Research on genesis of precious metals deposits in the Central Slovakian Neogene Volcanic Field

Peter Koděra

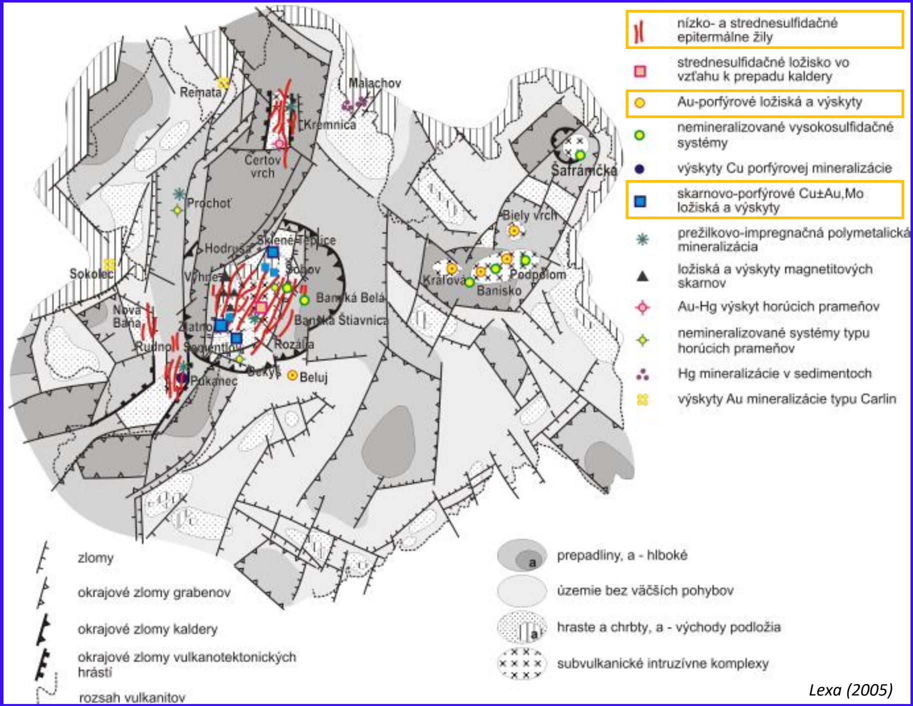
Recent related research projects

position: principal investigator

- **Genesis of precious metal epithermal and porphyry mineralisations in the stratovolcanoes Javorie and Štiavnica.** VEGA grant, 2020 – 2023
- **Complex model of base and precious metal mineralisation at the Rozália mine in Hodruša - Hámre.** APVV grant, 2016 – 2020
- **Mineralogy and genesis of economically important types of gold mineralisation in the Central Slovakian Neogene Volcanic Field.** VEGA grant, 2015 - 2018
- **Au-porphyry systems deposit models in the Central Slovakia Neogene Volcanic Field and environmental aspects of their exploitation**. APVV grant, 2011 - 2014

Precious metal deposits in the Central Slovakian Neogene Volcanic Field

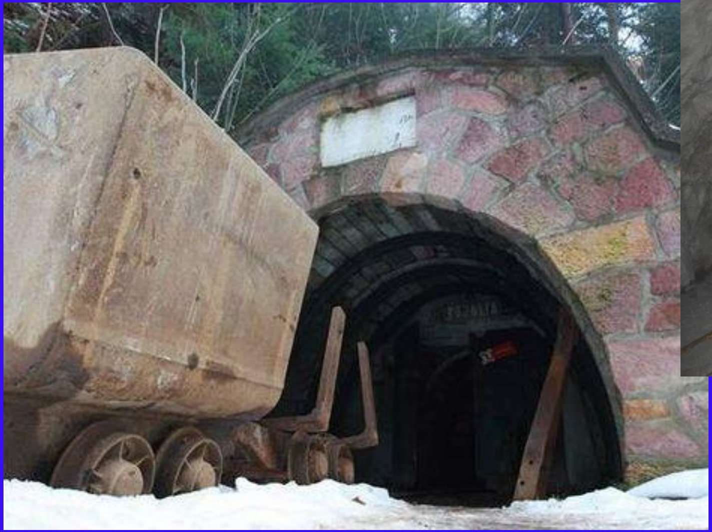
- **Main mineralised centers:**
  - *Štiavnica Stratovolcano* (mainly central zone)
  - *Kremnické Vrchy Mts.* (mainly Kremnica horst)
  - *Javorie Stratovolcano* (mainly central zone)
- **Active exploration, mining, ore reserves**



Horst-graben structure

Complex model of base and precious metal mineralisation at the Rozália mine in Hodruša – Hámre

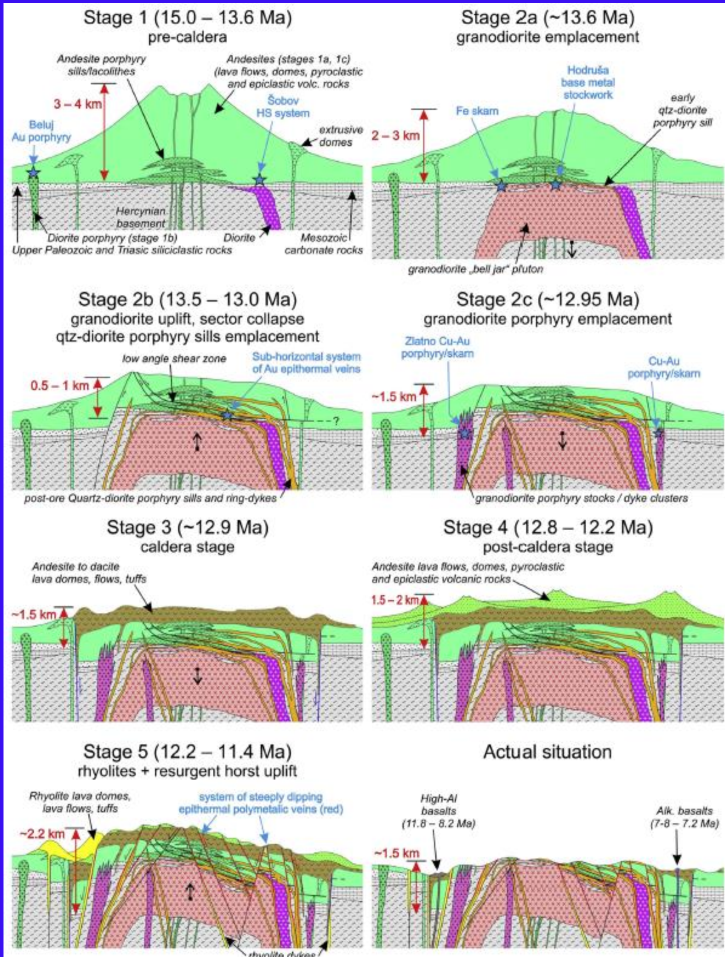
APVV grant, 2016 – 2020

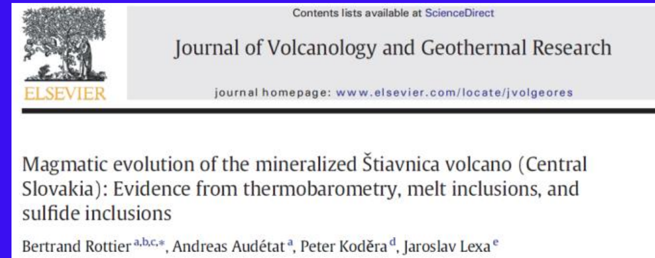


Outcomes of the project

- Structural-geological model of the deposit:
  - *Model of the central zone of the Štiavnica stratovolcano*
  - *Model of the magmatic evolution of the Štiavnica stratovolcano*
- Model of mineralisation at the deposit
- **Model of hydrotermal alteration at the deposit**
- **Genetic model of the deposit**
- Criteria for ore prognosis (regional, local)
- Modelling of the deposit in GIS
  - *Complex structured spatial database*
  - *3D model of mine works*
  - *3D model of geology of the deposit*
  - *3D model of distribution of Au-Ag at the deposit*

Magmatic evolution in the Štiavnica stratovolcano *(Rottier et al., 2020)*

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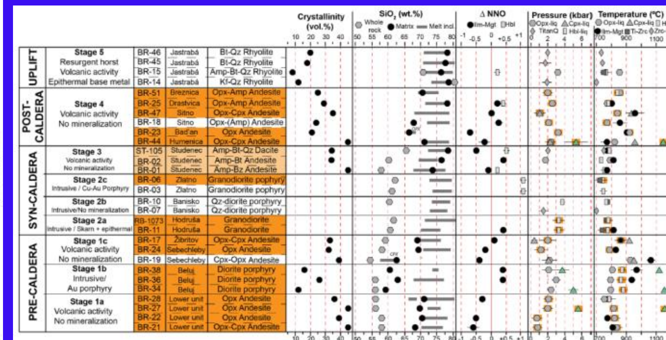
Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

ELSEVIER

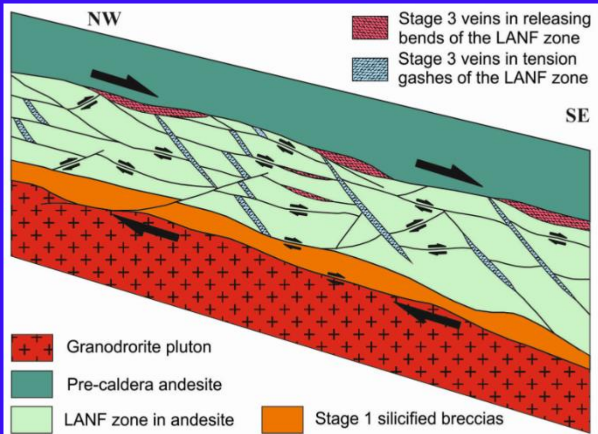
Magmatic evolution of the mineralized Štiavnica volcano (Central Slovakia): Evidence from thermobarometry, melt inclusions, and sulfide inclusions

Bertrand Rottier[a,b,c,*], Andreas Audétat[a], Peter Koděra[d], Jaroslav Lexa[e]



- **SHRIMP U-Pb dating** of associated intrusive and volcanic rocks
- the deposits were formed during periods of **upper crustal reservoir** cooling when the residual melt has reached fluid saturation

Mineralogical model of the deposit *(Kubač et al., 2018)*




Mineralogy and Petrology (2018) 112:705–731
https://doi.org/10.1007/s00710-018-0558-y

