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

I Pecher[1], B Davy[2], J Hillman[2], L Stott[3], R Coffin[4], A Prestage[1], P Rose[4], J Bialas[5]

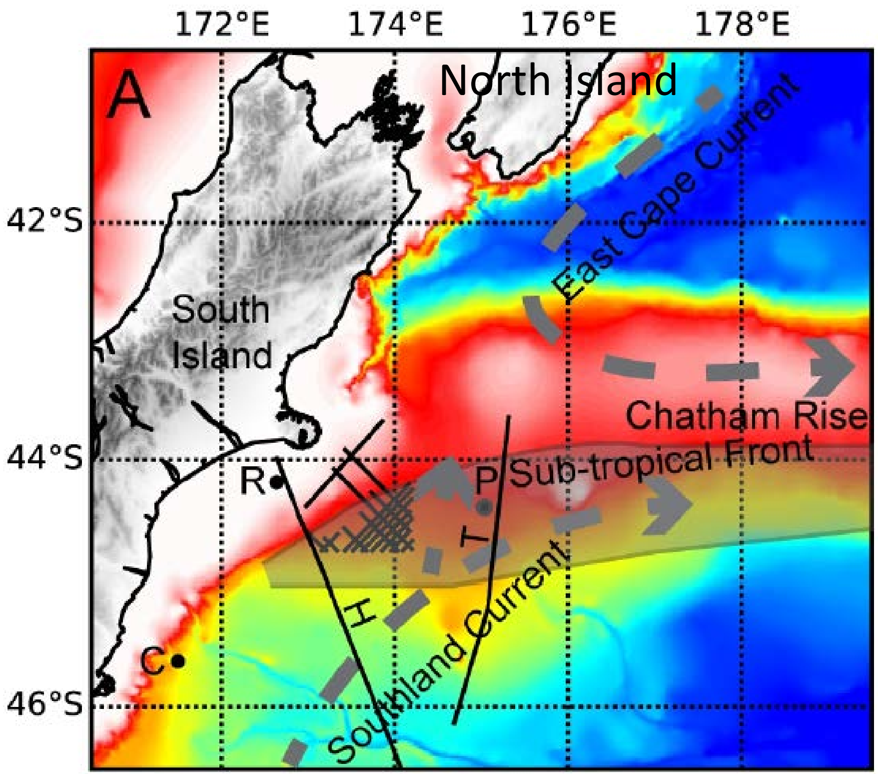
[1]University of Auckland, i.pecher@auckland.ac.nz

[2]GNS Science, Lower Hutt, New Zealand

[3]University of Southern California, Los Angeles, USA

[4]Texas A&M University, Corpus Christi, USA

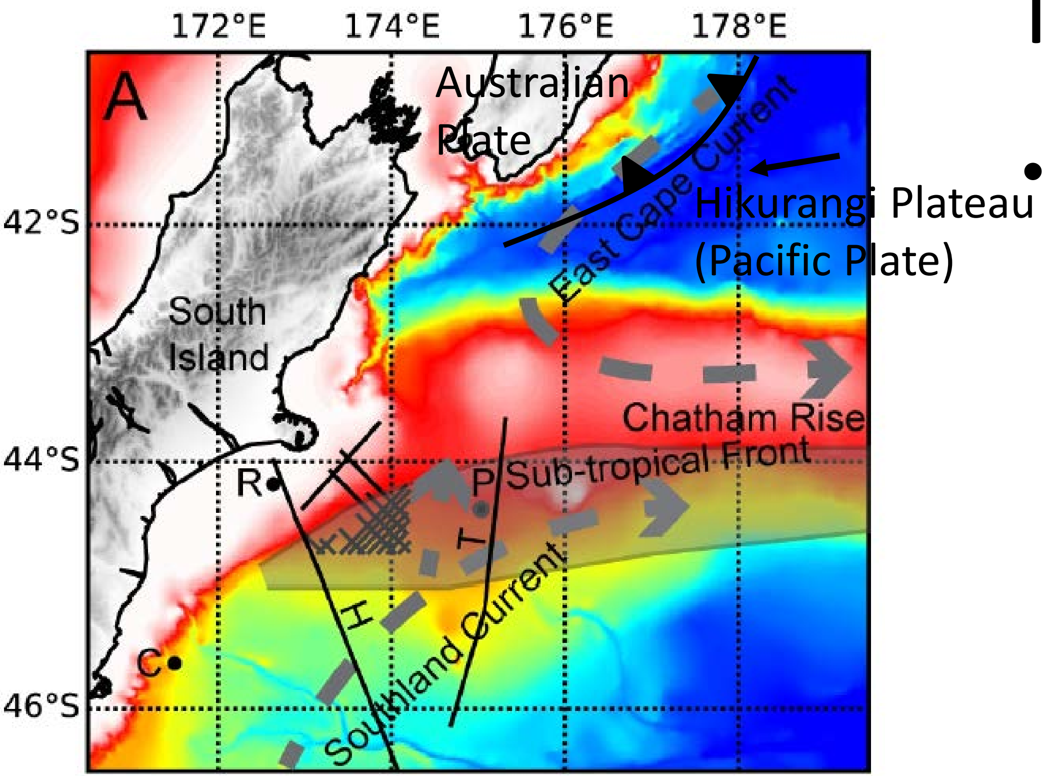
[5]GEOMAR, Kiel, Germany



Outline

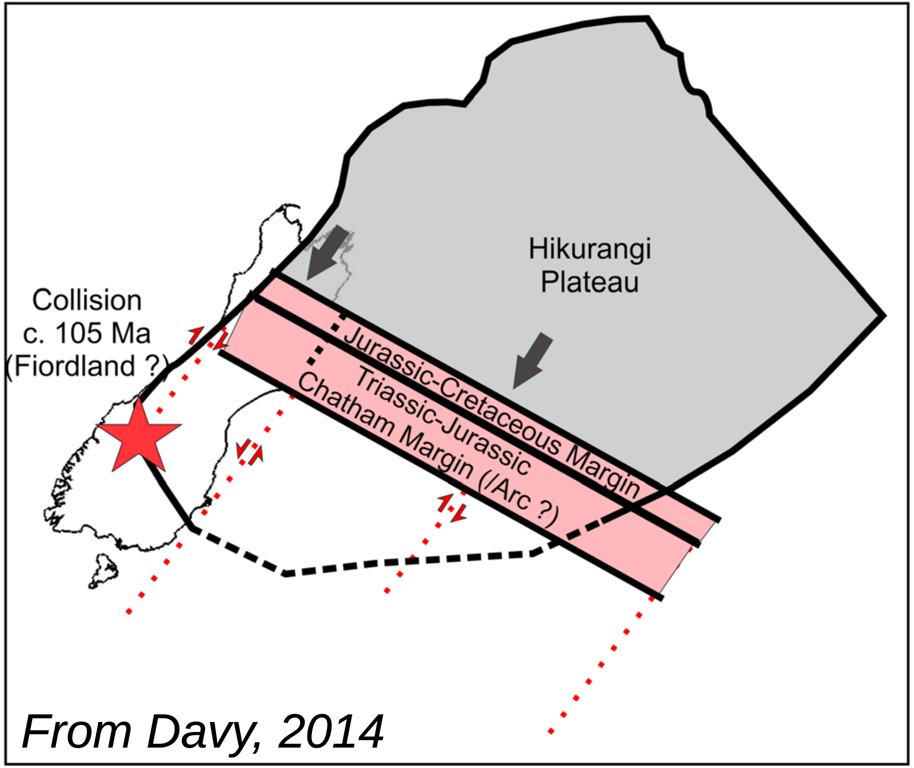
- Introduction
- Pockmark distribution
- Role of CO_2?
- Link to Hikurangi Plateau
- “Valve” mechanism
- Discussion

