

# Origin of Gold

## Geoforensic Passport

Dr Barbara Beck

*Unil*  
UNIL | Université de Lausanne

Dr Jonathan J. Jodry

**METALOR**<sup>®</sup>

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## Background

- Refiners receive thousands of doré lots every year – all have an announced origin

## Our goal

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

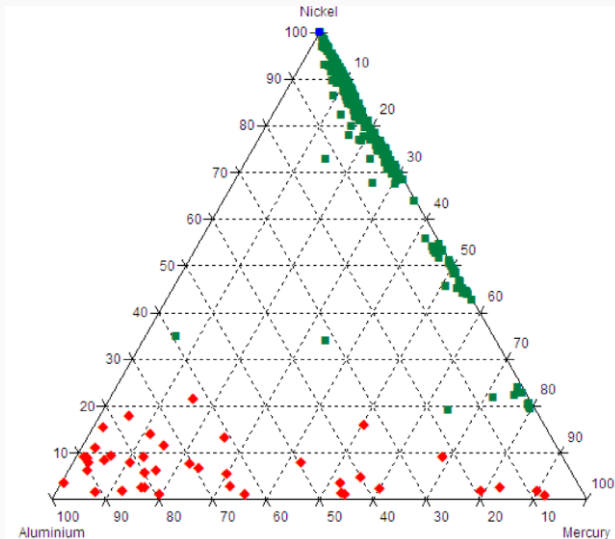
## Our requirements

- 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

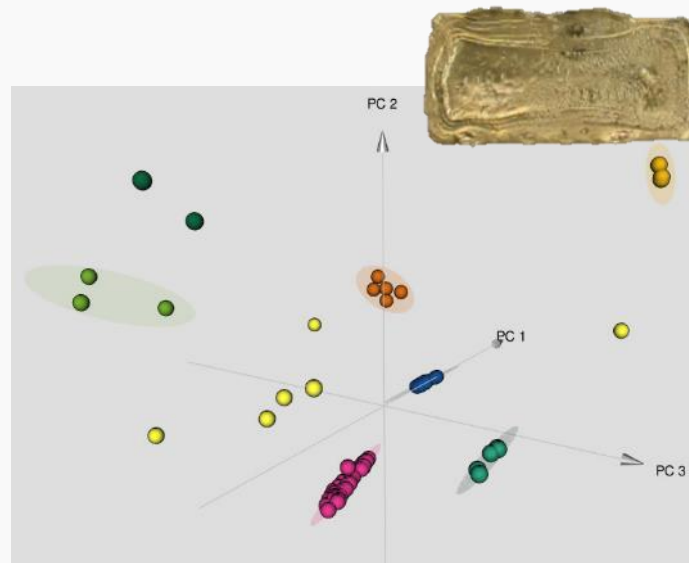
## State of the Art



## Geoforensic Passport

Creation

Validation



## Applications

Mines Collector's Case

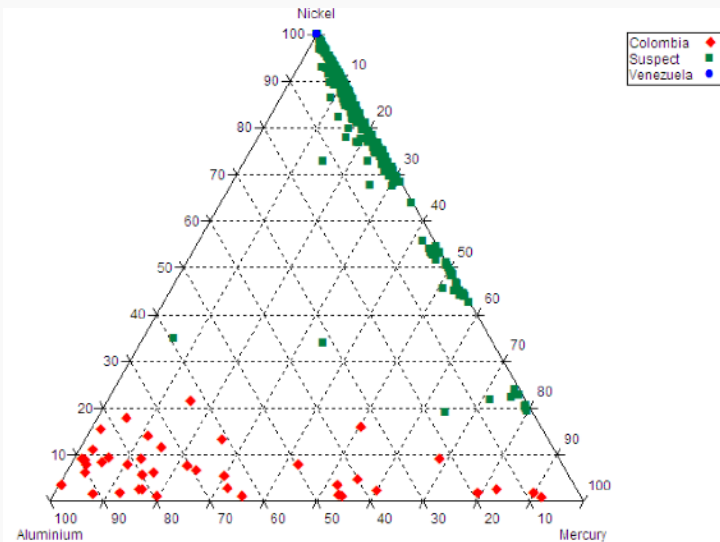
Complex cases...

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

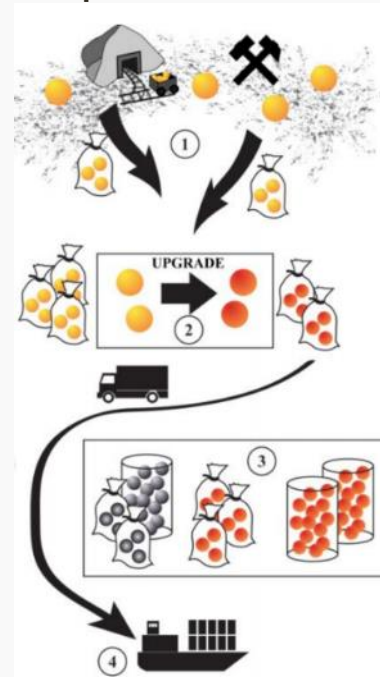


Detailed chemical composition  
(LA-ICP-MS)

## 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

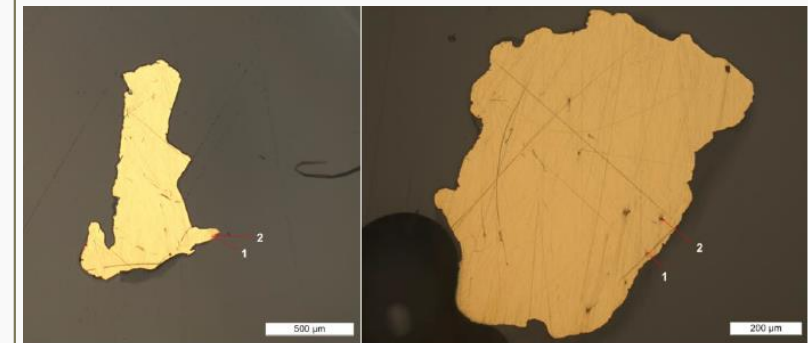
Complex  
mineralogical  
analyses  
(since 2006)



Schütte, Certified Trading Chains, BGR 2013

## BRGM (French Geological Survey)

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



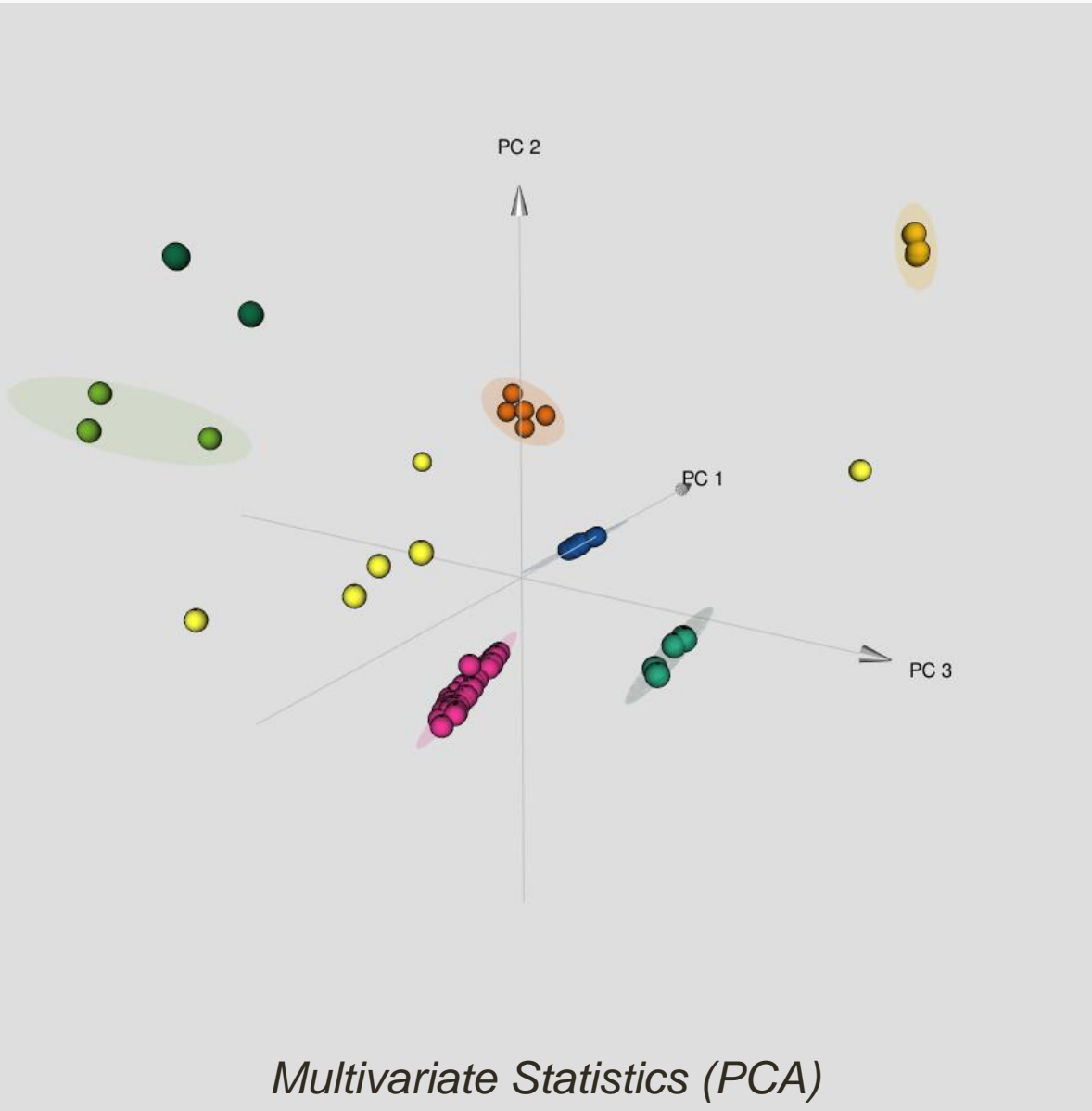
Metallographic (shape, inclusions),  
chemical & isotopic analyses  
(2014 / 2015)

