

The Application of a Probability Graph in Geothermal Exploration

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ABSTRACT

Like other geoscience surveys, the application of geochemistry in a geothermal survey involves a lot of data, so statistical methods are needed to solve it. One way to process data is the use of a **Probability Graph**, which basically divides the data into sub-populations. Each population represents a geological event, and commonly used approaches such as threshold value, background value, and average value are employed to define the anomaly value.

The advantage of this method is the ability to divide or filter a group of data into some sub-population which has a threshold value. If it is plotted on a map, it will show the area with different values between each other and make it possible to make a better interpretation.

This method is applied here to processing the geochemistry data (i.e. concentration of Hg and CO₂) in soil of Jaboi Geothermal Prospect, Nangroe Aceh Darussalam, Indonesia.

1. INTRODUCTION

Geology, geochemistry and geophysics surveys frequently involve huge amounts of data, so a method is often needed to process or filter it into classes or groups. The aim of classification is to simplify interpretation.

The properties of data from field observations (geology, geochemistry and geophysics) are independent, because

their values are responses to the surrounding circumstances or geological events such as mineralization or tectonics that occur naturally. Therefore, it is difficult to define an absolute threshold value for application in all areas.

1.1 Anomaly

Literally, the word of *anomaly* means a deviation from common rules or an irregularity, whereas the background value is a normal value or a value that formed originally and is not affected by geologic phenomena, such as mineralization. A group of data in a population have an anomaly if their values are noticeably different from the background value.

Figure 1 shows a cross section along a geothermal area, which has various anomalies that depend on the intensity of the hydrothermal activity.

The value of the anomalies vary depending on the degree of the geological event (e.g. mineralization or hydrothermal) and also represent the intensity of the geological event. Higher intensity geological events and lower distances between the anomaly and the heat source correspond to higher anomaly values.

If we classify these values on a map, it is possible to trace the sources of mineralization. The occurrence of sub-populations in a mineralization or geothermal area is shown in Figure 1. The background values also vary and are related to the history of the host rock genesis where the mineralization or geothermal activity occurred. Sometimes, the mineralization event more than once (overprinted) in the host rock.

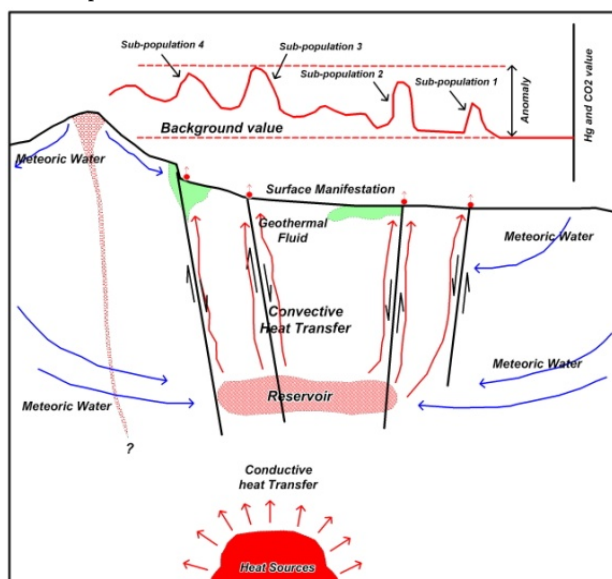


Figure 1: Illustration of anomaly and background value along mineralization or hydrothermal area

In Figure 1, mercury (Hg) and CO₂ values fluctuate around the mineralization/geothermal zone depending on the position relative to the source. However, the background values have no fluctuations and tend to be constant. In this sample, it is easy to distinguish anomaly values from background values. Sometimes, it is not easy to separate anomaly and background values, especially in areas which have complex mineralization/hydrothermal events (overprinted events).

2. IDENTIFICATION OF ANOMALY VALUE

2.1. Method

There are several methods to identify threshold values:

- Using simple statistical methods, divide into ranges of data, such as 25th percentile, 50th percentile and 75th percentile. The values that are greater than 75th percentile represent anomalies, and those less than 25th percentile are background values.
- Using formulas, calculate the mean value of the background and the mean value plus twice the standard deviation for threshold value.
- The percentile method has a threshold limit of the 97.5th percentile, beyond which a value represents an anomaly.
- Using a probability graph that basically divides the data into sub-populations. Each population represents a geological event, and the commonly used approaches such as threshold value, background value, and average value are employed to define the anomaly value.

