Geoscientific Survey Results from the Jailolo Geothermal Field, Northern Halmahera, Indonesia.

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ABSTRACT

The Jailolo geothermal field is located in a peninsula made up of the southernmost young volcanic piles of the volcanic arc that crosses the northwest arm of Halmahera Island. Early volcanism produced a large caldera forming Jailolo Bay. Later volcanism produced a maar at Bobo Payo. Dacitic pyroclastics have been erupted from the later Idamdehe volcanic centre, another maar, with the andesites of the prominent conical peak of G. Jailolo erupted later still. Surface thermal manifestations include steaming ground at the northern margins of the Idamdehe and Bobo Payo maars with the only hot springs lying on the coast; they are contaminated by seawater. Based on geochemical interpretations a water dominated system with reservoir temperatures of at least 212^0 C is found. MT survey results show shallow bases of the conductor at both Bobo Payo and Idamdehe and possibly Jailolo volcano. In addition, at Idamdehe there is a coincident gravity high possibly associated with a heat source at depth. Overall, the conceptual model supports a drilling programme at Idamdehe, possibly for a binary power plant development. However since the reservoir temperature is a minimum, higher temperatures at depth that may support a flash plant can not be excluded prior to drilling.

INTRODUCTION

Star Energy Geothermal Ltd. was awarded the Jailolo geothermal field concession at the end of 2008. This concession is located in the northwest arm of Halmahera Island (**Figure 1)**, lying administratively within Kecamatan Jailolo, Kabupaten Halmahera Barat, Propinsi Maluku Utara.

The available geological, geochemical, and geophysical data has been integrated into a conceptual model of the geothermal field. It serves as the basis for well targeting and a numerical simulation model, which is to be used to forecast the field's performance under different generation scenarios in order to assess various development options.

SCIENTIFIC RESULTS

1. Geology

Jailolo geothermal field lies within the Halmahera volcanic arc which originally formed in response to the dual subduction of the Molucca sea plate either side of the Sulawesi-Molucca collision zone. It has been interpreted (Hall, 1999) that the dual subduction has come to an end under both Halmahera and Sulawesi with a new west facing subduction zone forming between the older arcs (Figure 2). The Jailolo field is thus no longer directly related to active subduction, but as in general, remnant magmatism can occur for up to 5 Ma after subduction ceases (Gill, 1981) magmatic heat sources remains hot. Continued active volcanism occurs in the more northern volcanic centres of the arc. The change from active subduction may also have produced a less compressive stress regime with potential improvements in deep permeability.

Six major lithological units are distinguished (**Figure 3**), they are: Jailolo andesitic lava, Idamdehe andesitic lava with air fall deposits containing dacitic pyroclastics, Manjangan Scoria, Bobo Payo volcanic deposits, Tertiary volcanics, and Tertiary sedimentary rocks.

The geological structure of the Jailolo geothermal area is dominated by NW-SE lineations (**Figure 4**). The orientation of fractures is mainly aligned with major lineations but also with directions to the NE, NNE and NNW. Dips have values around 70^0-90^0.

Three volcanic depressions have been recognized. The oldest is a 15 km long caldera that forms Jailolo Bay; the more recent volcanism may be occurring on its western margin. This includes the Idamdehe depression with a diameter of 2 km, and the Bobo-Payo depression with a diameter about 1.5 km, of which only the southern rim is visible. The rest is buried by the younger volcanic products of Idamdehe. These smaller depressions are interpreted to be maars with the larger Idamdehe depression having a scalloped margin and inner ring pointing to it being a nested maar with repeated explosive activity. Exposures in the beach to the west contain base surge deposits indicative of explosive maar activity.

2. Geochemistry

Hot springs and steaming ground have been sampling during the survey on Jailolo. The hot springs occur mostly along the coastline. Other springs to the east are interpreted to be tectonic in origin. Steaming ground occurs on the northern margin of the Idamdehe maar and on the possibly buried northern margin of the Bobo Payo maar at the Manjanga hills near the west coast (**Figure 5)**.