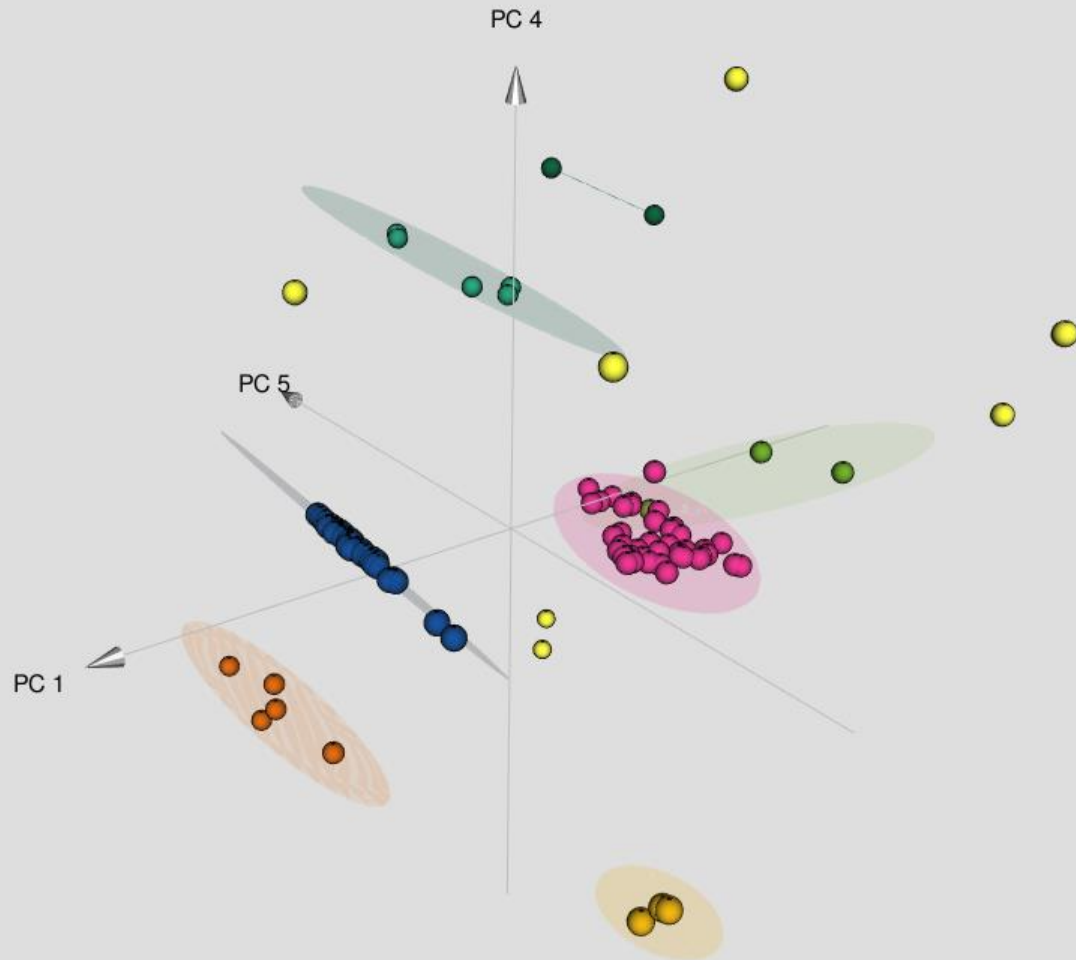
Augé, Report BRGM/RP-64880-FR 2015

## 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)



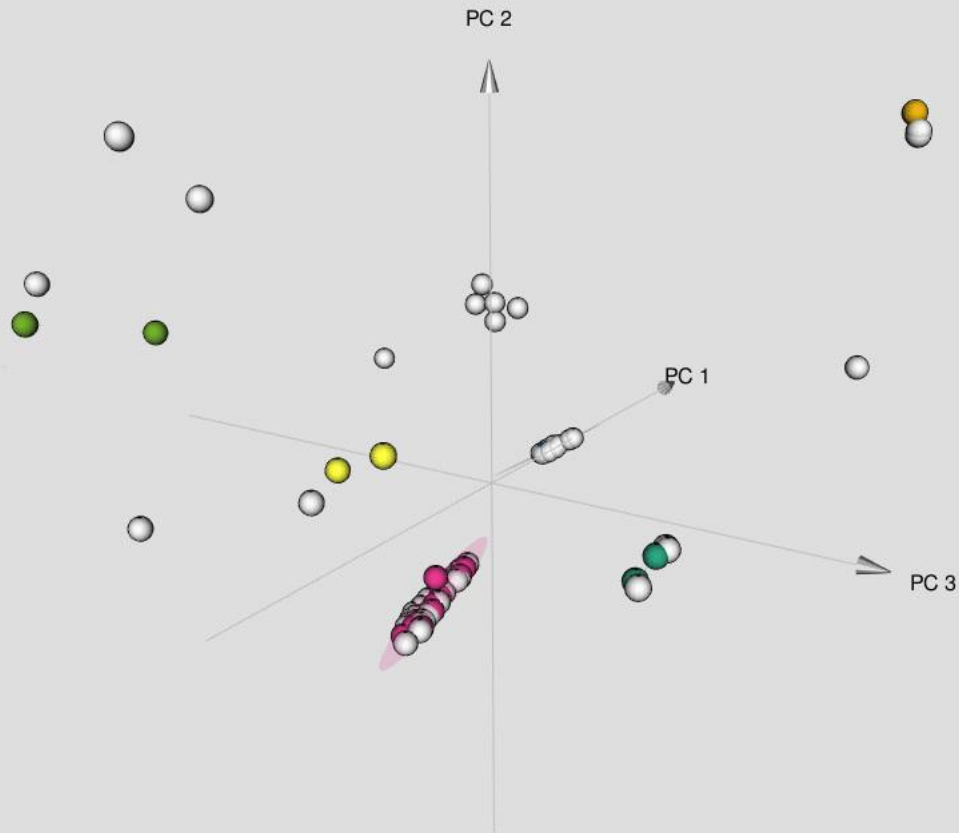


*only 3 dimensions represented  
geoforensic passport has typically 9-15 dimensions*

## A new paradigm in gold origin determination

### Geoforensic passport

- A complex signature of a given customer
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## A new paradigm in gold origin determination

