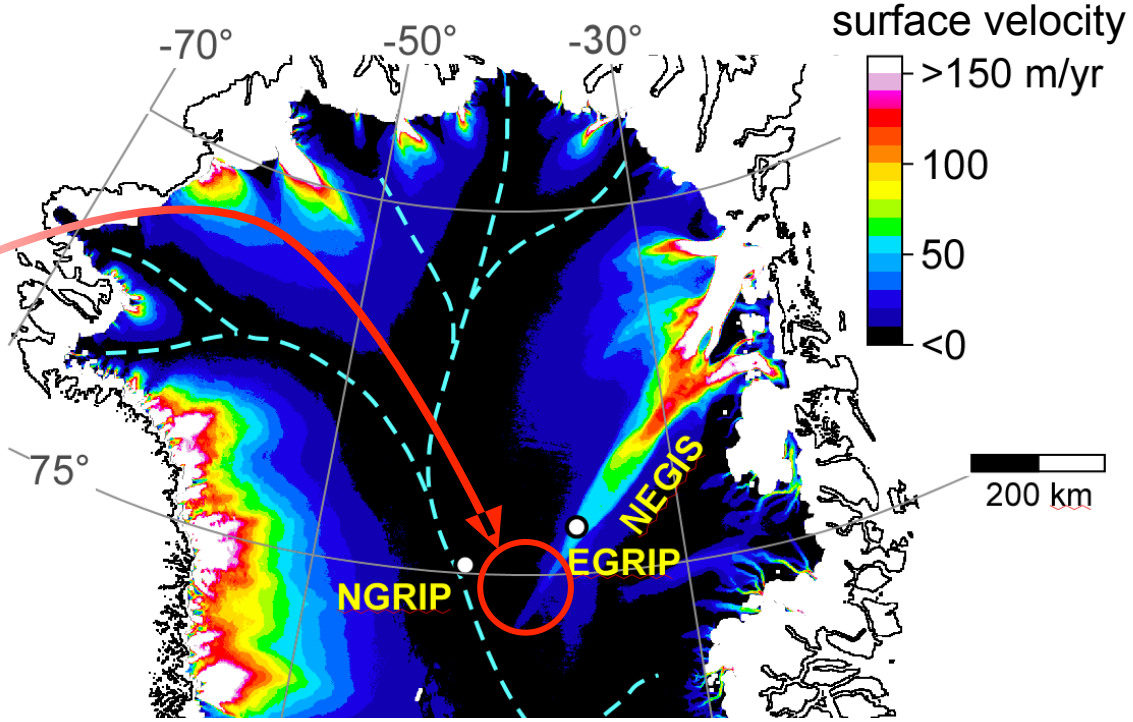
Heat flux and the North East Greenland Ice Stream

Very high heat flux at tip of NEGIS?



Paul D. Bons[1,2], Tamara de Riese[1], Steven Franke[3], Maria-Gema Llorens[4], Till Sachau[1], Nicolas Stoll[3], Ilka Weikusat[1,3], Julien Westhoff[5], Yu Zhang[1]

[1] Department of Geosciences, Eberhard Karls University Tübingen, Tübingen, Germany
[2] China University of Geosciences (Beijing), PR China
[3] Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
[4] Geosciences Barcelona, CSIC, Barcelona, Spain
[5] Physics of Ice, Climate and Earth, University of Copenhagen, Copenhagen, Denmark

High Geothermal Heat Flow, Basal Melt, and the Origin of Rapid Ice Flow in Central Greenland

