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Characteristic of Geothermal Chemistry Fluids at Seram Island, Maluku, Indonesia

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ABSTRACT

Preliminary characteristics of geothermal chemistry fluids are one of the methods used to understand geothermal behavior. This could be evaluated by the several types of geothermal manifestations; as result of thermal water analysis, the type of geothermal water manifestation, and the estimated consideration of the temperature reservoir with water geothermometry. Indonesia has 349 geothermal locations as of December 2018; from these, 33 locations are at Maluku, Eastern Indonesia. Seram Island is a medium sized Island at Maluku Province, a non-volcanic area and at least already having 5 geothermal areas. They are Tehoru, Banda Baru, Pohon Batu, Kelapa Dua, and Niff-Bula geothermal areas. Generally, it is included in the Outer Banda non volcanic arc which consist of metamorphic rocks in the Permian-Triassic. Mostly they only have hot springs, and generally the temperatures are about 37.3-99.6^oC with neutral pH. They are chloride and chloride-bicarbonate water type based on the Cl-SO_4-HCO_3 diagram and mostly plotted in a partial equilibrium zone based on the relative Na-K-Mg diagram. The temperature of the reservoir is medium at about 136-220^oC from Na-K geothermometry. Indonesia's government is focusing on the development of Eastern Indonesia. The characteristic of geothermal chemistry fluids in Seram Island could be a consideration for those who will develop geothermal, whether for direct use and for indirect use.

1. INTRODUCTION

Indonesia is an archipelagic country, blessed with many medium and small islands that are scattered throughout its territory. Because of its geological setting, Indonesia acquires an abundance of geothermal resources. The geothermal energy is sometimes placed in small, medium, and also remote islands. As of December 2018, the Geological Agency, MEMR has inventoried 349 geothermal areas, with total resources about 25.3 GWe which consists of 6,407 MWe of speculative resources; 3,852 MWe of hypothetical resources; 10,099 MWe of possible reserves; 2,016 of probable reserves; and 3,012.5 of proven reserves; but the installed capacity is still about 1,948.5 MWe. The Maluku and North Maluku provinces, which form part of Eastern Indonesian zone, have at least 33 geothermal areas and resources totaling about 1,259 MWe. Several of them (164 MWe) are in Seram Island and have a medium temperature reservoir. Seram Island has an area of about 18,625 km^2, length of 340 km and width of 60 km. It is located in the north of Ambon Island, in the Maluku province (figure 1). There are 3 (three) regencies: West Seram, Middle Maluku, and East Seram. The geothermal areas of Seram Island are 5 areas (Table 2), i.e.: Kelapa Dua, Pohon Batu, Banda Baru, Tehoru, and Niff-Bula. The resources consist of West Seram: Kelapa Dua (25 MWe speculative resources); Central Seram: Tehoru (35 MWe possible reserves), Banda Baru (33 MWe hypothetic resources and 21 possible reserves), Pohon Batu (37 MWe speculative resources and 13 hypothetic resources); and East Seram: Niff-Bula (only inventory of the hot springs); but there are no proven reserves nor any installed capacity. The availability of energy is important for the sustainability of the local people's economic life such as fisheries, plantation, forestry, tourism, and mining. Indonesia's government is focusing for the development of Eastern Indonesia. The characteristic of geothermal chemistry fluids in Seram Island could be a consideration for those who will develop geothermal at Maluku whether it is for direct use or for indirect use. Developing geothermal medium temperature is challenging for Indonesia, since it has been developed internationally and has been increasing in the total amount of resources with a temperature < 210 °C with pumped systems technology in recent years. Now approximately 7 - 10% of all global geothermal generation comes from these types of systems (Febrianto et. al, 2018).

2. METHOD

The fluids' characteristics of Seram Island geothermal areas are interpreted by the surface geothermal geochemical method. The characteristics were identified from the type of manifestations and the result of water manifestation analysis which could be interpreted from the reservoir which was already involved several processes. Water samples were analysed at the Center for Mineral, Coal, and Geothermal Resources laboratory. The cation-anion analysis was determined by volumetric method, UV-VIS spectrophotometry, Atomic Absorption Spectrophotometry, and ion chromatography. Analysis of stable isotopes (^{18}O and ^{2}H) used the PICCARO L2130-i laser spectrometer. This interpretation also combines secondary data from several literatures.

3. A BRIEF OF GEOLOGY

Seram is an island of the outer Banda Arc, eastern Indonesia. Based on the heat flow database at SE Asia region, Seram Island geothermal areas are having >80 mWm^2 from the middle to the west part of island and less heat flow at about < 80 mWm^2 from the middle to the east part of island, (Figure 2, Hall and Morey (2004)). The heat flow pattern on a region could affect the favorable heat source for a geothermal system. Surface thermal springs are extracting the heat from the depth, thus, Seram Island has considerable moderate heat flow to build a geothermal system.

