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Assessment of geological CO_2 storage potential in central Luconia province

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ABSTRACT

The objectives of this paper are to evaluate the suitability of the Central Luconia Province as a potential geological storage site for CO_2 in Malaysia and to estimate the theoretical storage capacity of the basin by using Carbon Sequestration Leadership Forum (CSLF) and US Department of Energy (US-DOE) methods. The Central Luconia that has a limited faulting and located within seismic-free zone and possessing suitable geothermal condition which is an attractive characteristic for potential site for CO_2 storage are found to be suitable for geological CO_2 storage in Malaysia. The Central Luconia Province is estimated to be able to store CO_2 from 56 Gt up to 75 Gt. The Central Luconia Province is believed to be a potential site for geological CO_2 storage and will give much help in reducing CO_2 emissions in atmosphere of Malaysia.

1. Introduction

The increasing amount of greenhouse gas in the atmosphere recently has become one of the discussed topics in relation with world's concern on climate change. According to projections of energy use worldwide, global carbon dioxide (CO_2) emissions are expected to increase by 55% between 2004 and 2030 or 1.7% per year. Malaysia is one of the main oil-producing countries. According to Oil and Gas Journal (OGJ), Malaysia held proven oil reserves of 4 billion barrels up to January 2011. CO_2 emission as a result of petroleum production has been identified as one of the contributor to the emission of CO_2 in Malaysia. It was projected that without any mitigation measures being taken up by the country, 285.73 million tone of CO_2 emitted in year 2030 (Safaai et al., 2011). In addition, the high use of fossil fuels, foreseen to continue well into the future, is the major contributor to increased emissions into the atmosphere of CO_2 (Jepma and Munasinghe, 1998). Plus, the rapid growth of primary energy consumption is resulting in fast increase of CO_2 emissions which brings the challenge of reducing greenhouse gas emissions. Taking into account the expected increase of energy demand for sustainable development in Malaysia, the potential for CO_2 geological sequestration opportunities in Malaysia should be investigated as a potential way of reducing CO_2 emission.

As suggested by Wilson et al. (2007), Geological storage of CO_2 is a viable method to reduce CO_2 emissions into the atmosphere. However, to provide a safe geological storage of CO_2 in sedimentary basin, CO_2 is required to be stored at depth varies from 1000 – 1500 m for a warm sedimentary basin (geothermal gradient > 40 °C/km) so that the CO_2 will be in the dense phase which will maximize the storage volume. The injection in shallower depth (<1000 m) may result in storage in gaseous phase which will occupy much larger unit volumes of pore space and increase the risk of leakage of highly buoyant CO_2 to the surface hence will give impact on human health. A good CO_2 geological storage media has to possess an excellent seal trap or thick regional cap rocks to prevent upwards migration through the overlying sedimentary sequence (Bachu and Adams, 2003).

Hasbollah and Junin (2015) proposed the Central Luconia Province as one of the potential sedimentary basins for CO_2 sequestration in Malaysia. With the score of 0.74, Central Luconia Province was ranked as the second most potential sedimentary basin after Malay Basin to be geological storage of CO_2 in Malaysia. The screening and ranking of sedimentary basins has been conducted by using Bachu (2007) method. A set of geological criteria has been set, scored and weighted based on the importance of the criteria and how much it will affect the performance of the basin as a CO_2 geological storage site (Fig. 1).

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Central Luconia Province is a geological province of the Sarawak Basin that covers area around 45 000 km^2, located 100 – 300 km from the present coastline in water depths of 60 – 140 m (Koša, 2015). It is bounded to the east and west by the Baram and West Luconia deltas respectively and to the south by the compressive Balingian Province and separated from Baram Delta by a major fault known in Sarawak as West Baram Line. The Central Luconia Province is a broad and stable continental shelf platform characterized by extensive development of Middle to Late Miocene carbonate build – ups. Concurrent crustal extension in the Central Luconia Province resulted in the development of a horst-graben pattern. There are two types of build-ups dominated the carbonate formation namely platform-type and pinnacle type. Platform-type of buildups usually developed on high areas whereas pinnacle-type of buildups usually formed in adjacent elected blocks within the basinal area where the distance from the source of clastic materials is closer. The carbonates consist of limestone and dolomites with porosities ranging from 0 to 40 percent. More than 200 carbonate buildups have been seismically mapped and some 65 buildups have been tested. The carbonates are producing some 65 trillion cubic feet of gas and have some minor oil reserves. More than 70% of major gas discoveries in Malaysia are found within carbonate reservoir of the Central Luconia Province (Embong et al., 2008).

