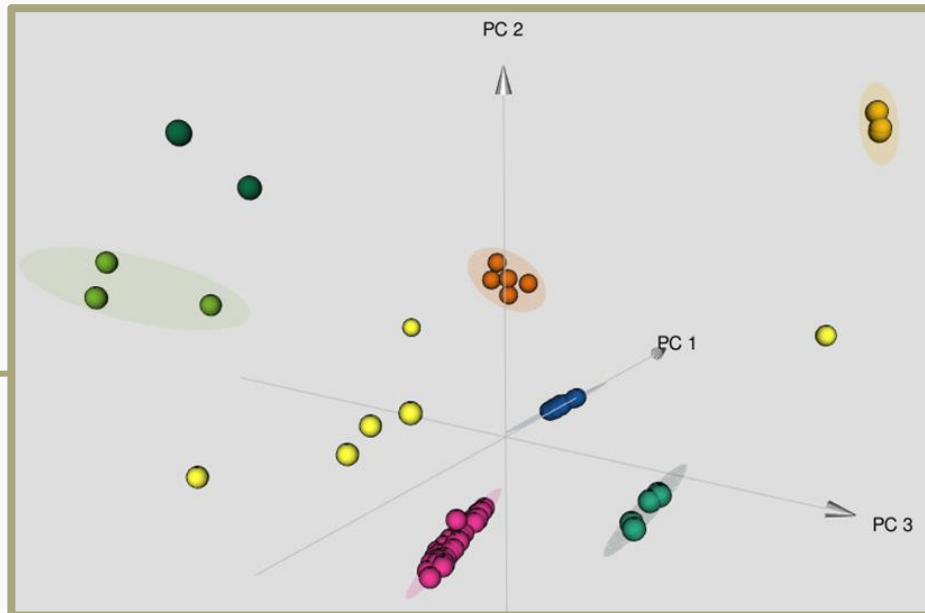
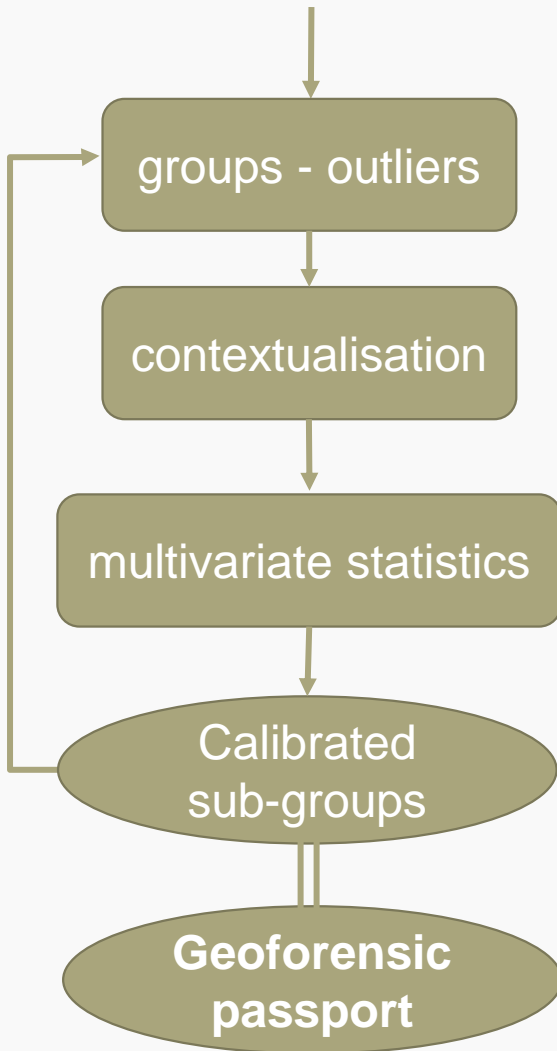
Supervised learning

- **Discriminant analysis (LDA)**
- **Confusion matrix**

Confusion matrix - hit rate >95%

	232A	232B	232C	232D	232F	232G	232H	232I	232K	232L	232M	232N	232O	232P	232X	Total
232A	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
232B	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4
232C	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	9
232D	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3
232F	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	6
232G	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	11
232H	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	4
232I	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	30
232K	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	6
232L	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	12
232M	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	6
232N	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	9
232O	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	6
232P	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
232X	2	1	0	0	0	1	1	0	0	0	3	0	0	1	10	19
Total	7	5	9	3	6	12	5	30	6	12	9	9	6	3	10	132

