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# Challenges in Managing Mercury in Field Development and Production

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# Understanding the Source, Genesis and Historical Trend Of Mercury in Gas Condensate Fields Of Central Luconia, Offshore Malaysia

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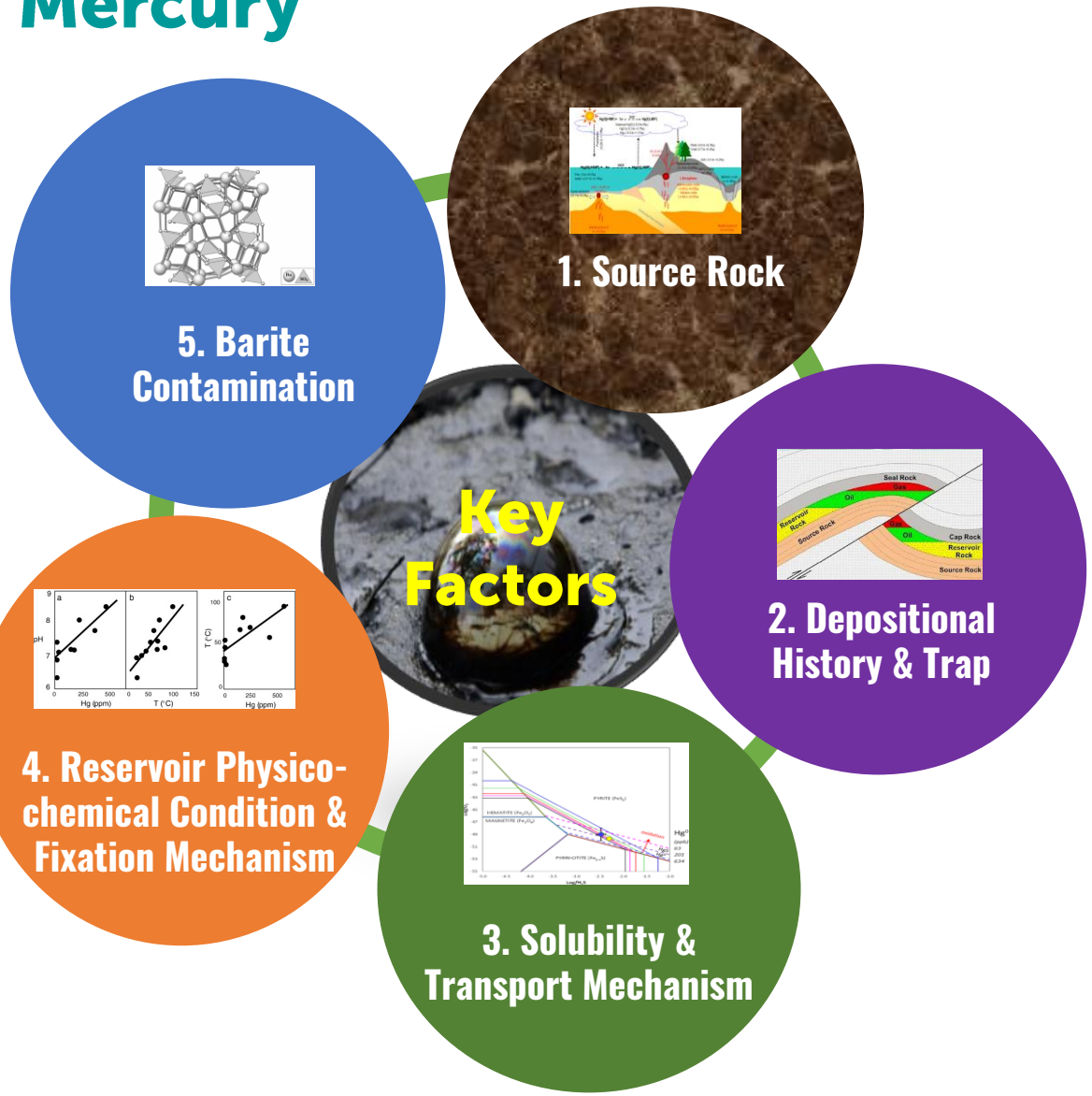
# Factors Shaping the Occurrence of Mercury

