Lahendong geothermal production field, PT Pertamina Geothermal Energy (Tbk) and geothermally heated brown sugar factory

Chapter 3, Part 1

Beneath the Archipelago: Indonesia's Geothermal Systems

Pri Utami, Kartika Palupi Savitri, and Yan Restu Freski, University of Gadjah Mada

Beneath Indonesia's complex geological framework lies a broad and largely untapped spectrum of geothermal potential. From deep superhot zones to heat-bearing sedimentary basins, radiogenic granitic formations, Indonesia's subsurface offers diverse opportunities for applications far beyond the conventional geothermal the nation uses today.

There is perhaps no better place to observe geothermal energy's massive potential than along the Ring of Fire, a tectonically active zone characterized by chains of active volcanoes and frequent seismic activity. The Indonesian archipelago, which forms the westernmost part of the Ring, is therefore blessed with abundant geothermal energy prospects. Geothermal gradients in the region exceed 30°C per kilometer, significantly above the global continental average.

The earliest attempt to develop the archipelago's geothermal resources was made by the Dutch colonial government, which began exploring areas fumaroles in Kamojang (West Java) in 1918.[1] After independence in 1945, Indonesia began exploring geothermal potential throughout its territory, primarily targeting high-temperature resources where significant underground heat supplied by recent volcanism is discharged at the surface (**Figure 3.1**).[2,3,4] Since the 1980s, the government has also expanded its focus to include medium- and low-temperature prospects, which are not always located within active volcanic regions.

Today, Indonesia is a world leader in geothermal, with more geothermal power than all but a few countries. As of 2025, Indonesia is home to 19 commercially operating high-temperature geothermal fields with a conventional total installed capacity of 2,653 megawatts of electricity,[5] making the country the second-largest producer of geothermal electricity in the world (see **Figure 3.2**). To date, all of Indonesia's geothermal capacity has been conventional

INDONESIA'S GEOTHERMAL DEVELOPMENT TIMELINE

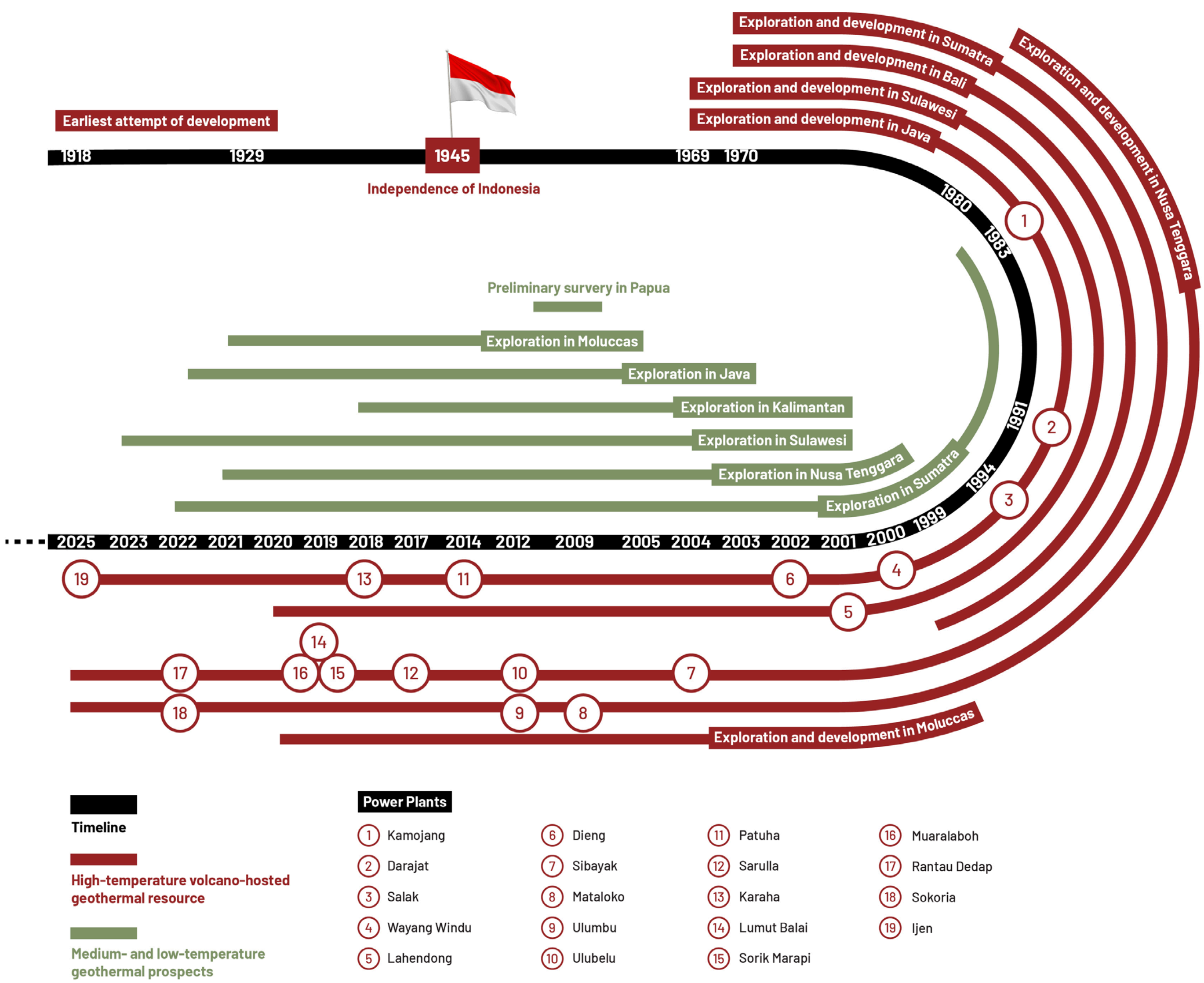

Figure 3.1: Indonesia's geothermal development milestones and the year of commissioning of geothermal power plants. Sources: Radja, V. T. (1975). Overview of geothermal energy studies in Indonesia. In *Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources*. San Francisco, CA, United States; Hochstein, M. P., & Sudarman, S. (2008). History of geothermal exploration in Indonesia from 1970 to 2000. *Geothermics*, *37*(3), 220–266; Ministry of Energy and Mineral Resources. (2023). *Profile of Indonesia's geothermal potential: Volumes 1 and 2*. Directorate of Geothermal, Directorate of New, Renewable Energy, and Energy Conservation, Ministry of Energy and Mineral Resources, Republic Indonesia; Ministry of Energy and Mineral Resources. (2024). *Exploration activities by geothermal permit holder business entities* [Presentation]. Used with permission.

hydrothermal, with naturally occurring reservoirs of heat, water, and permeability—typically associated with volcanic systems—lying relatively close to the surface. Such systems are considered conventional because they rely on these near-surface attributes, unlike enhanced or engineered geothermal systems that must artificially create flow paths in hot, dry rock. (See Chapter 1, "Geothermal 101: Overview of Technologies and Application.") The existing 2,653 megawatts of electricity are only a small fraction of the nation's total conventional geothermal potential, which was estimated at approximately 23.7 gigawatts of electricity by the Ministry of Energy and Mineral Resources in 2025.[6] These estimates include speculative and hypothetical resources as well as proven reserves, primarily within hydrothermal geothermal systems. (For a discussion of additional resources that could be developed through next-generation geothermal technologies, see "Expanding the Scope: Next-Generation Geothermal Opportunities," the supplement to this chapter.)

In other words, as explored later in this chapter, Indonesia has significant opportunities to develop geothermal resources beyond conventional hydrothermal systems. These next-generation technologies leverage oil and gas technologies to bring the Earth's heat to the surface for power or heating and cooling applications. Given Indonesia's diverse geological landscape, geothermal development can include all types of geothermal resources, regardless of temperature and whether the resource is onshore or offshore, as long as it is located within Indonesia's exclusive economic zone (EEZ), extending up to 200 nautical miles from the coast.

This chapter looks at Indonesia's enormous geothermal development potential and identifies locations for further site-specific study. With rising energy demand and a national commitment to both energy independence and 100% renewable energy, proactive research will help the country unlock new resources and support a resilient, sustainable energy future.

The potential for geothermal prospects beyond volcanogenic hydrothermal systems is based on an integrated analysis of geological conditions and regional geophysical data sets, including geothermal gradient maps. Where available, this information is further supported by published temperature data gathered from both geothermal and petroleum drilling, as well as additional fieldwork conducted to validate specific geological parameters. This chapter also includes examples from field exploration in countries with analogous geological settings. At the end of this chapter, we also attempt to qualitatively assess the Technological Readiness Level (TRL) of each geothermal system.

GLOBAL INSTALLED CAPACITY (MWE): TOP 10 COUNTRIES FOR POWER GENERATION

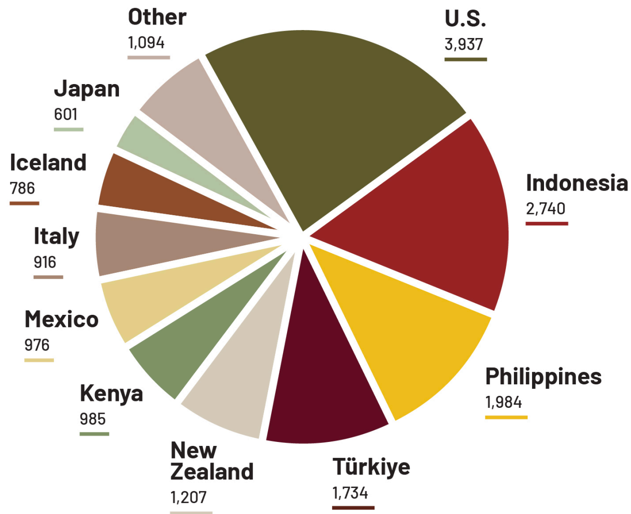

Figure 3.2: Geothermal installed capacity shows that Indonesia is second in the world for producing geothermal power but 74th in deploying direct-use geothermal resources. MWe = megawatts electrical. Source: Adapted from Al Asy'ari, M. R., Adityatama, D. W., Brilian, V. A., Erichatama, N., & Purba, D. (2024). Beyond electricity: Geothermal direct use business models and potential applications in Indonesia. In *Proceedings of the 49th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States; Cariaga, C. (2025, January 20). *ThinkGeoEnergy's top 10 geothermal countries 2024-power*. ThinkGeoEnergy.

GEOLOGY OF INDONESIA IN BRIEF

Indonesia's geological complexity can be traced to its unique position in the Earth's tectonic landscape. This includes interactions between three large tectonic plates—the Eurasian, Indo-Australian, and Pacific plates—as well as smaller plates such as the Caroline and Philippine Sea plates (**Figure 3.3**).[7,8]

This tectonic configuration reflects a long and dynamic geological evolution. Over the past 160 million years, the Indonesian region has been shaped by intermittent tectonic movements, resulting in the closure of ancient oceans and the gradual accretion of continental fragments.[9]

