

## Subsurface Geology and Hydrothermal Alteration of The “X” Geothermal Field, West Java: A Progress Report

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**ABSTRACT.** “X” geothermal field is one of the geothermal fields in West Java. PT. Y (Persero) developed it in 2014. The geothermal field has produced electricity, with an installed capacity amounted to 55 MWe. The “X” geothermal system is vapor-dominated. The geothermal manifestations are located at approximately 2,100 m ASL. The “X” field consists of three main upflow zones: Kawah Putih, Kawah Ciwidey, and Kawah Cibuni. This study analyzed the drill cuttings from 3 wells as the primary data with total depths ranging from 1,581 to 2,166 m with the well’s highest stable temperatures measured of  $\pm 230^{\circ}\text{C}$ . The three wells selected for this research—Well A, Well B, and Well C—were analyzed to describe the rock properties and estimate the prospect areas of present-day geothermal exploration in the “X” geothermal field.

The paper aims to understand better the subsurface geology and its correlation to the dynamic processes (i.e., hydrothermal alteration) in the “X” geothermal field. The hydrothermal minerals are formed by near-neutral pH fluids and are characterized by quartz, calcite, clays (smectite, illite, chlorite), wairakite, epidote, and actinolite. Acidic fluids are evident by forming acidic hydrothermal minerals, e.g., anhydrite, at various depths of the studied wells, particularly at Well C, located around the Sugihmukti-Urug area. Moreover, the previous studies by Reyes (1990), Layman and Soemarinda (2003), Rachmawati *et al.* (2016), Elfina (2017) on hydrothermal minerals, geothermal manifestation characteristics, fluid geochemistry, and conceptual model are adapted to improve the analysis and interpretation of this paper.

**Keywords:** Geology · Subsurface · Hydrothermal alteration · “X” geothermal field.

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### 1 INTRODUCTION

The “X” Geothermal Field, a vapor-dominated field (Layman *et al.*, 2003; Hochstein and Sudarman, 2008), is located at ~50 km southwest of Bandung and ~20 km west of Gunung Wayang Windu geothermal field (Figure 1). It is located at an elevation of ~2,000 m ASL. The “X” geothermal work area currently has 31 drilling wells, which includes 17 slim wells. The installed capacity is measured at 55 MWe and PT. Y (Persero) manages the operation since 2014.

The three wells are worth being studied due to their being frequently used as the main production wells. Thus, this study will enrich the information for future exploration in this area.

Despite the potentials mentioned above, Elfina (2017) reports that the “X” field has problems with declining production from 2014 to 2017, including the problem with drilling and production facilities. Such problems are predicted due to the existence of swelling clay in the subsurface. The problems are related to the natural characteristics of the geothermal system. This paper aims to analyze the interaction between hydrothermal fluid and surrounding rocks, which is predicted to elucidate the

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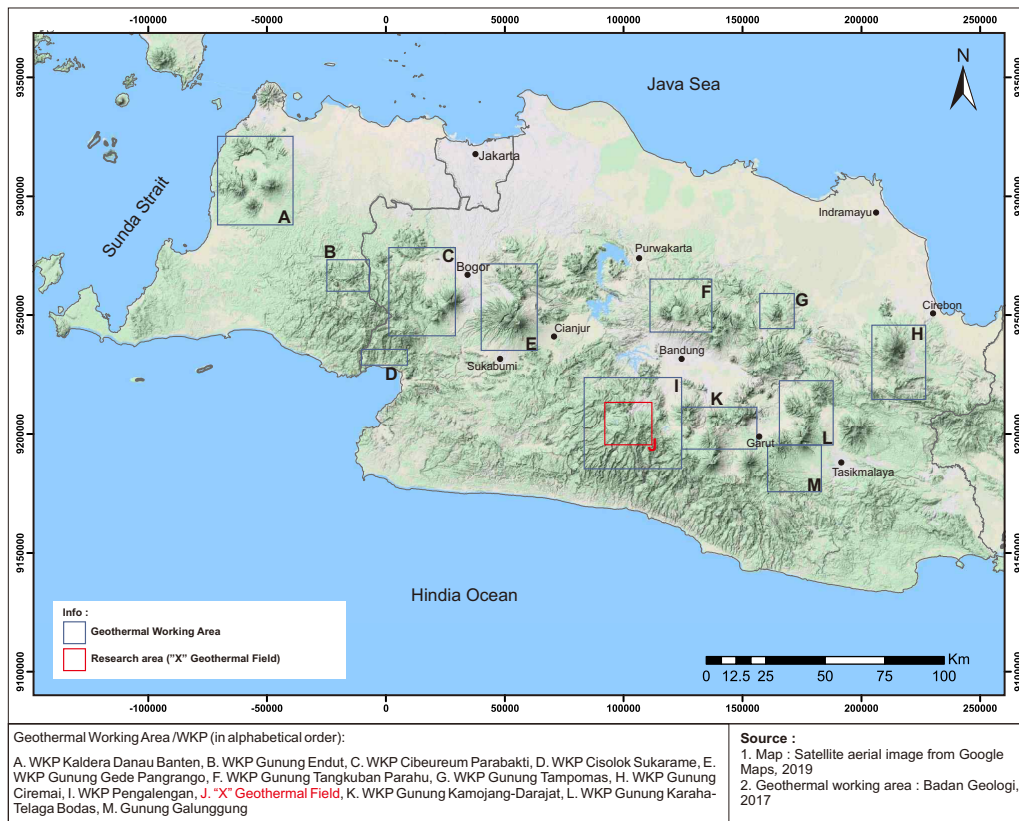


