Geological study of water rock interaction at a gabbro boundary in a fossil geothermal system within the Hafnarfjall-Skarðsheiði Central Volcano

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GEORG
GEOTHERMAL RESEARCH GROUP

UNU-GTP

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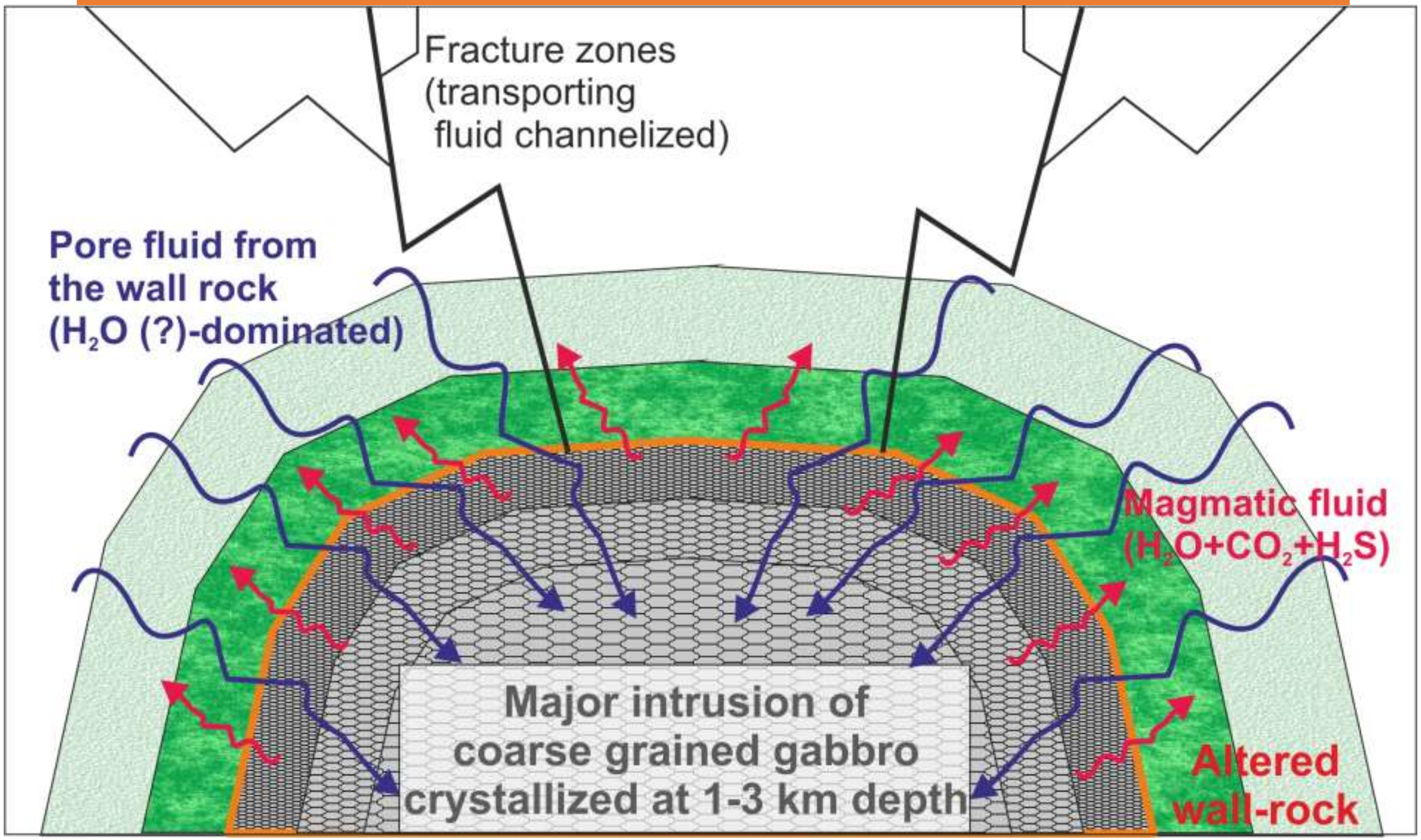
SIGILLUM UNIVERSITATIS ISLANDIAE

Is heat mining from a molten magma body through direct contact between fluid and magma or through conductive thermal gradient.

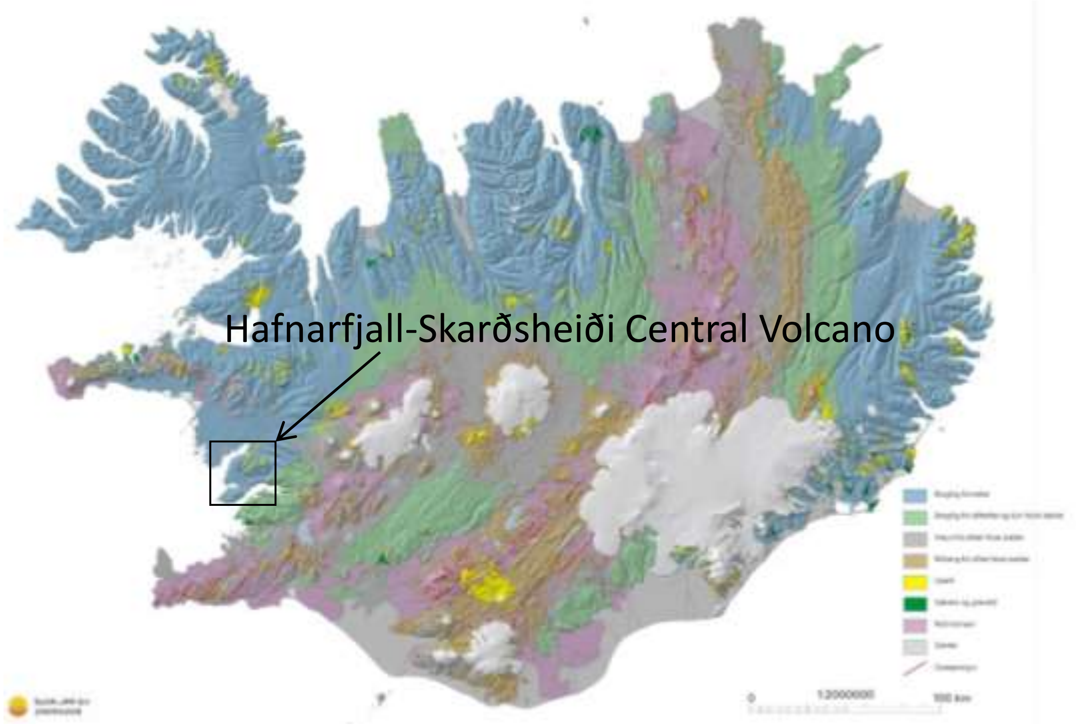


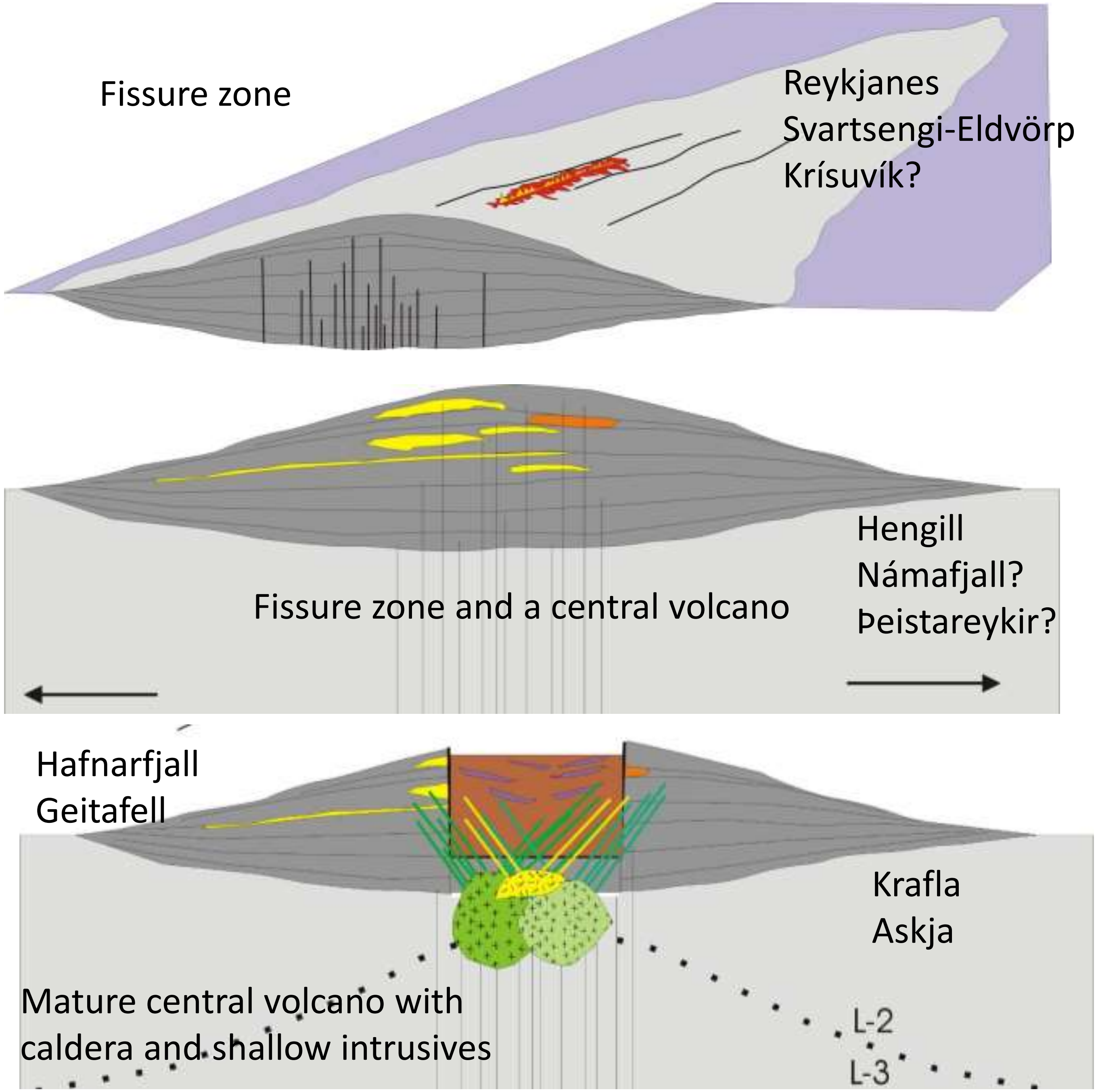
Enikö Bali

Outline

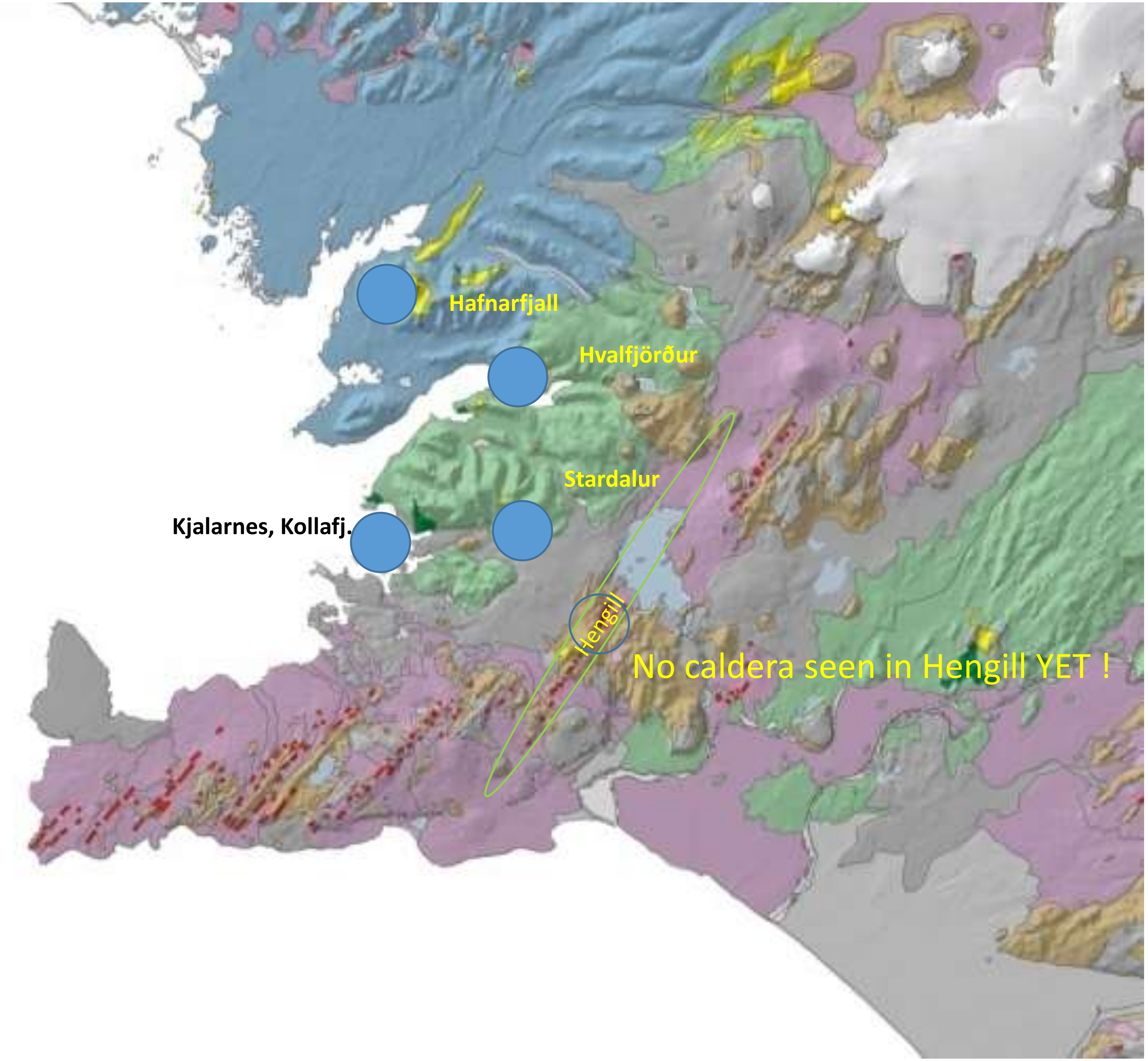
- Geological setting
- Hafnarfjall caldera and filling
- The Hrossatungur Gabbro (HTG)
- The geothermal systems and hydrothermal alteration
- The hornfels
- Comparison of HTG and present High-T systems
- What have we learned?

