Geochemistry and Stable Isotopes of the Rift-Related Quartz-Adularia-Type Gold-Silver Mineralization, Bergama, Izmir, Turkey

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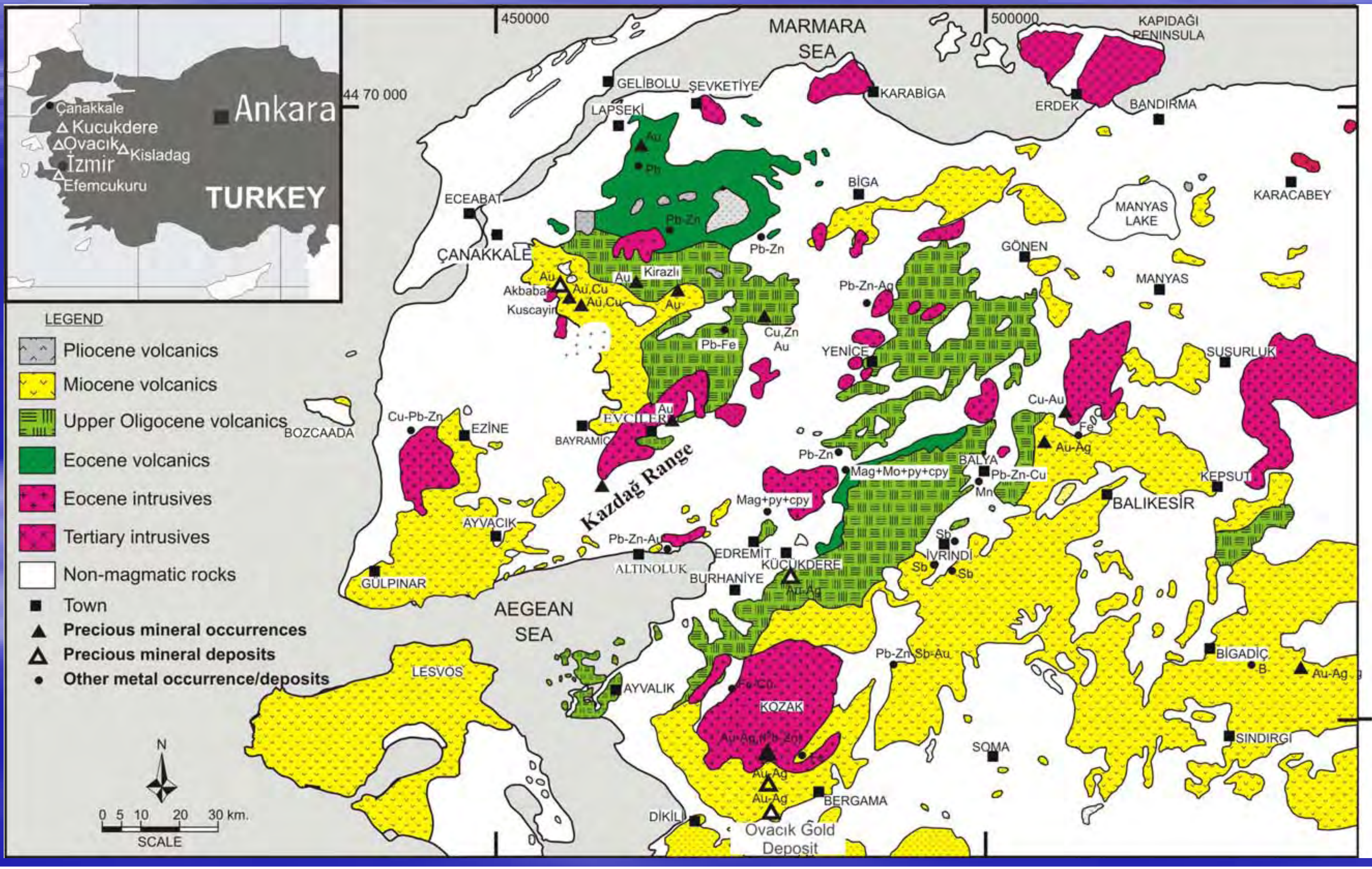
80 g/t Au and 91 g/t Ag

Presentation will be done under the following headings:

- Location / purpose of study
- Geological setting
- Vein system / mineralogy
- Hydrothermal alteration
- Hydrothermal Geochemistry
- Fluid inclusion
- Stable isotope studies
- Discussion

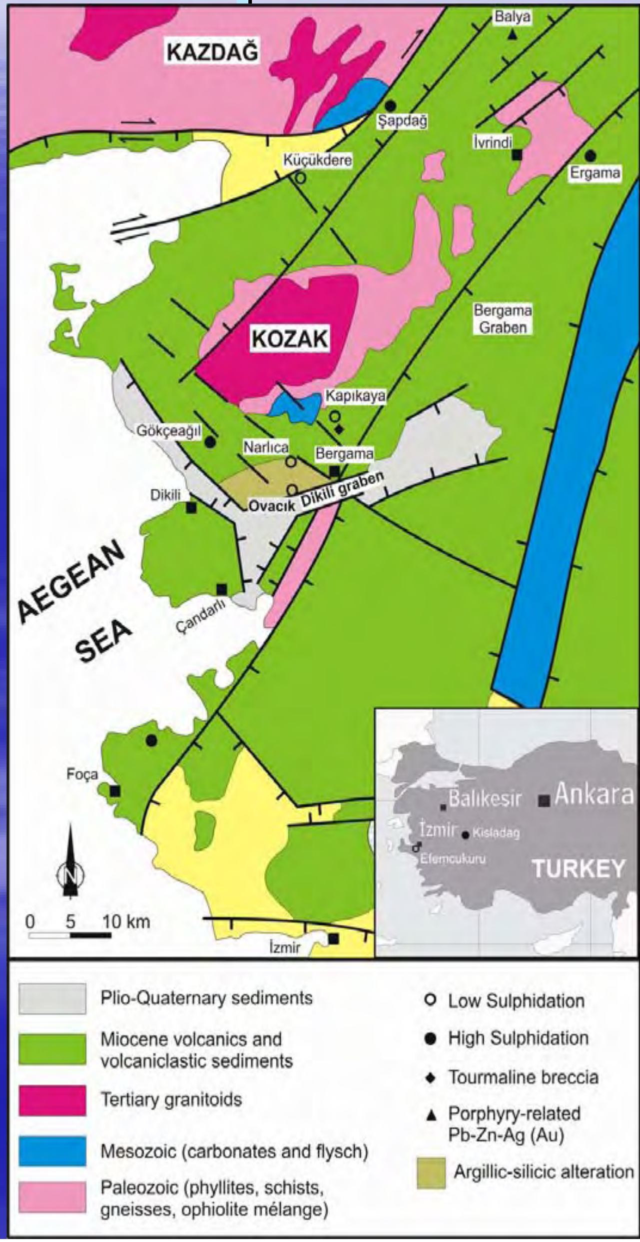
Location

Ovacık-Narlica epithermal gold deposits are located in the west Anatolian extensional province.



Oligo-Miocene subaerial volcanics hosting several epithermal Au deposits

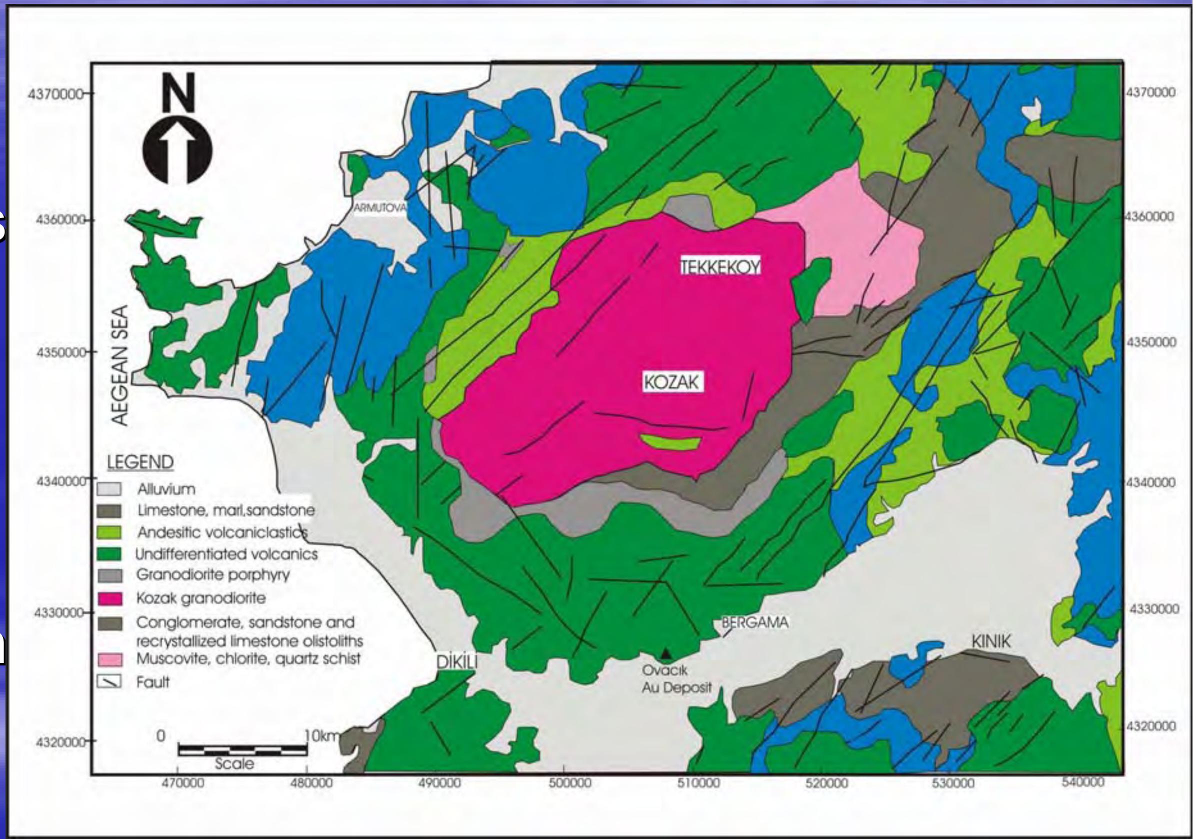
- Kuçukdere LS, 60 km N, 1.4 mt @6.5 g/t Au.
- Efemcukuru LS, 100 km S, 3.1 mt @ 14.6 g/t Au.
- Kisladag HS, 200 km E, 276 mt @1.2 g/t Au.



