Induced earthquakes in the Hellisheidi geothermal field

- Preliminary findings: Hverahlíð

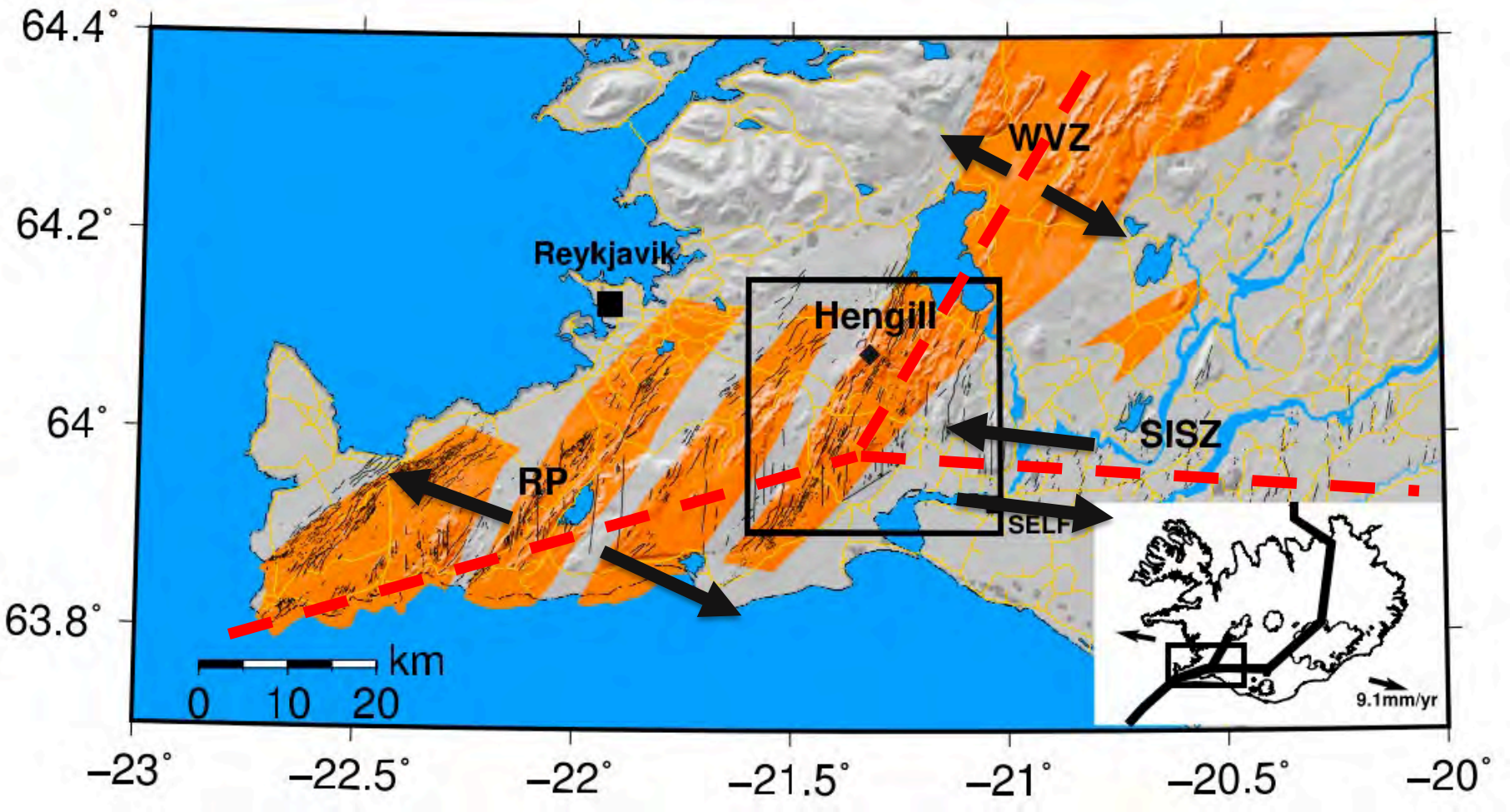
Vala Hjörleifsdóttir[1,2], Sandra Snæbjörnsdóttir[1], Madison MacKenzie[3], Kristín Vogfjörð[4], Kristján Ágústsson[5], Þorbjörg Ágústsdóttir[5], Gunnar Gunnarsson[1], Bergur Sigfússon[1], Sigurlaug Hjaltadóttir[4]

1 Reykjavík Energy (OR), 2 Universidad Nacional Autónoma de México (UNAM), 3 Iceland School of Energy (ISE), 4 Iceland Meteorological Office (IMO), 5 Iceland Geosurvey (ÍSOR)

Schatzalp Workshop on Induced Seismicity, 2019/03/06

Hengill

- Central volcano at a triple junction



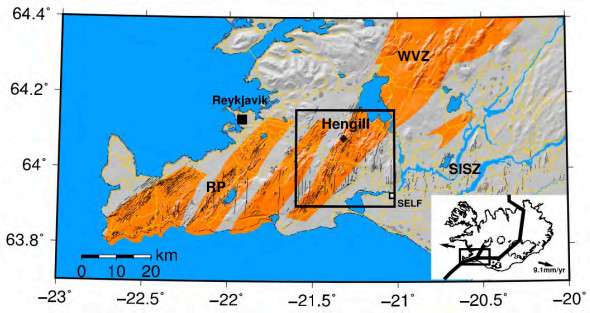
Juncu et al. 2016

Reykjavík Energy

Hengill

- Central volcano at a triple junction

- Last eruption ~2000 years ago
- Max. elevation 803 m
- Inflation in 1990s; M~5.5 earthquakes, tens of thousands of triggered earthquakes
- Subsidence since mid-2000s
- Two M6 earthquakes in the east part in 2008
- **Two sets of fractures:**
  NE-SW: from RP
  N-S: from SISZ



Halldór Geirsson et al.: The ups and downs of Hengill volcano, Iceland

Reykjavík Energy

Hengill

– a source of heat and electricity for Reykjavík

Two power plants

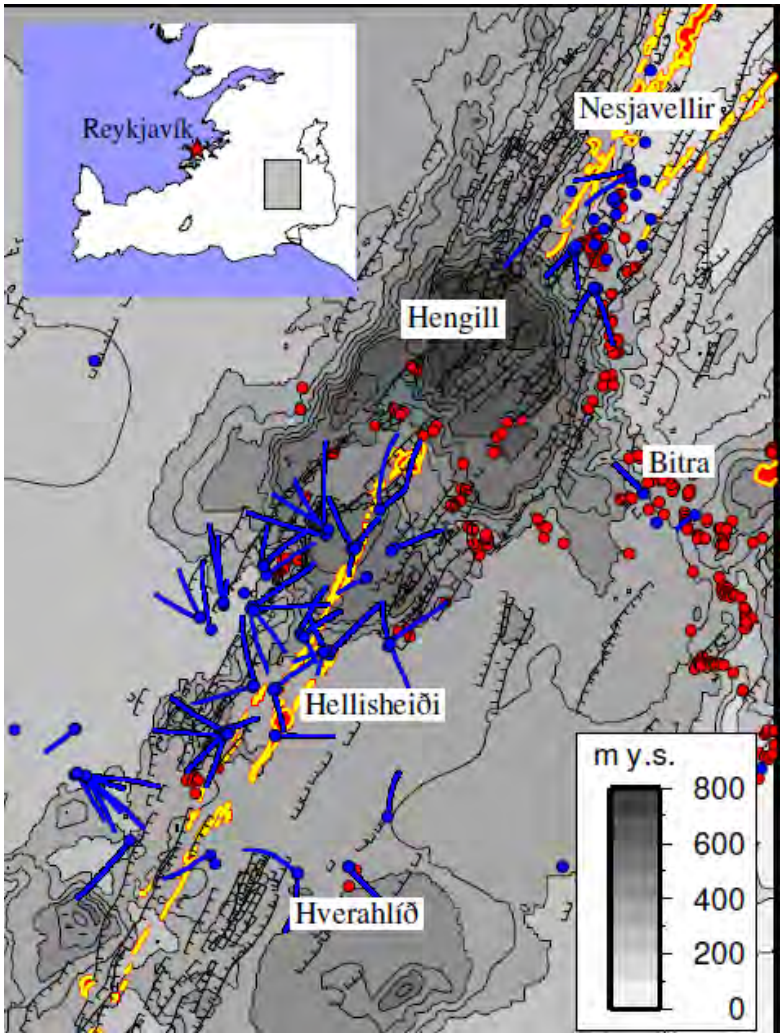
Nesjavellir (1990)

-120 $MW_{electric}$, 300 $MW_{thermal}$

Hellisheiði (2006)

-303 $MW_{electric}$, 133 $MW_{thermal}$

The plants supply the district heating system with hot water - keeps Iceland warm!

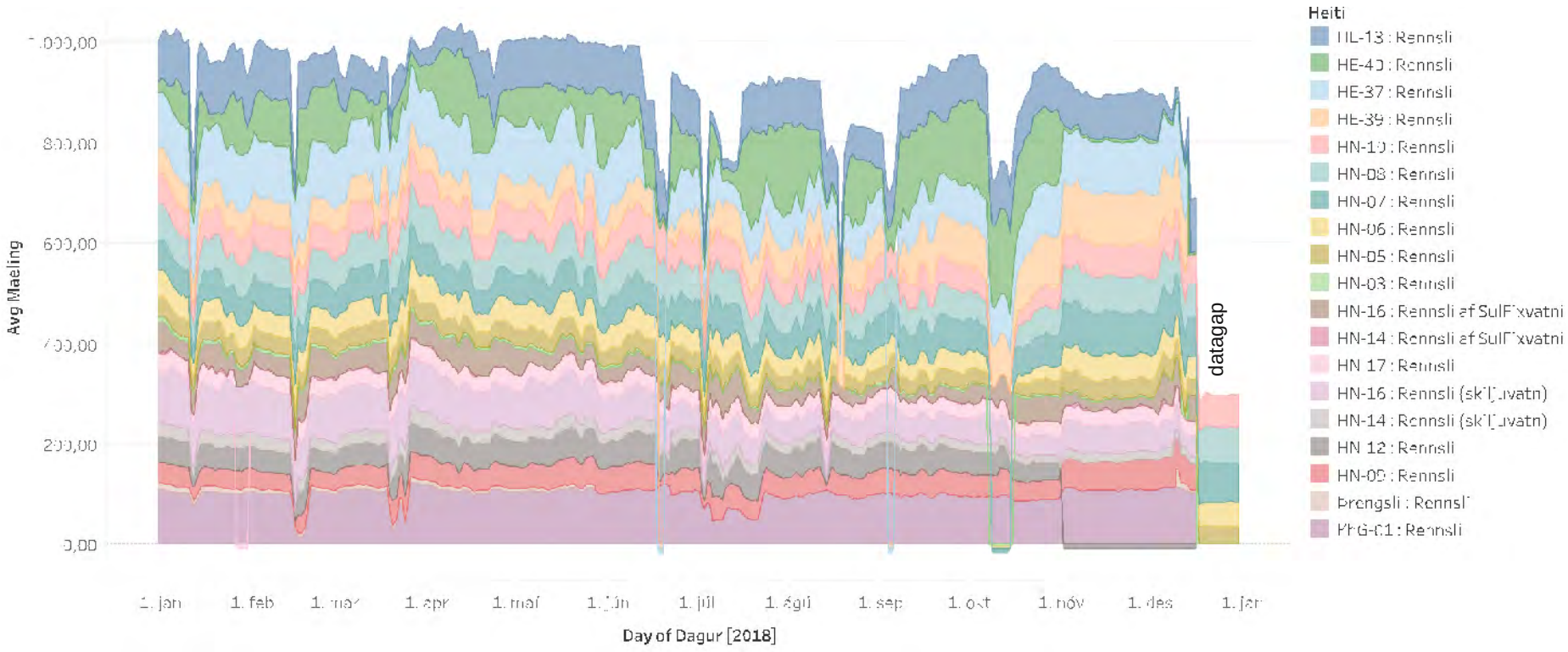


Reykjavík Energy

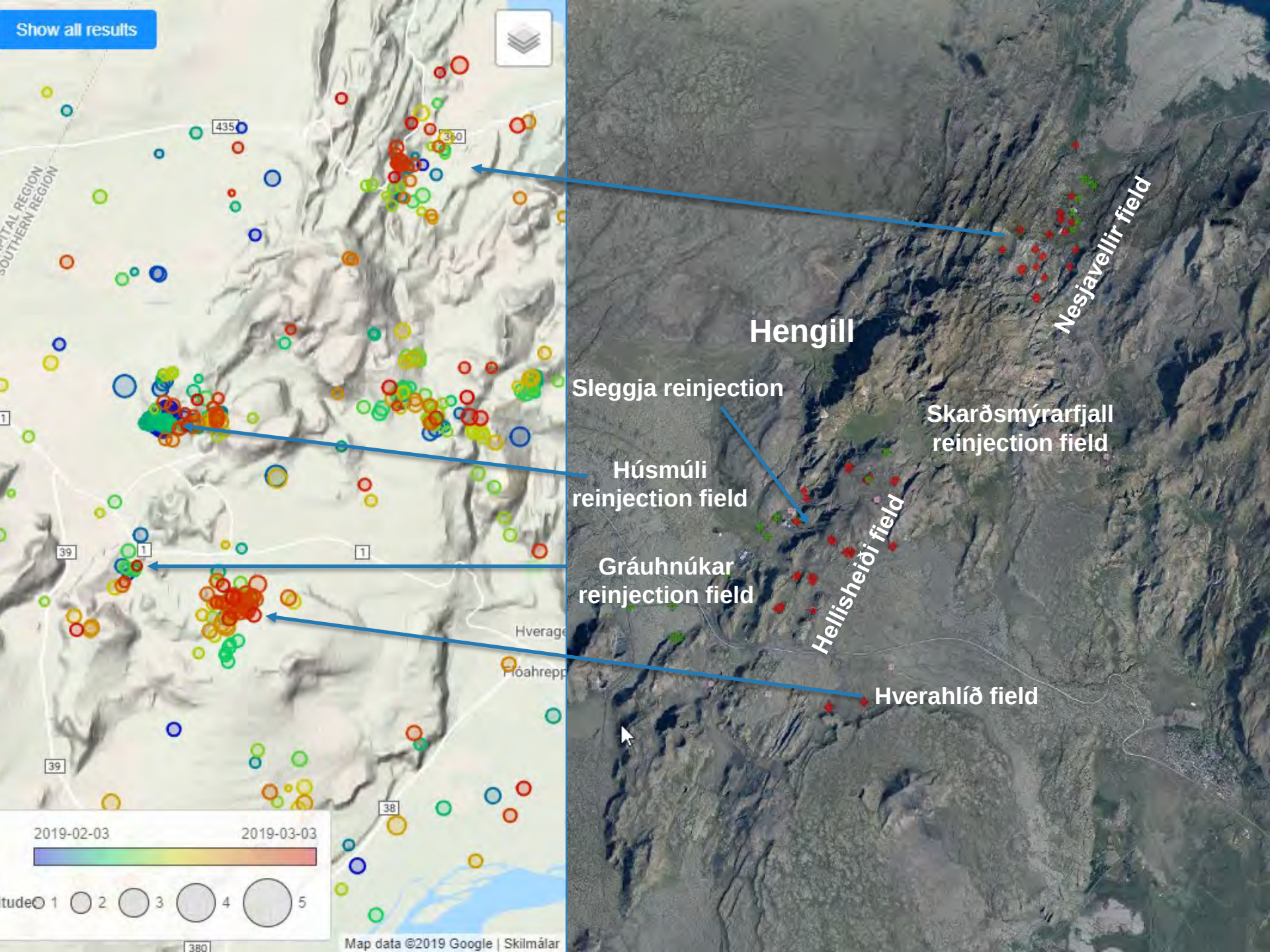
Hellisheiði Reinjection

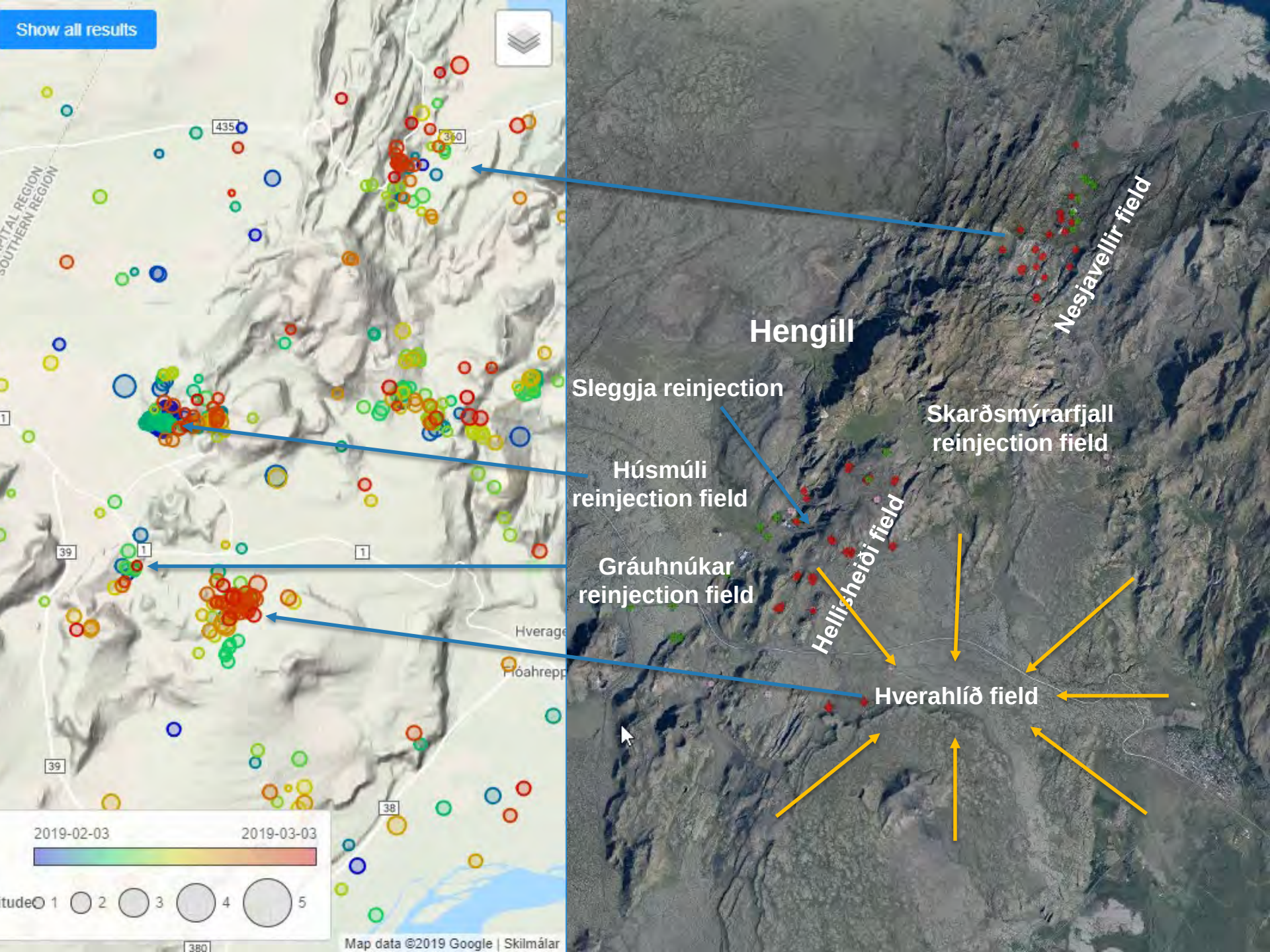
- Large scale (~900-1000 l/s), and dynamic
- 17 injection wells distributed over 4 reinjection areas

