Structural control and tectonic environment of the Cenozoic giant Kadjaran porphyry Cu-Mo and epithermal system, southern Armenia, Lesser Caucasus

HOVAKIMYAN, Samvel, et al.

Abstract

In this contribution, we focus on the Oligocene to Miocene structural evolution of the giant Kadjaran porphyry Cu-Mo deposit and its epithermal overprint. This evolution was controlled by long-lived regional faults during the Cenozoic tectonic and magmatic evolution of the Meghri-Ordubad composite pluton located in the southernmost Lesser Caucasus. We discuss the ore-bearing fracture network characteristics related with the deposit-scale ore-controlling structures in the frame of regional strike-slip faults. Stereonets summarizing the orientations of different generations of mineralized veins allow us to constrain the favorable fracture network environment for ore-formation at the giant Kadjaran deposit. During the middle - late Oligocene, NNE-oriented shortening created the major ~N-S- and NE-oriented steeply dipping ore-controlling deposit-scale faults under dextral strike-slip tectonics. The gently to moderately dipping NE-, ~N-S- and ~E-W-oriented fracture networks along the steeply dipping deposit-scale faults were the most important structural control for the emplacement of the main porphyry stockwork [...]
Structural control and tectonic environment of the Cenozoic giant Kadjaran porphyry Cu-Mo and epithermal system, southern Armenia, Lesser Caucasus

Samvel Hovakimyan*, Robert Moritz, Hervé Rezeau
Department of Earth Sciences, University of Geneva, Switzerland
*Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, USA

Marianna Harutunyan, Arshavir Hovhannisyan, Rafael Melkonyan, Rodrik Tayan
Institute of Geological Sciences of the National Academy of Sciences of the Republic of Armenia

Gevorg Iskandaryan
Zangezur Copper Molybdenum Combine CJSC, 3309 Kadjaran, Republic of Armenia

Abstract. In this contribution, we focus on the Oligocene to Miocene structural evolution of the giant Kadjaran porphyry Cu-Mo deposit and its epithermal overprint. This evolution was controlled by long-lived regional faults during the Cenozoic tectonic and magmatic evolution of the Meghri-Ordubad composite pluton located in the southernmost Lesser Caucasus. We discuss the ore-bearing fracture network characteristics related with the deposit-scale ore-controlling structures in the frame of regional strike-slip faults. Stereonets summarizing the orientations of different generations of mineralized veins allow us to constrain the favorable fracture network environment for ore-formation at the giant Kadjaran deposit. During the middle-late Oligocene, NNE-oriented shortening created the major ~N-S- and NE-oriented steeply dipping ore-controlling deposit-scale faults under dextral strike-slip tectonics. The gently to moderately dipping NE-, ~N-S- and ~E-W-oriented fracture networks along the steeply dipping deposit-scale faults were the most important structural control for the emplacement of the main porphyry stockwork mineralization. These deposit-scale ore-controlling faults were reactivated during the early Miocene under WNW-oriented shortening and NNE-oriented extension. The progressive anticlockwise rotation of paleostress orientations from middle-late Oligocene to early Miocene was linked to reorganization of tectonic plates during Arabia-Eurasia collision.

1 Introduction

The giant Kadjaran porphyry Cu-Mo deposit and its epithermal overprint (2244 Mt @ 0.23% Cu, 0.033% Mo, 0.02 g/t Au) is located in southern Armenia, in the southernmost Lesser Caucasus and belongs to the Central segment of the Tethyan metallogenic belt. The Kadjaran deposit is hosted by the Cenozoic Meghri-Ordubad composite pluton (Karamyan and Faramazyan 1960; Mkrchyan et al. 1969; Tayan 1984; Hovakimyan et al. 2015; Moritz et al. 2016; Rezeau et al. 2016).