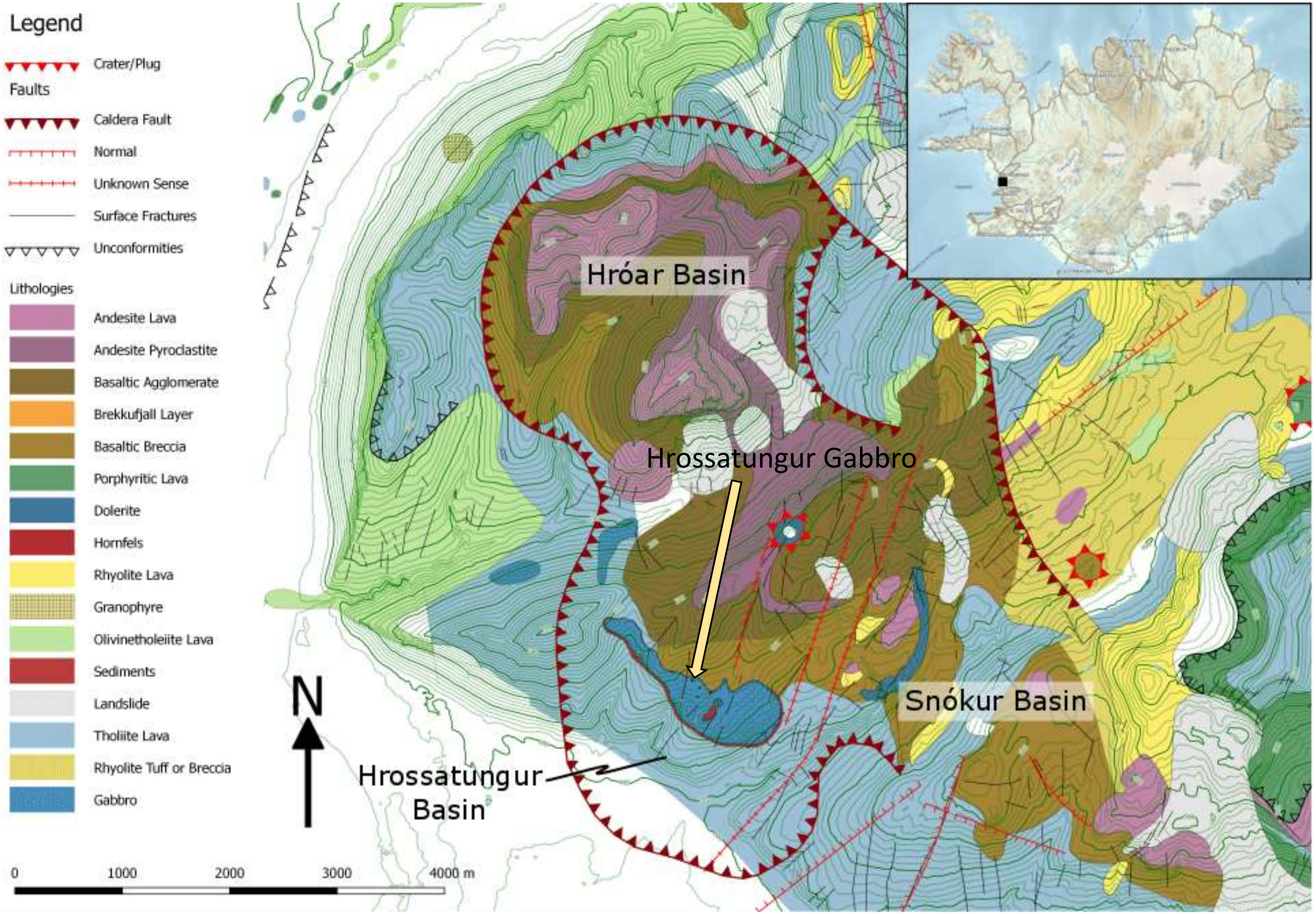
Types of high-T geological conditions



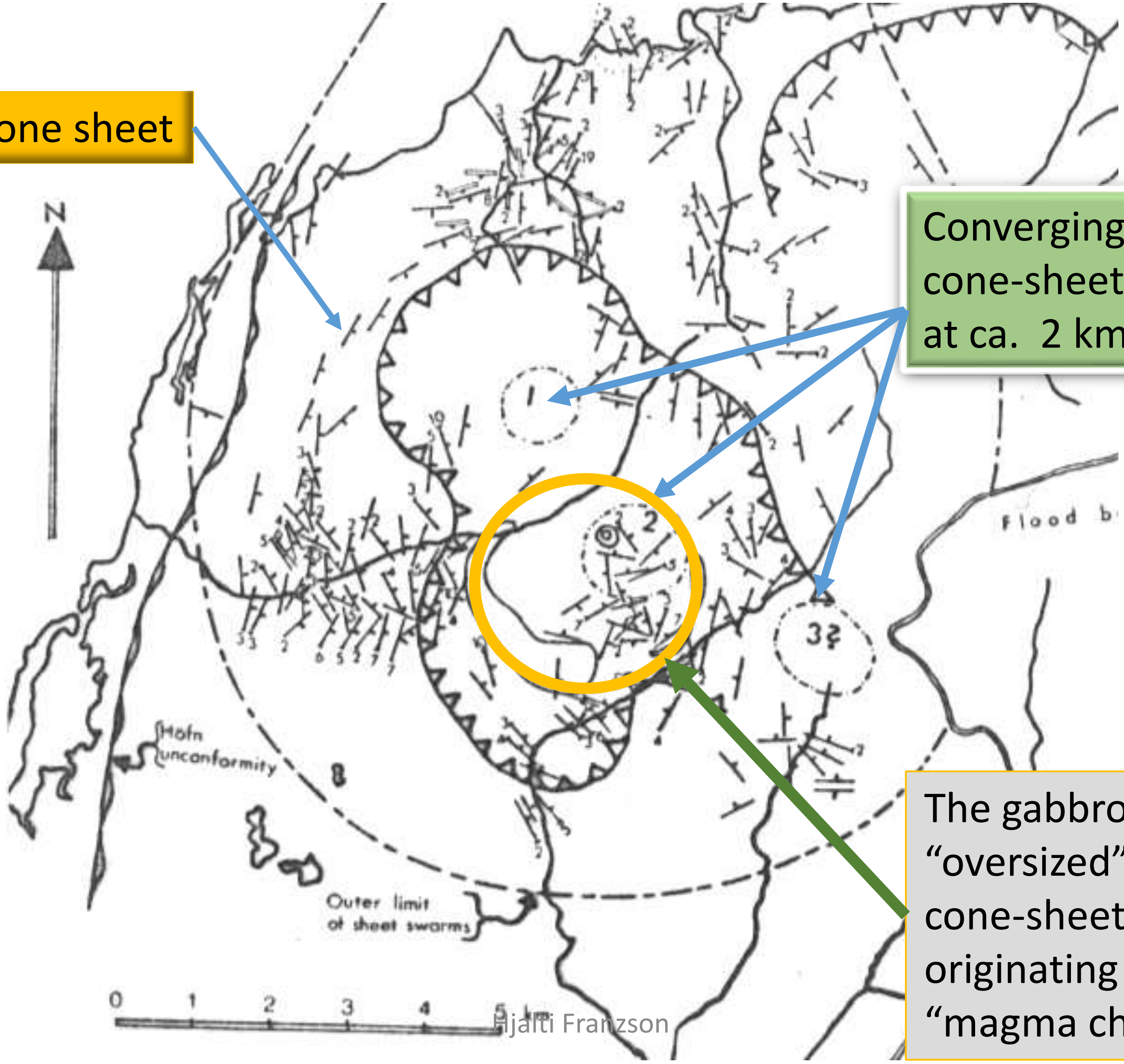


Are heatsources to our high-T systems getting shallower with increasing age of the central volcanoes?


Hafnarfjall
Hvalfjörður
Stardalur
Kjalarnes, Kollafj.
Hengill
No caldera seen in Hengill YET !


Legend
Crater/Plug
Faults
Caldera Fault
Normal
Unknown Sense
Surface Fractures
Unconformities
Lithologies
Andesite Lava
Andesite Pyroclastite
Basaltic Agglomerate
Brekkufjall Layer
Basaltic Breccia
Porphyritic Lava
Dolerite
Hornfels
Rhyolite Lava
Granophyre
Olivinetholeiite Lava
Sediments
Landslide
Tholiite Lava
Rhyolite Tuff or Breccia
Gabbro
N
0
1000
2000
3000
4000 m
Hróar Basin
Hrossatungur Gabbro
Snókur Basin
Hrossatungur Basin

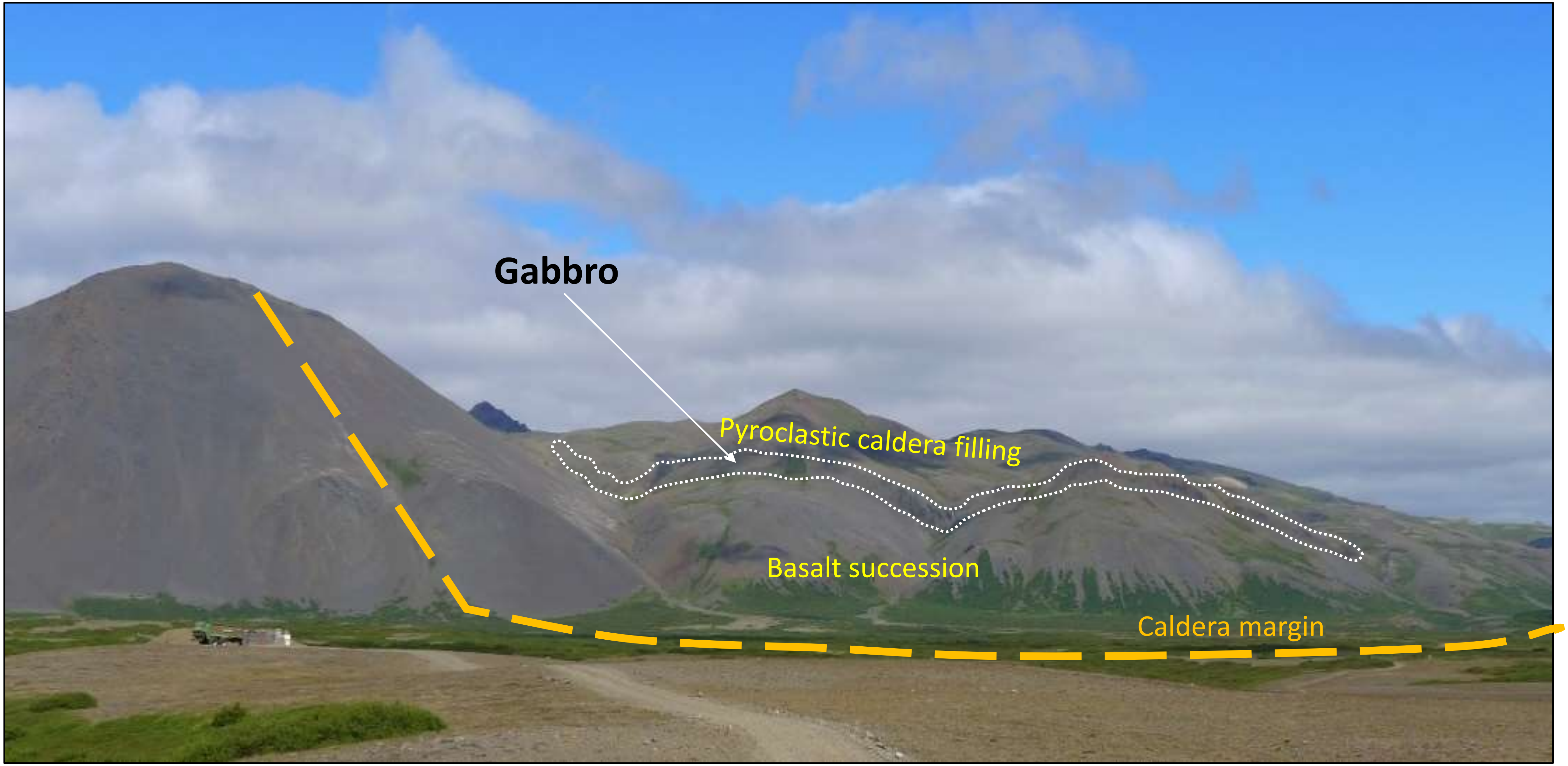
Hafnarfjall conesheet swarms

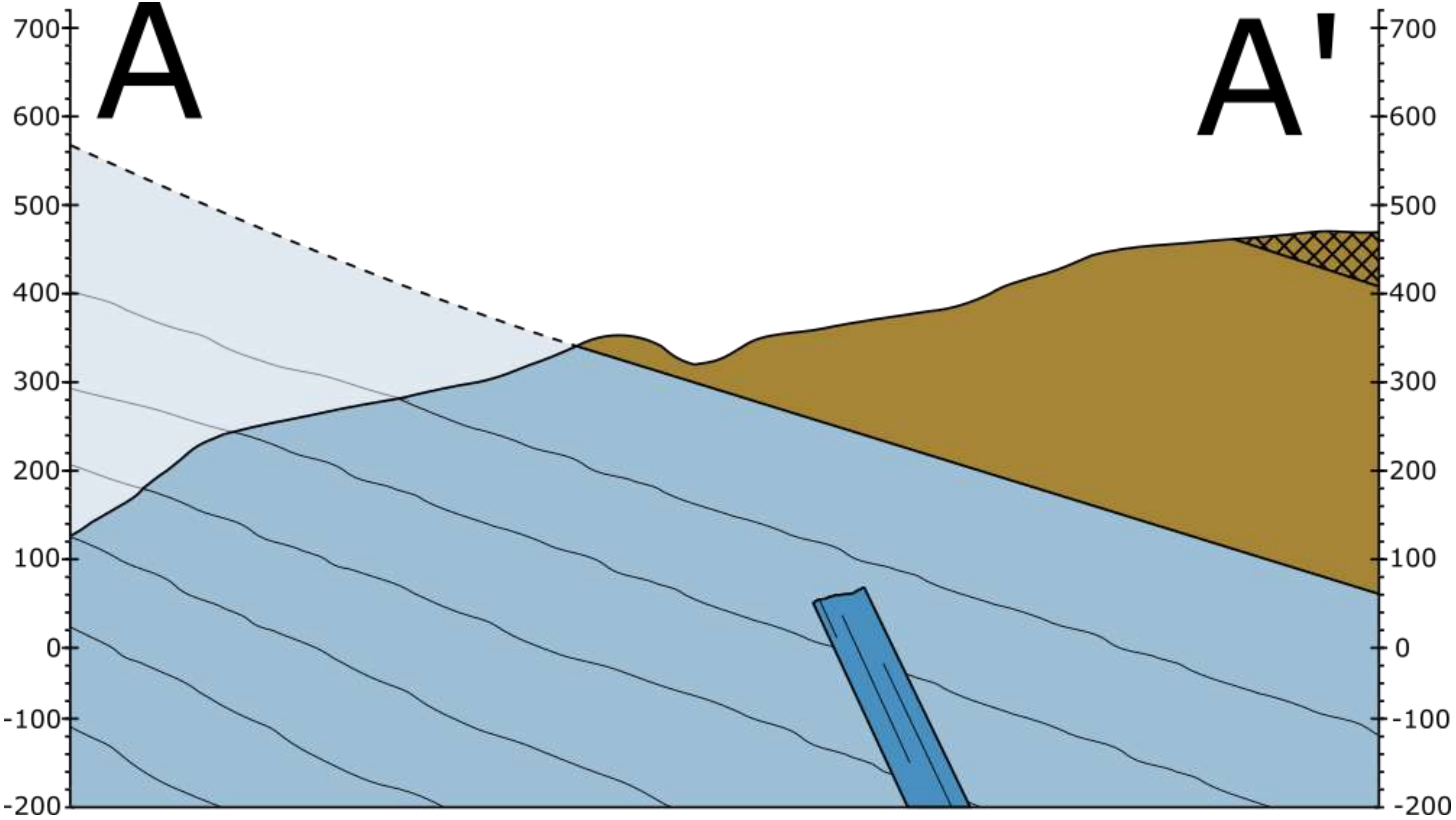


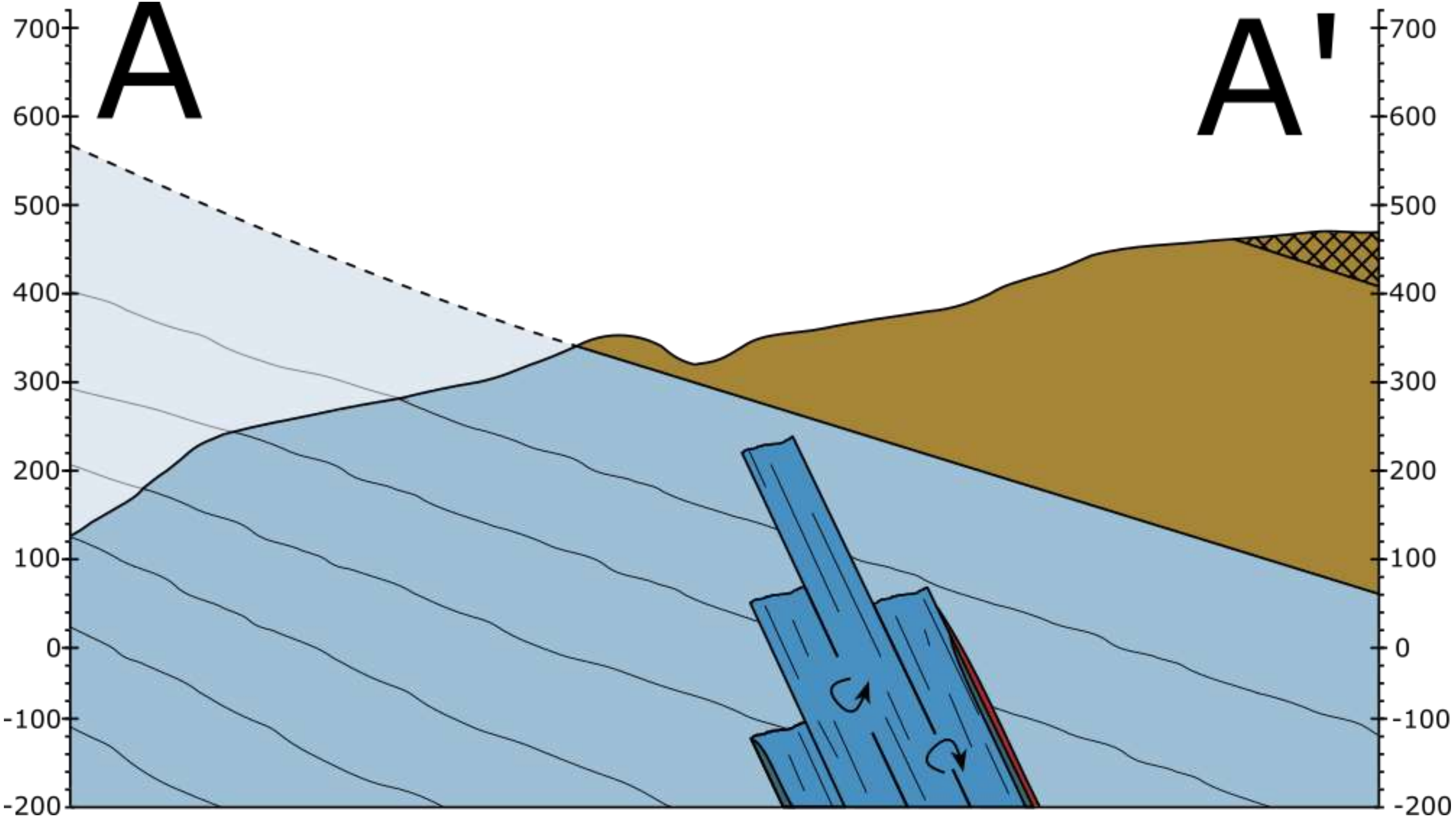
Cone sheet

Converging of cone-sheet swarms at ca. 2 km depth

The gabbro is an “oversized” rapidly injected cone-sheet swarm originating from a deeper “magma chamber”


