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GEOLOGY AND STRUCTURAL CONTROL ON MINERALISATION OF THE ARINEM AREA, GARUT, WEST JAVA

GEOLOGI DAN STUDI KONTROL STRUKTUR TERHADAP MINERALISASI DI DAERAH ARINEM, GARUT, JAWA BARAT

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ABSTRACT

Exploration by PT Aneka Tambang in 1981 identified several promising mineral prospects in West Java, categorized as low- to high-sulfidation epithermal types. One such prospect is the Arinem area in Garut, which became the focus of this study is still an active area for detailed exploration. Spanning 0.46 km², this area is located 45 km from Garut city.

The data used in this research include field data and core samples from seven boreholes provided by PT ANTAM Tbk drilled in 2011. This study aims to understand the geological and hydrothermal alteration processes of the region using field work measurements, petrographic, mineragraphy, and ASD specTERRA

The study area consists of volcanic and volcaniclastic units, intruded by Pyroxene Andesite and Hornblende Andesite, with prominent hydrothermal alteration zones. The geological structures include the Left-Lateral Arinem Fault and the Right-Normal Arinem Fault, both of which control hydrothermal processes. Sulphide minerals such as pyrite, chalcopyrite, galena, and sphalerite were identified, with quartz veins trending north – south. The results suggest that Arinem is a part of an en-echelon structure arrays part of a larger left lateral strike slip system in West Java that cross-cut by the younger NE – SW dextral faults. This provides crucial insight into the geology, subsurface alteration and mineralization distribution, highlighting its significance for ongoing exploration efforts.

Keywords: Arinem, Geology, Hydrothermal Alteration, Structure-control mineralisation

ABSTRAK

Eksplorasi yang dilakukan oleh PT Aneka Tambang pada tahun 1981 berhasil mengidentifikasi beberapa prospek mineral menjanjikan di Jawa Barat, yang dikategorikan sebagai tipe epitermal sulfidasi rendah hingga tinggi. Salah satu prospek tersebut adalah wilayah Arinem di Garut, yang menjadi fokus penelitian ini masih menjadi salah satu area aktif eksplorasi. Wilayah tersebut mencakup area seluas 0,46 km² dan berjarak sekitar 45 km dari Kota Garut.

Data yang digunakan dalam penelitian ini meliputi data lapangan serta sampel inti dari tujuh lubang bor yang disediakan oleh PT ANTAM Tbk yang di bor pada 2011. Tujuan dari penelitian ini adalah untuk memahami proses geologi dan alterasi hidrotermal di wilayah tersebut dengan menggunakan analisis petrografi, mineralografi, dan ASD specTERRA.

Wilayah studi terdiri atas unit vulkanik dan vulkanoklastik yang diintrusi oleh Andesit Piroksen dan Andesit Hornblende, dengan zona alterasi hidrotermal yang menonjol. Struktur geologi yang ada di daerah ini termasuk Sesar Mengiri Arinem dan Sesar Menganan Turun Arinem, yang keduanya mengontrol proses hidrotermal. Mineral-mineral seperti pirit, kalkopirit, galena, dan sfalerit teridentifikasi, dengan urat mineral yang berarah barat laut-tenggara. Hasilnya menunjukkan bahwa Arinem merupakan bagian dari sistem sesar mendatar mengiri besar di Jawa Barat yang menghasilkan struktur en-echelon pada bagian terminasi dari struktur yang dipotong oleh sesar mendatar menganan yang lebih muda. Hal memberikan wawasan penting mengenai alterasi dan distribusi mineralisasi di bawah permukaan, yang menunjukkan signifikansinya untuk upaya eksplorasi yang berkelanjutan.

***Kata kunci**: Alterasi Hidrotermal, Arinem, Geologi, Kontrol Struktur Geologi pada Mineralisasi*

INTRODUCTION

With the increasing demand for metallic minerals in Indonesia, previously underexplored regions such as the Southern Mountains of Java are now being investigated for their mineralization potential. The Southern Mountains, part of the Old Andesite Formation, represent an ancient volcanic arc that holds untapped resources. Several companies, including PT Aneka Tambang, have conducted successful exploration activities in these areas, identifying low- to high-sulfidation epithermal deposits. One such area is Arinem, located in Garut, West Java, which has become the focus of this study. Geochemical analysis of ore minerals shows that gold and silver grades range from trace amounts up to 17.5 g/t Au and over 100 g/t Ag, respectively. Base metal contents vary, with copper up to 0.12%, zinc up to 0.23%, and lead up to 0.16% (Yuningsih et al., 2010).