Hill (2013) described that Seram is placed between the passive margin tectonics of Australia's Northwest Shelf and the active margin tectonics of New Guinea, both of which have played an important role in the structure of this region. It is a confluence of three tectonic plates: Australian Plate, Pacific-Philippine Plate, and the Eurasian Plate. Seram Island is limited by 2 (two) horizontal fault systems, namely the fault system in the northern part of Sorong and the Tarera - Aiduna fault in the south. The configuration of Seram Island was formed by thrust faults at sharp angles to horizontal faults. Seram has a complex tectonic order.

Generally, upward and anticline axes that are northwest - southeast trending, indicate that the deformation in this area is affected by the compression that travels northeast – southwest (Imbron, 2017).

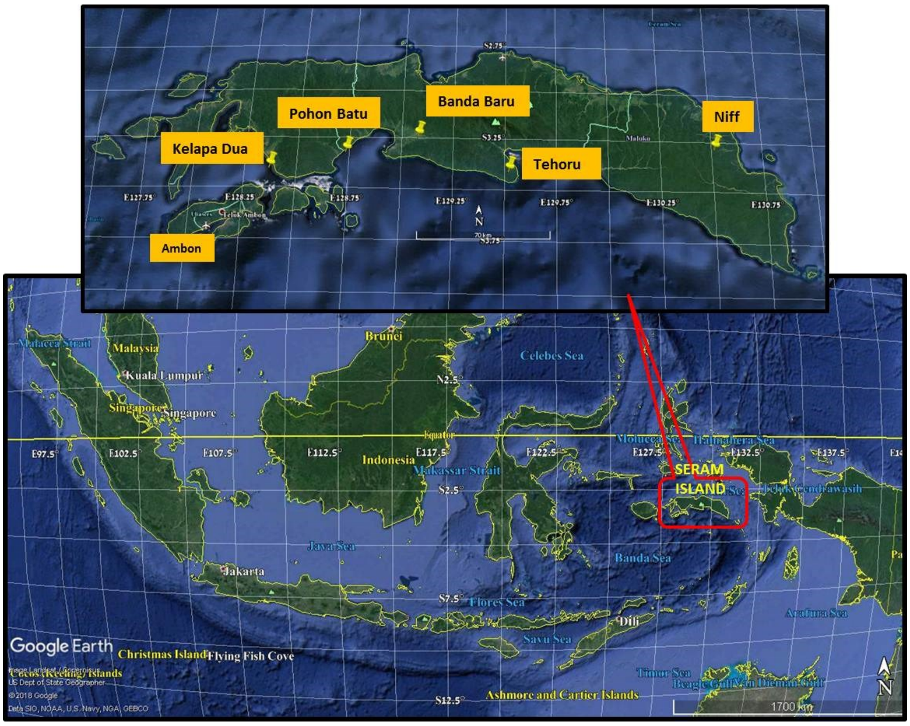

Figure 1: Map location of Seram Island, Indonesia (Google Earth)

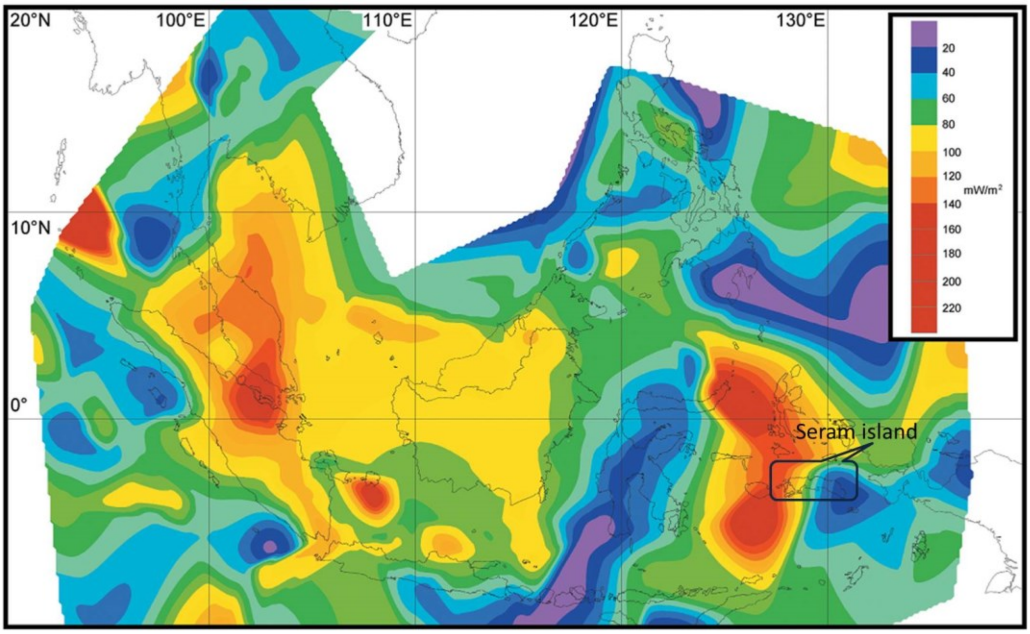

Figure 2: Contoured heat flow map for SE Asia (based on the database of *Pollack et al.* [1990; 1993] and oil company compilations *Kenyon and Beddoes*, 1977; *Rutherford and Qureshi*, 1981, in Hall and Morey, 2004)

