

GEOLOGY AND STRUCTURAL CONTROL ON THE ÇATALÇAM
(MANİSA, WESTERN TÜRKİYE) MINERALIZATION

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**GEOLOGY AND STRUCTURAL CONTROL ON THE ÇATALÇAM
(MANİSA, WESTERN TÜRKİYE) MINERALIZATION**

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

GEOLOGY AND STRUCTURAL CONTROL ON THE ÇATALÇAM (MANİSA, WESTERN TÜRKİYE) MINERALIZATION

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Çatalçam Zn-Pb-Au mineralization is located in the western part of the Sakarya Zone in western Türkiye. The Sakarya Zone includes segments affected by magmatism that existed from the Late Cretaceous to the Late Miocene as a result of the convergence of Laurasia and Gondwana which provided productive mineral deposits. Tectonically, Çatalçam lies to the west of the NNE-SSW-oriented İzmir-Balıkesir Transfer Zone (IBTZ), whose eastern and western borders are not clearly defined. There are six units identified in the study area; these units are Karakaya Complex, Soma Formation, Terziler Granodiorite, Yuntdağ Volcanics, Çatalçam Diorite and basaltic andesite dykes, generally located in the same orientation as most of ore-bearing veins.

The Çatalçam Pb-Zn-Au mineralization occurs along quartz±barite±carbonate±sulfide veins hosted in Miocene (~17 Ma) volcanic and sub-volcanic lithologies. Fault surfaces and vein exposures correlate well with surface geochemical anomalies. Geochemistry results show that Au mineralization

accompanies Pb-Zn mineralization in the west of the study area, while Pb-Zn anomaly is dominant in the east. This difference is explained by control of two main fault segments. The first one is the westward dipping normal P318 fault, whose orientation corresponds to the general orientation of the IBTZ, which caused the western subsidence of the site and erosion of the eastern block, which is observed as a 100 m vertical offset in the drilling data. The other is the P2 fault, mapped along the western sector.

Pb-Zn-Au mineralization at Çatalçam is mainly accompanied by widespread argillic alteration in the volcanic wall-rocks with predominant quartz-illite/smectite alongside varying amounts of chlorite and carbonate. Beneath the mineralized levels, argillic alteration transitions first into quartz-sericite and later into potassic alteration with increasing depth. Mineralized veins and breccias contain variable amounts of pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, and rare native gold. The abundance of base metals, presence of Mn-carbonates, and the ore assemblage suggest that Çatalçam is an intermediate-sulfidation epithermal system underlain by a weakly-mineralized porphyry Cu mineralization. This mineralization style differs from all known gold-rich systems in and around the IBTZ, which are generally of low-sulfidation epithermal style.

Keywords: Western Anatolia, İzmir-Balıkesir Transfer Zone, Epithermal Pb-Zn-Au Ore Deposits, Tethyan Metallogenic Belt

ÖZ

ÇATALÇAM (MANİSA, BATI TÜRKİYE) MİNERALİZASYONUNUN JEOLJİSİ VE YAPISAL KONTROLÜ

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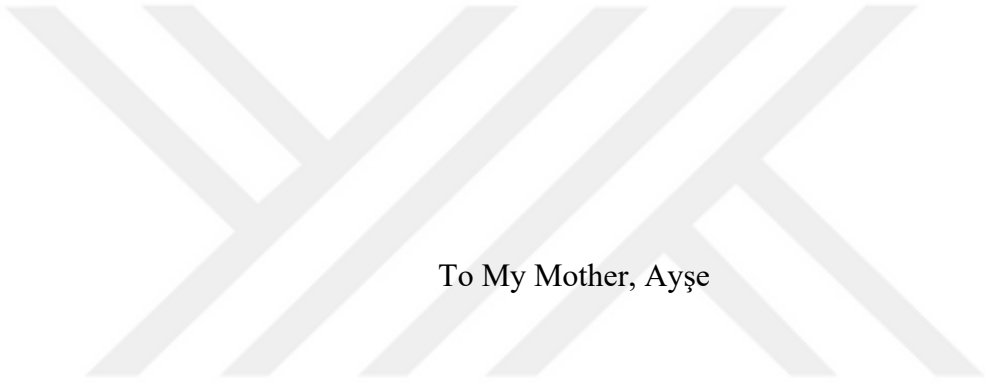
Çatalçam Zn-Pb-Au cevherleşmesi Türkiye'nin batısında Sakarya Zonu'nun batı kesiminde yer almaktadır. Sakarya Zonu, verimli maden yatakları sağlayan Laurasia ve Gondwana'nın yakınlaşması sonucu Geç Kretase'den Geç Miyosen'e kadar var olan magmatizmanın etkilediği kesimleri içermektedir. Tektonik olarak Çatalçam, doğu ve batı sınırları kesin olarak belirlenemeyen KKD-GGB yönlü İzmir-Balıkesir Transfer Zonu'nun (IBTZ) batısında yer alır. Çalışma alanında tespit edilen altı birim bulunmaktadır; bu birimler Karakaya Kompleksi, Soma Formasyonu, Terziler Granodiyoriti, Yuntdağ Volkanitleri, Çatalçam Diyoriti ve genellikle cevher içeren damarların çoğuyla aynı doğrultuda olan bazaltik andezit dayklarıdır.

Çatalçam Pb-Zn-Au cevherleşmesi Miyosen (~17 My) volkanik ve subvolkanik litolojilerde yer alan kuvars±barit±karbonat±sülfür damarları boyunca meydana gelir. Fay yüzeyleri ve damar yüzeylenmeleri yüzey jeokimyasal anormallikleri ile doğru ilişkilidir. Jeokimya sonuçları, çalışma alanının batısında Pb-Zn cevherleşmesine Au cevherleşmesinin eşlik ettiğini, doğusunda ise Pb-Zn anomalisinin hakim olduğunu göstermektedir. Bu fark iki ana fay bölümünün

kontrolü ile açıklanmaktadır. Bunlardan ilki, yönelimi IBTZ'nin genel yönelimine karşılık gelen, sondaj verilerinde 100 m'lik düşey ötelenme olarak gözlenen, alanın batıya doğru çökmesine ve doğu bloğunun aşınmasına neden olan batıya eğimli normal P318 fayıdır. Diğeri ise batı sektörü boyunca haritalanan P2 fayıdır.

Çatalçam'daki Pb-Zn-Au cevherleşmesine esas olarak volkanik yan kayaçlardaki yaygın arjilik alterasyon eşlik etmekte olup, baskın olarak kuvars-illit/simektit ve değişen miktarlarda klorit ve karbonat bulunmaktadır. Cevherli seviyelerin altında arjilik alterasyon derinlik arttıkça önce kuvars serisite, daha sonra potasik alterasyona geçer. Mineralize damarlar ve breşler değişken miktarlarda pirit, sfalerit, galen, kalkopirit, tetrahedrit ve nadir doğal altın içerir. Baz metallerin bolluğu, Mn-karbonatların varlığı ve cevher topluluğu, Çatalçam'ın zayıf mineralize porfiri Cu cevherleşmesinin altında yatan bir ara sülfidasyon epitermal sistemi olduğunu göstermektedir. Bu cevherleşme tarzı, IBTZ içinde ve çevresinde, genellikle düşük sülfidasyonlu epitermal tarzda olan, bilinen tüm altın bakımından zengin sistemlerden farklıdır.

Anahtar Kelimeler: Batı Anadolu, İzmir-Balıkesir Transfer Zonu, Epitermal Pb-Zn-Au Maden Yatakları, Tetis Metalojenik Kuşak



To My Mother, Ayşe

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CHAPTER 1

INTRODUCTION

1.1 Purpose and Scope

Mining of metals have been a crucial activity for humans since ancient times. Western Anatolia has been a major mining region, especially for mining of precious metals, since the Neolithic Period (Oy, 2017). During the past three decades, Western Anatolia has gained further significance as a part of the Tethyan Metallogenic Belt following the discoveries of economic magmatic-hydrothermal deposits including the Ovacık and Efemçukuru epithermal Au and Kışladağ porphyry Au deposits. Majority of the economic precious and base metal deposits and numerous other occurrences of porphyry, epithermal and skarn/carbonate replacement-type mineralization, are clustered in the Biga Peninsula and in the region that lies to the south of the Biga Peninsula, adjacent to the Kozak Pluton (Figure 1).

This study focuses the Çatalçam Pb-Zn-Au-Ag prospect, which is one of the recent and most significant discoveries in Western Anatolia. Tectonically, Çatalçam is positioned in the northern margin of the Bornova Flysch Zone, to the south of Biga Peninsula and approximately 30 km ENE of the Kozak Pluton (Figure 1). In the study area, Pb-Zn-Au-Ag mineralization is associated with epithermal-style quartz-carbonate-barite-sulfide veins hosted in Miocene volcanic and sub-volcanic lithologies. The prospect was initially targeted by the General Directorate of Mineral Research and Exploration (MTA) through surface geochemistry and subsequent

drilling campaigns. Following early exploration, MTA, claimed that Çatalçam contains gold reserves of ≥ 100 tons (or ≥ 3.2 Moz), which resulted in a major interest in the prospect. Since 2018, the prospect is owned by the Türkiye Wealth Fund (TWF), who continued with more detailed surface sampling and follow-up drilling of the prospect. A recent study by Sarı et al. (2022) presented preliminary geological, mineralogical, and ore paragenetic data from Çatalçam. Despite this, the true potential, detailed geology, geometry, and kinematics of the structural elements that controlled the mineralization in the prospect are not well-known at the present time. In this regard, one of the primary purposes of this study is to unravel the tectonic and structural controls as well as the geometry of Çatalçam related to epithermal ore formation.

For this purpose, the following tasks are performed within the scope of this thesis;

- i. Mapping out 3D geometry of the ore bodies and associated host rocks lithologies as well as alteration zones,
- ii. Mapping out structural elements related to the ore development and evolution,
- iii. Determining kinematic characteristics of the structural elements,
- iv. Investigating the spatial relationship between the existing epithermal mineralization and the deeper porphyry system.
- v. Providing insights into the spatial and temporal constraints on the development and emplacement mechanisms of minerals in the study area.

To reach these goals, an extensive field study was carried out, which also included sampling of the key lithologies and mineralized/altered rocks from Çatalçam. Field investigations are complemented with petrographic studies on collected samples. The obtained results are then interpreted to provide information regarding the genetic

relationship between the local (Çatalçam and regional (NW Anatolia) mineralization. Additionally, they help elucidate the lithological and structural controls on the mineralization within the study area.

1.2 Tectonic Setting

Mesozoic evolution of Anatolia is related to the opening of various branches of Neotethys Ocean and the convergence between Gondwana-derived continental fragments and Laurasia since the Paleozoic (Şengör and Yılmaz, 1981). Tectonic subdivisions of Anatolia were first made by Naumann (1896) based on geomorphological features such as mountain ranges. Afterwards, Staub (1924), Seidlitz (1931), Kober (1931), Arni (1939), Blumenthal (1946), and Egeran (1947) proposed their classification schemes. Most of these classifications have not survived the advent of plate tectonics, however, the classification scheme proposed by Ketin (1966) is partly still in use, which divides Anatolia into four major tectonic units. From north to south, these are: the Pontides in the north (north of 40°N latitude), the Anatolides are located at the center, Taurides lie at the southern margin of Turkey, and the Border Folds located in SE Anatolia. Recent studies indicated that Pontides have Laurasia affinity while the other tectonic units were mainly evolved in relation to Gondwana. After the seminal work of Şengör and Yılmaz (1981), the tectonic units of Anatolia are subdivided into three major units. These are from north to south; (1) Pontides that comprise all the Laurasia-derived units as well as the Sakarya Zone and is distinguished with metamorphosed Paleozoic basement except for the İstanbul Unit. (2) Taurides that, have Gondwana affinity and are characterized by almost continuous Paleozoic to Tertiary continuous sequences with metamorphic Precambrian basement. The metamorphosed northern part of the Taurides is named Anatolides (Ketin 1966). The age of Metamorphism is generally accepted as Late

Cretaceous to Early Cenozoic and resulted from the southwards obduction of the ophiolitic mélanges and the Pontides over the Taurides by Late Cretaceous (Şengör and Yılmaz 1981).

The southernmost tectonic units comprise 3) African and Arabian plates which have been shaping the recent tectonic scheme of Turkey.

The study area is located in the western part of the Sakarya Zone. The tectonic position of the Sakarya Zone is still under debate since it comprises Paleozoic to Triassic lithologies derived from the Taurides but unlike Taurides it comprises a metamorphosed Paleozoic basement.

The magmatism associated with the subduction and further convergence between the Laurasia and Gondwana-derived units resulted in widespread late Cretaceous to Late Miocene magmatism, creating a very fertile metallogenic environment containing calc-alkalic and alkalic porphyry Cu (-Mo-Au) and magmatic-hydrothermal systems introduced in various segments of the Sakarya Zone (Kuscu et al., 2019).

The present tectonic scheme of Türkiye is dominated mainly by two major tectonic processes. These are related to the westwards flee of the Anatolian Block along the dextral North Anatolian and sinistral east Anatolian Fault Areas Y and West Anatolian Extensional Regime that is associated with the back-arc extension related to slab roll-back processes manifested by migration of locus of extension and magmatism southwards (Uzel et al., 2020) as the northwards subducting African lithosphere below Anatolia migrated southwards along the South Aegean-Cyprean convergence zone (Şengör et al., 1985, Kaymakci et al., 2018, Uzel et al., 2020, Özkaptan et al., 2022).

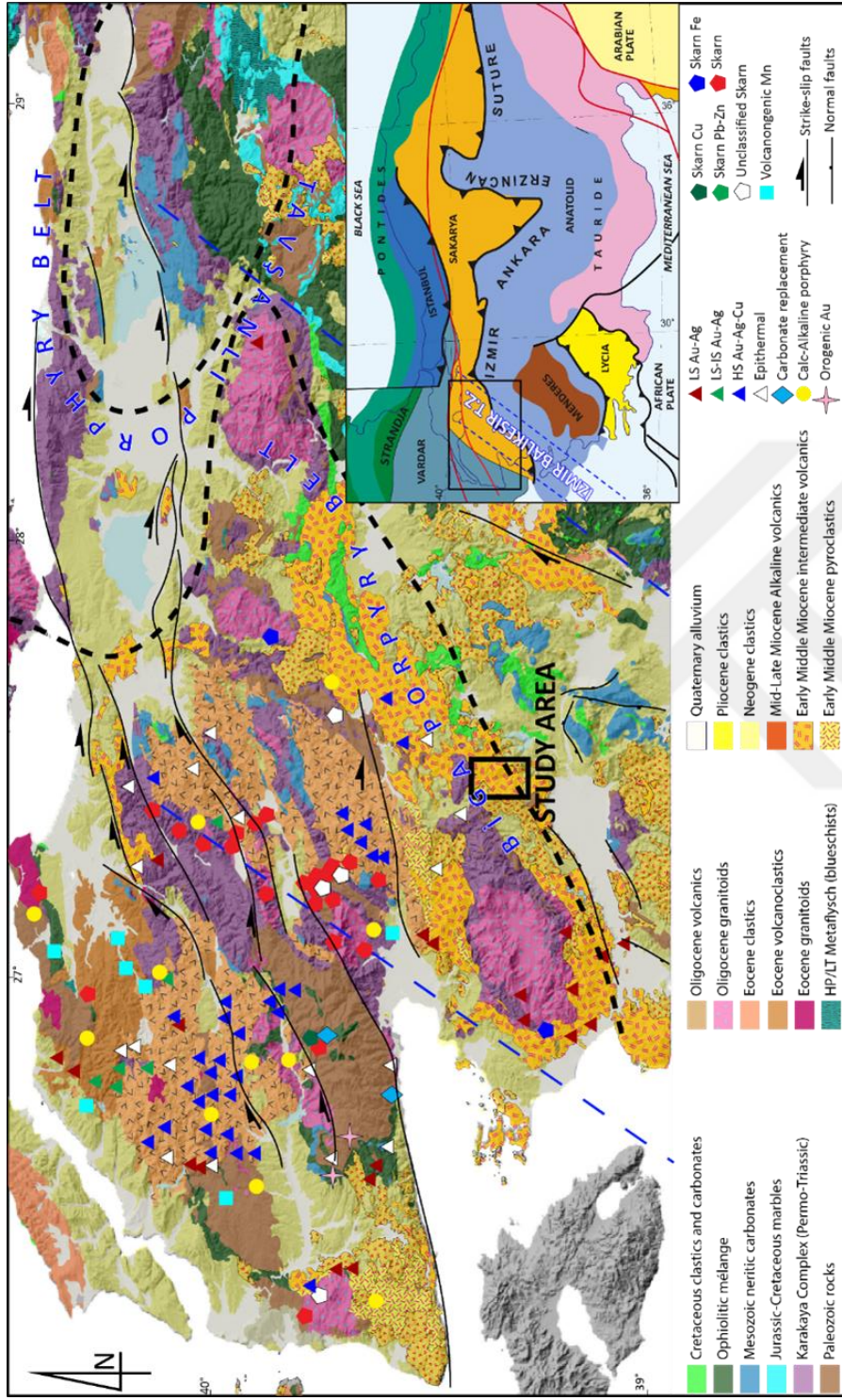


Figure 1. The geological map of the close-up view of the Western Anatolia (Kuşçu et al., 2019) with mineral deposit occurrences (Yigit, 2012) and b) regional tectonic units of the eastern Mediterranean (Kaymakçı et al., 2010).

One of the most prominent structures in western Anatolia is the recently recognized İzmir-Balıkesir Transfer Zone which transfers differential extension strain between Cycladic and Menderes Core complexes (Uzel et al., 2013). It is a wide NNE-SSW striking major transcurrent structure extending south of Marmara Sea to north of Crete Island in the south. Its western and eastern boundaries are not well defined, but the study area is located within central parts of the İBTZ (Uzel et al., 2015).

1.3 Metallogeny of NW Anatolia

The study area is located in the eastern margin of the Biga Porphyry Belt (Kuşçu et al., 2019) which is included within the late Cenozoic Western Anatolian Volcanic Province (WAVP) (Ersoy et al., 2012). The Biga porphyry belt is associated with 18.2-42.6 Ma porphyry belt dominated by porphyry Cu-Au and Mo deposits including quartz diorite to granite porphyry and andesite to dacite porphyries (Kuşçu et al., 2019). Yiğit (2012) claimed that Biga Peninsula magmatism is related to collision to post-collisional tectonics regime and contains almost all varieties of epithermal deposits ranging from high-, intermediate-, and low-sulfidation deposits as well as base metal skarn systems with high economic importance in addition to porphyry deposits. Yiğit (2012) further claimed that, of the 128 known ore deposits, 67 mineral deposits are reported as epithermal deposits, and the number of porphyry deposits is only 12 and 24 for skarns. In addition, the porphyry deposits in the Biga Peninsula are spatiotemporally associated with high-sulfidation epithermal deposits (Leroux, 2016).

In Biga Peninsula, exploration studies were focused on quartz alunite epithermal deposits which are Ağıdağı (Taylor, 1981; Kuşçu et al., 2019), Kuşçayır (Taylor, 1981; Kuşçu et al., 2019).

Leroux (2016) argued that there were at least three porphyry phases and two epithermal phases of mineralization in accordance with geochronological data (Figure 2) and Stage 1 magmatism produced porphyry and epithermal mineral deposits, while skarn type mineral deposits are the result of Stage 2 magmatism.

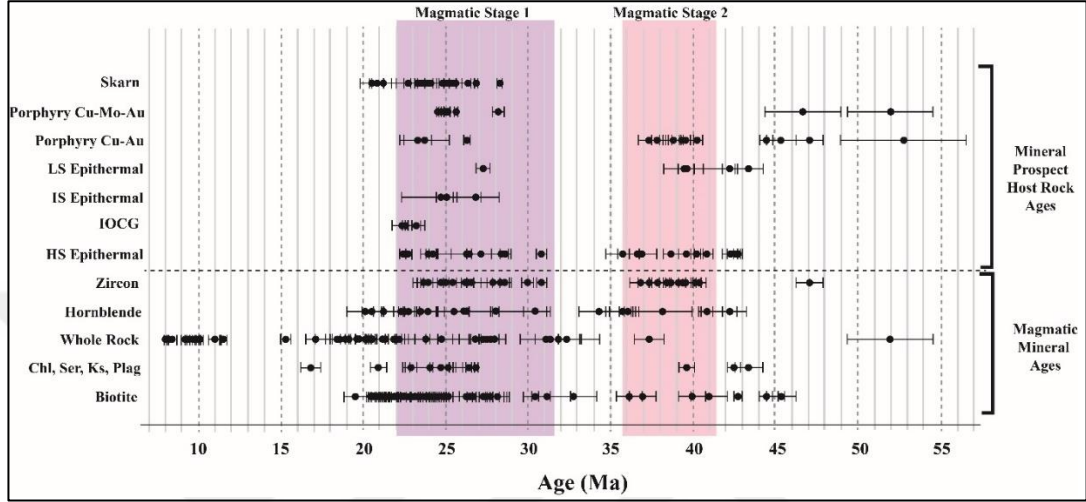


Figure 2. Age distribution of magmatic activity and metallic mineralization in western Türkiye (redrawn after Leroux, 2016; references paper for age database are inside).

In the Biga Peninsula, Cenozoic volcanism began in the Eocene extensively and is characterized by andesitic and dacitic calc-alkaline trend that continued with alkaline basaltic volcanism through the Late Miocene (Yılmaz, 1990). On the other hand, the middle Eocene volcanism starts with medium-K calc-alkaline character then continues with high-K calc-alkaline character during the Oligocene. Early Miocene volcanism is characterized by high-K shoshonitic lavas, while in the Middle Miocene to Late Miocene volcanism shifted from mildly alkaline to alkaline (Yigit, 2012, Uzel et al., 2020). Volcanism during the Middle to Late Miocene exhibits geochemical signatures with decreasing crustal contribution and it is accompanied by an enriched melt derived from the asthenospheric mantle (Altunkaynak and Genç, 2008).

CHAPTER 2

LOCAL GEOLOGY

The study area is located ~110 km northeast of İzmir, ~30 km northwest of Soma district of Manisa and in the southeast of the Biga Peninsula. The area comprises a number of lithologic units including the local basement rocks of the Karakaya Complex, and Late Cenozoic igneous rocks including the Terziler Granodiorite, Soma Formation, the Yuntdağ Volcanics, Çatalçam Diorite, and basaltic andesite dykes.

A large portion of the study area is covered by dense vegetation, and therefore surface exposures are relatively limited. However, based on outcrop observations combined with drill hole data an integrated geological map of the study area is prepared at a scale of 1: 30000 (Figure 3).

2.1 Karakaya Complex

The Karakaya Complex, which crops out in the northernmost part of the area, has undergone low-grade metamorphism, the veins cutting the Karakaya Complex are thought to be barren (Figure 4). Detailed descriptions of the lithological units are provided below.

The Karakaya Complex forms the local basement at and around the Çatalçam prospect. It is first recognized by Bingöl et al. (1975), who assigned the name “Karakaya Formation”. The Karakaya Formation includes two distinct lithologies, Nilüfer Unit and the Upper Blocky Series (also named as North Anatolian Mélange;

Tekeli, 1981). These consist mainly of sedimentary rocks, and the Karakaya Complex is characterized by the existence of exotic blocks Permian and Carboniferous limestone (Okay and Göncüoğlu, 2004).

The main lithologic unit of the Karakaya Complex in the study area is a metasandstone unit which crops out in the northern part of the study area. In the outcrop the rocks are gray (Figure 4a), whereas fresh surfaces are dark gray to dark green in color (Figure 4b). Quartz and subordinate plagioclase are the main minerals recognized in hand specimens. Same minerals were also identified in thin section as medium-grained, interlocking crystals, that are cemented by mica/sericite and chlorite (Figure 4c).

Metamorphic lithologies of Karakaya Complex are generally not associated with any mineralization in the study area, but these are locally cut by barren barite and quartz veins (Figure 4d). However, according to Sarı et al. (2022) chloritized metamorphic units contain weak disseminations of pyrite and chalcopyrite.

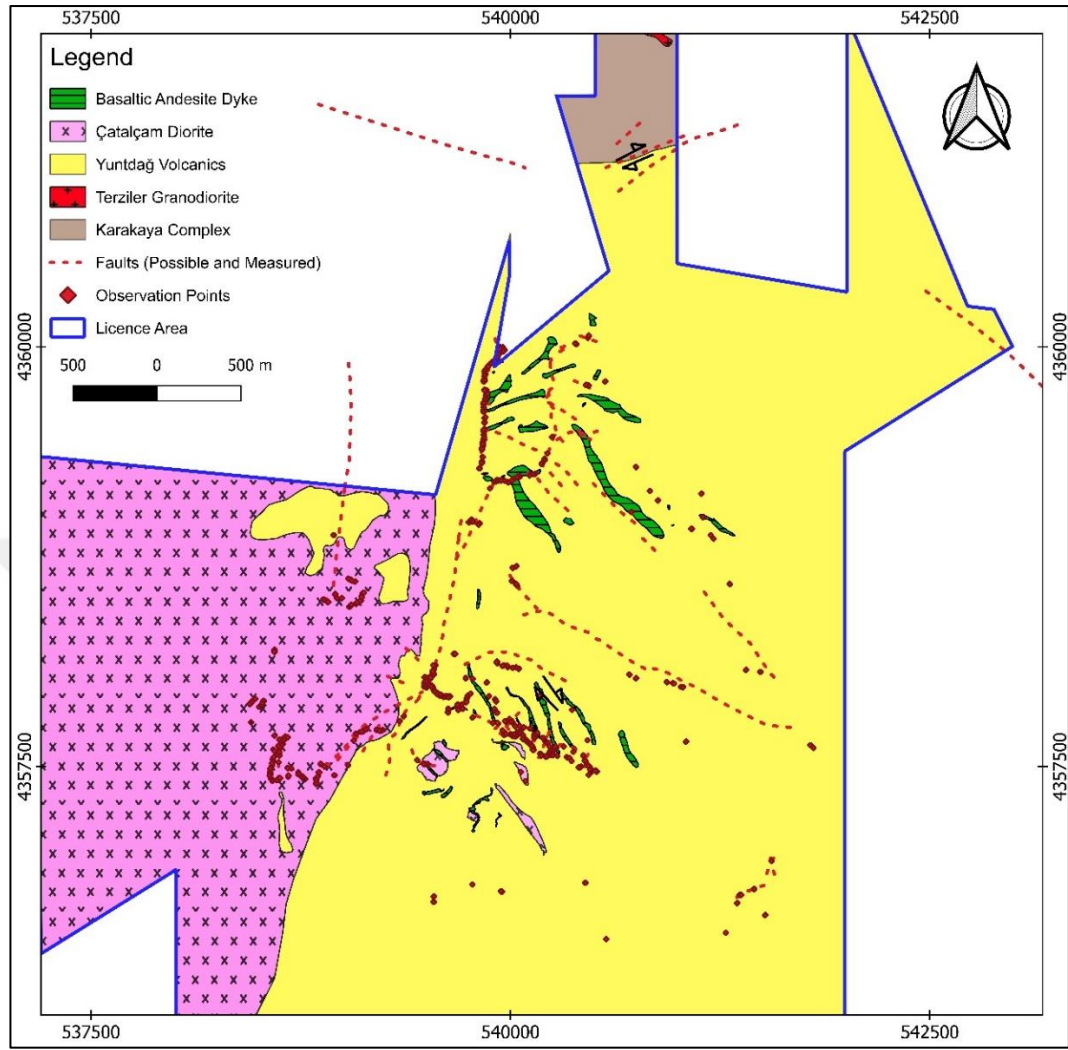


Figure 3. Geological map of the study area. Structural measurement points are also shown (red diamonds).

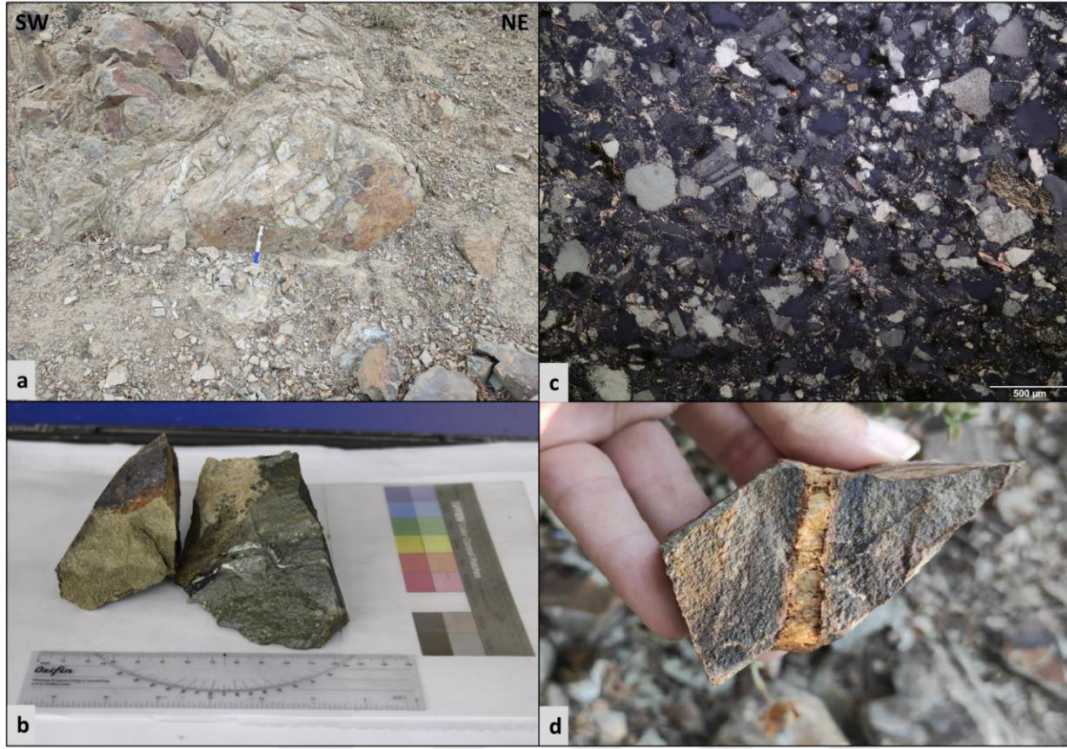


Figure 4. a) Outcrop, b) hand specimen, c) thin section images of weakly metamorphosed metasedimentary unit of the Karakaya Complex, d) barren barite vein cutting the Karakaya Complex.

2.2 Soma Formation

The Soma Formation (Philippon, 1910) comprises early to middle Miocene lacustrine and fan delta deposits, as well as shallow lake sediments that contain economic coal beds (İnci, 1998, 2002; Hokerek and Özçelik, 2015; Karayiğit et al., 2022). The Soma Formation is not exposed on the surface, but it is encountered in the drill holes, generally intersected beneath 250 m depth with thicknesses varying between 2 and 22 meters. It comprises intercalations of limestone, clay, marl, siltstone, sandstone and conglomerate in the north, west and southeast of Çatalçam outside the limits of the mapped area.

2.3 Terziler Granodiorite

The Terziler Granodiorite was first mapped by Özcan (1971). According to Özcan et al. (1971), this unit comprises orthoclase, plagioclase, quartz, hornblende, biotite, and opaque minerals, and local chloritization was observed after amphibole and biotite.

During field studies the Terziler Granodiorite was observed as a porphyritic unit dominated by quartz and lesser plagioclase and biotite (Figure 5a). Similarly, quartz, plagioclase and biotite are the main phenocryst phases in thin section, although both plagioclase and biotite have been affected from moderate to strong intensity hydrothermal alteration. Plagioclase has been transformed into sericite/clay and biotite has been completely altered to chlorite, calcite, and sericite. Amphibole was not detected in any of the collected samples. Quartz phenocrysts are commonly resorbed with embay textures (Figure 5b). Phenocryst phases are surrounded by a microcrystalline to glassy groundmass (Figure 5b).

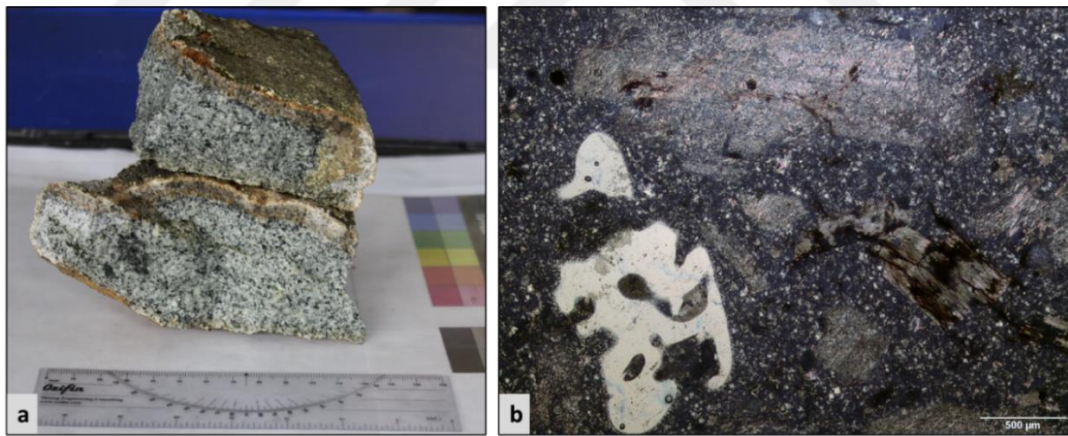


Figure 5. a) Hand specimen, and b) thin section images of Terziler Granodiorite.

2.4 Yuntdağ Volcanics

Middle Miocene – Pliocene Yuntdağ Volcanics were first mapped and named by Akyürek and Soysal (1981). The volcanic sequence consist of andesite and silicified tuffs, andesites, and lahar deposits. Seghedi et al. (2015) described Yuntdagi as a composite volcano. They identified various lithologies, which they dated through K/Ar dating. Main units from the Yuntdagi volcanic field were classified as andesitic and dacitic sub-volcanic intrusions (15.02 ± 1.75 Ma and 15.87 ± 0.69 Ma), andesite and rhyolite lava flows (15.79 ± 0.59 Ma, 15.90 ± 0.62 Ma, 17.22 ± 0.67 Ma, and 17.52 ± 0.67 Ma), and pyroclastic flow deposits with andesitic clasts (16.65 ± 0.62 Ma). Seghedi et al. (2015) highlighted that the main phenocryst of andesites in Yuntdağ Volcanics are plagioclase with sieve texture, pyroxenes, amphibole with marginal or total oxidation, and biotite that have rarely amphibole intergrowth.

At Çatalçam, the main lithology identified as a part of the Yuntdağ Volcanics is an andesite lava unit covering the eastern part of the prospect area (Figure 3). Andesitic lavas are quite friable in the outcrop due to intense alteration and low quartz content. Plagioclase occurs as the main phenocryst phase (up to 1.5 mm in length), but it is mostly altered into clays/sericite. In thin section, plagioclase phenocrysts display sieve and seriate porphyritic textures, and are surrounded by a fine-grained groundmass. Similar to plagioclase, all ferromagnesian (generally <500 microns) phases have also undergone complete replacement by sericite or they are opacitized, but former presence of biotite and amphibole is suspected due to their well-preserved crystal forms (Figure 6a,b,c). In the thin section, a zone of intense oxidation is also observed, which has affected both phenocrysts and groundmass (Figure 6d).

Andesitic lavas of the Yuntdag Volcanics are commonly cross-cut by epithermal-style quartz+barite±carbonate±sulfide veins, and in places these veins form dense stockworking zones in the outcrop (Figure 7).

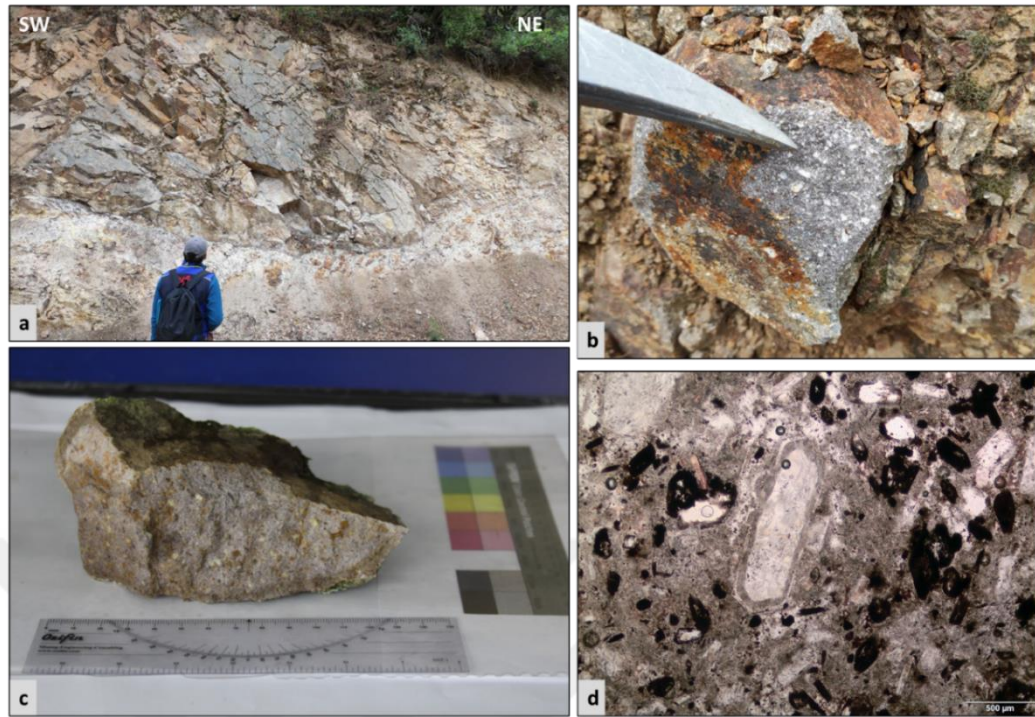


Figure 6. a) Outcrop, b-c) hand specimens, and d) thin section image of Yuntdag Volcanics.

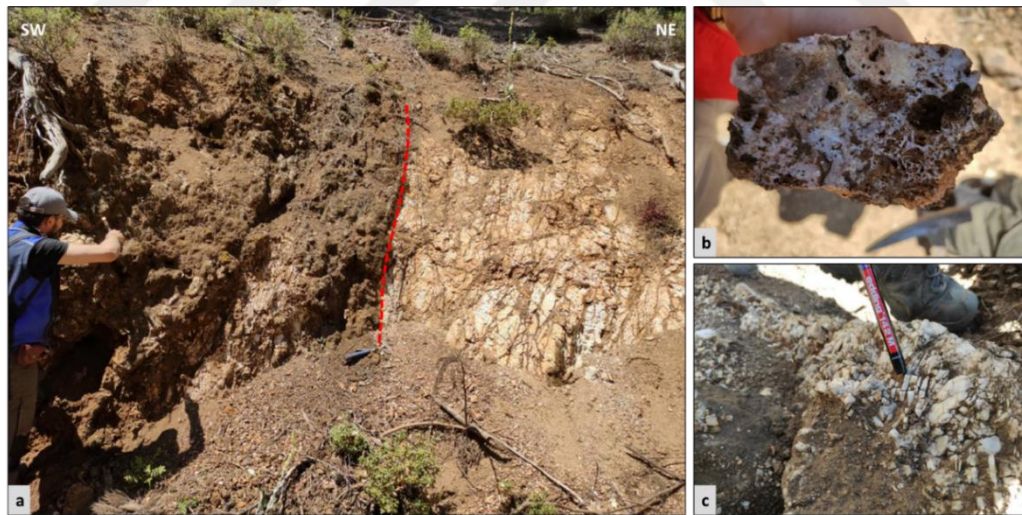


Figure 7. a) Strongly deformed and clay altered stockwork zone is cut by epithermal vein, and b-c) hand specimen images of epithermal vein.

2.5 Çatalçam Diorite

The Çatalçam Diorite is first identified by Sarı et al. (2022) as an intrusive phase, with dioritic composition and porphyritic texture. As such it is interpreted to be a sub-volcanic unit cross-cutting the Yuntdağ Volcanics (Figure 8a). Sarı et al. (2023) reported a U-Pb zircon age of ~17 Ma from this unit.

The Çatalçam Diorite is a porphyritic unit predominantly consisting of coarse-grained plagioclase and relatively finer-grained amphibole and biotite phenocrysts (Figure 8b). This unit is distinguished from the Yuntdağ Volcanics by higher intensity sericite/clay alteration and stockwork veining, as well as by the presence of coarser-grained plagioclase phenocrysts (Figure 8c). Plagioclase is accompanied by quartz and the ferromagnesian mineral content is significantly lower compared to the Yuntdağ Volcanics. Plagioclase phenocrysts have been affected by sericitization and clay alteration, whereas biotite has been replaced by a mixture of sericite, rutile, and quartz. Silicification is also present in the fine-grained groundmass.

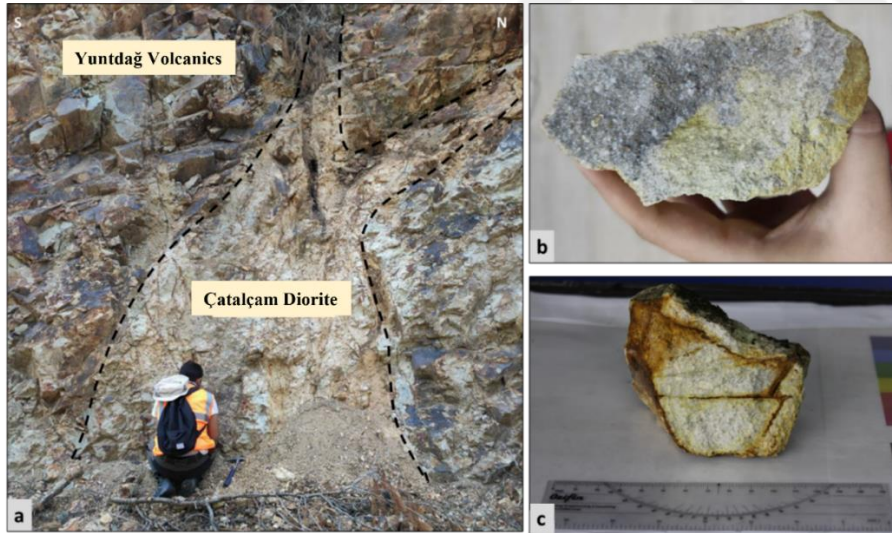


Figure 8. a) Outcrop image including boundary between Yuntdağı Volcanics and Çatalçam Diorite , b) hand specimen image with slightly clay alteration, and c) intensely clay altered and weathered hand specimen image.

2.6 Basaltic Andesite Dykes

At Çatalçam, the youngest identified igneous unit is represented by basaltic andesite dykes. These are observed to cross-cut the Yuntdağ Volcanics in the outcrop (Figure 3 and Figure 9a), and all other igneous units in drill core (Figure 9b, c). Where mapped basaltic andesite dykes predominantly trend in NW-SE, and less commonly in NE-SW direction (Figure 3). Dyke thicknesses range between 10 cm to 60 meters. Basaltic andesite dykes are generally green in color owing to hydrothermal alteration (Figure 9a, c) but the intensity of alteration is generally weaker particularly in comparison to that was observed in Yuntdağ Volcanics, the Çatalçam Diorite. Dykes have an overall low phenocryst-to-groundmass ratio, but this ratio may vary within individual dykes (Figure 9b).

Plagioclase is medium- to coarse-grained and is the most abundant phenocryst phase. It shows partial alteration to sericite/clay. Phenocrysts are set in a glassy to microcrystalline groundmass, which has been replaced by secondary minerals such as chlorite, clay, pyrite, and minor chalcopyrite (Figure 9d, e).

Basaltic andesite dykes observed in drill core generally show close spatial relationship to epithermal-style veins. Vein fragments were locally observed within some dykes, and in some places dykes were emplaced parallel to and along the vein margins.

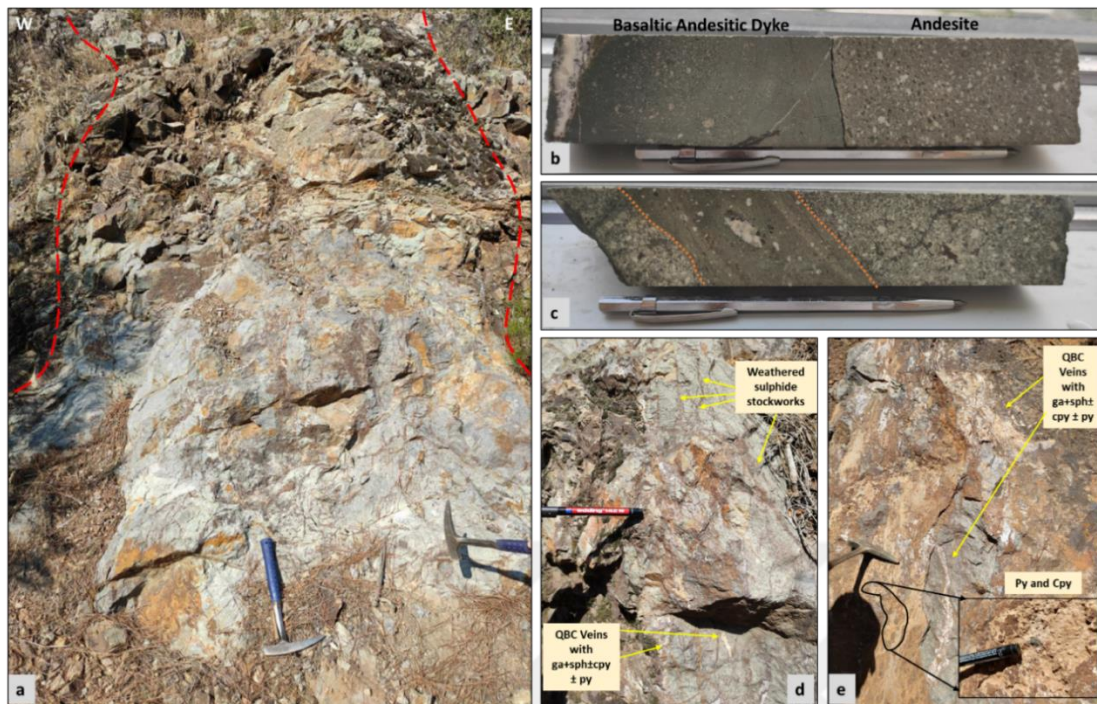


Figure 9. a) Outcrop image of basaltic andesite dyke, b) core sample showing boundary between basaltic andesitic dyke and andesite, c) core sample showing basaltic andesitic dyke with carbonate fragment, d) outcrop with quartz+barite+carbonate veins and weathered sulfide stockworks, e) outcrop images of basaltic andesitic dyke with quartz+barite+carbonate veins and patchy pyrite and chalcopyrite.

CHAPTER 3

METHODOLOGY

The methodology followed in this study includes

- ✓ Preliminary studies,
- ✓ Fieldwork,
- ✓ Relogging,
- ✓ Kinematic Analysis,
- ✓ Petrography and ore microscopy,
- ✓ Surface geochemistry
- ✓ 3D Modelling.

3.1 Preliminary Studies

Prior to fieldwork collection of literature, and study of the fieldwork and its vicinity using GoogleEarth imagery as well as collection of available geochemical data. The collected data were analysed in detail and used for the classification of the fieldwork area for its mineral potential and level of detail during fieldworks.

3.2 Fieldwork

Fieldwork was conducted with an aim to prepare the lithological, structural and alteration maps of the Çatalçam prospect. During lithological mapping, boundaries of various rock units were followed as much as possible despite dense vegetation. Rock sampling was also carried for accurate identification of the exposed rock units

and alteration zones. Surface data was later integrated with the available drill hole data.