Tectonic Setting



- Current subduction of Hikurangi Plateau to NW on Hikurangi Margin

Tectonic Setting

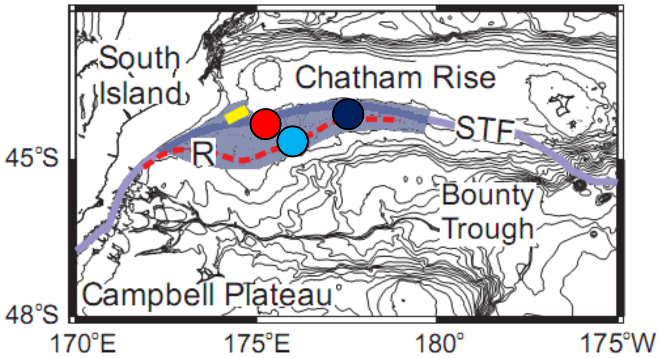


Davy, B., 2014, Rotation and offset of the Gondwana convergent margin in the New Zealand region following Cretaceous jamming of Hikurangi Plateau large igneous province subduction: Tectonics, v. 33, p. 2014TC003629.

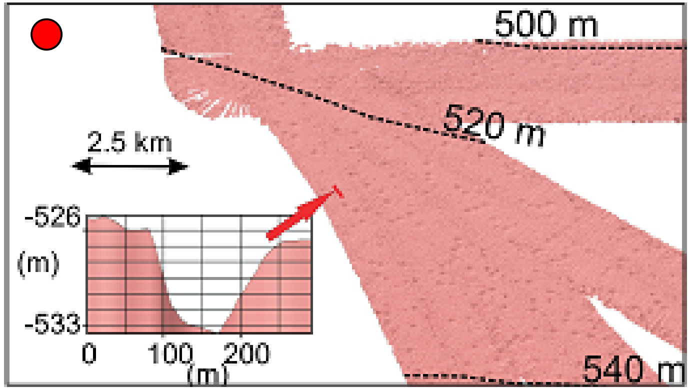
- Current subduction of Hikurangi Plateau to NW on Hikurangi Margin
- Subduction at Gondwana Margin to SW until ~105 Ma, when jammed (Davy, 2014)

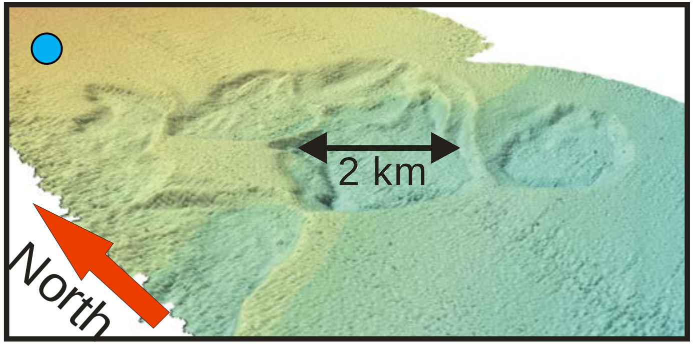
→ Chatham Rise

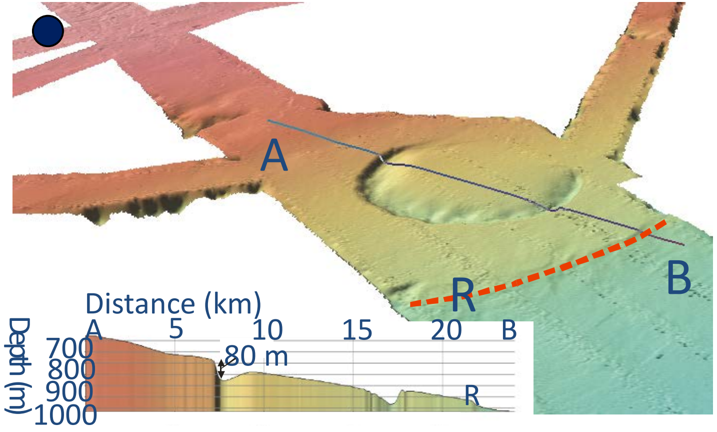
Seafloor Depressions



Grey: Pockmarked area (as of 2010)
R: Escarpment







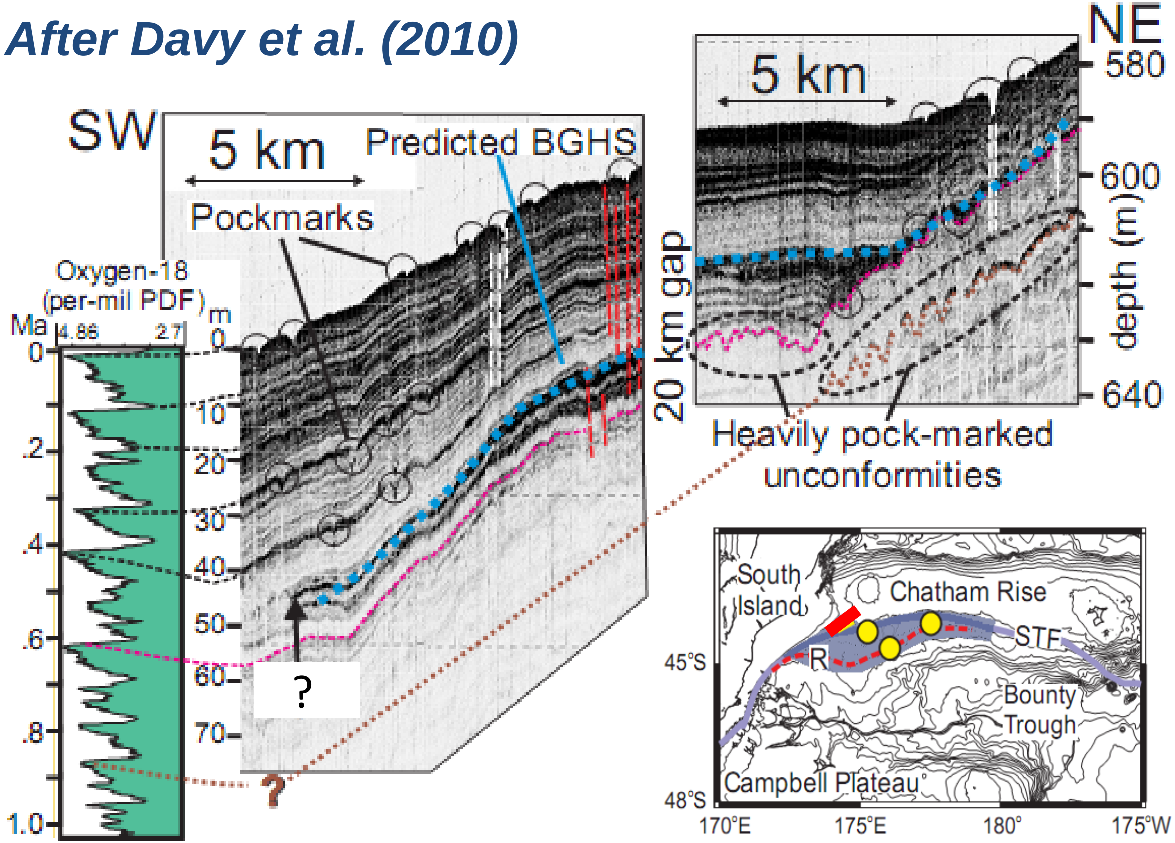
- 500-700 m water depth
  ↕ 4-8 m
  Ø 150 m
  (Focus here)
- 800-1100 m water depth
  ↕ 50-150 m
  Ø 1-5 km
- 800-1100 m water depth
  ↕ ~80 m
  Ø ~10 km