GEOLOGIC MAP OF INDONESIA

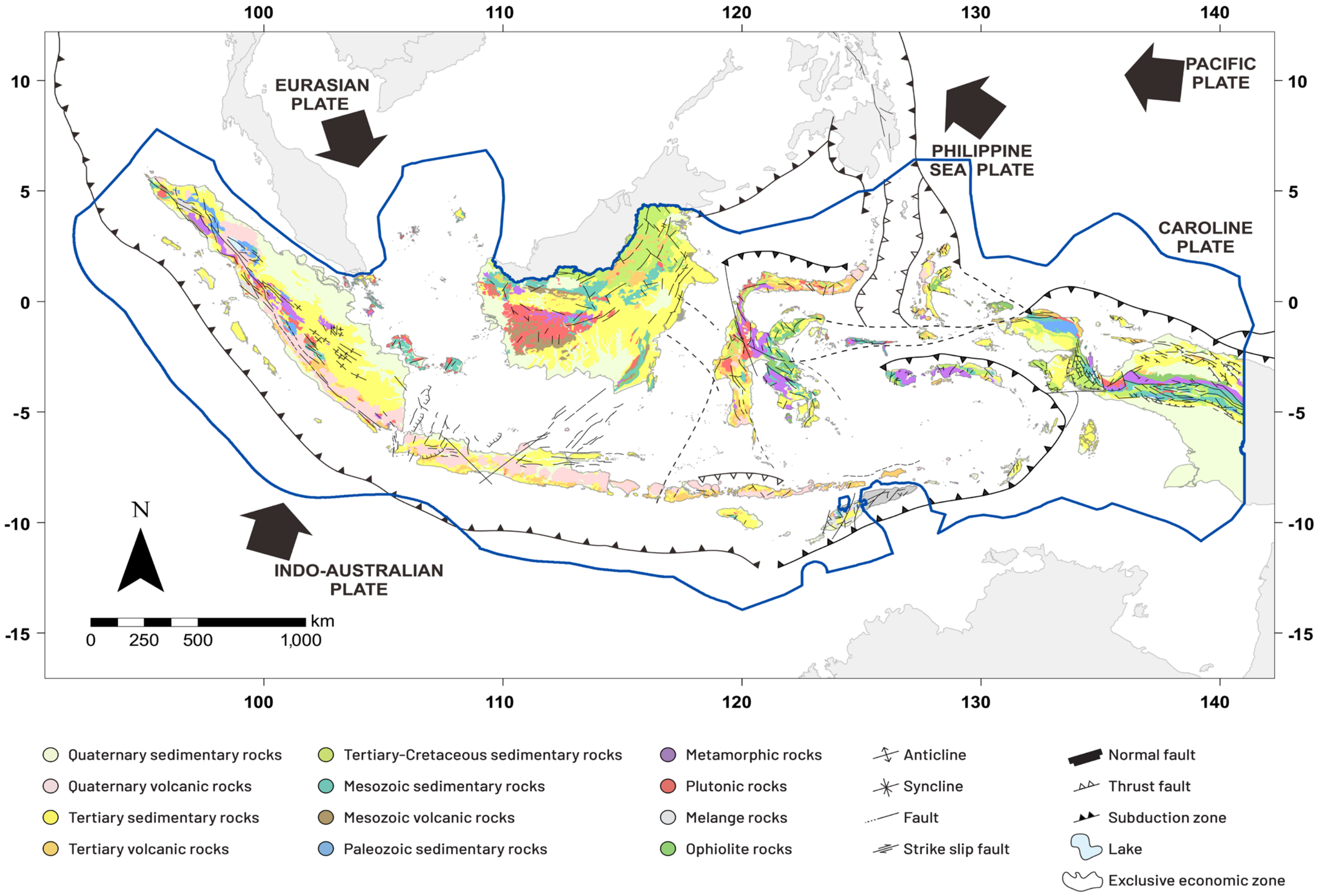

Figure 3.3: Map of the geology of Indonesia showing major tectonic plate boundaries, rock formations, and geologic structures. Sources: Sukamto, R. (2010). *Regional geological map* (D. Sukarna, Ed.). Ministry of Energy and Mineral Resources, Republic of Indonesia; Sukamto, R., Ratman, N., & Simandjuntak, T. O. (Eds.). (2011). *Geological map of Indonesia*. Ministry of Energy and Mineral Resources, Republic of Indonesia; Macpherson, C. G., & Hall, R. (2002). Timing and tectonic controls in the evolving orogen of SE Asia and the western Pacific and some implications for ore generation. *Geological Society, London, Special Publications*, *204*, 49–67; Setiawan, N. I., Osanai, Y., Nakano, N., Adachi, T., Yonemura, K., Yoshimoto, A., Setiadji, L. D., Mamma, K., & Wahyudiono, J. (2012). Geocehmical characteristic of metamorphic rocks from South Sulawesi, Central Java, South and West Kalimantan in Indonesia. *ASEAN Engineering Journal*, *3*(1), 107–127; Simandjuntak, T. O., & Barber, A. J. (1996). Contrasting tectonic styles in the Neogene orogenic belts of Indonesia. *Geological Society, London, Special Publications*, *106*, 185–201; Raharjo, P., Mellawati, J., & SBS, Y. (2016). Analysis of supposed capable faults as supporting data for the proposed site of the Bojonegara Nuclear Power Plant, Banten Province. *Journal of Nuclear Energy Development*, *18*, 39–48; Flanders Marine Institute. (2025). MarineRegions.org.

Around 45 million years ago, renewed northward movement of the Australian Plate initiated subduction beneath the Sunda Arc, which has remained active to the present day. The subducted lithosphere beneath much of Indonesia is Cretaceous or older, except in the westernmost Sunda Arc, where Cenozoic oceanic crust has been subducted within the last 20 million years.[9]

These complex plate interactions have produced an exceptional variety of geological features, including deep-sea trenches, thrust and strike-slip faults, volcanic arcs, sedimentary basins, and accreted terranes. The resulting rock assemblages contribute to Indonesia's diverse geothermal landscape, ranging from igneous intrusions to varied sedimentary and metamorphic types. This landscape includes high-temperature volcanic systems along active arcs and non-volcanic geothermal resources (explained in the next section).

INDONESIA'S GEOTHERMAL RESOURCES

Geothermal resources are thermal energy stored in the Earth's crust beneath a given area (measured from mean annual surface temperature) that could reasonably be extracted at costs that are competitive with other forms of energy at some specified time in the future. These resources are further classified as "economic" or "sub-economic" based on the conditions at the time of their assessment.[10] A geothermal resource is contained in a geothermal system—a natural configuration within the Earth's crust that allows heat to be stored, transferred, and potentially extracted for energy use.

Based on knowledge of the geologic setting and supported by regional geophysical data and, where available, downhole temperature measurements, we identify and explore at least five distinct types of geothermal resources in Indonesia:

1. Volcano-hosted hydrothermal-type geothermal resources (on land and submarine)

2. Subvolcanic supercritical geothermal resources (on land and submarine)

3. Granitic rock-hosted radiogenic geothermal resources: hydrothermal and hot dry rock (HDR) (on land and submarine)

4. Sedimentary rock-hosted geothermal resources (on land and submarine)

5. Metamorphic rock-hosted geothermal resources (on land)

These resource types are classified according to their host lithology, geologic environment, temperature, and the presence or absence of fluids within the system (**Figure 3.4**). While some of these resource types remain undiscovered or have low geological confidence, they are all considered accessible through drilling and potentially viable for future energy development.

VOLCANO-HOSTED HYDROTHERMAL-TYPE GEOTHERMAL RESOURCES (ON LAND AND SUBMARINE)

Reports of both on-land and submarine volcanoes and hydrothermal vents in Indonesia were first consolidated in *A Catalog of Active Volcanoes of the World* by Neumann van Padang in 1959. Updates, including real-time volcanic activity, are now monitored and published by the Center of Volcanology and Geological Hazard Mitigation (PVMBG) of Indonesia.[11]

On-Land Volcano-Hosted Hydrothermal-Type Geothermal Resources

Hydrothermal-type geothermal resources in volcanic terrain have historically been targeted for development in Indonesia. Typically, these systems involve igneous rock reservoirs containing hydrothermal fluids, mostly derived from rainwater, heated with or without direct magmatic input. The systems are commonly capped by impermeable hydrothermal clay. High-temperature systems often exhibit abundant surface expressions or thermal manifestations such as fumaroles, hot springs, steaming grounds, and hydrothermally altered grounds.

According to a 2023 inventory by the Geological Agency of Indonesia, there are 336 on-land hydrothermal-type geothermal prospect locations along the volcanic chains of Indonesia. Of these, 94 are classified as high-temperature.[12] Nineteen fields of this resource type currently produce electricity (see **Figure 3.5**).

GEOTHERMAL RESOURCE TYPES IN INDONESIA

No.	Geothermal Resource Type	Geologic Region	Environment and Prospective Locations	Temperature Class	Fluid
1	Volcano-hosted hydrothermal	Active volcanic chains	On land: Sumatra, Java, Bali, Nusa Tenggara, The Moluccas, North Sulawesi Submarine: Sabang Waters, Sangihe Arc; Banda Sea	High, medium, and low	Hydrothermal, with or without trace of magmatic fluids
2	Subvolcanic supercritical	Region beneath active volcanic chains	On land: Sumatra, Java, Bali, Nusa Tenggara, The Moluccas, North Sulawesi Submarine: Sabang Waters, Sangihe Arc; Banda Sea	Ultra-high	Supercritical fluid
3	Granitic rock-hosted radiogenic **hydrothermal**	Granite Tin Belt Granitic provinces	On land and submarine: Bangka and Riau Islands On land: Sumatra, Kalimantan, Sulawesi, East Nusa Tenggara, Halmahera, Sula Islands, Papua	Medium, low	Hydrothermal
	Granitic rock-hosted radiogenic **hot dry rock**	Granite Tin Belt Granitic provinces	On land and submarine: Bangka and Riau Islands On land: Sumatra, Kalimantan, Sulawesi, East Nusa Tenggara, Halmahera, Sula Islands, Papua	Medium, low	Fluid absence or scarce
4	Sedimentary rock-hosted	Sedimentary basins	On land, magmatically influenced: Sumatra, northern part of Java On land, hot sedimentary aquifer: Sumatra, Java, Kalimantan, Natuna, Sulawesi, northern part of Papua Submarine: the east of Sumatra, Riau Islands, the North Java Sea, and the Malacca Strait	Medium, low	Saline thermal fluids
5	Metamorphic rock-hosted	Metamorphic provinces	On land: Sumatra, Kalimantan, Sulawesi, Sula, Buru, Seram, Papua	Medium, low	Hydrothermal with metamorphic contribution, fluid possibly scarce

Figure 3.4: Summary of geothermal resource types in Indonesia. Source: the authors, based on the information they provided in Chapter 2.

In addition to prospects with obvious surface expressions, there are also prospects where surface manifestations are limited or even absent. These may represent parts of some deep-seated system with long lateral outflow, such as the Cisolok-Cisukarame geothermal field,[13] or waning systems that are gradually losing their heat supply or energy output over time.

GEOTHERMAL POTENTIAL INDICATORS IN INDONESIA

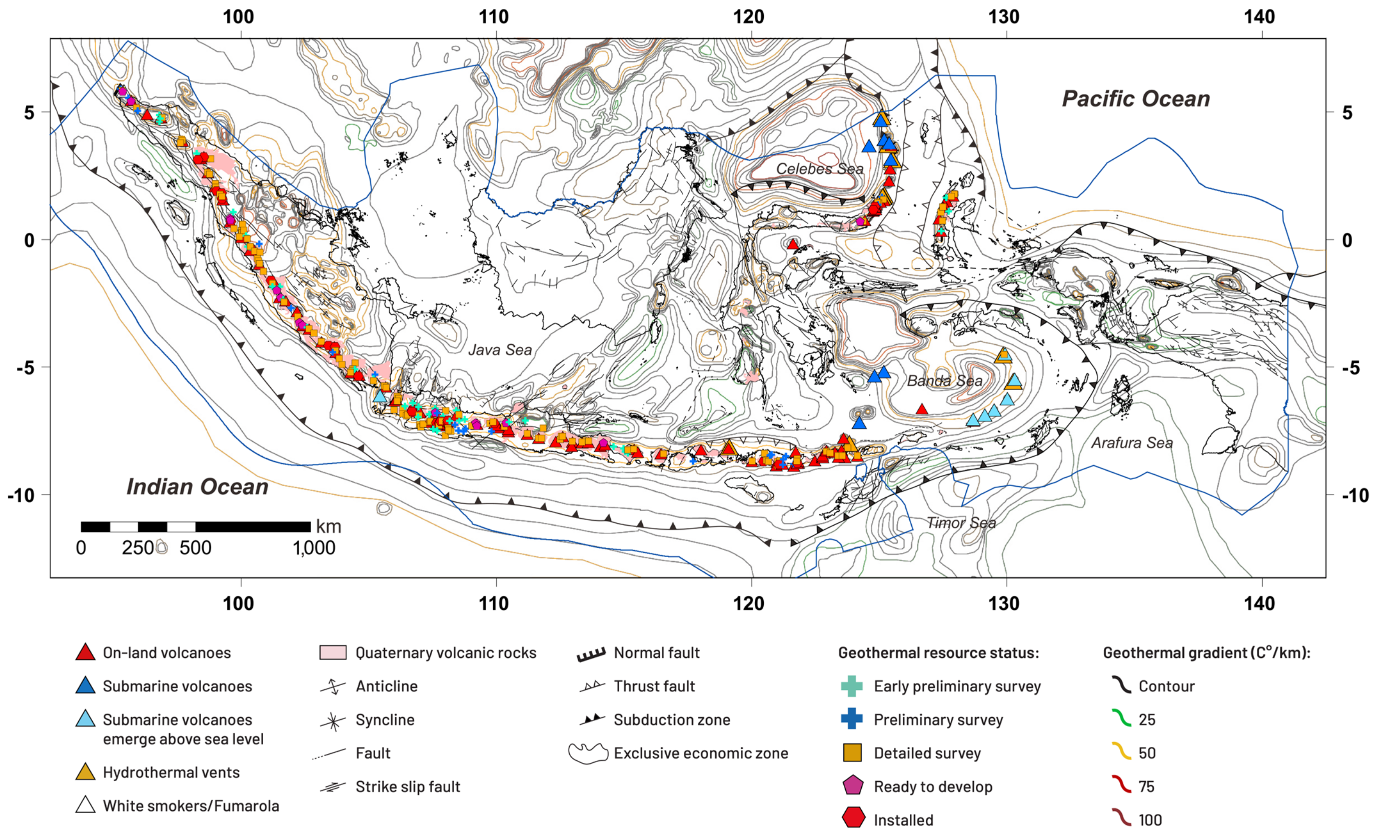

Figure 3.5: Map showing the distribution of on-land (Center for Volcanology and Geological Hazard Mitigation, 2021) and submarine volcanoes; hydrothermal vents (Abbott et al., 2024; Aryanto et al., 2023; Kurnio et al., 2015; Špičák et al., 2013); known and underexplored volcano-hosted hydrothermal resources (Indonesian Geological Agency, 2023); geothermal gradients (Darman, 2021), Quaternary volcanic rocks (Sukamto, 2010); major regional geologic structures (Raharjo et al., 2016; Sukamto et al., 2011); and the boundary of Indonesia's exclusive economic zone (EEZ; Flanders Marine Institute, n.d.). See full reference information at the end of this chapter.