Fieldwork also included collection of orientation data from bedding planes, and other geological structures such as faults, veins, and joints. These data are used to understand kinematic characteristics and paleostress configurations in the study area. During the field observations, veins and fractures are distinguished and recorded based on the presence and type of the infilling minerals. Relevant information was recorded on the spot and these were later verified through petrographic studies.

3.3 Relogging

Relogging comprises careful examination of the available drill cores and revision of existing drill hole data, which was obtained during separate drilling campaigns carried out by MTA and TWF. One of the most important aspects of relogging is the reclassification and standardization of the drill logs prepared by different exploration teams. During the relogging in addition to petrographic information, structural features such as veins and faults are recorded. The veins are classified according to their ore contents and thicknesses, while fault data were classified according to the thickness of the damage zone kinematic characteristics. These were compared and integrated into surface data.

3.4 Kinematic Analysis

In order to understand the kinematic evolution of the study area, 271 vein orientation measurements and 604 fault-slip data measurements were performed on 56 different fault planes in the field. Vein data is grouped according to their mineral content whereas fault-slip data are grouped and evaluated separately for each fault.

Paleostress studies were also carried out together with the fault data and vein data collected.

3.5 Petrographic Studies

Within the scope of the study, a total of 77 samples (76 drill core samples and 1 outcrop sample) were taken from 9 different drill holes for petrographic examination. Samples were taken from intervals considered to be representative of different lithologies, alteration styles, and mineralization types of the Çatalçam prospect as well as from intervals that have significant metal grades. Polished blocks and polished thin sections were prepared at the laboratories of MTA and Istanbul Technical University. For sampling, CTL002, CTL004, CTL006, CTL008, CTL011, CTL020, CTL030, CTL032, and SCS-15-8C drill holes were selected. Prepared polished blocks and polished thin sections were examined using a transmitted-reflected light polarizing microscope with a camera attached. Obtained data was used to determine primary rock forming minerals and primary rock textures, alteration and ore mineralogy, ore textures, and ore paragenesis.

3.6 Surface Geochemistry

In the study area, 991 soil samples were taken by MTA, and another 738 samples were taken by the Turkey Wealth Fund (TWF) for geochemical analyses. MTA samples were analyzed in-house for 8 elements (Ag, As, Au, Cu, Mo, Pb, Sb, Zn), whereas TWF samples were analyzed at the SGS and ALS Laboratories for >35 elements. Soil sampling was done on a grid pattern, which is useful for the gridding to be created for surface geochemistry. Soil anomaly maps were created using

Kriging method. While using the Kriging method, sill, range and nugget values were determined from the experimental variogram created for each element.

Apart from the pathfinder and indicator elements used to determine the alteration and mineralization areas together with the literature research, a correlation study was carried out within the data itself and the behavior of the elements relative to each other was examined. Correlation coefficients were calculated using the Geosoft-Target program using the Pearson method. Surface geochemistry studies were performed by creating anomaly maps and anomaly contours for both known pathfinder and indicator elements and elements indicated by correlation coefficients. Surface geochemistry studies have played an important role in the detection of mineralization, alteration, and post-mineralization faults.

3.7 3D Modelling

Both the lithological and structural model creation process, along with the drill core re-logging process were made using the Leapfrog Geo software. In the Leapfrog Geo software, data validation was performed in the geological and structural model creation processes, and then the topography surface was created. After the topography surface was created, the data collected from the surface along with the drill hole data were combined and the model was improved. At the same time, the cross-sections created together with the concept models created throughout the process were used to improve the models that were verified. Therefore, the implicit modeling was fed with additional data and the final model was obtained.

CHAPTER 4

STRUCTURE

Structural elements in this study comprise faults, veins and various non-systematic fractures observed during field studies. During the field studies 604 fault slip data from 33 different fault surfaces, and 268 vein data with different contents measurements are collected (Table 1).

Table 1. Information about the Amount and Characteristics of Measured Structures in the Field.

Type of Structure	Content	# measurement
Fault Slip Data	-	604
Vein	barite	268
	barite±galena±sphalerite±pyrite	
	quartz+barite+carbonate±galena±sphalerite±pyrite	
	quartz+barite	
	quartz+barite±galena±sphalerite±pyrite	
	quartz+pyrite	
	quartz+galena	

4.1 Faults

Paleostress and extensional regime studies were carried out with 604 measurements taken from 33 different fault surfaces. Faults are grouped spatially so that they can be examined in detail visually (Figure 10).

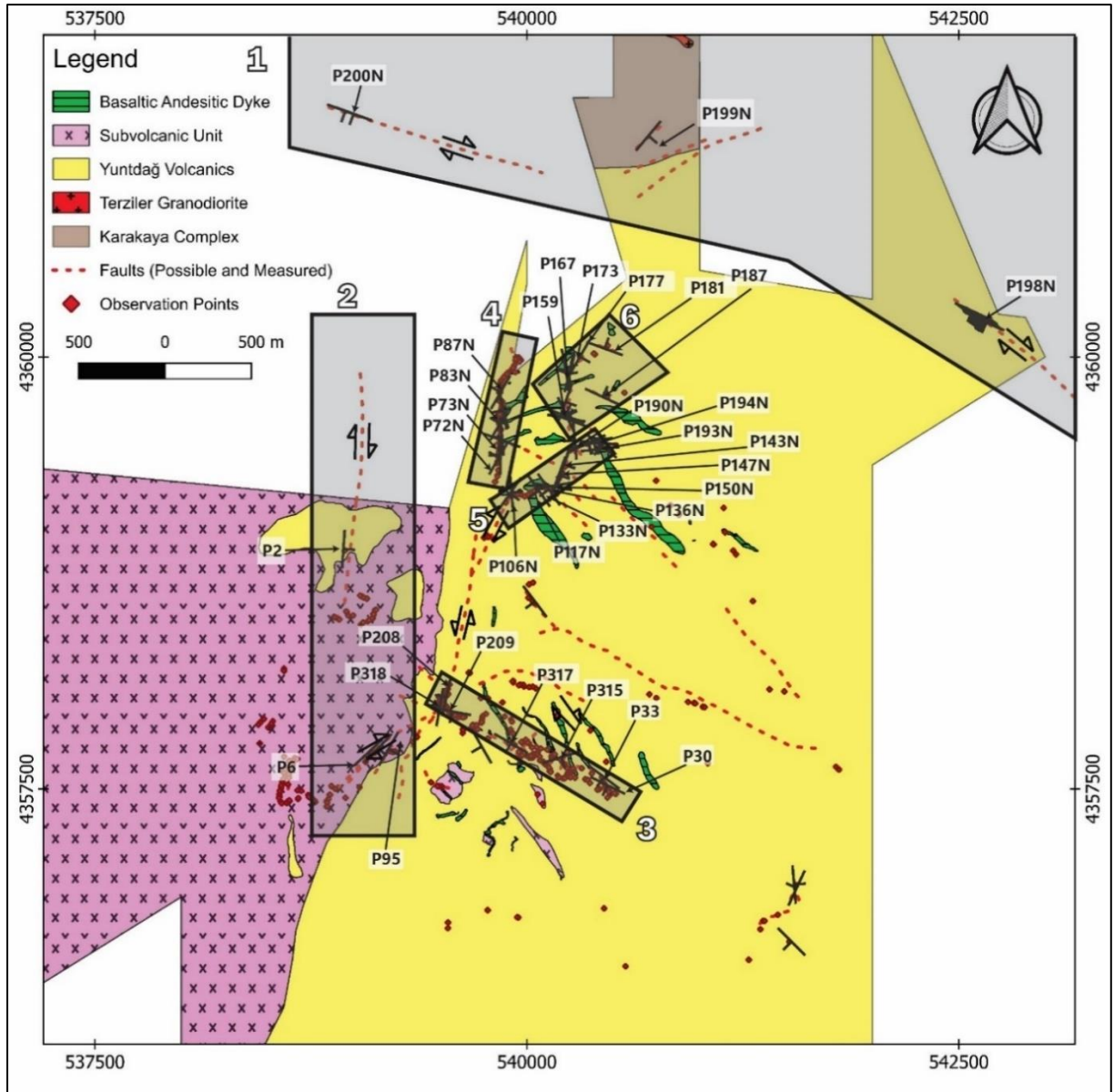


Figure 10. Geological map showing the studied fault structures and the main Fault Areas.

4.1.1 Fault Area 1

Fault Area 1 comprises the faults P198N, P199N and P200N. A total of 53 measurements are collected from the P198N fault. The kinematic indicators and slicken sides on the fault indicate that it is a normal fault with slight right-lateral strike-slip component (Table 2). While the fault

named P198N can be followed on the surface for approximately 50 meters, slight hematite coating was also observed on the fault surface. In addition, measurements are collected on the fault surface named P199N to the west of the P198N fault. The P199N fault surface is fresh and does not appear to be mineralized. Also, this fault is classified as a strike-slip fault with normal component. In addition, the fault surface named P200N is located to the west of the P199N fault. A total of 17 measurements are collected from the P200N fault which is interpreted as a normal fault with right-lateral strike-slip component (Figure 11).

Table 2. Summary Table of Fault Measurements in Fault Area 1

				Principal Stress Axes		
Name of Fault	#nt	n	R	σ_1 (D/P)	σ_2 (D/P)	σ_3 (D/P)
P198	53	53	0.17	314N/77	123N/13	214N/02
P199	10	7	0.27	246N/45	031N/40	137N/18
P200	17	17	0.39	319N/86	128N/04	218N/01

#nt: total measurements, n: used number of measurements, R: stress ratio, D: Direction, P: Plunge

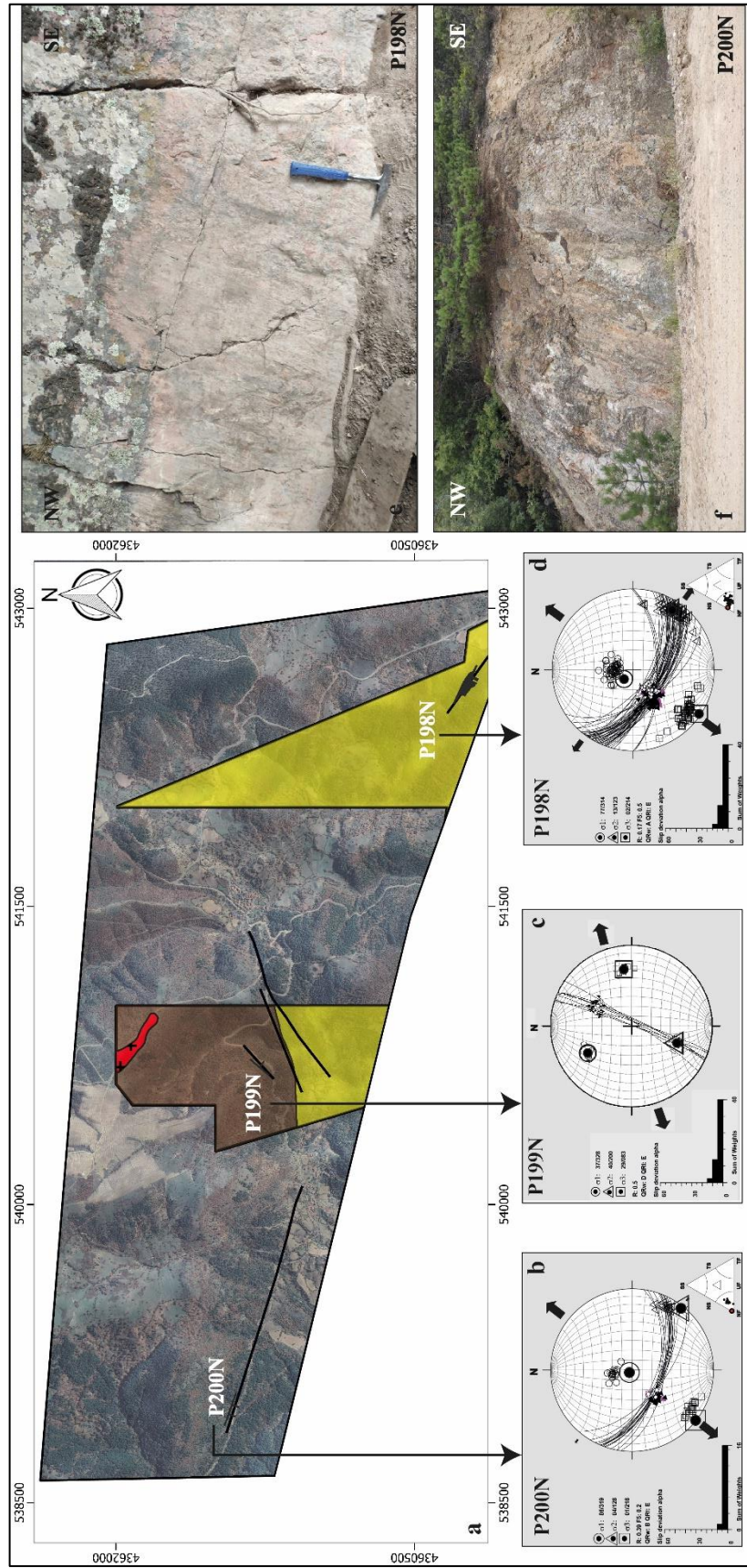


Figure 11. The figure includes Fault Area 1 which includes P198N, P199N, and P200N faults with outcrop images and kinematic analyses.

4.1.2 Fault Area 2

Fault Area 2 includes the faults P2, P6 and P95 (Figure 12a). The P2 fault is interpreted as a normal fault with right-lateral strike component from slicken-sides and kinematic indicators. (Table 3; Figure 12b; Figure 12e).

Fault P95 is a right-lateral strike-slip fault with normal component from the kinematic indicator and slicken-sides. A total of 5 measurements were taken from the surface of the P95 fault. The rocks along the fault are partially weathered and clay alteration is observed on the fault surface visible along the roadcuts (Table 3; Figure 12c; Figure 12f).

Fault P6 is interpreted as normal fault with a right-lateral strike component. A total of 11 measurements are taken from this fault surface. Extensive clay alteration is observed along the fault. However, no metallic mineralization took place along the fault (Table 3; Figure 12d; Figure 12g).

Table 3. Summary Table of Fault Measurements in Fault Area 2.

				Principal Stress Axes		
Name of Fault	#nt	n	R	σ_1 (D/P)	σ_2 (D/P)	σ_3 (D/P)
P2	12	10	0.24	237N/75	008N/10	100N/11
P95	5	5	0.2	236N/17	053N/73	146N/01
P6	11	11	0.51	225N/65	070N/23	336N/09

#nt: total measurements, n: used number of measurements, R: stress ratio, D:

Direction, P: Plunge

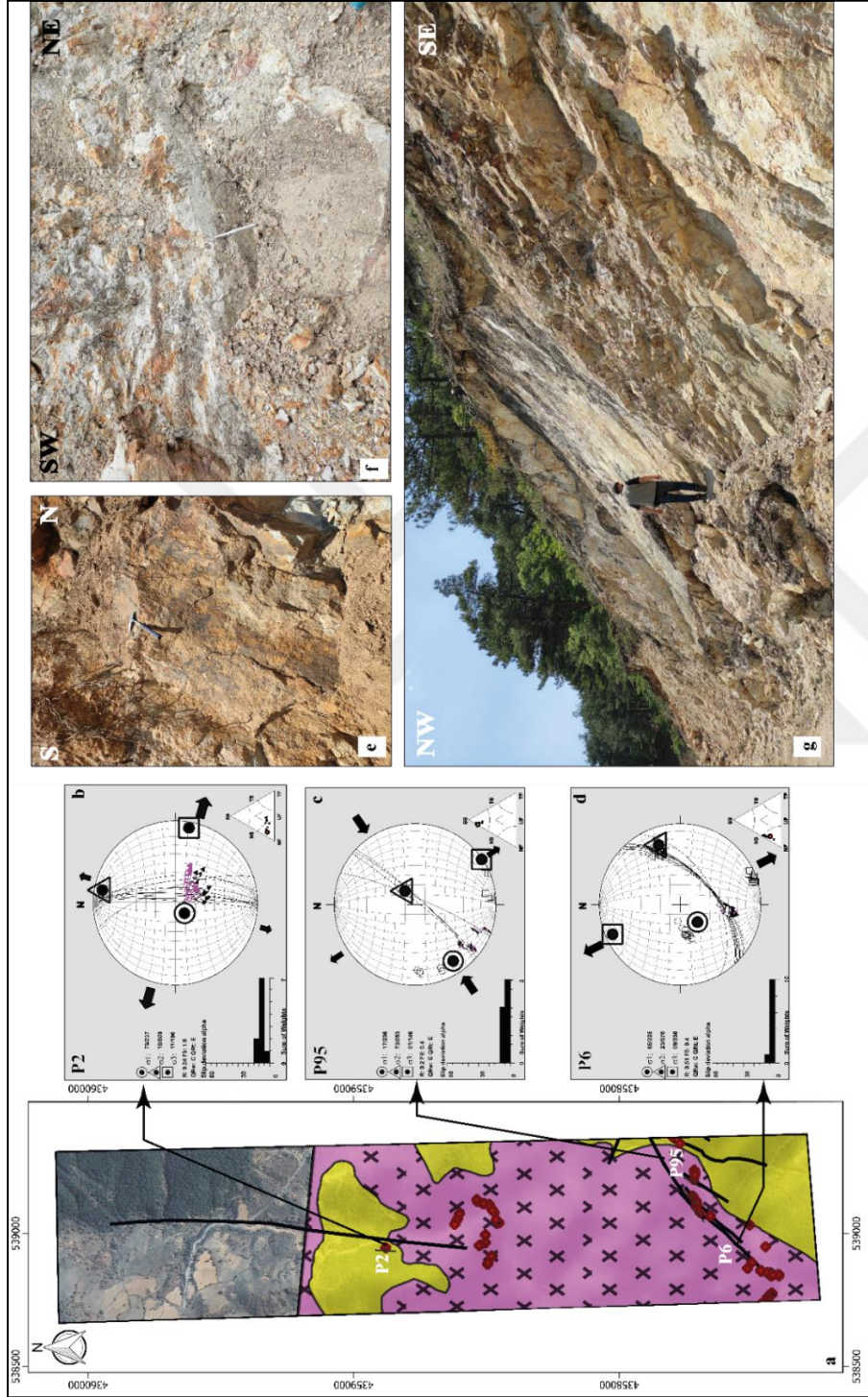


Figure 12. The figure including a) geological map of Fault Area 2 which includes P2, P95, and P6, b) stereonet of P2, c) stereonet of P95, d) stereonet of P6 with measurements, e) outcrop image of P6, f) outcrop image of P95, g) outcrop image of P2, h) outcrop image of P95.

4.1.3 Fault Area 3

Fault Area 3 comprises the faults P209, P318, P208, P317, P315, P33, and P30. There is a normal fault with slight left-lateral strike component fault located in the river named P318 in the northwest of the designated Fault Area 3, and this fault is a normal fault with left-lateral strike component (Figure 13; Figure 14a). Slickensides were also observed on the silica-rich vein on the fault surface named P318. Fault P208, which is located at the north of fault P318, is classified as a normal fault with left-lateral strike component (Table 4; Figure 13). On the surface of the P208 fault, slickensides were found over the hematite (Figure 14b). The fault surface named P209 lies to the east of the faults named P318 and P208. By examining kinematic analysis and slicken-lines, this fault is classified as a normal fault with right-lateral strike component. This fault surface vein was traced along the surface of the silica vein, but no ore mineral was found in the surface studies within this silica vein (Figure 14c). The fault surfaces named P317 and P315 are located to the east of the abovementioned faults (Table 4; Figure 13). P317 is classified as a left-lateral strike slip fault with normal component, and P315 fault is interpreted as normal faults with left-lateral strike component, and it was observed that the fault surfaces were fresh, and no ore mineral was encountered (Figure 14e). P30 and P33 faults are located in the easternmost part of the Fault Area 3 (Table 4; Figure 13). While oxidation is observed on its surface, pyrite decompositions are also observed in places (Figure 14d; Figure 14f). Both P33 and P30 faults are normal faults with left-lateral strike-component.

Table 4. Summary Table of Fault Measurements in Fault Area 3.

				Principal Stress Axes		
Name of Fault	#nt	n	R	σ_1 (D/P)	σ_2 (D/P)	σ_3 (D/P)
P209	25	21	0.55	316N/53	127N/37	316N/53
P318	22	22	0.46	135N/82	330N/07	240N/02
P208	8	8	0.19	194N/60	325N/21	064N/21
P317	6	6	0	084N/02	184N/78	354N/12
P315	11	11	0.23	033N/67	263N/15	168N/17
P33	10	7	0.09	237N/75	116N/08	024N/13
P30	4	4	0.22	089N/60	293N/27	198N/10

#nt: total measurements, n: used number of measurements, R: stress ratio, D:

Direction, P: Plunge

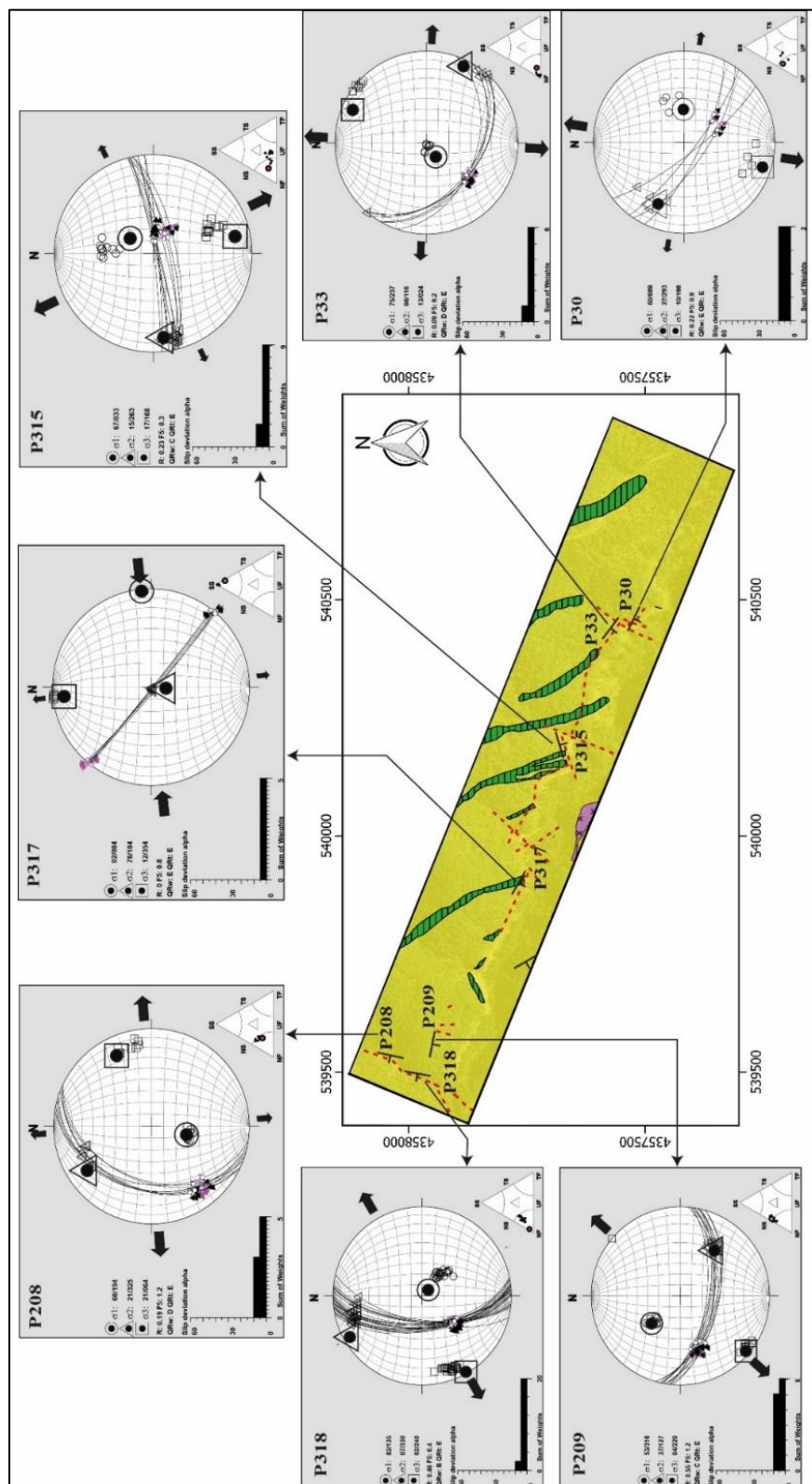


Figure 13. The figure including Fault Area 3 with faults which are named as P209, P318, P208, P317, P315, P33, and P30.

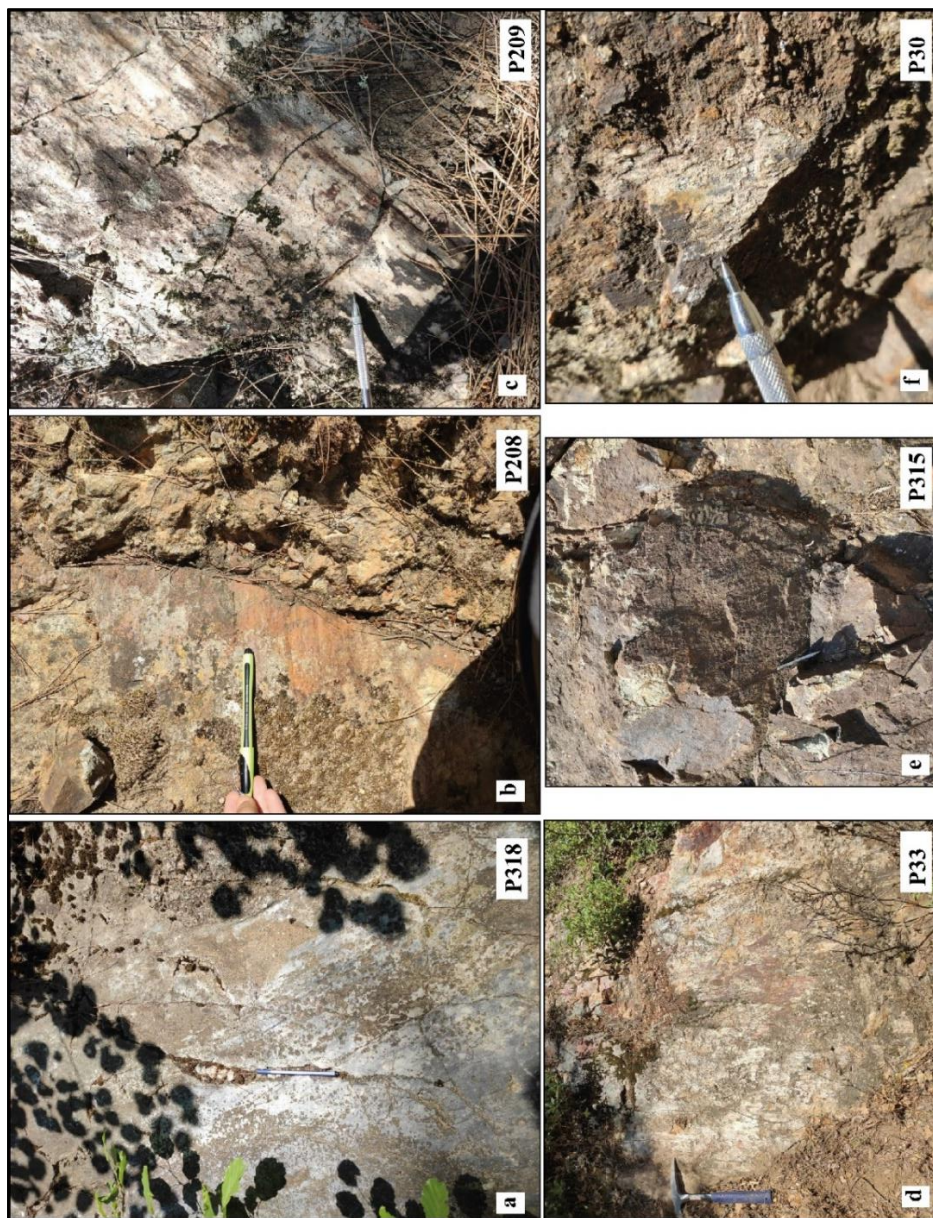


Figure 14. The outcrop image of a) P318 fault, b) P208 fault, c) P209 fault, d) P33 fault, e) P315 fault, and f) P30 fault.

4.1.4 Fault Area 4

Fault Area 4 includes the faults P87N, P83N, P82N, P73N, and P72N from north to south (Figure 16a).

Surface of P87N fault is is oxidized, clay alteration has been observed, at the same time there are brown-colored veinlets on the surface caused by pyrite weathering (Figure 15a). This fault is classified as a normal fault with left-lateral strike component from kinematic analysis and surface studies (Figure 16b; Table 5).

Just south of the P87N fault lies the fault surface named P83N. While there is no mineralization on the surface of the P83N fault (Figure 15d). This fault is classified as a right-lateral strike slip fault with normal component (Figure 16c; Table 5).

A total of 15 and 9 measurements are collected from the faults named P73N and P72N. On the fault surfaces, strong clay alteration is observed on this fault surface, there is also a small amount of weathering (Figure 15b, c). Both of these faults are classified as a normal fault with left-lateral strike component (Figure 16d, e; Table 5).

Table 5. Summary Table of Fault Measurements in Fault Area 4

				Principal Stress Axes		
Name of Fault	#nt	n	R	σ_1 (D/P)	σ_2 (D/P)	σ_3 (D/P)
P87N	9	9	0.33	267N/76	022/06	114N/12
P83N	10	8	0.36	357N/15	223N/69	091N/15
P73N	20	15	0.1	128N/76	014N/06	283N/13
P72N	9	9	0.11	172N/69	034N/16	300N/13

#nt: total measurements, n: used number of measurements, R: stress ratio, D: Direction, P:

Plunge

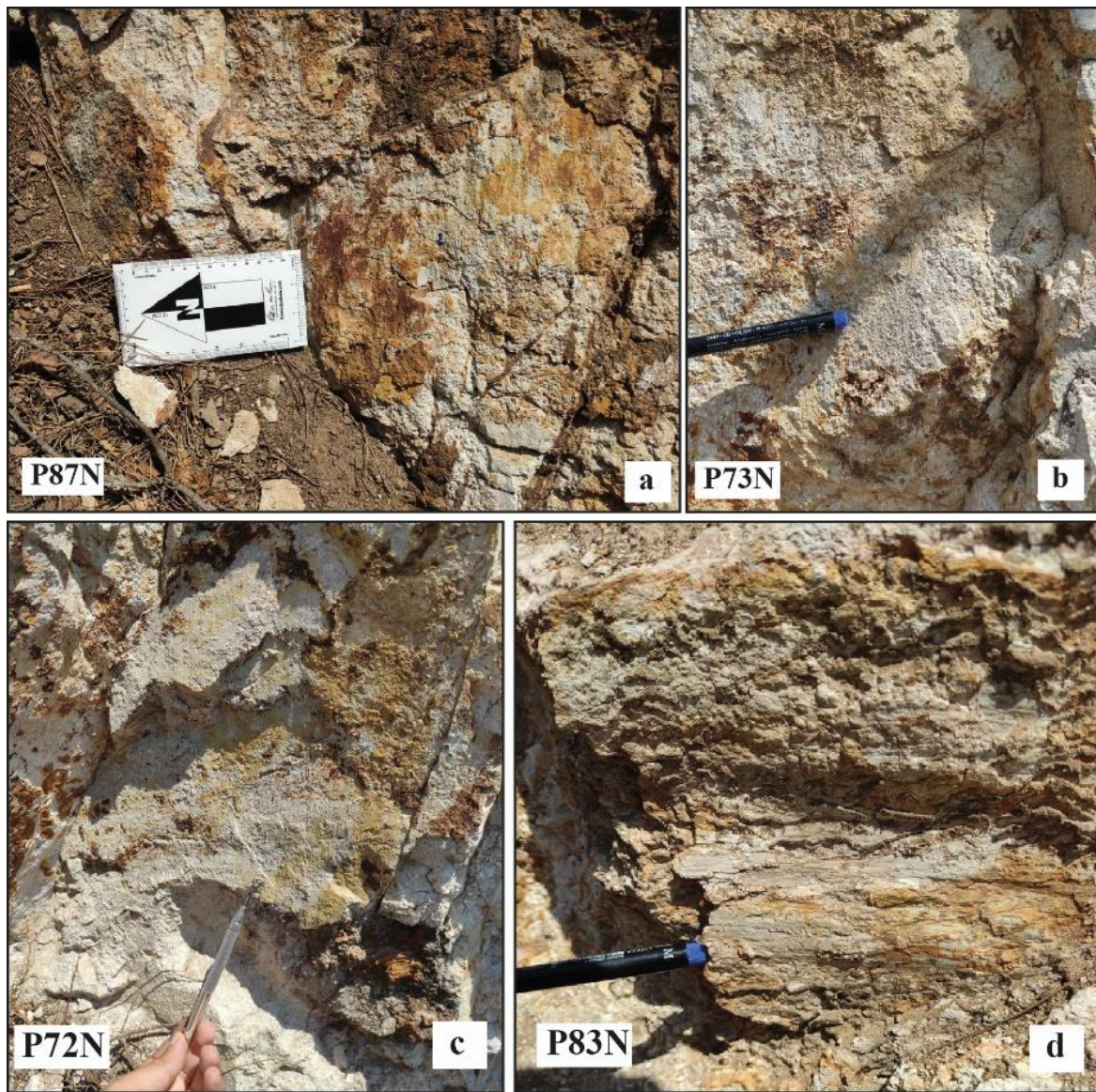


Figure 15. The outcrop image of a) P87N fault, b) P73N fault, c) P72N fault, and d) 83N fault.

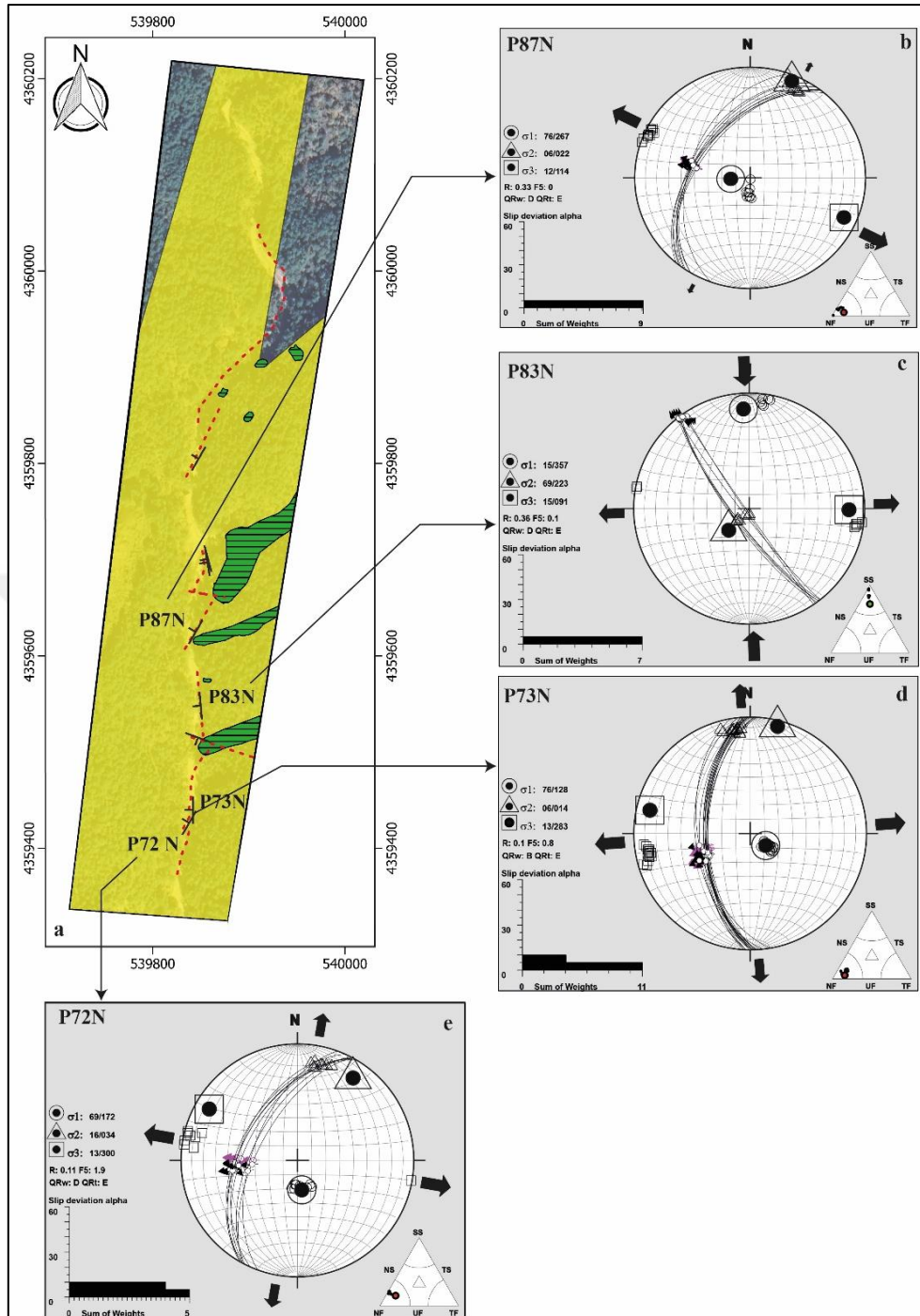


Figure 16. The figure including a) Fault Area 4 with faults which are named as b) P87N, c)P83N, d) P73N, and e) P72N.

4.1.5 Fault Area 5

Fault Area 5 includes 9 different fault surfaces as shown in Figure 17.

A total of 16 measurements are collected from the fault surface named as P106N at the far southwest of Fault Area 5. In the kinematic analysis studies and surface studies, the P106N fault is interpreted as a normal fault with slight right-lateral component, and this fault surface is well oxidized, and pyrites appear from place to place (Table 6; Figure 17; Figure 18a).

P150N fault surface is partially weathered and slicken-sides can be observed on dark gray colored quartz vein on the fault surface. This fault is classified as a normal fault with slight right-lateral component from kinematic analysis and surface studies (Table 6; Figure 17; Figure 18b).

A total of 9 measurements are collected from P117N fault. From the kinematic indicators and slicken-sides, the P117N fault is interpreted as a normal fault with slight right-lateral component. On the fault surface, oxidation is observed, and slickensides are also observed on gray colored silica veins on this surface (Table 6; Figure 17; Figure 18c).

There are P133N and P136N fault surfaces to the east of the P106N and P117N. P133N is a normal fault with left-lateral strike component and P136N is a left-lateral strike-slip fault with normal component based on kinematic indicators and slickensides. Both of these surfaces are partially weathered (Table 6; Figure 17; Figure 18d).

There is a fault named P147N and 6 are collected from this surface. Based on kinematic indicators and slickensides from the fault surface, the fault is a right-lateral strike-slip with normal component. This fault surface is severely weathered and breccias are observed in places (Table 6; Figure 17).

There are fault surfaces named as P190N, P193N, and P194N in the far northeast of the mentioned faults and a total of 52, 15 and 9 measurements are collected from these surfaces. Clay alteration is visible on the surface of fault P190N which is interpreted as normal fault with right-lateral strike component (Table 6; Figure 17; Figure 18e). On the P193N fault surface, disseminated pyrite is observed. The fault is interpreted as a normal fault with slight right-lateral strike component (Table 6; Figure 17; Figure 18f). There are fault breccias on surface of faults P194N which is interpreted as normal fault with left-lateral strike component, although slickensides are not as clear as other fault surfaces (Table 6; Figure 17).

Table 6. Summary Table of Fault Measurements in Fault Area 5

				Principal Stress Axes		
Name of Fault	#nt	n	R	σ_1 (D/P)	σ_2 (D/P)	σ_3 (D/P)
P106N	16	16	0.32	187N/67	071N/11	337N/20
P117N	10	9	0.51	239N/60	009N/21	107N/21
P150N	18	18	0.38	326N/64	098N/18	194N/18
P147N	10	6	1	207N/67	060N/20	326N/12
P190N	55	52	0.24	226N/74	093N/16	002N/02
P193N	15	15	0.16	063N/70	331N/01	241N/20
P194N	9	9	0.5	059N/85	271N/04	180N/03
P136N	12	12	0.5	113N/39	335N/42	223N/22
P133N	6	6	0.5	066N/88	176N/01	266N/02
P106N	16	16	0.32	187N/67	071N/11	337N/20
P117N	10	9	0.51	239N/60	009N/21	107N/21
P150N	18	18	0.38	326N/64	098N/18	194N/18

#nt: total measurements, n: used number of measurements, R: stress ratio, D: Direction, P:

Plunge

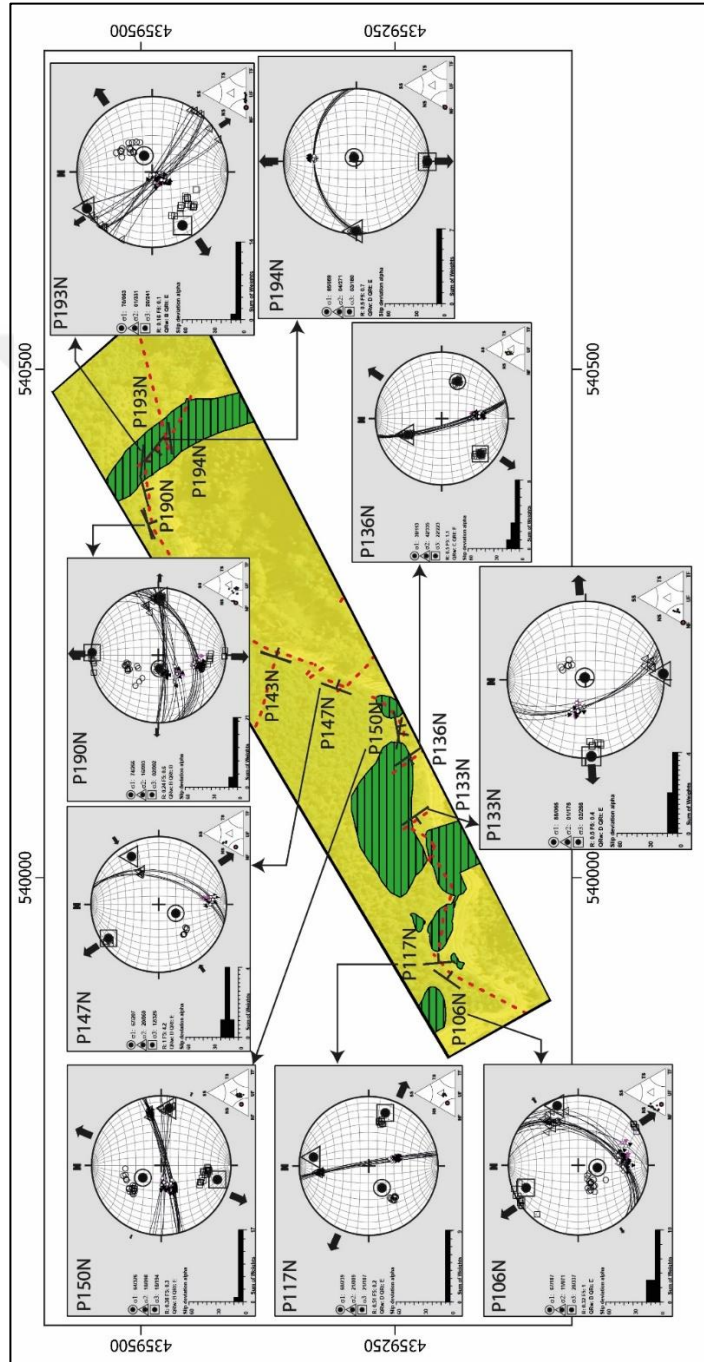


Figure 17. The figure including Fault Area 5 with faults which are named as P106N, P117N, P150N, P147N, P190N, P193N, P194N, P136N and P133N.

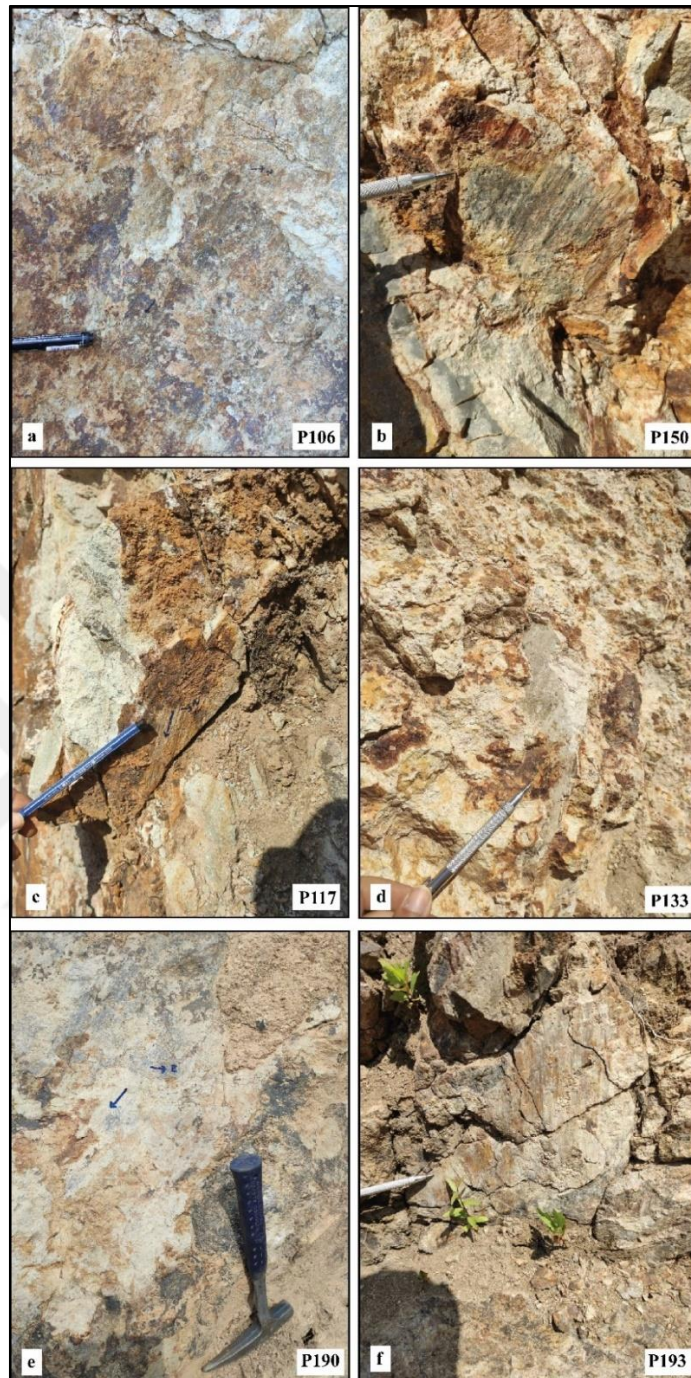


Figure 18. The outcrop image of a) P106N fault, b) P150N fault, c) P117N fault, d) P133N fault, e) P190N fault, and f) P193N fault.

4.1.6 Fault Area 6

Fault Area 6 consists of six faults as shown in Figure 19.

A total of 9 and 17 measurements are collected from the faults P187 and P159 (Table 7). From kinematic indicators and slickensides observed on the fault surfaces, P187 fault is a normal fault with sinistral-lateral strike component, whereas P159 fault is a normal fault with right-lateral strike component (Figure 19). The clay alteration and oxidation observed along the fault is thought to be facilitated by mechanical wearing and tearing along the fault (Figure 20b, c).

