Overview of Microseismic in Sustainable Monitoring of Geothermal Reservoirs in Indonesia*

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Abstract

Indonesia has a large geothermal energy potential, spread across the islands of Sumatra, Java, West Nusa Tenggara, Sulawesi, and especially in North Sulawesi (Figure 1). Indonesia has the greatest potential in the world with about 28.5 GWe (Geological Agency, 2009), equivalent to 40% of world reserves. This potential is equivalent to 12 billion barrels of oil over 30 years of operation. From all this potential, only 1,194 MW are utilized to date.

Geothermal exploration has been developed in many regions of Indonesia by using geophysical exploration methods such as Geomagnetics, Resistivity or Magnetotelurics (MT). Geophysical methods are also utilized in the exploitation phase in order to control and monitor activity of geothermal reserves and production. One of these methods for continuous monitoring is Microseismic. Monitoring helps with numerous aspects, such as in determining direction of fractures in the reservoir, and determining conditions of the reservoir which is the source point for injection fluid.

Microseismic serves to record seismic events caused by small earthquakes occurring below the surface of the Earth. Microseismic is studied by installing a network of receivers (geophones) using a specific pattern to catch maximal events. The source of the waves is the extraction fluid resulting from exploitation of the geothermal resource, generating cracks in the Enhanced Geothermal System which occurs during injection and production. But the number of events and small magnitudes are typically used as a source from injection wells to increase the number of events recorded by the receiver. Injection into wells is expected to promote hydraulic fracturing or thermal shock events that become microseismic events.

Microseismic is used for monitoring changes in the character of the reservoir (the direction of fluid flow, density and direction of fracturing) that emerge from instability (changes in temperature, pressure causing fracturing), measuring seismic events caused by production and fluid injection. Microseismic monitoring is expected to aid Indonesian geothermal industries in increasing geothermal production in Indonesia.

Introduction

Background

Indonesia is at the junction of three tectonic plates, the Eurasian Plate, Pacific Plate, and Indo-Australia Plate and is part of the ring of fire of volcanoes. The volcanoes provide the geothermal source of energy, derived from heat from the Earth's interior. This heat can be held in hot water or steam, or in the rocks themselves and represents a potentially vast energy resource, estimated by Armstead and Tester (1987) to be more than 300 times the energy held in fossil fuels.

Geothermal systems in Indonesia are composed of volcanic rocks. The main components of a geothermal system (Dwikorianto, 2006) are the (1) heat source, (2) permeable rock, (3) cap rock, and (4) fluid circulation (Figure 2). The heat source is from the magma chamber, permeable rocks are the reservoir, impermeable cap rock is tuff modified to clay minerals, and high pressures and temperatures promote fluid circulation through heated rock which forms steam. Most geothermal systems in Indonesia are hydrothermal systems with high temperatures.

Microseismic method is one of the tools in exploration using passive seismic sources from the subsurface (micro Earthquakes). Microseismic can detect natural small waves in the Earth and can be used to monitor the migration pattern of injection fluids and determine reservoir boundaries. This article describes the characteristics of microseismic induced by small Earthquakes, fluid injection and steam extraction, and their application in defining the permeability sources (fractures and faults) and migration patterns of the injection fluid. Microseismic data for the monitoring of geothermal fields has not been systematically applied yet. An example of microseismic source located in the subsurface is represented by micro Earthquakes triggered by small faults or local tectonics or fluid injection during reservoir production or fracturing. One application of microseismic is monitoring of fluid injection in brittle reservoirs when microseismic evolution in time correlates with fluid movement in reservoirs.

Location

The Wayang Windu area is located 40 km south of Bandung in West Java, Indonesia (Figure 3). Wayang Windu is part of a complex mountain quarter characterized by several phases in the volcanic eruption of Mount Wayang, Mount Windu, Mount Bedil and Mount Malabar. Generally, the volcanic rocks in the center of eruption consist of lava and pyroclastics. Wayang Windu has a shallow permeable zone and consists of fumaroles, hot springs and hydrothermal alteration bicarbonate on surface rock (Bagie et al., 2008)

Regional Stratigraphy

Subsurface rock in the Wayang Windu area is a product of andesite strato-volcanic activity. These include andesite lava flows, breccia flows, and various types of pyroclastic rocks from massive lapilli, breccia tuff and crystal tuff (Bagie et al., 2008)

Stratigraphy of the Wayang Windu area is discussed by Bogie and Mackenzie (1998) and based on models of volcanics (Figure 4).They have divided various volcanic units based on similarities of facies. Volcanic facies are distributed in the Wayang Windu, Malabar, Pangalengan, Waringin and Loka formations.

Tectonics Setting

Typical structural patterns have indicated visible faults around the Wayang Windu dome and the structure longways to the southern slope of Malabar (Figure 5). Alluvial and human activities may have covered the structural features in the valley which is relatively flat on both sides of the dome. The southeast structures are the most important drill targets in the area, such as Karaha Bodas Kamojang and Darajat, where entry has been correlated with permeable fractures from surface imaging and structural lineaments (Huntoro et al., 1996; Pramod, 2001; Nemcok et al., 2001b).

Methodology

Microseismic Source Point

Microseismic events can be produced from small Earthquakes from volcanic activity, faults or local tectonics, and can indicate the migration path of steam in a geothermal system. Microseismic stations are spread around the Wayang Windu area. In the development phase of geothermal production, microseismic is paired near the wellbore with time events expanded laterally and moved deeper, eventually extending to depths of more than 5 km below sea level for the source injection fluid (Figure 6). Microseismic can produce deeper resolution that is correlated with these wells. Microseismic can be used to monitor the migration of fluids during reservoir production, hydro fracturing operations in brittle formations, or in studies of naturally occurring Earthquakes in fault zones.

This study uses some stations as microseismic observation points. We have installed six permanent stations and eight temporary stations to record microseismic waves (Maryanto, 2008). At the development phase, the installation of stations around the injection and production wells obtains micro-earthquake events from injection.

Microseismic Data Acquisition

Fractures formed due to Earthquakes, faults, local tectonics or fluid injection from wells will be detected by the geophones. The data is obtained in the form of the wave velocity. The wave is divided into two waves, pressure wave (P-wave) and shear wave (S-wave) (Figure 7). P-waves are faster than S-waves (Giancolli, 2001) and P-waves can propagate through solid and liquid mediums and form longitudinal waves.

While the S-waves are slower and propagate only in solids and are generally transverse. Wave data is then processed (Hypoinvers, etc.) then the data is interpreted.

