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GEOLOGY AND GEOTHERMAL MANIFESTATIONS OF MOUNT PANDAN, EAST JAVA

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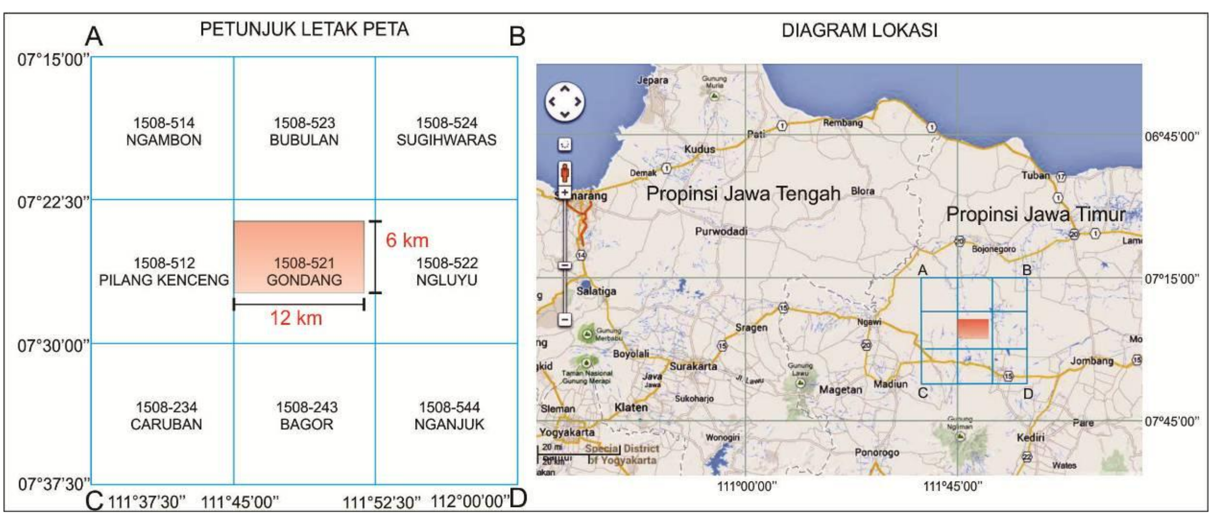
ABSTRACT

Mt. Pandan is a Quaternary volcano formed on Early Pleistocene. It consists of several volcanic eruption centers and geothermal manifestations. This study focused on the northern slopes of Mt. Pandan and its surrounding areas, which are located in the Klino village, Ngambon district, Nganjuk-Bojonegoro-Madiun borders. The methods used in this study were geological mapping supported by petrographic and geological structure analysis.

Volcanic rock units that build research areas can be divided into four, namely Mt. Nangka volcanic rocks unit, Mt. Telogo Gebang volcanic rocks unit, Mt. Lawang volcanic rocks unit, and Mt. Pandan volcanic rocks unit. The areas were controlled by Kali Banjar lateral fault, Kali Sambongrejo lateral fault, Kali Gandong lateral and reverse faults, and Bladogan lateral fault. Banyu Kuning hot spring located in Kali Pacal was controlled by Kali Banjar fault. Characteristics of this hot spring were T: 38°C, Total Dissolved Solid (TDS): 1295 mg/L, and pH: 6-7. Jari Kasinan hot spring located at Jari village was controlled by Kali Jati fault. Characteristics of Jari Kasinan hot spring were T: 32° C, TDS: 1930-1940 mg/L, pH: 6, with travertine calcite and argillic alteration type. The average discharge of both hot springs is 1 liter/second and the residents use them directly.

INTRODUCTION

Pandan volcano is a non-active volcano with 800 meters altitude that emerged on Early Pleistocene, Quaternary (Dyufjes, 1938 in van Bemmelen, 1949). Pringgoprawiro and Sukido (1992) generally explain that volcanic constituents of Mt. Pandan are andesite breccia and andesite intrusions. Nevertheless, there has been no detailed study about volcanic stratigraphy of Mt. Pandan. In the other hand, ESDM Jawa Timur (2012) finds geothermal manifestations on the northern slope of Mt. Pandan. This situation creates need to understand further about Mt. Pandan especially on the northern part. We try to answer this problem by doing study at Klino village, Gondang district, Bojonegoro-Madiun-Nganjuk borders (Fig.1). In this paper we give up-to-date informations about volcanic rocks units, control of geological



structure, and geothermal manifestation at Mt. Pandan northen slope.

Smyth, et al. (2005) divides eastern Java based on the stratigraphy and tectonic aspects into four zone, from south to north, i.e. 1) Southern Mountain Zone, 2) Present-day Volcanic Arc, 3) Kendeng Zone, and 4) Rembang Zone.

Kendeng zone is major depocenter for Eocene-Miocene sediments contained of thick volcanogenic and pelagic sequences. This zone is influenced by E-W fold and thrust fault (Prasetyadi, 2007). Kendeng zone can be separated into three parts, 1) western part, 2) central part, 3) and eastern part (van Bemmelen, 1949). Location of our study lies in the central part of Kendeng zone.

Pringgoprawiro (1983, 1992) explains that stratigraphy of the Kendeng Zone Central Part consists of a) Kalibeng Formation, b) Klitik Formation, c) Sonde Formation, d) Pucangan, and e) Mt. Pandan. Pliocene Kalibeng Formation consists of *Globigerina* massive marl, greenish and silty marl, with local bedded structures, and convolute structures. At the upper of Kalibeng Formation, there is interfingering of Atas Angin Member characterized by volcanic sandstone, tuff, conglomerate and breccia. Klitik Formation consists of limestone, marl, and clay. Sonde Formation consists of intercalation between claystone and volcanic sandstone as an end of marine depositional series in the Upper Pliocene. Dyufjes (1938, in van Bemmelen, 1949) explains that Pucangan Formation is dominated by terrestrial sediments influenced by Willis Volcano activity in Lower Pleistocene in form of volcaniclastic conglomeratic sandstones, tuffaceous sandstones, and volcanic breccias. Pringgoprawiro (1983, 1992) explains that Mt. Pandan Formation consists of andesite breccia and andesite intrusions from Mt. Pandan volcanic.

