Voluminous crustal degassing and immiscible sulfide genesis caused by magma-shale interaction in Large Igneous Provinces

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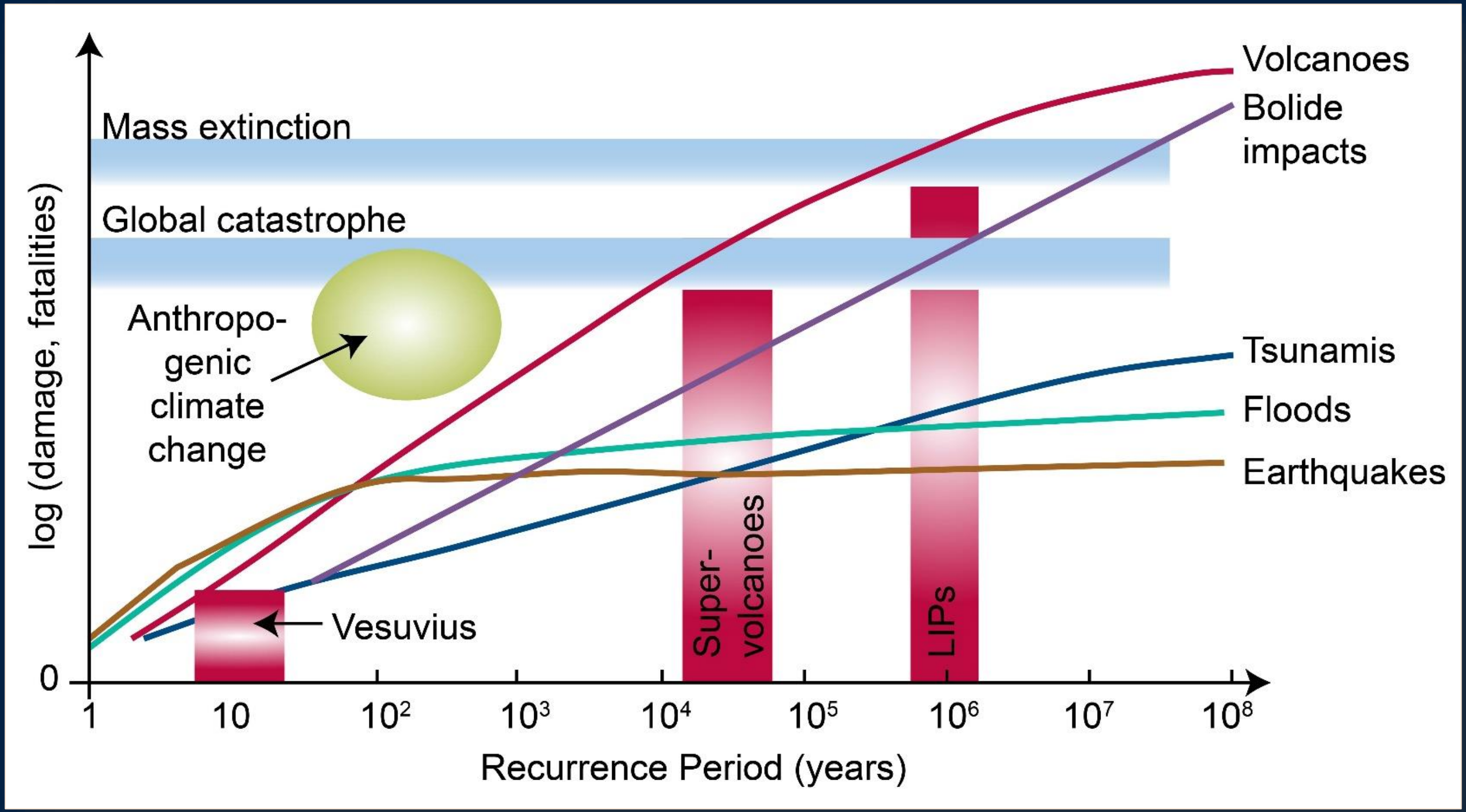
A deadly kiss from the LIPs



Red bars show the frequency of i) volcanic events with magnitudes similar to Vesuvius (79 AD), ii) super-volcanoes such as Toba (75 ka), and iii) LIP eruptions such as the Deccan Traps (65 Ma). Anthropogenic climate change can also produce global impacts. Thus, understanding the mechanisms and consequences of geologic global catastrophes (LIPs) is of utmost relevance for today's planet.

Figure modified after Plag et al. (2015).

