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Origin of high concentration of carbon dioxide in some wells of satellite field of Mumbai Offshore

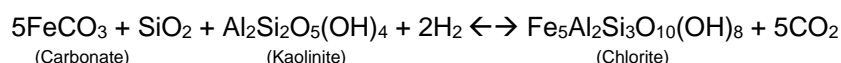
Abstract

The occurrence of carbon dioxide in high concentrations has a detrimental effect on quality of the natural gas as it reduces the calorific value of the gas and has corrosive effect on surface handling facilities during its transportation through pipelines. High concentration of CO₂, ranging from 17% to 98.5% was observed in some of the wells of B-A structure in satellite fields of Mumbai High region as a result some wells had to be closed. Studies were conducted to investigate the origin of unusual high concentration of carbon dioxide in some of these wells. The CO₂ can be originated from both organic and inorganic sources, exhibiting their unique carbon isotopic signatures. Molecular and stable isotopic studies were used to genetically characterize the gases and unravel the source of CO₂ in these wells. The studied gases are genetically correlated and thermogenic in nature. The organic and atmospheric origin and the volcanic degassing as the source of CO₂ were ruled out on the basis of stable carbon isotopic values of CO₂. The high concentration CO₂ in B-A structure wells was inferred to be of inorganic origin, arising from the decomposition of carbonates, as the δ¹³C values of CO₂ from these gases range from +1.2 to -0.9‰.

Introduction

Mumbai High is one of the most hydrocarbon prolific regions of Western Offshore Basin. The occurrence of carbon dioxide in high concentrations has been observed in B-A satellite field which is situated in the south-west of Mumbai High, comprising of more than 25 wells. It has been observed that gases from the various wells of B-A structure, especially in Mukta, Bassein and Basal Clastic formations, studied in the past, exhibited very high and unusual concentration of carbon-dioxide ranging from 17% to 98.5%. Some of the wells were thus closed. Studies were conducted to investigate the origin of very high concentration of carbon dioxide in these structures.

There are three important sources of carbon dioxide, one organic and two inorganic. The first source is from the thermal degradation of organic matter, which occurs during diagenesis and catagenesis and is mostly completed at the end of the oil window. Continental derived humic materials contribute mostly as the organic source of carbon dioxide. Up to 75 liters of carbon dioxide per kilogram of coal (2700 ft³/ton) are released during the maturation of coal from lignite to anthracite stage. (Karweil, 1969). The second important source involves a reaction between kaolinite and carbonates to produce chlorite and CO₂ (Hutcheon and Abercrombie, 1989). This reaction appears to occur at temperature above 100°C and reaches equilibrium at 160°C.



The third source of CO₂ is volcanic activity. When high temperature magma penetrates carbonate rocks, the carbonate decomposes, giving off CO₂. The CO₂ migrates as a gas and can be trapped in reservoir rocks of nearby structures. This relationship between carbon dioxide generation and high temperature igneous intrusions was first discussed by Holmquest (1965) for the Delaware-Val Verde basins of New Mexico and Texas. Stable carbon isotopic studies may be successfully used in distinguishing the source of carbon dioxide in reservoirs.

The different sources of carbon dioxide show distinct $\delta^{13}\text{C}$ values as shown in the table below (Hunt, 1996):

Source	$\delta^{13}\text{C}$ (‰) of CO_2
1. Thermal degradation of organic matter	-8 to -12
2. Thermal destruction of carbonates	+4 to -5
3. Bacterial oxidation of methane	-20 to -59
4. Volcanic degassing	-8
5. Atmospheric CO_2	-8

Thermogenic carbon dioxide from organic matter has a more negative $\delta^{13}\text{C}$ than that from the decomposition of carbonates. Bacterial oxidation of CH_4 to CO_2 can result in a wide range of $\delta^{13}\text{C}$ values for the CO_2 , depending on the $\delta^{13}\text{C}$ of the original CH_4 . In comparison, volcanic and atmospheric CO_2 are essentially identical (Hunt, 1996). The variations in the table above can thus be used to evaluate multiple CO_2 sources.