Geological Setting

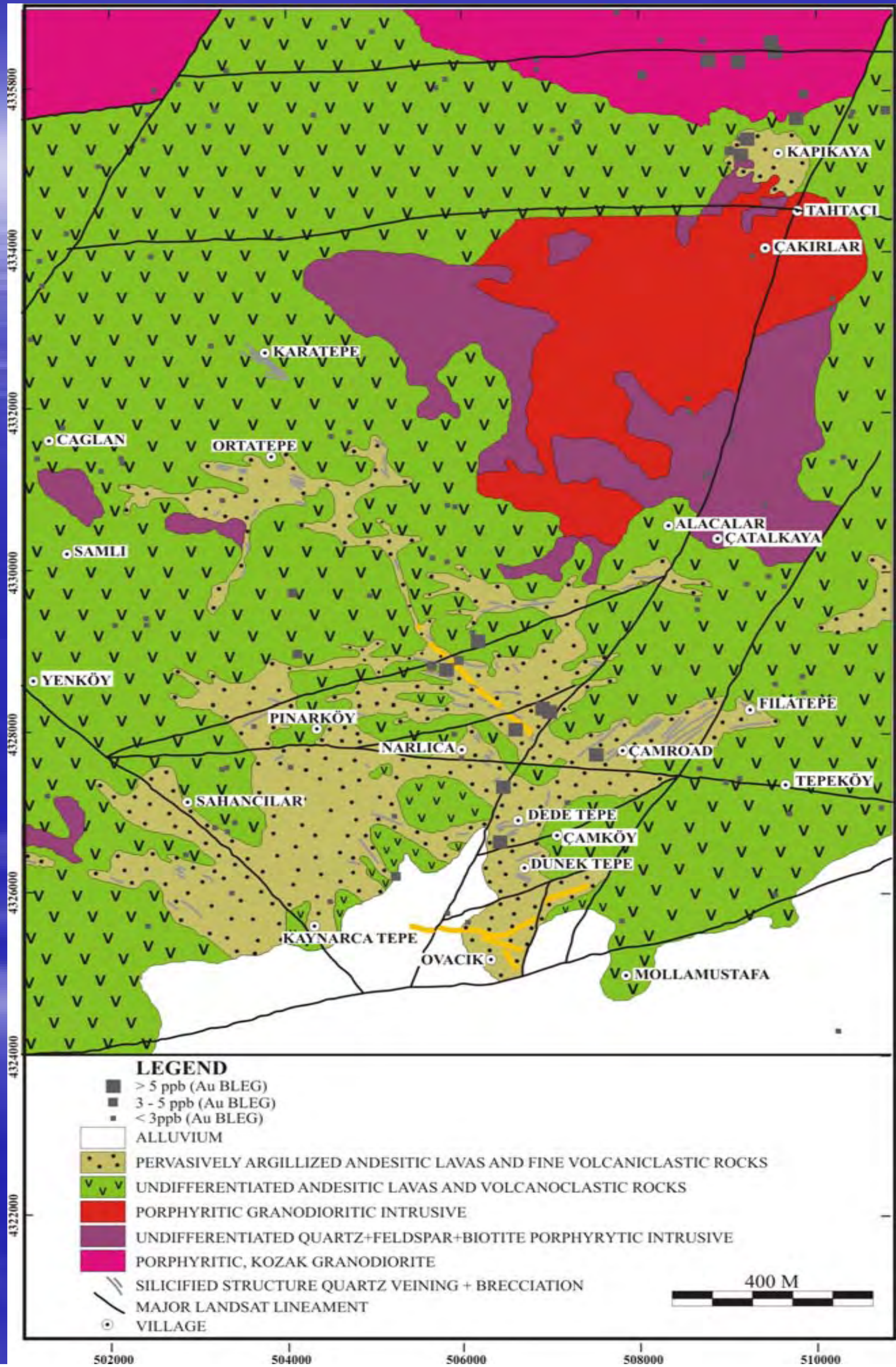
Regional Geology

- A major granodiorite intrusive, surrounded by calc-alkaline volcanic rocks such as andesite, dacite and rhyodacite.
- Tectonics: A strong compression from Eocene to Miocene, causing the generation of anatectic granitic melts.



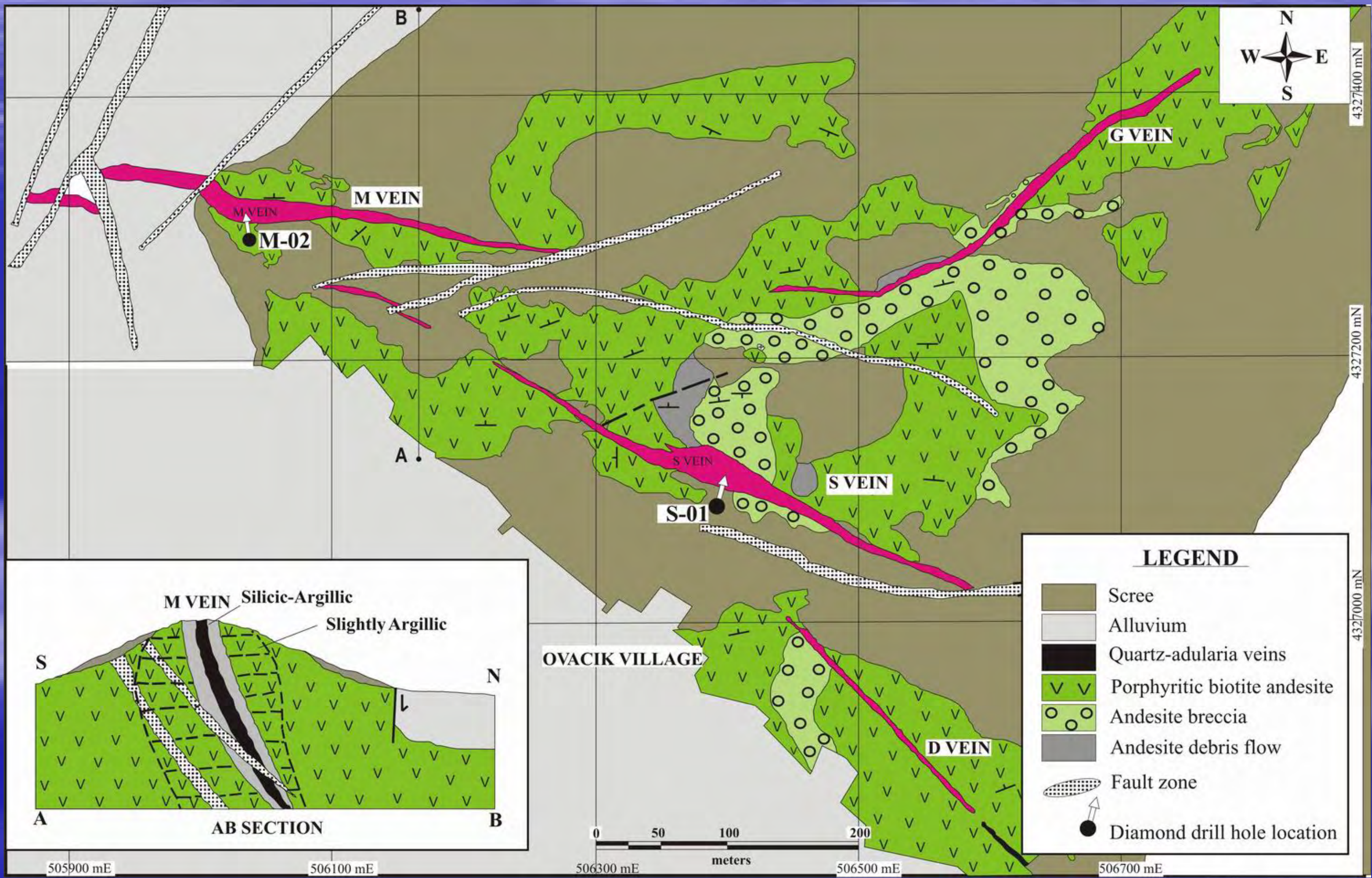
Local Geology

- The Ovacik-Narlica lithologies consist mainly of K-rich subaerial andesite and dacite with minor latite andesite
- Ovacik and Narlica veins are located next to graben margin.



Characteristics of vein system

Ovacik vein system consists of four epithermal quartz veins; of these M and S veins are economically significant, both having a total mapped strike length of 900 m.



Vein and Breccia Textures

- Main textures are: **Colloform/Crust-form banding**, occurring in veins and breccia clasts (3 m @ 28 g/t Au)

- **Coarse, bladed carbonate** replacement textures occurring as distinct bands or infilling vugs (0.08 g/t Au)

- **Matrix-supported fluidized (milled) breccia**
- **consisting of quartz-adularia vein material with common crustiform banding, bladed calcite (2 m @ 39.2 g/t Au)**