RESEARCH METHOD

Our research method began with volcanic rock sampling, fault/joint identification, and geothermal measurement. We followed up our research with petrographic and geological structure analysis to make geological maps.

We focused our geological mapping on lithologic character and morphologic expression to identify the order of volcanic rock units. We identified geological structures of the research area in order to know their relationship with geothermal manifestations. We measured temperature (T), TDS (Total Dissolved Solid), pH, flow rate, and conductivity DHL (Debye-Hückel-Lidiard) at the geothermal manifestations.

We used petrographic analysis to know more detailed comparison about mineral composition of volcanic rocks. We did geological structure analysis using stereographic projection to know the movement and fault types.

QUATERNARY VOLCANIC ROCK UNITS OF MOUNT PANDAN NORTHERN SLOPE

We divided volcanic rock units in the northern slope of Mt. Pandan into four, namely Mt. Nangka volcanic rocks unit, Mt. Telogo Gebang volcanic rocks unit, Mt. Lawang volcanic rocks unit, and Mt. Pandan volcanic rocks unit.

Mount Nangka Volcanic Rocks Unit

Mt. Nangka volcanic rocks unit was composed by pyroclastic flow breccia, pyroclastic fall, and hornblende andesite lava. This unit was the oldest volcanic rocks unit located in the central part of volcanic area. Morphology expressions of Mt. Nangka volcanic rocks unit was characterized by a gentle slope, with lava dome volcanic cone surrounding its eruption center.

The deposits of pyroclastic flow type were found at Tadahan village. These deposits were characterized by light brown color, pebble to boulder size, unconsolidated tephra, angular, poorly sorted, open-fabric, andesitic fragment breccias (Fig. 2).

Fig. 2: Pyroclastic flow deposits at Tadahan village

The deposits of pyroclastic fall type were found along Kali Bandotan. These deposits were characterized by light brown color, coarse tuff, consolidated, angular-subrounded, sorted, closed-fabric tuff. The mineral compositions were hornblende, pyroxene, and pumice clast. We found the bedding structure and graded bedding (Fig. 3) with charcoal as evidence of Mt. Nangka volcanic eruption (Fig. 4)

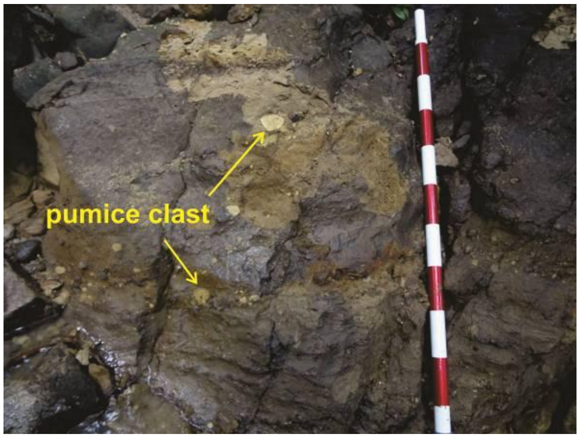


Fig. 3: Pyroclastic fall deposits at K. Bandotan, show gradded bedding structure

Fig. 4: Charcoal (black, 3cm) in K. Bandotan as evidence of Mt. Nangka volcanic eruption

Hornblende andesite lavas were found in the Mt. Watu and Mt. Puru. Mt. Watu lava dome (Fig. 5) was characterized by dark gray color, hypocrystalline, euhedral-subhedral mineral shape, inequigranular vitroveric andesite. The minerals of andesite were plagioclase, hornblende, and pyroxene. We found andesitic xenoliths with smoother textured than main hornblende andesite lavas (Fig. 6) and vesicular structure. We also found hornblende andesite lava at Mt. Puru with its texture resembled to Mt. Watu and volcanic bomb fallout deposits or agglomerat.

Petrographic analysis of hornblende andesite lava (Fig. 5) showed brown color, hypocrystalline, subhedral-euhedral mineral shape, 2 to 0.1 mm size, inequigranular vitroveric andesite. The hornblende andesite lavas were composed by:

a) Plagioclase (45%) with white color, anhedral-euhedral mineral shape, showing twinning albite, 0.6-1mm Andesine (An47) type as primary minerals, that evenly existed in section.

b) Pyroxene (3%) with brown color, anhedral-euhedral crystal form, and presented locally.

c) Hornblende (15%) with brown color, euhedral crystal form, and presented locally.

d) Volcanic glass (15%), as a groundmass.

e) Black opaque minerals (10%).

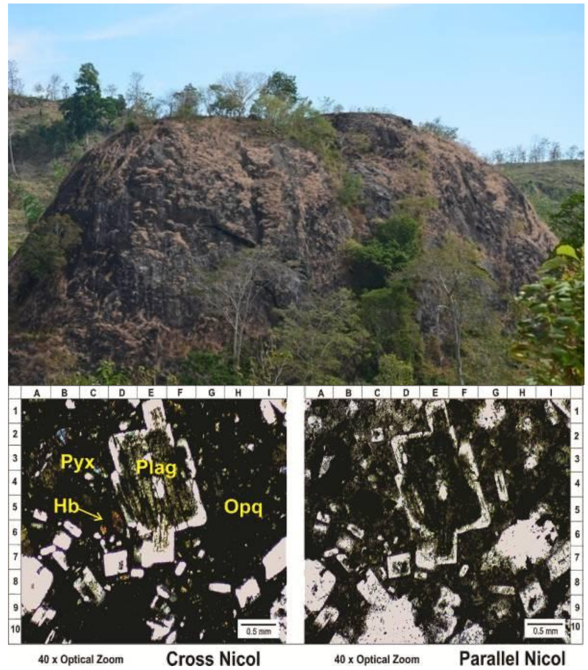


Fig. 5: Mt. Watu horblende andesite lava dome (upper), and its petrographic analysis (lower)

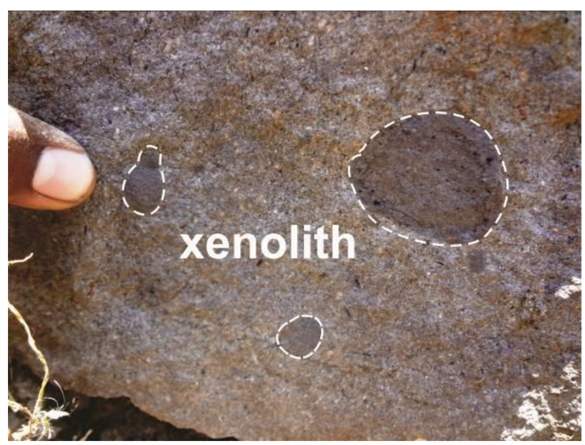


Fig. 6 Andesitic xenolith with finer texture and darker color than main hornblende andesite lava in Mt. Watu.