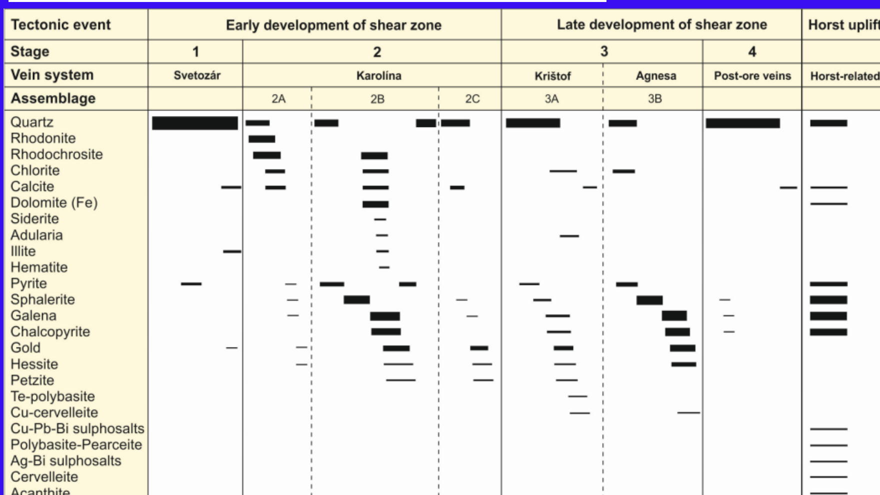
ORIGINAL PAPER

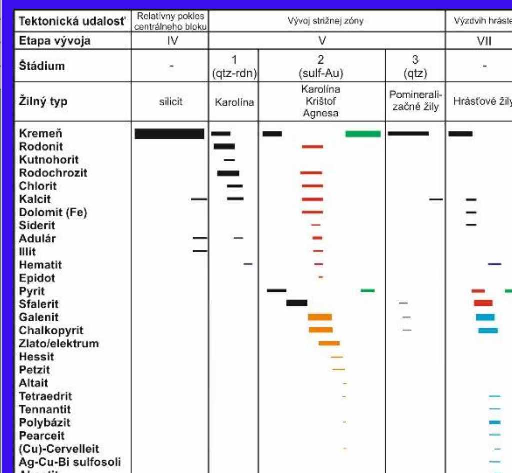
CrossMark

Mineralogy of the epithermal precious and base metal deposit Banská Hodruša at the Rozália Mine (Slovakia)

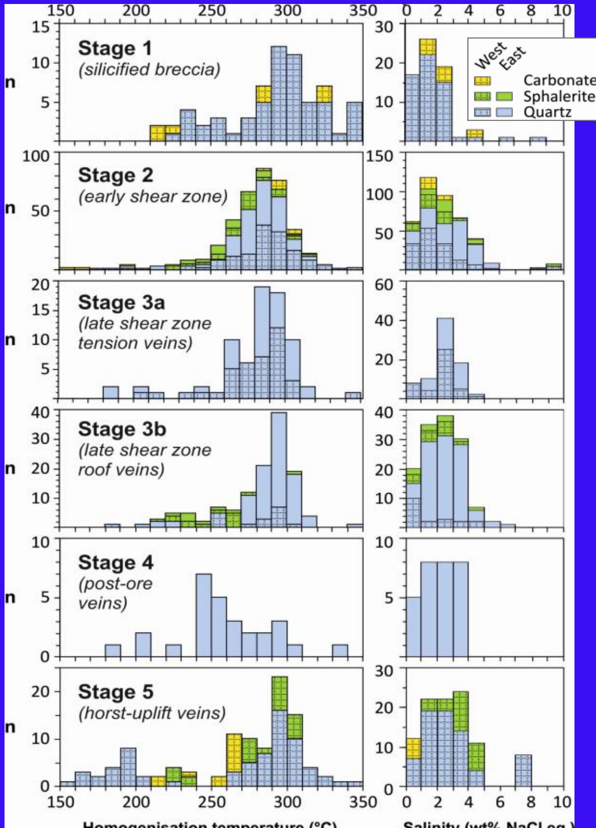
Alexander Kubač[1] · Martin Chovan[2] · Peter Koděra[1] · J. Richard Kyle[3] · Peter Žitňan[4] · Jaroslav Lexa[5] · Rastislav Vojtko[6]

- The ore is hosted by a **shear zone**
- **Paragenetic charts:** 3 types of epithermal ore veins, different structural setting and mineralogy with 3 stages of evolution

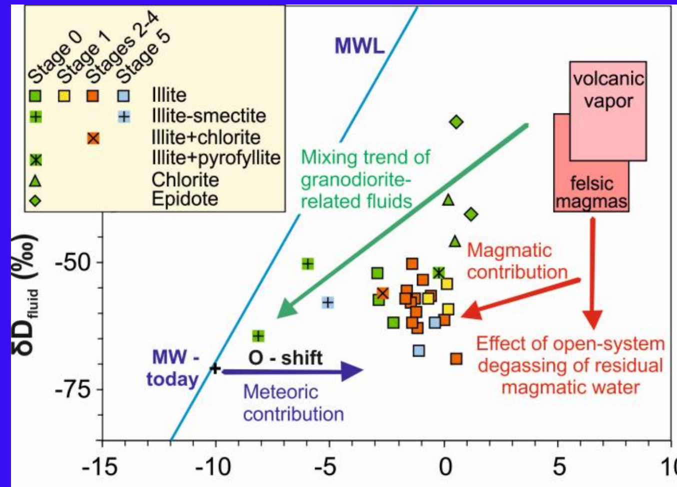


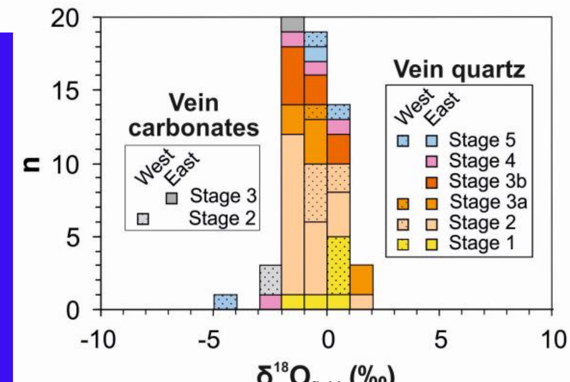


Properties of paleofluids at the Rozália mine



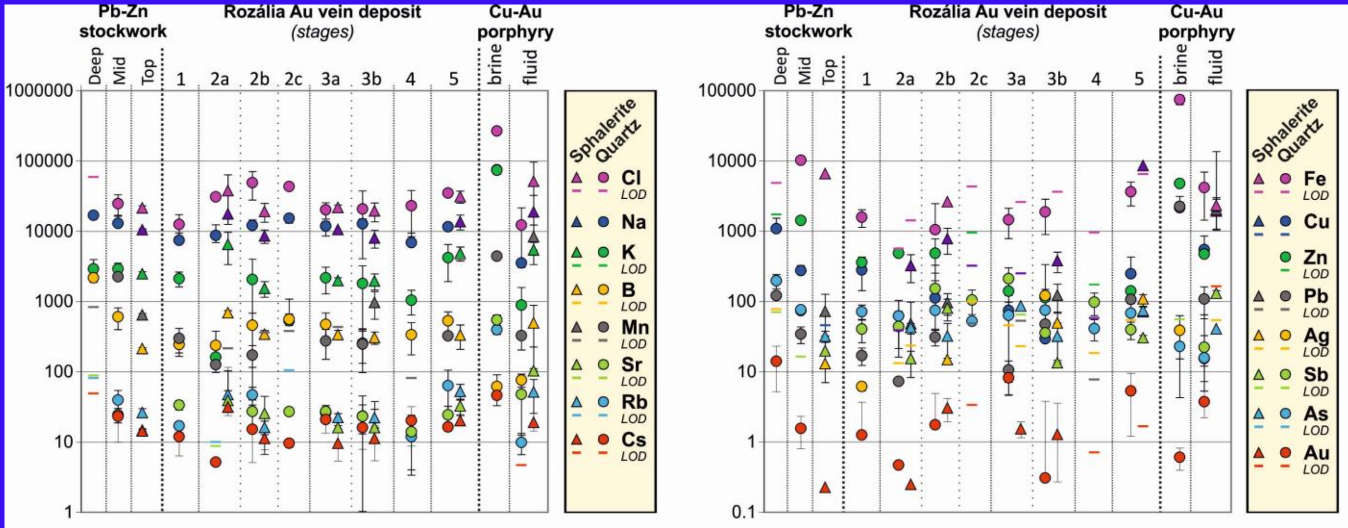
- homogeneous $\delta^{18}O_{fluid}$ of magmatic origin



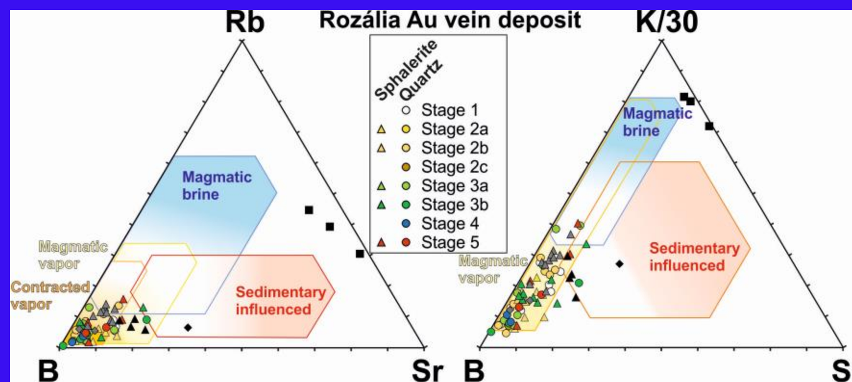


- No apparent differences between stages, neither W and E parts of the deposit

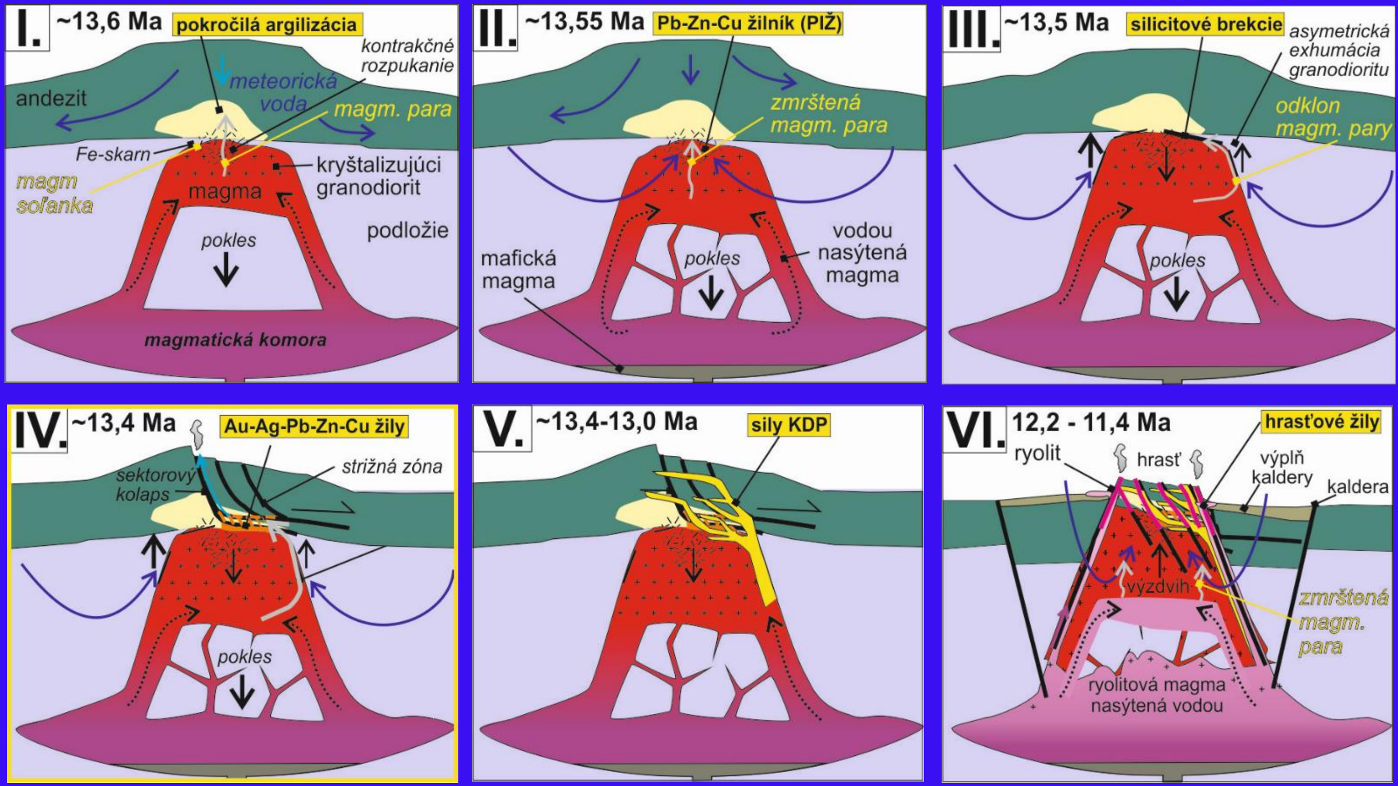
Properties of paleofluids at the Rozália mine (LA ICPMS)