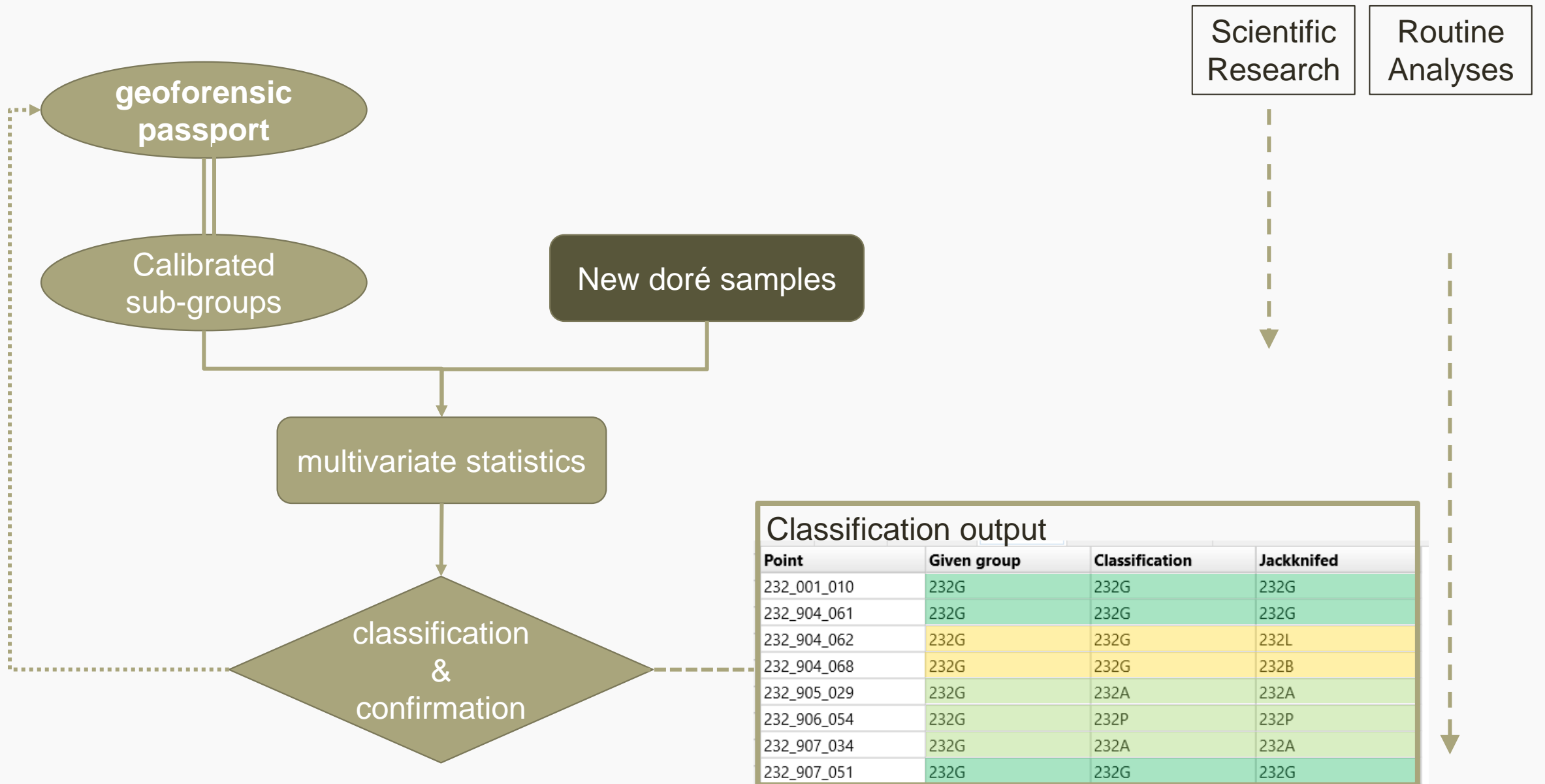
Geoforensic Passport – Creation



Scientific Research Routine Analyses

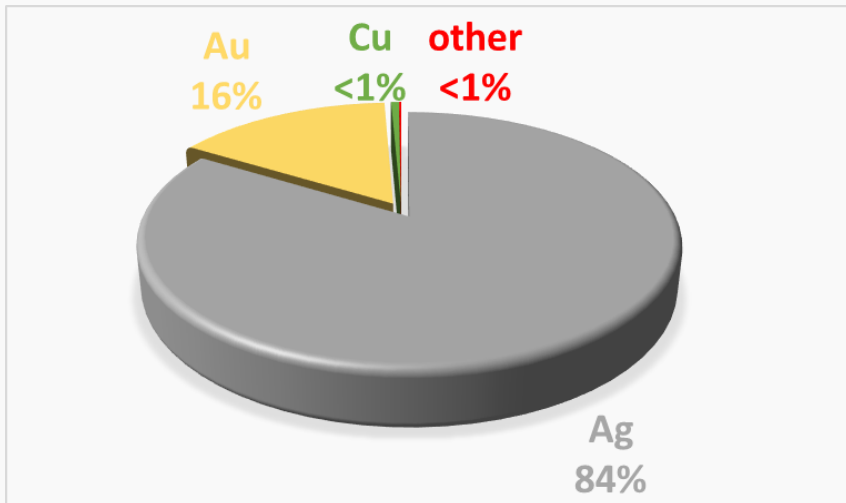


Geoforensic Passport – Creation



Example of validation: using 100 doré received at Metalor

- 100 doré samples randomly selected between 1st July and 15th November 2020 from South American shipments
- Each sample provided with its declared origin (country + customer name)
- Using exclusively ED-XRF to **confirm** the origin of the doré
- But 1 sample was manipulated !



One typical doré sample from a South American mine...

... was replaced by a doré sample from Asia

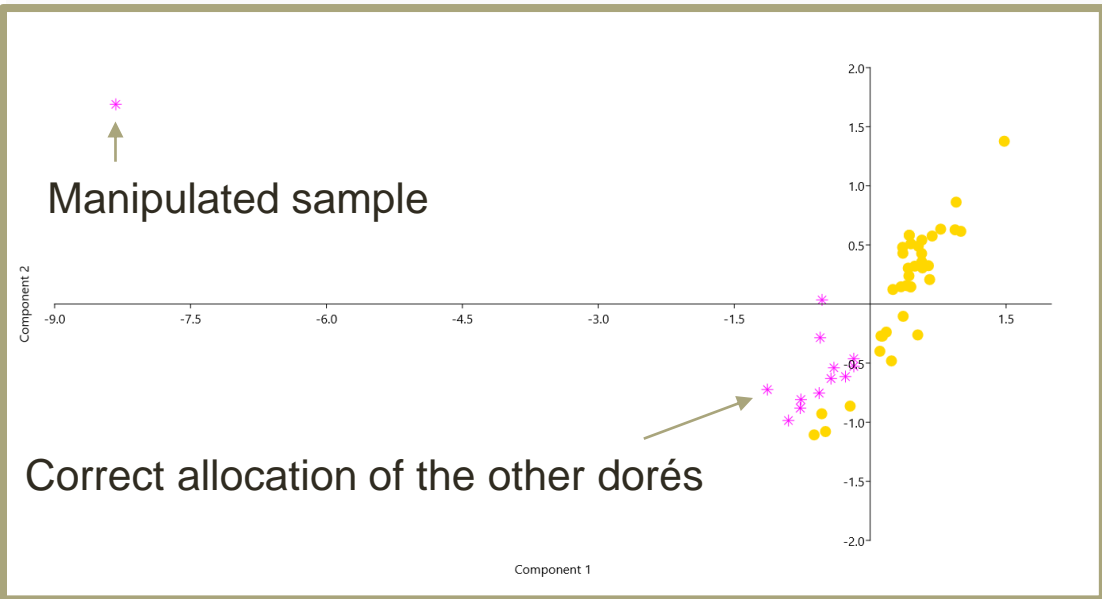
Ag	835.8	836.4
Au	156.1	154.8
Cu	5.7	5.0
Pb	1.4	0
Se	0	3.3

in w‰

98 doré origins were confirmed – 2 samples came out as problematic

The manipulated sample was immediately detected

Another sample (P19) showed incoherence



Multivariate statistics (PCA)