Key observation: Vast area covered by pockmarks, bathymetrically controlled

Profile shown in next slide

After Davy et al. (2010)

After Davy et al. (2010)

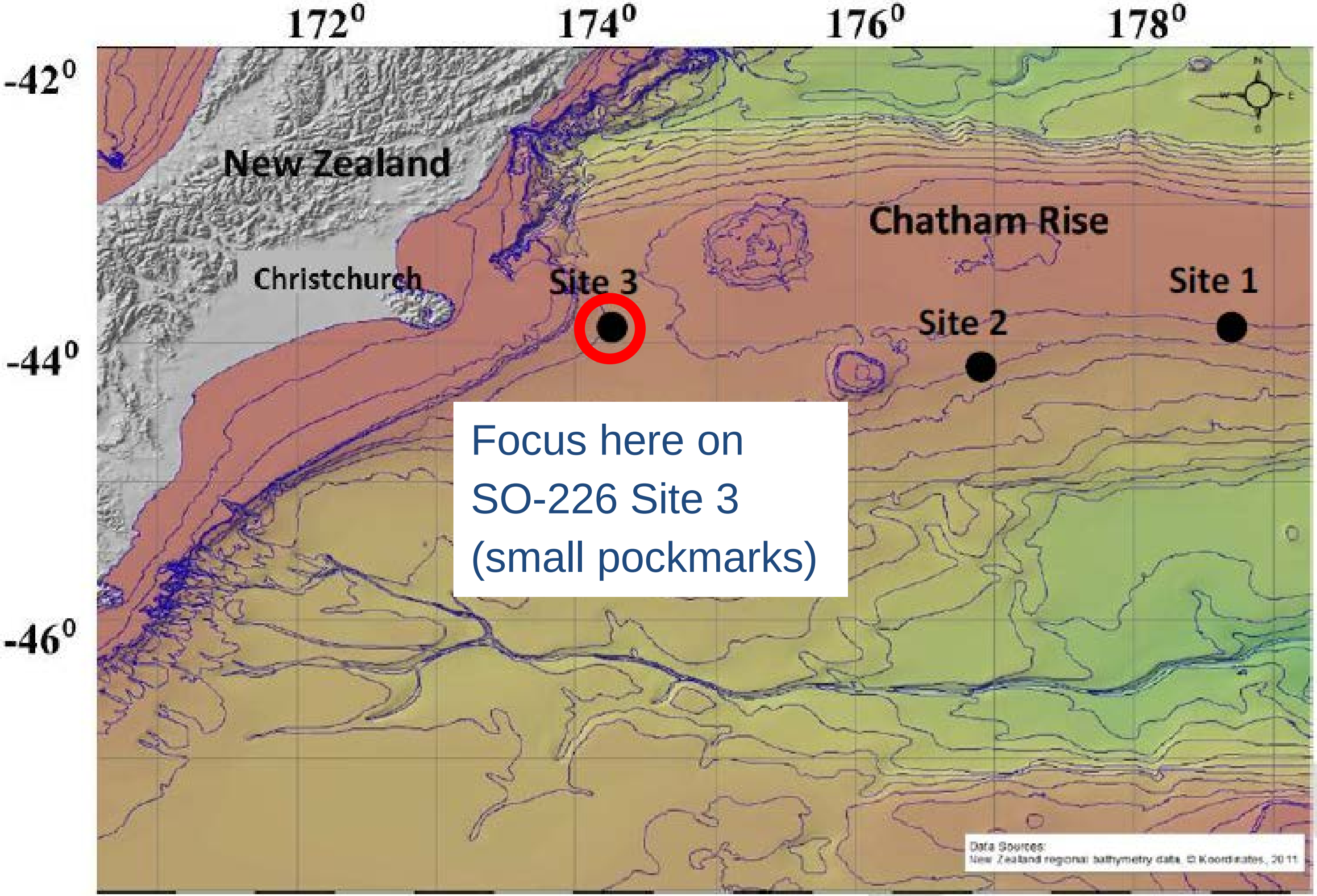


Davy, B., et al. (2010). "Gas Escape Features off New Zealand – Evidence for a Massive Release of Methane from Hydrates?" *Geophys. Res. Lett.* **37**: L21309.

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.



SO-226 Study Areas

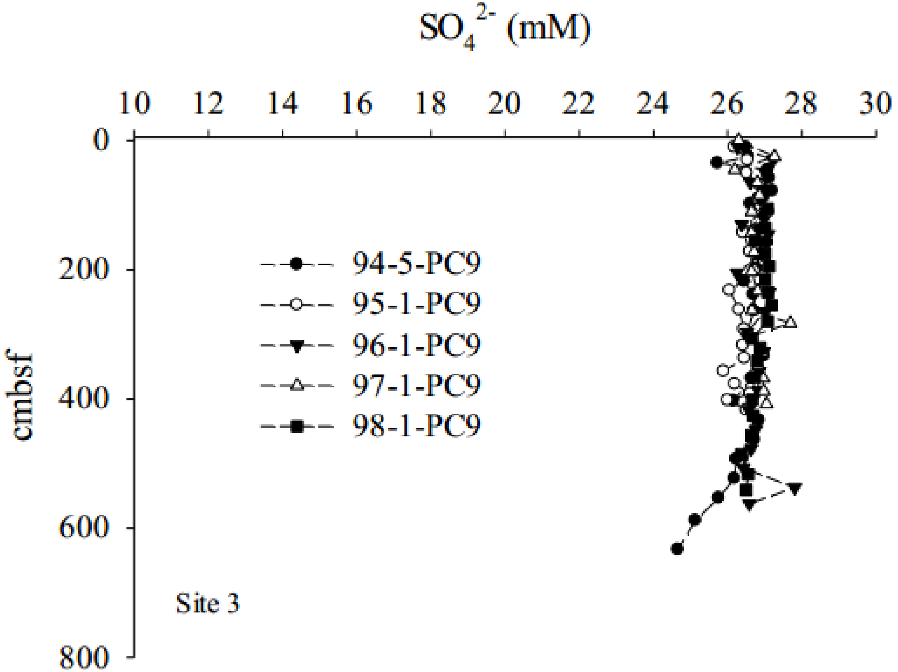
R/V Sonne, 2013, seismic and coring

Led by GEOMAR, with NRL, GNS Science et al.