- All deposits and stages have similar composition and **increased B, As, Sb, Cs**
- **Magmatic vapor** exsolved from evolved interstitial melt and **contracted to liquid** during ascent from magma reservoir
- Accumulated fluid was liberated during **periodical tectonic events**

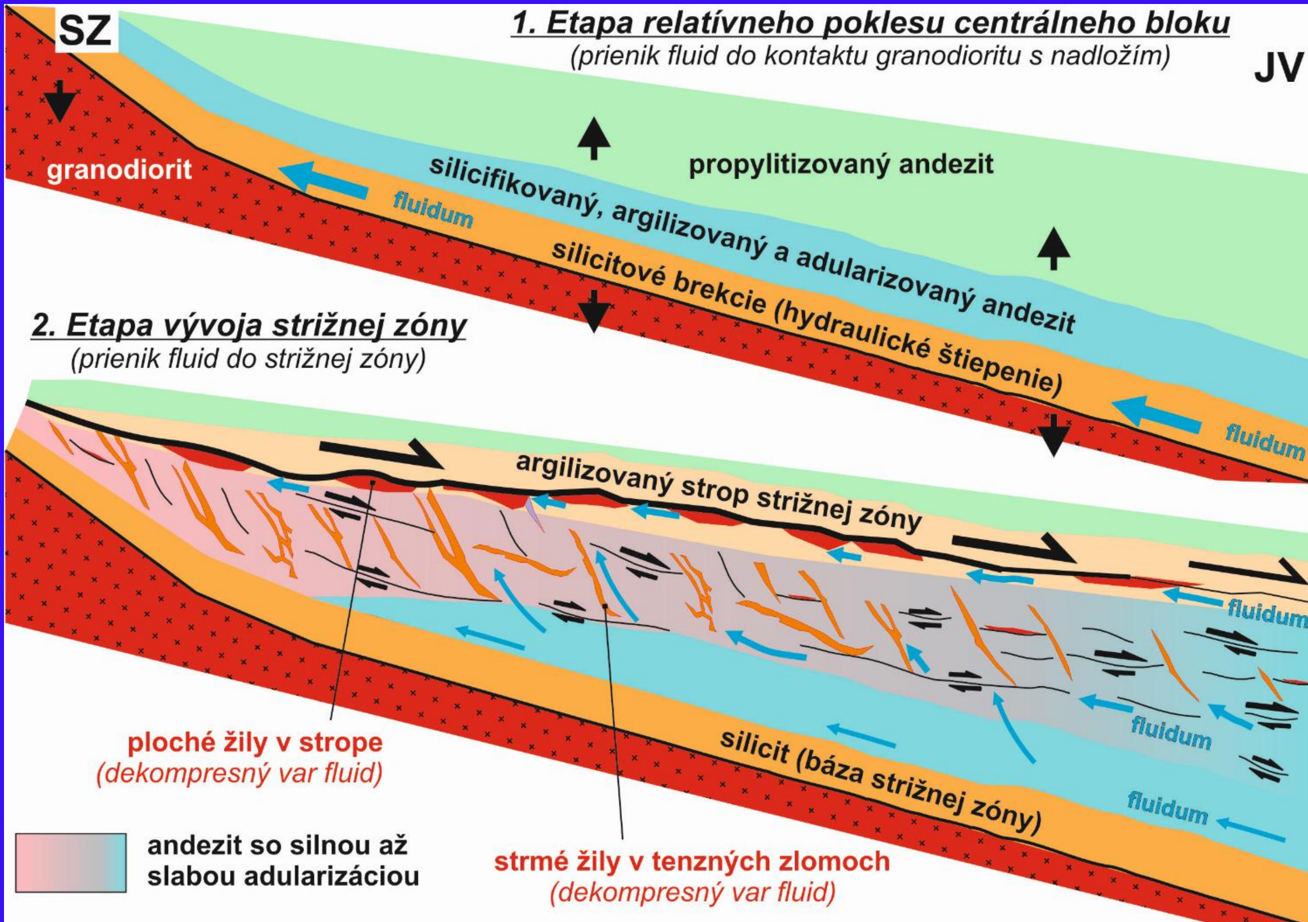


Model of magmatic-hydrothermal evolution of mineralisations at the Rozália mine

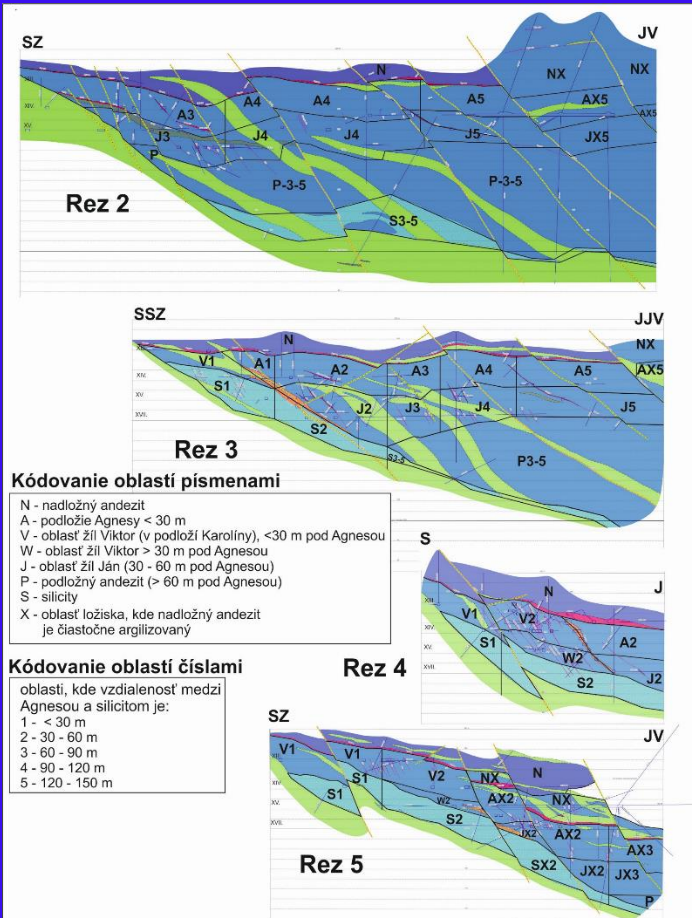


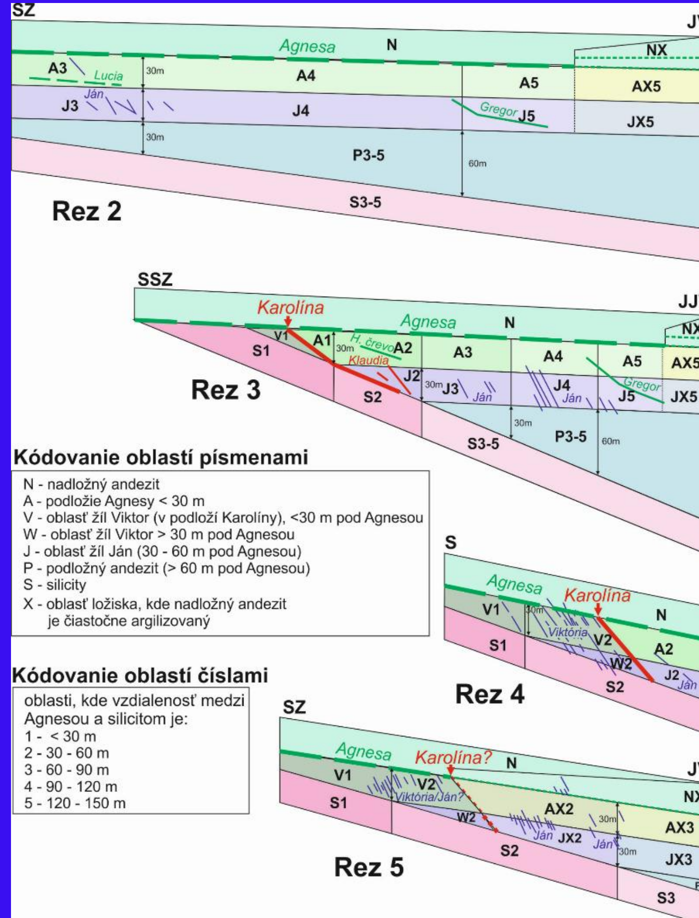
- Au-Ag at Rozália mine is related to **quick uplift of granodiorite and sector collapse of stratovolcano**