Microseismic Interpretation and Ouput Data

Acquisition of data is converted into events. The events are either due to a small Earthquakes in the area or hydraulic pressure of fluid injection (Figure 8). 3D data analysis helps determine the direction of the events and the dominant fractures, and then in placing new injection wells for more efficient production.

Results

Microseismic Play

The Geology Agency has monitoring stations at volcanos Papandayan, Galunggung, Tangkuban Perahu, Ciremai, Salak and Gede in West Java. The microseismic stations improve coverage of the microseismic network in the Wayang Windu area. Some local tectonic Earthquakes were felt in the Wayang Windu area using microseismic stations (Figure 10). Maryanto et al. (2010) recognized 189 events as local tectonic earthquakes and selected 101 earthquakes with well-defined P- and S-waves recorded by permanent stations at Guntur, Papandayan, Galunggung, and a temporary station.

Hypocenters of local Earthquakes were determined by using arrival times of P-waves and S-waves at more than three stations. The velocity structure used the hypocenter calculation adopted by Kartodinomo (1996) in West Java and determined three layers of velocity: top layer at 4.3 km/s, middle layer at 6.1 km/s, and bottom layer at 7.0 km/s, with respective thicknesses of 4 km, 12 km and 17 km from S-waves; Vp/Vs= 1.73. With that data we can determine features of faults and tectonics. Events of hypocenters can determine the potential of geothermal in the Wayang Windu area, and migration pathways with manifestation at the surface.

Direction of Fractures and New Well Production Imaging

Hypocenter data from microseismic stations can help interpret fractures and faults of the geothermal system. Microseismic surveys in the development phase conducted at the injection wells will produce data on the fracture geometry. Once the fracture geometry and directional spread through the reservoir is determined, we can add new production wells near the fractures to expand the geothermal production field (Figure 11).

Conclusion

Microseismic exploration in the Wayang Windu area can determine features of faults and fractures using hypocenter data from microseismic stations Papandayan, Galunggung, Tangkuban Perahu, Ciremai, Salak and Gede in West Java. Microseismic field monitoring data can help determine the spread of faults and fractures and the direction of fluid injection, which can then be used to enhance production during the development phase. We hope all production wells in Indonesia will be developed using this method.

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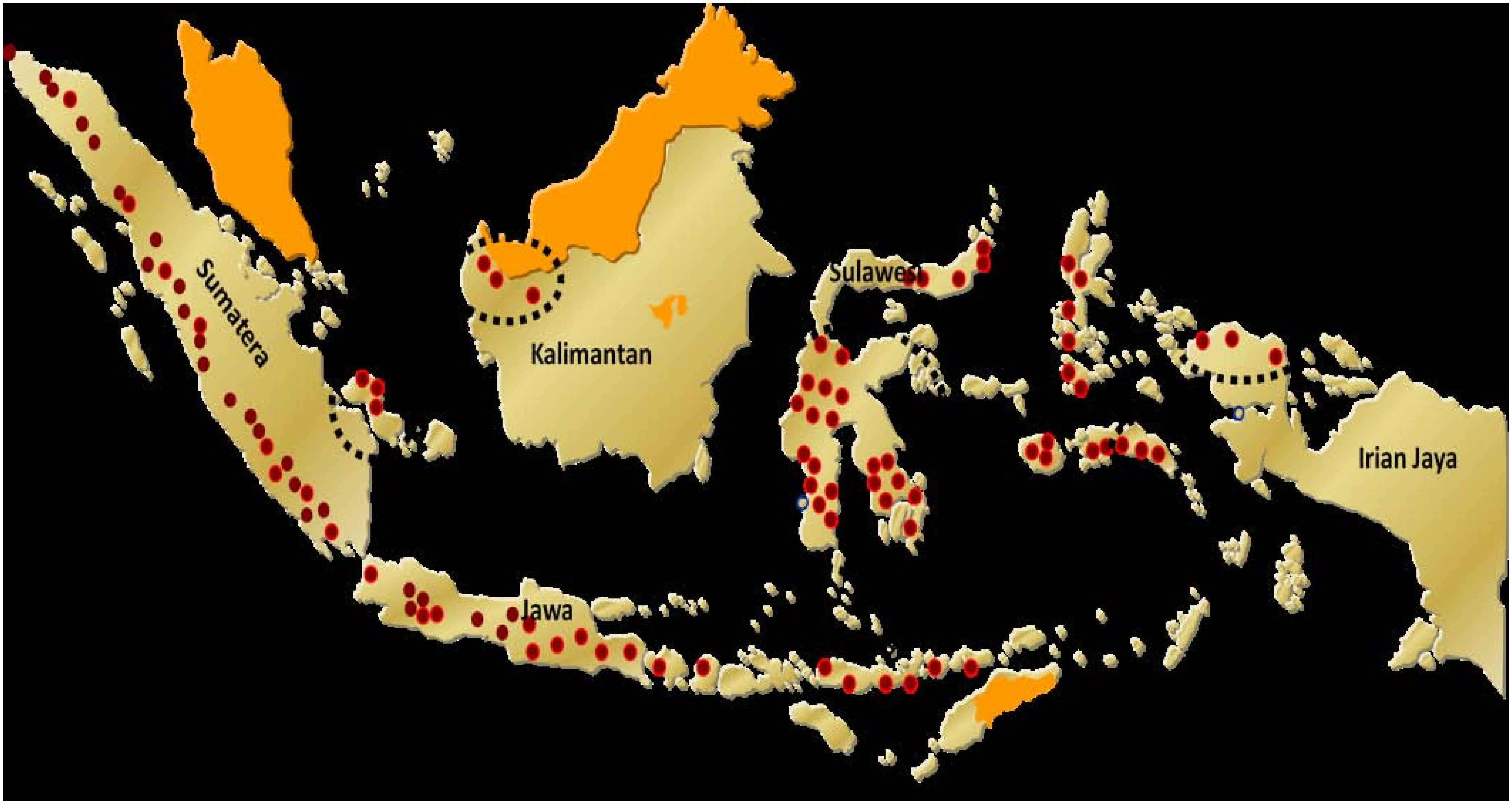

Figure 1. Geothermal potential in Indonesia (Geology Agency, 2012).