Average flowrate per well



Reykjavík Energy


Show all results
2019-02-03
2019-03-03
Map data ©2019 Google | Skilmálar
Hengill
Nesjavellir field
Sleggja reinjection
Skarðsmýrarfjall
reinjection field
Húsmúli
reinjection field
Hellisheiði field
Gráuhnúkar
reinjection field
Hverahlíð field


Show all results
435
360
39
1
38
380
2019-02-03
2019-03-03
1
2
3
4
5
Map data ©2019 Google | Skilmálar
Hengill
Nesjavellir field
Sleggja reinjection
Skarðsmýrarfjall
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Húsmúli
reinjection field
Hellisheiði field
Gráuhnúkar
reinjection field
Hverahlíð field

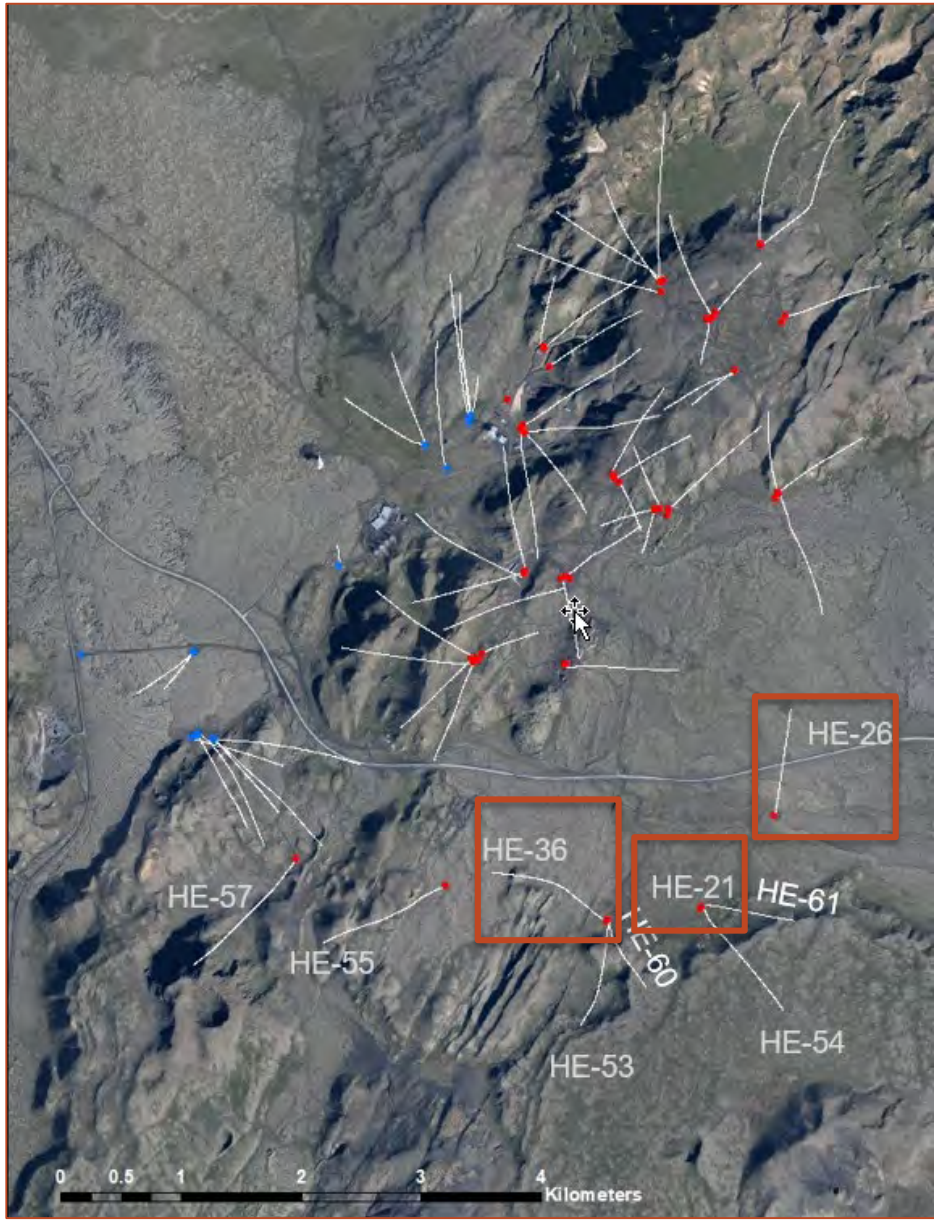
Seven wells drilled to date

HE-21 and HE-26 (2006)

- Hot but (21: 337°!) but so not permeable

HE-36 (2007)

- Permeable but problematic in drilling
- Temperature reversal



Reykjavík Energy

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Commision of Hverahlíð Power Plant (2007)

Orkuveita Reykjavíkur

HVERAHLÍÐARVIRKJUN,
Allt að 90 MW_e
jarðvarmavirkjun

Frummatsskýrsla

Ágúst 2007

Reykjavík Energy

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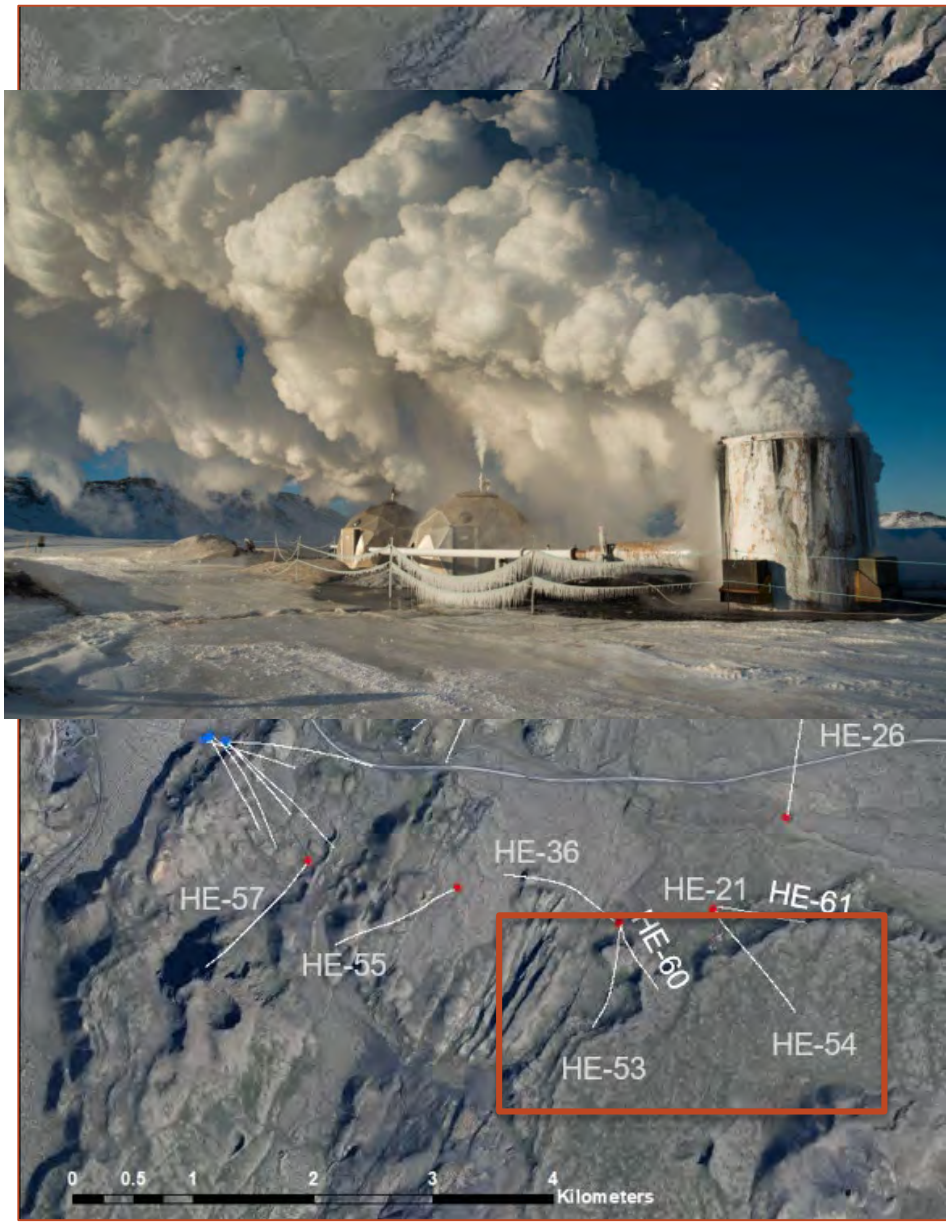
- Drilling of both wells problematic. Drill string stuck during drilling.
- Among the most powerful geothermal wells drilled in the Hengill system



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Reykjavík Energy

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HE-60,61 (2017-2018)

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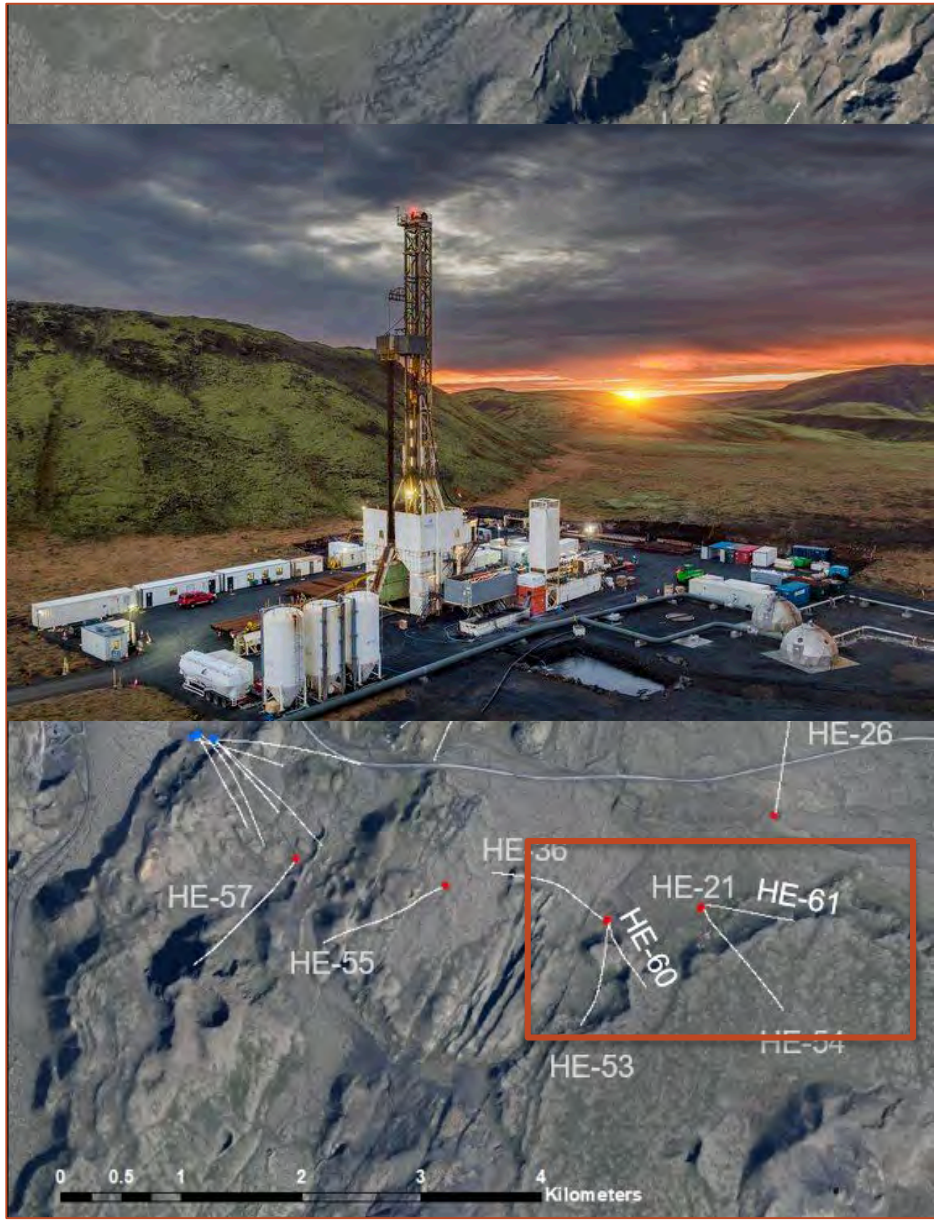
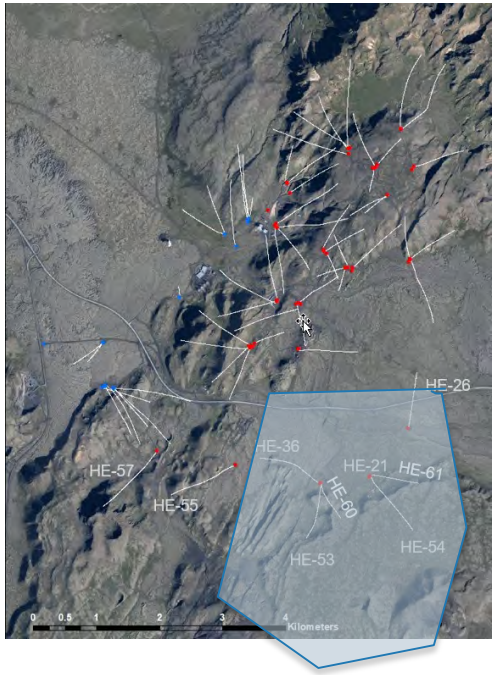
- Among the most powerful geothermal wells drilled in Iceland