Model of shear zone evolution and fluid flow

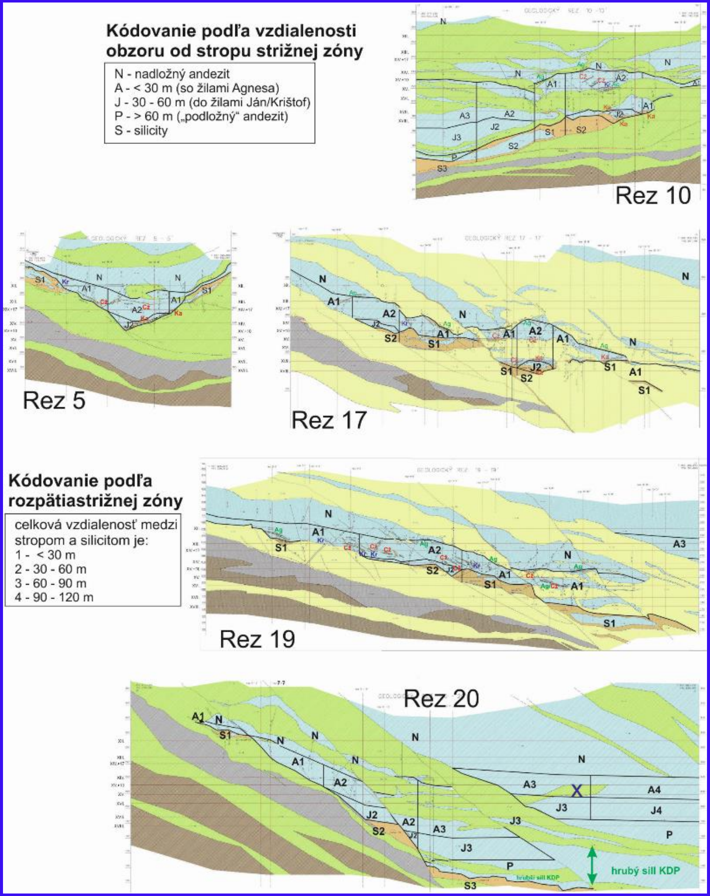


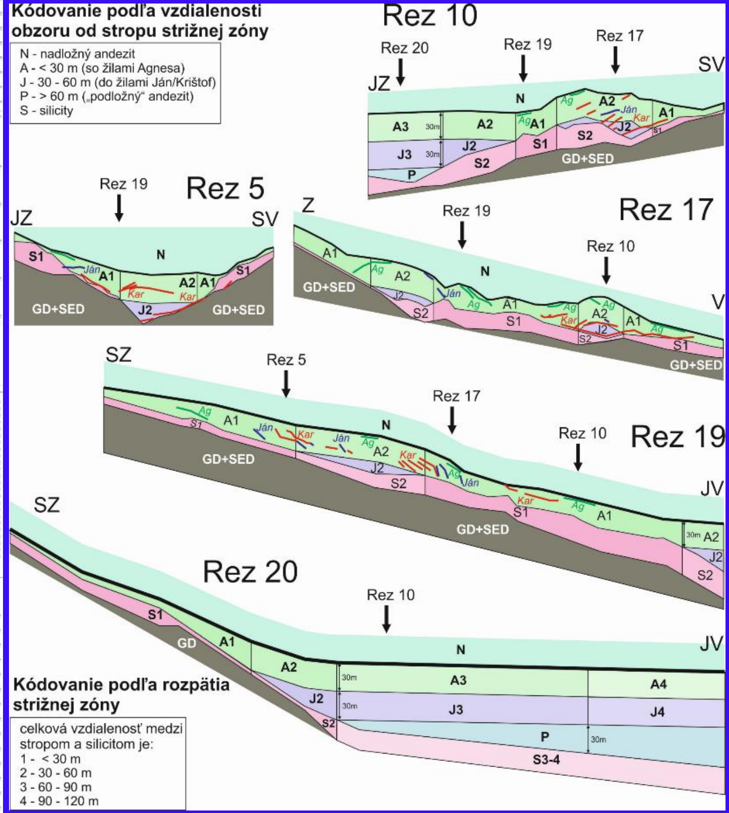
Distribution of zones and vein types in shear zone – eastern deposit





Distribution of zones and vein types in shear zone – western deposit

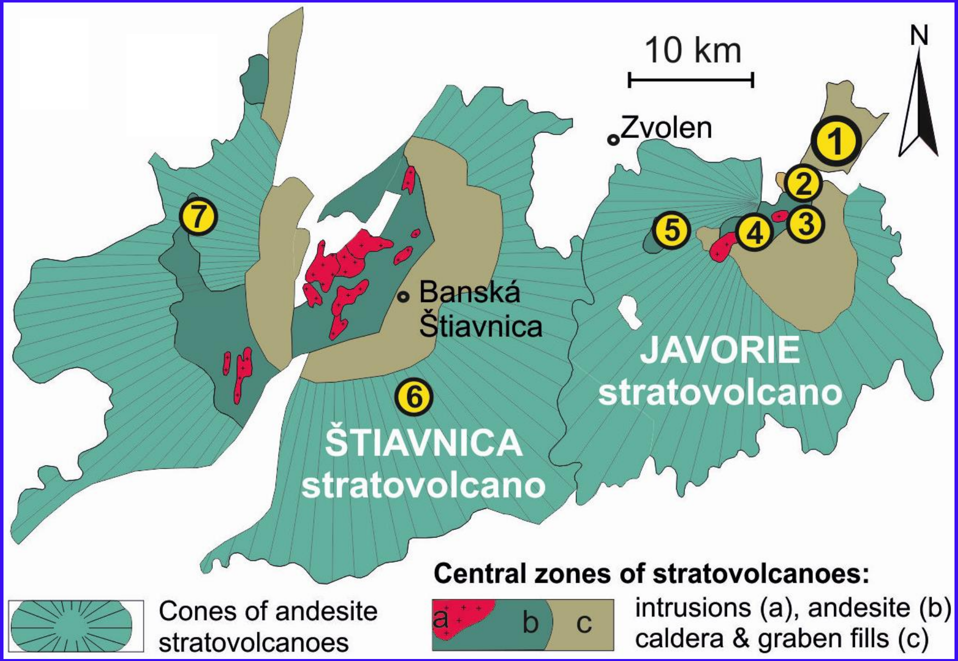




Genéza zlata v Au-porfýrových systémoch

APVV (2010-2015), VEGA (2008-2021)

Au-porphyry systems in the Central Slovakian Neogene Volcanic Field



Deposit

1 – Biely Vrch

Occurrences

2 – Podpolom
3 – Slatinské lazy
4 – Banisko
5 – Kráľová
6 – Beluj
7 – Župkov

- Centered on small **diorite** porphyry stocks
- **Biely Vrch - biggest** and best explored
- **Exceptionally low Cu/Au ratio**

Locality	Resources (Mt)	Au (ppm)	Cu (ppm)	Cu/Au
Biely vrch	140	0.57	178	176
Kráľová	47.8	0.29	456	813
Slat. Lazy	12.5	0.3	243	360
Beluj	58.4	0.2-0.4	250	578

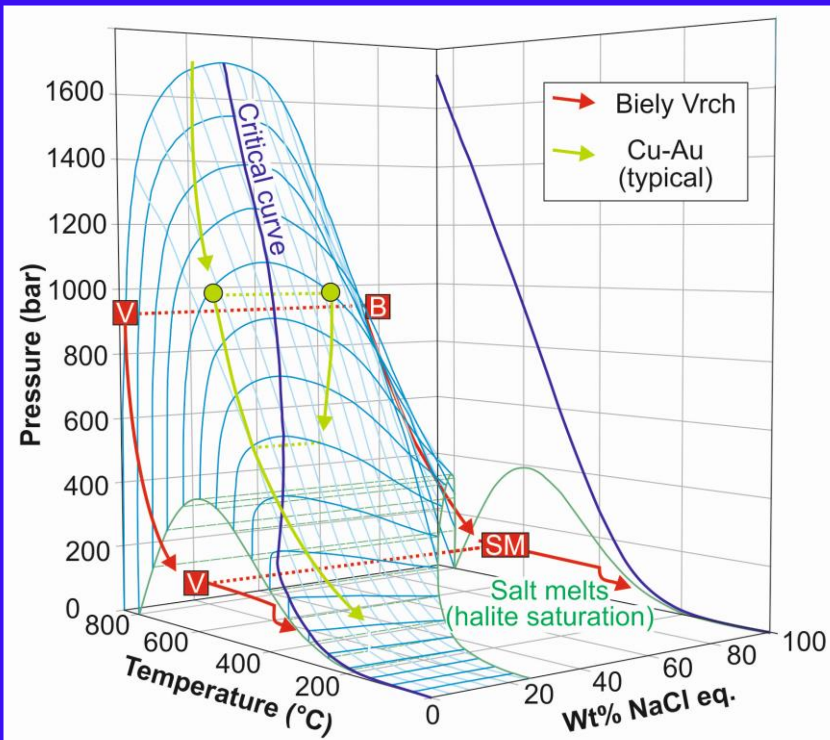
Genesis of the porphyry Au deposit Biely Vrch

- Gold mineralization formed from nearly **anhydrous Fe-K-Na-Cl salt melt**, coexisting with **hydrous vapor of very low density**

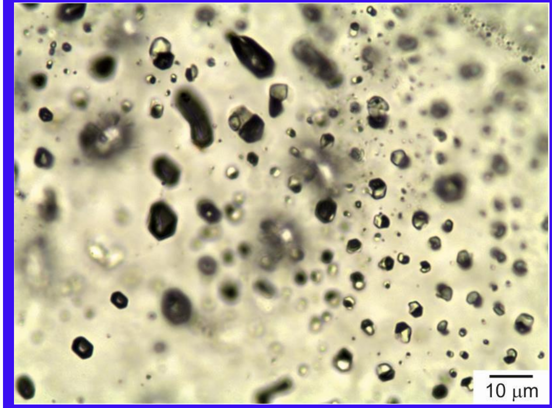
Magmatic salt melt and vapor: Extreme fluids forming porphyry gold deposits in shallow subvolcanic settings

Peter Koděra[1], Christoph A. Heinrich[2], Markus Wälle[2], and Jaroslav Lexa[3]
[1]Department of Geology of Mineral Deposits, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava,

GEOLOGY, June 2014; v. 42; no. 6; p. 495–498; Data Repository item 2014177 | doi:10.1130/G35270.1 | Published online 10 April 2014

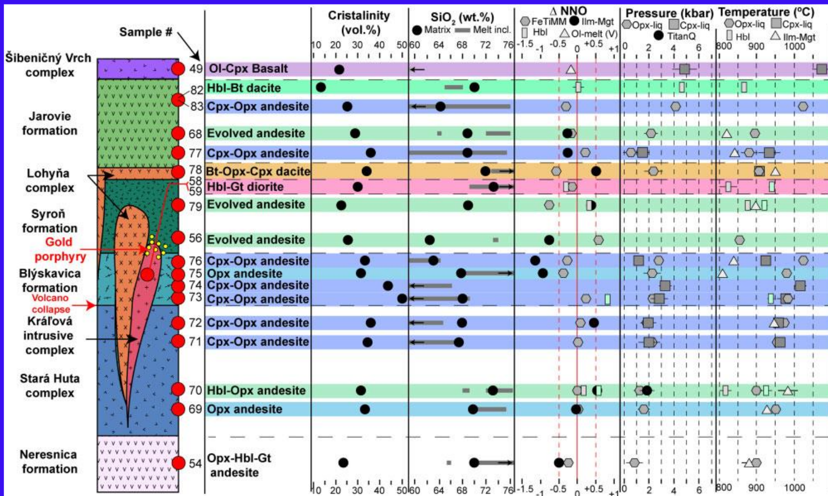


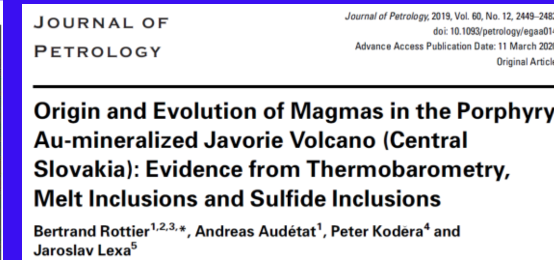
- Low depth of emplacement of magma → low density of vapor (and sulfur fugacity) prevented transport of Au and crystallisation of Cu sulfides