Submarine Volcano-Hosted Hydrothermal-Type Geothermal Resources

Submarine geothermal resources hold vast, untapped energy with immense potential to provide a sustainable energy supply. Volcano-hosted submarine geothermal systems share similar characteristics with their onshore counterparts but offer significantly greater energy potential. Due to this higher potential, these resources have recently gained attention as promising candidates for energy extraction.[14,15] Although the submarine geothermal systems remain poorly studied, the preliminary explorations described in this section highlight their potential.

Based on the occurrence of submarine volcanoes and hydrothermal vents, along with high geothermal gradients (**Figure 3.6**), there are at least three main zones of prospective resources:

1. **Pulau Weh**, at the western end of the Indonesian Archipelago, hosts the Jaboi geothermal system, an on-land, volcano-hosted hydrothermal site with submarine fumarole activity indicating the presence of underwater geothermal potential. The water depth reaches approximately 0.5 kilometers, and the area exhibits relatively high geothermal gradients, ranging from 50°C to 60°C per kilometer. Studies by Kurnio et al.[16,17] have explored rare earth element transport and enrichment around the fumarolic vents.

DISTRIBUTION OF SUBMARINE VOLCANOES AND HYDROTHERMAL VENTS

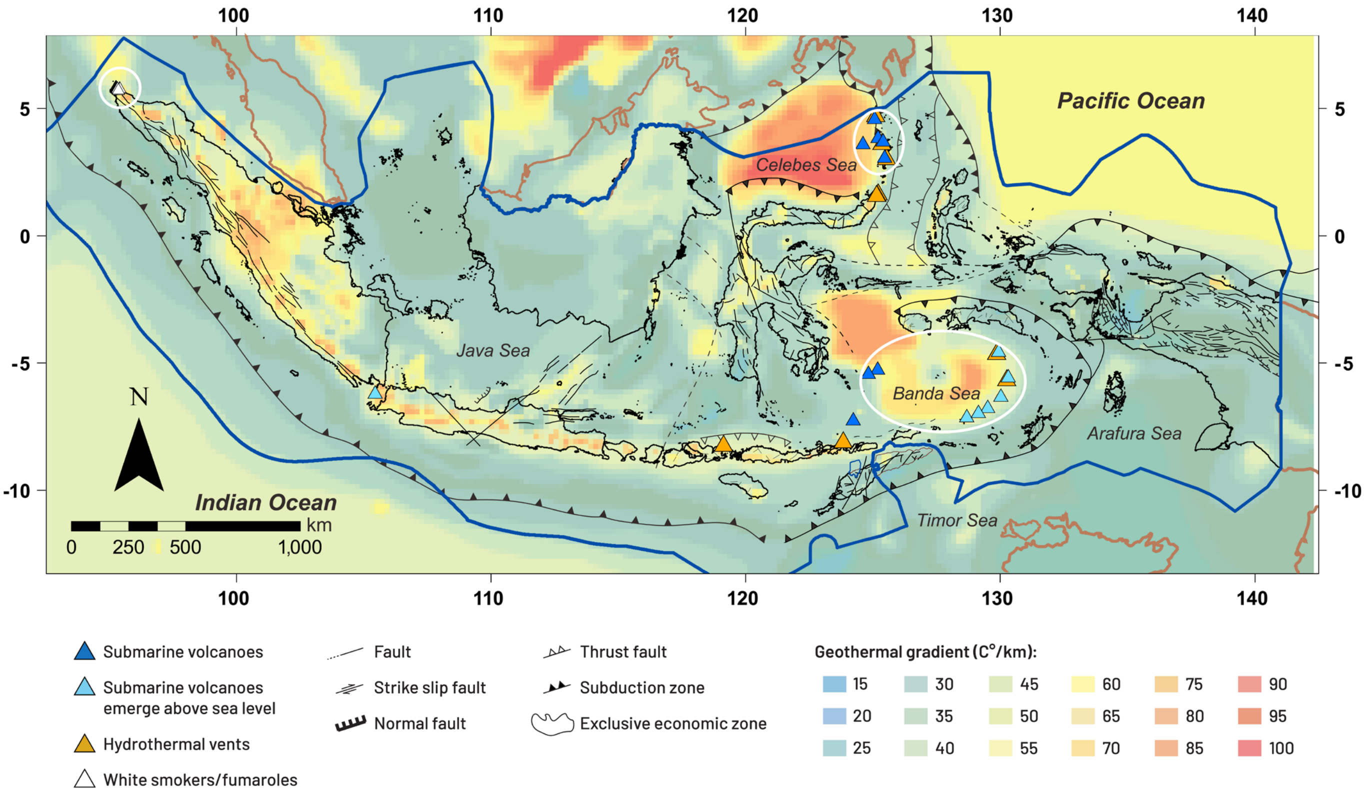

Figure 3.6: Map showing the distribution of submarine volcanoes and hydrothermal vents (Abbott & Rubenstone, 2024; Aryanto et al., 2023; Kurnio et al., 2015; Špičák et al., 2013), superimposed with maps of geothermal gradients (Darman, 2021); major regional geologic structures (Raharjo et al., 2016; Sukamto et al., 2011); and the EEZ boundary (Flanders Marine Institute, 2025). White circles indicate the prospective sites for further exploration. On-land volcanoes are omitted for clarity. See full reference information at the end of this chapter.

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2. **The Sangihe Arc**, in northern Sulawesi, also exhibits high geothermal gradients (50°C–75°C per kilometer), with seafloor depths reaching up to 4.5 kilometers. Submarine volcanoes and hydrothermal sites in the region include Banua Wuhu (0 kilometers to 2.5 kilometers below sea level), Naung (0.5 kilometers to 1.5 kilometers), Kawio Barat (1.5 kilometers to 4.5 kilometers), and the suspected Maselihe old hotspot (1.5 kilometers to 4.5 kilometers, as explored by McConachy et al.[18]).

3. **The Banda Arc**, a horseshoe-shaped volcanic arc, features active volcanoes such as Banda Api, Wetar, Manuk, Damar, Emperor of China, Nieuwerkerk, and Romang, of which the last three are offshore. The Banda Sea's depths range from 0.5 kilometers to 5.5 kilometers, with geothermal gradients ranging from 50°C to 60°C per kilometer. Hydrothermal activity has been documented in the offshore volcanoes of the Emperor of China and Nieuwerkerk.[19]

In addition to these three prospect zones, other potential submarine geothermal sites in Indonesia include areas in the Sunda Strait and in the Bay of Tomini, where hydrothermal manifestations have also been observed.[19]

Further geological, geophysical, and geochemical research is crucial for modeling these systems. Offshore development minimizes land disruption and avoids conflicts over land use; however, the feasibility of geothermal extraction requires thorough assessments of submarine volcanic hazards and environmental impacts. International submarine geothermal studies—such as those conducted in Mexico,[20,21] Papua New Guinea,[22] New Zealand,[23,24] Japan,[25] and California[26]—provide valuable exploration insights for Indonesia. By leveraging advanced on-land geothermal and offshore hydrocarbon production technologies, submarine geothermal resources can offer a cost-effective and scalable energy solution for various applications.

Sub-Volcanic Supercritical Geothermal Resources (On Land and Submarine)

Supercritical geothermal resources are hosted by geothermal systems in which a fluid is present in a state above a critical threshold (>374°C and >22 megapascals) where distinct liquid and gas phases do not exist. These systems can yield much higher energy than conventional hydrothermal systems. They are thought to be located at the roots of volcano-hosted hydrothermal systems at depth near or below the brittle-ductile transition zone (BDT), where rock behavior changes from brittle fracturing to ductile flow due to increasing temperature and pressure with depth.[27]

Exploration of supercritical geothermal resources in several countries has yielded significant results. For example, in Kakkonda, Japan, researchers have developed a technology to estimate subsurface temperatures[28] where deep drilling has reached the BDT.[29] Exploratory drilling in Krafla and Reykjanes, Iceland, has successfully discharged supercritical fluids and identified the transition zone between hydrothermal systems and magma.[30] Research in Larderello, Italy—the birthplace of geothermal power production—has discovered supercritical fluids using seismic methods and contributed to the advancement of drilling technologies.[31]

However, drilling into supercritical conditions presents significant challenges, particularly in managing fluids at very high temperatures and pressures. Addressing these issues requires advancements across multiple areas of geothermal development. Key priorities include improving resource assessment methods, conducting laboratory studies on fluid and rock behavior under supercritical conditions, developing advanced drilling technologies, and enhancing logging and monitoring strategies. In addition, robust numerical simulations and the establishment of dedicated field laboratories are essential for a better understanding of these types of resources.

A comprehensive plan for the exploration and development of the supercritical geothermal resources has been undertaken in New Zealand through its Geothermal: The Next Generation program in the Taupo Volcanic Zone. The program includes geoscientific research and engineering modelling to investigate subsurface conditions deeper than the known hydrothermal systems. It also includes resource inventory, the development of strategic pathways, assessments of economic viability, regulatory considerations, and stakeholders' engagement and communication efforts.[32]

By learning from these international experiences, Indonesia could explore its own supercritical geothermal resources, which are expected to occur beneath high-temperature hydrothermal systems along volcanic chains (**Figure 3.5**).

Similarly, large calderas in Indonesia—such as Tondano (North Sulawesi), Toba (North Sumatra), Batur (Bali), and Rinjani (West Nusa Tenggara)—are believed to host supercritical geothermal resources at depth. Notably, Tondano and Toba have yielded voluminous rhyolites comparable to those found in the Taupo Volcanic Zone, suggesting geothermal potential.

Tondano Caldera is one of Indonesia's largest historically active calderas,[33] hosting two productive geothermal systems: Lahendong and Tompaso (**Figure 3.7**). Both fields feature productive wells with average temperatures around 250°C.[34] Lahendong belongs to a magmatic vapor-cored geothermal system and exhibits stable temperatures reaching from between 350°C and close to 400°C at depths of between 2 kilometers to 2.5 kilometers in several wells.[35] This exceptionally high heat source at relatively shallow depth highlights the immense geothermal energy potential of the region.

Meanwhile, the Toba Caldera in North Sumatra is a large silicic volcanic system formed by multiple super-

TONDANO CALDERA DEPRESSION

Figure 3.7: Tondano Caldera depression, now partly filled by a lake, seen from the Kasuratan Hill, Minahasa, North Sulawesi. Source: the authors.

Indonesia could eventually extend its efforts to include the exploration of submarine supercritical geothermal resources, tapping into the vast potential of its offshore volcanic environments.

eruptions over the past 1.3 million years.[36] Geophysical studies using receiver function methods reveal a thickened crust (depth to mantle boundary around 31 kilometers) and low-velocity zones at depths of between 8 kilometers and 25 kilometers beneath Lake Toba, indicating partial melt zones or a large crustal magma body.[37] The association with a slab tear at the western end of the Sunda Arc supports the existence of persistent high heat flux and deep magmatic input.[38] These features suggest that supercritical conditions may exist at depth under the caldera.

Looking ahead, studies and exploration of onshore supercritical geothermal systems should be prioritized to build foundational knowledge and technical expertise. As understanding of these high-temperature systems improves, Indonesia could eventually extend its efforts to include the exploration of submarine supercritical geothermal resources, tapping into the vast potential of its offshore volcanic environments.

Granitic Rock-Hosted Radiogenic Geothermal Resources, Hydrothermal and Hot Dry Rock (HDR) (On Land and Submarine)

Granitic rocks enriched in uranium, thorium, and potassium generate heat through radiogenic decay,[39,40] providing a long-lasting crustal heat source distinct from the transient magmatic pulses in volcanic systems. While other lithologies such as felsic volcanic rocks or sedimentary units may also host radiogenic heat,[41] their heterogeneity complicates exploration. Granites with elevated radiogenic heat remain the most promising and tractable lithology for focused geothermal development, ranging from naturally convecting hydrothermal systems to engineered hot dry rock (HDR) solutions.