This study aims to integrate the geological framework of the Arinem area using field geology, petrographic, mineralographic, and ASD specTERRA analyses.

The study area of Arinem is covering 0.46 km² and located 45 km from Garut. The geology comprises of volcanic and volcaniclastic rocks intruded by andesite, and its alteration processes are largely controlled by the region's structural framework (ANTAM, 1993). Understanding these geological processes, especially the structures that control the alteration is essential for targeting potential mineralization zones. A structural model model is particularly useful in visualizing the spatial distribution structure that may influence the alteration process and guiding exploration efforts and aiding in resource estimation.

GEOLOGY OF ARINEM

The Arinem area is located in the transition zone from the Southern Mountains Zone to the Quaternary Volcanic Zone in West Java, specifically within the Old Andesite Formation (Figure 1). This formation, consisting of volcanic and volcaniclastic rocks, represents an ancient volcanic arc that has undergone multiple episodes of volcanic activity and subsequent hydrothermal alteration.

These volcanic and volcaniclastic units are intruded by Pyroxene Andesite (Tpap) and Hornblende Andesite (Tpah), indicating later magmatic activity. The intrusions cut through the older volcanic units, suggesting they are younger and possibly related to the region's mineralization processes (Alzwar et al., 1992; ANTAM, 1993). Stratigraphically, the Andesite Breccia is the oldest unit, followed by successive tuff and lapilli layers. The Andesite intrusions are interpreted as younger based on their cross-cutting relationships with the surrounding rock units (Alzwar et al., 1992). Similar geological setting for mineralization were also recognized in many parts of western Java region around the Bayah Dome such as Cikotok (Noya et al., 1994), Cibaliung (Widyariestha et al., 2019), and many others.

MATERIALS AND METHODS

The study utilized both field data and core samples from seven boreholes provided by PT ANTAM Tbk. Field mapping was conducted to characterize the surface geology, while petrography and mineragraphy analyses on 8 surface and 9 core samples were performed to identify primary and secondary minerals. Additionally, ASD specTERRA analysis on 9 surface samples was employed to identify alteration minerals, particularly clays. SpecTERRA analyses will employ infrared reflectance and emission of the samples to be compared to USGS mineral database using ENVI and Specmin Pro software.