From the faults P167, P173, P181 total of 13, 14, and 11 measurements are collected respectively (Table 7). The dominant azimuth and plunges of each of these faults are 106N/52, 072N/59, and 070N/56. Based on slickensides and kinematic indicators observed in the field, all these faults are normal faults with right-lateral strike-slip component (Figure 19). Similarly, oxidation is also developed on each fault surface (Figure 20a, d).

A total of 25 measurements from the fault surface called P177 are collected from 5 different fault surfaces (Table 7). This fault is classified as a normal fault with left-lateral strike-slip component (Figure 19). On the fault surface, quartz+barite+galena+sphalerite vein can be observed (Figure 20e, f, g).

Table 7. Summary Table of Fault Measurements in Fault Area 6.

				Principal Stress Axes		
Name of Fault	#nt	n	R	σ_1 (D/P)	σ_2 (D/P)	σ_3 (D/P)
P187	9	9	0.18	150N/68	004N/18	270N/11
P159	49	47	0.41	193N/80	354N/09	085N/03
P167	13	13	0.54	243N/53	039N/35	137N/11
P173	14	12	0.37	131N/67	001N/15	266N/17

				Principal Stress Axes		
Name of Fault	#nt	n	R	σ_1 (D/P)	σ_2 (D/P)	σ_3 (D/P)
P177	25	25	0.36	238N/56	353N/16	093N/29
P181	11	11	0.47	152N/68	004N/19	270N/11

#nt: total measurements, n: used number of measurements, R: stress ratio, D:

Direction, P: Plunge

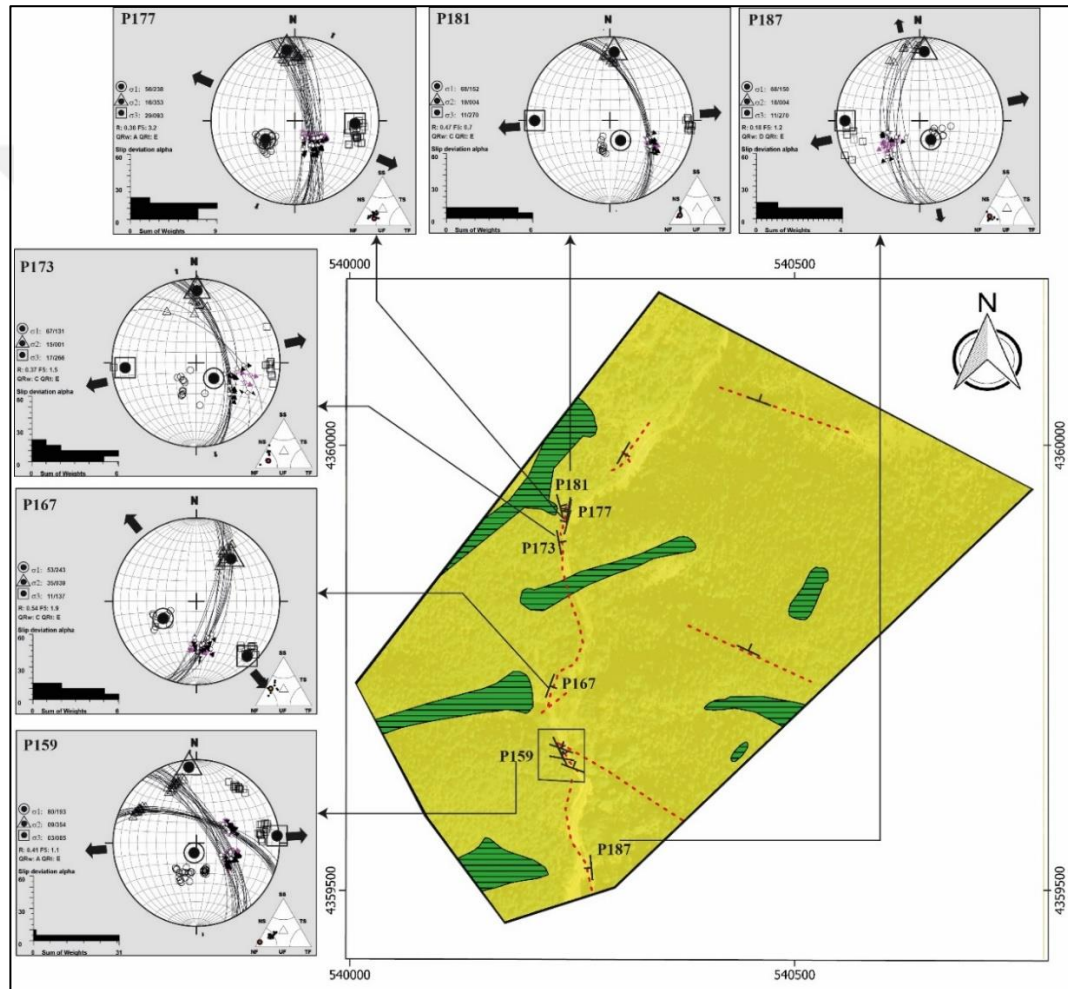


Figure 19. The figure including Fault Area 6 with faults which are named as P187, P159, P167, P173, P177, and P181.

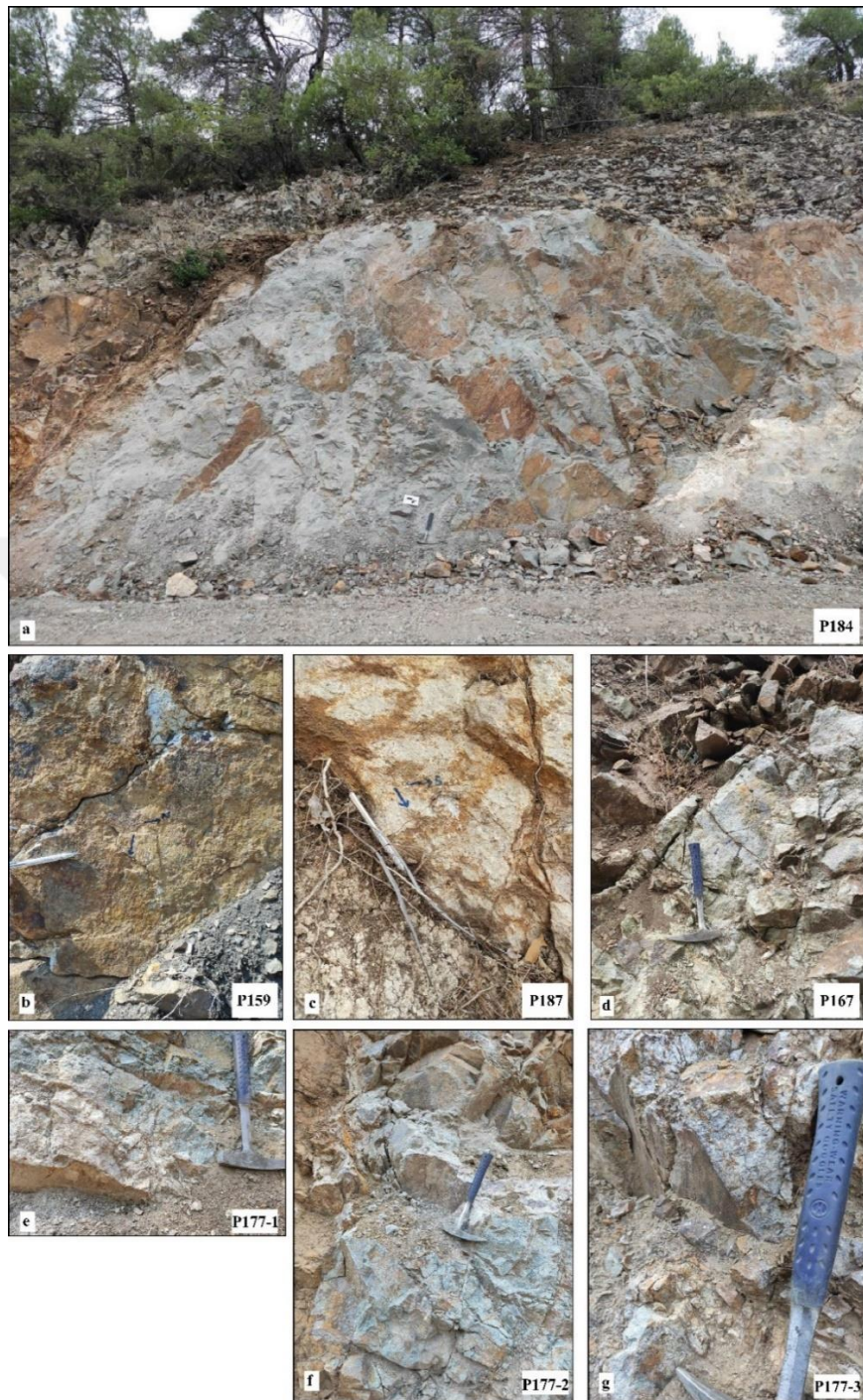


Figure 20. The outcrop image of a) P181 fault, b) P159 fault, c) P187 fault, d) P167 fault, e) P177-1 fault, f) P177-2 fault, and g) P177-3 fault.

4.2 Veins

A total of 268 measurements were taken from exposed veins(lets) in the Çatalçam prospect. Except for less common barren silica veinlets, most epithermal veins contain quartz, barite, calcite, pyrite, and sulfide ore minerals as vein fill. The veins were initially classified into 22 types based on vein content. For simplicity and ease of modeling, however, these were later divided into 7 different groups based on the dominant vein fill and on the basis of mineralization, as shown in Table 8. Veins are generally exposed in or around stream channels and valley floor as well as along the road cuts.

Table 8. Main Vein Groups Identified at Çatalçam.

Vein Content (from field)	Grouped Vein
qtz+ba+ga	Mineralized quartz-barite-dominant veins
qtz+ga+py	
qtz+ba+hem	
qtz+ba+ga+hem	
qtz+ba+ga+sph	
qtz+ba+ga+sph+hem	
qtz+ba+ga+py+aspy	
ba+ga+sph	Mineralized barite-dominant veins
ba+sph+hem	
qtz+ba+ga+py	
ba+cpy+mh	
ba+ga	
ba+hem	
ba	Barren barite veins
ga	Galena veins

Vein Content (from field)	Grouped Vein
qtz+ga	
qtz+ba	Barren quartz-barite-dominant veins
qtz+ba+ca	Mineralized quartz-barite-carbonate-dominant veins
qtz+ba+ca+ga+sph	
qtz+ba+ga+py+cpy+mh	
qtz+py+hem	Barren quartz-pyrite veins
qtz+py	

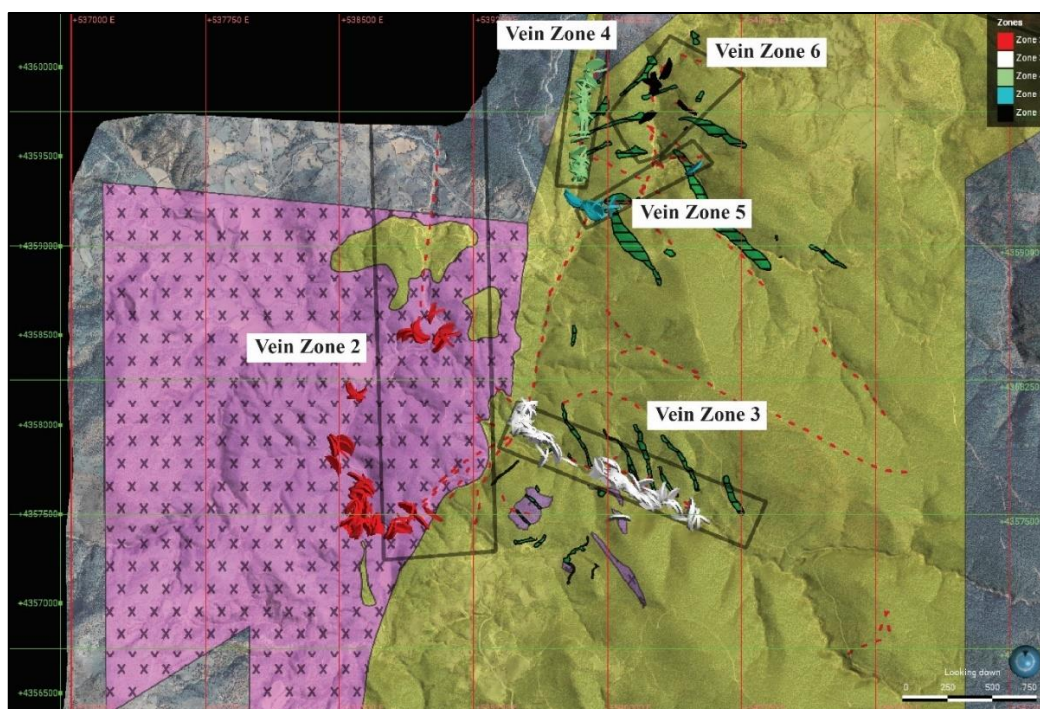


Figure 21. Map view showing spatial distribution of vein zones prepared using Leapfrog Geo.

All 268 vein measurements were plotted on a stereonet to detect extensional directions and sets based on density of measurements. By looking at density of all vein measurements, three different vein sets named 1m: Set A, 2m: Set B, and 3m:

Set C are defined. 1m: Set A contains the most measurements; although this set includes all different types of veins, it includes dominantly barren quartz-pyrite veins and mineralized quartz-barite-dominant veins. The dip direction and dip of the mean plane of this set are 228N/58 (Figure 22).

2m: Set B contains 32 different measurements; this set includes mainly barren quartz-pyrite veins. Although this set contains mineralized veins, it mostly consists of veins called barren. The dip direction and dip of the mean plane of this set are 029N/67 (Figure 22).

Finally, one more set is defined as 3m: Set C which includes 10 different measurements; therefore, the direction is not as major as the other sets. No major vein type is seen in this set, it contains both mineralized and barren veins. The dip direction and dip of the mean plane of this set are 108N/75 (Figure 22).

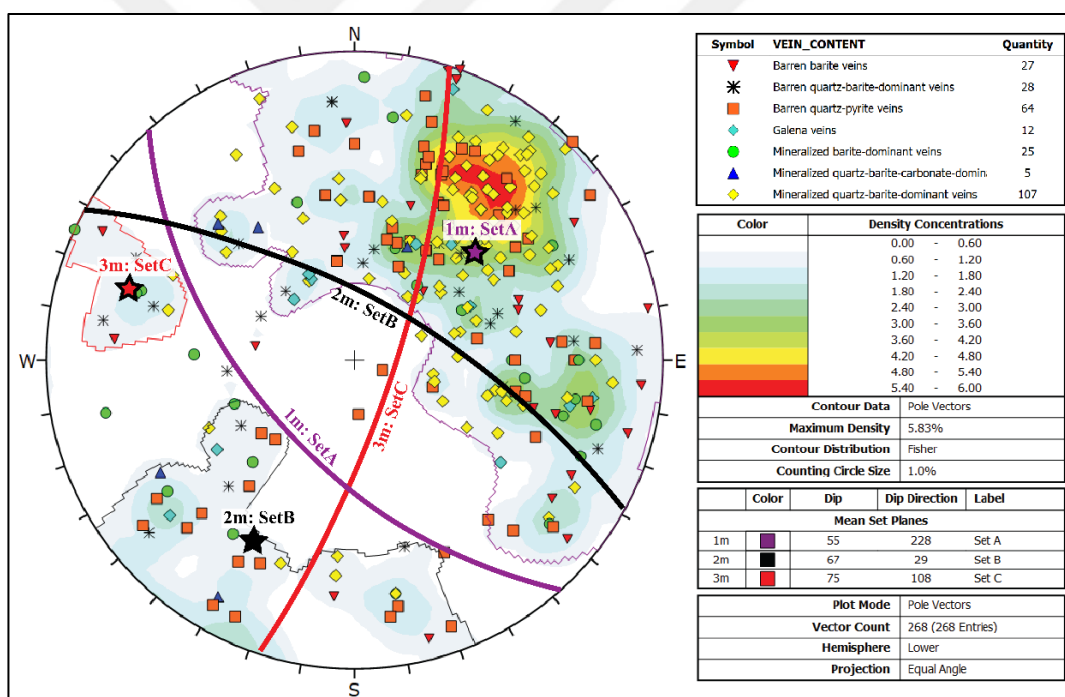


Figure 22. The stereonet projection (Equal Angle, Lower Hemisphere) displaying poles of all veins colored and shaped according to vein content, and 3 sets of these veins with plane directions.

4.2.1 Vein Zone 2

The Vein Zone 2 includes 75 different vein measurements which include dominantly mineralized quartz-barite-dominant veins, barren quartz-barite veins, and barren quartz-pyrite veins (Figure 23). The measurements of Vein Zone 2 are generally collected in river in stockwork zones whose intensity is varied throughout the river (Figure 24). Especially since the river erodes the rocks, the detection of veins containing more silica, which is resistant to erosion, has become easier (Figure 25a, c). In addition, it is possible to observe that some veins are offset, cut by other vein(let)s and contain different phases with same orientation or different orientation (Figure 25b). The veins in this set are divided into two different groups according to measurements. The first group, which is named as 1m: Set 1, mainly contains mineralized quartz-barite-dominant veins, and consists of minor amount of barren vein types. Dip direction and dip of the first set is 229N/41 (Figure 23). The number of veins in the second group, which is named as 2m: Set 2, is less than the veins of the first group. In addition, this set includes mainly barren vein types. Dip direction and dip of the first set is 043N/73 (Figure 23).

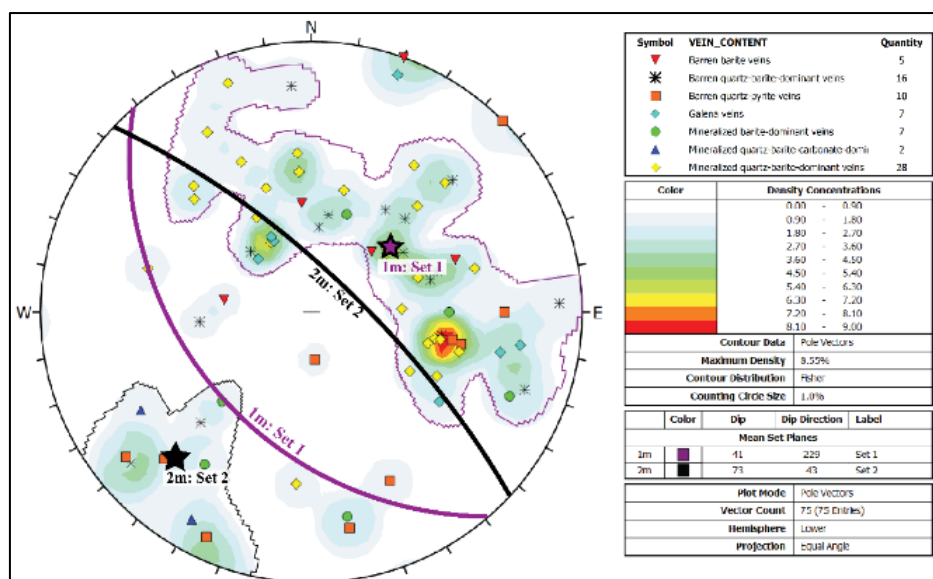


Figure 23. The stereonet projection (Equal Angle, Lower Hemisphere) displaying poles of Vein Zone 2 veins colored and shaped according to vein content, and 2 sets of these veins with plane directions.

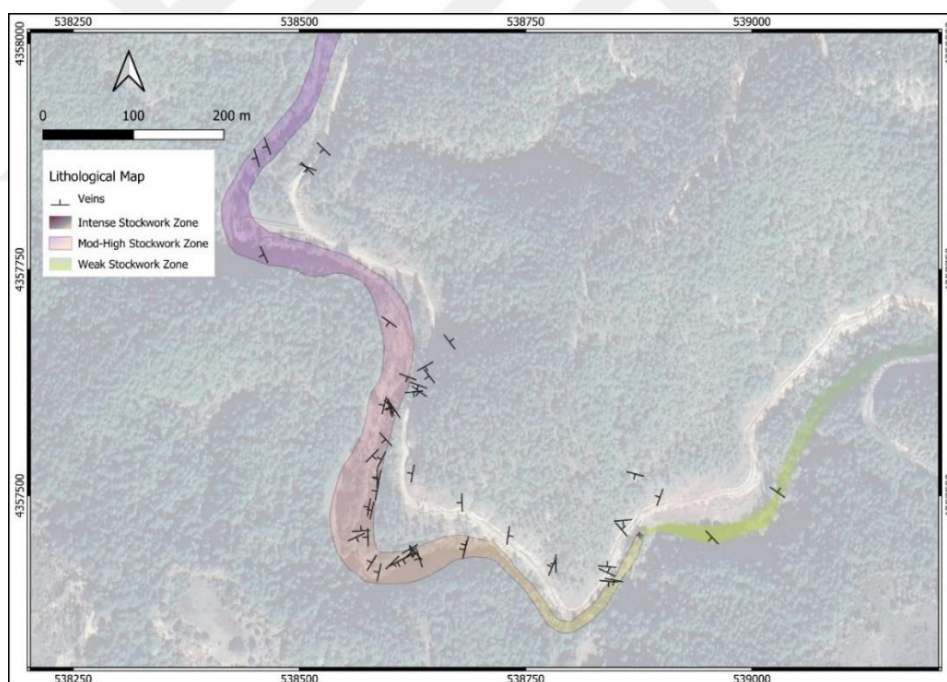


Figure 24. The plan view of stockwork and epithermal veins in Vein Zone 2 measured along a river valley.



Figure 25. Outcrop photographs of different vein types from Vein Zone 2 as well-exposed along stream floors. a) Quartz vein with minor galena, b) quartz+barite+galena+sphalerite+hematite vein, and c) quartz+galena vein.

4.2.2 Vein Zone 3

Vein zone 3 comprises mainly mineralized quartz-barite-dominant veins. In addition, mineralized barite-dominant veins, barren quartz-pyrite veins which have always been observed as veinlets, and barren barite veins can be observed in Vein Zone 3. In the zone 121 veins are measured, and there is a vein set in measurements which include dominantly mineralized quartz-barite-dominant veins and barren quartz-pyrite veins. Dip direction and dip of this set is 220N/63 (Figure 26).

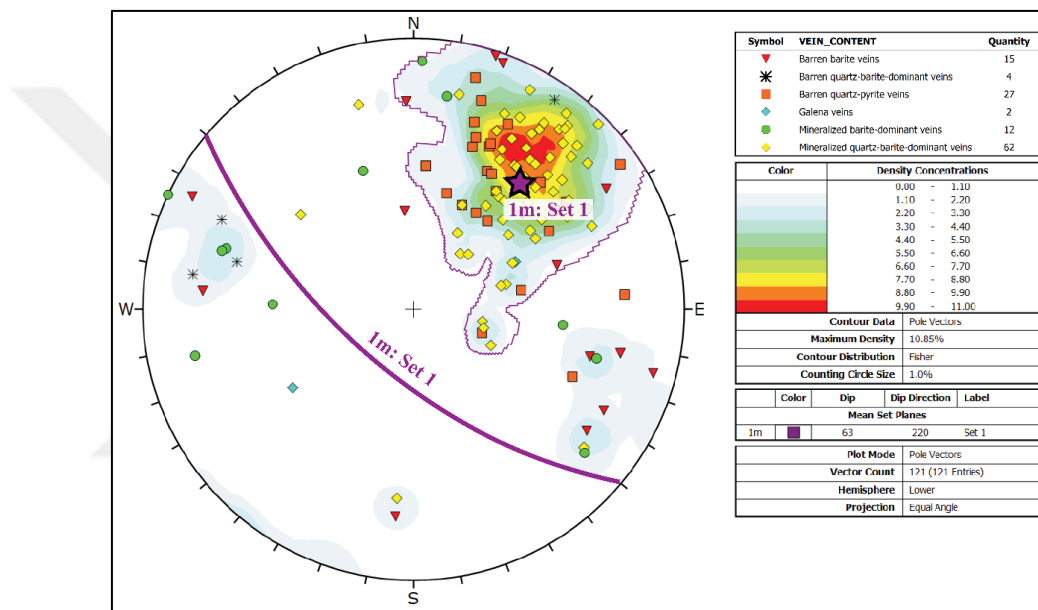


Figure 26. The stereonet projection (Equal Angle, Lower Hemisphere) displaying poles of Vein Zone 3 veins colored and shaped according to vein content, and 2 sets of these veins with plane directions.

In this vein zone, veins are mostly observed in high weathered and high clay altered areas. The vein thickness in this area is thicker than the general area. With the increase in the thickness of the veins in this area, it is possible to catch some changes in the content of the veins. Although it is not a common situation, barite is dominant in the center of a mineralized quartz-barite-dominant vein with a thickness of 2

meters in this area, while the quartz content increases towards the walls of the vein (Figure 27a). In addition, a highly galena-dominant vein is observed in this zone, it is also parallel to the mineralized quartz-barite-dominant vein which is a wide vein zone including this galena-dominant vein. There are orange colored carbonate veinlets inside the galena- dominant vein (Figure 27b). A similar galena-dominant vein is not observed elsewhere in the field.

In this zone, the observation of veins in strongly deformed areas has been observed quite frequently. This deformation causes clay alteration, but these deformations occurred both before and after the formation of the veins. Subsequent deformations provided the offset of the veins (Figure 28a). In addition, hematite content may increase in the vein content (Figure 28b). Apart from these general features, some quartz-barite-dominant veins may also be difficult to observe due to weathering and alteration (Figure 28c).

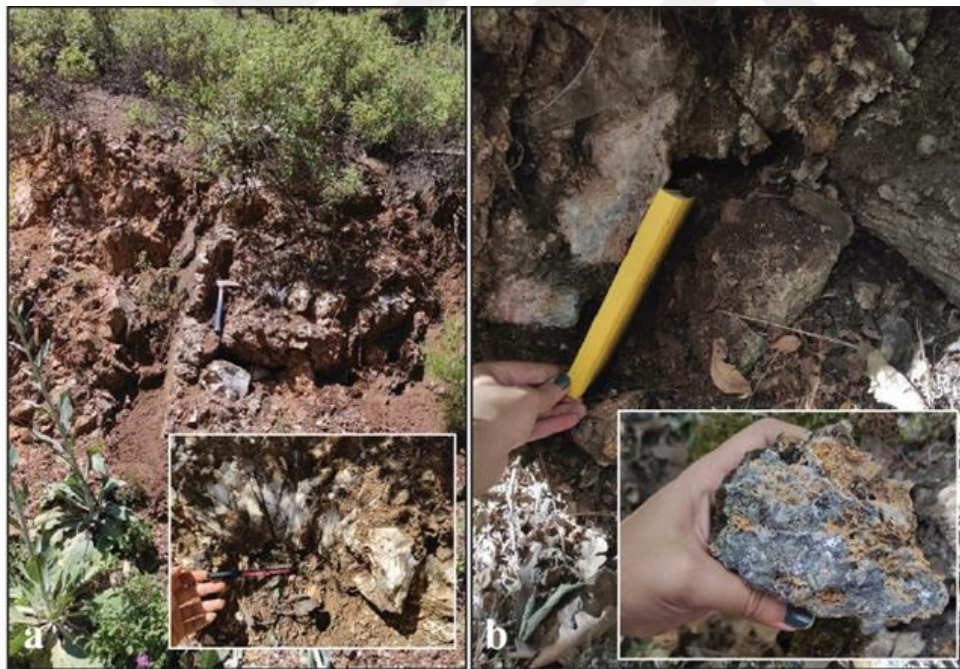


Figure 27. Outcrop photographs of a) quartz+barite+galena vein, and b) massive galena vein in quartz+barite+galena vein.

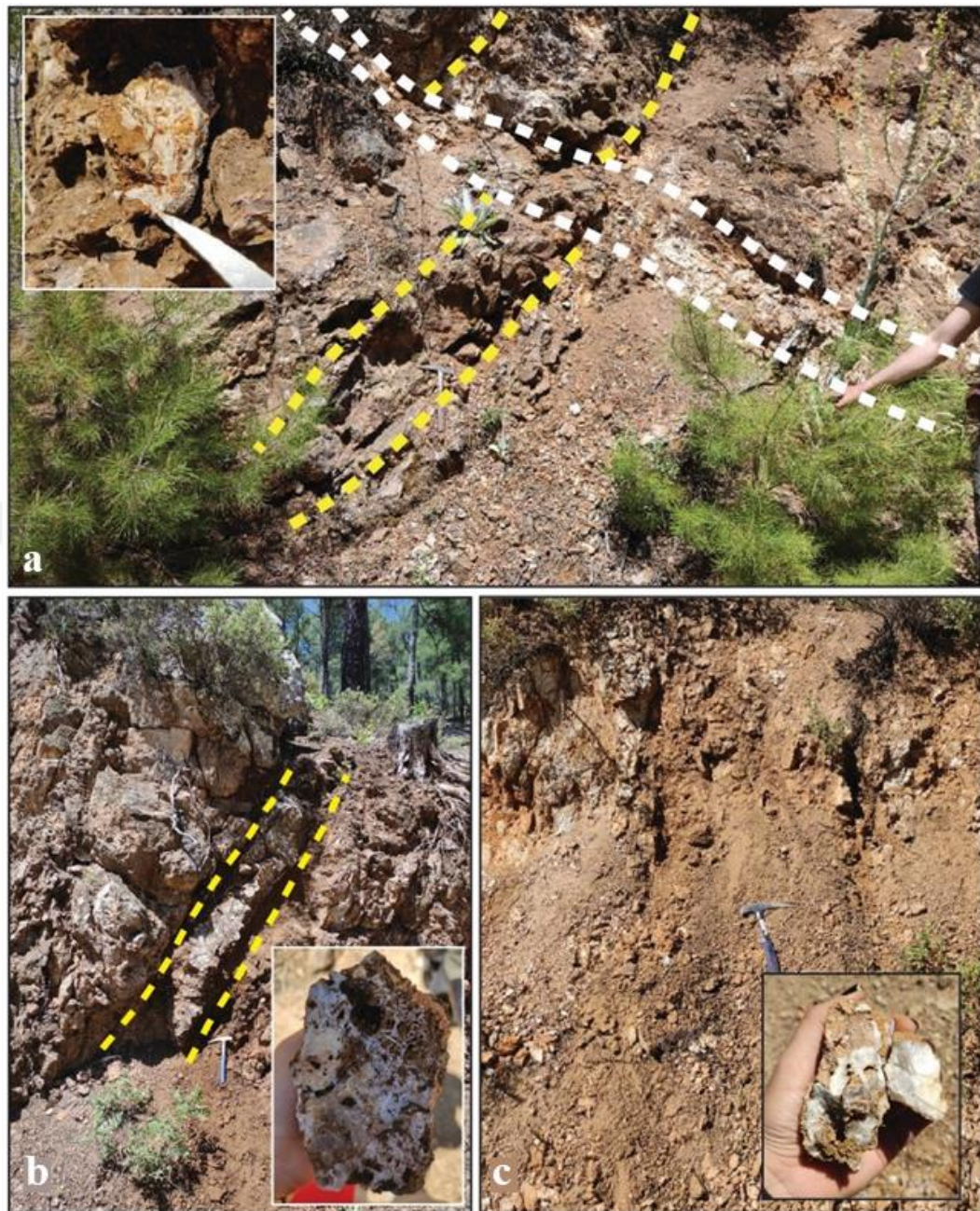


Figure 28. Outcrop photographs of a) quartz-dominant vein, which is cut and offset by a fault, b) oxidized quartz-dominant vein with fault gauge, and c) fragmented silica vein with intensely clay altered host rock.

4.2.3 Vein Zone 4

Vein Zone 4 consists of 43 different vein measurements. The most dominant vein type in this zone is barren quartz-pyrite veins which are thinner than other quartz-dominated veins. In addition, mineralized quartz-barite-dominant veins are also dominant. However, fewer measurements are taken from veins of this zone as these veins are subjected to intense deformation causing strong disturbance of vein planes. From the measurement, one set can be identified which consists of mainly mineralized quartz-barite-dominant veins and barren quartz-pyrite veins, like all of the Vein Zone 4. Dip direction and dip of this set is 251N/62 (Figure 29).

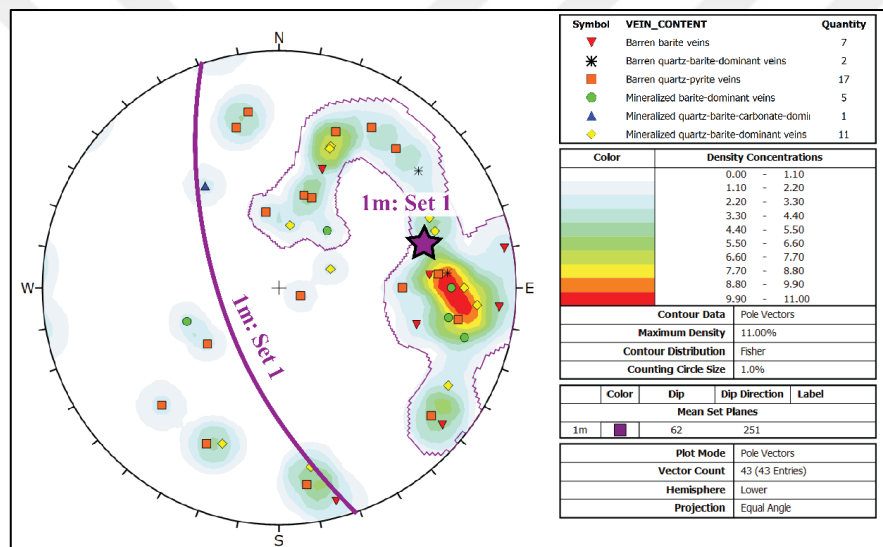


Figure 29. The stereonet projection (Equal Angle, Lower Hemisphere) displaying poles of Vein Zone 4 veins colored and shaped according to vein content, and 2 sets of these veins with plane directions.

In addition to the alteration of the host rocks of the veins observed in Vein Zone 4, the veins are also exposed to clay alteration, especially the veins including high amount of galena and trace amounts of sphalerite (Figure 30a). However, the mineralized quartz-barite-dominant vein observed with less clay alteration and banded texture. It is observed that the amount of quartz and ore minerals increase

while approaching the center of the vein; on the other hand, barite content increases towards the walls of the vein (Figure 30b).



Figure 30. Outcrop photographs of a) intensely altered mineralized quartz-barite-dominant vein, and b) mineralized quartz-barite-dominant vein with banded texture.

4.2.4 Vein Zone 5

A total of 13 measurements are collected in this zone. This lack of measurements is caused by severe deformation. Therefore, it is expected that the statistics of the study conducted in this area will be less informative than other zones. The most dominant

vein type is barren quartz-pyrite veins; however, there exist only 5 of this type veins. One set can be identified in this vein zone, and this set includes only 6 different vein measurements which are mainly barren quartz-pyrite veins. The dip direction and dip of this set are 053N/60 (Figure 31).

Most of the Vein Zone 5 area consists of basaltic andesite dykes. Basaltic andesite dykes have not undergone a strong alteration in this area as in other outcrops in the area, unlike other units. Especially barren quartz-pyrite veins and quartz-dominant veins can be observed on basaltic andesite dykes (Figure 32a). In cases where basaltic andesite is not a host rock, it has been observed that the veins, in andesite, are also undergone to severe clay alteration (Figure 32b). At the same time, systematically oxidized quartz-pyrite veinlets are also common in andesites that have been strongly exposed to clay alteration in this area (Figure 32c).

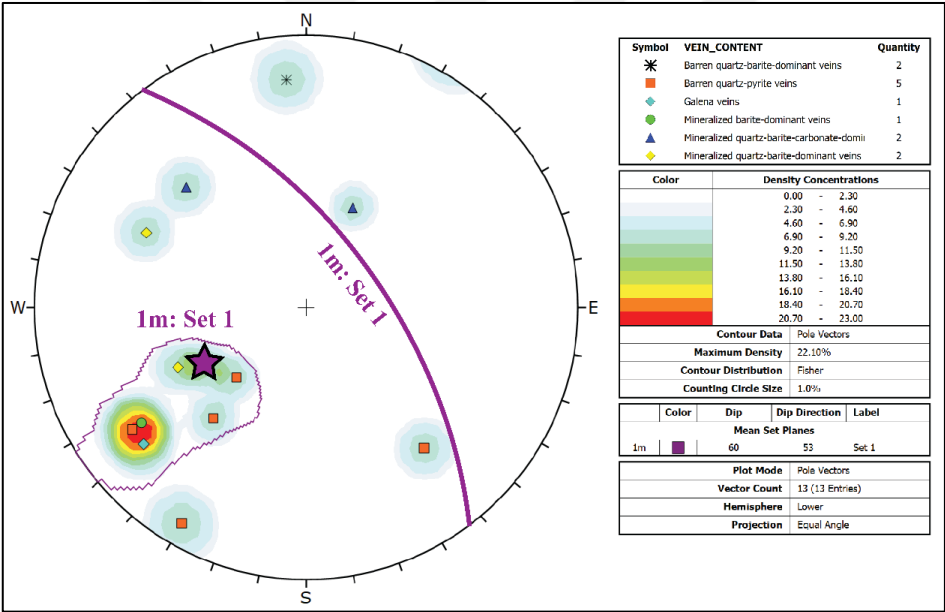


Figure 31. The stereonet projection (Equal Angle, Lower Hemisphere) displaying poles of Vein Zone 5 veins colored and shaped according to vein content, and 2 sets of these veins with plane directions.

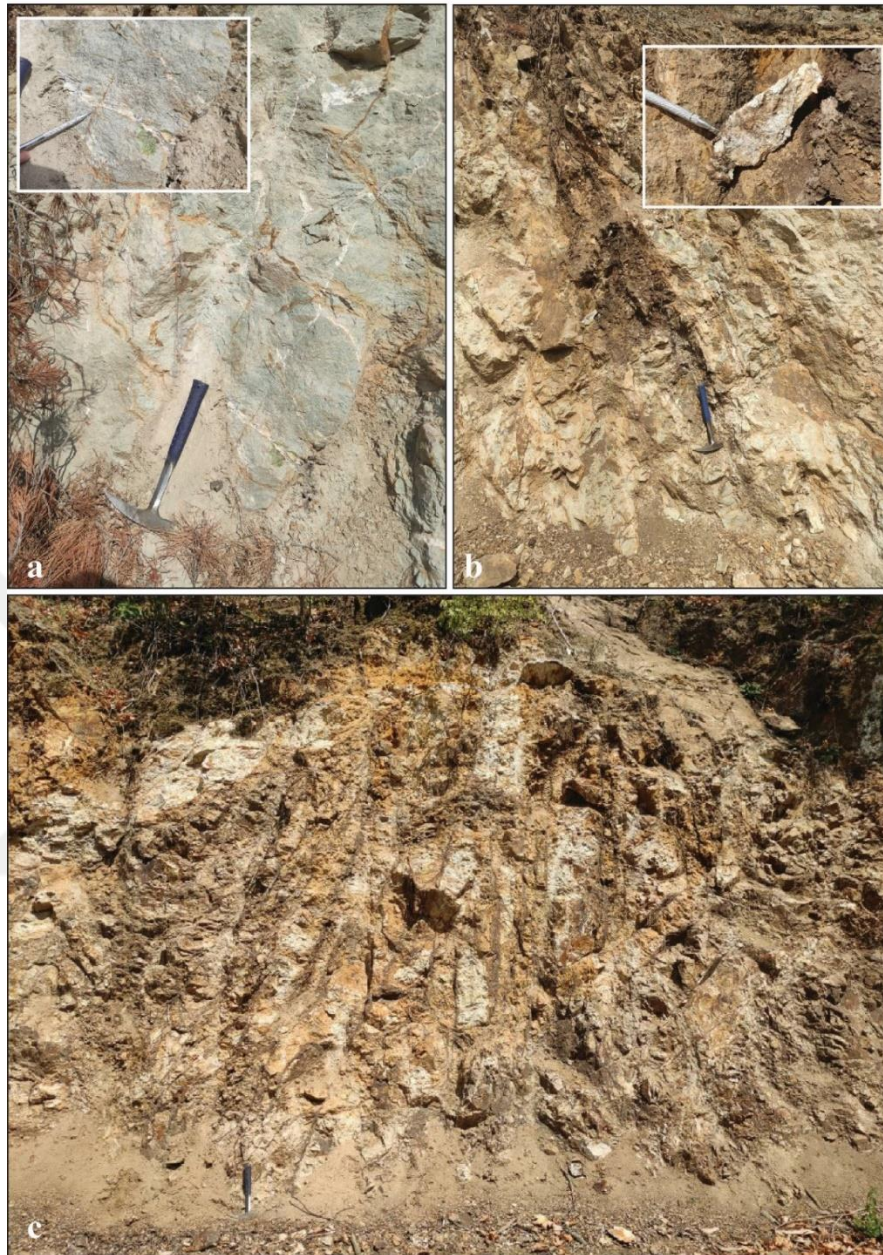


Figure 32. Outcrop photographs of different vein types from Vein Zone 5. a) Mineralized barite-dominant veins which is cut by oxidized quartz-pyrite veinlets, b) highly clay altered mineralized quartz-barite-dominant vein and c) sets of systematic oxidized quartz-pyrite veinlets.

4.2.5 Vein Zone 6

Vein Zone 6 consists of 6 different measurements because of intense deformation relative to other zones. Due to the low number of veins, a certain clustering cannot be performed in Vein Zone 6 (Figure 33). The dominant vein type is mineralized quartz-barite-dominant veins, and these veins are relatively thicker compared to veins in Vein Zones 4 and 5 (Figure 34a). In addition, these veins have also undergone strong clay alteration, unlike host rock which is basaltic andesite dyke. Moreover, veins in this zone includes trace amount of malachite, which is not observed in other zones, in addition to galena and sphalerite (Figure 34b).

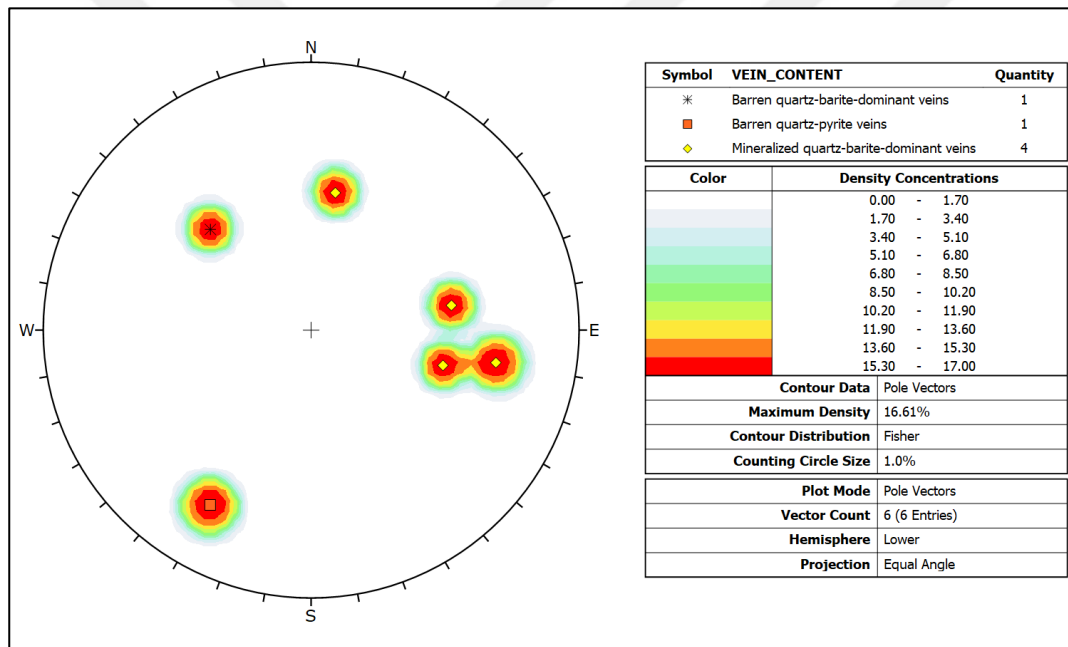


Figure 33. The stereonet projection (Equal Angle, Lower Hemisphere) displaying poles of Vein Zone 6 veins colored and shaped according to vein content, and 2 sets of these veins with plane directions.



Figure 34. Outcrop photographs of different vein types from Vein Zone 6. a) Intensely deformed mineralized quartz-barite-dominant vein, and b) strongly deformed mineralized quartz-barite-dominant vein including malachite.

CHAPTER 5

HYDROTHERMAL ALTERATION

The Çatalçam prospect shows widespread hydrothermal alteration developed in association with vein-type mineralization. Hydrothermal alteration is particularly well-developed in the Çatalçam Diorite and also in the andesitic rocks of the Yuntdağ Volcanics. Four main types of hydrothermal alteration were identified at Çatalçam during field work and on the basis of petrographic observations. These are: (i) sericite-clay alteration, (ii) quartz-sericite-pyrite (QSP) alteration, (iii) carbonate-clay alteration, and (iv) sericite-chlorite-clay alteration. Clay minerals are almost ubiquitous in most of these alteration zones and therefore identified alteration styles are regarded as variations of an overall argillic alteration system.

5.1 Sericite-Clay Alteration

Sericite-clay alteration is a common alteration that can be observed in drill cores from different depths. This alteration is particularly well-developed in the Çatalçam diorite and also locally in andesitic lavas, but not in basaltic andesitic dykes. Rocks showing this alteration style preserve their original igneous textures. Sericite-clay alteration is characterized by sericite replacement of ferromagnesian minerals including hornblende and biotite, and by replacement of plagioclase and groundmass material by finer-grained clays (Figure 35a, e). In andesitic rocks clays are more abundant possibly owing to the relatively finer-grained nature of these units (Figure 35). In addition, with increasing depth the abundance of sericite gradually increases,

likely due to an increase in fluid temperatures. At such levels, quartz+pyrite veins with sericitic haloes also appear (Figure 35f).

Clay dominant alteration can be classified as a sub-title of sericite-clay alteration. Although sericite mineral is not observed as much as clay, it can rarely be found together with tourmaline mineral (Figure 36).