2. Tectonic setting of central Luconia province

The continental shelf of Sarawak is the easternmost segment of the Sunda Shelf. The shelf is very broad, exceeding 300 km from coast to shelf edge and exhibits a relatively smooth and gentle topography. The tectonics and sedimentation in offshore Sarawak are largely controlled by the continuous opening of the South China Sea Basin from the Middle Oligocene to the Middle Miocene. The Luconia Shoal (platform) is a micro-continental block bounded by transform faults, which separate it from the Baram Delta Province to the east and the Rajang (West Luconia) Delta Province to the west. The area remained stable throughout the Tertiary, resulting in carbonate deposition and reef growth, contemporaneous with clastic deposition in the Baram and Rajang deltas. The basin fill consists of several kilometers of sediments of Oligocene to Recent age, ranging from coastal plain to deeper marine sequences, representing 8 regressive depositional cycles.

3. Stratigraphy of central Luconia province

The Central Luconia Province is known to have undergone several episodes of sedimentation which form the basis for the subdivision of the stratigraphy into 8 regressive cycles separated by major transgressions. These cycles are numbered I to VIII and ranging in age from the Eocene to Present. Carbonates are found throughout the stratigraphy but a regional extensional event happened mostly during Middle Miocene (at the end of Cycle III). Based on stratigraphic review, Cycles IV, V and VI, where extensive Miocene carbonate buildups discovered, are the best potential area for CO_2 sequestration. These cycles are located at depth up to 4 km from the seafloor. Considering the Central Luconia Province as a warm basin, the required depth for safe CO_2 storage is from 1000 m to 1500 m. These strata fulfill the typical minimum depth requirement for average reservoir condition which is greater than 800m. Intermediate depths between about 800 to 3500 m are the most favorable condition for CO_2 storage (Kaldi and Gibson-Poole, 2008). However, Cycle IV, V and VI are thought to be potentially attractive for CO_2 because they represent about 80% of total reservoirs in the Central Luconia Province. Hence they are expected to provide an extensive storage sites for CO_2. Besides, these strata provide an excellent top and lateral seal that consists of mid-cycle shales and also regressive clastic wedges and basal transgressive sands establish potential seal rocks. The porosity of Cycle IV (34%) and Cycle V (20%) are also attractive reservoir properties that should be taken into account during anticipating the theoretical storage capacity. Limestone (Cycle IV) and sandstone (Cycle V) reservoir are proven to be the best reservoir due to its high porosity and permeability properties. Although Cycles I, II and III are also possessing attractive reservoir properties for CO_2 storage, in terms of depth, these strata are not favorable because depths over 3500 m will impact on the economic feasibility as the greater depth involves extra drilling works. Besides, there are also common reduction in reservoir permeability and additional works when dealing with overpressure condition which at the end will increase the project costs. Meanwhile, Cycle VII and VIII are not advisable to be CO_2 storage sites as they are too shallow in depth and also they are possessing high sand content.

4. Methodology for storage capacity assessment

In this basin-assessment, the storage capacity of Central Luconia Province is also estimated. In this paper, theoretical storage capacity of this basin is determined by using two methods that currently available to the public which is CSLF method by Bachu (2007) and method by US-DOE (2012). The practice of these two methods in this paper is to compare and to build confident in the result obtained.

5. CSLF method for CO_2 storage capacity estimation

This method is developed by Bachu (2007) for CSLF. Carbon Sequestration Leadership Forum (CSLF) is an initiative that is focused on the development of improved cost-effective technologies for the separation and capture of carbon dioxide (CO_2) for its transport and long term safe storage.