- Mercury (Hg) is a naturally occurring, redox-sensitive and chalcophile element that exists in multiple forms—elemental (metallic), inorganic, and organic.
- Most of economic mercury deposits are of **hydrothermal origin**, typically found near **organic-rich sediments**, such as black shales, and in regions of **recent volcanic activity**.
- The main natural sources of Hg are:
  - Inorganic minerals
    - Hydrothermal deposit
    - Vein deposit
    - Volcanic deposits – tuff, volcanic shale
  - Hg deposit in coal basins
  - Organic black shales having Hg content (1 -3 ppm)
- A detailed investigation into mercury occurrence in gas and condensate reservoirs identified five key influencing factors.



# Mercury Species in Petroleum

| Phase | Mercury Species | Description | *Potential sources |
|---|---|---|---|
| **Dissolved mercury** | Elemental mercury (pure) | **Volatile** and distributes between gas, liquified fractions and oil/condensate. ***Relatively insoluble in water*** | • HC Source rock<br>• organic shales<br>• Coal shale<br>• Hydrothermal |
| | Organic mercury | Highly soluble in crude oil, gas & condensate. ***Virtually insoluble in water.*** | |
| | Organo-metallic | Typically, **non-volatile** and partition into the oil/condensate phase | |
| | Inorganic (ionic) mercury | Soluble in oil and gas condensate, but **preferentially partition to water phase.** | • Inorganic origin **(Mantle degassing?)**<br>• Barite |
| **Particulate mercury** | Amalgamated mercury | Insoluble in liquids and **remain suspended** as solid fine particles. Examples include mercury sulphide (HgS) | • Presence could be due to barite mud contamination and/or HgS content in formation rock. |
| | Weakly adsorbed mercury | Mercury not dissolved, but rather **adsorbed** on inert particles such as sand or wax | |

*Source: Table based on Wilhelm & Bloom 2000, *petroleum system modelling results for CO2 and Hg content trending analysis.*

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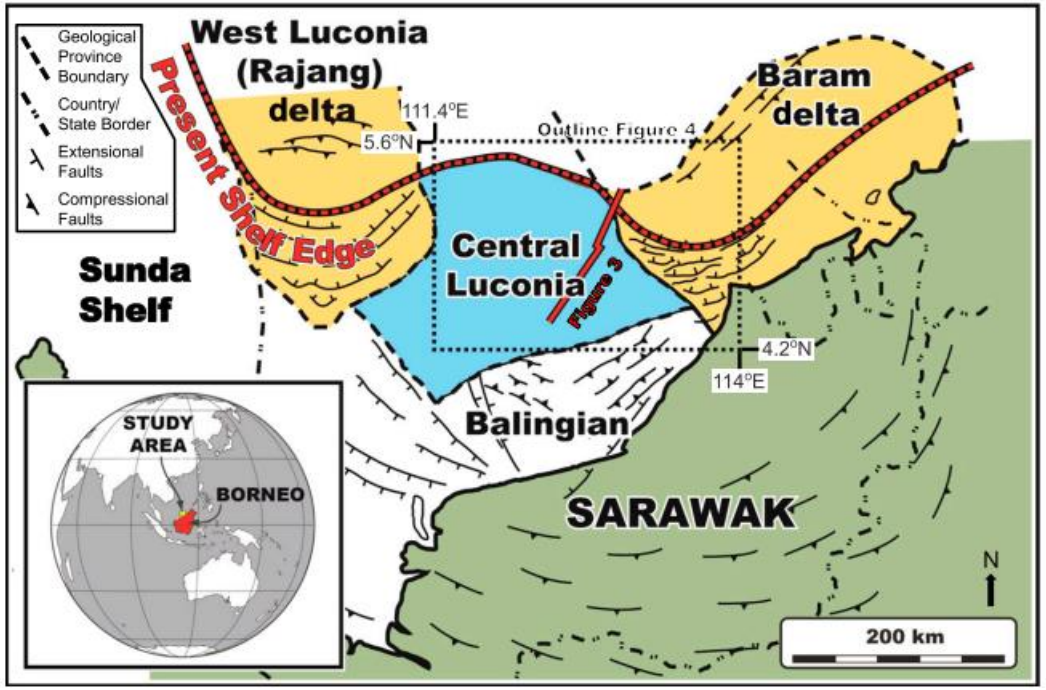
# Geological Setting of Central Luconia