- **Hypotheses explaining lethal LIPs:**
  - LIP + bolide impact
  - Volcanogenic volatiles
  - Methane hydrate dissociation (“runaway greenhouse” or “clathrate gun”)

- **Relatively recent advances (ca. last decade):**
  - Baking of sedimentary basin rocks by high-level LIP intrusions
  - Emission of organic and inorganic CO_2, S, ozone-destroying halogens

Geology

Climate changes caused by degassing of sediments during the emplacement of large igneous provinces

Clément Ganino and Nicholas T. Arndt

Geology 2009;37;323-326
doi: 10.1130/G25325A.1

Earth and Planetary Science Letters 277 (2009) 490–500
Contents lists available at ScienceDirect
ELSEVIER
Earth and Planetary Science Letters
journal homepage: www.elsevier.com/locate/epsl

Siberian gas venting and the end-Permian environmental crisis

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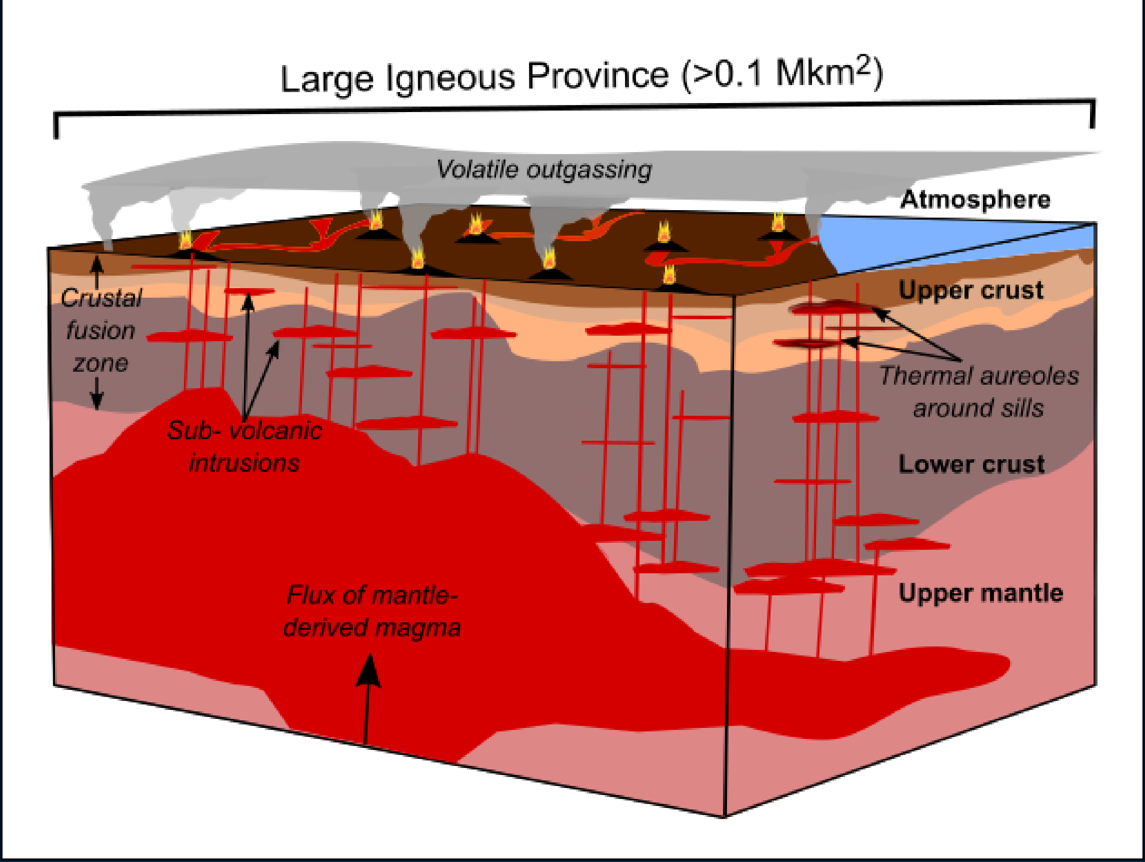
Emissions from baking of sedimentary basin rocks?

LIPs and their intrusive roots

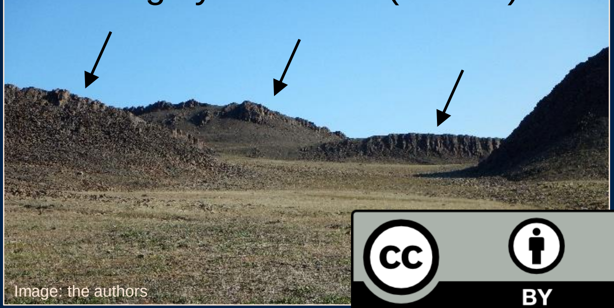
- LIPs are vast volcanic provinces (“traps”)
- Eroded LIPs have their plumbing systems exposed
- High-level intrusions (sills and dykes - magma feeder systems)
- Thermal aureoles often form around sills