From Bialas et al. (2013)

Bialas, J., Klaucke, I., and Mögeltönder, J., 2013, FS Sonne Fahrtbericht / Cruise Report SO 226 CHRIMP, Volume 7: Kiel, GEOMAR, p. 124.

Sulfate gradient, Site 3



From Coffin et al. (2013)

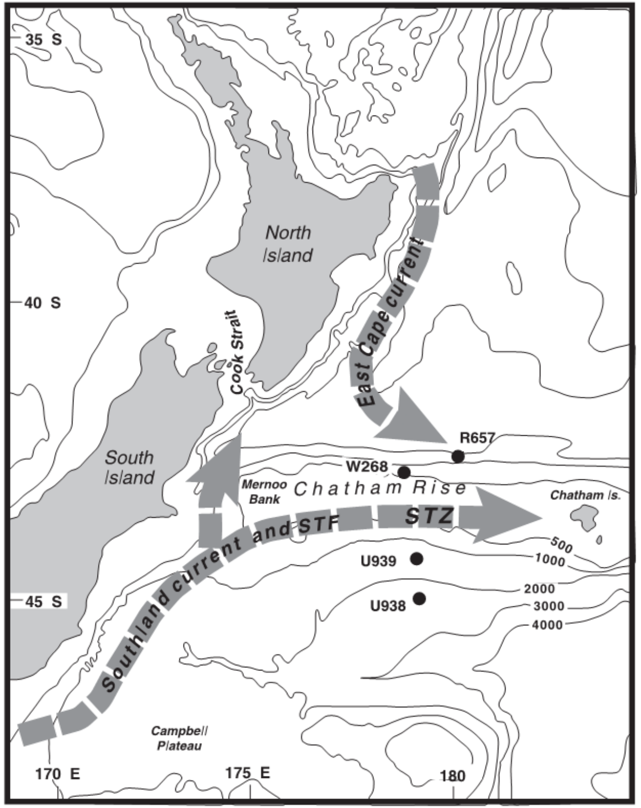
Coffin, R. B., Rose, P. R., Yosa, B., and Millholland, L., 2013, Geochemical evaluation of climate change on the Chatham Rise: US Naval Research Laboratory

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

→ 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)?

Alternative Mechanisms



Oceanographic Setting (4)

(4) Sikes, E. L., Howard, W. R., and Neil, H. L., 2002, Glacial-interglacial sea surface temperature changes across the subtropical front east of New Zealand based on alkenone unsaturation ratios and foraminiferal assemblages: Paleoceanography, v. 17, no. 2, p. 1012.

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

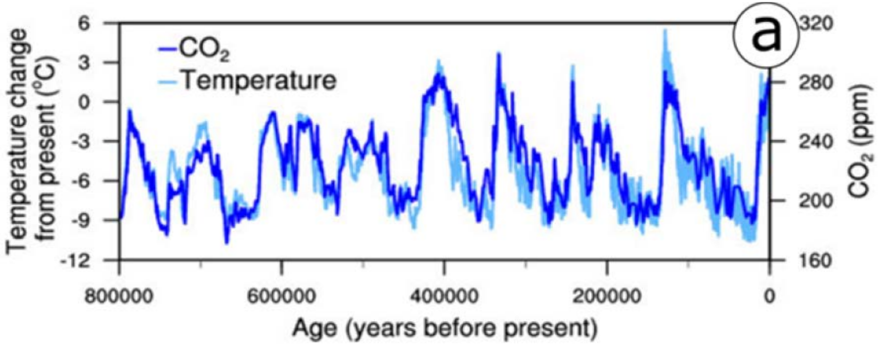
(1) Hillman, J. I. T., Klaucke, I., Pecher , I. A., Gorman , A. R., Schneider von Deimling, J., and Bialas, J., 2018, The influence of submarine currents associated with the Subtropical Front upon seafloor depression morphologies on the eastern passive margin of South Island, New Zealand: N. Z. J. Geol. Geophys., v. 61, no. 1, p. 112-125.

(2) Waghorn, K., Pecher, I., Strachan, L., Crutchley, G., Bialas, J., Coffin, R., Davy, B., Koch, S., Kroeger, K., Papenberg, C., and Sarkar, S., 2018, Paleo-Fluid Expulsion and Contouritic Drift Formation on the Chatham Rise, New Zealand: Basin Research, v. 30, p. 5-19.

(3) Klaucke, I., Sarkar, S., Bialas, J., Berndt, C., Dannowski, A., Dumke, I., Hillman, J. I. T., Koch, S., Nodder, S., and Schneider von Deimling, J., 2018, Giant depressions on the Chatham Rise offshore New Zealand – morphology, structure and possible relation to fluid expulsion and bottom currents: Mar. Geol., v. 399, p. 158-169.

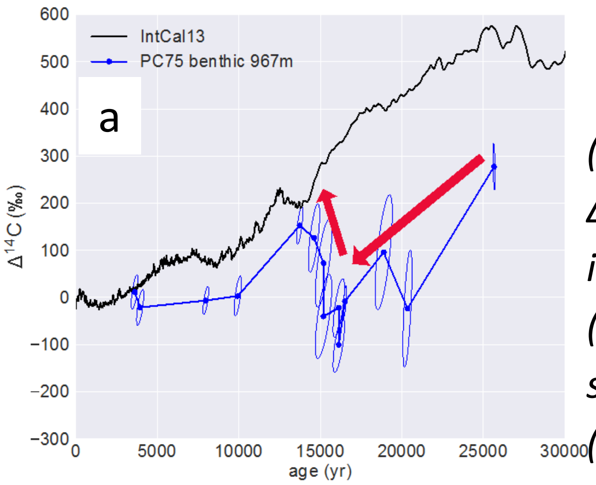
Scientific Background – CO_2

- Overarching motivation: What mechanisms regulated the concentration of atmospheric pCO_2 between 280 and 190ppm 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).
- $\Delta^{14}C$ 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 pCO_2 and Antarctic air temperature during the late Pleistocene glacial/interglacial cycles (Jouzel et al., 2007; Lüthi et al., 2008)

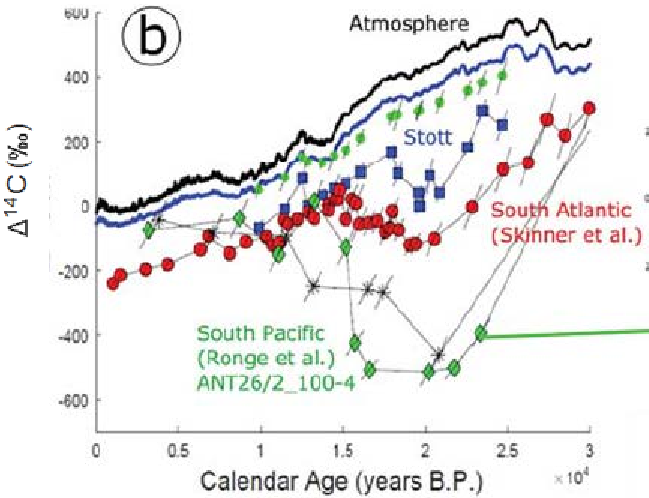
The Case for Old (Geologic) CO_2: $\Delta^{14}C$