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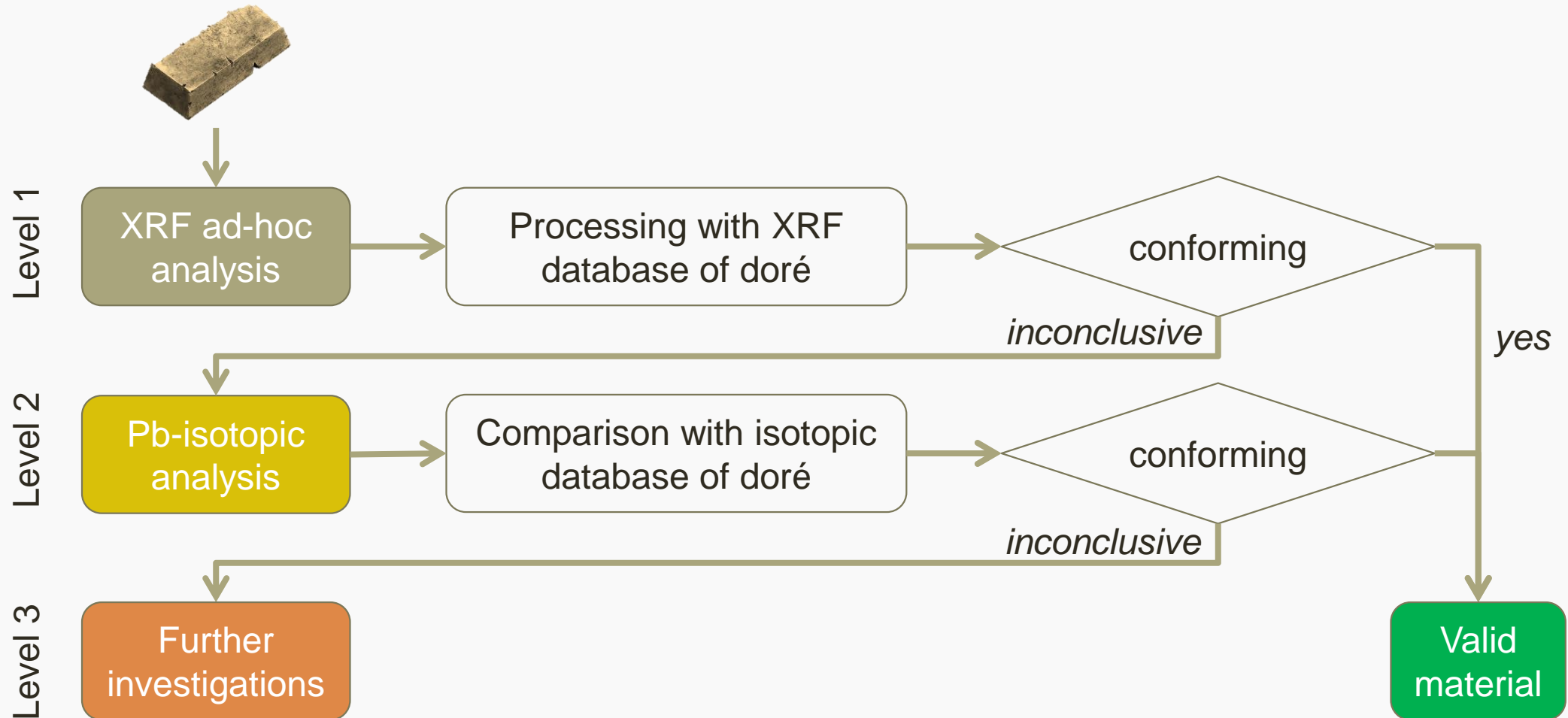
### Time adaptation

- 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)

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

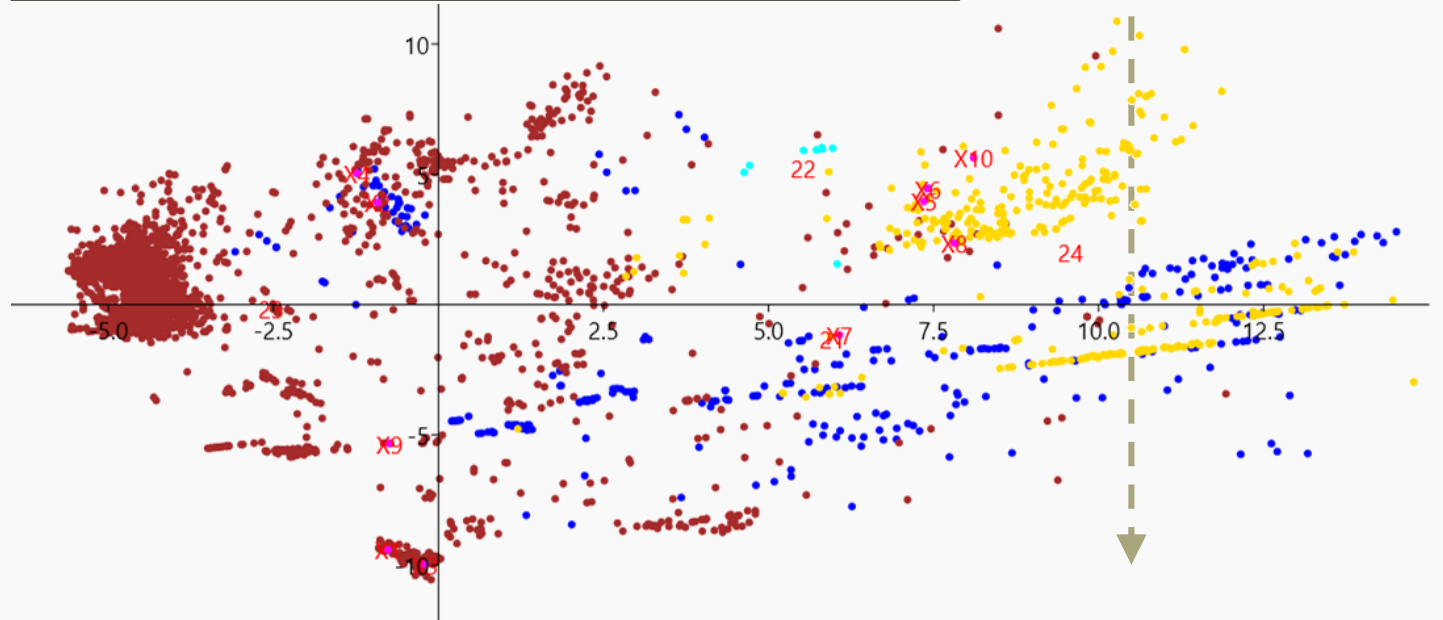
ED-XRF  
historic data

multivariate statistics

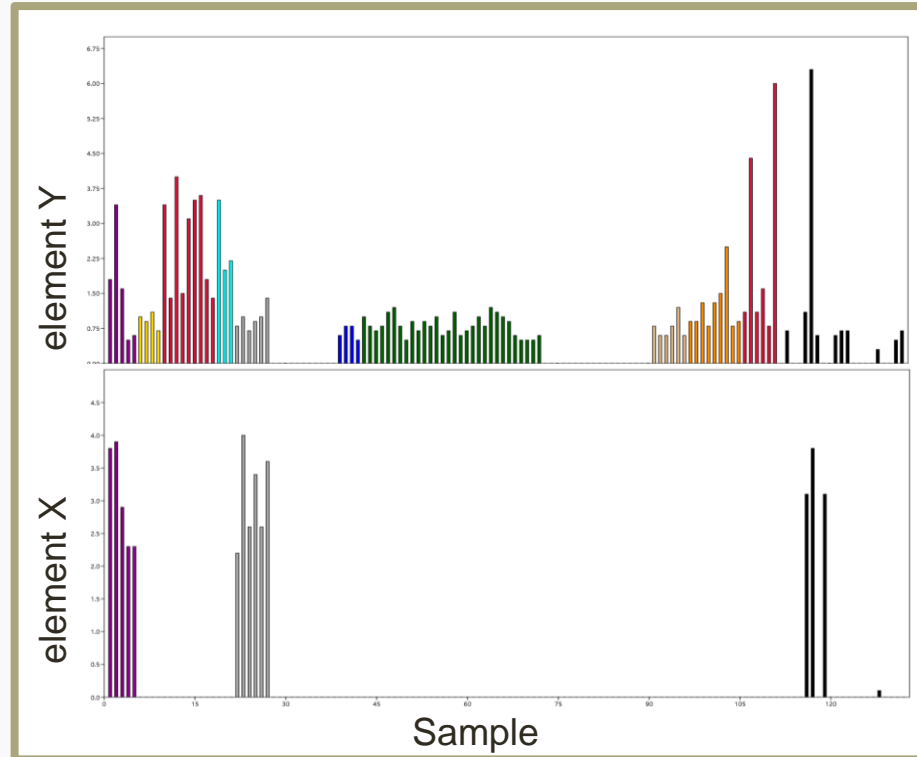
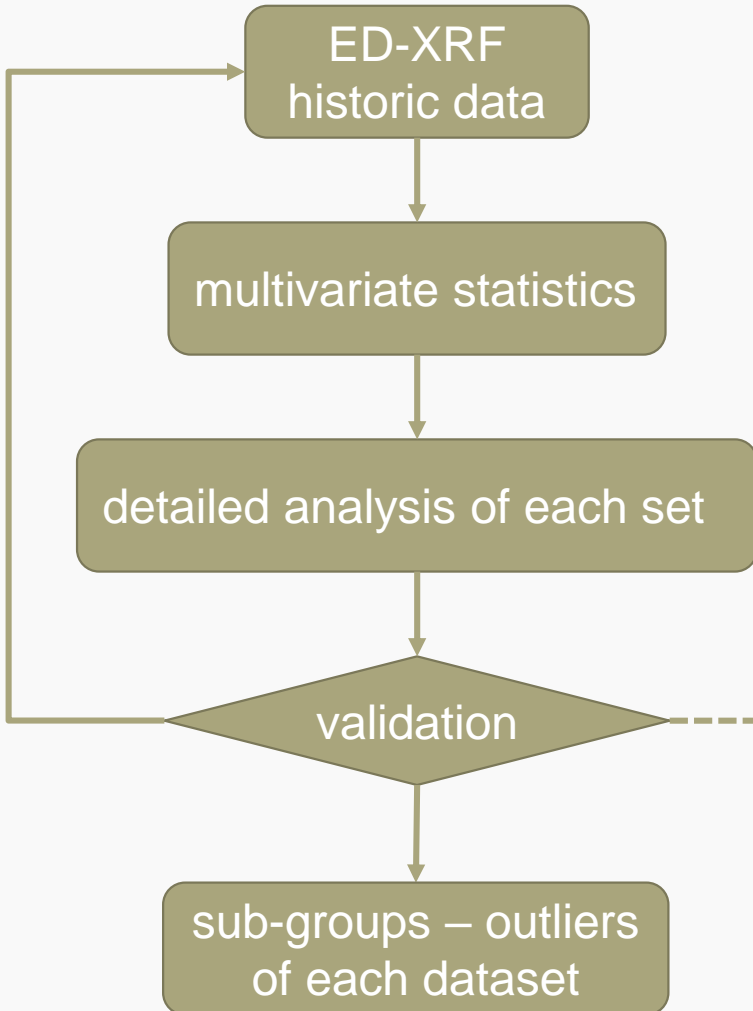
detailed analysis of each set

