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ARTICLE

Unlocking High CO_2 Gas Fields in the Central Song Hong Basin, Vietnam: Implication for Carbon Storage

Vo Thi Hai Quan

Geochemical Department, Vietnam Petroleum Institute, Ho Chi Minh City 700000, Vietnam

ABSTRACT

CO_2-dominated gases in the A, B, C pools were resulted from gas chromatography analysis in the central Song Hong basin. These data were integrated with additional information on regional geology, properties of source rocks and reservoirs from Rock-Eval pyrolysis and petrology data in the Pliocene and Pleistocene formations that were used to imply the impacts of geological features on the origin of gases. Compositions of gases comprise the dominance of CO_2, followed by C_1, small contents of N_2, minor contents of C_2 and absence of C_3–C_8, H_2S, He, Ar, H_2, and CO. These gases could be generated from deeper sources and probably small amounts of them released from shallow sources that are strongly impacted by the rapid sedimentation rate, biochemical and geothermal alteration phases. The main period of gas migration and entrapment in the A, B, C fields could be in the period of Pliocene–Pleistocene. The dominance of CO_2 contents in these gas reservoirs mainly came from the dissolving carbonate in sandstone reservoirs, interacting between feldspar and clay minerals with carbonate cement, the process of CH_4 generation in the early stage of sediment diagenesis at shallow depths. Understanding where the CO_2 comes from and regional geological activities are useful for unlocking these high CO_2 accumulations and finding out suitable geological formations for CO_2 storage. Stratigraphic correlation shows the consistent properties of the reservoirs including geological units, high pore spaces, carbonate cements, and high pressures, which are suitable geological formations for potential CO_2 storage.

Keywords: CO_2; Gas Field; Carbon Capture and Storage (CCS); Gas Composition; Carbonate; Song Hong Basin

*CORRESPONDING AUTHOR:

Vo Thi Hai Quan, Geochemical Department, Vietnam Petroleum Institute, Ho Chi Minh City 700000, Vietnam; Email: quanvth@vpi.pvn.vn

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1. Introduction

Song Hong is one of the largest Tertiary sedimentary basins in Vietnam that covers from the onshore areas in the North of Vietnam to offshore areas and spreading along the coastal shelf from the north to the middle part of Vietnam. A number of commercial gas fields in this basin have been explored and produced with CO_2 contents varying from very low up to 91%. In recent years, huge potential gas pools have been discovered in the central part of the Song Hong basin, attracting more oil companies to invest in this area for exploring petroleum. Variations of structural styles and depositional environments through space and time are controlled by the very complicated evolution history with various phases of extension-compression, inversion tectonics, uplift-subsidence, erosion-truncated, thermal subsidence, and sea level changes in the whole basin. The basin is characterized by the rapid sedimentation rate with the maximum deposition up to 1.4 mm/year[1] and a high geothermal gradient ranging from 3.7–4.6 °C/100 m, the thicknesses of the sediments up to 14 km in the central part[2]. Therefore, the processes of gas accumulation and preservation in this basin are very complicated. In terms of gas charging and accumulation, gas pools in this basin are characterized by several types of generation, migration, and entrapment from Mesozoic to Quaternary. Gas accumulations in the central Song Hong are typically found in the period of Neogene-Quaternary. This study examines the characteristics of gas and implying their origins from the impacts of geological features on gas accumulations that support CO_2 storage purposes.

2. Geological Background

Song Hong Basin is located within 105°30′–110°30′ E longitude and 14°30′–21°00′ N latitude and covers about 220,000 km^2 of the surface area. Geographically, the basin comprises a small onshore area named the Hanoi trough, and a large offshore area in the Gulf of Bac Bo and the central Vietnam from Quang Ninh to Binh Dinh. This basin is of rhombic shape, extending from the Hanoi trough to the Gulf of Bac Bo and the Central coastlines (**Figure 1**) with Tertiary (Paleogene to Quaternary) sediment thickness exceeding 14 km. Mesozoic-Paleozoic basement is exposed along the western and eastern blanks of the basin. The basin is bordered by the Weizou/Beibu Wan basin to the NE, with the SE Hainan basin and Hoang Sa basin to the SE, and the Phu Khanh basin to the south[3].