The lithology of Seram island consists of non-volcanic rocks age Permian (Paleozoicum) until Holocene. Briefly, Pairault, Hall, and Elders (2003) explained that geologically, Seram Island could be divided into two zones: the northern belt and southern belt. A northern belt, covering the north part of the island in the west and all of it in the east, consists of imbricated sedimentary rocks of Triassic to Miocene age whose fossils and facies resemble those of the Misool and New Guinea continental shelf. The southern belt is dominated by low-grade metamorphic rocks.

The area of Seram Island and Ambon Island are part of the Banda Bow. Based on the second, stratigraphic data also shows the development of tectonics from Paleozoic to Miocene. The tectonic development of the two islands is very closely related to the tectonic development of the continent of Australia. Convergent interactions between the Eurasian, Indo-Australian and Pacific plates in the Late Miocene, followed by rotation of the Bird's Head counterclockwise in Mio-Pliosen, have led to tectonic development the two different regions, so that lithology units from Seram and Ambon Island can be divided into Australian Series and Seram Series. The oldest sedimentary rock on Seram Island is the Kanikeh Formation which is deposited on the outer neritic, in the form of sandstones and mudstones and is out of alignment with the above igneous and metamorphic rocks (basement). The age of the Kanikeh Formation is the Central Triassic - Late Triassic. Above the Kanikeh Formation, there are gradations in the Saman-Saman Formation in the form of limestone. Then on a runway above the Saman-Saman Formation, there is the Manusela Formation in the form of limestone and is deposited in the neritic environment - batial. The Salas complex is deposited on the outer shelf - bathyal, which consists of claystone, mudstones, and contains clastic, lumps and blocks of rock before the rapture experience. In addition to the Salas Complex, erosion from the removal of rocks on Seram Island also caused the Wahai Formation to be deposited in the form of clastic deposits on the –bathy outer shelf in the Pliocene - Early Pleistocene. Above the Wahai Formation, there is the Fufa Formation which is a shallow (nile zone) sea sediment from erosion when the lifting process still takes place at the beginning of leistocene. The Wahai Formation consists of mudstones, claystone,sandstones, siltstone, conglomerates, and limestones.