This method is explained here in more detail.

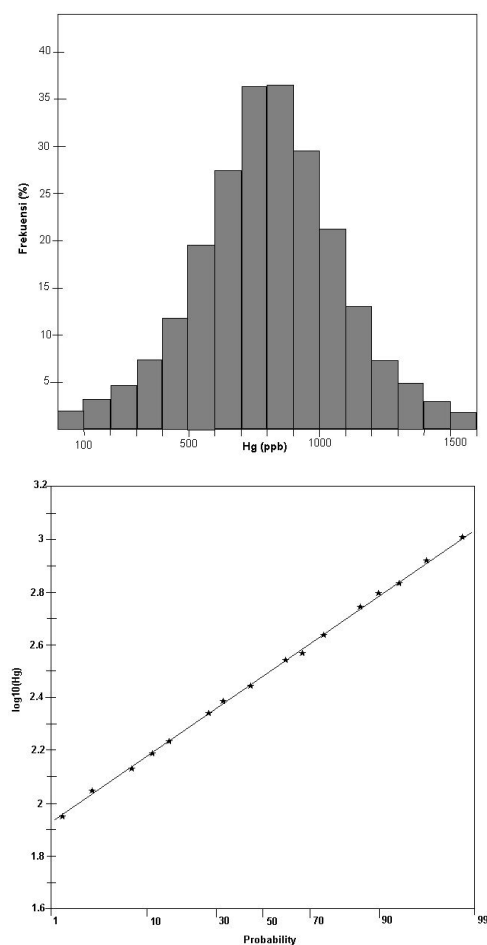


Figure 2: Histogram and Probability Graph

2.2. Graphs of Histogram and Probability

A histogram is the most common graph used to display the distribution of data. It consists of bars that represent the range of data on the abscissa axis (X-axis) and the frequency of data on the ordinate axis (Y-axis). Visually, we can use histograms to easily assess the properties of data distribution (e.g. a group of data that is distributed normally will have a symmetrical curve that looks like a bell).

In contrast, probability graphs are made in such a manner that normal data distribution is displayed as a straight line. This graph consists of a logarithmic scale on the X-axis and a normal scale on the Y-axis. The advantage of this graph is the ability to know the properties of the data population (unimodal, bimodal or polymodal) easily.

Another advantage is the classification of data in sub-populations. Examples of a histogram and a probability graph are shown in Figure 2. Note that the histogram is symmetrical, and the probability graph is a straight line, indicating that these data have a normal and unimodal distribution.

2.3. Unimodal vs Bimodal

As explained above, the unimodal distribution has a single mode. Normal distribution is an example of unimodal distribution.

Bimodal distribution data have two mode values, and are displayed as lines with a single flexure when plotted in probability graphs like the one in Figure 3. Polymodal distribution data has many flexures in these graphs. Each flexure in a probability graph represents a sub-population in a data population. The sub-populations themselves are formed by the intensity differences of mineralization/hydrothermal processes.

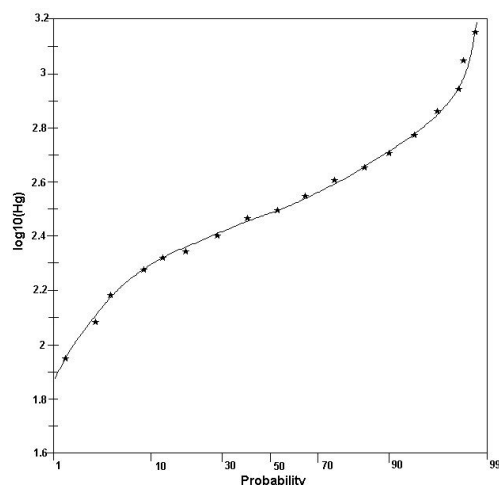


Figure 3 : Bimodal distribution data in a Probability Graph

3. DATA PROCESSING

An example of bimodal distribution data that has two sub-populations is presented here. Data processing is supported by the Discovery v.4 or 4.1 computer software in Mapinfo 6 or 7.

An example of bimodal data processing of Mercury (Hg in ppb) using a probability graph is displayed in Figure 4. The first step after finding the data population distribution in a probability graph (star mark) is to separate the sub-populations.

Sub-populations are separated by the flexure points in a probability graph. In this example, the flexure is found at 60 on probability graph (X-axis), yielding two sub-populations: A and B at a ratio of 60:40, respectively.