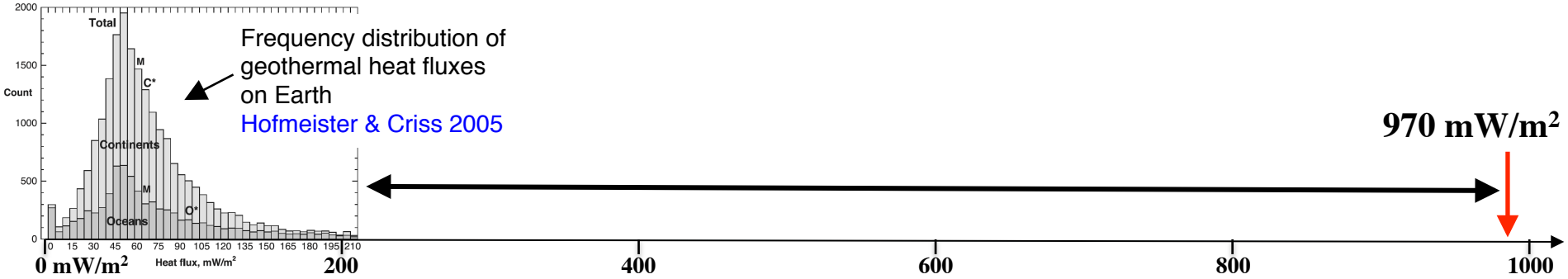
Mark Fahnestock,[1] Waleed Abdalati,[2] Ian Joughin,[3] John Brozena,[4] Prasad Gogineni[5]

Age-depth relations from internal layering reveal a large region of rapid basal melting in Greenland. Melt is localized at the onset of rapid ice flow in the large ice stream that drains north off the summit dome and other areas in the northeast quadrant of the ice sheet. Locally, high melt rates indicate geothermal fluxes 15 to 30 times continental background. The southern limit of melt coincides with magnetic anomalies and topography that suggest a volcanic origin.

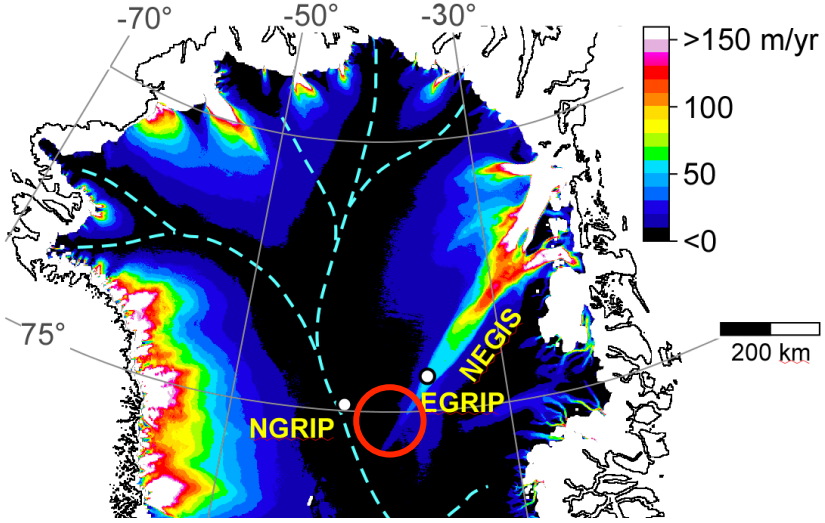
970 mW/m²!

- Fahnestock, M., Abdalati, W., Joughin, I., Brozena, J., and Gogineni, P.: High Geothermal Heat Flow, Basal Melt, and the Origin of Rapid Ice Flow in Central Greenland, Science, 294, 2338–2342, 2001.