FIGURE 1. Location of the "X" Geothermal Field (red square) with other geothermal working areas in West Java.

cause of the drilling problems. The analysis is based on examining cuttings obtained from three wells, e.g., Well A, Well B, and Well C (1,500 to 2,200 m depth). The cuttings from these wells were examined using petrography and X-ray diffractometry (XRD) methods to identify the alteration minerals. These data are then used to understand subsurface geology and hydrothermal minerals.

## 2 GEOLOGY

The "X" Geothermal Field is located within the Bandung Zone, bounded by the Bogor Anticlinorium Zone in the north and West Java's Southern Mountain Range Zone in the south. The main feature of this geothermal field is Mt. Patuha, with the peak reaching an elevation of 2,429 m ASL. This mountain is part of the NW-SE Quaternary volcanic chain, located on the verge of Bandung Zone and West Java's Southern Mountain Range Zone (van Bemmelen, 1970). The ongoing tectonism of Java Island is characterized by the subduction of the Indian-Australian plates below Eurasian Conti-

ental plates, initiated from the Late Cretaceous until Early Tertiary (Hamilton, 1979).

The compressional forces of this period affected the structural geology configuration in Java. It then represented in the structural configuration as series of structural lineament and volcanic arc in the NE-SW orientation, named Meratus trend lineament. The major fault following the Meratus trend lineament in the West Java area is the Cimandiri fault (Purnomo & Pichler, 2014). Along with other lineament orientation formed by tectonic evolution since Late Cretaceous to Quaternary, such as N-S Sunda lineament and E-W Java lineament, Meratus lineament formed the main structural configuration of Java, especially West Java (Pulunggono and Martodjojo, 1994 and Satyana, 2007 in Fauzi *et al.*, 2015).

Volcanoes in the "X" geothermal field are mostly monogenetic volcanoes scattered along the NW-SE trend line. Previous studies (Anderson, 1951; Cas and Wright, 2012; Watanabe *et al.*, 1999; Marliyani *et al.*, 2020) reported how the stress orientation is perpendicular to

the lineament of monogenetic volcanoes. The magma upwelling through vertical fractures to the ground is an indication of a monogenetic volcano forming process.

The "X" field is composed of lava domes and volcanic calderas. According to radiometric dating by Fauzi *et al.* (1994) in Layman and Soemarinda (2003), the geological age of rocks in the "X" field are ranging from 0.12–1.25 million years. There are several quaternary monogenetic volcanoes in the "X" geothermal area such as Urug, Sumbul, Puncaklawang, Puncakopsi, Patuha Utara, Patuha Selatan, Tilu, Masigit, Tambakruyung, and Tikukur. Numerous volcanic centers or vents are differentiated by the degree of dissection based on remote sensing analysis of aerial photographs. The degree of dissection by erosion might correlate to the age of volcanic processes.

The oldest volcano in the "X" field is Kendeng in the north-northwest. It was active during the Early Pleistocene. Later, the other younger volcanoes, like Patuha Tua in the center part of the field and Masigit, Tilu, and Tikukur in the north part, were active. The last phase of volcanic activity is marked by Sugihmukti, Urug, and Patuha Muda from the central part to the southeast part of the field. The volcanic centers, along with NW–SE trending, are associated with geothermal manifestations. The primary geothermal manifestation is fumarolic steam discharges, such as Kawah Putih, Kawah Ciwidey, and Kawah Cibuni. The geological map showing the distribution of lithological units and volcanoes within the "X" geothermal field and the location of manifestations and geological structures is presented in [Figure 2](#).

