

## CO<sub>2</sub> and N<sub>2</sub> contamination in J32-1, SW Luconia, offshore Sarawak

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**Abstract:** The SW Luconia area, offshore Sarawak, is prone to CO<sub>2</sub> and N<sub>2</sub> contamination. The level of CO<sub>2</sub> contamination is extremely high (>60%), especially in the carbonate, when compared to other areas in the Sarawak Basin. This is further evident from the recent exploration well, J32-1, drilled by SSB in the area. The well discovered five separate gas-bearing reservoirs in Neogene sands and limestones. Analysis of the gas from all the reservoirs indicate contamination of CO<sub>2</sub> (2-76%) and N<sub>2</sub> (1-12%). A high concentration of CO<sub>2</sub> was observed in the limestones and an even higher level was recorded in the overlying reservoir sands. Although these contaminants (CO<sub>2</sub> & N<sub>2</sub>) are generally thought to be basement derived, the vertical gas distribution trends of J32-1 identify the sudden influx of CO<sub>2</sub> in these reservoirs as late *in situ* inputs. It is possible that the gas was released from low temperature reactions of the carbonates with formation waters and from the oxidation of methane in oxygenated waters. This is possible as fluid samples from the reservoirs suggest freshwater conditions and the region experiences a high heat flow. The invasion of meteoric water may have occurred during the Pliocene major uplift when Sundaland emerged in the South China Sea. The distribution trend of N<sub>2</sub> suggests contribution from basement. Another possible origin is from humic organic matter which is in abundance in Oligocene deposits. However, the probable inputs from surface via dissolved atmospheric N<sub>2</sub> and from humic acids of peat swamps cannot be ruled out. The presence of the contaminants in the well is apparently in general agreement with the overall CO<sub>2</sub> and N<sub>2</sub> contamination trend seen in the area.

### INTRODUCTION

CO<sub>2</sub> and N<sub>2</sub> contamination is generally more common in Pre-Tertiary reservoirs (North, 1985). Concentration levels of 80–90% of CO<sub>2</sub> have been recorded in the Pre-Tertiary reservoirs of Paradox Basin, Utah and the Overthrust Belt, Wyoming, U.S.A. Similarly, Pre-Tertiary reservoirs of San Juan Basin, N. Mexico and the Rotliegendes Basin, Danish N. Sea, registered up to 90% N<sub>2</sub> contamination. However, in the Tertiary reservoirs, only a few cases of CO<sub>2</sub> and N<sub>2</sub> contamination have been reported. The Paleogene gas-bearing limestones and sandstones of Indus Basin, Pakistan are reported to contain high CO<sub>2</sub> and N<sub>2</sub> concentrations. Closer to home, in the South China Sea, up to 88% CO<sub>2</sub> and high N<sub>2</sub> are known to occur in Neogene reservoirs offshore Natuna and Sarawak.

In Sarawak, CO<sub>2</sub> and N<sub>2</sub> contamination in gas-bearing reservoirs is mainly concentrated in the SW Luconia area on the western flank of the Sarawak Basin (Fig. 1). Concentration level of up to 88% CO<sub>2</sub> and 40% N<sub>2</sub> have been recorded from