Then, graphs are plotted for each sub-population. In this example, 30% (X mark) is used.

$$30/60 \times 100\% = 50 \text{ (Y mark)}$$

In this way, points representing the value of sub-population A (small circle mark) are obtained. The line along the small circles is sub-population A. Line A has a normal distribution and a mean value that is the same as its median (50th percentile), and the standard deviation value is about 68th-percentile. Thus, the threshold of population A is as follows.

Threshold = mean + 2 (standard deviation)

$$= 50\% \text{ percentile} + 2(68\% \text{ percentile})$$

$$= 50\% \text{ percentile} + 86\% \text{ percentile}$$

$$= 2.425 + 2.64$$

$$= \text{invlog}(2.425) + \text{invlog}(2.64)$$

$$= 266.07 + 436.51$$

$$= 702.58 \text{ ppb}$$

Whereas,

Background = mean + standard deviation

$$= 50\% \text{ percentile} + 68\% \text{ percentile}$$

$$= 2.425 + 2.52$$

$$= \text{inv.log}(2.425) + \text{inv.log}(2.52)$$

$$= 266.07 + 331.13$$

$$= 597.20 \text{ ppb.}$$

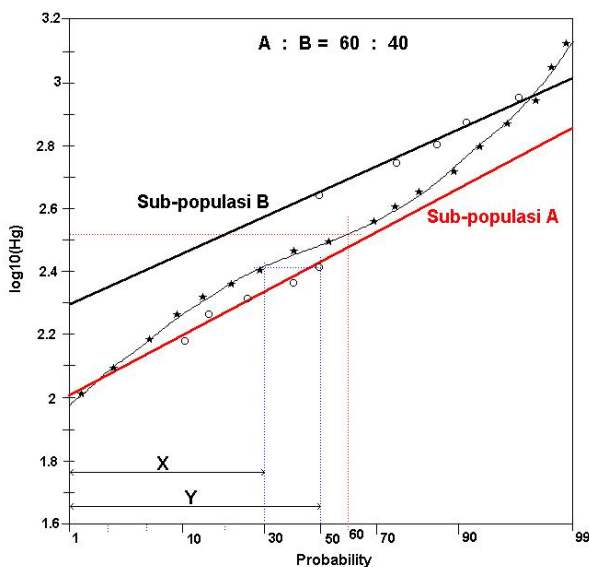


Figure 4: Example of data processing using Probability Graph

The threshold and background values for sub-population B were calculated in the same way to yield values of 1133.16 and 994.11 ppb, respectively.

All values greater than 1133.16 ppb correspond to anomaly 1, and this is the first priority in the follow up survey. Anomaly 2 values range from 1133.16 – 994.11 ppb, anomaly 3 values range from 994.11 – 702.58 ppb, and anomaly 4 values range from 702.58 – 597.20 ppb.

The background value is 597.20 ppb and is valid for the entire population. Values lower than the background are considered to be undisturbed values. The range of values between anomaly 1 and anomaly 4 reflects different mineralization/hydrothermal processes and lithological properties.

4. CASE STUDY

Probability graph are applied to the data processing of the Jaboi Geothermal Prospect located on Weh Island, Nangroe Aceh Darussalam, Indonesia, as shown in Figure 5. Only geochemical data (Mercury and CO₂ of soil sampling) were processed, and this result is a component for integrated interpretation.

4.1. Geologic Setting

The Jaboi prospect is located in Weh Island, Sabang Regency, Nangroe Aceh Darussalam Province, Indonesia. This prospect has a geographic position is between 05° 46' 17.20" – 05° 54' 26.68" N and 95° 12' 52.86" – 95° 22' 37.72" E and an area of 150 km². Figure 5 is the index map of the Jaboi geothermal prospect.