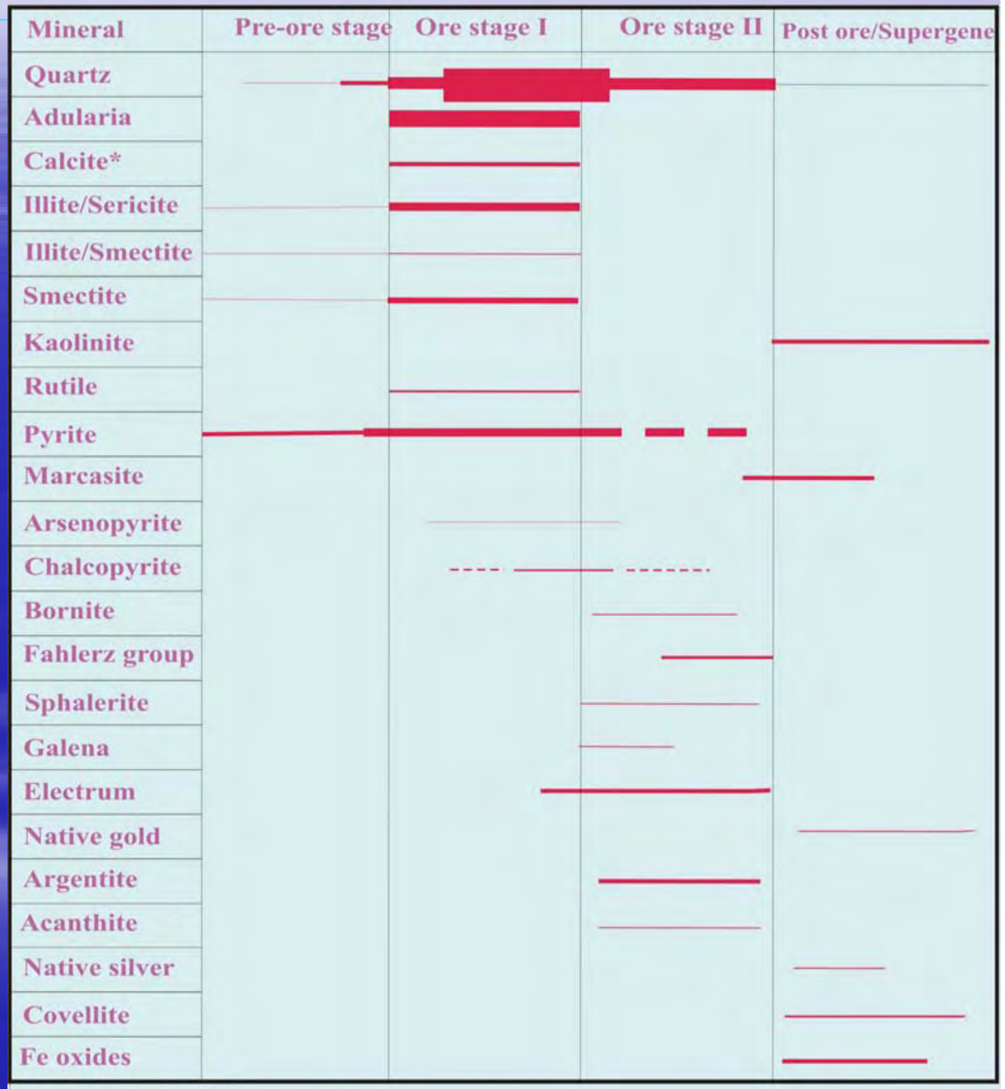
- Clast-supported crackle (shatter) breccia
- consisting of qurtz-adularia vein material with common crustiform banding (1 m @ 24.5 g/t Au)

Vein Mineralogy

Mineral paragenesis

An approximate sequence of mineralization is:

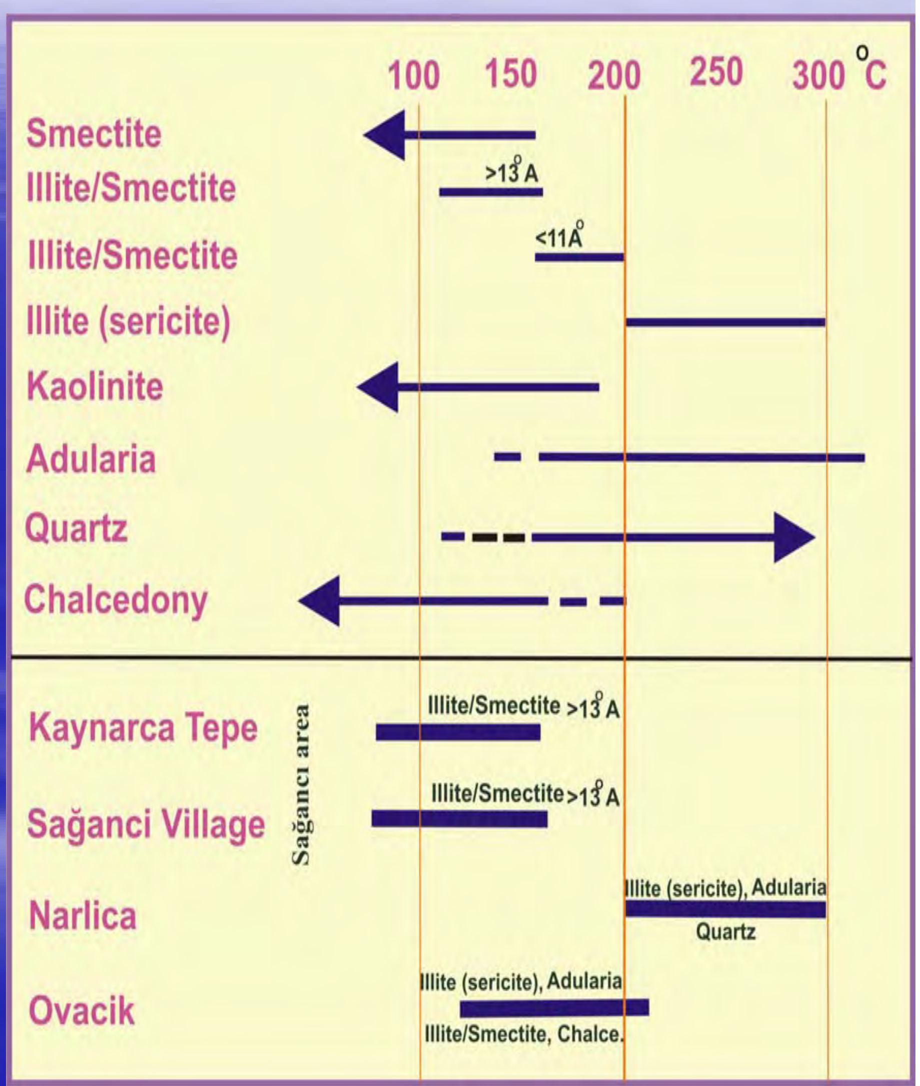
- **Quartz + Pyrite + Illite + Smectite >**
- **Quartz + Pyrite + Illite + Smectite + Calcite + Adularia + Arsenopyrite + Chalcopyrite + Electrum >**
- **Chalcopyrite + Bornite+ Fahlerz + Galena + Electrum + Argentite +Acanthite + Marcasite + Pyrite >**
- **Kaolinite + Marcasite + Native Au + Native Ag + Covellite**



*Mainly replaced by quartz

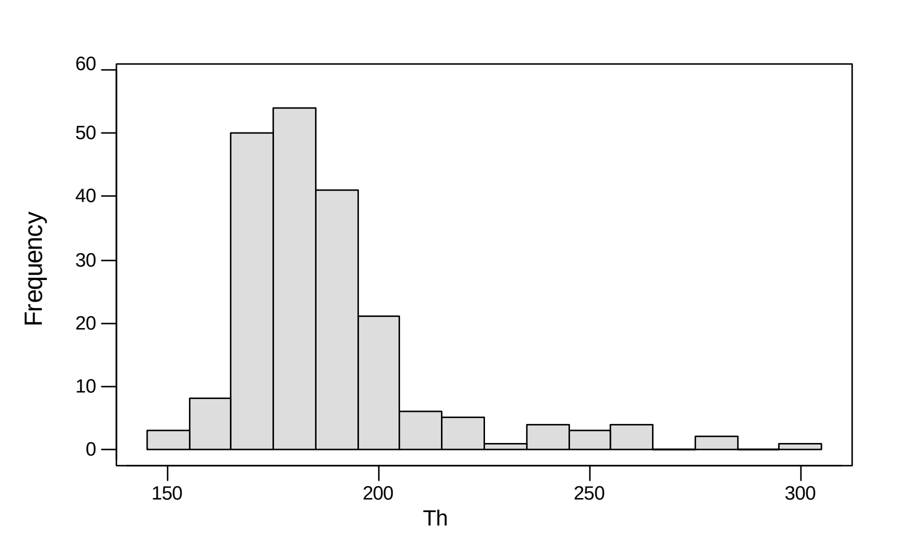
Hydrothermal Alteration

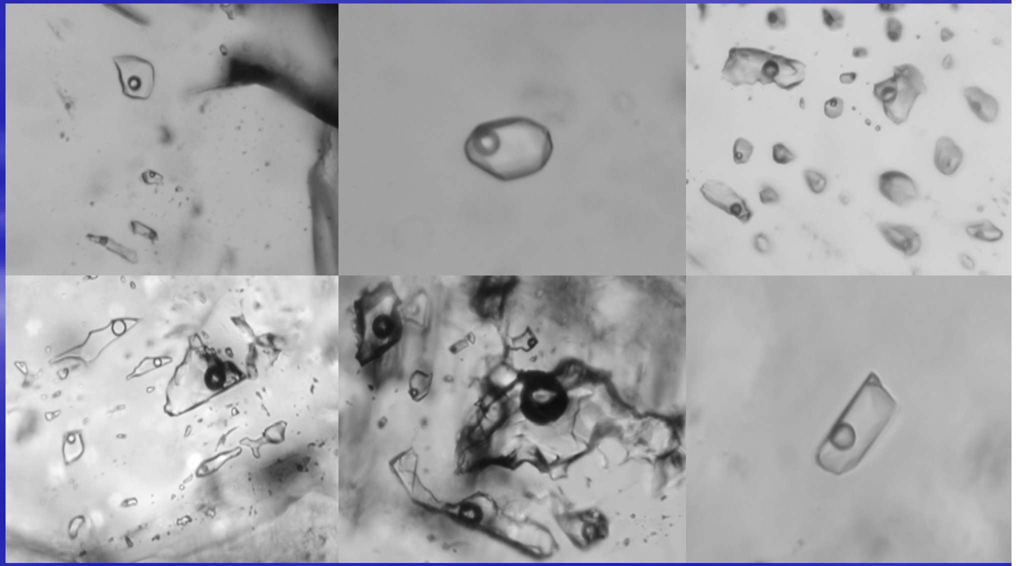
- **Silica alteration enveloped by illite/sericite, minor mixed layer illite/smectite.**
- **Adularia occurring as vein material and as mass replacement of andesite.**
- **Ovacik deposit forming at 200 °C evidenced by the presence of illite, adularia, illite/smectite whereas Narlica deposit forming at higher temperatures > 200 °C evidenced by the occurrence of highly crystalline quartz.**