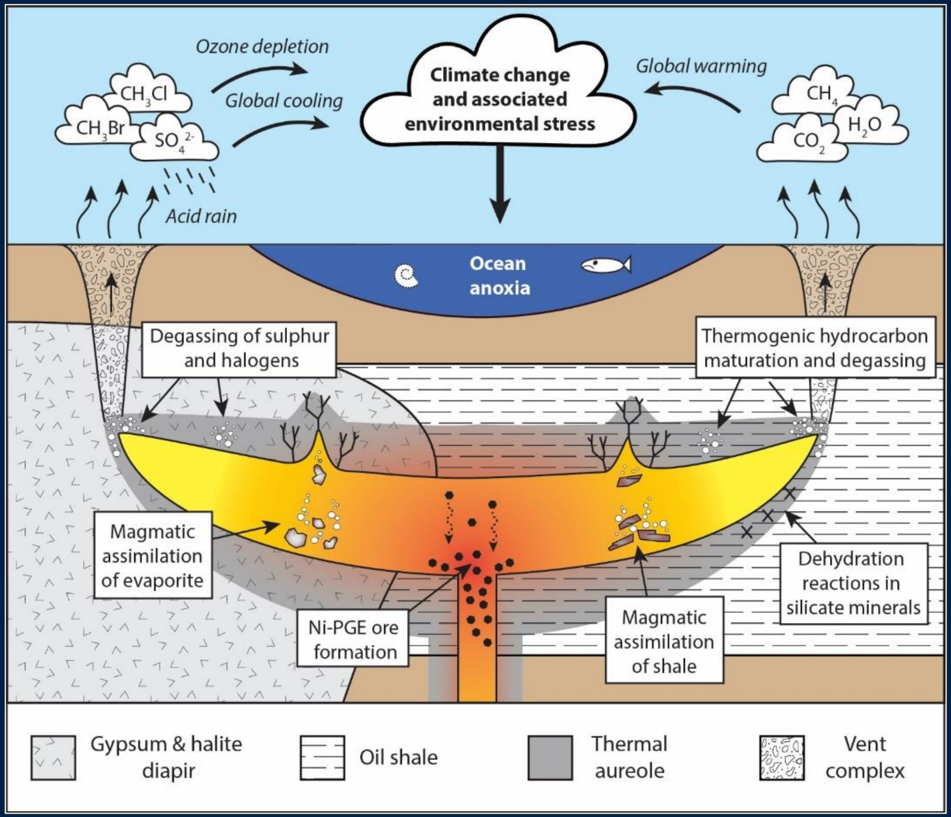
Traps: flood lavas (Deccan)

Plumbing system: sills (HALIP)

Plumbing system: sills (HALIP)



The role of sedimentary basins



- **Role of sedimentary basins:**
  - Siberian LIP, c. 20 000 Gt of magmatic CO_2
  - But up to 114 000 Gt metamorphic CO_2 released from basin sediments

  [Svensen et al. 2009]

- Additional source of LIP-related gases can also explain neg. $\delta^{13}C$ excurions assoc. with many extinctions

- The role of sedimentary basins is likely very important in controlling the severity of environmental crises assoc. with LIPs
- **How exactly do these sedimentary rocks respond to magmatic heating events during LIP emplacement?**

