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A new idea: The possibilities of offshore geothermal system in Indonesia marine volcanoes

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Abstract. High temperature geothermal systems in Indonesia are commonly associated with volcanic systems. It is believed that volcanoes are acting as the heat source for a geothermal system. Right now, most of the operating geothermal fields in the world are assosiating with volcanic settings which known as the conventional geothermal system. Volcanoes are created in active tectonic zone such as collision zone and MOR (mid oceanic ridge). The later is the one which formed the marine volcanoes on the sea floor. The advances of today's technology in geothermal energy has created many ideas regarding a new kind of geothermal system, including the ideas of developing the utilization of marine volcanoes. These marine volcanoes are predicted to be hotter than the land system due to the shorter distance to the magma chamber. Seamounts like NEC, Banua Wuhu, and Kawio Barat in Indonesia Sea are good spots to be studied. Methods such as remote sensing using NOAA images, sonar, and MAPR are commonly used, eventhough these would be more accurate with more detailed techniques. This has become the challenge for all geothermal scientists to overcome for a better study result.

1. Introduction

The offshore geothermal has begun to intrigue some of the scientist minds as a result of out-of-the-box thinking in geothermal. Even though there are a lot of issues that needs to be handled, this doesn't stop them to research more about the possibilities of offshore geothermal system. The research has begun in several countries such as Italy, known as the Marsili Project, and Iceland. Some said there is also an underway project for offshore geothermal project in Gulf of California. So far Italy leads in offshore geothermal energy development with its Marsili Project which was planned to be finished around 2015. Many studies have been conducted, from the study of the marine volcano as the heat source to the technologies to exploit the energy in the future, especially the power plants and the pipes.

As we know volcanoes are not only located on land but there are still a lot more in the ocean, which called seamount. Some of the examples are Mt. Emperor of China and Mt. Niewerkerk, or known as NEC volcanic complex. Both of these mountains located in Banda Sea, although they are not much known since there was only one expedition conducted in 1934 by Snellius. There are also Mt. Banua Wuhu, Mt. Submarin, and Mt. Kawio Barat which located around Sangihe Island. Unlike NEC volcanic complex, these seamounts are more known. There are several records of their eruption which starts around 1800 and some still considered active.

Located around more than 3000 m in depth, these underwater volcanoes are predicted that it could be acting as the heat source of the offshore geothermal system. With the surrounding sea water it means the system has literally unlimited supply water for the system. The cracks in the sea floor are allowing the water to go in and out the system becoming the recharge and the discharge zone. Even though all of these are still possibilities, the idea of offshore geothermal is interesting to be discussed and studied further.

2. Seamounts

Marine volcanoes are believed to be a result of sea floor spreading and mostly found in Mid Oceanic Ridge (MOR). The spreading caused the magma to move towards surface. The usual type of eruption is effusive thus creating a shield type volcano which spread several times larger than the stratovolcano type. Magma is rapidly cooled from the impact with the sea water, causing the magma to form an igneous rock with pillow lava structure. The rapid cooling could also create autobreccia, a type of breccia where the component and the matrix are the same. The magma type is different than the magma in on land volcanoes. In marine volcanoes the magma is basaltic due to the magma path to the surface is shorter thus minimizing the contact with surrounding rocks.

According to the volcano height, underwater volcanoes can be divided into 3 kinds; (1) Seamounts, marine volcanoes which can stand up to 1000 m from the sea floor, (2) Hills, a smaller volcano with the height below 1000 m from the sea floor, (3) Pinnacle, which looks like a small pillar. In this paper, seamount is the main focus because it is predicted to have a significant heat to be considered a heat source.

2.1. Seamounts Types

Usually the research for the study of seamounts is conducted using remote sensing images taken from ships or close up videos and pictures taken by a drone. This equipment can be found in National Oceanic and Atmospheric Administration (NOAA). These remote sensing images are limited to the shipping line around the world. Up close images and videos taken by a drone or Remotely Operated Vehicle (ROV) gave detailed information regarding the seamounts. These seamounts can be located several thousand under the mean sea level, like Mt. Kawio Barat and Mt. Submarine 1922. Some are not even having enough information such as Mt. Emperor of China and Mt. Niewerkerk.

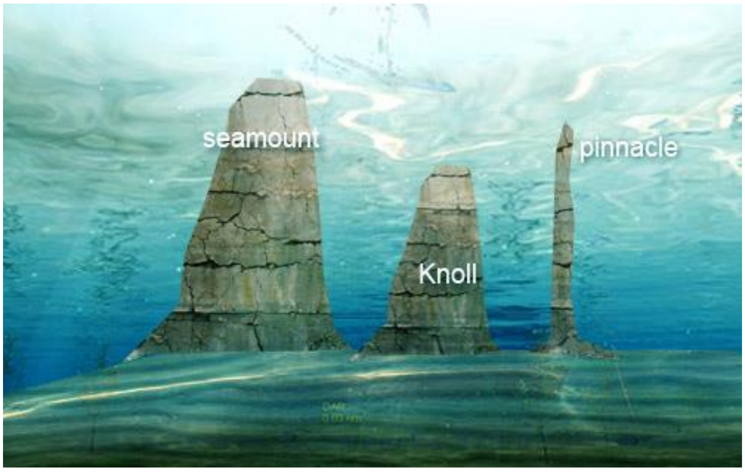

Figure 1: Illustration of seamount type (Seamount, Sea Knoll, and Pinnacle)

Seamount type's elevation can vary from 1000 m to a smaller elevation feature which has the same function as the larger feature. Sea knolls, hills, and pinnacle can even be as low as 100 m[1]. Pinnacles are important in marine ecological system, often isolated and can reach near the surface.