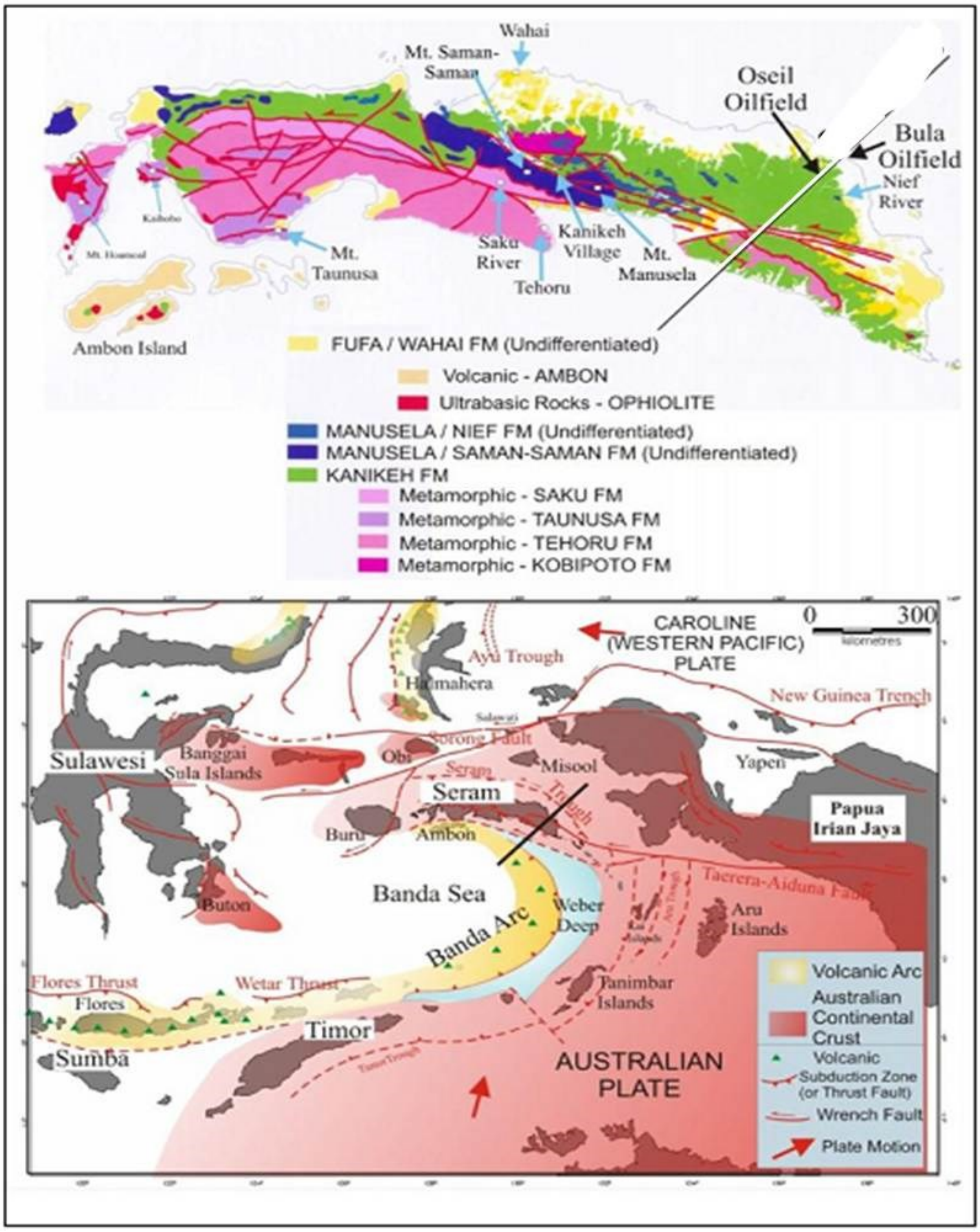

Figure 3: Tectonic setting of the Banda Arc and simplified geology map of Seram showing the location of the regional cross section (courtesy of Kufpec (Indonesia) Limited in Hill, 2012)

Local geology of 5(five) Seram geothermal areas, briefly (Fredy, Bangbang, Janes, Arif, and Robertus, 2009; Pusat Sumber Daya Geologi, 2010; Pusat Sumber Daya Geologi, 2011; Sulaeman, Widodo, and Hermawan, 2011; Hermawan and Yushantarti, 2014; Yushantarti and Mustofa, 2016; Yushantarti and Hermawan, 2018), i.e.:

The geology of Kelapa Dua consists of the metamorphic rock lithology of the Upper Perm age Taunusa (non-volcanic) complex. The absence of volcanic rocks is revealed on the surface in the Kelapa Dua area. Then the heat source of the Coconut manifestation; two estimated body intrusions that do not appear on the surface. The structure that controls the appearance of geothermal manifestations is a relatively flat cascading trending fault Northeast - Southwest.

The Pohon Batu geology is composed of non-volcanic rocks consisting of metamorphic and sedimentary rocks. The establishment of a geothermal system in the research area is closely related to tectonic activity which is still active today. The oldest rocks outcrop that can be discovered in the research area is Phyllit with Perm age. The younger lithology is Schist of Perm. The younger lithology is sedimentary rock, Conglomerate with Pliocene –Pleistocene age. The lithology which is younger than Conglomerate is Limestone with Holocene age. The youngest unit is alluvium. The geological structure generally has northwest-southeast and southwest-northeast orientation. Those faults may be controlled by the occurrence of hot springs in the research area.

Rock types in the Tehoru geothermal area can be grouped into four rock units which are metamorphic rocks, and surface sediment (alluvium). The order of rock units or stratigraphy from old to young is a filite unit (PTf), biotite schist (PTsb), mica schist (PTsm), green schist (PTsh), and alluvium (Qal) (Sulaeman, Widodo, and Hermawan, 2011). The geological structure consists of folds (anticlines) and faults. The geological structure that plays a role in controlling the emergence of geothermal manifestations is the horizontal synistral fault relative to the east-west along the Yapana River.

Banda Baru has rock types that can be grouped into seven rock units which consists of one unit of metamorphic rock, one unit of igneous rock, three units of sedimentary rocks, and two surface deposits. Sequences of rock units or stratigraphy from old to young are units of schist (PTs), gabro (Jkg), sandstones (TQp), limestones (Qbg), conglomerates (Qkl), coastal deposits (Qep), and alluvium (Qal). The geological structure consists of a horizontal-northwest and southeast-northeast fault as well as a southwest-northeast direction oblique fault which causes a depression zone to form within the central part of the survey area and controls the emergence of the Banda hot springs.

The Niff-Bula hot springs is in the Bula basin and is based on the regional geological map of the Bula, Watubela and Maluku sheets. The Nif warm springs are located in the Salas Complex rock, which consists of various exotic boulders with a clay matrix, aged Mio-Pliocene.

