Modeling of methane bubbles released from large sea-floor area : Condition required for methane emission to the atmosphere


Yamamoto Akitomo[1], Yamanaka Yasuhiro[1], Tajika Eiichi[2]

[1] Hokkaido University
[2] The University of Tokyo

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We discussed
• the possibility of methane release from the methane hydrate to the atmosphere
• the degree of global warming caused by decomposition of methane hydrate
Introduction ~Methane hydrate and climate change~

CH$_4$ \cdot 5.75H$_2$O


Worldwide distribution of methane hydrate

Futures
• The large inventory of several thousands GtC
• Sensitive to the changes in temperature and pressure

Hypothesis
The massive methane release (~2000GtC) from methane hydrate has been hypothesized as a cause of past (i.e. end of Paleocene) and possibly future global warming (Dickens et al, 1995: IPCC, 2007).

Question
We have not well understand the degree of caused global warming.
The methane flux to the atmosphere is crucial to evaluate the climate response to decomposition of methane hydrate.
Objectives

Early studies
The observations and modeling of present methane seep suggest almost all released bubbles would not reach the atmosphere (Greinert et al, 2006; McGinnis et al, 2006).

What about massive methane release, such as 2000GtC?

What we have done
1. We calculated the methane saturation in the seawater required for methane bubble reaching the atmosphere using our numerical model.

2. We discuss the methane release to the atmosphere by comparing the area density of the methane input required for the methane bubble reaching the atmosphere VS the methane amount in the sediment in the form of methane hydrate and free gas
Our one-dimensional numerical model combines (1) bubble and (2) water column components. We can calculate the methane saturation in the water column necessary for methane bubble reaching the atmosphere in this model.

Based on McGinnis et al, 2006

\[
\frac{\partial C_i}{\partial t} = S_i + \gamma C_i + e_i C_i \bigg|_{\text{surface}}
\]

\[S_i\text{ mol/sec m}^3\]

\[C_i\text{ mol/m}^3\]

\[\gamma\text{: oxidation rate (1.5yr}^{-1}\text{or 10yr}^{-1})\]

\[e_i\text{: gas exchange coefficient (Wanninkof, 1992)}\]

A grid size of $1\text{m}^2$(area) $\times$ $5\text{m}$ (height)

The effects of advection and diffusion are not included.
Conditions: global average temperature, salinity, methane and oxygen concentration
sea-floor depth of 1000m, initial bubble radius of 0.3 cm
a methane flux of \(2.5 \times 10^{-2}\) mol/s•m\(^2\) (equivalent of forty bubbles/s•m\(^2\))
the integration period of 50 days

These reversals are caused by the difference of dissolution rate below and above this depth.
Discussion

~comparison the two amounts~

The amount of methane hydrate calculated from Kvenvolden and Claypool (1998), assuming of hydrate fraction 20, 10, 5%

- Assuming a typical hydrate fraction of 2% (Davie and Buffett, 2003) and free gas of two-thirds of the methane hydrate (Hornbach et al., 2004), the methane amount in the sediments is significantly lower than the required methane input.

It is, therefore, suggested that the massive methane bubbles released from sea-floor methane hydrate would not reach the atmosphere directly but dissolved into the ocean.

The methane input required for methane bubble reaching the atmosphere

- 100% saturated (no bubble)
- 85~90% saturated (for a bubble with r = 0.3cm)
- 50~60% saturated (for a bubble with r = 0.6cm)
For the case of warmer condition, the necessary methane input slightly change, while the methane amount in the sediment greatly decreases. It is more difficult for the methane bubble to reach the atmosphere.
Summary

• We discussed the possibility of the methane release from sea-floor to the atmosphere in order to evaluate the climate response to the decomposition of massive methane hydrate.

• Our results suggested that the methane released from hydrate with typical amount would not reach the atmosphere but dissolve into the ocean except extraordinary methane flux.

• With regard to global warming, the methane release due to decomposition of methane hydrate may cause a small contribution to warming.

• The advection and diffusion processes are not included in our calculation. Considering these processes, it is more difficult for methane bubbles to reach the atmosphere.
Thank you for your attention!
1. Introduction
   - Methane hydrate and climate change

2. Model
   - Assumptions and Our one-dimensional numerical model

3. Results
   - Control experiment
   - Comparison between the methane input required for bubble reaching the atmosphere and methane amount in the sediments

4. Summary & Remarks
Introduction

PETM and massive methane release

Paleocene-Eocene Thermal Maximum (55Ma)

Observations (within 10 ky)

- Carbon isotopic excursions of -2.5‰
- Global warming of ~5°
- A large increase in CaCO₃ dissolution

indicate massive injection of isotopically light carbon to the oceans and atmosphere

Hypotheses

subjects of this study

- Methane release of ~2000GtC due to decomposition of methane hydrate (Dickens et al., 1995)
- Release of metamorphic methane from sill intrusion into carbon-rich sediment in the Northeast Atlantic (Svensen et al., 2004)
- The oxidation of terrestrial and marine organic carbon (Kurtz et al., 2003; Higgins and Schrag, 2006)
Results

~control experiment~

Conditions: global average temperature, salinity, methane and oxygen concentration sea-floor depth of 1000m, initial bubble radius of 0.3 cm. a methane flux of $2.5 \times 10^{-2}$ mol/s$ \cdot$ m$^2$ (equivalent of forty bubbles/s$ \cdot$ m$^2$) the integration period of 50 days.

Time evolutions of bubbles

Large bubbles ($r > 1$cm) break apart by oscillation.

Reduction due to dissolution is balanced by growth due to reduction of hydrostatic pressure with the bubble’s ascent.
Results ~parameter studies~

Parameter studies

- Initial radius x2 (0.6cm)
- Global average temp +5°C
- Water depth of 1500m

CH$_4$ saturation of 52%

CH$_4$ saturation of 91%

CH$_4$ saturation of 90%
Introduction

Methane hydrate


The massive methane release (2000GtC) from methane hydrate has been hypothesized as a cause of past (i.e. end of Paleocene) and possibly future global warming (Dickens et al, 1995: IPCC, 2007).

How does methane release affect climate?
Reserve

〜メタンプルームのモデルによる再現〜

McGinnis et al, 2006
Model

〜single bubble model ①〜

・泡の溶解速度(球形を仮定)

\[ \frac{\Delta N}{\Delta t} = k_{Li} 4 \pi r^2 \left( C_i - P_{Bi}/H_i \right) \]

\( N_i \):モル含有量  \( k_{Bi} \):ガス移動速度

\( C_i \):海水中の濃度  \( H_i \):ヘンリー定数(変形版)

海水中と泡の濃度差

\[ P_{Bi} = P_A + \rho_w g z + 2 \sigma/r \] バブルの内部圧力

・泡の半径を求める方程式(理想気体の場合)

\[ V \frac{\Delta P_B}{\Delta t} + P_B \frac{\Delta V}{\Delta t} = RT \frac{\Delta N}{\Delta t} \]

\[ V = 4/3 \pi r^3 \]

\[ \frac{\Delta r}{\Delta t} = \frac{1}{r} \left( q \frac{\Delta N}{\Delta t} - \rho_w g \frac{\Delta z}{\Delta t} \right) \times (3(P_A + \rho_w g z) + 4 \sigma/r)^{-1} \]

状態方程式を解くと、半径変化は溶解速度、静水圧変化に依存。