Some seamounts can erupt above the sea level somewhere in the ocean so the peak will submerge above the surface. After a long time waves then will eroded the top portion thus making it flat. The sea floor will gradually move away from the oceanic ridge thus making the seamounts submerged. This is known as guyots or tablemount. Guyots located around 200 m below the surface and the width can exceed 10 km. Seamount never reach the surface thus maintained its volcanic shape.

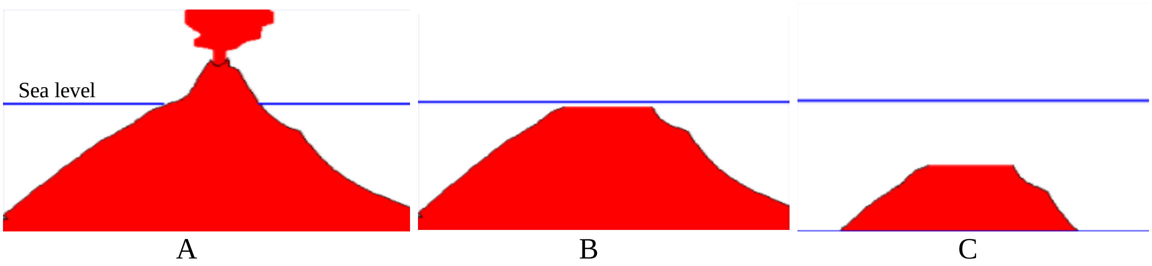

Figure 2. Illustration of Guyots establishments steps. Seamounts which erupt above the sea level will be eroded, then will be submerged due to the sea floor movement

2.2. Seamounts Profile

Although there are quite a lot of seamounts in Indonesia, only some of the seamounts are written here as examples. The reasons are these seamounts are widely known around the world and sparked some interests for the researcher. Informations about the seamount, such as height and eruption record, are already available from earlier researches. The unique characteristics are also one of the other reasons. But some are still very much unknown but still debatable about their existences. The seamounts mentioned below are some of the most infamous seamounts in Indonesia Sea.

2.2.1. Kawio Barat

This seamount is pressumed to be the biggest seamount in Indonesia. Research was conducted by a joint operation between Indonesia-United States in Sangihe Sea in 2010. The image and sonar taken from NOAA's Okeanos showed that this seamount is approximately has height around 3000 m and located around 1800 m below the sea level. A video was taken by the *Little Hercules* ROV during its second dive in June 2010 showed active hydrothermal vents (white smoker and black smoker) on the west side of the seamount[2]. The volcanic rocks around the hydrothermal vent was covered in white sulfur deposits and became the home of many underwater organism, such as shrimp and stalked barnacles. Along with the barnacles, imagery disclosed a field of sulphide chimneys, pressumably precipitating from the hot, mineralized vent fluids as they cooled and mixed with seawater. This hydrothermal vents proved that Kawio Barat Seamount is still active and the size is indicating a large heat source underneath.[3]

Figure 3. Pictures taken from the Little Hercules ROV in June 2010. A picture of sulphide chimneys in Kawio Barat Seamount (above). An active hydrothermal vent was found on the summit (below, left). Sulphide-rich hydrothermal vents was also found created home for many underwater organism (below, right).[2]

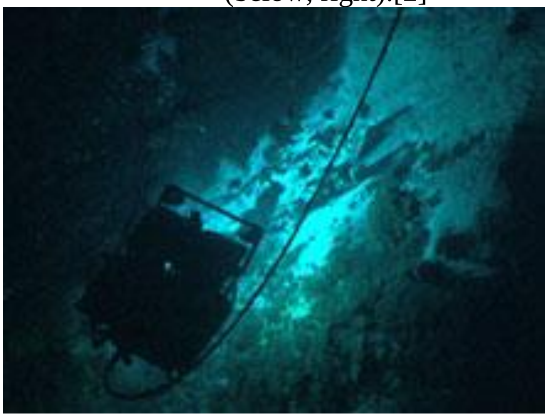

Figure 4. An active hydrothermal vent in Kawio Barat Seamount taken from the "Little Hercules" ROV, Jne 2010[2]

Figure 5. A sulphide-rich qhydrothermal vent in Kawio Barat Seamount taken from the "Little Hercules" ROV, Jne 2010.[2]

2.2.2. Submarine

There are not much record of this seamount except that it was erupted in 1922 after a series of earthquakes since 1912 in between Mindanau and Sangir Talaud Island. Geographically this seamount is located between 4°-6° LU and 124°-126° BT. The nearest city is Tahuna. The eruption in 1922 created a big wave along the Sulawesi northern beach. After that there were no eruption recorded. The eruption were dated around February 1, 1922.[4]

2.2.3. Banua Wuhu

Banua Wuhu Seamount, or Banua Buaya, located southwest of Manghetang Island in North Sulawesi province. Geographically it is located in 3°08'16" LU and 125°29'26" BT. The only access to this seamount is by using small boats from Tagulandang[5]. The summit depth is estimated only around 5 m from the sea level. The eruption type is considered an explosive type and the history is a prove. In 1835 the summit was around 90 m above the sea level and in 1919 it was around 12 m above the sea level. It is predicted that the eruption destroyed the summit making it smaller each time. Right now it's still considered ative due to the presence of the bubbles from the cracks in the seamount. It is composed mostly by fall pyrocalstic and lava. The eruption was predicted around April 16 – Agustus 27, 1904[6].

The eruption on August 27 is treted by the Catalogue of Active Volcanoes as an independent event[6]. Banua Wuhu eruption in 1889 was an extrusion of a lava dome and catagorized as a submarine eruption. This eruption created tsunami. While in 1904 was described that the eruption was located in the central crater as a submarine eruption which created a volcanic island[3][4].

Figure 6. Location of Banua Wuhu (south), Kawio Barat (north) and Submarine 1922 Seamounts (west of Sangihe Islands). All of them are located in Sangihe Ridge, to the north of Sulawesi Island.