- Central Luconia is in continental shelf of Sarawak offshore
- It is a most productive carbonate province for gas condensate reservoirs, contains about 65 trillion cubic ft of GIIP with minor contribution of oil rims.
- The geological structure of Central Luconia was deformed by tectonic regional extension following seafloor spreading in the South China Sea, resulting in several horst and graben structures over the region.
- Six regressive cycles observed in Central Luconia, (Hammad et.al. 2017).
- Carbonate deposition started during the early Miocene (Cycle III), but the mega-carbonate deposited during the middle to late Miocene (Cycles IV and V) time.
- Over 200 carbonate buildups grew during the Miocene period.
- Calcareous shale (Pre Cycle I) and coaly shale (Cycle I) are possible source rocks for hydrocarbon in Central Luconia.
- Hg frequently found in association with CO2 and H2S in gas, condensate and water (in some cases).

Geographical and geological location of the Central Luconia

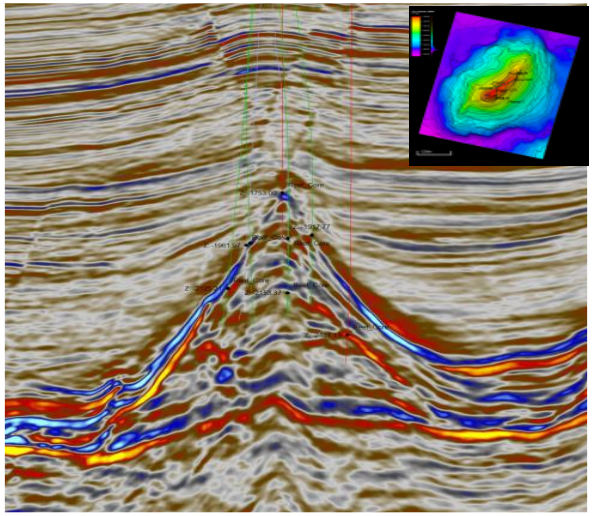


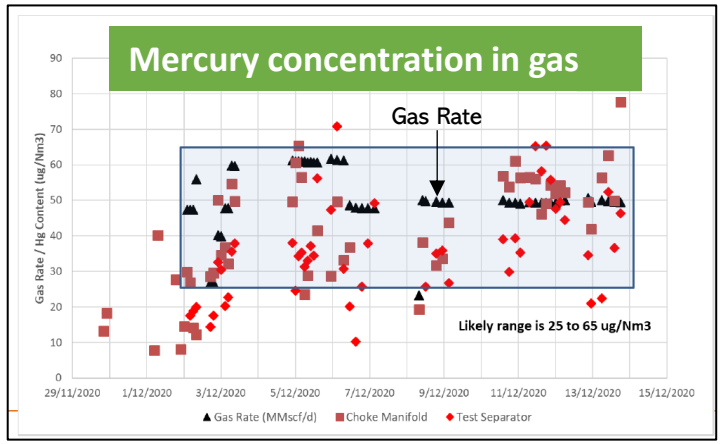

Source: Article in AAPG Bulletin Marc 2019

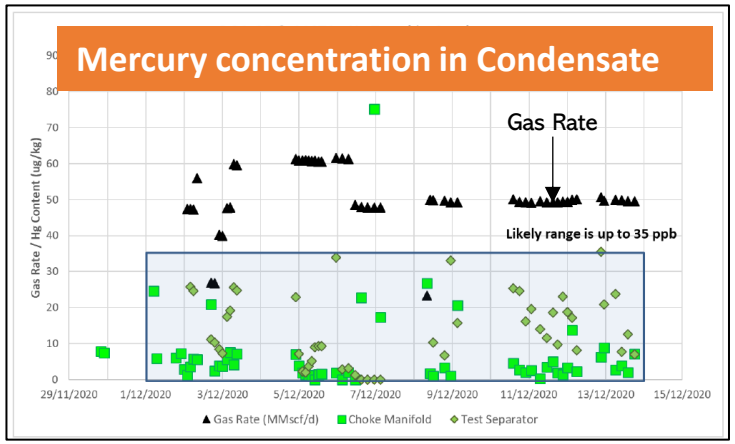
# Field History 1: SKO-A

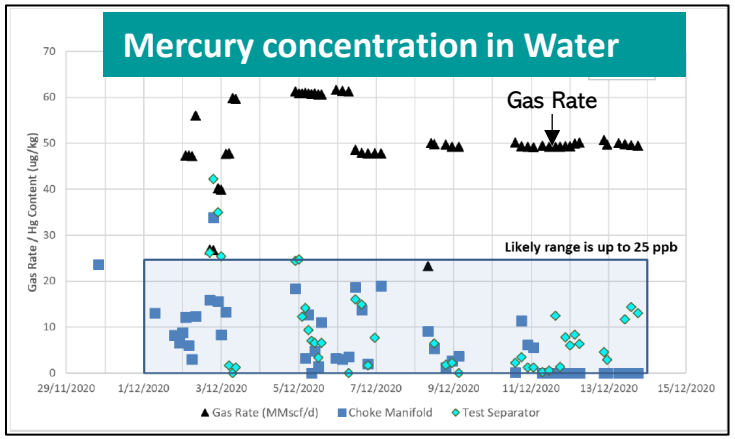
- The field SKO-A is a carbonate pinnacle buildup in Central Luconia.
- Medium size gas condensate field came in onstream since 2020.
- Mercury was discovered in fluid sample from the exploration well, but the analysis was inconclusive.
- Decision was made to procure MRU after 1st HC hydrocarbon.
- The surface fluid samples collected both at choke manifold and separator during field production indicated presence of mercury beyond threshold limit (gas 0.8 µg/Nm3, condensate 5ppb).
- The mercury found in all three phases (i.e. gas, condensate and water).
- No significant change in Hg trend during initial 15 days was observed of production except water.
- Production curtailment by 19 months to install of mercury removal unit (MRU).