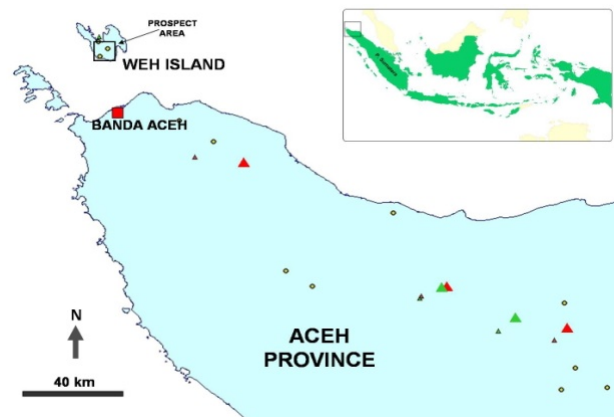


Figure 5 : Jaboi geothermal prospect index map

Weh Island is a volcanic island with at least 6 young volcanic cones that yielded material during activity to form a polygenetic volcanic zone. The lithology of the prospect area is dominated by volcanic rocks with andesitic to dacitic compositions, including lava and pyroclastic flows.

The basement of the prospect area is Miocene tuffaceous sandstone. The prospect area is part of the Sumatra regional active fault system. Due to right lateral movement in many parts along the fault zone that includes the prospect area, extensional deformation has been accommodated by normal faults. The geothermal resource is indicated by surface thermal manifestations, such as fumaroles, solfataras, hot steaming ground, alteration, and some hot springs. According to geothermometer calculations from the hot spring water samples, the reservoir temperature is approximately 170 – 250 °C. Two shallow wells indicate that the temperature gradient here is up to 35 °C/100 m, or about 11 times the normal thermal gradient (3 °C/100 m).

4.2. Distribution of Mercury (Hg) in Soil Sample

A total of 114 soil samples were taken randomly along the grid on the most interesting zone. Figure 6 is the result of data processing using a probability graph for Mercury in soil samples. It appears that there are 3 sub-populations: A, B and C. They represent the existence of geothermal activity in this prospect. Sub-population A is lower than the others, so the background value is calculated from this. Using common statistical formulas (i.e. background is mean plus standard deviation), a background value of 493.41 ppb was calculated. Note that the mean and standard deviation values are determined using the probability graph (i.e. 50th percentile and 84th percentile for mean and standard deviation values, respectively).

Threshold A = mean + standard deviation

= 50th percentile + 84th percentile

= 169.82 + 323.59

= 493.41 ppb.

The threshold value for sub-population A was found to be 493.41 ppb, indicating that all values greater than 493.41 ppb are anomalies. The thresholds for B and C sub-populations were directly determined to be 933.25 ppb and 2137.96 ppb, respectively, by taking the 99th percentile. A map of Mercury (Hg) distribution is shown in Figure 8.

4.3. Distribution of Gas CO₂

The probability graph of CO₂ distribution is shown in Figure 7. There are two sub-populations (A and B). Due to its narrow range (0.35 – 5.95 %), the determination of minimum and maximum value was a bit different.

Sub-populations of A that have low values can be used as a reference to determine the background value. In this sub-population, the mean value is the background value (i.e. the 50th percentile of sub-population A is 1.65%, so all values greater than 1.65% are anomalies). Threshold values were taken to be the 99th percentile, resulting in threshold values of 3.5% and 4.3% for sub-populations A and B, respectively. Figure 9 is a map of the background and threshold values for CO₂ in the prospect area.