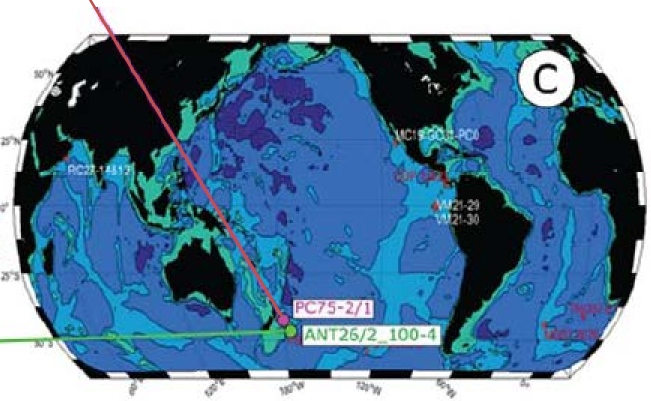


(a) Benthic $\Delta^{14}C$ from SO-226 core 75 compared to atmospheric Δ14C (IntCal13, Reimer et al., 2013; from Shao et al., 2019) → influx of "old" carbon at last glacial termination.

(b) $\Delta^{14}C$ anomalies indicate release of "old" carbon, one particularly strong site on Chatham Rise (ANT26/2_100-4; Ronge et al., 2016).

(c) Location map.





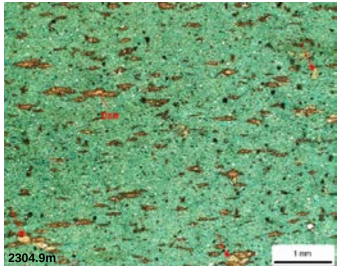
Shao, J., Stott, L., Gray, W. R., Rae, W. B., Greenop, R., Pecher , I., and Coffin, R., 2019, Atmosphere-Ocean CO_2 Exchange Across the Last Deglaciation from the Boron Isotope Proxy: Paleoc. Paleoclim., v. 34, no. 10, p. 1650-1670.

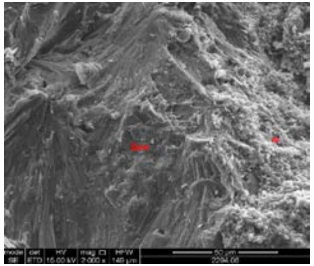
Ronge, T. A., Tiedemann, R., Lamy, F., Kohler, P., Alloway, B. V., De Pol-Holz, R., Pahnke, K., Southon, J., and Wacker, L., 2016, Radiocarbon constraints on the extent and evolution of the South Pacific glacial carbon pool: : Nat. Commun., v. 7, p. 11487.

See also: EGU2020-4241: Storage/Release of Geologic Carbon Influenced Pleistocene Glacial/Interglacial Atmospheric pCO_2 Cycles by Lowell Stott et al.

The Case for CO_2: Dawsonite

Eocene Amplitude 3: 2280 - 2378m

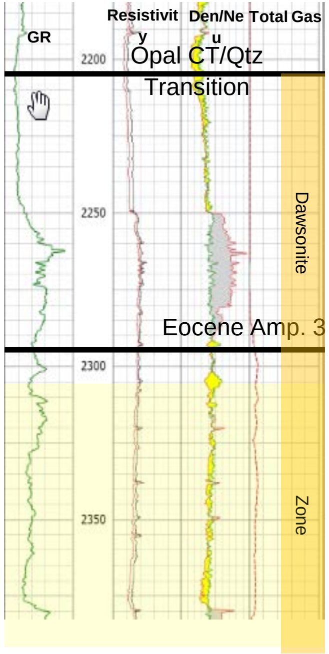




Avg. SWC Porosity: 32%
Avg. Kair (2200psi): 0.40md

XRD Mineralogy:
55% Quartz
1% K-Feldspar
3% Siderite
3% Pyrite
28% Clays (Kaolinite, Illite, Mica)

9% Dawsonite
$NaAl(OH)_2(CO)_3$



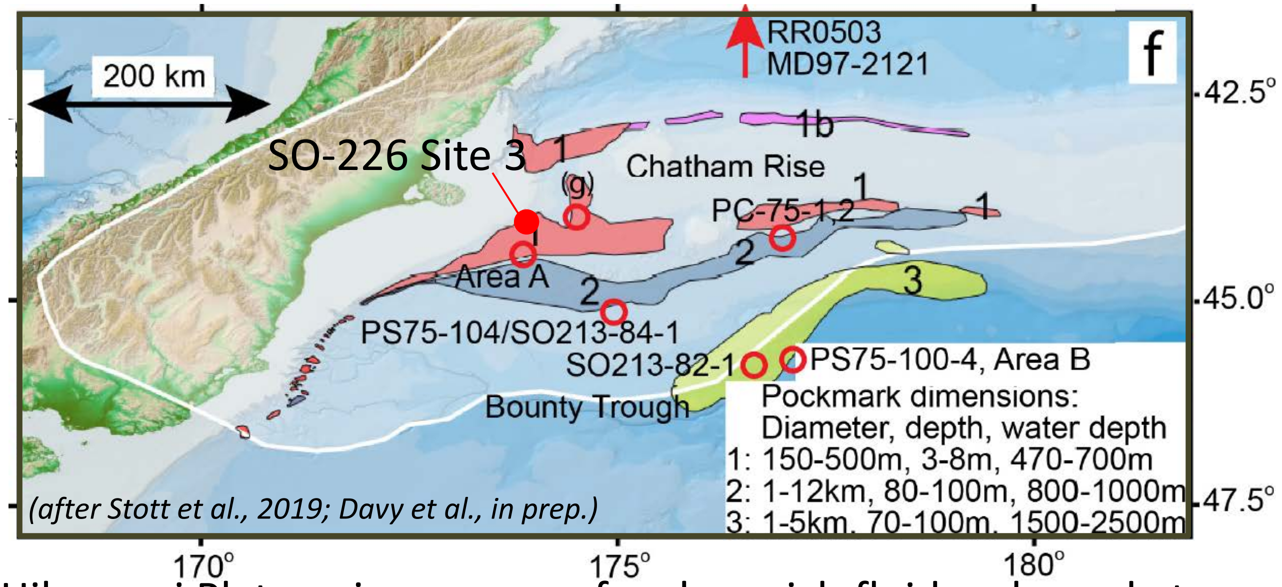
Dawsonite rare carbonate that requires supply of CO_2 over long time span

Courtesy Anadarko Petroleum Corp. (Blanke et al., 2015)

Blanke, S., Caravel-1: Lessons Learned in the Deepwater Canterbury Basin, *in* Proceedings International Conference and Exhibition, Melbourne, 2015, Society of Exploration Geophysicists and American Association of Petroleum Geologists, p. 519.

Pockmarks and the Hikurangi Plateau?

Extent of subducted Hikurangi Plateau (white-shaded area) compared to pockmark occurrences (numbers, indicating different types of pockmarks)



Subducted limestone sequences on Hikurangi Plateau could be a carbon source.