*Unsupervised learning (machine learning)*

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



# Geoforensic Passport – Creation



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

Scientific Research      Routine Analyses

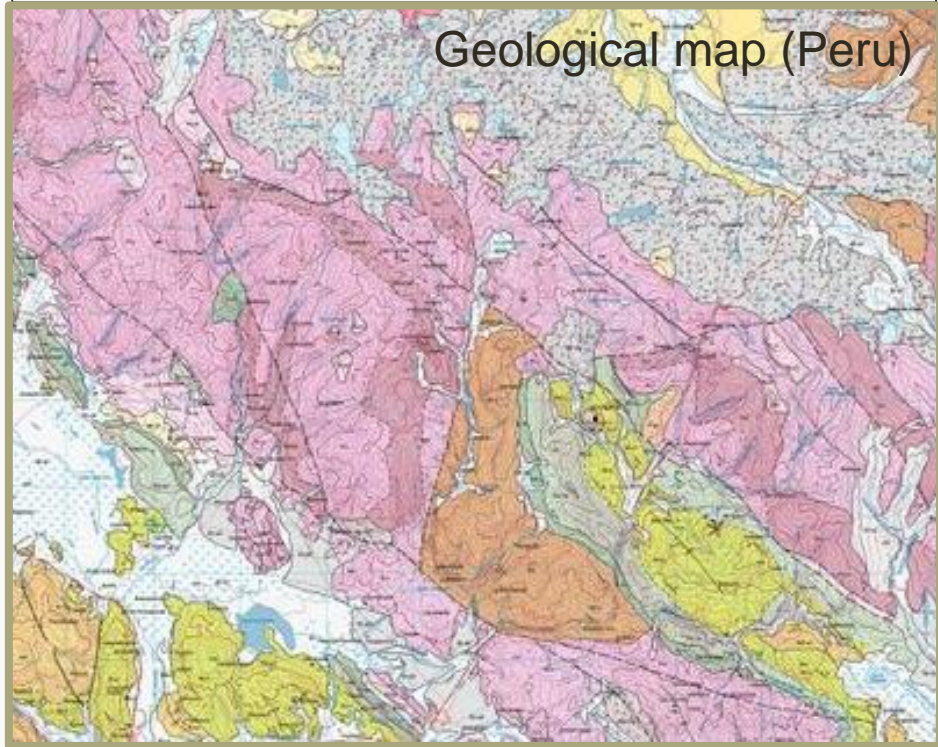


# Geoforensic Passport – Creation

sub-groups – outliers  
of each dataset

contextualisation

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



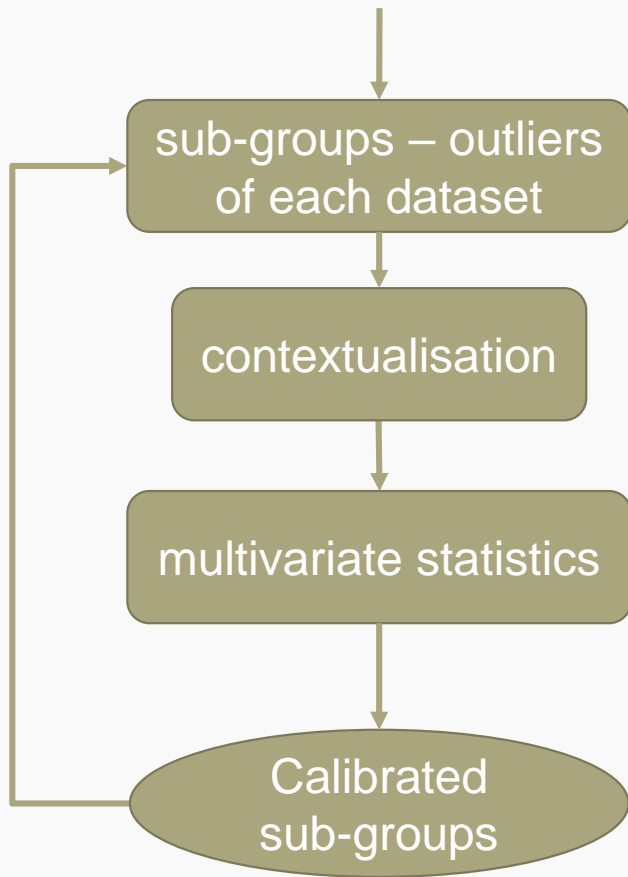
Scientific  
Research

Routine  
Analyses



# Geoforensic Passport – Creation

Scientific Research      Routine Analyses



*Supervised learning*

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

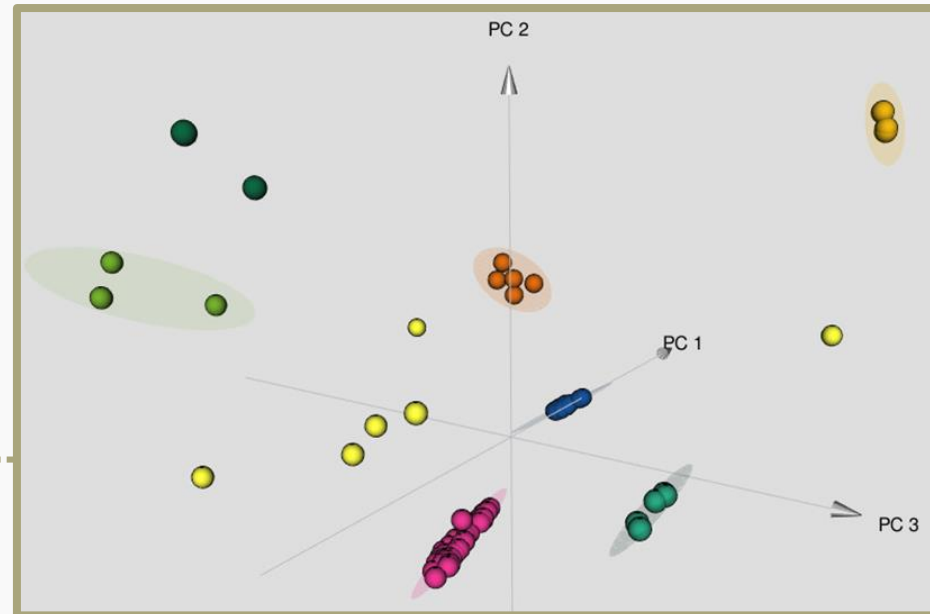
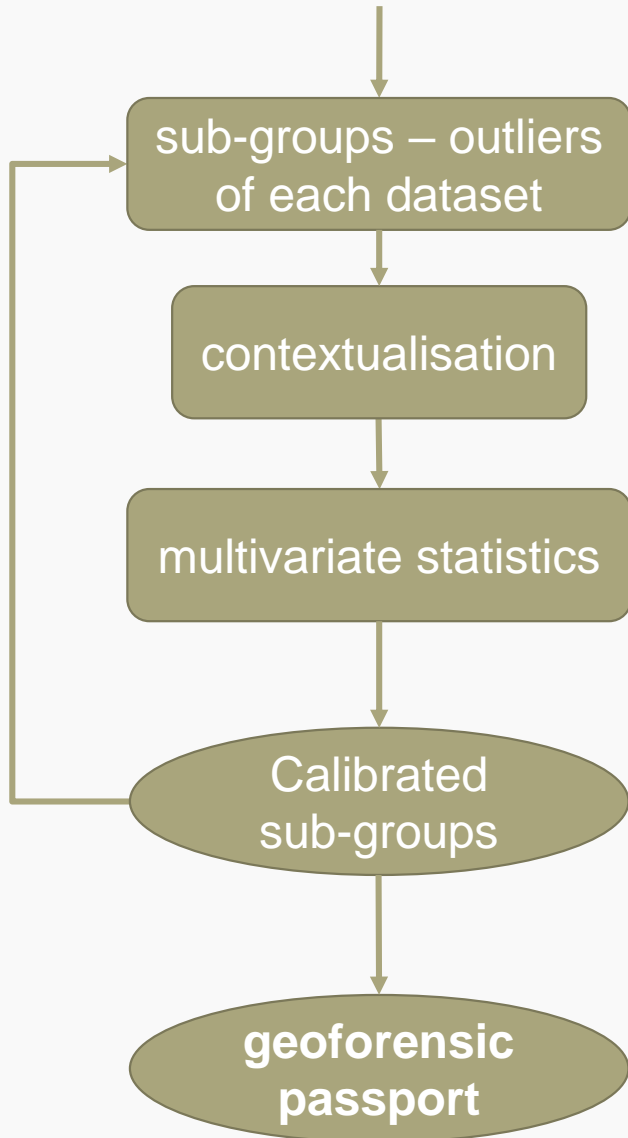
**Confusion matrix - hit rate >95%**