2.2.4.Emperor of China – Nieuwerkerk (NEC)

Both of this seamount presences were still questioned by some scientist and has become an interesting debate topic wether they are real. There was only one expedition regarding these seamounts, and that was Snellius Expedition in 1934. Some believed that these seamounts were mere reefs. In 1929 there was a phenomena where many dead sea turtles and fished washed ashore, which usually caused by underwater eruption. Emperor of China was a seamount rising nearly 1500 m above its surroundings, having a summit which was 2850 m below the sea level. Nieuwerkerk was a NNW – SSE stretching seamount with two tops at a mutual distance of more than 7 km, rising about 1800 m and 1900 m above the bottom of the sea. These seamounts created a ridge called NEC. Both these seamounts are predicted to have typical shield-volcanic topography.[4]

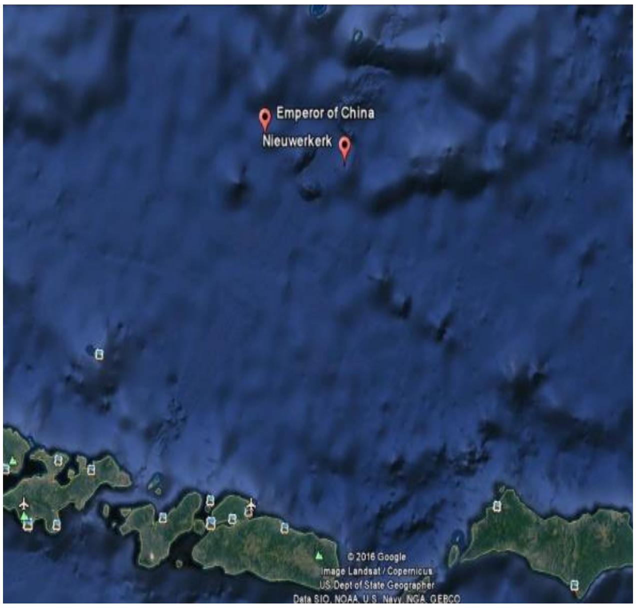

Figure 7. Location of Emperor of China and Niewerkerk Seamounts. Also known as NEC Seamounts Complex. Both are located in the Banda Sea.

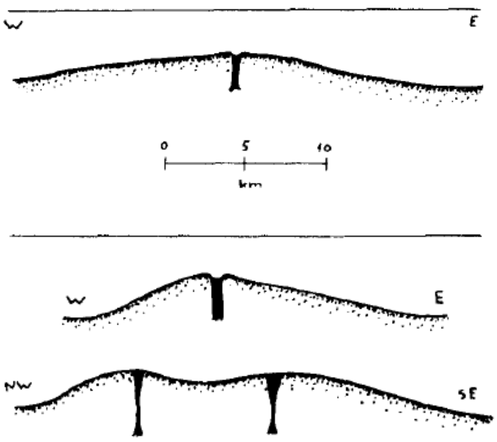

Figure 8. An estimated cross section of Emperor of China (above) and Nieuwerkerk Seamount (below) according to Neumann van Padang.[4]

3. Offshore Geothermal System

Until now there hasn't been many real practices regarding the utilization or even research on offshore geothermal system. The main reason being is that the cost is still too high comparing the systems on land and there are still much on land system that hasn't been discovered yet. But it still cheaper and more reliable in the long run compared to wave power, according to Engineering Committee on Oceanic Resources (ECOR). It is predicted that most of this system is a liquid dominated system since the excess of sea water around the system and the fluid discharged from the system is in liquid form due to high pressure since most seamounts located several thousand meters deep.

Offshore geothermal project has started for quite a long time. The first attempt to utilize the offshore geothermal is Italy, which conducted by Unione Geotermica Italiana. This project is known as the Marsili Project. The research target area is around Marsili Seamount. Its main target is to have an early production of 600 MW after 10 years and approximately 1200 MW after 15 years. Although until now the technology still under research and not yet published. Other countries have also put interest in offshore geothermal energy and began to study other places with good potential, such as in Iceland and Gulf of California. For Iceland, this research is the result of "out of the box" thinking, to always one step ahead in geothermal utilization technology since Iceland's electricity is depending very much with geothermal power. There is also research on hydrothermal vent in Gulf of California which being conducted by the National University of Mexico. This research also for testing their prototype for submarine power plant, an new technology for utilizing heat from hydrothermal vents.

There are also advantages in using offshore geothermal system. In any resource production, either oil, geothermal, or even mining, there will always a need for land to build the site for drilling and production. In offshore geothermal, no land space is required so there's no need for a detailed visual environmental assessment although it will need some general environmental assessment. The surrounding seawater provides literally an unlimited supply of geothermal fluid and the cold seawater can work as the cooing fluid so there will be no need for condenser or cooling tower

Aside from the cost, there is also another problem that need to be taken care of which is the technologies. Even though the system is not supposed to be so different with the land system geothermal, but the material and production techniques need to be adjusted with the environment. For example the fluid which contain high level of salinity since the fluid used in this system is sea water, the power plant structure that can withstand wave, and pipes that can hold higher pressure or preserve the heat.

There are several concept methods visualization in terms of utilizing the offshore geothermal system; platform based power plant, land based power plant, underwater power plant, binary power plant based on land, and thermoelectricity power station.

3.1. Offshore Geothermal System Components

In general, there are 4 main components for the system to work; heat source, reservoir, recharge, and discharge. Each one of these components holds specific characteristics. Heat source is the main energy in this system which will heat up the fluid. Reservoir is acting as the storage of that fluid and usually composed of rocks with high permeability. Recharge is a zone where the fluid comes into the system to refill the system. The heated up fluid will be moving upwards toward the surface due to it's low density through cracks in the rock to the surface which called the discharge. Both recharge and discharge are contain high permeability.