Mt. Nangka volcanic rocks unit occupied 40% of the volcanic area located in Tadahan, Krondonan, Bandotan villages. The southern part of this unit was overlain by Mt. Pandan volcanic rocks unit and the northern part was overlain by Mt. Telogo Gebang volcanic rocks unit.

Mount Telogo Gebang Volcanic Rocks Unit

Mt. Telogo Gebang volcanic rocks unit was lava dome complex, composed by andesite hornblende and pyroxene andesite. The morphology of this unit was characterized by the tight slope expression of volcanic cones which extended from east to west. We conducted our field observations on Mt. Telogo Gebang, Mt. Keramat, and Mt. Jari.

Pyroxene andesite lavas are found at Mt. Telogo Gebang lava dome (Fig. 7) characterized by gray color, hypocrystalline, fine-medium, subhedral, inequigranular vitroveric andesite. The minerals of andesite were pyroxene, hornblende, and plagioclase. The bottom of the outcrop showed autobreccia structure with 20-50 cm fragment lineations (Fig.7A), columnar joints (Fig.7B), massive structures in the upper part (Fig.7C) We found andesitic xenoliths with lighter color and finer texture than main pyroxene andesite lavas.

Petrographic analysis of pyroxene andesite lavas (Fig. 8) showed the rocks were composed by:
a) Plagioclase (48%), with white color, anhedral-euhedral, showing twinning albite, 2 mm, Andesine (An 49) type that evenly presented in section.
b) Pyroxene (17%), with brown color and subhedral-anhedral mineral shape.
c) Hornblende (11 %), with brown color, 0.6-1.2 mm, subhedral – anhedral mineral shape.
d) Volcanic glass (15%), as a groundmass.
e) Black opaque minerals (10%).

Fig. 7: Mt. Telogo pyroxene andesite lava dome at Gebang showing autobreccia structure (A), columnar joint with vesicular structure (B), and massive structure (c).

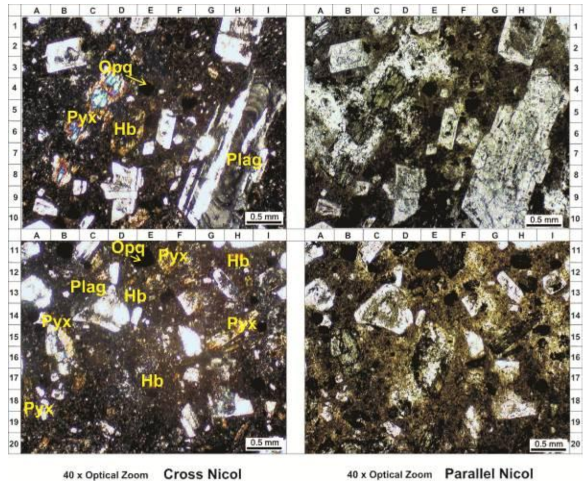


Fig. 8: Petrographic analysis of Mt. Telogo Gebang pyroxene andesite lava dome

Pyroxene andesite lavas are found at Mt. Kramat Telogo Gebang lava characterized by grey color, hypocrystalline, anhedral-subhedral mineral shape, inequigranular vitroveric andesite. The minerals of andesite were hornblende, pyroxene,and plagioclase. We found massive structure lavas showed the presence of gas holes.

Petrographic analysis of pyroxene andesite lavas (Fig. 9) showed the rocks were composed by:
a) Plagioclase (50%), with white color, anhedral-euhedral mineral shape, showing twinning albite, 0.5-1 mm, Andesine (An47) type that evenly presented in section.
b) Pyroxene (15%), with brown color, anhedral-euhedral mineral shape.
c) Hornblende (5%), with brown color, euhedral mineral shape.
d) Volcanic glass (15%), as a groundmass.
e) Black opaque minerals (15%).

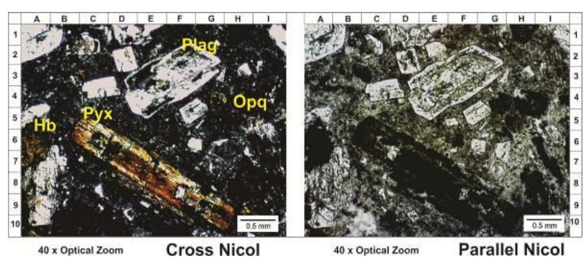


Fig. 9:Petrographic analysis of Mt. Kramat pyroxene andesite lava shows large phenocryst of pyroxene mineral, 2.5 mm.

Hornblende andesite lavas were found at Mt. Jari, characterized by gray color, hypocrystalline, anhedral-subhedral mineral shape, inequigranular vitroveric andesite. We found 13 cm hornblende phenocryst on our observation site (Fig. 10).

Petrographic analysis of hornblende andesite lavas showed the rocks were composed by:
a) Plagioclase (45%), with white color, anhedral-euhedral mineral shape, showing twinning albite, 0.5-1 mm, strong zoning structure Andesine (An47) type.
b) Pyroxene (15%), with brown color, anhedral-euhedral mineral shape.
c) Hornblende (20%), with brown color, euhedral mineral shape.
d) Volcanic glass (10%), as a groundmass
e) Black opaque minerals (10%).