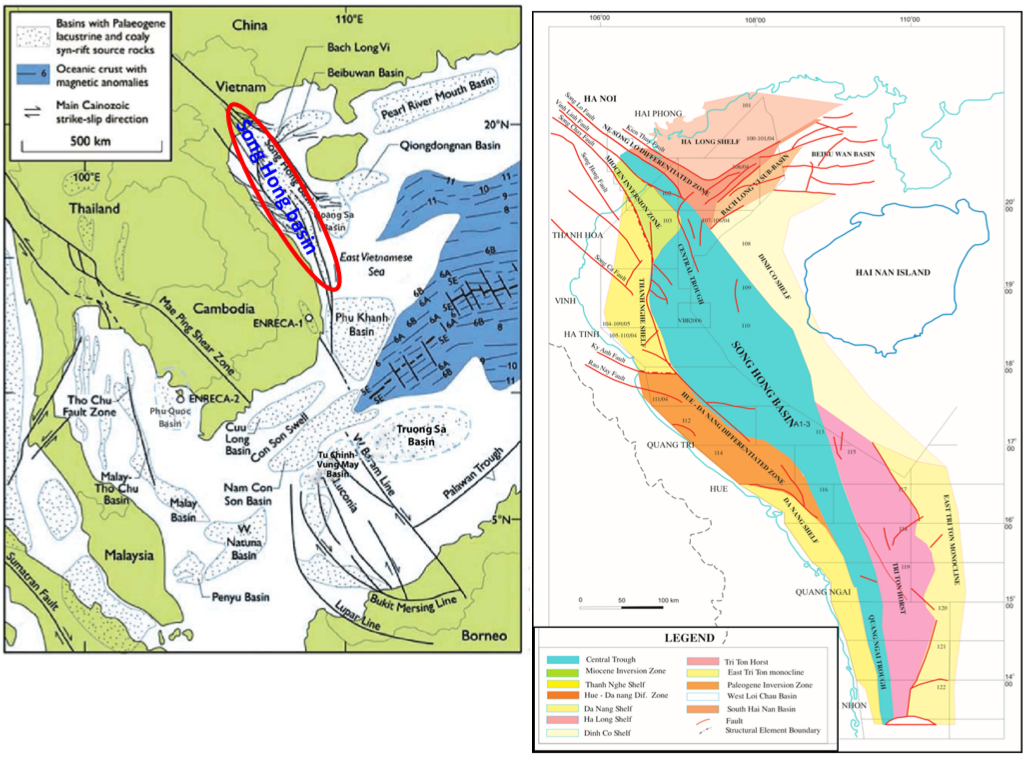

Figure 1. Location map and structural elements in the SH basin[2,3].

2.1. Tectonic Activities

Song Hong Basin is a tertiary sedimentary basin formed from a NW-SE, which is bounded by strike-slip and normal fault systems (**Figure 1**). These fault systems were triggered by the collision between the Indian and the Eurasian plates during the Eocene-Early Oligocene. Left lateral strike-slip movement in the Oligocene, right lateral movement in the Late Miocene, and pull-apart extension are the major geodynamic elements that form the Song Hong basin. Immediately following the Middle-Late Miocene tectonic inversion, the basin continued to steadily undergo thermal subsidence until the present. Having a very complicated evolutionary history, the Song Hong basin has undergone various phases of extension-compression, tectonic inversion, uplift-subsidence, erosion-truncation, and thermal subsidence coupled with sea level changes. Consequently, its structural style and depositional environment vary in time and space, from the North to the South, from onshore to offshore, and from the (Pre-Tertiary) basement to the (Holocene) surface. For this reason, the Song Hong Basin is made up of different structural units with different hydrocarbon potential. **Figure 1** reveals that from the NW to the center and to the South, the basin is composed of these structural units. The cation of these structural units is based on the basin's present day architecture, taking into account its hydrocarbon potential [3].

2.2. Stratigraphy

Sediments in the central SH basin were strongly affected by tectonic activity. Sediments in the depocenter part are mostly fine-grained atop Upper Miocene-Pliocene shale diapirs [4]. The Pliocene sediments had undergone tectonic uplift and inversion in the NW of the Gulf of Bac Bo to form the uplifted Dong Son. Due to the sediment influx, sand bodies in the Upper Miocene-Lower Pliocene were usually deposited in submarine fans and turbidity facies, spreading from the NW to the SE (**Figure 2**). Significant prospects include low magnitude four-way dip closures on the Dong Son uplift and four-way dip closures developed on the shale diapirs [3], i.e., the Dong Fang and Le Dong gas wells in China or turbidities/submarine fans to the east of central blocks.