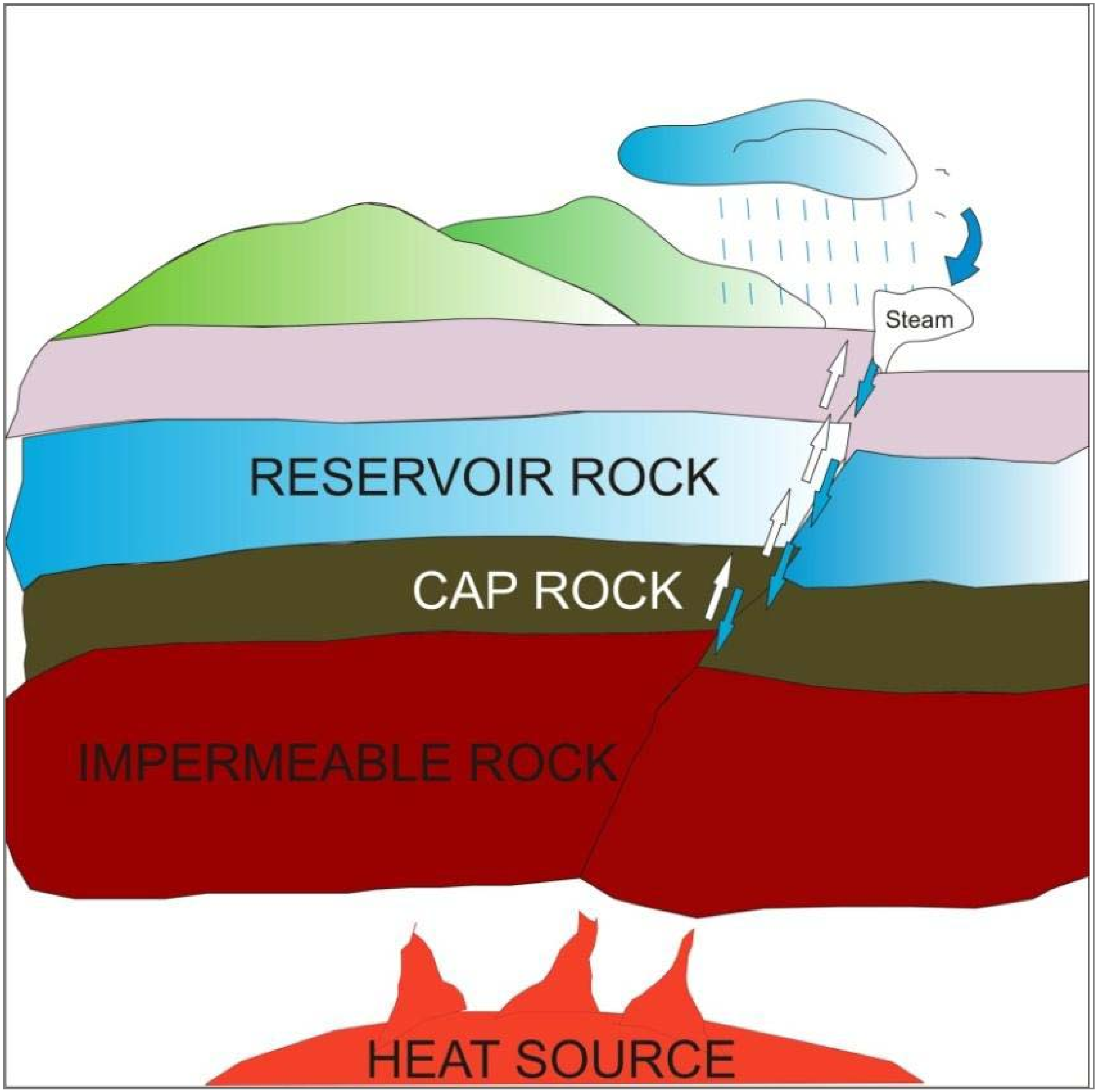

Figure 2. Model of a geothermal system in Indonesia.