Point	Given group	Classification	Jackknifed
P17	1C	1E	1E
P18	1C	1A	1A
P19	1C	1C	1X
P2	1C	1A	1A
P20	1C	1A	1A
P21	1C	1B	1B

Point	Given group	Classification	Jackknifed
P17	1E	1E	1E
P18	1E	1A	1A
P19	1E	1E	1X
P2	1E	1A	1A
P20	1E	1A	1A
P21	1E	1B	1B

Classifier based on confusion matrix

This ingot was part of a shipment of 4 doré (the origin of the 3 others was later confirmed)



12-14 kg



3.3 kg

Announced later by the customer as coming from a different process...

In June 2019, Metalor announced it would stop sourcing gold from mine collectors, for multiple reasons:

- Difficulties in relying on local authorities
- Low levels of compliance
- Challenging traceability

How can the geoforensic passport help us understand the mine collector's business?

Can different sources of gold be distinguished in the collector's context?

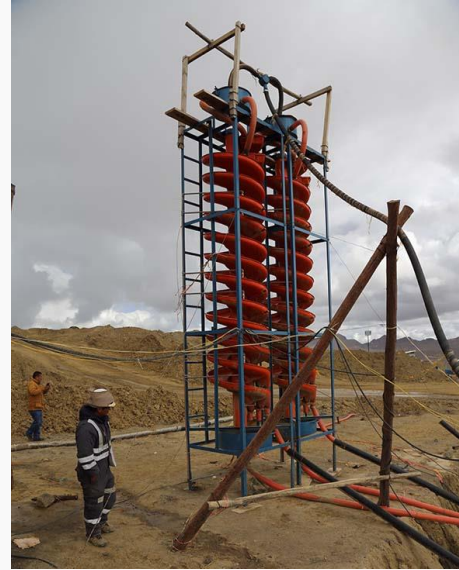
June 17, 2019

Metalor Technologies SA announced its decision to stop all artisanal mines and mine collector's business to concentrate the sourcing of precious metal in the industrial mining sector.

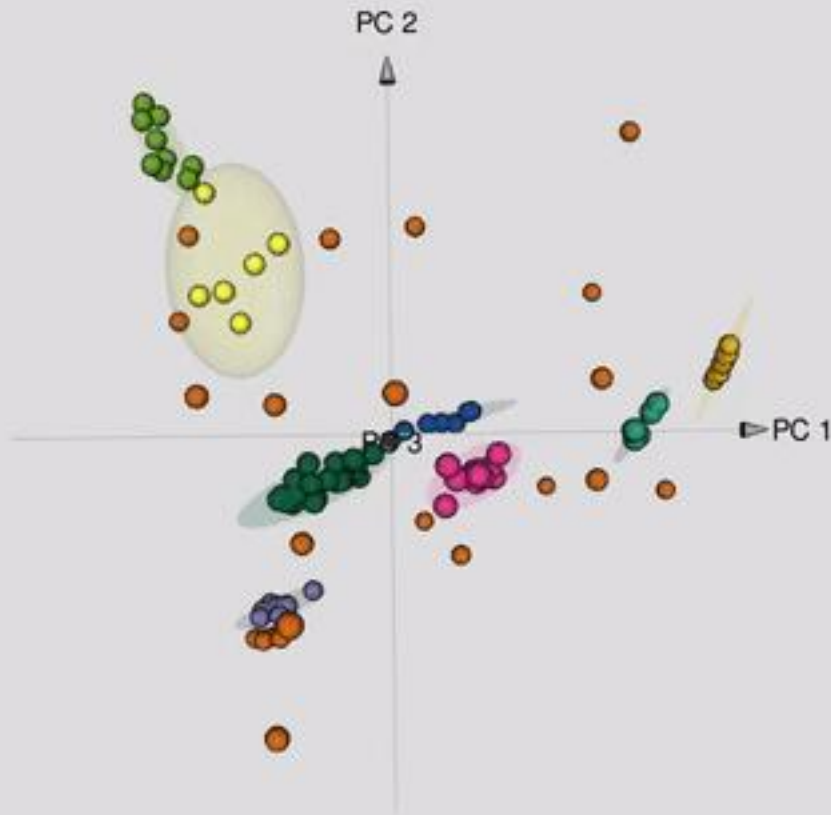
Despite putting in place all required due diligence measures and a strict verification process, the increasing resources to secure compliance and the challenging conditions at the mining regions have forced Metalor to re-assess its approach to artisanal mining.

As a result of this decision, Metalor will cease its operations in Colombia, after having already announced its decision to stop any business relationship with collectors/aggregators of gold doré in Peru.

Mine collector's case study



*Semi-artisanal mine in the process of formalisation in the Peruvian altiplano
Pictures taken by S. Ansermet & B. Beck*



Geoforensic passport of a Peruvian collector (data collected from June 2018 to June 2019)

- Several discreet grouped signatures, each with very similar geological properties
- One less defined group with **heterogeneous signatures**
- A large **cloud of outliers** with no coherent signatures

The geoforensic passport allows to identify
... which materials come from larger, well-defined mining operations...



... which ones are from smaller, probably artisanal/semi-industrial mining...

... and which ones are not understood!