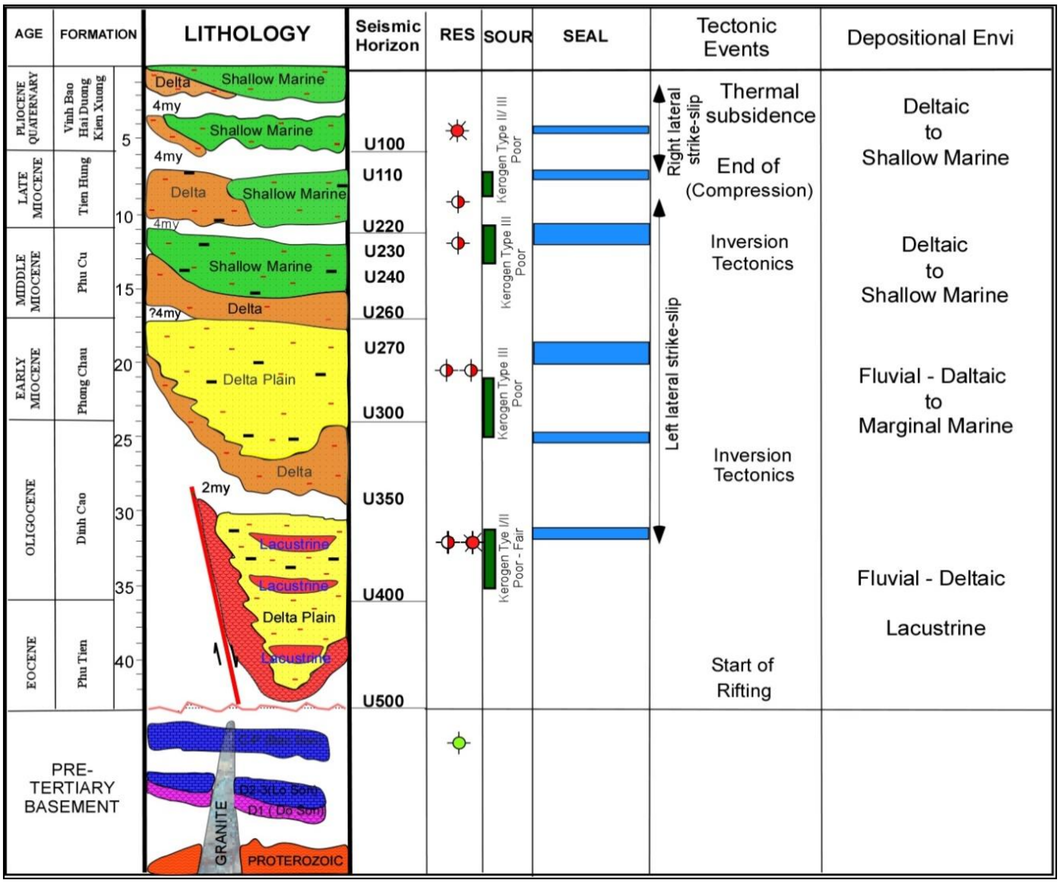

Figure 2. Stratigraphic column in the central Song Hong basin [5].

Along the coast of the central part of the Song Hong basin, the basement mainly consists of Upper Ordovician-Silurian carbonates, gritstone/conglomerates, sandstones, and schist of the Long Dai and Song Ca Formations, Lower Devonian sandstones and conglomerates of the Tan Lam formation, Middle-Upper Devonian carbonates of the Cu Bai formation, and other granite-biotite intrusive, etc. (**Figure 2**). These formations tend to develop seawards, and have possibly been formed by buried traps that later turned into important hydrocarbon reservoirs as discovered in the Bach Tri and Hai Yen structures[3].

The Hue-Da Nang shelf is restricted by the onshore Song Ca and Rao Nay fault systems. This area was dominated by left lateral strike-slip fault systems, forming a whole series of echelon blocks of horst and graben structures at the end of Oligocene (**Figure 1**). The most important geological structures in this region are the Anh Vu-Da Nang graben and Hai Yen-Bach Tri-Than Nong high, which were uplifted prior to the Lower Oligocene and syn-sedimentation continued in the Lower Miocene. Upper Oligocene-Lower Miocene inversion occurred in some grabens or half-grabens, i.e. prospects in blocks 111 and 114. Middle-Upper Devonian carbonate drapes developed on top of the basement highs, i.e., Hai Yen and Bach Tri prospects, four-way dip closures formed in the Miocene clastics, i.e., The Dai Bang prospect; Oligocene-Lower Miocene inversion and minor reef build-up are important exploration targets in this region[3].

3. Materials and Methods

Five gas samples were taken from 3 wells A, B, C in two blocks in the central Song Hong basin that were used for identifying the compositions of gas from gas chromatography analysis and implying their origin based on assessment of source rock and reservoir properties from Rock-Eval pyrolysis and petrology analyses with a reference from well logging data.

- **Gas Sampling**

These gas samples were taken on the well site following ASTM-D-1145. The procedure of sampling was performed as follows: (i) all gas sample cylinders had been cleaned by anhydrous isopropyl alcohol and 1,1,1-Trichloroethane, then dried to keep them in good condition in the laboratory prior to sampling; (ii) On the well site, the samples were obtained from the injection tubing string at the wellhead and were captured by connecting the sample bottles to sample taps in the main pipeline; (iii) the cylinders were purged for several minutes with the sample gas in the field; (iv) samples were slowly collected by allowing gases to flow into the cleaned cylinders at the wellhead[6].

- **Gas Chromatography Analysis**

This test was performed on a temperature programmed gas chromatography instrument, GC HP-6890, which was equipped with a thermal column detector (TCD) following GPA standard 2286-14. This test is used to identify the chemical compositions of natural gas and similar gaseous mixtures that precise physical property data of the hexanes and heavier fractions are required. The procedure is applicable for mixtures which may contain components of N_2, CO_2, and/or hydrocarbon compounds C_1–C_{14}. Components to be determined in a gaseous sample are physically separated by GC and compared to calibration data obtained under identical operating conditions on a mixture of known composition. Fixed volumes of sample in the gaseous phases are isolated in suitable sample inlet valve and each volume will be injected into a chromatographic system. The chromatograms are interpreted by comparing the areas of the component peaks obtained from the unknown sample with corresponding areas obtained from an analysis of a selected reference standard on the computer. The analysis is used to calculate the mole percentage of each component using the procedures of allocation and/or bridging[6].