There are not much differents between on land geothermal and offshore geothermal system. Generally the basic concept is the same, but the components may consisted of different material. As stated before the seamount can become the heat source for the offshore geothermal system. The difference is the magma isn't as acidic as the one on land due to shallow magma kitchen. The temperature is usually hotter too with approximately around 800 – 1200ºC. Seamounts are created from seafloor spreading thus located mostly in a ridge. Seamounts are composed mostly by igenous rocks and pyroclastic. This also creates prediction that the reservoir rocks will mostly has the same composition. Seawater is cooling the lava rapidly and making igneous rocks with autobreccia texture, creating cracks in the rocks and increase its permeability for the reservoir. These cracks, together with the underwater geological structure, can also become the fluid pathway to the surface or into the system and become the recharge and discharge zone. One of the seamounts that has both recharge and discharge is Mt. Banua Wuhu. The bubbles emitted from the seamount indicates that there might be cracks which become the path for the fluid to go in and out of the system.

The most common surface manifestation is hydrothermal vent. It starts with the seawater seeps into the sea floor through cracks then get heated up and moved upwards toward the seafloor. This hot fluid also contains minerals from the interaction with surrounding rocks. After discharge to the surface it meets with cold sea water and decrease the temperature. With the temperature decreasing the minerals dissolved are deposited near the discharge area. After a while it will accumulate and create sulphide-rich chimney. Hydrothermal vent can discharge black smoke or white smoker depending on the composition. Black smoke indicates there are mafic minerals involved such as magnesium and iron minerals while white smoke indicates that felsic minerals are the main dissolved minerals in the fluid[7]. These hydrothermal vents can be measured up to ~200 – 400ºC. Hot seawater from the vent won't be turned into steam because of extreme pressure underwater. Mineral ore deposits such as copper ore are commonly found near hydrothermal vent and some even become the world's richest ore deposit.

Looking at the surrounding environment, it can be predicted that the system might be a volcanic hydrothermal system with high terrain and it will be liquid dominated. The hot fluid discharge might mostly be in liquid form due to extremely high pressure.

3.2. Exploration Method

The differences in environmental aspect between on land and offshore geothermal have created different methods to explore it. The main difference is that offshore geothermal system isn't as visible as land geothermal since it's located deep underwater. Basically the first thing to do is check wether the system is available or not. Special tools needed to study this subject. Scientists have developed some research methods and have been used in some explorations including Marsili Project and offshore geothermal prospect around Iceland.

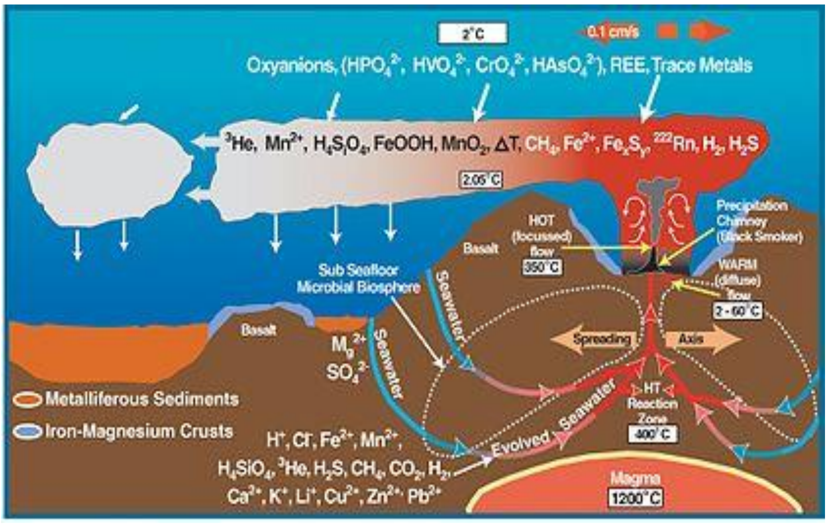

Figure 9. Hydrothermal vent forming process

3.2.1. Sound Navigation and Ranging (SONAR)

This method is often called by multibeam swath bathymetry or echo sounding and used for mapping the ocean floor. It can be useful to locate hydrothermal vents on the sea floor. Basically, hydrothermal vents will emit gas bubbles from within the sea floor and this will create accoustic scatter which is used to locate the hydrothermal vent. The analysis for the accoustic scatter can be seen in figure 11[8].

There are another method called side scan sonar. This method is using the back scattering strength of multibeam data and then analyze it. There are several datas that can be obtained from side scan sonar. It could be used to identify rock types and structures so the ocean floor composition and geological settings could be obtained. It could also identify and distinguish between each lava flow event, landslide, and fault so it can tell the differences in the igneous rocks source and magma characteristic.

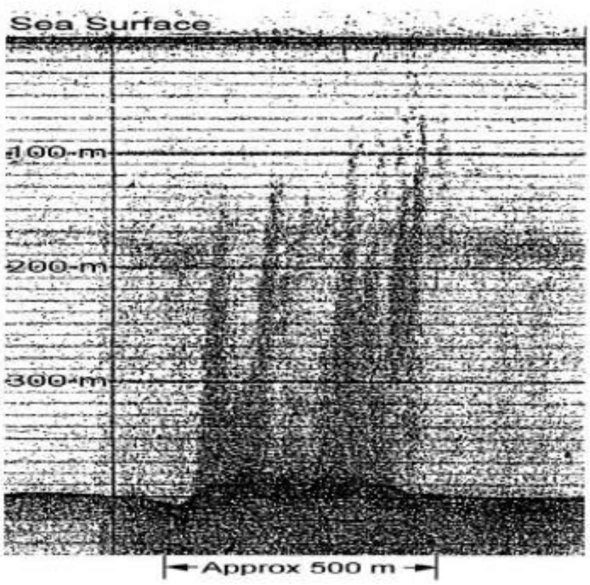

Figure 10. An example of accoustic scatter from hydrothermal vents

There is also method called passive sonar. Its hydrophones array can cover wide areas and it's commonly used for military purpose, such as locating submarines. This method are not yet proven but with further study maybe it could prove useful in the future. The idea is to recognize the particular frequencies from hydrothermal vents using the frequency shift. The array can detect, isolate, and display a wide range of acoustic frequencies in the water. Several requirements are needed for this method to work. Clear and strong signal is a must if one want this method to work. Also clear area is important so the there will not be any disturbance in the data. Things like shipping traffic is a disturbance since it is giving too much noise so the data won't be accurate.