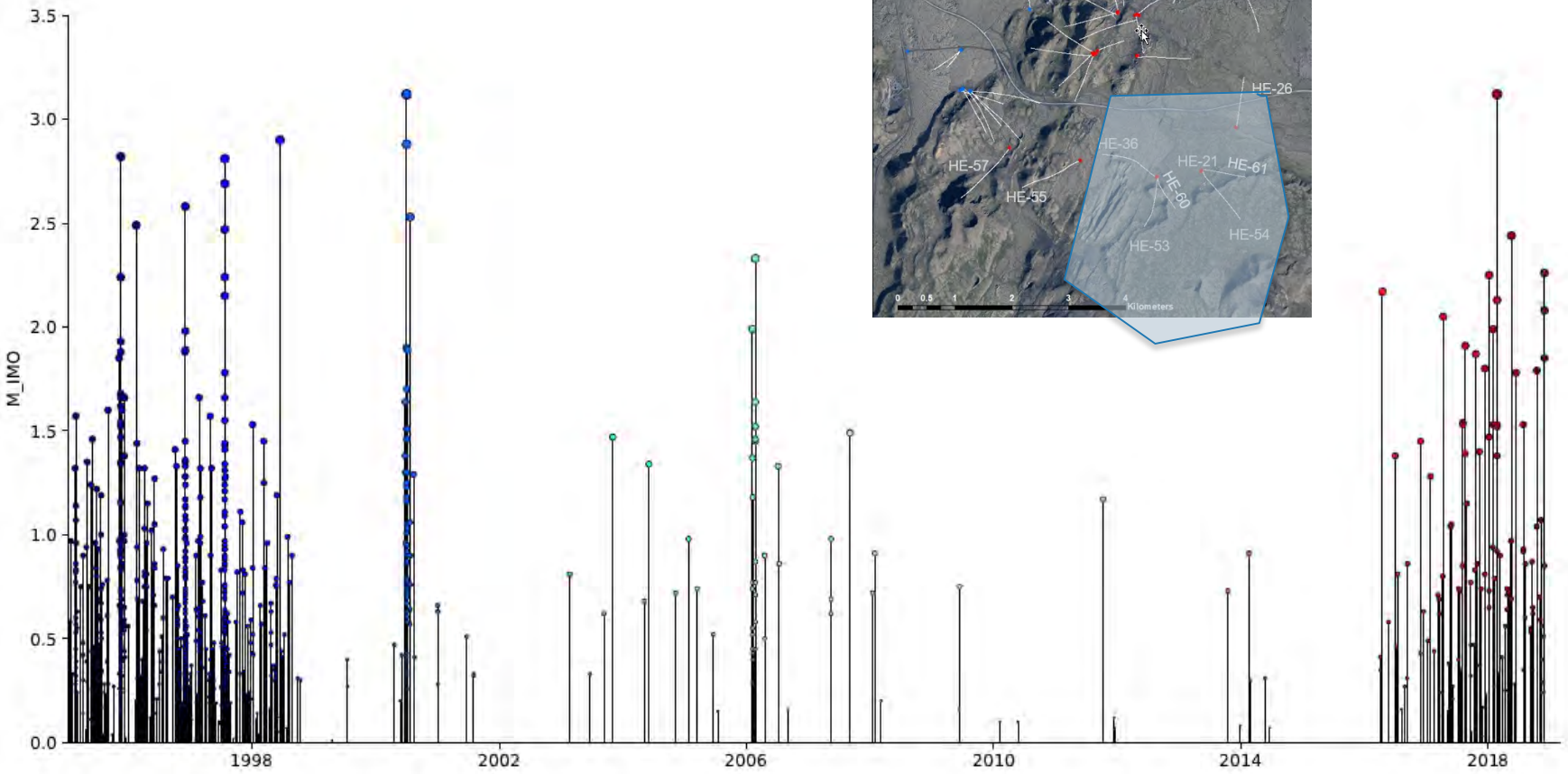


Reykjavík Energy

Hverahlíð

Seismicity last 24 years

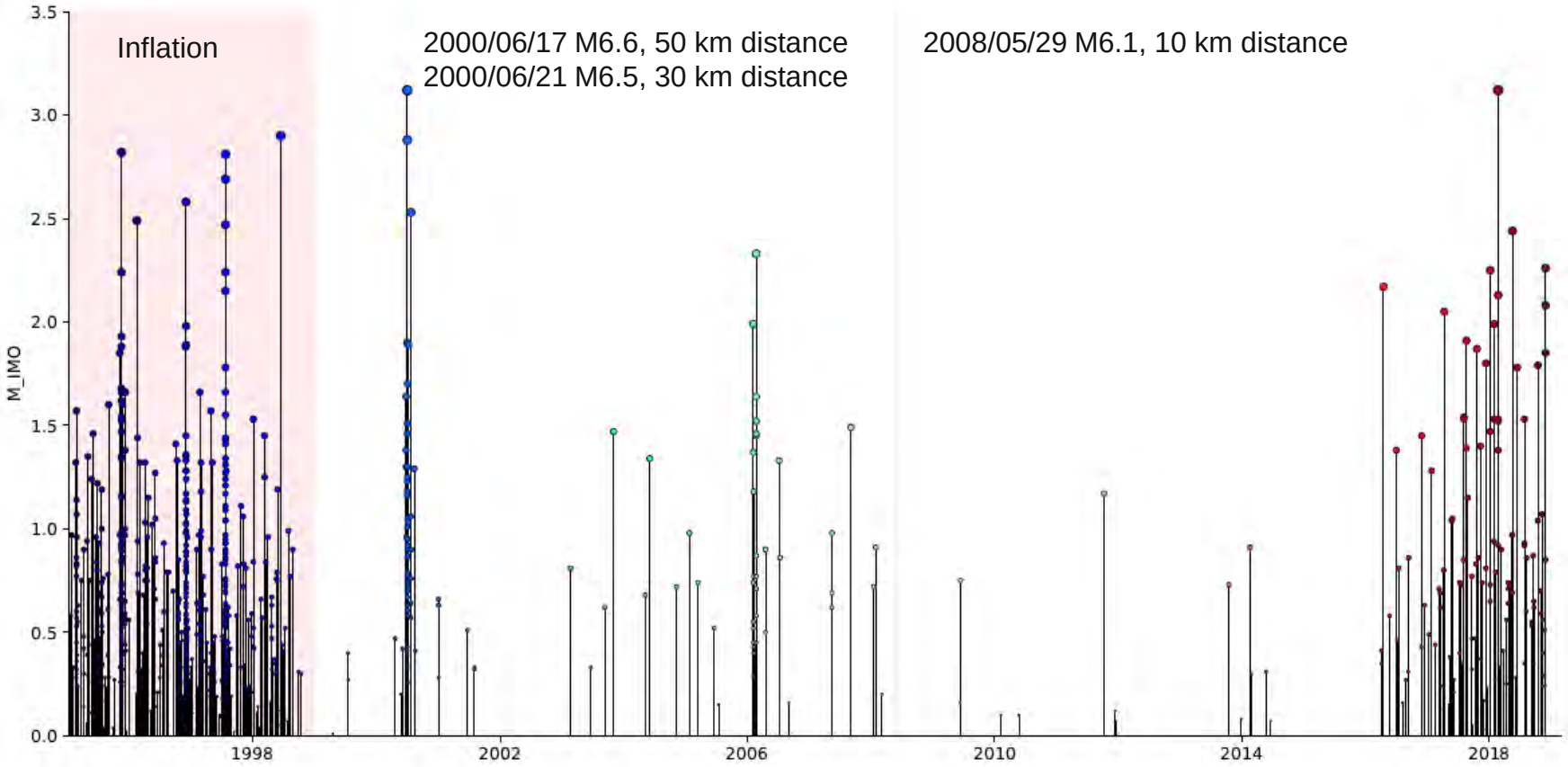




Reykjavík Energy

Hverahlíð

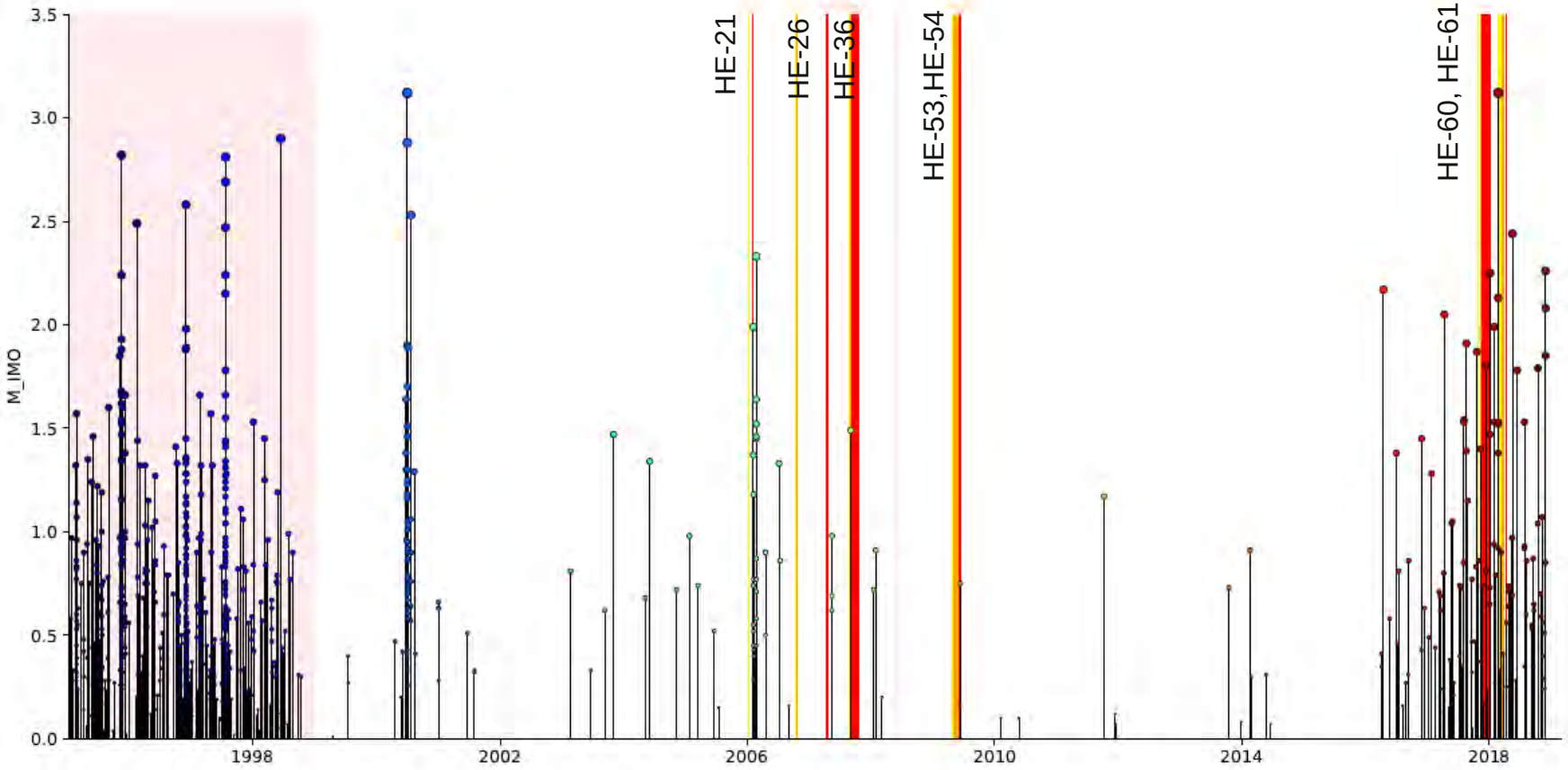
Volcanotectonic events



Reykjavík Energy

Hverahlíð

Drilling (yellow: 0-~100 m, orange: ~100-~900m, red: ~900-2200)



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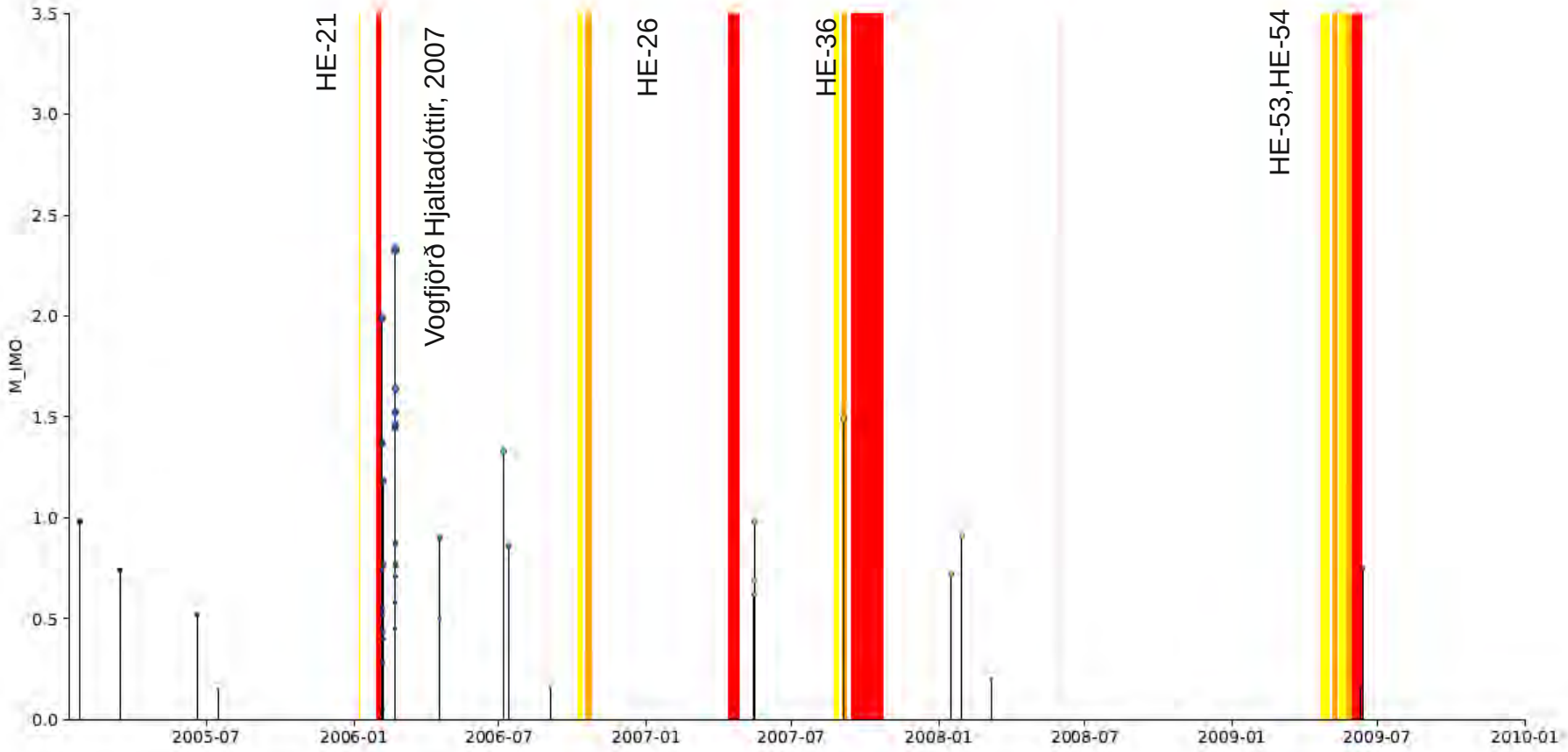