4. Results

4.1. Main Properties of Source Rocks and Reservoirs

Three prospect wells A, B and C belong to adjacent blocks X and Y that were drilled for identification of hydrocarbon potential filling in sandstone reservoirs. These shallow stratigraphic wells were drilled to Pliocene with the deepest deposition at 2,267 m in the well A. As the biostratigraphy analysis results, the sediments are divided into stratigraphic units as follows:

- Well A-1X: 520–1,599 m (Pleistocene), 1,599–2,267 m (Pliocene);
- Well B-2X: 800–1,200 m (Pleistocene), 1,200–1,750 m (Pliocene);

- Well C-4X: 900–1,160 m (Pleistocene), 1,160–1,667 m (Pliocene).

Depending on reference data from seismic and well logging, the lithologies of the sediments are mainly composed of thick calcareous shales interbedded with thin sandstones and siltstones (**Figure 3**). Therefore, several shale intervals in the Pliocene were selected for better understanding of hydrocarbon generation potential if they play roles not only as local seals but also as potential source rocks in this shallow formation.

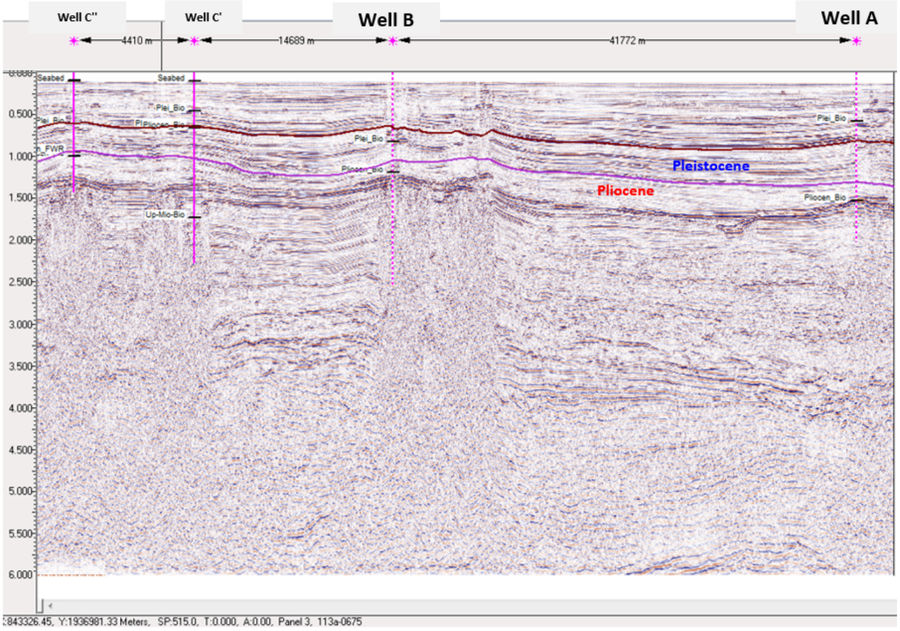

Figure 3. Seismic section of wells A and B. Well C′ located next to well C″ with the same stratigraphic units[6].

Depending on Rock-Eval pyrolysis parameters of these wells, Pliocene shales are mainly composed of poor to fair hydrocarbon generation potential with TOC varying from 0.33–0.71 wt.% and pyrolysis yields (S1 + S2) ranging from 0.36–2.34 mgHC/g rock. The Pliocene shales mainly contain organic matter derived from Type III kerogen of higher plant land, with a minor contribution from Type II kerogen of algae, and a Hydrogen Index ranging from 164–385 mgHC/g TOC. Tmax values are less than 435 °C, indicating the organic matter has not reached the mature stage yet. However, Productivity Index (PI) values ranging from 0.07 to 0.26 indicate that the organic matter is mostly in early mature to mature stages. Therefore, the shales could be considered as potential source rocks generating gas only (**Table 1**, **Figure 4**).

The rapid sedimentation rate causes a high geothermal gradient of around 4.3–4.6 °C/100 m in this area. Therefore, these shallow shales rapidly entered the high temperature zone at shallow depths. It means that the organic matter quickly reached the early mature to mature stages in a short time. This is consistent with the measured Productivity Index (PI) from Rock-Eval pyrolysis. In addition, S1 values indicate that a small amount of free hydrocarbons was probably generated and released from the Pliocene shales. Among them, S1 values from source rocks of the A-1X well are slightly higher than those of the other wells. The cross-plots of S1 vs. TOC show a gas effect zone in the interval 2,195–2,230 m of well A (**Table 1**, **Figure 5**).

Table 1. Rock-Eval parameters for source rock evaluation.