Magmatic evolution in the Javorie stratovolcano

(Rottier et al., 2019)



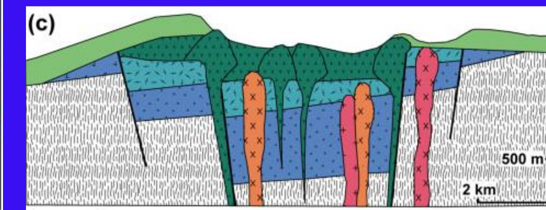


Journal of Petrology

Journal of Petrology, 2019, Vol. 60, No. 12, 2449–2482
doi: 10.1093/petrology/egaa014
Advance Access Publication Date: 11 March 2020
Original Article

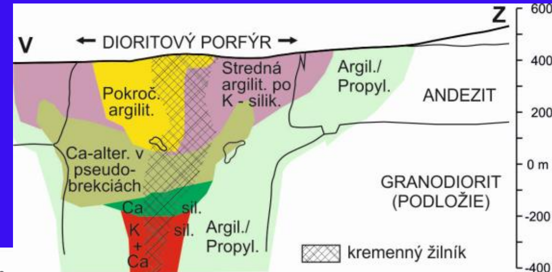
Origin and Evolution of Magmas in the Porphyry Au-mineralized Javorie Volcano (Central Slovakia): Evidence from Thermobarometry, Melt Inclusions and Sulfide Inclusions

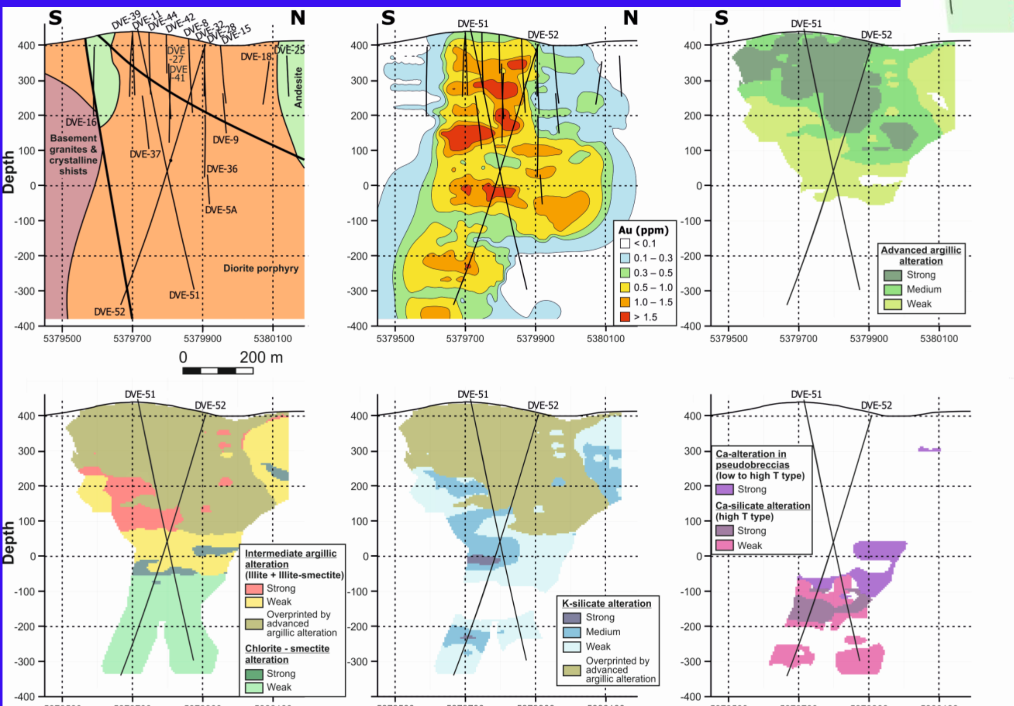
Bertrand Rottier[1,2,3,*], Andreas Audétat[1], Peter Koděra[4] and Jaroslav Lexa[5]



- two levels of magma chambers, sulfide saturated during entire evolution
- **Cu/Au ratios** in magmatic sulfides and predicted in exsolved fluids are up to 100 times higher than in porphyry deposits → **extremely low Cu/Au ratios acquired during hydrothermal stage**
- recent SHRIMP U-Pb dating of the Biely Vrch intrusion (13.53 ± 0.15 Ma)

Hydrothermal alteration & Au distribution - Biely vrch deposit 3D models





- *criteria for the 3D GIS alteration model* → corellation of mineral and chemical composition of rocks

Gold in Au-porphyry systems

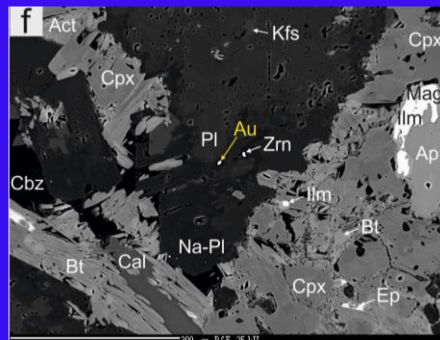

Mineralium Deposita
https://doi.org/10.1007/s00126-018-0798-0
ARTICLE

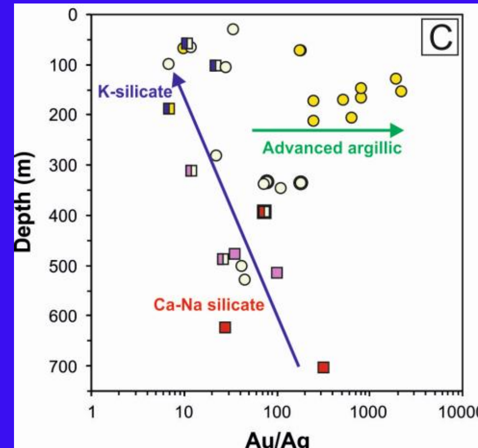
Distribution and composition of gold in porphyry gold systems: example from the Biely Vrch deposit, Slovakia

Peter Koděra[1] · Jaroslav Kozák[1] · Jana Brčeková[1] · Martin Chovan[2] · Jaroslav Lexa[3] · Michal Jánošík[1] · Adrián Biroň[4] · Peter Uhlík[1] · František Bakos[5]

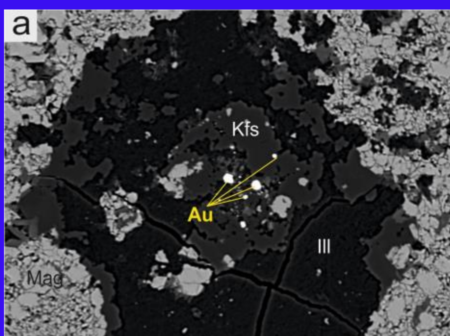
Typical mineral paragenesis

Primary in high T alteration →

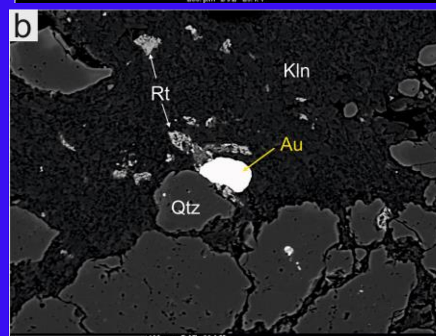




- *Decrease in fineness towards surface* → cooling of ascending fluids
- *Increase in gold fineness in advanced argillic alteration* → partial remobilisation at low pH



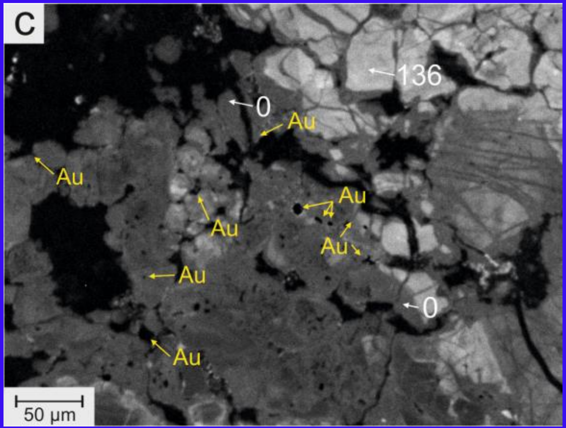
Residual in intermediate alteration

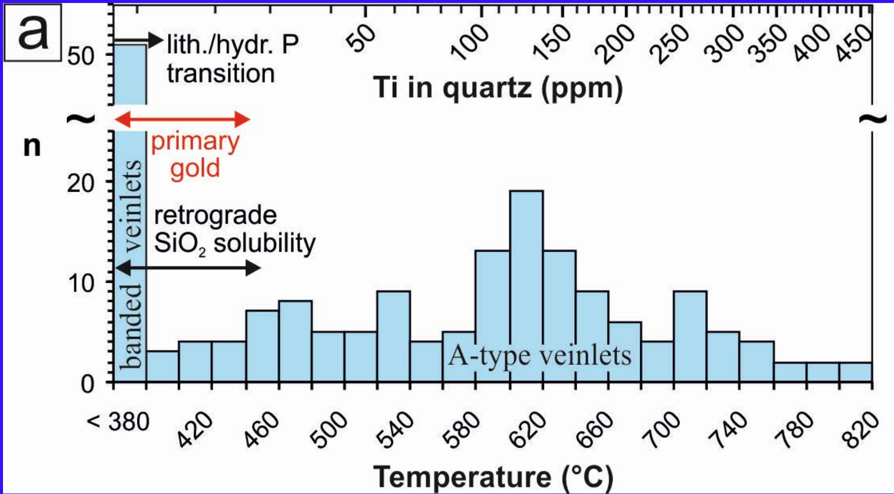


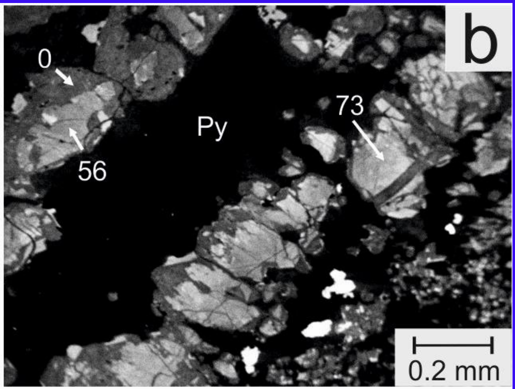
Remobilised in advanced argillic alteration