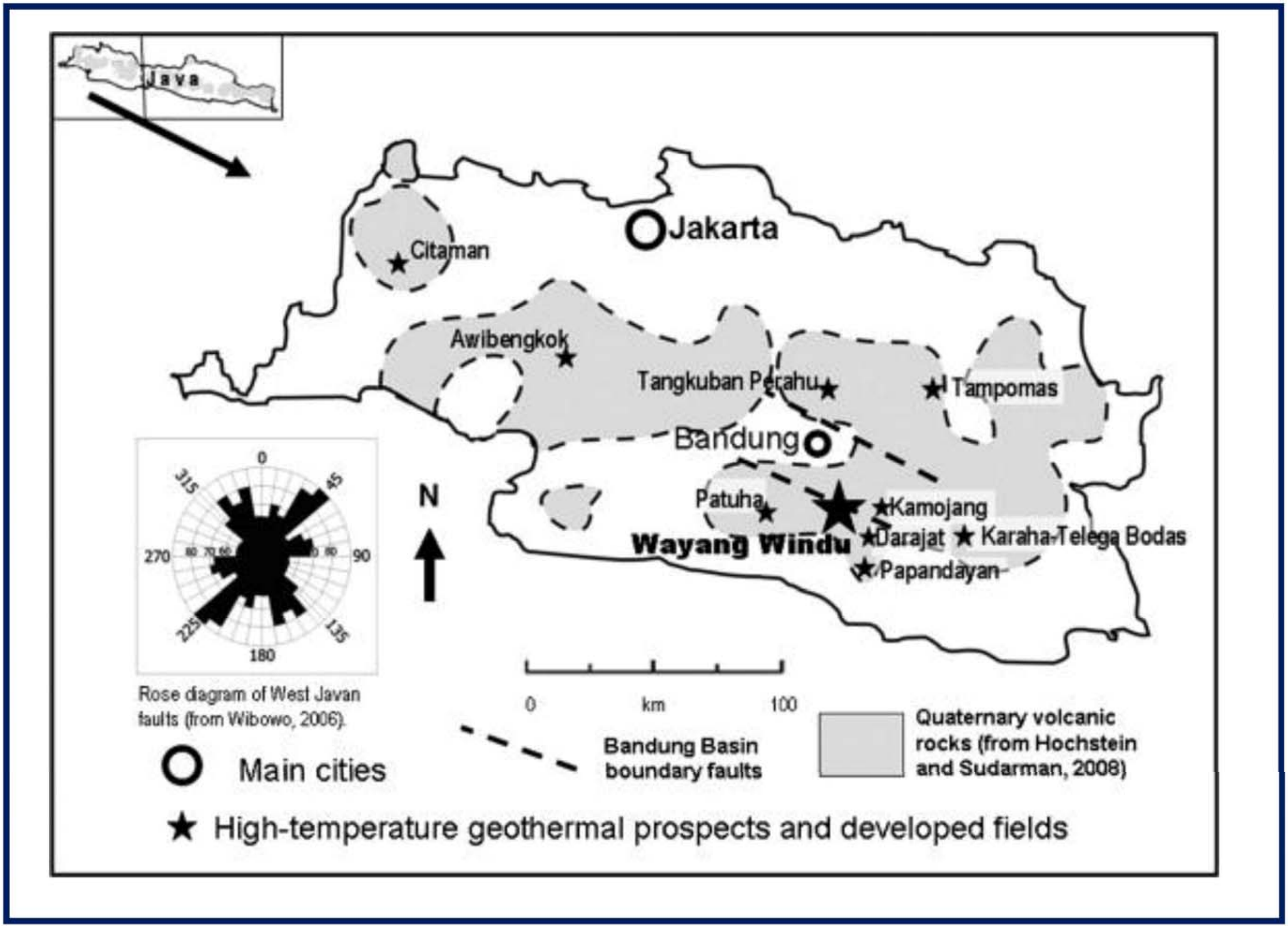

Figure 3. Location of the Wayang Windu area (Bogie et al., 2008).

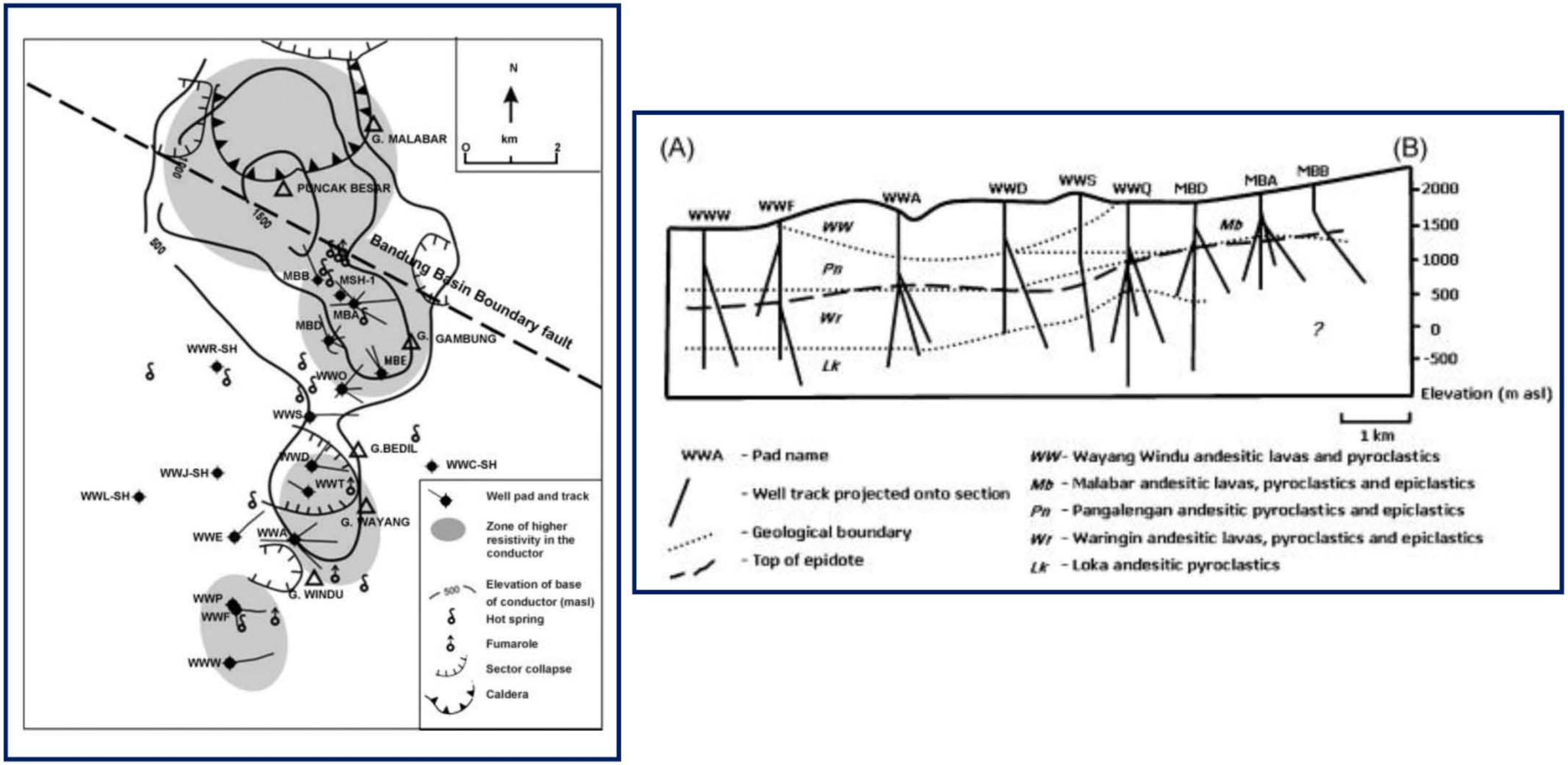

Figure 4. Map and cross section of the Wayang Windu area (Bogie et al., 2008).