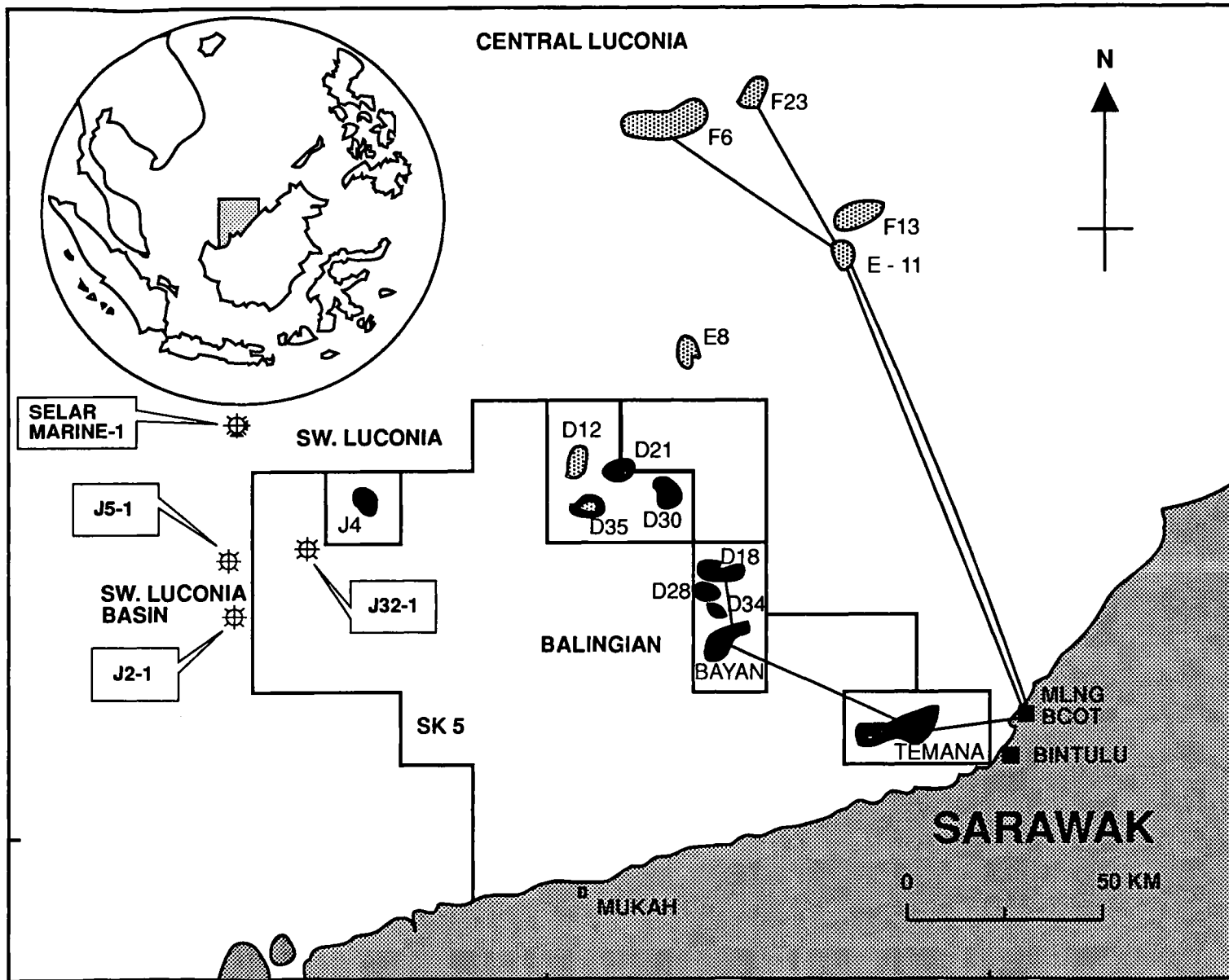


Figure 1: Location map offshore Sarawak

these reservoirs. The higher contamination levels of CO<sub>2</sub> mainly occur in the Miocene carbonate and younger clastic reservoirs, whereas the clastic reservoirs below the carbonates registered only up to 40%. In contrast, the CO<sub>2</sub> and N<sub>2</sub> contamination in the central part and eastern flank of the Sarawak Basin is generally low (<18% CO<sub>2</sub> and <2% N<sub>2</sub>), even in the Miocene carbonate and younger clastic reservoirs.

Although these contamination trends are readily observed regionally, most of the samples were from selective reservoirs (mainly from single reservoir level). However, a more complete sampling is available from the most recent well, J32-1 which sampled the Miocene carbonate and the clastic reservoirs below and above it.