### 3 THERMAL MANIFESTATION

Thermal manifestations on the ground can be found at ~2,100 m ASL. Thermal manifestations are associated with the NW–SE trending volcanic centers and are perpendicular with regional horizontal principal stress. The fumaroles and solfataras dominated them with a significant amount of sulfur deposit, hot and warm thermal springs with near-neutral and acidic fluid, gas vent, mud pools, mud pots, steaming grounds, and altered grounds. The surface alteration minerals include smectite, il-

lite, chlorite, kaolinite, halloysite, and a sparse amount of cristobalite (Pusat Penelitian Panas Bumi FT UGM, 2020, unpublished). Near-neutral pH fluid can be found in numerous hot and warm thermal springs, such as Rancaupas, Cimanggu, Cibunggaok, and Punceling in the northern and center part of the field. Acidic fluid is mainly found in primary fumaroles and crater lakes in Kawah Putih, Kawah Cibuni, and Kawah Ciwidey.

### 4 MATERIALS AND METHODS

Sixty wellbore cutting samples were collected from three wells, selected from the total of 31 wells drilled in the "X" geothermal field. The depth of selected wells ranges from 1,500–2,200 meters. First, the samples were inspected immediately using a binocular microscope to identify any alteration products. The samples were then processed and examined using petrographic and x-ray diffraction analysis. The petrographic analysis was performed to determine the lithological composition of the cutting samples in detail, including the primary and secondary mineral assemblage, the texture, and the style of alteration. The x-ray diffraction is used to analyze the mineralogy composition. The analysis was interpreted from the stable well temperature data to build the present-day thermal data model.

### 5 RESULTS AND DISCUSSION

This study is combined its data from the surface and the subsurface geological data from previous studies, i.e., Reyes (1990), Layman and Soemarinda (2003), Rachmawati *et al.* (2016), and Elfina (2017), to develop a better understanding of the geology of the "X" field. Layman and Soemarinda (2003) suggest that the main volcanic centers in the "X" field are Kawah Putih, Kawah Ciwidey, and Kawah Cibuni. The main upflow zone is located on Kawah Putih. Three wells, i.e., Well A, Well B, and Well C, have been chosen to be studied to understand better the geological condition of the interest area, the dynamic of the hydrothermal processes, and the exploration and production's main problems.

#### 5.1 Stratigraphy

The detailed surface geology of the "X" field consists of 25 units of volcanic products. Be-