The hot springs have neutral pH -chloride compositions, but are subject to sea water contamination; a few have a bicarbonate composition. The springs closest to the Manjunga steaming ground have the highest proportion of geothermal reservoir waters, but share the same mixing trend as the neutral pH-Cl springs northwest of the Idamdehe steaming ground. This suggests a hydrological connection between them.

The seawater contamination renders cation geothermometry moot and produces a minimum, due to dilution, for silica geothermometry of 188^0 C. Mixing models give a less reliable (due to the added assumptions inherent in the method) of 212^0 C, but as there may have been silica deposition prior to the sampling point this may also represent a minimum.

Gas from the steaming ground is too heavily contaminated with air to provide geothermometry, but detectable amounts of H_2S and H_2 indicate that it is derived from a geothermal reservoir. This is consistent with the O and H isotopic composition of the steam that indicates that the steam is derived from a high temperature geothermal reservoir (ELC report, 2010).

3. Geophysics

A MT survey defined up-doming structures in the base of the conductor at Idamdehe and Bobo Payo (**Figure 6**). A less well defined eastern up-doming structure may be related with the Jailolo volcano, but requires further investigation. A positive gravity anomaly and resistive body at depth at Idamdehe may represent an intrusive acting as a heat source.

4. Geothermal resource

The three possible areas of up-doming in the base of the conductor may be related to the different major episodes of volcanic activities in the Jailolo peninsula. The oldest is the Bobo-Payo, followed by Idamdehe, and most recently with the Jailolo volcanism. Each of those three episodes of volcanism may have associated geothermal upflows, but at the least, the Idamdehe and Bobo Payo areas may be hydrologically connected. The geothermal reservoir is interpreted to be hosted at depth by Tertiary volcanic rocks (Hakim and Hall, 1991), which out-crop in the uplifted area to the east. Breccias zones at the maars margins may locally be important sources of permeability at least shallowly as they may feed the steaming grounds. Other potential high permeability intervals may occur within faulted Tertiary volcanics.

The main heat source for the system is probably a shallow intrusive body below the Idamdehe depression, indicated by a positive gravity anomaly and resistive body at depth. This is most likely related to the differentiated Idamdehe dacitic volcanism.

The minimum reservoir boundary is based on the boundary delineated from updoming of the base of conductor inside the Idamdehe maar.It has an area of approximately 3 km^2 (**Figure 7**).

The maximum reservoir boundary is based on the boundary delineated from updoming of the base of conductor in and outside of the Idamdehe maar, it has an area of approximately 9 km^2.

The top of the reservoir (TOR) range is from 300- 600 bsl. It is interpreted from the elevation of updoming of the base of the conductor.

Based on the interpreted isotopic composition of meteoric water in the hot springs, recharge may be from Jailolo volcano (**Figure 8**).

The currently estimated size and temperature of the resource point towards a binary development, but as current temperature estimates are minimums and three separate areas of upflow may be present there is significant potential for upside to the project.

CONCLUSIONS

The Jailolo geothermal system is considered to consist of a main heat source from a young cooling intrusion below Idamdehe, but other geothermal centres may be present at Bobo Payo and Jailolo.

Liquid geothermometry temperatures indicate a minimum temperature of 188°C. Mixing models indicate a minimum of 212°C. Gas chemistry is indicative of a geothermal reservoir at depth but does not provide clear geothermometry results.

Based on MT results the minimum reservoir boundary may encompass approximately 3 km^2 and the maximum reservoir boundary approximately 9 km^2.

The permeability distribution at depth is most likely fault related secondary permeability in Tertiary volcanics, but brecciated maar margins may be important locally.

Fluid is likely to circulate from the west from Jailolo volcano to fractures and faults in Idamdehe maar and flow to the surface at locations of steaming ground and hot springs.

The Idamdehe area is interpreted to represent the best initial area for drilling, possibly for a binary development, but as geothermometry temperatures are minimums, the possibility of utilising a flash plant can't be ruled out before drilling.