Recent structural investigations of the southernmost Lesser Caucasus emphasize the fundamental role of regional dextral strike-slip tectonics controlling the emplacement of porphyry Cu-Mo and epithermal deposits and prospects and the associated magmatism of the Meghri-Ordubad pluton (Hovakimyan et al. in press). This contribution is focused on the local fracture network characteristics of the Kadjaran deposit. Our aim is to understand the favorable structural conditions leading to the emplacement of this giant porphyry deposit and its epithermal overprint. This study is based on detailed district and deposit-scale structural mapping and data collected during the past 30 years, during the progressive development and mining of the deposit. The data set consists in thousands of measurements of different mineralized veins and fractures, crosscutting relationships of dikes and mineralized veins, and the kinematic analysis of the main ore-controlling structures. This data set allows us to constrain the Oligocene to Miocene structural evolution of the Kadjaran deposit, controlled by long-lived regional faults, which were active during the Cenozoic tectonic and magmatic evolution of the Meghri-Ordubad composite pluton.

2 Geological setting

The Kadjaran deposit formed at the intersection of the regional NNW-oriented Tashtun oblique-slip fault and the E-W-oriented Voghji sinistral strike-slip fault. It is hosted by monzonite and quartz-monzonite belonging to the composite Cenozoic Meghri-Ordubad pluton dated at 28.3 - 28.1 Ma (Rezeau et al. 2016).

The Kadjaran deposit is the result of two successive magmatic-hydrothermal events dated at 27.3 - 26.4 Ma and 22.2 - 20.5 Ma (Rezeau et al. in press), which can be associated with two distinct tectonic environments (Hovakimyan et al. in press). The structural framework of the deposit consists of an orthogonal system of steeply dipping (65-85°) ~E-W-, ~N-S- and NE-oriented sub-parallel deposit-scale ore controlling faults (Tayan 1984). They were formed during an early Oligocene dextral strike-slip tectonic environment, under a NE-oriented compressive regime, in a collisional setting, and were reactivated in a sinistral strike-slip tectonic regime during the early Miocene (Hovakimyan et al. in press).

3 Geometry of veinlets and veins

The main porphyry Cu-Mo ore consists of a ~N-S-elongated stockwork confined to a more than 3.5 km-long and about 2 km-wide corridor, and subsidiary isolated veins (Tayan 1984). The majority of the porphyry ore-bearing zones contain gently dipping (25-40°), sub-parallel sets of mm- to 5 cm-thick mineralized veins (Tayan 1984; Hovakimyan et al. in press). The relatively larger subsidiary, isolated porphyry Cu-Mo veins are hosted by ~N-S- and ~E-W-oriented structures. The main porphyry stockwork consists of gently dipping thin, veinlet systems. Crosscutting and displacement relationships of the mineralized fractures and detailed studies of the age relationship between different paragenetic mineral associations were the criteria for distinction of ten stages of mineralization at the Kadjaran deposit (Karamyan and Faramazyan 1960).

The stereonets summarizing the data of the different mineralized veins and veinlets show significant variations in orientations at the different historical mining levels of the open pit (Fig. 1). In the central part of the open pit, the majority of the ore-bearing fractures are NE-oriented with a moderate dip to the NW. The porphyry ore consists of quartz-molybdenite, quartz-molybdenite-chalcopyrite, and quartz-chalcopyrite veinlets hosted by NE-oriented extension fractures dipping gently to moderately to the SE and ~E-W-oriented extension fractures dipping 15-25° to the south, and 60° to the north (Fig. 1: stereonets 3, 5, 6 and 7). The other dominant orientation of quartz-molybdenite veinlets in the central part of the open pit consists of ~N-S-oriented subparallel extension fractures gently dipping to the W (20-35°) (Fig. 1: stereonets 2 and 3), and ~N-S-oriented ore-bearing fractures, steeply dipping to the W (75-80°). This structure also hosts isolated thick veins having the same ~N-S-strike.

In the central part of the open pit, at the historical mining level 1965m (not shown in Fig. 1), ~N-S-oriented fractures hosting quartz-polymetallic veinlets overprint thick quartz-molybdenite veins within the gently dipping fracture systems, dipping 20-40° to the W (Tayan 1984). They also host late carbonate and chalcedony veins.