Geology of the area

Mumbai offshore Basin, a divergent passive continental margin basin, is located on the continental shelf off the west coast of India. The wells B-A-1 and B-A-8 are located north of D-1 structure which is predominantly a granitic/granitic gneissose paleo high like Mumbai high south with basaltic cover in patches. The basal clastics unit directly overlies basement highs in this area. These wells are structurally in favourable position of a fault closure, of a NW-SE trending fault, and located in the most South Westerly part of the prospect (Alat and Manohar, 1992 and Vohra, 2000). The generalised stratigraphy of Mumbai Offshore Basin is given in figure below (Figure 1).

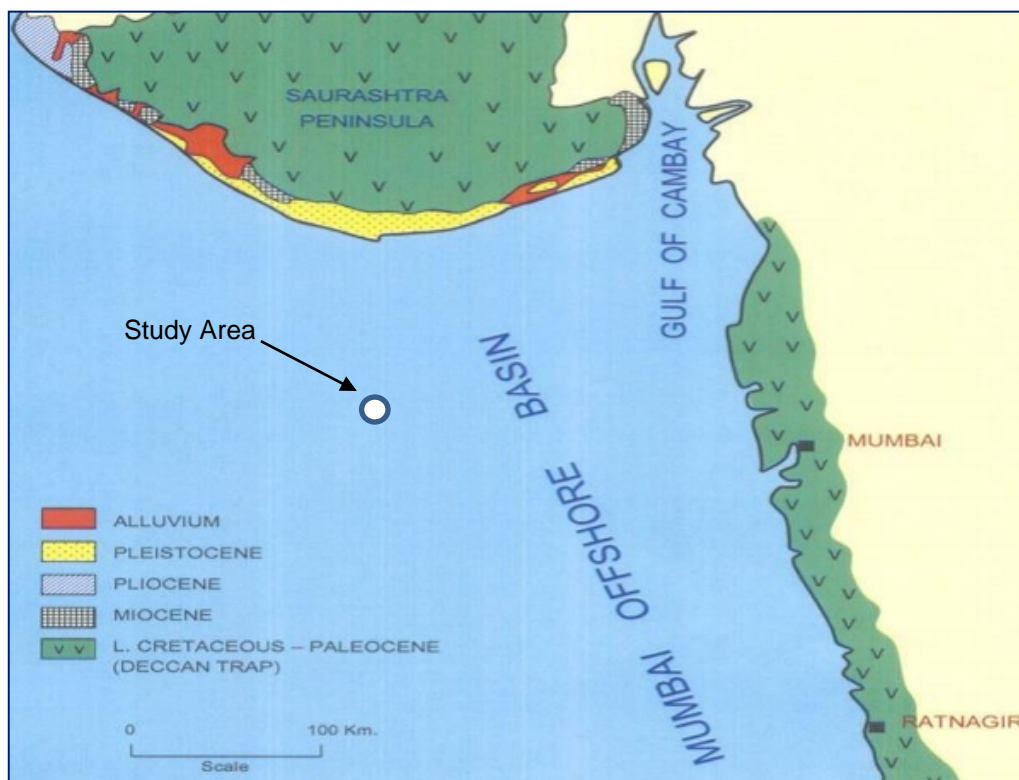


Figure 1: Location of the study area

The generalised stratigraphy of Mumbai Offshore Basin is given in figure 2.