J32-1 is SSB-CARIGALI'S fifth commitment well in Block SK5 PSC acreage. It was drilled in May 1991, on the J32 prospect which is located on the western flank of the SW Luconia Basin, offshore Sarawak (Fig. 1). The well discovered five separate gas-bearing reservoirs which contain CO<sub>2</sub> (up to 76%) and N<sub>2</sub> (up to 12%) contaminants. The possible origins of these non-hydrocarbon gases are discussed below.

### J32-1 CO<sub>2</sub> AND N<sub>2</sub> CONTAMINATION

#### General Profile

The five gas-bearing reservoirs in J32-1 occur in Oligocene and Miocene sands and Miocene carbonates, referred to as Reservoirs 1 (A & B) – 5 (Fig. 2A). The highest CO<sub>2</sub> contamination of 76% was registered in Miocene sands of Reservoir 4 whereas the older limestones of Reservoir 3 yielded 68%. The Oligocene sands of Reservoirs 1 and 2 contain low, 2–3%, CO<sub>2</sub> and the youngest Miocene sands of Reservoir 5, 12%.

A different profile is observed for N<sub>2</sub> contamination. The highest N<sub>2</sub> concentration (12%) is observed in Reservoir 2 while the older Reservoir 1 recorded only 5%. A gradual decrease from 8–7% occurs through Reservoirs 3 and 4, respectively. The topmost Reservoir 5 contains only 1% N<sub>2</sub>.

#### Vertical variations of CO<sub>2</sub>, N<sub>2</sub> and the hydrocarbon gas components

The plot of the vertical distribution of J32-1 gas components is provided in Figure 2B. N<sub>2</sub>, the lightest and smallest molecule, reaches a maximum level in Reservoir 2 and gradually increases towards the topmost reservoir 5. On the other hand, CO<sub>2</sub> did not show any significant change until in the limestones of Reservoir 3, where it increases abruptly, increasing again in Reservoir 4 and depleting markedly in Reservoir 5. The distribution of methane (C<sub>1</sub>) in Reservoirs 3 – 5 is a mirror-image of CO<sub>2</sub> but in the early phases (Reservoirs 1–2), its trend follows that of CO<sub>2</sub>. The lighter and smaller gas components, C<sub>2</sub> – nC<sub>5</sub>, exhibit similar distribution trends with a gradual build-up from Reservoirs 1A to 1B, depleting slightly in Reservoir 2 and distinctly in the limestones of Reservoir 3. Although there is an increase of the C<sub>3</sub> component in Reservoir 4, only minor amounts of these