Gabbro
Pyroclastic caldera filling
Basalt succession
Caldera margin


A
A'
700
600
500
400
300
200
100
0
-100
-200
700
600
500
400
300
200
100
0
-100
-200


A
A'
700
600
500
400
300
200
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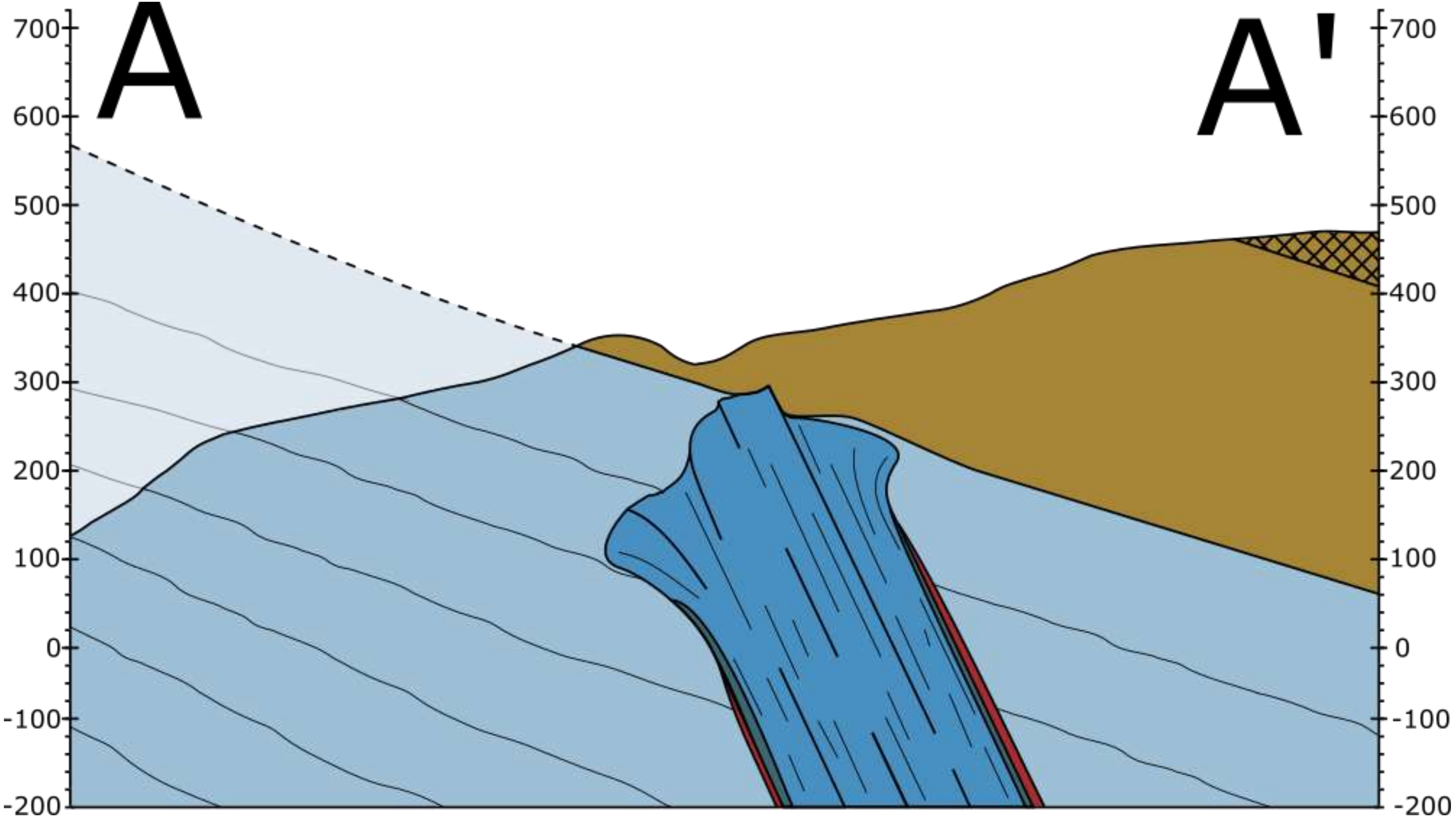
0
-100
-200
700
600
500
400
300
200
100
0
-100
-200


A
A'
700
600
500
400
300
200
100
0
-100
-200
700
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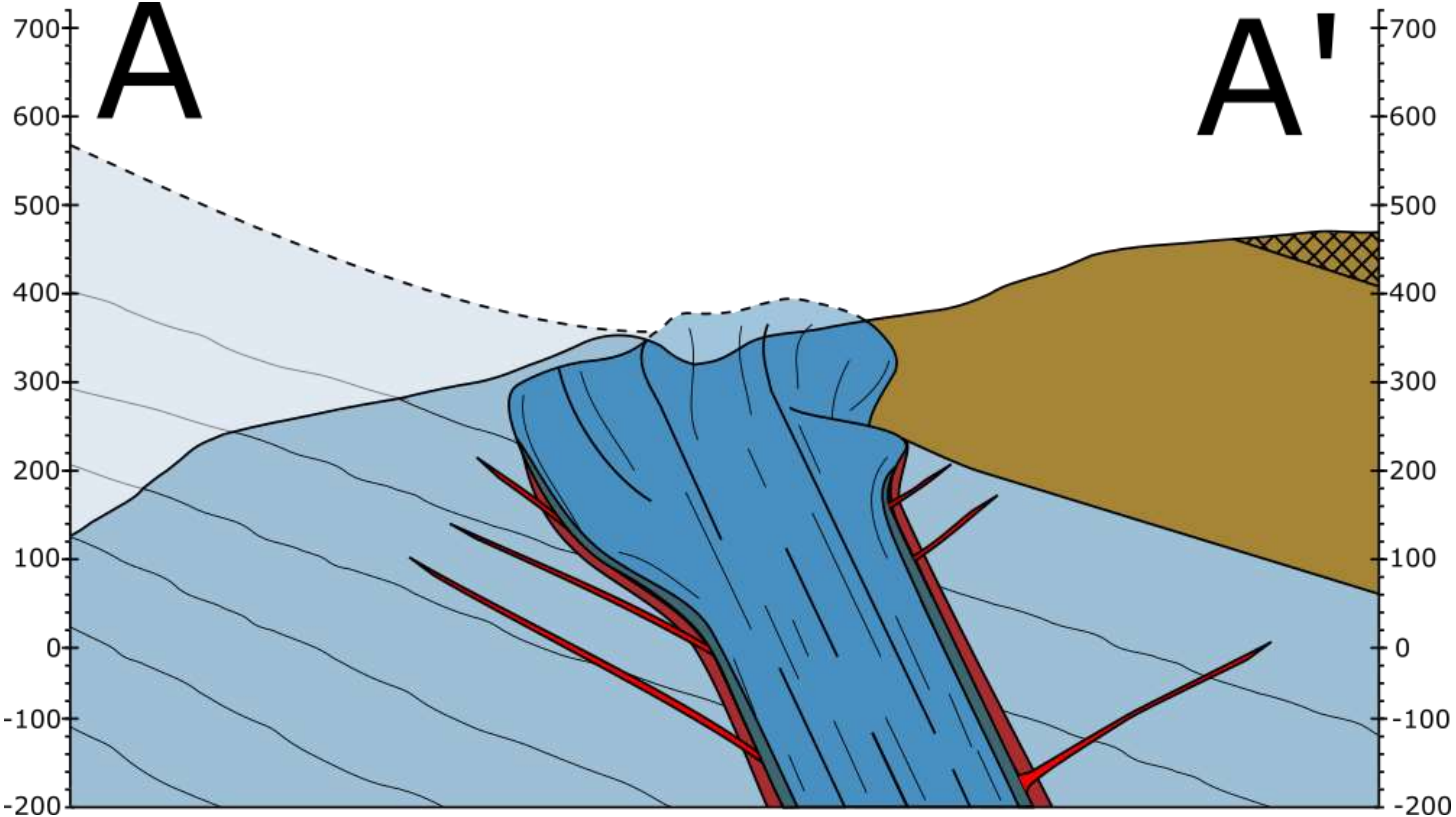
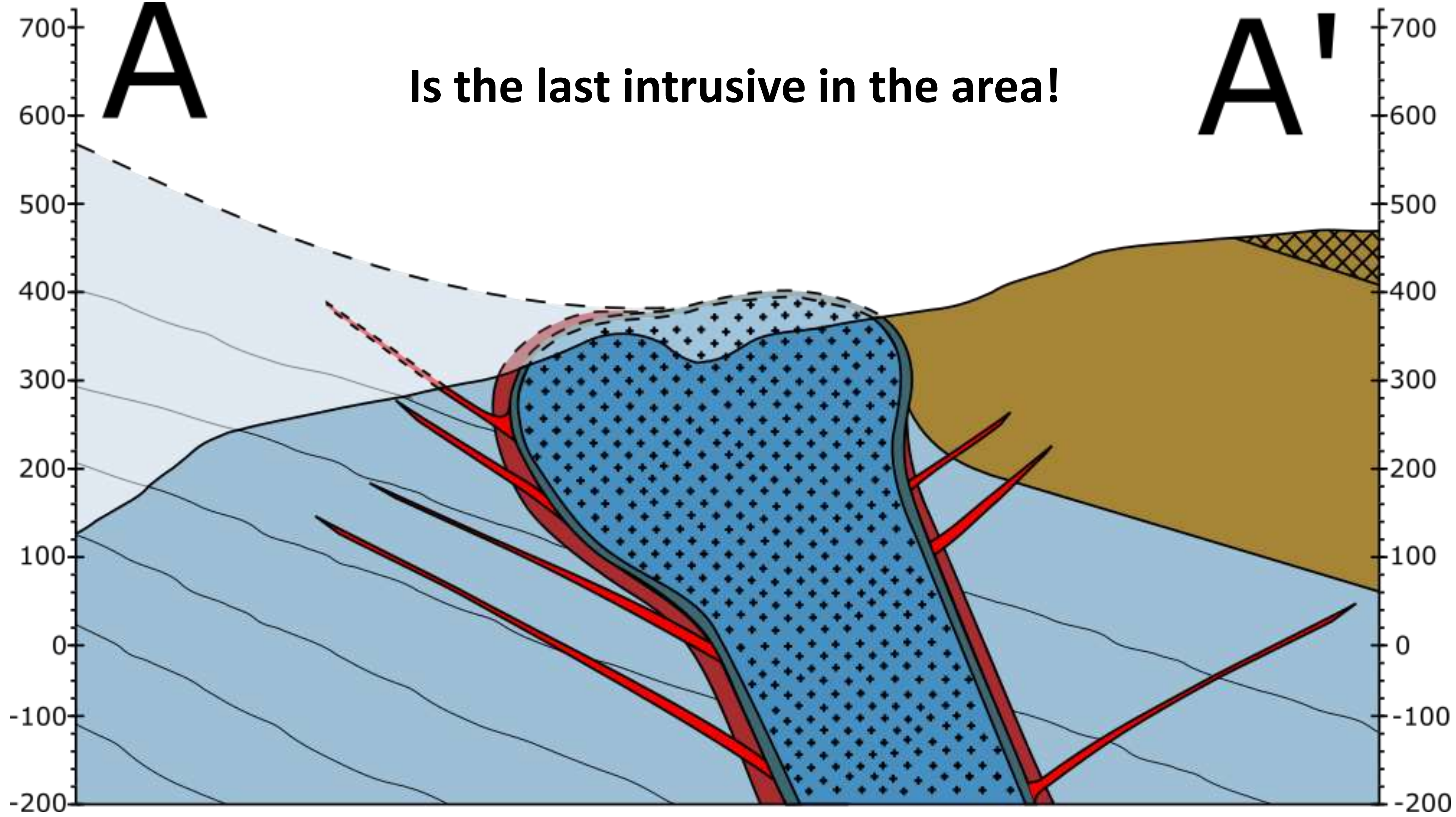
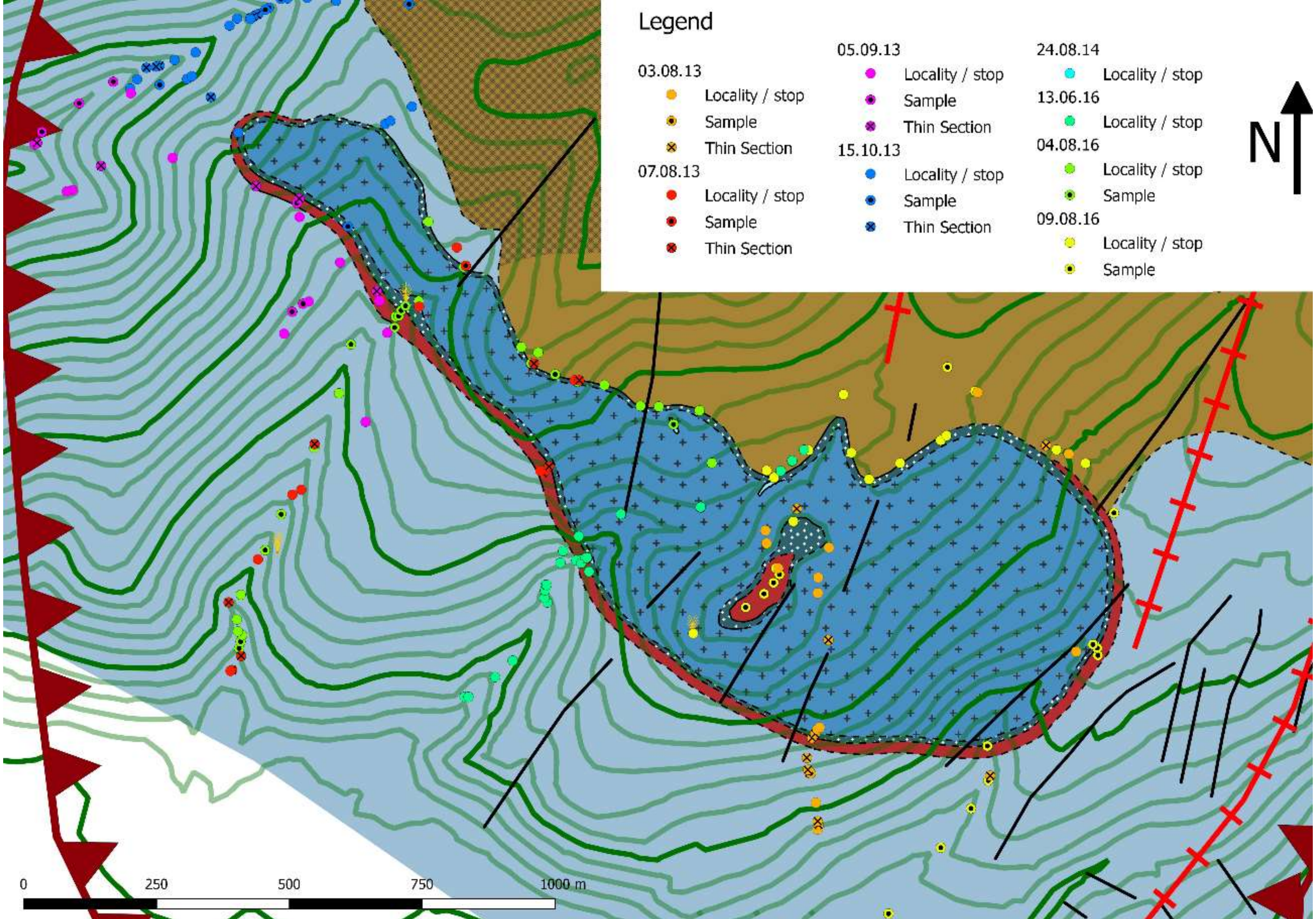
100
0
-100
-200