Well	TOC (wt.%)	S1 (mg/g)	S2 (mg/g)	S1 + S2 (mg/g)	PI	HI (mg/g)	Tmax (°C)
A	$\frac{0.44\text{–}0.76}{0.61}$	$\frac{0.11\text{–}0.78}{0.38}$	$\frac{0.72\text{–}2.63}{1.85}$	$\frac{0.83\text{–}3.38}{2.23}$	$\frac{0.13\text{–}0.26}{0.17}$	$\frac{164\text{–}379}{295}$	<400
B	$\frac{0.33\text{–}0.52}{0.43}$	$\frac{0.06\text{–}0.34}{0.14}$	$\frac{0.30\text{–}2.00}{0.73}$	$\frac{0.36\text{–}2.34}{0.88}$	$\frac{0.13\text{–}0.22}{0.17}$	$\frac{75\text{–}385}{160}$	$\frac{405\text{–}422}{417}$
C	$\frac{0.40\text{–}0.53}{0.46}$	$\frac{0.09\text{–}0.28}{0.15}$	$\frac{0.85\text{–}1.67}{1.31}$	$\frac{0.94\text{–}1.93}{1.46}$	$\frac{0.07\text{–}0.15}{0.1}$	$\frac{212\text{–}369}{280}$	<400

Note: (min–max)/average.

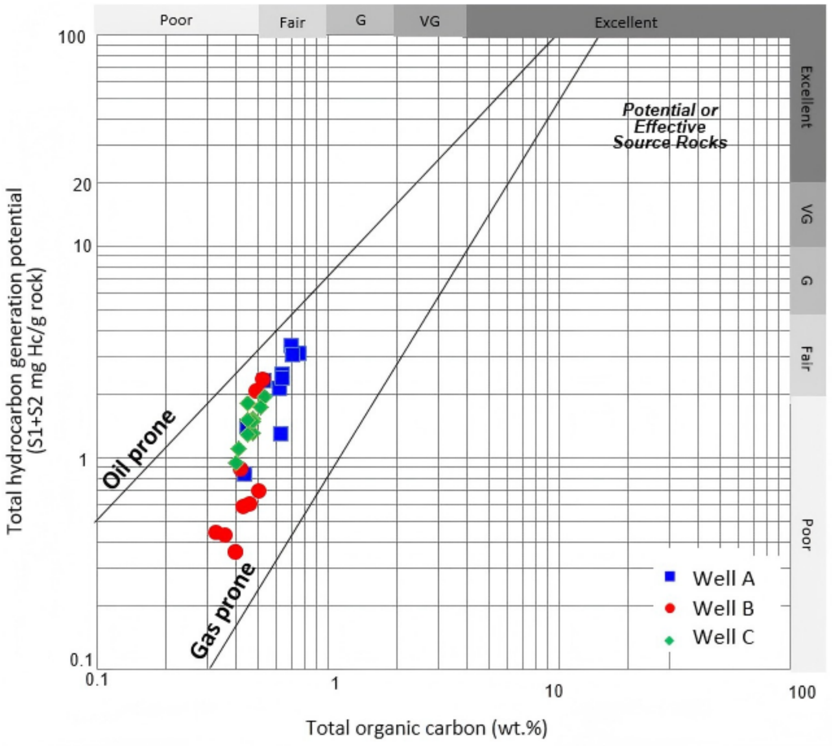

Figure 4. Total hydrocarbon generation potential.

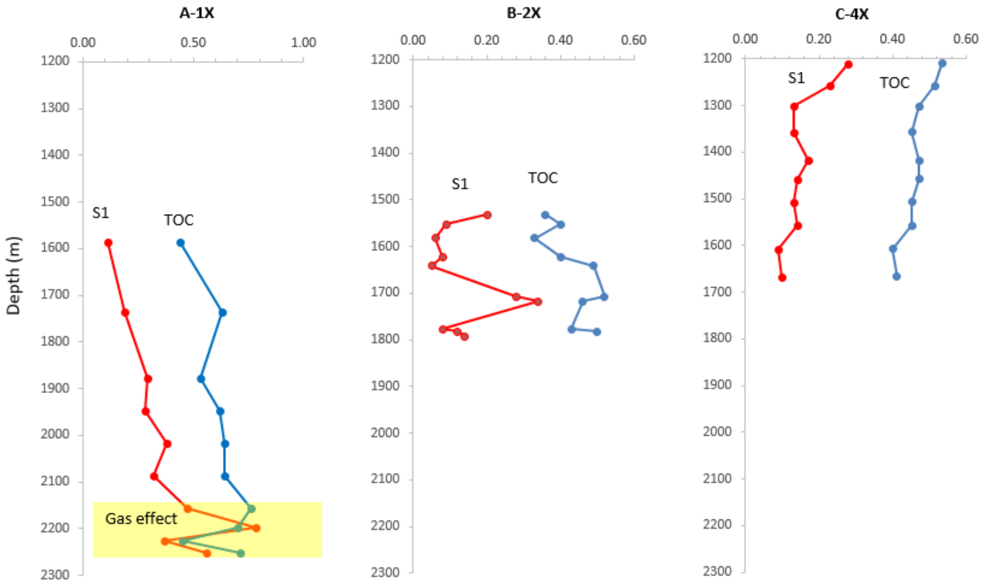

Figure 5. Cross-plot of S1 and TOC showing gas effect in A-1X well.