Complex case study... using level 2 analyses



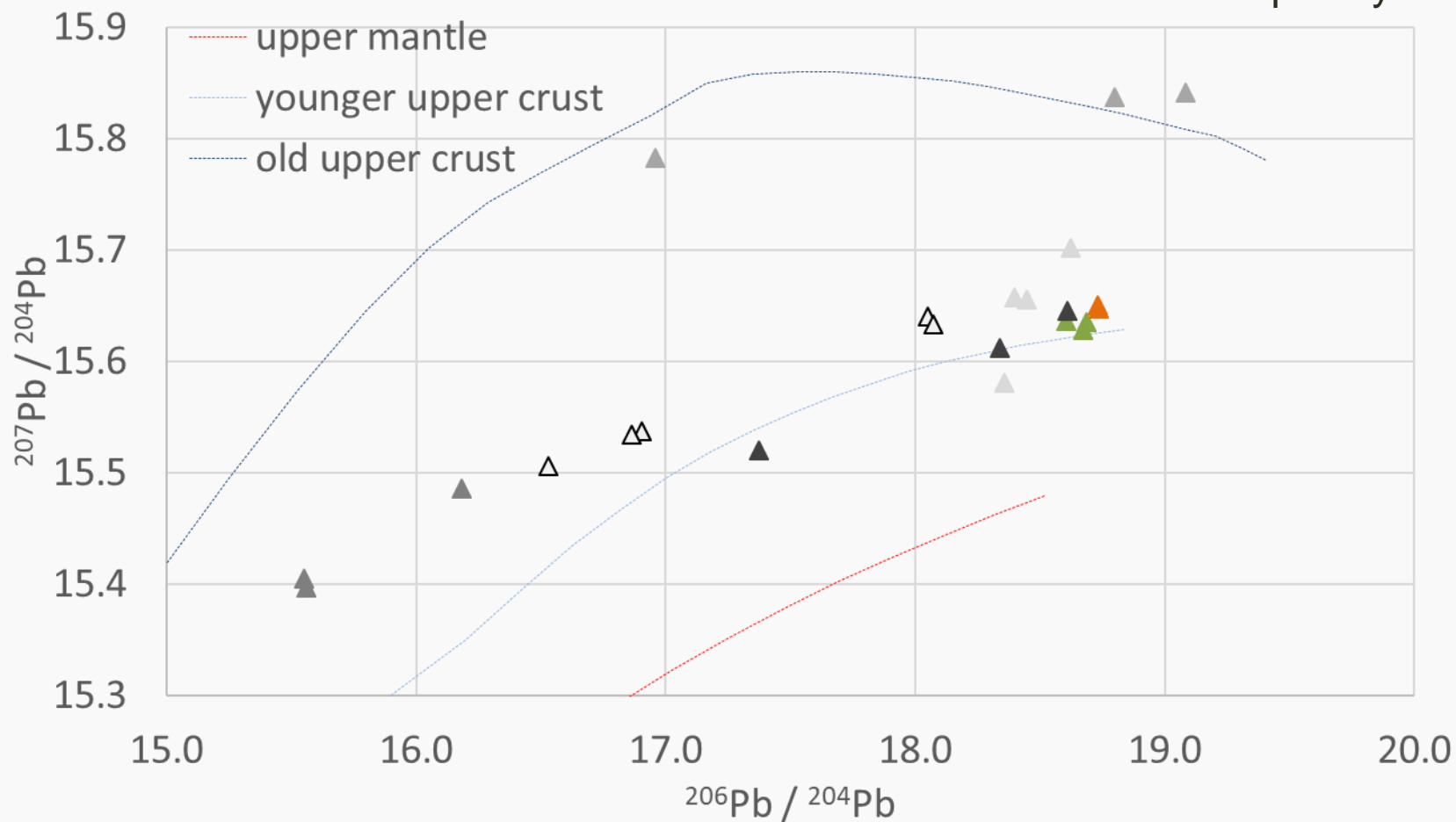
In some cases, samples which are supposed to be from exactly the same origin have a very different, apparently incompatible geoforensic passport



		
Ag	505.4	139.4
Au	475.6	73.9
Cu	14.0	396.4
Fe	0	3.6
Ni	0	381.5
Se	0	3.4

in w‰

Complex case study... using level 2 analyses

Isotopic analyses (level 2) can confirm that the origin of the gold is identical, although processes to obtain the doré were apparently completely different



		
Ag	505.4	139.4
Au	475.6	73.9
Cu	14.0	396.4
Fe	0	3.6
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in w‰

La Rinconada

Highest city in the world (a shantytown at 5300 m), where more than 60 000 people live and work in extreme social and climatic conditions.

How can we ensure no gold from there is entering a reputable refinery ?