ACKNOWLEDGMENT

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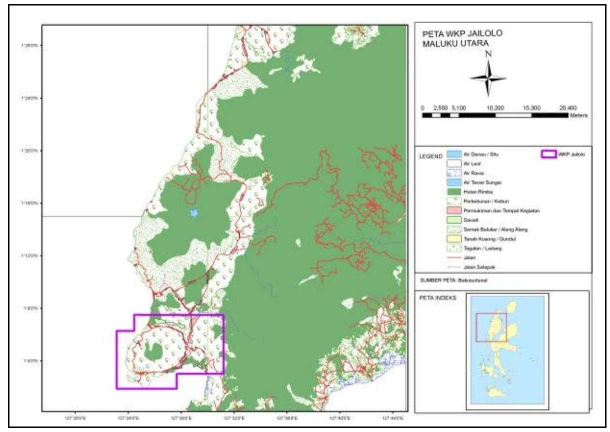

Figure 1. Location of Jailolo prospect area.

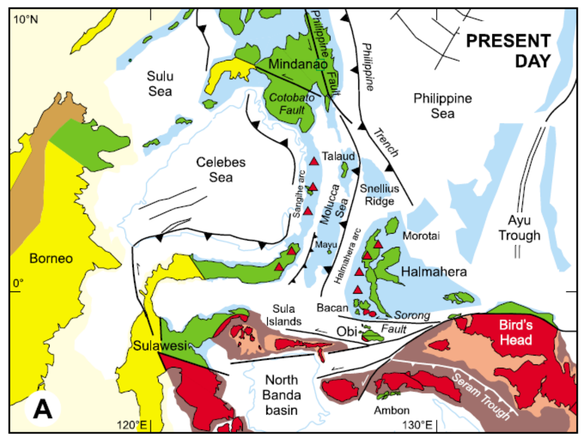

Figure 2. Plate tectonic setting of Halmahera (from Hall, 1999).

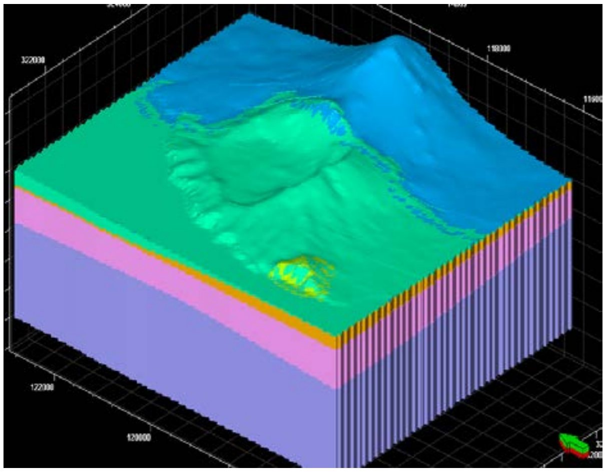

Figure 3. The stratigraphic sequence position based on geology model of Jailolo prospect area. Purple is Tertiary Lava and Sedimentary rock, pink is Tertiary pyroclastics, orange is Bobo Payo Volcanics, yellow is Manjanga Scoria, the green with relief is the Idamdehe Formation (the flat green is the sea) and blue is Jailolo Formation.

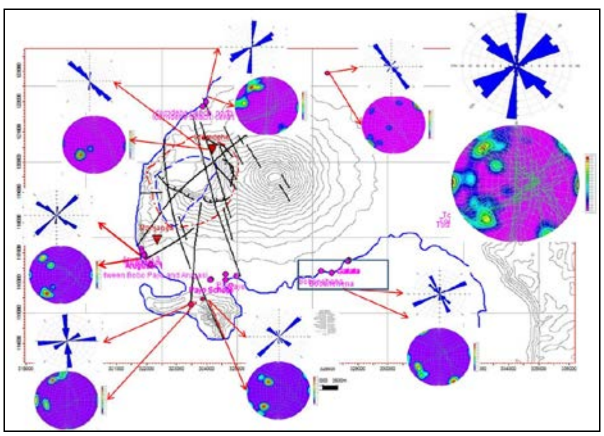

Figure 4. Structural geology map with rosette diagrams and dip angle from field measurement on Jaiolo. Dip direction is dominantly NE and SE direction.

