

Epithermal Ag-Au mineralization at Galim-Legalgorou, Cameroon Volcanic Line: evidence from ore mineralogy and electrum microchemistry

Terence C. Ngang

Institute of Applied Mineralogy and Economic Geology (IML), RWTH Aachen University, Germany

Summary

Galim-Legalgorou is a hub of extensive artisanal gold mining. However, there exists no literature describing the style and origin of the mineralization. The association of the mineralization with tertiary volcanic rocks raises the question of whether or not it is an epithermal system in a region dominated by orogenic gold deposits. In this contribution, we present the first dataset on ore mineral assemblages, and electrum microchemistry of this mineralization, in a bid to constrain its origin and evolution. Pyrite and sphalerite±galena, electrum, acanthite and Ti-magnetite are the major ore minerals observed ore samples in hand specimens and thin section. Electrum composition is characterized by the suite Au-Ag-Bi-Hg-Te with Au (44.35 wt%) and Ag (53.1 wt%) being the major alloy components. The presence of acanthite, hydrothermal breccia, the very low gold fineness (455) and high Ag contents of electrum are all consistent with characteristics of epithermal Ag-Au occurrences around the world.

Key words: Cameroon volcanic line, epithermal Ag-Au mineralization, Galim-Legalgorou, electrum microchemistry, breccia.

Theory, methods and workflow

Galim-Legalgorou district (**Fig 1**) is part of an emerging metallogenic province in north Cameroon with active gold exploration as well as extensive hard-rock artisanal mining by locals. Despite the exploration and artisanal mining, there is no published literature on the nature, occurrence and classification of the gold mineralization in this district. Preliminary field data and recent updated geological map of Cameroon shows that the district is largely underlain by volcanic rocks of the Cameroon Volcanic Line (CVL), and that the mineralization is hosted by these volcanic rocks.

Electrum grains were obtained by crushing and panning about 70 kg of ore from the Morgue, Akouri and Koutouri artisanal mining pits in the weathered zone of the mineralization. This study makes use of 55 electrum grains and 2 mineralized core samples from Galim-Legalgorou. Mineralized zones of core samples were cut, embedded in epoxy, polished and observed in reflected light on a LEICA-DM4500-P polarizing microscope and Electron microprobe analyzer (EMPA) at the Institute of Applied Mineralogy and Economic Geology (IML), RWTH Aachen University, Germany.

