Seismic reflection survey at Ayer Hangat site to investigate shallow subsurface structures

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Abstract. Ayer Hangat site is located in the island of Langkawi, northwest Malaysia. The site is characterized by the presence of hot spring. This hot spring is believed to be related to granitic intrusion nearby. Hence the present work is focusing on defining the shallow subsurface structures that control the migration of hot water to the surface. Seismic reflection method is used to achieve the goal of the present study. Forty three shot points were used with an offset of 5m of the nearest geophone. The shot-points interval is set to 1m. Seismograms were recorded on 24 channel TERRALOC instrument. The Geophone interval used was 1m. Conventional seismic data processing scheme was adopted. However, due to the fact that TERRALOC produce SEG2 data files, a script based on Obspy was written and used to convert to SEG-Y format. Afterwards, analyses were carried out using SU Package. The processed data is used to develop a model for the subsurface controlling structures. Such model will help in the understanding of the geothermal hot spring system in the area.

1. Introduction

Seismic reflection method is usually used for hydrocarbon exploration at relatively deeper depths. In that direction, the method gives high resolution images of the target structure relative to other geophysical techniques. For shallow depths, however, the method is less used and apparently losing ground for other geophysical techniques including seismic refraction method. The reason for that may be due to the extensive data processing labor required to produce meaningful seismic section. This doesn't tell all the story, some efforts were exerted to use seismic reflection to explore shallow depths adopting a simplified technique called optimum offset (e.g. [1], [2] and [3]). In the present work we will use that technique with some additional processing steps to enhance the resulting model.

The method is applied to Ayer Hangat complex site. The site is hot spring complex that currently undergoing development. The present study is applied there among other studies in order to help identifying the presence of hot water aquifer or pathway to the surface. The basic objective of the present work is to identify the near surface structures that may be responsible for water seepage to the surface. The structures are believed to be either faults or chimney like structures. Determination of such structure may help in decision on where to drill and where to build certain facilities.

Data processing in the present survey is carried out using both OBSBY [7] and Seismic Unix ([8] and [9]). Both are free and open source software. The use of OBSPY is restricted to preparing the field data by removing the DC-offset and to convert the original SEG-2 format into SEG-Y format. The rest of data processing are carried out using Seismic Unix packages on Ubuntu 14 ‘trusty’ version.
2. Site and Geology
The area under investigation is located at Langkawi Island in the north western peninsular Malaysia (Figure 1). Geographically, the area of investigation lies at latitude 6° 25’ 20.75” N and longitude 99° 48’ 46.52” E. The surface is rather flat at the site with the presence of pavement rocks and channels as parts of the complex. This features posed some problems during data acquisition stage and some measures were followed to avoid their negative effects. Langkawi itself is a Geopark that comprises 99 islands that form what is known as legendary archipelago [4].

![Figure 1. Location map of Ayer Hangat site.](image)

The geology of Langkawi is a result of long depositional history under the various paleo-environmental conditions, followed by the tectonic and magmatic events. The principal geologic units (Figure 2) encountered in Langkawi Islands are listed below in reverse order ([5] and [6]):

6. Superficial Deposits.
5. Gunung Raya Granite (Late Triassic).
4. Chuping Formation (Middle Permian to Early Triassic).
3. Singa Formation (Late Devonian and Early Permian).
2. Setul Formation (Early Ordovician to Early Devonian).
1. Machinchang Formation (Late Cambrian).

The Machinchang Formation is considered to be the oldest sedimentary rock succession in Langkawi. This formation covers the northwest side of Langkawi. Machinchang Formation is a deltaic
sequence, and it is composed of grey, brown, purple, and red, coarse to medium grained quartzite, arkose, and sub-greywacke [5].

Setul Formation is conformably overlying the Machinchang Formation, and exhibits a long period of marine transgression when the sediments deposited in relatively shallow marine environments ([6] and [4]). This formation composed of hard, brittle, dark-colored, thick-bedded limestone, with subordinate detrital facies [5]. The outcrops of this formation can be found on the eastern limb of the Machinchang anticline, and appear as a continuous belt along the eastern coast of Langkawi Island.

The Singa Formation rests unconformably on the Setul Formation, and it is surrounding the east and the south sides of the Gunung Raya granite dome in the middle of Langkawi Island [6]. Singa Formation deposited in the shallow marine environment, and it is composed of dark-grey or black well-bedded carbonaceous flagstones, grey and black shale, and siltstones with subordinate grey and brown immature quartzites and sub-greywackes [5].