4. GEOTHERMAL MANIFESTATION

This will describe the active geothermal manifestations (Tabel 1and Table 2) from West Seram to East Seram (Fredy, Bangbang, Janes, Arif, and Robertus, 2009; Pusat Sumber Daya Geologi, 2010; Pusat Sumber Daya Geologi, 2011; Sulaeman, Widodo, and Hermawan, 2011; Hermawan and Yushantarti, 2014; Yushantarti and Mustofa, 2016; Yushantarti and Hermawan, 2018). Previous studies estimated that the heat loss of the manifestation 0.85-850 kWth and the geothermal system, are probably a heat sweep on the plate collision setting associated with the formation of young intrusive rocks. Seram Island is mostly consisted of metamorphic rock. It has 5 geothermal areas and they are all manifested in low terrain, i.e.: West Seram: Kelapa Dua; Central Seram: Tehoru, Banda Baru, Pohon Batu; and East Seram: Niff-Bula.

4.1 Kelapa Dua Manifestations

The preliminary survey in Kelapa Dua was in 2009. There are only 2 (two) hot springs, i.e. Kelapa Dua-1 and Kelapa Dua-2. They are manifested near the shore of the sea/ Piru strait, so it is clear that they are mixing with sea water and could not be interpreted furthermore. It is located at Kairatu village, West Seram regency, and the coordinate is 431059 mE, 9626494 mU, elevation of 2 asl. There is an evident temperature of about 58-60.4°C, neutral pH, electrical conductivity of about >20,000 µS/cm, and flow rate of 0.2 l/s manifested at sandstone lithology.

4.2 Pohon Batu Manifestations

The detailed survey in Pohon Batu was in 2014. The geothermal manifestations are only Pohon Batu's 1-7 hot springs and light alteration. The temperatures are about 40-60.9°C with neutral pH. This paper however, only refers to Pohon batu-5 hot spring. The hot spring Pohon Batu-5 is located at Sanahu village with coordinates of 471455 mT and 9635850 mU and an elevation of 27 asl. It appears at Way Popupula River. The temperature of the hot springs are about 49.7°C (air temperature is 30.2°C), pH 6.34, with an electrical conductivity of about 5,640 µS/cm, and a flow rate is about 0.1 l/s.

4.3 Banda Baru Manifestations

The detailed survey in Banda Baru was in 2011. It is located in the Banda Baru village, Amahai district, Middle Seram Regency and the coordinates are 510054 mT and 9644662 mU with an elevation of 40 asl. The only geothermal manifestations at Banda Baru are 1-6 hot springs, with temperatures of about 37.3-67.8 °C, (air temperature is 25.5°C), with neutral pH 6.39-7.10, an electrical conductivty of about 3,550-8,740 µS/cm, and a flow rate of about 0.4-2 l/s. But this paper only refers to the Banda Baru-4 hot spring.

4.4 Tehoru Manifestations

The detailed survey in Tehoru was in 2011. The only geothermal manifestations at Tehoru are 1-5 hot springs and argillic alteration, and they are close each other. The temperatures are about 68-99.6°C (air temperature is 30.2°C), with a pH of 7.33, an electrical conductivity of about 1,580-3,760µS/cm, and a flow rate is about 0.5 l/s. There is evident, travertine deposition, and iron oxide. The hot spring of Tehoru is located at Tehoru village and the coordinates are 559078 mT and 9625458 mU with an elevation of 40 asl. But this paper only refers to the Tehoru-1 hot spring (2011) and the Tehoru-2 hot spring (2009).

4.5 Niff-Bula Manifestations

The geothermal manifestation was inventoried in 2018, near Bula basin oil field, and only hot springs and alteration were found. It is located at Dawang village, Teluk Waru district, East Seram regency, and the coordinates are 669877 mE, 9639782 mS, with an elevation of 83 asl. The only geothermal manifestations are 2 hot springs, i.e.: Niff-1 and Niff-2 hot springs with temperatures of about 44.9-49.1 °C, a neutral pH, an electrical conductivity of about 4,810-5,380 µS/cm, and a flow rate of 0.1-3 l/s. It was manifested as limestone lithology; clear, sulphur odour, and oily smell because of oil seepage near the hot springs. But this paper only refers to the Niff-2 hot spring.

