Seafloor pockmarks on the Chatham Rise, New Zealand: Possible causes and links to glacial cycles

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Outline

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- Pockmark distribution
- Role of CO₂?
- Link to Hikurangi Plateau
- “Valve” mechanism
- Discussion
Tectonic Setting

- Current subduction of Hikurangi Plateau to NW on Hikurangi Margin
Tectonic Setting

• Current subduction of Hikurangi Plateau to NW on Hikurangi Margin

• Subduction at Gondwana Margin to SW until ~105 Ma, when jammed (Davy, 2014)

→ Chatham Rise

Key observation: Vast area covered by pockmarks, bathymetrically controlled

After Davy et al. (2010)
Shallow pockmarks: Link to glacial-stage sealevel lowstands

Buried pockmarks tied to glacial-stage lowstands (high-amplitude reflections due to changing carbonate content, Schaefer et al., 2005)

In 2010, suggested link to methane hydrate dissociation during glacial-stage lowstands.

Focus here on SO-226 Site 3 (small pockmarks)

SO-226 Study Areas
R/V Sonne, 2013, seismic and coring
Led by GEOMAR, with NRL, GNS Science et al.

*From Bialas et al. (2013)*

Sulfate gradient, Site 3

- Similar for other study areas
- Absolutely no current methane flux
- $\delta^{13}$C: No evidence for past methane flux

$\rightarrow$ Something is wrong:
- Geochemistry “flawed” (shallow cores over low-permeability chalk layers)?
- Pockmarks unrelated to methane flux?
  - Unrelated to gas escape?
  - Different gas (CO$_2$)?

*From Coffin et al. (2013)*

Coffin, R. B., Rose, P. R., Yosa, B., and Millholland, L., 2013, Geochemical evaluation of climate change on the Chatham Rise: US Naval Research Laboratory
Alternative Mechanisms

- Linked to Southland Current (intensifying during glacial stages)? Small depressions caused by groundwater flow through canyon walls (1)?
- Large seafloor depressions contouritic mounds (2)?
- Diagenetic and compaction processes: Fluids released from underlying polygonal fault systems and/or Opal-A to Opal-CT transform (3)

Scientific Background – CO₂

• Overarching motivation: What mechanisms regulated the concentration of atmospheric pCO₂ between 280 and 190 ppm during each of the glacial cycles of the late Pleistocene?

• Often suggested: Sequestration of carbon into an isolated abyssal water mass (e.g., Toggweiler, 1999).

• Δ¹⁴C anomalies indicate release of “old” carbon, compatible with above (isolated water mass).

• Alternatively, release of geologic carbon through the seafloor.

″EPICA East Antarctic ice core record of atmospheric pCO₂ and Antarctic air temperature during the late Pleistocene glacial/interglacial cycles (Jouzel et al., 2007; Lüthi et al., 2008)″
The Case for Old (Geologic) CO₂: ∆¹⁴C

(a) Benthic ∆¹⁴C from SO-226 core 75 compared to atmospheric ∆¹⁴C (IntCal13, Reimer et al., 2013; from Shao et al., 2019) → influx of “old” carbon at last glacial termination.
(b) ∆¹⁴C anomalies indicate release of “old” carbon, one particularly strong site on Chatham Rise (ANT26/2_100-4; Ronge et al., 2016).
(c) Location map.


The Case for CO$_2$: Dawsonite

Eocene Amplitude 3: 2280 - 2378m

Avg. SWC Porosity: 32%
Avg. Kair (2200psi): 0.40md

XRD Mineralogy:
55% Quartz
1% K-Feldspar
3% Siderite
3% Pyrite
28% Clays (Kaolinite, Illite, Mica)
9% Dawsonite
NaAl(OH)$_2$(CO)$_3$

Dawsonite rare carbonate that requires supply of CO$_2$ over long time span

Courtesy Anadarko Petroleum Corp. (Blanke et al., 2015)
Hypothesis: The subducted Hikurangi Plateau is a source of carbon-rich fluids released at the end of glacial-stage maxima modulated through pockmarks (Stott et al., 2019)

Key question: What is the “valve” mechanism modulating carbon release?