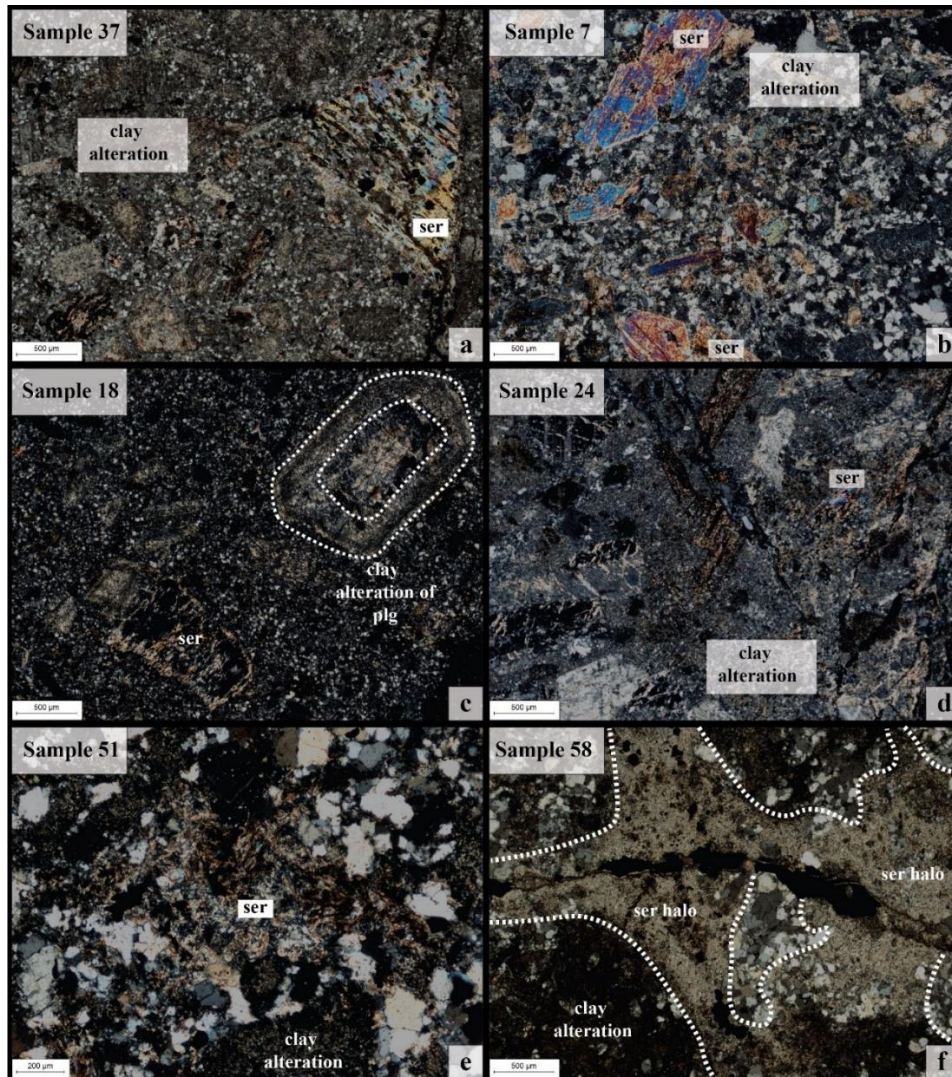


Figure 35. Microphotographs of rock units showing sericite-clay alteration. a) Diorite/andesite that has undergone moderate sericite-clay alteration (Sample 37;

drill hole: CTL020, 202.00 meters), b) diorite which has undergone slight sericite-clay alteration with sericitized biotite and hornblende (Sample 7; drill hole: CTL004, 95.10 meters), c) sericite-clay altered andesite (Sample 18; drill hole: CTL004, 180.50 meters), d) highly sericite-clay altered andesite (Sample 24; drill hole: CTL004, 227.40 meters), e) diorite which has undergone moderate sericite-clay alteration (Sample 51; drill hole: CTL008, 329.00 meters), f) diorite that includes quartz+pyrite veinlets with sericite halo (Sample 58, drill hole: SCS-15-8C, 613.20 meters) under XPL, Abbreviations: ser: sericite, plg: plagioclase.

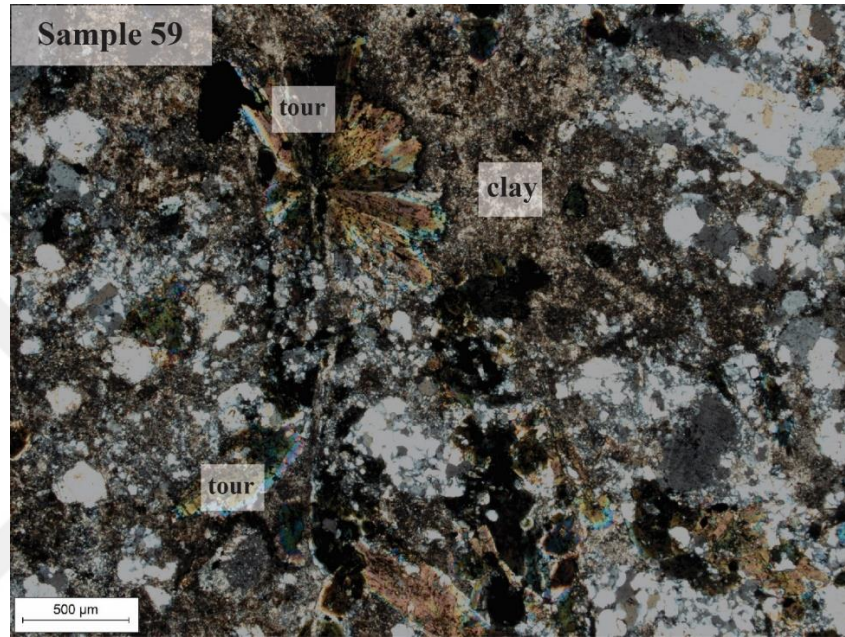


Figure 36. Microphotographs of rock units showing clay dominant alteration with tourmaline (Sample 59; drill hole: SCS-15-8C, 626.20 meters). Abbreviations: tour: tourmaline.

5.2 Quartz-Sericite-Pyrite Alteration

Quartz-sericite-pyrite alteration is less common compared to sericite-clay alteration in Çatalçam. In rocks showing this alteration style, sericite has replaced mafic minerals and plagioclase that occur as phenocrysts and also in the groundmass (Figure 37a, b). Quartz and disseminated pyrite generally occur in the groundmass

(Figure 37). Similar to sericite-clay alteration, quartz-pyrite veins with sericitic haloes were identified with increasing depth in zones of quartz-sericite-pyrite alteration. This is also accompanied by an overall increase in grain size of quartz and pyrite with respect to depth (Figure 37c).

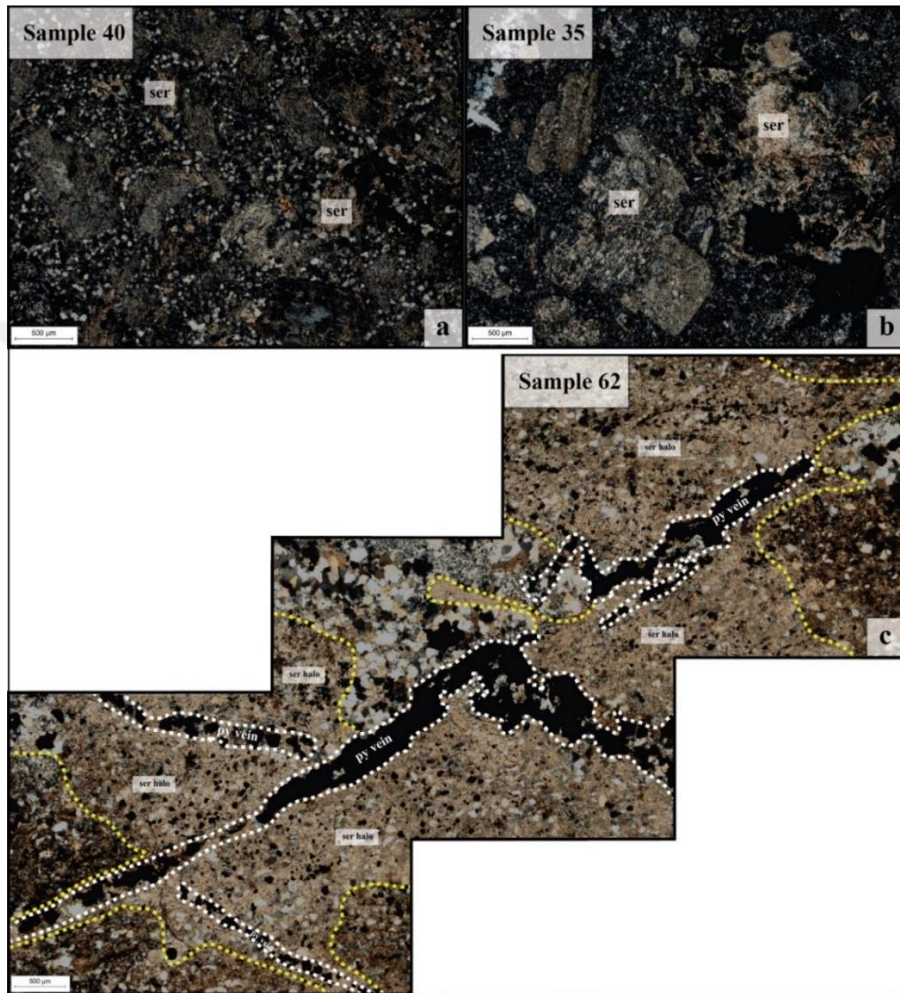


Figure 37. Microphotographs of rock units showing quartz-sericite-pyrite alteration. a) Andesite which includes groundmass with dominant anhedral quartz minerals (Sample 40; drill hole: CTL020, 182.00 meters), b) Andesite which includes groundmass with dominant anhedral and fine quartz minerals and anhedral sericite grains (Sample 35, drill hole: CTL020, 130.80 meters), and c) Diorite that has undergone strongly quartz-sericite-pyrite alteration (Sample 62, drill hole: SCS-15-8C, 682.00 meters) under XPL, Abbreviations: ser: sericite, py: pyrite.

5.3 Carbonate-Clay Alteration

At Çatalçam, narrow intervals of carbonate-clay assemblage are observed in both diorite and andesite. This alteration is restricted to shallower depths (<200 m) in drill holes. The degree of alteration is highly variable among the sampled drill holes. Ankerite, dolomite, or manganoan calcite are the main carbonate phases in the altered rocks. Dolomite can be observed as rhombic and coarse grains, calcite is generally identified as finer, anhedral grains. In addition, ankerite is generally observed as haloes of veins, but it can also occur in the groundmass of volcanic and sub-volcanic units (Figure 38). Clay minerals are typically more abundant compared to carbonates. Clay alteration is present in groundmass and phenocrysts; however, carbonate alteration is only dominant in the groundmass. These are primarily thought to be illitic clays since they are found alongside carbonate, which requires relatively higher pH conditions. Disseminated pyrite accompanies clay minerals and carbonate (Figure 39).

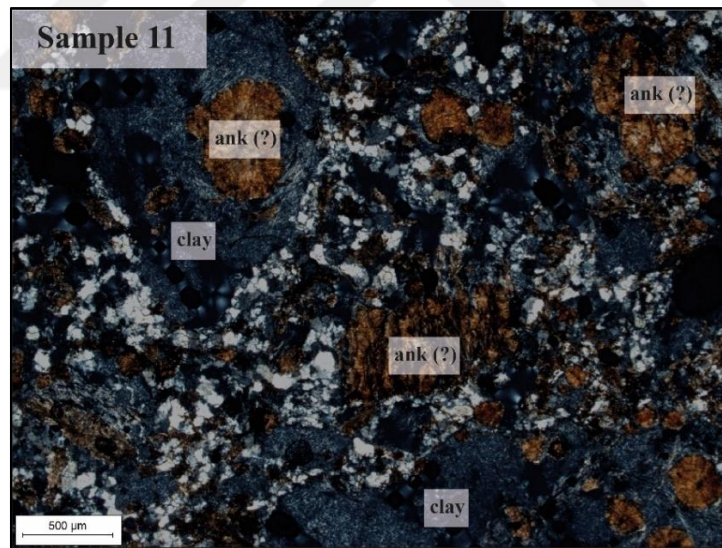


Figure 38. Microphotographs of rock units showing carbonate (ankerite)-clay alteration (Sample 11; drill hole: CTL004, 155.50 meters). Abbreviations: ank: ankerite.

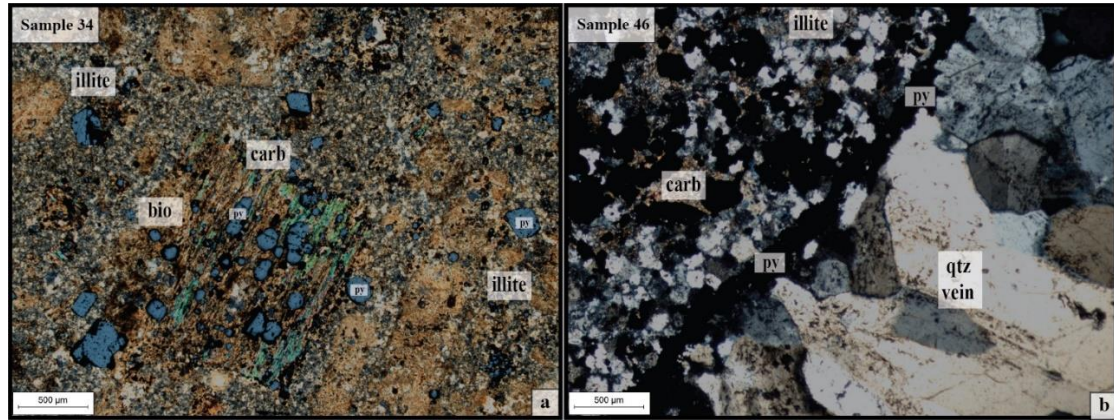


Figure 39. Microphotographs of rock units showing carbonate-clay alteration. a) Andesite, which has undergone moderate carbonate-clay alteration (Sample 34; drill hole: CTL020, 111.00 meters), and b) Boundary between carbonate-clay altered host rock and quartz vein (Sample 46; drill hole: CTL020, 284.20 meters) under XPL, Abbreviations: bio: biotite, carb: carbonate, py: pyrite, qtz: quartz.

5.4 Sericite-Chlorite-Clay Alteration

Sericite-chlorite-clay is a rare alteration type in Çatalçam. The degree of this alteration style changes with depth. Samples with relatively high chloritic alteration are typically green colored at drill core (Figure 40a, b). Chlorite typically replaces phenocryst phases of ferromagnesian minerals, and also occurs as infill in narrow veinlets (Figure 40c, e). Sericite and clays on the other hand are overgrown after plagioclase in phenocrysts and in the groundmass, and clay minerals are relatively more abundant compared to sericite (Figure 40d, f).

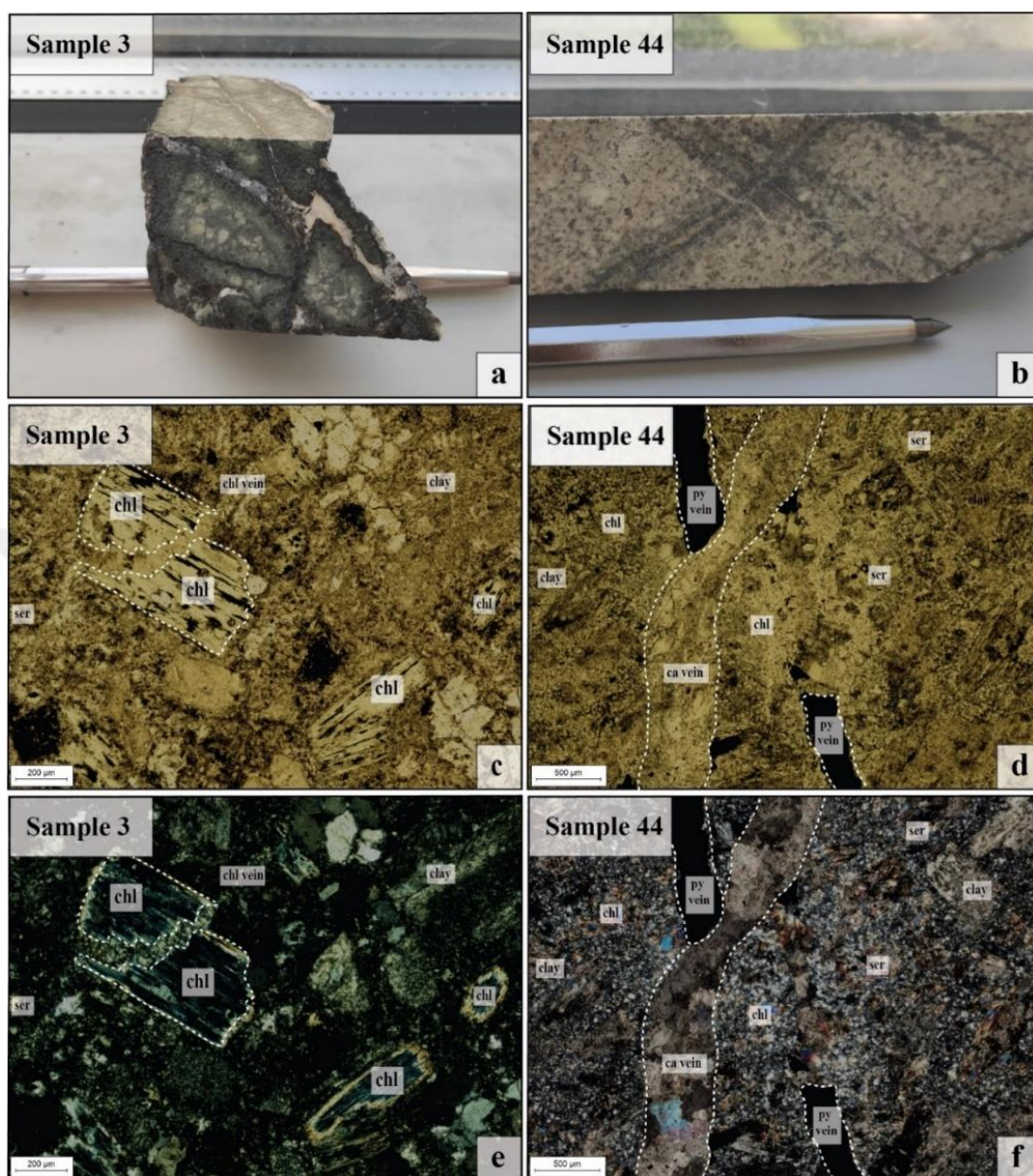


Figure 40. Microphotographs of rock units showing sericite-chlorite-clay alteration. a) Hand specimen of andesite which has undergone strong sericite-chlorite-clay alteration (Sample 3; drill hole: CTL004, 89.10 meters), b) hand specimen of andesite which has undergone slight sericite-chlorite-clay alteration (Sample 44; drill hole: CTL020, 223.00 meters), c) thin section of andesite which has undergone strong sericite-chlorite-clay alteration and chlorite mineral cut by another chlorite vein (Sample 3; drill hole: CTL004, 89.10 meters) under PPL, d) thin section of

andesite which has undergone slight sericite-chlorite-clay alteration (Sample 44; drill hole: CTL020, 223.00 meters) under PPL, e) thin section of andesite which has undergone strong sericite-chlorite-clay alteration and chlorite mineral cut by another chlorite vein (Sample 3; drill hole: CTL004, 89.10 meters) under XPL, f) thin section of andesite which has undergone slight sericite-chlorite-clay alteration (Sample 44; drill hole: CTL020, 223.00 meters) under XPL. Abbreviations: chl: chlorite, chl vein: chlorite vein, py vein: pyrite vein, ser:sericite.



CHAPTER 6

MINERALIZATION

Çatalçam mineralization is related with steeply-dipping veins, which are classified as epithermal-style veins and porphyry-style veins. Characteristics of distinct vein types that are identified in the study area are described below.

6.1 Epithermal-style Veins

Polymetallic Zn-Pb-Au mineralization at the Çatalçam prospect occurs along epithermal-style veinlets and breccia veins. Examination of drill cores and surface mapping allowed identification of a number of vein types based on their mineral infill and textural features. These veins generally have one or more of the gangue minerals of quartz, barite, and/or carbonate as the main infill material. In this study, epithermal veins are first classified into four groups as quartz-dominant veins, barite-dominant veins, carbonate-dominant veins, and brecciated veins.

6.1.1 Quartz-dominant Veins

The majority of the observed veins at Çatalçam are quartz-dominant veins, which are present throughout the area. These have an average thickness of ~20 cm. Quartz dominant veins are divided into 4 different groups based on contents which are quartz $\pm$ sulfide, quartz+carbonate $\pm$ sulfide, quartz+barite $\pm$ sulfide, quartz+barite+carbonate $\pm$ sulfide veins.

6.1.1.1 Quartz $\pm$ Sulfide Veins

Quartz $\pm$ sulfide veins are commonly emplaced in igneous wall-rocks showing sericite/clay-quartz $\pm$ chlorite alteration. Quartz-bearing veins may host a significant portion of mineralization where they also contain sulfide infill, but they also occur as barren quartz veins.

In quartz-dominant veins, main vein infill is represented by medium- to coarse-grained quartz that commonly occurs as subhedral interlocking crystals with typical jigsaw/mosaic textures (Figure 41; Figure 42). Quartz generally shows undulose extinction due to deformation. Quartz-dominant veins can be seen in core samples, and barren quartz veins and sulfide-bearing quartz veins are recorded. Drill hole database indicates an average thickness of 15 cm for barren quartz veins and vein thicknesses vary from about 1 mm up to 1 m.

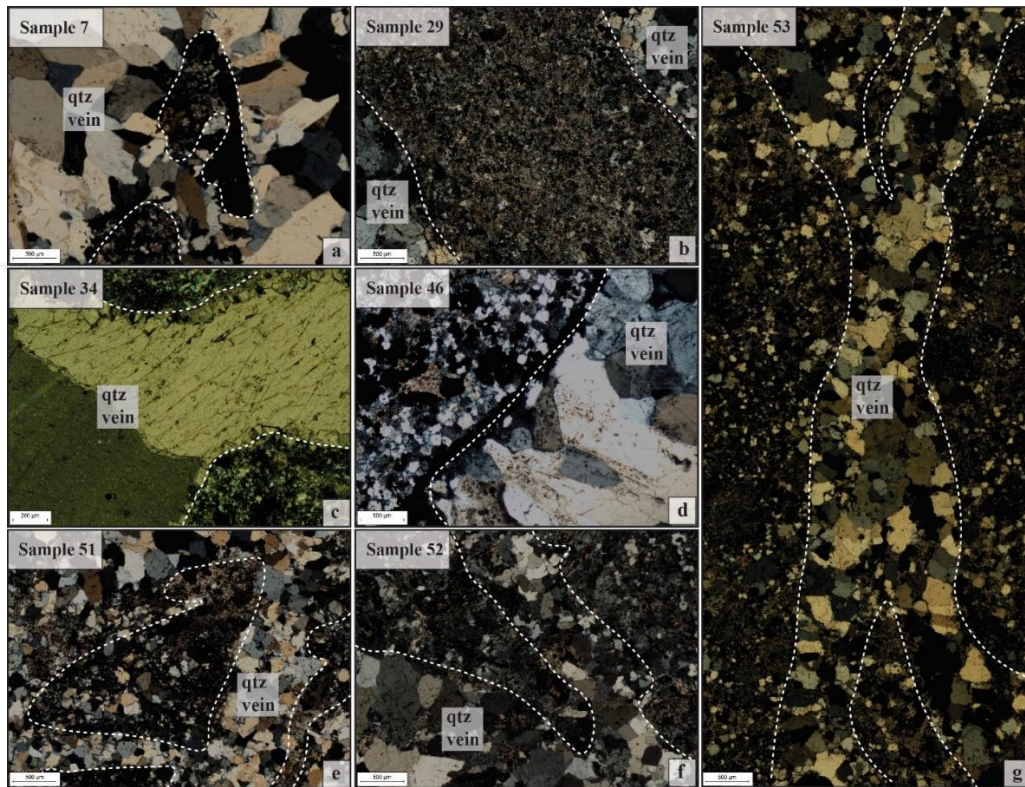


Figure 41. Thin section photographs showing general characteristics of quartz-dominant veins. a) Barren quartz vein consisting of interlocking crystals of coarse-grained, subhedral quartz (Sample 7; drill hole: CTL004, 114.80 meters) , b) A set of parallel veins with jigsaw/mosaic quartz cross-cutting intensely clay-altered (Sample 29; drill hole: CTL020, 85.00 meters) , c) barren quartz vein including grain, and comb texture at walls of the vein (Sample 34; drill hole: CTL020, 168.50 meters) , d) Jigsaw textured and coarse-grained quartz vein (Sample 46; drill hole: CTL006, 65.40 meters) , e) Intersections of quartz veins, and clay altered diorite (Sample 51; drill hole: SCS-15-8C, 612.90 meters) , f) barren medium grained quartz veins with clay altered andesite between some quartz grains (Sample 52; drill hole: SCS-15-8C, 613.20 meters) , g) panoramic view of barren quartz vein formed by subhedral grains (Sample 53; drill hole: SCS-15-8C, 626.20 meters), under XPL. Abbreviations: qtz: quartz.

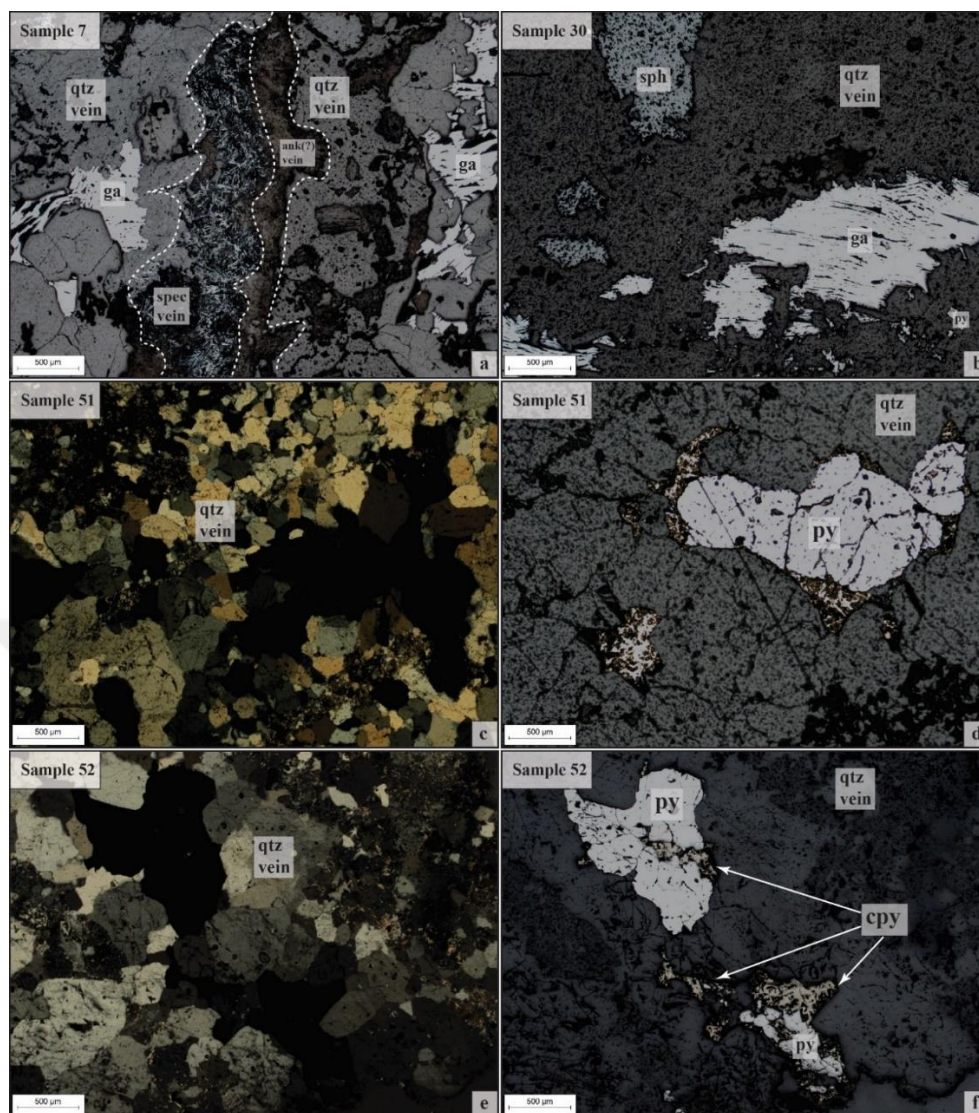


Figure 42. Thin section photographs showing general characteristics of quartz veins with sulfide minerals. a) Massive quartz vein including galena, and ankerite and specularite veins which are located at between the quartz veins (Sample 7; drill hole: CTL004, 114.80 meters) under reflected PPL, b) Massive quartz vein consisting of galena, pyrite, and sphalerite (Sample 30; drill hole: CTL004, 107.30 meters) under reflected PPL, c) Quartz vein with jigsaw texture including pyrite which is surrounded by chalcopyrite (Sample 51; drill hole: SCS-15-8C, 612.90 meters) under XPL, d) Quartz vein with jigsaw texture including pyrite which is surrounded by chalcopyrite (Sample 51; drill hole: SCS-15-8C, 612.90 meters) under reflected PPL, e) Quartz vein consisting of subhedral to euhedral grains and jigsaw texture including pyrite that is surrounded and cut by chalcopyrite (Sample 52; drill hole: SCS-15-8C, 613.20 meters) under XPL, f) Quartz vein consisting of subhedral to euhedral grains and jigsaw texture including pyrite that is surrounded and cut by chalcopyrite (Sample 52; drill hole: SCS-15-8C, 613.20 meters) under reflected PPL. Abbreviations: py: pyrite, sph: sphalerite, cpy: chalcopyrite, qtz: quartz, ga: galena, spec: specularite, ank: ankerite.

6.1.1.2 Quartz+Carbonate±Sulfide Veins

Quartz+carbonate veins are not common in Çatalçam. These occur both as barren veins or may contain sulfide minerals. In drillhole database, average thickness of quartz+carbonate+sulfide and quartz+carbonate veins are 0.60 cm and 1 cm, respectively.

In this vein type, quartz grains are subhedral to euhedral and coarse; on the other hand, carbonate grains are fine and anhedral (Figure 43). Barren quartz+carbonate veins are generally cut the sulfide minerals (Figure 43a), unlike ore bearing quartz+carbonate veins (Figure 44). In addition to these, specularite veins are common with in quartz+carbonate+sulfide veins (Figure 43a).

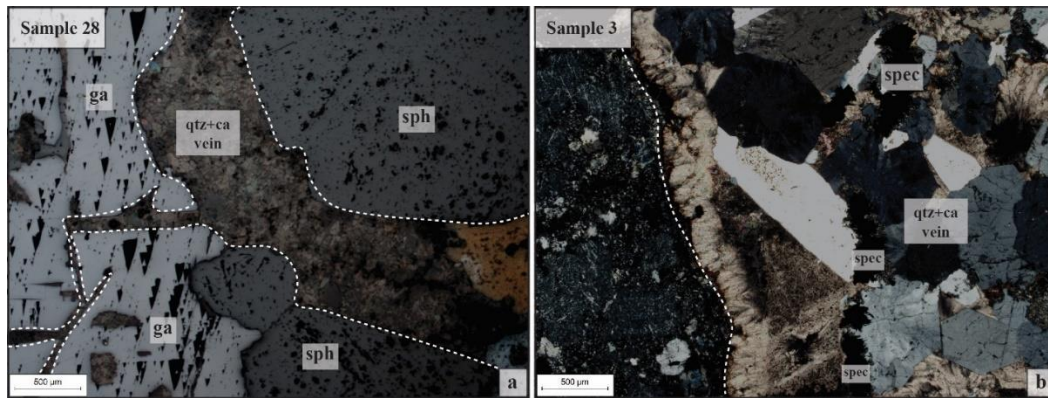


Figure 43. Thin section photographs showing general characteristics of quartz+carbonate veins
a) Quartz+carbonate vein cutting sulfide minerals, but sphalerite and galena which includes fragment of carbonate vein (Sample 49; drill hole: CTL020, 68.50 meters) under reflected XPL,
b) quartz+carbonate vein with jigsaw texture including specularite vein cutting highly sericite-clay altered andesite (Sample 3; drill hole: CTL004, 114.80 meters) under XPL. Abbreviations: sph: sphalerite, qtz: quartz, ca: carbonate, ga: galena, spec: specularite.

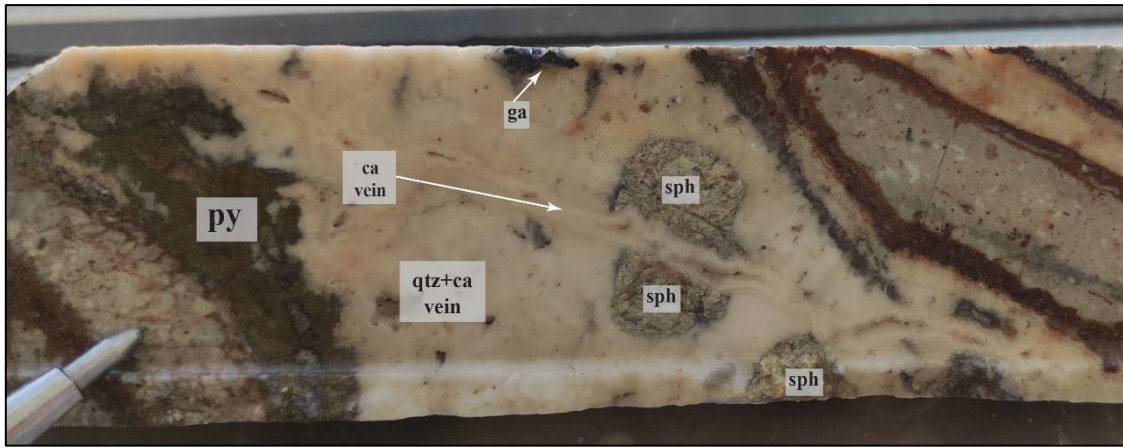


Figure 44. Breccia quartz+carbonate vein with sulfide minerals, and one sphalerite mineral cut by colloform carbonate vein (Drill hole: CTL004, 132.00 meters). Abbreviations: sph: sphalerite, qtz: quartz, ca: carbonate, ga: galena, py: pyrite.

6.1.1.3 Quartz+Barite±Sulfide Veins

Quartz+barite veins are common vein types in Çatalçam. These veins may contain ore, or they may occur as barren. In polished thin section studies, quartz is generally defined as subhedral and coarse grain in quartz+barite veins, while minerals with thin-long appearance and systematic cleavages are defined as barite (Figure 45). Average thickness of ore bearing quartz+barite and barren quartz+barite veins are 2 cm and 4 cm, respectively (Figure 46).

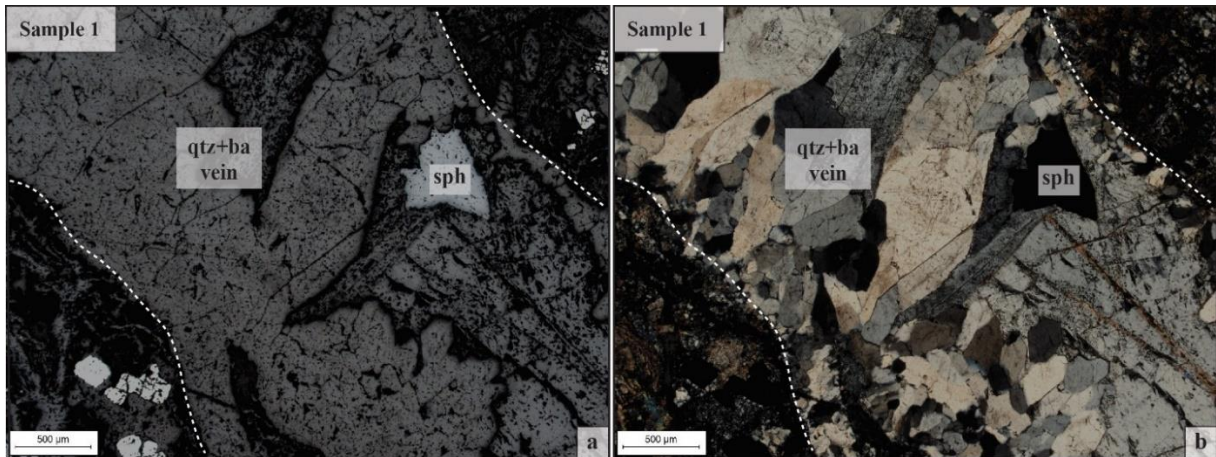


Figure 45. Thin section photographs showing general characteristics of quartz +barite veins a) Quartz+barite vein including sphalerite cutting strongly clay altered andesite with pyrite

dissemination (Sample 1; drill hole: CTL004, 29.80 meters) a) under reflected PPL, and b) under XPL. Abbreviations: sph: sphalerite, qtz: quartz, ba: barite.

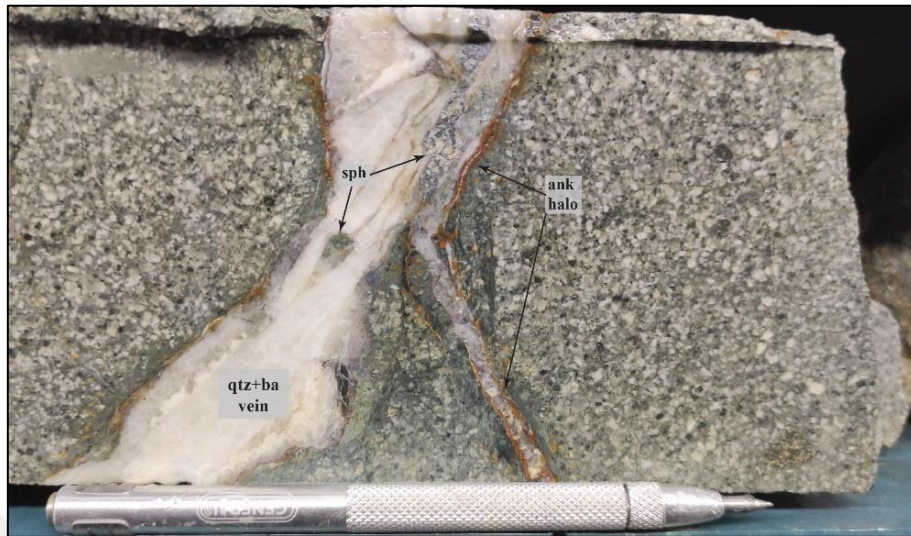


Figure 46. The core sample photograph shows quartz+barite vein including sphalerite with ankerite halo (Drill hole: CTL004, 58.60 meters). Abbreviations: sph: sphalerite, qtz: quartz, ank: ankeritic, ba: barite.

6.1.1.4 Quartz+Barite+Carbonate±Sulfide Veins

Quartz+barite+sulfide veins are the most common vein types in core samples. Average thickness of these veins is 2 cm. This vein types are usually ore bearing, but there exists some barren quartz+barite+carbonate veins. Quartz is anhedral to subhedral and medium- to coarse-grained, whereas barite occurs as thin tabular prismatic crystals and carbonate occurs as fine-grained crystals (Figure 47). In addition, carbonate content is generally lower than quartz and barite content.

Especially when the cores are examined, it is possible to observe that the veins, which can be named as quartz+barite+carbonate, are formed in relatively more deformed areas and the vein itself is deformed (Figure 47a, b; Figure 48).

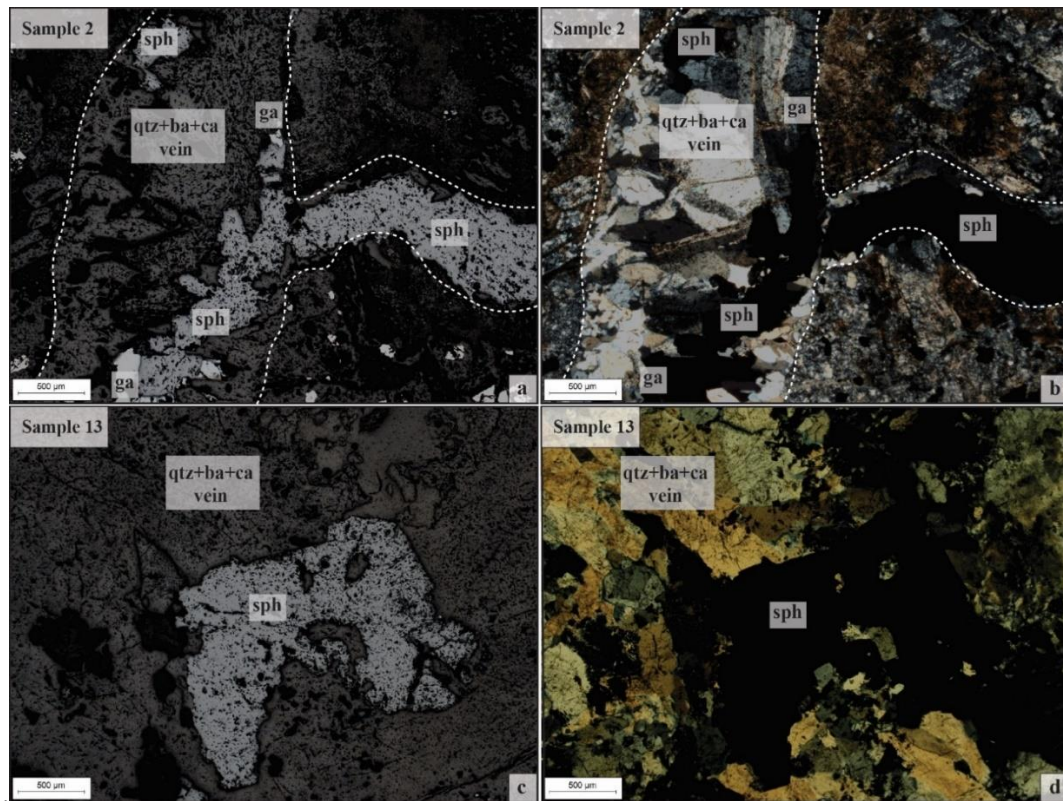


Figure 47. Thin section photographs showing general characteristics of quartz+barite+carbonate veins. a) Quartz+barite+carbonate vein including deformed sphalerite, and galena (Sample 1; drill hole: CTL004, 29.80 meters) under reflected PPL, b) Quartz+barite+carbonate vein including deformed sphalerite, and galena (Sample 1; drill hole: CTL004, 29.80 meters) under XPL, c) Q quartz+barite+carbonate vein including sphalerite (Sample 13; drill hole: CTL004, 159.00 meters) under reflected PPL, d) quartz+barite+carbonate vein including sphalerite (Sample 13; drill hole: CTL004, 159.00 meters) under XPL. Abbreviations: sph: sphalerite, ga: galena, qtz: quartz, ba: barite, ca: carbonate.

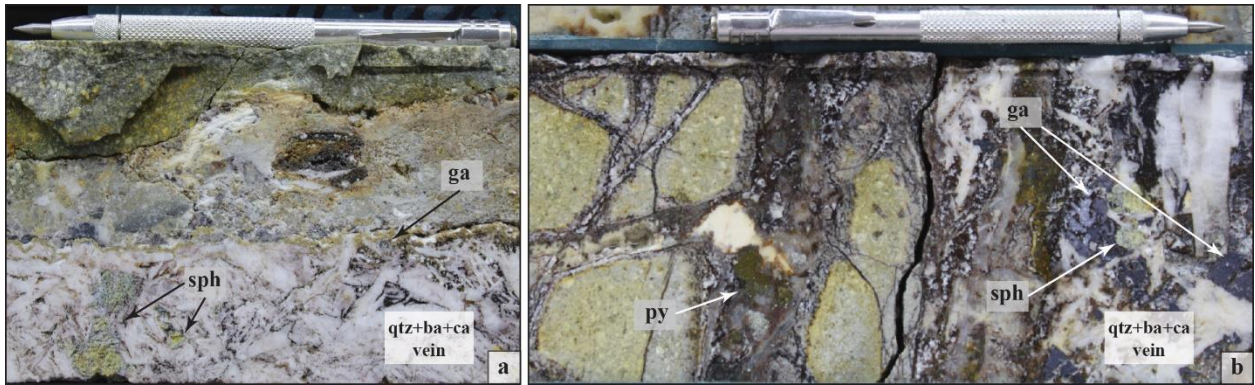


Figure 48. Core sample photographs of a) quartz+barite+carbonate vein shows fault boundary between quartz+barite+carbonate vein including sphalerite and galena and clay altered wall rock (Drill hole: CTL004, 240.00 meters), and b) quartz+barite+carbonate vein includes quartz+barite+carbonate vein with dominant galena and low amount of sphalerite (Drill hole: CTL004, 133.50 meters). Abbreviations: sph: sphalerite, ga: galena, qtz: quartz, ba: barite, ca: carbonate.

6.1.2 Barite-dominant Veins

Barite-dominant veins are not common relative to quartz-dominant veins. Barite-dominant veins are divided into two groups which are barite+carbonate±sulfide, and barite±sulfide. Barite-dominant veins are generally observed in the west of the prospect with an average thickness of 10 cm. Geochemistry results revealed that barite-dominant veins, which are not commonly observed in drilling, are associated with Au-Pb-Zn mineralization.

6.1.2.1 Barite+Carbonate±Sulfide Veins

Barite+carbonate veins are not common in not only drill holes but also surface studies. The average thickness of these veins is 1 cm based on drill hole database. Barite grains can be observed as not deformed and the grains have long tiny appearances with cleavage. Carbonate minerals are not euhedral, and coarse grains same as quartz dominant veins (Figure 49a, b, d, e). However, some veins may include coarse and euhedral carbonate grains (Figure 49c, d). In addition to sulfide content of these veins, generally wall of these veins are occupied by specularite veins, like quartz+carbonate veins (Figure 49b).

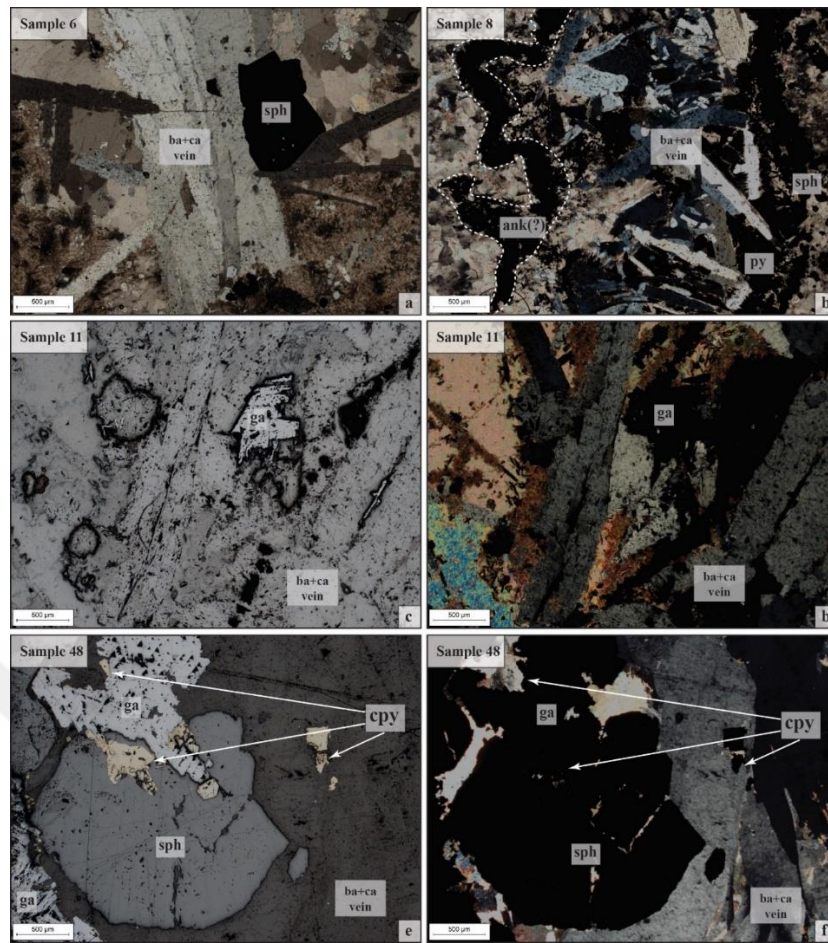


Figure 49. Thin section photographs showing general characteristics of barite+carbonate veins. a) Barite dominant barite+carbonate vein with anhedra and fine grained carbonate minerals including sphalerite (Sample 6; drill hole: CTL004, 109.40 meters) under XPL, b) barite+carbonate veins with disseminated pyrite and sphalerite, the domination of carbonate increases towards to wall of the vein which is bounded by ankerite (Sample 8; drill hole: CTL004, 121.00 meters) under XPL, c) barite+carbonate vein with coarse barite and carbonate grains including galena (Sample 11; drill hole: CTL004, 155.50 meters) under reflected PPL, d) barite+carbonate vein with coarse barite and carbonate grains including galena (Sample 11; drill hole: CTL004, 155.50 meters) under XPL, e) barite dominant barite+carbonate veins with anhedra carbonate grains including sphalerite which is cut by chalcopyrite and galena that is surrounded by chalcopyrite (Sample 48; drill hole: CTL030, 396.70 meters) under reflected PPL, f) barite dominant barite+carbonate veins with anhedra carbonate grains including sphalerite which is cut by chalcopyrite and galena that is surrounded by chalcopyrite (Sample 48; drill hole: CTL030, 396.70 meters) under XPL. Abbreviations: sph: sphalerite, ga: galena, ba: barite, ca: carbonate, py: pyrite, cpy: chalcopyrite, ank: ankerite.