Global geothermal heat fluxes (GHF) on Earth



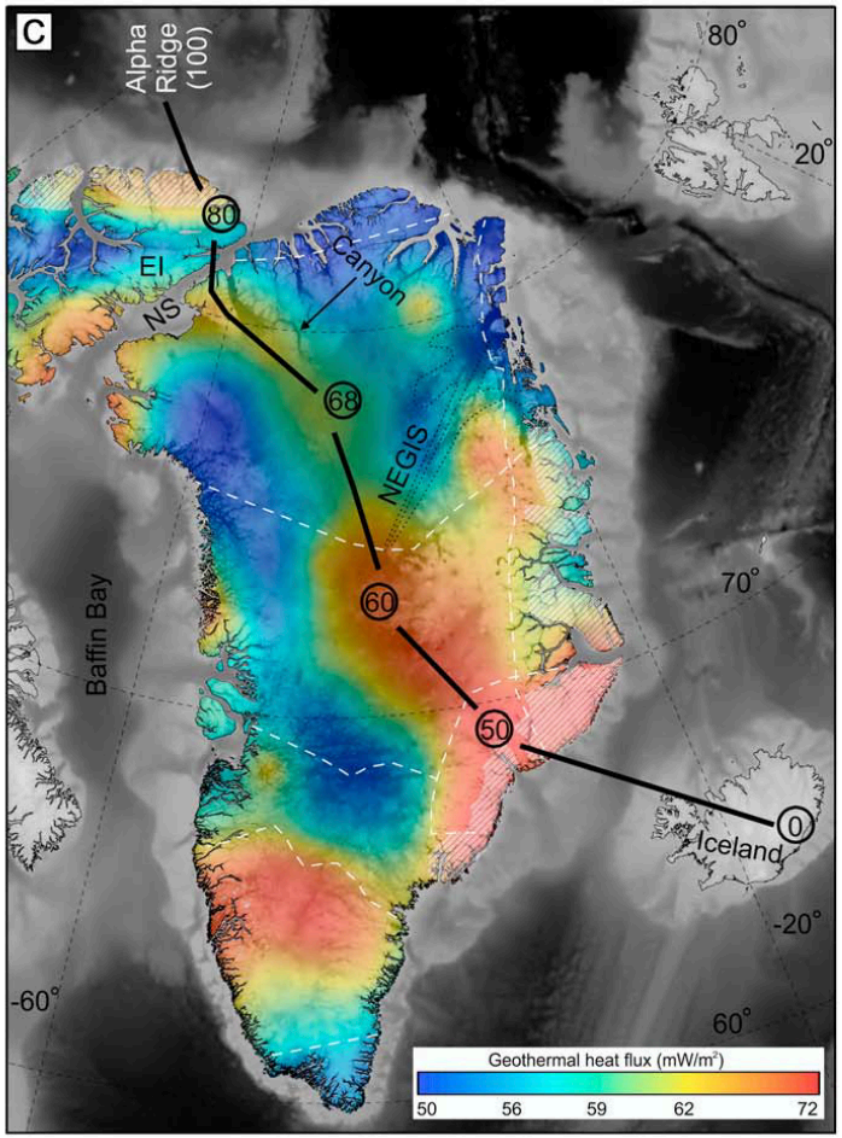
Hofmeister & Criss. 2005. Earth's heat flux revised and linked to chemistry, *Tectonophys*. 395, 159-177



- **Heat fluxes >>200 mW/m² are *extremely rare* on Earth**
- **Elevated heat fluxes occur in places of enhanced tectonic activity**
  - **plate boundaries**
  - **graben structures**
- **Central Greenland does not seem to be such a place**

Why a high GHF at NEGIS? Iceland hotspot?