Table 1: Geothermal Manifestation in Seram Island, Indonesia

No.	Thermal Surface Features, Location (Number in Geothermal Map, Potency)	Coordinate			Temperature Thermal Features °C	Temperature Air °C	pH	Flow Rate l/s.	Conductivity (µS/cm)	Lithology	Type of The Water	Photo and additional description
		X (mE)	Y (mN)	Elevation (m)								
1.	KELAPA DUA (2 hotsprings) Kelapa Dua-Kairatuvillage, West Seram Regency (264)	431059	9626494	2	58-60.4	28.5	7	0.2	>20,000	Alluvium and Metamorphic	Chloride	 Indication mixing with sea water, manifested near the shore of the sea, clear, salty, gas, chloride type because of the sea water, could not be interpreted furthermore
2	POHON BATU (7 hotsprings) Sanahu village, West Seram Regency (263)	471645	9635670	27	40.5-60.9	28.2-30.2	5.63 - 6.95	0.1-0.5	3,280-9,760	Alluvium	Chloride-bicarbonate	 Clear, salty, bubling gas, iron oxide deposition
3	BANDA BARU (6 hotsprings) Banda Baru village, Amahai district, Middle Seram Regency (262)	510054	9644662	40	37.3-67.8	25.5	6.39 - 7.10	0.4-2	3,550-8,740	alluvium	Chloride-bicarbonate	 Travertine deposition, clear water, sulphur odour, bubble gas
4	TEHORU (4 hotsprings) Tehoru village, Middle Seram regency (261)	559061	9625460	30	68-99.6	27.8	6.58 - 7.93	0.5	1,590-3,640	schist	bicarbonate	 Clear water, sulphur smell,
5	NIFF hotsprings (2 hotsprings) Dawang village, Teluk Waru district, East Seram regency	669877	9639782	83	44.9-49.1	28.1	7.21 - 8.02	0.5-3	4,810-5,380	limestone	Chloride-sulphate-bicarbonate	 Clear, oily and sulphur odour, sulphur deposition, close to the oil well of Bula field

Table 2: Geothermal Resources and Systems in Seram Island, Indonesia

No	No. Indonesia Potency Map	Name	Region	Potency Speculative (Mwe)	Potency Hypothetic (MWe)	Potency Possible (MWe)	Reservoir Temperature (°C)	Heat Loss	Probably Geothermal System
1	261	Tehoru	Middle Maluku	0	0	35	210	700 kWth	heat sweep on the plate collision setting associated with the formation of young intrusive rocks.
2	262	Banda Baru	Middle Maluku	0	33	21	190	850 kWth	heat sweep on the plate collision setting associated with the formation of young intrusive rocks.
3	263	Pohon Batu	Middle Maluku	35	15	0	155	107.03 kWth	heat sweep on the plate collision setting associated with the formation of young intrusive rocks.
4	264	Kelapa Dua	West Seram	25	0	0	139	0.85 kWth	not yet being interpreted
5	n/a	Niff	East Seram	n/a	n/a	n/a	155	4.9 kWth	not yet being interpreted

5. CHARACTERISTIC FLUIDS

There are 6 samples of hot springs for interpreting the geothermal fluids in Seram island which all are at low terrain. The diagram chemical analysis of the water samples is shown on Figure 6. The results of hot spring analysis are dominated by Cl-SO_4-HCO_3. This diagram does not compare for Kelapa Dua, since it is mixing with sea water, so the chloride ion is very high.

5.1 Classification of the Fluids

The type of all hot springs in Seram (Figure 3) based on the Cl-SO_4-HCO_3 diagram, are chloride (Kelapa Dua), chloride-bicarbonate (Pohon Batu, Banda Baru, and Tehoru) and chloride-sulphate-bicarbonate (Niff-Bula) type with all neutral pH. This could be an indication of a light dilution process. The chloride type for Kelapa Dua is probably because of the mixing with sea water, so it will be difficult for interpretation. Based on Cl-Li-B diagram (Figure 5), hot springs fall into Cl-B zone, while Kelapa Dua is plotted in Cl corner due to the sea water mixing. Based on Na/1000-K/100-$Mg^{0.5}$ diagram (Figure 4), all of the hot springs (Kelapa Dua, Pohon Batu, Banda Baru, Tehoru, and Niff) fall into the partial equilibrium zone. It is an indication that the reaction between fluids and reservoir rocks were mixed with surface water, but not too much for Pohon Batu, Banda Baru, Tehoru, and Niff. The Tehoru hot springs, however, could be very minor mixing with ground water because it is very close to the full equilibrium line. Hence, Tehoru is most representative for geothermal fluid from reservoir. This could be an indication that all geothermal fluids in Seram Island are mature waters which have equilibrium with relevant hydrothermal minerals from the water-rock interaction process.