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)

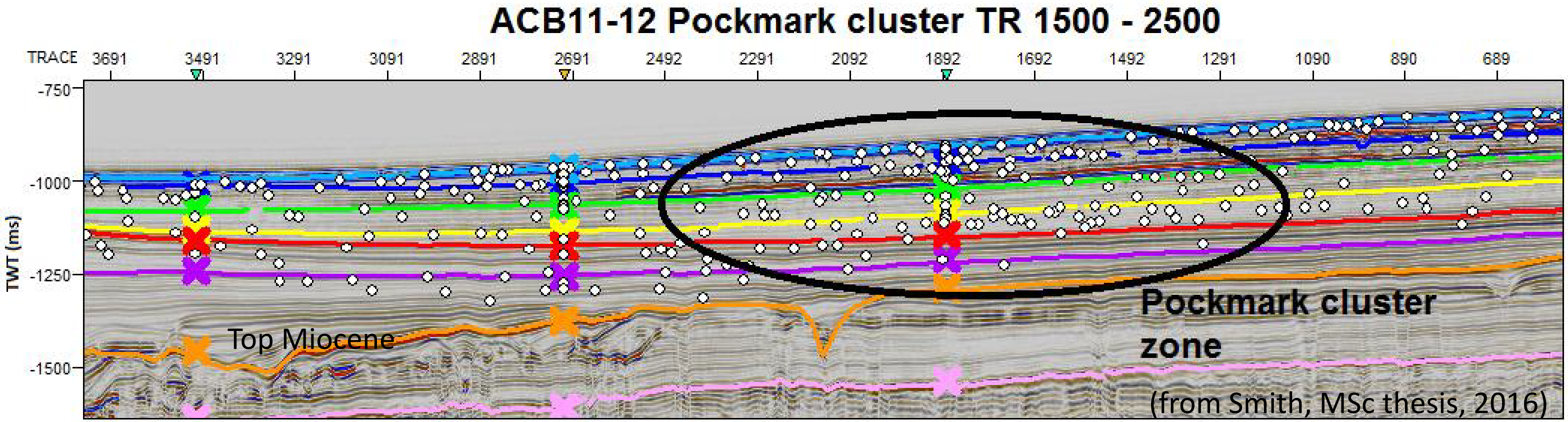
Key question: What is the “valve” mechanism modulating carbon release?

Stott, L., Davy, B., Shao, J., Coffin, R., Pecher , I., Neil, H. L. R., P., and Blanke, S., 2019, CO_2 Release from Pockmarks on the Chatham Rise-Bounty Trough at the Glacial Termination: Paleoc. Paleoclim., v. 34, no. 11, p. 1726-1743.

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)



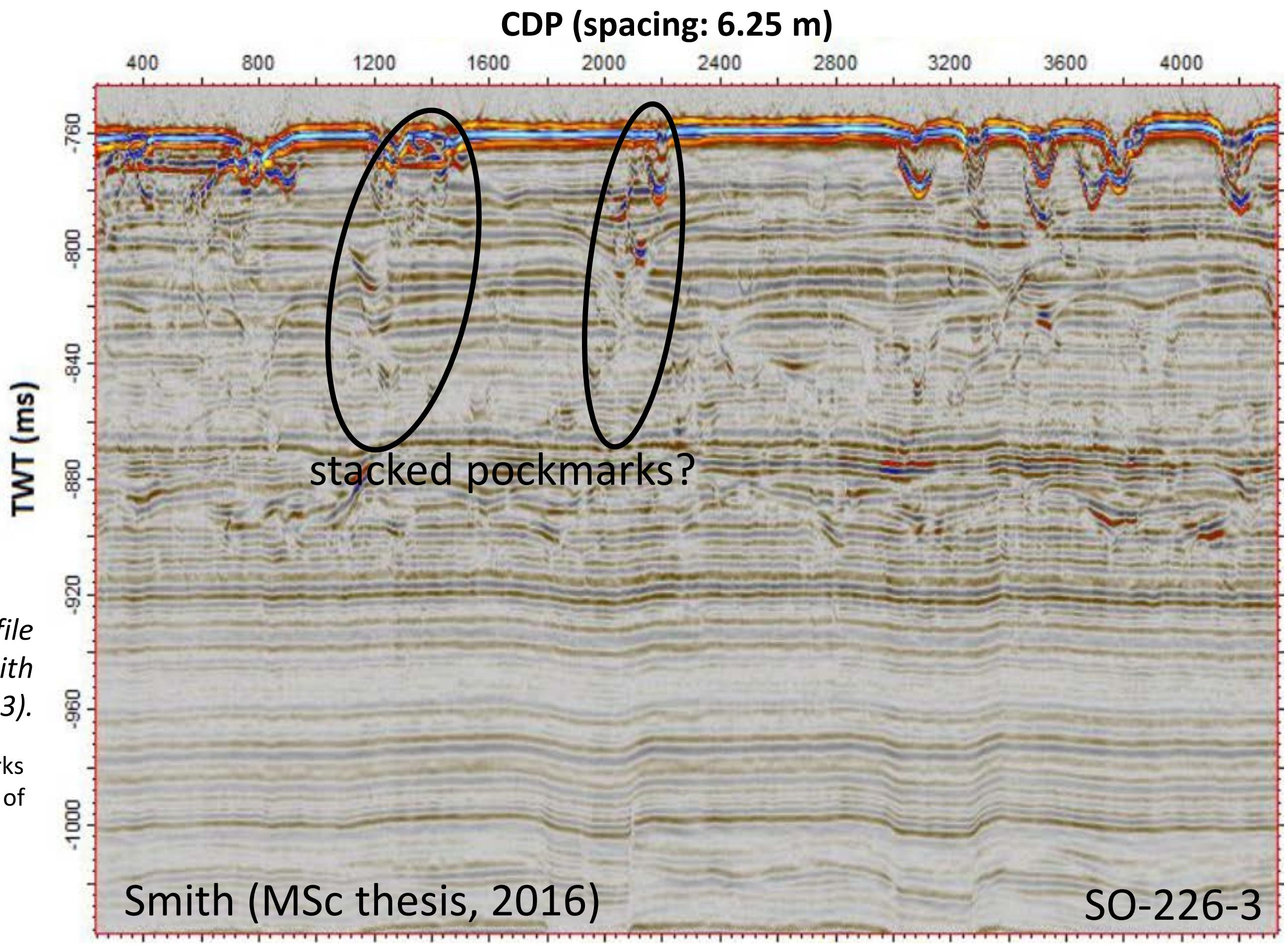
Left: Seismic profile collected for hydrocarbon exploration near SO-226 Site 3. Pockmarks only occur above the Top Miocene. There may also be some pockmark clusters which still need to be confirmed statistically (not discussed here). From Smith (2016)

Naish, T. R., and Wilson, G. S., 2009, Constraints on the amplitude of Mid-Pliocene (3.6–2.4 Ma) eustatic sea-level fluctuations from the New Zealand shallow-marine sediment record: Phil. Trans. R. Soc. A, v. 367, p. 169-187.
Smith, A. E., 2016, Seismic studies of paleo-pockmarks on the Chatham Rise, New Zealand (MSc: University of Auckland), 84 pp.
Prestage, A., Pecher, I. A., Campbell, K. A., and Davy, B., in revision, Plio-Pleistocene Pockmark Activity on the Chatham Rise, New Zealand: Evidence from Seismic Data: Mar. Geol.