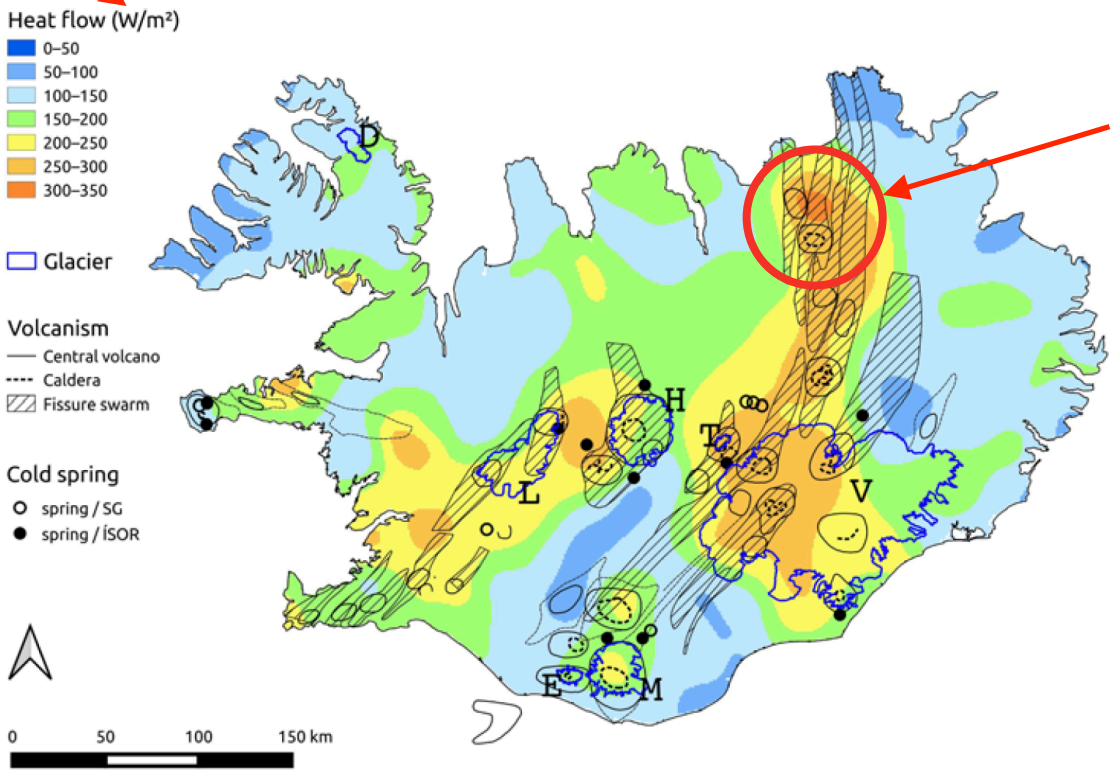
- **The Iceland plume was below east Greenland >50 Myr ago**
- **Note broad swath of moderately elevated GHF (<75 mW/m^2)**



- Martos, Y. M., Jordan, T. A., Catalán, M., Jordan, T. M., Bamber, J. L., and Vaughan, D. G.: 2018. Geothermal heat flux reveals the Iceland hotspot track underneath Greenland. Geophys. Res. Letts, 45, 8214–8222. https://doi.org/10.1029/2018GL078289, 2018.

typo in figure

How hot is Iceland itself?