Pleistocene and Pliocene core samples were taken for petrological analysis to predict reservoir quality based on mineral compositions and visual porosities. The sandstones were described as fine-grained, well-sorted, sub-rounded, quite clean with strongly cemented by carbonate. These samples mostly comprise high brittle minerals (quartz, K-feldspar, carbonates, etc.), low ductile minerals (kaolinite, illite, chlorite) that are favorable conditions for forming fractures and conduits for fluid flow. These sandstones are poor to very good reservoirs with visual porosities ranging from 6%–27%. In addition, high brittle minerals of the Pliocene and Pleistocene shales also show a favorable condition for fracturing. These shales could also be considered as self-sources for generating gas.

4.2. Gas Compositions

Five gas samples were taken from three wells to test for possible gas in shallow sandstone zones in Pliocene-Pleistocene. Gas compositions of these samples are composed of high CO_2 contents (43.39–90.67%), followed by CH_4 contents (5.50–51.17%), small contents of N_2 (1.87–3.78%), minor contents of C_2 (0.13–1.07%) and no noticeable amounts of C_3–C_8, H_2S, He, Ar, H_2, CO (**Table 2**, **Figure 6**). High CO_2 contents in the gases probably imply the pollutant of CO_2 in traps.

Table 2. Gas compositions.

Well Name	**A-1X**		**B-2X**		**C-4X**
Sample Code	**A1**	**A2**	**B1**	**B2**	**C**
Hydrogen Sulfide (H_2S)	0.0	0.0	0.0	0.0	0.0
Helium (He)	0.0	0.0	0.0	0.0	0.0
Argon (Ar)	0.0	0.0	0.0	0.0	0.0
Hydrogen (H_2)	0.0	0.0	0.0	0.0	0.0
Carbon monoxide (CO)	0.0	0.0	0.0	0.0	0.0
Carbon dioxide (CO_2)	81.97	90.67	53.53	43.39	57.63
Nitrogen (N_2)	3.47	3.60	3.26	3.78	1.87
Oxygen (O_2)	0.00	0.00	0.02	0.02	0.00
Methane (C_1)	14.05	5.50	41.71	51.17	38.67
Ethane (C_2)	0.29	0.13	0.88	1.07	1.05
Propane (C_3)	0.08	0.03	0.23	0.28	0.26
i-butane (iC_4)	0.04	0.01	0.05	0.06	0.06
n-butane (nC_4)	0.02	0.01	0.05	0.06	0.06
i-pentane (iC_5)	0.01	0.01	0.03	0.04	0.04
n-pentane (C_5)	0.01	0.00	0.02	0.02	0.03
Hexanes (C_6)	0.01	0.01	0.04	0.04	0.06
Heptanes (C_7)	0.03	0.01	0.07	0.04	0.11
Octanes (C_8+)	0.03	0.02	0.11	0.04	0.17

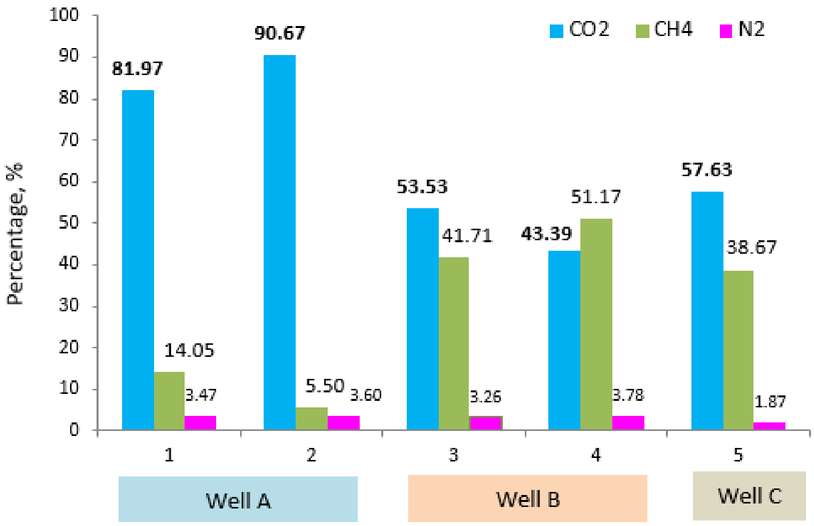

Figure 6. Distribution of CO_2, CH_4 and N_2 compositions in the gas fields.