In granite-hosted systems, geothermal heat may be accessed through natural groundwater circulation in

GEOLOGIC FEATURES RELEVANT TO RADIOGENIC GEOTHERMAL POTENTIAL IN INDONESIA

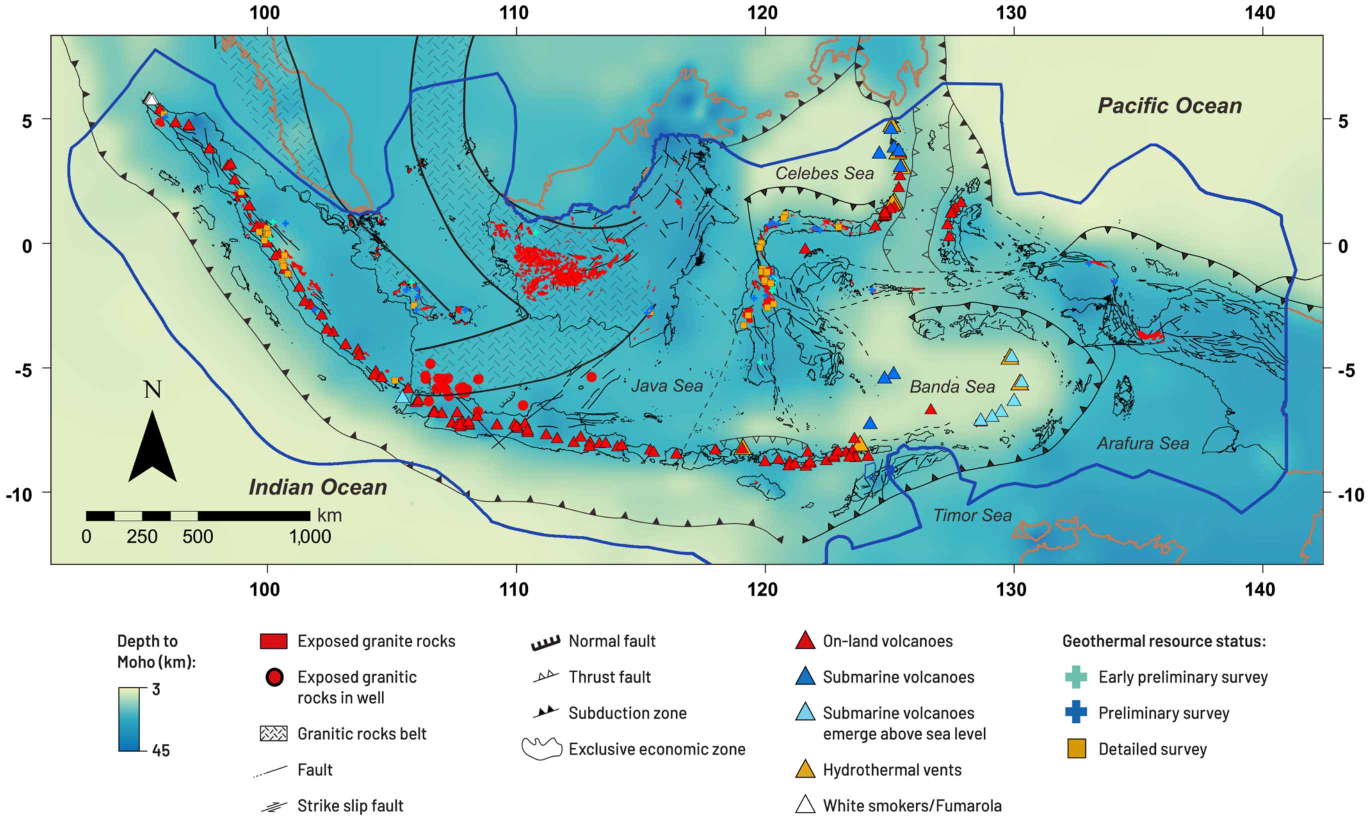


Figure 3.8: Compiled map of Moho depth (i.e., depth to mantle; Mooney et al., 2024); granitic rock distributions (Hamilton, 1979; Ng et al., 2017; Sukamto, 2010); geologic structures (Sukamto et al., 2011; Raharjo et al., 2016); on-land volcanoes (Center for Volcanology and Geological Hazard Mitigation, 2021); submarine volcanoes (Abbott & Rubenstone, 2024; Aryanto et al., 2023; Kurnio et al., 2015; Špičák et al., 2013); locations of known and underexplored granite-hosted geothermal resources (Indonesian Geological Agency, 2023); and the EEZ boundary (Flanders Marine Institute, n.d.) as a guide to explore radiogenic geothermal resources. See full reference information at the end of this chapter.

fractured granites or via artificial stimulation using an enhanced or engineered geothermal system (EGS).[42] Hydrothermal systems rely on pre-existing permeability that enables fluid to circulate, heat up, and ascend, whereas HDR systems target impermeable, dry granites that require hydraulic fracturing to create flow paths.

Indonesia hosts promising and relatively underexplored granitic terrains, such as the tin-granite provinces of Bangka-Belitung, Cretaceous-to-Jurassic plutons in West Kalimantan, and granitic belts in western Papua and Central Sulawesi (**Figure 3.8**). Surface indicators such as warm springs and elevated groundwater temperatures suggest the presence of shallow hydrothermal activity.

The occurrence of surface manifestations depends on permeability, which is controlled mainly by fractures

Indonesia hosts promising and relatively underexplored granitic terrains, such as the tin-granite provinces of Bangka-Belitung, Cretaceous-to-Jurassic plutons in West Kalimantan, and granitic belts in western Papua and Central Sulawesi.

in the granitic plutons, as seen in the exposed granitic rocks in the Batu Ketak Beach on Bangka Island (**Figure 3.9**). These fractures are often confined to shallow depths, leaving most of the heat retained below the hydrothermal systems. This condition points to the potential for HDR resources underlying the radiogenic hydrothermal systems in these granitic bodies. Additionally, tectonically uplifted or shallowly exposed granitic bodies—which are often associated with elevated geothermal gradients at relatively shallow depths—may serve as promising HDR sites even in the absence of surface manifestations.

Submarine granitic systems may also represent a promising frontier. Submerged plutonic outcrops along the Sunda Shelf and in eastern Indonesia (**Figure 3.8**) could support geothermal activity, especially where the subsurface is structurally fractured and fluid-saturated. These underwater granitic exposures mirror on-land systems and may harbor either convective or EGS geothermal resources.

Globally, several projects underscore the feasibility of granitic geothermal systems. In China's Huangshadong field, uranium- and thorium-rich granites support thermal springs and wells producing over 120°C at 3 kilometers depth.[43] France's Soultz-sous-Forêts and Australia's Cooper Basin represent HDR successes where hydraulic stimulation has enabled deep granite heat extraction.[44,45,46] These cases from different

BATU KETAK BEACH, BANGKA ISLAND

Figure 3.9: Exposed densely fractured granitic rocks in the Batu Ketak Beach, Bangka Island. Source: the authors.

> ***Indonesia's granite-hosted geothermal systems, encompassing both hydrothermal and HDR, represent a promising and increasingly recognized geothermal resource.***

parts of the world highlight the viability of both natural and engineered systems, particularly in tectonically stable settings.

Indonesia's granite-hosted geothermal potential remains largely untapped despite the abundance of uranium- and thorium-enriched granitoid intrusions, with systematic geothermal assessments only recently gaining momentum. Radiometric and heat flow surveys—standard in international exploration—are increasingly recognized as valuable for Indonesia's non-volcanic terrains,[47] while emerging marine geoscience technologies such as underwater gamma spectrometry, marine heat flow probes, and seabed drilling platforms offer promising avenues for exploring submarine granitic systems. Studies reporting elevated uranium and thorium concentrations in tin-granites, particularly in western Indonesia, underscore the significance of radiogenic enrichment and the need for further investigation. To advance exploration, an integrated approach combining structural mapping, radiometric and geochemical surveys, and shallow heat flow assessments—many adapted from mineral exploration—can be effective for early-stage evaluation, with remote sensing, marine geophysics, and deep-sea drilling playing a critical role in validating offshore resources.

In sum, Indonesia's granite-hosted geothermal systems, encompassing both hydrothermal and HDR, represent a promising and increasingly recognized geothermal resource. Strategic investment in exploration, resource assessment, and enabling technologies could facilitate the development of these systems and contribute to the diversification of Indonesia's geothermal sector beyond its volcanic provinces.

Sedimentary Rock-Hosted Geothermal Resources (On Land and Submarine)

The complex tectonic evolution of Indonesia has resulted in the formation of numerous sedimentary

SEDIMENTARY BASINS AND GEOTHERMAL FEATURES

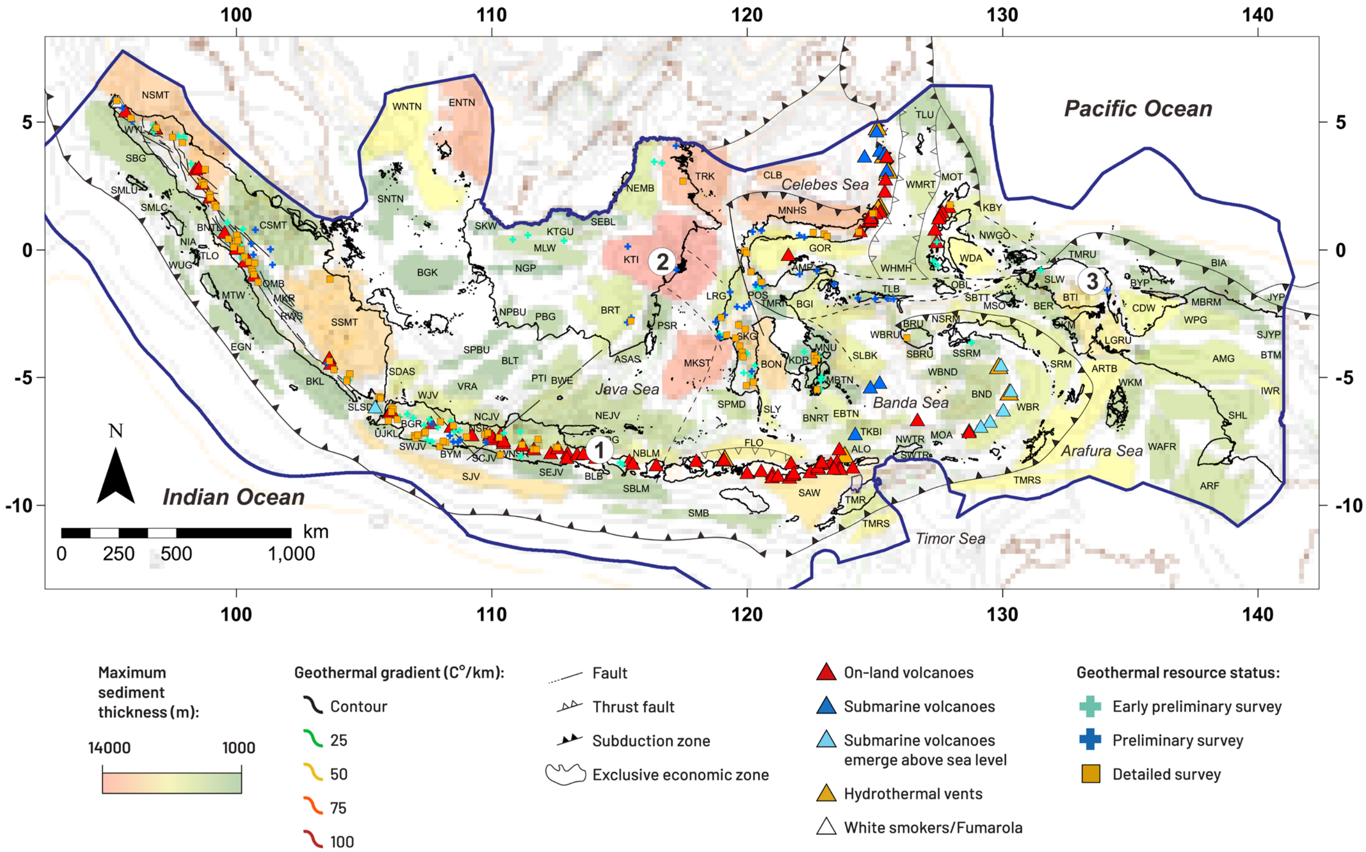
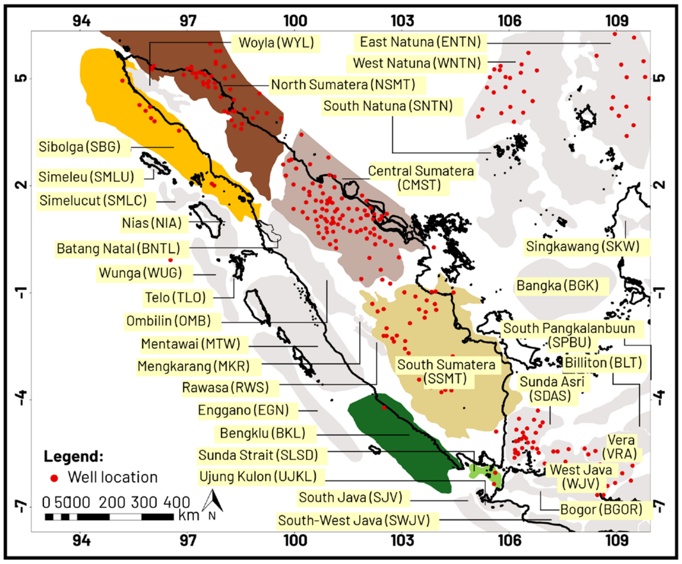


Figure 3.10: Compiled map of the sedimentary basins (Darman, 2019; MEMR, 2022); geothermal gradients (Darman, 2021); regional geologic structures (Raharjo et al., 2016; Sukamto et al., 2011); distribution of on-land (Center for Volcanology and Geological Hazard Mitigation of Indonesia, 2021) and submarine volcanoes (Abbott & Rubenstone, 2024; Aryanto et al., 2023; Kurnio et al., 2015; Špičák et al., 2013); locations of known and underexplored sedimentary-hosted geothermal resources (Indonesian Geological Agency, 2023); and the EEZ boundary (Flanders Marine Institute, n.d.). Numbers in circles indicate surface manifestations discussed in the text: 1. Lusi, 2. Dondang, and 3. Ransiki-Momi Waren. See full reference information at the end of this chapter.