	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

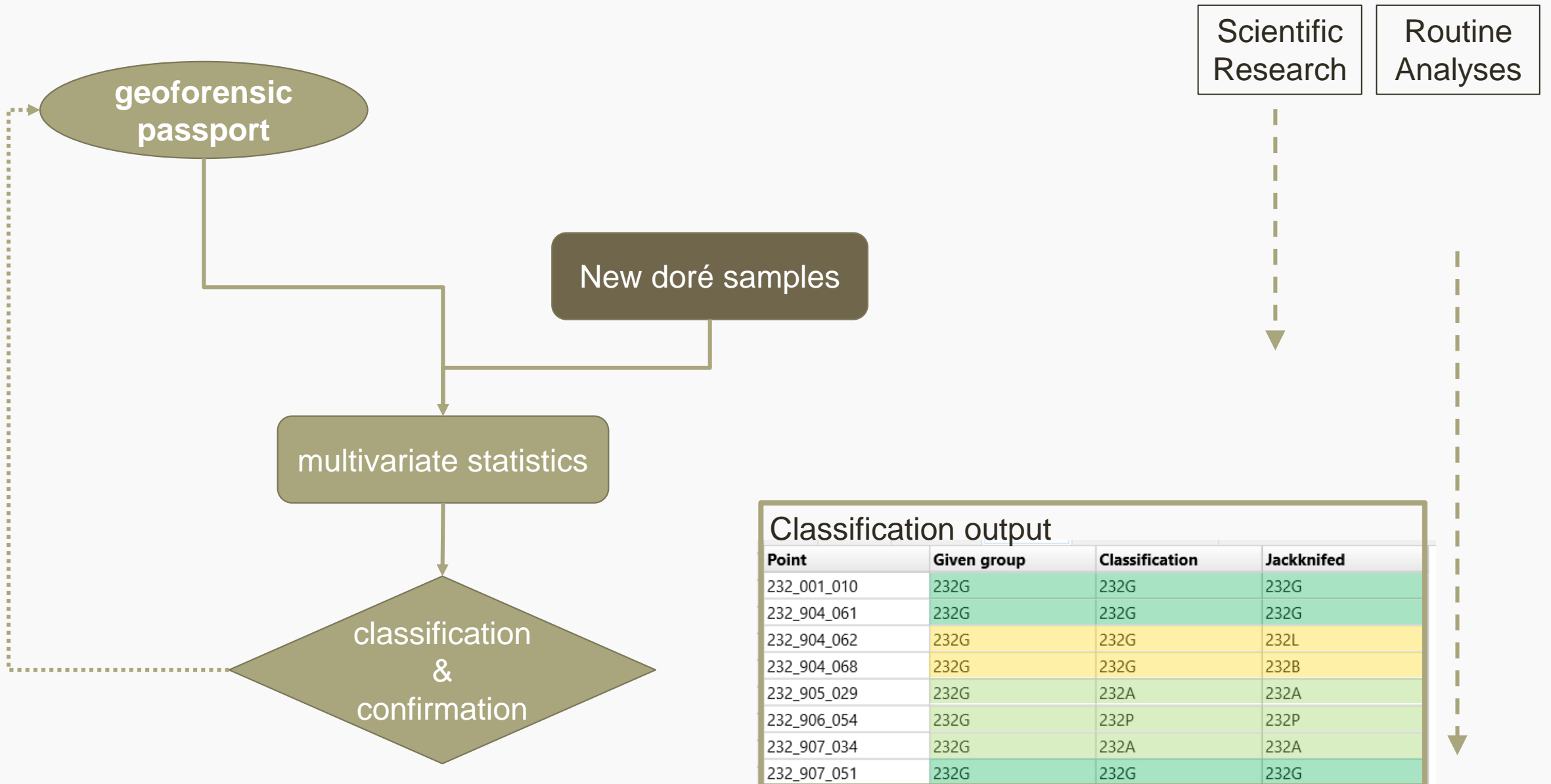
# Geoforensic Passport – Creation

Scientific  
Research

Routine  
Analyses



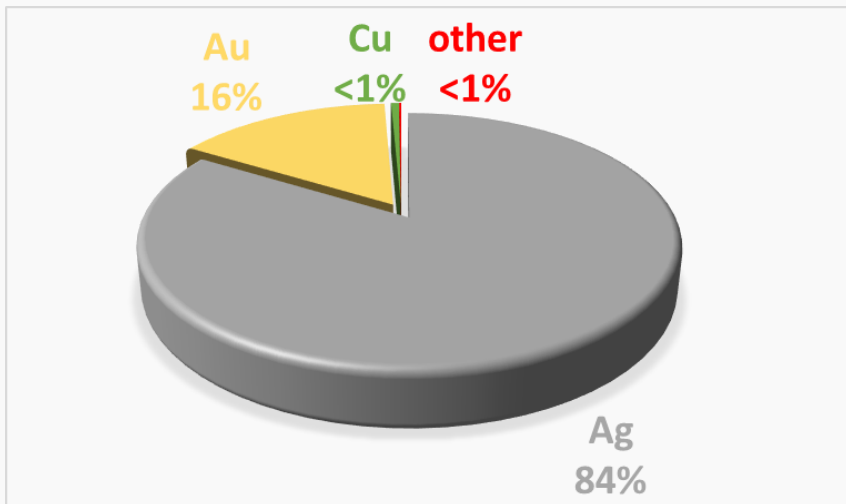
# Geoforensic Passport – Creation





## Example of validation : using 100 doré received at Metalor

- 100 doré samples randomly selected between 1st July and 15 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

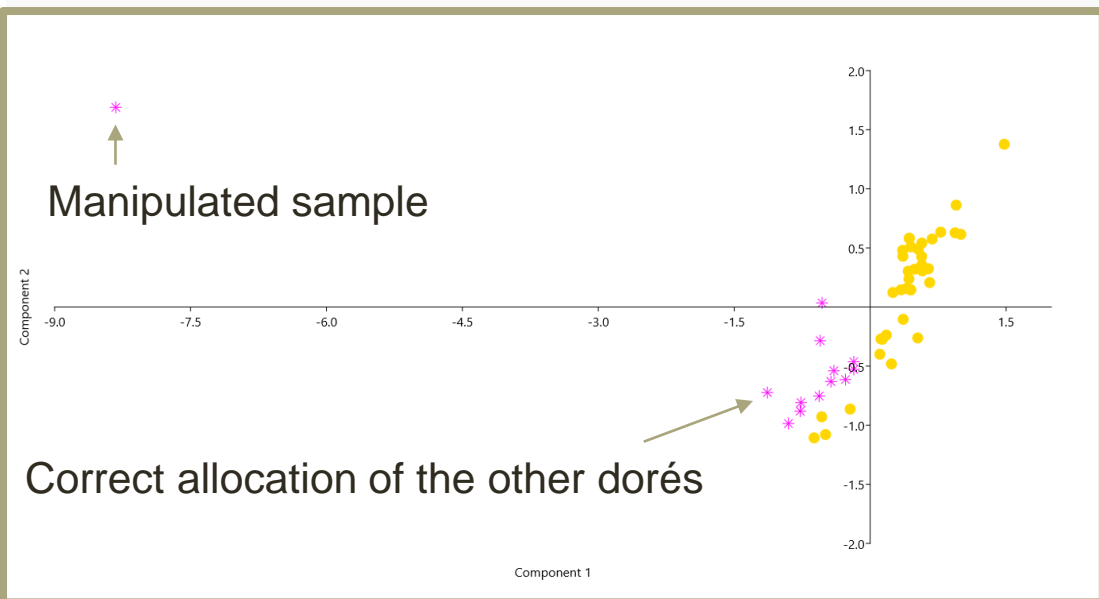
Ag	835.8	836.4
Au	156.1	154.8
Cu	5.7	5.0
Pb	1.4	0
Se	0	3.3

# Geoforensic Passport – Validation

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

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 were later confirmed)



12-14 kg



3.3 kg

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

# Mines Collector's Case

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

- Difficulty to rely on local authorities
- High compliance risk
- Challenging traceability

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

Can different sources of gold be distinguished in the collectors context?