6.1.2.2 Barite±Sulfide Veins

Barite-only veins are rare compared to other vein types. From drillhole database, the average thickness of this vein type is 1 cm. In the thin section studies, barite-only veins can be observed in only two samples. This vein type may contain sulfide minerals or may occur as barren. Barite+sulfide veins are associated with Pb-Zn-Au mineralization based on geochemical results of drillholes, even if these veins are not common. In the microscope study, sulfide minerals are galena, and commonly pyrite in these veins (Figure 50a, b). Grains of barite minerals can be observed as long tiny appearances with cleavage (Figure 50d). However, when barite vein is severely deformed, then the appearance of the grains can be changed (Figure 50d).

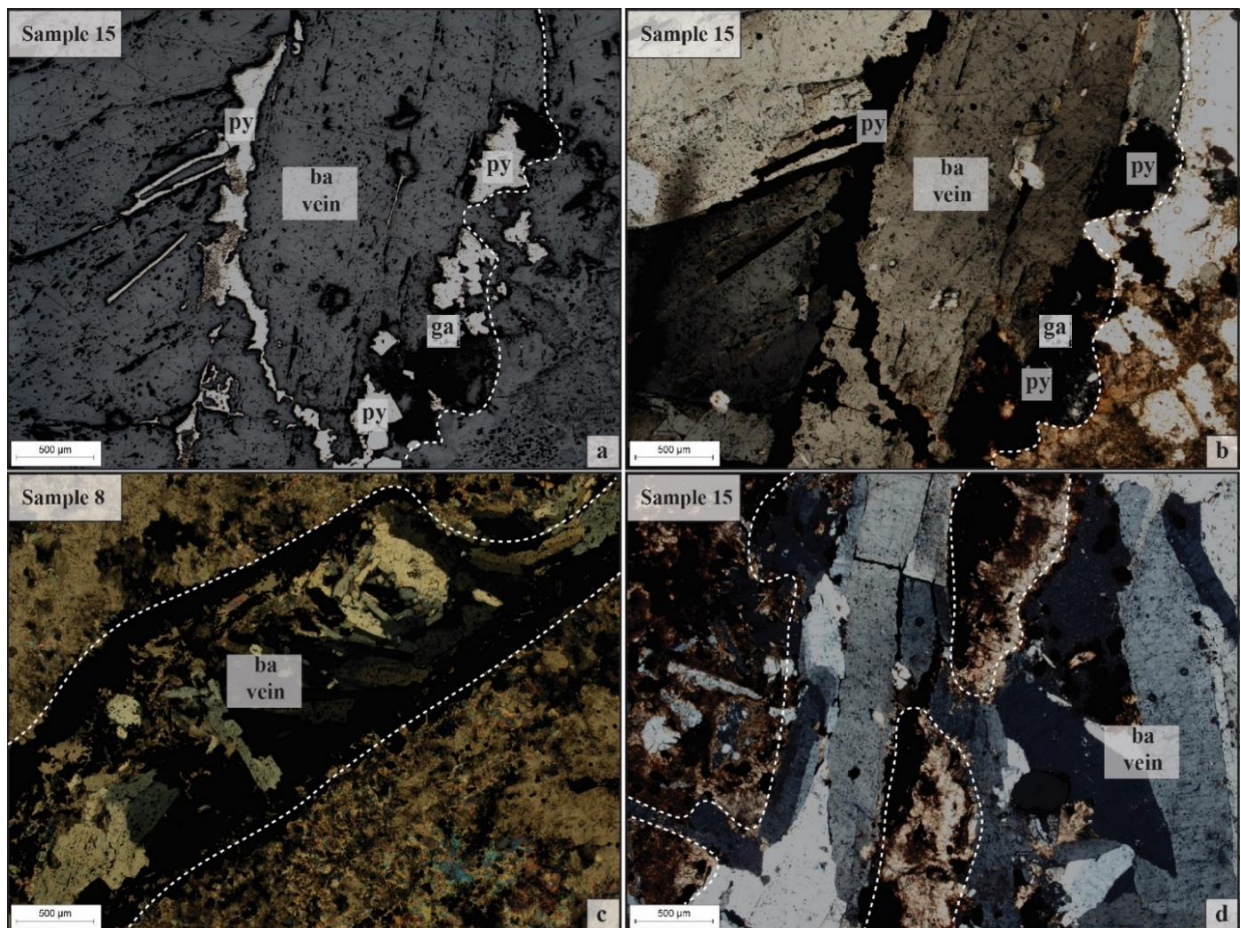


Figure 50. Thin section photographs showing general characteristics of barite±sulfide veins. a) Barite vein with disseminated and fracture filled pyrite with minor galena (Sample 15; drill hole: CTL004, 170.70 meters) under reflected PPL, b) barite vein with disseminated and fracture filled pyrite with minor galena (Sample 15; drill hole: CTL004, 170.70 meters) under

XPL, c) Deformed barite vein with bounded by ankerite vein (Sample 8; drill hole: CTL004, 121.00 meters) under XPL, d) barren barite veins which are cut carbonate veins formed with tiny carbonate grains cutting clay altered andesite (Sample 15; drill hole: CTL004, 170.70 meters). Abbreviations: ba: barite, py: pyrite, ga: galena.

6.1.3 Carbonate-dominant Veins

Carbonate only veins which are not common in Çatalçam. These occur both as barren veins or may contain sulfide minerals. In database, average thicknesses of barren carbonate veins and ore bearing carbonate veins are 1 cm and 0.60 cm, respectively.

Grains of barren carbonate veins are generally anhedral to subhedral, and medium to coarse (Figure 51a, b, d). However, in some cases, grains can be observed as tiny and anhedral. In addition, some of barren carbonate veins are altered to clay, unlike others. From the microscope study, clay altered barren carbonate vein with anhedral and tiny grains includes chlorite, which is not a common case (Figure 51c). In addition to these, these types of veins can cut other vein types (Figure 51d).

Carbonate+sulfide veins are more common relative to barren carbonate veins in microscope studies, unlike surface studies. Grains of carbonates in carbonate+sulfides are tiny and anhedral, and these veins are most likely altered to clay (Figure 52). In addition, carbonate+sulfide veins can include some rock fragments and carbonate can have rhombic crystals (Figure 52a, b). In these veins, different sulfide minerals which are galena, pyrite, sphalerite, and chalcopyrite can be observed (Figure 52c, d, e, f, g, h).

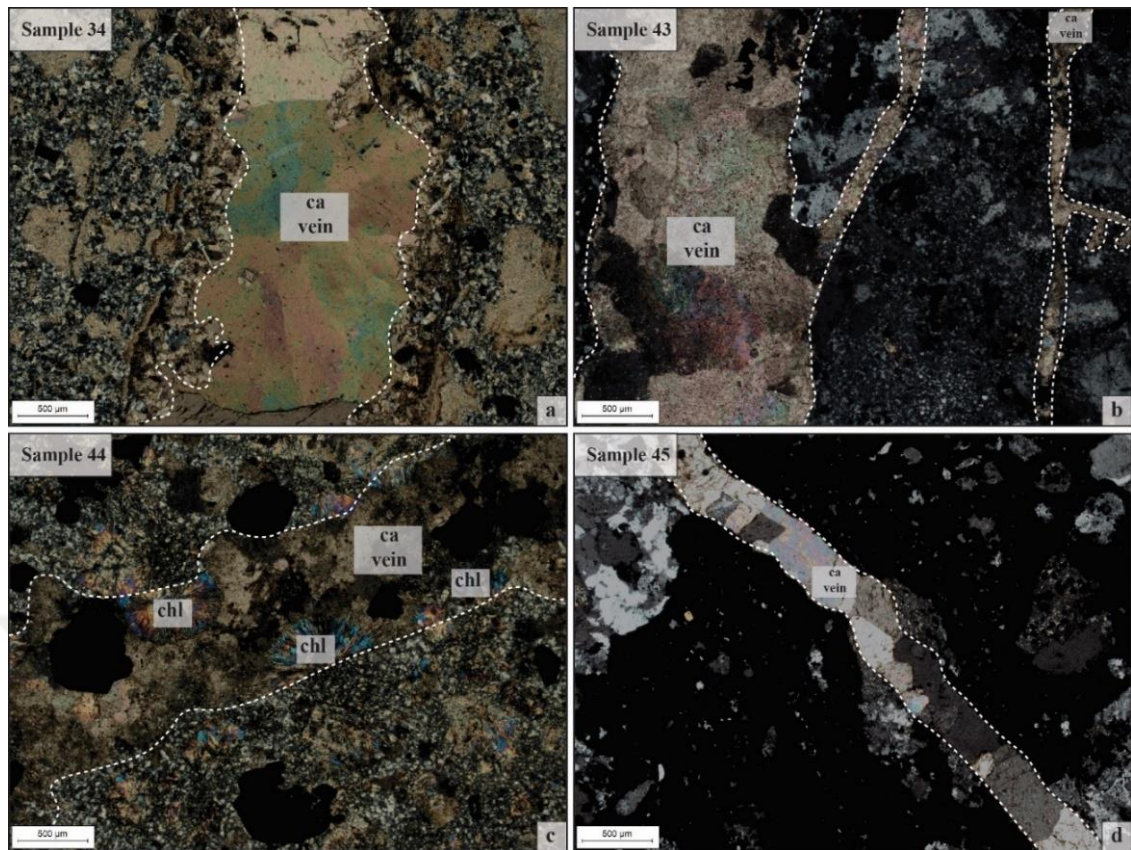


Figure 51. Thin section photographs showing general characteristics of carbonate veins. a) Barren carbonate veins with coarse grains cutting clay altered quartz dominated andesite (Sample 34; drill hole: CTL020, 132.90 meters) , b) barren carbonate vein with anhedral grains cutting weakly clay altered andesite (Sample 43; drill hole: CTL020, 323.00 meters) , c) barren carbonate vein with chlorite and pyrite dissemination cutting clay altered andesite including chlorite and disseminated pyrite in matrix (Sample 44; drill hole: CTL020, 406.00 meters) , and d) barren carbonate vein with subhedral grains which cutting quartz-dominant vein (Sample 45; drill hole: CTL008, 329.00 meters) under XPL. Abbreviations: ca: carbonate, chl: chlorite.

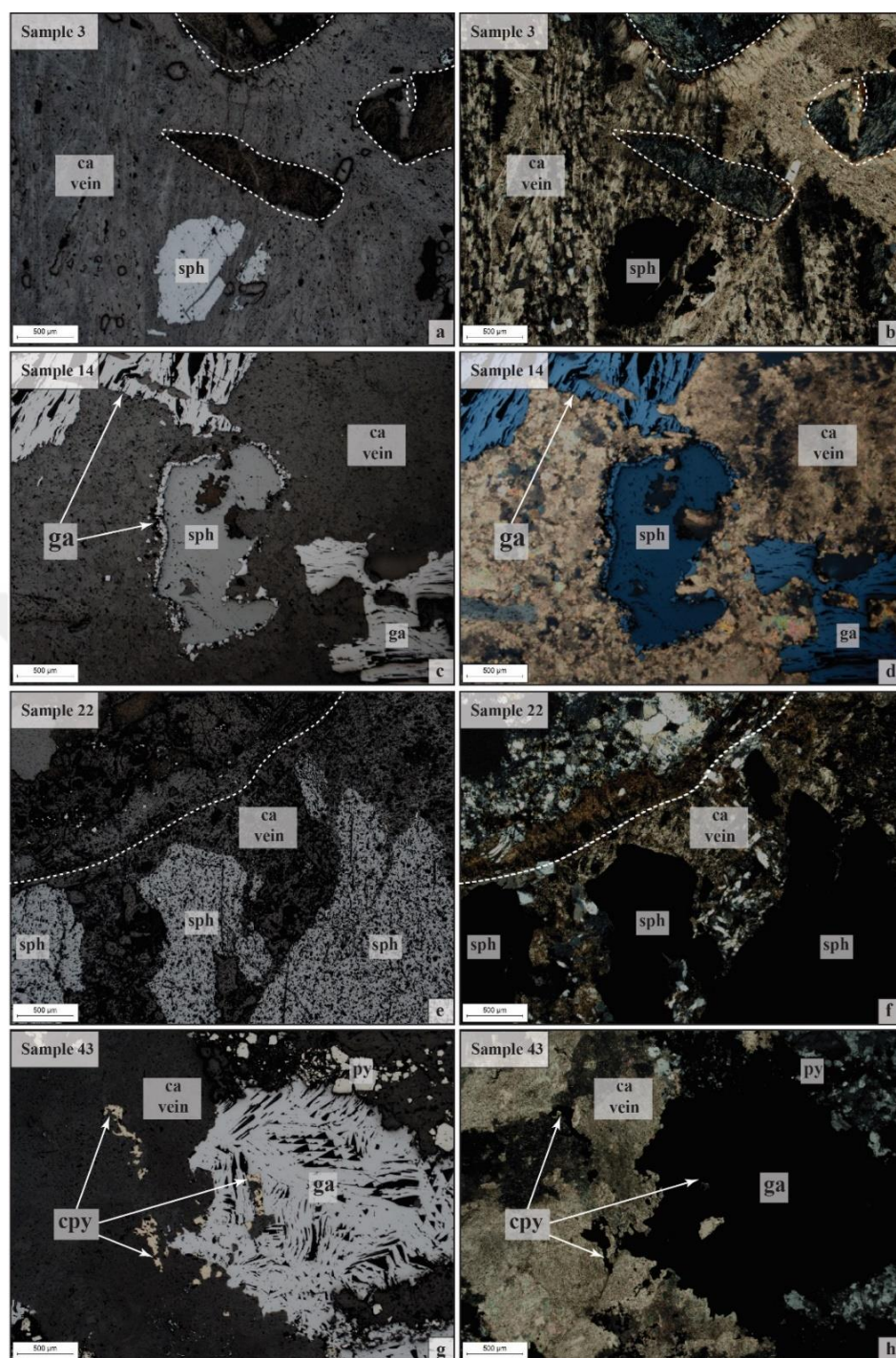


Figure 52. Thin section photographs showing general characteristics of carbonate+sulfide veins. a) Sphalerite in carbonate vein with rhombic crystals including clay altered andesite fragments (Sample 3; drill hole: CTL004, 89.10 meters) under reflected PPL, b) sphalerite in carbonate vein with rhombic crystals including clay altered andesite fragments (Sample 3; drill hole: CTL004, 89.10 meters) under XPL, c) fine grained carbonate+sulfide vein including sphalerite which is bounded by galena (Sample 14; drill hole: CTL004, 161.90 meters) under

reflected PPL, d) fine grained carbonate+sulfide vein including sphalerite which is bounded by galena (Sample 14; drill hole: CTL004, 161.90 meters) under XPL, e) clay altered carbonate+sulfide vein including sphalerite with ankerite boundary (Sample 22; drill hole: CTL004, 229.20 meters) under reflected PPL, f) clay altered carbonate+sulfide vein including sphalerite with ankerite boundary (Sample 22; drill hole: CTL020, 229.20 meters) under XPL, g) carbonate+sulfide vein including galena which is surrounded and cut by chalcopyrite and pyrite (Sample 43; drill hole: CTL020, 323.00 meters) under reflected PPL, h) carbonate+sulfide vein including galena which is surrounded and cut by chalcopyrite and pyrite (Sample 43; drill hole: CTL020, 323.00 meters) under XPL. Abbreviations: ca: carbonate, sph: sphalerite, ga: galena, py: pyrite.

6.1.4 Breccia Veins

Breccia veins are grouped as epithermal-style veins; however, the contents of the breccia veins are different, the matrices generally contain sulfide. Breccia veins have different matrix/clasts ratios, at the same time the matrices of veins which vary in terms of angularity and sorting can be observed as volcanic, plutonic, or belonging to part of another veins in Çatalçam mineralization.

Clasts belonging to Çatalçam diorite can be observed as subangular to angular and poorly sorted (Figure 53). Matrices of these veins are generally oxidized or fresh sulfide minerals with hematite, quartz, and barite. Jebrak (1997) published a schematic illustration of the brecciation mechanisms in hydrothermal vein deposits, and from this study, some of breccia veins that observed in Çatalçam can be classified as fluid-assisted brecciation (Figure 53a, c). Replacement can be observed at the boundaries of clasts of diorite.

Breccia veins also contain andesite clasts which are generally large and can be described as medium to well sorted, subangular to angular clasts. Although matrices are generally formed by sulfide minerals, quartz, barite and beige colored carbonates are also encountered (Figure 54).

Pyrite matrix is the most common matrix in breccia veins, and clasts:matrix ratio changes from 60:40 (Figure 54a) to 30:70 (Figure 53c).

These breccia veins including large angular clasts surrounded by a fine-grained matrix or finely-crystalline cement can be classified as tectonic breccia (Figure 53a, Figure 54a,b). However, there is no specific orientation due to tectonic movement. Therefore,

breccia veins observed in Çatalçam mineralization can be strongly related to hydrothermal activity with minor amounts of fault-related breccias.

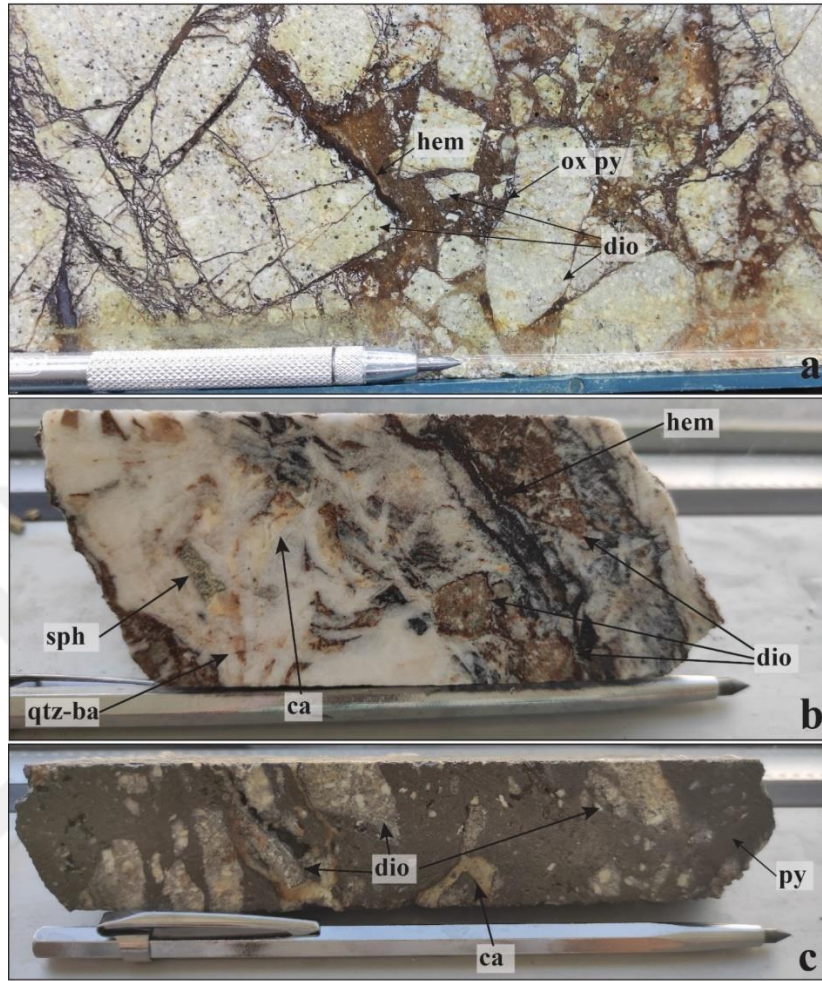


Figure 53. Breccia vein types in Çatalçam. a) Hematite-pyrite matrix containing poorly sorted, slightly clay altered diorite clasts (drill hole: CTL004, 151.90-152.40 meters), b) quartz+barite+carbonate+sphalerite+pyrite matrix including mediumly sorted, angular, strongly clay altered diorite clasts (drill hole: CTL004, 155.90 meters), c) matrix dominated which including pyrite+beige colored carbonate vein containing poorly sorted, subangular, and slightly clay altered diorite clasts (drill hole: CTL008, 329.00 meters).

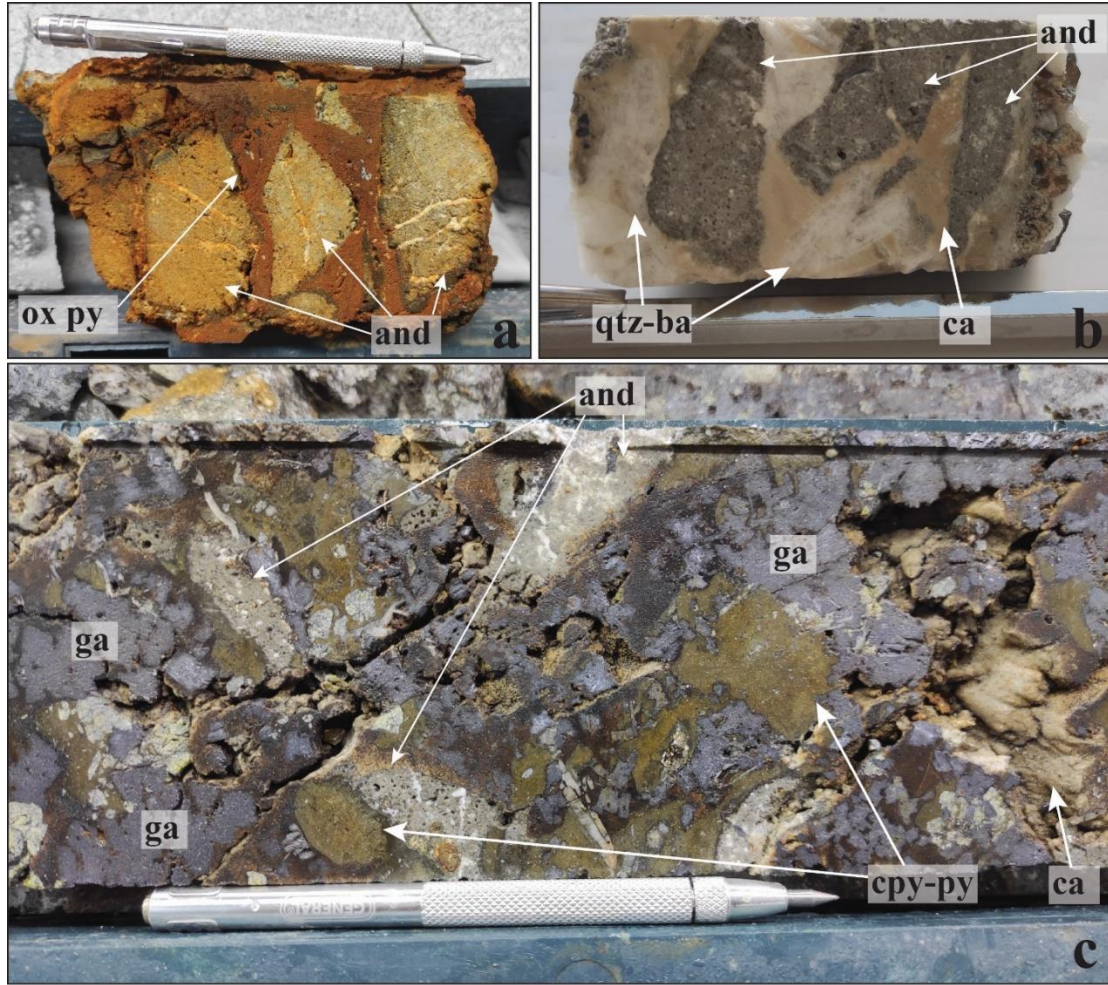


Figure 54. Breccia vein types in Çatalçam. a) oxidized pyrite matrix including subhedral-euhedral, moderately clay altered andesite clasts (drill hole: CTL004, 176.00 meters), b) quartz+barite+carbonate matrix containing subhedral-euhedral, poorly sorted andesite clasts (drill hole: CTL020, 132.90 meters), and c) galena+chalcopyrite+pyrite+carbonate vein including slightly clay altered, poorly sorted, relatively rounded andesite clasts (drill hole: CTL004, 216.00 meters).

In polished thin section studies, brecciated and fractured pyrite can be seen with clasts in breccia veins. Clasts are generally pieces of Yuntdağ Andesite (Figure 55a, b, c) and Çatalçam Diorite (Figure 55d); however, pieces of other veins can be observed (e, f). Angularity of clasts can vary from rounded to angular (Figure 55e, f).

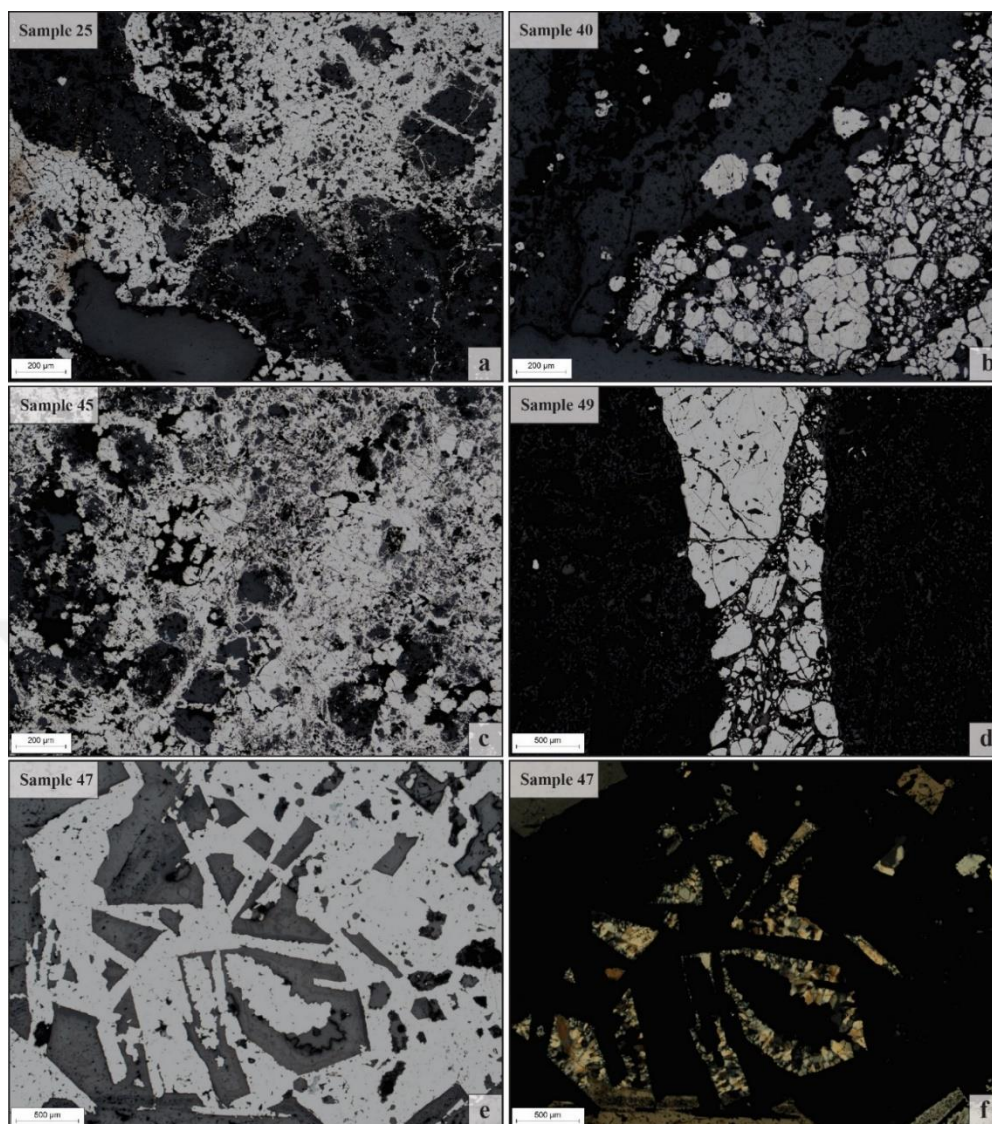


Figure 55. The thin section photographs showing breccia veins. a) Fractured fine grained pyrite (Sample 25; drill hole: CTL020, 46.50 meters) under reflected PPL, b) fractured medium- to coarse-grained pyrite and fine-grained galena filling into spaces between pyrite (Sample 40; drill hole: CTL020, 284.20 meters) under reflected PPL, c) fractured fine grained pyrite (Sample 45; drill hole: CTL008, 329.00 meters) under reflected PPL, d) fractured medium- to coarse-grained pyrite (Sample 49; drill hole: CTL030, 397.50 meters) under reflected PPL, e) fractured and brecciated pyrite matrix with quartz filling (Sample 47; drill hole: CTL032, 49.00 meters) under reflected PPL, and f) fractured and brecciated pyrite matrix with quartz filling (Sample 47; drill hole: CTL032, 49.00 meters) under XPL.

6.2 Porphyry-style Veins

Porphyry-style quartz veins appear in deeper parts of the Çatalçam prospect, beneath levels of epithermal mineralization. These were initially intersected during MTA drilling campaign, and were described by Sari et al. (2022), who identified various vein-types including high temperature A- and B-type veins. In this study, however, porphyry-style veinlets were only encountered in a few of the drill holes, where epithermal-style quartz-sericite/clay $\pm$ chlorite $\pm$ carbonate alteration extends down to depths of >850 meters. The main veinlets observed are narrow (up to 2 cm), planar veins dominated by medium-grained, anhedral quartz with lesser amounts of pyrite and chalcopyrite (Figure 56; Figure 57). Pyrite and chalcopyrite may occur as centerline fill (Figure 56), and pyrite often shows evidence for cataclastic deformation as it is brecciated (Figure 57). Such veins form weak stockworks or may have developed as sheeted veins and are locally cross-cut by pyrite or barren carbonate veins (Figure 57d).

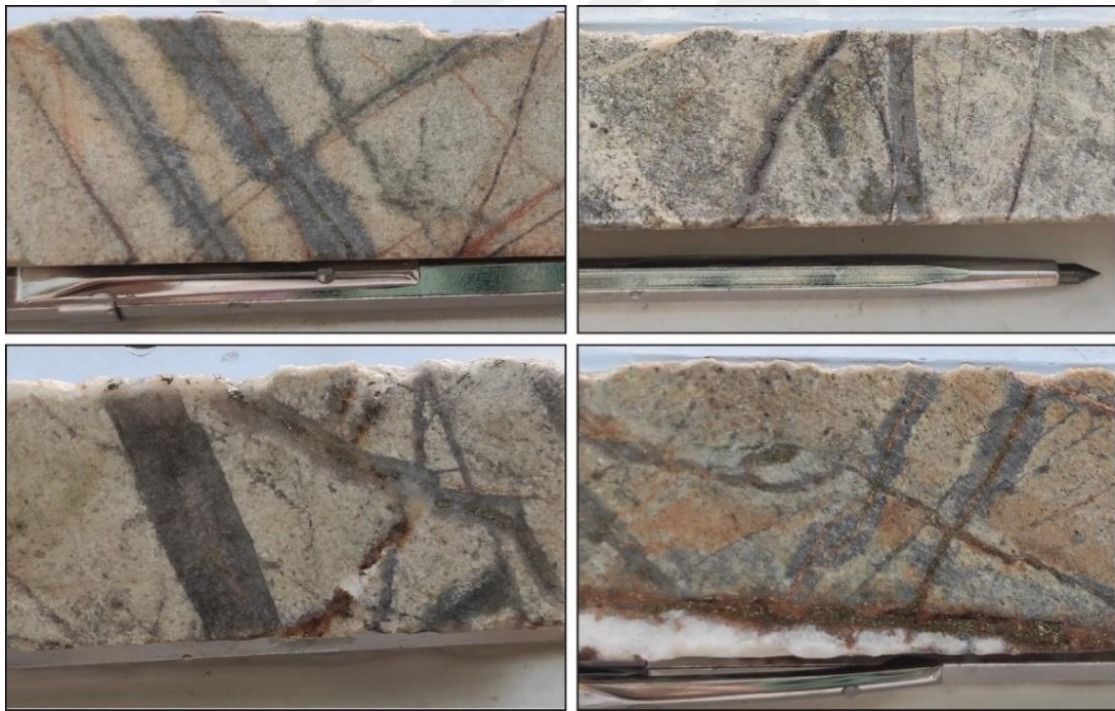


Figure 56. The core sample photographs taken from different depths include porphyry veinlets (Drill hole: SCS-15-8C, >850.00 meters).

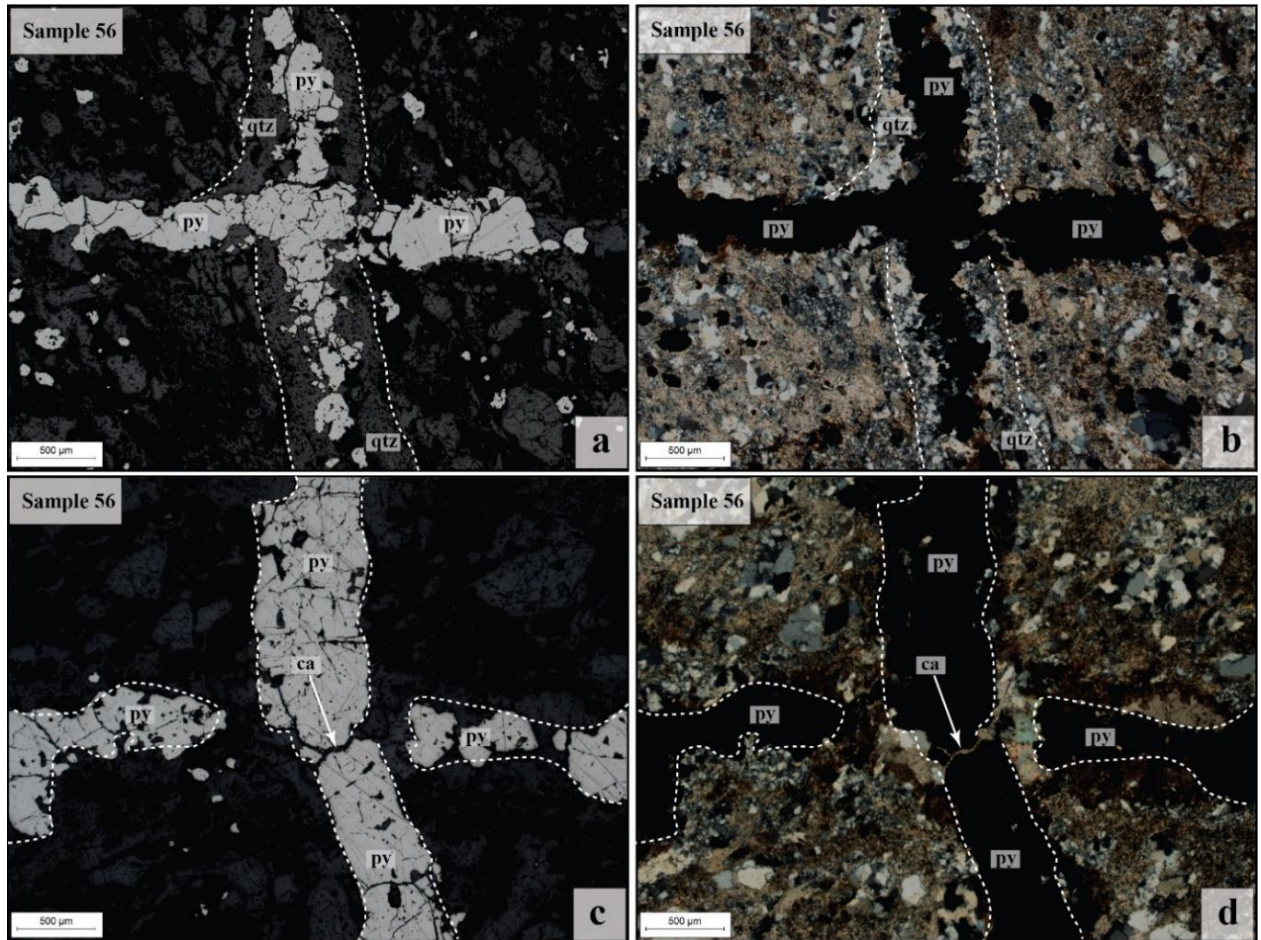


Figure 57. Thin section photographs showing general characteristics of porphyry veinlets. a) Deformed and fractured quartz+pyrite veinlets, which is cut by another veinlet, cutting clay altered diorite including pyrite dissemination (Sample 56; drill hole: SCS-15-8C, 883.90 meters) under reflected PPL, b) deformed and fractured quartz+pyrite veinlets, which is cut by another veinlet, cutting clay altered diorite including pyrite dissemination (Sample 56; drill hole: SCS-15-8C, 883.90 meters) under XPL, c) quartz+pyrite veinlets which are cut by barren carbonate veinlet cutting clay altered diorite (Sample 56; drill hole: SCS-15-8C, 883.90 meters) under reflected PPL, and d) quartz+pyrite veinlets which are cut by barren carbonate veinlet cutting clay altered diorite (Sample 56; drill hole: SCS-15-8C, 883.90 meters) under XPL. Abbreviations: qtz: quartz, py: pyrite, ca: carbonate.

6.3 Vein Relations

Existing veins also have spatial and structural relations with each other. Veins parallel to or intersecting each other were selected for polished thin section studies and included in paragenesis studies.

Parallel veins with different content and different alteration grades can be observed macroscopically and microscopically (Figure 58, Figure 59). Veins are generally symmetric, and vein relations show that there is a latest carbonate phase which is provided by polished thin section studies in epithermal-style veins. Grains of barren carbonate veins are generally large and subhedral to euhedral, and these grains can show rhombic texture. Also, barite veins can be observed with or without sulfide minerals. From vein relation studies, barren barite veins are older phase relative to barite veins including sulfide minerals.



Figure 58. The core sample photograph includes parallel veins.

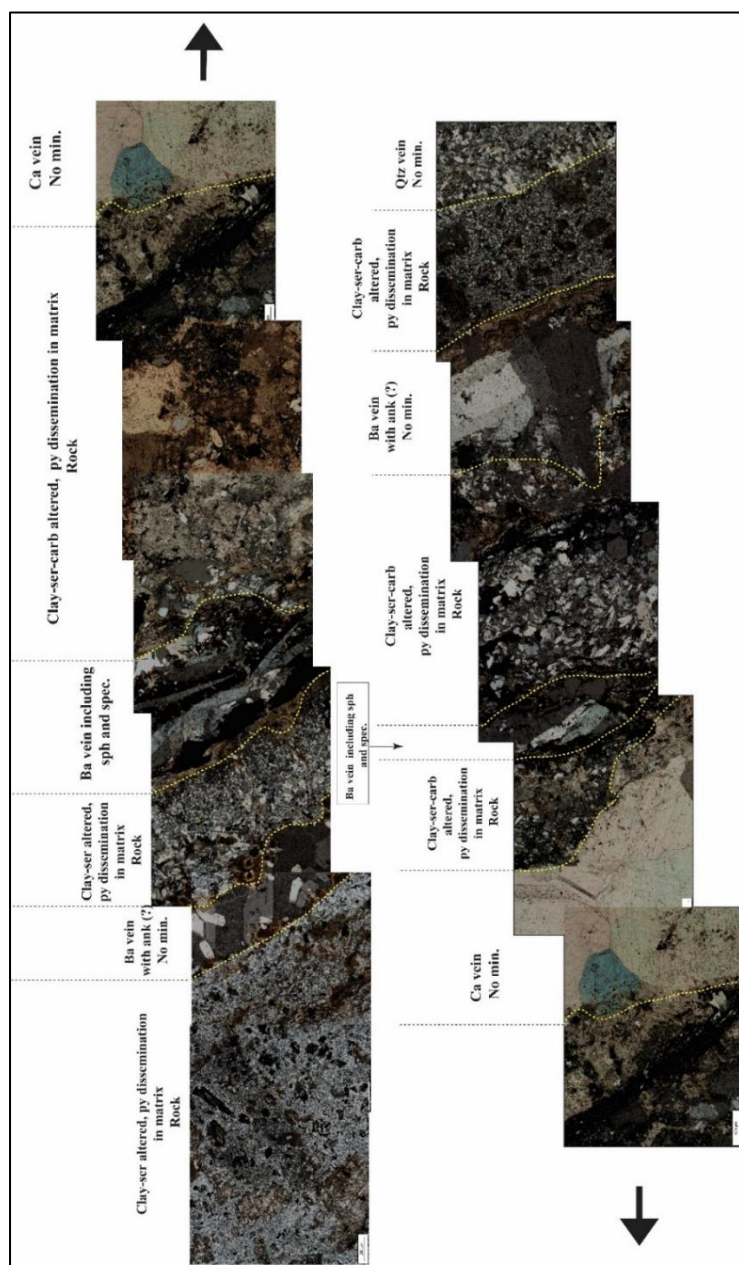


Figure 59. The panomeric photographs of clay-sericite altered and porphyritic textured andesites with pyrite dissemination in matrix are defined as host-rock. While going from the walls of the vein towards the middle, there is a barren barite vein after the host rock, and then host rock is encountered again. After host rock, host rock appears again with a barite vein containing sphalerite and specularite. Then there is the carbonate vein, which is considered as the last phase. When moving from the carbonate vein to the other wall of the vein, it was observed that it was placed in the above-mentioned order. Therefore, considering that there is a relative symmetry and the carbonate vein is the latest phase, ore-bearing barite vein and then barren barite vein are located after the barren carbonate vein (Sample 9; drill hole: CTL004, 128.10 meters).

6.4 Ore Paragenesis

The mineralized system at the Çatalçam prospect shows evidence for incremental development as many of the vein populations appear to be superimposed. A striking feature of the Çatalçam mineralization is that these vein populations developed along the same planes of weakness as paragenetically late veins opened along the earlier vein populations. Additionally, basaltic andesite dykes are also often emplaced in the same structural domains. In general quartz- and quartz-barite-dominant veins seem to be early in paragenesis, whereas carbonate minerals appear to be more dominant towards the later stages. Polymetallic Zn-Pb-Au mineralization is commonly associated with early stage, sulfidic dark gray quartz veinlets with or without barite. Main sulfide minerals identified in the mineralized veins are pyrite, chalcopyrite, galena, sphalerite, and tetrahedrite group minerals. Pyrite is the main sulfide mineral and occurs in most vein types, including barren quartz-pyrite veins. At least two different pyrite generations are present in the veins. Early pyrite (pyrite I) is medium- to coarse-grained, is euhedral in form, and is associated with quartz. Pyrite I is not associated with any mineralization. Pyrite I is overgrown by pyrite II, which is much finer grained than pyrite I. Pyrite II has a porous appearance and is weakly anisotropic, suggesting higher arsenic contents (Figure 60a, c, f). Chalcopyrite, galena, and sphalerite are also later in paragenesis with respect to pyrite I (Figure 61). Among these, coarse-grained galena and sphalerite are intergrown, whereas chalcopyrite and minor tetrahedrite, marcasite as well as pyrite II seem to overprint galena and sphalerite (Figure 60b, d, e; Figure 61). In addition, there are some cases that sphalerite and tetrahedrite group minerals cut the chalcopyrite (Figure 62e, f). Sphalerite is yellowish in color, and is semi opaque under transmitted light, suggesting low Fe contents. Relatively high Ag concentrations generally correlate with the abundance of galena and tetrahedrite

group minerals. This indicates that these two sulfide phases are the main host for silver.

At Çatalçam, rare fine-grained native gold was detected in ankerite-bearing quartz-carbonate-sulfide veins, alongside pyrite, chalcopyrite, galena, sphalerite, and tetrahedrite group minerals. However, paragenetically earlier quartz-dominant veins without native gold also contain anomalous gold grades. In such veins, gold likely occurs in association with arsenical pyrite (pyrite II), either in pyrite lattice or as sub-microscopic inclusions (Figure 62).



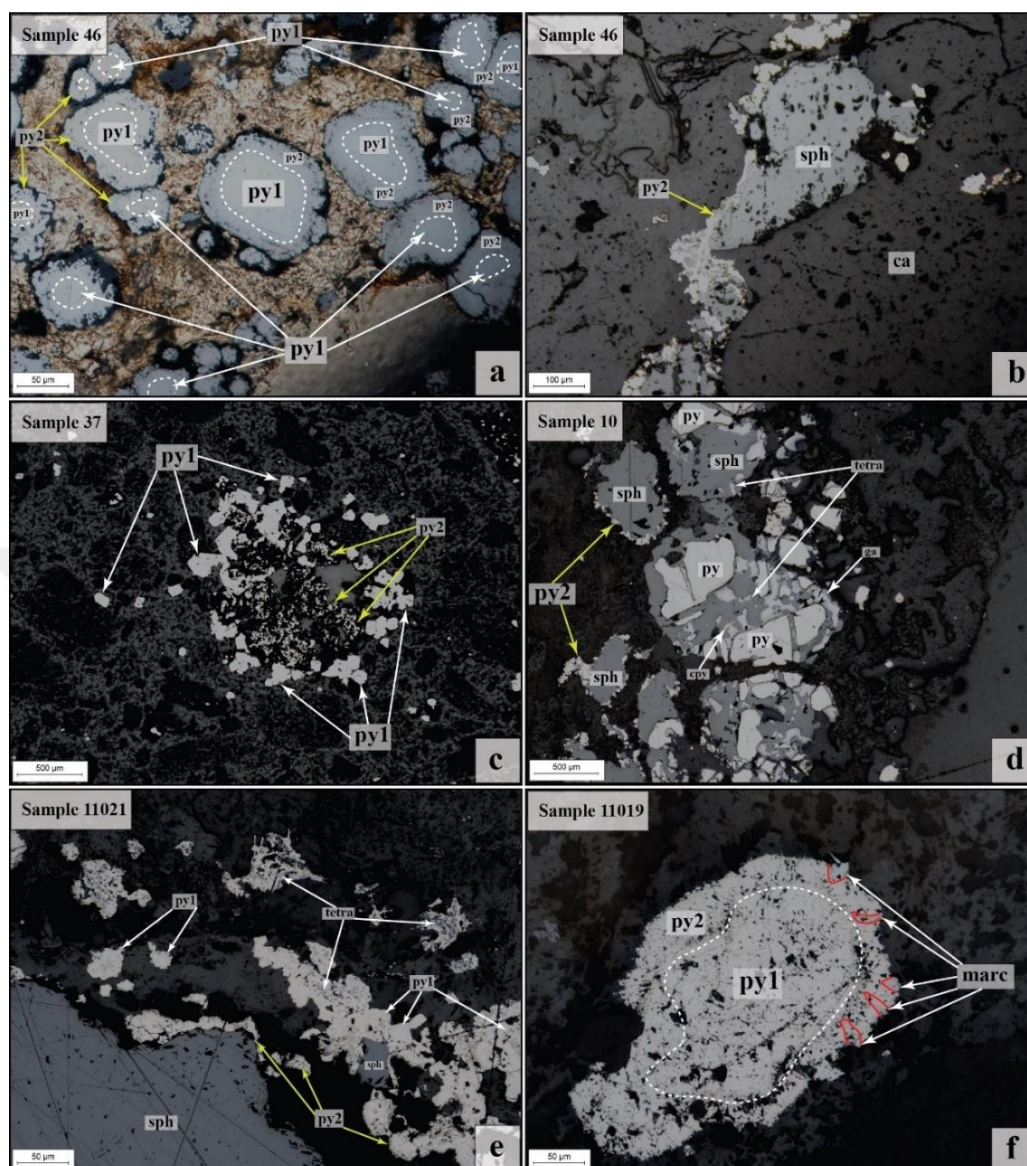


Figure 60. Thin section photographs of pyrite II phase and other metallic minerals. a) Pyrite II surrounding the pyrite I phases (Sample 46; drill hole: CTL006, 65.40 meters), b) pyrite2 surrounding the sphalerite in carbonate vein (Sample 46; drill hole: CTL006, 65.40 meters), c) fractures of pyrite1 filling with pyrite2 (Sample 37; drill hole: CTL020, 202.00 meters), d) pyrite II surrounding pyrite1, sphalerite, chalcopyrite (Sample 10; drill hole: CTL004, 150.00 meters), e) pyrite II surrounding other ore minerals (Sample 11021; drill hole: CTL004, 216.50 meters), f) pyriteI surrounded by pyrite II which consists of minor amount of marcasite (Sample 11019;

drill hole: CTL004, 204.00 meters) under reflected PPL. Abbreviations: py1: pyrite I, py2: pyrite II, sph: sphalerite, cpy: chalcopyrite, tetra: tetrahedrite group minerals, ca: carbonate, marc: marcasite.