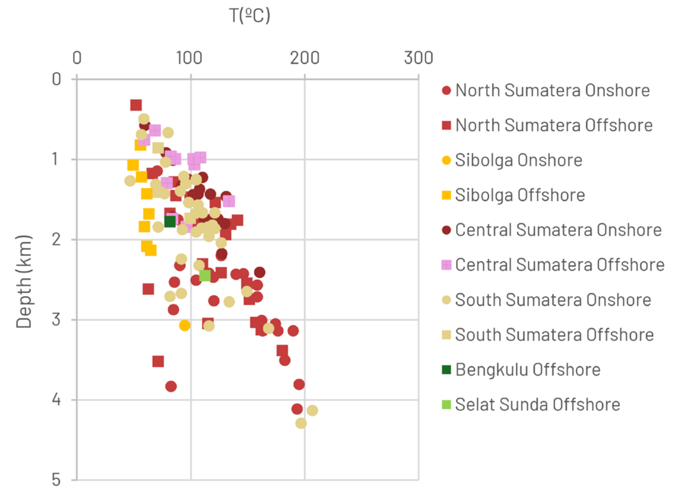
basins across the country. While some are relatively thin, others reach substantial thickness (**Figure 3.10**). Temperature measurements from wells across these basins often indicate elevated geothermal gradients, suggesting notable geothermal potential (**Figure 3.11**). Sedimentary rock-hosted geothermal resources (SHGR) store thermal energy primarily in porous, permeable, and saturated sedimentary rocks such as sandstone. Although porosity and permeability typically decline with depth due to compaction, sandstones may retain porosities as high as 15% at 3 kilometers depth,[48] which is adequate for fluid circulation and within the viable development depth.

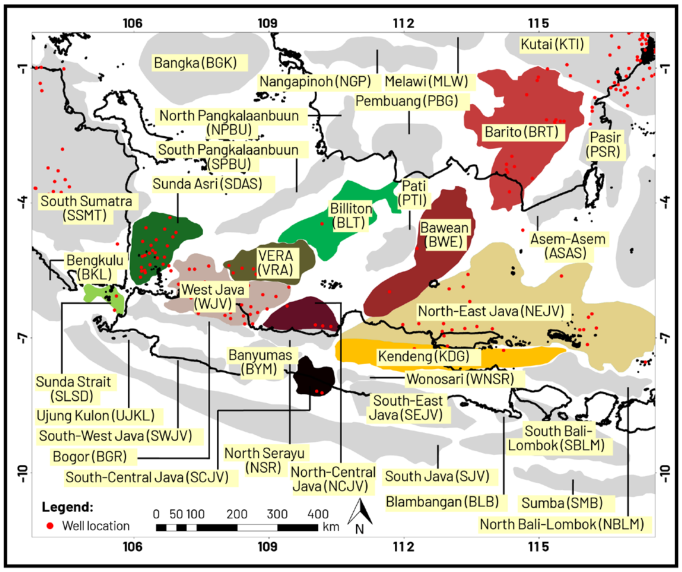
Magmatically influenced SHGRs are characterized by elevated temperatures from nearby magmatic activity. This influence is often detected through gas composition, particularly elevated levels of inorganic carbon dioxide (from magma degassing) and methane (from microbial activity or thermal maturation of organic matter in sedimentary rocks).[49] Regions with thick sedimentary sequences adjacent to active volcanic zones, such as parts of central Italy, have been identified as promising for magmatically influenced SHGR.[50]

GEOTHERMAL GRADIENTS IN OIL WELLS

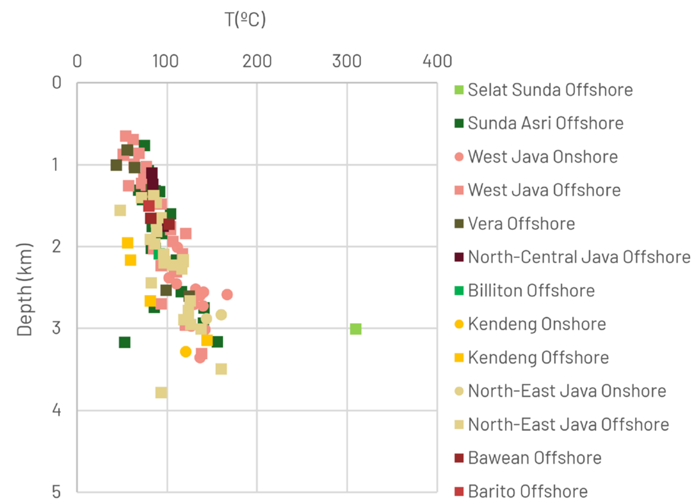


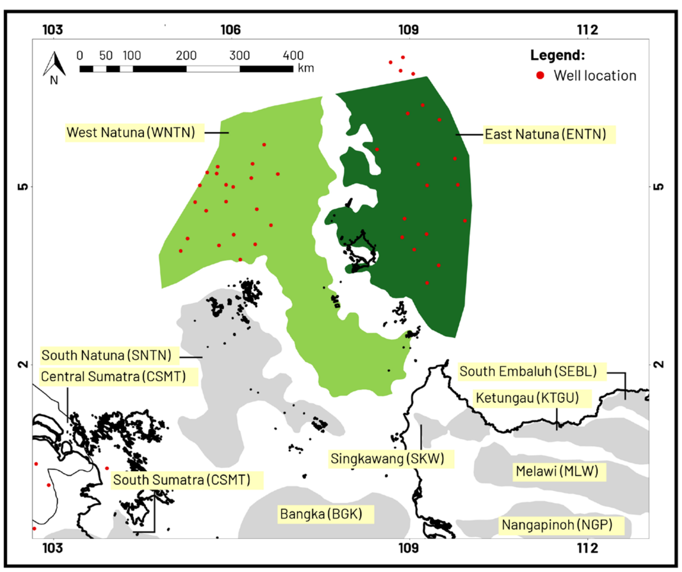
Sumatra Region





Java Region





Natuna

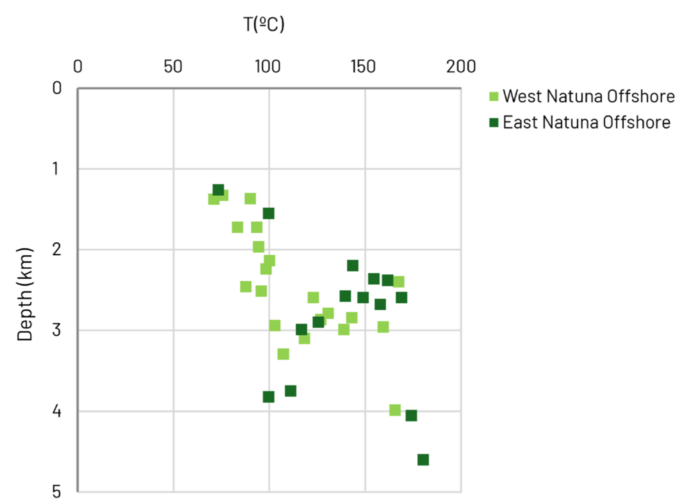


Figure 3.11: Geothermal gradients in selected onshore and offshore oil wells. Source: Compiled from various sources, including Indonesian Petroleum Association. (1981). *Geothermal gradient map of Indonesia* (2nd ed.). AAPG Archives Datapages.

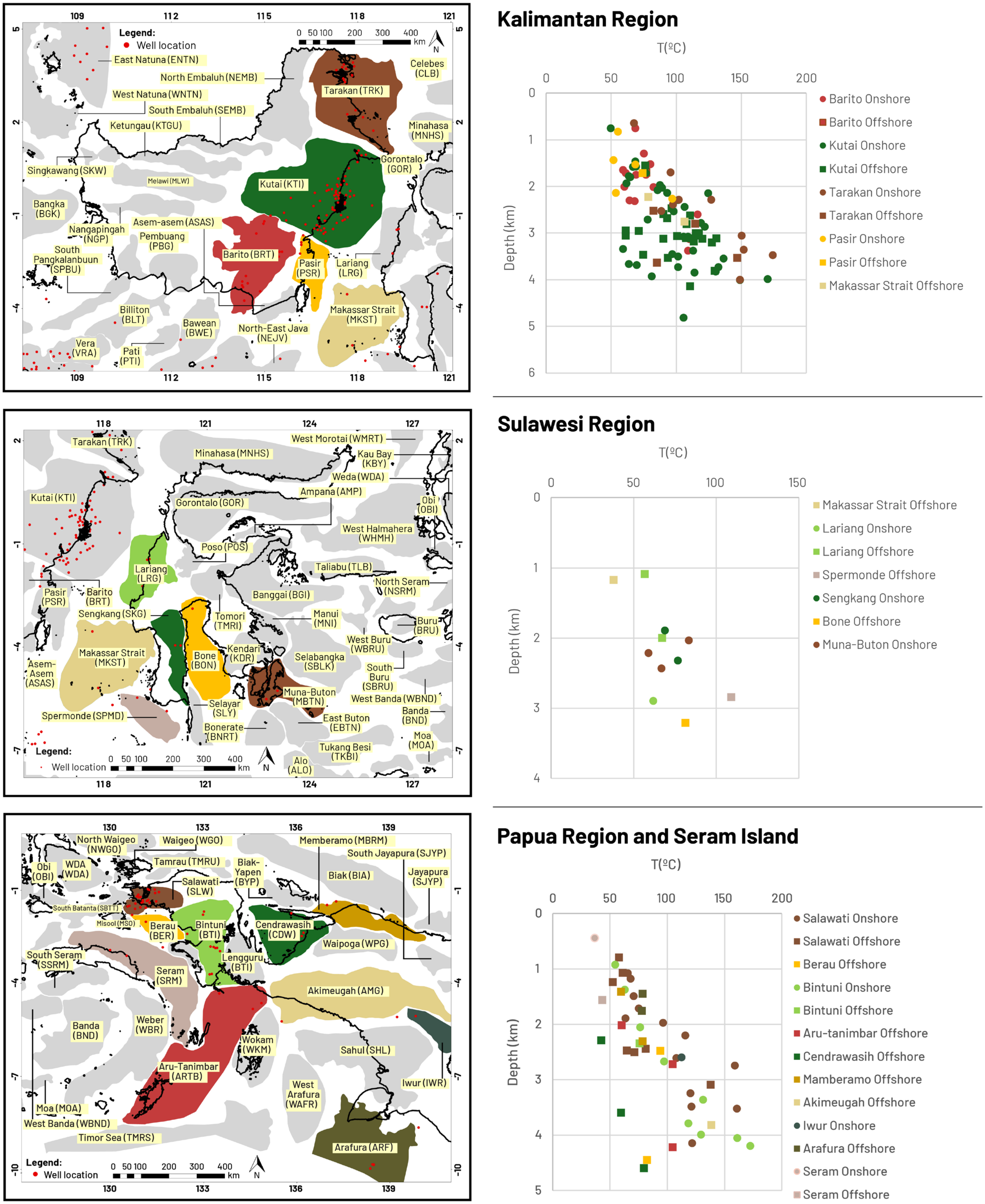


Figure 3.11 continued.