A cross section along Seismic line



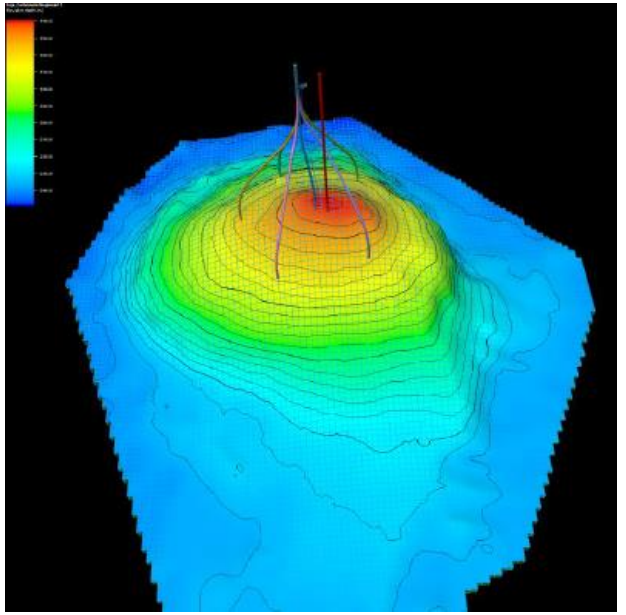


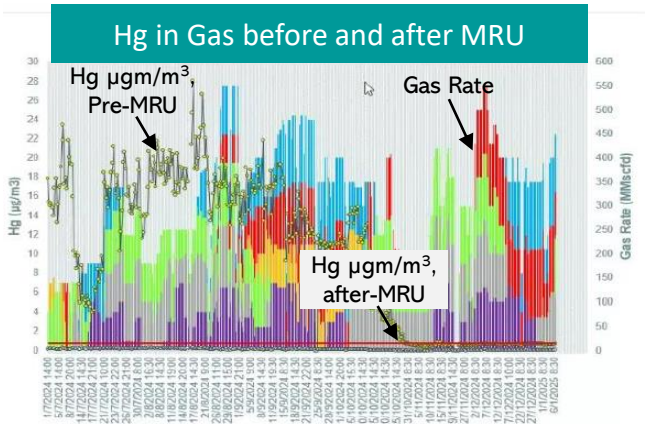



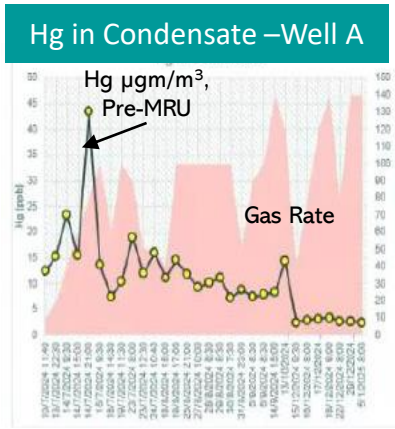



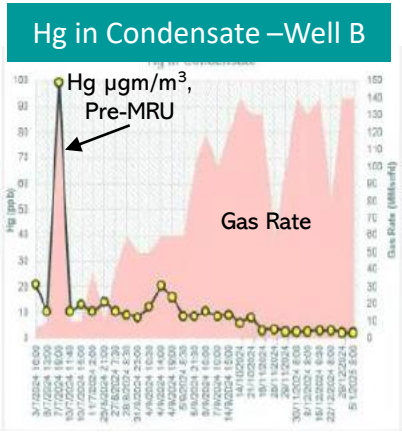
# Field History 2: SKO-B

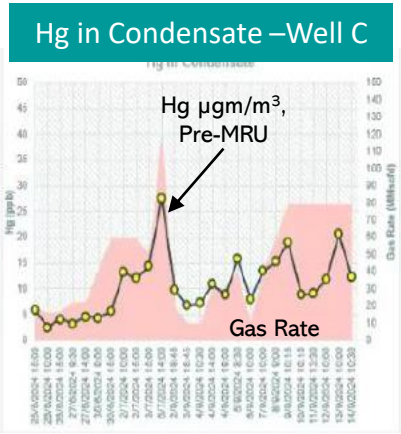
- Circular carbonate pinnacle buildup in Central Luconia
- Initially gas production was curtailed and MRU was installed as high content of Mercury was found in surface samples.
- Hg trends is monitored for about 6 months from 1st production. The trend indicates continuous reduction .
- The recent Hg content in samples is below the export limit (gas <0.8 µg/m3, condensate <8ppb) since FGD +3 months.
- Production is currently on bypass mode (CMRU) as the Hg content is within limit.
- All wells demonstrate decreasing Hg content in recent sampling except well C.
- Well C has heavy mud loss during drilling, high skin factor, observed solids production. **Is it because of Barite mud filtrate?**