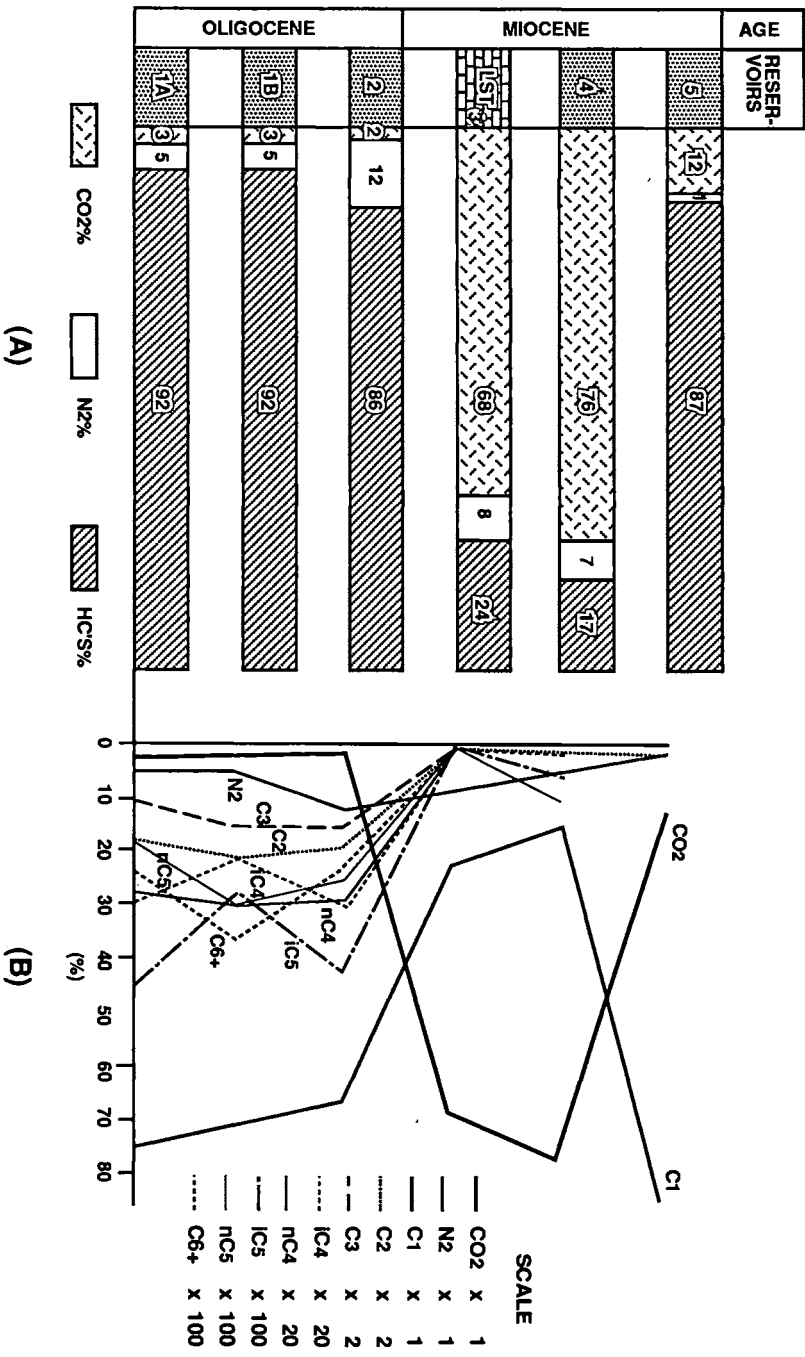


Figure 2: Gas profile (A) and vertical distribution of its component gas (B).

gas-types were recorded in Reservoirs 4 and 5. In contrast, the larger molecules of  $iC_4 - iC_5$ , behave differently. A significant decrease in concentration is observed within Reservoir 1 and a faster build-up occurs between Reservoirs 1B and 2. Subsequently, the trends mimic those seen for  $C_2 - nC_5$  gases. The heavier gases,  $C_{6+}$  has a similar trend with those of  $C_2 - nC_5$ , but a distinct reduction in concentration is seen between Reservoirs 1B and 2.

These trends which imply seepages within Reservoir 1 are the greatest and easiest for all gases except for  $iC_4$  and  $iC_5$  probably because of their larger molecular configurations which inhibit migration through the smaller pores at this level. Movements between Reservoirs 1B and 2 is easiest for  $N_2$ ,  $iC_4$  and  $iC_5$ , the other gases are slightly hampered, the heavier  $C_{6+}$ 's being the most affected. The seal between Reservoirs 2 and 3 is very effective as there is a general depletion of all gas types. In view of this, the sudden increase of  $CO_2$  is most likely due to diagenetic changes within the limestones of Reservoir 3. The presence of large amount of  $CO_2$  in Reservoir 3 enable an improved transportation capacity of heavier gases into the overlying Reservoir 4 which is exhibited by an increase of the component gases ( $C_3 - C_{6+}$ ). Since the composition of  $CO_2$  is lower in Reservoir 3, and seepage is less pronounced as indicated by the decrease of  $N_2$  between Reservoirs 3 and 4, the higher  $CO_2$  content of 76% in Reservoir 4 is most likely due to changes occurring within the reservoir (see below). The sudden influx of methane in Reservoir 5, which contradicts the distribution trend of the gases, especially  $N_2$ , strongly suggest an additional late input, probably due to biogenic activity.