Temperature of gold precipitation

- **Predominance of gold in altered rock rather than vein quartz** can be explained by **retrograde solubility of quartz** during isobaric cooling from **~450° to 375°C** at low pressure (Fournier, 1985)
- Rare precipitation of **primary gold in vein quartz** occurred at **<380°C** as indicated by the **low Ti content** (<8 ppm) of the quartz



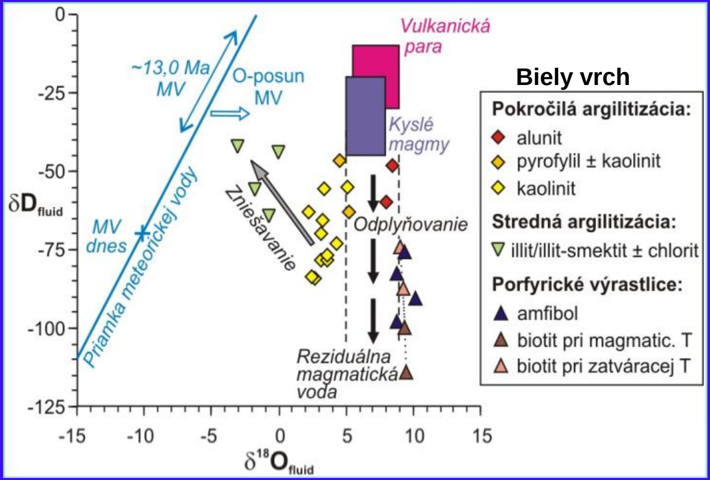


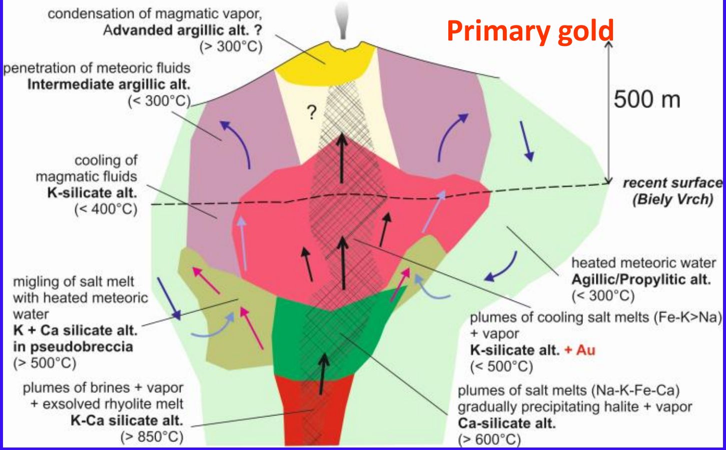


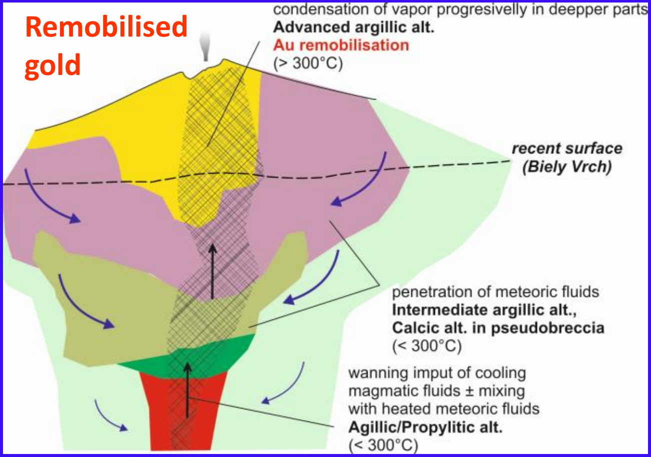
TitaniQ geothermometry
(Thomas et al., 2010)

Genetic model of Au-porphyry systems

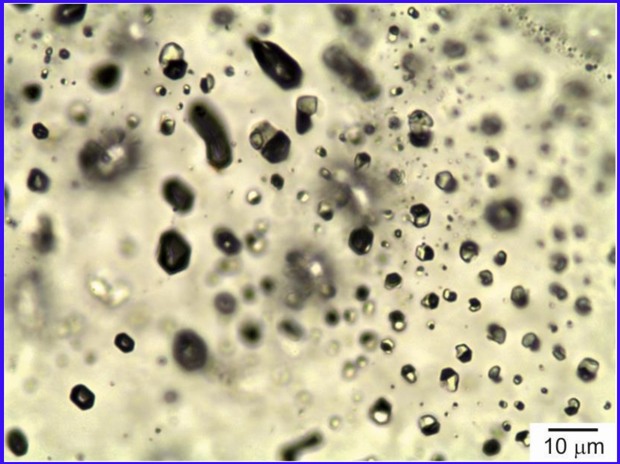
- Synthesis of geological and microanalytical data and 3D models of alteration and mineralisation
- Fluid sources – mostly magmatic (vapor and salt melts), intermediate argillic mostly meteoric



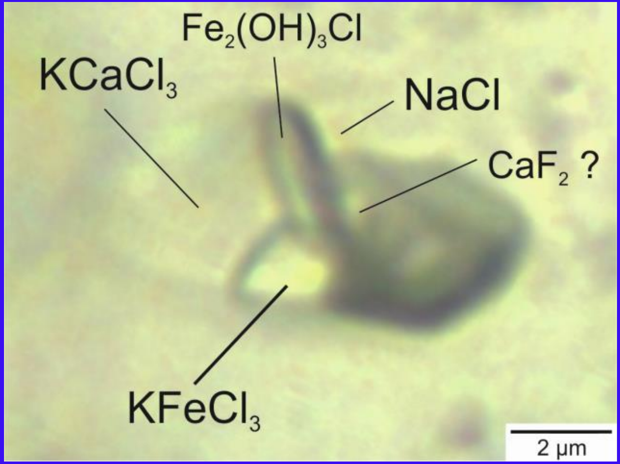


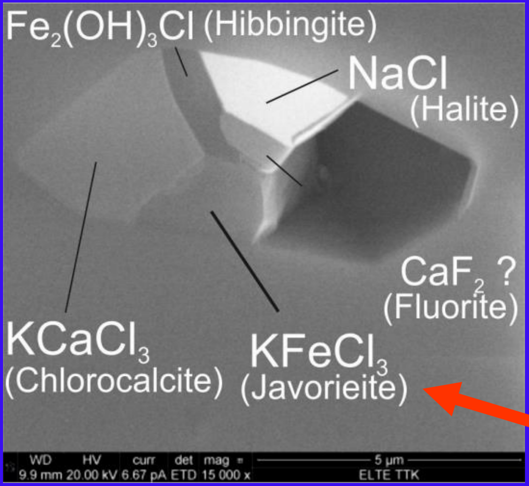


Paleofluids



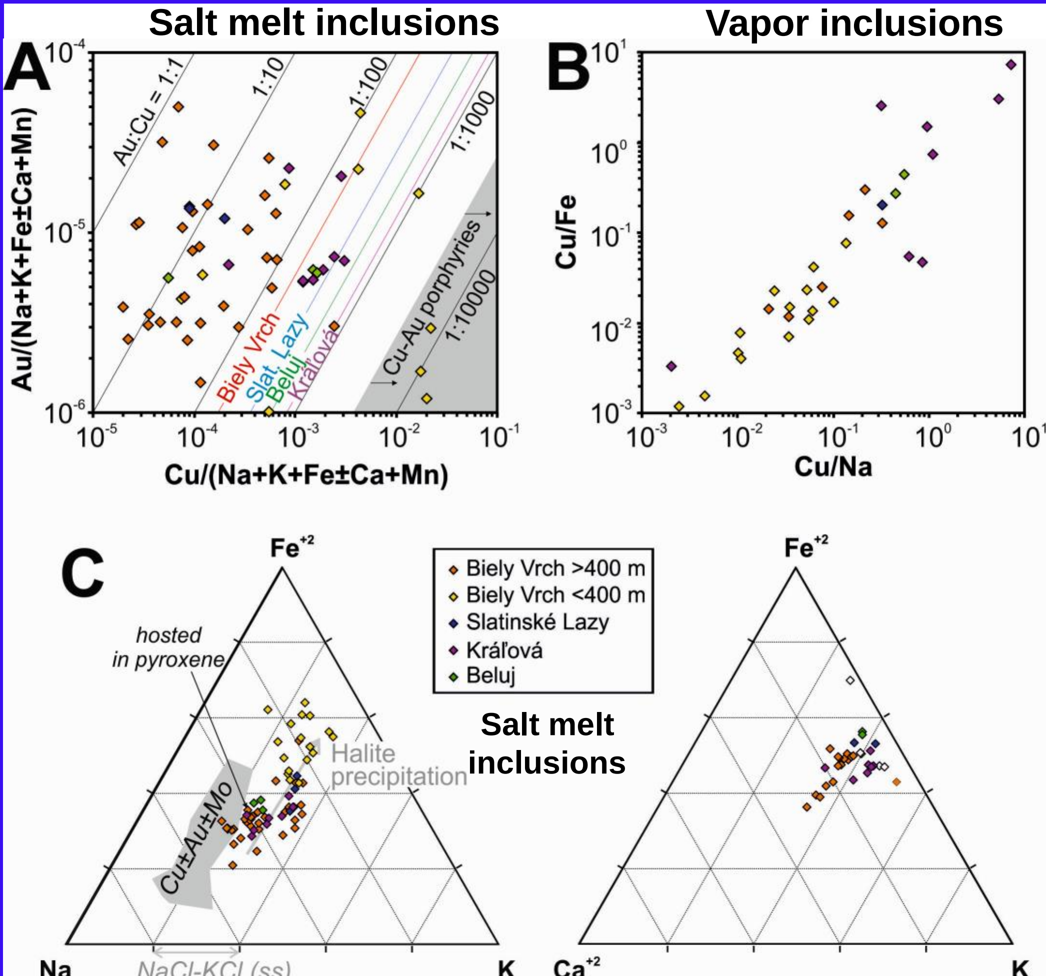
- **Fluid inclusions** in vein quartz (all localities):
  - **Vapor** (most common)
  - **Crystallised salt melts** (mainly in A-type veins, Th>600°C)
  - **Aqueous solutions** (rare, secondary, also in calcite) – related to low-temperature alteration





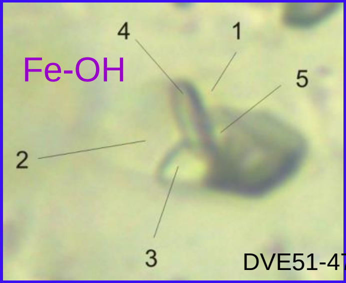
A NEW MINERAL

Composition of paleofluids – LA ICPMS data



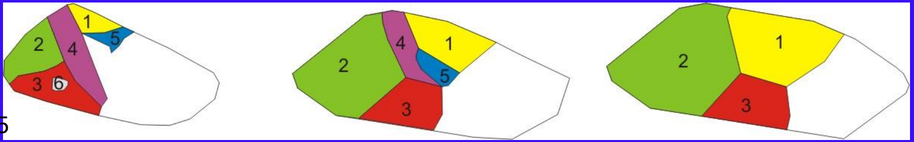
- **Salt melts** have **tens ppm Au** and Cu/Au ratio is lower than in ore
- Deepest parts of B. Vrch (> 400 m) and on other localities the **composition of salt melts is close to Cu-Au-Mo porphyries**
- In shallow parts of B. Vrch (< 400 m) salt melts have **higher content of Fe on the extent of Na**
- **Vapor inclusions** - **inreased Cu,** (xx – xxx ppm Cu), but **without Au and S** → low fS_2 prevented sulfide