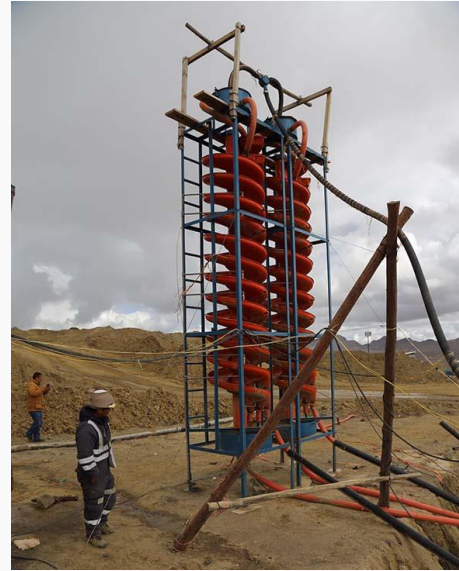
June 17, 2019

*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.*

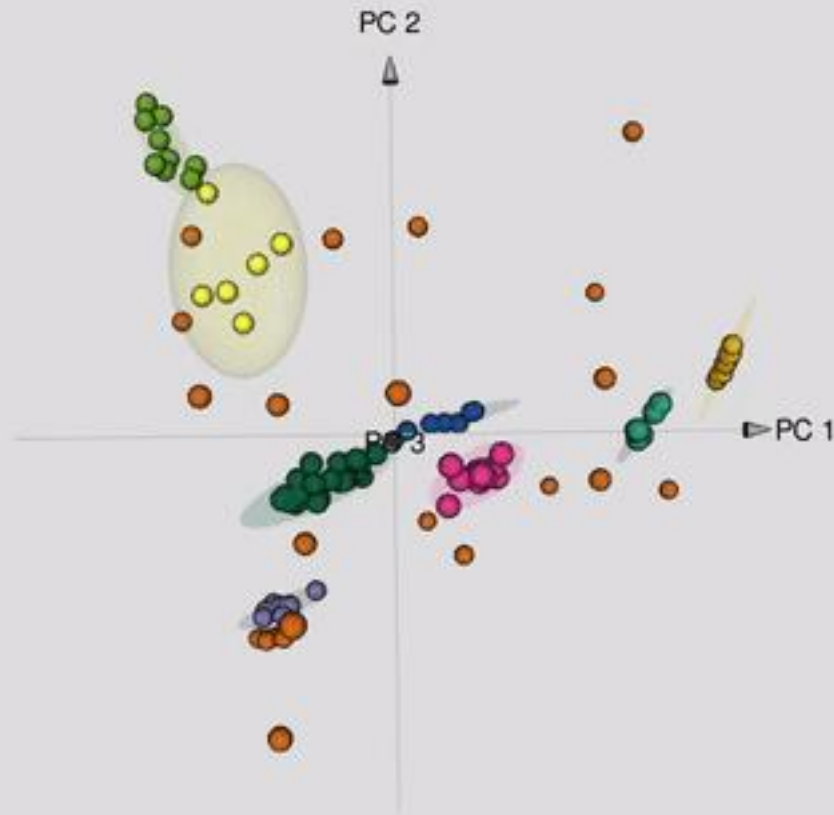
*Despite putting in place all required due diligence measures and a strict verification process, the increasing resources to secure compliance and the challenging conditions at the mining regions have forced Metalor to re-assess its approach to artisanal mining.*

*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.*

# Mines Collector's Case



*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 geochemical 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 are coming from larger, well-defined mining operations...



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

... and which ones are not understood!

# Complex cases... Using Level 2 analyses

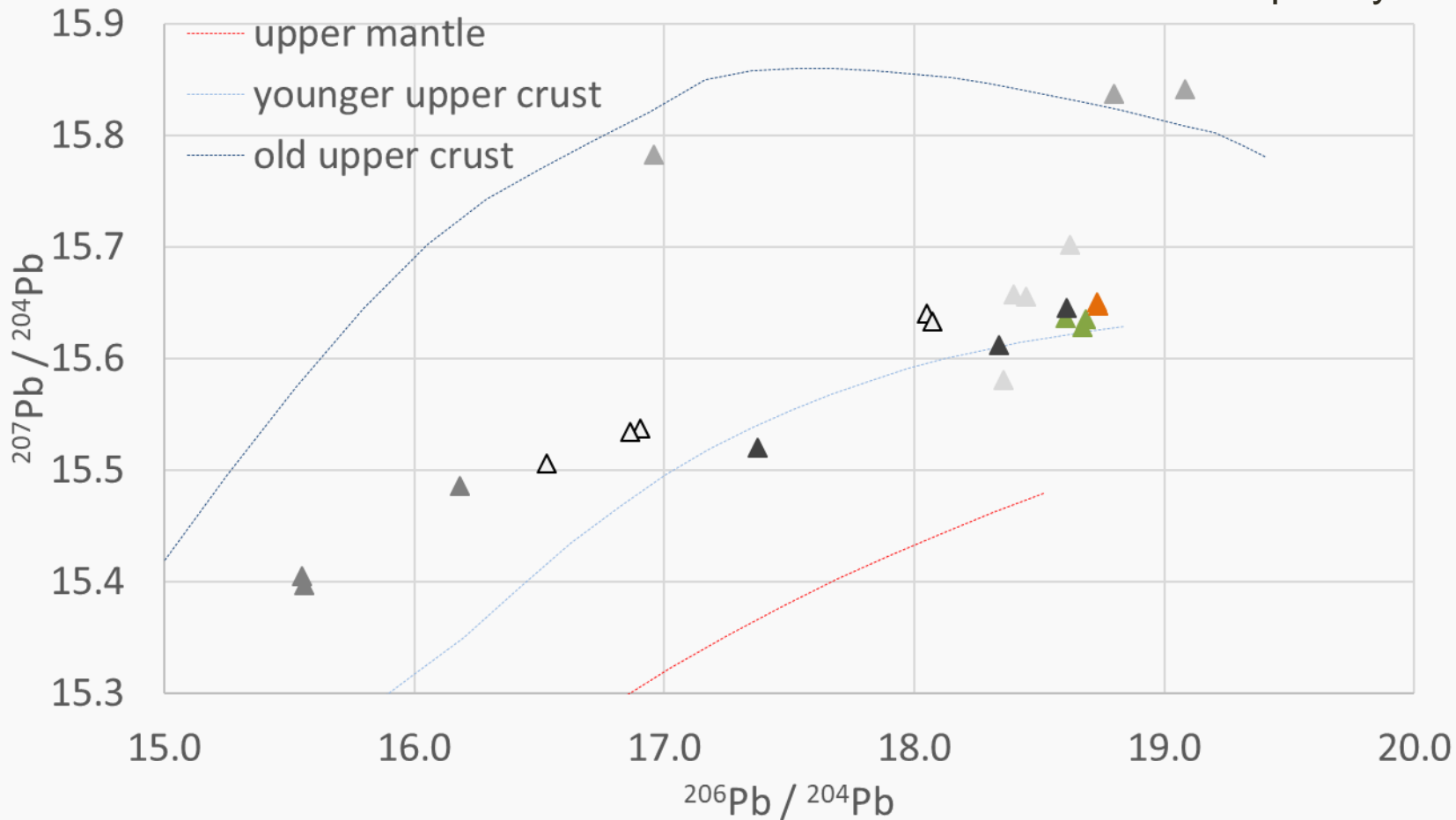




In some cases, samples which are supposed to be from exactly the same origin have a very different, apparently incompatible geoforensic passport

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

# Complex cases... Using Level 2 analyses

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



		
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# 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 to ensure no gold from there is entering a serious refinery ?