The cumulative (%) plot of J32-1 component gases indicates all gas-types, except  $CO_2$ , exhibit exponential trends. The later inputs of  $CO_2$ ,  $C_1$  and the late increase of  $iC_5$  and  $C_{6+}$  become more apparent. The plot affirms the effectiveness of the seal between Reservoirs 2 and 3 as the hydrocarbon gas curves peak here. However, the lighter and smaller molecules of  $N_2$  and  $C_2$  manage to seep through. Seepage of  $N_2$  seems to decline only in Reservoir 4.

## ORIGIN OF CONTAMINATION

The origin of  $CO_2$  contamination in hydrocarbon-bearing reservoirs has been attributed to occur through organic transformation, subsequent carboxylation of organic matter, low temperature reaction of carbonates with formation waters and origin from volcanic sources or metamorphism of basement rocks (Selly, 1985). Experimental pyrolysis of organic matter has proved that  $CO_2$  is greatly dominant over methane in the early stages.

In J32-1, the vertical distribution and cumulative plots of the gas components strongly suggest  $CO_2$  as late additional input via diagenetic changes in Reservoirs 3 and 4 (Fig. 3). The low  $CO_2$  content seen in the older Reservoirs 1 and 2 suggest that the  $CO_2$  has not been derived by vertical leakage from the basement. In the limestones of Reservoir 3,  $CO_2$  is probably released from gentle heating of carbonic acid which were produced when the carbonates dissolved in fresh water of meteoric origin and the oxidation of methane in the presence of oxygenated waters (Fig. 4). Some of the  $CO_2$  may have also come from the atmosphere. A meteoric origin is