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).



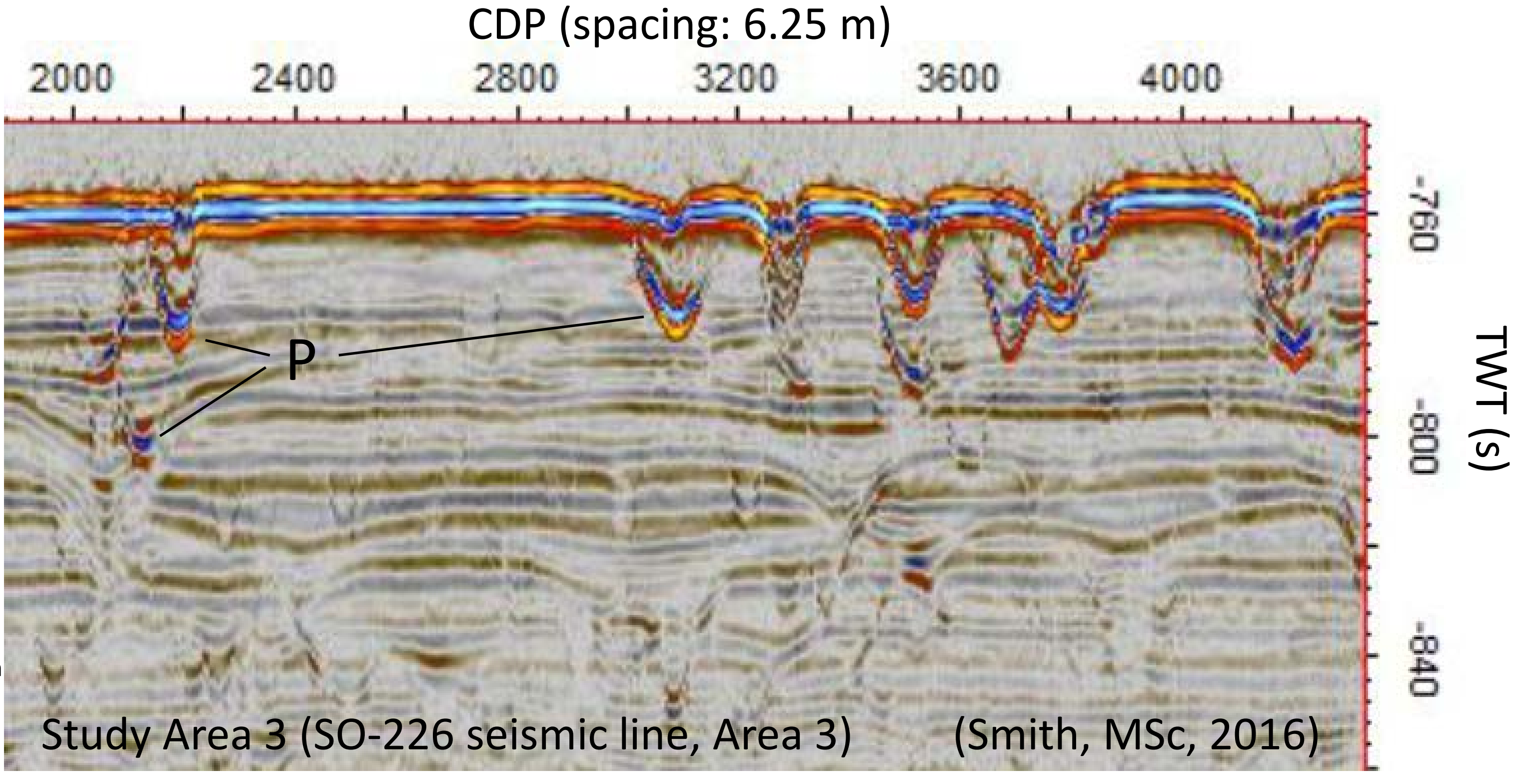
Smith, A. E., 2016, Seismic studies of paleo-pockmarks on the Chatham Rise, New Zealand, MSc: University of Auckland, 84 pp.
Bialas, J., Klaucke, I., and Mögeltönder, J., 2013, FS Sonne Fahrtbericht / Cruise Report SO 226 CHRIMP, Volume 7: Kiel, GEOMAR, p. 124.

High-velocity/density material?

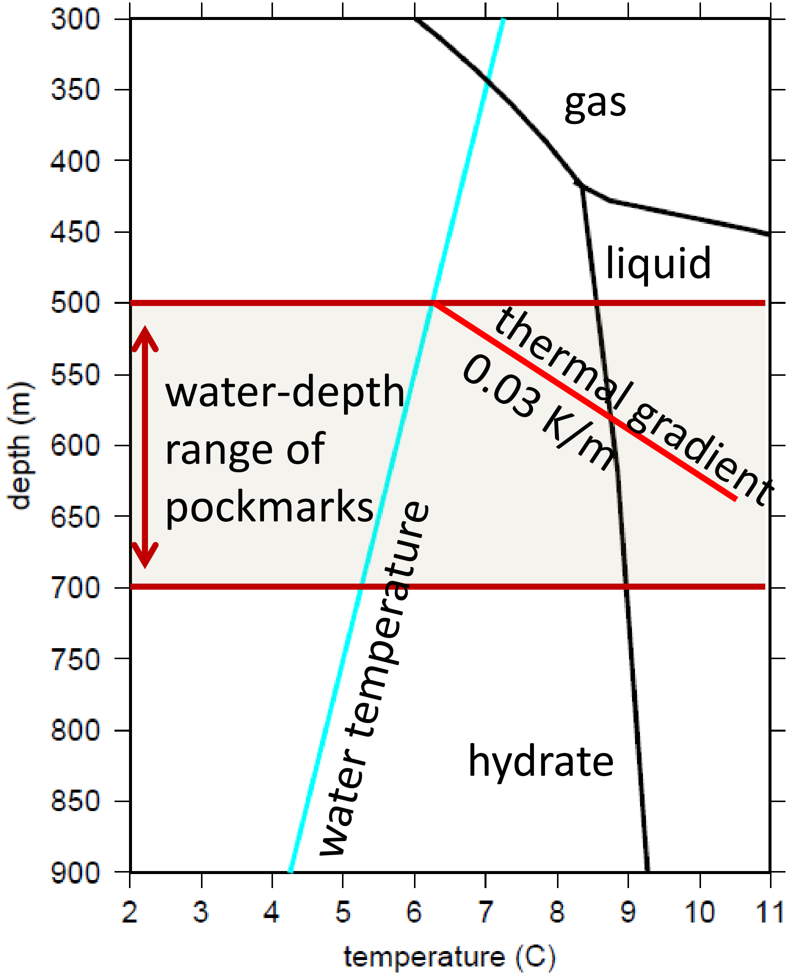
Positive-polarity reflections → authigenic processes?

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?