Timing of Pockmark Formation

Possible link between pockmarks and sealevel fluctuations:

- Pockmarks in Pleistocene and Pliocene (Smith, 2016; Prestage et al., in rev.)
- Upper Pliocene often considered time of onset of eustatic sealevel fluctuations (e.g., Naish and Wilson, 2009)


Smith, A. E., 2016, Seismic studies of paleo-pockmarks on the Chatham Rise, New Zealand (MSc: University of Auckland), 84 pp.


Left: Seismic profile collected for hydrocarbon exploration near SO-226 Site 3. Pockmarks only occur above the Top Miocene. There may also be some pockmark clusters which still need to be confirmed statistically (not discussed here). From Smith (2016)
Stacked pockmarks?

- Pockmarks stacked, at lateral offsets?
- 2-D data → out-of-plane reflections possible: Events may be shallower than they appear and offset laterally.

Right: High-resolution seismic profile across SO-226 Site 3 collected with GI-gun (Bialas, 2013).

Smith, A. E., 2016, Seismic studies of paleo-pockmarks on the Chatham Rise, New Zealand, MSc: University of Auckland, 84 pp.
High-velocity/density material?

Positive-polarity reflections → authigenic processes?

Study Area 3 (SO-226 seismic line, Area 3) (Smith, MSc, 2016)

P: Events with same polarity as seafloor reflection

Right: Part of profile shown in previous slide

Smith, A. E., 2016, Seismic studies of paleo-pockmarks on the Chatham Rise, New Zealand, MSc: University of Auckland, 84 pp.
Shallow pockmarks: Link to CO$_2$ hydrates?

- Modern setting: Pockmarks well within CO$_2$ hydrate stability field
- If pockmarks caused by dissociation of hydrates due to depressurization, difficult to explain upper limit of pockmarks

Thermal gradient: based on Hikurangi Margin (e.g., Henrys et al., 2003)

Water temperatures after Chiswell (2002)


Shallow pockmarks: Link to CO$_2$ hydrates?

- Glacial setting but assuming unchanged water temperature profile. A 2$^{°}$/oo step in benthic $\delta^{18}$O profiles in core PC75-1 (Stott et al., 2019) further to the southeast suggest a temperature change of 3-4$^{°}$ C.
- Need additional mechanism to destabilize gas hydrate ~during glacial-stage maxima (temperature?).
- Dissociation from seafloor and/or base of gas hydrate stability zone (BGHS)?
- If dissociation from BGHS, deeper water-depth limit of pockmark zone controlled by propagation of thermal pulse from seafloor to BGHS?
Discussion: “Valve” mechanism

- Supply of deeply-sourced CO$_2$ from Hikurangi Plateau unlikely to be affected by glacial fluctuations → need mechanism that modulates release of CO$_2$.
- Time-coincidence of pockmark formation and $\Delta^{14}C$ anomalies suggests link between CO$_2$ release and pockmarks.
- Stacked pockmarks: Pockmark formation likely to be linked to deeper conduit transporting fluids and/or pre-existing weakness in sediments.
- Offset-stacking (if confirmed by 3-D data): Permanent seal may form after formation of pockmarks that fluids need to bypass.
- Positive-polarity reflections: Precipitation of authigenic material?
- Questions:
  - Ephemeral seal – seal disappearing or weakening during glacial-stage maxima? What could it be?
  - Ephemeral source – CO$_2$ stored in capacitor near seafloor, increased release during glacial-stage maxima? Why?
Discussion and Conclusions

Discussion:
• Still somewhat speculative, could be other causes (including methane hydrate?)
• Cannot ignore evidence for CO$_2$ flux.
• How to prove hypotheses?

Future work: (Pseudo-)3-D seismic survey over SO-226 Site 3 planned.

Conclusions:
• Link between pockmarks and sealevel fluctuations.
• Possible link between pockmarks and Hikurangi Plateau.
• Evidence for CO$_2$ flux.
• Need to put all these pieces together.
• Focus of this study on “valve” mechanism.
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Captain and crew R/V Sonne SO-226.

Thank You

Smith, A. E., 2016, Seismic studies of paleo-pockmarks on the Chatham Rise, New Zealand, MSc: University of Auckland, 84 pp.