In the Sunda Shelf region, particularly in Sumatra and Java, many major petroleum systems lie in proximity to active magmatic arcs. Surface manifestations have been observed in these areas, although no magmatically influenced SHGR has been formally identified. In northeast Java, the Lusi mud eruption is an example of deep magmatic-sedimentary interaction. Hydrocarbon generation in this region is also linked to intrusion from the Arjuno-Welirang volcanic complex.[51] Seismic evidence from the Kendeng Basin suggests magmatic activity is actively reshaping subsurface structures.[52] While gas composition data would provide more definitive identification, these indicators suggest the presence of magmatically influenced SHGR.

In Sumatra, direct evidence remains limited, but elevated geothermal gradients and well temperature data suggest potential resources (**Figures 3.10** and **3.11**). For instance, while the Sibolga Basin reflects a normal geothermal gradient (<30°C per kilometer), eastern basins such as North and South Sumatra record higher temperatures, with reservoir temperatures reaching up to 200°C, which is strong evidence of magmatic influence, though it may be localized.

In contrast with magmatically influenced SHGR, hot sedimentary aquifer (HSA) systems derive heat primarily from radioactive decay within sediments or from conductive heat transfer from the deep crust or upper mantle.[53,54,55] The latter is related to regional geothermal gradients, which are influenced by crustal thickness and age.[56] Fine-grained sedimentary rocks such as shales and mudrocks are important in HSA systems, not only for their relatively high radiogenic heat production but also for acting as low-conductivity layers that trap heat beneath them (e.g., the Gulf of Mexico Basin in Texas and the Gippsland and Otway basins in Australia).

Sedimentary basins distant from modern volcanic arcs are likely candidates for HSA-type SHGR. For example, the Central Sumatra Basin has been modeled as an HSA resource, with its central zone holding the highest potential.[57] In southern Java, surface manifestations are observed throughout the basin (**Figure 3.10**), but these basins rest on older volcanic deposits and are structurally separated from the active arc by thrust faults,[58] which suggests that residual heat or radiogenic decay is the dominant heat source, pointing to HSA potential.

Other promising HSA prospects are found in Kalimantan (e.g., Tarakan, Kutai, Barito) and Natuna (West and East). These areas lack recent volcanic overprinting and exhibit thick sediment accumulations (>5 kilometers), favoring HSA development. Subsurface data further the potential in these areas, indicating elevated temperature gradients. Surface manifestations have been documented in all three Kalimantan basins. Notably, the Dondang site in the Kutai Basin lies near the core of a pronounced geothermal gradient anomaly and corresponds with the thickest part of the basin (**Figure 3.10**).

In Sulawesi, numerous geothermal manifestations have been identified, especially in the south and southeast. However, available reservoir temperature data suggest that geothermal gradients remain within normal ranges (**Figure 3.11**). Given the manifestation occurrences, basin thickness, and absence of magmatic activity, these regions are theoretically hot sedimentary aquifer candidates, though confirmation will require further study.

In Papua, sedimentary basins are generally thin, and the geothermal gradient is mostly normal, except in the Bird's Head region. Surface manifestations are rare both within and outside sedimentary basins, with the Ransiki–Momi Waren system in the Bintuni Basin being an exception (**Figure 3.10**). Nevertheless, the Bintuni and Salawati basins show subsurface temperatures exceeding 150°C between 3 kilometers and 4 kilometers depth (**Figure 3.11**). The combination of high geothermal gradient and limited surface manifestations suggests the presence of hot sedimentary aquifer potential where permeability, particularly near the surface, may be limited.

Offshore basins such as those in East Sumatra, the Riau Archipelago, the North Java Sea, and the Malacca Strait show deep sedimentation coupled with thermal anomalies, conditions that are favorable for SHGR. Classification as magmatically influenced or hot sedimentary aquifer type can be preliminarily assessed based on reservoir temperature and proximity to

GEOLOGIC FEATURES RELEVANT TO METAMORPHIC GEOTHERMAL POTENTIAL IN INDONESIA

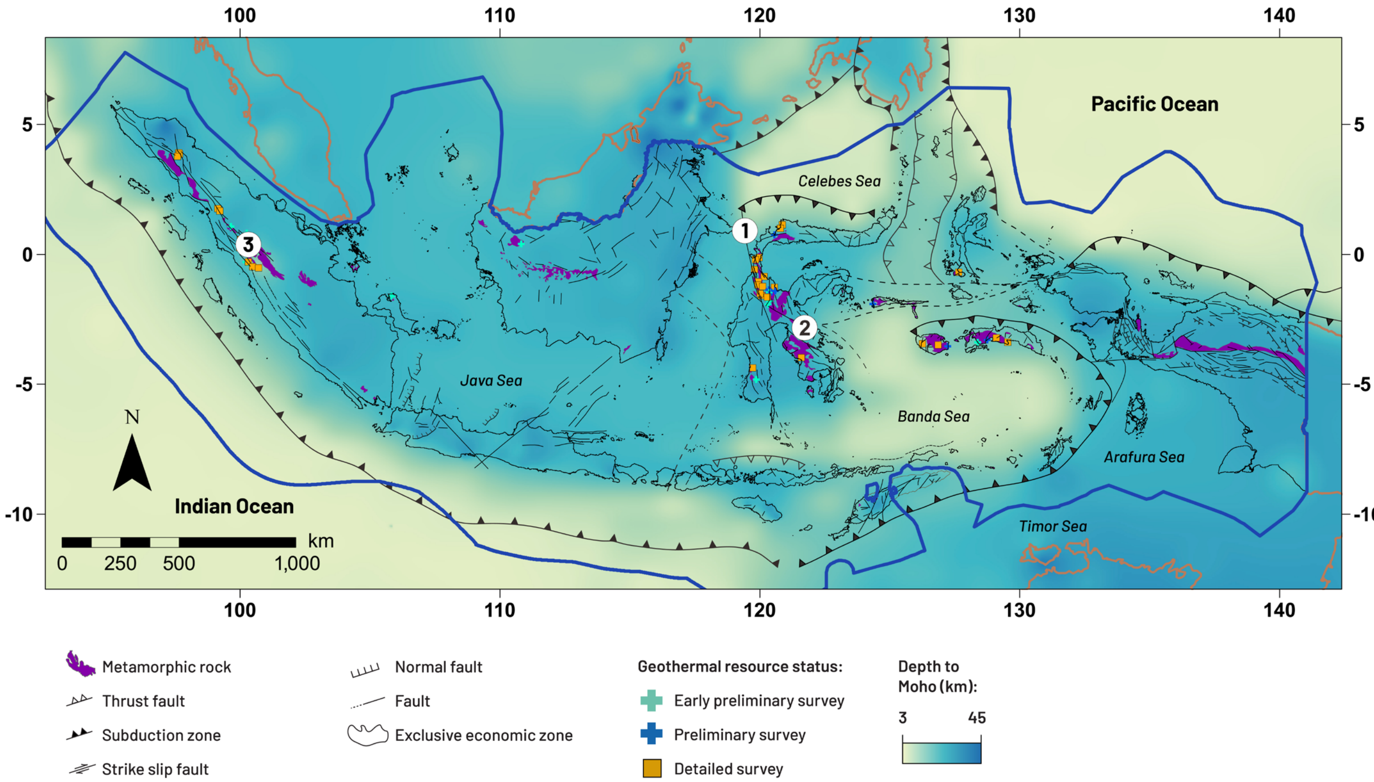


Figure 3.12: Compiled map illustrating the distribution of metamorphic rocks (Setiawan et al., 2012; Sukamto, 2010); geologic structures (Raharjo et al., 2016; Sukamto et al., 2011); locations of known and underexplored metamorphic-hosted geothermal resources (Indonesian Geological Agency, 2023); the Moho depth (Mooney et al., 2024); and the EEZ boundary (Flanders Marine Institute, n.d.). Numbers in circles indicate faults mentioned in the text: 1. Palu-Koro Fault and 2. Matano Fault. See full reference information at the end of this chapter.

volcanic centers. For example, the Sunda Strait Basin exhibits anomalously high temperatures (**Figure 3.11**), likely linked to magmatism from Krakatau, suggesting magmatically influenced SHGR.

Development of SHGRs may benefit from approaches tailored to their distinct thermal and geological characteristics, which differ from those of high-temperature, volcano-hosted systems. Given the typically lower temperature of SHGRs, binary-cycle power plants could serve as a suitable conversion technology. In regions where petroleum production coexists, co-produced geothermal power systems may be considered to harness residual heat from brine or water produced during oil and gas extraction.[59] Furthermore, abandoned petroleum wells could offer promising sites for closed-loop geothermal systems, allowing heat extraction without the need to circulate fluid through the reservoir.[60,61]

Metamorphic Rock-Hosted Geothermal Resources (On Land)

While not yet universally standardized like volcanic- or sedimentary-hosted systems, the term *metamorphic-hosted geothermal resource* (MHGR) is used to describe geothermal systems in which the dominant host rocks are schist, gneiss, or other rocks formed through the metamorphism of sedimentary or igneous protoliths.

Due to their crystalline nature, metamorphic rocks typically have low matrix permeability, making fluid flow highly dependent on fractures and fault systems. Consequently, permeability in MHGRs is often complex, spatially heterogeneous, and temporally variable.[62]

The eastern part of Indonesia—including Sulawesi, Sula, Buru, and Seram—is notable for both the extent of its metamorphic rock exposures and its highly complex structural geology (**Figure 3.11**). Metamorphic units in Sulawesi are closely associated with major fault zones, particularly in the central part of the island.[63,64] These fault–metamorphic interfaces offer favorable conditions for MHGR development by enhancing permeability, enabling deep heat transport, and facilitating fluid circulation. This geothermal potential is further supported by the widespread presence of surface manifestations, especially in proximity to the Palu-Koro and Matano faults (**Figure 3.11**), such as the Bora and Pulu areas.[65] Given that massive granite plutons are present in this region, the primary heat sources for MHGR are most likely the shear heating along faults or radioactive decay from the granite rocks.

Southern Sulawesi may also hold potential for metamorphic-hosted geothermal systems (MHGS), although they are likely less significant than those found in the central region. Evidence of hydrothermal activity within metamorphic rocks has been documented in the Mangolo area, where hot springs and gas emissions emerge from fractures in metamorphic limestones.[66] Similar MHGR potential is observed in Buru, such as in the Wapsalit area[67] and in Seram. In these regions, the heat source is more likely attributed to shear heating, crustal thickening related to active tectonics near the subduction zone, or magmatic activity associated with the subduction process.

In Sumatra, metamorphic rocks occur along the Medial Sumatra Tectonic Zone, with surface exposures mainly in the northern and central regions (**Figure 3.12**). Toward the southeast, the continuity of these units are obscured by thick volcanic and sedimentary cover, although geological evidence supports their subsurface presence.[68,69] Geothermal manifestations in proximity to these metamorphic units suggest active systems. Furthermore, as the Sumatran metamorphic belt intersects the volcanic arc, hybrid geothermal systems may occur, combining magmatic heat sources with metamorphic (and possibly sedimentary) heat reservoirs. Proximity to the Sumatran Fault Zone suggests that these metamorphic rocks may have sufficient permeability for geothermal development.