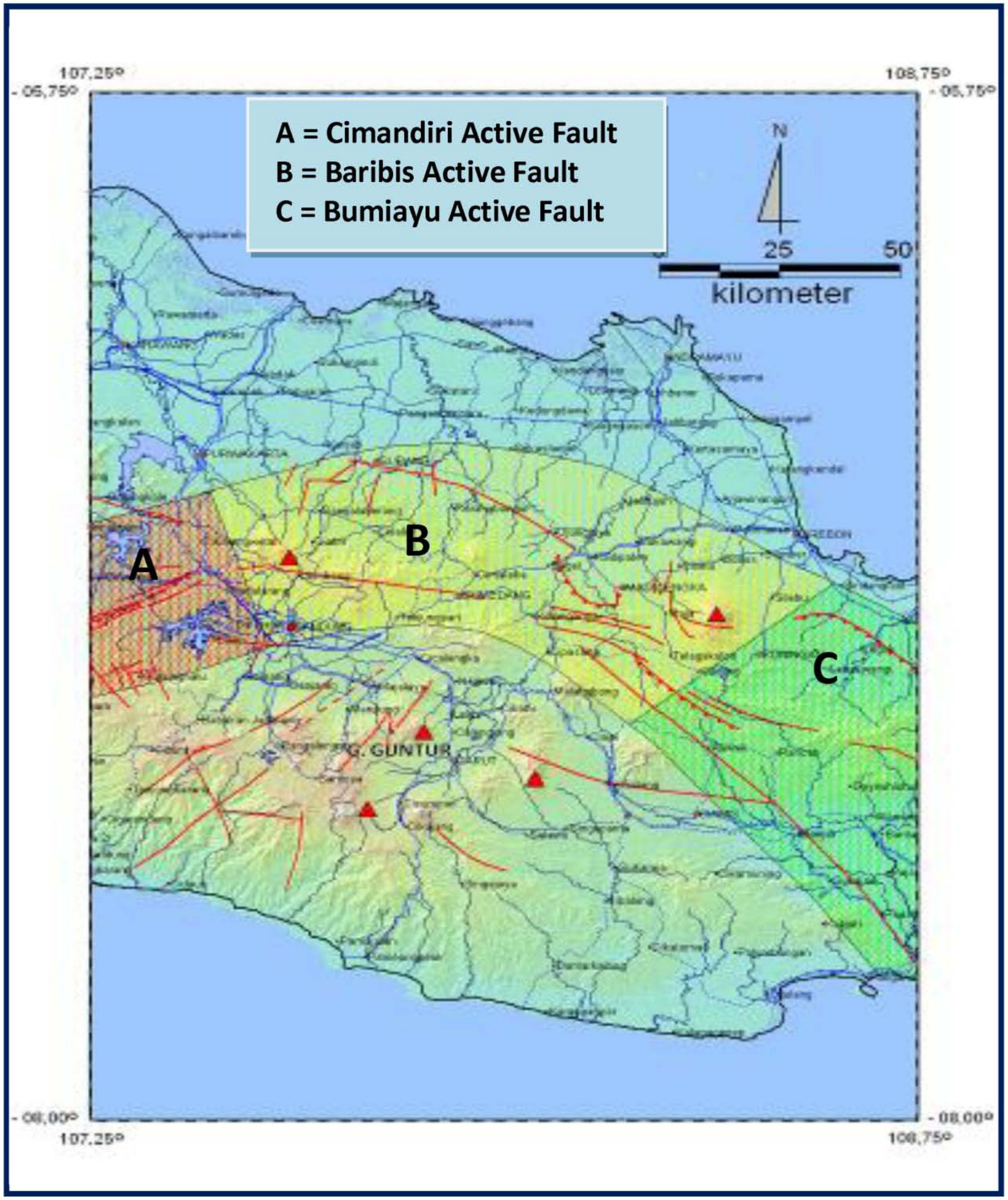

Figure 5. Tectonic setting of the Wayang Windu area (Maryanto, 2010).

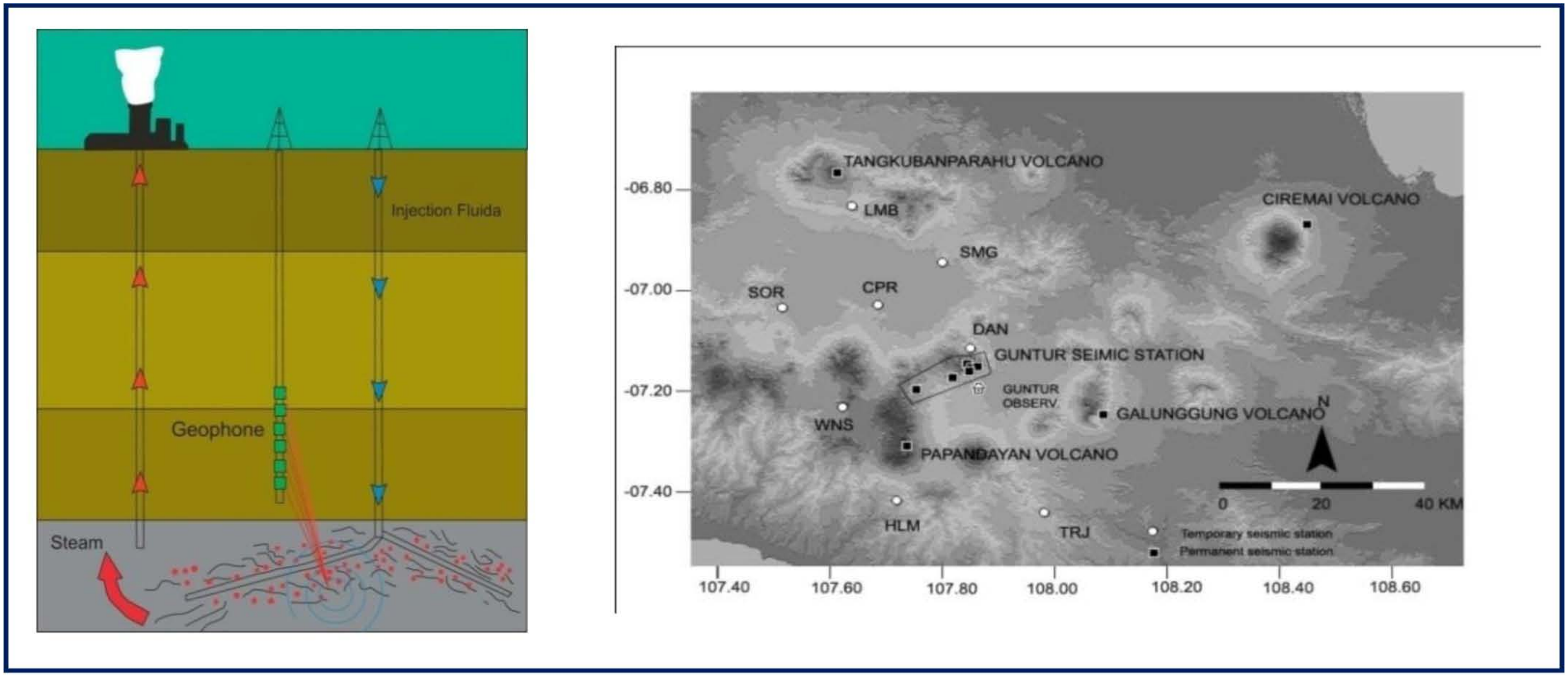

Figure 6. Microseismic source point in well bore and microseismic volcano stations (Maryanto, 2010).