CH_4

CO

Toxic metals

H_2O

CO_2

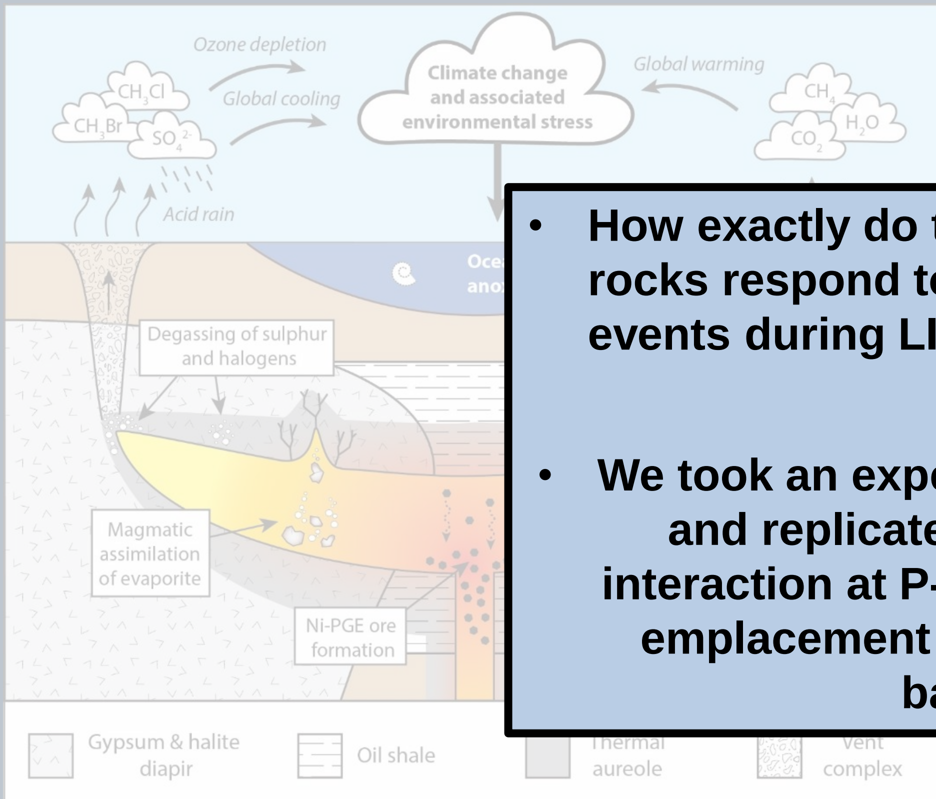
SOx

Halogens (F, Cl, Br)

The role of sedimentary basins

- **How exactly do these sedimentary rocks respond to magmatic heating events during LIP emplacement?**

- **We took an experimental approach and replicated magma-shale interaction at P-T conditions of sill emplacement into sedimentary basins**



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  - …t al. 2009]

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- **How exactly do these sedimentary rocks respond to magmatic heating events during LIP emplacement?**

Our case study: the High Arctic LIP

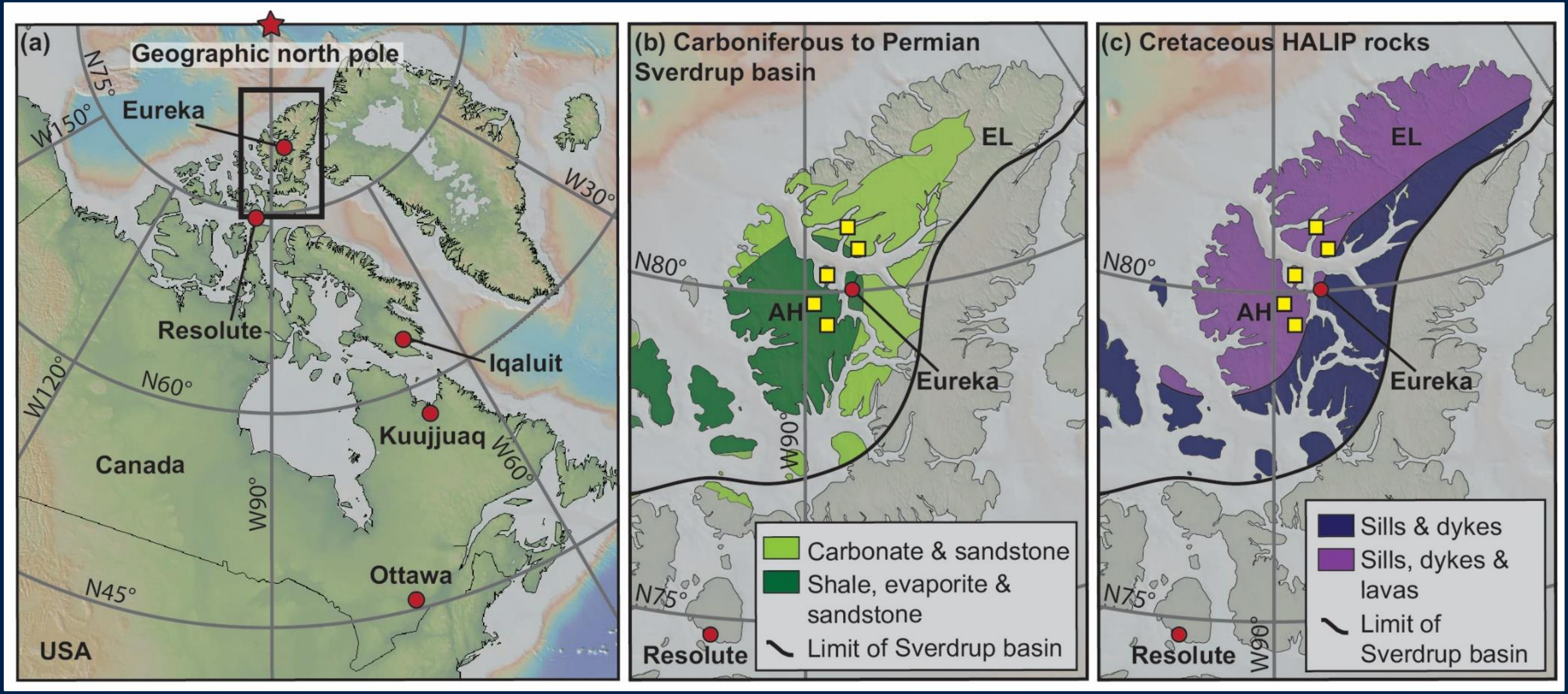
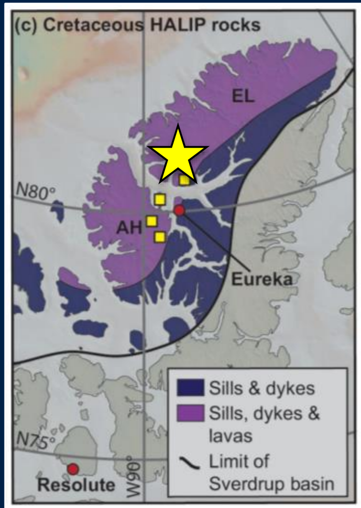