Large and small igneous stocks are found scattered over Langkawi Island. The largest one found in the middle of Langkawi Islands called the Gunung Raya granite dome. The granite intruded into all older sedimentary rocks formations turning them into several types of metamorphic rocks.

![Figure 2. Geologic map of Langkawi Archipelagos](image)

### 3. Methodology and data analysis

The method used in this survey can be termed as common offset method (e.g. [1] and [2]). In this method we tried to imitate the optimum offset method using data recorded at 24 geophones land streamer. Different common offsets were investigated in order to choose the one that produced the best resolution among the 24 geophones recorded for each shot. Subsequent processing techniques are then applied to enhance amplitude of the reflected data.
3.1 Data Acquisition

Seismic survey was carried out using land streamer with 24 geophones at 1 m interval. The source is 5 kg hammer at an offset of 3 m from the nearest geophone. This produce a maximum offset of 26 m. For the survey we used 48 shots points at 1 m offset. Hence the total length of the data acquired is 70 m (Figure 3). The first shot is located at the hot spring site. Seismic data are recorded by TERRALOC MK-8 instrument at sampling interval of 0.0001 sec. The total length of each recorded trace is 0.8192 seconds. Data files produced by TERRALOC are exported in special SEG-2 format. When trying to convert these file formats with seg2segy code accompanied with SU software we encountered problems and conversions could not be made. Another problem with the data recorded by TERRALOC is the DC-shift. Such shift must be removed before applying any data processing steps because it produced Gibb’s phenomena due to the sharp change in amplitude at both start and end.

![Figure 3. Location map of Seismic line at Ayer Hangat complex.](image)

3.2 Data Processing

From the previous section we realize that two problems are encountered with the data files obtained. The DC-shift is crucial and may lead to false reflection on the final seismic section. OBSPY is used to solve recorded data problems. Python script is developed using OBSPY [7] methods to remove both DC-shift and to convert the data into SEG-Y format. Fig. 4 shows shot gather plot after correction of data using OBSPY. At this point common offset gather at 10, 20 and 26 m are investigated in order choose the best offset to use. The common offset gather at 26 m shows the best resolution and hence will be used for further analysis. Seismic UNIX (e.g. [8] and [9]) is then used to process the data. Starting by resampling the data to 0.008 sec in order to reduce processing time. Static corrections
which account for the change in the depth of the layer just below the surface and is then removed by aligning first arrival. Pullan et al. [1] pointed out that data processing is rather a cosmetic process to make the seismic more readable. Hence the second step is to adjust the gain using AGC for amplitude balancing of the seismic traces. Taper is then applied to reduce the amplitudes of both the earlier arrivals and arrivals near the end of the records that are not reflection data. Digital band-pass filter is then applied to remove unwanted signals or noise. We used band-pass filter to filter out the data outside the band from 10 to 50 Hz. The aforementioned steps are the same proposed by [1] and [2]. We applied more processing steps to remove high frequency noise and to migrate the final seismic section (Figure 5).

4. Discussion
Common offset technique used in the present work aimed towards identifying the near surface structure that may control hot water flow in to the surface. The final seismic section shown in Figure 5 shows that the area near the hot spring is dissected by step faults that apparently dipping in the
direction of hot spring (Figure 6). This may indicate that these step faults are controlling hot water flow into the surface. Current analysis using common offset prove successful in determining the structures at near two way times (about 0.2 sec). Depth determination is not included in the present work due to some limitations in the data acquired. However, the deduced result is useful for pointing out where to drill for the development of the geothermal complex.

Figure 6. Sketch showing the interpreted subsurface structure.

5. Conclusion
Near surface structures is investigated using common offset seismic reflection technique in order to help define hot water accumulation and pathway to the surface. Forty eight shot points were used at horizontal offset of 1 m. Reflection data were recorded using TERRALOC MK8 instrument with land streamer of 24 geophones at 1 m interval. The record length is 0.8192 sec with sampling interval of 100 us. Data are processed and analyzed using both OBSPY and Seismic Unix software. The final section obtained using common offset of 26 m shows the existence of step faults that dip in the direction of the hot spring. These faults may control the flow of the hot water to the surface. The results of the present study may help in the development plan of the hot spring complex.

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