Mt. Jari volcanic rocks unit occupied 30% of the volcanic area located in Jari and Kramat villages. The northern part of this unit was overlain by Mt. Lawang volcanic rocks unit.

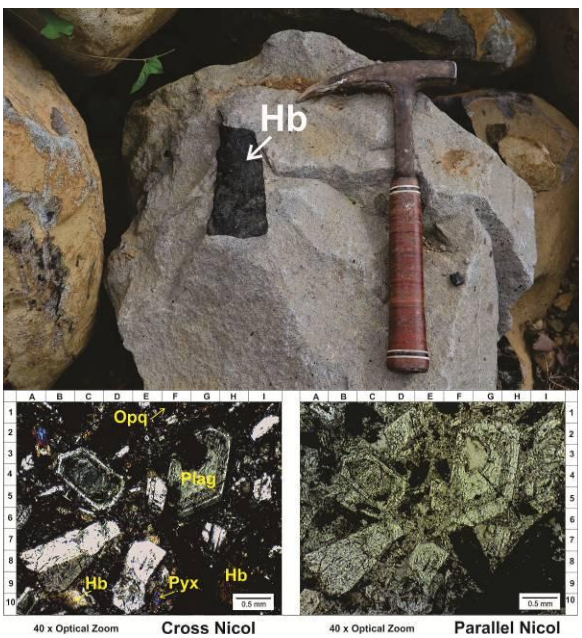


Fig. 10: Outcrop (upper) and petrographic analysis of Mt. Jari hornblende andesite lava(lower)

<u>Mount Lawang Volcanic Rocks Unit</u>

Mt. Lawang volcanic rocks unit is composed by hornblende andesite lava (volcanic neck) with columnar and sheeting joint structures. This unit was located on Mt. Lawang and its two younger cones (Mt. Kendil and Mt. Butak). Observed morphological expression showed that this rocks unit completely covered Mt. Lawang complex. The center of this rocks unit is located on Mt. Lawang as the eruption center with 400 meters altitude. We found agglomerates at mountain slope with smaller size as the area being farther from the center of eruption falls.

Hornblende andesite lavas are found at Mt. Lawang (Fig. 11) characterized by light gray color, hard material, hypocrystalline, subhedral mineral shape, inequigranular vitroveric andesite.
The minerals of andesite were plagioclase as the main phenocrysts, hornblende, and pyroxene. We found 4 cm hornblende phenocryst locally, columnar joint structures (Fig. 12), sheeting joints (Fig. 13), massive structure, and tortoise crack with planar flow banding structure (Fig.14).

Petrographic analysis of hornblende andesite lavas showed the rocks were composed by:
a) Plagioclase (50%) with white-gray, anhedral-euhedral mineral shape, 3.8 mm grainsize, twinning albite andesine (An47).
b) Pyroxene (12%) with brown-greenish color, subhedral-anhedral mineral shape.
c) Hornblende (15%) with brown color, subhedral-anhedral mineral.
d) Volcanic glass (10 %), as a groundmass.
e) Opaque minerals (9%).
(e) Chlorite (4%) with green color as alteration from pyroxene and hornblende in local spot.

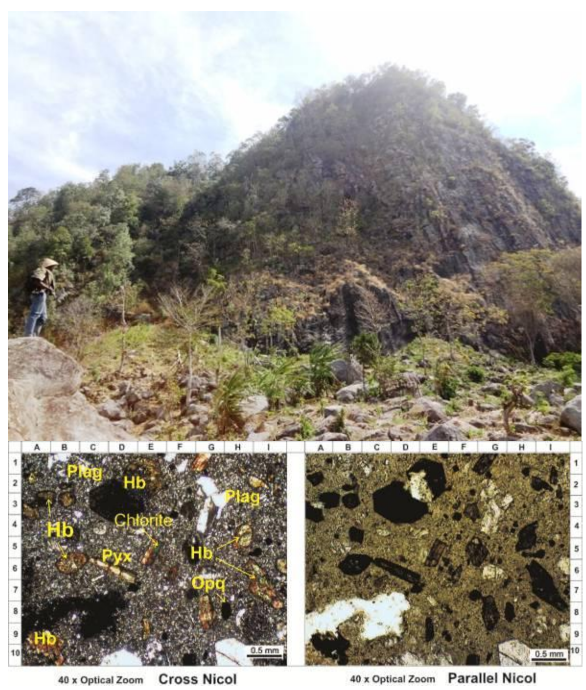


Fig. 11: Mt.Lawang horblende andesite lavas (upper),and its petrographic analysis(lower)

Fig. 12: Collumnar joint structure at Mt. Lawang.

Fig. 13: Sheeting joint at Mt. Lawang

Fig. 14: Tortoise crack with planar flow appeared in agglomerate at Mt. Lawang

Hornblende andesite lavas were found at Mt. Butak characterized by light gray color, hypocrystalline, fine faneric size, subhedral-anhedral mineral shape, inequigranular vitroveric andesit. The minerals of andesite were plagioclase as main phenocrysts, hornblende, and pyroxene. We found sheeting joint structures (Fig.15) and local sandstone xenoliths that were probably derived from old sediment **(?)**.

Petrographic analysis of hornblende andesite lavas showed the rocks were composed by:

a) Plagioclase (40%) with white-gray color, anhedral-euhedral mineral shape, showing twinning albite, zoning structure, 1.6-3.3 mm grainsize, Andesine (An47) that evenly presented in section.

b) Pyroxene (10%) with brown color, subhedral-anhedral mineral shape, and evenly present.

c) Hornblende (18%) with brown color, subhedral-anhedral mineral shape, and evenly presented.

d) Volcanic glass (15 %), as a groundmass.

e) Opaque mineral (10 %).

f) Chlorite (10%) with green color as alteration from pyroxene and hornblende, and evenly presented.

The local xenoliths in hornblende andesite lavas were brown, clastic, mud supported, very fine (<0.01 mm), rounded, well sorted. These xenoliths were consisted of clay, feldspar, opaque, open fracture, porosity, and quartz vein (Fig. 16, 17).