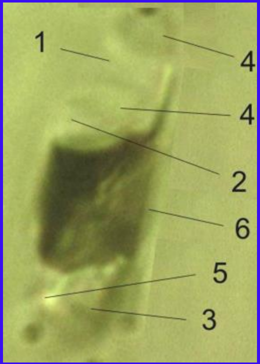
Combined Raman and FIB-SEM-EDX-EBSD-SAED analyses of salt melt inclusions

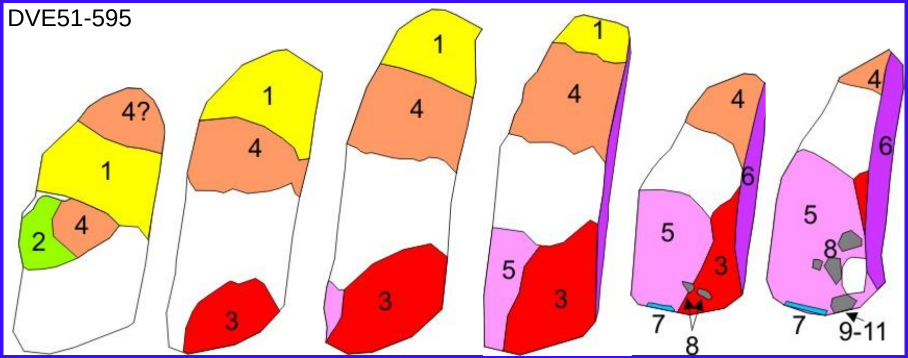


- Phases with the characteristic Raman spectra were exposed to the surface in vacuum by FIB technique

4 - Fe-OH phase

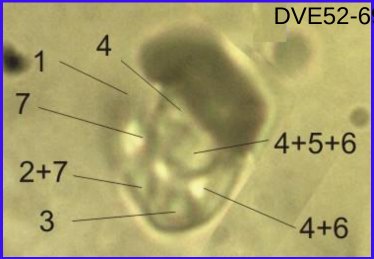


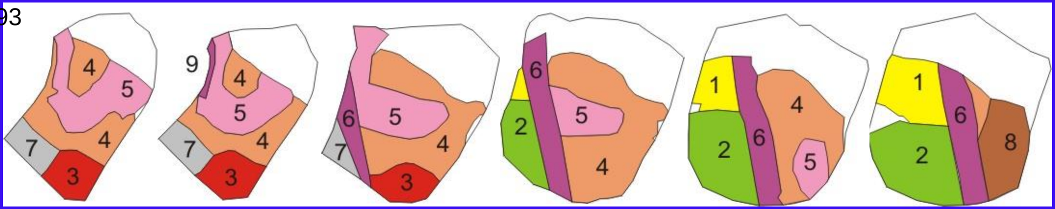




6 - Fe-OH phase

6 - Fe-OH phase





1 – NaCl, 2 – $KCaCl_3$, 3 – $KFeCl_3$, 4 – NaK_3FeCl_6, 5 – K_2FeCl_4

Daughter minerals in salt melt inclusions

Eur. J. Mineral.
2017, **29**, 995–1004
Published online 22 September 2017

Javorieite, $KFeCl_3$: a new mineral hosted by salt melt inclusions in porphyry gold systems

PETER KODĚRA[1,*], ÁGNES TAKÁCS[2], MARTIN RACEK[3], FRANTIŠEK ŠIMKO[4], JARMILA LUPTÁKOVÁ[5], TAMÁS VÁCZI[2,6] and PETER ANTAL[7]

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Identification of anhydrous $CaCl_2$ and $KCaCl_3$ in natural inclusions by Raman spectroscopy

Svetlana Grishina[a], Peter Koděra[b,*], Lucas M. Uriarte[c,d], Jean Dubessy[d], Aleksandr Oreshonkov[e,f], Sergey Goryainov[a], František Šimko[g], Igor Yakovlev[a], Evgenii M. Roginskii[h]

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DOI: 10.1002/jrs.6005
Journal of RAMAN SPECTROSCOPY WILEY

RESEARCH ARTICLE

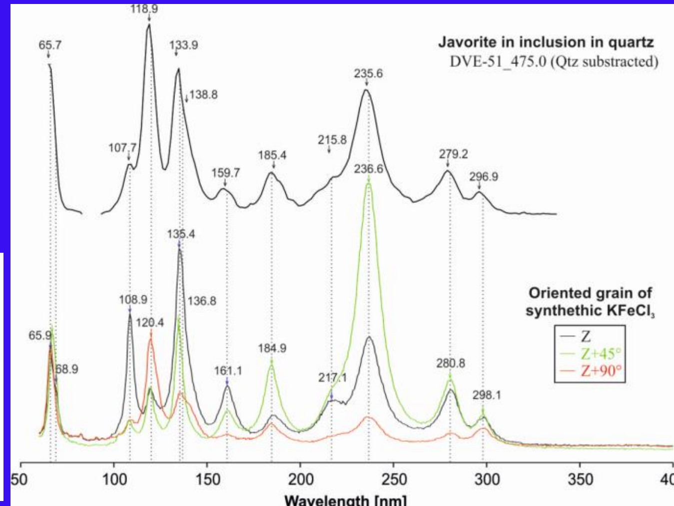
Application of Raman spectroscopy for identification of rinneite ($K_3NaFeCl_6$) in inclusions in minerals

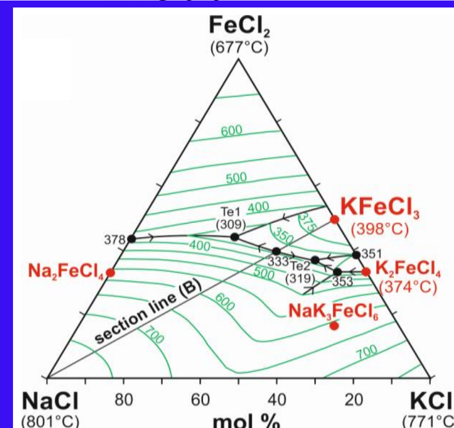
Svetlana Grishina[1] | Peter Koděra[2] | Sergey Goryainov[1] | Aleksandr Oreshonkov[3,4] | Yurii Seryotkin[1,5] | František Šimko[6] | Alexander G. Polozov[7]

Ferrous hydroxychlorides hibbingite (γ-$Fe_2(OH)_3Cl$) and parahibbingite (β-$Fe_2(OH)_3Cl$) as a concealed sink of Cl and H2O in ultrabasic and granitic systems

Peter Koděra, Juraj Majzlan, Kilian Pollok, Stefan Kiefer, František Šimko, Eva Scholtzová, Jarmila Luptáková, and Grant Cawthorn

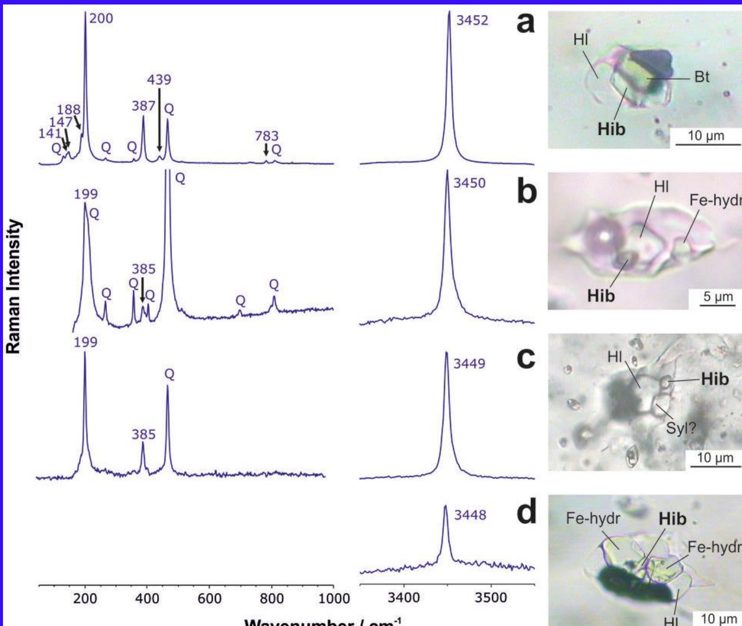
American Mineralogist

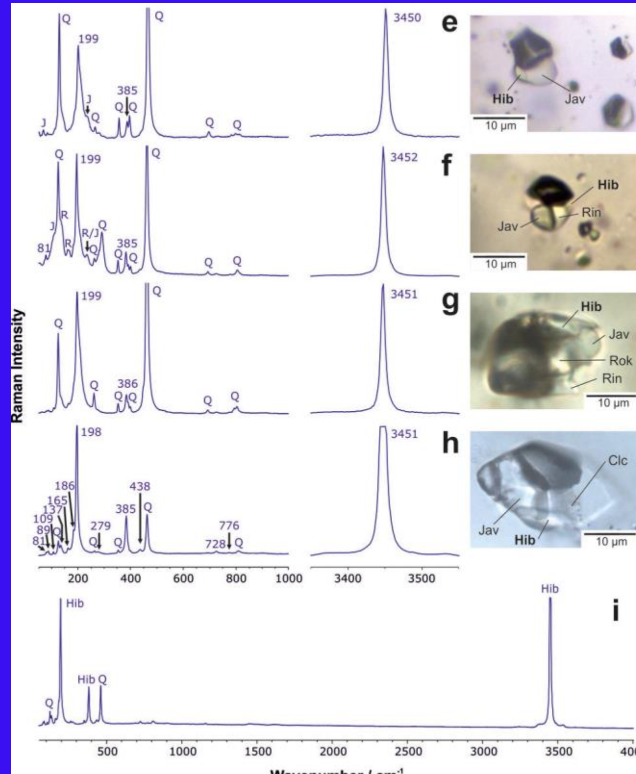




Hibbingite γ-$Fe_2(OH)_3Cl$ in inclusions

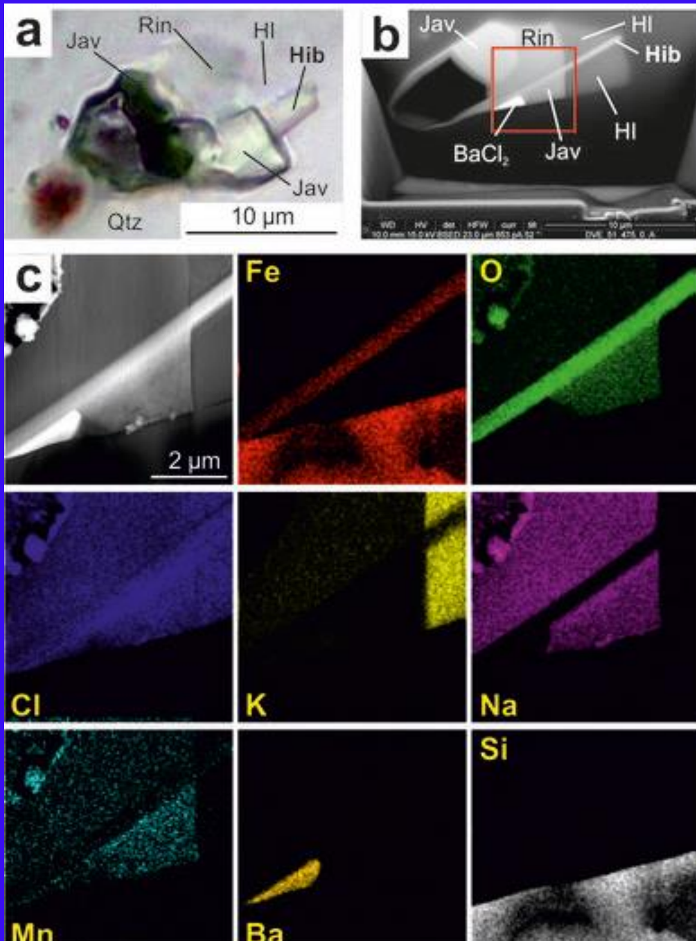
- Hibbingite described from altered mafic intrusives, but not identified in inclusions yet