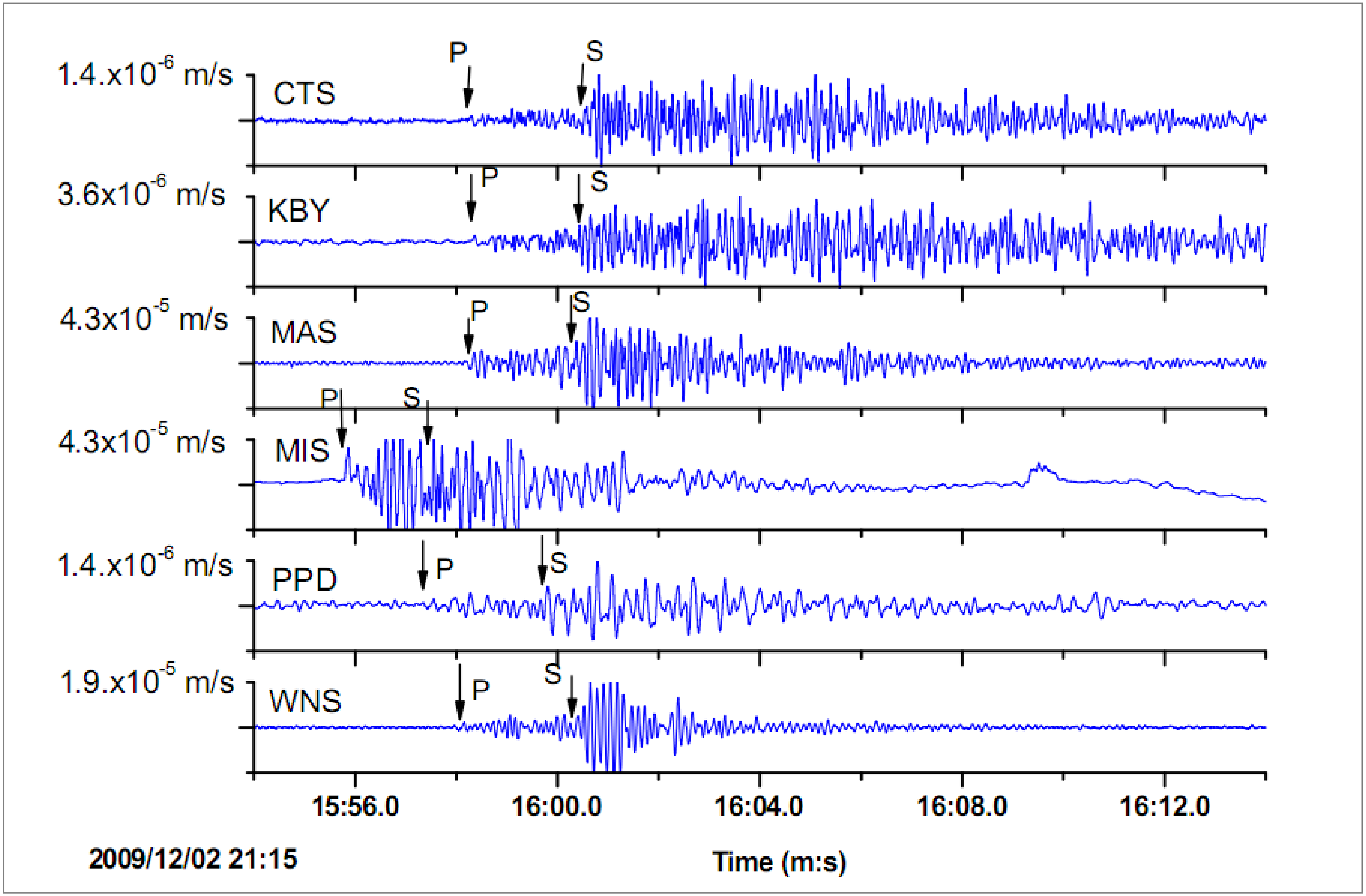

Figure 7. P-wave and S-wave signatures (Maryanto, 2010).