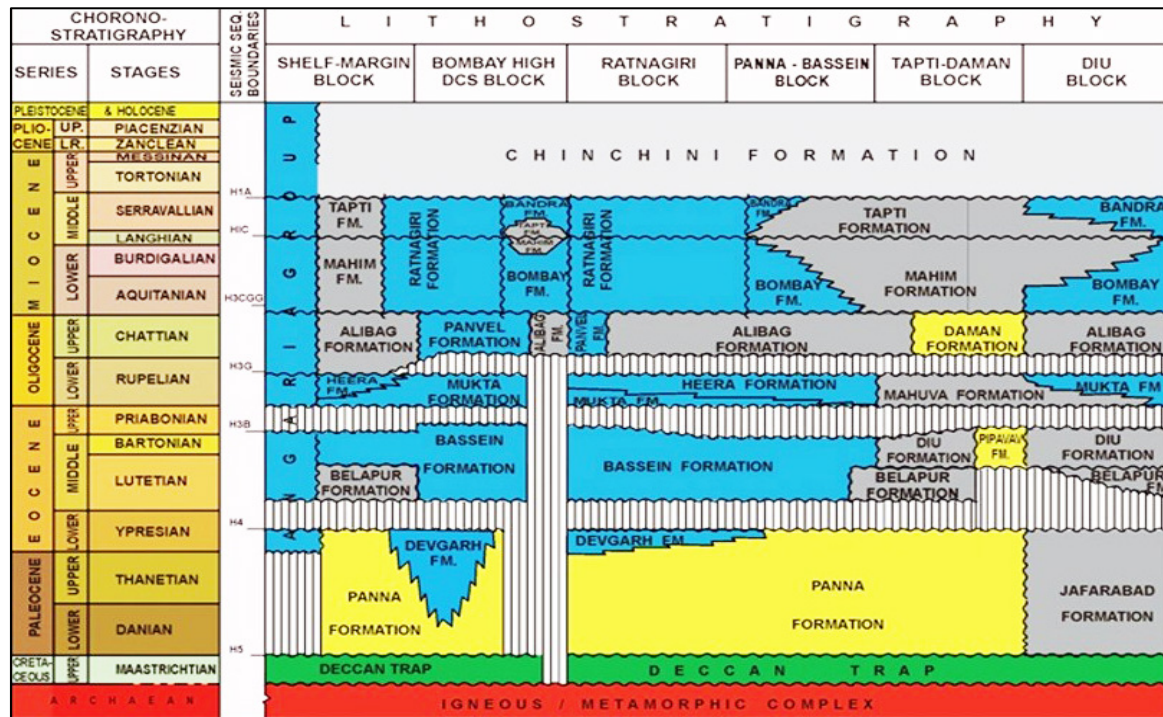


Figure 2: Generalised stratigraphy of Mumbai Offshore Basin

Experimental methods

The molecular compositional analyses of gas samples were carried out on Varian GC CP-3800 Natural gas analyser. The column oven temperature was programmed for an initial temperature of 40°C with the hold time of 12 minutes. A temperature ramp of 20°C per minute was followed up to a final temperature of 200°C with final hold time of 20 minutes. The injector temperature was 220°C. Molecular composition data are given in volume %.

Stable carbon isotopic study of gas samples was carried out on Thermo Delta V plus Continuous Flow-Isotope Ratio Mass Spectrometer interfaced with trace GC Ultra, having an Agilent HP plot-Q capillary column (30m x 0.32mm x 20 μm). The oven was programmed for an initial temperature of 30°C with the hold time of 10 minutes. A temperature ramp of 10°C per minute was followed up to a final temperature of 180°C with a final hold time of 15 min. The eluents from the GC were passed through a combination of CuO/NiO at 960°C to convert the carbon compounds to CO₂. Helium was used as carrier gas. A laboratory standard CO₂ gas was employed as reference for measuring the isotope ratios of the samples. The results were reported as δ¹³C ‰ with respect to PDB. The mass spectrometer was standardised using the mixture NGS-2 (NIST, USA).

The isotopic ratio is expressed in the usual delta (δ) notation as follows:

$$\delta^{13}\text{C} (\text{‰}) = \left(\frac{^{13}\text{C}/^{12}\text{C}_{(\text{sample})}}{^{13}\text{C}/^{12}\text{C}_{(\text{standard})}} - 1 \right) \times 1000$$

Results and discussion

The chemical composition and stable carbon isotopic data together with sample details of the samples are presented in table below.