5. Discussion

5.1. Implication of Gas Origin and Impacts of Geological Features on Gas Accumulations

Natural gas is generally generated from biogenic and thermogenic sources that are controlled by biological activities and geothermal alteration[7]. Organic matter in shallow depths below 1,500 m was often degraded by bacterial activities and probably generated some biogenic gases[8–11]. Meanwhile, the formation and occurrence of gas fields are closely related to many geological factors such as tectonic setting, basin type and size, geographic position, geological age, reservoir lithology, trap style and gas origin[12–14]. Small variations exist in the gas source rocks, reservoirs and cap rocks due to the similar structure and sedimentation rate. Huge gas fields associated with sub-reservoir gas kitchens often occur in areas that have experienced extensive tectonic folding and faulting activities, with thick shales acting as the top seals[15,16].

Gas is often composed of hydrocarbons and non-hydrocarbons with a high ratio of H/C and low high molecular weight and high mobility. However, high contents of non-hydrocarbons such as CO_2, N_2, H_2S are sometimes found in gas reservoirs. A large amount of gas will escape during its migration, only a small amount of gas retained in the trap. Normally, about 82% of CH_4 and C_2+ are generated in the catagenesis stage (70–150 °C)[17]. Gases are formed from different organic sources and huge amounts of CH_4 come from woody and higher plant sources in terrestrial settings and shallow deposits in the basin. Basically, stable carbon isotope data are used as an indicator of the origin of organic matter and provide additional information for the relationship between gas and their source rocks. However, with the limitation of the data, the origin and occurrence of gases in these wells are mainly implied from geological features with references to information from adjacent successful gas fields[18].

The very complicated geological activities in the central Song Hong basin significantly impact the process of gas accumulations. Therefore, in recent years, huge gas accumulations have been discovered in this area, which is strongly affected by the active tectonic zone with high rates of sedimentation and subsidence occurred in the Upper Miocene-Pleistocene. The presence of shale diapirs and a high geothermal gradient of about 4.3–4.6 °C/100 m. These provide favorable conditions for shale source rocks quickly reaching the mature stage and entering the primary gas generation stage in a short period of time.

Gas systems in these gas pools may have similar critical moments in the Pleistocene and Pliocene. Small amount of gas probably generated from Pliocene shales or deeper shales as self-source that has been presented in previous studies[19]. It means that there are multiple source rock intervals existing in this area, and some deeply-buried gases probably migrated along faults and finally accumulated in the shallower sandstone reservoirs. Thus, if oxygen is enriched in the pore water zone, CH_4 from these gases might be oxidized by aerobic bacteria forming CO_2. This indicates that the whole process of generation, migration and accumulation of these gas pools occurred in the Neogene–Quaternary period, which was completed in a short period of time with a rapid accumulation. Therefore, the main period of gas migration and entrapment in the A, B, C fields could be in the period of Pliocene–Pleistocene.

5.2. Unlocking High CO_2 Gas Fields for CO_2 Storage

5.2.1. Unlocking High CO_2 Gas Fields

The difference between CH_4-dominated and CO_2-dominated gases is confirmed by light hydrocarbon data. CH_4-dominated gas has higher iC_4/nC_4 and iC_5/nC_5 ratios than the CO_2-dominated gas. It simply implies that CH_4-dominated gas was generated at a lower mature level relative to CO_2-dominated gas. In addition, CO_2-dominated gas has a large contribution from organic matter, where CO_2 was probably generated by thermal decomposition of carbonate[20].

During the sedimentation process, CO_2 is produced by aerobic respiration and is also associated with the process of CH_4 generation in the early stage of sediment diagenesis at shallow depths. Besides, CO_2 also comes from the dissolving carbonate rocks under high temperature and pressure conditions, biodegradation of crude oil, thermal cracking of kerogen, regional metamorphism, etc. by-product of oil generation process via the decomposition of oxygen-bearing function groups in 80–120 °C and interaction between feldspar and clay minerals with carbonate cement in 120–140 °C[21].

Based on the classification of CO_2 gas fields of Dai et al. (1997)[20], gas compositions of these reservoirs contain high to very high CO_2 contents (43.39–90.67%) that could be separated into 2 types, such as: (i) High CO_2 gas reservoir with CO_2 contents varying from 15–60% in wells B and C; (ii) CO_2 gas reservoir with CO_2 content of greater than 90% in well A. This indicates that CO_2 was formed from different sources that are controlled by key geological factors such as (i) the presence of cement carbonate in the sandstone reservoirs; (ii) pressure is one of the factors that will cause the increase of solubility and density of CO_2 in water with the increase of pressure in the reservoirs, such as samples B_2 and B1 with the lowest pressures (850 and 878 psia) contain the lowest CO_2 contents, followed by sample C (897.8 psia) and samples A1 and A2 with the highest pressures (991.8 and 1,026.9 psia) contain the highest CO_2 contents.

5.2.2. CO_2 Storage

CO_2 contaminant is one of the unlocked gas pools that are associated with high CO_2 gas fields. Commitments to greenhouse gas emissions and producing sustainably are key reasons for oil and gas companies to produce from gas pools containing over 40% CO_2. Therefore, to unlock the gas fields, some advanced technologies have recently been applied to such high CO_2 gas fields with lower cost and risks, such as: CCS, producing additives for synthetic gas and lubricants, using CO_2 for enhanced oil recovery, etc. This study focuses on using CO_2 for CCS purposes based on implications from geological and reservoir perspectives.