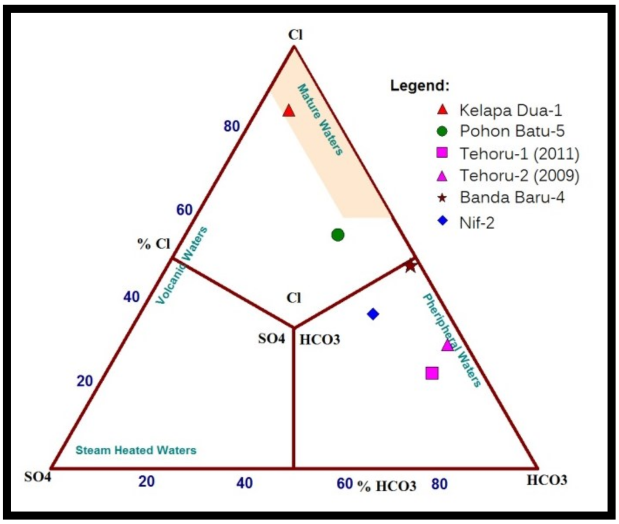

Figure 3: Cl-SO_4-HCO_3 Ternary Diagram

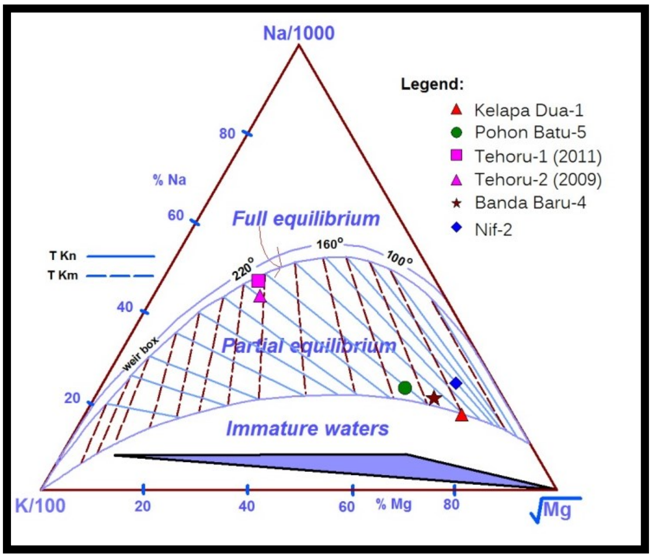

Figure 4: Na-K-Mg Ternary Diagram

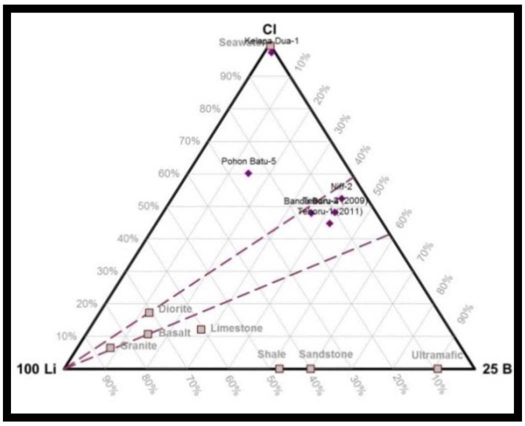

Figure 5: Cl-Li-B Ternary Diagram

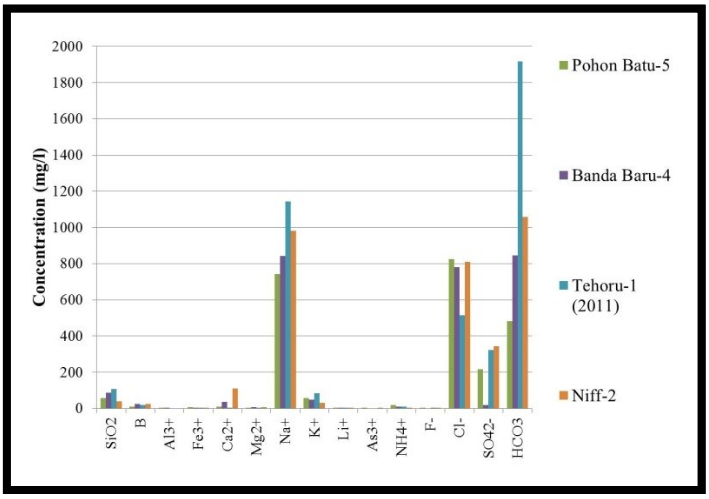

Figure 6: Diagram of Water Result Analysis in Seram Island Geothermal Area, Maluku

5.2 Geothermometry

The consideration of reservoir temperature is calcullated with eight (8) different geothermometer equations (Tabel 3). The calculation results are shown in Table 3. Since the temperature of surface manifestations is relatively medium to high, the silica geothermometers to not seem too realistic for the depth one. The Tehoru hot springs are plotted in nearly full equilibrium zone, so it is a good sample for representing the geothermal fluid reservoir. Tehoru suggests the temperature reservoir of 192-220°C (from Na/K Fournier and Na/K Giggenbach). Pohon Batu, Banda Baru, and Niff-Bula are in partial equilibrium zone, so it could be a more realistic result of a temperature prediction with Na-K. Pohon Batu suggests that the temperature of the reservoir is 196-213°C (from Na/K Fournier and Na/K Giggenbach). Banda Baru gives the temperature of the reservoir at 172-190°C (from Na/K Fournier and Na/K Giggenbach). Niff-Bula only gives 136-155°C of reservoir temperature (from Na/K Fournier and Na/K Giggenbach). All reservoir temperatures at Seram Island show medium temperature systems with consideration only from surface hot springs.