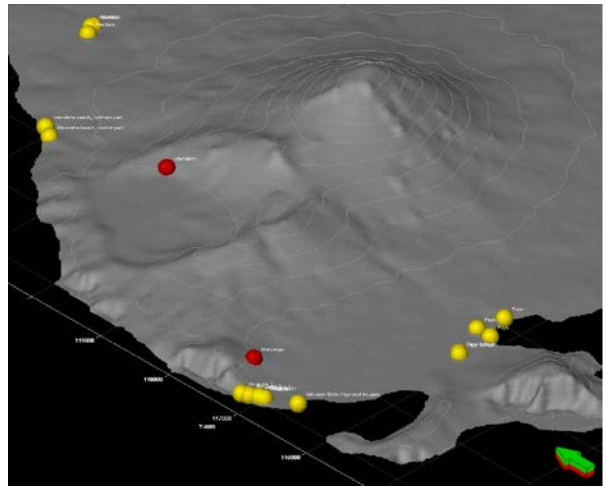

Figure 5. Surface manifestations on Jailolo, yellow dots show thermal springs, red dots show steaming ground.

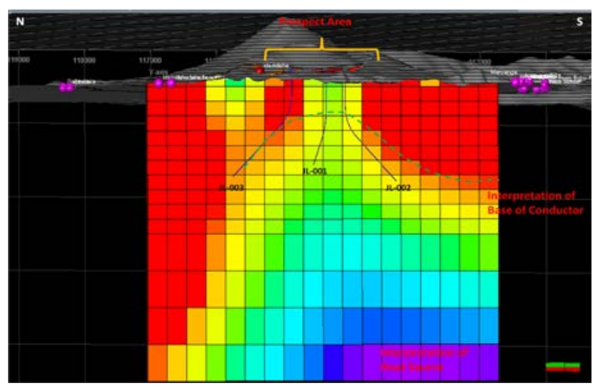

Figure 6. MT cross section from N-S. Colored pixels are resistivity from MT model, green stripped lines are the Base of the Conductor: red dots are steaming ground; pink dots are springs along the coastline; black solid line are presumably well trajectory options.

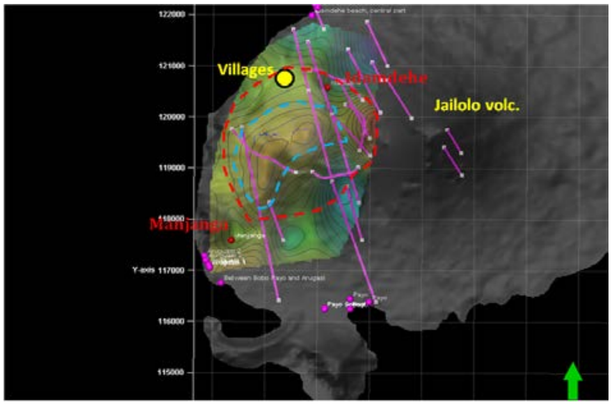

Figure 7. Estimated boundary of the reservoir. Coloured shape is the MT base-of-conductor: thin pink lines are fault traces in the surface; red dashed lines is maximum reservoir boundary; while blue dashed lines are the minimum reservoir boundary; red dot is steaming ground on Idamdehe and Manjanga.

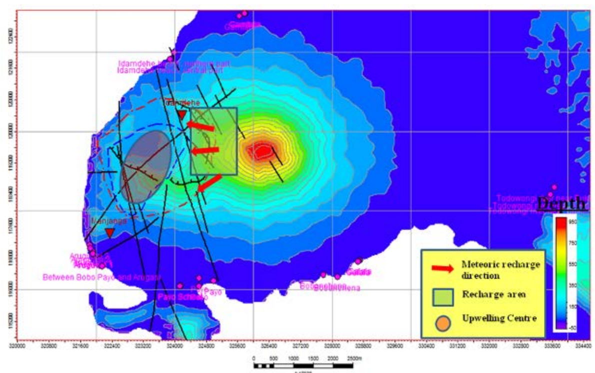

Figure 8. Hydrology Map, showing, infiltration path of meteoric water and recharge area with possible upwelling centres based on exploration conducted to date.