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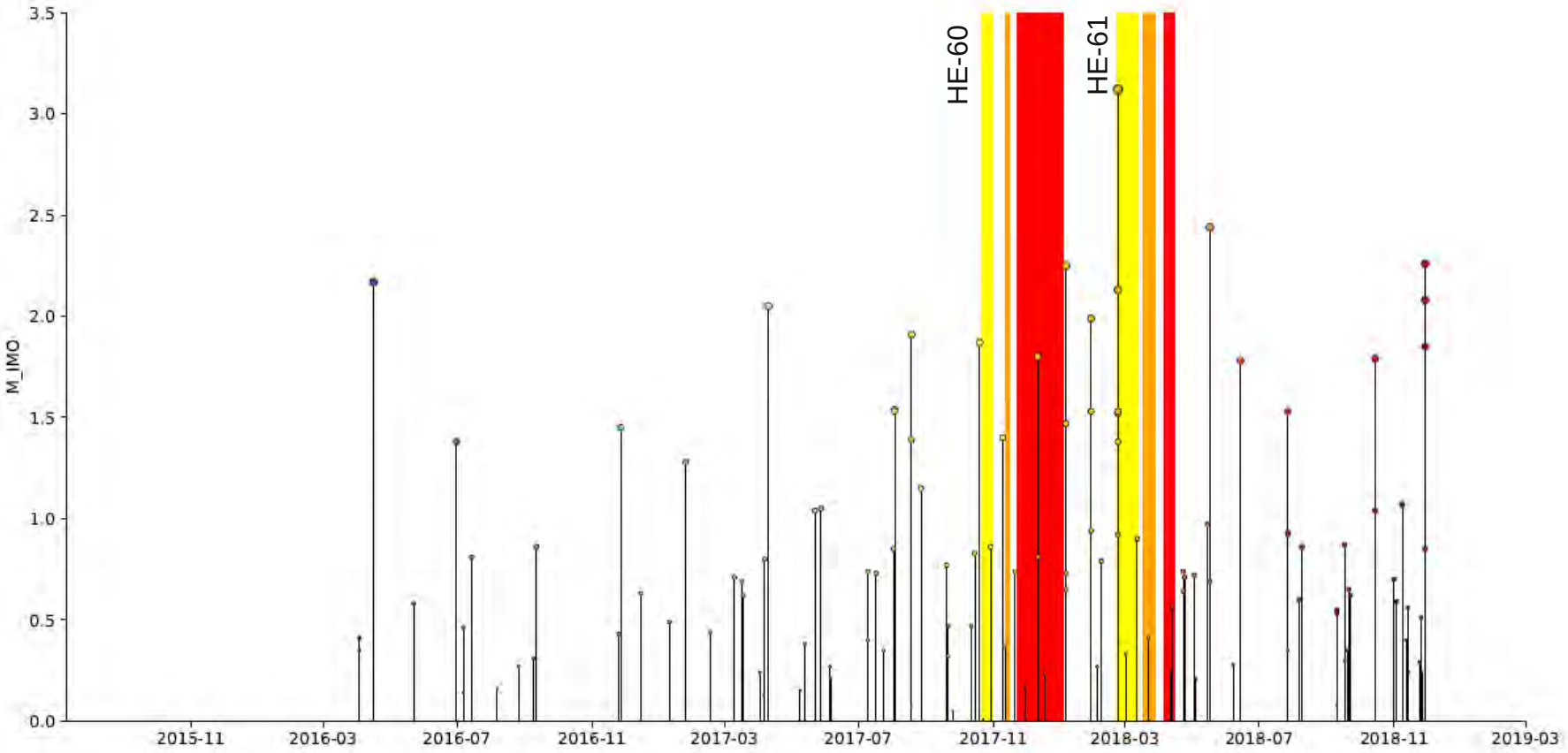
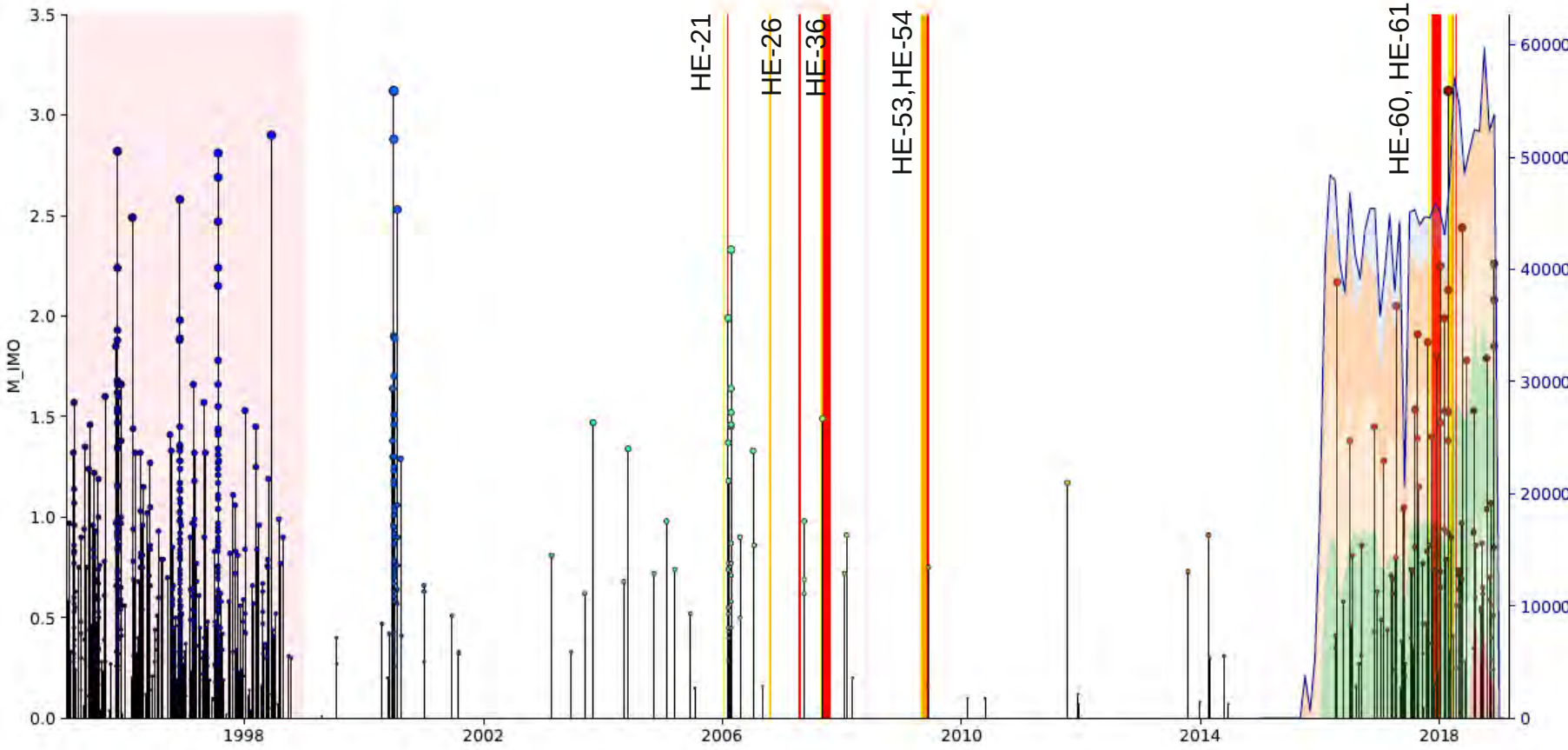


Reykjavík Energy

Hverahlíð

Production (blue) – individual wells, separate colors



Reykjavik Energy

Hverahlíð

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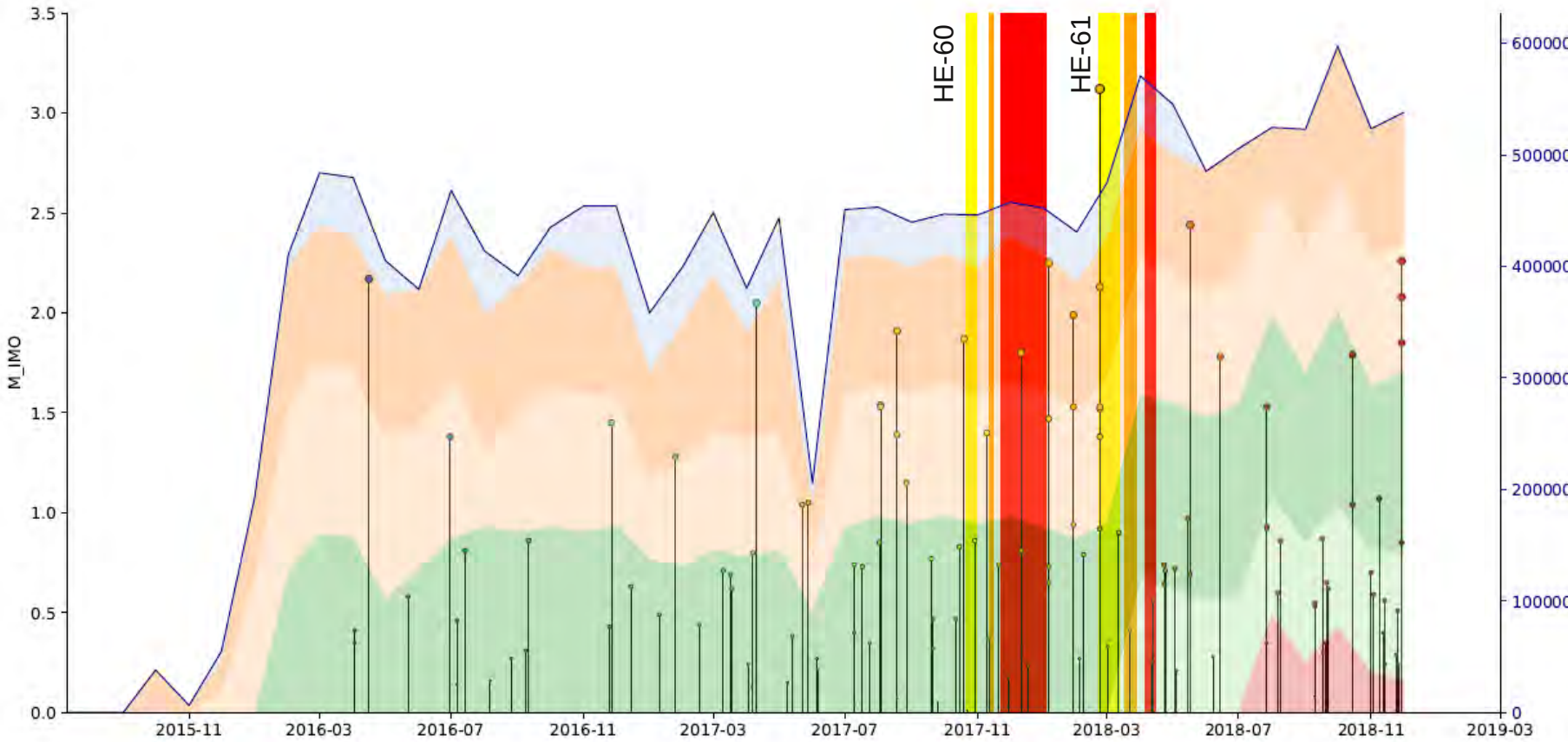


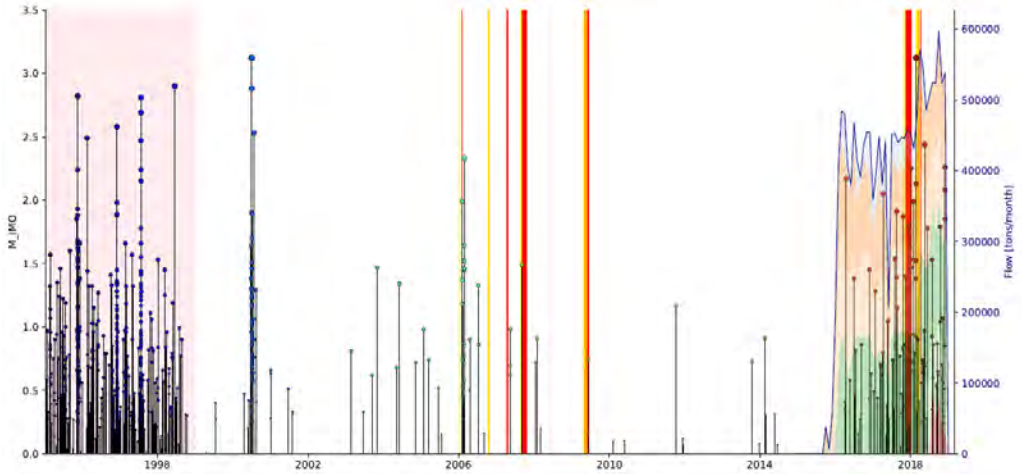
Reykjavik Energy

Hverahlíð

Observations

Hverahlíð responded:

- to the two 2000 events (M6.6, 6.5) about 30-50 km away, but not the 2008 event (M6.1) about 10 km away
- to the drilling of one well out of seven
- Very strongly to production