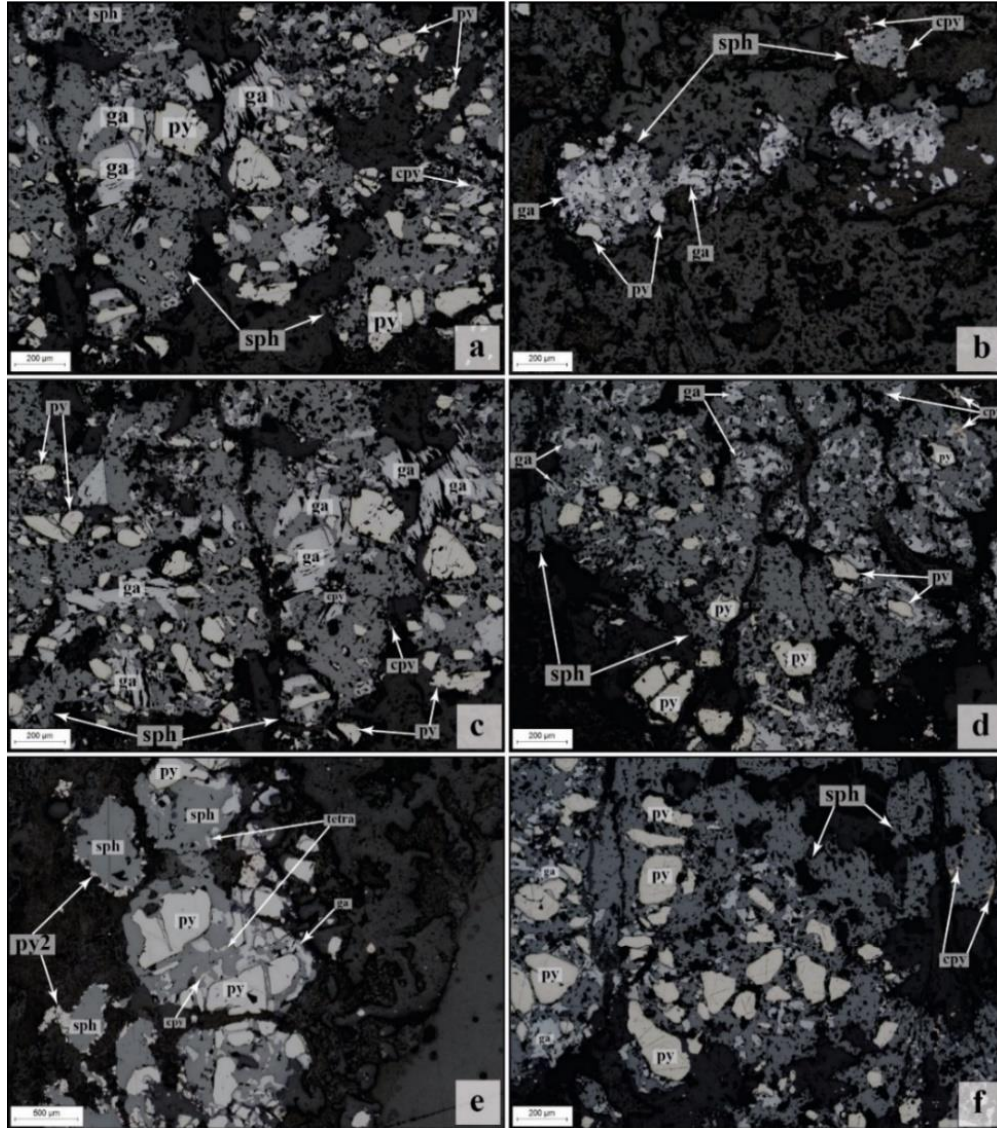


Figure 61. Thin section photographs show relationship between ore minerals. a-b-c-d) Pyrite I cutting by sphalerite and galena which are surrounded by chalcopyrite, e) pyrite I fractures filled by sphalerite and galena which are replaced with chalcopyrite and tetrahedrite group minerals, and f) pyrite I cutting and surrounding by galena and sphalerite, and sphalerite cut by chalcopyrite (Sample 10; drill hole: CTL004,

150.00 meters) under reflected PPL. Abbreviations: ca: carbonate, py: pyrite I, py2: pyrite II, sph: sphalerite, cpy: chalcopyrite, ga: galena, tetra: tetrahedrite group minerals.

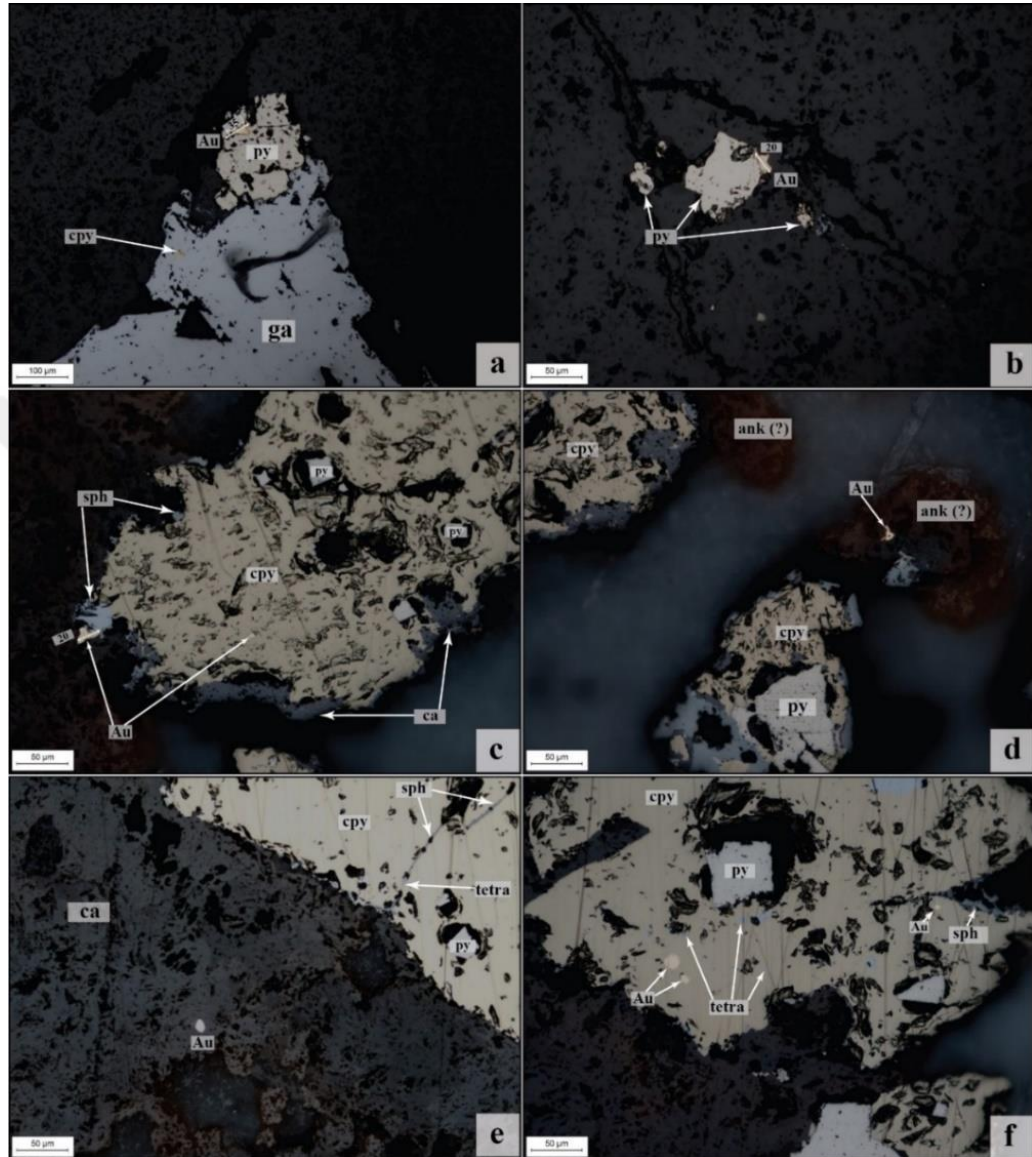


Figure 62. The thin section photographs of gold. a) Gold in anhedral pyrite surrounding galena (Sample 28; drill hole: CTL020, 68.50 meters), b) Gold in subhedral pyrite (Sample 28; drill hole: CTL020, 68.50 meters), c) chalcopyrite and sphalerite including gold and euhedral pyrite, and carbonate surrounds these minerals (Sample 11017; drill hole: CTL002, 256.40 meters) , d) gold in ankerite

surrounding chalcopyrite and sphalerite (Sample 11017; drill hole: CTL002, 256.40 meters) , e) carbonate veins including gold, and ore minerals which are pyrite surrounded by chalcopyrite which are cut by sphalerite and tetrahedrite group minerals (Sample 11017; drill hole: CTL002, 256.40 meters) , f) carbonate vein including pyrite surrounded by chalcopyrite including visible gold which are cut by sphalerite and tetrahedrite group minerals (Sample 11017; drill hole: CTL002, 256.40 meters) under reflected PPL. Abbreviations: ca: carbonate, py: pyrite, tetra: tetrahedrite group minerals, sph: sphalerite, cpy: chalcopyrite, Au: gold, ank: ankerite, ga: galena.



CHAPTER 7

SURFACE GEOCHEMISTRY

Two separate soil sampling campaigns were carried out at Çatalçam, first by MTA in 2020 and later by the Turkish Wealth Fund for 3 years. This chapter describes the analytical details as well as statistical evaluation of soil geochemistry.

7.1 Database

The soil geochemistry database was created by combining 3 different assay databases: one database from MTA (in-house lab) and two separate databases from TWF, one through SGS and the other through ALS Laboratories. A total of 8 elements are included in the MTA soil sampling programme, whereas the TWF database sourced from two labs contains 35 and 50 elements. A total of 991 soil samples were taken by the MTA, while a total of 738 samples were collected by the TWF, and some of these 738 samples were planned to be considered duplicate samples. Soil samples were taken from 1668 different locations from across the prospect. 1668 analysis results include a total of 8 elements (Au, Ag, As, Cu, Mo, Pb, Sb, and Zn), 736 analysis results in total for 27 elements (Al, Ba, Be, Bi, Ca, Co, Cr, K, La, Mn, Na, Ni, S, Sc, Th, Tl, and U), 134 analysis results in total for 15 elements (Ce, Cs, Hf, In, Lu, Nb, Rb, Se, Sn, Ta, Tb, Te, Y, Yb, Zr; Table 9).

Analysis results that are reported below the lower detection limit are reported from the laboratory with the “<” sign. The assay database was created by taking the half of the lower detection limit for values under the lower detection limit. Lower detection limits may differ for each analysis method and laboratory. Therefore, lower detection limits of elements in the analysis results reported from three different laboratories differ. On the other hand, an analysis result higher than the upper detection limit is not present for any element.

In the central sector of the study area, sampling was done at a 50 m by 50 m grid, while on the peripheral zones grids were designed to be as 150 m by 150 m and 200 m by 200 m (Figure 63).

For each sample, coordinates (easting, northing, and elevation above sea level), depth at which soil samples are taken, moisture, organic content, slope of the point, color, soil horizon, sampling depth, material size, zone, and lithology data were also collected. Approximately 55% of the soil samples are sand, 25% of silt, 14% of clay, and 6% of gravel size. Also, 3% of the soil samples were taken from the transition of the A-B zone, 80% from the B zone and 17% from the transition of the B-C zone, with an average sampling depth of 20 cm.

7.2 Analytical Methods

As mentioned before, the assay database was created by combining the reports of the analysis results from three different laboratories. Geochemical analysis of soil samples at ALS and SGS Laboratories was carried out by fire assay method for Au and 4-acid digestion for the remaining element suite. During analysis carried out at MTA, aqua regia digestion was used for Au and 2-acid digestion was used for the other elements.

In a volume ratio of 1:3, concentrated HNO₃ and HCl produce a valuable reagent which is named as aqua regia that have stronger oxidizing and dissolving powers than

HNO₃ because of complexing power of Cl₂ (Jarvis, 1991). Known for its ability to dissolve elements such as gold, platinum, and palladium, aqua regia is principally used for dissolving metals, alloys, silicates, and sulfides; however, the fire assay (FA) technique is generally used in order to pre-concentrate and separate the precious metals, including PGEs, Au, and Ag, from a large amount of complex matrices that may include Cu- Ni-PGE ores, mafic or ultramafic rocks, minerals, and soils (Hu and Qi, 2014). For most mineral constituents of soil, the 4-acid digestion method, which utilizes a mixture of HCl, HNO₃, HClO₄, and HF, results in a complete dissolution (Smith et al., 2009). On the other hand, some of the more resistant and refractory minerals such as rutile (for Ti), barite (for Ba), chromite (Cr), monazite (for rare earth elements), cannot be fully dissolved by 4-acid digestion method (Briggs, 2002). Smith et al. (2009) stated that yttrium, which is often incorporated in zircon, cannot be completely dissolved with 4-acid digestion as well. Unlike 4-acid digestion method, the 2-acid digestion method does not include HF, and is therefore relatively cheap, simple, and fast (Hu and Qi, 2014). However, since 2-acid digestion method validation is not sufficient in samples where complete dissolution is required, it is recommended to compare the analysis results by performing 4-acid dissolution (Sastre et al., 2002; Walsh et al., 1997). Therefore, 4-acid digestion is at a disadvantage due to its cost and time required, but the analytical data is more precise than that of the 2-acid digestion method.

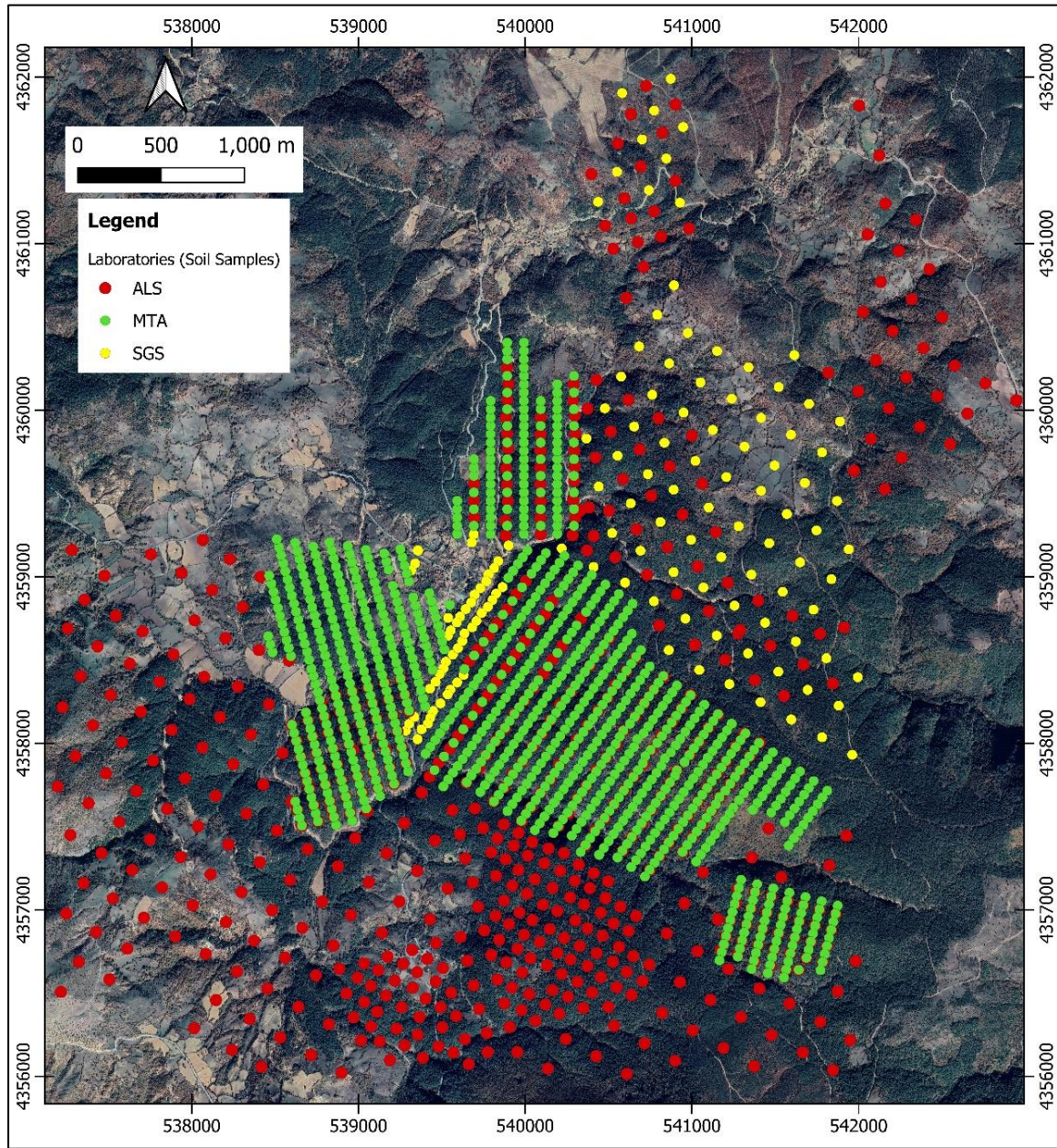


Figure 63. Soil sampling locations which are colored with respect to laboratories at Çatalçam

7.3 Statistical Analysis of Soil Geochemical Results

There are 50 different elements in total in the created database. As explained in the previous sections, although 50 elements are not available for each sample, Table 9 contains simple statistical values of these elements. The table includes count, mean, minimum, median, and maximum values for each element.

Table 9. Descriptive Statistics of Elements Analyzed During Soil Sampling

Name	Count	Mean	Standard deviation	Minimum	Median	Maximum
Ag (ppm)	1668	5.22	16.9	0.07	0.5	213
Al (%)	736	8.84	0.97	5.3	8.8	14.3
As (ppm)	1668	121.55	229.78	2	44	4342
Au (ppm)	1668	0.02	0.03	0	0.02	0.73
Ba (ppm)	736	1637.52	1253.73	400	1320	10000
Be (ppm)	736	2.85	0.71	1.2	2.8	7.2
Bi (ppm)	736	1.07	0.72	0.02	1	6
Ca (%)	736	0.68	0.77	0.05	0.4	8.3
Cd (ppm)	736	1.27	5.4	0.07	0.25	109.5

Name	Count	Mean	Standard deviation	Minimum	Median	Maximum
Ce (ppm)	134	82.78	19.51	44.7	79.6	161
Co (ppm)	736	14.1	7.87	0.5	13	77
Cr (ppm)	736	45.01	27.32	9	41	448
Cs (ppm)	134	16.85	18.43	1	11	118
Cu (ppm)	1668	31.85	171.81	1.5	19	6590
Fe (%)	736	3.55	0.77	1.62	3.5	9.62
Ga (ppm)	736	19.81	2.54	10	20	30
Hf (ppm)	134	2.6	0.8	0.86	2.53	8.32
In (ppm)	134	0.05	0.01	0.03	0.05	0.1
K (%)	736	3.92	1.71	0.49	3.55	9.15
La (ppm)	736	38.32	9.05	10	40	120
Li (ppm)	736	25.49	11.3	7	20	110
Lu (ppm)	134	0.24	0.07	0.13	0.23	0.74

Name	Count	Mean	Standard deviation	Minimum	Median	Maximum
Mg (%)	736	0.71	0.38	0.18	0.59	4.5
Mn (ppm)	736	1377.44	1627.86	24	844	19700
Mo (ppm)	1668	2.87	9	0.21	2.5	347
Na (%)	736	0.64	0.51	0.03	0.44	2.36
Nb (ppm)	134	11.42	3.41	6.5	10.4	28.5
Ni (ppm)	736	24.26	23.5	0.5	21	454
P (ppm)	736	668.85	470.74	0.02	660	2730
Pb (ppm)	1668	261.83	515.89	7	80	7680
Rb (ppm)	134	194.2	103.59	60.7	154	471
S (ppm)	736	0.08	0.11	0.01	0.04	0.75
Sb (ppm)	1668	33.8	66.82	0.43	16	1140
Sc (ppm)	736	13.62	3.34	6	13	35.3

Name	Count	Mean	Standard deviation	Minimum	Median	Maximum
Se (ppm)	134	1.02	0.15	1	1	2
Sn (ppm)	134	1.85	0.34	1.2	1.8	3.3
Sr (ppm)	736	182.17	139.76	30.6	130	1080
Ta (ppm)	134	0.75	0.25	0.35	0.7	2.27
Tb (ppm)	134	0.55	0.16	0.27	0.54	1.05
Te (ppm)	134	0.1	0.13	0.03	0.03	0.68
Th (ppm)	736	17.21	4.33	9.2	20	31.9
Ti (%)	736	0.38	0.07	0.16	0.37	0.78
Tl (ppm)	736	5.85	3.2	0.39	5	30
U (ppm)	736	4.99	1.29	1.44	5	10
V (ppm)	736	102.32	20.83	55	100	240
W (ppm)	736	16.1	24.07	0.5	5	174

Name	Count	Mean	Standard deviation	Minimum	Median	Maximum
Y (ppm)	134	16.68	6.89	6.8	15.5	42.4
Yb (ppm)	134	1.74	0.57	1	1.6	5.6
Zn (ppm)	1668	300.11	1088.42	6	116	40600
Zr (ppm)	134	74.52	19.21	30.2	72.4	130

7.4 Correlation Coefficients

Pearson's correlation coefficient (Pearson, 1896) and Spearman's Rank Correlation (ρ) (Spearman, 1904) are the most classical and widely used coefficients for determining statistical associations among variables. The Pearson method assumes that there is a linear relationship between two variables, and the The Spearman's Rank Correlation has been designed to assess the monotonicity of data (even non-linear data) and minimize the impact of outliers (extremely high or low values), which are very common in geochemical datasets due to outlier values (Campos and Licht, 2021).

Correlation coefficients of the results of geochemical analysis of soil samples were calculated using Microsoft Excel program. Microsoft Excel uses the Pearson method when calculating the correlation coefficient; therefore, the coefficients shown in Table 10 are Pearson Correlation Coefficients.

As mentioned above, the Pearson coefficient examines the behavior of two different variables relative to each other. The coefficients are between -1 and +1, the coefficient approaching +1 indicates a direct relationship between the variables, while a

coefficient value approaching -1 indicates a reverse relationship between the two variables. Correlation coefficients calculated for soil geochemical analysis results are provided in Figure 64, where Pearson correlation coefficients of elements are shown particularly in relationship with the main ore elements (Au, Ag, Pb, and Zn) at Çatalçam. Additionally, Figure 65 provides a scatter plot showing relationship between Pb, Zn, and Au.

According to Figure 16, Au is reasonably correlated with Ba (0.36) and Pb (0.32), but it does not display a direct or inverse relationship with other elements. Ag on the other hand is positively correlated with the elements Ba (0.42), Be (0.35), Cd (0.58), Co (0.35), Mn (0.48), P (0.36), and Rb (0.36). Similar to Au, Ag does not have a direct or inverse relationship with the remaining elements.

At Çatalçam Pb and Zn grades often show a positive correlation as mineralized veins have intergrown sphalerite and galena. Soil analyses indicate that Pb correlates positively with Au (0.32), Ba (0.68), Cd (0.44) Mn (0.36), P (0.34), and Zn (0.38) (Figure 16). For Zn, positive correlation coefficients are established with the elements Ba (0.36), Be (0.36), Cd (0.87), Co (0.40), Mn (0.40), Ni (0.43), and Pb (0.38).

Apart from the main ore metals, there are strong direct and reverse relationship between two variables which can be seen in Table 10.

While K has a reverse relationship with Ca, Mg, Na, Sc and Sr, it has a direct relationship that can be considered almost strong among themselves.

Table 10. Pearson Correlation Coefficient for Soil Geochemical Analysis.

Element	Au	Ag	Al	As	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Fe	Ga	Hf	In	K	La	Li	Lu	Mg	Mn
Au	1.00																							
Ag	0.07	1.00																						
Al	-0.07	-0.07	1.00																					
As	-0.04	0.06	-0.17	1.00																				
Ba	0.36	0.42	-0.18	0.19	1.00																			
Be	0.03	0.35	0.15	0.07	0.29	1.00																		
Bi	0.00	0.12	0.05	-0.02	0.06	-0.01	1.00																	
Ca	-0.06	-0.12	0.10	-0.17	-0.19	-0.03	-0.12	1.00																
Cd	0.12	0.58	-0.12	0.08	0.44	0.34	0.05	-0.04	1.00															
Ce	0.04	0.03	0.15	-0.22	-0.11	0.06	0.02	-0.14	0.01	1.00														
Co	0.04	0.35	0.08	-0.01	0.21	0.54	0.07	0.12	0.47	0.12	1.00													
Cr	-0.03	0.05	0.07	0.02	-0.01	0.19	0.09	0.00	0.06	0.03	0.48	1.00												
Cs	-0.03	0.01	-0.05	0.12	0.06	-0.07	-0.06	-0.11	-0.01	0.06	-0.06	-0.03	1.00											
Cu	0.01	0.07	0.04	0.00	0.03	0.10	0.30	0.01	0.12	0.10	0.17	0.16	-0.16	1.00										
Fe	0.02	0.28	0.09	0.09	0.14	0.48	0.07	0.15	0.24	0.11	0.67	0.48	0.06	0.36	1.00									
Ga	-0.06	-0.04	0.49	-0.08	-0.02	0.18	0.10	-0.13	-0.13	0.44	0.12	0.22	0.06	0.03	0.19	1.00								
Hf	-0.09	-0.02	0.00	0.04	-0.12	-0.04	-0.14	0.00	-0.10	0.37	0.06	0.06	0.04	-0.12	0.03	0.08	1.00							
In	0.01	0.15	0.26	-0.01	-0.03	0.34	0.55	-0.21	0.08	0.35	0.59	0.56	-0.08	0.63	0.64	0.63	0.05	1.00						
K	-0.08	0.17	-0.22	0.38	0.26	0.19	0.05	-0.47	0.01	-0.18	-0.02	-0.01	0.27	-0.05	0.02	-0.05	0.08	-0.11	1.00					
La	0.06	0.18	0.01	-0.02	0.06	0.24	0.06	-0.06	0.08	0.95	0.21	0.16	0.10	0.35	0.34	0.18	0.34	0.22	-0.06	1.00				
Li	-0.08	0.04	-0.08	0.03	-0.03	0.19	0.04	0.14	0.05	-0.10	0.33	0.34	0.12	0.03	0.30	0.05	0.23	0.38	0.05	0.02	1.00			
Lu	-0.01	0.03	0.15	-0.09	0.01	0.21	-0.09	0.12	0.04	0.64	0.22	0.15	0.00	0.03	0.14	0.38	0.73	0.21	-0.10	0.60	0.11	1.00		
Mg	-0.10	-0.20	0.29	-0.26	-0.32	0.00	-0.16	0.58	-0.09	0.14	0.22	0.25	0.10	0.00	0.25	0.16	0.08	0.22	-0.56	0.06	0.22	0.22	1.00	
Mn	0.09	0.48	-0.12	0.07	0.37	0.50	0.21	-0.08	0.44	-0.03	0.61	0.22	-0.09	0.46	0.49	-0.03	-0.08	0.28	0.25	0.32	0.21	0.11	-0.20	1.00

Element	Au	Ag	Al	As	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Fe	Ga	Hf	In	K	La	Li	Lu	Mg	Mn
Mo	0.13	0.02	-0.10	0.17	0.09	-0.04	0.00	-0.06	0.02	-0.03	-0.07	-0.02	-0.03	0.01	0.04	0.00	-0.07	0.01	0.04	0.01	-0.04	0.01	-0.10	-0.02
Na	-0.03	-0.20	0.23	-0.28	-0.24	-0.02	-0.09	0.54	-0.08	-0.12	0.08	0.02	-0.39	-0.04	0.06	0.03	-0.15	-0.02	-0.58	-0.06	-0.02	-0.05	0.37	-0.19
Nb	-0.18	0.01	0.06	0.14	-0.14	0.23	0.36	-0.21	-0.15	0.27	0.40	0.58	0.08	0.29	0.48	0.41	0.39	0.53	0.14	0.24	0.40	0.37	0.23	-0.02
Ni	-0.02	0.20	0.08	0.01	0.05	0.39	0.03	0.07	0.38	0.07	0.68	0.76	-0.05	0.18	0.53	0.13	0.03	0.49	-0.05	0.16	0.31	0.15	0.34	0.37
P	0.10	0.36	0.07	-0.07	0.26	0.20	0.37	0.01	0.34	0.32	0.31	0.07	-0.21	0.09	0.18	0.00	0.00	0.39	0.00	0.08	0.00	0.20	-0.13	0.41
Pb	0.32	0.23	-0.16	0.06	0.68	0.29	0.09	-0.12	0.44	-0.03	0.22	0.03	-0.03	0.08	0.19	-0.07	-0.09	0.03	0.06	0.09	0.02	0.02	-0.23	0.36
Rb	-0.12	0.36	-0.15	0.55	0.19	0.20	-0.09	-0.51	0.01	-0.08	-0.13	0.02	0.34	-0.19	0.17	0.07	0.12	-0.02	0.97	0.00	0.10	-0.03	-0.45	0.17
S	0.23	0.17	-0.13	0.30	0.33	-0.16	0.04	-0.24	0.11	-0.04	-0.26	-0.12	-0.01	-0.01	-0.08	-0.06	-0.04	0.00	0.01	0.08	-0.26	-0.11	-0.27	-0.09
Sb	-0.02	0.04	-0.21	0.69	0.29	0.12	-0.05	-0.18	0.11	-0.25	-0.03	0.02	0.12	0.00	0.12	-0.06	-0.03	-0.08	0.39	-0.05	0.05	-0.05	-0.25	0.14
Sc	-0.01	0.14	0.43	-0.20	-0.02	0.40	-0.01	0.28	0.12	0.46	0.53	0.46	-0.10	0.09	0.51	0.37	0.41	0.54	-0.34	0.34	0.18	0.58	0.50	0.18
Se	-0.02	-0.01	-0.09	-0.06	-0.07	-0.11	-0.02	-0.10	-0.03	0.19	-0.10	-0.10	-0.01	-0.02	-0.05	-0.09	-0.06	0.05	-0.08	0.26	-0.18	0.02	-0.06	-0.05
Sn	-0.03	0.11	0.24	0.00	-0.05	0.22	0.43	-0.06	0.08	0.34	0.44	0.48	-0.08	0.44	0.47	0.53	0.19	0.70	-0.16	0.20	0.34	0.30	0.24	0.09
Sr	-0.02	-0.14	0.17	-0.15	-0.13	-0.06	-0.16	0.76	-0.03	-0.11	0.07	-0.05	-0.18	-0.04	0.11	-0.07	-0.02	-0.23	-0.50	-0.03	-0.04	0.09	0.48	-0.15
Ta	-0.19	-0.02	-0.04	0.09	-0.09	0.18	0.21	-0.14	-0.12	0.17	0.22	0.28	0.01	0.13	0.20	0.18	0.20	0.28	0.06	0.13	0.31	0.17	0.10	-0.07
Tb	-0.05	0.03	0.35	-0.21	-0.10	0.25	-0.02	0.23	0.04	0.66	0.41	0.30	-0.04	0.25	0.27	0.49	0.27	0.29	-0.25	0.60	0.04	0.74	0.39	0.18
Te	0.12	-0.01	-0.22	-0.22	0.00	-0.07	0.12	-0.30	0.04	0.33	-0.13	-0.16	-0.20	0.00	-0.09	-0.05	-0.05	0.14	-0.32	0.36	-0.23	-0.01	-0.11	-0.08
Th	0.05	-0.08	0.03	-0.08	-0.03	-0.11	0.01	-0.06	-0.13	0.75	-0.11	-0.08	0.12	-0.07	-0.05	0.06	0.42	-0.05	-0.06	0.29	-0.09	0.54	0.02	-0.16
Ti	-0.11	-0.03	-0.14	0.11	-0.06	-0.01	0.23	-0.16	-0.10	0.02	0.19	0.44	0.06	0.00	0.27	0.11	0.18	0.34	0.29	0.15	0.24	0.02	-0.08	0.08
Tl	-0.03	0.13	-0.11	0.29	0.14	-0.08	0.26	-0.14	0.03	-0.14	0.06	0.01	0.16	0.04	0.01	0.00	-0.02	-0.01	0.37	-0.11	0.07	-0.04	-0.30	0.21
U	-0.02	0.08	0.02	0.00	0.12	-0.06	0.25	0.20	0.02	0.34	0.03	-0.06	0.01	0.01	0.02	0.03	0.39	0.05	0.00	-0.03	0.12	0.34	-0.06	0.02
V	-0.02	0.08	0.31	-0.06	-0.02	0.20	0.16	0.12	0.02	0.20	0.34	0.40	0.07	0.10	0.52	0.32	0.16	0.57	-0.11	0.17	0.16	0.18	0.35	0.06
W	-0.08	0.01	-0.23	0.70	0.09	0.01	-0.04	-0.23	-0.04	-0.29	-0.06	0.03	0.17	-0.04	0.03	-0.08	0.06	-0.10	0.59	-0.07	0.03	-0.16	-0.31	0.07
Y	-0.09	-0.07	0.24	-0.19	-0.17	0.21	-0.05	0.12	-0.08	0.72	0.31	0.24	0.05	0.10	0.19	0.47	0.45	0.23	-0.19	0.73	0.09	0.84	0.38	0.08
Yb	-0.05	-0.02	0.16	-0.12	-0.10	0.20	-0.03	0.07	-0.03	0.67	0.23	0.19	0.01	0.05	0.15	0.42	0.71	0.26	-0.12	0.64	0.14	0.98	0.25	0.07
Zn	0.04	0.14	-0.12	0.05	0.36	0.36	0.04	-0.05	0.87	-0.06	0.40	0.06	-0.01	0.11	0.21	-0.14	-0.11	0.05	0.03	0.05	0.05	0.01	-0.09	0.40
Zr	-0.12	0.06	0.07	0.25	-0.07	-0.15	-0.26	0.20	-0.09	-0.21	0.13	0.18	0.08	-0.08	0.09	-0.21	0.38	-0.19	0.28	-0.24	0.15	-0.02	0.11	0.00

Element	Mo	Na	Nb	Ni	P	Pb	Rb	S	Sb	Sc	Se	Sn	Sr	Ta	Tb	Te	Th	Ti	Tl	U	V	W	Y	Yb	Zn	Zr
Mo	1.00																									
Na	-0.07	1.00																								
Nb	0.00	-0.12	1.00																							
Ni	-0.04	0.05	0.50	1.00																						
P	0.09	-0.05	0.07	0.09	1.00																					
Pb	0.18	-0.16	-0.15	0.06	0.34	1.00																				
Rb	0.14	-0.68	0.22	-0.11	-0.08	-0.01	1.00																			
S	0.28	-0.20	0.06	-0.18	0.19	0.30	0.30	1.00																		
Sb	0.16	-0.30	-0.03	-0.02	-0.07	0.26	0.44	0.24	1.00																	
Sc	-0.07	0.28	0.43	0.47	0.19	0.06	-0.28	-0.15	-0.22	1.00																
Se	0.01	-0.05	-0.08	-0.07	0.04	-0.03	-0.05	-0.02	-0.07	-0.06	1.00															
Sn	0.04	0.08	0.71	0.38	0.23	0.03	-0.10	0.01	-0.12	0.56	-0.08	1.00														
Sr	-0.05	0.69	-0.21	0.00	-0.02	-0.11	-0.46	-0.10	-0.15	0.28	-0.09	-0.02	1.00													
Ta	-0.05	-0.03	0.61	0.26	0.07	-0.13	0.09	0.01	-0.11	0.25	-0.07	0.44	-0.14	1.00												
Tb	-0.09	0.05	0.23	0.35	0.30	-0.04	-0.18	-0.31	-0.18	0.61	0.06	0.29	0.18	0.08	1.00											
Te	0.06	0.02	-0.03	-0.10	0.27	0.05	-0.28	0.27	-0.23	-0.04	0.37	0.03	-0.22	-0.04	-0.08	1.00										
Th	0.01	-0.04	0.02	-0.13	0.01	-0.04	0.02	0.02	-0.06	0.01	0.21	-0.01	-0.06	0.01	0.37	0.24	1.00									
Ti	-0.01	-0.07	0.80	0.29	0.02	-0.11	0.25	-0.11	0.07	0.02	-0.10	0.46	-0.14	0.49	0.06	-0.12	0.13	1.00								
Tl	0.18	-0.25	0.00	-0.07	0.32	0.05	0.70	0.05	0.27	-0.21	-0.08	-0.09	-0.16	-0.09	-0.07	-0.24	-0.02	0.22	1.00							
U	0.01	0.05	0.08	-0.10	0.31	0.10	0.34	0.02	-0.02	0.02	0.01	0.07	0.06	0.05	0.15	0.07	0.09	0.09	0.29	1.00						
V	0.01	0.05	0.54	0.31	0.16	0.01	0.03	-0.10	-0.09	0.57	-0.07	0.61	0.09	0.27	0.28	-0.08	0.05	0.36	0.01	0.15	1.00					
W	0.03	-0.35	0.18	-0.03	-0.13	-0.05	0.72	0.11	0.57	-0.32	-0.08	-0.13	-0.18	0.07	-0.29	-0.30	-0.08	0.25	0.31	-0.06	-0.11	1.00				
Y	-0.12	-0.06	0.28	0.29	0.18	-0.10	-0.08	-0.30	-0.16	0.61	0.12	0.18	0.05	0.11	0.89	0.03	0.55	0.04	-0.11	0.14	0.18	-0.23	1.00			
Yb	-0.05	-0.06	0.43	0.19	0.18	-0.04	-0.03	-0.16	-0.11	0.61	0.04	0.32	0.03	0.19	0.75	0.03	0.54	0.07	-0.09	0.29	0.20	-0.17	0.87	1.00		
Zn	0.02	-0.08	-0.17	0.43	0.28	0.38	0.03	0.07	0.12	0.09	-0.04	0.00	-0.03	-0.13	-0.02	0.02	-0.09	-0.07	0.01	0.02	0.01	-0.03	-0.09	-0.05	1.00	
Zr	-0.06	-0.10	0.02	0.19	-0.09	-0.08	0.23	-0.05	0.13	0.00	-0.17	-0.16	0.15	0.05	0.00	-0.41	-0.16	0.35	0.17	0.12	0.15	0.31	-0.06	-0.07	-0.08	1.00

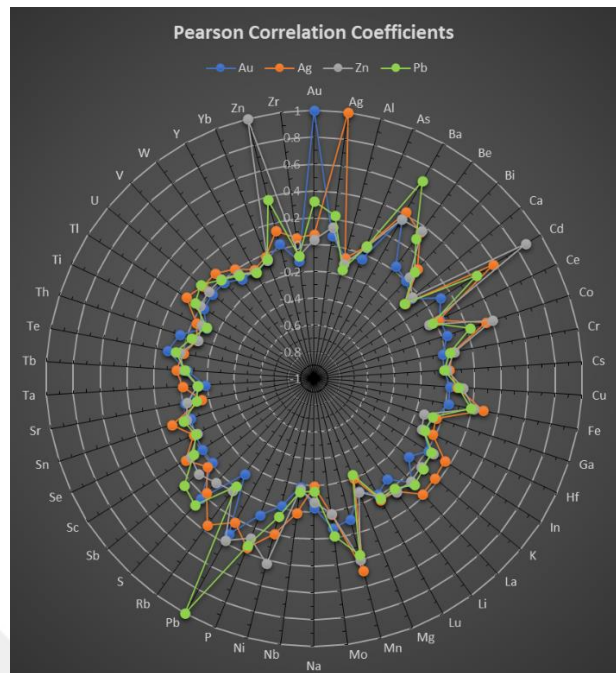


Figure 64. Radial plot showing the correlation coefficients of Ag, Au, Pb, Zn with respect to other elements.

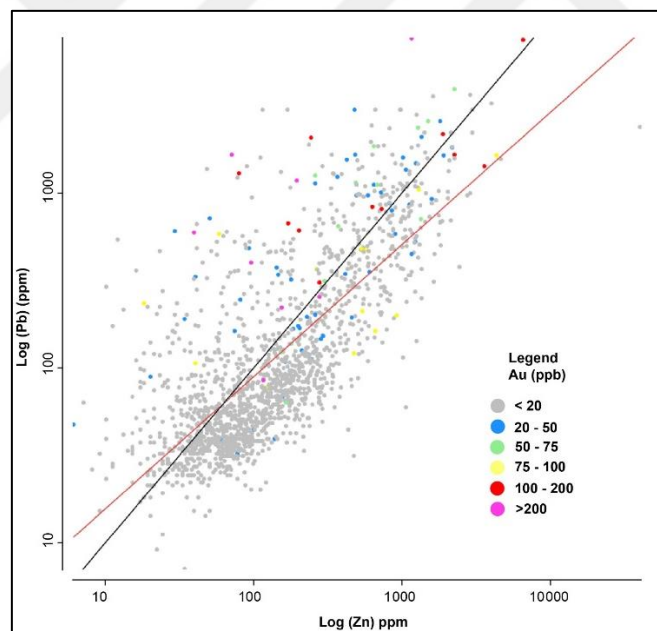


Figure 65. Log(Pb) vs. log(Zn) scatter plot. Data points are colored with respect to Au grades (ppm).

7.5 Soil Geochemical Anomaly Maps

Anomaly maps for the soil geochemistry data were created via Geosoft Target program using the kriging method which interpolates data using a geostatistical gridding method to determine a value at each grid node. This method is ideal when data is clustered and randomly distributed, and also this method is not used the data which vary smoothly between data points. This case is not valid for soil sampling, or any surface geochemistry studies. For each element, sill, range, and nugget values were determined separately according to the variogram suggested by Geosoft-Target and maps were created accordingly. When using the kriging method, the cell size was chosen as 50 meters. On all maps, fault structures are also plotted. In the study area, the target metals are Pb, Zn, and Au so anomaly maps of these three elements were created. In the maps created afterwards the anomalies in the drilled locations and the anomalies in the areas where drilling was not carried out were compared, and it was aimed to detect especially the ore-bearing veins.

During creation of the anomaly maps, the background value for an element is taken as the mean of all the values of the said element, and the other threshold values are determined by adding standard deviations. No significant Au anomaly was identified in the eastern part of the prospect, but highly anomalous values areas are highlighted in the western sector (Figure 66). Also the northern sector of the prospect, where is Fault Area 4, 5, and 6, does not show significant anomalies for Au. Identified Au anomalies show close spatial relation to certain faults (Figure 66). In the anomaly map created for Ag, especially in Fault Areas 4-5 and 6, Ag anomaly increased significantly. On the other hand, around the P2 fault, where the anomaly of the Au element is observed to rise, a relative Ag anomaly also increases (Figure 67). The Pb anomaly is increasing in connection with the faults according to the field studies almost everywhere in the area. However, the Pb anomaly in the southernmost part of the field does not coincide with any known structure (Figure 68). The correlation coefficient between Zn and Pb indicates that Zn is already highly correlated with Pb. Therefore, it has been observed that the anomalies for Zn are compatible with the faults in the field studies, except for the area in the southernmost part of the prospect (Figure 69).

In addition to these, as in Au and Ag anomalies of Pb and Zn, anomalies around the P2 fault have increased towards the west of the area. Although Cu is not a target commodity in Çatalçam

mineralization, the anomalies of Ag, Pb, Zn elements increase in areas where Cu is also anomalous. However, in the westernmost part of the area, and in the northernmost part of the metamorphic domain, a wide area shows Cu anomalies although other metals do not seem to be anomalous in the same sector (Figure 70). Additional anomaly maps of As, Sb, Bi, Mo, and Mn are also prepared as these are common pathfinder and indicator elements especially for gold-rich systems. Anomaly maps of these elements can provide important information regarding hydrothermal alteration, lithological controls, or direct location of the ore. In the anomaly maps created for Sb and As, anomalies increase towards the northeast of the field, especially the areas where the anomaly increases are completely outside the areas where Pb-Zn anomalies appear. The anomalies in the northeast increase in areas of probable faults with NW-SE orientation drawn on the surface. However, it is also observed to be consistent with basaltic andesitic dykes that have the same orientation as the faults. W increases in same with As and Sb in the northeastern part of the field (Figure 71; Figure 72). At the same time, there are anomalies around the faults drawn in the southeast of the area, outside As-Sb (Figure 73). In the anomaly maps of these three elements, there is no anomaly around the P2 fault, where Au-Pb-Zn-Ag anomalies increase. The Bi anomaly has a direct relationship with a part of the anomaly map created for Cu. Only Cu anomaly in the northernmost area of the field also increases Bi anomaly. However, the Bi anomaly located to the north of Fault Area 3 and not very high is compatible with the Pb and Zn anomalies (Figure 74).

In the geochemical analysis results, the average of Mo, which is not very high, is 3. In the northeast of the field, especially in the area where As-Sb anomaly rises, the anomaly of Mo increases in the area where As-Sb anomalies decrease. However, Mo shows anomaly around the P2 fault (Figure 75). There are high anomalies for Mn especially in the east of the field. While Mn increases in the northernmost areas where Cu and Bi increase, Mn anomalies increase in severely deformed Fault Area 4-5-6 while descending towards the south. However, Mn is generally below the background value in the area where anomaly of As-Sb increases. Going further south, Mn is compatible with Pb-Zn anomalies (Figure 76).