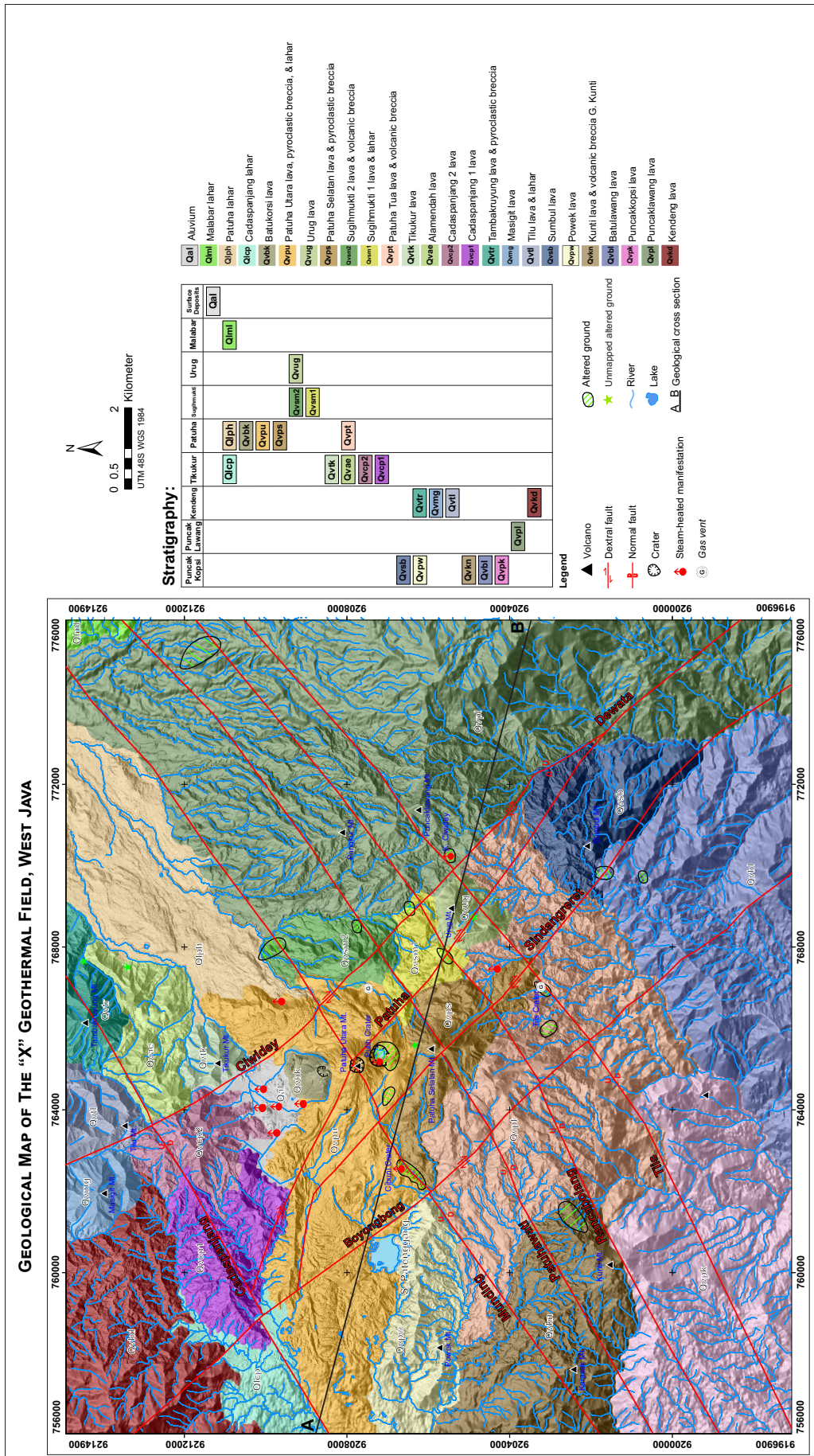


FIGURE 2. Geological map of the "X" geothermal field in West Java, showing the volcanoes, the location of manifestations, the direction of cross-section, and the geological structure interpretation (modified from Lidar and IFSAR-DEM of "X" geothermal field; volcanoes from Koesmono *et al.*, 1996; manifestations from Pradipta *et al.*, 2016).

sides the primary data, the interpretation of this research is influenced by previous studies from Kusdji (2013) and unpublished research by Pusat Penelitian Panas Bumi FT UGM (2020). The previous studies divided the stratigraphic division of the subsurface rocks into Quarternary volcanic products of Puncakkopsi, Puncaklawang, Kendeng, Tikukur, Patuha, Sugihmukti, Urug, and Malabar. The subsurface stratigraphic correlation was interpreted based on the characteristics and spatial association of the rocks with the volcanic products.

Based on the examination results of the primary data and previous studies, the subsurface stratigraphy of the "X" field, in general, was composed of Quarternary andesitic - dacitic lava, pyroclastic rocks, and diorite. Based on the petrographic analysis, the subsurface rocks are categorized into three groups: andesitic lava, dacitic lava, pyroxene andesitic lava, and diorite. The andesitic lava consists of plagioclase and pyroxene in a groundmass of microcrystalline plagioclase and glass. These rock units are considered to be part of the Puncaklawang products. The Puncaklawang products are interpreted as the lowermost volcanic sequence found in the wells, also found at the bottom of Well D and Well E, located at the southeastern part of the research area.

The Quarternary dacitic lava with pyroclastic rocks found from three wells is considered part of Patuha Tua and Urug products. The Patuha Tua products are the most widespread volcanic sequence found in the wells. The products can be found at the center and the southern part of the research area. The dacitic lava consists of plagioclase, quartz, and pyroxene as phenocrysts. The phenocrysts are embedded in a groundmass of microcrystalline crystals of similar mineralogy and minor volcanic glass. The dacitic lava is found in large thickness in Well A, Well B, Well C. The dacitic lava thins out to the southeast, as observed in Well D and Well E. The pyroxene andesitic lava consists of plagioclase, pyroxene, hornblende, and sparse amounts of biotite in a groundmass of microcrystalline plagioclase, pyroxene, and clay minerals. The pyroxene andesitic lava is considered to be part of Sugihmukti 1 product. This pyroxene andesitic lava can be found mainly in Well B and Well C in the shallow or upperparts.