CO_2 is usually stored in depleted oil and gas reservoirs, saline aquifers, active oil and gas fields both onshore and offshore[22]. Basically, key factors are needed for CCS, including a place to store CO_2 (reservoir), a trap to prevent CO_2 from reaching the surface again and leakage (cap rock), and a well in the reservoir to pump down the CO_2[23]. Therefore, gases were generated from these A, B, C pools probably coming from their entire active petroleum systems, including shallow shale source rocks, deeper shale source rocks, reservoirs and cap rocks, which are key factors necessary for CCS as follows:

(1) **The reservoir:** these sand reservoirs have large storage capacities from pore space (porosity) that are favorable conditions for high daily injection rates. According to Halland et al. (2014)[24], about 4–8% of the total reservoir pore volumes are considered safe. Therefore, the porosities in the sandstones of A, B, and C pools range from 6–27%, indicating very good pore spaces for storing CO_2. In addition, the depths of these sand reservoirs are greater than 800 m, and it is desired to have a reservoir pressure and temperature where the CO_2 is in a supercritical phase.

    In addition, high brittle minerals of thick Pliocene shales in these wells indicate that these shales also play a role as self-sources but with no commercial production. Therefore, they are considered as an additional option with good potential containment stratigraphic horizons for CO_2 injection in this area.

(2) **The cap rock:** overlays the reservoir and prevents the CO_2 from reaching the surface again. Caprock thickness is particularly important when pressure breaks through the mechanical strength of the caprock[25]. In this study, Pleistocene shales overlying the Pliocene sandstone reservoirs play a role as good cap rocks to prevent the leakage of CO_2 through pore spaces and fractures from Pliocene sandstone reservoirs.

(3) **The well:** well is needed to reach the underground storage sites trapping the CO_2 in various ways. This is already standard procedure in the oil and gas industry, and with small adjustments made to facilitate CO_2 flow, it is a technology which is readily available. Therefore, the A, B, C wells are suitable for storing CO_2 with lower cost, risks and rate of development because of the existence of available infrastructure and assessments of the active gas fields.

6. Conclusions

This study presents properties of source rocks, reservoirs and implications of gas origin to find out the suitable geological formations for CCS based on analytical results and geological features as follows:

(1) **Properties of Source Rocks and Reservoirs**

    Thick shale beds in the A, B, C wells are considered poor to moderate potential source rocks that are dominated by higher plants-derived from type III kerogen with a small amount of algae from type II kerogen, entering in early mature to mature stages. Therefore, a small volume of free hydrocarbons could be released from these source rocks and an amount of gas probably retained in the shales but not reached petroleum expulsion in the hydrocarbon phase.

    Mineral compositions of the sandstones in Pliocene and Pleistocene mostly comprise high quartz, K-feldspar, carbonates and low clay minerals that are defined as poor to very good reservoirs, predicting the large areas of porous reservoir beds in gas-generating places not only provide big-volume pore spaces for gas accumulation but also act as good conducting layers for gas migration in these reservoirs and also give favorable conditions for the fracturing process.

(2) **Implication of Gas Origin and Impacts of Geological Features on Gas Accumulation**

    CO_2 is dominated in the composition of these gases, following C_1, small contents of N_2, minor contents of

C_2 and absence of C_3–C_8, H_2S, He, Ar, H_2, CO. These gases were probably generated from the deeper source rocks and a small amount from the shallow Pliocene shales that were mainly impacted by the rapid sedimentation rate and entered the biochemical and geothermal alteration phases. These gas pools may have similar critical moments in the Pleistocene and Pliocene. The gases are generated from different organic sources with huge amounts of woody and higher land plants that are controlled by biochemical and thermal factors.

(3) Unlocking High CO_2 Gas Fields for CO_2 Storage

CO_2 was formed from different sources that are controlled by key geological factors such as (i) the presence of cement carbonate in the sandstone reservoirs; (ii) pressure is one of the factors that will cause the increase of solubility and density of CO_2 in water with the increase of pressure in the reservoirs. Gases were generated from the gas pools probably coming from their entire active petroleum systems including shallow Pliocene shales, deeper shales, Pliocene and Pleistocene sand reservoirs and cap rocks, which are key factors necessary for CCS. These are active gas fields with available infrastructure and no commercial production, therefore, they show favorable conditions for CCS purposes.

7. Recommendations

Further data on reservoirs and stable carbon isotopes are useful for providing additional information about the origin of the gases and producing states. For CCS purposes, it needs to collaborate with additional geological and geophysical data in the ongoing evaluation of the area as a potential carbon storage site.

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Informed Consent Statement

Not applicable.

Data Availability Statement

The data will be provided upon request to the author.

Conflicts of Interest

The author declares no conflict of interest.

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