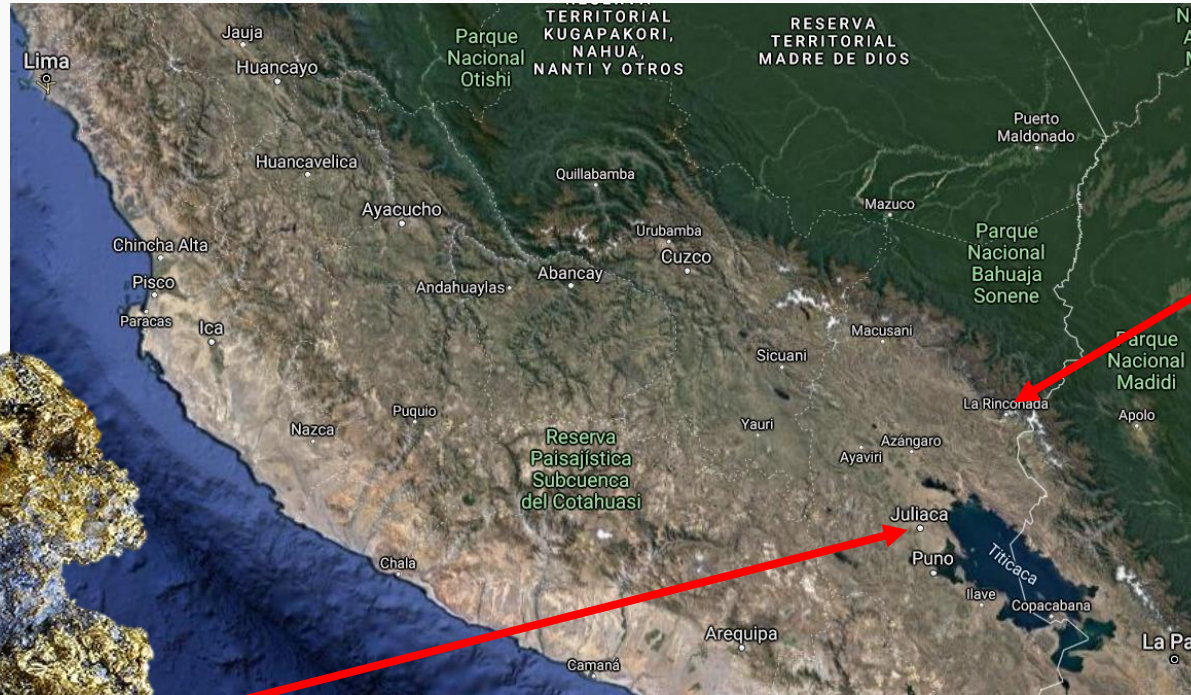
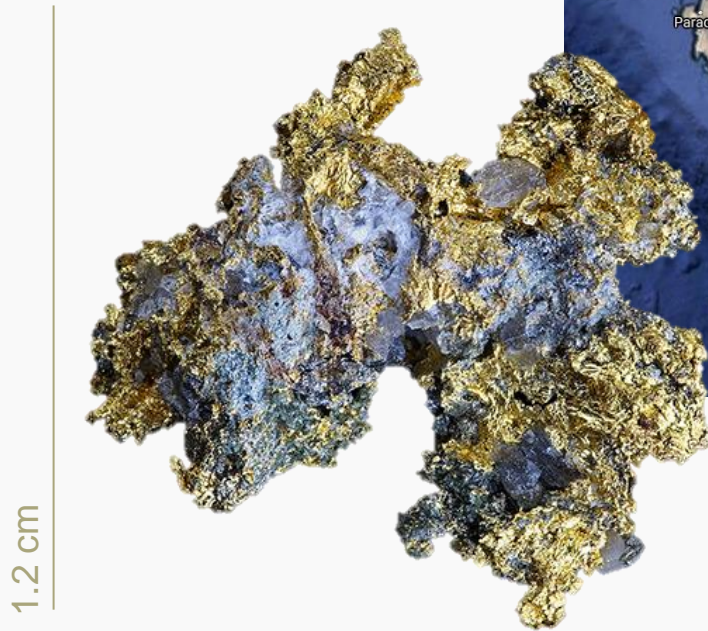
Pictures taken by S. Ansermet & B. Beck

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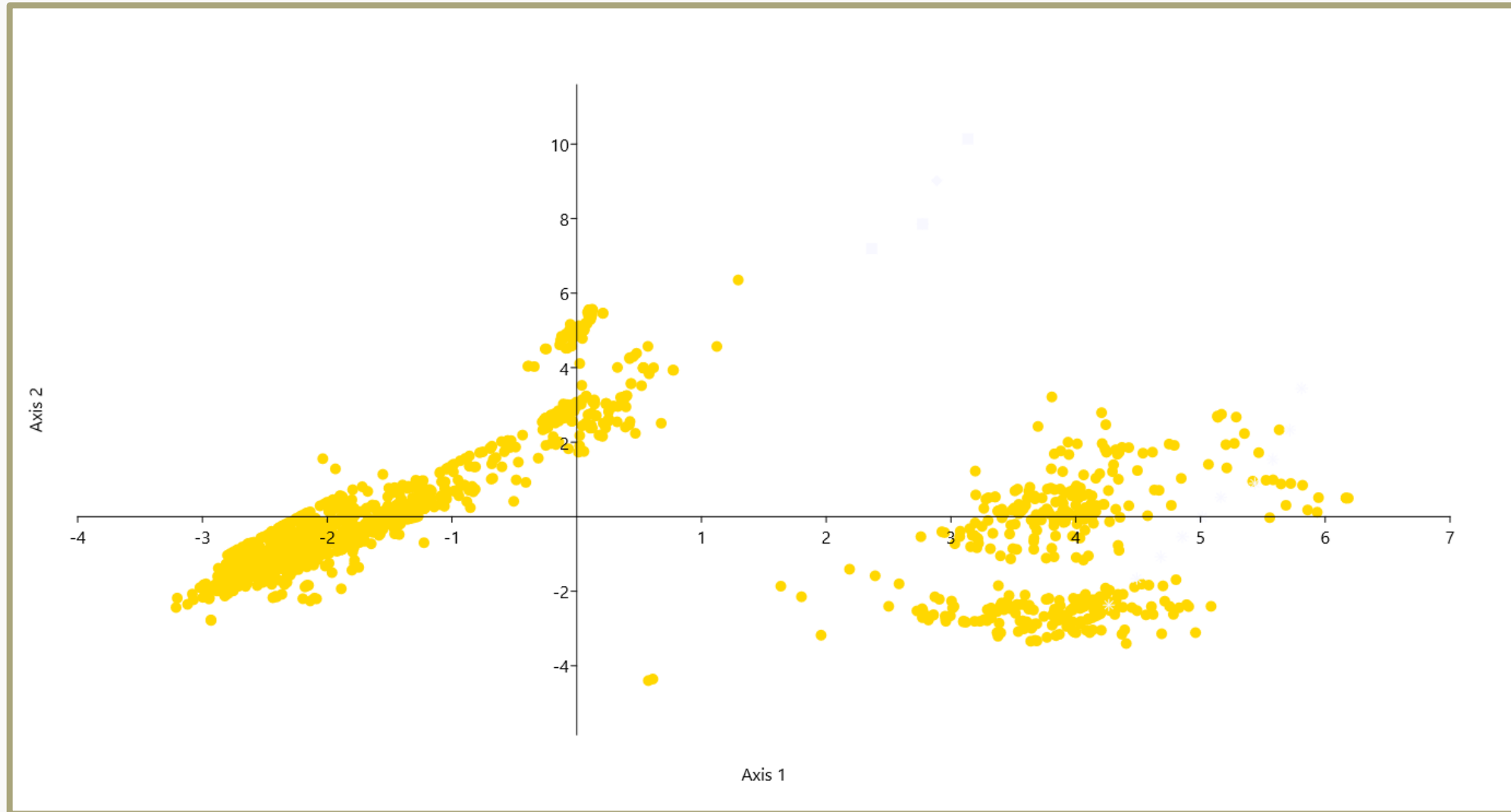
Gold nugget purchased at a gold comptoir in Juliaca