Table 1: Chemical and isotopic compositions of studied gases

Sl. No.	Well	Depth (m)	Formation	Chemical Composition % (v/v)										Stable Carbon Isotopic Values ($\delta^{13}\text{C}$ ‰)			
				C ₁	C ₂	C ₃	iC ₄	nC ₄	iC ₅	nC ₅	C ₆	N ₂	CO ₂	$\delta^{13}\text{C}_1$	$\delta^{13}\text{C}_2$	$\delta^{13}\text{C}_3$	$\delta^{13}\text{C}_{\text{CO}_2}$
1	BA-8-4	2942-2920	Mukta	63.1	6.2	4.8	0.8	0.9	0.2	0.2	0.1	0.4	23.52	-38	-27.8	-24.3	+1.2
		2974-2959	Bassein														
2	BA-8-5	2583-2572	Mukta	58.5	4.7	2.7	0.5	0.7	0.2	0.2	0.1	1.7	30.41	-38.2	-28.4	-24.6	+1.0
3	BA-1-6	2755-2767	Mukta	40.1	2.5	2.1	0.4	0.5	0.1	0.1	0.1	1.3	52.90	-37.9	-28.5	-25.4	-0.9
4	BA-1-3	2995-3000	Basal Clastics	45.4	4.1	2.8	0.5	0.6	0.2	0.1	0.1	0.5	45.94	-37.4	-28.2	-24.9	-0.2

The inferences of the source rock data from the nearby wells of the structure B-A are as follows:

1. In structure B-A, the sediments have entered top of oil window, at 2050m.
2. The Upper Oligocene sediments (2050 to 2285m) have in general poor hydrocarbon generation potential. The sequence between 2140- 2150m, shows 'good source' potential.
3. Lower Oligocene and Basal Clastics sediments (2285-2355m) have only poor generation potential.

The inferences of the source rock data of wells from the nearby structures D-A and D-B (Saxena et.al 2004) are as follows:

1. Good source rock characteristics are inferred in Bassein formation of Eocene age in the area. The sediments are in the oil generation window. High Uranium and variations in Thorium/Potassium ratios indicate fluctuating environment of deposition. These sections are capable of generating liquid/gaseous hydrocarbons.
2. The lower Eocene to Paleocene section of D-A (2975-3075m) of Devgarh Formation has shown frequent variation in lithology and fair to good concentration of uranium and potassium. High Thorium indicates organic rich sediments deposited in an anoxic environment. Rock Eval analysis has shown excellent source rock characteristics and adequate maturity.
3. Geochemical studies of selected samples of Devgarh Formation in D-A have revealed that these sequences are argillaceous carbonates with mix source input, which are dominantly terrestrial. The depositional environment is oxic. Homohopane isomerisations have reached the equilibrium values showing adequate maturity. The argillaceous sequences of Devgarh formation appear to have charged the nearby reservoirs in DA and DB areas.

Prima facie it appears that the sediment in B-A area had experienced higher geothermal gradient compared to those in D-A and D-B areas which located south of Bombay High. This is evident from shallow level of top of oil window at 2050m in B-A structure, as compared to wells in D-A and D-B structures which are at depths greater than 3000m.

The chemical composition analyses of the studied gases reveal the high concentration of CO₂ ranging from 23.52% to 52.90%, whereas the methane composition ranges from 40.13% to 63.10%. All the gases show full spectrum of hydrocarbons. The δ¹³C values of CO₂ are ranging from +1.2 to -0.9‰ confirming their origin from thermal decomposition of carbonates. The bottom hole temperature of the wells, ranging between 115°C to 125°C is favourable for inorganic reaction between kaolinite and carbonates to produce chlorite and CO₂. However, presence of an igneous intrusion or that of kaolinite/chlorite in the Mukta/Bassein/Basal clastics has not been reported in the studied wells of B-A structure to know the exact reason for the decomposition of carbonates. The organic source of CO₂ is ruled out from this study. It also rules out origin from volcanic degassing and from atmospheric source. While comparing the δ¹³C values with their wetness (C₁/C₂+C₃) on Bernard diagram all the hydrocarbon gases from these wells exhibit thermogenic origin and similar methane, ethane and propane carbon isotopic compositions indicate genetic correlation of hydrocarbon gases (figures 3 and 4).