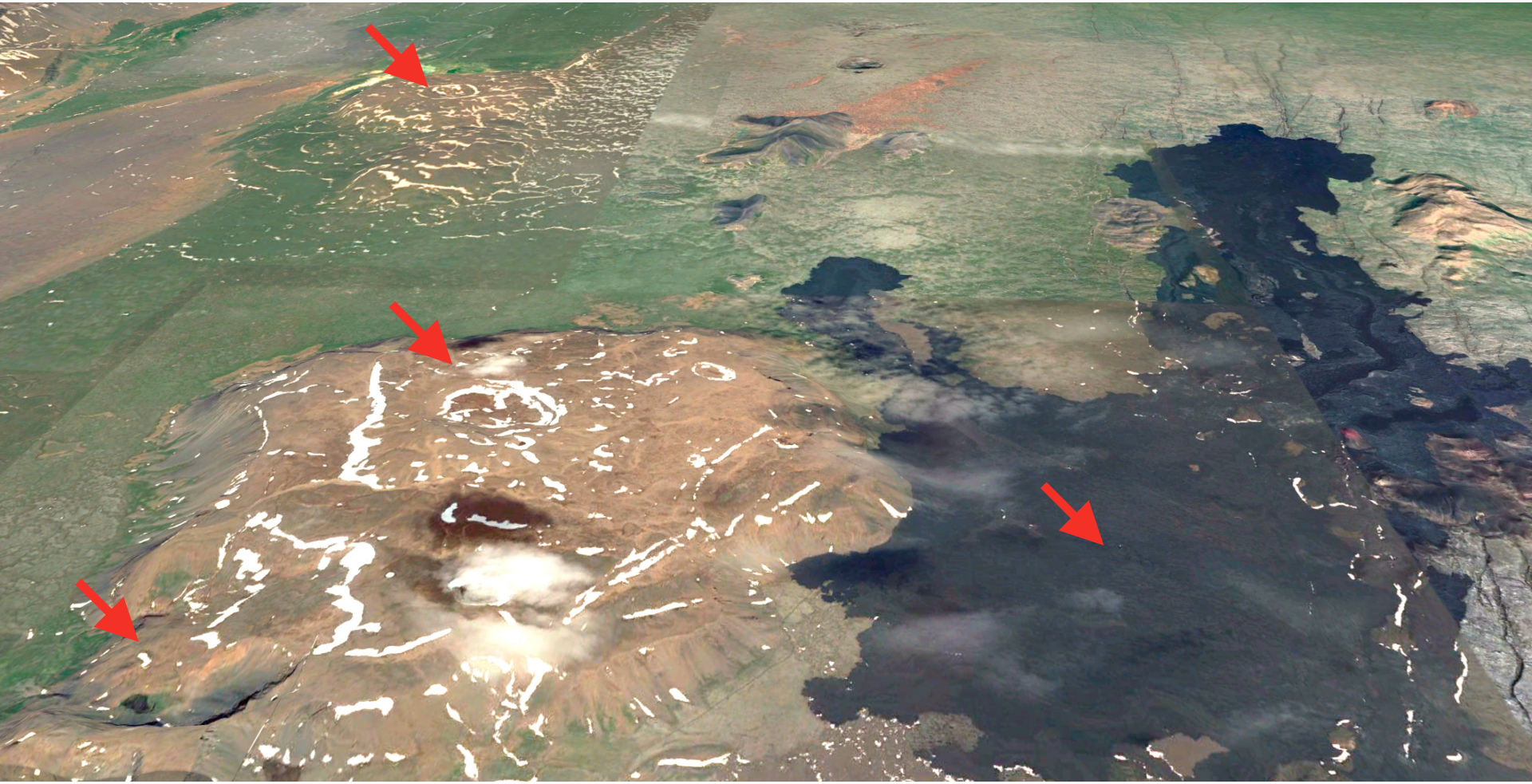


One spot with >300 mW/m² radius ca. 20 km

Jóhannesson T, Pálmason B, Hjartarson Á, Jarosch AH, Magnússon E, Belart JMC, Gudmundsson MT (2020). Non-surface mass balance of glaciers in Iceland. J. Glaciol., 1–13. https://doi.org/10.1017/jog.2020.37.

- ***"The geothermal heat flow in Iceland is highest, typically in the range 200–300 mWm^{-2}, in the neo-volcanic zone that runs across Iceland from SW to NE"***
- **If Iceland's GHF<350 mW/m², it is unlikely its trail is hotter**

What does >300 mW/m^2 look like?



- **Calderas and recent lava flows**

Image from GoogleEarth

How about shallow intrusions?

- **Stevens et al. 2016:** ***"ice-age cycling could help it migrate upward to shallow depth or erupt, contributing to the high observed geothermal heat flux, if melt occurs at depth"***

- **But Iceland (≤350 mW/m^2) and Yellowstone (≤150 mW/m^2) have such shallow intrusions**

- **And why would there be melt at depth to rise?**

Stevens, N. T., Parizek, B. R., and Alley, R. B.: Enhancement of volcanism and geothermal heat flux by ice-age cycling: A stress modeling study of Greenland, J. Geophys. Res. Earth Surf., 121, 1456–1471, 2016

Hydrothermal fluid flow?