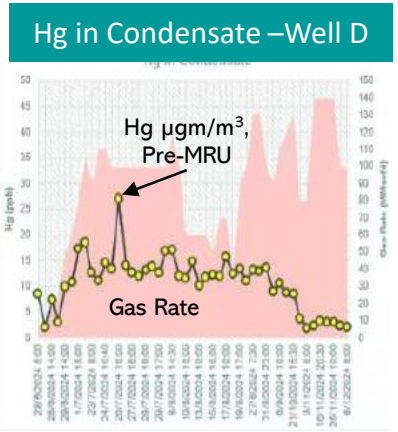




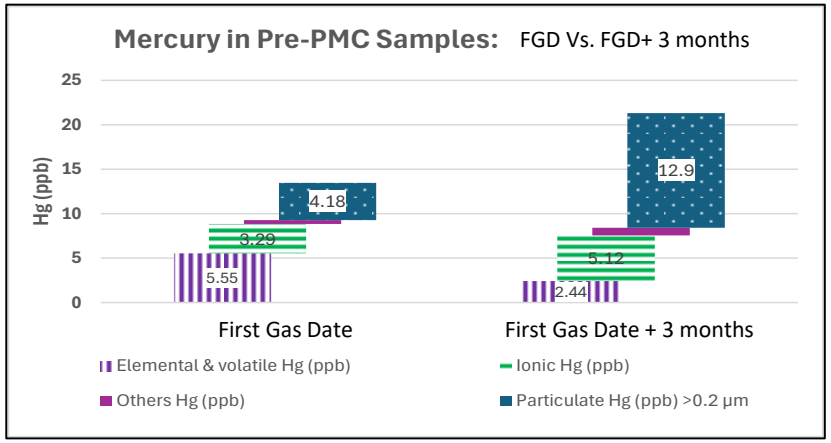



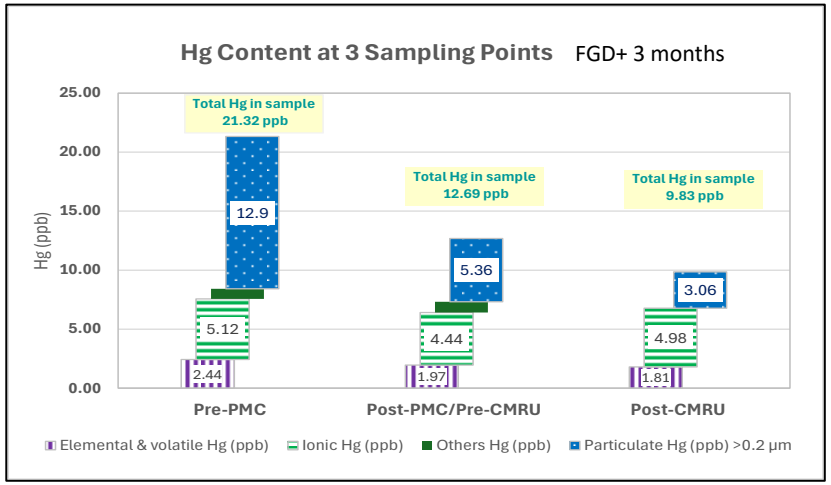
# Field History 2: Mercury Speciation Analysis

- Mercury speciation analysis of the samples collected **“before PMC filter”** indicate increase in particulate Hg,.
- XRD analysis of solids produced during production indicates to be Barite in origin. It suggests particulate mercury could from Barite source and be attributed to wellbore clean-up.
- However, no major change in dissolved Hg is observed
- The speciation analysis of Hg shows significant drop in particulate Mercury after passing through the PMC filter and CMRU.




## Summary of Mercury Speciation study Data

| Sample ID | 17 | 18 | 19 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|
| Date | First Gas Date | | | First Gas Date + 3 months | | |
| Sample Location | Pre-PMC | Post-PMC/Pre-CMRU | Post-CMRU | Pre-PMC | Post-PMC/Pre-CMRU | Post-CMRU |
| **Total Hg in sample (ppb)** | **13.472** | **11.08** | **11.06** | **21.32** | **12.69** | **9.83** |
| Total Dissolved Hg (ppb) | 9.29 | 8.93 | 8.11 | 8.42 | 7.33 | 6.77 |
| Particulate Hg (ppb) >0.2 µm | 4.18 | 2.15 | 2.95 | 12.9 | 5.36 | 3.06 |
| Elemental & volatile Hg (ppb) | 5.55 | 5.4 | 4.95 | 2.44 | 1.97 | 1.81 |
| Ionic Hg (ppb) | 3.29 | 3.33 | 2.92 | 5.12 | 4.44 | 4.98 |
| Others Hg (ppb) | 0.45 | 0.2 | 0.24 | 0.86 | 0.92 | 0 |



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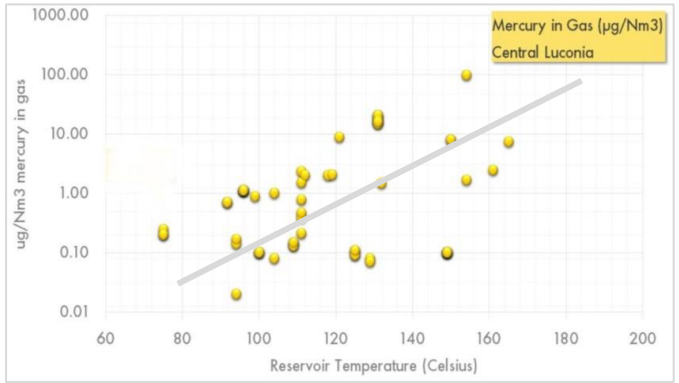
# Thermodynamic Factors Governing Mercury Solubility