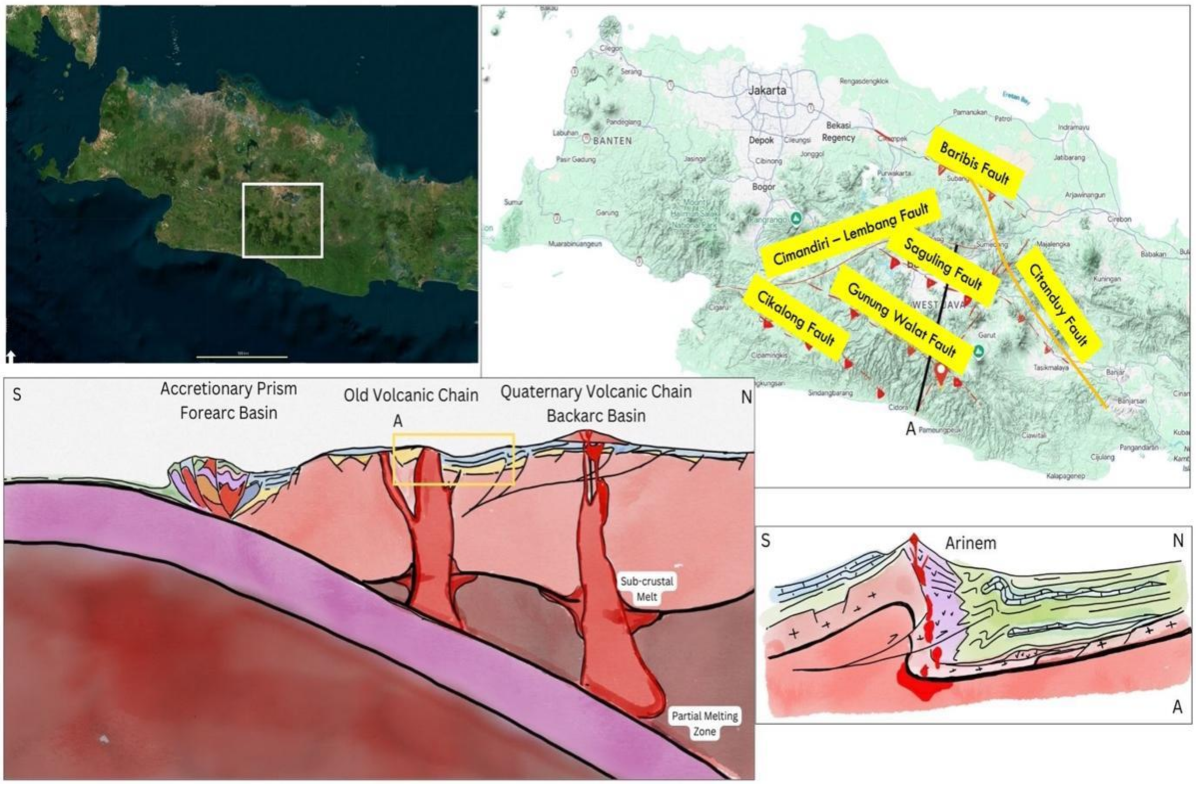

Figure 1. Study area location in Arinem Prospect, near Jatiwangi, Garut Regency. The area belongs in the transition between the Quaternary Volcano and the Southern Mountain Zones where Neogene fold thrust belt (dashed red lines in image on top right; modified from multiple sources (including Pulunggono & Martodjojo (1984); Alzwar et al. (1992); Clements & Hall (2007), Yulianto et al. (2007); van Gorsel (2018); PusGen (2017); Arisbaya et al. (2021)), appear to be intruded by the volcanic complex. Schematic cartoon cross-section from the Java Subduction Zone showing relative position of the Arinem area (A) is redrawn and modified from Pertamina BPPKA (1996). Orange lineament represent the right lateral Citanduy Fault (van Gorsel, 2018)

RESULTS: RECENT FIELD OBSERVATIONS

Based on field mapping and core sample analysis, lithology complexes in the Arinem area consist of several sequences of breccia-tuff, lapilli tuff, and andesite breccias. The Tuff Breccia Unit found in exposed in the northeast corner of the area consists of greenish-gray, well-compacted tuff with calcite veinlets and poorly sorted lapilli- to block-sized fragments. The Lapilli Tuff Unit which dominates the area contains poorly sorted, carbonate-rich lapilli tuff with strong alteration and oxidation. Alzwar et al. (1992) suggest that these two exposed volcanics are of the Early Pliocene age. The Andesite Breccia Unit is exposed to the south of the are and includes andesitic and lithic tuff fragments with open packing, calcite veins, and hematite oxidation, correlated to Late Pliocene volcanism (Alzwar et al., 1992). Lastly, the Andesite Unit found at depth (283–300 m) comprises porphyritic andesite with chlorite-altered plagioclase, quartz veinlets, and a thermal alteration zone, intruded in the Late Pliocene.

Geological Structure

The geological structure of the study area is dominated by two major fault systems:
The Left-Lateral Arinem Fault (N191°E/75°), with slickensides 24° ,N194°E *pitch* 3°) which trends NNE - SSW and cuts across all lithological units (Figure 2 A-B-C).

The Right-Normal Arinem Fault (N163°E/85°)), trending northwest - southeast, which intersects the Left-Lateral Fault (Figure 2 D-E-F). This fault system has played a significant role in controlling hydrothermal fluid flow and the spatial distribution of mineralization. The quartz veins measured in the study area are distributed in a northwest–southeast direction (Figure 2; Map on the right) with an average width of 4 meters. There are two vein sets with different dip directions, oriented at N157–170°E/72–78° and N308–359°E/54–86°. Antam (1993) recognized three vein zones namely Bantarhuni, Arinem and Halimun. These vein zones are interpreted to be cross-cut by the ENE – WSW local left lateral fault system.