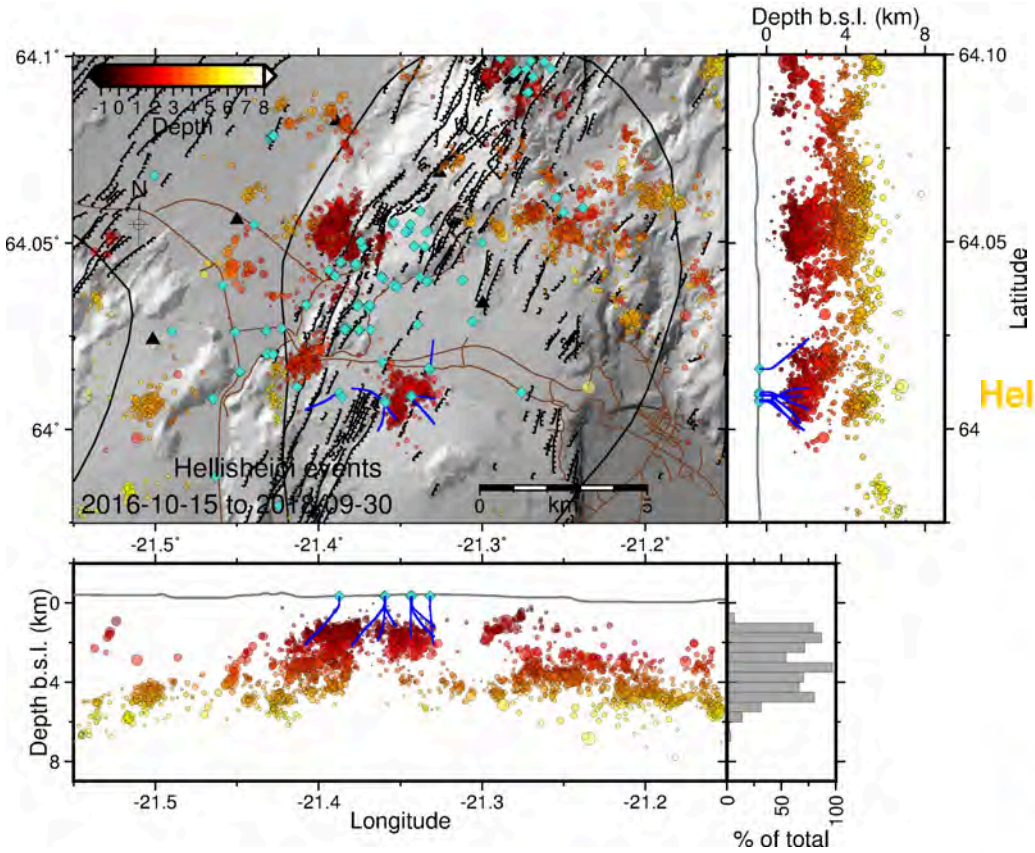


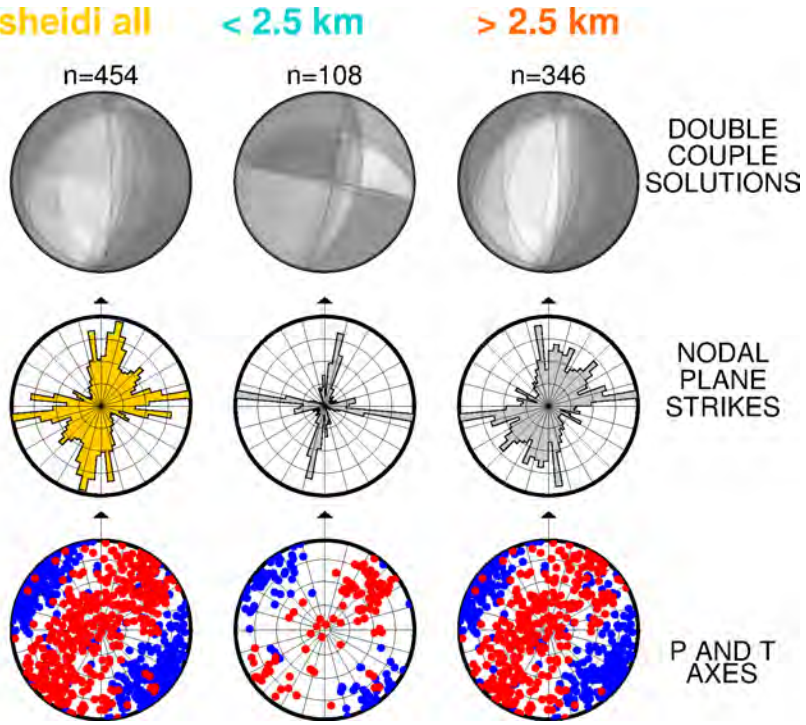
Reykjavík Energy

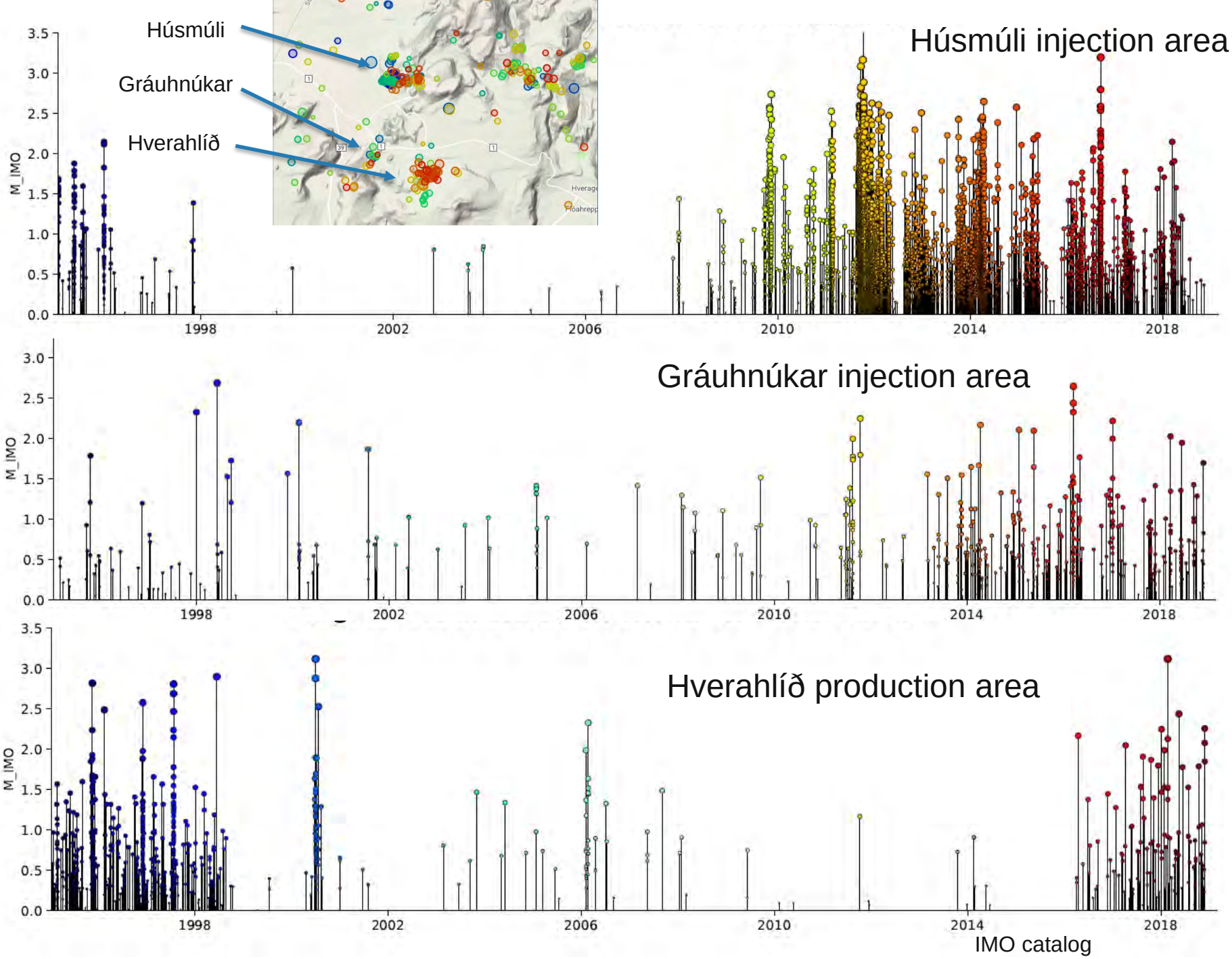
Þorbjörg Ágústsdóttir, ÍSOR –

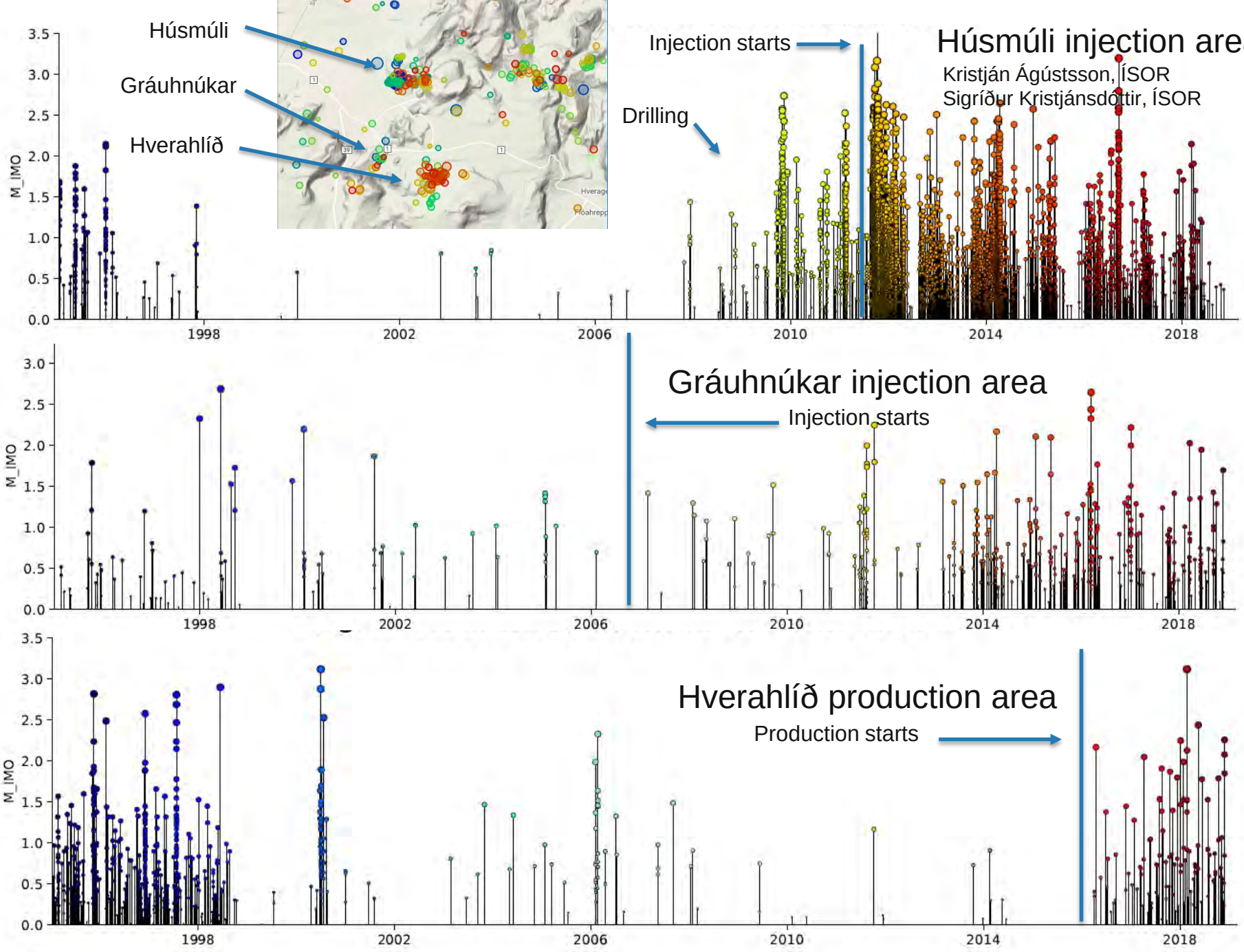
Poster 3441 – board P1-17 Wednesday afternoon:

Seismicity rate and earthquake source mechanisms in the Hengill and Hverahlíð geothermal fields, SW-Iceland, October 2016-2018






Húsmúli
Gráuhnúkar
Hverahlíð
Húsmúli injection area
Gráuhnúkar injection area
Hverahlíð production area
M_IMO
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
1998
2002
2006
2010
2014
2018
IMO catalog


Húsmúli
Gráuhnúkar
Hverahlíð
Injection starts
Drilling
Húsmúli injection area
Kristján Ágústsson, ÍSOR
Sigríður Kristjánsdóttir, ÍSOR
Gráuhnúkar injection area
Injection starts
Hverahlíð production area
Production starts
M_IMO
1998
2002
2006
2010
2014
2018

Observations

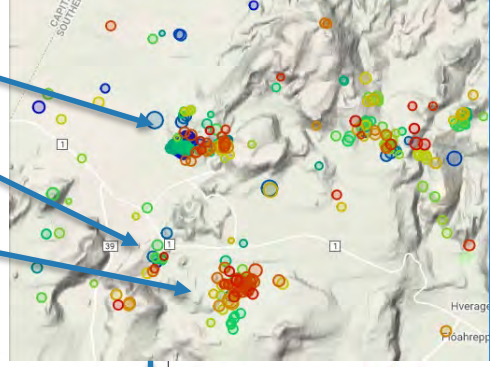
Hverahlíð more active during magmatic event in late 1990s

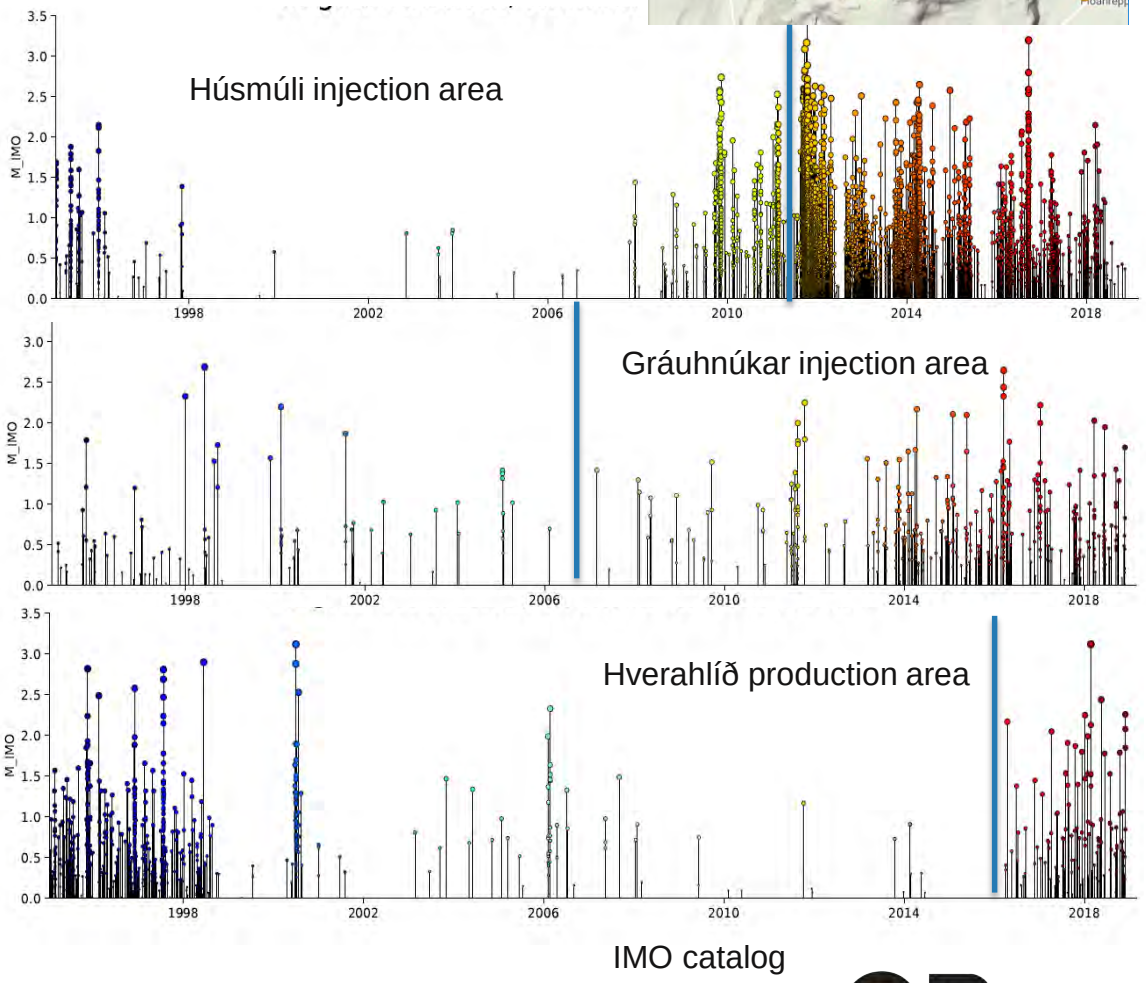
Hverahlíð is only area that responded strongly to events in 2000

Wells in Húsmúli respond much stronger during drilling.

Gráuhnúkar did not immediately respond to injection.

Activity in Húsmúli has decreased with falling injection levels





IMO catalog

Reykjavík Energy

Questions

Hverahlíð more active during magmatic event in late 1990s

Hverahlíð is only area that responded strongly to events in 2000

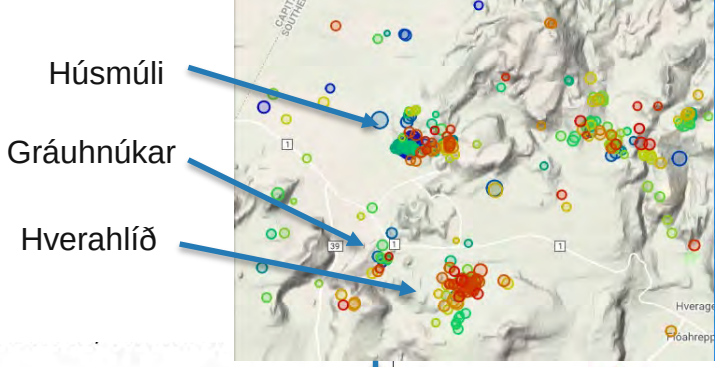
One well out of seven responded to drilling in Hverahlíð

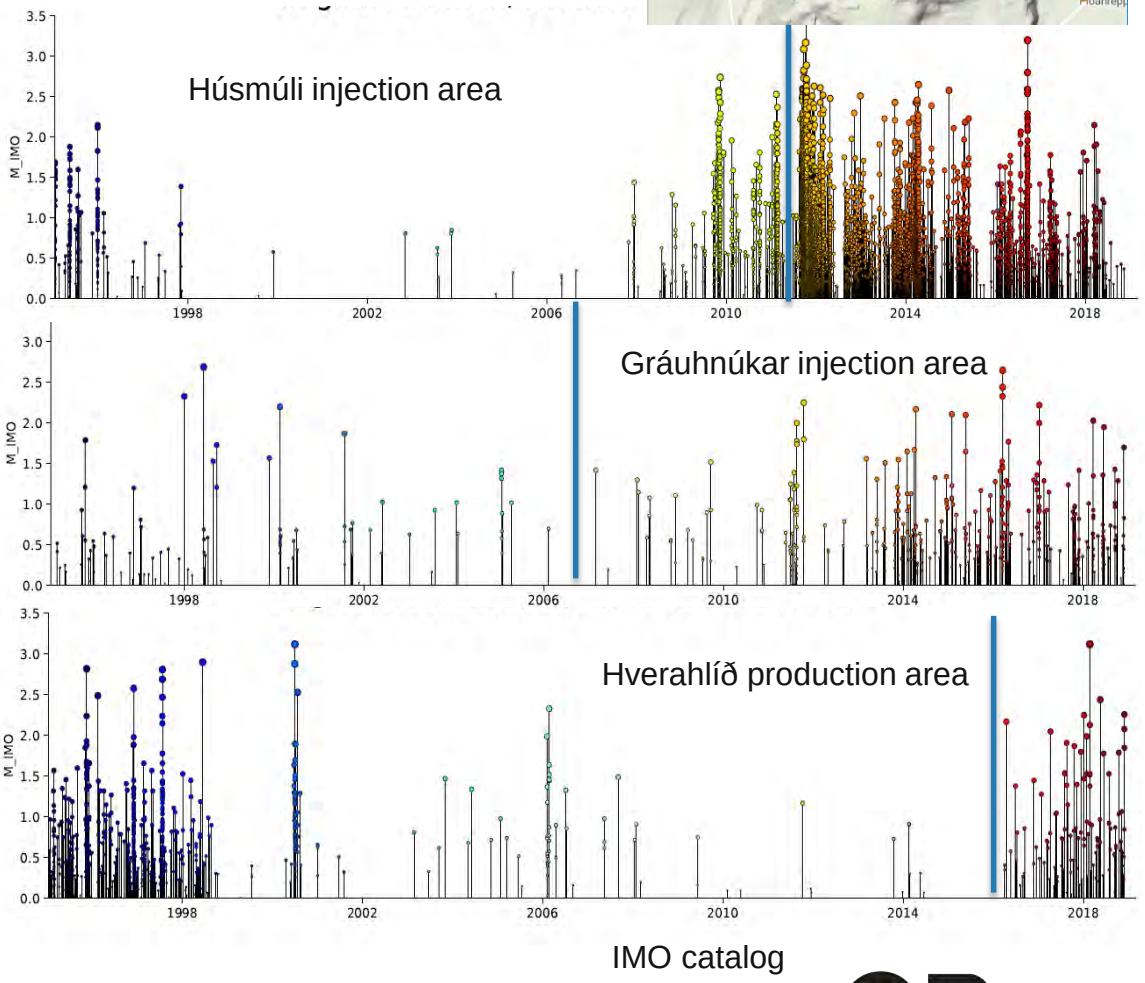
Wells in Húsmúli respond much stronger during drilling.

Gráuhnúkar did not immediately respond to injection.

Activity in Húsmúli has decreased with falling injection levels

WHY?





IMO catalog

Reykjavík Energy

Questions

- Injection (Gráuhnúkar) cause similar level of seismicity as production (Hverahlíð) – why ?
- The most productive area responds strongest to production – why?
- Can we use the induced seismicity to tell us where to drill?
- Does the seisicity line up on fluid bearing fractures? Or are those aseismic?
- How are the seismicity, the extreme permeability and problems in drilling related?
- And many more!