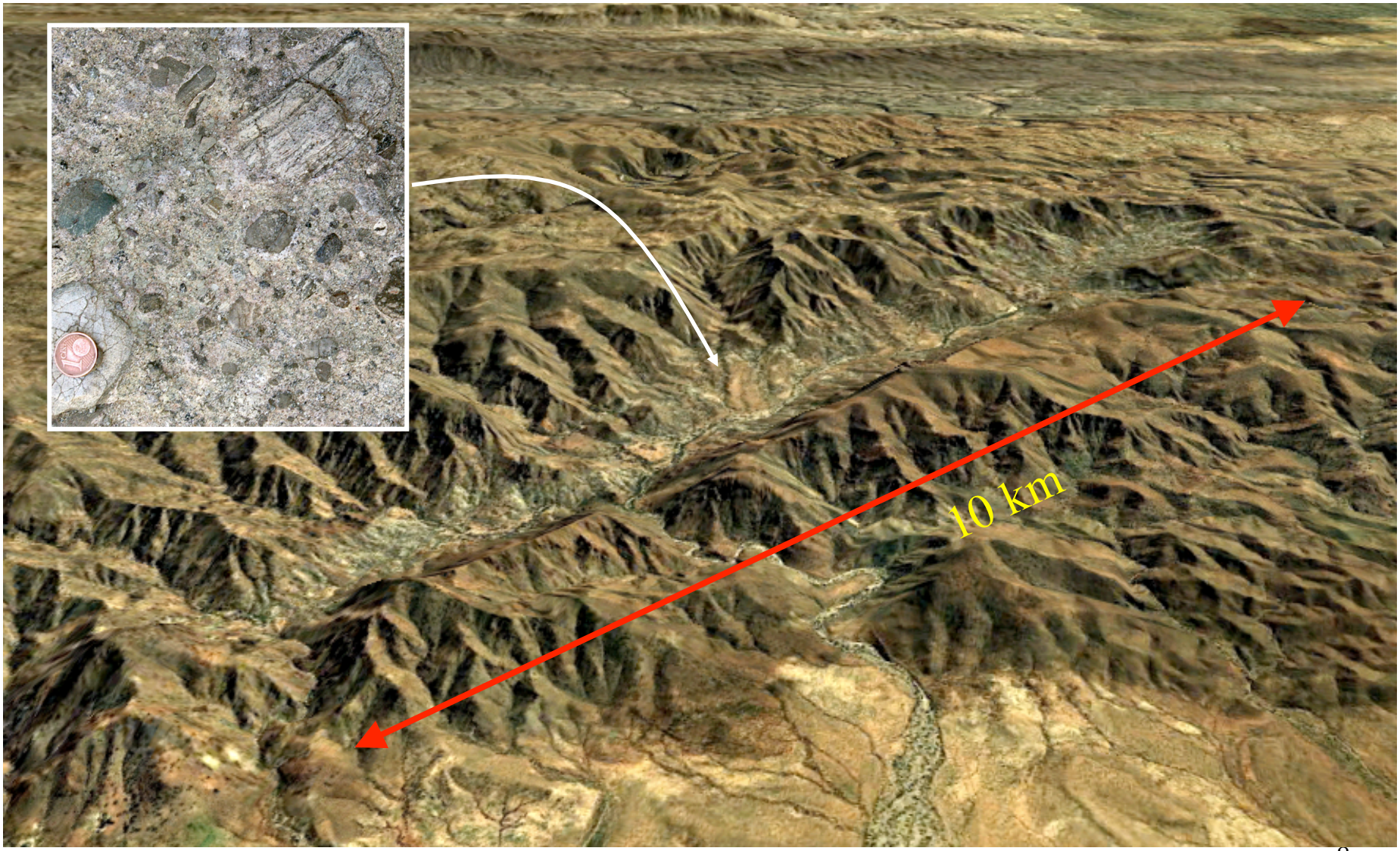