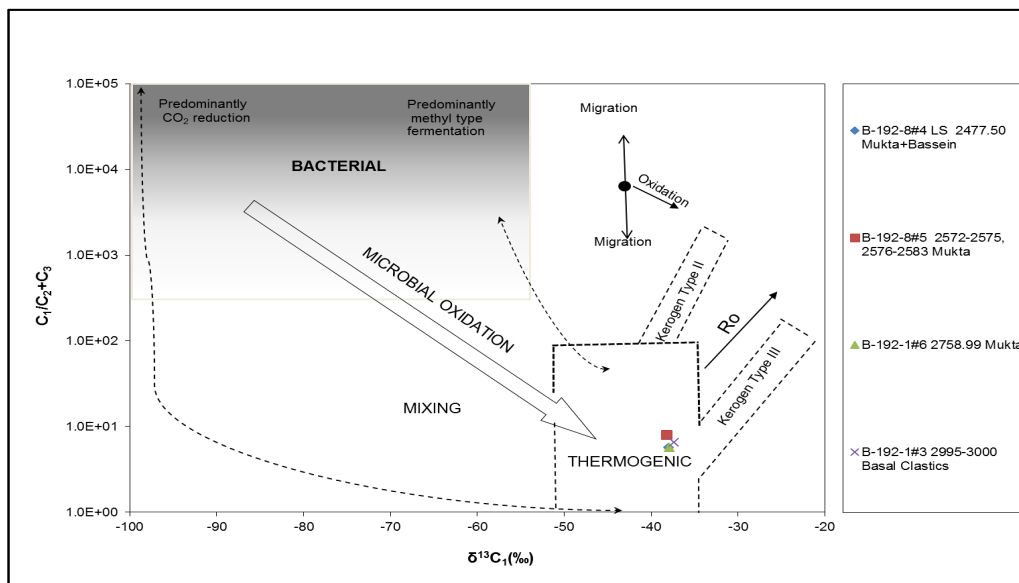


Figure 3: Bernard diagram showing genetic characterization of studied gases

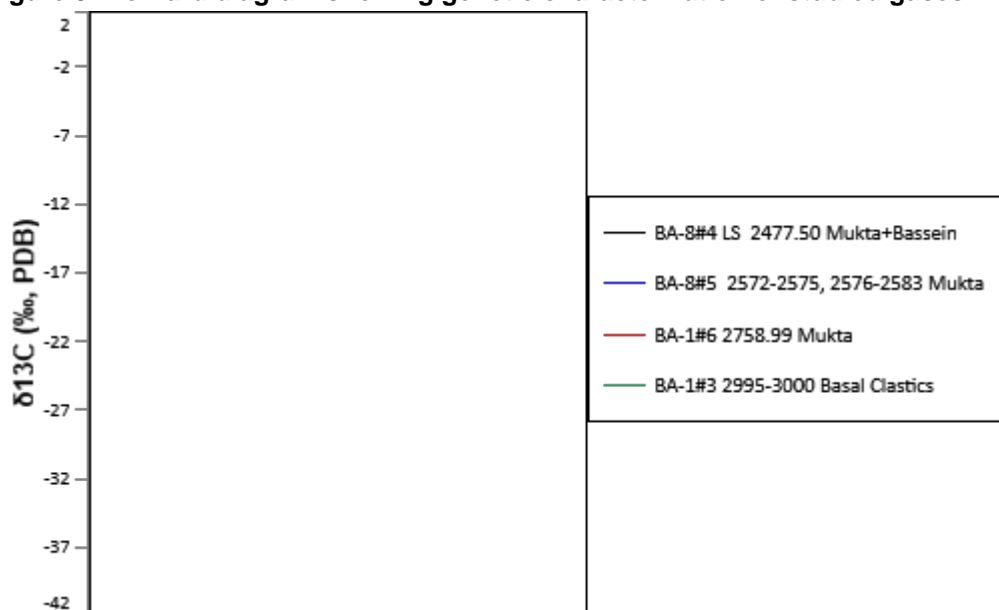


Figure 4: CSIA profile of studied gases showing correlatability

Conclusions

1. The studied gases are thermogenic in origin and are genetically correlated.
2. The organic, atmospheric and volcanic origin of CO₂ is ruled out on the basis of stable carbon isotopic values of CO₂ from the studied wells.
3. The CO₂ is inferred to be originated from the decomposition of carbonates at high temperature, as indicated by the $\delta^{13}\text{C}$ values of CO₂ from these gases (+1.2 to -0.9‰).

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