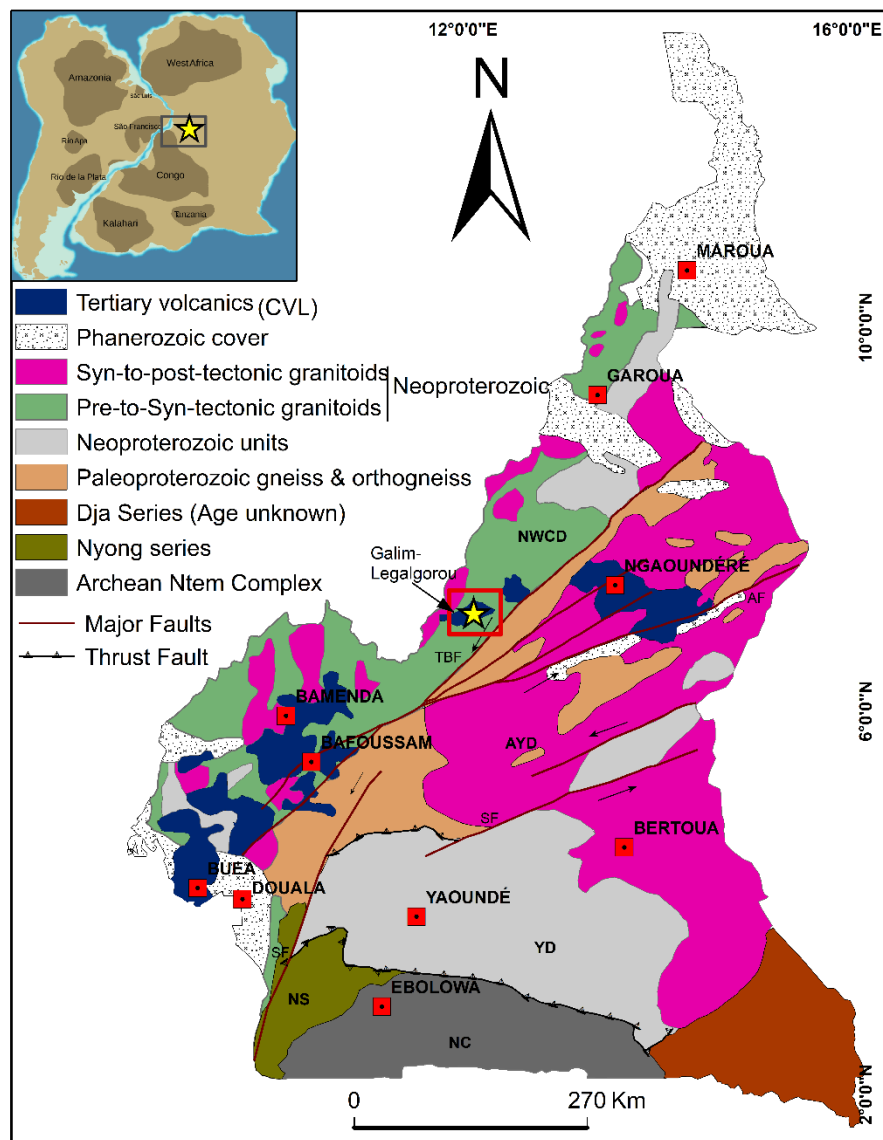


Fig. 1. Geologic map of Cameroon, showing the location of study area (yellow star in red square) on the Cameroon volcanic line (CVL). Figure modified Toteu *et al.* (2001).

The heavy mineral concentrate containing electrum was embedded in epoxy, polished and principally analyzed by SEM and EMPA for morphological and chemical composition, respectively. Quantitative data as well as elemental maps were obtained by Wavelength dispersive spectrometry in JXA-iSP100 JEOL Super probe at an accelerating voltage of 25.0 kV and a current of 2.8×10^{-8} A for all elements.

Results, Discussion and Conclusions

Electrum (El), pyrite (Py), sphalerite (Spl), galena (Gn), Ti-magnetite (Mt), acanthite (Aca), goethite (Gth), and specular hematite (hem) constitute the hydrothermal ore mineral phases in the mineralization. It should be noted that Py, Spl, Gn and Au-bearing rutile were only observed in the fresh ore while El, Aca, Mt, Gth and Hem were only observed in the weathered ore samples (heavy mineral concentrate). The term ‘electrum’ is used here to denote any naturally occurring particle, composed essentially of Ag (>20 wt%) and gold (<80 wt%). In the fresh ore, pyrite is disseminated deep within the hydrothermally altered host rock fabric and also occupies healed micro-fractures, maintaining a close spatial relationship with quartz and dickite. Sphalerite occurs both as inclusions (exsolutions) in pyrite and also fills voids and fractures within the rock matrix, while galena is observed exclusively as tiny inclusions in pyrite. The rutile phase occurs within quartz and dickite-healed microfractures. Acanthite occurs as inclusions in electrum and frequently shows significant Se (7.97%) and TI (2.24%) impurities in its composition. The mineral also occurs as a separate phase in the heavy mineral concentrate.

A total of fifty-five electrum grains from the concentrate were analyzed in this study. In polished sections, most grains show irregular, elongated to kidney shapes with bent or folded edges in reflected light photomicrographs (**Fig 2**) and define a wide size range between 20- μ m and 514- μ m. Many grains are physically heterogenous and show primary rim to core zonation. The boundary between the Ag-rich rims and Au-rich cores is gradational with an almost fifty-fifty Au-Ag distribution.