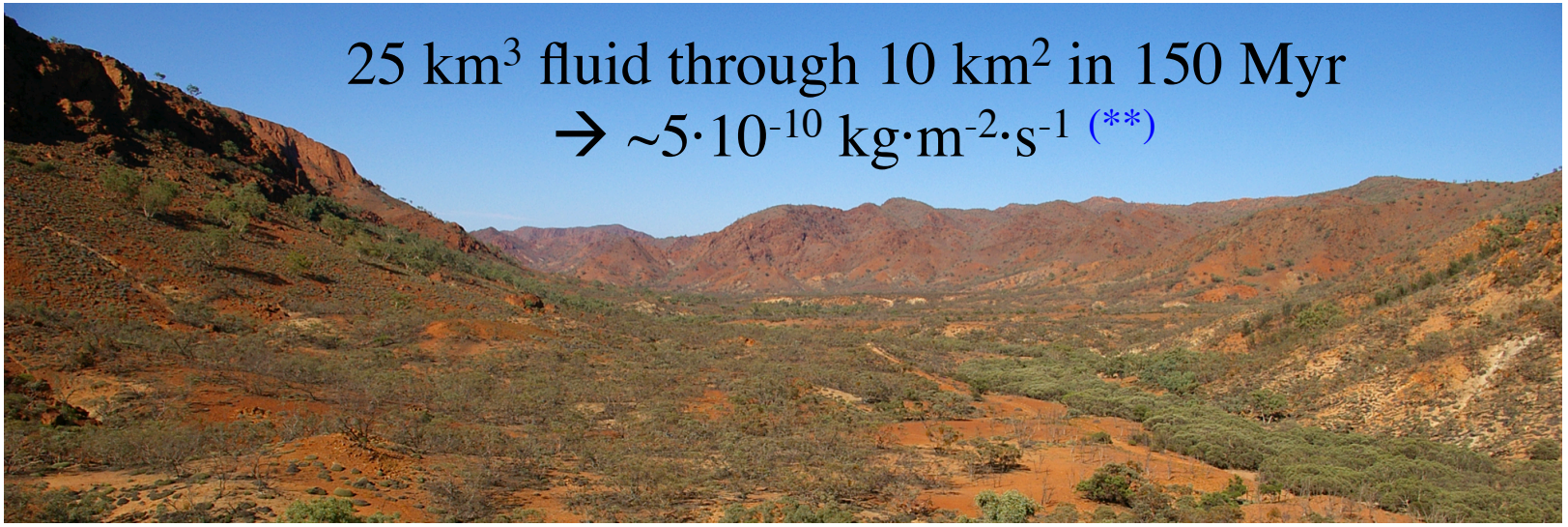