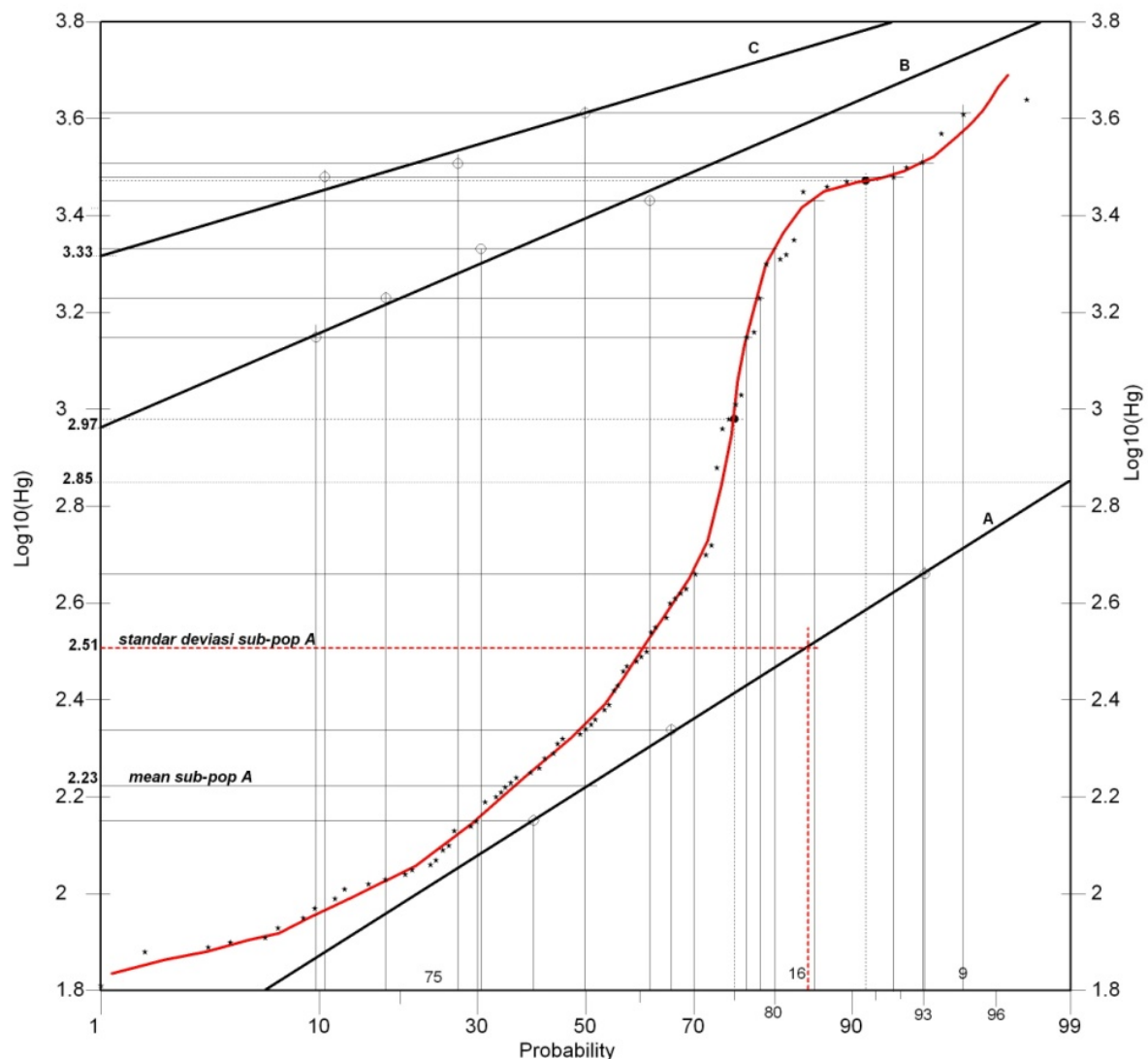


Figure 6: Distribution of Mercury (Hg) on probability graph

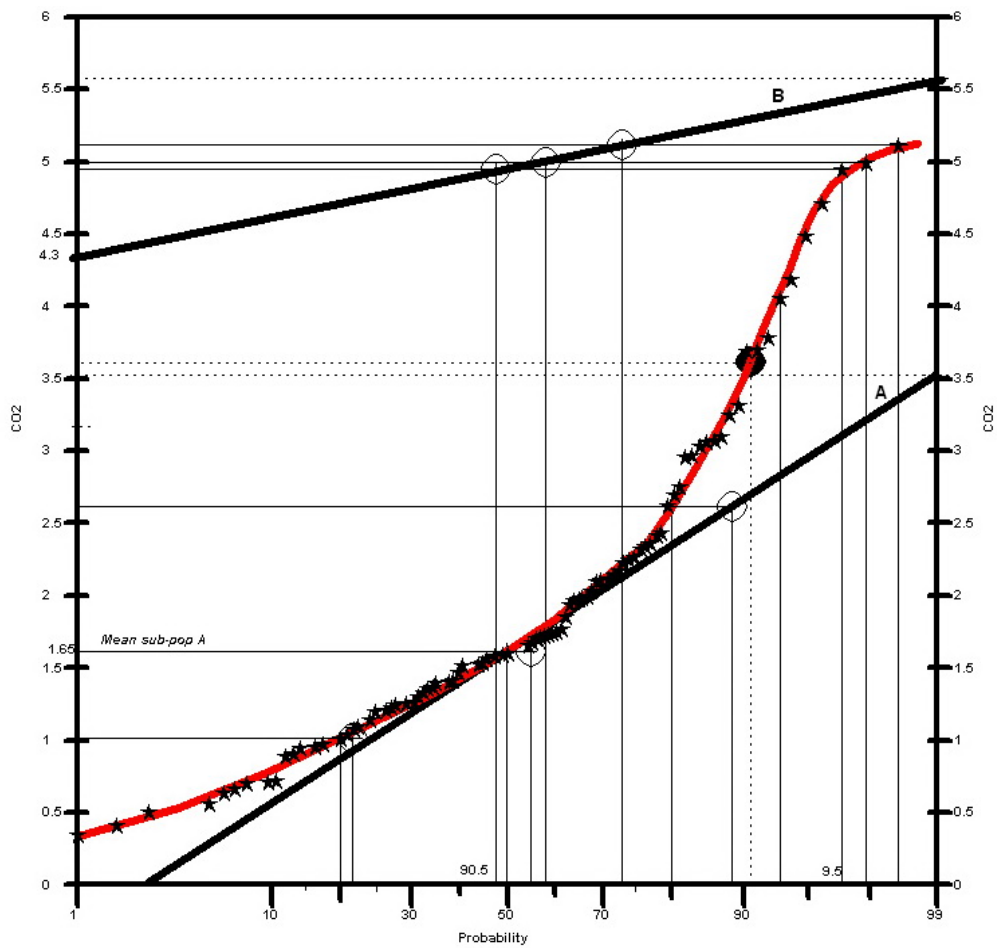