Electron microprobe data (Table 1) show that electrum contains several minor elements in addition to Au (36.85-70.59 wt%) and Ag (27.31-60.67 wt%), with Bi (0.08-0.54 wt%), Hg (0.39-1.05 wt%), Te (0.06-0.19 wt%) being the most significant. In summary, the average elemental concentrations and respective standard deviations (SD) in electrum are as follows; Ag (53.26 wt%; 6.65 SD), Au (44.38; 6.64 SD), Bi (0.29 wt%; 0.07 SD), Hg (0.67 wt%; 0.14 SD) and Te (0.12 wt%; 0.02 SD). Ag shows the strongest effect on the data, correlating negatively with Au, Bi and Hg, but positively with Zn, S and Te Conversely, Au is observed to show positive correlations with Bi and Hg, a strong negative correlation with Ag, and no correlation at all with Z, S, or Te

Table 1. Microchemistry (wt %) of representative electrum particles from Legalgorou.

| Analysis | Grain No | Zone | Bi | Ag | Te | Hg | Au | Total | Fineness |
|----------|----------|------------|------|-------|------|------|-------|-------|----------|
| 1 | G1-1 | Au-core | 0.33 | 45.70 | 0.07 | 0.78 | 51.86 | 98.69 | 531.6 |
| 2 | zoned | Au-core | 0.36 | 44.03 | 0.11 | 0.80 | 54.07 | 99.26 | 551.2 |
| 3 | | Au-core | 0.37 | 44.45 | 0.13 | 0.82 | 53.47 | 99.11 | 546.1 |
| 4 | | Au-core | 0.34 | 44.16 | 0.11 | 0.82 | 53.76 | 99.09 | 549.0 |
| 5 | | transition | 0.32 | 54.40 | 0.07 | 0.69 | 43.62 | 99.03 | 445.0 |
| 6 | | transition | 0.35 | 54.84 | 0.09 | 0.71 | 42.83 | 98.72 | 438.5 |
| 7 | | transition | 0.30 | 54.46 | 0.11 | 0.67 | 42.84 | 98.28 | 440.3 |

| | | | | | | | | | |
|----|------|------------|------|-------|------|------|-------|-------|-------|
| 8 | | transition | 0.28 | 54.50 | 0.11 | 0.59 | 42.67 | 98.03 | 439.1 |
| 9 | | Ag-core | 0.23 | 58.57 | 0.14 | 0.66 | 39.42 | 98.91 | 402.3 |
| 10 | | Ag-core | 0.22 | 59.15 | 0.12 | 0.61 | 38.66 | 98.65 | 395.3 |
| 11 | | Ag-core | 0.25 | 58.73 | 0.11 | 0.62 | 39.19 | 98.80 | 400.2 |
| 12 | | Ag-core | 0.24 | 59.29 | 0.10 | 0.62 | 38.77 | 98.94 | 395.4 |
| 13 | | Ag-core | 0.22 | 58.91 | 0.09 | 0.63 | 38.60 | 98.37 | 395.9 |
| 14 | | Ag-core | 0.21 | 58.50 | 0.19 | 0.60 | 39.34 | 98.65 | 402.1 |
| 15 | G1-2 | core | 0.26 | 58.57 | 0.11 | 0.66 | 39.36 | 98.23 | 401.9 |
| 16 | | core | 0.33 | 58.76 | 0.11 | 0.82 | 39.23 | 98.32 | 400.3 |
| 17 | | core | 0.28 | 58.58 | 0.14 | 0.49 | 39.56 | 98.44 | 403.1 |
| 18 | | core | 0.27 | 58.65 | 0.12 | 0.69 | 39.64 | 98.58 | 403.3 |
| 19 | | core | 0.27 | 56.48 | 0.11 | 0.61 | 40.90 | 97.65 | 420.0 |
| 20 | | core | 0.32 | 54.31 | 0.13 | 0.71 | 43.95 | 98.62 | 447.3 |
| 21 | | core | 0.31 | 54.66 | 0.12 | 0.50 | 42.44 | 97.42 | 437.1 |
| 22 | | core | 0.22 | 54.65 | 0.12 | 0.97 | 41.77 | 96.66 | 433.2 |
| 23 | | core | 0.27 | 54.60 | 0.09 | 0.61 | 42.60 | 97.51 | 438.3 |
| 24 | | core | 0.30 | 54.09 | 0.13 | 0.62 | 44.60 | 99.01 | 451.9 |
| 25 | | core | 0.20 | 58.59 | 0.11 | 0.62 | 40.43 | 99.23 | 408.3 |