Fluid Inclusion

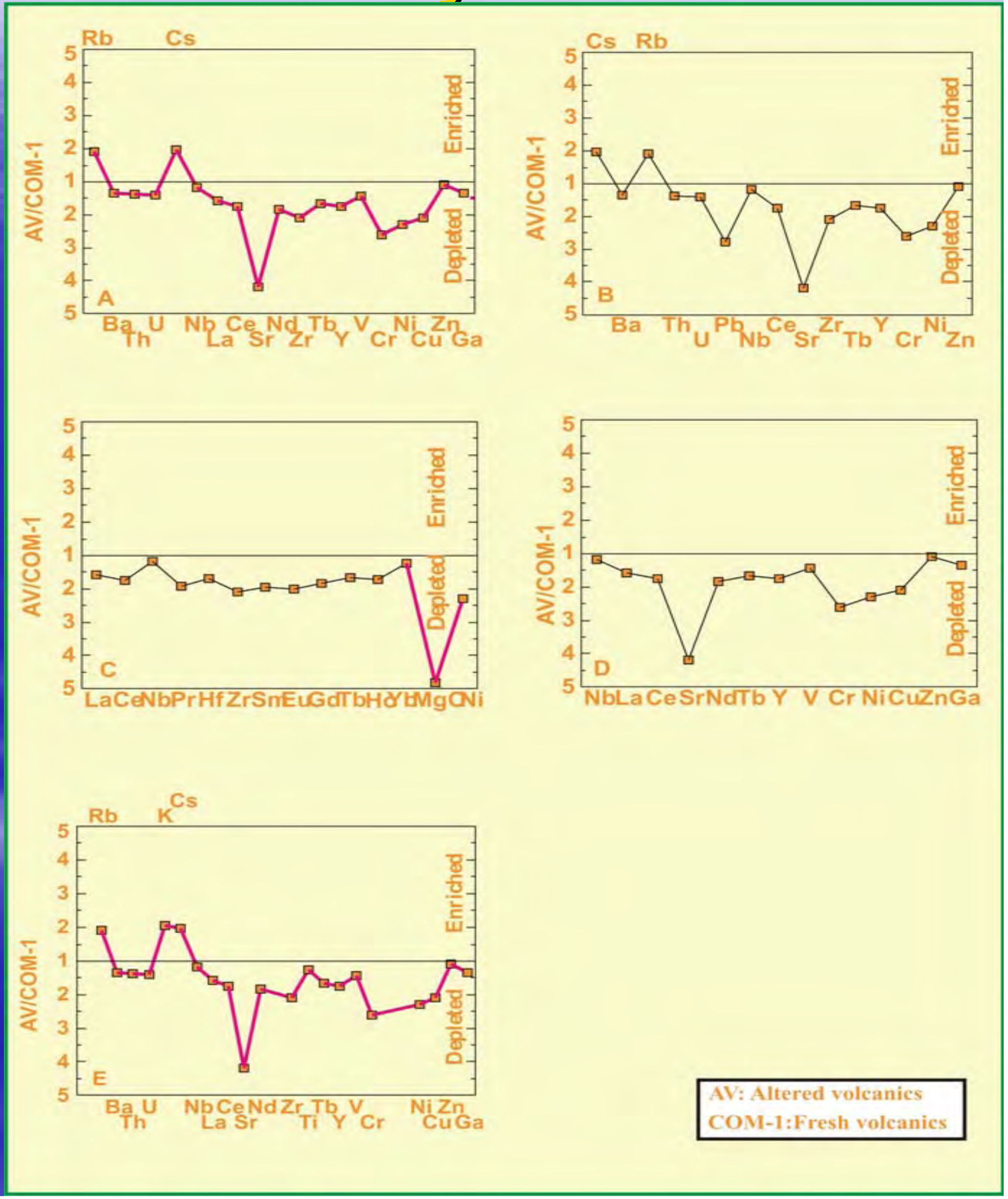
- **Homogenization temperatures of quartz veins range from 147-298 °C, with an average mode of 190 °C.**
- **The presence of vapor-rich inclusions, variable liquid-to-vapor ratios and large ranges in temperatures (indicate phase separation /boiling).**
- **Ice melting temperatures (*T*m) range from -0.4 to 1.2 degree °C, indicating a very dilute salinity less than 2 eq. Wt.%.**





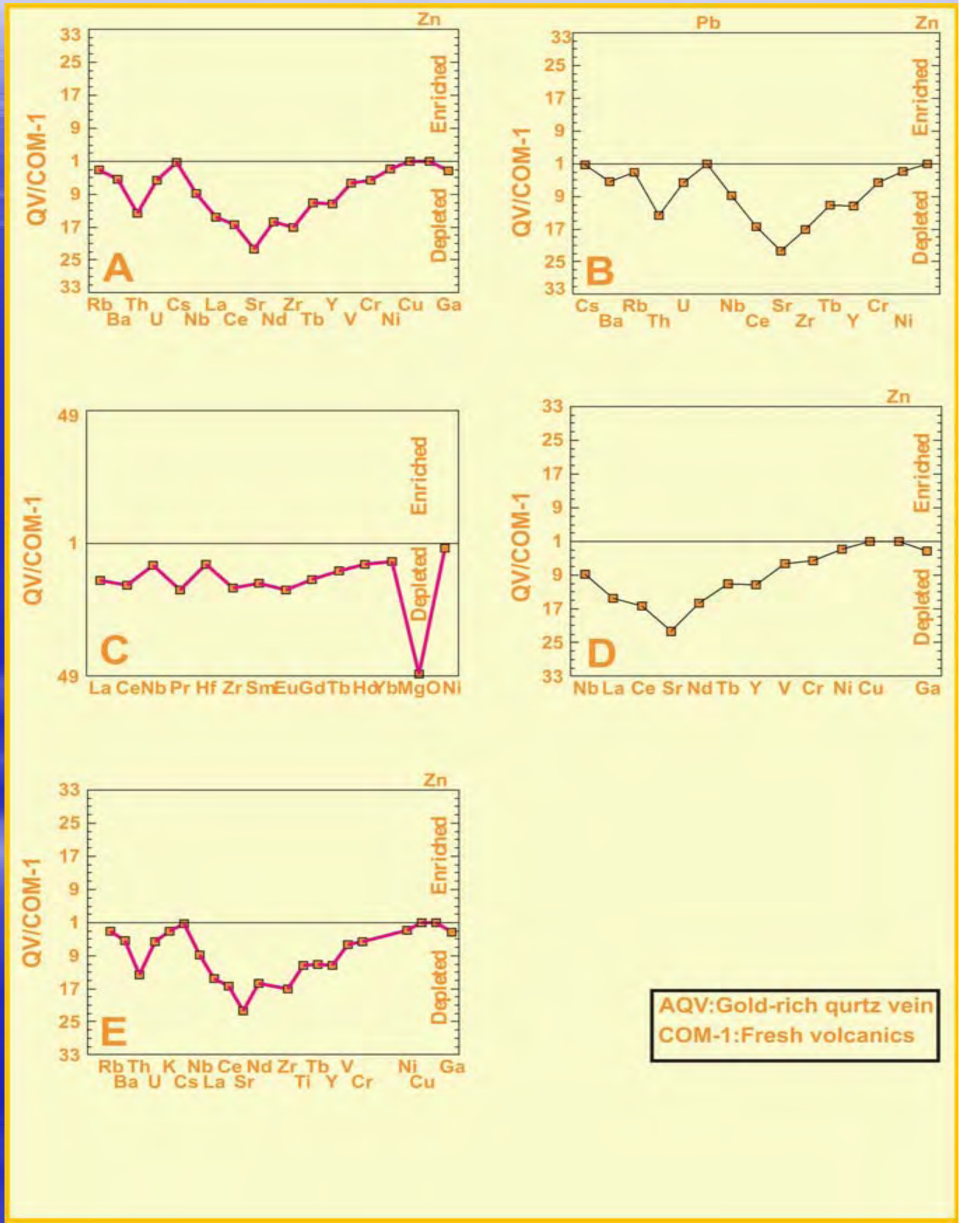
Hydrothermal Geochemistry
Wallrock Geochemistry

- K, Rb and Cs show two-fold enrichments caused by formation of adularia or illite/sericite.
- Ba, Th, U, Nb, Sr, Nd, Zr, Ti, Y, Cr, Ni, Cu and Pb depletions are generally <three-folds whereas Sr is depleted by a factor of 5.
- REE display a flat pattern.



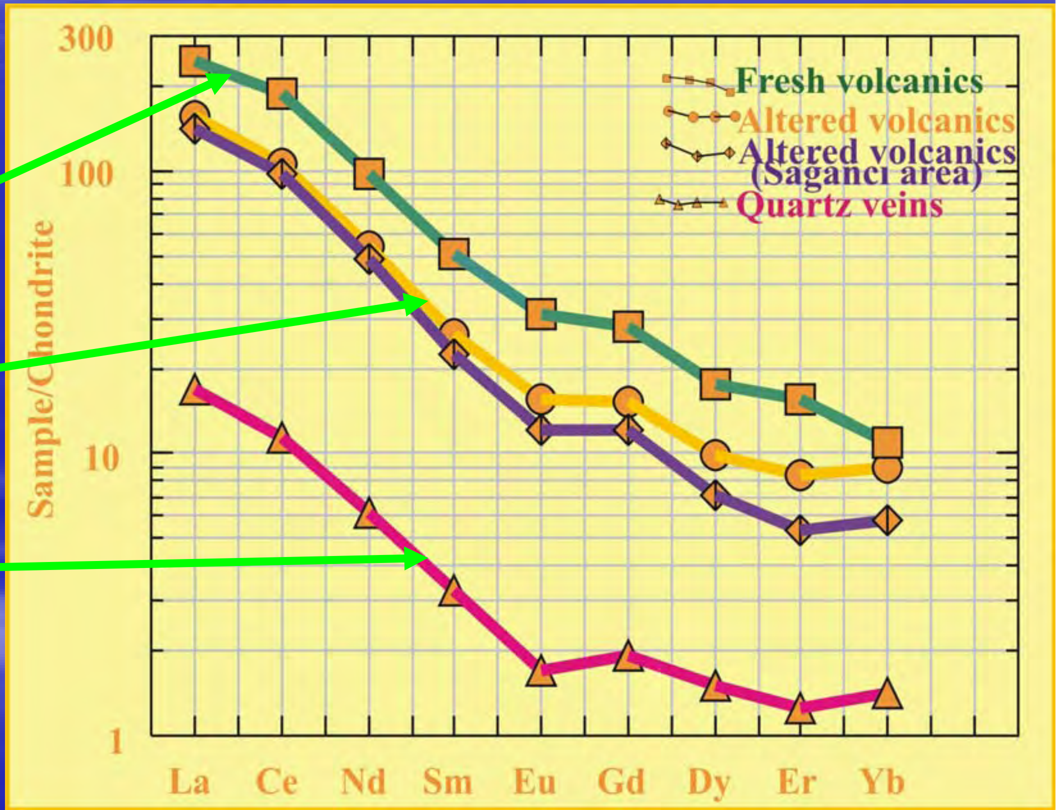
Hydrothermal Geochemistry
Quartz Veins

- Ba, Th, U, Nb, La, Ce, Sr, Nd, Zr, Ti, Tb, Y and Cr depleted by factors of 4 to 23 with negative anomalies for Th at 13 and for Sr at 23.
- Mg, Ca and Na are reduced by factors of 48, 60 and 84, respectively.
- LREE (La-Eu) values are reduced by factors of 7 to 15.
- HREE showing a linear trend from Gd to Yb appears with depletion factors of 4 to 9.