*Pictures taken by S. Ansermet & B. Beck*

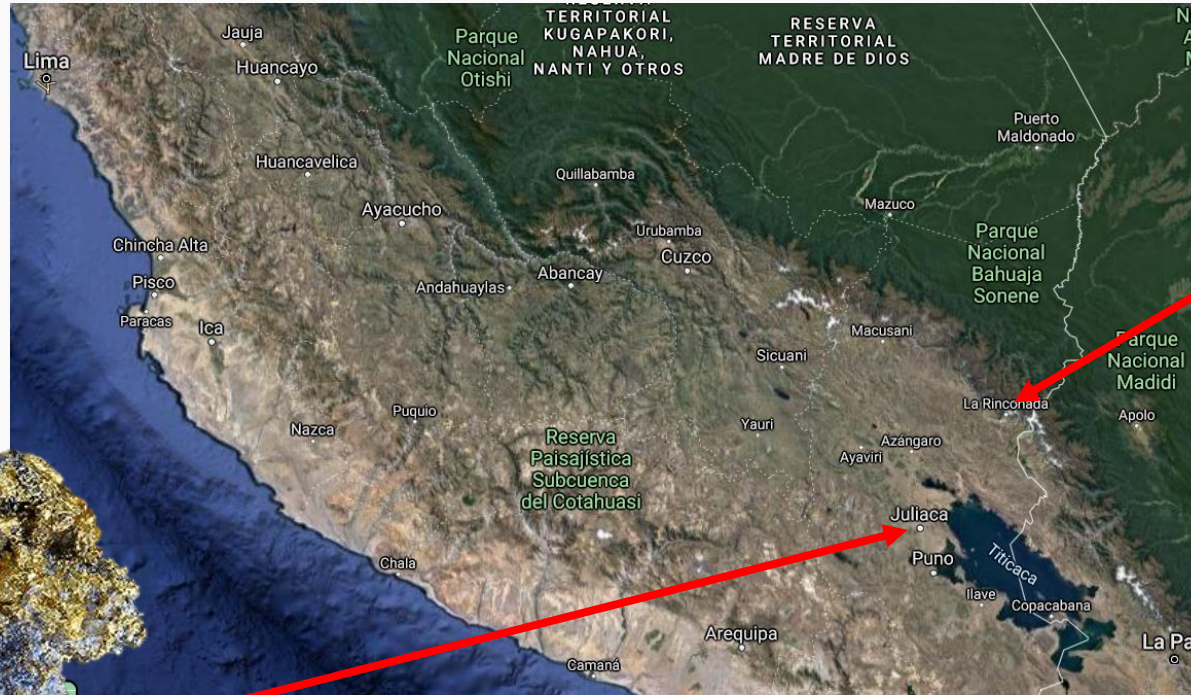
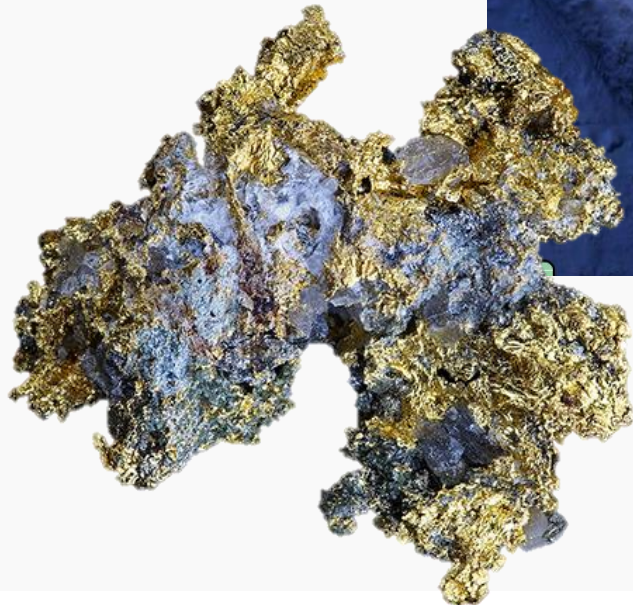


# La Rinconada

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How to ensure no gold from there is entering a serious refinery ?

*Gold nugget purchased at a gold comptoir in Juliaca*



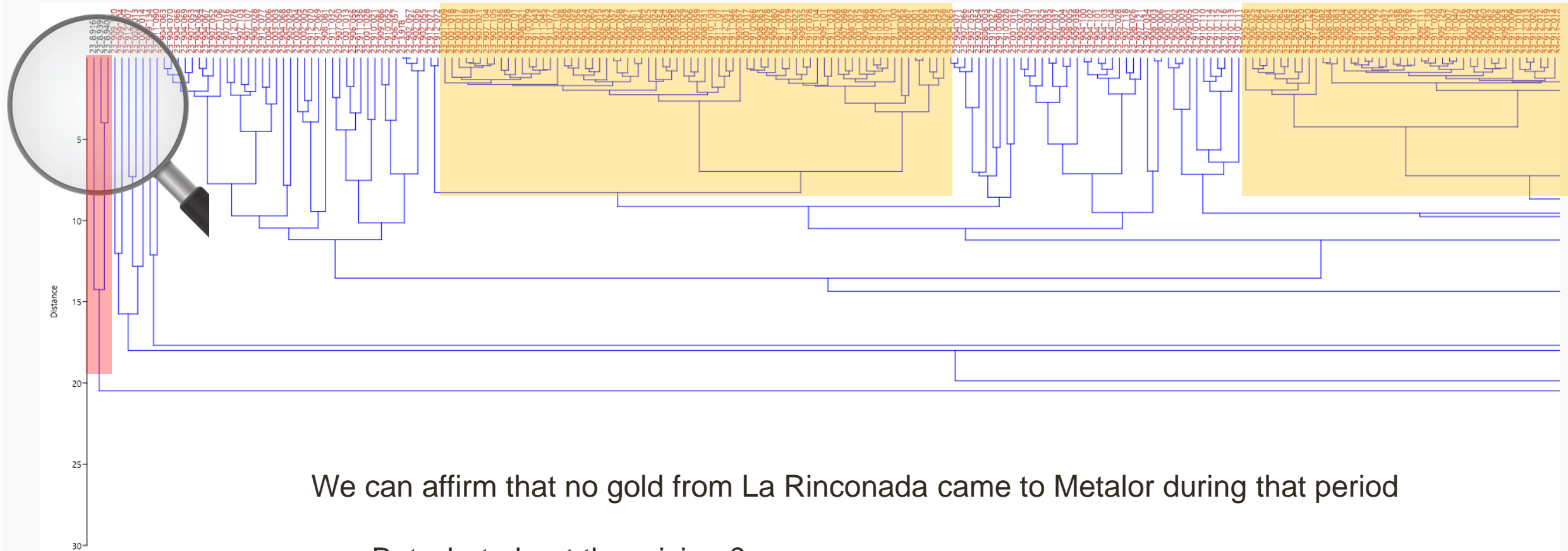
*Gold after amalgamation from La Rinconada*



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

For two years, all the doré from Peru were analysed once they arrived at Metalor (several thousands)

The geoforensic passports of Metalor samples and these collected first-hand from La Rinconada are completely incompatible