Information garnered from physical and chemical heterogeneities in electrum grains and mineralized rock samples, coupled with field observations in Galim-Legalgorou, suggest that Ag and Au were deposited by rapidly evolving hydrothermal fluids, in two intermittent hypogene stages and later went through a supergene process. This is evident in the primary chemical zonation observed on zoned electrum grains (**Fig 2 a-f**).

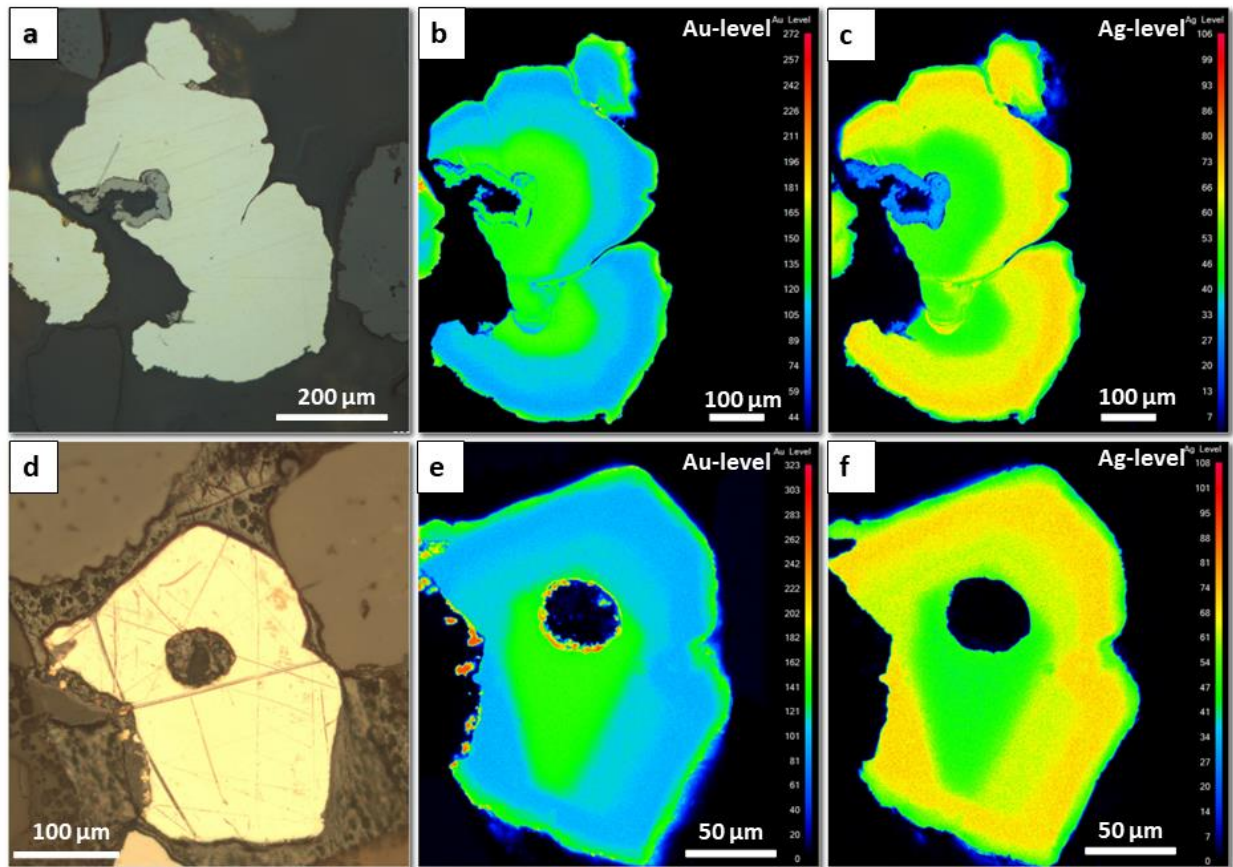


Fig 2. EMPA element maps of selected zoned electrum grains (a & d) Two selected electrum particles shown in reflected light. Both grains are apparently homogeneous when viewed in reflected light (b & e) Inner-core to outer-core gradational variation of Au (c & f). Inner-core to outer-core gradational variation of Ag.