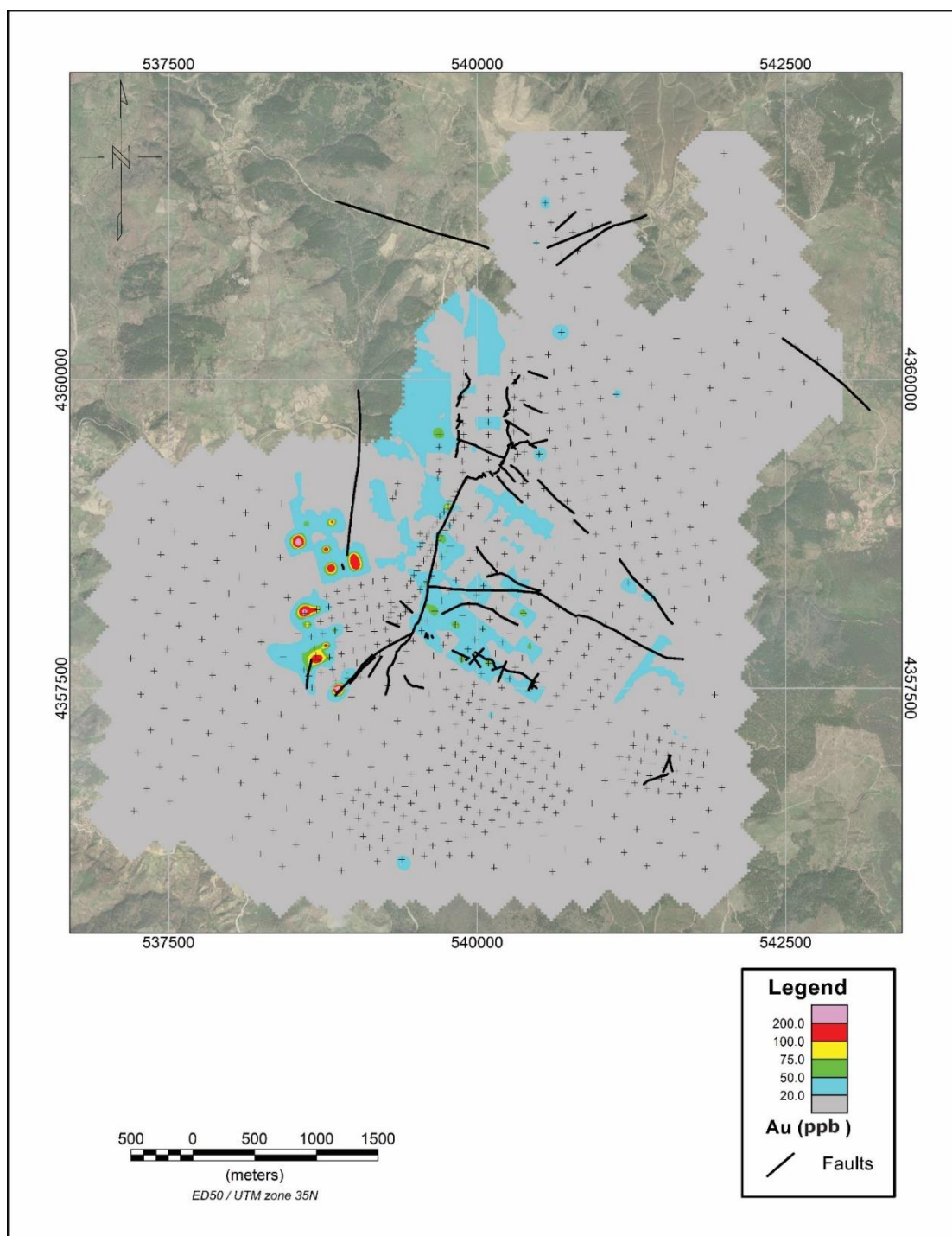


Figure 66. Soil anomaly map of Au (ppm).

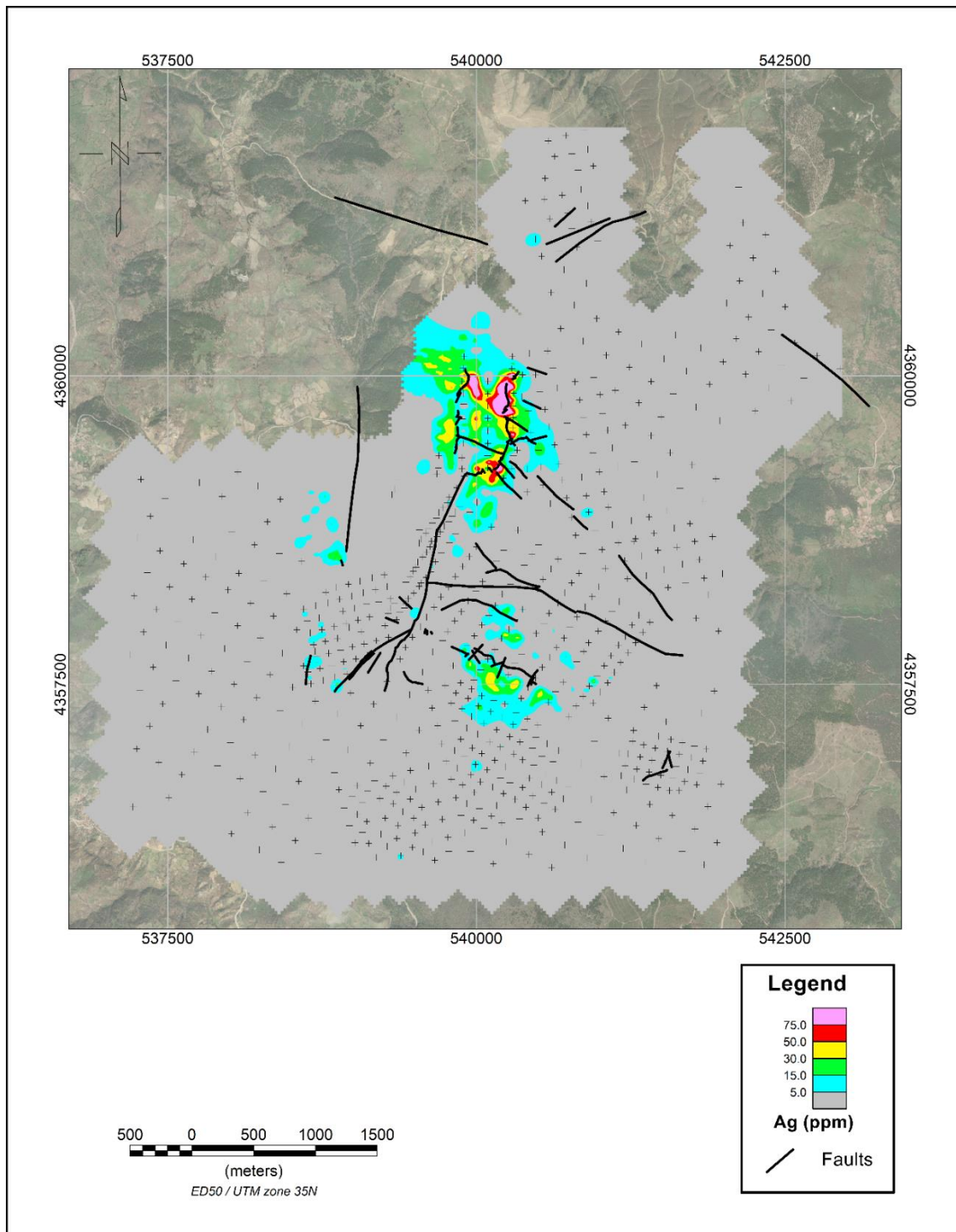


Figure 67. Soil anomaly map of Ag (ppm).

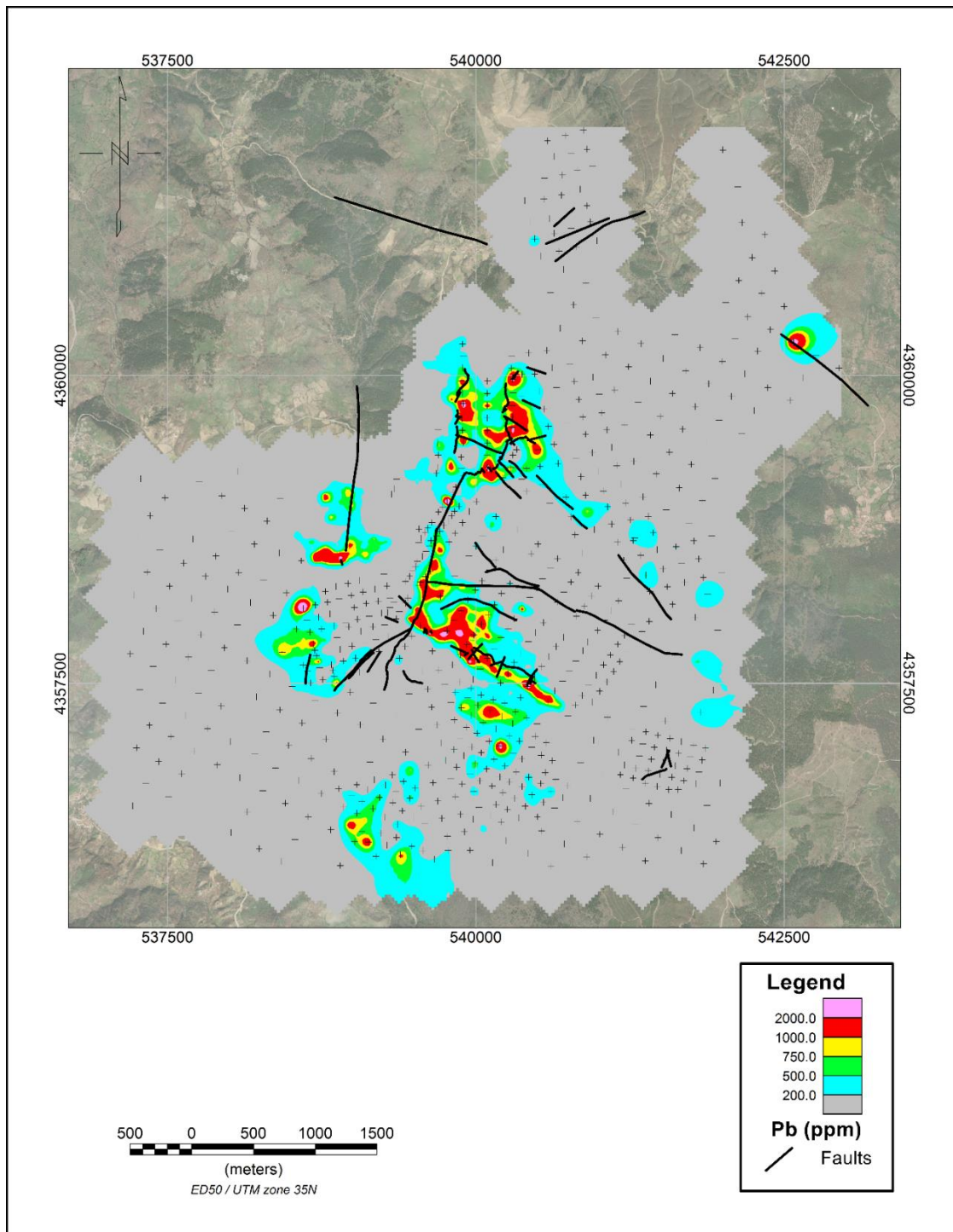


Figure 68. Soil anomaly map of Pb (ppm).

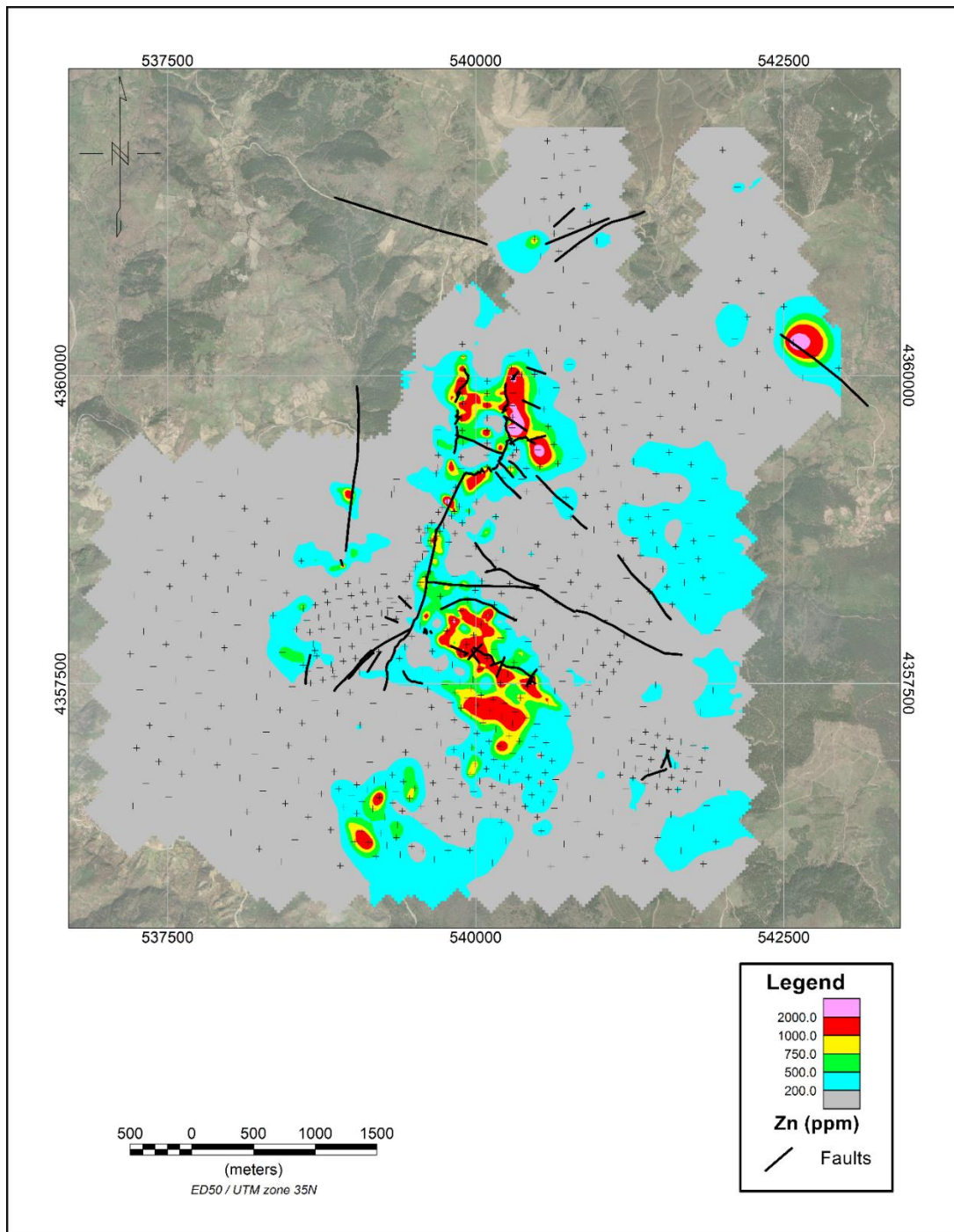


Figure 69. Soil anomaly map of Zn (ppm).

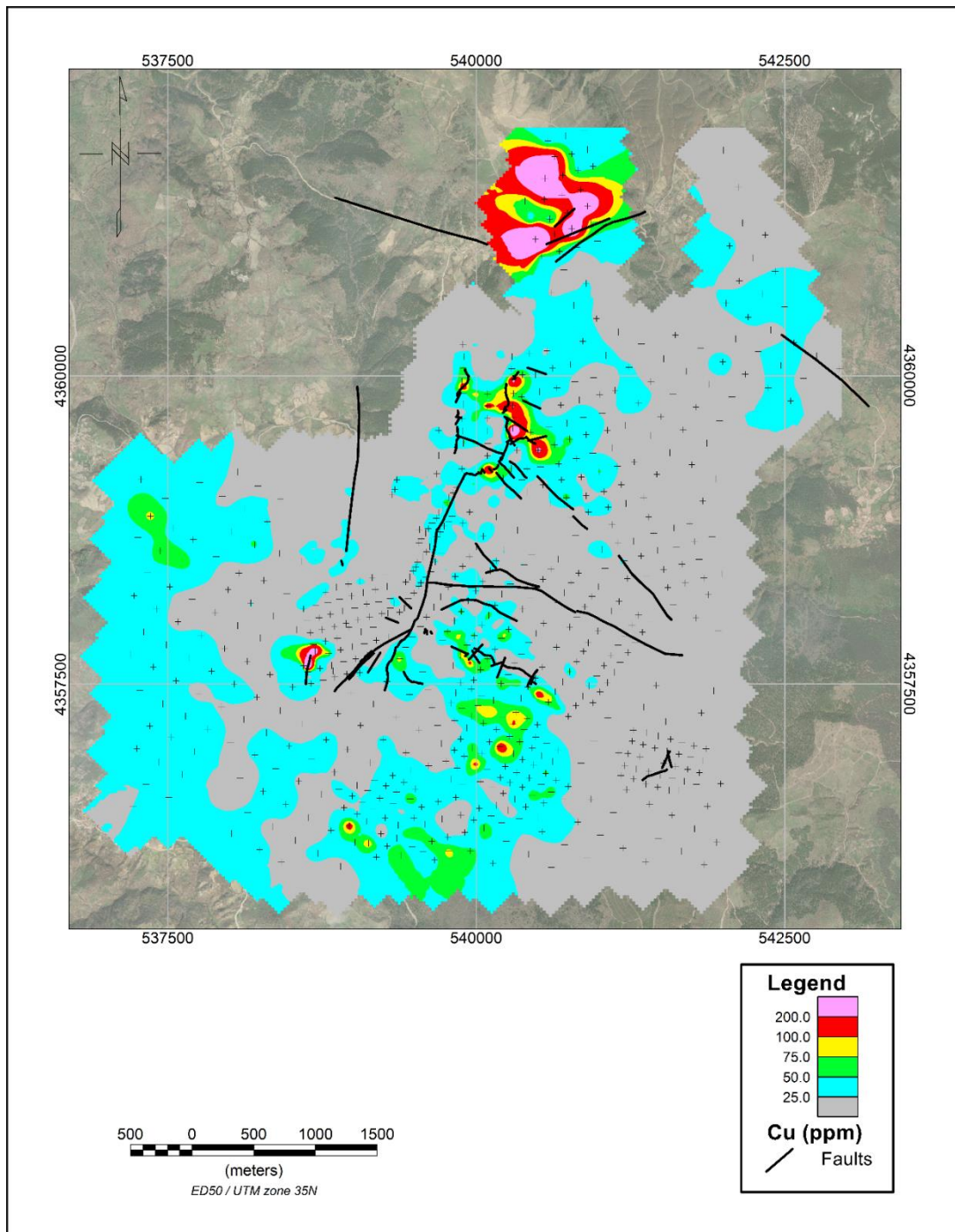


Figure 70. Soil anomaly map of Cu (ppm).

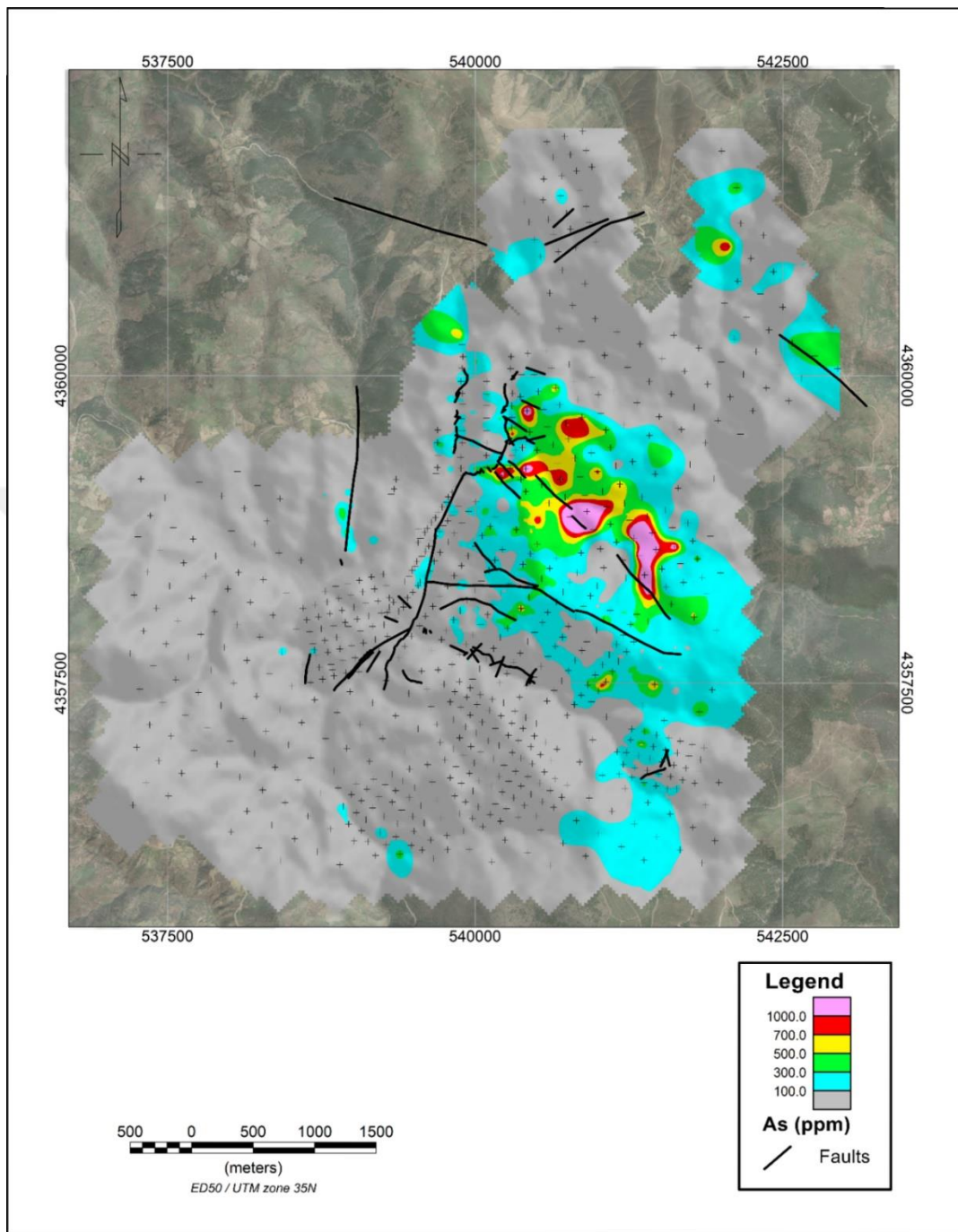


Figure 71. Soil anomaly map of As (ppm).

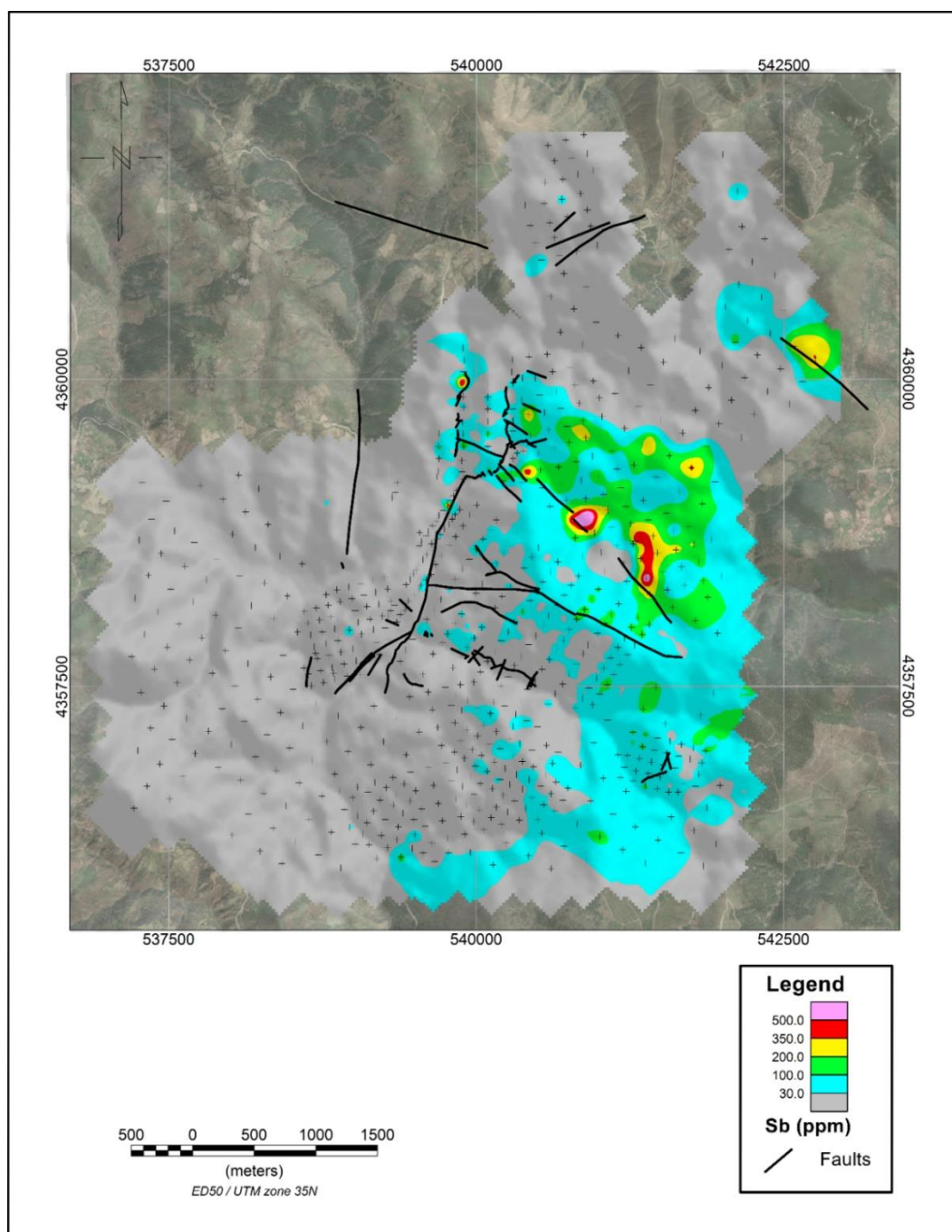


Figure 72. Soil anomaly map of Sb (ppm).

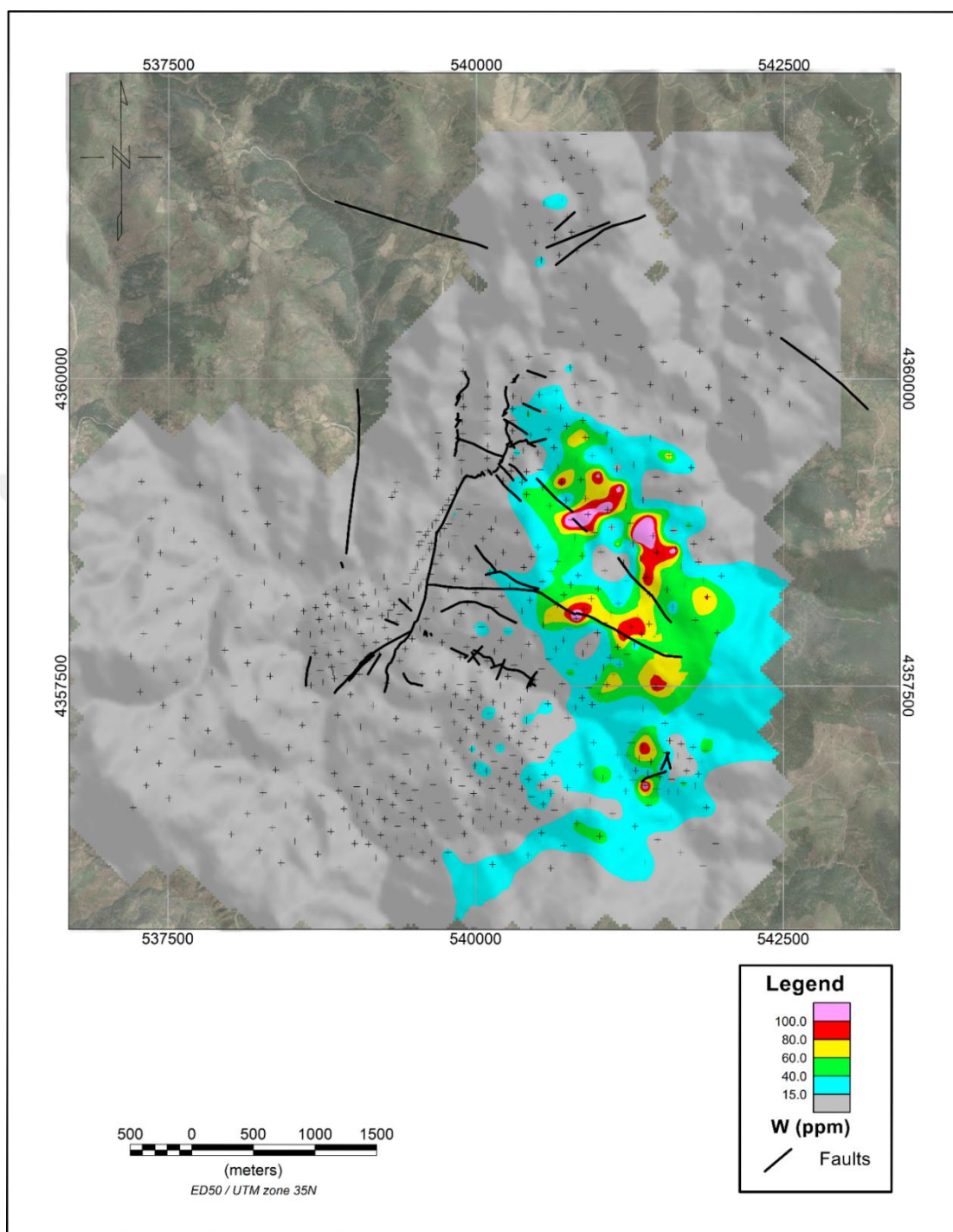


Figure 73. Soil anomaly map of W (ppm).

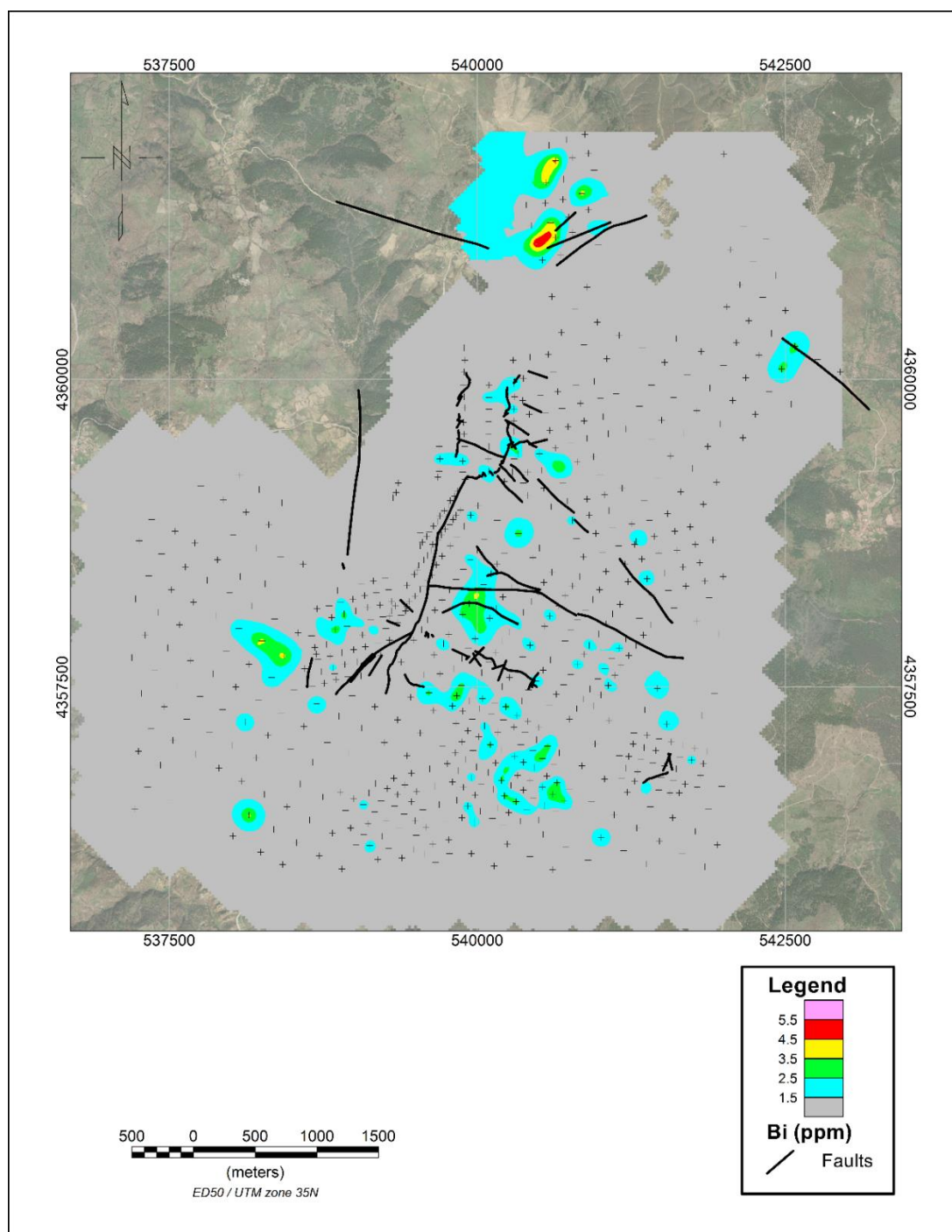


Figure 74. Soil anomaly map of Bi (ppm).

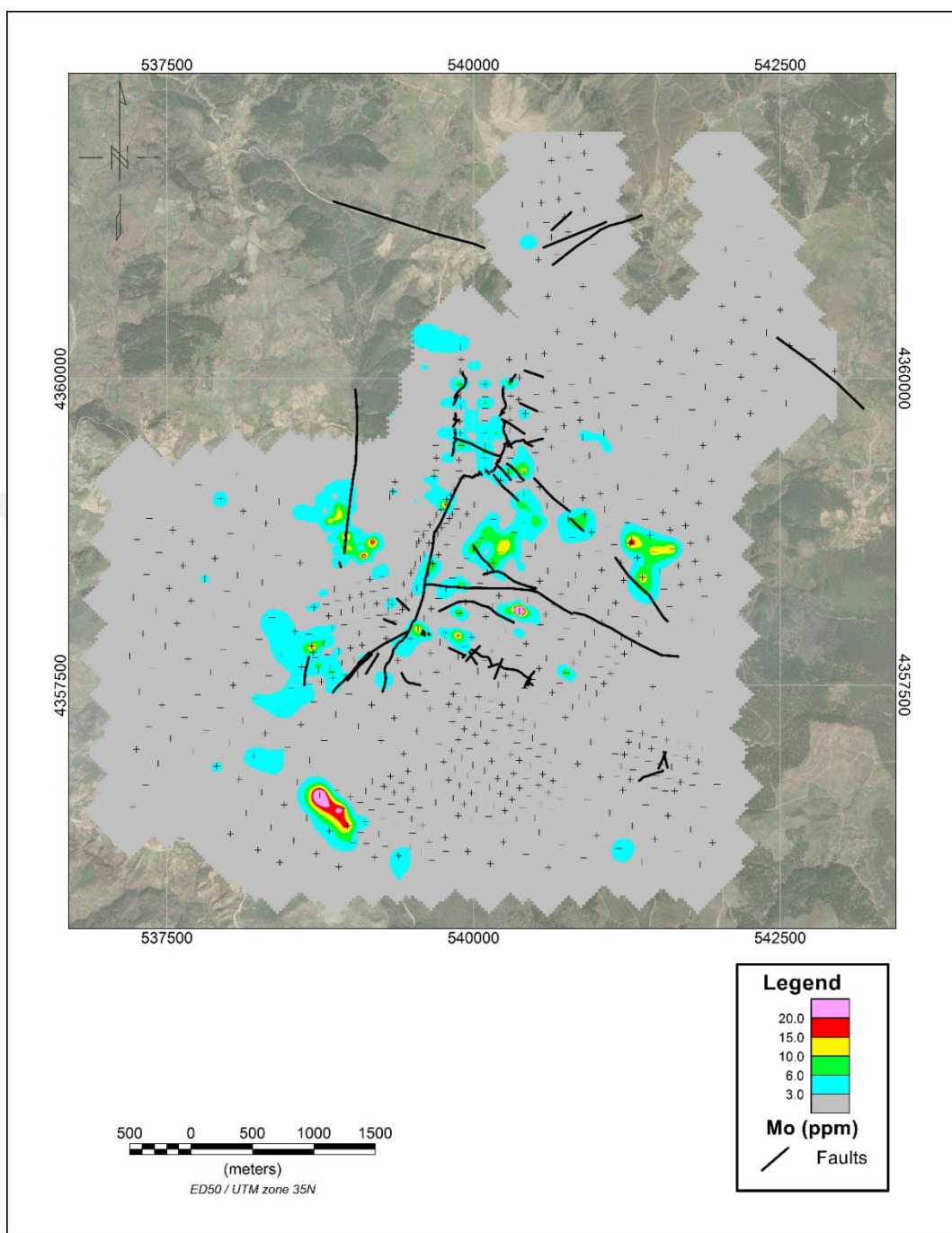


Figure 75. Soil anomaly map of Mo (ppm).

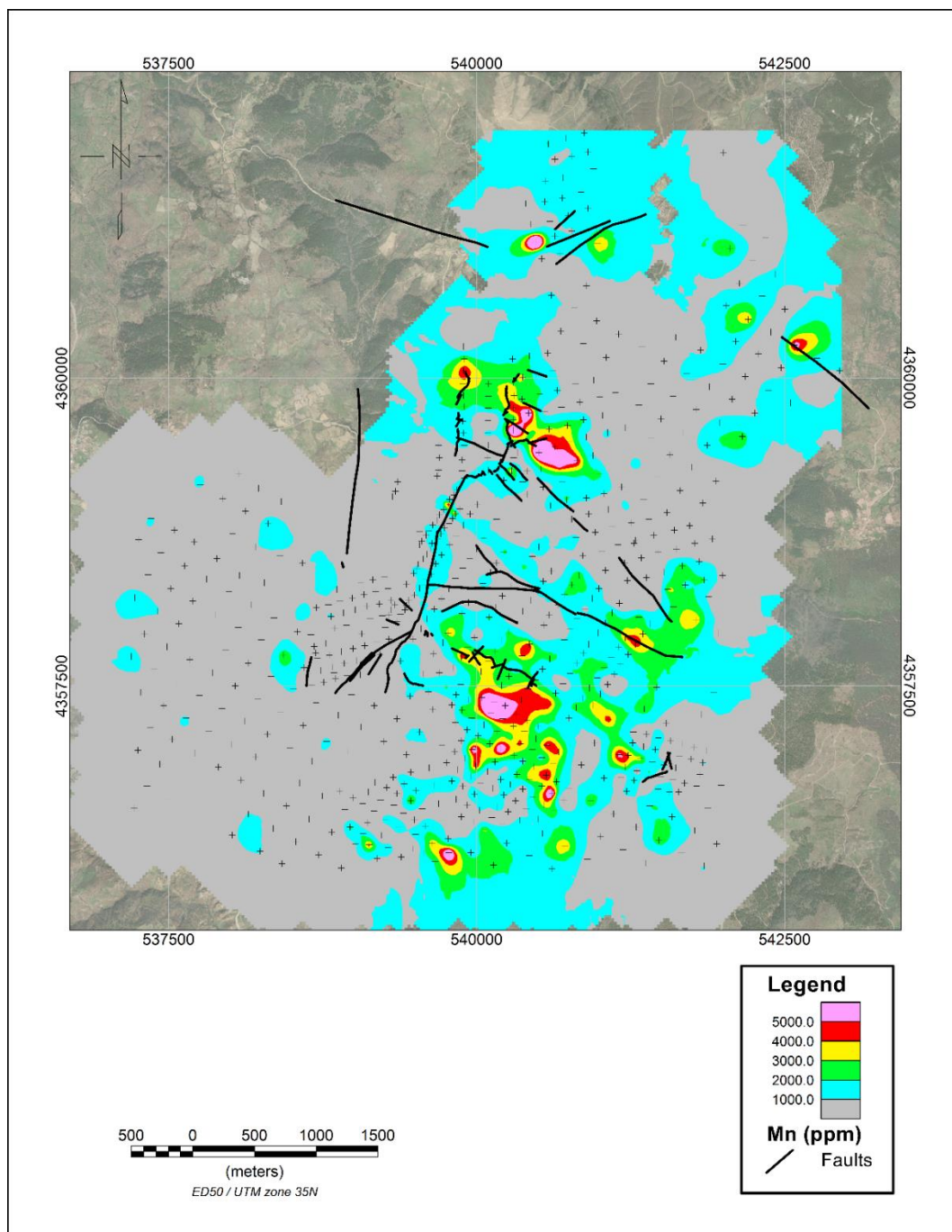


Figure 76. Soil anomaly map of Mn (ppm).

CHAPTER 8

3-D MODELLING

A 3-D model of the Çatalçam prospect is prepared, in which the model incorporates geological modelling, structure, and domaining by constructing solid volumes with respect to drill hole data provided by TWF. The 3-D modeling process is completed using the Leapfrog Geo software. Initially, quality control study was carried out to check the accuracy of the data by using Leapfrog Geo, and if there was a conflict in the database, it was corrected. Then, after the data was brought into a single format, the topography data is introduced, which was acquired using a drone at the 1:1000 scale resolution.

8.1 Data Sets

8.1.1 Drill hole Data

Data from 82 separate drill holes are used during modelling studies. The geological log from the drill hole data is used for the 3-D geological model, and the results of the geochemical analysis of the drilling data are used for domaining of mineralization. In addition, the fault intervals included in the structural log are also included in the model, along with the fault data collected on the surface. Re-logging work is done to create the veins included in the 3-D geological model.

Boundary surfaces are generated for andesite, basaltic andesitic dyke, metasedimentary unit and diorite, except for 6 different vein volumes, namely Au-

Pb-Zn mineralized quartz+barite+carbonate, Pb-Zn mineralized quartz+barite+carbonate, Au-Pb-Zn mineralized quartz, Pb-Zn mineralized quartz, Au-Pb-Zn mineralized quartz+barite, au mineralized quartz+barite+carbonate based on vein fill and assay result.

8.1.2 Maps and Auxiliary Data

Maps include geological maps created during field studies and geochemical distribution maps. Auxiliary data include drainage networks, satellite images, and roads draped over the topography.

8.2 3-D Model Elements

3-D model elements include lithological and structural data extracted from drill logs. These elements are obtained by re-classification and simplification of the database. The lithological elements are classified into 5 groups as overburden (OB), andesite (AND), Çatalçam Diorite (DIO), basaltic andesitic dyke (BAK), and metasedimentary units (MS).

8.2.1 3-D Fault Modelling

During construction of the fault model, surface measurements and drill hole data were used. 4 major fault planes (orange- and purple-colored faults; Figure 77) and 2 different possible faults (red and blue colored faults; Figure 77) are modelled.

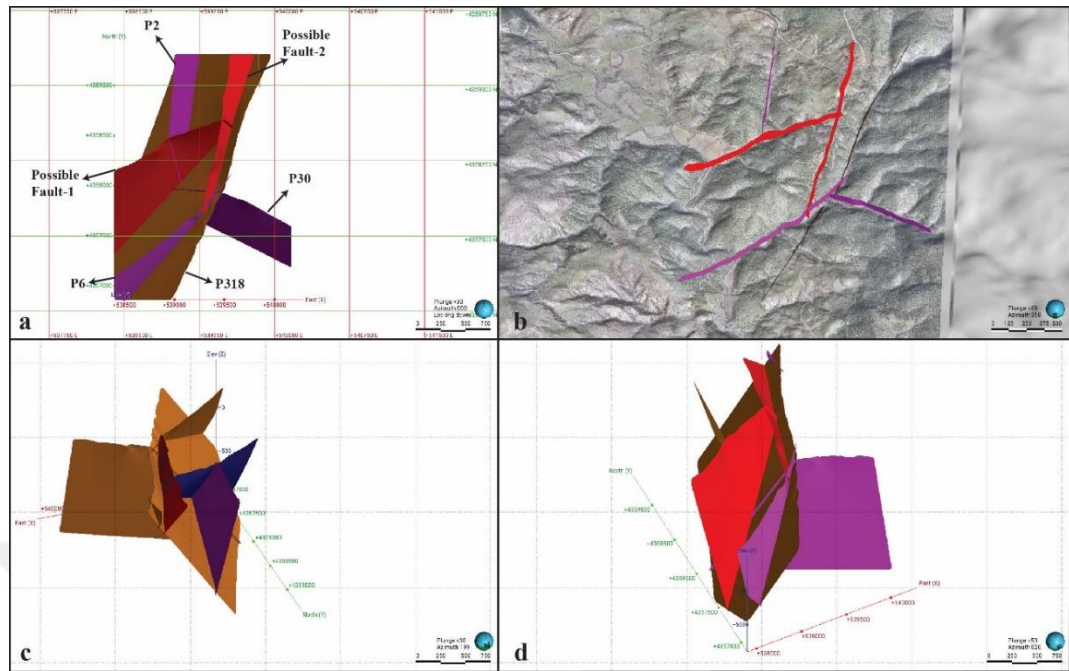


Figure 77. The 3-D fault model, including 6 different planes, 4 of these planes are measured planes, and two of them are possible faults, of a) plan view, b) view from an angle with satellite image, and c-d) view from an angle.

8.2.2 3-D Geological Modelling

The geology model is not limited to the entire mapped area, but to the area where drilling data is concentrated (Figure 78).

During geological modelling, andesite, diorite and metasedimentary unit contacts are constructed using geological logs. Re-logging study is done for the basaltic andesitic dyke since this unit is described at Çatalçam for the first time in this study, thus it was not present in the geological logs.

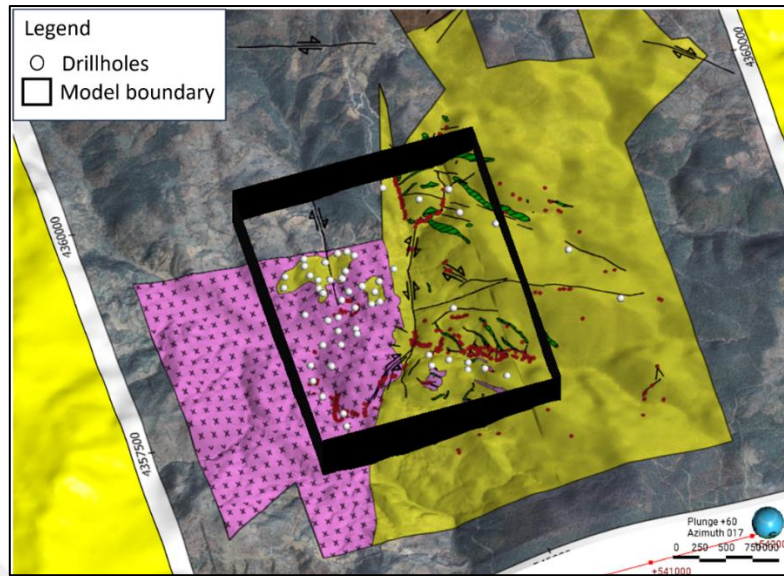


Figure 78. The figure includes the location of drillholes and boundary of the model.

Some parameters are applied to the surfaces after generating the surfaces from the geological logs to model the andesite and diorite contact (Figure 79a). The changed parameters during the generation of the surface are the interpolation parameters including a change from “linear” to “spheroidal” interpolation. This is because spheroidal interpolation tends to generate curvilinear surfaces (as opposed to planar surfaces), as would be the more likely case for an intrusive contact. Total sill is corrected to 505 to equal the total variance of all data. The base range value controls the extent of the surface by affecting the weight of drill holes, allowing them to connect. Base range value is set as 100 meters, 2 times the average drill hole spacing. Then, drift is changed from “linear” to “none”. The drift option, on the other hand, is related to how the drilling data included in the interpolation will behave after exceeding the base range.

For the basaltic andesitic dyke surface, same changes are made. Interpolant type is set as spheroidal, and total sill is changed as 0.14. Base range value is set as 100 meters, and the drift is changed from “linear” to “none” (Figure 79b).