3.2.2. Chemical Analysis

Gas and hot fluid discharged from the hydrothermal vent can be a proof that there are system working underneath it. It means that there is an active heat source below it and there are cracks which allow the seawater to seep into and flow out the system. Gases and hot fluid emitted from hydrothermal vents can give informations regarding the characteristic of the system. For example, analyzing the isotop ratio like $^3He/^4He$ ratio which become indication for hydrothermal activity. Dissolved gas and substances such as CH_4, CO_2, Si, H_2, H_2S, Fe, and Mn are also potential indicator of hydrothermal activity. There are several real-time instruments to measure the chemical components in the fluid like electrochemical redox (eH) and pH sensor[8].

3.2.3. Camera

A close up pictures and videos of hydrothermal vent is the most satisfying and direct way to study it. This method using a towed instruments with camera attached usually called Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs). Little Hercules used in Kawio Barat expidition is one of the example of ROV. From the pictures and videos taken, we can study the area more detailed thus giving more accurate informations, providing clues on how big the estimated area and temperature[8].

3.2.4. Dredging

Rock samples from dredging can give information of hydrothermal vent existence because rocks are usually affected by the hydrothermal activity. Sulphide minerals in the rocks are common indicators of hydrothermal activity[8].

3.2.5. Magnetic Survey

The basic concept is not different with on-land geothermal system. This method is searching for the magnetic anomalies caused by the heat thus it can also locate hydrothermal vents. A reduction of magnetic value is usually found near hydrothermal upwelling zones and can reach approximately a few hundred meters across so more detailed magnetic survey is needed.

A rapidy cooled basalt contain titanomagnetites and normally has high value of magnetism. That's why sea floor, especially young mid-ocean basalts are highly magnetized. Hot fluid from hydrothermal vents can alter the mineral in the rocks and the heat could lower the magnetic value of the surrounding area. Hot fluid could also leech out the iron content in rocks making it demagnetized. This lowering value of magnetic attribute could cause anomaly which then later identified as hydrothermal vents[8].

3.2.6. Conductivity, Temperature, Depth (CTD) Sensor

This instrument is usually attached to vehicles towed from the ships and used to measure the conductivity, temperature, and pressure.The measuring usually real-time so the data can be obtained right away. This instrument package can also equipped by other instruments such as optical sensor, camera, pH sensor, chemical detectors, and sampling bottle. There is also similar instrument called

Miniature Autonomous Plume Recorder (MAPR). This intstrument is inexpensive and can be operated by someone with little special training[8].

3.2.7. Remote Sensing
The usage of remote sensing for many exploration has been renown. Many things can be obtained, like lineaments analysis. Lineament analysis are predicted to be a potential geological structure which give a geothermal system permeability although field studies are still need to be done in order to check geological structure availability. Lineaments analysis are conducted using image taken from satelite. Basically the concept between on-land and offshore lineaments analysis is the same, but since satelite imaging can't reach underwater, offshore remote sensing analysis is using underwater image taken by NOAA. These lineaments can give clues about the existence of underwater structure on sea floor. The example of remote sensing for offshore can be seen in figure 18 and figure 19.

3.3. Offshore Geothermal Utilization
Although there are no studies or current development of offshore geothermal energy, there are several ideas of how utilize it[9].

3.3.1. Platform Based Power Plant
This concept of power plant works by installing the power plant in the middle of the ocean. The steam is delivered through the seabed to the power plant using pipeline dircetly from the seabed to the surface. Then the steam will be converted into electricity and delivered to land to be distributed later. The structure for platform based power plant like this need to be able to withstand the wave[9].

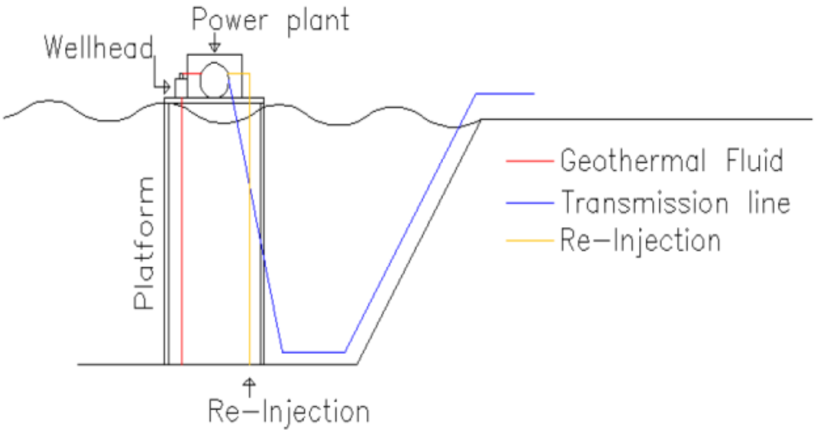

Figure 11. Conceptual model of platform based power plant. All of power plant instrumens are located above the sea. A strong structure is needed in order to withstand the wave impact

3.3.2. Land Based Power Plant
Wave and underwater current may give a promising threat to any platform build in the sea. Another concept was initiated in order to prevent this by building the separator on the seabed, separating the two phased fluid, and then transport the pure steam onto the land. This way the wave won't be a problem. But there is a possibilites of steam changing back to liquid form due to the decreasing of temperature during trasport. To prevent this the pipeline must be calculated so that the steam will stay in the gas form by using certain material or by installing the pipeline under the seabed[9].