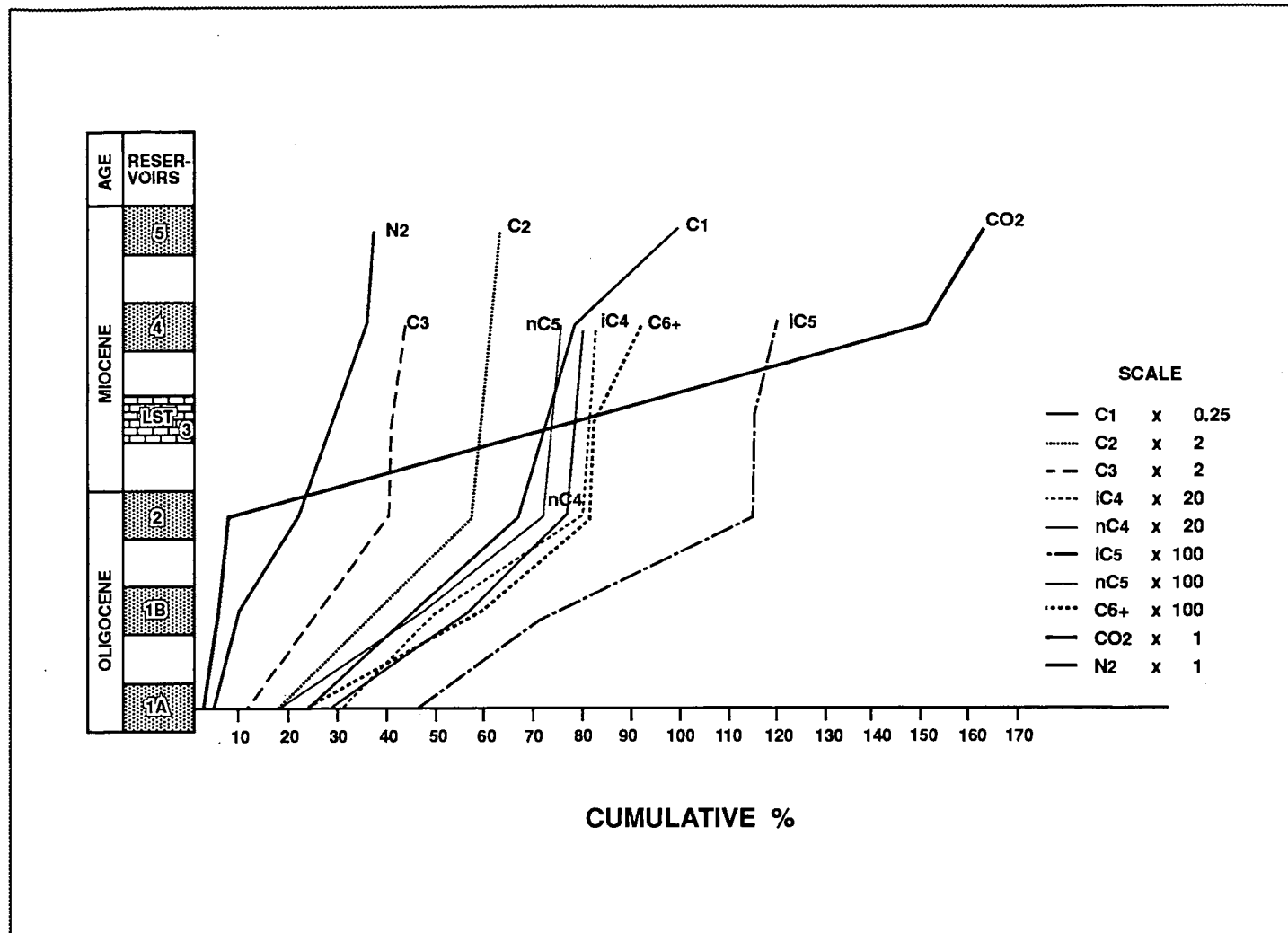


Figure 3: J32-1 cumulative (%) gas.