Meanwhile, the diorite was identified in wells Well C and Well F, at about 1,000 depth. Based on petrography analysis, diorite consists of primary minerals, e.g., plagioclase, quartz, and sparse amounts of pyroxene and hornblende, embedded in microcrystalline crystals of similar mineralogy. [Figure 3](#) and [4](#) show a cross-section that shows the distribution of lithological units and isotherms of present-day well stable temperatures.

## 5.2 Geological structures

The evidence of the geological structures on the surface was difficult to recognize because of the high intensity of hydrothermal alteration and diagenesis of the lithology. Most of the region has been converted into tea plantations and has reduced the amount of rock exposure in the area. This research relied on its geological structure understanding from previous studies, in addition to the limited remotely- and field-based mapping with the IFSAR-DEM as the base map.

Our mapping indicated the occurrence of NE-SW and NW-SE trending faults (presented in [Figure 2](#)). These faults were recognized through outcrop observation and were supported by the alignment of volcanic centers and the distribution of the geothermal manifestation zones related to the regional structures.

Many active geothermal manifestation zones are associated with volcanic centers, i.e., Kawah Putih (associated with Patuha Utara), Sugihmukti (associated with Urug), Patengan, and Kawah Ciwidey. The NE-SW and the NW-SE trending faults were connected to the subsurface, as indicated by some losses of circulation in drilling wells. Some losses of circulation in drilling wells were found at 1150 m ASL, and 1115 m ASL in Well A, 1055 m ASL and 750 m ASL in Well B, and 1135 m ASL in Well C. These faults were further interpreted as permeability providers in the "X" geothermal system, proven by present thermal activity in geothermal manifestation areas. On the other hand, the volcanic structures interpreted as crater rims are associated with Mt. Patuha Utara and Kawah Putih (presented in [Figure 2](#)).