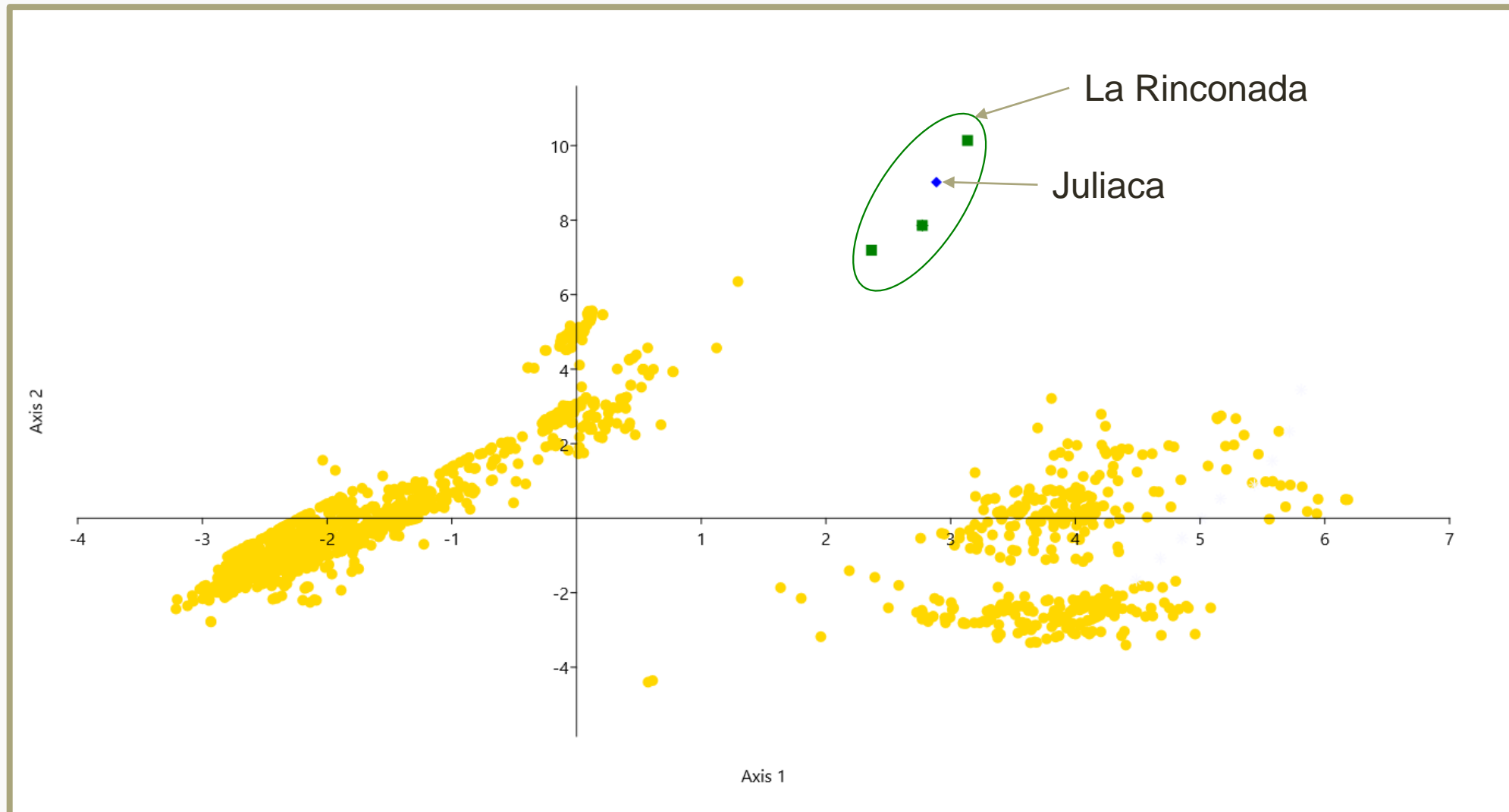
Gold after amalgamation from La Rinconada

The geoforensic passport of this gold nugget confirms the gold is from La Rinconada