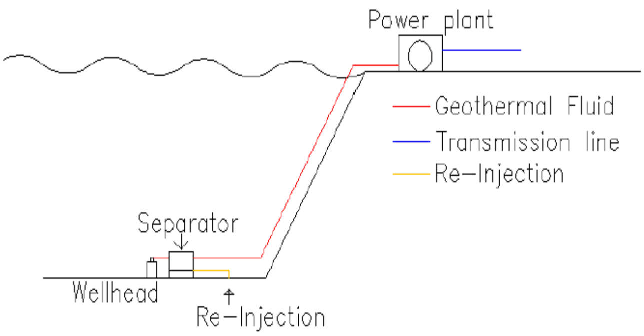

Figure 12. Conceptual model of land based power plant. The separator is installed on the seabed then transport the fluid onto the power plant on land

3.3.3. Underwater Based Power Plant

There are other concept of power plant which is hoped can overcome problems such as wave impact and a decrease in temperature, by building the power plant underwater and distribute the electricity onto the land. This way both the wave and temperature decrease will not be a problem. Although the design for power plant must be carefully calculated to withstand the underwater pressure which of course will be enourmous and to keep the seawater out from all the components. This concept proves to be risky and may need special design for the construction[9].

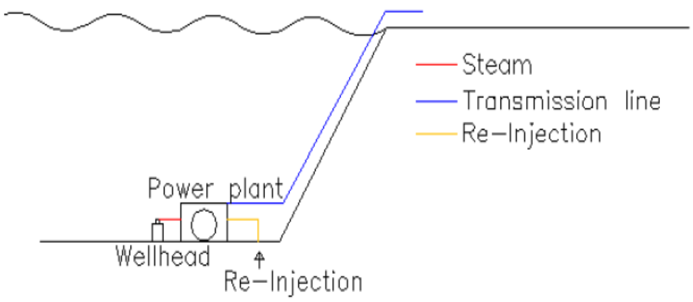

Figure 13. Conceptual model of underwater based power plant. The design must be a ble to withstand the underwater pressure

3.3.4. Binary Power Plant

This concept is similar to the binary power plant concept on land. The only difference is this one is build underwater. The heat exchanger is build on the seabed and the working fluid is transported onto the land.

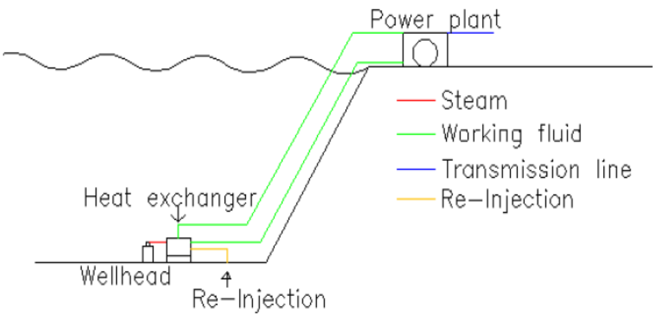

Figure 14. Conceptual model of binary power plant

Recently there is a new concept for this design by building a small submarine where the working fluid, heat exchanger, and generator are placed inside the submarine. This design was developed by The National University of Mexico. The submarine has 2 spiral tubes on the side containing the working fluid. The first spiral is located above the hydrothermal vent where the hot fluid from the vent will heat up the working fluid in the spiral and turn it into steam. Steam will be used to move the turbine in the generator. After this the steam of the working fluid will be streamed into the second tube which will work as the condensor where the tube located in cold seawater, cool down the steam and turn it into liquid phase again[9].

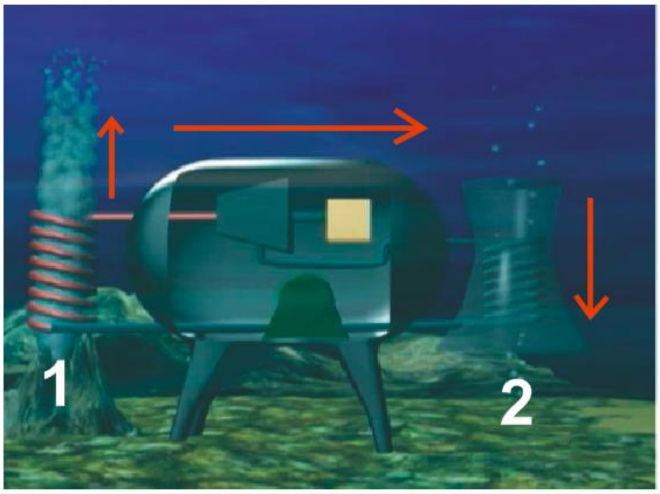

Figure 15. Conceptual model of submarine binary power plant. The hot fluid from vent will heat up the working fluid in tube 1, then transported it to the generator, and cooled in tube 2 by expose the tube to cold seawater changing it back to liquid form

3.3.5. Thermoelectricity

This concept is utilizing the temperature difference between the geothermal fluid and the seawater through a pipeline[9].

