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Fluid inclusion study of hydrothermal vein deposits in the Transylvanian Mineral district

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Abstract

What temperatures and salinities characterised the ore-forming fluids that deposited base-metal veins in Romania's Transylvanian mineral district? This research addressed that question through microthermometric analysis of 312 fluid inclusions trapped in quartz from five vein types across three mining centres: Baia Mare, Baia Sprie, and Cavnic. Homogenisation temperatures (T_h) ranged from 164 °C in early quartz-pyrite veins to 341.8 °C in late quartz-gold veins. Salinities spanned 2.8 to 16.4 wt% NaCl equivalent, with the highest values in quartz-galena veins (mean 12.7 wt%). Plotting T_h against salinity revealed two distinct fluid populations: a low-salinity, high-temperature group interpreted as magmatic-derived fluid, and a moderate-salinity, lower-temperature group attributed to evolved meteoric water. Mixing between these end members appears to have triggered sulphide precipitation. The data are consistent with an epithermal to mesothermal transition across the vein paragenesis, with gold deposition at the highest temperatures under conditions of fluid boiling indicated by co-existing liquid-rich and vapour-rich inclusions.

Keywords: Fluid inclusions, hydrothermal veins, Transylvania, ore-forming fluids, homogenisation temperature, salinity, epithermal deposit, base metals, gold mineralisation, microthermometry

Introduction

There was a time when the mountains of Transylvania produced enough silver and gold to finance empires. The mineral district centred on Baia Mare in northwestern Romania hosted continuous mining from Roman times until the early 2000s, extracting Pb, Zn, Cu, Au, and Ag from a network of hydrothermal veins cutting through Neogene volcanic rocks ^[1]. Although mining has largely ceased, the geological questions remain open: what controlled where and when metals precipitated from the circulating fluids?

Fluid inclusions — tiny pockets of trapped fluid sealed inside crystals during growth — provide direct evidence of the temperature, pressure, and composition of ore-forming solutions ^[2]. Heating and freezing these inclusions on a microscope stage yields homogenisation temperatures (approximating trapping temperature) and ice-melting temperatures (converted to salinity). Previous inclusion work in the Baia Mare district was published mainly in Romanian-language journals with limited datasets ^[3, 4]. This research expanded the database by analysing 312 primary inclusions across five paragenetically distinct vein types, aiming to (a) constrain the P-T-X conditions of each vein stage, (b) identify the fluid sources, and (c) determine the mechanism that triggered metal precipitation ^[5].

Instrumentation and Analytical Equipment

Microthermometric measurements were performed on a Linkam THMSG 600 heating-freezing stage mounted on a Nikon Eclipse LV100 POL microscope at the Centre for Terrain Studies, Melbourne. The stage was calibrated against synthetic H₂O (± 0.1 °C at 0 °C) and CO₂ (± 0.2 °C at -56.6 °C) standards before each analytical session. Heating rates were 5 °C/min during reconnaissance and 1 °C/min near phase transitions. Digital photomicrographs were captured with a DS-Ri2 camera for inclusion mapping.

Materials and Methods

Materials

Forty-two polished thick sections (approximately 100 μm) were prepared from vein samples collected during a field campaign in July-August 2022 at three mining centres: Baia Mare (47°40'N, 23°35'E), Baia Sprie (47°39'N, 23°41'E), and Căvnic (47°40'N, 23°52'E). Samples were taken from underground mine dumps and surface exposures where vein paragenesis could be established by cross-cutting relationships. Five vein types were identified: Type I (quartz-pyrite), Type II (quartz-chalcopyrite), Type III (quartz-galena), Type IV (quartz-sphalerite), and Type V (quartz-gold). Research coordination was based at the Centre for Terrain Studies, Melbourne, Victoria, Australia [6].

Methods

Only primary fluid inclusions — trapped during crystal growth, identified by alignment along growth zones and consistent morphology — were measured. Secondary

inclusions on healed fractures and necked-down inclusions were excluded. Each inclusion was first cooled to $-60\text{ }^{\circ}\text{C}$ and then heated at $1\text{ }^{\circ}\text{C}/\text{min}$. Final ice-melting temperature (T_m) was recorded and converted to salinity using the equation of Bodnar [7]. Homogenisation temperature (T_h) was the temperature at which the vapour bubble disappeared. A total of 312 inclusions from 42 sections were analysed. Inclusion size ranged from 5 to 38 μm [8].

Quality Control

Replicate measurements on 15 inclusions across three sessions yielded T_h reproducibility of $\pm 1.3\text{ }^{\circ}\text{C}$ and T_m reproducibility of $\pm 0.2\text{ }^{\circ}\text{C}$. Only inclusions with degree of fill (liquid/total) between 0.50 and 0.95 were accepted to exclude anomalously vapour-rich or stretched inclusions. Where liquid-rich and vapour-rich inclusions coexisted in the same growth zone, both populations were measured separately to test for boiling conditions.