Figure 7: Distribution of CO₂ on probability graph

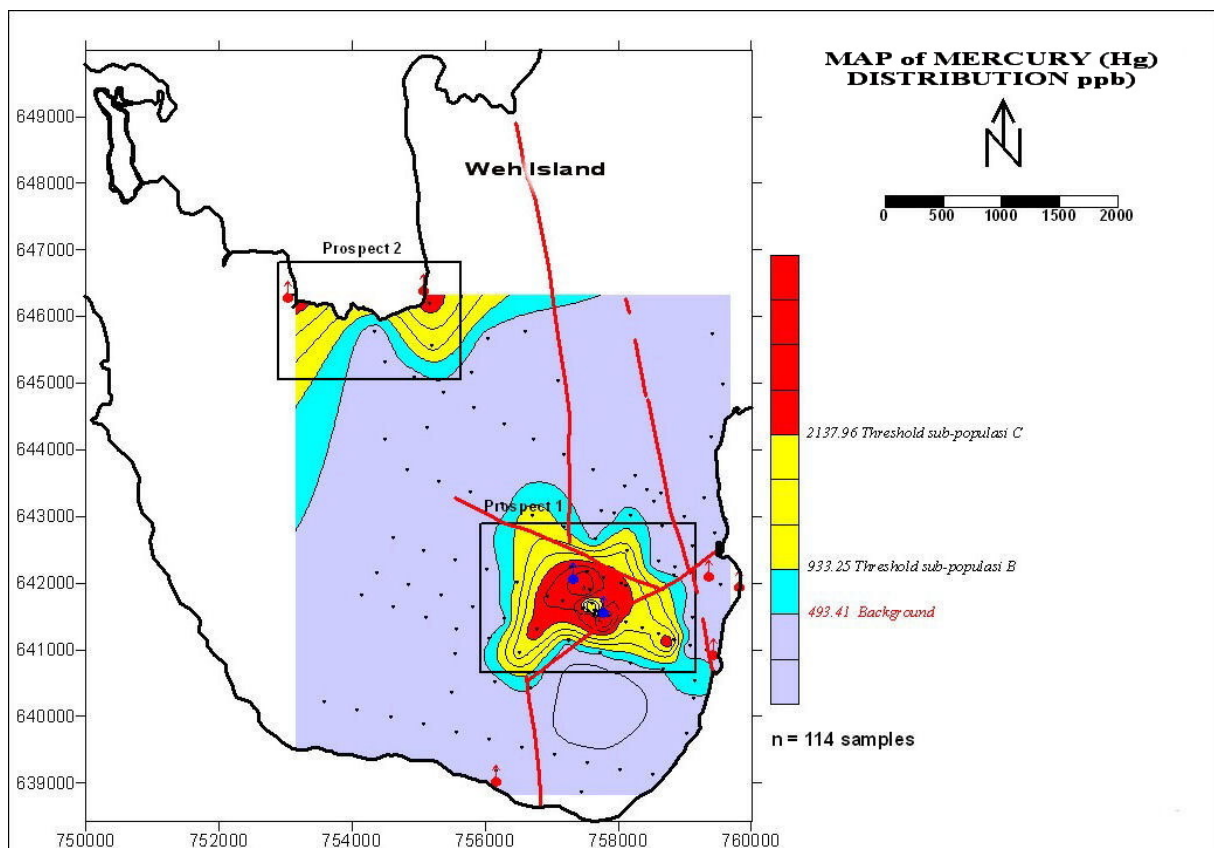


Figure 8: Map of Mercury (Hg) distribution (ppb)