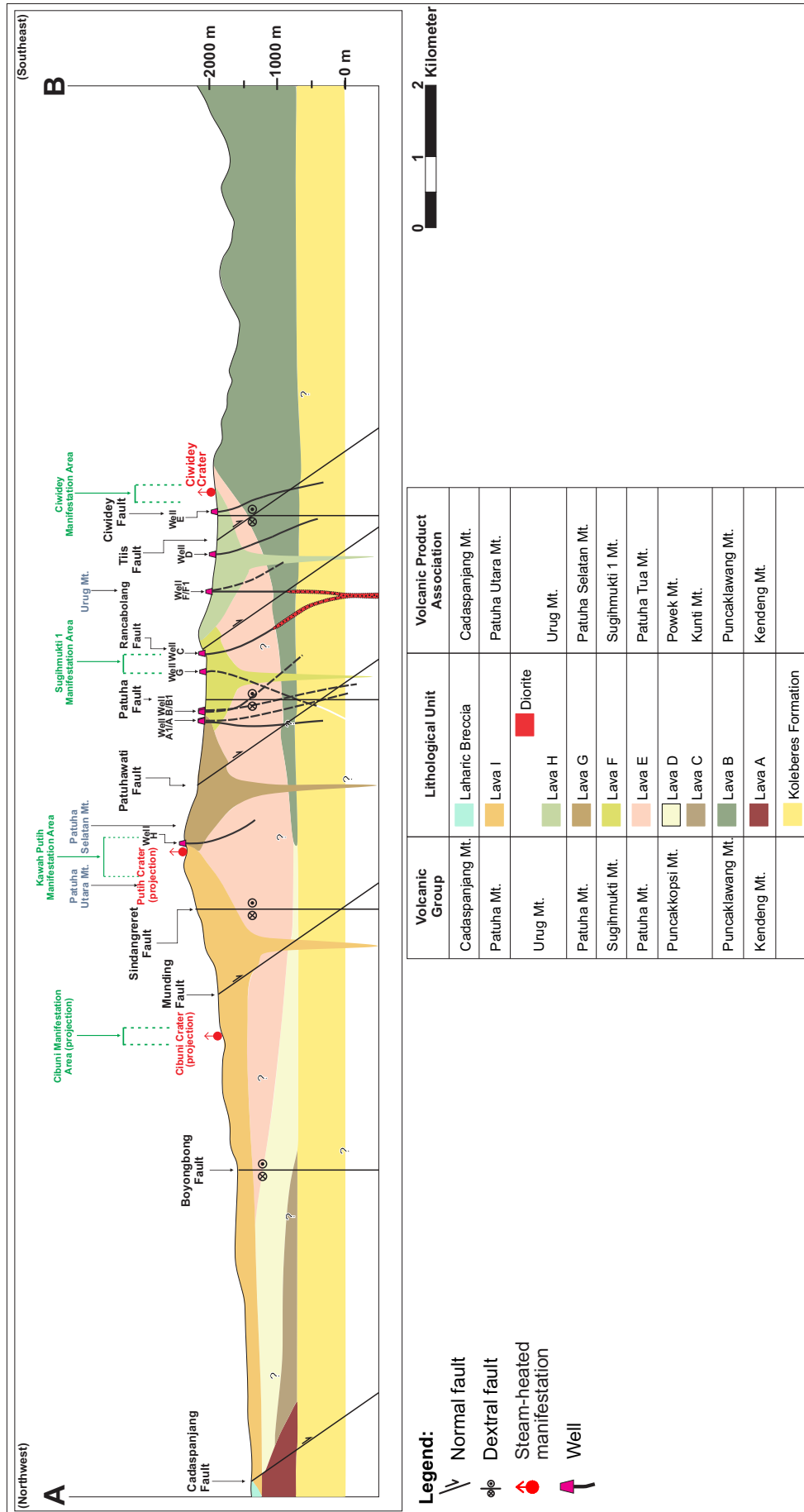


FIGURE 3. Cross-section showing the distribution of lithologic units in "X" geothermal field.

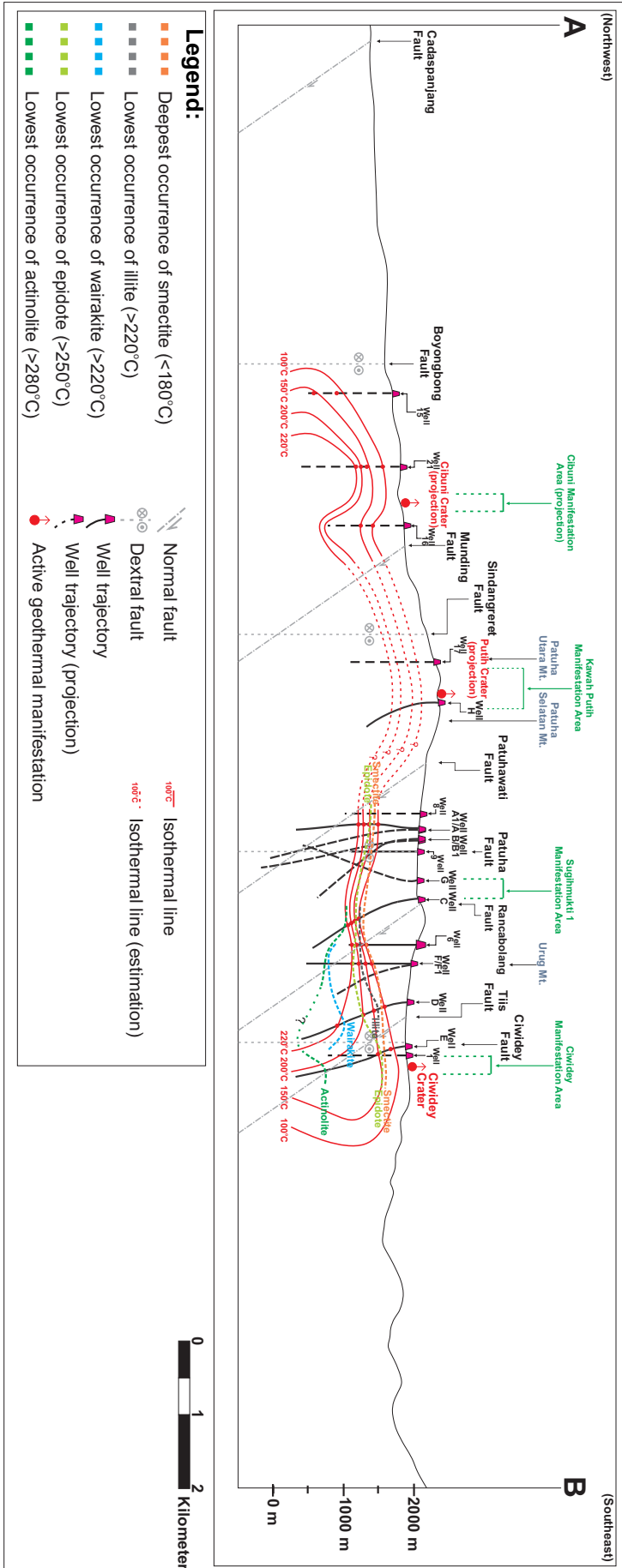


FIGURE 4. Cross-sections show the shallowest occurrence of some important hydrothermal minerals and the isotherms of present-day temperatures (°C).