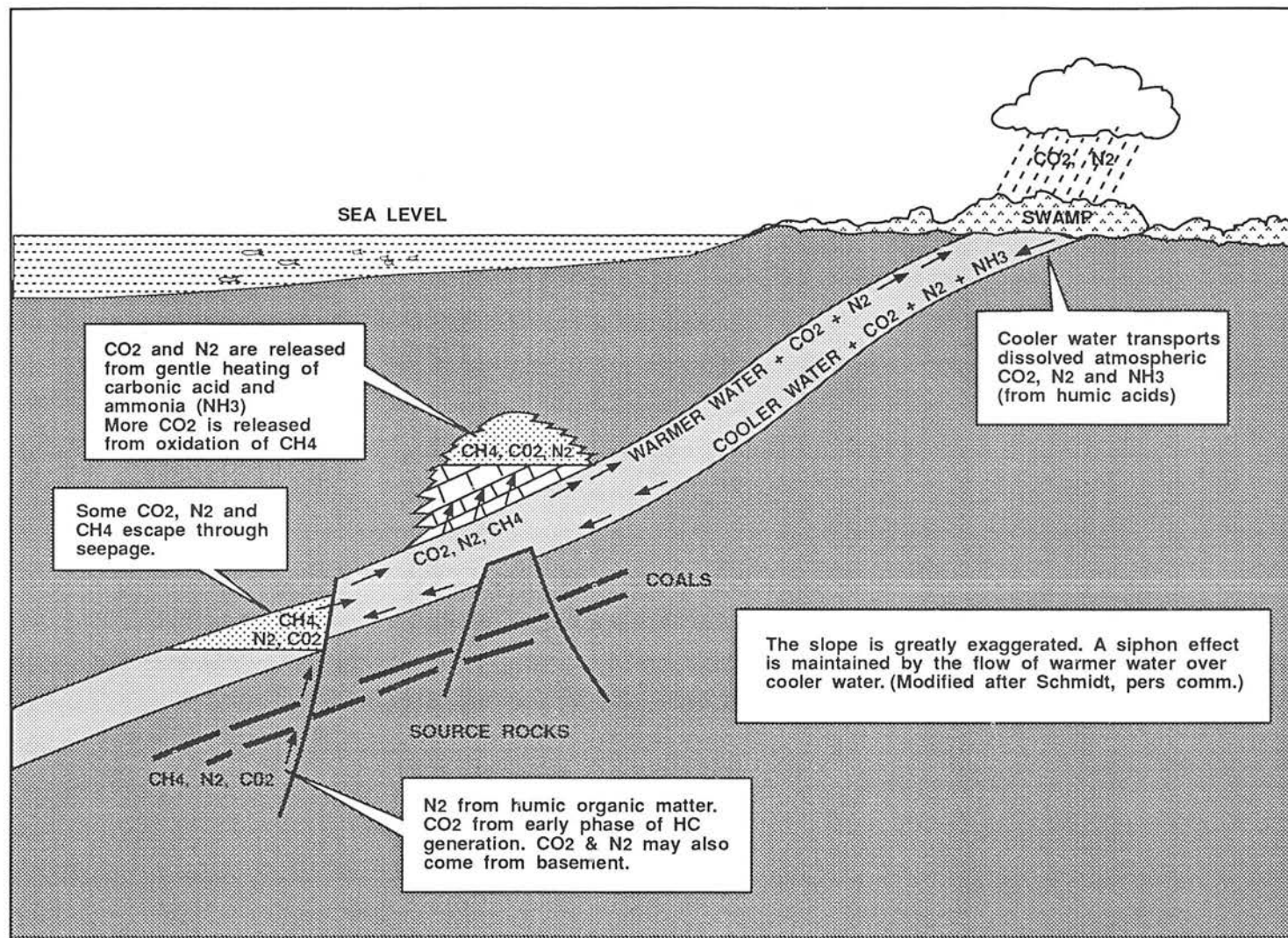


Figure 4: Simplified schematic presentation of possible sources of CO<sub>2</sub> and N<sub>2</sub> contaminations.

likely as fluid samples from all the reservoirs indicate freshwater conditions. The invasion of meteoric waters into Reservoirs 3 and younger may have occurred during the Pliocene uplift when Sundaland emerged (Beddoes, 1981). The necessary heat required is provided by the high heat flow experienced in the SW Luconia-Natuna Region. A similar level of CO<sub>2</sub> (67–82%) contamination have been recorded in the limestones of well AL-1X, offshore Natuna (Sangree, 1981). The increase in CO<sub>2</sub> concentration in Reservoir 4 may be explained by the oxidation of methane (CH<sub>4</sub>) in the presence of oxygenated waters.

The origin of the N<sub>2</sub> contamination is less certain but most likely it was released from the basement. In J32-1, the gas curves do not suggest any late input for N<sub>2</sub>. Other theories are that it has come from 'fossil air' trapped in sediments, released by humic organic matter in rocks (Fig. 4). Possible inputs from surface via dissolved atmospheric N<sub>2</sub> and from humic acids of peat swamps cannot be ruled out.

### CONCLUSIONS

1. Generally, the presence of CO<sub>2</sub> and N<sub>2</sub> contaminants in J32-1 is consistent with the general trend of high CO<sub>2</sub> and N<sub>2</sub> contamination level seen in the SW Luconia.
2. The vertical variations of CO<sub>2</sub> in the J32-1 well are most likely due to diagenetic changes within the limestones of Reservoir 3.
3. Preferential vertical migration of the lighter N<sub>2</sub> and C<sub>1</sub> molecules appears to have taken place.
4. The origin of the N<sub>2</sub> contamination is not clear but is most likely released from the basement. Other possible origins are from humic organic matter and dissolved atmospheric N<sub>2</sub>.

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