For saline aquifers, the boundary conditions are considered to be open. The theoretical volume, M_{CO2t} available for CO2 storage in structural and stratigraphic traps of saline aquifers can be calculated with the Eq. 1:

$$M_{CO2t} = A\ x\ h\ x\ \phi\ x\ (1 - S_{wirr}) \quad (1)$$

where, M_{CO2t} is the geometric volume of the structural or stratigraphic trap down to the spill point, Φ is the average porosity of the sediment and S_{wirr} is the irreducible water saturation. In this paper, the S_{wirr} was assumed to be 0.4 based on suggestion by Szulczewski et al. (2012). a and h are the trap area and average thickness, respectively.

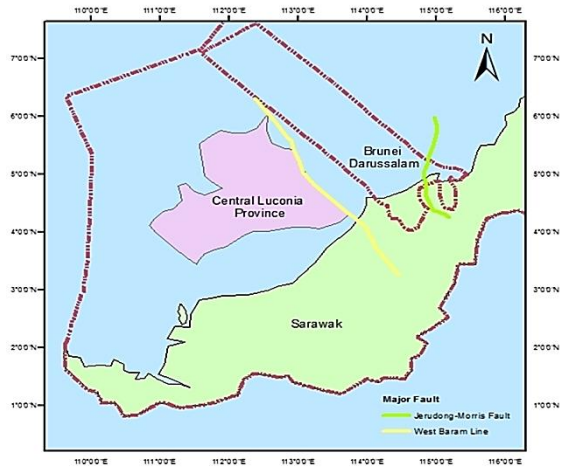

Fig. 1: The location of central Luconia province

6. US-DOE method for the development of geologic storage potential for CO_2

The U.S Department of Energy (US-DOE) method by Goodman et al. (2013) is intended for external users to produce prospective CO_2 resource assessments of potential CO_2 storage reservoir at regional and national scale. For saline aquifers, the boundary conditions are considered to be open. The volumetric equation to calculate the CO_2 storage resource mass estimate, G_{CO2} for geologic storage in saline formations is Eq. 2:

$$G_{CO2} = A_t \times h_g \times \phi_{tot} \times \rho \times E_{saline} \quad (2)$$

where, A_t is the total geographical area of the basin being assessed for CO_2 storage, h_g is the gross thickness of the saline formation for which CO_2 storage is assessed within the basin, ϕ_{tot} is the total porosity in volume defined by the net thickness, ρ is the density of CO_2 within the reservoir and assumed to be 620 kg/m^3 across the basin (Koukouzas et al., 2009).

According to Goodman et al. (2013), carbon dioxide storage efficiency, E_{saline} gauges the fraction of the accessible pore volume that will be occupied by the injected CO_2. In this paper, the calculation of theoretical storage capacity is made by assuming E_{saline} to be 2.0% for clastic and 1.5% for limestone formations based on 50th percentiles.

7. Results

Central Luconia Province is thought to be a foreland basin. Up to 2009, very limited inactive normal faults have been identified within Central Luconia Province area. Besides, JMG Malaysia reported there are only a few seismic activities detected within Central Luconia Province (4.0 – 4.9 Ma) up to year 2011. Seismic activity will determine whether area is suitable or not to be geological storage for CO_2.

The area with less seismic activity is more attractive to be considered as a candidate for CO_2 storage sites. The geothermal condition in the sedimentary basin of Central Luconia is mostly ranging from 36 °C/km to 45 °C/km that makes the basin considered as warm basin. Moreover, based on Petronas, Central Luconia Province is considered as mature and productive sedimentary basin and where a lot of commercial discoveries took place. The maturity of the basins will give a direct impact on the overall project cost (Table 1).