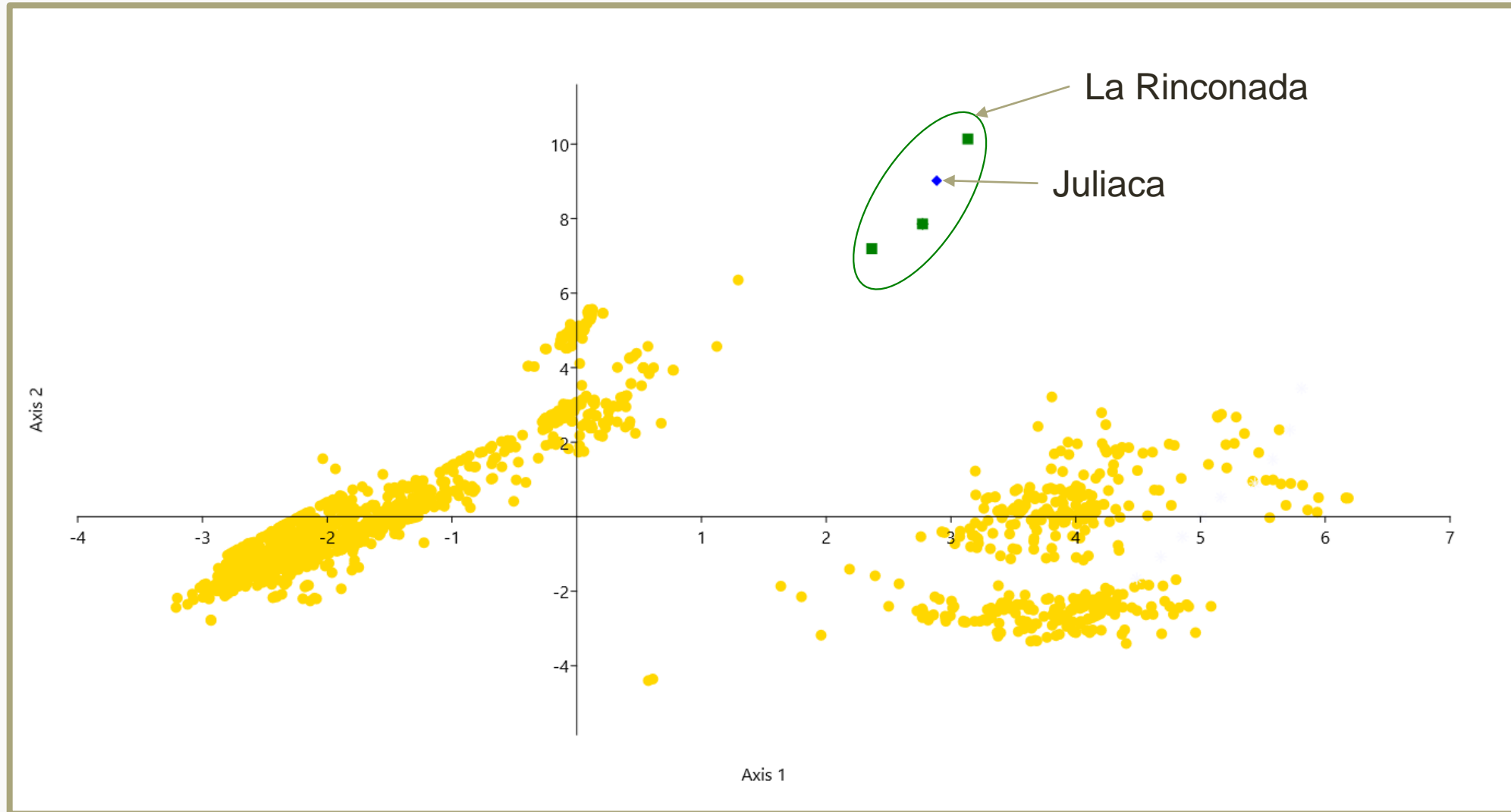


We can affirm that no gold from La Rinconada came to Metalor during that period

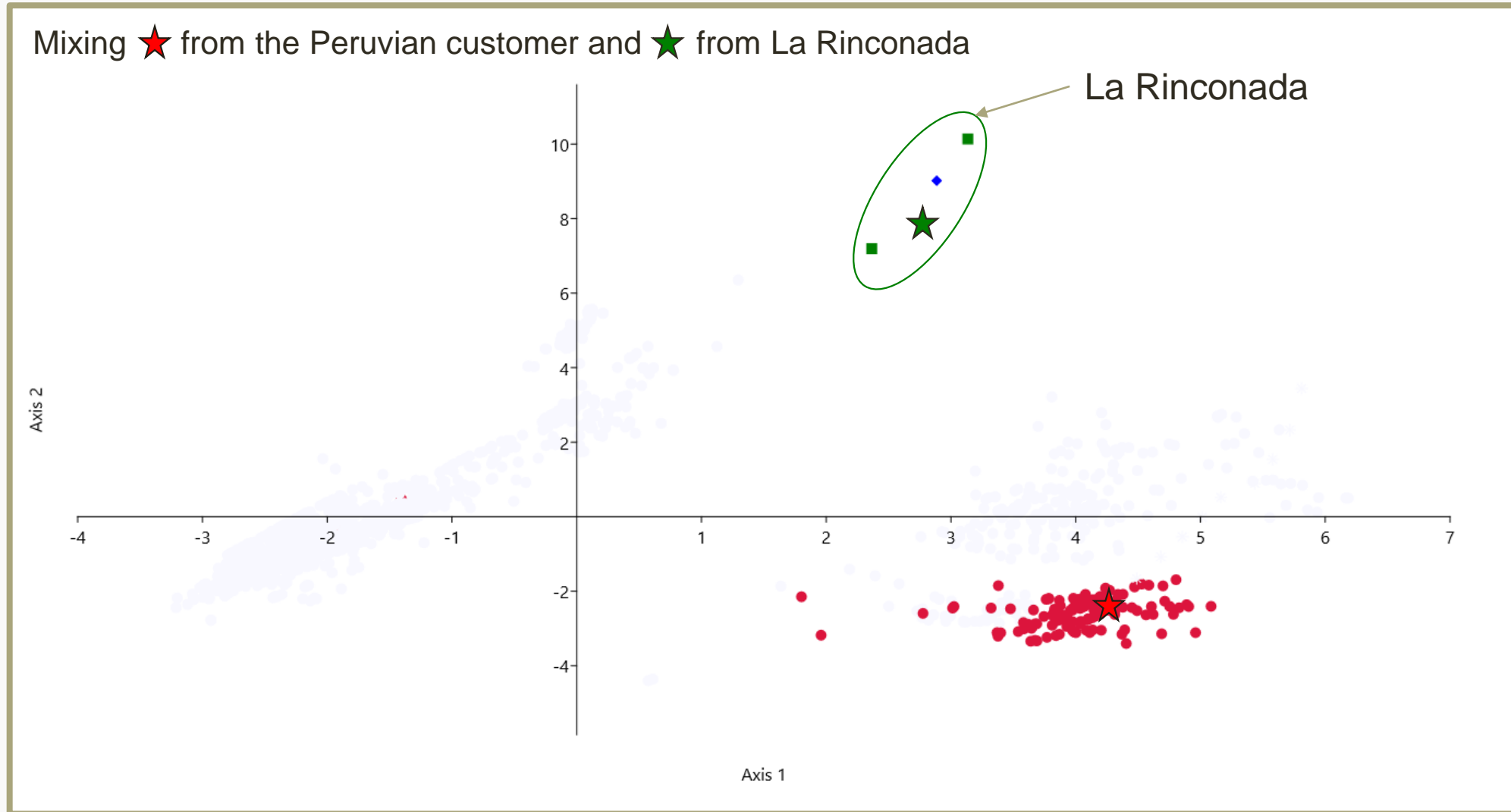
But what about the mixing ?

All samples from Peru are represented on this 2D multivariate statistics (LDA)

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

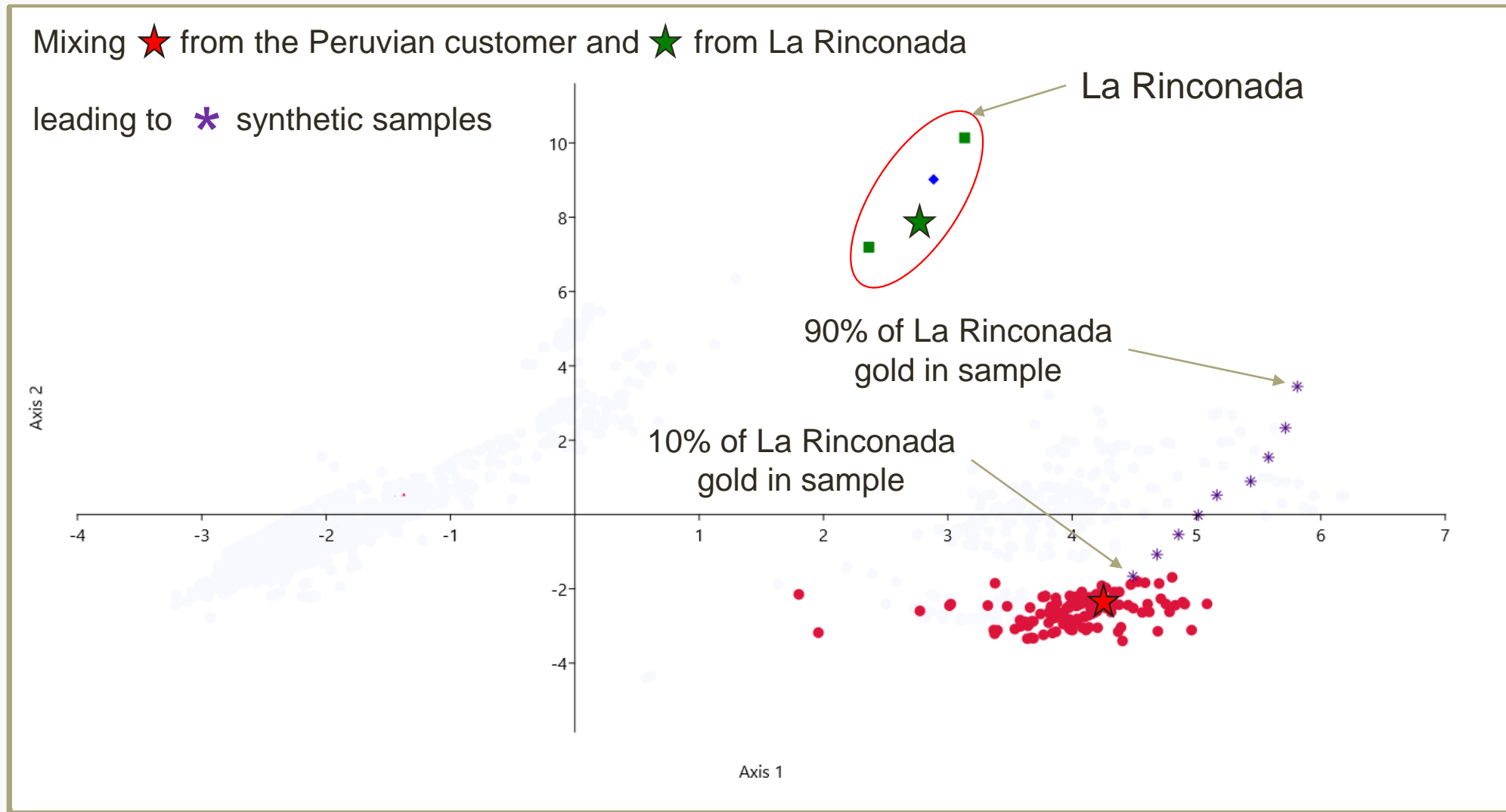


Simulation of mixing gold from La Rinconada with gold from a nearby mine production was performed



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 a confirmation and not on a determination of origin
- Creation of the 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 on arrival at the refinery

## Refiner's requirements

- Systematic analysis
- Quick method on existing analytical equipment
- Integration in existing flows & Low cost

## Next steps

- Fully-automated data processing
- Better understanding of the doré-outliers through well-targeted field studies

# Acknowledgements



Michel Maignan

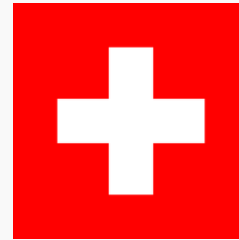
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Swiss Embassy in Peru



**UNIVERSITÉ  
DE GENÈVE**

Massimo Chiaradia



**Better Gold Initiative**  
Oro Responsable

Thomas Hentschel

**SBGA** SWISS **BETTER GOLD**  
ASSOCIATION

Diana Culillas

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