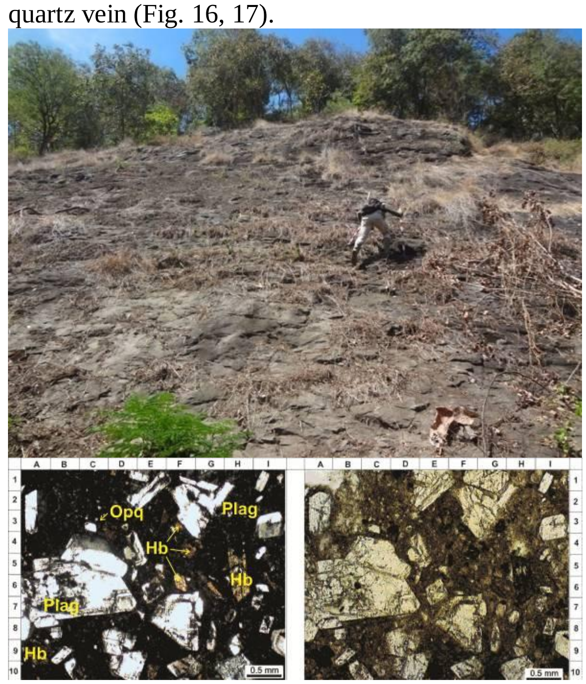


Fig.15: Hornblende andesite lava at Mt. Butak (upper), and its petrographic analysis (lower)

Fig.16: Sediment xenoliths at Mt.Butak lava

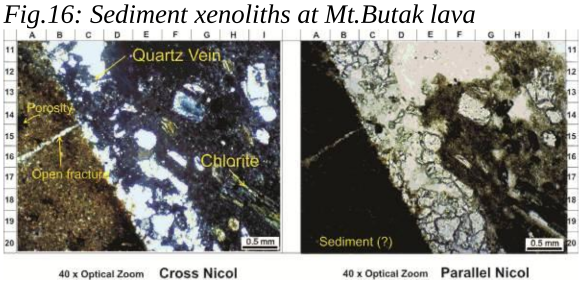


Fig.17: Petrographic analysis of xenolith at Mt. Butak

Hornblende andesite lavas were found at Mt. Kendil (Fig. 18) characterized by gray-orange color, strong weathered, partially hard material, hypocrystalline, fine-medium phaneric size, euhedral-subhedral mineral shape. The minerals of andesite were plagioclase as the main phenocrysts, hornblende and pyroxene. We locally found 3 cm hornblende phenocrysts in massive structures.

Petrographic analysis of hornblende andesite lavas showed the rocks has brown color, hypocrystaline type, 0.01-3.8 mm mineral size, subhedral-anhedral mineral shape, inequigranular vitroveric and porphyritic andesite. The rocks are composed by:

a) Plagioclase (35%) with white-gray color, anhedral-euhedral mineral shape, zoning structure, twinning albite, Andesine (An47).

b) Pyroxene (5%) with brown-greenish color, subhedral-anhedral mineral shape, and unevenly presented.

c) Hornblende (15%) with brown color, subhedral-anhedral mineral shape, and unevenly presented.

d) Volcanic glass (15%), as a groundmass.

f) Black opaque mineral (7%).

g) Chlorite (23%) with green color as alteration from pyroxene and hornblend, and evenly presented.

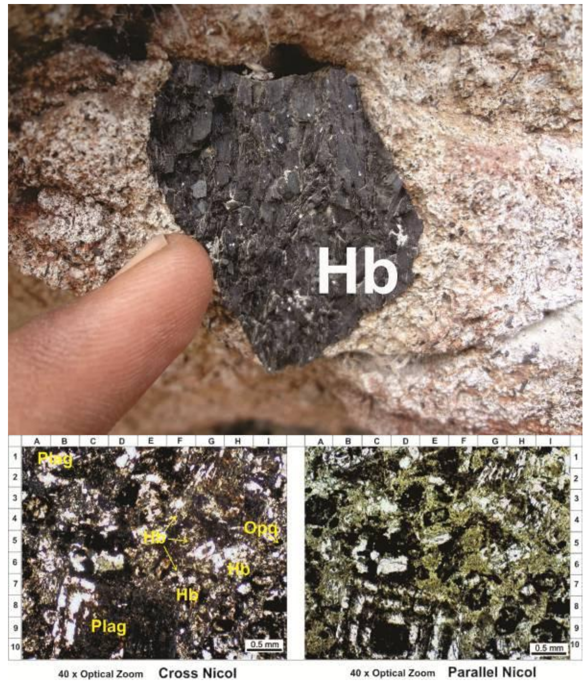


Fig. 18: Horblende andesite lava at Mt. Kendil (upper) and its petrographic analysis (lower)

Mt. Lawang volcanic rocks unit occupied 10 % of the volcanic area located in Jari village. This unit overlaid Mt. Telaga Gebang.

Mount Pandan Volcanic Rocks Unit

Mt. Pandan volcanic rocks unit consists of pyroclastic falls and pyroclastic flows breccias. We observed this unit along Kali Pacal, in southern part of the research area. This unit was the youngest volcanic rocks unit that occupied 20% of volcanic area covered Klino village.

Pyroclastic falls breccias were found in Kali Pacal. These deposits were characterized by brown color, fine-boulder size, well-sorted, rounded, closed fabric, and inversed graded bedding structure breccias (Fig. 19).

Pyroclastic flows breccias were found in Kali Pacal. These deposits were characterized by gray color, coarse-boulders size, poorly sorted, subrounded-angular, open fabric breccias. We found the bottom part of these deposits has been already consolidated and the upper parts consist of tephra. (Fig. 20)

Fig 19. Pyroclastic flow and fall breccias contact in Kali Pacal, Mt. Pandan volcanic rocks units

Fig 20. Pyroclastik flow breccias outcrop in Kali Pacal with poorly sorted andesitic fragment.

We summarized Mt. Nangka volcanic rocks unit, Mt. Telogo Gebang volcanic rocks unit, Mt. Lawang volcanic rocks unit, and Mt. Pandan volcanic rocks unit in a new geological map (Fig. 21).