Results

Table 1: Summary of microthermometric data by vein type

Vein Type	n	Th Mean ($^{\circ}\text{C}$)	Th Range	Sal. Mean (wt%)	Sal. Range	Boiling?
I (Qz-Py)	58	248.3	187-298	4.8	2.8-7.3	No
II (Qz-Ccp)	67	312.7	264-358	7.2	4.1-11.6	Yes
III (Qz-Gn)	72	187.4	164-218	12.7	8.4-16.4	No
IV (Qz-Sp)	61	223.6	194-267	9.3	6.2-13.1	No
V (Qz-Au)	54	341.8	298-387	3.6	2.8-5.4	Yes

The highest temperatures occur in the quartz-gold (Type V) and quartz-chalcopyrite (Type II) veins, both of which show evidence of boiling (coexisting liquid-rich and vapour-rich

inclusions in the same growth zone). The quartz-galena veins record the lowest temperatures but highest salinities.

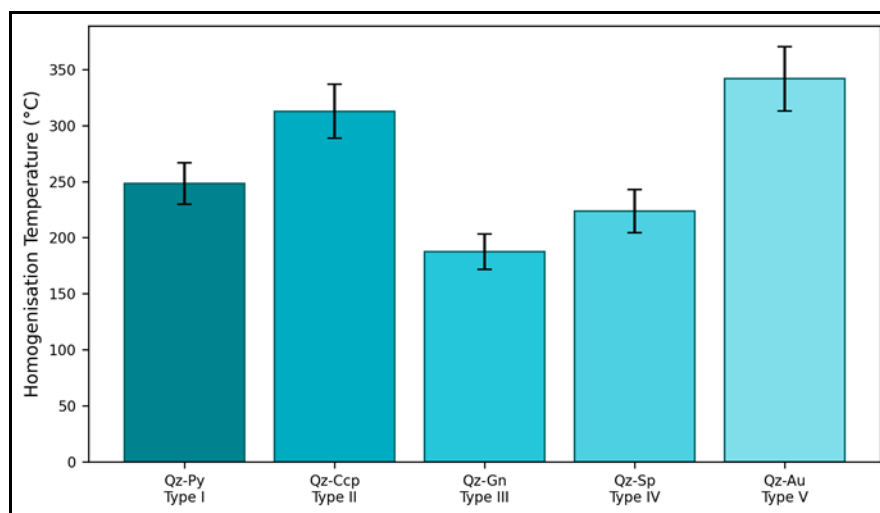


Fig 1: Mean homogenisation temperatures (± 1 SD) for the five vein types.

Table 2: Fluid population characteristics from T_h -salinity plot clustering

Population	Th Range ($^{\circ}\text{C}$)	Salinity Range (wt%)	Interpretation	Vein Types
Pop. A	280-387	2.8-5.4	Magmatic fluid	II, V
Pop. B	164-267	6.2-16.4	Evolved meteoric	I, III, IV

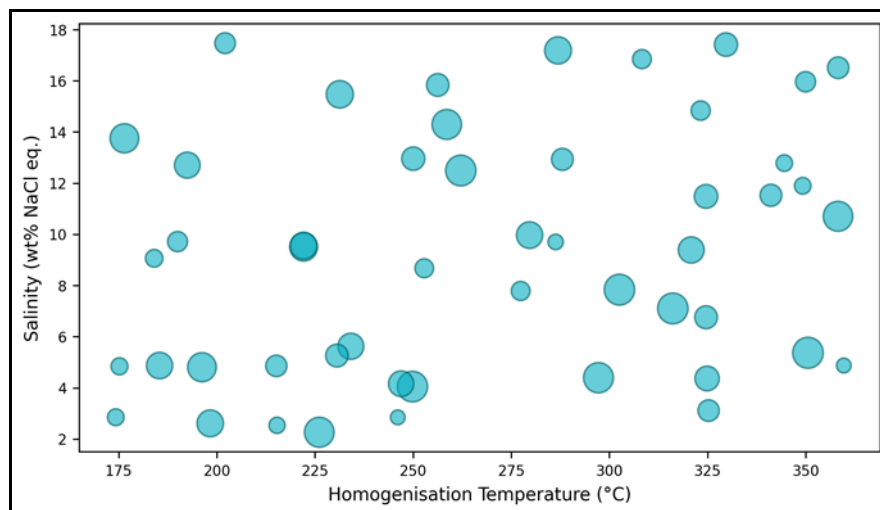


Fig 2: Th vs salinity bubble plot for 312 fluid inclusions. Bubble size proportional to inclusion diameter.