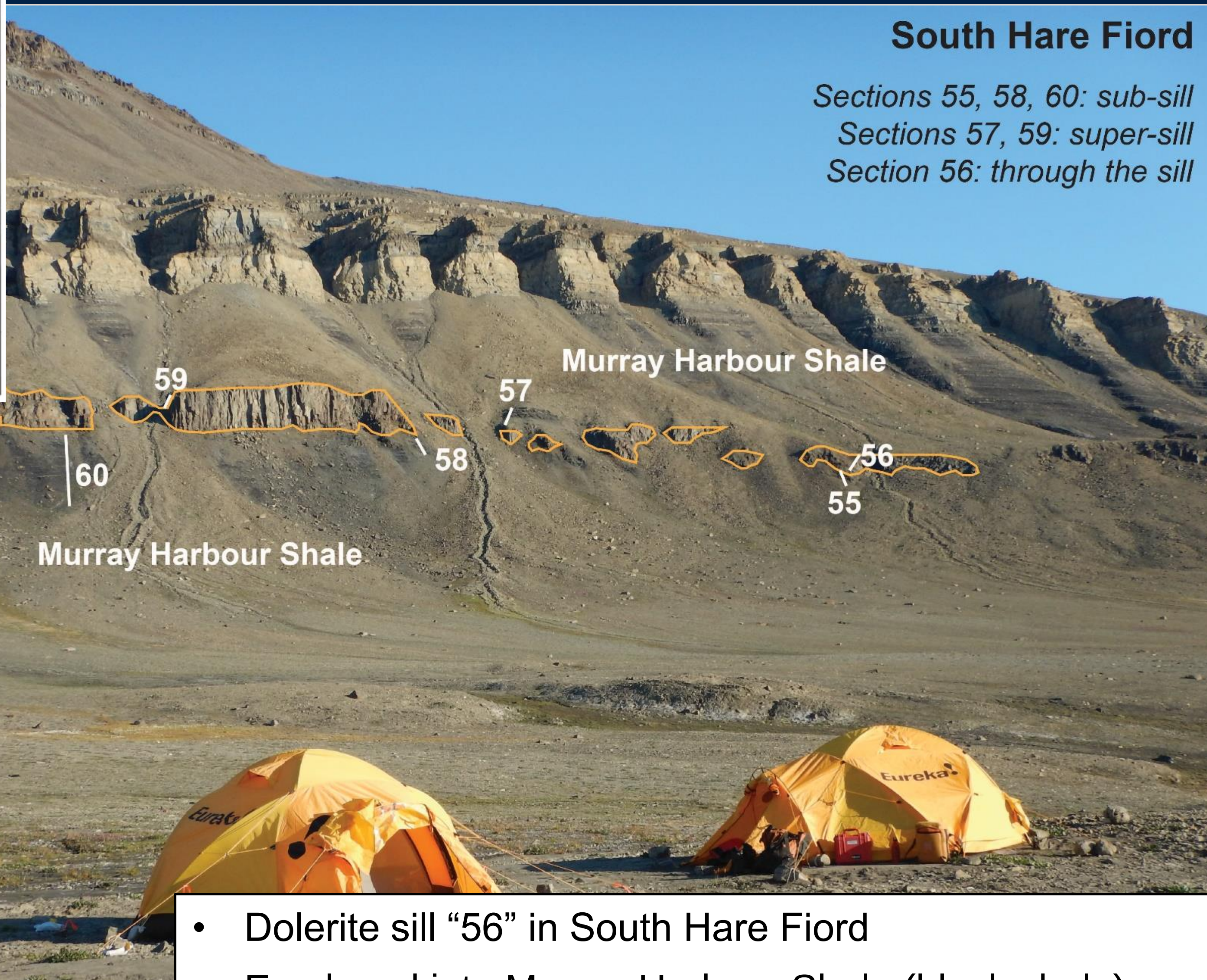
Image: the authors

- Mesozoic continental LIP
- Intrusions at 130 to 120 Ma
- Mainly tholeiitic magmatism
- Host rocks for Canadian HALIP: Carboniferous to late Cretaceous Sverdrup Sedimentary Basin
- Sverdrup Basin in-fill: shale, carbonate, evaporite, sandstone