GEOLOGICAL STRUCTURES

The encountered structures in this research were Bladogan lateral fault, Gedibal lateral fault, G. Prabu lateral fault, Kali Gandong lateral and reverse faults, Kali Samborejo lateral lault, Kali Jati lateral fault, and Mt. Butak-Krondonan joint (Fig. 22). The faults with NE-SW (i.e. Kali Banjar lateral fault) and NW-SE trend (i.e. Bladogan lateral fault) were interpreted as reactivated Kendeng fault (Upper Miocene-Lower Pliocene). Those faults formed intersection that probably caused some fissures for rising magma and triggering appearance of Mt. Pandan in Lower Pleistocene (Fig. 23, 24). Gandong reverse fault was the exposed evidence of Kendeng overthrust fault in the central part of Kendeng zone. As the youngest unit, Mt. Pandan volcanic rocks unit was cut through by Banjar fault and made the occurrence of Banyukuning hot spring. Jari Kasinan hot spring was controlled by Jati fault.

GEOTHERMAL MANIFESTATIONS

Based on field observations, there were three geothermal manifestations as hot springs. They are Banyukuning, Jari Kasinan, and Tadahan hot springs.

Banyukuning hot spring was located at Kali Pacal on volcanic breccia outcrop, in Mt. Pandan volcanic rock unit (Fig. 25). Banyukuning hot spring characterized by fluids temperature of 38°C, air temperature of 24°C, TDS 1295 mg/L, pH 6-7, debit flow 1L/s, and DHL (conductivity) 1.92 ms.

Jari Kasinan hot spring was located at Jari village on Mt. Telogo Gebang rocks units. The lithology in this area was andesite lava with argillic alteration type (Fig. 26). Jari kasinan hot spring characterized by fluids temperature of 38-39°C, air temperatures 32° C, TDS 1930 to 1940 mg/L , pH 6, debit flow 0.67 L/s, and DHL 2.58 ms. The travertines (carbonate sinters) were found in several places around the manifestation (Fig. 27).

There was hot spring with strong sulphuric odor at Kali Tadahan with low temperature (Fig. 28). The lithology in this area was breccias with argillic alteration type (Fig. 29).

DISCUSSION

The volcanic unit division that has been presented in this paper can be more comprehensive if we used integrated method on volcanic facies identification. Bronto (2006) explains the method consists of five elements: 1) remote sensing and geomorphology, 2) volcanic rock stratigraphy, 3) physical volcanology, 4) structural geology, and 5) petrology-geochemistry. Therefore, we are interested to continue this study in order to obtain a model of Mt. Pandan (including tectonic frame, volcanic rock genetic, and different manifestation type) that is previously explained by Setijadji (2012) as a back-arc side of Wilis volcano.

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REFERENCE

Alzwar M., Samodra H., and Tarigan J.I., *"Pengantar Dasar Ilmu Gunungapi"*, Nova, Bandung, 1987.

Bronto, S., Fasies Gunungapi dan Aplikasinya. Jurnal Geologi Indonesia, Vol.1 No.2 Juni 2006:59-71

ESDM Jawa Timur. "*Laporan Pendahuluan Pekerjaan : Survey Pendahuluan Geologi, Geokimia, Geofisika Gunung Pandan (Kab. Nganjuk, Kab. Madiun, dan Kab. Bojonegoro) Provinsi Jawa Timur, Surabaya*" Report, 2012. unpublished.

McPhie J., Doyle M., Allen R. *"Volcanic Texture"*. Center for Ore Depositand Exploration Studies. University of Tasmania, Tasmania, 1993

Prasetyadi. C., *"Evolusi Tektonik Paleogen Jawa Bagian Timur"*. Dissertation, ITB, 2007. unpublished.

Pringgoprawiro H. "*Biostratigrafi dan Paleogeografi Cekungan Jawa Timur Utara, Suatu Pendekatan Baru"*. Dissertation, ITB, 1983. unpublished.

Pringgoprawiro H. and Sukido. "*Geologi Lembar Bojonegoro, Jawa, Lembar 1500-5*, Departemen Pertambangan dan Energi, Direktorat Jenderal Geologi dan Sumber Daya Mineral, Pusat Penelitian dan Pengembangan Geologi, Bandung, 1992.

Setijadji L.D, "*Segmented Volcanic Arc and its Association with Geothermal Field in Java Island, Indonesia".* Proceeding World Geothermal Congress, Bali, 2010.

Smyth, H., East Java ; Cenozoic Basins, Volcanoes and ancient basement". *Procceding Indonesian Petroleum Association*, 33th Annual Convention and Exhibition, 2005

Van Bemmelen, R W 1949, *The Geology of Indonesia*. Govt. Printing Office, The Hague, vol. I A, p. 579