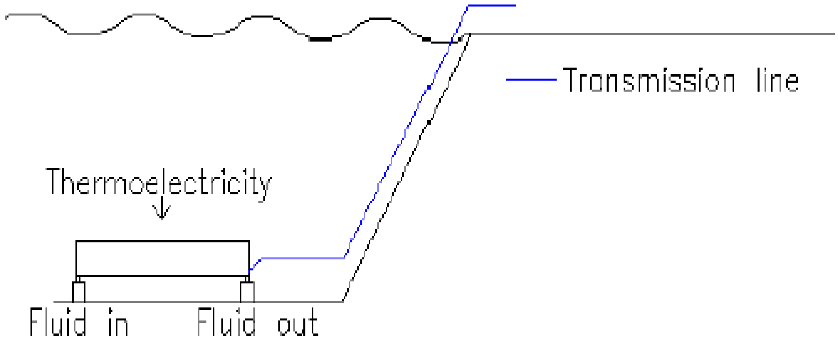

Figure 16. Conceptual model of thermoelectricity power station

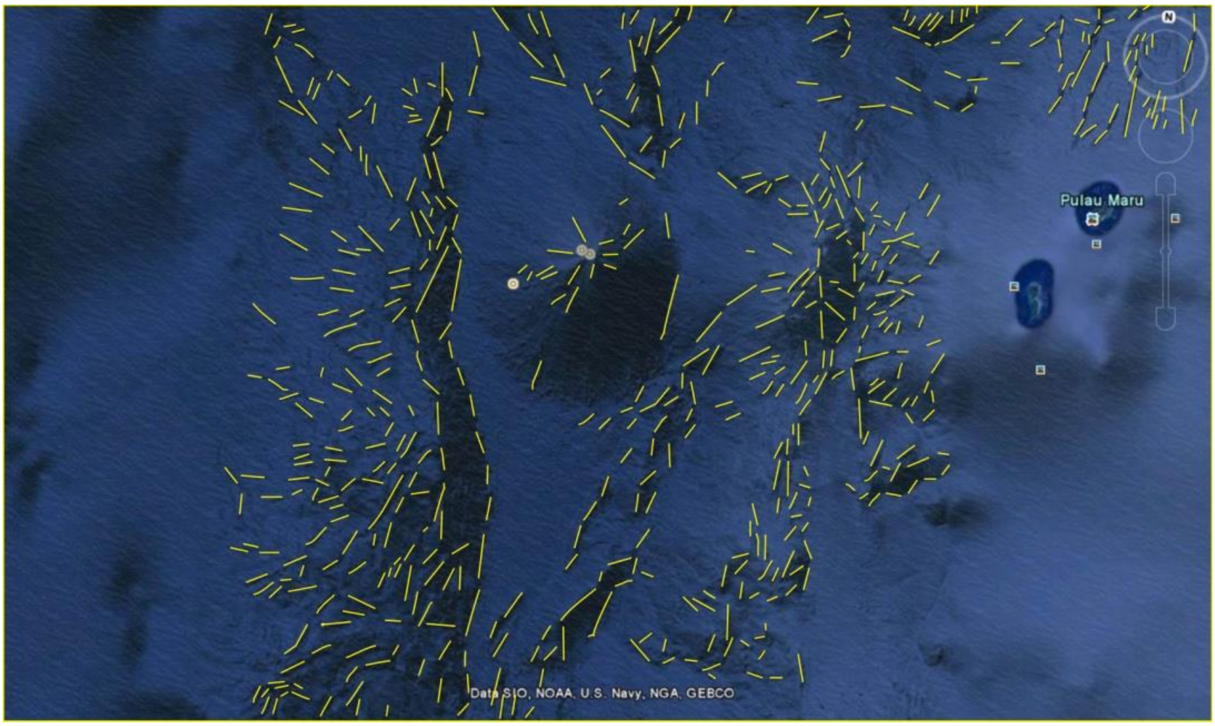

Figure 17. Lineaments from remote sensing image using NOAA image. These lineaments are predicted to be the underwater structures and need to be studied more to prove it

4. Discussion and Conclusion

It is clear from all the information obtained from many experiments around the world that seamounts are indeed can become a great potential for heat source in offshore geothermal system. They are located around spreading sea floors around the world and contain mafic magma. The temperature are possibly hotter than on land volcanoes and not as acidic as one. This is due to the short range for the magma to reach the surface so minimized the contact with the surrounding rocks. There are several seamounts in Indonesia, such as Banua Wuhu, NEC, Submarine, and Kawio Barat. The lava from seamounts will cooled rapidly by the seawater thus creating cracks in the igneous rocks which increase the permeability of the system. These cracks together with underwater structures become the fluid pathway in and out the system.

There hasn't been many detailed researched regarding the offshore geothermal system. Athough some methods for exploration and the technology concepts are available, there are still not enough researched yet to locate all offshore geothermal potential location. Looking from the heat contained in