Image: GoogleEarth

Mt Painter Inlier (SA): a "fluid hotspot"

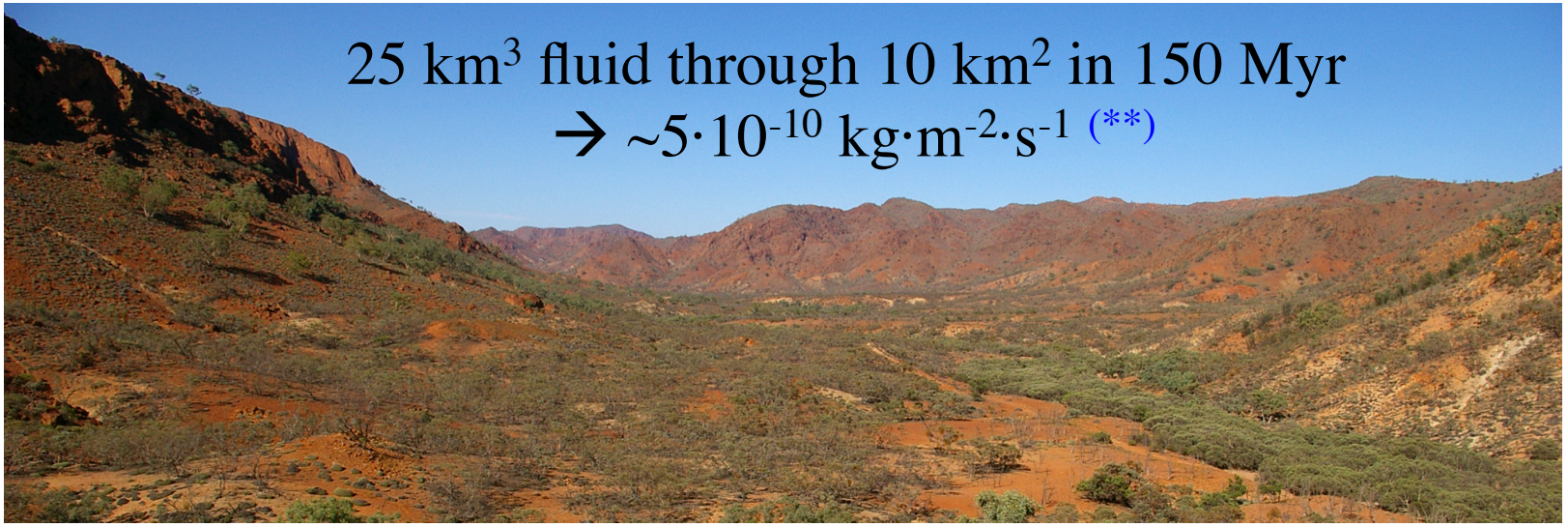


- **The U-rich Mt Painter Inlier is one of the hottest* non-igneous continental hotspots associated with extensive hydrothermal fluid flow****
- **Maximum (palaeo-) GHF: ~120 mW/m^2 (*)**

* Sandiford, M., Hand, M., and McLaren, S.: High geothermal gradient metamorphism during thermal subsidence, Earth Planet. Sci. Letts, 163, 149-165 (1998).

** Weisheit, A., Bons, P.D., Danisik, M., Elburg, M.A. 2013. Crustal-scale folding: Palaeozoic deformation of the Mt. Painter Inlier, South Australia. Geol. Soc., London 394.

Mt Painter Inlier (SA): a "fluid hotspot"



- **For 970 mW/m^2 we need about 10,000x a geologically reasonable fluid flux**
- **What could cause such a flux?**
- **Same causes as for shallow intrusions**
  - **Back to Yellowstone and Iceland...**

Maybe radioactive heat production?

- **Intrusions of the Gardar Province in S. Greeland do carry U-deposits. Here in the Ilímaussaq Intrusion, Narsaq**

Maybe radioactive heat production?

- **Mt Painter has (shallow) U-deposits and very "hot" granites, but heat flow ≤120 mW/m^2**
- **In the sediments above the world's largest known U-deposit, Olympic Dam in South Australia, the GHF is raised by only 43 mW m^{-2} from a background value of 73 mW m^{-2} (**)**
- **Radioactive heat production of U-deposits does not raise the GHF enough**

- ** Houseman, G.A., Cull, J.P., Muir, P.M., and Paterson, H.L.: Geothermal signatures and uranium ore deposits on the Stuart Shelf of South Australia, GEOPHYSICS 54, 158-170, https://doi.org/10.1190/1.1442640, 1989.

Conclusions

- **A heat flux of 970 mW/m^2 is extremely unlikely**
- **NEGIS was not formed or controlled by this**
- **Read more in:**
- **Bons, P.D., de Riese, T., Franke, S., Llorens, M.-G., Sachau, T., Stoll. N., Weikusat, I., Westhoff, J., Zhang, Y. (2021) Comment on "Exceptionally high heat flux needed to sustain the Northeast Greenland Ice Stream by S. Smith-Johnsen et al.", The Cryosphere**