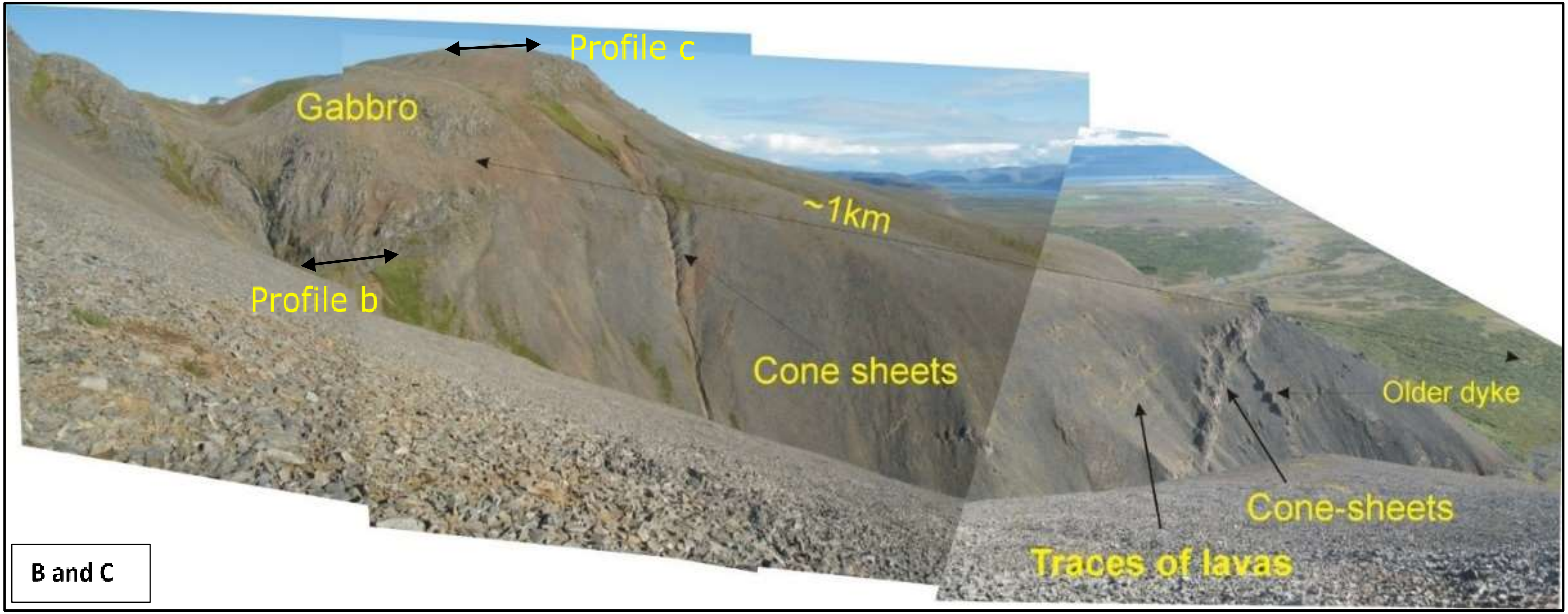


A
A'
700
600
500
400
300
200
100
0
-100
-200
700
600
500
400
300
200
100
0
-100
-200

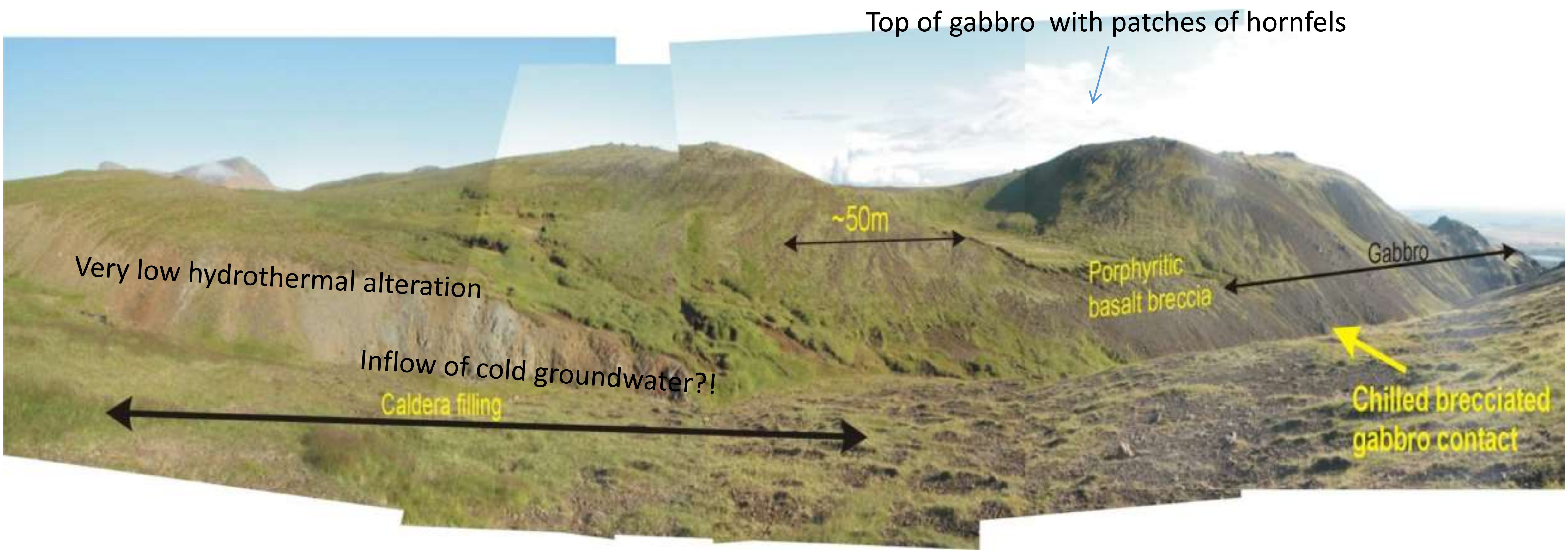
Is the last intrusive in the area!

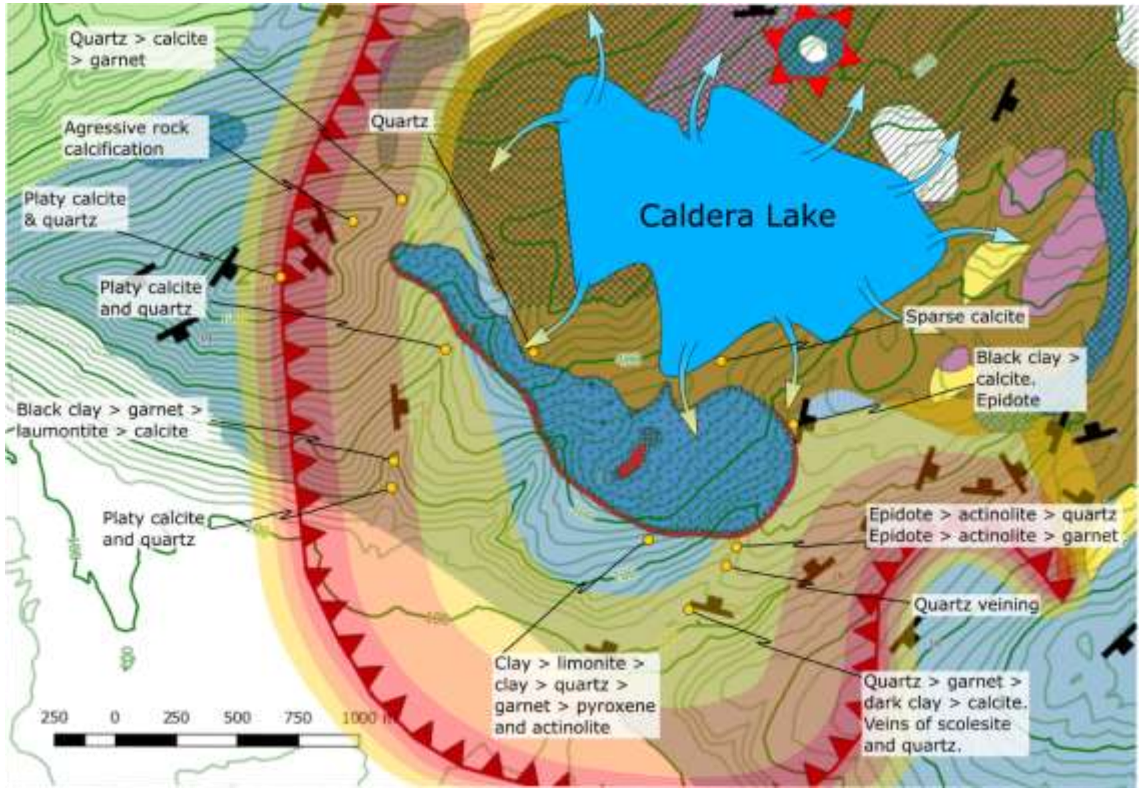



Legend
03.08.13
Locality / stop
Sample
Thin Section
07.08.13
Locality / stop
Sample
Thin Section
05.09.13
Locality / stop
Sample
Thin Section
15.10.13
Locality / stop
Sample
Thin Section
24.08.14
Locality / stop
13.06.16
Locality / stop
04.08.16
Locality / stop
Sample
09.08.16
Locality / stop
Sample
N
0
250
500
750
1000 m


Profile c
Gabbro
~1km
Profile b
Cone sheets
Older dyke
Cone-sheets
Traces of lavas
B and C

Gabbro-pyroclastite

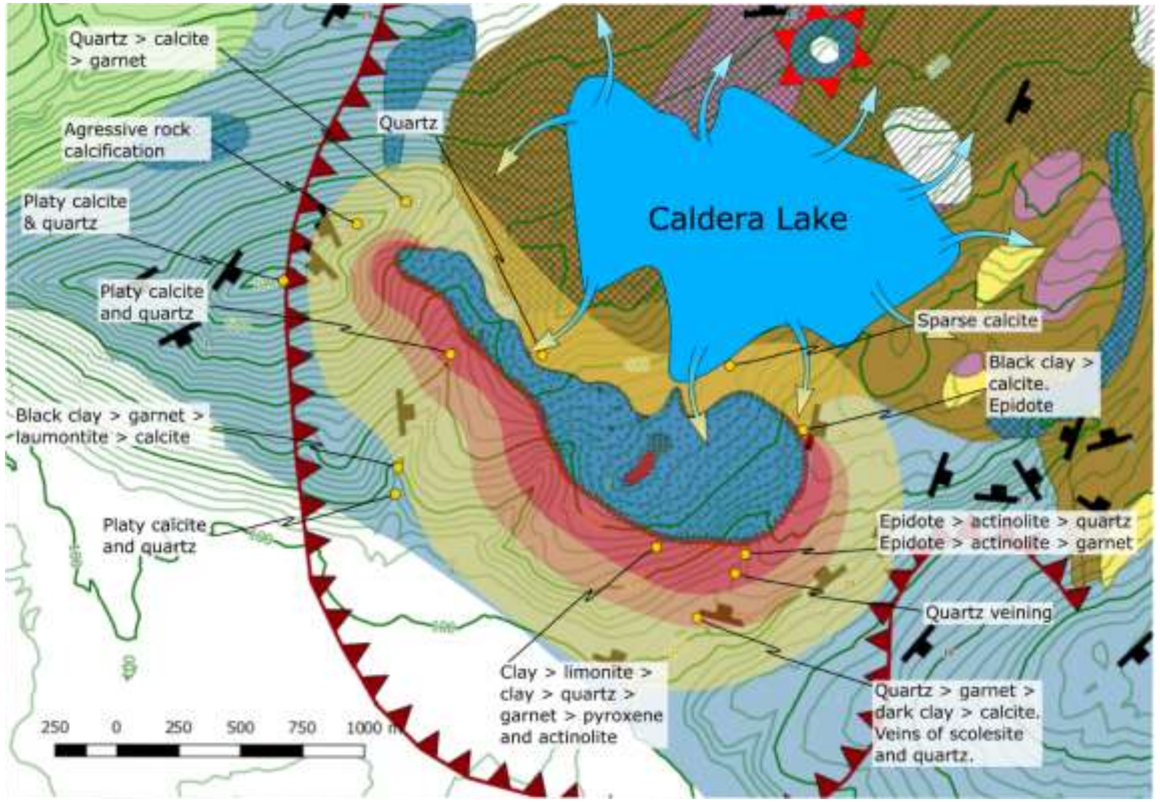




A high-temperature system related to the caldera margin

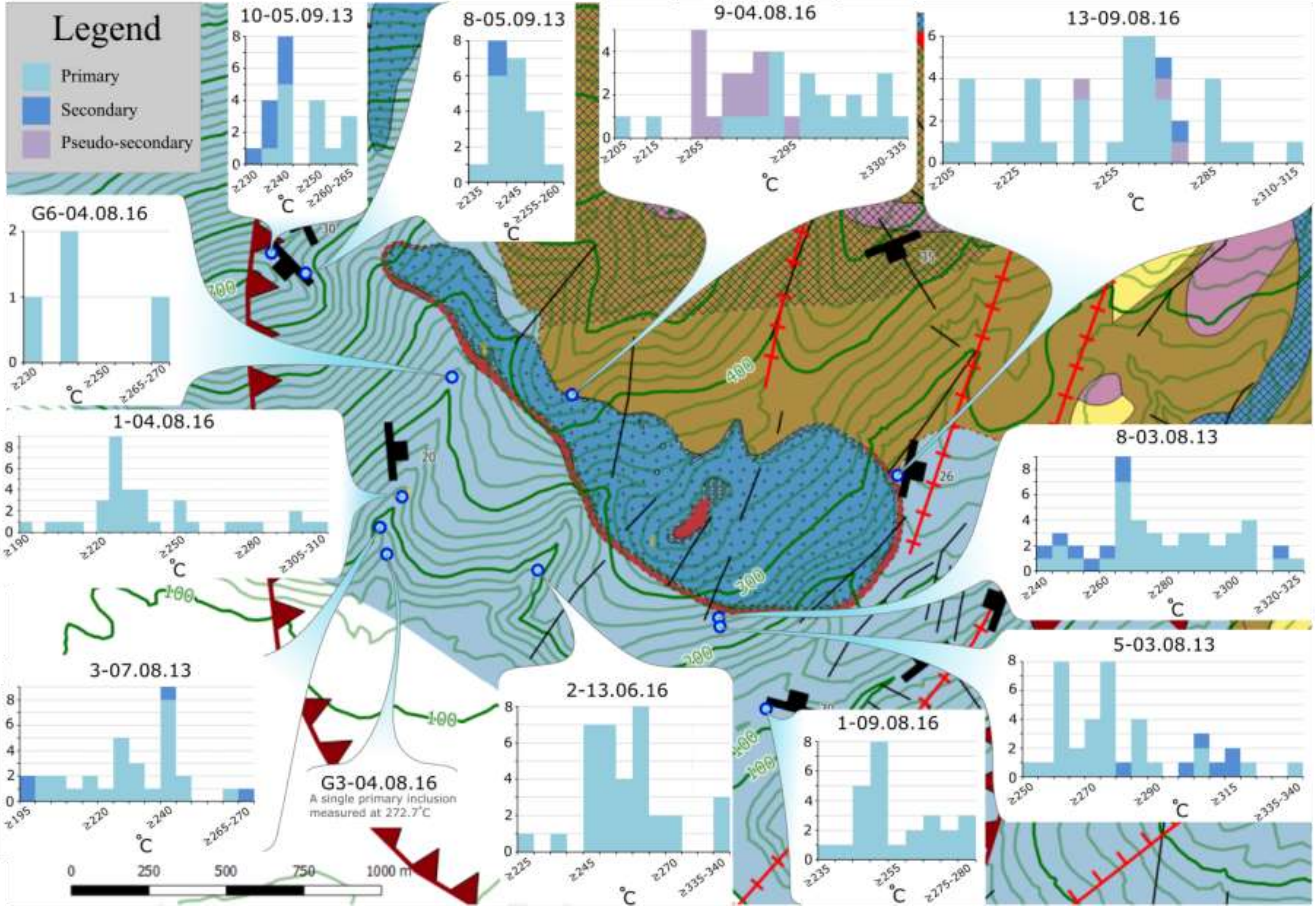
A high-T system related to the gabbro intrusion