Hydrothermal Geochemistry
Chondrite-Normalized REE

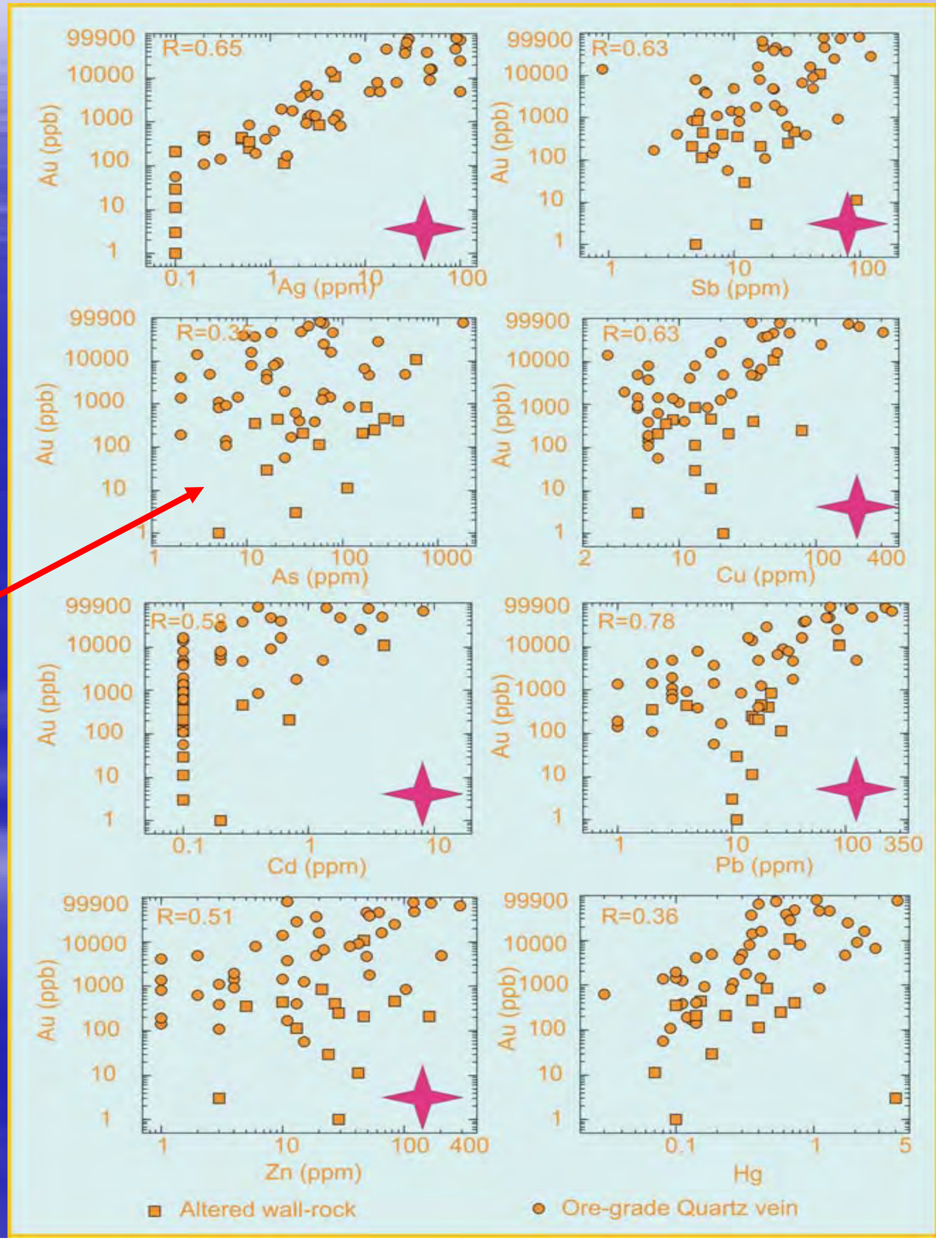
- Evidence for remobilization of REE at Ovacik-Narlica is provided by their consistent decrease from fresh volcanics through clay and adularia-altered wallrock to quartz-adularia veins.



Hydrothermal Geochemistry
Au and Other Metals Associations

- **Moderate to strong correlations occur between Au and Ag, Pb, Zn, Cd, Cu, Sb indicating similar mineralizing event.**

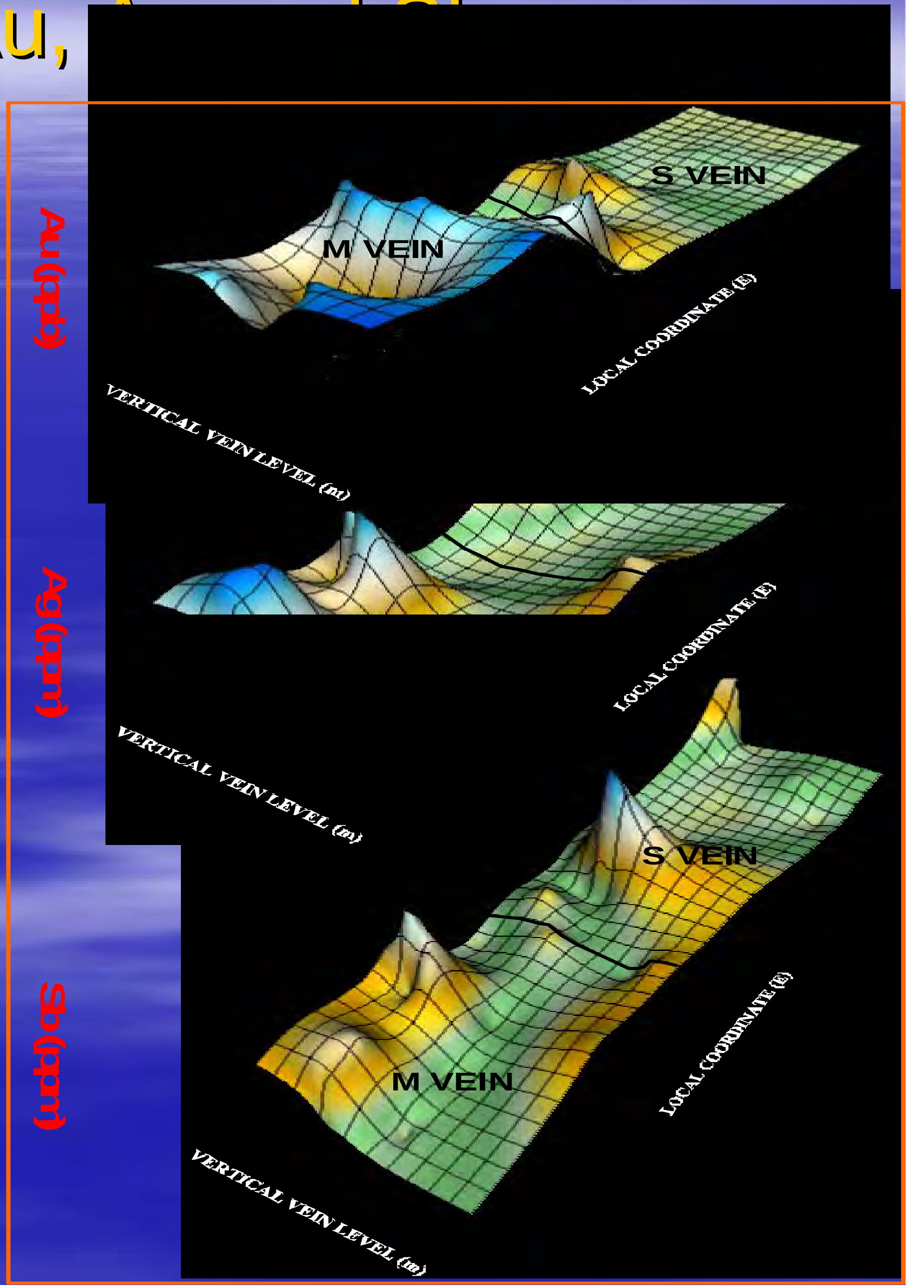
- **Very weak correlation between Au and As may suggest possible introduction of As and Au in different phases.**