### 5.3 Subsurface hydrothermal alteration

There are three alteration styles in the subsurface rocks in the "X" field, namely direct deposition, replacement, and leaching. Replacement and leaching indicate interactions between host rock and hydrothermal fluid. Leaching implicates the displacement of primary minerals without substituting them. Leaching is identified in Well A, Well B, dan Well C at varying depth, at about 1600 m ASL, 1500 m ASL., 750 m ASL, and 500 m ASL (presented in Figure 5). Replacement implicates mass exchange between primary minerals and hydrothermal fluid. Hydrothermal minerals in the vein or veinlets were deposited from the fluid that flows through open spaces, i.e., fractures and cavities. Subsurface rocks have been altered with alteration intensity from 0,1 to 1. Pyroclastic rocks are more altered than lavas and diorites.

The dynamics of thermal conditions in the system are reflected in the distribution of hydrothermal minerals. The past thermal structure of the "X" geothermal system is concluded from geothermometer minerals in the field. The hydrothermal minerals found in studied wells include carbonate (calcite), silica (quartz), calc-silicate (epidote, actinolite, prehnite), clays (smectite, illite, chlorite), and zeolite (wairakite). These minerals were formed from near-neutral pH fluid. Nevertheless, the appearance of anhydrite at the varying depth indicated the presence of acidic fluids. The distribution of hydrothermal minerals and their relative depth is presented in Table 1.

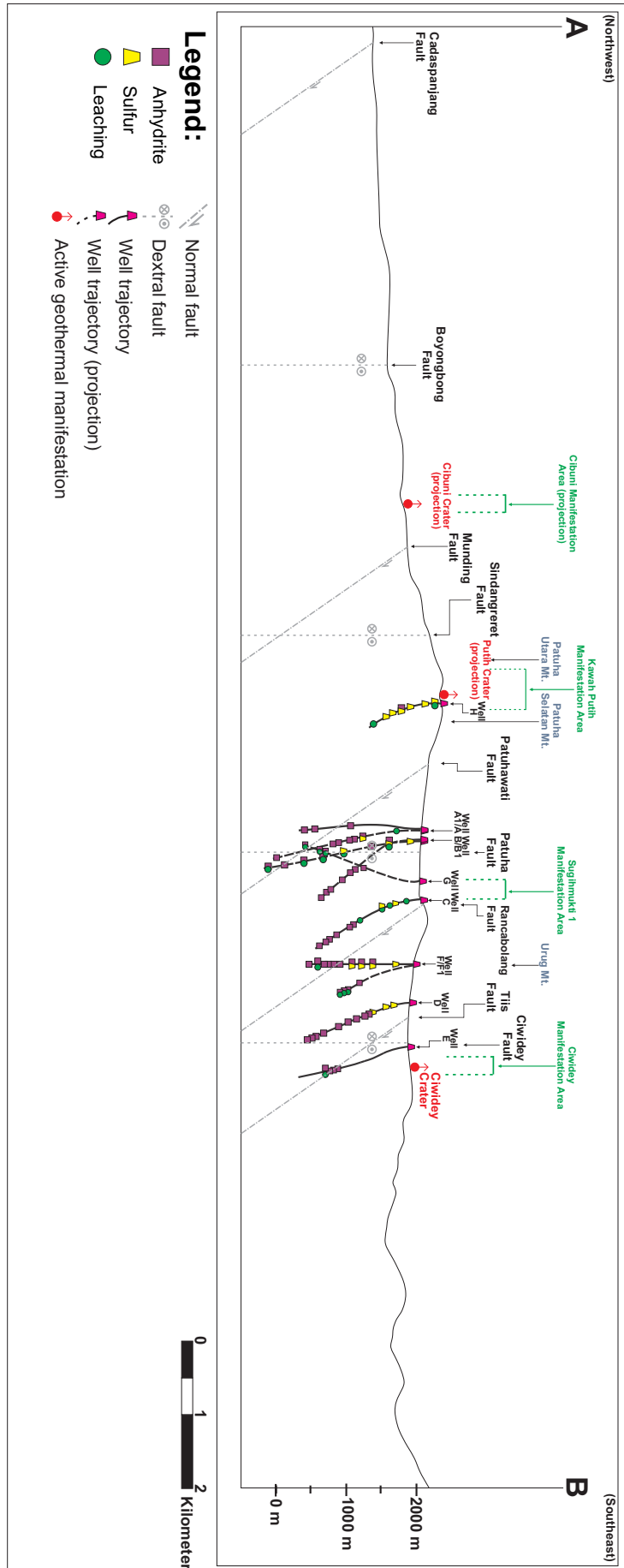
The geothermometer minerals found were illite, wairakite, epidote, and actinolite. The occurrence of epidote is the shallowest in Well C, i.e., 1315 m ASL, and deeper in other wells. In Well A and Well B, located in the Sugihmukti area, epidote occurs about 1200 m ASL. The formation of epidote indicates that the temperature is  $\geq 250^{\circ}\text{C}$  (Reyes, 1990). The stable downhole temperature at this depth is less than  $200^{\circ}\text{C}$ . It shows that the systems seem to experience cooling. Actinolite was found at about 810 m ASL in Well A and found at 1085 m ASL in Well C. The formation of actinolite indicates that the temperature is  $\geq 280^{\circ}\text{C}$  (Reyes, 1990).