The youngest geothermal system

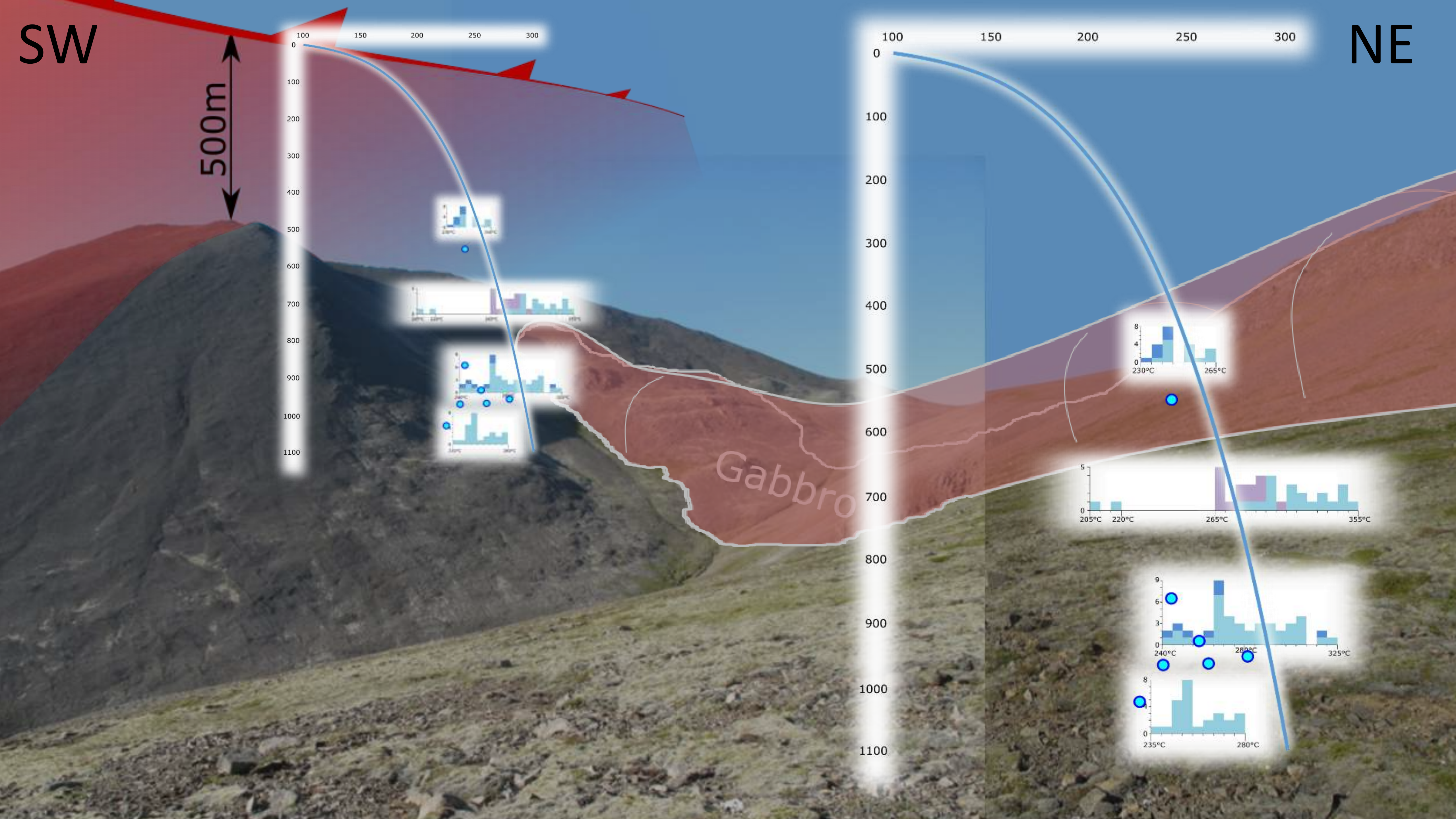


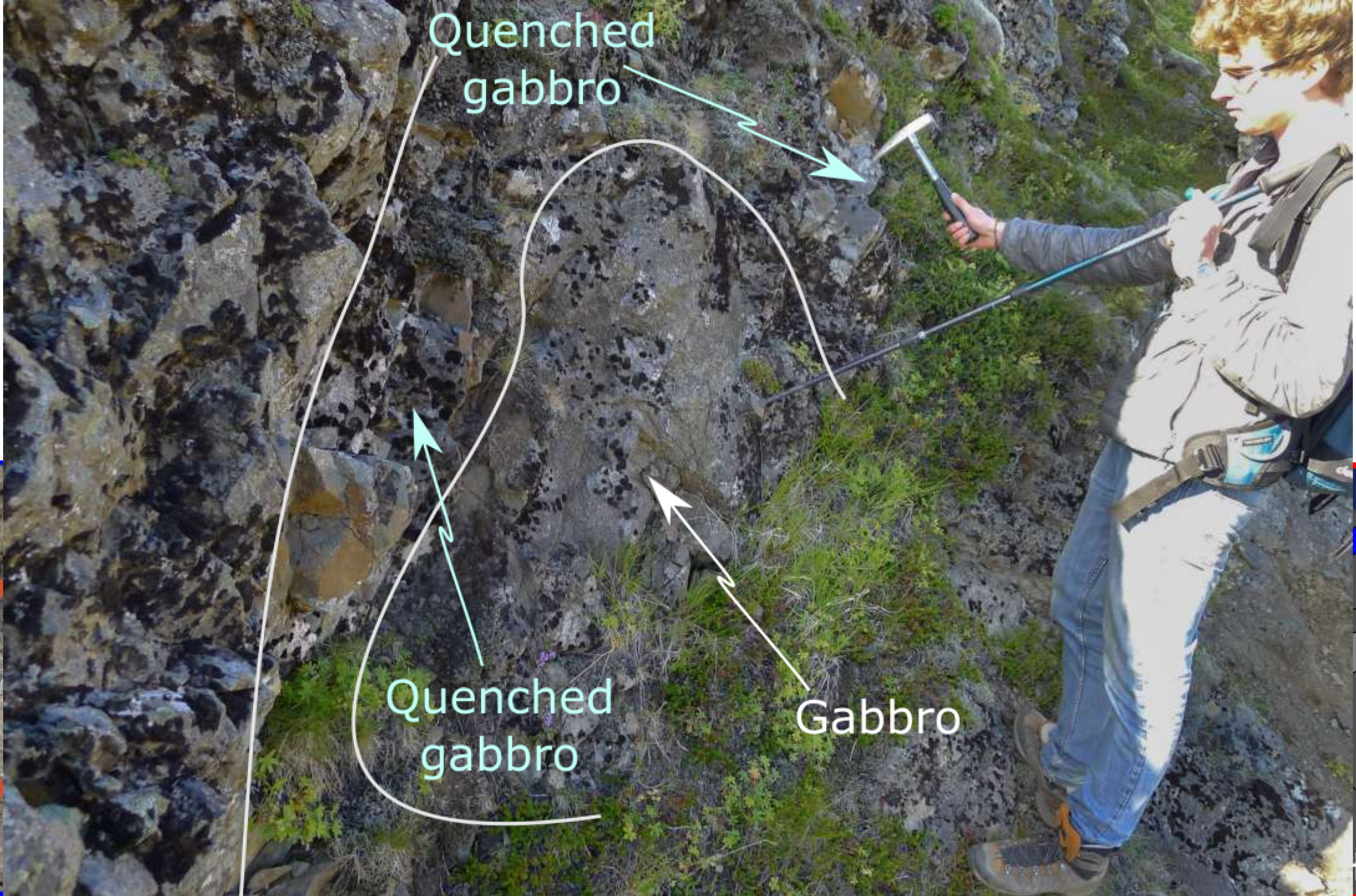
Fluid inclusion temperatures

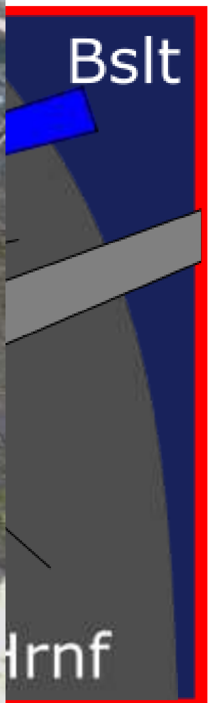
Temperatures in the geothermal system

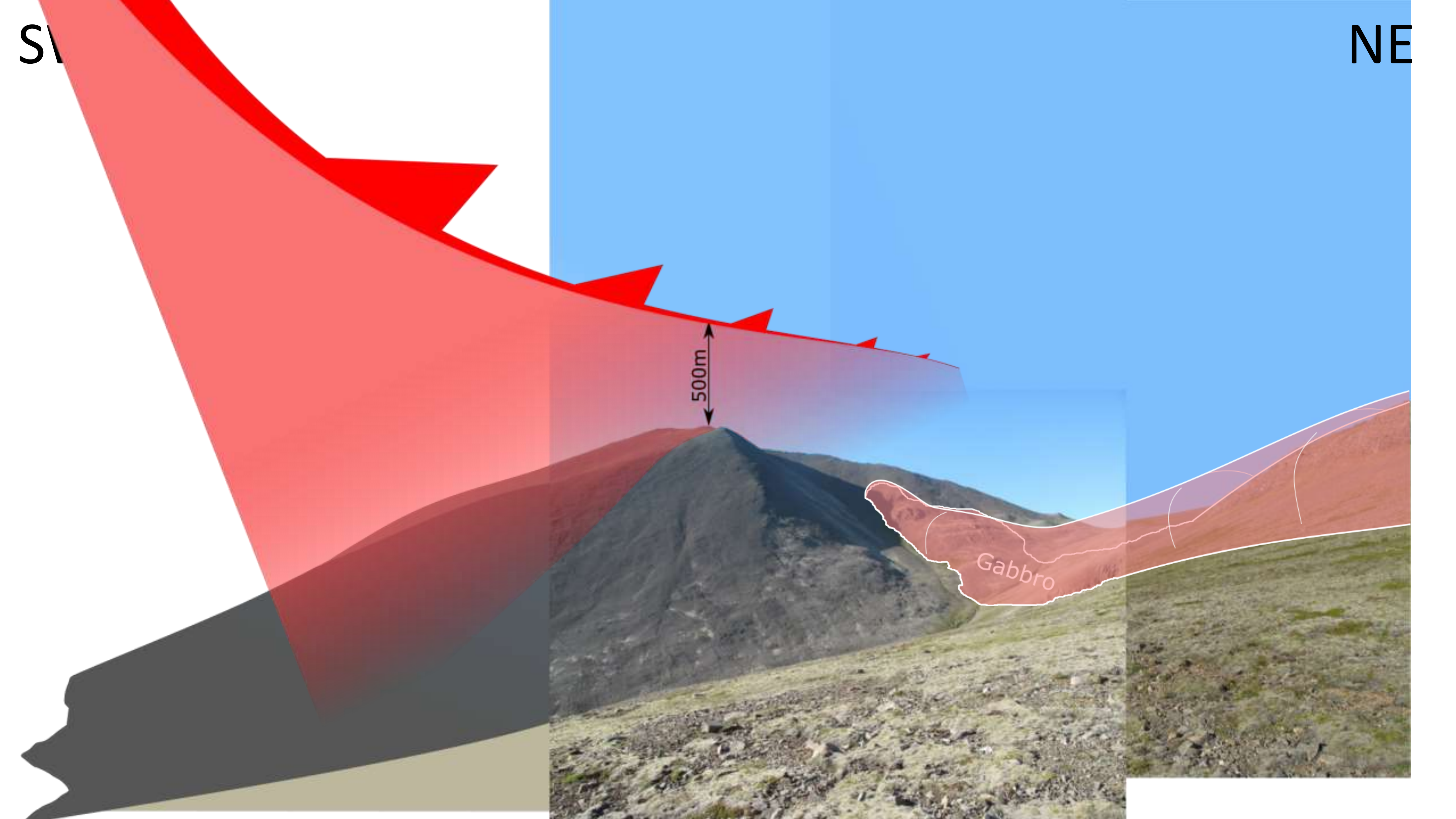


James Brett

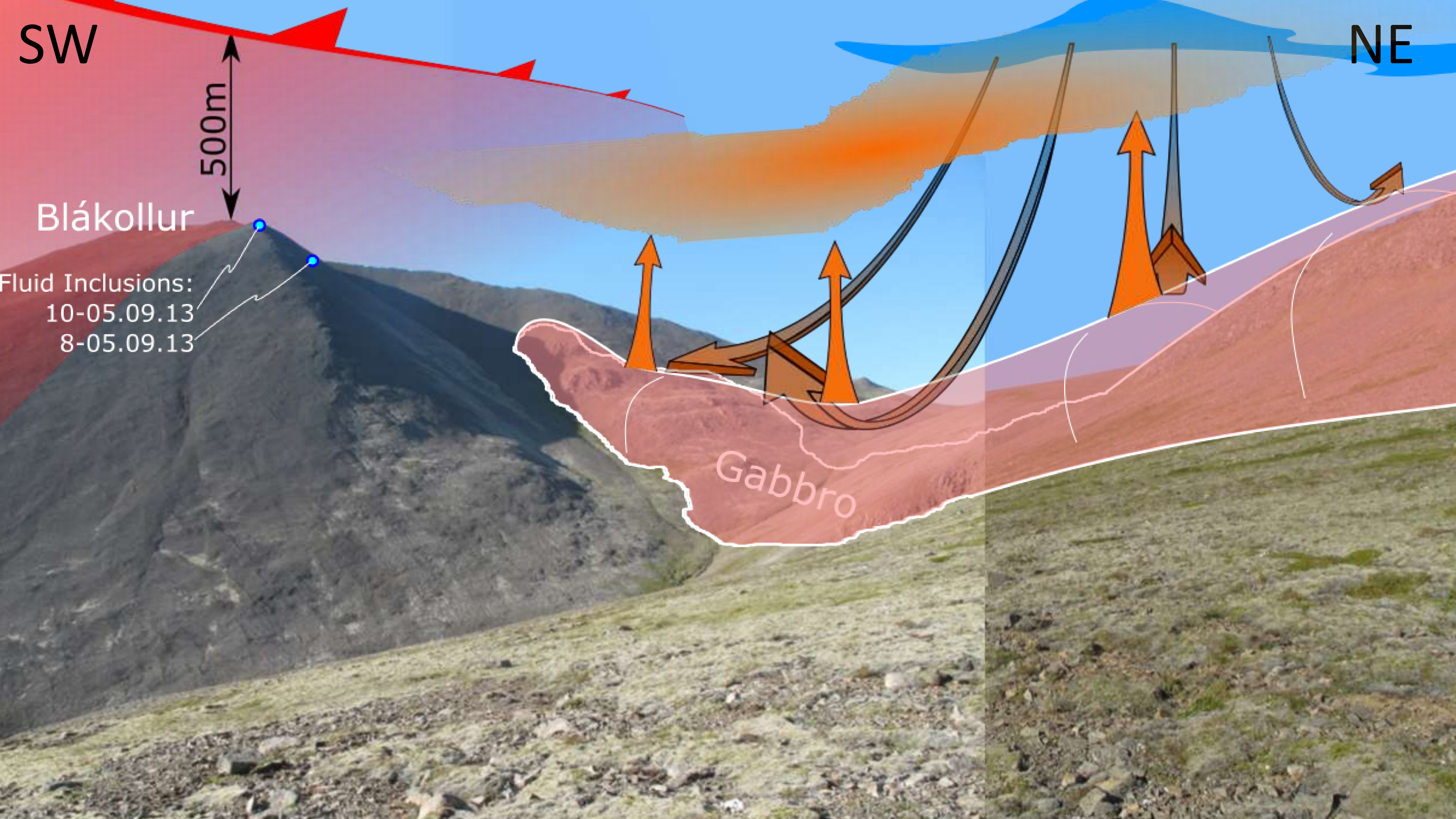

SW
NE
500m
Gabbro
100
150
200
250
300
0
100
200
300
400
500
600
700
800
900
1000
1100
230°C
265°C
205°C
220°C
265°C
355°C
240°C
280°C
325°C
235°C
280°C