HYDROTHERMAL ALTERATION - MINERALIZATION

Hydrothermal alteration in the Arinem area is controlled by the structural framework, with fluids migrating along fault planes and fractures. Two primary alteration zones were identified through petrographic, ASD specTERRA, and mineralographic analyses:

<u>Chlorite-Smectite-Illite-Calcite Zone</u>

This zone occupies about 80% of the study area and is primarily located in the northeastern and southwestern parts. The rocks in this zone exhibit moderate to intense alteration, characterized by a greenish coloration due to the presence of chlorite. Other secondary minerals include smectite, illite, and calcite, with traces of sericite and epidote. The presence of calcite veins, up to 3 cm thick, indicates carbonate precipitation from hydrothermal fluids. Additionally, oxidation has resulted in the formation of goethite, limonite, and hematite in certain areas.

<u>Kaolinite-Illite-Smectite Zone</u>

This zone covers approximately 20% of the study area, trending along the northwest-southeast fault line. It is characterized by intense oxidation and weathering, with altered rocks displaying white to reddish-brown colors. Kaolinite, illite, and smectite are the dominant minerals in this zone, indicative of lower-temperature hydrothermal alteration. The formation temperature of minerals in this zone, as determined by the Kingston Morrison Ltd. (1997) diagram, ranges from 140°C to 260°C. These temperatures are consistent with low-sulfidation epithermal systems.

Both alteration zones indicate hydrothermal activity within the epithermal range, with near-neutral ph conditions facilitating the formation of clay and quartz minerals (Pirajno, 1992, White and Hedenquist, 1995; Lawless et al., 1998; Pirajno, 2009; Yuningsih, 2011).

The stratigraphic relationships between these units are clearly shown, with the andesite intrusions cutting through the older breccia and tuff layers. The model also depicts the orientation and extent of the major fault systems, which control the distribution of hydrothermal fluids.

The Left-Lateral Arinem Fault and Right-Normal Arinem Fault are key structural features in the model, guiding the movement of mineralizing fluids and influencing the formation of alteration zones (Figure 2). The Kaolinite-Illite-Smectite Zone is concentrated along the northwest-southeast fault trend, represented by the occurrence of N-S trending veins (Map in Figure 2), while the Chlorite-Smectite-Illite-Calcite Zone is more widely distributed across the area.

The observed quartz veins (Map in Figure 2), with their crustiform and colloform textures (Figure 3 a – c), are indicative of episodic fluid flow and boiling within the hydrothermal system (Morisson et al., 1990). Calcopyrite, pyrite, galena and sphalerite (Figure 3 d – e) are a result of such boiling process. The presence of alteration minerals such as chlorite, illite, kaolinite, and calcite (Figure 3 f) reflects moderate hydrothermal temperatures (140°C to 260°C) and neutral pH conditions (Morrison, 1997), which are typical of such systems (Corbett and Leach, 1997; Figure 3 g-h).