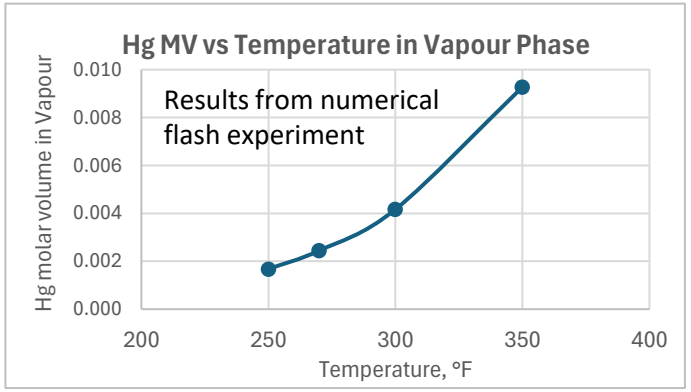
The solubility of mercury (Hg) in hydrocarbons is strongly influenced by both pH and temperature as evident from lab studies, EOS modelling and field data.

- Observations from several gas condensate fields in Central Luconia indicate that **mercury concentration in the gas phase increases with reservoir temperature**.
- A mixture containing hydrocarbon components (C1–C3), $CO_2$, $H_2S$, Hg, and 93% water was flashed at 5000 psia using an EOS application at five different temperatures: 250°F, 250°F, 270°F, 300°F, and 350°F. The results suggest that **Hg tends to vaporize into the gas phase as temperature increases**.
- Multiple studies have investigated the solubility of elemental mercury ($Hg^0$) in liquid hydrocarbons, with solubility measured in the C5–C7 range across various temperatures. These studies indicate that **mercury solubility increases with temperature**.
- Varekamp and Buseck (1984) reported that the solubility of aqueous elemental mercury ($Hg^0_aq$) in hydrothermal fluids is enhanced by **elevated pH and temperature.**

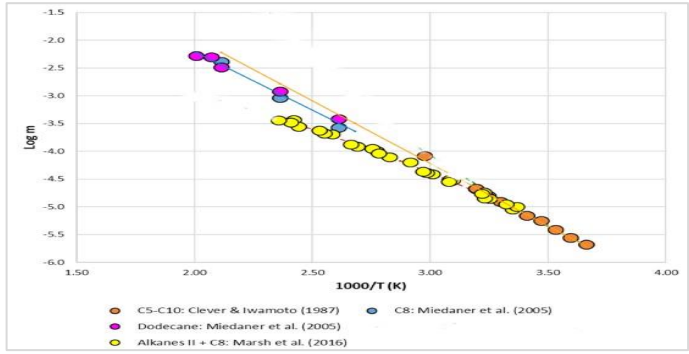
## Mercury in gas – Central Luconia




## Hg in Vapour Phase -PVTSim

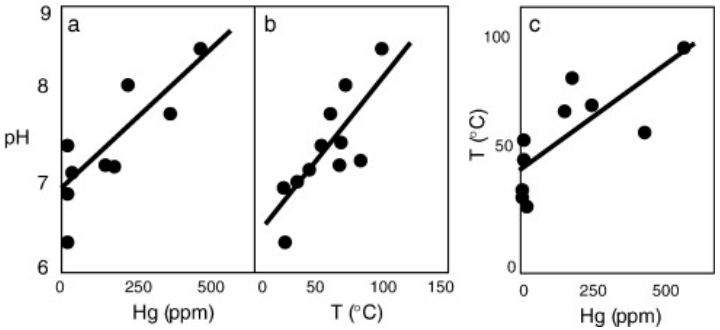



## $Hg^0$ solubility - Experimental Data




Solubility of $Hg^0$ in alkenes and alkane mixture from Clever & Iwamoto (1987), Miedaner et.al. (2005, Gallup and Bloom (2010 and Marsh et.al. (2016. (Source: modified picture from SPE-212271-pa)