Hydrothermal Geochemistry

Distribution of Au,

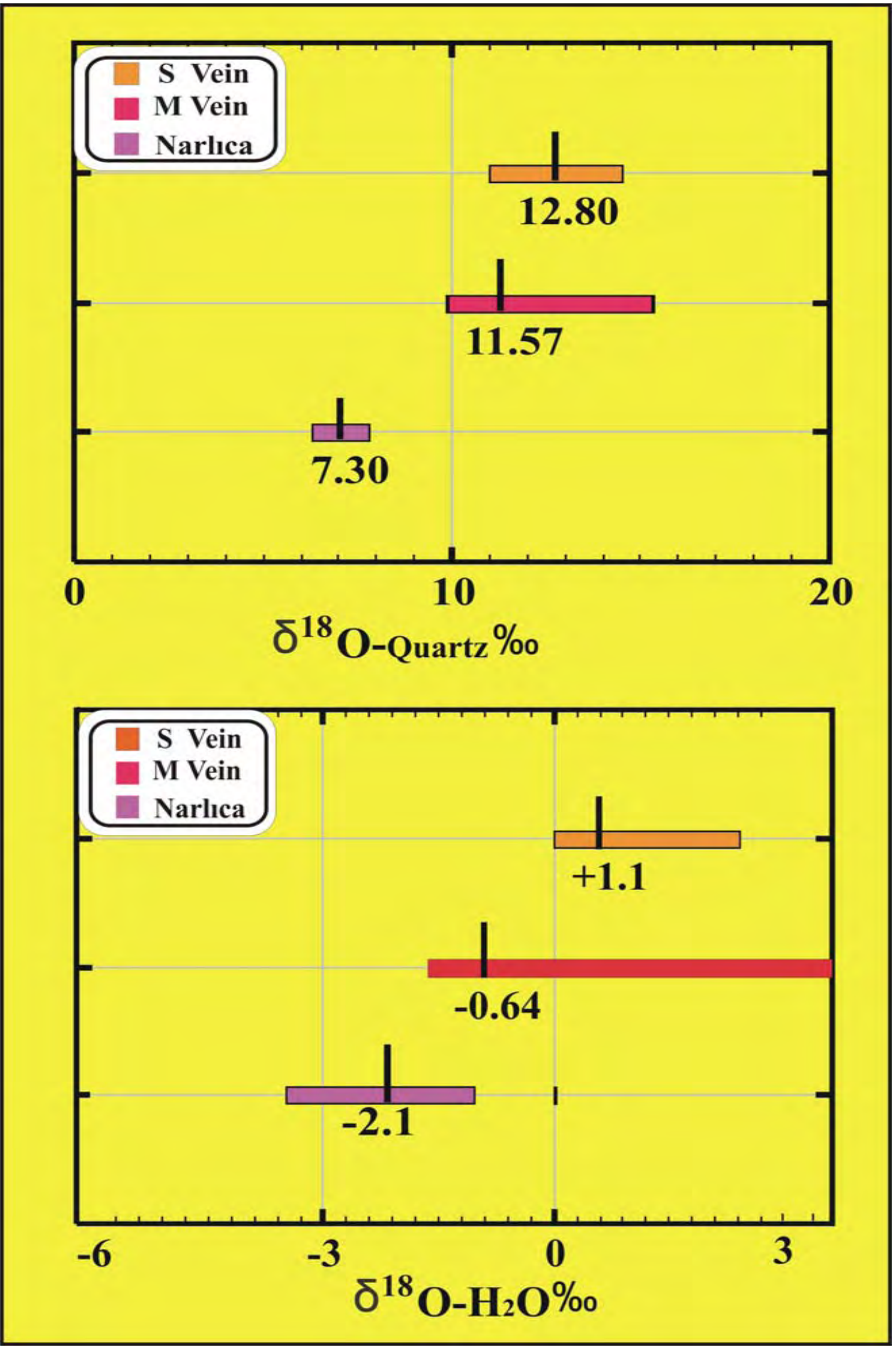
- **Very high gold values are confined to M vein and decease remarkably eastward (S vein).**
- **High silver values are confined to upper portion of M vein.**
- **Antimony values are confined to upermost portion of the two veins**



Stable Isotope
Oxygen Isotope

- $\delta^{18}O_{-quartz}$ values in M and S veins from Ovacik deposit range from +9.46 to +15.71 ‰, and calculated $\delta^{18}O\text{-}_{H_2O}$ values range from -2.86 to +3.51 ‰ (variation.:6.4)

- Average $\delta^{18}O\text{-}_{H_2O}$ value (-0.64 ‰) of M vein is relatively lower than that of S vein (+1.1‰).
- Calculated $\delta^{18}O\text{-}_{H_2O}$ values at Narlıca range from -3.90 to -6.27 ‰ (variation.:2.4).

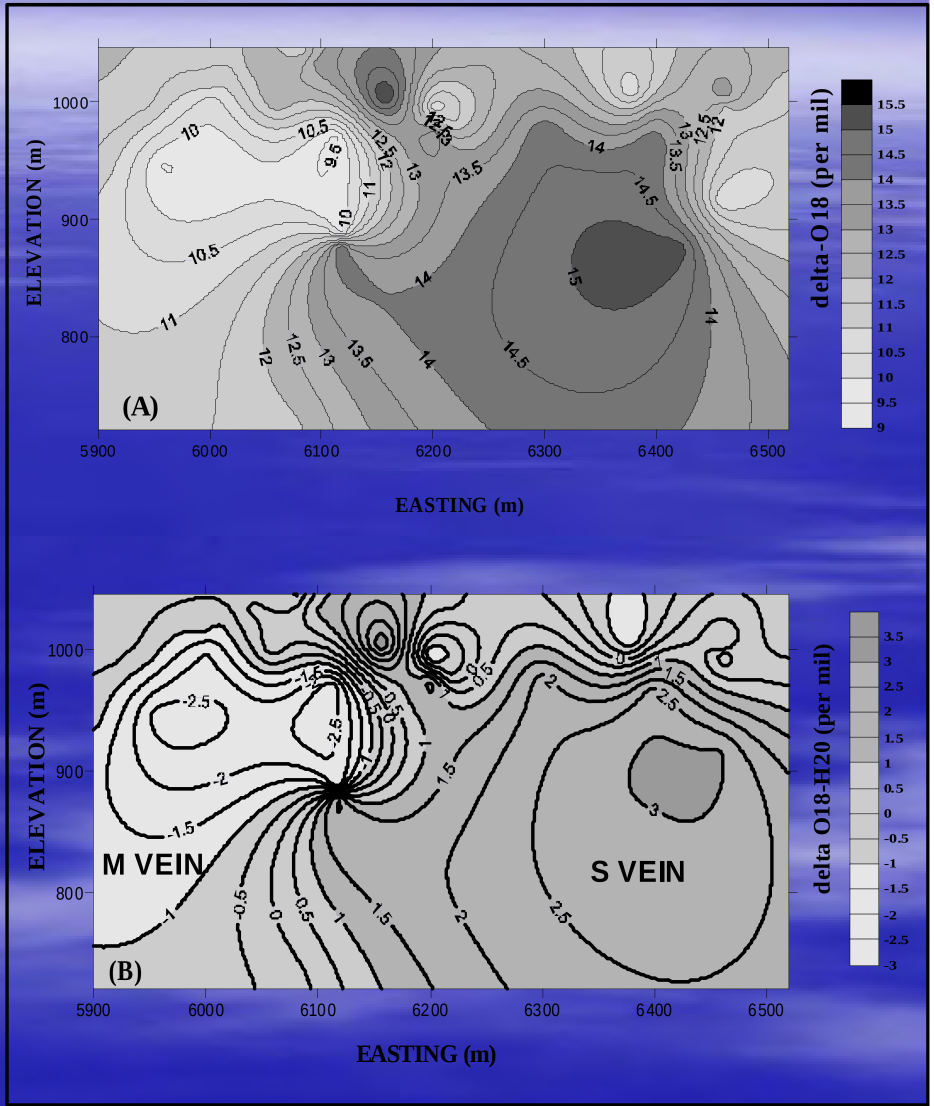


Stable Isotope

Oxygen Isotope

- Oxygen isotope distribution at deeper levels are relatively homogenous and they exhibit significant variations at higher levels.

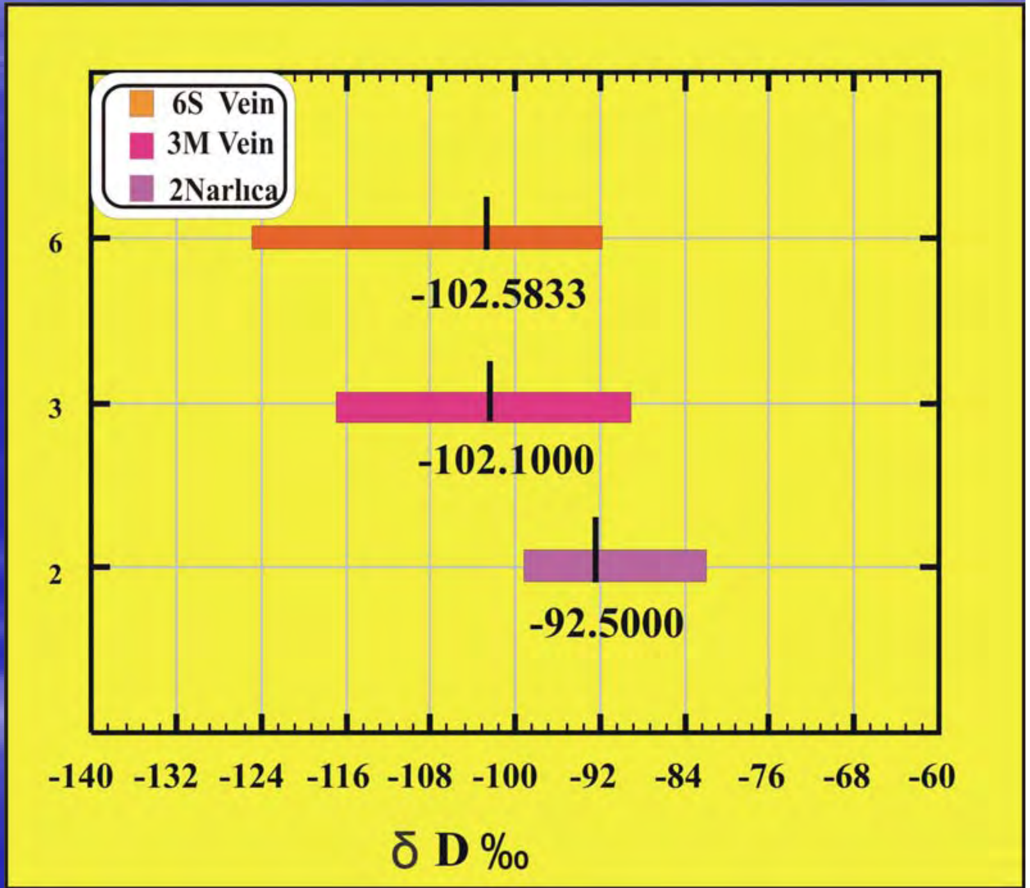
- Fluid inclusion water at Ovacik have isotopic compositions (Ave+0.6‰) which are enriched in heavy $\delta^{18}O$ as compared to present-day meteoric (Ave-5.4‰) and geothermal water (Ave-6.8 ‰).