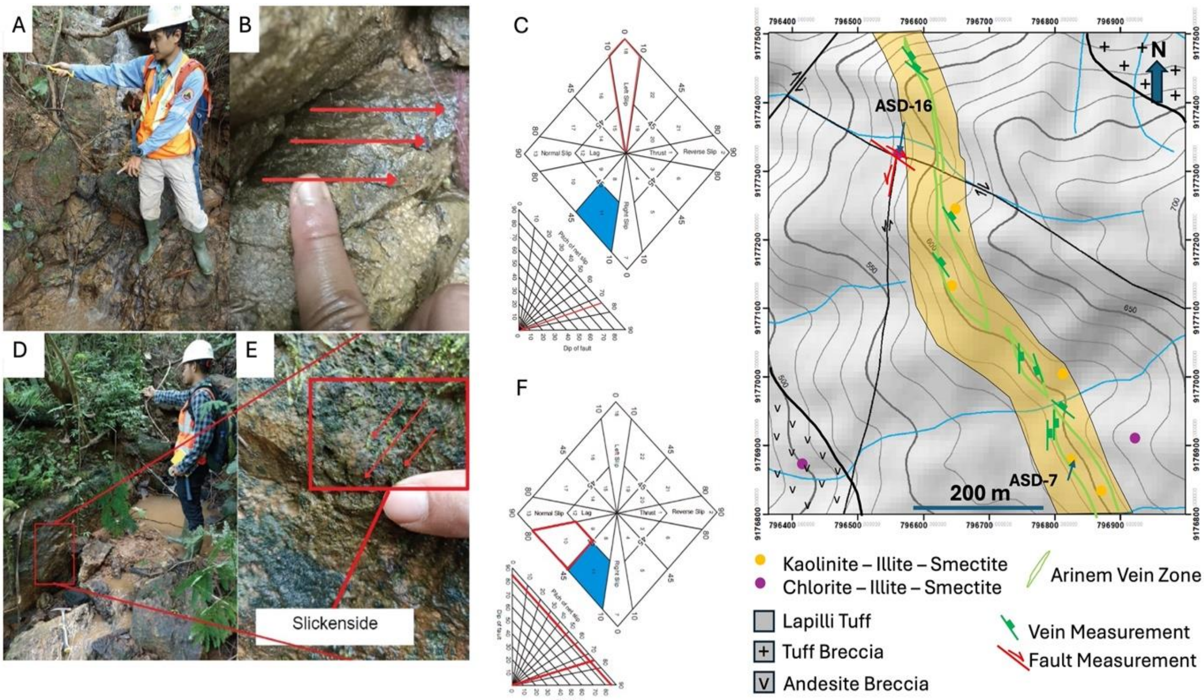

Figure 2. Structural measurements in the Arinem Area. A-B are the North – South trending left lateral Arinem Fault with left lateral fault analyses (C); D-E are the slickenside observed on Northwest – Southeast trending right normal Arinem Fault, analyses shown in F. The map on the right shows the observation location including for alteration and structural observation as well as ASD sample location for Figure 3. Transparent orange area on the map showing the Kaolinite –Illite – Smectite – Calcite alteration zone. Outside the orange the alteration is dominated by Chlorite – Illite – Smectite minerals. Lithology are shown by symbols.

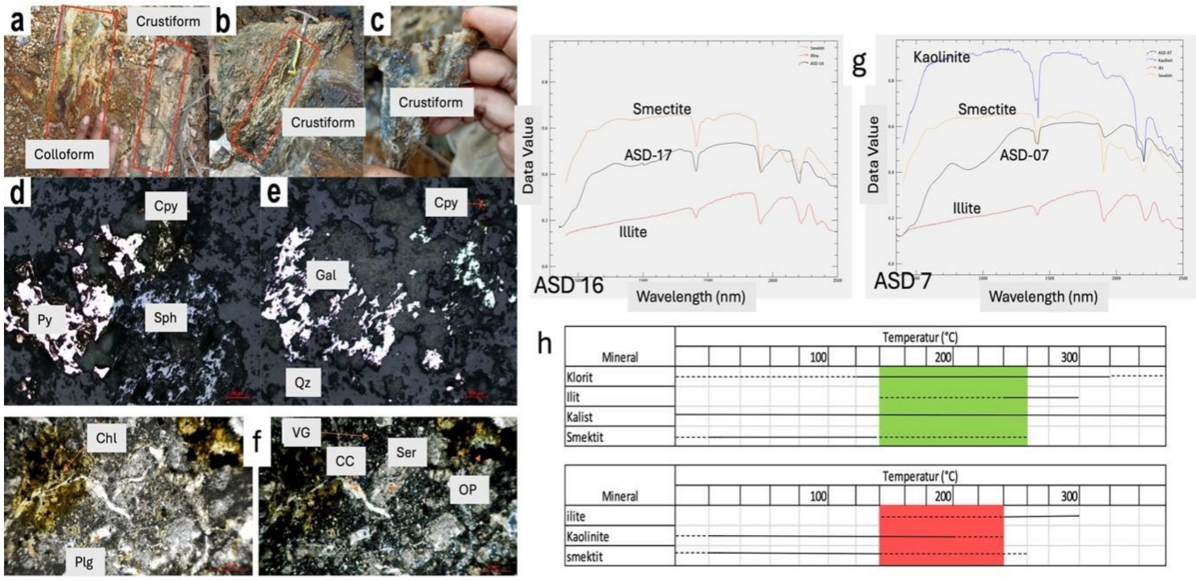

Figure 3. (a – c) crustiform and colloform texture of the quartz veins in the Arinem Veins Zone; (d – e) sphalerite, chalcopyrite, pyrite and galena from the photomicrograph; (f) thin section of the altered volcanics showing chlorite, sericite, calcite and opaque minerals replacing primary minerals; (g) ASD results from sample ASD 16, ASD 7 (location in Figure 2) confirms the occurrence of two alteration facies (Chlorite – Smectite – Illite and Kaolinite – Illite – Smectite); (h) Alteration temperature interpretation from both system.