## $Hg^0$ solubility in hydrothermal fluid




Varekamp and Buseck, 1984

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# Potential Source of Hg in hydrocarbon Fluids

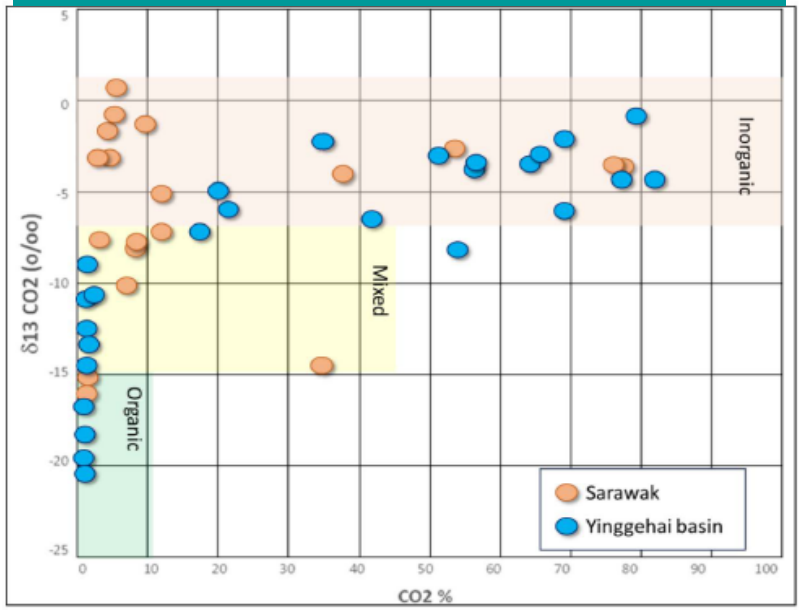
## Key Observations:

- Mercury is commonly associated with **$H_2S$ and $CO_2$**.
- $CO_2$ gas concentration and isotopic cross-plot analysis (SPE 215443-MS) suggest **three distinct sources of $CO_2$ in offshore Sarawak**.
- Basin modeling and geochemical data indicate that the origin of $CO_2$ in the Sarawak Basin is linked to **calcareous shale (Pre-Cycle I), coaly shale (Cycle I), and magmatic activity**.
- Central Luconia is situated in a **moderately high-temperature region**.
- Results from PVT modeling, mercury solubility experiments, mercury speciation studies, and the thermodynamic conditions of Central Luconia reservoirs suggest that **mercury may be soluble in hydrocarbon gas**.

## Potential Source of Mercury

1. Given that dissolved mercury species in the Central Luconia gas fields originate from both organic and inorganic sources, it is possible that **mercury shares a common origin with $CO_2$**.
2. Mercury may have originated from **sedimentary rocks subjected to thermal maturation and cracking and** was subsequently transported during hydrocarbon charging.

**CO2 gas concentration and isotope cross plot***




***Source Rahim Masoudi, Nayak et.al, 2023, SPE215443-MS**

# Summary and Conclusions

- Mercury phases identified in Central Luconia are derived from both **organic and inorganic sources**.
- Solubility studies and EOS modelling indicate that mercury solubility in the gas and condensate phases **increases with temperature**.
- Petroleum system modelling of $CO_2$ origin and mercury solubility in hydrocarbons suggests that the mercury in Central Luconia likely originates from **calcareous shale (Pre-Cycle I), coaly shale (Cycle I), and magmatic inputs**.
- Given that dissolved mercury species in the Central Luconia gas fields originate from both organic and inorganic sources, it is possible that **mercury shares a common origin with $CO_2$**.
- Mercury may have originated from **sedimentary rocks subjected to thermal maturation and cracking and** was subsequently transported during hydrocarbon charging
- A declining trend in particulate mercury in gas and condensate streams has been observed over time, with **Barite identified as the most probable source** of particulate mercury.
- Although mercury sampling and quantification during the pre-development stage is challenging—due to its **volatile and corrosive nature**—speciation studies is **crucial for facility design and Mercury Removal Unit (MRU) planning**.

# Acknowledgement

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