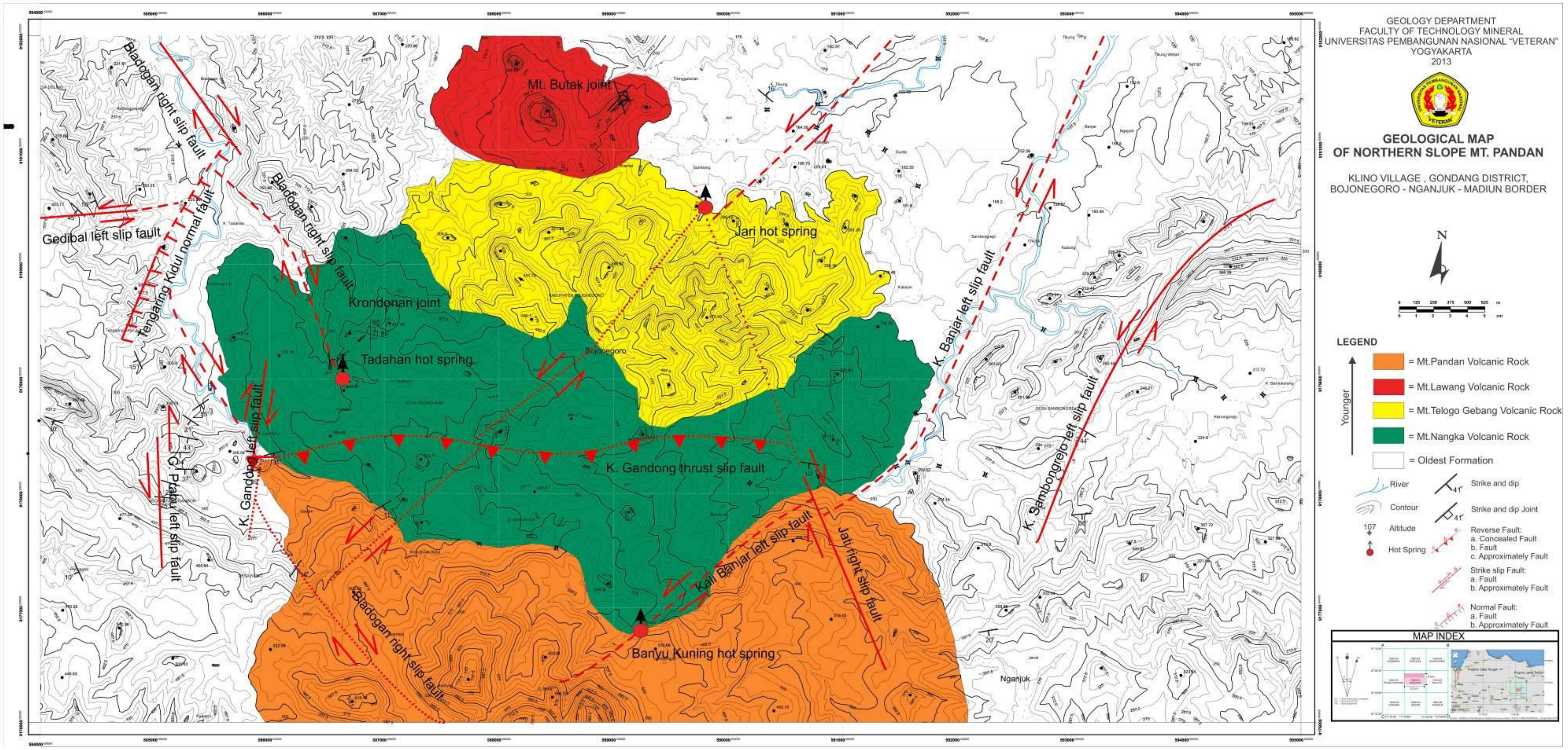

Fig. 21: Geological map of Mt. Pandan northern slope

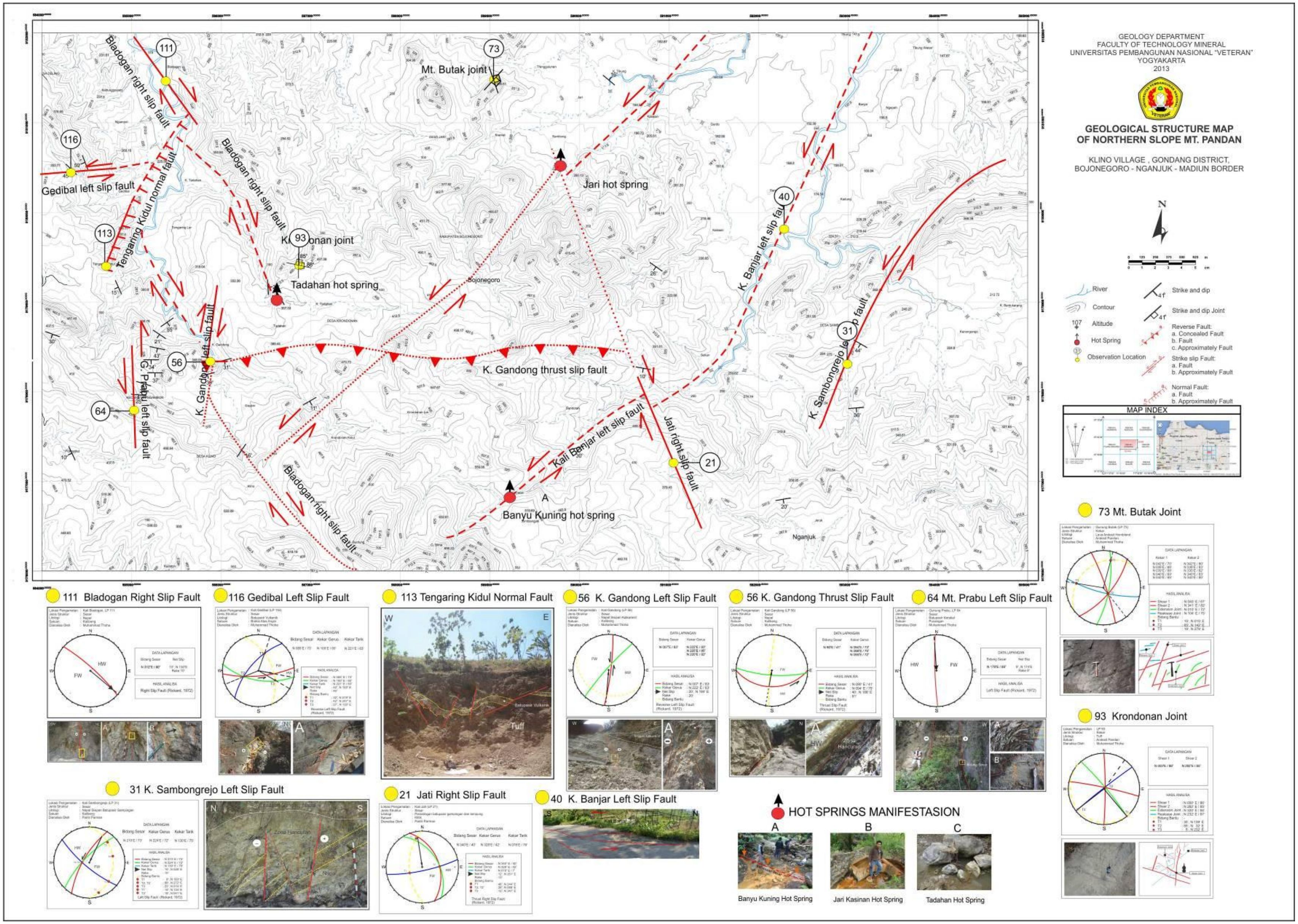

Fig. 22 Geological structure map of Mt. Pandan northern slope

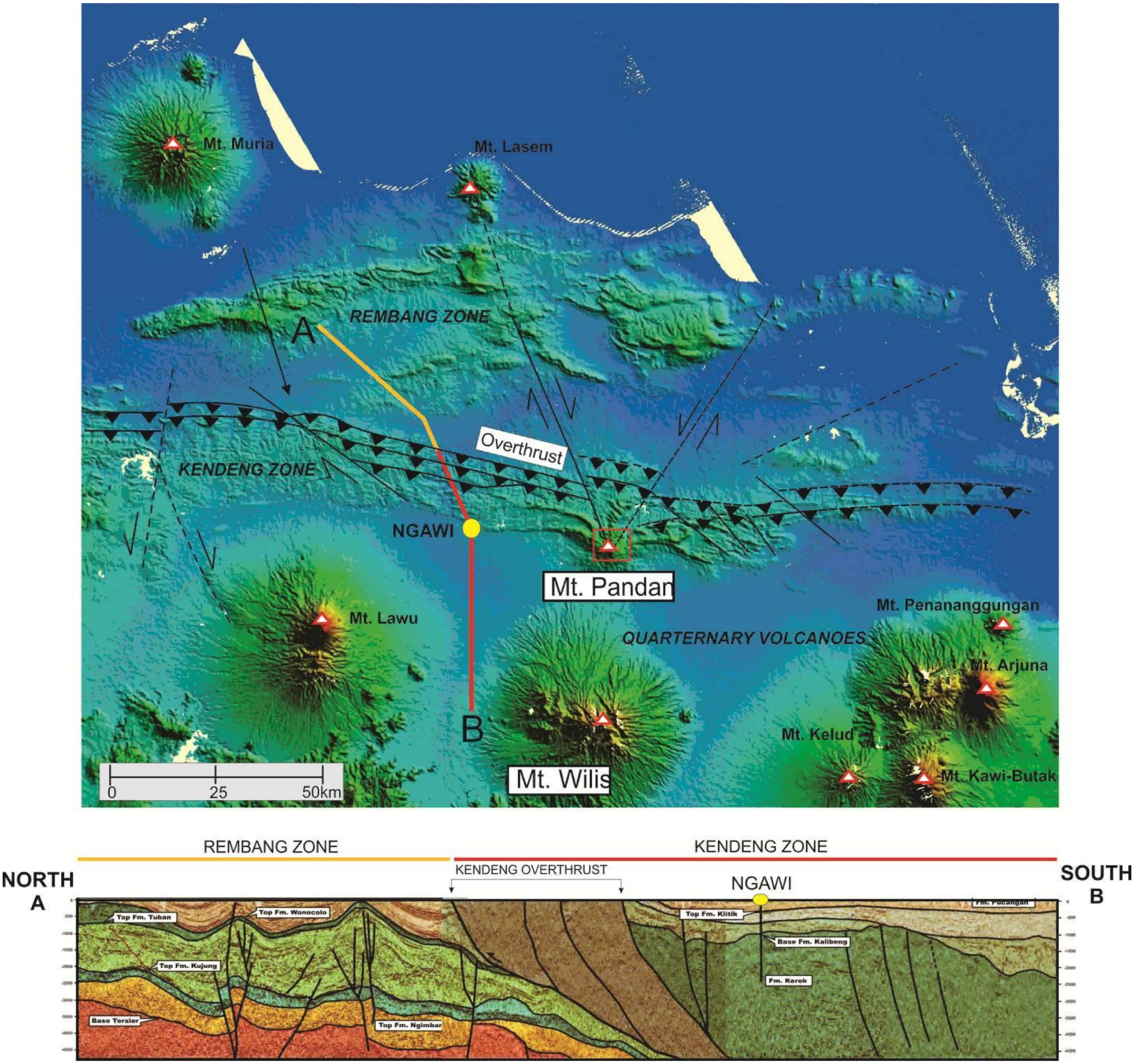

Fig. 23: NE-SW Faults (Kali Banjar and Kali Sambongrejo lateral faults) and NW-SE Fault (Bladogan lateral fault) interpreted as reactivated Kendeng (Upper Miocene-Lower Pliocene) faults forming fault corridor, triggering the appearance Mt. Pandan (Lower Pleistocene). (seicmic data is taken and modified from Prasetyadi, 2007)