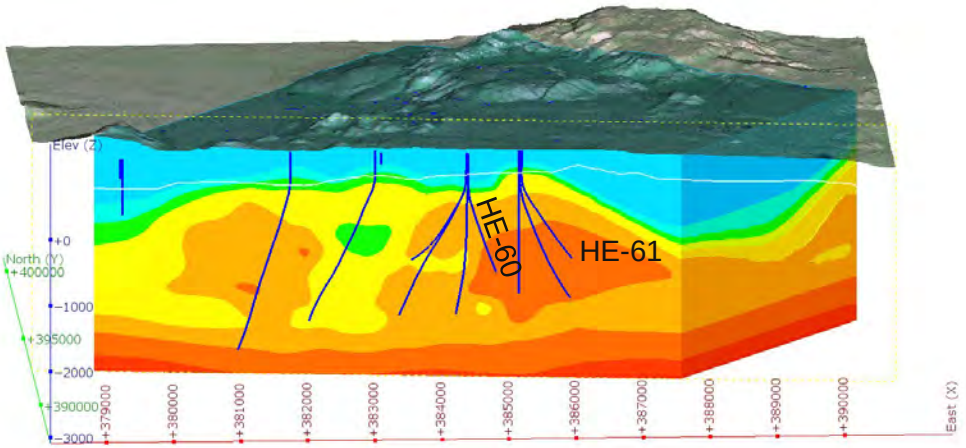
Reykjavík Energy

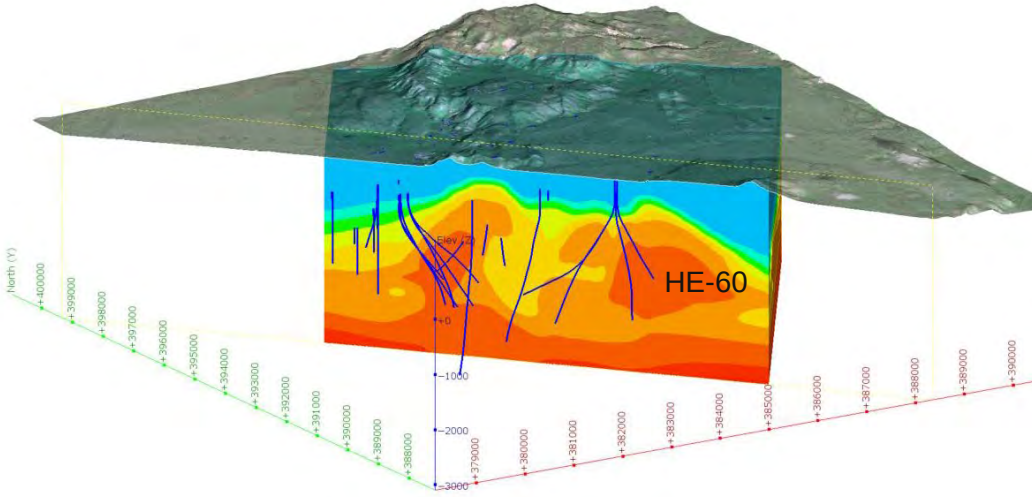
Thank you

Reykjavík Energy

Temperatures in Hverahlíð

- As previously mentioned, highest temperatures measured in S-Hengill
- Highest quartz temperatures in wells in Hverahlíð
- Young system. Alteration minerals vs. formation temperatures indicate that the area is warming up.
- Depth of alteration minerals greater than in HH and NV
- Recent magmatic activity in Hverahlíð?





Reykjavík Energy

The Hverahlíð power plant

- In 2007(!) a decision is made to continue geothermal exploration for the commission of the Hverahlíð plant
- Based on the three wells + surface manifestations + resistivity measurements (TEM) at the site
- A 90 MWe power plant
- Exploration to be started the same year (2007)
- The plant up and running in 2010

Orkuveita Reykjavíkur

HVERAHLÍÐARVIRKJUN,
Allt að 90 MW_e
jarðvarmavirkjun

Frummatsskýrsla

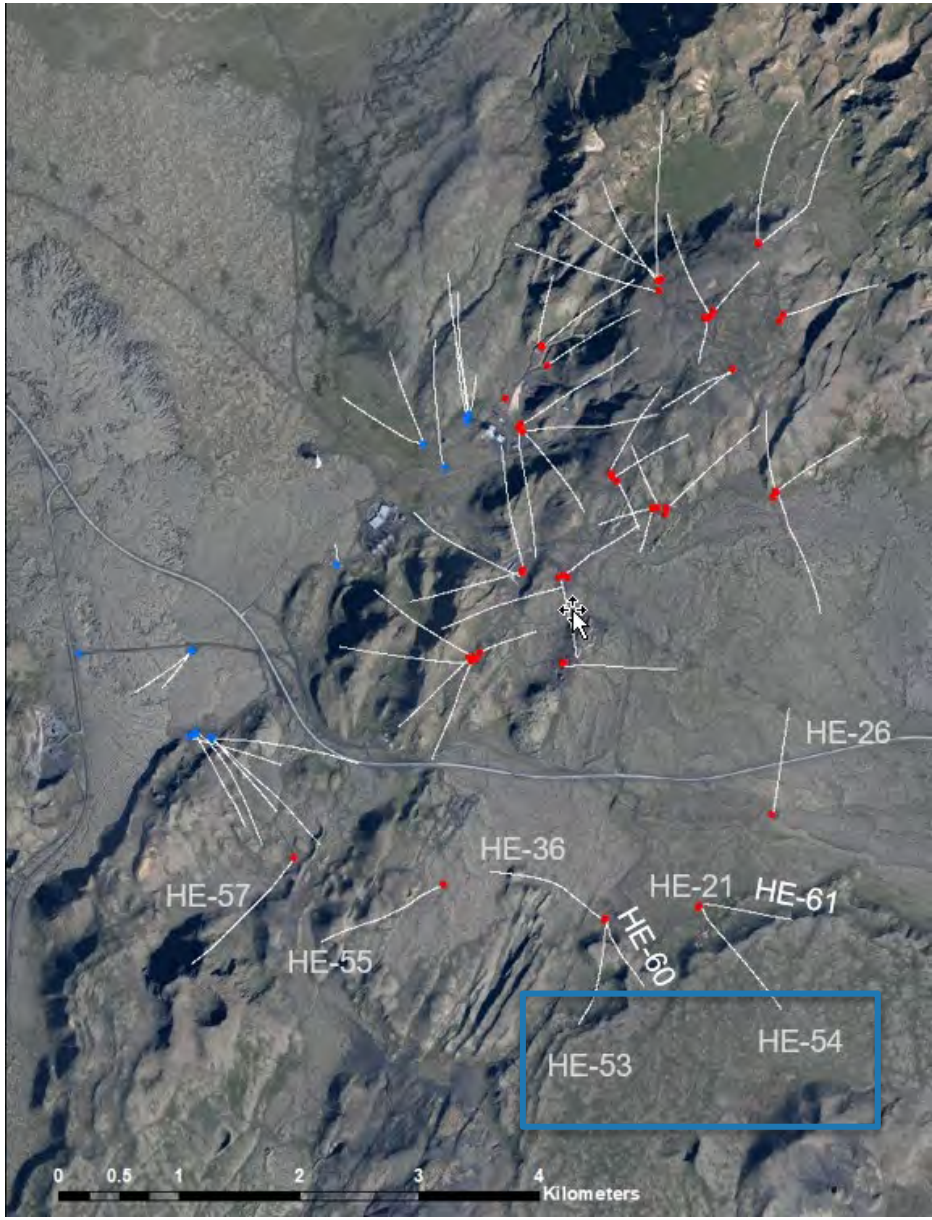
Ágúst 2007

OR Reykjavík Energy

Seven wells drilled to date

- Preparation phase

- The „sisters“ HE-53 and HE-54
- Drilled in 2009;
  - HE-53: 2507 m,
  - HE-54: 2436 m,
- Drilling of both wells problematic. Drill string stuck during drilling.
- Among the most powerful geothermal wells drilled in the Hengill system
- Good news for Hverahlíð power plant!



Reykjavík Energy


IE-54

The Hverahlíð power plant

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CANCELLED

Orkuveita Reykjavíkur

HVERAHLÍÐARVIRKJUN,
Allt að 90 MW_e
jarðvarmavirkjun

Frummatsskýrsla

Ágúst 2007

Reykjavík Energy

Problems in maintaining power production at Hellisheiði Power Plant

- The Hellisheiði field not able to sustain the production of the 303 MWe installed capacity
- Decision made to build a pipeline from Hverahlíð to supply the plant
- The Hverahlíð pipeline up and running in 2016

Iceland Geothermal Power Plant Unsustainable

Studies of the Hengill geothermal area off the capital region have concluded that the area currently exploited by the Hellisheiðarvirkjun power plant, run by Reykjavík Energy (OR), will not be able to supply the plant with energy for full production long term.

Electricity production has already be

The area currently exploited by the p
rapidly.

According to ruv.is, Left Green MP Lil

Hellisheiðarvirkjun ósjálfbær

10.06.2013 - 07:29 · Innlent · Höfuðborgarsvæðið · Suðurland · Tækni og vísindi · Umhverfismál

Dalandi vinnslugeta Hellisheiðarvirkjunar

11. júní 2013

Hverahlíð · Reykjafell · Stóri Meitill · Dauðadalur · Innstidalur · Hverfell · Skarðsmýrarfjall · Hellisheiðarvirkjun · Sleggjuás · Sleggja · Husmúli

Samdráttur er að verða í raforkuframleiðslu Hellisheiðarvirkjunar vegna niðurdráttar í

ndur ekki undir fullri

ritna í gögn sem blaðið hefur

urþartur vinnslu

Hellisheiðarvirkjunar einskorðist við þröngt svæði og lítið virðist vera að finna utan þess. Vinnslusvæði virkjunarinnar sé því minna og ekki eins orkuríkt og talið var. Þegar hafi dregið úr framleiðslu virkjunarinnar.

Haft er eftir Bjarna Bjarnasyni forstjóra Orkuveitunnar að ef ekkert verði gert haldi framleiðslan áfram að minnka, jafnvel nokkuð hratt.

Hlusta

Tengdar fréttir

Ágeng nýtingarstefna ástæða vandræða

Reykjavík Energy


Drilling of HE-60, HE-61
2017-2018

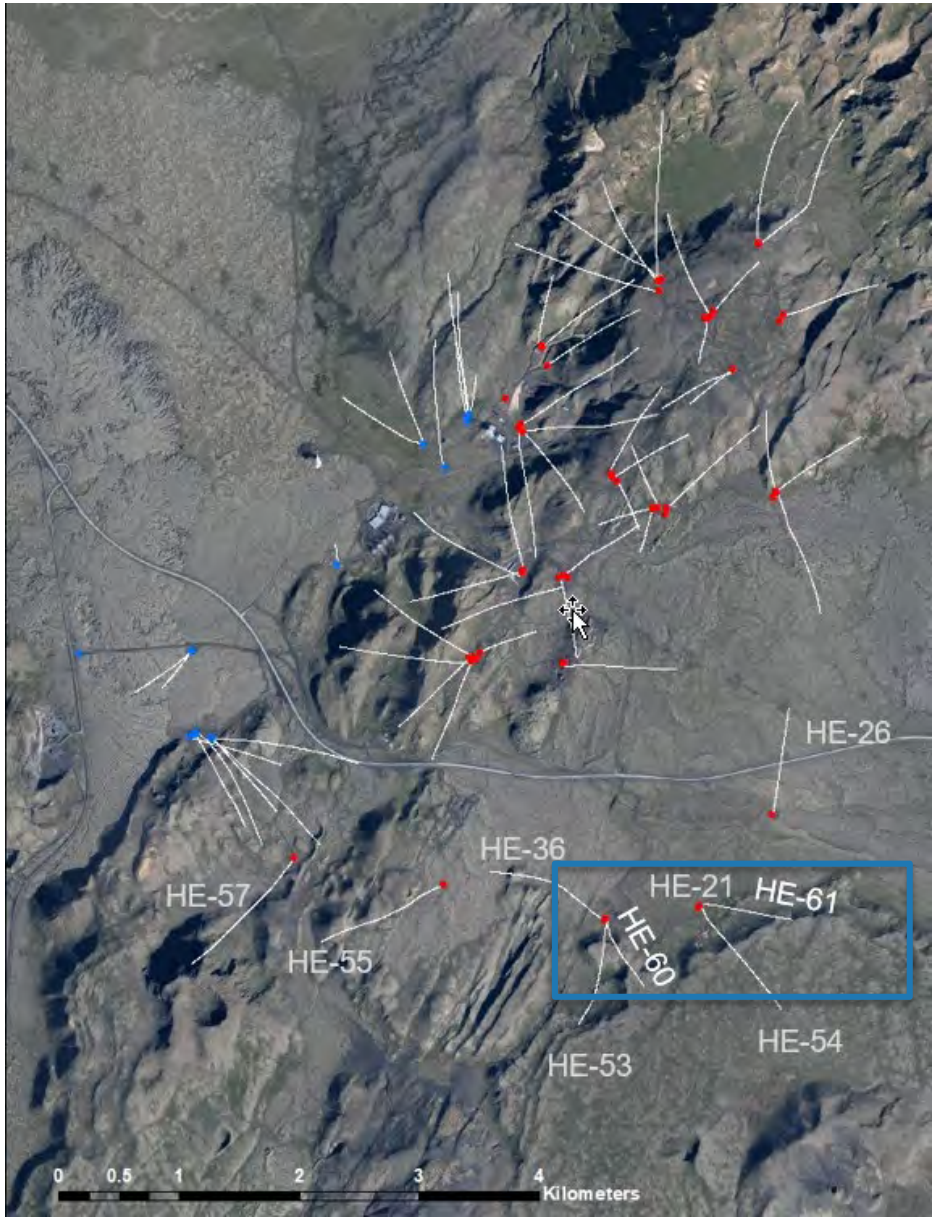
Seven wells drilled to date

Production phase

Sisters HE-60, HE-61 drilled in 2017 and 2018

- Very problematic drilling; drill-string stuck in hole.
- Among the most powerful geothermal wells drilled in Iceland

Both wells now connected and producing



Reykjavík Energy

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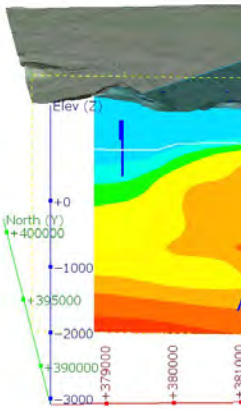
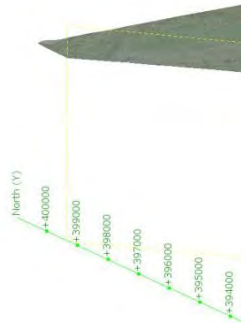
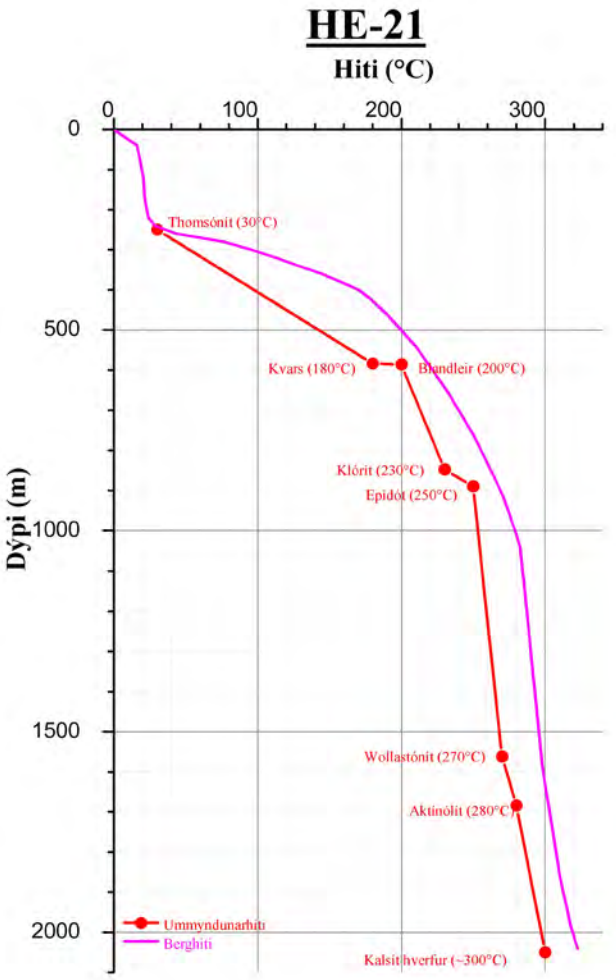