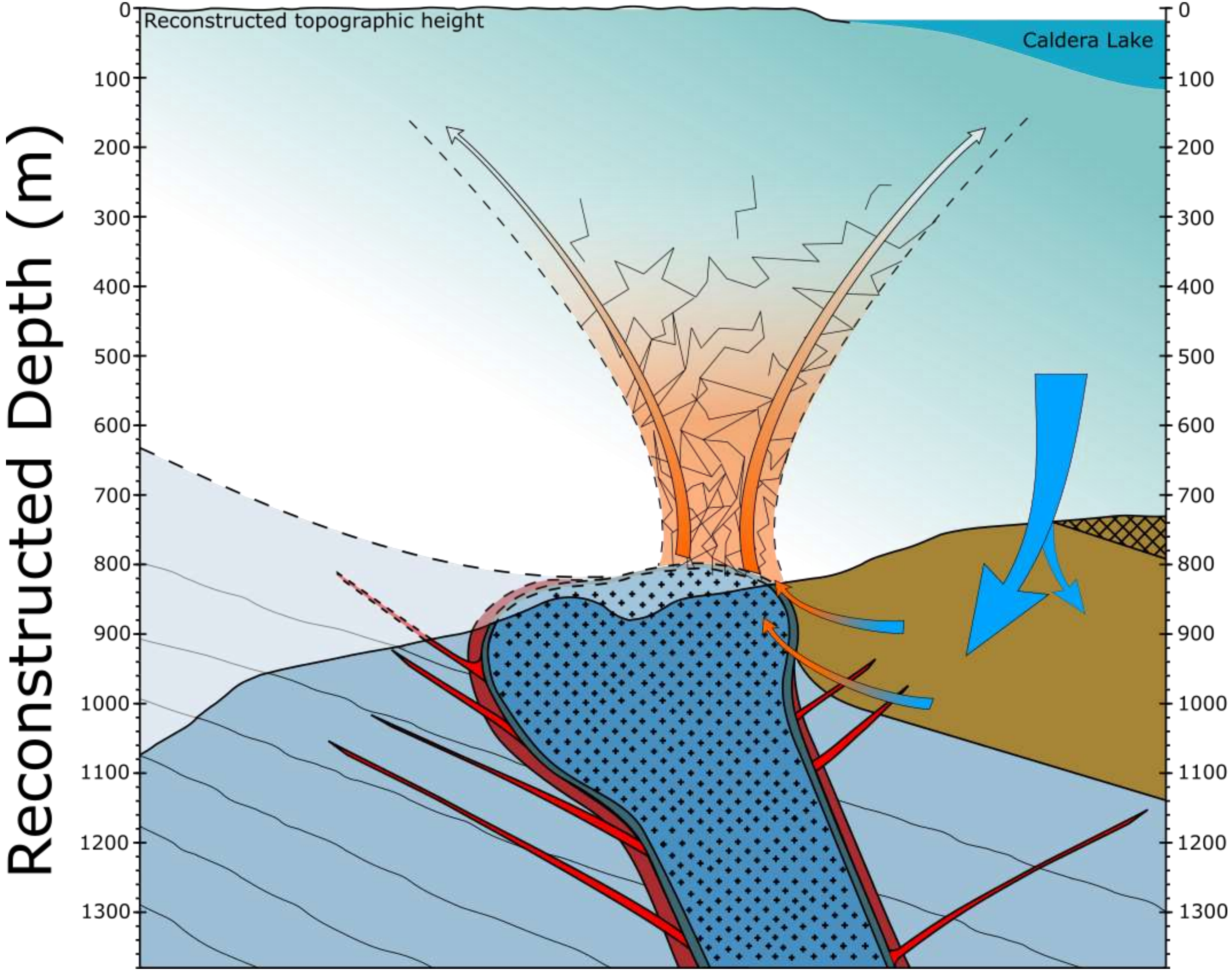

Quenched
gabbro
Quenched
gabbro
Gabbro


Bslt

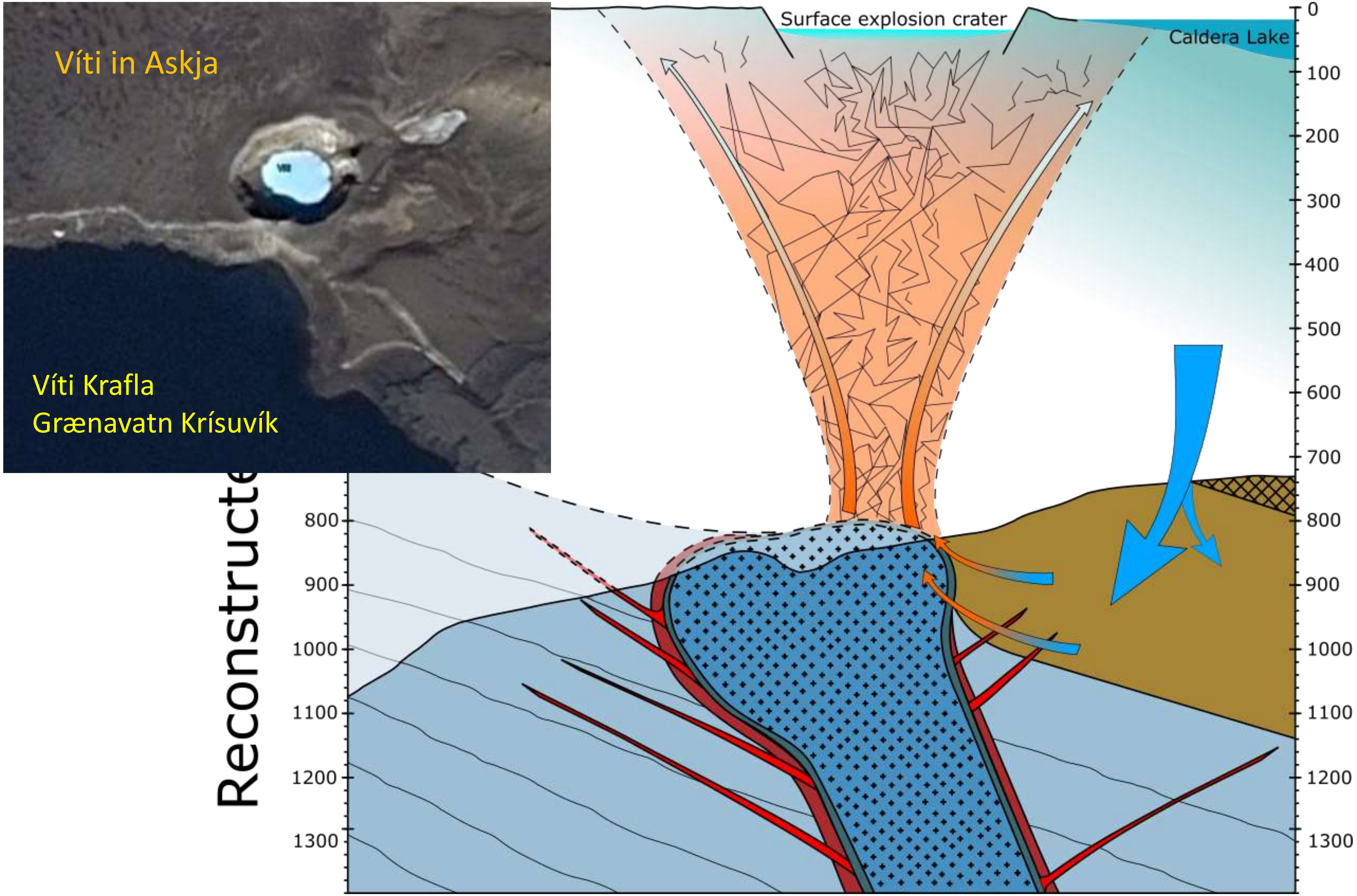


SW
NE
500m
Gabbro


SW
NE
500m
Blákollur
Fluid Inclusions:
10-05.09.13
8-05.09.13
Gabbro



Reconstructed Depth (m)
Reconstructed topographic height
Caldera Lake
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300


Víti in Askja
Víti Krafla
Grænavatn Krísuvík
Surface explosion crater
Caldera Lake
Reconstructe
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300

Hornfels MSc. study of Moneer Altenhary UI

Main research question:
Is the hornfels hydrophile or hydrophobic?

Field relations
Petrography
Geochemistry, LOI
SEM/EMP

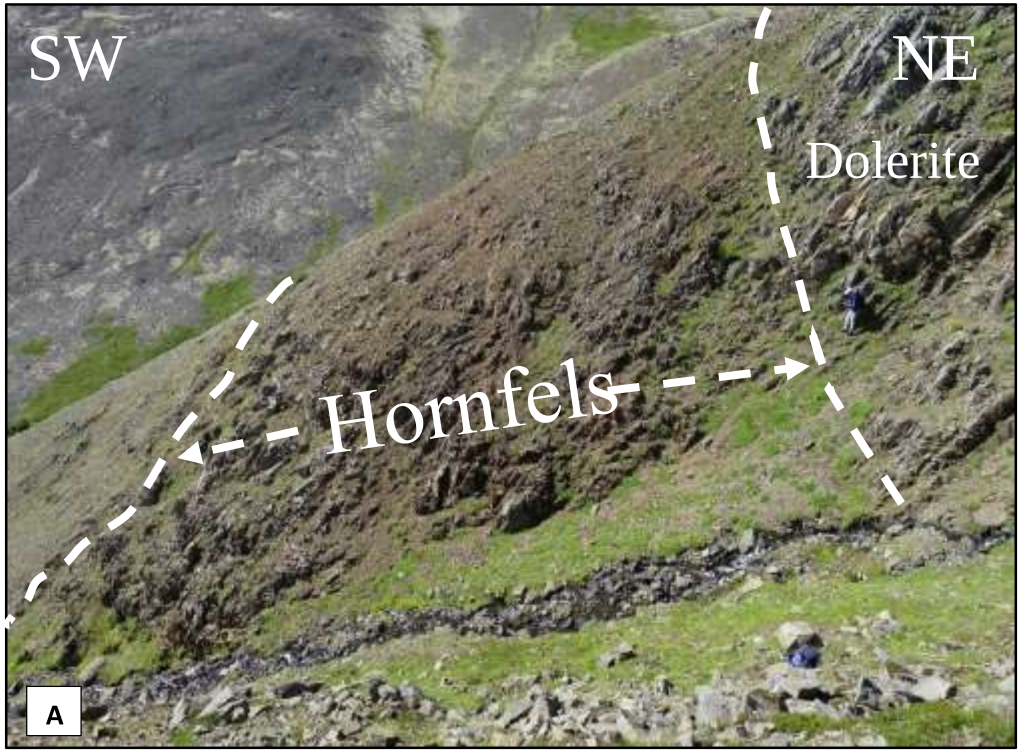
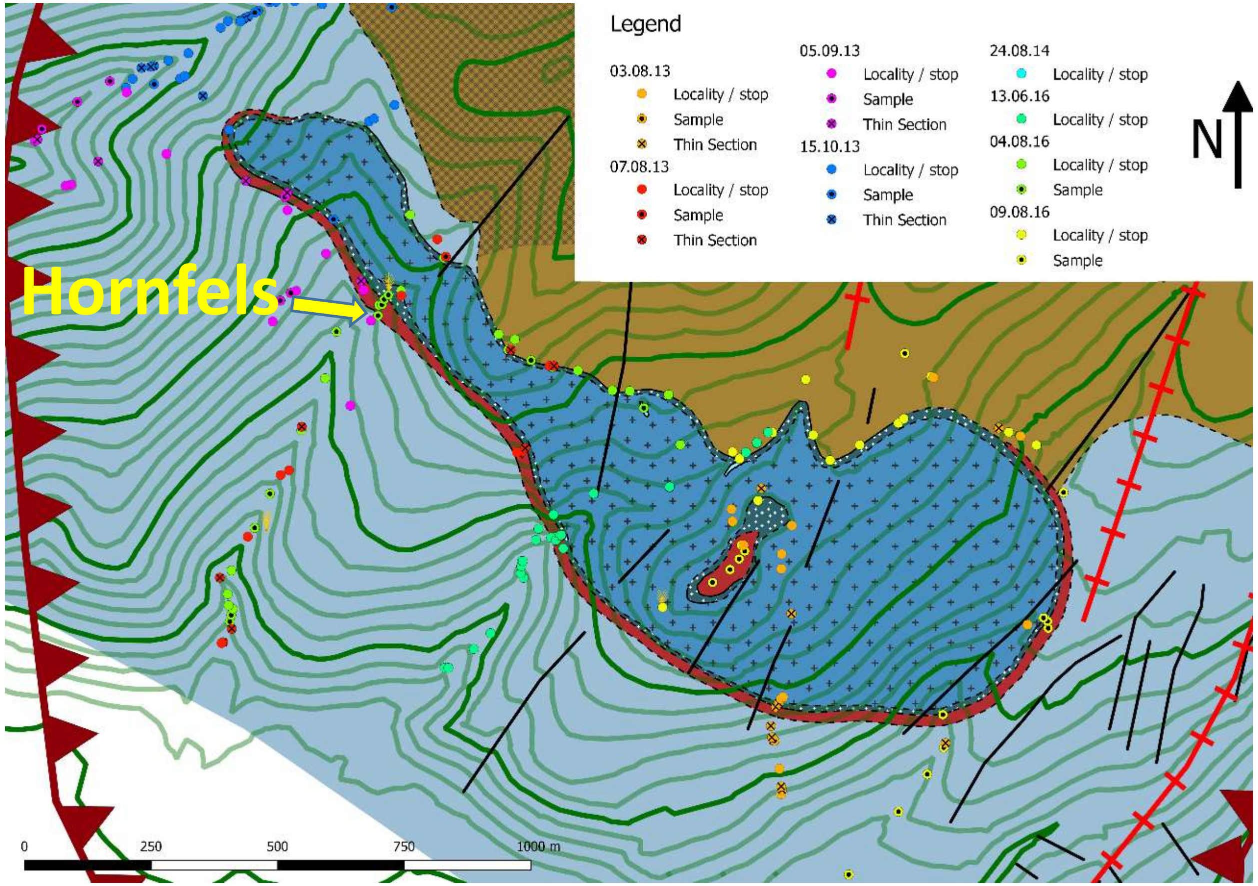
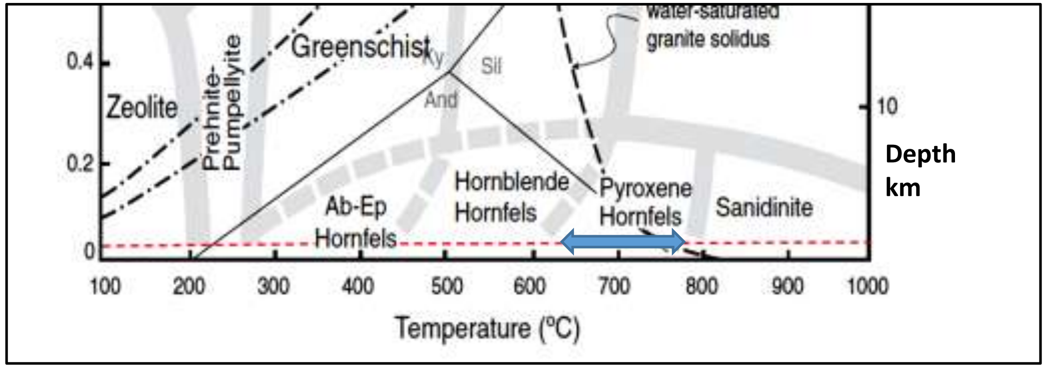


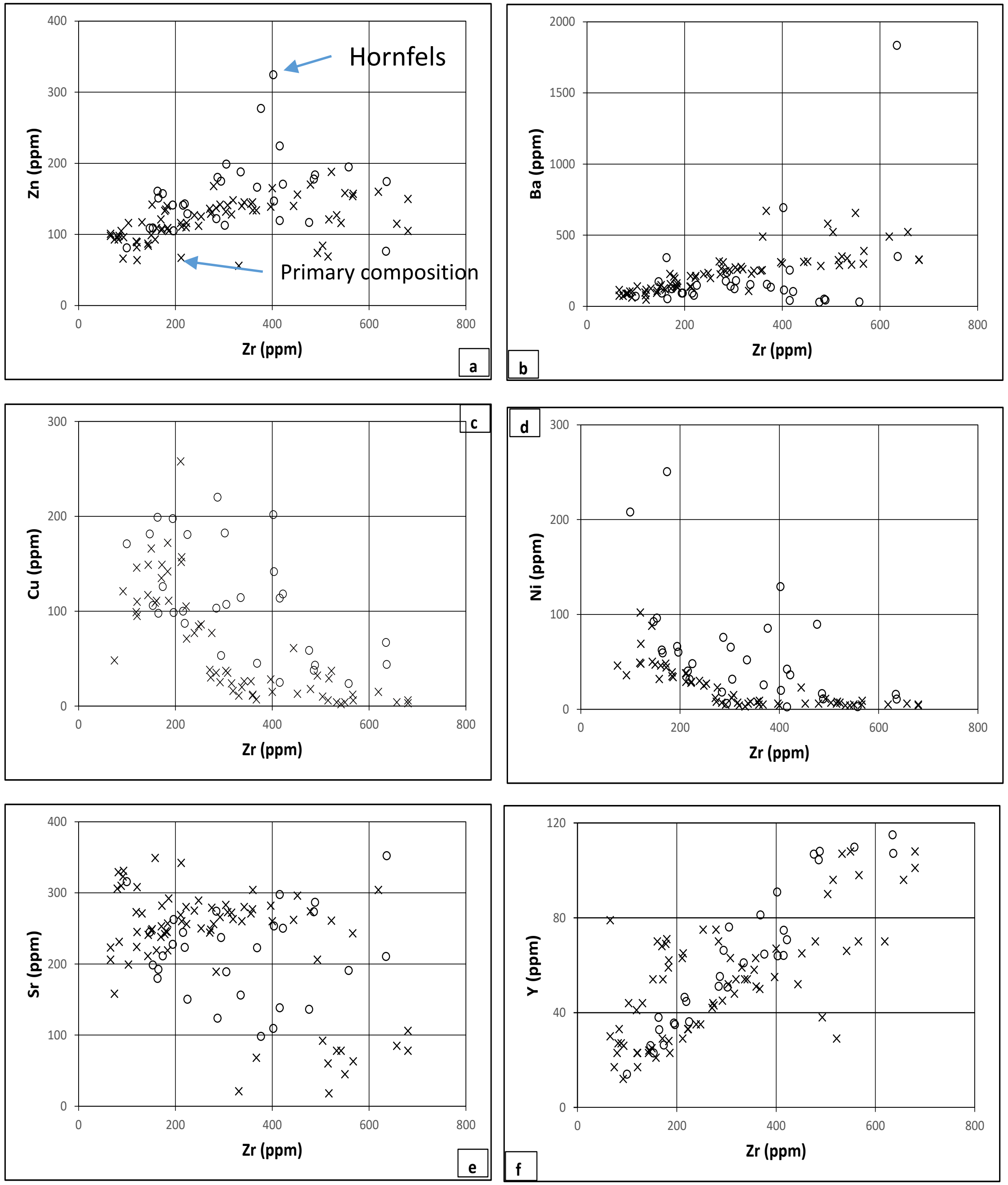
Figure 10: Hornfels zone in profile (a).