Fig. 24 Fe oxide and limonite clay present in Banyukuning hot spring. T: 38° C

Fig. 25: Fe oxide shows at Jari Kasinan hot spring.

Fig. 26: Argilic alteration type, consist of kaolinite, hematite and carbonate veins in Jari Kasinan hot spring

Fig. 27: Carbonate sinter, 50 m west trending from Jari Kasinan hot spring

Fig. 28: Tadahan hot spring

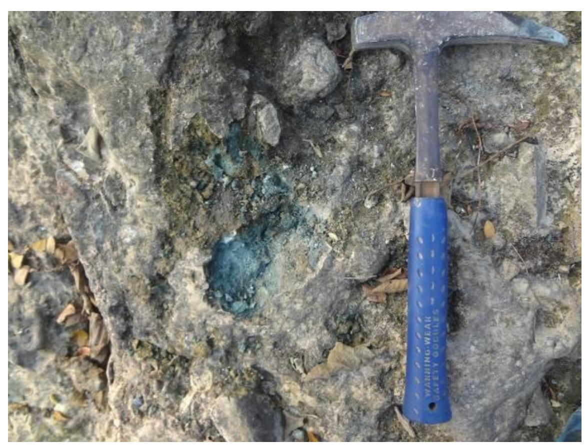

Fig. 29: Argilic alteration type on volcanic breccias, around tadahan hot spring

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