For the metasedimentary unit surface, changed parameters are interpolant type, total sill, base range, and drift. Interpolant type is set as spheroidal, total sill is changed as 588, and base range is set as 100 meters. For this base range value, drift is changed as none. Also, Metasedimentary unit extension is limited by using polylines to be on the safe side (Figure 79c).

The re-logging work is done by combining both the geological logs and the geochemistry results, since the geological logs lack sufficient detail for the vein volumes to be included in the geological model. As a result of the re-logging study, 6 different veins are modeled. In order to be on the safe side, a buffer zone of 50 meters is drawn using the polyline with an average drilling spacing during construction of the vein volumes. Since the interpolation technique was not used in vein modeling, no parameter changes are made. However, the trend is assigned to each vein type by combining the dip-dip direction measurements taken from the Optic Televiewer and field studies (Table 11; Figure 80).

Table 11. General Orientations and Number of Modelled Vein for Each Vein

Vein Type	Number of Veins	Dominant Vein Orientation(s)
Au-Pb-Zn mineralized quartz+barite	3	NW-SE
Au-Pb-Zn mineralized quartz	7	NW-SE, NE-SW
Pb-Zn mineralized quartz,	11	E-W
Pb-Zn mineralized quartz+barite+carbonate	6	NE-SW
Au-Pb-Zn mineralized quartz+barite+carbonate	14	NE-SW, NW-SE
Au mineralized quartz+barite+carbonate	8	NNW-SSE

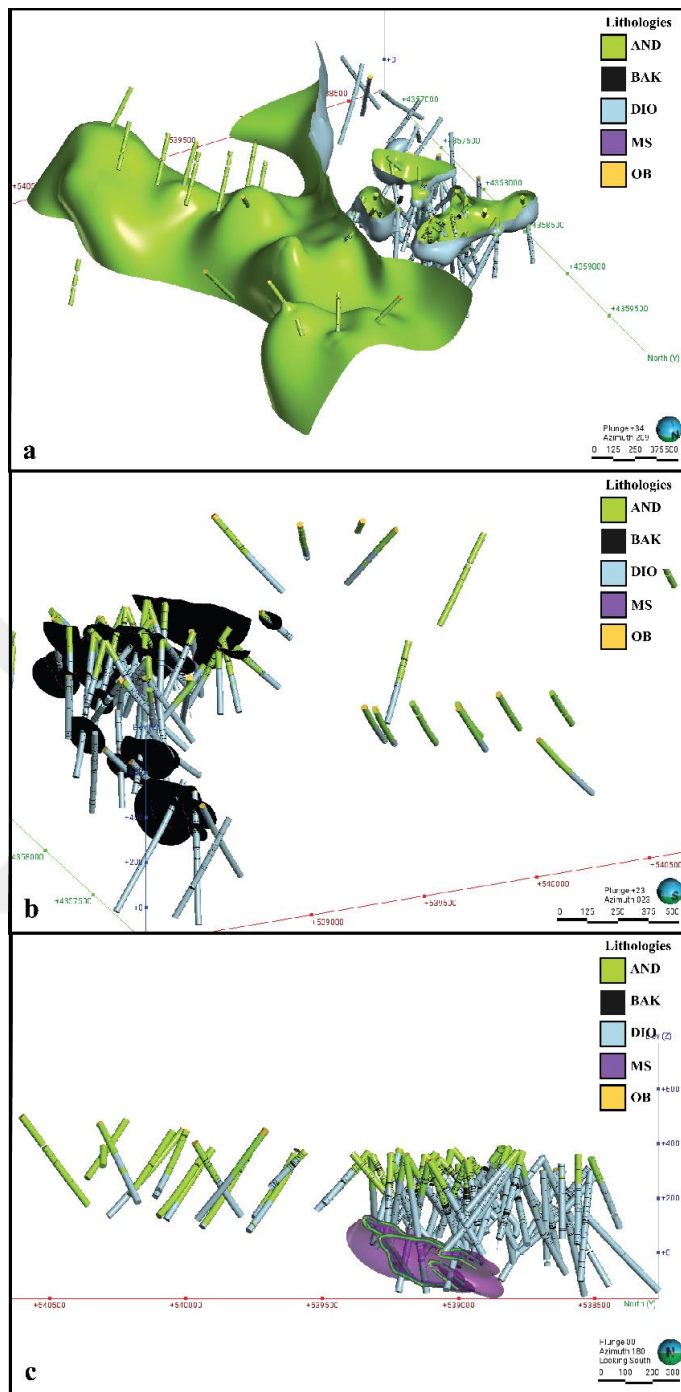


Figure 79. Contact surfaces of a) andesite-diorite, b) basaltic andesitic dyke, and c) metasedimentary unit.

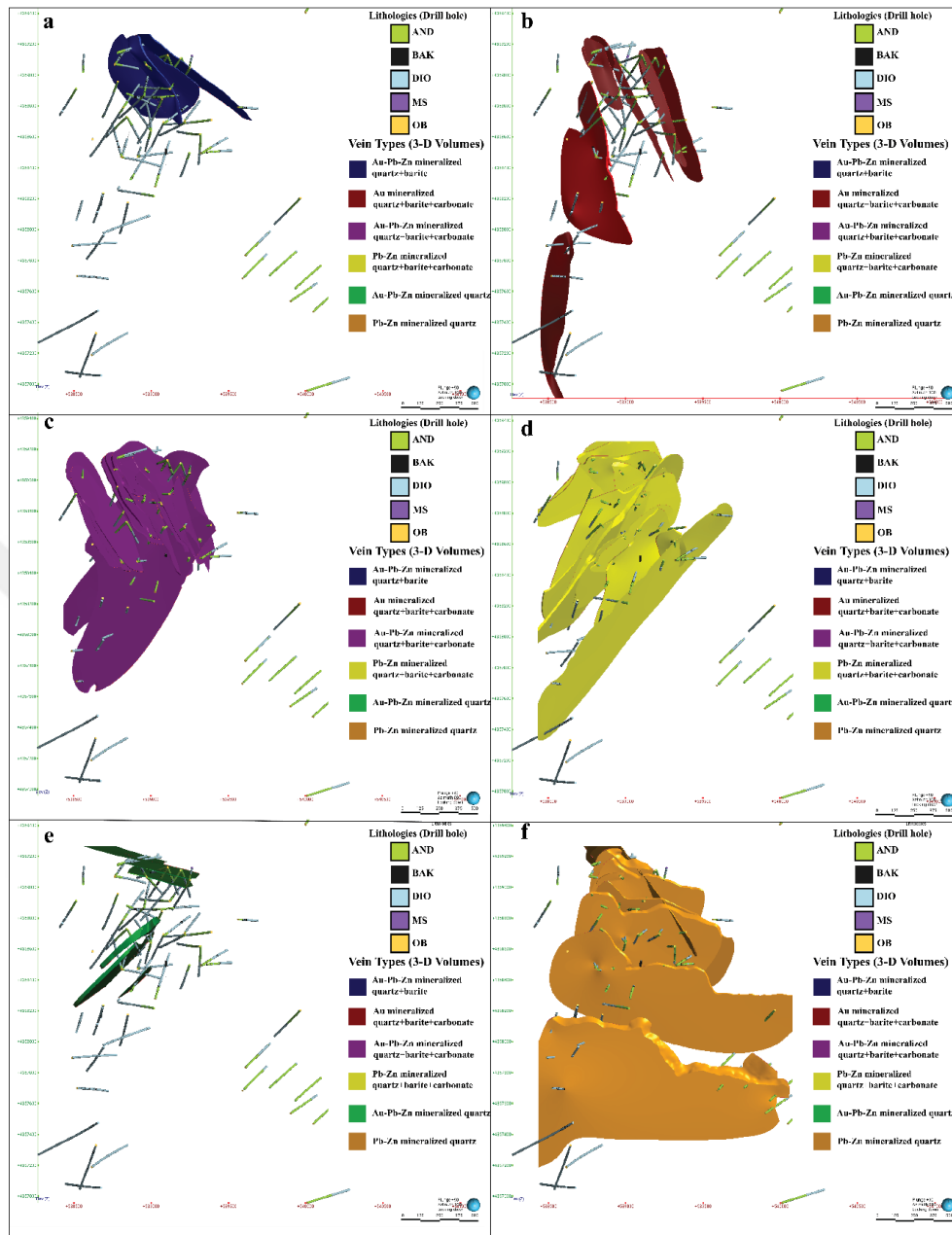


Figure 80. 3-D volumes of veins. a) Au-Pb-Zn mineralized quartz+barite, b) Au mineralized quartz+barite+carbonate, c) Au-Pb-Zn mineralized quartz+barite+carbonate, d) Pb-Zn mineralized quartz+barite+carbonate, e) Au-Pb-Zn mineralized quartz, and f) Pb-Zn mineralized quartz.

Volumes are generated after all the surfaces are constructed. To achieve 3D volumes, chronology of these surfaces should be decided first. The relative positions of the surfaces outside the veins are created according to published literature as well as through field observations. In this case, the surfaces are transformed into volume from young to old as: basaltic andesitic dyke, diorite, andesite, and metasedimentary unit. Cross-cutting relationships are decided at this step. However, no definite decision is made regarding the relative timing of the veins. However, the veins are converted into volumes to crosscut the basaltic andesite dykes (Figure 81).

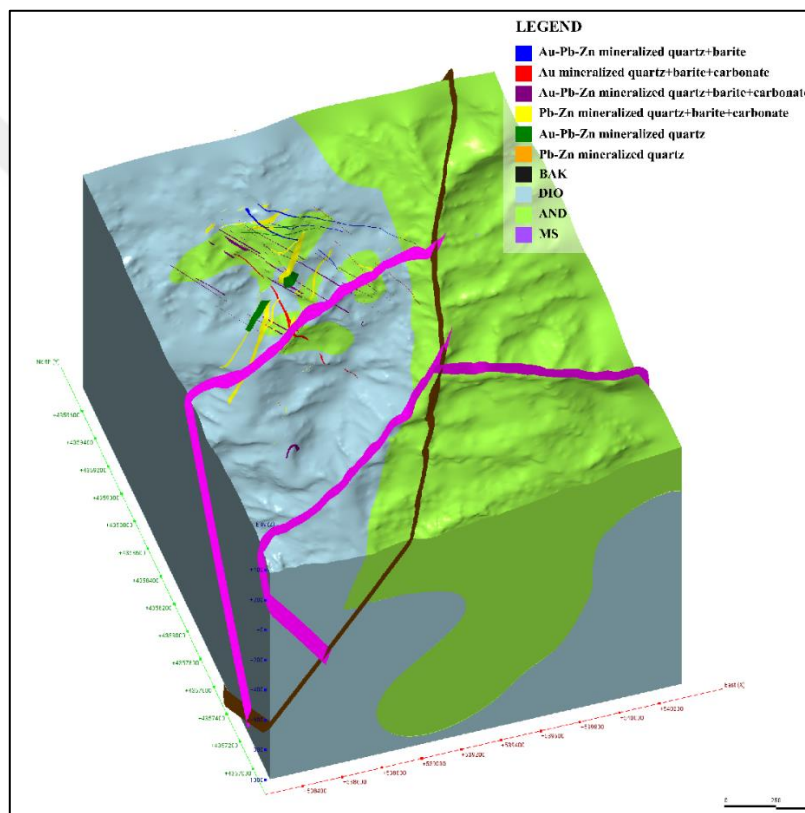


Figure 81. The geological model of the study area.

CHAPTER 9

DISCUSSIONS

9.1 Lithological Units

In the study area, five different lithologies can be defined and distinguished and these are metasedimentary units of the Karakaya Complex and igneous units including the Terziler Granodiorite, Yuntdağ Volcanics, Çatalçam Diorite, and the basaltic andesite dykes. The detailed field studies and other studies were done on Yuntdağ Volcanics, Çatalçam Diorite, and basaltic andesite dyke. From the field study, the Yuntdağ Volcanics are described as younger than Karakaya Complex, and Terziler Granodiorite, and the volcanics are older than Çatalçam Diorite which cut by Basaltic Andesitic Dyke. Distinction of Çatalçam Diorite and Yuntdağ volcanics which includes ore-bearing and barren epithermal-style and porphyry-style veins is almost impossible, especially on the surface, as a result of strong alteration, but Çatalçam Diorite includes relatively larger grains relative to Yuntdağ Volcanics, this differentiation can be done relatively easily in the drill core. However, Basaltic Andesitic Dyke differentiation, which has never been reported in this area, is made in this study. Basaltic andesite dykes, which are observed as relatively less-altered compared to other igneous lithologies, are commonly observed in certain orientations in the east of the area in the geological map study. In the east of the area, basaltic andesite dykes generally have NW-SE orientation consistent with the dominant vein trends in this area. In addition, basaltic andesite dykes mapped in the

north of the area are observed in NE-SW orientation. Therefore, basaltic andesite dykes may have intruded using extensional regimes that allow veins to form.

9.2 Structural Elements Combining Surface Geochemistry

The study area is structurally located at the western boundary of the İzmir-Balıkesir Transfer Zone (IBTZ), which was defined as a NNE-SSW-oriented trending major strike-slip Fault Area (Okay et al., 1990). During field studies, 33 different fault planes are observed and included in the geological map. Most of these faults are normal faults with strike-slip component, and a small number of them are strike-slip faults with normal component. Identified faults are divided into 6 different groups. In Fault Area 1, faults P198N and P199N, which are also mapped in the anomaly maps created from the results of the geochemical analysis on the surface of the structural measurement studies on the surface, affect the mineralization. In Figure 82, Pb anomaly is examined on the surface of the fault P198N in the Pb anomaly map (Figure 82). The anomaly here is not through the all-fault plane; therefore, contamination during sampling can be a reason for this anomaly, or the fluids can come from a specific point by using the weakness of the fault surface. While no Cu anomaly is located on the hanging wall of the fault P199N, it is seen that the Cu anomaly increased in the footwall. Therefore, there is a possibility that a possible continuation of the Cu anomaly detected in the surface geochemistry may be deeper in the hanging wall (Figure 82). Since the surface geochemistry study is not carried out in the area where the fault surface P200N was mapped, it is not possible to comment on the fault-mineralization relationship there.

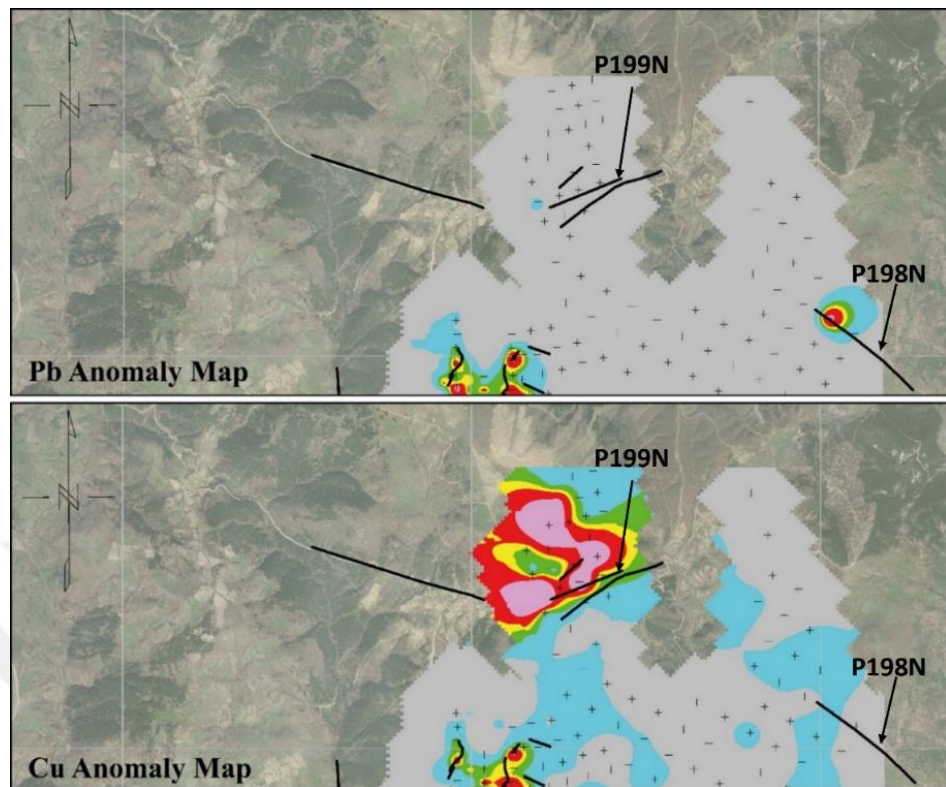


Figure 82. Anomaly maps of Pb and Cu show the relationship between faults and Pb-Cu anomalies.

When the area covered by the Fault Area 3 of the anomaly map prepared for the Zn element is examined, the geochemical analyzes of the soil samples also show that the anomaly is offset along this zone with a left-lateral slip. Although the surfaces of the faults that formed this offset is weathered, no ore mineral is encountered, but a small amount of pyrite was observed, but pyrites are not only related to veins, they are also found in the matrix of volcanics (Figure 83). The surface of the P30 fault was observed in a very small area and there was slight oxidation on the surface. However, while fragments of quartz-barite veins can be observed on this fault surface, these fragments are not affected by the faulting, so it is possible that vein formation developed at least after P30 fault.

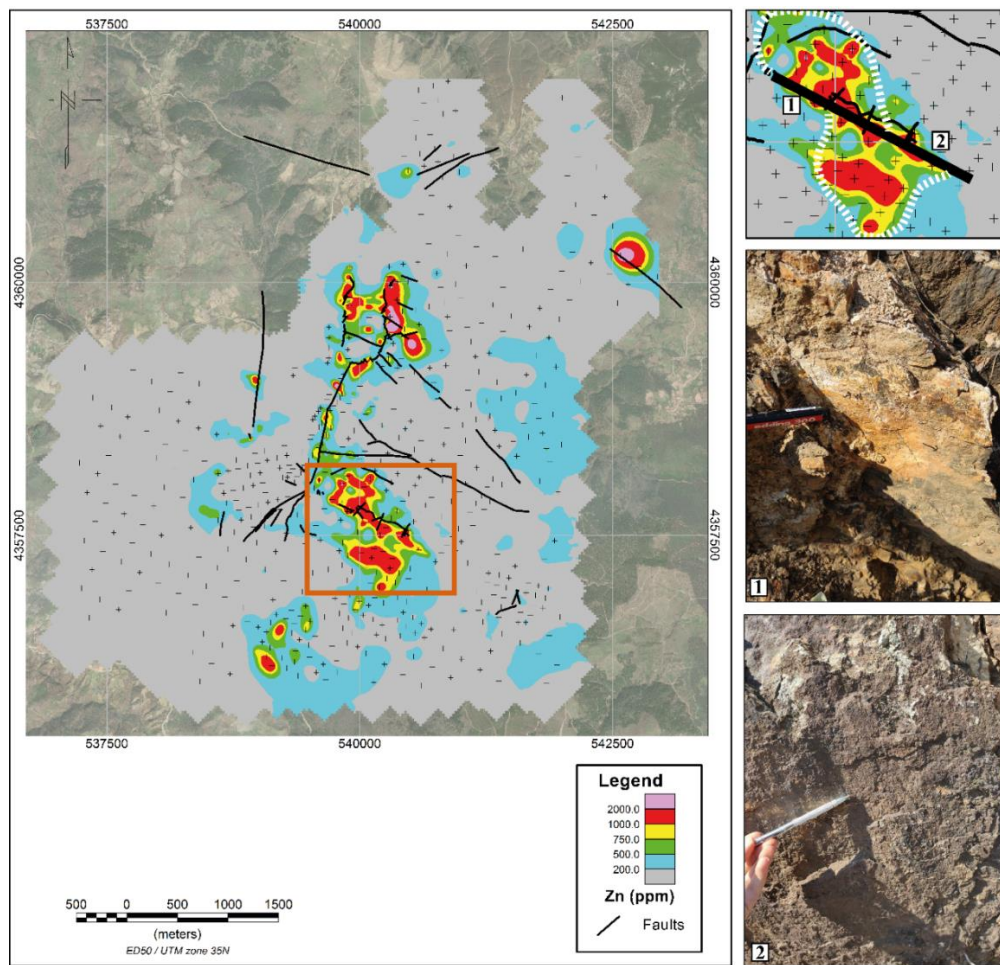


Figure 83. The figure including anomaly map of Zn, close up a region that is an example for offset of Zn anomalies with respect to normal faults with left-lateral component, and weathered but no mineralized fault surface which are P317 and P315.

In the anomaly map made for the Zn element, it was observed that the anomaly is offset to the right in the area covered by the Fault Area 4 (Figure 84). In this zone, observed veins has undergone strong clay alteration and deformation; therefore, this normal faults with right-lateral strike-slip component may classify as post-mineralization faults.

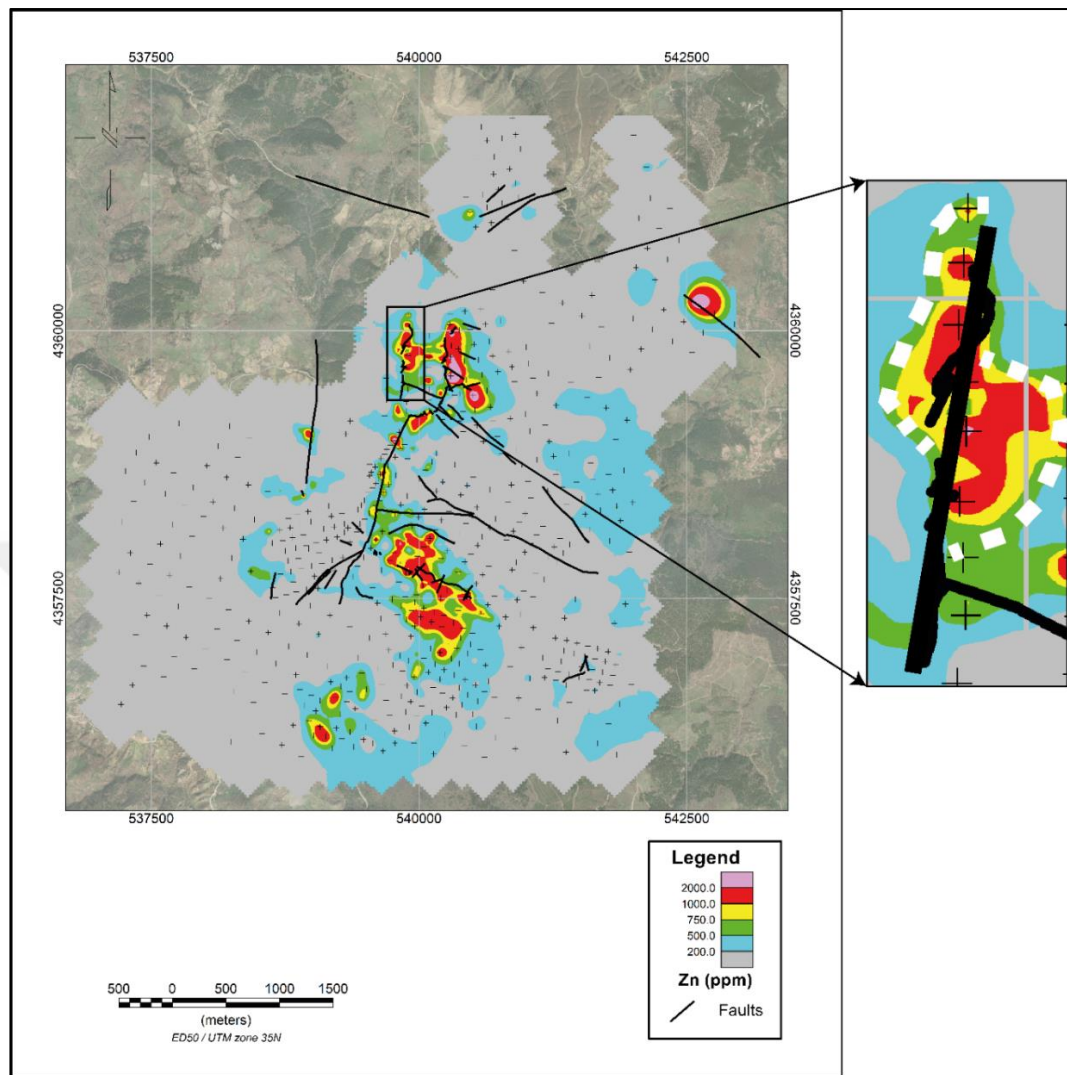


Figure 84. Anomaly map of Zn with offset of anomaly of Zn with respect to faulting in Fault Area 4l.

In Fault Area 5, when soil geochemistry analyzes are examined, it is possible to observe a right lateral offset. Considering that the Pb-Zn-containing veins in this area, similar to Fault Area 4, are subjected to clay alteration and severe deformation, it can be interpreted that the faults in this area may have occurred after the formation of the vein (Figure 85).

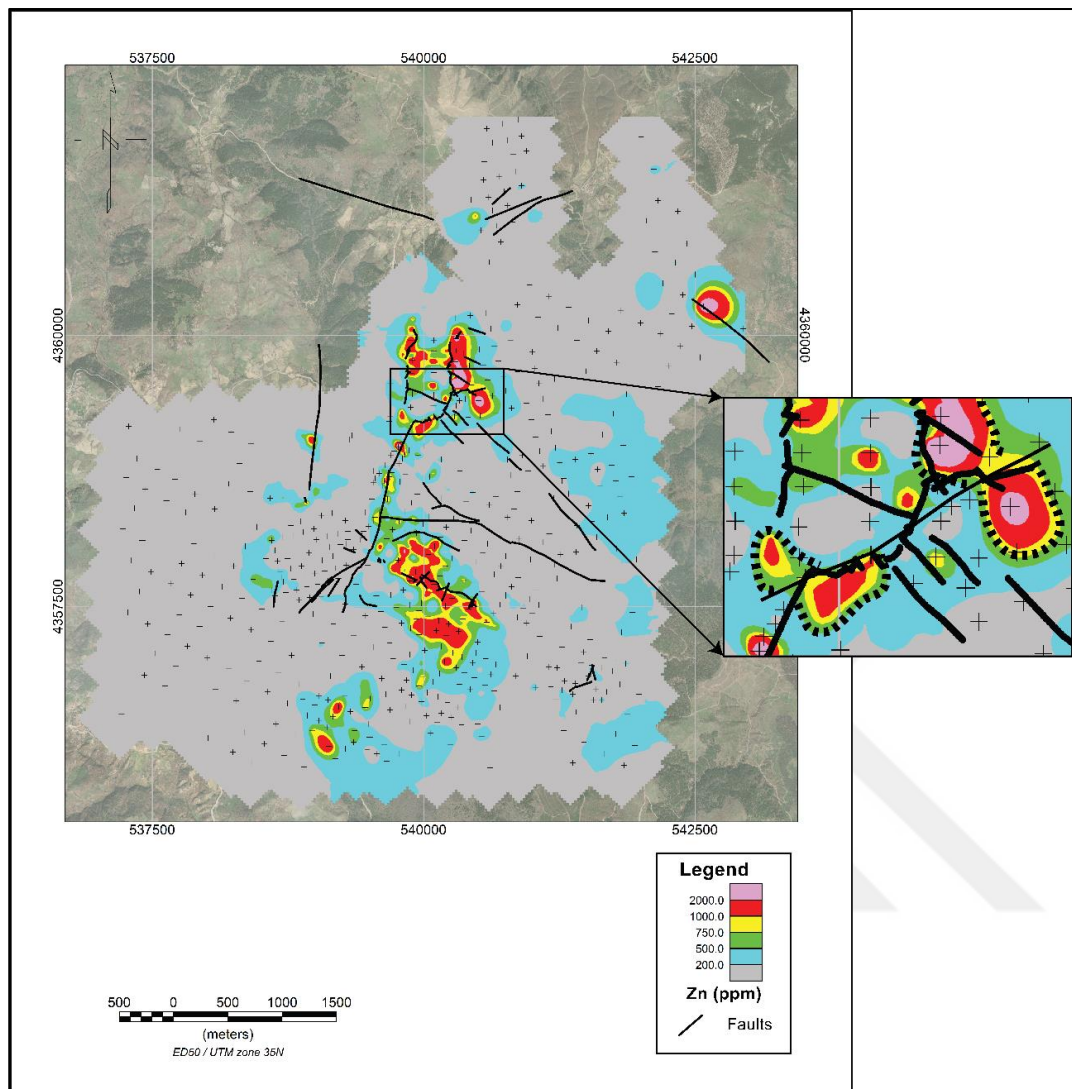


Figure 85. Anomaly map of Zn with offset of anomaly of Zn with respect to faulting in Fault Area 5.

Measurements which are taken from all veins are grouped according to groups of Fault Areas based on spatial and filling material. When viewed from a broad perspective, the vein measurements are collected in 3 main directions. Dip direction and dip measurements are from dominant to non-dominant, first set: 228N/55, second set: 029N/67, and third set: 108N/75. NE-SW for first and second set and

NW-SE for third set extensional regimes are needed to form these vein sets. These regimes are also observed in the kinematic analysis of the faults. Faults that mostly develop in accordance with the NE-SW extensional regime are located in Fault Area1, Fault Area3 and Fault Area5, which includes offset of the anomaly when combined with soil geochemistry. However, it is among the possibilities that the faults will form with the next same directional regime in the areas or that the fluid will move together with the fault with the advent of the fault (synmineralization). In particular, it is possible to observe that the vein sets formed in this opening direction are rich in base metal (Pb-Zn-Cu). However, NW-SE extensional regimen is required for the formation of third set veins, which mostly contain quartz-pyrite veins. This extensional regime was mostly found in Fault Area 2 and Fault Area 4 by kinematic analysis. Especially since Fault Area 2 is an area with a lot of drilling data, drillhole assay results show that the Au value in the area determined as Fault Area 2 is richer than the rest of the field. Therefore, it may be possible to say that the P2 fault, especially in Fault Area 2, developed as synmineralization for Au with Pb-Zn-Ag (Figure 86).

While Au mineralization is located in the west of the study area, Pb-Zn mineralization in the east is dominantly observed when both surface samples and drilling data are examined. The reason for this sharp separation may be the P318 fault, which has the same orientation as the IBTZ in Fault Area 3. The P318 fault is a normal fault dipping west, which means that the west of the site is the hanging wall of the P318 fault. However, it is possible to see slickenlines on a quartz-dominant vein on the surface of the P318 fault (Figure 86). Therefore, P318 may have lowered the west of the field after mineralization, and therefore possible Au mineralization in the east of the field may have gone with erosion. Based on the drilling data, the mineralization is in the east, approximately 100 meters above the western zone.

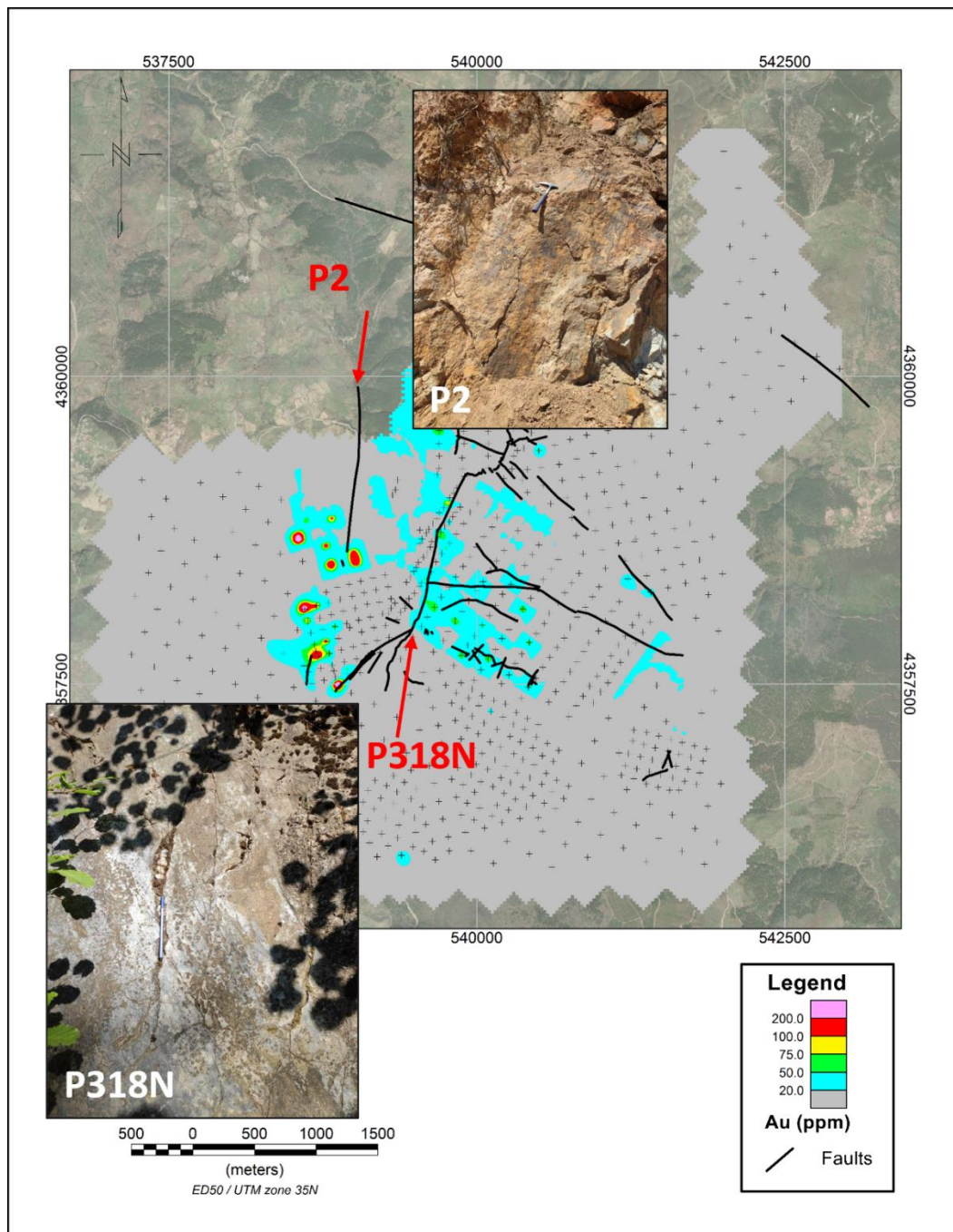


Figure 86. Au anomaly map includes two important faults (P2, P318) for gold mineralization.

Apart from these, there are E-W, N-S and ENE-WSW directional extensions in the kinematics of the faults. However, from the vein measurements collected in the field, no mineralization was observed that predominantly points to these directions. On the other hand, when we examine the vein volumes created from the drilling data, there are vein volumes suitable for the extension regimes interpreted based on the veins measured on the surface. However, the dominant orientation of Pb-Zn mineralized quartz veins is E-W and the dominant orientation of Au mineralized quartz+barite+carbonate veins is NNW-SSE, which may indicate that N-S and ENE-WSW extensional regimes lead to mineralization.

9.3 Alteration and Mineralization

Alterations are classified as sericite-clay, quartz-sericite-pyrite, carbonate-clay, and sericite-chlorite-clay which are typical for epithermal deposits. Clay minerals alongside quartz are ubiquitous in the altered wall-rocks surrounding epithermal veins in Çatalçam and are accompanied by varying amounts of chlorite, carbonate, and rare tourmaline. The dominant clays are illite/smectite type clays, and with the common presence of carbonate, these indicate that fluid pH was not significantly low at Çatalçam. The observed alterations at Çatalçam prospect can be defined as sub-types of argillic alteration which are products of medium to low temperature fluids between 200 and 300 degrees centigrade. Moreover, presence of chlorite alongside clay minerals indicates intermediate argillic zone same as Temora (Gidginbung) Mine in Australia and Peschanka porphyry-epithermal Cu-Mo-Au deposit in Russia (Allibone et al., 1995; Marushchenko et al., 2014). In addition, absence of adularia, which is characteristic mineral for low sulfidation and intermediate sulfidation epithermal deposits, can be interpreted that it has completely transformed into illite

or kaolinite like Favona Epithermal Au-Ag deposit, New Zealand (Simpson and Mauk, 2007).

In Çatalçam prospect, the veins are divided into two as epithermal-style and porphyry-style. While there is mainly quartz-dominant in epithermal-style veins, there is also lack of quartz veins. Veins are grouped according to infill content. The textures of quartz veins have been studied to understand the boiling mechanism. Boiling has a huge negative effect on stability of gold-bisulfide complexes; therefore, identification of boiling is quite important for understanding gold formation of epithermal gold deposits (Cooke and McPhail, 2001; Pokrovski et al., 2014; Keith et al., 2020; Falkenberg et al., 2021). To understand if boiling occurs, carbonate and quartz textures should be studied. Characteristic textures such as bladed, moss, and colloform are not observed in the field studies. Veins usually have a massive texture macroscopically. However, in microscope studies, it is possible to say that quartz grains are generally observed as medium to coarse, subhedral to euhedral and there are textures that can be called jigsaw/mosaic, interlocking, massive and comb on their walls. In addition, carbonate veins are defined as two different phases. Carbonate grains are defined as tiny and anhedral in ore-bearing carbonate-dominant veins, while carbonate grains are observed as subhedral to euhedral and coarse in barren carbonate-dominant veins. In Figure 87 indicates rapid deposition textures that may have been occurred during boiling and textures are not precipitated during boiling (Moncada et al., 2012).

In the studies, only jigsaw texture is observed among the textures that precipitated during boiling. This texture is mostly observed in quartz-dominant veins and other dominant textures are observed in both carbonate and quartz grains. Therefore, it can be mentioned that different mineralization stages occur at a deeper and shallower level than the boiling level.

Firstly, carbonate grains with rhombic texture are not related with mineralization and this carbonate phase is the latest phase like Mexican epithermal deposits (Camprubí and Albinson, 2007). Jigsaw texture is mostly observed in quartz+sulfide veins, but when the assay results of these veins are examined, no serious anomaly has been observed, so it is not possible to talk about a very high Au precipitation, which is also supported by the drilling assay results. The highest analysis result in the drilling database is 13 ppm for Au and this sample is very short (40 cm) and specific. In Çatalçam prospect, massive veins are the most observed veins, this texture is observed in both quartz grains and carbonate grains. Generally, sphalerite, galena, pyrite and chalcopyrite minerals are included in these veins; in addition, native gold is also mostly in these minerals.

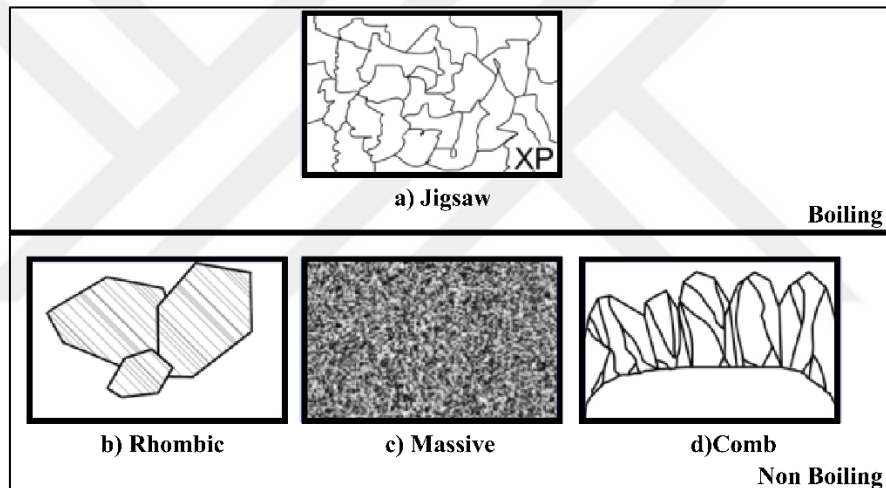


Figure 87. Various quartz and carbonate textures observed in Çatalçam mineralization. a) Jigsaw texture quartz which is characteristics for rapid deposition such as might occur during boiling, b) rhombic, c) massive, d) comb textures indicate that precipitation of minerals is not during boiling (Moncada et al., 2012).

Therefore, it may be possible to say that Pb-Zn-Au mineralization did not occur during boiling. According to the epithermal quartz veins model of textural zoning revealed Morrison et al. (1991), Çatalçam mineralization may have occurred below the boiling level. However, some textures indicate boiling in Çatalçam

mineralization, and Sarı et al. (2022) and Kumral et al. (2022) stated that textures and fluid inclusion studies indicate boiling.

In ore paragenesis studies, minerals are summarized from the earliest to latest phases as follows: pyrite I, galena+sphalerite, chalcopyrite±tetrahedrite group minerals, sphalerite±tetrahedrite group minerals, and pyrite II. In addition to these, the latest carbonate phase which is explained before, the latest carbonate phase has no relation with mineralization, and it is possible to see ore minerals cutting by carbonate (Figure 25b; Figure 44).

9.4 Metallogenic Significance

The Çatalçam prospect is located in western Anatolia, along the northern limits of the Bornova Flysch Zone, and to the east of the Kozak Pluton. This region is known for the widespread occurrence of epithermal-style mineralization, including Miocene low-sulfidation epithermal Au-Ag systems at Karadere, Güneylidere, Gömeç, Kubaşlar, Ovacık, and Çukuralan (Yiğit, 2012; Oyman, 2019).

The prospect hosts vein swarms mainly enriched in Pb and Zn, with some Au and Ag, which distinguishes Catalcam from many other gold systems developed around the Kozak Pluton. Mineralized veins are texturally classified as epithermal-style veins mainly with quartz, barite, and carbonate infill alongside base metal sulfides. Additionally, dark gray quartz veinlets and stockworks can also be observed in the study area. Pb-Zn-Au mineralization can be related with epithermal-style veins; however, dark gray colored quartz veinlets and stockworks are related with Au mineralization rather than base metals. Porphyry-style veinlets are examined in the deeper levels. The abundance of base metal sulfides with the characteristic assemblage of chalcopyrite-galena-sphalerite-tetrahedrite/tennantite, locally high copper abundance of the veins, and relative enrichments in Mn particularly in

carbonate-rich veins point to a possible intermediate-sulfidation-style epithermal mineralization at Çatalçam (Sillitoe and Hedenquist, 2003; Wang et al., 2019).

A preliminary U-Pb zircon age of approximately 17 Ma from the mineralized sub-volcanic intrusions (Sarı et al., 2023) likely points to a Miocene timing for mineralization, yet there is no direct radiometric age constraint on alteration or mineralization. This age seems to be a reasonable approximation to the formation age of Çatalçam, since many of the aforementioned low-sulfidation epithermal systems in the vicinity of the Kozak Pluton, as well as the other nearby low-sulfidation epithermal systems along the Kiziltepe-Sindirgi gold corridor formed nearly at 18–17 Ma period (Wedin, 2013). In addition, salinity values from Sarı et al. (2022) for Çatalçam mineralization support idea of intermediate-sulfidation epithermal deposits.

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Çatalçam prospect may be a candidate to be the first intermediate sulfidation epithermal deposit reported in this area; although all epithermal deposits around Çatalçam prospect are reported as low sulfidation epithermal deposits (Oyman, 2019). However, there is also the potential for a deeper porphyry deposit. Apart from

this study, Sarı et al. (2022) also mentions that there is a porphyry mineralization in Çatalçam and the presence of potassic alteration. However, when looking at the core samples in the given ranges, no such alteration is interpreted, but veinlets that can be named as porphyry-style are observed. Therefore, Çatalçam prospect can be a prospect where the intermediate sulfidation epithermal deposit overprints the porphyry deposit, similar to the Çöpler Porphyry-Epithermal Au Deposit (İmer et al., 2013). Moreover, if the 17 Ma age presented by Sarı et al. (2023) is accepted as true, it is younger than the porphyry deposits around Çatalçam prospect, its age can be correlated with Pınarbaşı (18.2-21.02 Ma; Kuşçu et al., 2019).



CHAPTER 10

CONCLUSIONS

The geology, characteristics, and structural control of Çatalçam prospect are studied with field studies, polished thin section, soil geochemistry, 3-D geological and fault model studies. The results of these studies can be summarized both at the mineral deposit scale and at the regional scale as follows:

- The inference made from the field and drilling data is that there are two 6 different lithological units. These are from old to young: metasedimentary units of Karakaya Complex, Soma Formation, Terziler Granodiorite, Yuntdağ Andesite, Çatalçam Diorite, and basaltic andesite dykes. Epithermal veins that cut the Yuntdağ Andesite and Çatalçam Diorite also cut the basaltic andesite dykes, but in the areas where the basaltic andesite dykes are mapped, it was observed that dykes have a highly compatible orientation with the epithermal veins. However, the fact that the dykes are not as altered as other units and contain epithermal vein fragments indicates that they are related to mineralization structurally and temporally.
- In Çatalçam Pb-Zn-Au mineralization, the mineralization is highly related to the veins. While wall rock alteration is observed, it can be suggested that there is no mineralization in wall rocks based on assay results. Therefore, mineralization is controlled by structural features. It is observed that NE-SW and NW-SE extensional regimes, which enable the formation of faults from the kinematic analyzes made from the fault surfaces measured in the field. These regimes also lead to the formation of ore or barren epithermal veins based on surface studies of veins. However, the directions of the vein

volumes included in the 3-D geological modeling show that the N-S and ENE-WSW extensional regimes, which are also effective in the formation of faults, have also a role in the formation of mineralization.

- The faults observed on the surface are spatially divided into 6 different groups. Each of these Fault Areas (except Fault Area 6) contains offsets that indicate offset of the ore (post-mineralization fault) or that the ore was formed at the same time as the faulting and therefore may move together with the fault (syn-mineralization fault) based on the results of the surface geochemistry.
- Surface geochemistry and drilling assay results show that there is a difference in Au mineralization between the west and east of the field. While Au accompanies Pb-Zn in the west of the field, this is not the case in the east. This difference is explained by two faults:

1) The extensional regime of the P2 fault, located in Fault Area 2, is compatible extensional regime of the vein studies carried out throughout the field. At the same time, Au values increase dramatically in assay results in drillings surrounding of the P2 fault.

2) The south dipping normal fault with left-lateral strike-slip component P318 in Fault Area 3 caused the western part of the site to subside. Therefore, if there is a higher Au mineralization in the east, it is highly likely that this mineralization has been eroded. It has been proven by the drilling data of this fault that it causes a vertical movement of approximately 100 meters.

- Four different alteration definitions are made from the samples taken from the cores, each of these alterations can be characterized as variations of the

argillic alteration. For these alterations to occur, low temperature and not very low pH close to neutral are required (presence of carbonate).

- Ore paragenesis from the polished thin section studies and precipitation depth and temperature of the veins are tried to be predicted from the textures of the veins. Ore paragenesis can be summarized from the earliest phase to latest phase: pyrite I, galena+sphalerite, chalcopyrite±tetrahedrite group minerals, sphalerite±tetrahedrite group minerals, and pyrite II which is related with Au mineralization. In addition to these, many quartz and carbonate textures are observed in thin section studies indicating boiling and not occurring during boiling.
- Çatalçam mineralization may be a possible intermediate-sulfidation-style epithermal mineralization because of abundance of base metal sulfides with the characteristic assemblage of chalcopyrite-galena-sphalerite-tetrahedrite/tennantite, and relative enrichments in Mn, especially in carbonate-rich veins. In addition to these, porphyry type veins and other studies carried out in this area have revealed that there is a deeper porphyry mineralization. At the same time, considering that the age data of this area is 17 Ma (Sarı et al., 2023), while the Çatalçam mineralization is important as the first intermediate-sulfidation epithermal deposit around it due to its difference from the surrounding low-sulfidation deposits, being the youngest porphyry mineralization brings this mineralization to a valuable point.

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