DISCUSSION

The hydrothermal alteration and mineralization processes in the Arinem area are consistent with those found in low-sulfidation epithermal system. Along the fault-controlled pathways, the alteration zone is more concentrated. Quartz textures observed in the Arinem Vein Zone further support the interpretation of an episodic boiling process, which is a key characteristic of low-sulfidation systems. Such textures suggest periodic increases in fluid pressure, likely caused by tectonic stress or fault movement, which intermittently closed and opened fluid pathways, allowing for repeated mineral deposition. Our recent observation align with the typical setting of low suphidation epithermal system that occured in Arinem area as reported by Yuningsih and Matsuda (2014), Yuningsih (2019) and Purwanto et al. (2019).

The spatial distribution of alteration zones, particularly the alignment of the Kaolinite-Illite-Smectite Zone along the relatively N-S trending vein complexes known as the Arinem Veins (Figure 2), suggests that mineralization is structurally controlled. This understanding is crucial for future exploration efforts, as it provides insights into where high-grade mineralization may be concentrated. The intersection of these faults created areas of increased permeability, allowing for the concentration of mineralization.

Surface geology combined with geomorphological observation indicates that Arinem area is located within the right lateral fault system that deformed the southern coastline of Garut extending far to the northeast region as far as Sumedang. This fault system is interpreted to have caused the recent M 4.9 earthquake in southern Java, known as the Garsela Fault that is interpreted to have oblique slip movement (BMKG, 2024). Recent earthquakes relocation studies carried out by Supendi et al (2019) indicating a predominantly NE-SW strike slip faulting in the southern region of Garut. This is broadly similar to the result from geological mapping in this study.

Our observation agrees with the regional structural interpretation. However, it appears that this oblique right lateral fault diverge into a roughly 15 km wide relay zone. Subtle depression to the east of the study area suggest relay ramp between the right lateral Arinem Fault and another fault zone to the east of it. To the north of the area, near Mnt. Guntur similar depression feature also exist and appear to be intruded by volcanic product (Figure 4A).

The N – S trending vein complex in Arinem were formed limited near the Talagawangi Depression, interpreted as a relay zone, between two strike slip. However, the general trends of the vein complexes are N – S which will be less likely to have resulted from the recent NE – SW trending dextral fault system that deformed the southern coast of Garut. Therefore, the vein complexes are interpreted to be developed by a more regional NE – SW sinistral strike slip faults similar- or parallel- to Cimandiri Faults, or alternatively the elusive NW – SE right lateral Citanduy Fault (van Gorsel, 2018). It also important to note that the N – S trending structural lineaments were identified to be prominent in West Java represented by sedimentary basin formation in the Cenozoic as proposed by Clements and Hall (2007) suggesting a role of basement fabric that could influence the younger structures.