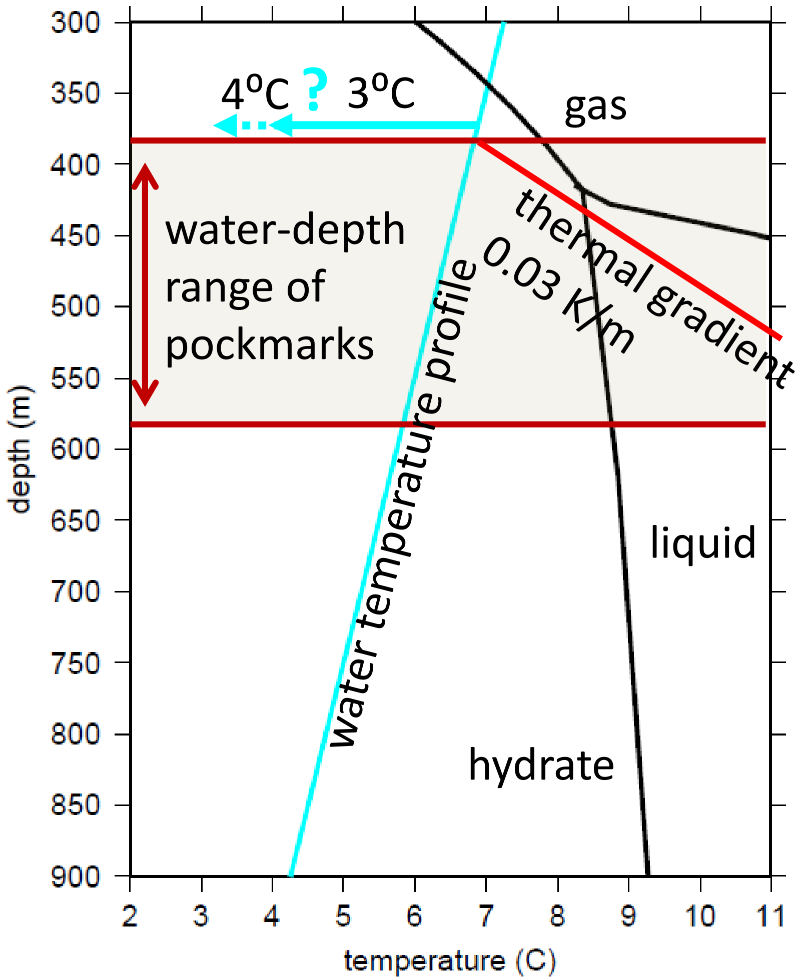
- Modern setting: Pockmarks well within CO_2 hydrate stability field
- If pockmarks caused by dissociation of hydrates due to depressurization, difficult to explain upper limit of pockmarks

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

Water temperatures after Chiswell (2002)

Chiswell, S., 2002, Temperature and salinity mean and variability within the Subtropical Front over the Chatham Rise, New Zealand: N. Z. J. Mar. Freshw. Res., v. 36, p. 281-298.

Henrys, S. A., Ellis, S., and Uruski, C., 2003, Conductive heat flow variations from bottom-simulating reflectors on the Hikurangi margin, New Zealand: Geophys. Res. Lett., v. 30, p. 1065.



Shallow pockmarks: Link to CO_2 hydrates?

- Glacial setting but assuming unchanged water temperature profile. A 2‰ 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:

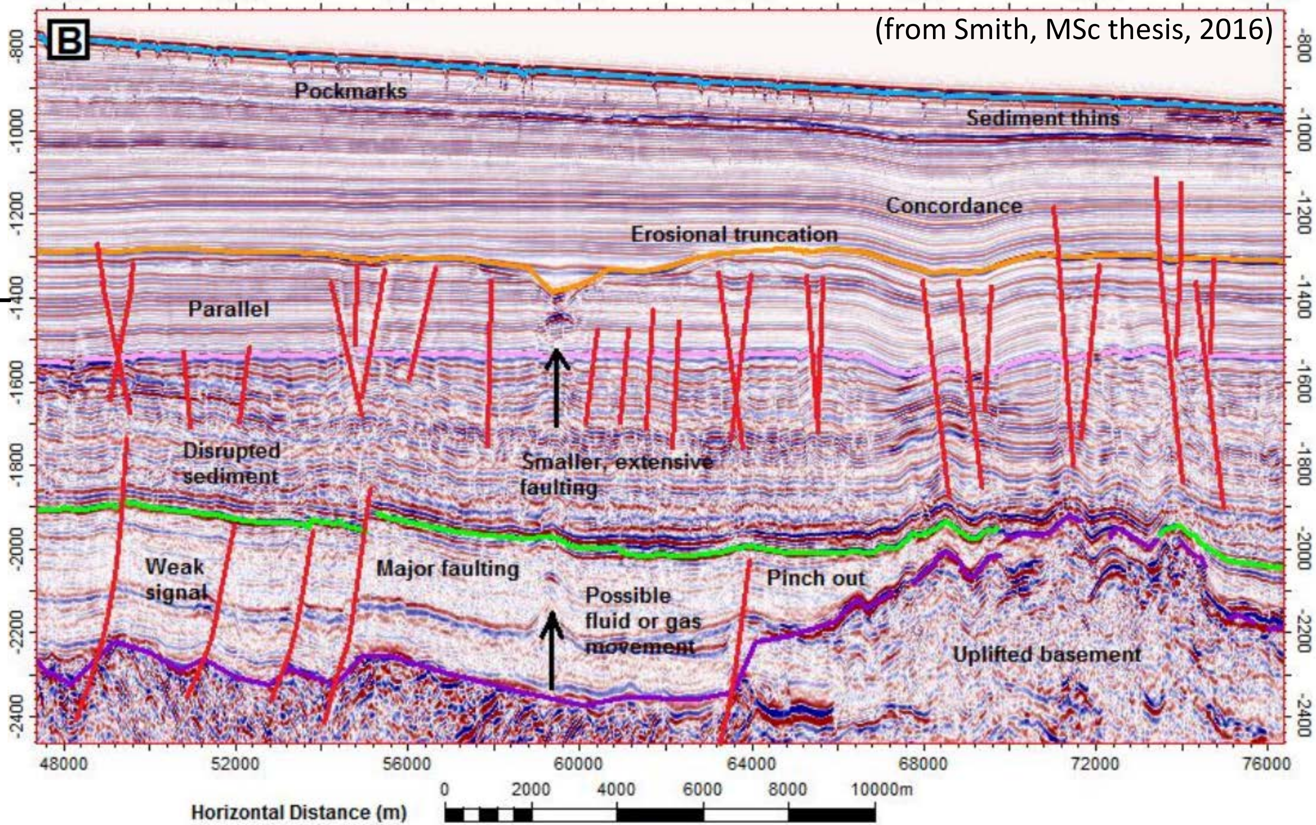
- Link between pockmarks and sealevel fluctuations.
- Possible link between pockmarks and Hikurangi Plateau.
- Evidence for CO_2 flux.
- Need to put all these pieces together.
- Focus of this study on “valve” mechanism.

Acknowledgments

Funding: New Zealand "Marsden" Fund (UOA1022), German Science Foundation, U.S. Office of Naval Research – Global, and others.

Captain and crew R/V Sonne SO-226.

Thank You



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