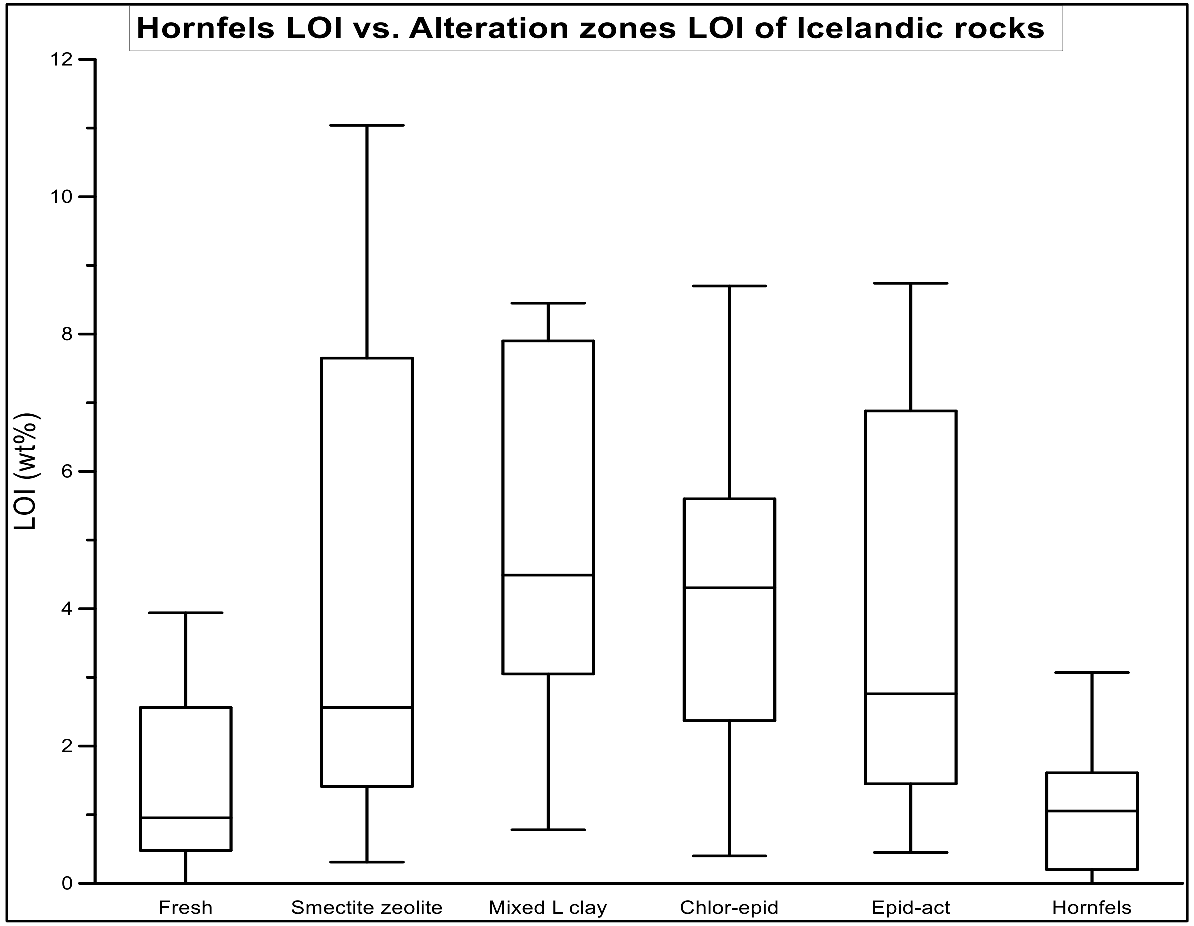
Geochemistry of hornfels

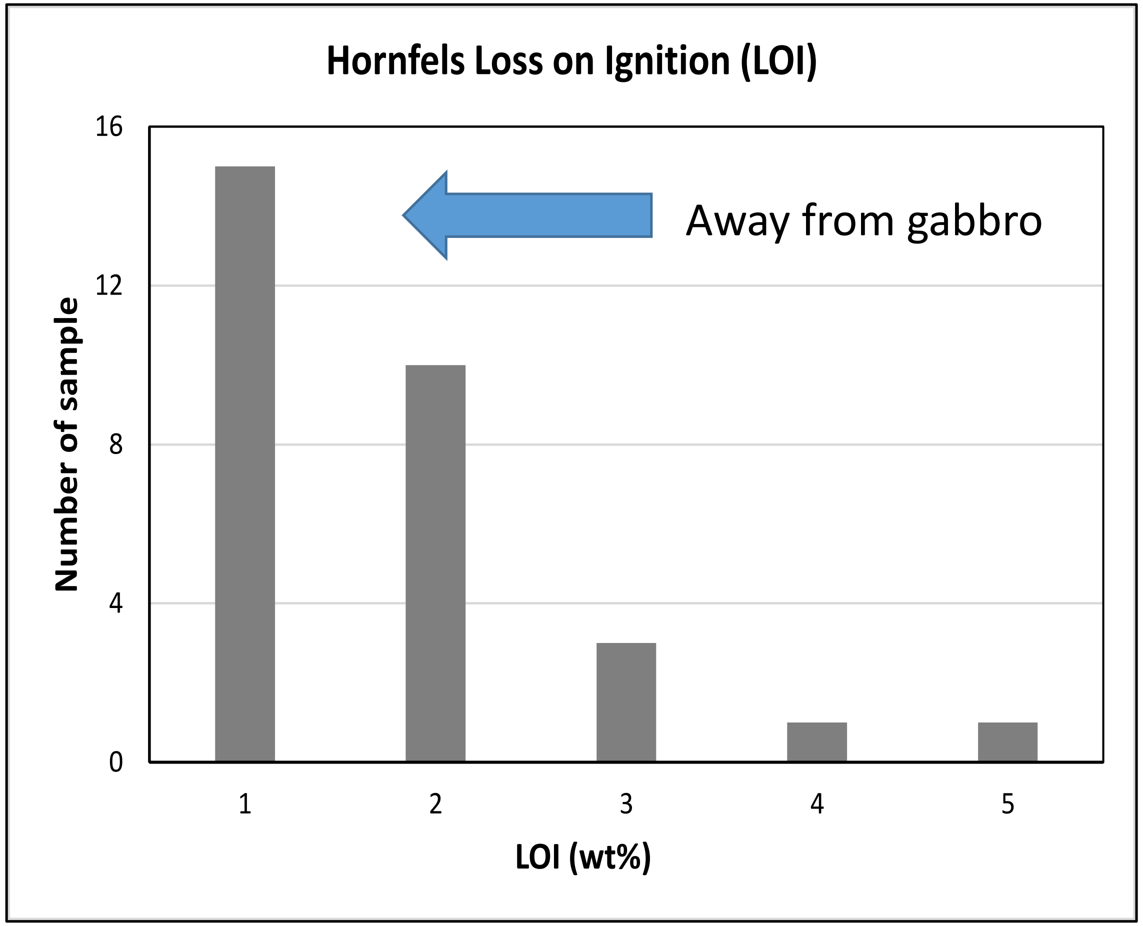
- No major chemical change compared to the protolith, i.e. Rock is recrystallized in situ
- No apparent chemical flux from the adjacent gabbro, though minor increase in Ni, Cu, Zn and minor decrease in Ba and Sr is implied



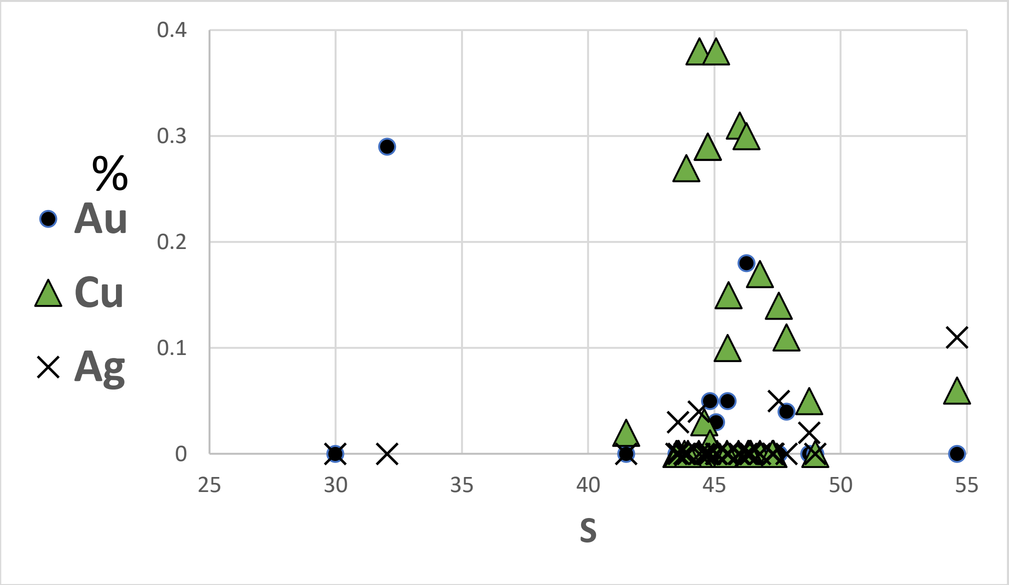
LOI = Volatile content (H_2O+ CO_2+ H_2S)

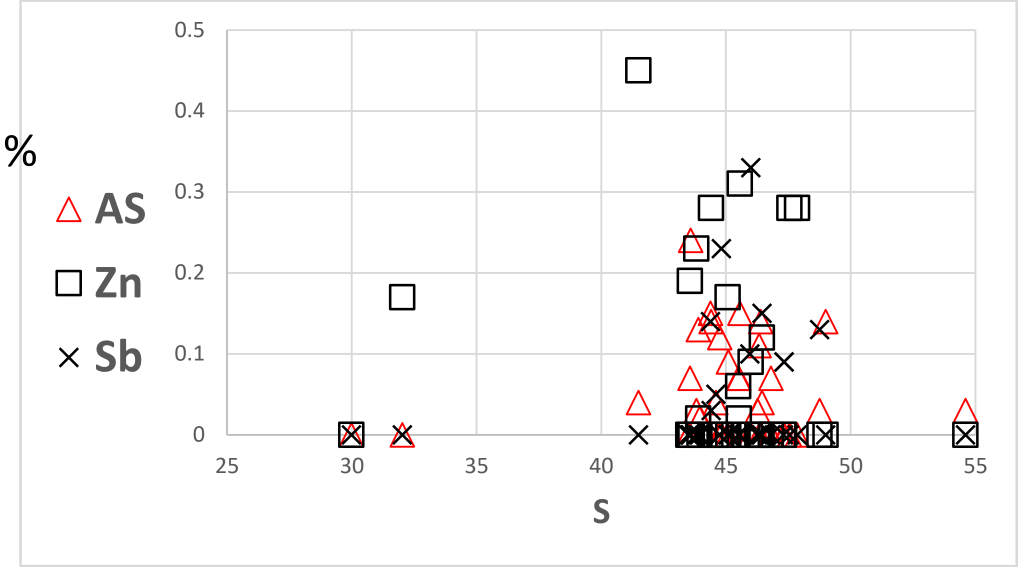
Near total dehydration of the rock within the hornfels zone

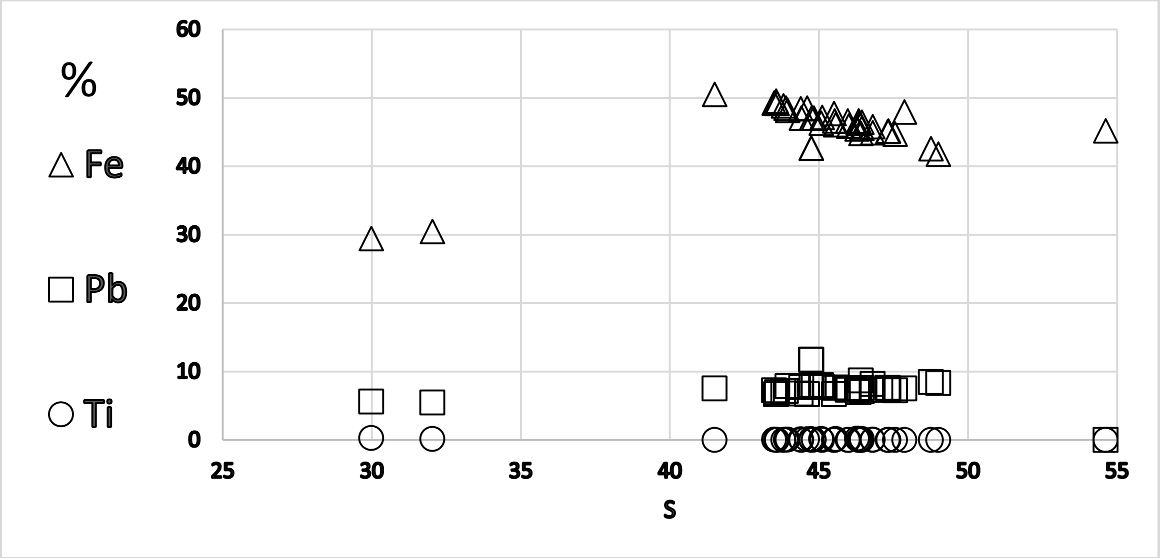




Sulphide Volatile excape







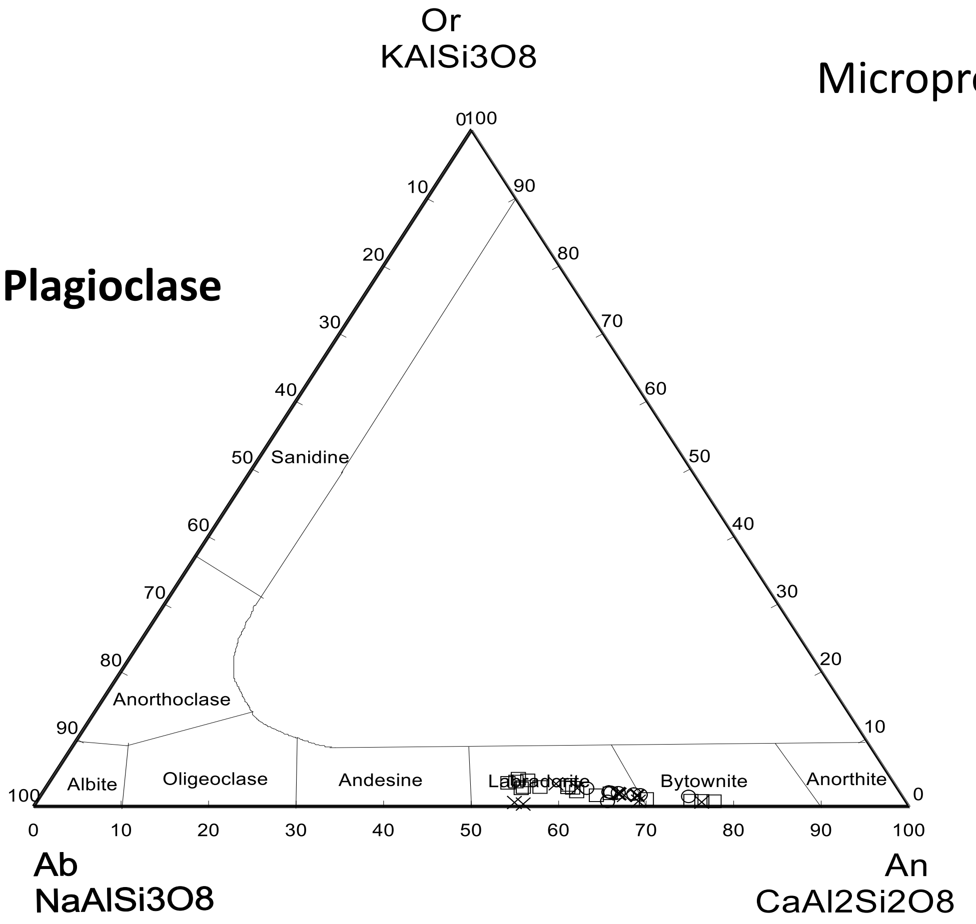
Sulphite „Chimneys“ Late stage volatile excape from gabbro.
Elevated Pb, Ag, As, Sb, Zn and Au values (SEM analysis)