Table 1: Compilation of Central Luconia Province characteristics from various published data

Criteria	Central Luconia Province
Tectonic setting	Foreland
Faulting intensity	Limited faulting
Seismic activity	No seismic activity recorded in the area
Geothermal regime	Warm basin
Maturity	Matured
Size	Large
Average porosity	20%
Seal formation	Shale

8. CO_2 storage capacity estimation

In this paper, it is assumed that saline aquifers provide clastic and limestone reservoirs and transmit CO_2 – bearing waters by acting as heterogeneous porous media. Sandstone reservoir with average porosity 20% and the thickness of the formation that is going to be used for CO_2 storage is 500 m as the required depth for CO_2 injection in warm basin is between 1000 m to 1500 m so that the injected CO_2 will be in supercritical condition. Sandstone reservoirs that are located in Cycle V and VI sediments are thought to be the best candidates for early deployment of CO_2 sequestration project.

Table 2 shows the estimated CO_2 storage capacity at the depth of 1000 m to 1500 m in Miocene sediments of Central Luconia Province. From the calculation using CSLF (2007) method, the estimated storage capacity of CO_2 is approximately 75 Gt while using US-DOE (2012) method, the storage capacity obtained is approximately 56 Gt. The efficiency and reliability of these two methods is profoundly discussed and compared in Goodman et al. (2013).

9. Discussion

Fig. 2 shows Cycle V and VI sediments are the perfect candidate for potential injection site for CO_2 in Central Luconia Province. This is because the cycles are located within the required depth to provide safe storage for CO_2 which 1000 m to 1500 m considering Central Luconia is a warm basin. With average geothermal temperature of 36 °C/km to 45 °C/km, CO_2 has to be injected within that depth to provide a safe storage. In addition, the injection that commences at this depth will make sure the CO_2 to be stored in dense phase that will maximize the storage volume.

Table 2: CO_2 storage capacity estimation based on 50th percentile

Method	CO_2 Storage Capacity (Gt)
CSLF (2007)	75
US-DOE (2012)	56

Besides, Cycle V and VI Miocene sediments are mostly consist of carbonates buildups and sandstones. These cycles are also possessing attractive reservoir properties with average porosity of 20%. With thickness of Cycle V around 680 m and Cycle VI around 90 m with length approximately 150 km, promise an abundant storage volume for CO_2. Besides, these Miocene sediments are overlaid by Cycle VII which is rich with shale and sand content that will be acting as a lateral sealing for this area. Moreover, limited faults have been identified within the province of Central Luconia. This is a good characteristic as it will minimize leakage and upward migration of stored CO_2. Based on the nature of the faults, it minimizes the risk for containment breaches via conductive faults and fractures and also the amount of faulting indicates the potential for compartmentalization of individual reservoirs which could reduce the storage volume (Kaldi and Gibson-Poole, 2008). With this circumstance, it is also minimizes the risk of the faults to be reopened during injection. Hence this proposes that Central Luconia Province is suitable for geological CO_2 storage.