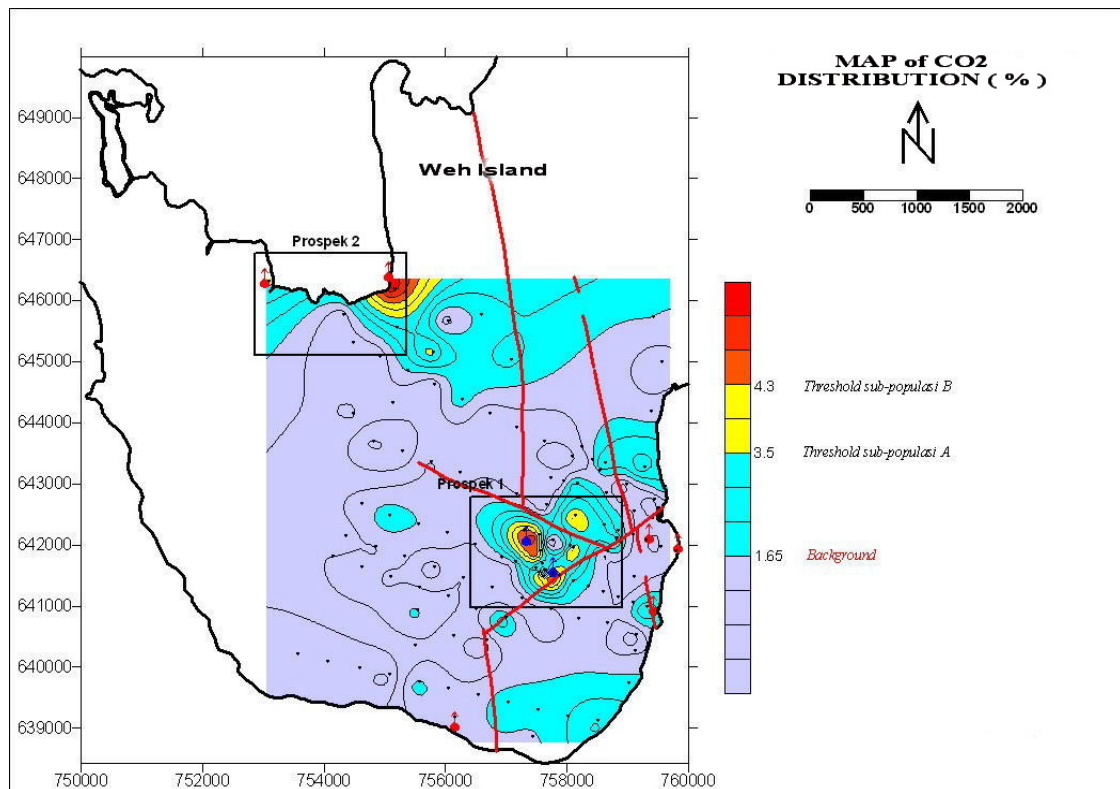


Figure 9: Map of CO₂ distribution (%)

5. DISCUSSION AND CONCLUSION

The application of the probability graph to geochemistry data processing in geothermal exploration is discussed.

Compilation of two anomaly maps (Hg and CO₂) indicated two interesting areas that should be subject to further study: Prospects 1 and 2, which are shown in Figures 8 and 9, respectively. Prospect 1 is more interesting than Prospect 2, because of the existence of geochemical anomalies that coincide with the intersection of N-S, NW-SE and NE-SW faults. The intersection of faults may form a permeability zone at depth and trap geothermal fluids in a reservoir. Lithology also partially controls the formation of the geochemical anomaly.

The probability graph can be used to divide data into sub-populations according to geological phenomena (a hydrothermal/geothermal event in this case). In the probability graph, processing is performed at a sub-population level so that the anomaly represents each sub-population. The application to a geothermal prospect shows that this method is applicable for data processing in geothermal exploration.

6. ACKNOWLEDGEMENT

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