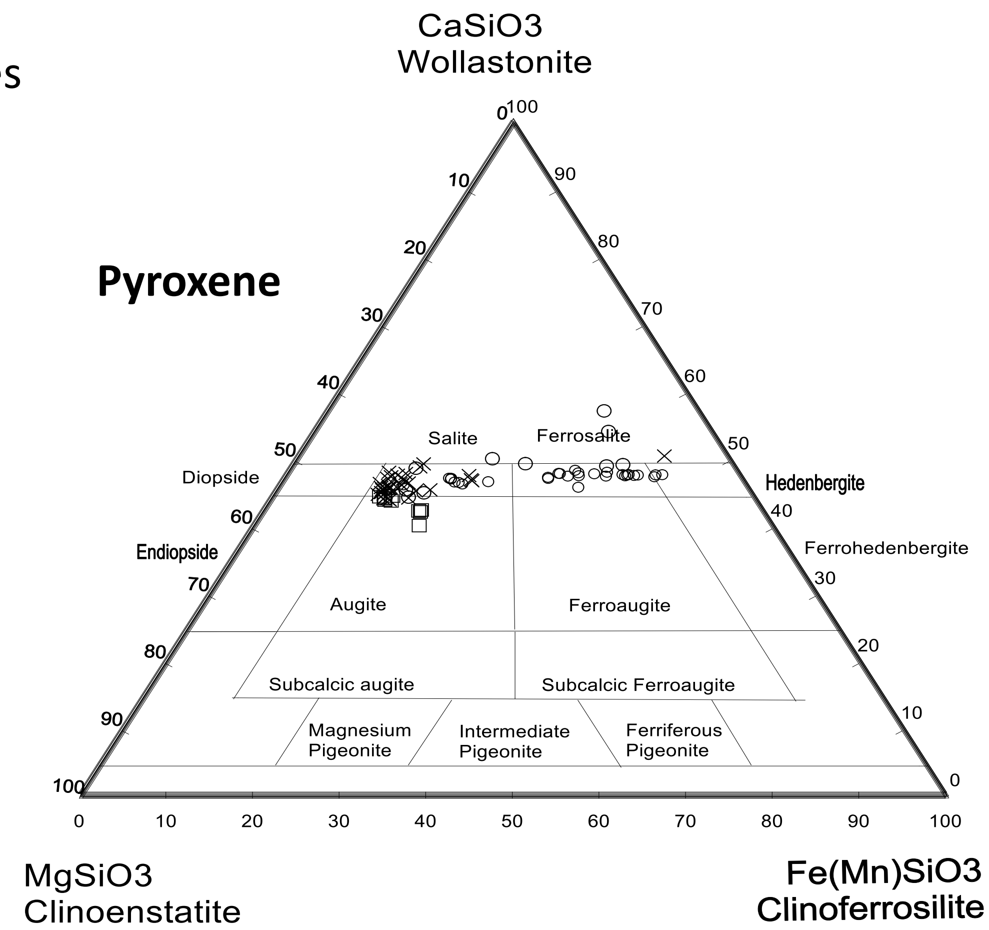
Only locations which show a marked compositional geochemical change, indicating rock dissolution and formation of permeability.

Mineralogy of pyroxenes and plagioclase in hornfels

- Compositions similar as found in other hornfels locations (Geitafell, Hellisheiði, Reykjanes, Eldvörp, Krafla)

Microprobe analyses

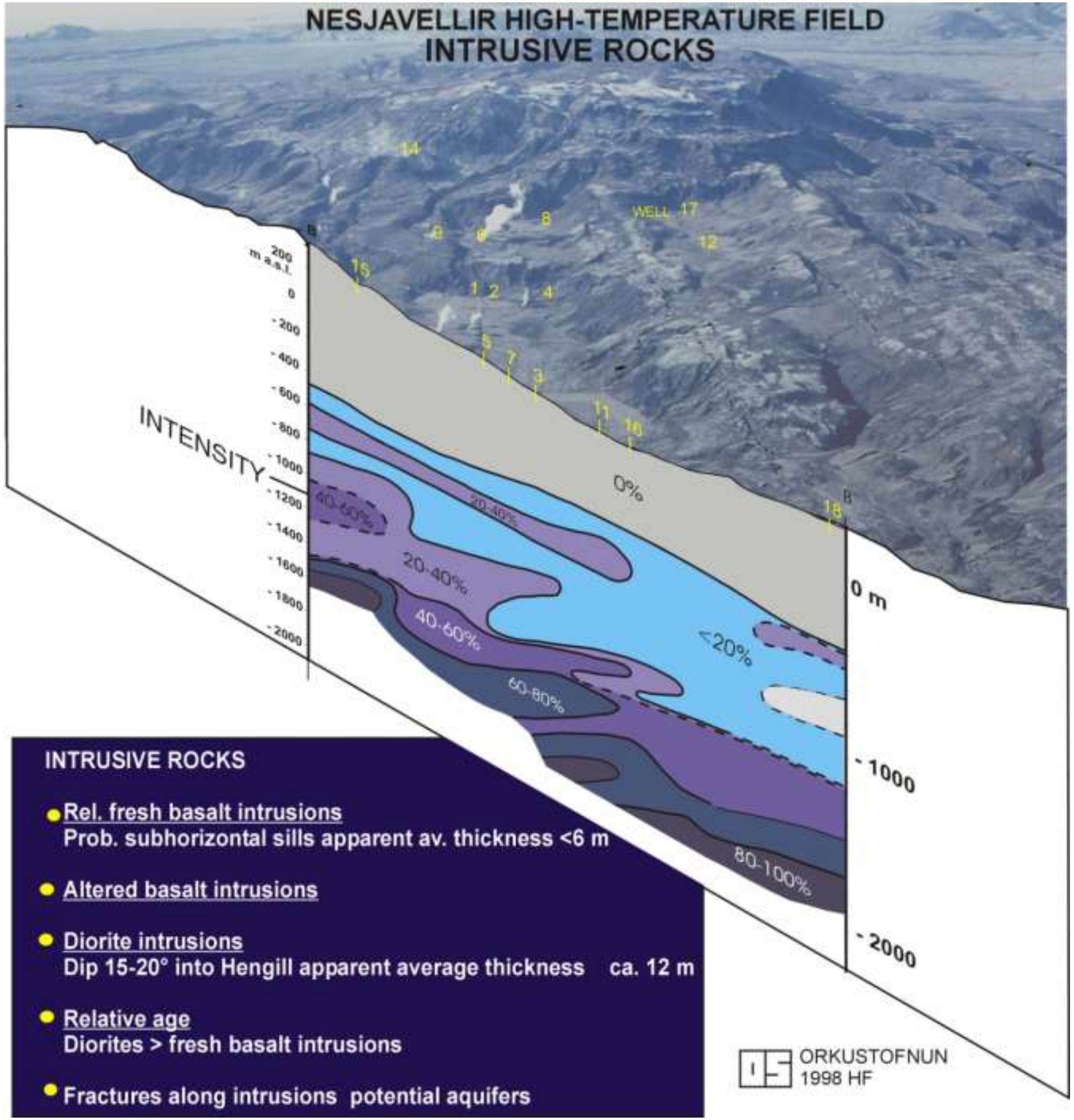




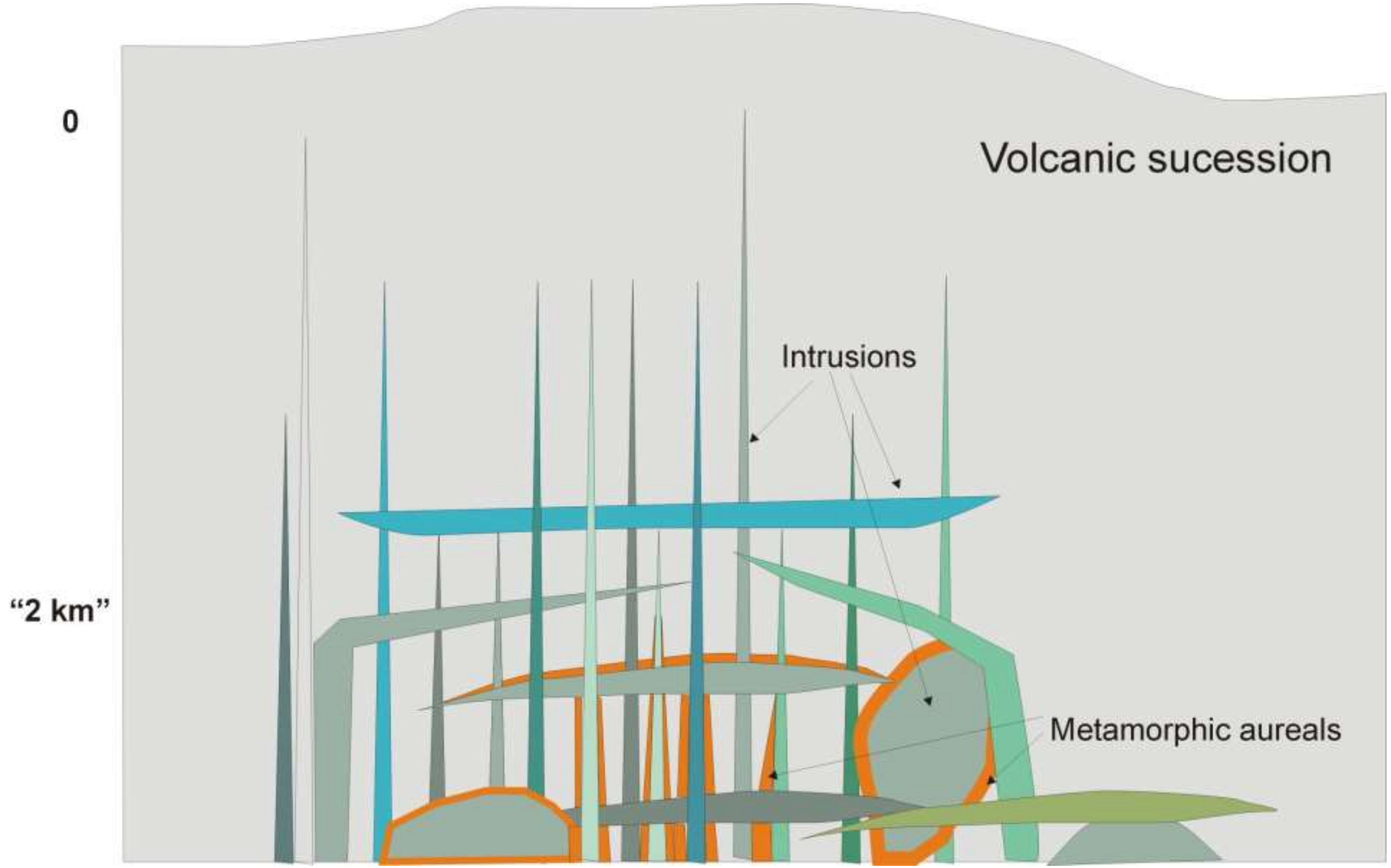
Hrossatungur Gabbro
Conclusions so far….

- **Unique**. Shallow emplacement. Access to very permeable groundwater system. „Last volcano/tectonic event“ which excludes formation of further permeability structures into the cooling gabbro.
- **Hornfels.** If groundwater limited, then hornfels forms rapidly a tight hydrophobic coat which inhibits fluid intrusion. That leads to a conductive heat transfer across the hornfels towards the geothermal system to be mined at sub-magmatic temperatures.

How does this relate to the presently active high-temperature systems?

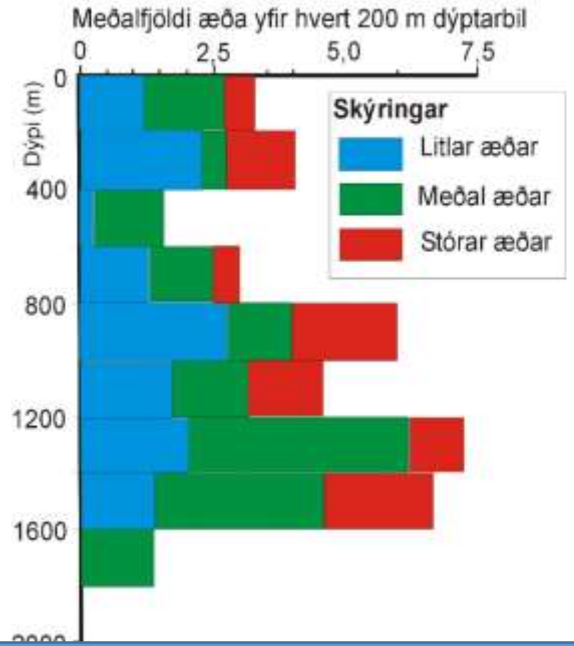

NESJAVELLIR HIGH-TEMPERATURE FIELD
INTRUSIVE ROCKS
14
WELL 17
12
8
9
15
1 2 4
5
7
3
11
16
18
200
m a.s.l.
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
INTENSITY
0%
40-60%
20-40%
20-40%
40-60%
<20%
60-80%
80-100%
0 m
-1000
-2000
INTRUSIVE ROCKS
Rel. fresh basalt intrusions
Prob. subhorizontal sills apparent av. thickness <6 m
Altered basalt intrusions
Diorite intrusions
Dip 15-20° into Hengill apparent average thickness ca. 12 m
Relative age
Diorites > fresh basalt intrusions
Fractures along intrusions potential aquifers
ORKUSTOFNUN
1998 HF

Intrusions and metamorphic aureals

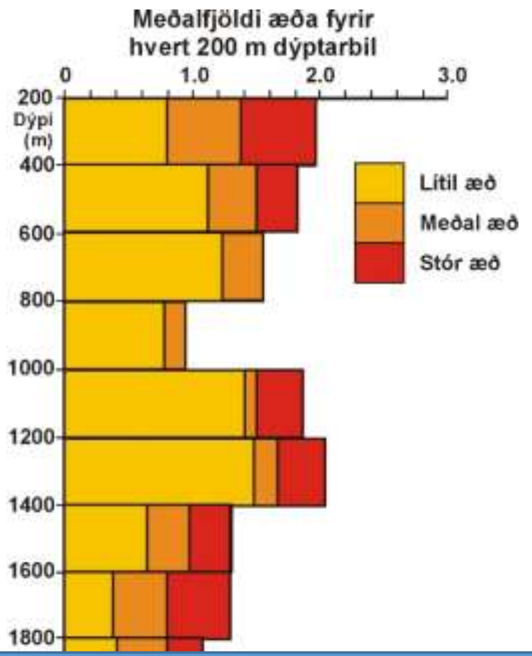


Distribution of aquifers within high-T systems

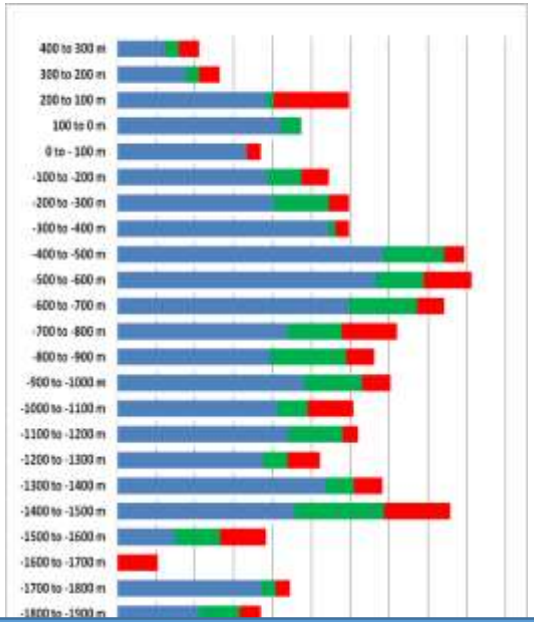
Svartsengi



Nesjavellir



Hellisheiði



Permeability decrease below ~2 km depth

High-T system dependent

This decreases the probability of direct large fluid influx into a deeper molten magma intrusion

Main conclusions

Is heat mining from a molten magma body through direct contact between fluid and magma or through conductive thermal gradient.

If a magmatic intrusion does not intersect a very permeable fluid resource during its emplacement, it will rapidly form a surrounding hydrophobic zone (up to hornfels facies) which inhibits inflow but transfers the heat into the surrounding rocks by conduction. If a later permeability structure forms it mines the thermally heated rock.

The probability of water/magma interaction diminishes with depth


Thank you

Main points

- Magma intruding the lower and upper crust move the heatsource towards the hydrothermal system, consolidate and conduct the heat into the surrounding formation. The heat anomaly mined is mostly derived from:
- fluid flow along fractures mining this heat anomaly
- A direct fluid/magma interaction is less common and probability of that happening decreases with depth due to decreasing overall permeability