Stage I is characterized by the precipitation of quartz, dickite, chlorite/smectite, Au-rich electrum, pyrite, sphalerite ± galena, hematite, Ti-bearing magnetite and rutile at relatively higher temperatures and near neutral pH (5-7) conditions while Stage II is represented by the Ag-rich zone in zoned electrum and characterized by the deposition of Ag-rich electrum, acanthite, pyrite, sphalerite ± galena and kaolinite at relatively lower temperatures and more acidic conditions (pH 2-4). The presence of acanthite in stage II suggests a low temperature epithermal environment (<177 °C) in which acanthite is more stable than argentite, and provides the first indication that depressurization and boiling may have accompanied ore deposition at Galim-Legalgorou. Colloform quartz and hydrothermal breccia are also indications of boiling in epithermal systems (Simmons et al., 2000).

Magnetite is normally an important component of magmatic rocks which is more stable under reducing conditions (low fO_2) while hematite shows maximum stability in oxygen saturated conditions. Both redox and non-redox transformations can occur between magnetite and hematite in hydrothermal solutions at temperatures above 100 °C at pH 2-6 (Otake et al. 2010). The coexistence of magnetite (titanomagnetite) and specular hematite in the ore at Galim-Legalgorou, therefore, reflects the composition of a strongly reducing fluid that evolved with time to become more oxidizing as it ascended and cooled.

Electrum from Galim-Legalgorou exhibits a relatively wide range of high Ag contents (27.31 wt% to 60.67 wt%). This high Ag content in electrum is akin to fluids from magmatic hydrothermal systems in which bisulfide complexation ($\text{Au}(\text{HS})_2^-$) is the dominant mechanism of gold transport, while Ag transport is dominated by chloride complexation (AgCl_2^-) under reduced, near-neutral fluid conditions (Morrison et al., 1991; Chapman et al. 2009; Chapman et al., 2021a). Experiments have shown that increasing Ag contents of electrum are directly associated with falling fluid temperatures, reducing Au/Ag ratios in solution, reduced acidity and increasing H_2S activity at the expense of Cl^- activity in hydrothermal solutions (Gammons and Williams-Jones 1995). Increasing Au contents of electrum are believed to have the reverse effect on the hydrothermal fluid. Electrum in this study is characterized by the element suite Au-Ag-Bi-Hg-Te, which closely conforms to the trace element inventory of gold alloys from epithermal deposits globally (Liu and Beaudoin, 2021; Chapman et al. 2021b). According to Liu and Beaudoin (2021), these elements could have been incorporated into electrum a result of the loss of H_2S from the hydrothermal fluid triggered by pressure drops, boiling, and sustained temperature reduction.

According to Liu and Beaudoin (2021), gold fineness is related to the fluid composition and physicochemical characteristics such as temperature, pH, Eh, and transport ligands and could be exploited to discriminate the environment of deposition of gold. Fineness values for Au in Galim-Legalgorou range from 378.8 to 721 with a deposit average of 455. This relatively low fineness, coupled with high Ag contents is closer to the values observed for low sulfidation epithermal systems according to the classification of Morrison et al. (1991). Higher Ag concentrations in electrum could be attributed to a high saturation of Ag in the ensuing hydrothermal fluid to form Ag-rich minerals (e.g., acanthite) under low temperature conditions, leading to low gold fineness.

Conclusion

1. Galim-Legalgorou Au-Ag mineralization is hosted in brecciated felsic to intermediate tertiary volcanic rocks of the Cameroon volcanic line, and bears the principal hallmarks of an epithermal Ag-Au system.