TABLE 1. The relative distribution of subsurface hydrothermal minerals with depth.

Relative depths	Mineralogy	Well A		Well B		Well C	
		R	S	R	S	R	S
Shallow	Calcite	v	v	v	v	v	v
	Quartz		v		v		v
	Adularia				v		
	Pyrite	D		D			
	Smectite	v		v		v	
	Kaolinite	v		v			
	Chlorite	v	v	v		v	v
	Hematite	v		v		v	
	Anhydrite			v			
Intermediate	Calcite	v	v	v	v	v	v
	Quartz	v	v	v	v	v	v
	Chlorite	v	v	v	v	v	
	Epidote	v	v	v	v	v	
	Actinolite	v					
	Adularia		v		v		
	Anhydrite	v	v	v		v	
	Pyrite	D		D		D	
	Hematite	v		v			
	Smectite			v		v	
	Kaolinite	v					
Halloysite	v						
Illite	v		v		v		
Deep	Calcite	v	v	v	v	v	v
	Quartz	v	v	v	v	v	v
	Chlorite	v		v		v	
	Epidote	v	v	v	v	v	v
	Actinolite	v		v		v	
	Wairakite	v	v			v	
	Prehnite	v		v	v		
	Anhydrite	v		v	v	v	
	Adularia		v		v		v
	Pyrite	D		D		D	
	Hematite	v	v	v		v	
	Cristobalite	v	v				
Natrolite	v						
Zoisite				v			

\*R = Replacement, S = Space-fill, D = Dispersed





The occurrence of actinolite in Well C is associated with the existence of a diorite intrusion.

Meanwhile, anhydrite and leached rocks found in the studied wells at varying depths indicate that the acidic fluids were circulating dynamically within the system. The cross-section that shows some hydrothermal minerals as geothermometers and the occurrence of anhydrite, sulphur, and leached rocks in the studied wells are presented in [Figure 4](#) and [5](#).

## 6 CONCLUSION

The subsurface stratigraphy of the "X" geothermal field comprises andesitic – dacitic lava and pyroclastic rocks. At some point, diorite intrusion occurred beneath Mt. Sugihmukti and Mt. Urug, around Well C and Well F well area. The existence of hydrothermal minerals indicates that hydrothermal fluid was near-neutral pH, but there has been some acidic fluid circulating in the system in some parts of the system. This acidic fluid formed anhydrite and native sulphur and caused leaching processes in the system, especially in studied wells.

The present-day stable temperatures (as represented by isothermal lines in [Figure 4](#)) indicate that the main thermal areas in the "X" geothermal system are located in Kawah Putih, Kawah Ciwidey, and Kawah Cibuni. Sugihmukti-1 manifestation area is associated with Sugihmukti and Urug Mt and is recognized as a minor thermal area. Hydrothermal minerals, which are considered geothermometer, reveal that the "X" geothermal system experiences cooling, based on the comparison of present-day stable well temperature and the occurrence of geothermometer minerals.

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