Maps: the authors (Deegan et al., 2016; Geology Today)

Key locality: South Hare Fiord

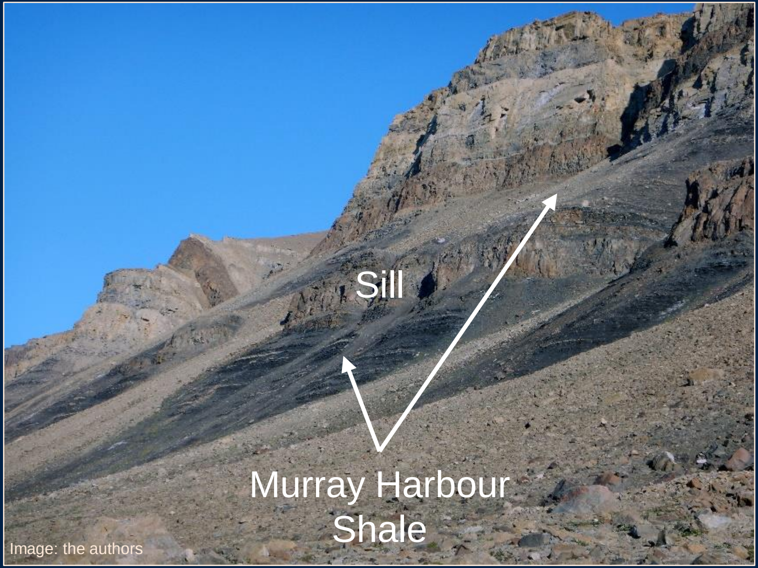


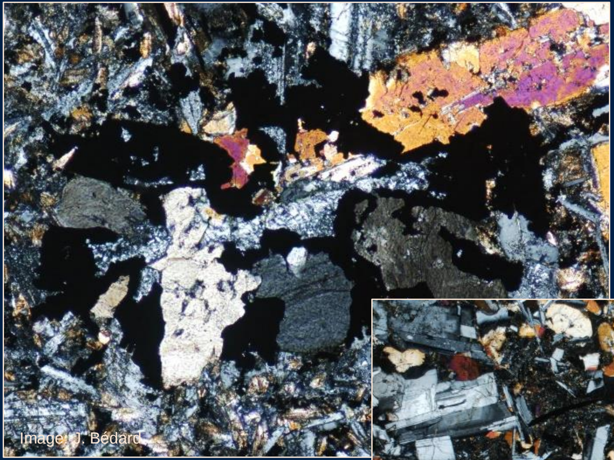


- Dolerite sill “56” in South Hare Fiord
- Emplaced into Murray Harbour Shale (black shale)
- Carbonate-rich silty layers in the black shale too

Key locality: South Hare Fiord

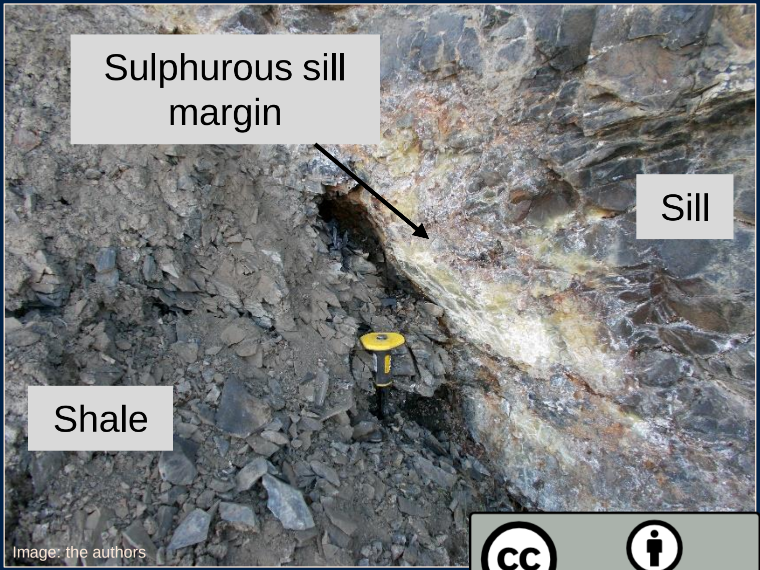
- Sills generally separated by 10s to 100s m of country rock
- Some have sulphurous margins
- Murray Harbour Shale is particularly rich in organic carbon
- Source rock for hydrocarbons