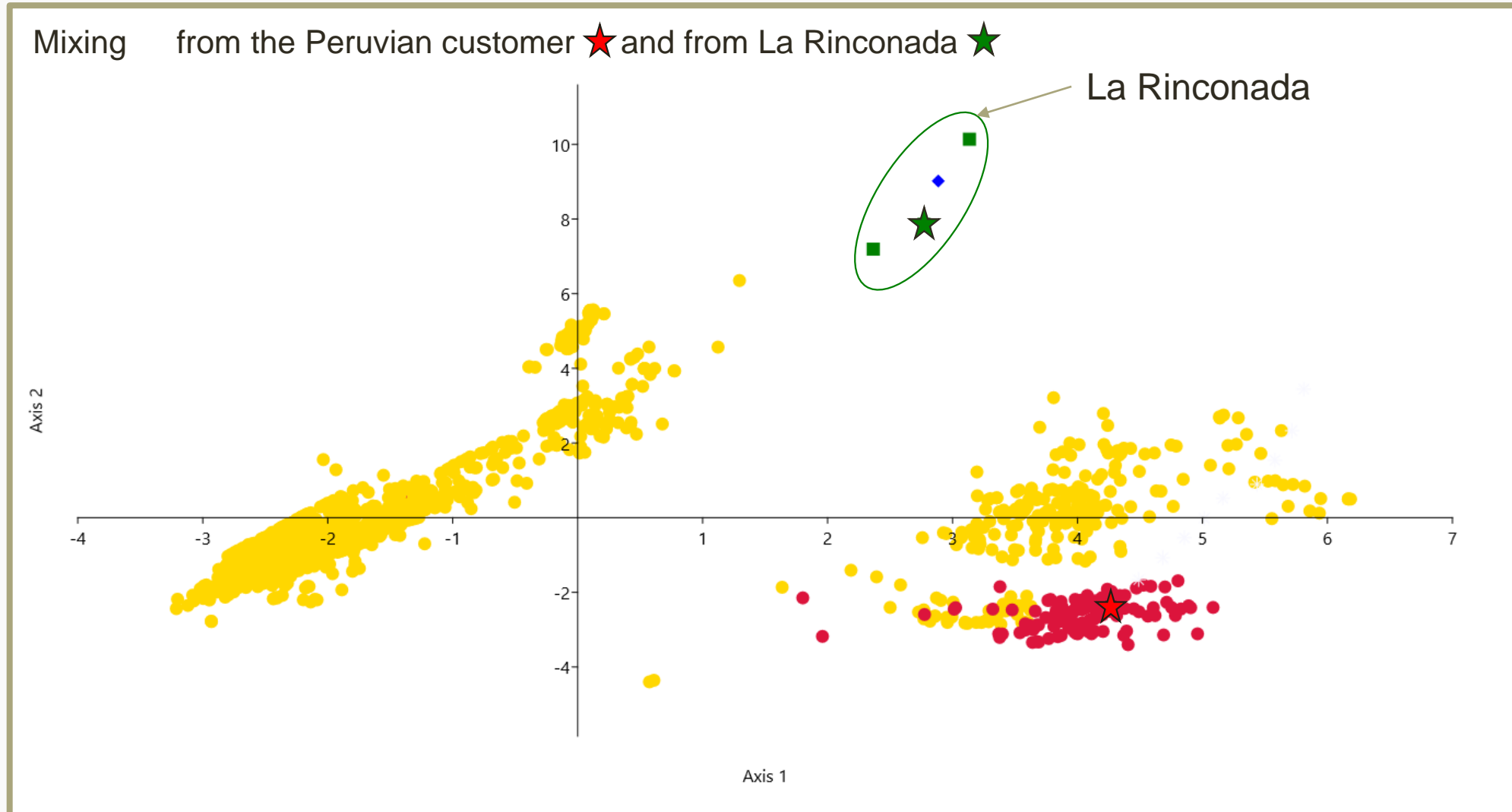
For the past two years, several thousand doré coming from Peru were analysed on arrival at Metalor. All samples from Peru are represented on this 2D multivariate statistics chart (LDA).



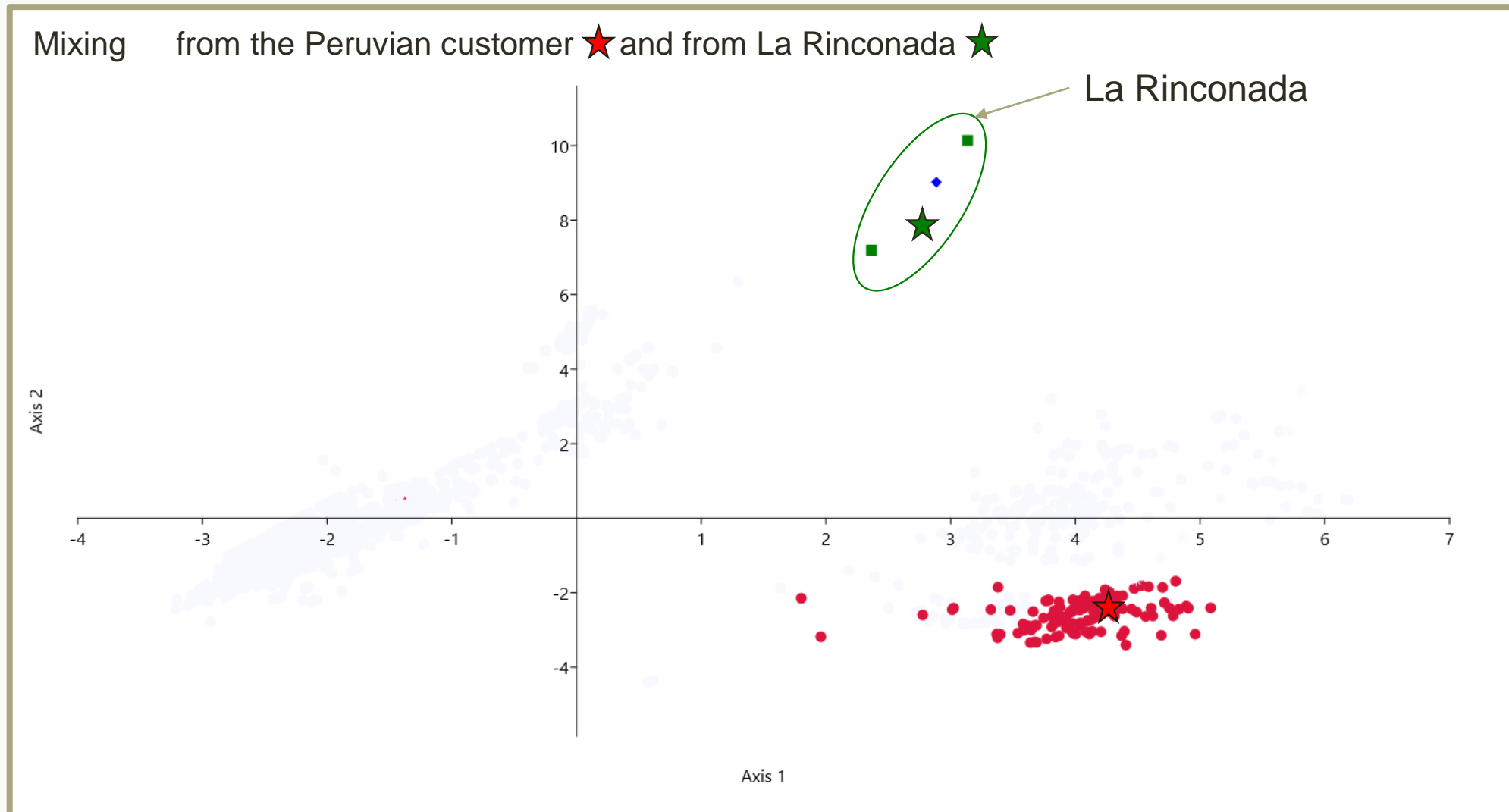
Geoforensic passports of doré from Peru and first-hand collected samples from La Rinconada are incompatible.