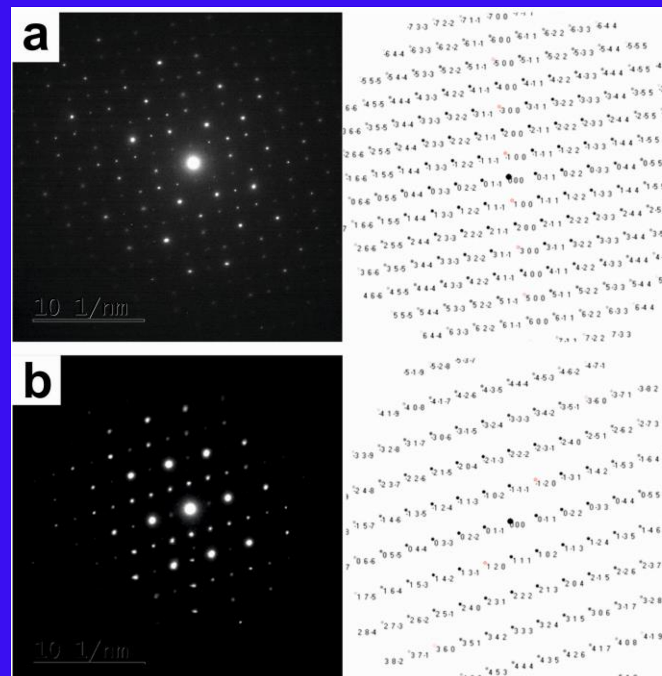


- Distinct Raman spectrum of the mineral – not published yet
- In salt melt inclusion it is the only phase which stores water (OH group)

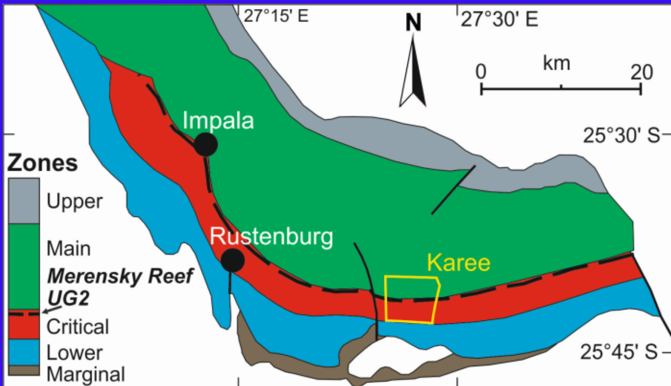
Hibbingite γ-$Fe_2(OH)_3Cl$ in inclusions



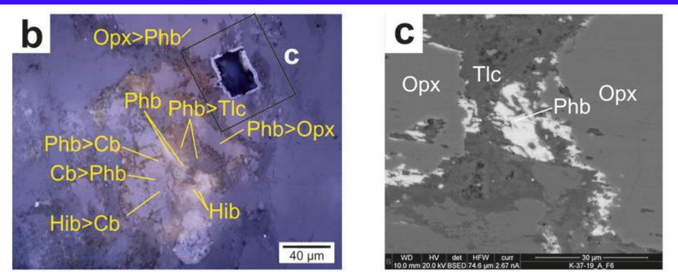
- Hibbingite identified by combination of Raman and FIB-SEM-TEM (TEM-EDX and TEM-SAED)

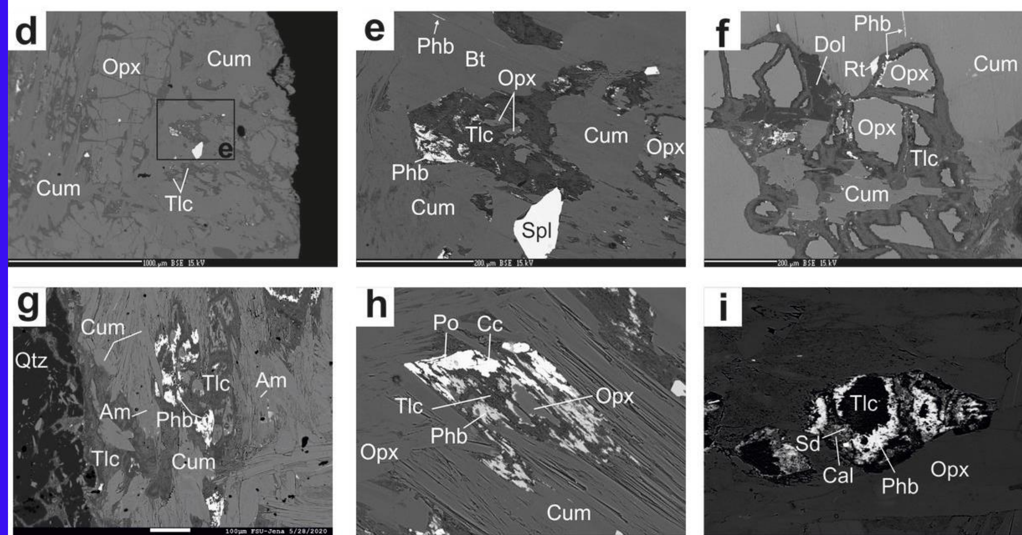


Parahibbingite β-$Fe_2(OH)_3Cl$ – a new mineral



- Parahibbingite found in pyroxenite from the Karee Pt mine in Bushveld Complex, South Africa

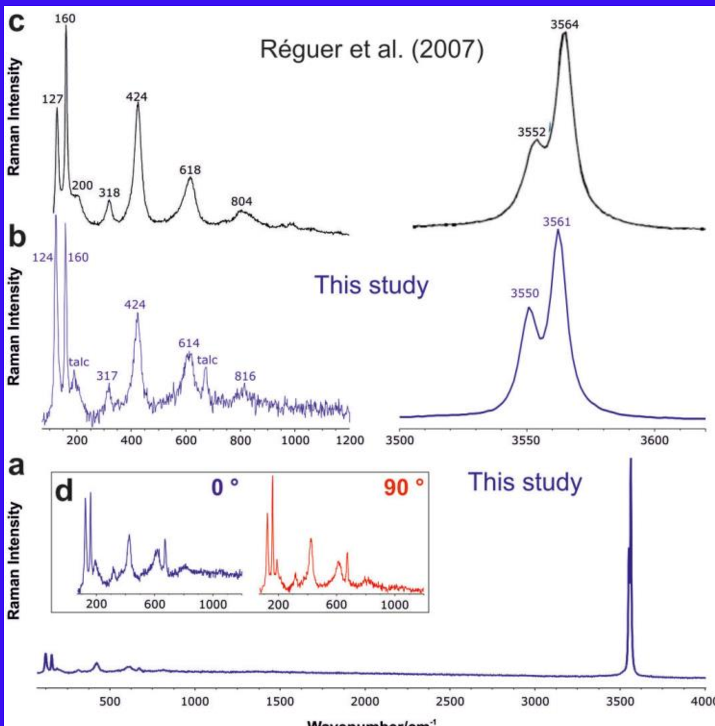


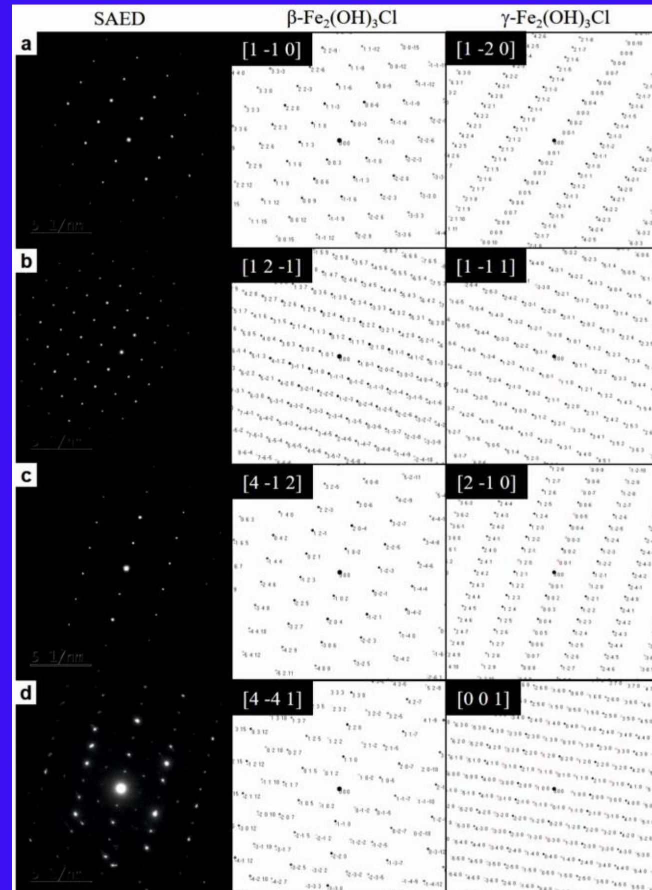


- β-$Fe_2(OH)_3Cl$ often found as a product of corrosion of iron interacting with Cl-rich anoxic brines (in archaeology)

Parahibbingite β-$Fe_2(OH)_3Cl$ – a new mineral

- Parahibbingite identified by combination of Raman and FIB-SEM-TEM (TEM-EDX and TEM-SAED)





Conclusions – future plans

- $BaCl_2$ – a new mineral in salt melt inclusions
- publications on genesis of the Rozália mine
- publications on genesis of the Biely vrch deposit
- publication on perlite genesis
- publication on bentonite genesis
- submitted new APVV project: **Complex model of the W-Mo deposit Ochtiná-Rochovce and environmentally acceptable possibilities of its exploitation**