Stable Isotope

Hydrogen Isotope

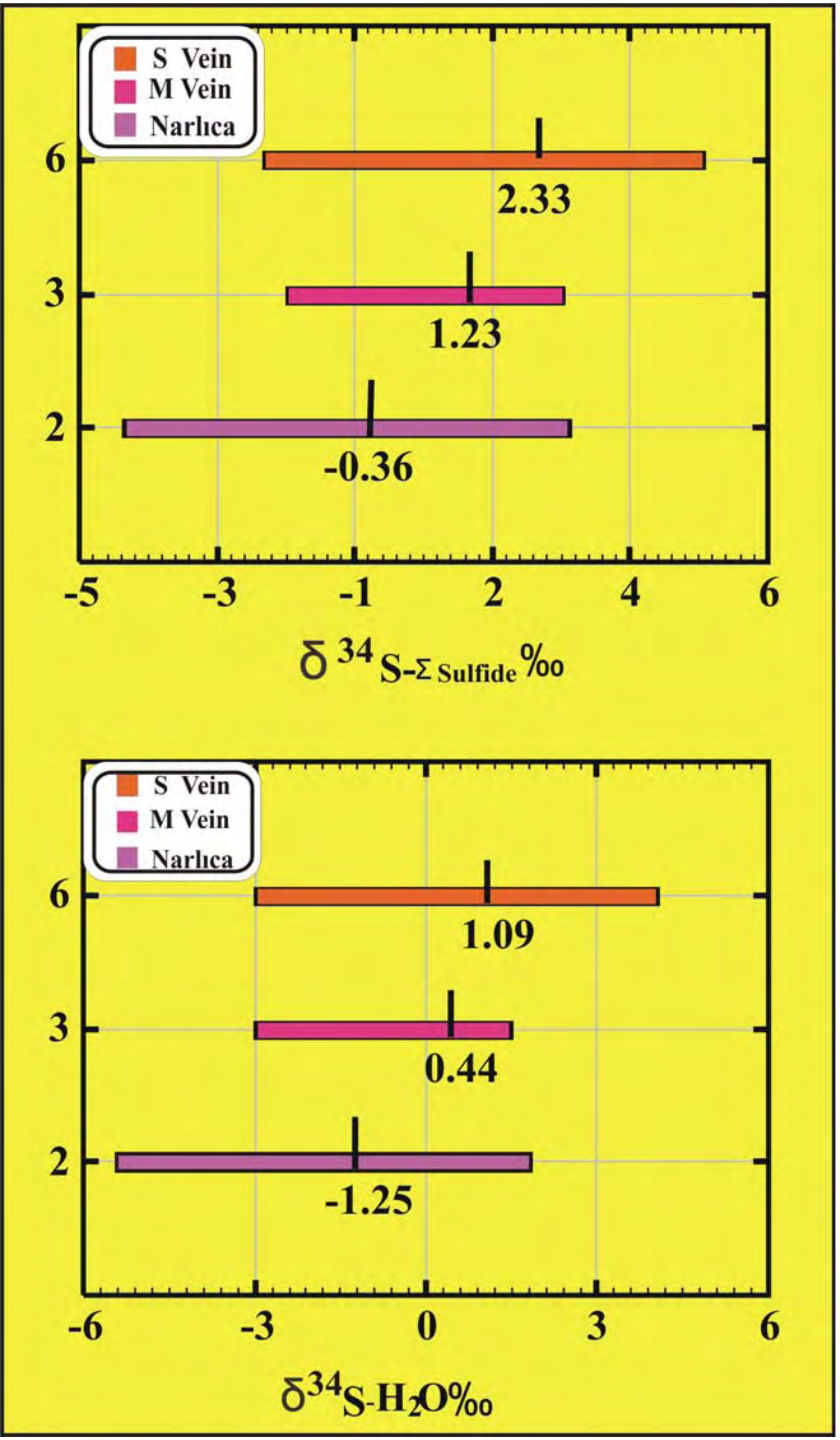
- **Ovacik-Narlica quartz samples yield δD-H_2O isotopic compositions of -92 to -117 ‰ with an average of 102 ‰.**
- **The quartz has low δD-H_2O isotopic values as compared to recent active geothermal waters (Ave. δD: -42 ‰).**



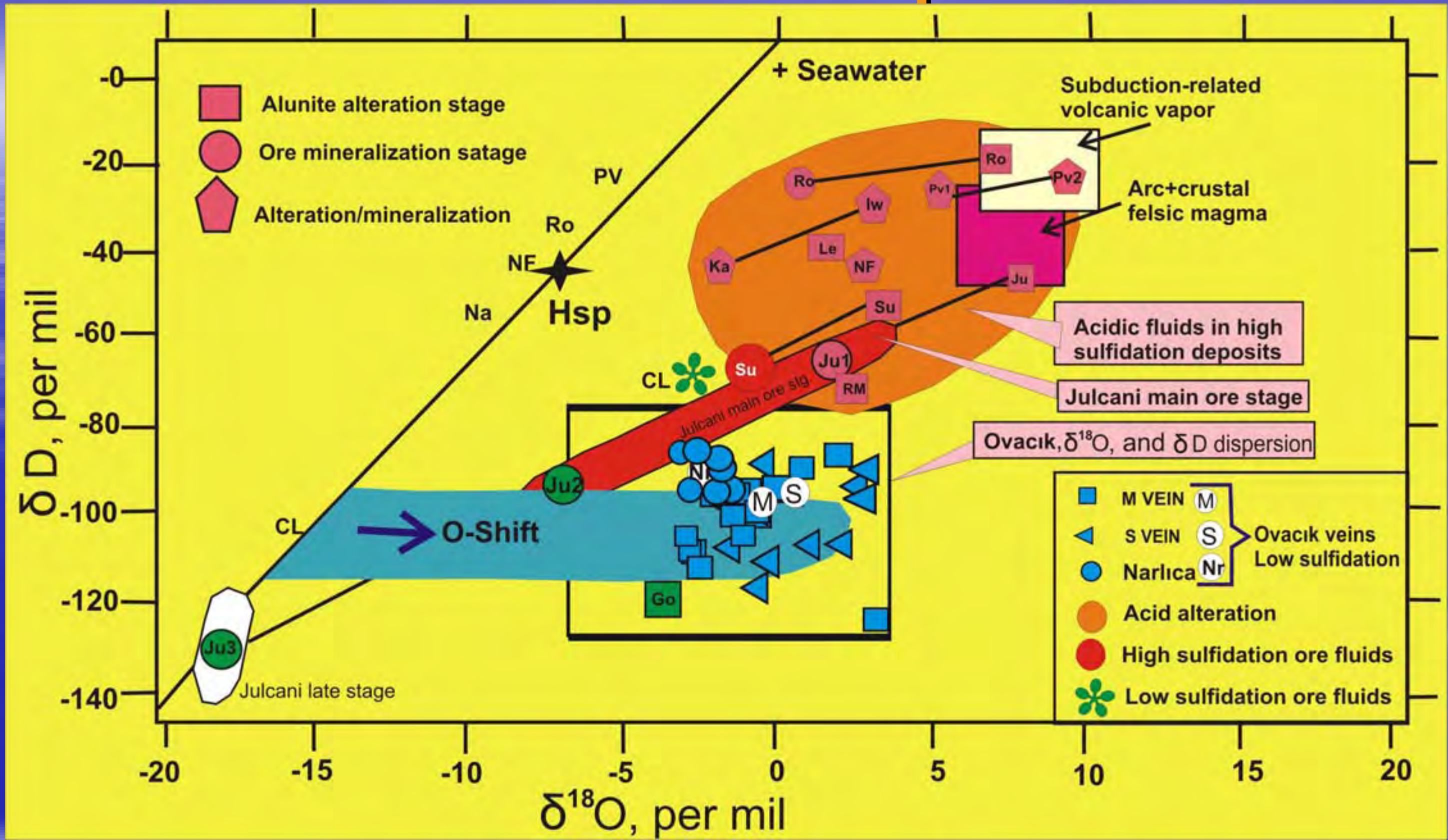
Stable Isotope

Sulfur Isotope

- $\delta^{34}S_{-H_2O}$ compositions of S and M veins range between -2.98 and +2.5 ‰ (Ave.:+0.44 ‰) and -2.98 and +4.4 ‰ (Ave.:+1.1).
- $\delta^{34}S_{-H_2O}$ values of sulfides are clustered near zero (ave. for M and S vein:+0.8 ‰), indicating presence of H_2S as probable dominant species.