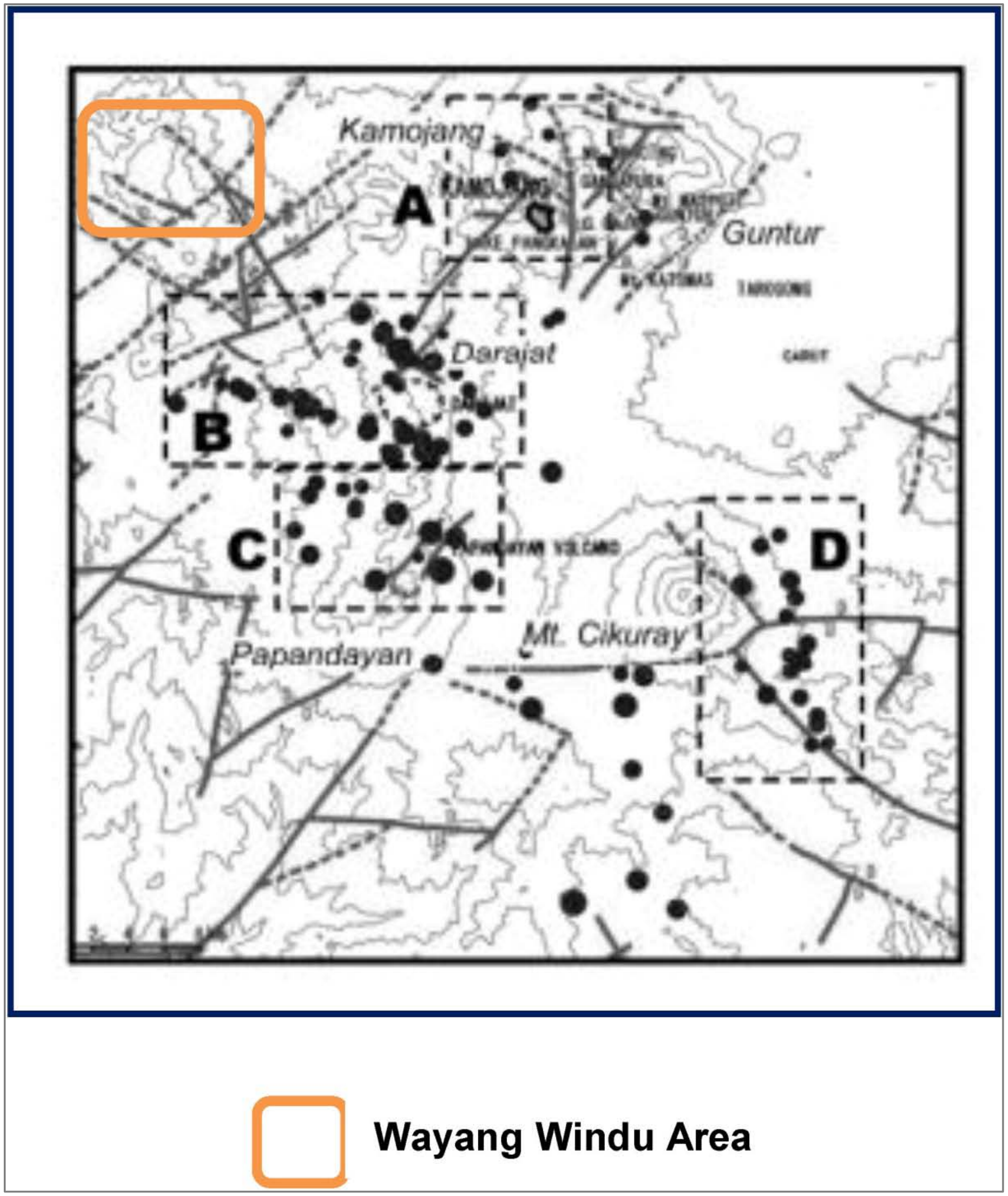

Figure 8. Hypocenter distribution and faults in the Guntur Volcano, Papandayan Volcano and Cikuray Volcano regions, with the Darajat Geothermal Field shown. Wayang Windu area is in the northwest.

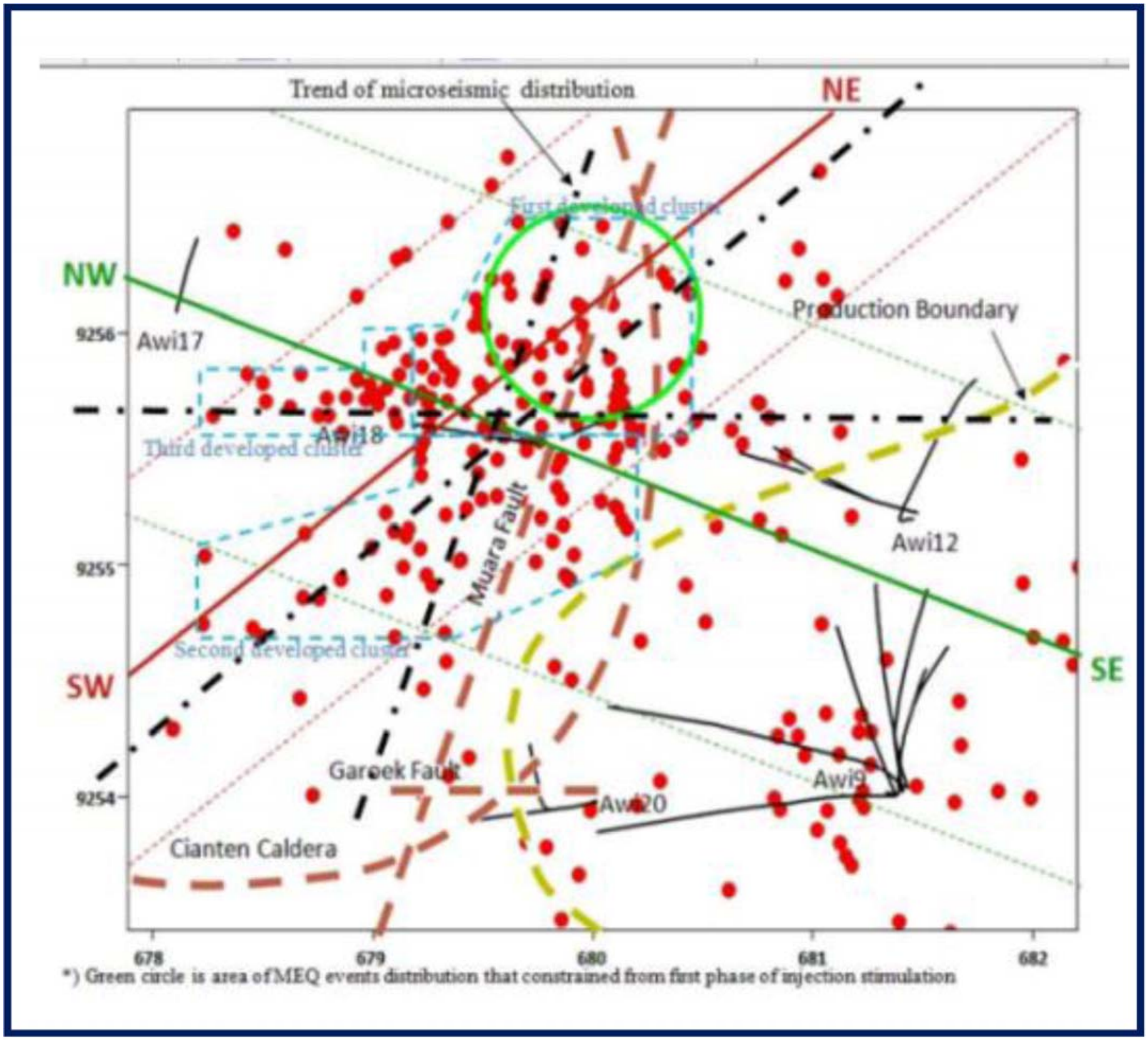

Figure 9. Record of event fractures (Djoko, 2012).