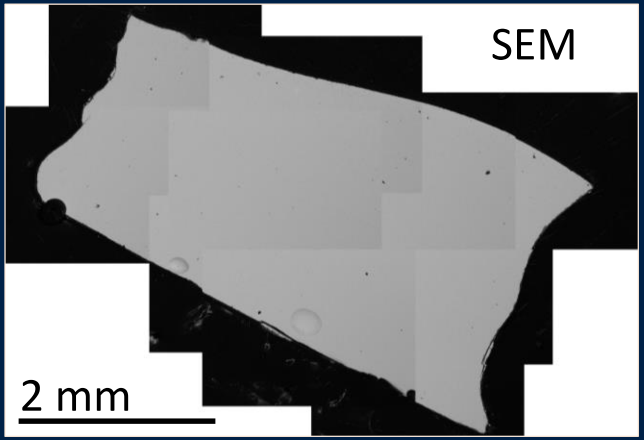


Top: thin section view of contact margin of sill 56 showing sulphide intergrowing with pl and cpx.

Bottom: thin section view of sample 120 cm into sill 56. Slightly coarser groundmass.



Experiment time!
Starting material: fused dolerite rock powder from a relatively “pristine” HALIP sill

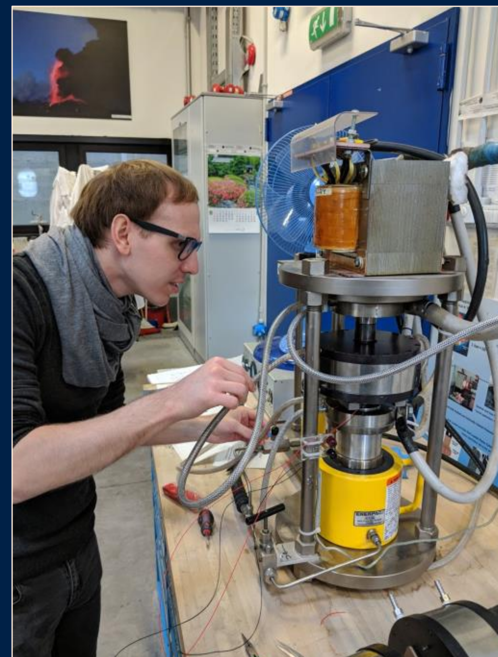


Result: Perfect glass for use in experiments

Images: F. Deegan & H. Geiger

Carrying out the experiments employing a "quick press" piston cylinder at INGV Rome