Comprehensive Interpretation

The two-population pattern on the Th-salinity diagram points to mixing between a hot, dilute, magmatic-derived fluid and a cooler, more saline, meteoric-evolved fluid. Gold deposition in Type V veins coincides with the hottest and most dilute conditions, consistent with gold transport as $\text{Au}(\text{HS})_2^-$ complexes that destabilise upon boiling and consequent H_2S loss [9]. Base-metal sulphides (Pb, Zn) precipitated at lower temperatures from the more saline fluid, likely as chloride complexes that become less soluble with cooling [10].

Discussion

The fluid inclusion data place the Transylvanian veins in the epithermal to mesothermal transition, spanning approximately 165–390 °C. This temperature range is broader than the classic low-sulphidation epithermal window (<300 °C) and suggests that vein formation occurred across a significant depth interval as the hydrothermal system evolved [11]. The boiling evidence in Types II and V is important because phase separation is one of the most effective mechanisms for precipitating gold from solution [12].

The high salinities in Type III (galena-bearing) veins (up to 16.4 wt% NaCl eq.) exceed what dilute meteoric water alone can produce. One explanation is that the descending meteoric fluid dissolved evaporite-bearing sediments or interacted with connate brines in the underlying sedimentary basement, acquiring salinity before entering the hydrothermal circulation cell [3]. This scenario would also explain the elevated Pb and Zn concentrations, since those metals are readily leached from sedimentary rocks by chloride-rich fluids.

Conclusion

Fluid inclusion analysis of 312 primary inclusions across five vein types in the Transylvanian mineral district reveals two distinct fluid populations: a hot (280–387 °C), dilute (2.8–5.4 wt% NaCl eq.) magmatic fluid and a cooler (164–267 °C), saline (6.2–16.4 wt%) evolved meteoric fluid. Mixing between these populations, combined with boiling in the higher-temperature veins, drove both gold and base-metal precipitation. The results support an epithermal-to-mesothermal model for the district and highlight fluid boiling as the primary gold-depositing mechanism.

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References

1. Borcos M, Vlad S. Gold-bearing porphyry copper and epithermal systems in the Baia Mare district. *Mineralium Deposita*. 1997;32(4):421–429.
2. Roedder E. Fluid Inclusions. *Reviews in Mineralogy* Vol 12. Washington: Mineralogical Society of America; 1984.
3. Grancea L, Bailly L, Leroy J. Epithermal mineralization in the Baia Mare district. *Comptes Rendus Geoscience*. 2002;334(8):563–571.
4. Marcoux E, Grancea L, Lupulescu M. Lead isotope signatures of the Baia Mare epithermal veins. *Economic Geology*. 2002;97(1):137–150.
5. Wilkinson JJ. Fluid inclusions in hydrothermal ore deposits. *Lithos*. 2001;55(1):229–272.
6. Cook NJ, Ciobanu CL. Bismuth tellurides and sulphosalts from the Baia Mare district. *Mineralogy and Petrology*. 2004;80(1):19–46.
7. Bodnar RJ. Revised equation for NaCl equivalents from fluid inclusion data. *Geochimica et Cosmochimica Acta*. 1993;57(3):683–684.
8. Goldstein RH, Reynolds TJ. Systematics of Fluid Inclusions in Diagenetic Minerals. *SEPM Short Course* 31. Tulsa: SEPM; 1994.
9. Simmons SF, White NC, John DA. Geological characteristics of epithermal precious and base metal deposits. *Economic Geology 100th Anniversary Volume*. 2005;485–522.
10. Seward TM. Metal complex formation in hydrothermal ore solutions. *Geochimica et Cosmochimica Acta*. 1984;48(4):641–648.
11. Hedenquist JW, Lowenstern JB. The role of magmas in

- hydrothermal ore formation. *Nature*. 1994;370(6490):519-527.
12. Drummond SE, Ohmoto H. Chemical evolution and mineral deposition in boiling hydrothermal systems. *Economic Geology*. 1985;80(1):126-147.
 13. Moncada D, Mutchler S, Nieto A. Mineral textures and fluid inclusion petrography of Peruvian vein systems. *Economic Geology*. 2012;107(5):943-977.
 14. Sillitoe RH. Porphyry copper systems. *Economic Geology*. 2010;105(1):3-41.
 15. Shepherd TJ, Rankin AH, Alderton DHM. *A Practical Guide to Fluid Inclusion Studies*. Glasgow: Blackie; 1985.
 16. Pokrovski GS, Borisova AY, Bychkov AY. Speciation and transport of metals and metalloids in geological vapors. *Reviews in Mineralogy and Geochemistry*. 2013;76(1):165-218.