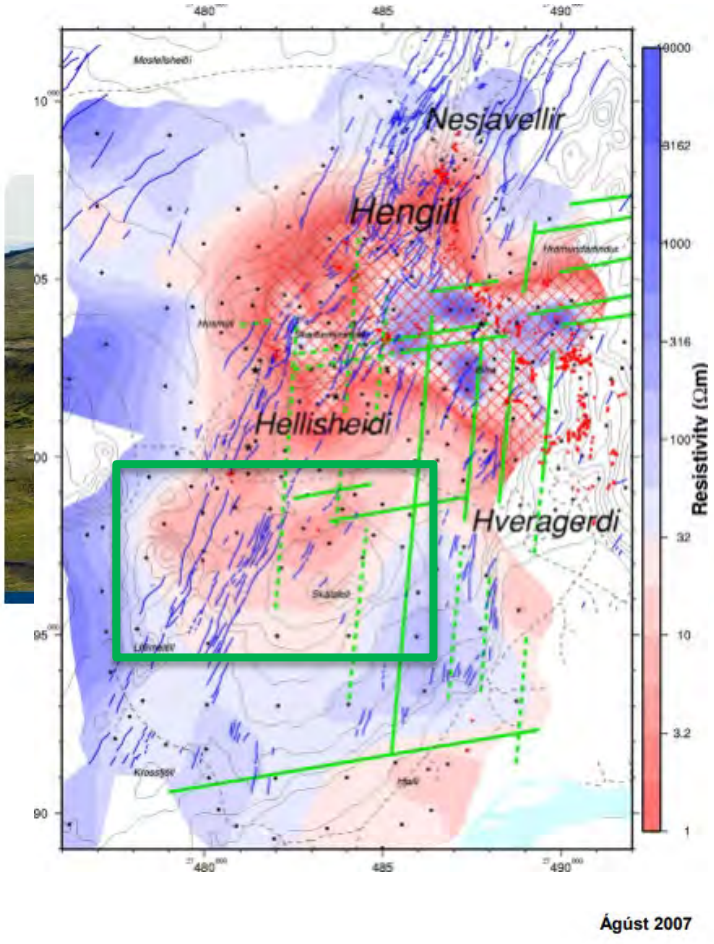




Reykjavík Energy

The Hverahlíð power plant

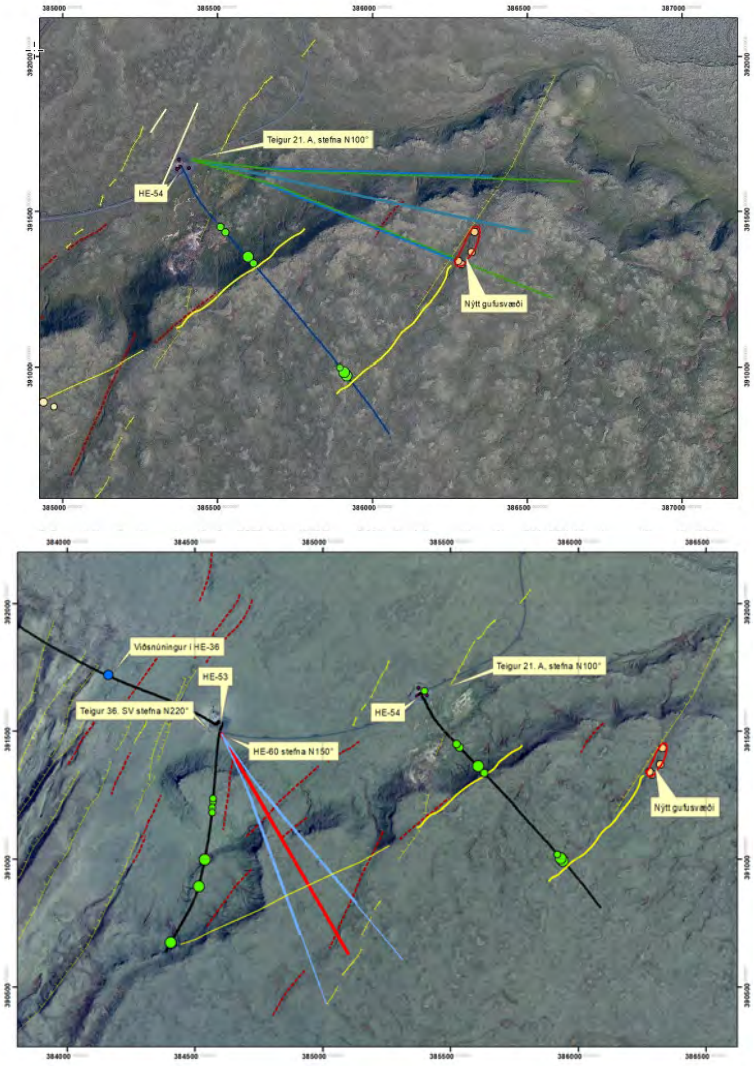
- In 2007(!) a decision is made to continue geothermal exploration for the commission of the Hverahlíð plant
- Based on the three wells + surface manifestations + resistivity measurements (TEM) at the site
- A 90 MWe power plant
- Exploration to be started the same year (2007)
- The plant up and running in 2010



Reykjavík Energy

Permeability in Hverahlíð

- Permeability of the wells seems to be in connection with large faults, which are causing problems in drilling, but seem to be very powerful feedzones
- Intersecting faults; NA-SW faults in connection with the fissure swarm, W-E faults in connection with the SISZ



Reykjavík Energy

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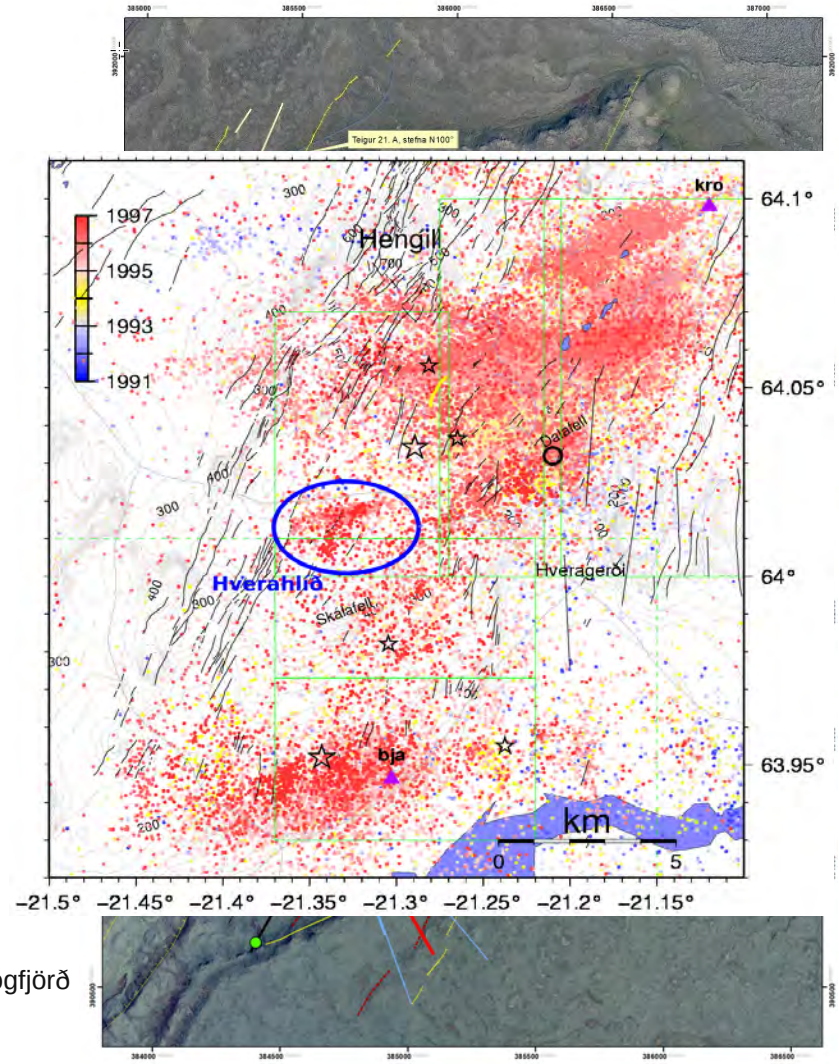


Image from Kristín Vogfjörð

Reykjavík Energy

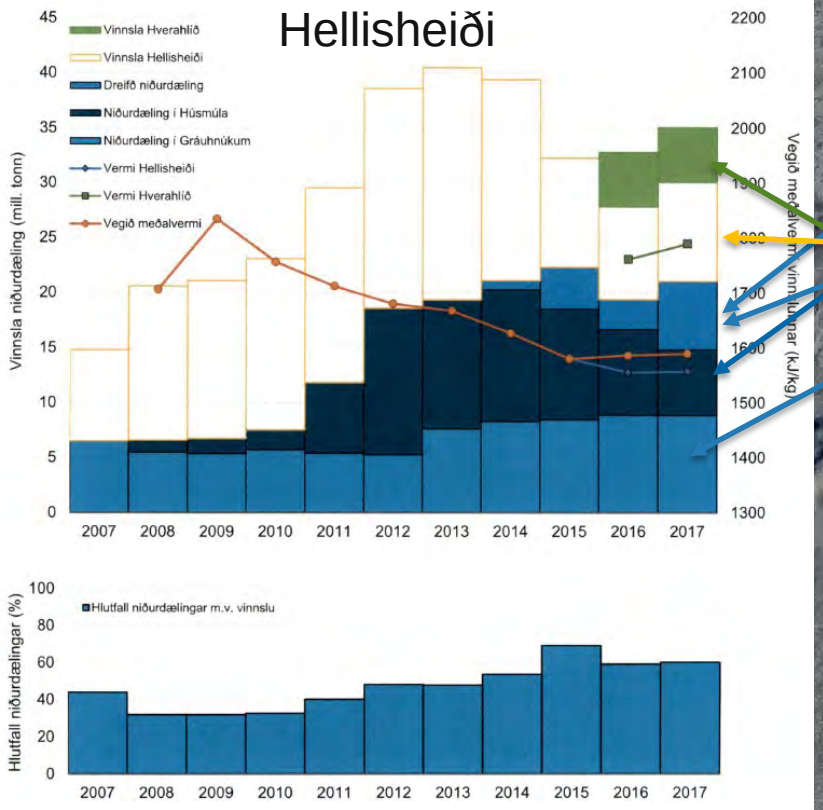
Reykjavík Energy (OR)

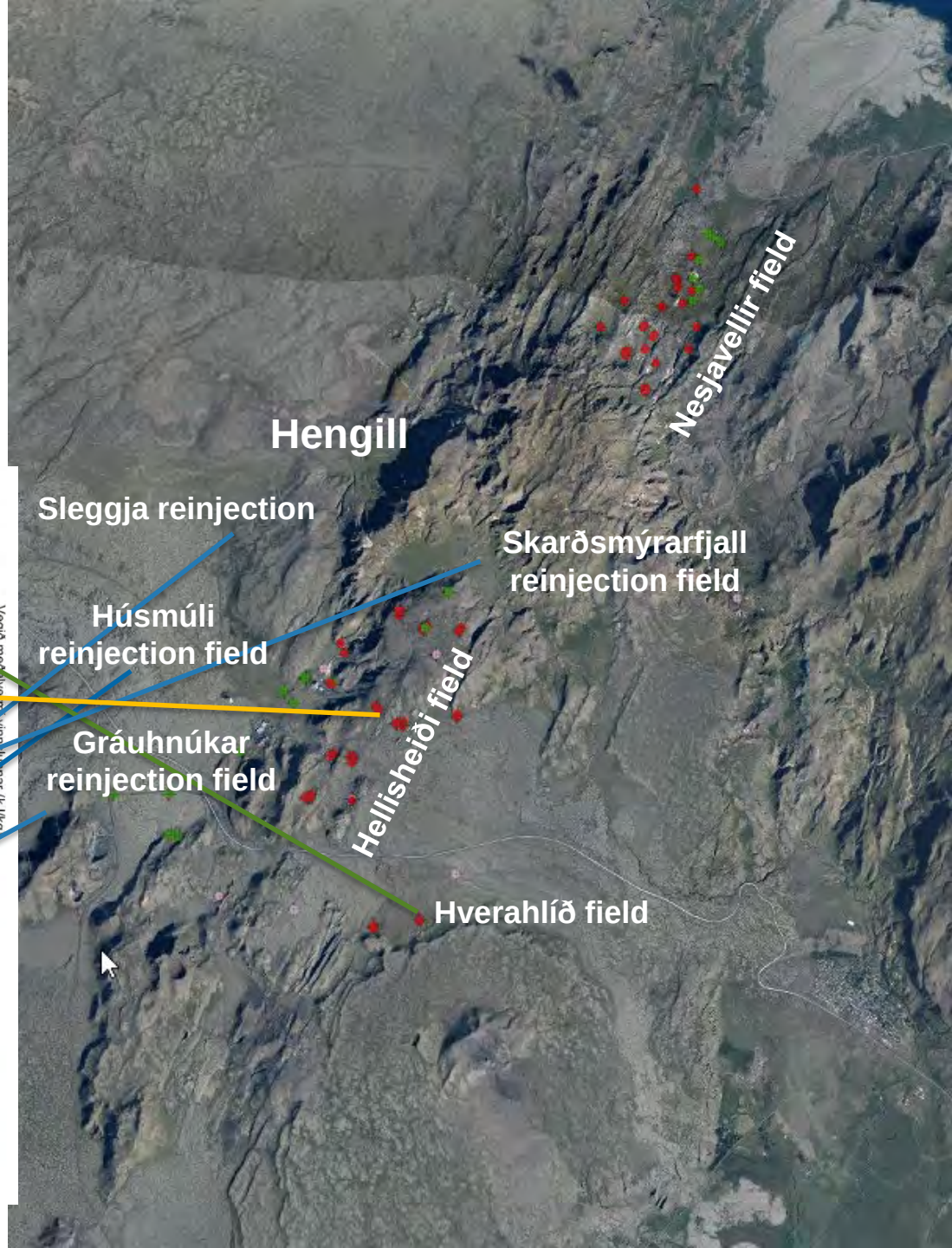
2 power plants:

Hellisheiði & Nesjavellir

63 & 30 production wells

17 & 7 injection wells





Seven wells drilled to date

Production phase

HE-60

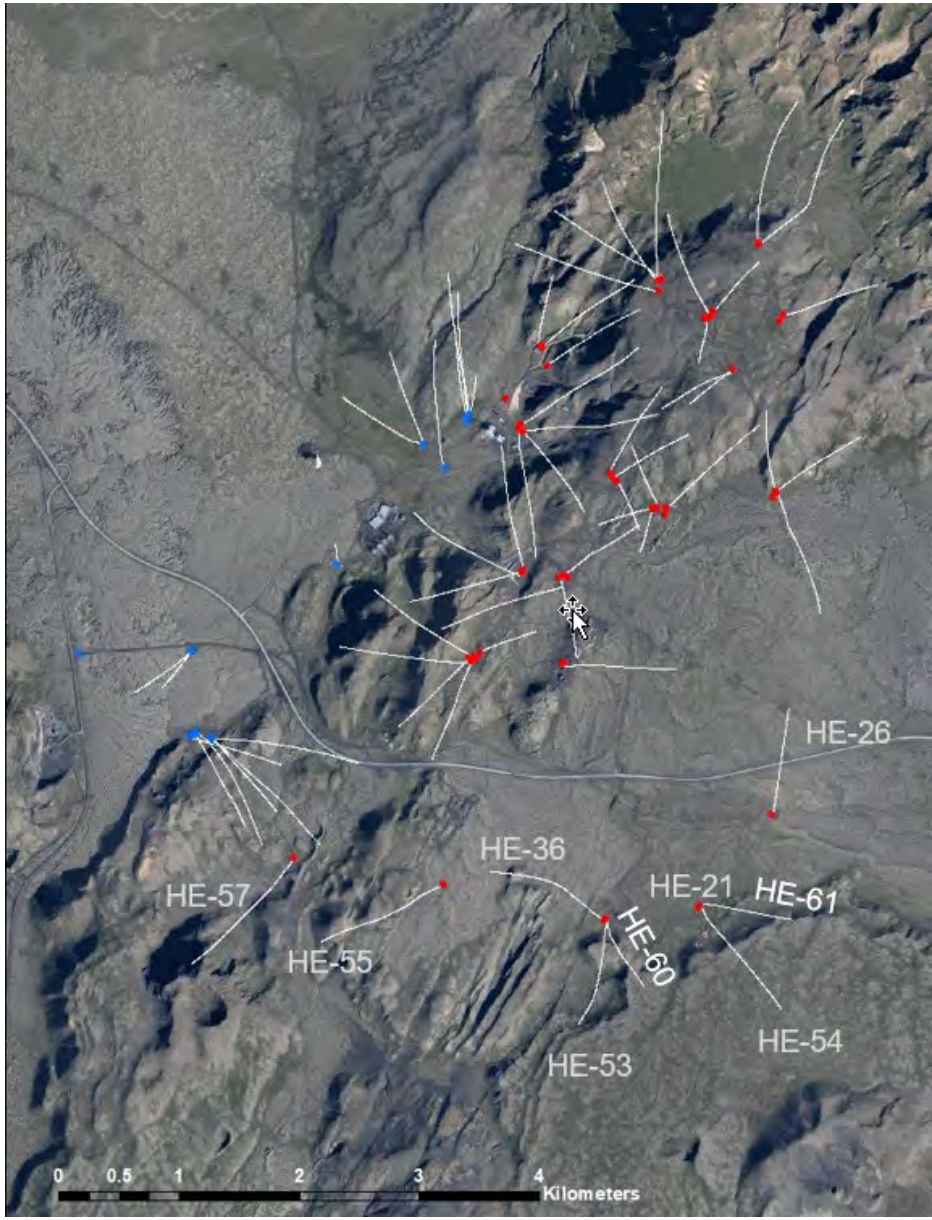
- HE-60 drilled in 2017-2018 from same drill pad as HE-36 and HE-53. Deviated to SA.
- Very problematic drilling; drill-string stuck in hole. Explosives were needed to cut string and back off.
- Drilling was stopped at m depth after drill string got stuck again – but this time the drillers managed to pull string out of hole.

HE-61

- HE-61 drilled in 2018 from same drill pad as HE-21 and HE-54. Deviated to A.
- Drilling was stopped at 1857 m measured depth after drill string got stuck in hole.
- Drillers managed to pull string out of hole.