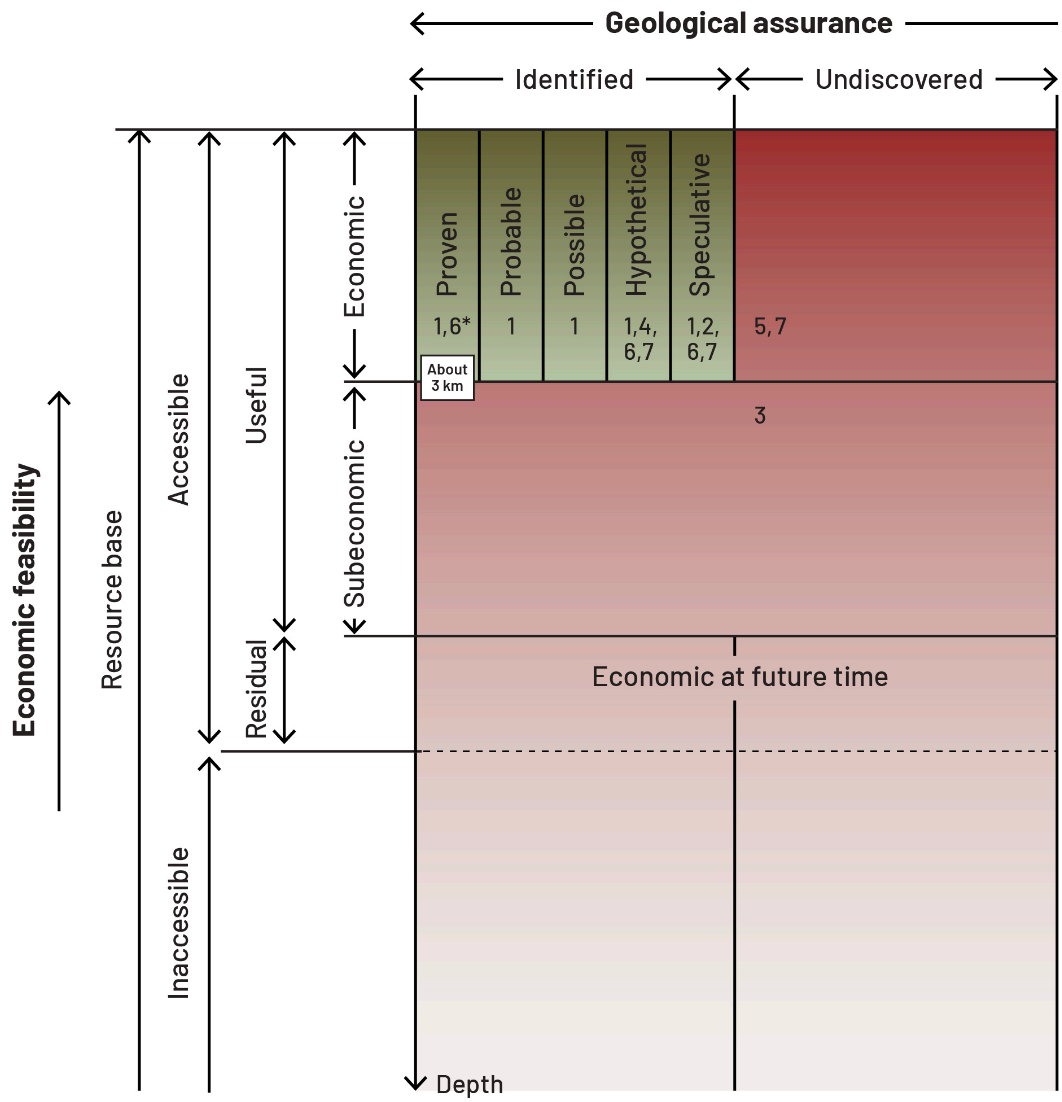
Metamorphic rocks in Kalimantan and Papua may also offer potential for MHGR, despite limited surface manifestations. These regions have undergone intensive faulting, which may enhance permeability in metamorphic formations. In Java, metamorphic rock exposures are localized and too limited in extent for regional mapping. Due to this restricted distribution, they are unlikely to play a significant role in geothermal systems formation. As current mapping is limited to onshore areas, the potential for submarine MHGRs in Indonesia remains largely unexplored.

While intensely fractured, metamorphic rocks can host hydrothermal systems suitable for geothermal production, as demonstrated in Taiwan.[70,71] Moreover, their inherently high thermal conductivity makes them effective heat reservoirs. In areas with limited fracturing, metamorphic rocks present strong potential HDR systems, as demonstrated in the Northwest Geysers project in California in the United States.[72]

However, the development of MHGRs is often constrained by limited knowledge of subsurface system characteristics. Parameters such as temperature, permeability, and fluid chemistry are frequently poorly understood in these settings. Additionally, many metamorphic terranes are associated with mineralization, such as gold deposits in Southeast Sulawesi.[73] These mineral-rich environments often benefit from extensive data sets collected during mining exploration, including geophysical surveys, drill core analyses, and downhole temperature logs. Leveraging these existing data sets can significantly enhance geothermal system characterisation in metamorphic terrains.

This mining-geothermal synergy is demonstrated by the Lihir gold mine in Papua New Guinea. Although Lihir is a volcanic-hosted system rather than MHGR, it demonstrates practical and economic advantages of integrating geothermal energy into mining operations.

GEOTHERMAL RESOURCE ASSURANCE – McKELVEY DIAGRAM



Geothermal resource type:

1. Volcano-hosted hydrothermal (on-land)
2. Volcano-hosted hydrothermal (submarine)
3. Subvolcano supercritical
4. Granite rock-hosted radiogenic hydrothermal
5. Granite rock-hosted radiogenic hot dry rock
6. Sedimentary rock-hosted (* = proven by oil well)
7. Metamorphic rock-hosted

Resource
Energy which could be extracted economically and legally in the near future

Reserve
That part of resources which can be extracted ecnomically and legally at present

Figure 3.13: McKelvey diagram showing the geological assurance levels of various geothermal resources. The division of the "identified" resource follows SNI 6009:2017. Sources: Muffler, P., & Cataldi, R. (1978). Methods for regional assessment of geothermal resources. *Geothermics*, *7*(2-4), 53-89; National Standardization Agency of Indonesia. (2017). *SNI 6009:2017 Classification of geothermal energy resources and reserves in Indonesia (in Bahasa Indonesia)*. Government of Indonesia.

Since 2003, geothermal production at Lihir has reliably supplied electricity, producing 56 megawatts electric as of 2010 to support mine operations and associated infrastructure.[74]

SUMMARY

Indonesia is the second-largest producer of geothermal electricity in the world, yet the existing 2,653 megawatts of electricity produced from conventional resources are only a small fraction of the 23.7 gigawatts of electricity estimated by MEMR. As explored in the next section this number could be significantly higher. Due to Indonesia's diverse geological setting, geothermal resources across the country vary significantly. This variability requires a range of exploration techniques and energy extraction strategies rather than a one-size-fits-all approach. In this chapter, we identified five distinct types of geothermal resources: (1) volcano-hosted hydrothermal, (2) subvolcanic supercritical, (3) granitic rock-hosted radiogenic (hydrothermal and hot dry rock), (4) sedimentary rock-hosted, and (5) metamorphic rock-hosted.

By evaluating the geological assurance levels of these geothermal resource types using the McKelvey diagram (**Figure 3.13**), this chapters shows that resources such as submarine volcano-hosted hydrothermal, radiogenic, and metamorphic rock-hosted systems require additional exploration efforts to elevate their geological assurance classification. Exploration methods should be selected based on their suitability for each geothermal type. Drilling will ultimately prove or disprove a method's technical and economic feasibility. Particularly for the submarine geothermal systems, the study of the environmental baseline must be conducted in a way that mitigates potential negative impacts on the marine ecosystem.

International research advancements in the study of supercritical geothermal should be encouraging for Indonesia—given its numerous volcanoes and high geothermal gradients—to begin systematically exploring the development of such resources. However, significant work remains, particularly in adapting resource identification techniques, establishing development risk mitigation strategies, and ensuring economic feasibility. Supercritical geothermal resources provide a new area of renewable energy development that can produce enormous amounts of energy, yet this resource is the least understood and carries the most development risk due to its extreme temperatures and pressures and its geochemistry. Development requires advanced drilling technologies and strict environmental protections. To overcome these challenges, all stakeholders must have a high level commitment. Above all, the Indonesian government and regulators must provide clear policy frameworks, funding plans, permitting, and special business plans to reduce uncertainty and attract investment.

Chapter 3, Part 2

Expanding the Scope: Next-Generation Geothermal Opportunities

Higinia Torregrosa, Project InnerSpace

Indonesia's unique geological setting offers an exceptional opportunity to advance next-generation geothermal technologies, particularly within its hot sedimentary basins and high-heat-gradient formations that lack the permeability of conventional hydrothermal systems. These resources could support diverse applications, from space cooling and industrial heat to power generation. Using the same methodology that underpinned the IEA's Future of Geothermal *report, Project InnerSpace's national-scale assessment finds Indonesia's geothermal resource base is far larger and more diverse than previously recognized, extending well beyond conventional hydrothermal. We estimate more than 2,000 gigawatts of geothermal technical potential within the first 5 kilometers of the subsurface (excluding protected areas). This amount is two orders of magnitude higher than Indonesia's current conventional geothermal resource potential.*

WHY INDONESIA'S NEXT-GENERATION GEOTHERMAL POTENTIAL MATTERS

As the world's second-largest geothermal power producer, Indonesia already has all of the elements necessary to enter a new phase of geothermal development. While the nation's volcanic arc has long supported conventional hydrothermal projects, these resources represent only a fraction of Indonesia's total geothermal potential. Vast untapped reserves within sedimentary basins and conductive, low-permeability formations—unlockable through technologies pioneered in the oil and gas sector—could enable large-scale deployment of next-generation geothermal systems for heat, cooling, and power across the archipelago.

As discussed in Chapter 1, "Geothermal 101: Overview of Technologies and Applications," next-generation geothermal systems employ technologies originally developed in the oil and gas industry. These technologies include horizontal drilling, improved drill bits, and hydraulic fracturing to access subsurface heat in areas with little or very slow natural fluid circulation (unlike conventional hydrothermal systems).

This chapter expands the scope of Indonesia's geothermal analysis beyond the volcanic arc geological context to include all subsurface heat resources. It outlines the country's total geothermal potential; distinguishes between conventional and next-generation opportunities; and explores how these opportunities can be applied across power, heating, and cooling. The maps in the chapter, made with Project InnerSpace's GeoMap tool,[1] illustrate resource potential, providing a framework for identifying promising regions for development.

Whether for power generation, direct-use industrial heat, or geothermal cooling, this new frontier of geothermal energy can play a transformative role in Indonesia's economy.

As energy and cooling demand accelerates, Indonesia's transition toward sustainable cooling becomes increasingly urgent. Household air-conditioner ownership in Indonesia is expected to increase significantly, from less than 15% today to 50% by 2035 and 85% by 2050,[2] driving a sharp rise in electricity demand and emissions. The projected escalation in cooling demand highlights the need to prioritize geothermal systems as a sustainable pathway for cooling to meet Indonesia's growing thermal energy requirements.