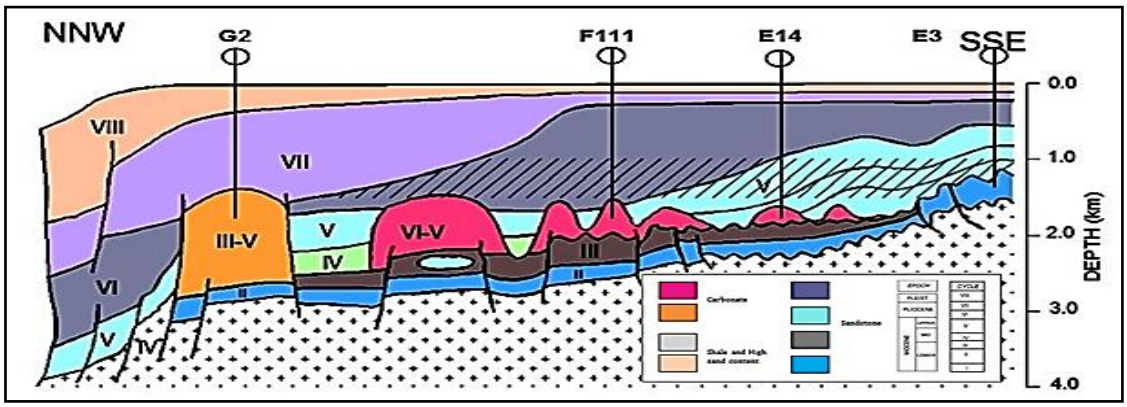

Fig. 2: Potential injection site in Central Luconia Province

As active seismic activity could pose potential dangers on the carbon storage equipment and facilities such as the compression equipment, injection pump, wellheads, pipeline, monitoring equipment and so on for most of the infrastructures used in CO_2 sequestration in geological formation are typically located on or near the ground surface, it is recommended that the CO_2 to be injected in the area with less seismic hazard. Although seismic hazard is not a fatal flaw, the cost of mitigating the risk using higher engineering standards should be considered as it will increase the project cost efficiency. It can be inferred that seismic risks can significantly impact decisions about where to store the CO_2 in geological formations.

According to Bachu and Adams (2003), for temperature greater than 31.1°C and pressures greater than 7.38 MPa, CO_2 is in a supercritical state where it will behaves like a gas by filling all the available volume but possessing a liquid density the increases depending on pressure and temperature. Therefore, with such range of geothermal gradients, the Central Luconia Province is believed to have a suitable geothermal condition to be a geological storage for CO_2.

Based on data that have been compiled, the Central Luconia Province is identified as a mature basin. This type of sedimentary basin indicates that it has a large amount of existing relevant data that will be beneficial in decision making in the next level of assessment and will minimize the risk of contamination due to the lack of related data available. And also, economic considerations in geological sequestration of CO_2 have to do with the existing or needed infrastructure. In mature sedimentary basins, the infrastructure is already in place (access roads, pipelines and wells) and injection sites are easy to access and inexpensive to develop (Bachu and Adams, 2003). Therefore, this makes Central Luconia Province a potentially attractive location for early deployment of CO_2 sequestration project as it has a higher degree of certainty compared to other less explored sedimentary basins in Malaysia.

From the calculation of theoretical storage capacity by using CSLF (2007) and US-DOE (2012) methods, the Central Luconia Province (depth 1000 m to 1500 m) is predicted to be able to store CO_2 up from 56 Gt (US-DOE, 2012) up to 75 Gt (CSLF, 2007) when the injection is commences at depth 1000 m.

The injection has to be commenced at depth 1000 m, to make sure CO_2 is in supercritical condition and it will maximize the storage capacity considering the Central Luconia province is a warm basin. This indicates the Central Luconia Province promises an abundant of geologic storage for CO_2 in Malaysia. The difference value of storage volume obtained from these 2 methods is due to the wide variety of definitions and rules prescribed by the individual methods for applying efficiency. The comparison of these methods is profoundly discussed by Goodman et al. (2013).

10. Conclusion

This paper discussed a basin-scale assessment on the Central Luconia Province located in offshore Sarawak to evaluate the suitability of this Miocene sedimentary basin for geologic storage of CO_2 and estimate the theoretical storage capacity of this sedimentary basin at depth 1000 m to 1500 m considering this basin as a warm basin. This Miocene sedimentary basin possesses a good geological characteristic to be a safe geological CO_2 storage for long term CO_2 storage. The Central Luconia Province has very limited faults, located at seismic-free zone, mature basin are making the basin has a good prospect to be developed as a geological storage for CO_2. Cycle VII that consists of shale interbedded with high-sand content sediment will act as lateral seal for the storage to prevent upward migration and leakage of CO_2. The results also show the Central Luconia Province can store from 56 Gt up to 75 Gt of CO_2 which has been estimated using US-DOE (2012) and CSLF (2007) methods respectively. The findings indicate that Central Luconia Province has a great potential for CO_2 geological storage and will give much impact in reducing CO_2 emissions in atmosphere of Malaysia. The results from this basin-scale assessment will be used in the next prospective site assessment before the deployment of the project can take place and can be used in making decisions for large scale implementation of such operations.

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