Blowout tests

- Blowout tests carried out after drilling of the two wells revealed that the wells are both very powerful
- Among the most powerful geothermal wells drilled in Iceland
- Some challanges related to the blowout tests, due to the high flow of steam, but both wells are now connected

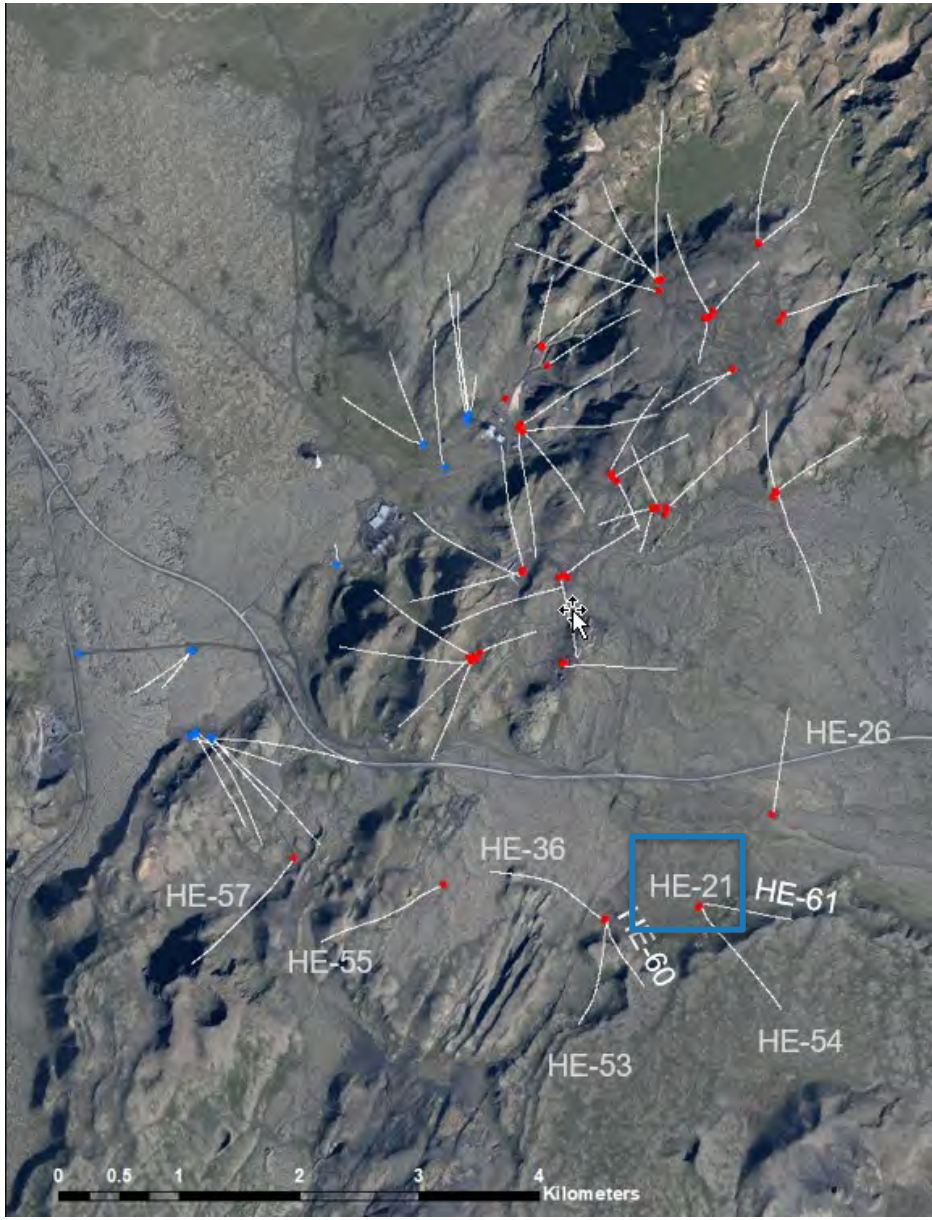


Reykjavík Energy

Seven wells drilled to date

- Exploratory phase

- First well, HE-21, drilled in 2006
  - A vertical well, 2165 m deep
  - Highest temperature measured in the S-Hengill area; 337°C
  - High temperatures, but lacking permeability
- Second well, HE-26, drilled in 2006
  - Deviated to NNA, 2668 measured depth
  - Also quite high temperatures, but even less permeable than HE-21. Third well, HE-36, drilled in 2007
- Third well, HE-36, drilled in 2007.
  - Deviated to W, 2808 measured depth
  - More permeable well but very problematic drilling, including drill string getting stuck in hole
  - T°C logging shows temperature reversal (cooling).



Reykjavík Energy

Seven wells drilled to date

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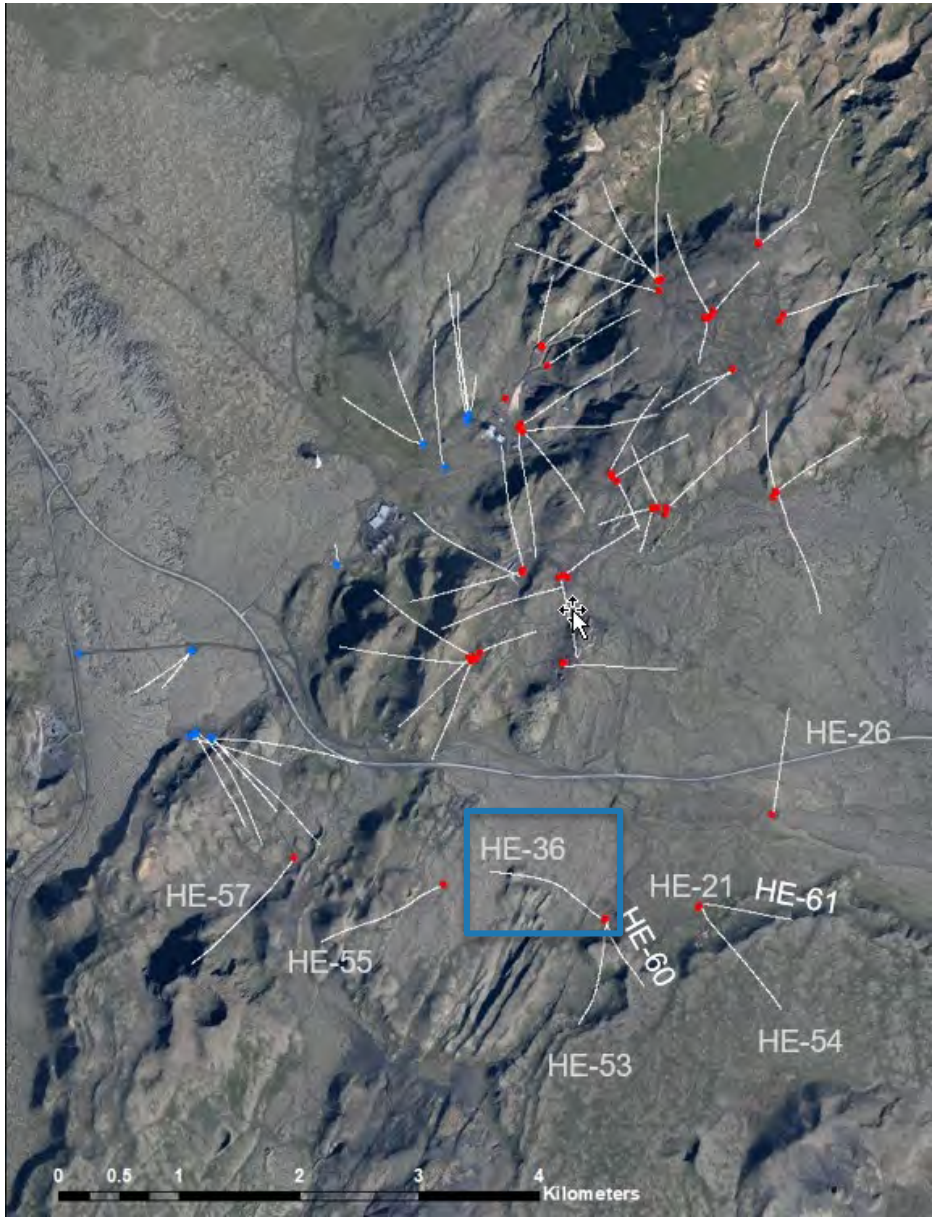

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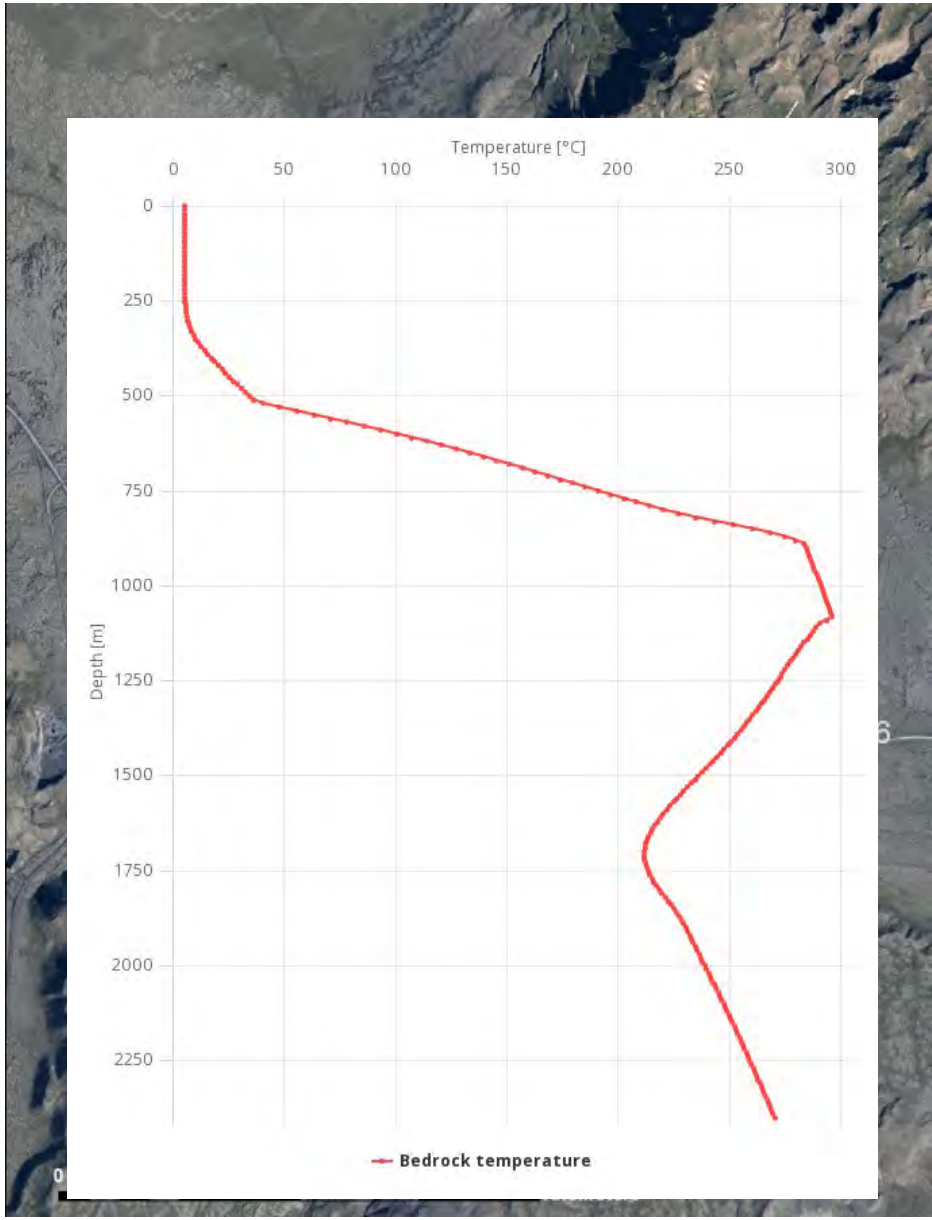

Reykjavík Energy

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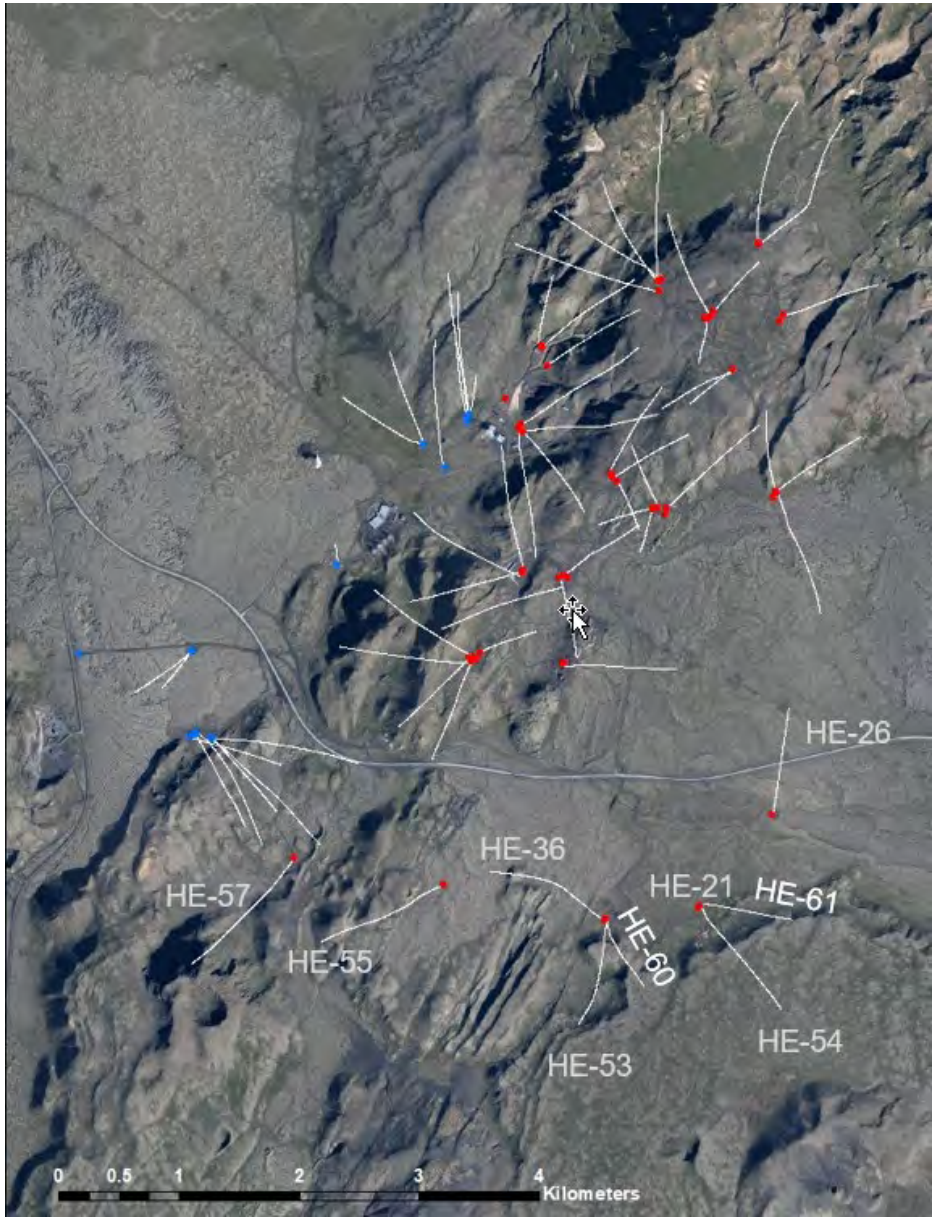

Reykjavík Energy

HE-60 and HE-61 – blowout tests

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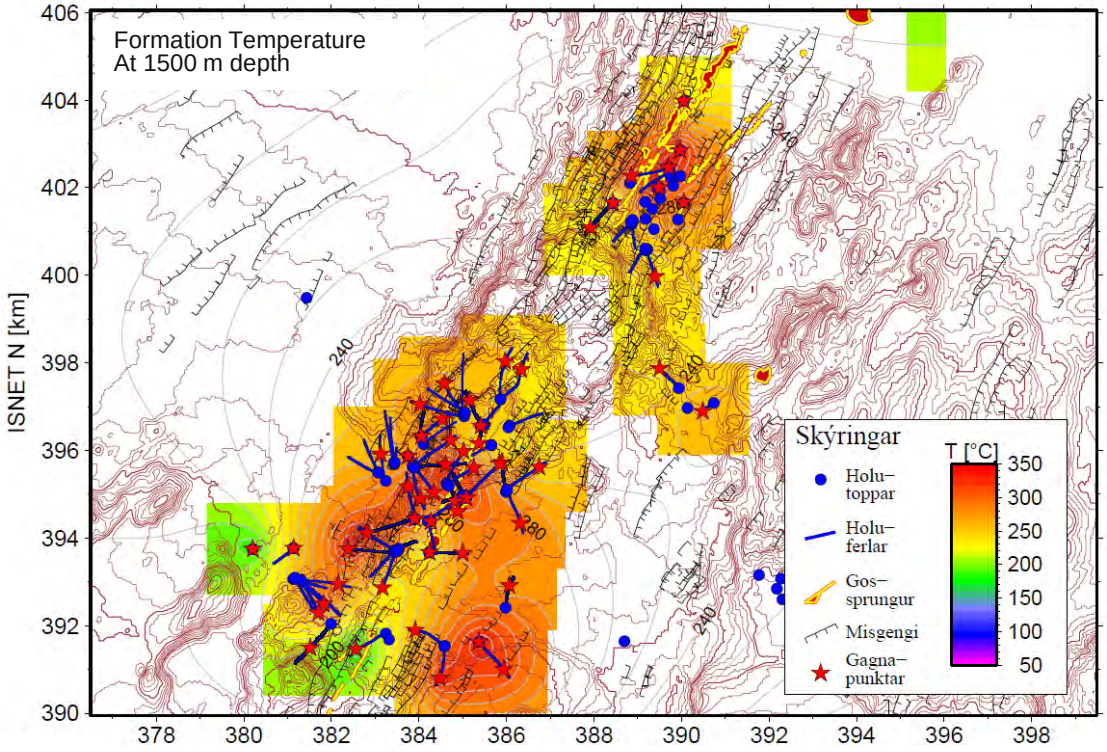
Reykjavík Energy



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