INDONESIA'S TOTAL GEOTHERMAL HEAT-IN-PLACE WITH PROTECTED AREAS

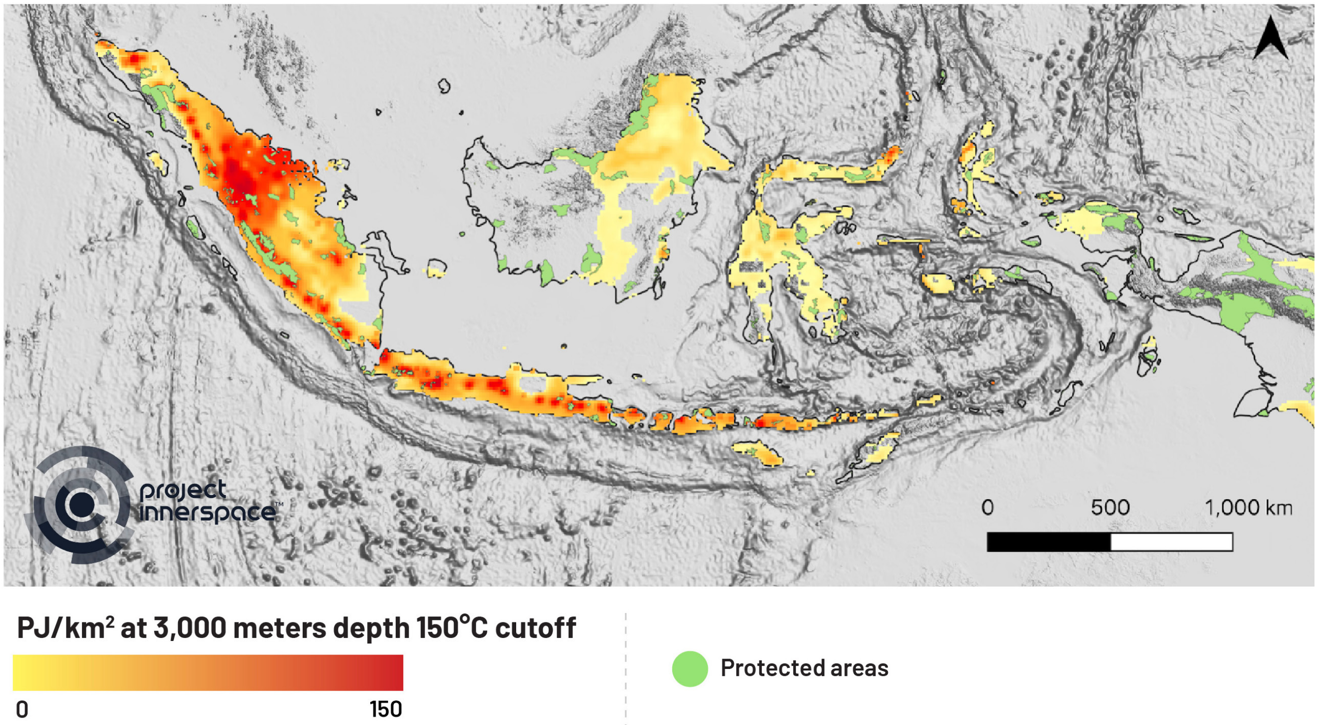


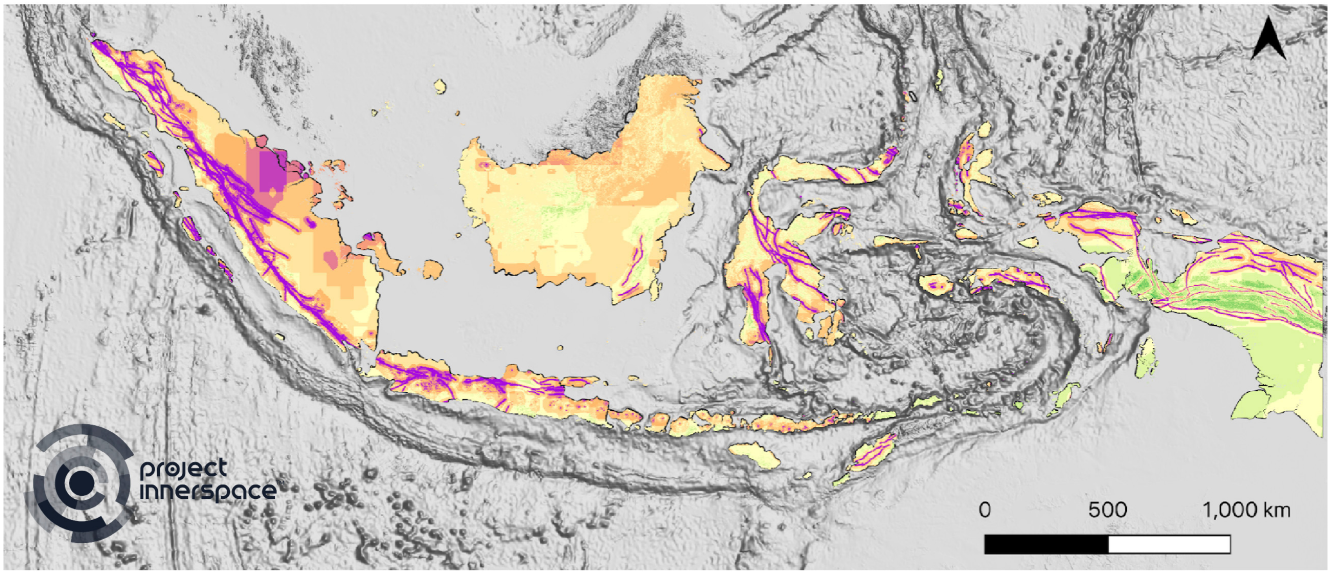
Figure 3.14: Indonesia total geothermal heat-in-place from GeoMap with Indonesia Protected Areas Overlay. The purpose of this map is to highlight the regions with the highest geothermal potential in Indonesia. It represents the cumulative potential up to a depth of 3 kilometers to ensure clear differentiation between areas. Extending the analysis to 5 kilometers would result in almost the entire map appearing red, eliminating meaningful contrasts and insights. Source: Project InnerSpace. (2025). *Heat in Place (PJ/km2) up to 3000 m 150°C cutoff Data Set*. GeoSpace; UNEP-WCMC and IUCN (2025), Protected Planet: [The World Database on Protected Areas (WDPA)][On-line], [October/2025], Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net

Beyond cooling, geothermal heat can play a transformative role in Indonesia's industrial sector. Moderate-temperature resources offer a stable and low-carbon source of process heat for manufacturing, food processing, and other energy-intensive industries. At higher temperatures, engineered geothermal systems developed in low-permeability formations could enable electricity generation in areas previously overlooked. Together, these applications demonstrate the versatility of geothermal energy in meeting Indonesia's growing energy demand while advancing its sustainability and decarbonization goals. (See Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential," for more information.)

TOTAL GEOTHERMAL RESOURCE POTENTIAL

To visualize the spatial distribution of geothermal resources across Indonesia, regardless of resource type, Project InnerSpace produced the map shown in **Figure 3.14**, which highlights onshore areas with the greatest geothermal theoretical potential. Geothermal theoretical potential refers to the physically usable energy supply, or heat-in-place (HiP). The underlying data set was generated using the HiP method, following

INDONESIA'S GEOTHERMAL RESOURCES MAP



Potential geothermal resources based on **Weighted Overlay Analysis (WOA):**

- Conventional (hydrothermal power)
- Next-generation (power)

Next-generation (direct use):

- Direct use and district cooling
- Low-temperature industrial heating and cooling
- Geothermal heating and cooling

Figure 3.15: Indonesia's geothermal resource map identifying regions best suited for geothermal technologies based on underlying thermal and subsurface characteristics, via the Project InnerSpace Weighted Overlay Analysis, designed to identify and prioritize areas with geothermal potential based on key geological and geophysical factors. Source: Project InnerSpace. (2025). *Indonesia Weighted Overlay Analysis Data Set*.

the approach of Pocasangre and Fujimitsu.[3] This method divides the total subsurface heat into two components: heat stored in the rock matrix and heat contained within the pore fluid. The map presents HiP estimates in petajoules per square kilometer (PJ/km^2) for a 3,000 meter thick interval between 0 meters and 3,000 meters depth, applying a minimum subsurface temperature cutoff of 150°C.

The map in **Figure 3.14** reveals extensive warm zones beyond Indonesia's volcanic arc, with notably high values across the Central and South Sumatra sedimentary basins, as well as regions underlain by granitic and metamorphic basement complexes in Java, Sumatra, and Sulawesi. These areas, characterized by low natural permeability but elevated subsurface temperatures, represent good candidates for next generation geothermal technologies that rely on engineered reservoirs to enhance fluid circulation and heat recovery. Additionally, volcanic and volcanic-sedimentary formations near existing hydrothermal fields offer near-field unconventional targets, where next-generation technologies could expand resource use beyond conventional systems.

In late 2024, the International Energy Agency (IEA) published an analysis of the technical heat energy provided by geothermal resources around the world.[4] The analysis relied on subsurface data calculations from Project InnerSpace's GeoMap tool to estimate the resource potential. The report calculated the recoverable quantities of geothermal energy at various price points given today's technology. For Indonesia, the team calculated the cumulative geothermal technical potential in gigawatts electric (GWe), derived from HiP estimates for a 5000 meters thick isopach interval between 0 meters and 5000 meters depth, using 150 °C as the minimum subsurface temperature cutoff. Using Augustine's methodology,[5] the team converted petajoules into gigawatts, considering a recovery factor (20%), capacity factor (0.9), efficiency (calculated as function of temperature), and plant life (20 years). Project InnerSpace's data show that if Indonesia were to develop all available geothermal resources within the first 5 kilometers of subsurface (excluding protected areas), the country would have a geothermal technical potential of 2,160 gigawatts, or more than 21 times its 2024 total installed power capacity and two orders of magnitude greater than current estimates of conventional geothermal potential. This technical potential is a fraction of the theoretical potential that can be used with current technology.

CONVENTIONAL AND NEXT-GENERATION RESOURCES IN INDONESIA

The map in **Figure 3.15** illustrates the distribution of geothermal potential across Indonesia and helps identify suitable areas for different types of development. It distinguishes among the following potential geothermal resources:

- Conventional (hydrothermal-power)
- Next-generation geothermal (power)
- Next-generation geothermal (direct-use):
    - Direct use and district cooling
    - Low-temperature industrial heating and cooling
    - Geothermal heating and cooling

These categories are derived from GeoMap's weighted overlay analysis,[6,7] a GIS-based method that integrates multiple geological and geophysical data sets, applying relative weights to each factor to pinpoint areas with the greatest geothermal potential. The resulting map highlights the volcanic arc, where potential and proven conventional hydrothermal systems are concentrated, as well as potential near field regions and other hot dry rock regions that offer promising conditions for next-generation geothermal power development. Beyond these areas, extensive sedimentary basins present opportunities for geothermal direct-use applications such as cooling and heating.

Together, these patterns illustrate the range of both established and emerging geothermal opportunities across Indonesia's diverse resource base.

Chapter 1, "Geothermal 101: Overview of Technologies and Applications," details the various types of geothermal applications available today, but each has specific uses in Indonesia.

Conventional Hydrothermal Resources

Indonesia's geothermal industry is predominantly based on volcano-hosted hydrothermal systems located along the Sunda–Banda volcanic arc, which stretches across Sumatra, Java, Bali, Flores, and parts of Sulawesi. These active volcanic zones host the country's most productive geothermal fields, including Gunung Salak (West Java), Sarulla (North Sumatra), Darajat (West Java), Kamojang (West Java), Wayang Windu (West Java), and Ulubelu (South Sumatra).

Most of Indonesia's geothermal power generation relies on high-enthalpy hydrothermal resources, primarily exploited through flash-type power plants. Among these, the Gunung Salak and Sarulla plants, both flash-type plants, stand out not only as Indonesia's largest geothermal facilities but also as two of the top 10 geothermal power plants worldwide. A smaller portion of production comes from dry-steam systems, such as those operating at Kamojang and Darajat in West Java.

Next-Generation Geothermal Power Resources

Next-generation geothermal power systems offer the potential to expand geothermal electricity production beyond Indonesia's volcanic regions. These technologies enable the extraction of heat not only from naturally permeable volcanic rocks but also from adjacent or near-field low-permeability formations and non-volcanic terrains. Next-generation approaches show potential in Indonesia's granitic formations with high radiogenic heat production, metamorphic complexes, and other potential crystalline basement types, including the tin-granite belts of Bangka-Belitung; the South Sumatra basin basement; and the granitic complexes of Kalimantan, Western Papua, and Central Sulawesi.

Next-Generation Geothermal Direct-Use Resources

While conventional and next-generation geothermal systems focus primarily on electricity production from high-temperature resources, new approaches are extending geothermal potential into moderate-temperature environments such as sedimentary basins. This shift moves geothermal energy beyond power generation toward broader direct-use applications, including cooling and heating, that can advance both energy efficiency and decarbonization goals.

In Indonesia's tropical climate, where space heating has limited relevance, geothermal direct-use opportunities are better suited for industrial processes, agricultural activities, district cooling for large commercial or residential developments, and data center operations. Together, these opportunities demonstrate how geothermal energy can provide continuous, low-carbon heating and cooling solutions across diverse environments, complementing power generation and enhancing overall energy resilience. For more information about cooling and heating opportunities in Indonesia see Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential."

Next-Generation Geothermal Cooling

Sedimentary basins across Indonesia offer highly favorable conditions for geothermal cooling, characterized by high porosity, good permeability, and moderate temperatures ranging from 40°C to 150°C. These geological settings provide an excellent foundation for next-generation geothermal cooling systems that use the Earth's natural heat exchange capacity to deliver efficient, low-carbon cooling solutions.

Next-generation geothermal cooling refers to the use of geothermal reservoirs or ground source systems to replace conventional, energy-intensive air-conditioning with more sustainable and energy-efficient alternatives. As Indonesia's cooling demand is projected to rise sharply over the coming decades, geothermal cooling technologies such as ground source heat pumps (GSHPs) and district cooling networks (DCNs) offer scalable pathways to reduce electricity consumption, lower grid stress, and enhance climate resilience. Furthermore, data center cooling applications can leverage geothermal loops or aquifer systems to dissipate waste heat and maintain stable year-round temperatures. See Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential," for more insights on geothermal and data centers.

Next-Generation Geothermal Industrial Heat

Several sedimentary basins across the country demonstrate strong potential for next-generation geothermal heating, especially where moderate-temperature resources (40°C–150°C) coincide with major industrial corridors and agro-processing hubs. In Central Java's Dieng Basin, geothermal heat is being planned for greenhouse nurseries that support high-value crops such as citrus, avocado, and coffee. In South Sumatra, sedimentary formations could support fish curing and sugarcane processing, while in East Java, similar geothermal gradients align with dairy and textile industries that require steady heat below 150°C. These examples (drawn from Chapter 4, "Beyond Electricity: Indonesia's Thermal Energy Demand and Direct Use Potential") illustrate how sedimentary geothermal systems—due to their permeability, porosity, and broad distribution—can provide reliable, low-carbon process heat to industries and agro-processing hubs, offering a practical pathway to decarbonize Indonesia's manufacturing and agricultural sectors.

CONCLUSION

In Indonesia, while volcanic regions display the highest thermal gradients, vast conductive systems dominate much of the archipelago's subsurface. The nation's sedimentary basins and crystalline regions contain enough thermal energy to support hundreds of gigawatts of clean electricity, direct-use heat, and low-carbon cooling. Using the same methodology that underpinned the IEA's *Future of Geothermal* report, Project InnerSpace's national-scale assessment finds that Indonesia's geothermal resource base is far larger and more diverse than previously recognized, extending well beyond conventional hydrothermal. Project InnerSpace estimates that more than 2,000 gigawatts of geothermal technical potential can be found within the first 5 kilometers depth (excluding protected areas), two orders of magnitude higher than current estimates of hydrothermal potential. By harnessing subsurface heat for power, heating, and cooling, Indonesia can turn its geologic diversity into a foundation for sustainable, low-carbon growth.

ADDITIONAL SOURCE INFORMATION

Figure 3.5 References

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