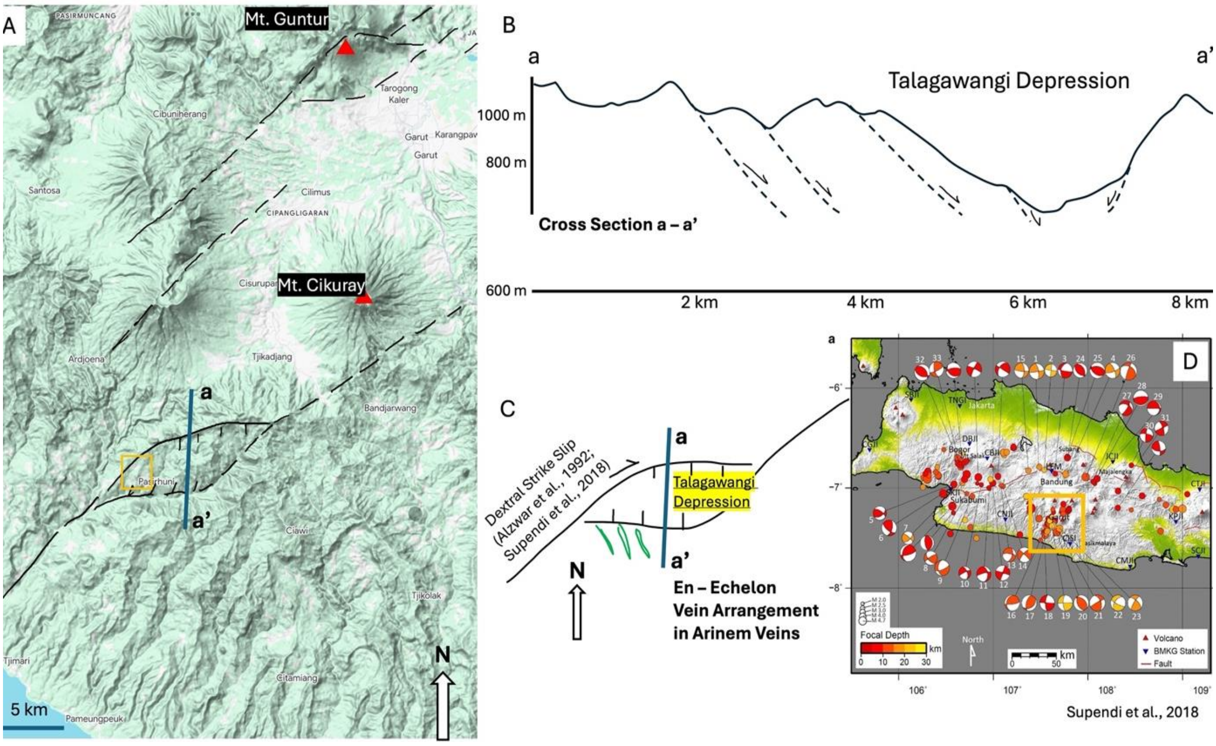

Figure 4. Map on the left (A) depicted the recent right lateral faults correspond to the recent earthquake occurred in southern Java shown in map (D) on the bottom right by Supendi et al. (2018). Topographical cross-section a – a' (B) showing a 6 km wide depression, here named Talagawangi Depression, is interpreted to be caused by the overlap between two dextral strike slips (C). These NE – SW trending right lateral strike slip faults are less likely to create N – S veins system in Arinem. Therefore the Arinem Veins zone is interpreted to formed earlier or alternatively formed limited in the Talagawangi Depression as a result of the relay zone.

CONCLUSIONS

The geological characteristics observed in the Arinem area strongly support its classification as a low-sulfidation epithermal system. The hydrothermal alteration minerals, including chlorite, illite, kaolinite, and calcite, along with moderate temperature indicators, align well with the conditions typical of these systems, demonstrating that mineralization occurred under neutral pH and moderate thermal environments. The textures within the quartz veins, specifically the crustiform and colloform structures, indicate episodic boiling events, which are characteristic of low-sulfidation systems and suggest repeated cycles of fluid pressure increase, likely influenced by tectonic activity along fault-controlled pathways.

The structural analysis of the region reveals that mineralization in the Arinem area is heavily influenced by structural controls, particularly along the N-S trending vein complexes in the Kaolinite-Illite-Smectite Zone, as seen in the alignment of the Arinem Veins. This structural alignment underscores the importance of fault intersections in creating zones of increased permeability, which in turn facilitated the accumulation of hydrothermal fluids and, consequently, mineral deposits. The presence of such faults, including the significant Garsela Fault and potentially oblique relay ramps, highlights the tectonic complexity influencing the area's mineralization.

Further supporting this, regional fault systems like the NE-SW trending Cimandiri and some that are parallel in movement to it as well as the NW-SE trending Citanduy Faults appear to play a role in the broader structural development of the area. Although the recent dextral faulting along the southern coast of Garut does not directly align with the N-S trending vein complexes, it suggests that the mineralization and structural configuration of the Arinem area are products of a larger, possibly intersecting, regional fault network. This structural understanding offers valuable insight into potential high-grade mineralization zones for future exploration.

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