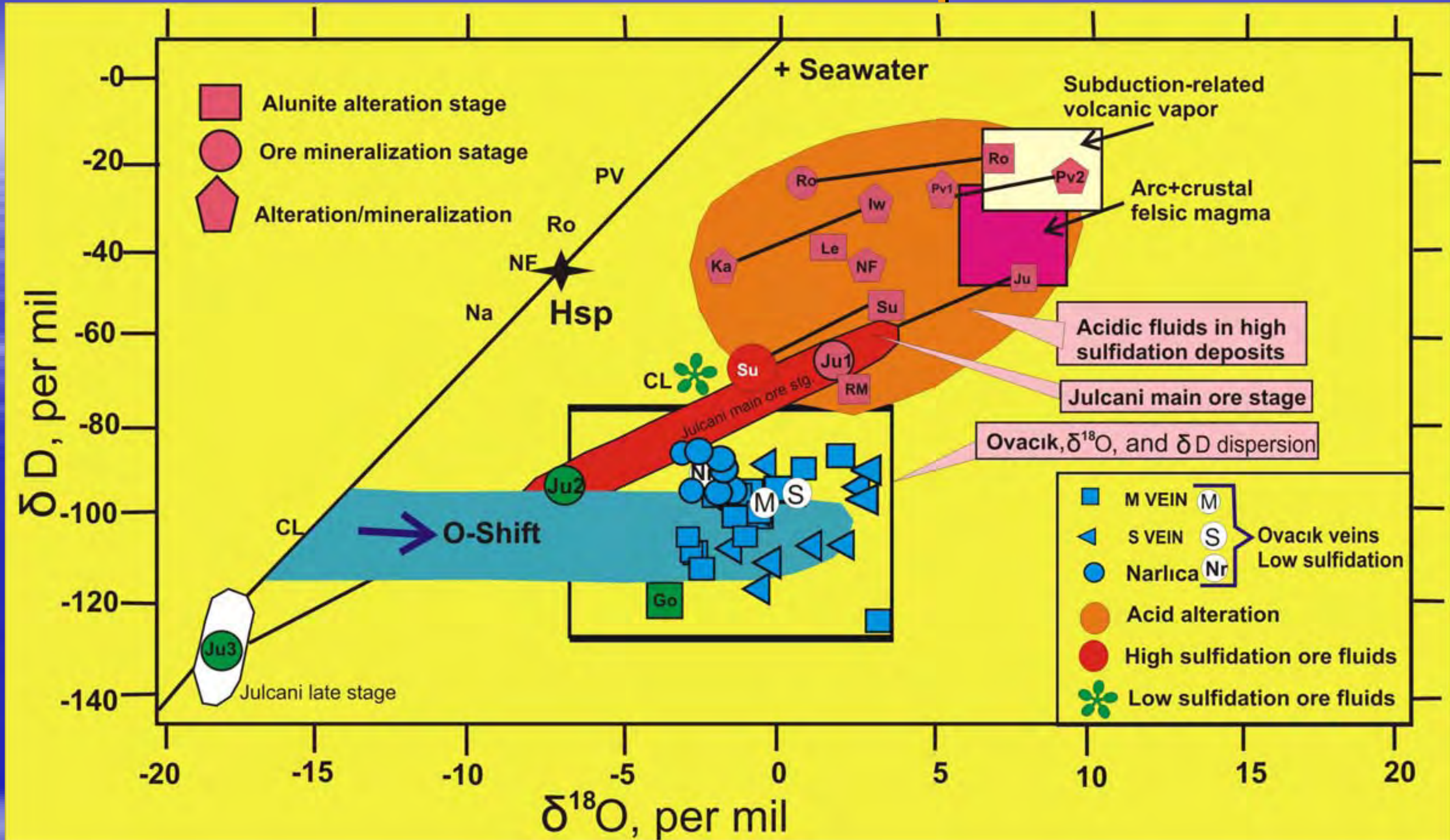


Stable Isotope



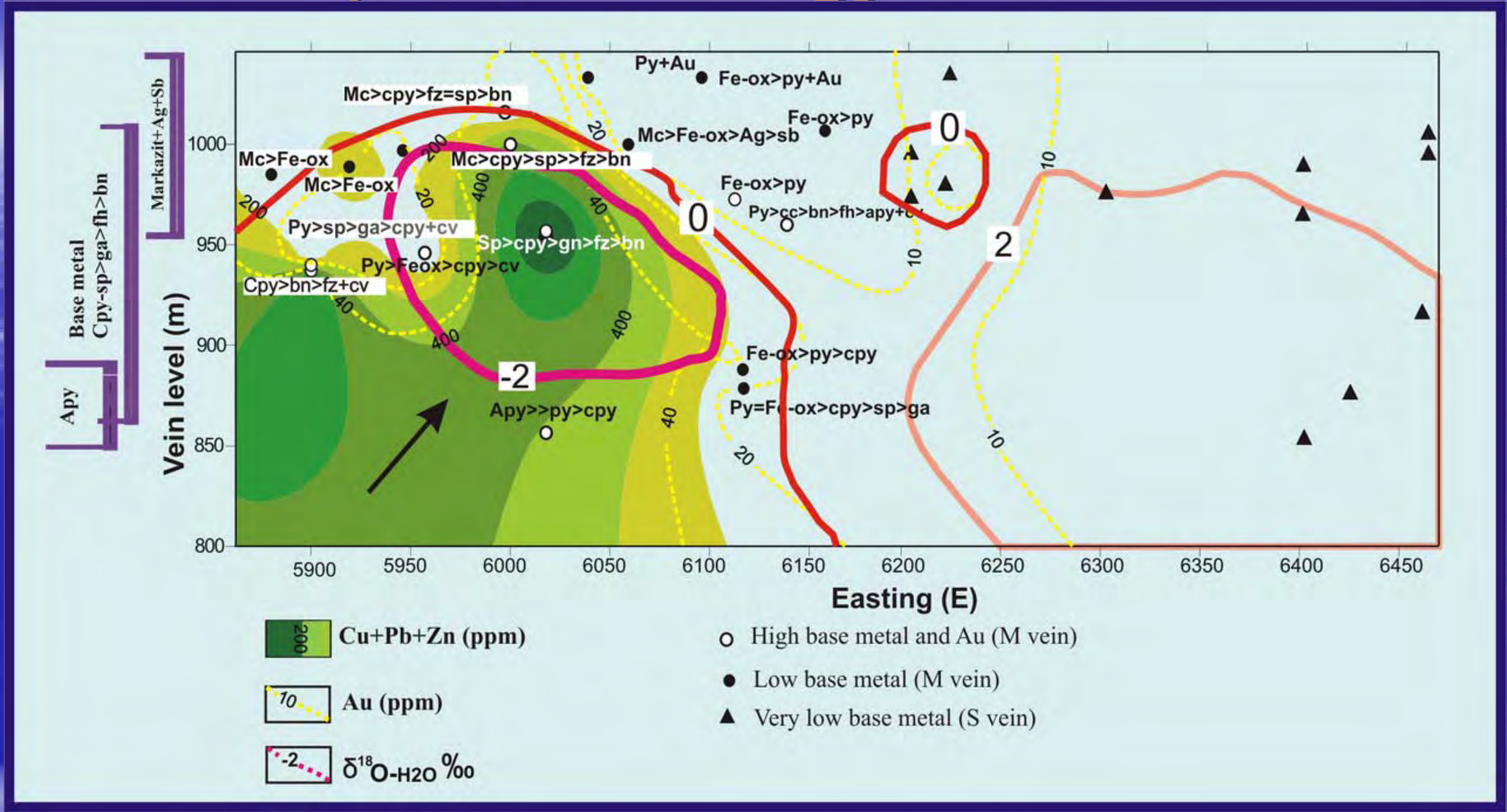
- Fluids of meteoric origin appear to be dominant with lesser magmatic contribution at Ovacik deposit.
- LS deposits elsewhere in the world commonly show an O-shift from local meteoric water values, whereas high-grade ore samples as in the Comestock Lode epithermal gold deposit have both an O- and D-isotopic shift from local meteoric water, likely caused by magmatic water addition (Hedenquist and Lowenstern,1994)
- Such significant shift at Ovacik deposit can not only be caused by boiling of meteoric water.

Stable Isotope



- Kodera et al. (2005) suggested that boiling of 90 % of liquid would result in a maximum enrichment of 3.9 ‰ $\delta^{18}O$ and a maximum relative depletion of 13 ‰ in δD.
- The variation in the samples reported at Ovacik (up to 6.4 ‰ for $\delta^{18}O$ fluid and 25 ‰ for δD fluid) therefore, demonstrate that the end stages of open-system boiling and fractionation could not have been reached everywhere, but locally.

Stable Isotope/Mineralogy/Au Geochemistry



- **In M vein (Ovacik W), spatial association of highest Cu+Pb+Zn and Au values with depleted $\delta^{18}O\text{-}_{H_2O}$ is noticed.**
- **The low $\delta^{18}O\text{-}_{H_2O}$ (bulls-eye) may represents the locus of the highest water/rock ratio.**
- **Therefore, this may be considered as an important guide for further exploration in the region.**

Conclusions

- **Gold deposits are of low sulfidation.**
- **Ore minerals are mainly electrum, acanthite, tetrahedrite ($Cu_{12}Sb_4S_{13}$), rare pyrargyrite (Ag_3SbS_3), mostly in M vein.**
- **Temperatures of the formation of the alteration and mineralization are~ 200 ºC at Ovacik and 260 ºC, at Narlica, deduced from fluid inclusion and alteration minerals. Salinity is< 2 eq. wt. % NaCl.**
- **Enrichment of K, Rb, Cs (in Adularia, sericite) by a factor of 2 and depletion of Mg, Na, Ca, Sr by a factor of >5 *in altered wall rock* show that significant water/rock interaction occurred.**
- **Depletions of Sr by a factor of 23 and, of Mg, Ca and Na and by factors of 48, 60 and 84, respectively, in *mineralized quartz veins* points to a very significant water/rock interaction.**
- **LREE (La-Eu) concentrations in quartz veins were reduced by factors of 7 to 15, indicating mobilization of REE under conditions of significant fluid flow. This may be important guide/hint in exploring for potential Au-Ag fields.**

Conclusions

- Moderate to strong positive correlations ($R=0.51-0.72$) between Au and Ag, Pb, Zn, Cu, Sb suggest that they may be related to the same mineralizing event.
- Very weak correlations between Au-As and Ag-As indicate different mineralizing events, introduction of As and Au-Ag in different phases.
- Ore-forming hydrothermal fluids have $\delta^{18}O_{-H_2O}$ values (Ave: -0.6‰), where ^{18}O is enriched compared with present-day geothermal water (-6.8 ‰, from hot springs and production wells).
- $\delta^{18}O$ values in the Ovacik deposit have been shifted from meteoric (-5.4‰) to hydrothermal (-0.6‰), to more ^{18}O-rich compositions by water/rock interactions or probably by some magmatic water contributions.

Conclusions

- In M vein, coincidence of high Cu+Pb+Zn and Au values with depleted $\delta^{18}O_{-H_2O}$ isotope values (bulls-eye) may represent the locus of the highest water/rock ratio.
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- A larger area with clay-adularia alteration (~30 km^2) in the study area may be sampled for *Oxygen Isotope* analysis to identify the *$\delta^{18}O$-depleted* locations, which may further lead us to identify the potential fields for gold mineralizations.

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