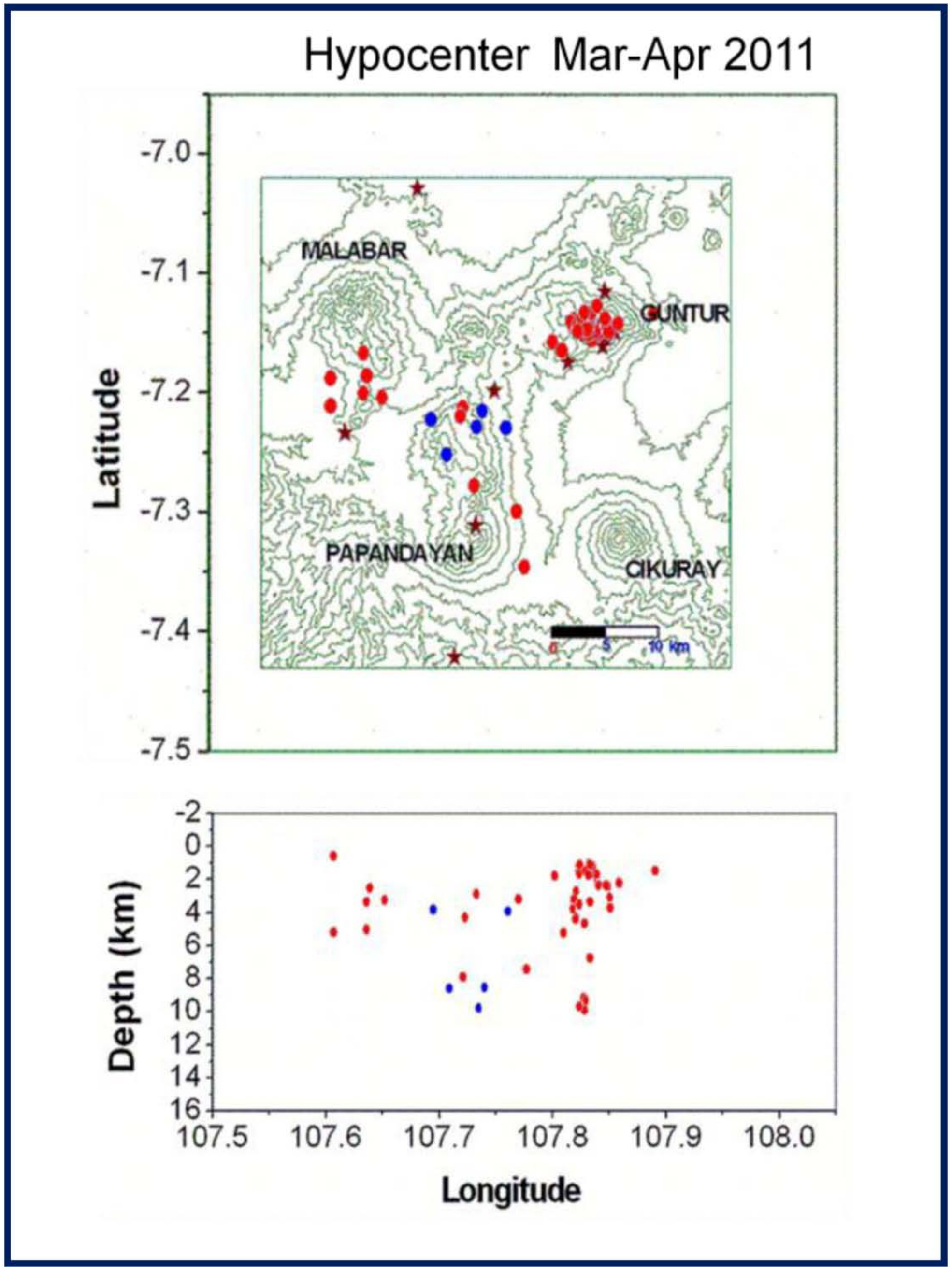

Figure 10. Record of event fractures and local tectonics in the Wayang Windu area.

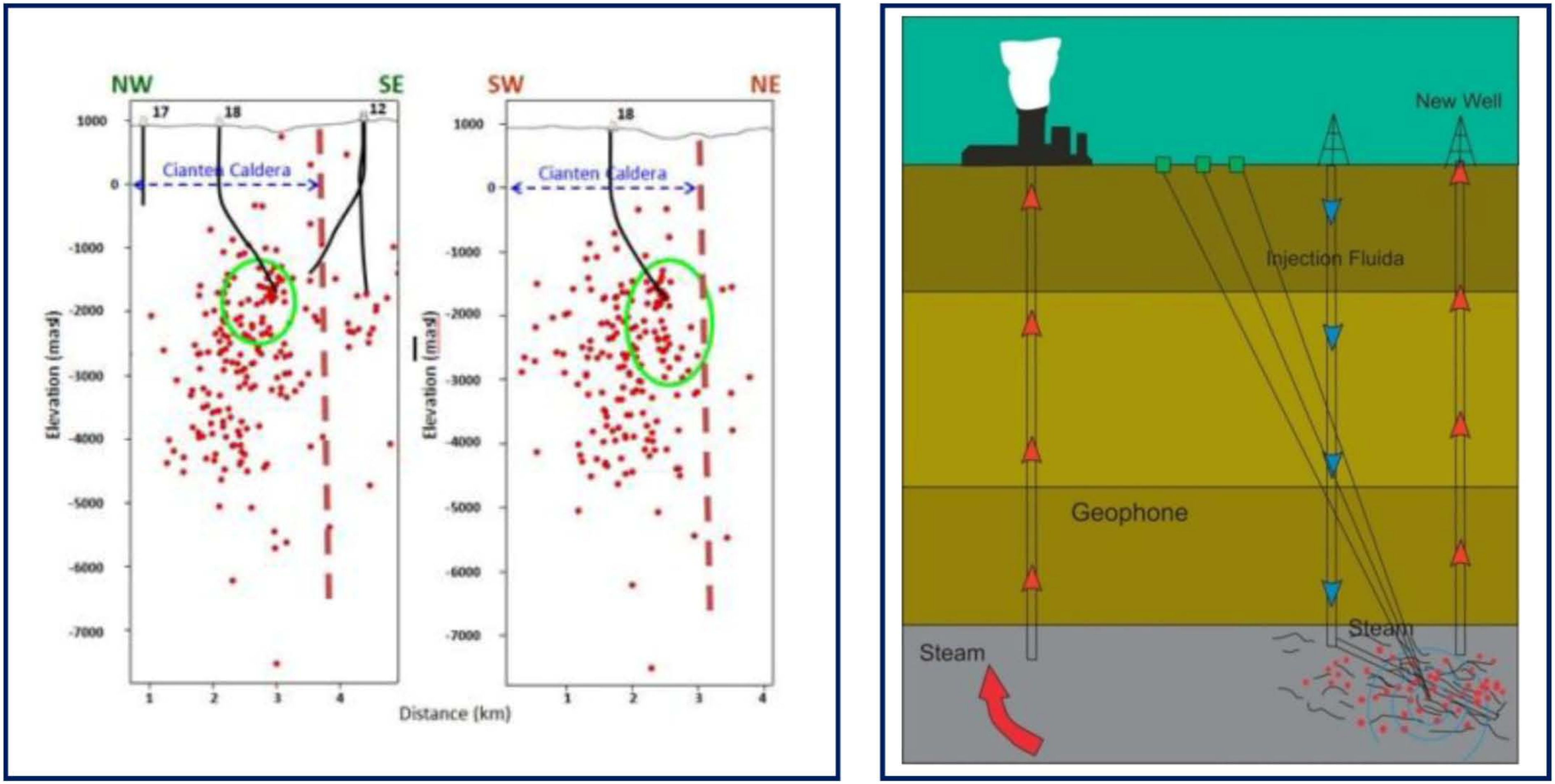

Figure 11. Microseismic events 2D injection well phase (Djoko, 2012), and new well production model.