2. Ag-Au deposition at Galim-Legalgorou occurred through hydrothermal fluids with rapid, but complex evolutionary cooling paths in two stages. Primary zonation in electrum with increasing inner-core to outer-core Ag-concentrations provide evidence of two stages of rapidly evolving Ag-rich fluid. This is also interpreted as evidence that ore deposition was accompanied by decompression and boiling, especially with the presence of hydrothermal breccia.

Novel Information

The discovery of epithermal Ag-Au system on the CVL (a non-hotspot, intra-plate volcanic system) is a major offset in current ore geology models, and opens a whole new frontier for research and exploration of epithermal/porphyry mineralization in Cameroon and similar volcanic units around the world.

Acknowledgements

This publication is part of the PhD thesis the first author (Terence Cho Ngang). Funding for research stay in Germany is provided by the German Academic Exchange Service (DAAD) within the framework of the bi-nationally supervised doctorate scholarship program, in collaboration with

the universities of Bamenda (Cameroon) and the Geofluids laboratory of the Institute of Mineralogy and Economic Geology (RWTH Aachen University), Germany. The management of Daewoo International Cameroon S.A. is also acknowledged for providing fresh mineralized core samples for this study.

References

- Chapman, R.J., Banks, D.A., Styles, M.T. (2021a). Chemical and physical heterogeneity within native gold: implications for the design of gold particle studies. *Miner Deposita* 56, 1563–1588 (2021). <https://doi.org/10.1007/s00126-020-01036-x>
- Chapman, R. J., Moles, N. R., Bluemel, B., & Walshaw, R. D. (2021b). Detrital gold as an indicator mineral. In M. Reolid, L. V. Duarte, E. Mattioli, & W. Ruebsam (Eds.), *Carbon Cycle and Ecosystem Response to the Jenkyns Event in the Early Toarcian (Jurassic)* (Vol. SP516). (Geological Society, London, Special Publications). Geological Society. <https://doi.org/10.1144/SP516-2021-47>
- French S.W. and Romanowicz B.A. (2014), Whole-mantle radially anisotropic shear velocity structure from spectral-element waveform tomography. *Geophys. J. Int.* (2014) 199, 1303–1327. doi: 10.1093/gji/ggu334
- Gammons C. H, Williams-Jones A. E. (1995). Hydrothermal geochemistry of electrum; thermodynamic constraints. *Economic Geology* 90:420–432. <https://doi.org/10.2113/gsecongeo.90.2.420>.
- Liu H. and Beaudoin G. (2021). Geochemical signatures in native gold derived from Au-bearing ore deposits. *Ore Geology Reviews* 132 (2021) 104066.
- Moreau, C., Regnault, J.M., Deruelle, B., & Robineau, B. (1987). A new tectonic model for the Cameroon Line, Central-Africa. *Tectono physics*, 141 (4), 317–334.
- Morrison, G.W., Rose, W.J. and Jaireth, S., (1991). Geological and geochemical controls on the silver content (finesness) of gold in gold-silver deposits. *Ore Geol. Rev.*, 6: 333-364.
- Njome, M.S. and de Wit, M.J. (2014) The Cameroon Line: Analysis of an Intraplate Magmatic Province Transecting Both Oceanic and Continental Lithospheres: Constraints, Controversies and Models. *Earth-Science Reviews*, 139, 168-194.
- Otake T., Wesolowski D. J., Anovitz L. M., Allard L. F., Ohmoto H. (2010). Mechanisms of iron oxide transformations in hydrothermal systems, *Geochimica et Cosmochimica Acta*, Volume 74, Issue 21, 2010, Pages 6141-6156, ISSN 0016-7037, <https://doi.org/10.1016/j.gca.2010.07.024>.
- Simmons SF., Mauk JL and Simpson MP (2000). The mineral products of boiling in the Golden Cross epithermal deposit. 2000 New Zealand Minerals & Mining Conference Proceedings 29-31 October 2000
- Toteu, S.F., Van Schmus, W.R., Penaye, J. & Michard, A. (2001). New U–Pb and Sm–Nd data from north-central Cameroon and its bearing on pre-Pan African history of central Africa. *Precambrian Research*, 108, 45 – 73.