In the northwestern part of the open pit, next to the...
Tashtun fault, abundant NE-oriented quartz-molybdenite veins dip 25-30° to the NW and NW-oriented quartz-molybdenite veins dip 25-35° to NE. Quartz-pyrite veins are hosted by N-S-oriented fractures, and dip 60-70° to the W (Fig. 1: stereonet 1).

In the northeastern part of the deposit, the ore type is significantly different from the central part of the open pit. The ore-controlling structures of this part are mainly NE-oriented, strike-slip deposit-scale faults dipping 55-70° to NW. The ore is mainly composed of quartz-chalcopyrite veins (Fig. 1: stereonet 4). Single, isolated quartz-molybdenite veins are scarce. Late mineralization stages, consisting of quartz-pyrite, quartz-sphalerite-galena, quartz-carbonate and chalcedony veins are abundant (Tayan 1984). They are hosted by NE-oriented fracture systems, steeply dipping to the NW and SE. The thick, isolated veins are confined within the NE-oriented structures. In the NE part of the deposit (Fig. 1: stereonet 4), there are also NE-oriented reverse structures, steeply dipping to the NW (75-85°). Quartz-molybdenite and quartz-pyrite veinitles moderately dipping to the NW have the same strike. E-W-oriented thrusts steeply dip (80°) to the south. Epithermal veins in the 6th vein zone are emplaced along ~E-W-oriented fractures zones (Fig. 1; Rezeau et al. in press).

The southeastern part of the open pit in the Schlorkut area mainly contains quartz-chalcopyrite veins, and only subsidiary quartz-molybdenite and quartz-pyrite veins. The epithermal overprint is controlled by subvertical N-S-oriented structures (Hovakimyan et al. 2015).

4 Kinematic analyses of the ore-controlling structures

Kinematics along the deposit-scale ore-controlling faults varies consistently with orientation: ~N-S- and NE-oriented structures record dextral strike-slip kinematics during the late Oligocene. The displacement pattern is kinematically coherent, and consistent with NNE-oriented shortening (Fig. 2). The geometry and dominant NE- and ~N-S-orientation of porphyry veinlets and veins are consistent with dextral strike-slip kinematics along the ~N-S and NE-oriented steeply dipping structures in the central and northern parts of the open pit, formed under a NNE-oriented shortening (Peacock and Sanderson 2018) (Fig. 2a).

Many of the steeply dipping ore-controlling structures in Kadjaran record reverse kinematics, favorable for the opening of gently dipping extensional fractures (Fig.3a). The major ~E-W-oriented deposit-scale faults in the central and northeastern part of the open pit are dipping to the north (75-80°) and record sinistral strike-slip kinematics and repeated reaction. We recognize different mineralization events along the same structures. Younger ~E-W- to WNW-oriented porphyritic granodiorite dikes (22.2 Ma; Moritz et al. 2016; Rezeau et al. 2016) are also related with the early Miocene sinistral reactivation of ~E-W-oriented strike-slip structures, which is consistent with the re-orientation of the tectonic plate kinematics and re-organization of the Arabia-Eurasia collision during the early Miocene.

5 Paleostress reconstructions and evolution in time

Paleostress orientation analysis in middle to late Oligocene host monzonte and monzodiorite indicates NNE-oriented shortening direction and WNW-oriented extension (Fig. 2a) during Arabia-Eurasia collision (Hovakimyan et al. in press). The same shortening direction is indicated by the kinematics analyses of quartz-molybdenite porphyry veins (Fig. 2b).

In late Oligocene rocks dated at 24.5 Ma (Rezeau et al. 2016), paleostress reconstructions document N-S-oriented shortening and E-W-oriented extension (Fig. 2c). In early Miocene porphyritic granite dated at 22.6 Ma (Moritz et al. 2016; Rezeau et al. 2016), paleostress reconstructions indicate WNW-ESE-oriented shortening and NNE-oriented extension (Fig. 2d).