1. Load capsules & build assembly

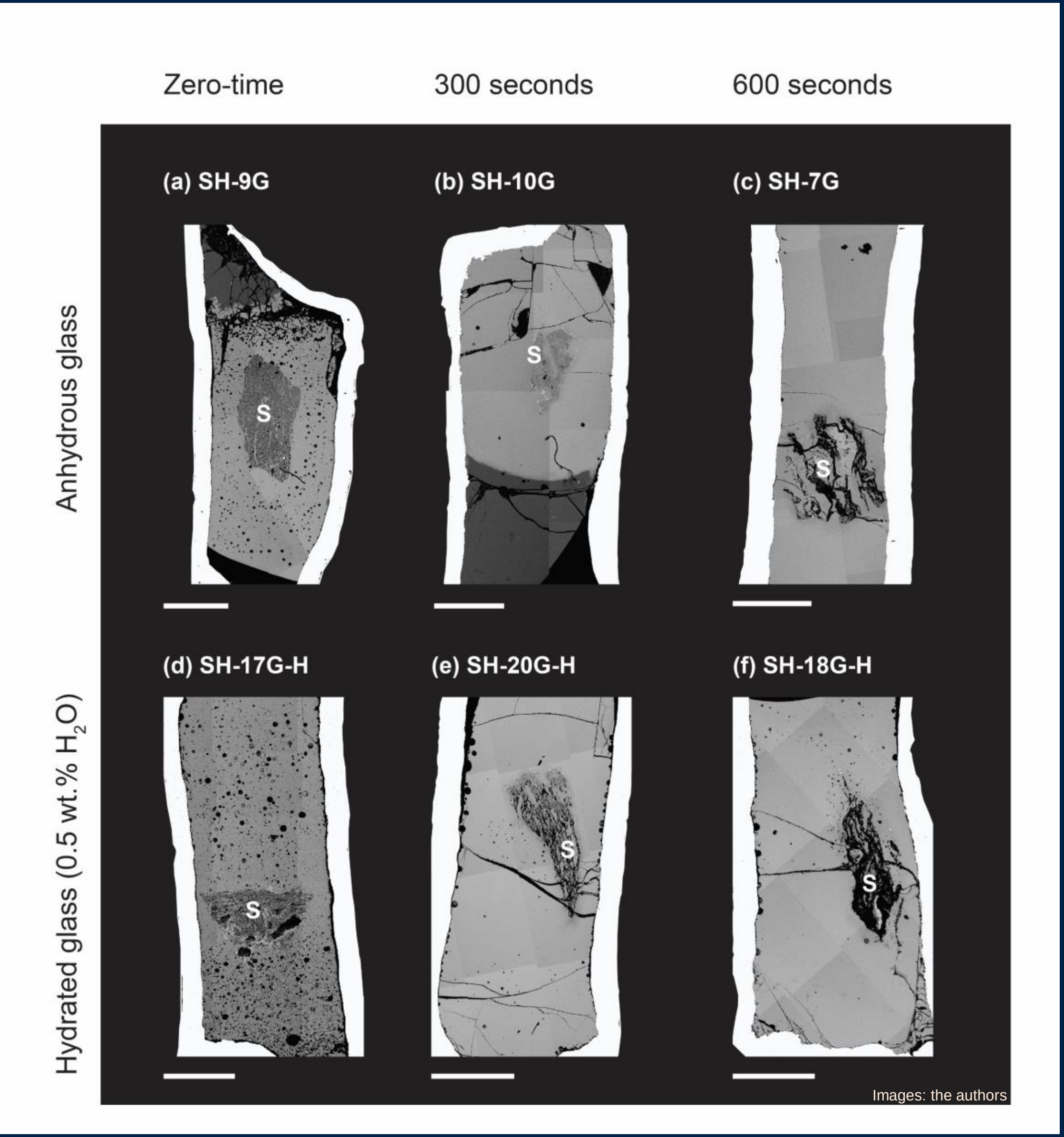


2. Construct & run experiment

3. Mount & polish capsules for SEM

Exp-conditions:
T = 1200°C
P = 150 MPa
Dwell time = 0 s, 300 s, 600 s
H_2O = nom. anhydrous and 0.5 wt.%

A sneak peek of the experimental results…



Results of shale assimilation experiments. Scanning Electron Microscopy (SEM) mosaic images of experiments that were conducted utilizing both anhydrous diabase glass (a to c) and hydrated diabase glass (d to f) as the magmatic starting material. Dwell time was set at 0, 300 and 600 s. Zero-time runs (a and d) showcase intense syn-magmatic degassing of shale. Runs held for 300 s (b and e) show abundant sulfide globules at the magma-shale interface (note that zero-time runs also contain sulfide, but as smaller, disseminated globules). Runs held for 600 s (c and f) show a large degree of melt homogenization. Scale bars are 1 mm; S = magma-shale reaction site.

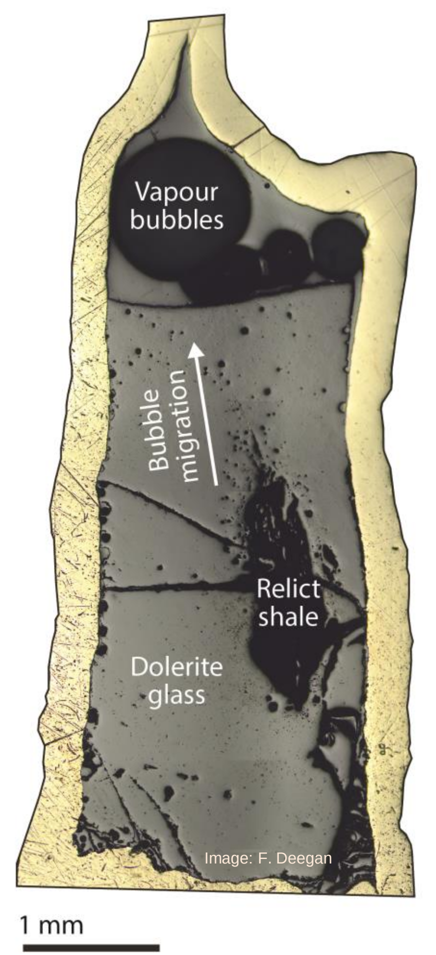
Initial observations

Magma-shale interaction results in:

- Syn-magmatic production of H-C-S volatiles
- Strongly reducing environment, which leads to segregation of sulfide melt
- Local Ca-S enriched melt at reaction site
- Initially immiscible silicate melts, which homogenise with time
- Sulfide precipitation at the magma-shale interface

Implications for LIPs:

- We can empirically demonstrate that short time-scale generation of sedimentary volatiles can add dramatically to the volatile load of LIPs
- This process may, in turn, affect the environmental damage caused by LIPs …
- …and is intrinsically linked to metalogenesis at LIPs



Above: 600 s experiment, reflected light image

Thanks for your interest at ShareEGU20!

This study is in preparation for publication so I have only shown a selection of results.

Please contact me if you would like to discuss further.

My email address is **frances.deegan@geo.uu.se** or find me on Twitter: **@FMDeegan**

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