Simulation of mixing gold from La Rinconada with gold from a nearby mine production was performed

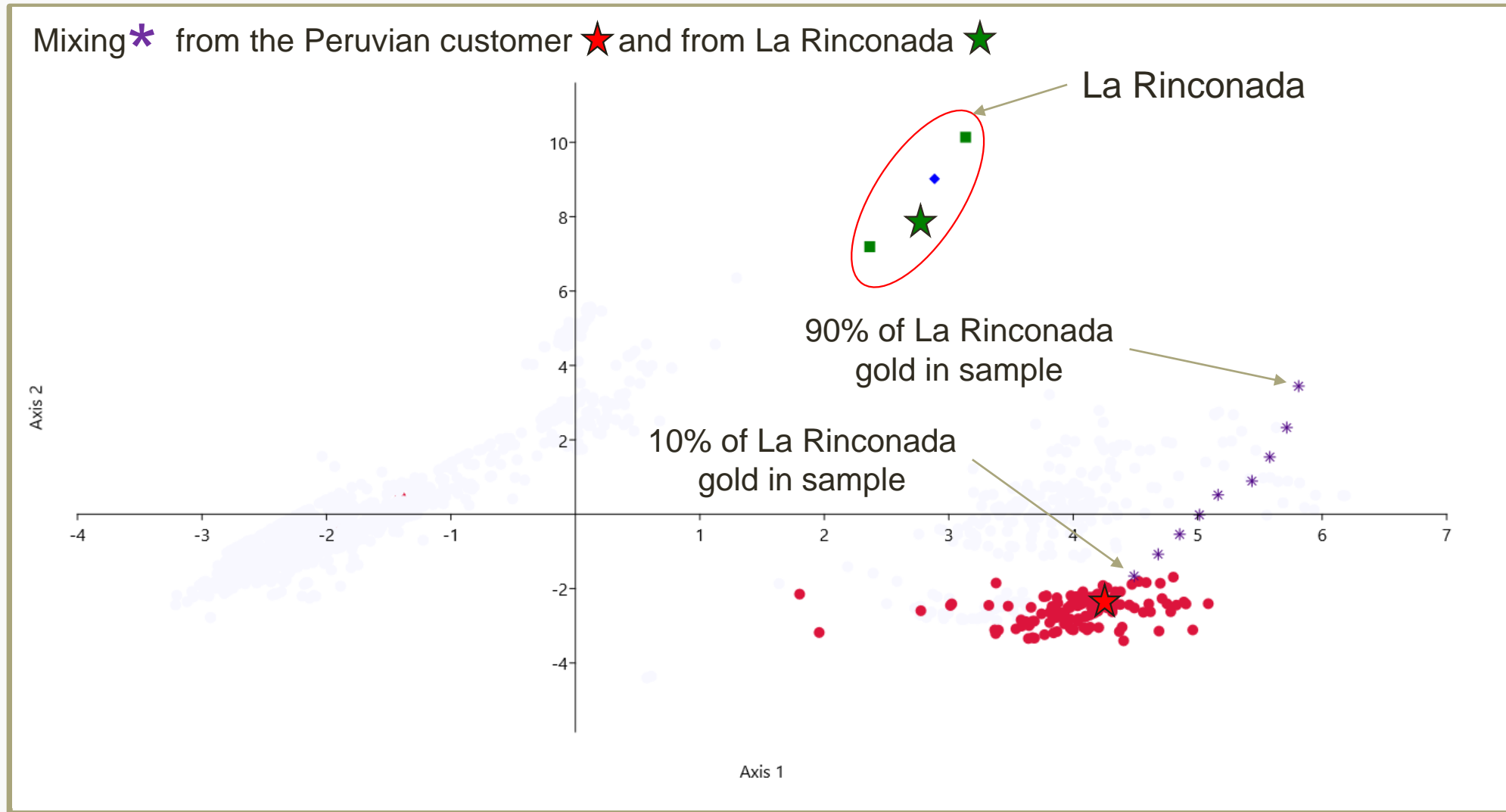


Simulation of mixing gold from La Rinconada with gold from a nearby mine production was performed



Even when 10% of gold from La Rinconada is added in a sample, it is immediately detected!

This confirms that the geoforensic passport is a **very robust tool** to identify manipulation of the doré



Technical feasibility

- Confirmation of origin is possible using a scientific, multistep method
- Our approach is based on the confirmation and not on the determination of origin
- Creation of a geoforensic passport for each customer is effective
- Even small percentage mixtures (< 10%) can be detected
- No large-scale field study needed: the samples are studied at the bottleneck of the gold supply chain, on arrival at the refinery

Refiner's requirements

- Systematic analysis
- Quick method using existing analytical equipment
- Integration in existing flows & low cost

Next steps

- Automation of level 1 to facilitate the selection of outlier doré as soon as they arrive at the refinery
- Better understanding of the doré-outliers through well-targeted field studies

Acknowledgements



Michel Maignan

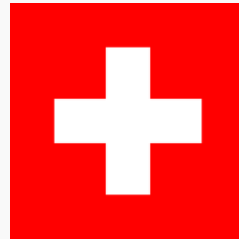
Geological Museum of Lausanne
(Nicolas Meisser, Stefan Ansermet, Gilles Borel)

Valérie Boisvert, Suren Erkman

Geostatistical team of the University of Lausanne (Fabian Guignard, Federico Amato)



Jamel Belgacem
Quentin Bochud
Yannick Tuller



Swiss Embassy in Peru



**UNIVERSITÉ
DE GENÈVE**

Massimo Chiaradia



Better Gold Initiative
Oro Responsable

Thomas Hentschel

SBGA SWISS **BETTER GOLD**
ASSOCIATION

Diana Culillas

A research project funded by :

- InnoSuisse, the Swiss Innovation Agency
- Metalor Technologies