6 Discussion and conclusions

6.1 Middle to late Oligocene ore controls and tectonic regime

Paleostress reconstructions indicate two main tectonic events in the Kadjaran mining district. They are consistent with progressive anticlockwise rotation of paleostress orientations from the middle - late Oligocene to the early Miocene (Fig. 2), which was linked to the reorganization of the tectonic plates during Arabia-Eurasia collision (Hovakimyan et al. in press). During the middle to late Oligocene, NNE-oriented shortening and WNW-oriented extension initiated the major N-S- and NE-oriented ore-controlling structures under dextral strike-slip tectonics. This regime is compatible with the emplacement of N- to NE-oriented fine-grained porphyritic granodioritic and lamprophyre dikes (Tayan et al. 1984; Harutunyan et al. 2002) dated between 26.6 and 24.5 Ma (Rezeau et al. 2016) and dominantly NE-

Figure 2. Paleostress reconstructions of the Kadjaran mining district, based on the geometry of conjugate fracture systems in magmatic rocks (a, c, d), and the slickensides along the quartz-molybdenite porphyry veins (b).
and N-S-oriented porphyry veins and veins dated at 27.3 to 26.4 Ma (Moritz et al. 2016; Rezeau et al. 2016). During the NNE-oriented shortening regime (Fig. 2c), many E-W-oriented deposit-scale faults behaved as thrust faults, which was favorable for the opening of gently dipping extension fractures (Fig. 3a). This fracture network resulted in high permeability around the steeply dipping deposit-scale faults and was the most important structural control for the emplacement of stockwork mineralization, which consists predominantly of gently to moderately dipping veins (Fig. 1).

![Figure 3. Models for the relationship among extension fractures, faults and principal stresses: (a) reverse (thrust) faulting, (b) normal dip-slip faulting (Mikhailov 1984; Blenkinsop 2008).](image)

6.2 Early Miocene reactivation of preexisting ore-controlling structures

During the early Miocene event, WNW-oriented shortening and NNE-oriented extension resulted in reactivation of pre-existing structures in a sinistral strike-slip tectonic regime (Hovakimyan et al. in press). This setting played an important role in controlling the emplacement of the early Miocene ~E-W-oriented coarse-grained porphyritic granodioritic dikes dated at 22.2 to 21.2 Ma (Rezeau et al. 2016), which represent the youngest dike generation in the district (Tayan et al. 1984; Harutunyan et al. 2002). This paleostress setting controlled the emplacement of an epithermal overprint at 22.2-20.5 Ma (Rezeau et al. 2016; in press). Epithermal veins were mainly emplaced along ~E-W-oriented fractures zones, steeply dipping to the north and south, but also along ~N-S-oriented structures, as a result of repeated reactivation during the entire ore forming life of the deposit. In the southeastern part of the open pit, the epithermal mineralization consists of gently dipping Cu-rich veins merging with the major steeply dipping structure (Fig. 3a). The early Miocene epithermal overprint at the Kadjaran porphyry deposit and the sinistral fault reactivation are linked to late Neogene tectonic plate reorganization.

The long tectonic history of the Meghri-Ordubad district preceding ore-formation explains the favorable geological and structural settings for the emplacement of the Kadjaran deposit. The available structural data allow us to conclude that the fracture and plumbing systems were formed continuously during the entire life span of the formation of the Kadjaran deposit. N-S-, NE and E-W-oriented deposit-scale faults, characterized by different kinematics, controlled ore formation under a regional dextral strike-slip tectonic regime.

Acknowledgements

This study was financially supported by the National Academy of Sciences of Republic of Armenia, the SCOPES projects IB7620-118901 and I27320-128324 and the Swiss National Science Foundation projects 200020-138130, 200020-155928 and 200020-168996. S. Hovakimyan has been funded by the Swiss Government Excellence Postdoctoral Scholarship, Foundation Ernst et Lucie Schmidheiny (University of Geneva), Foundation Azad and the Swiss Chapter of the Armenian General Benevolent Union (Taline Avakian). We thank Marion Grosjean for participation in fieldwork, and the staff of the Zangezur Copper-Molybdenum Combine for access to the Kadjaran mine and for logistical help.

References