Table 3: Consideration of temperature Reservoir in Seram Island Geothermal Areas, Maluku.

Sample Name	Chalcedony cond	Quartz cond	Quartz adiabatic	Na-K-Ca	Na-K-Ca Mg corr	Na/K Fournier	Na/K Truesdell	Na/K (Giggenbach)
Kelapa Dua-1	86	115	113	181	-312	163	123	182
Pohon Batu-5	77	107	107	202	55	196	162	213
Banda Baru-4	102	130	126	173	63	172	133	190
Tehoru-1 (2011)	114	141	136	233	233	192	157	209
Tehoru-2 (2009)	125	150	143	225	225	204	171	220
Niff-2	60	91	93	139	86	136	91	155

5.3 Isotope

In general, geothermal fluids will undergo the process of adding oxygen-18 isotopes from their original water, in this case meteoric waters (Craig, 1963 in Nicholson, 1993). The stable water isotope data of Seram Island, plots commonly in the local meteoric water line (Figure 7). The isotope diagram of the Seram island geothermal waters shows that they are of meteoric water origin. Several isotopes of hot springs near the local meteoric water line, could be an indication that the contributions of deep fluids are minor. Only Niff-Bula shows indication of high water-rock interaction even though the temperature at the surface only reaches 49°C. The others, Pohon Batu, Tehoru, and Banda Baru are more positive than local waters. This could be an indication that geothermal fluids have been enriched with O^{18} because of rock-water reactions at depth (Nicholson, 1993). Kelapa Dua is having a trend to the sea water mixing. This strengthens the surface data that are manifested at shore of the sea.

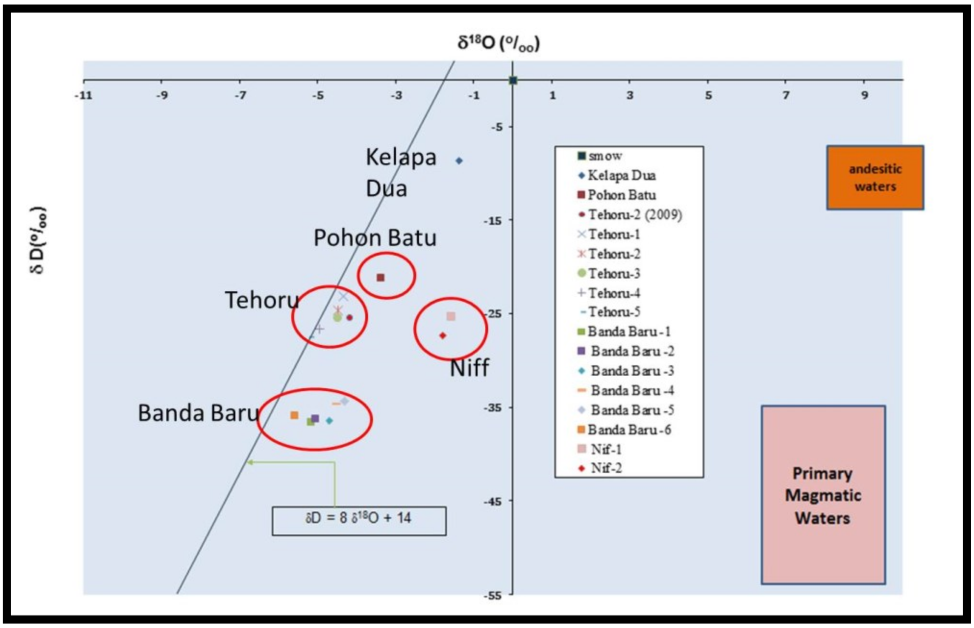

Figure 7: Water Isotopes Diagram

6. CONCLUSION

A brief review of Geothermal Fluids Characteristic At Seram Island, Indonesia shows that it is a metamorphic environment in the Permian-Triassic. The hot springs are of neutral pH, only having the highest temperature of about 99.6°C (Tehoru hot spring). The concentration of water analysis tend to be medium concentration and the geothermal manifestations are only hot springs and alteration namely; Kelapa Dua, Pohon Batu, Banda Baru, Tehoru, and Niff-Bula. The type of the waters are chloride (Kelapa Dua), chloride-bicarbonate (Pohon Batu, Banda Baru, and Tehoru) and chloride-sulphate-bicarbonate (Niff-Bula). They are plotted in partial equilibrium (Pohon Batu, Banda Baru, Niff-Bula) and nearly to full equilibrium zone (Tehoru). The isotope waters show more positive O^{18}, showing a good interaction of rock-water at depth. All are medium temperature reservoirs of about 136-220°C (Na-K) which is a good indication for mature geothermal waters. So, Seram Island as a part of East Indonesia, has mature medium temperature geothermal systems that will be challenging to develop for mostly local people.

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