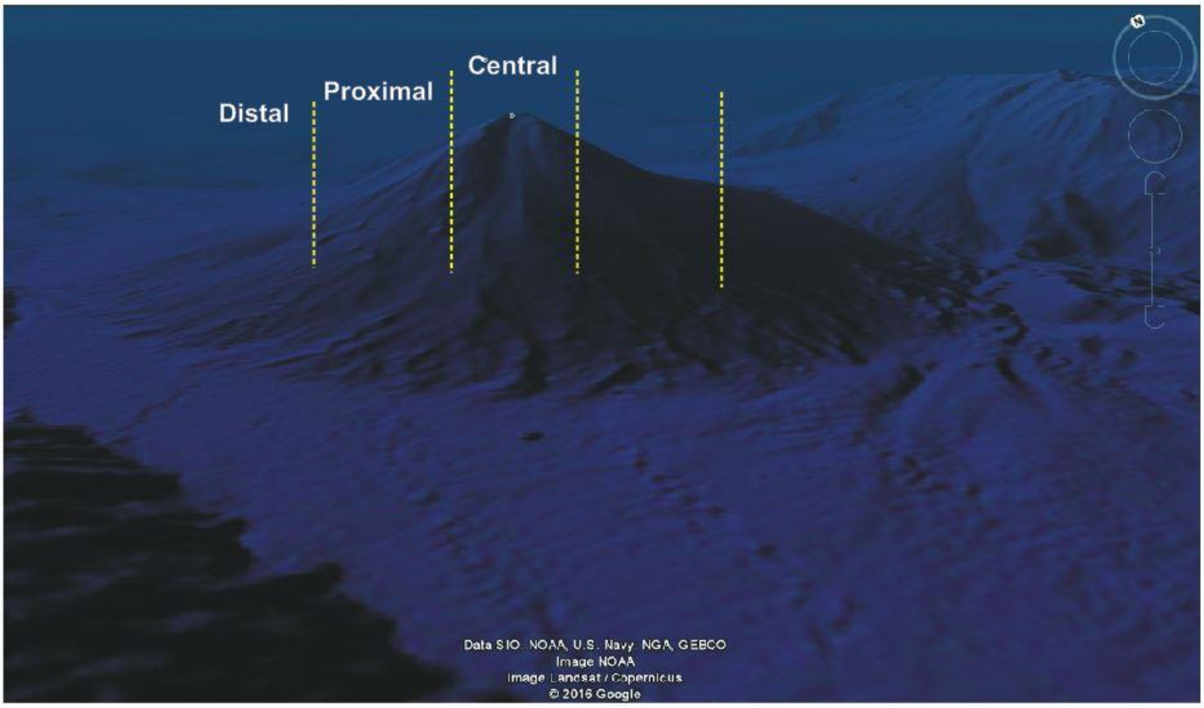

Figure 18. 3D underwater image of Kawio Barat Seamount taken from NOAA image database. It can be divided into 3 parts; central, proximal, distal.

seamounts and the permeability provided, it can be said that offshore geothermal energy is a quite interesting topic to be discussed and studied further. Seawater also provides literally unlimited fluid recharge and can be used as a condenser so there will be no need for cooling tower. Since it's located underwater the land usage for building the facilites can be minimalized.

Even with all those advantages, there are still many disadvantages and quite the vital one too. Some problems such as wave could threat the facilities construction so a strong construction is needed in order to withstand it. For equipments located underwater must be able to hold an enormous pressure in the seafloor. All of these need special materials, constructions design, and routine maintenance which mean an extremely high operation cost. Compared to land geothermal system, of course that offshore geothermal system is not a good choice since it will cost a lot of money. But it will serve as a back up plan for future alternative energy. So further research regarding the best and effective methods and technologies must be conducted. This may give better informations about the offshore geothermal system.

In conclusion, offshore geothermal potential in Indonesia is a very interesting topic since it is located in active rifting area, and as an archipelago state, Indonesia is surrounded by sea which can become the unlimited supply of recharge fluid for offshore geothermal system. Despite its possibility, offshore geothermal potential in Indonesia is not the main development priority due to many reason. It still needs to be studied even more since there are not much data regarding its seamounts, and until now Kawio Barat Seamount maybe the best choice since many researches have been conducted there beside the other seamount, although it is still not enough. The priority to develop conventional on-land geothermal is also one of the reason offshore geothermal system is not to be considered for now. Maybe one day in the future where the demands for geothermal energy has increased, offshore geothermal system can be considered as one of the options.

5. References

[1] Clark, Malcom R., Watling, Les, Rowden, Ashley A., Guinotte, John M., and Smith, Craig R 2010 *A Global Seamount Classification to Aid the Scientific Design of Marine Protected Area Networks* Elsevier

[2] Malik, M., Lobecker, E., Stuart, E., Peters, C., and Verplanck, N 2010 NOAA Ship Okeanos Explorer maps Kawio Barat, latitude: 4.6449°N, longitude: 125.03°E. NOAA Ocean Explorer website

[3] Kusumadinata, K 1979 Data dasar gunungapi Indonesia: *Catalogue of References on Indonesian Volcanoes with Eruption in Historical Time*, (Bandung: Direktorat Vulkanologi) p 726-727

[4] Hedervari, Peter 1984 *Catalog of Submarine Volcanoes and Hydrological Phenomena Associated with Volcanic Events 1500 B.C to Desember 31, 1899. World Data Center A for Solid Earth Geophysics* (United States: National Oceanoc and Atmospheric Administration)

[5] Prasojo, Hadi, Kurniawan, Temmy S, and Syaifulloh, Hanata 2014 *Potensi Panas Bumi Lepas Pantai di Kawasan Gunung Api Bawah Laut Kawio Barat, Banua Wuhu, dan Submarin 1922 di Kepulauan Sangihe, Sulawesi Utara: Energi Masa Depan* Bandung

[6] Siebert, Lee, Simkin, Tom, and Kimberly, Paul 2010 Volcanoes of The World. *The Journal of Geology 91, no. 5 September 1983*: 609-610.

[7] Tivey, Margaret K. 2014 *Black and White Smokers* (Netherlands: Springer)

[8] Atkins, Darren and Audunsson, Haraldur 2013 Exploration Technique for Locating Offshore Geothermal Energy Near Iceland *Proceedings Thirty-Eighth Workshop on Geothermal Reservoir Engineering* Standford California

[9] Karason, Baldur, Gudjonsdottir, Maria S, Valdimarsson, Pall, and Thorolfsson, Geir 2013 Utilization of Offshore Geothermal Resources for Power Production *Proceedings Thirty-Eighth Workshop on Geothermal Reservoir Engineering* Standford California

[10] Engineering Committee on Oceanic Resources 2008 *Report of Working Group on Marine Geothermal Energy*

[11] Hiriart, Gerardo 2010 *Submarine Geothermics: Hydrothermal Vents and Electricity Generation* (Proceeding World Geothermal Congress 2010. Bali, Indonesia)

[12] Encyclopedia Britannica Seamount. accessed on 19 August 2017 https://www.britannica.com/science/seamount

[13] EarthSky 2011 Seamonts and Knolls are Largely Unknown Ocean Oases access on 19 August 2017 http://earthsky.org/earth/seamounts-and-knolls-are-largely-unknown-ocean-oases-2

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