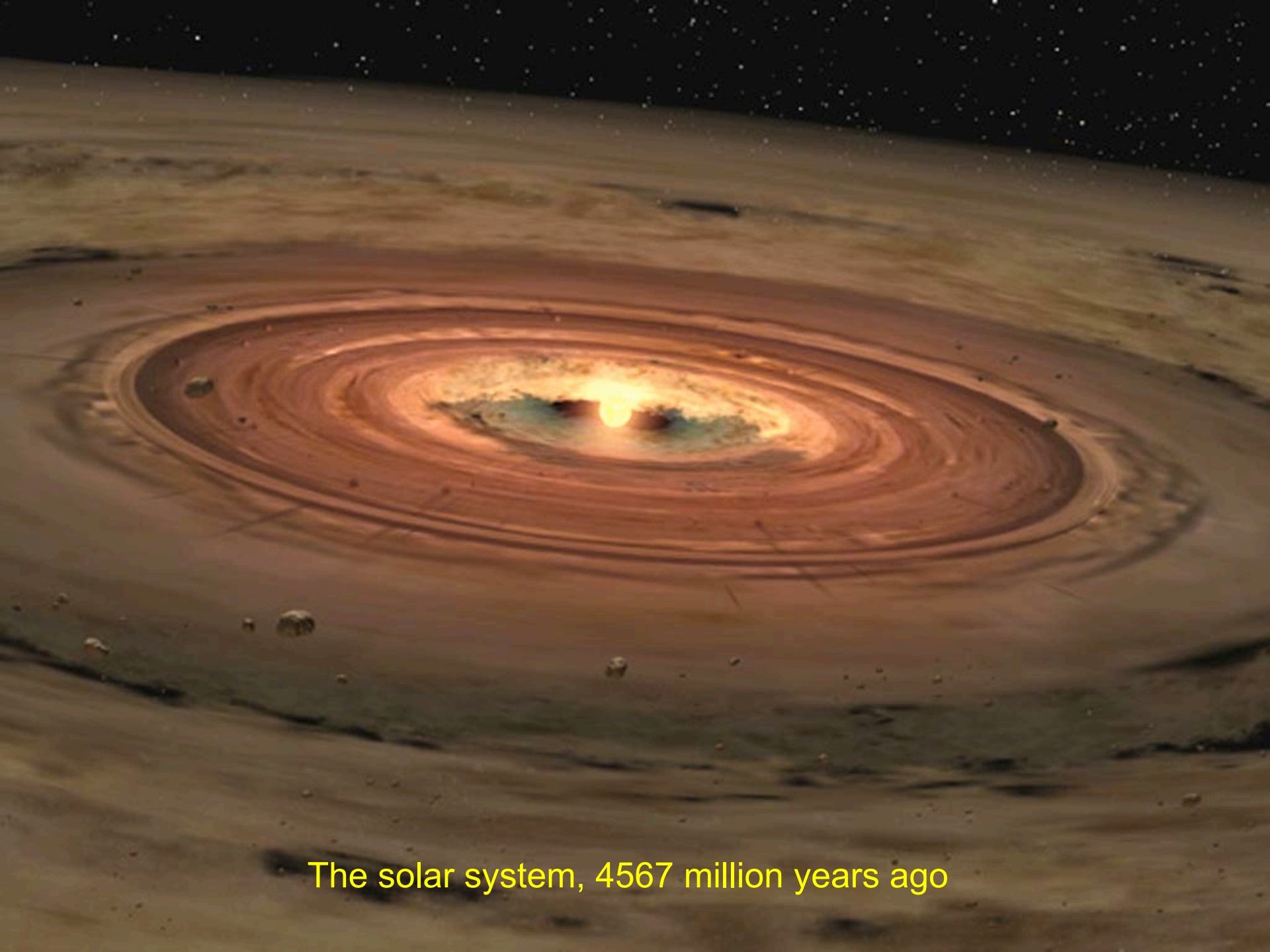
How to find meteorites? Experience from Arabia and Switzerland

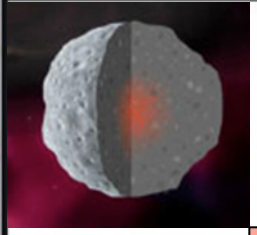
Beda A. Hofmann
Natural History Museum Bern
Institute of Geological Sciences, University of Bern

NATURHISTORISCHES MUSEUM BERN
UNIVERSITÄT BERN
beda.hofmann@geo.unibe.ch

Meteorite with fusion crust, Oman


The solar system, 4567 million years ago

The solar system today



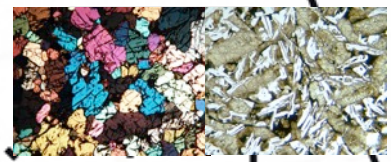
Klassifikation der Meteorite

Undifferenzierte Meteorite

- Chondrite
  - Kohlige Chondrite
    - CI
    - CM
    - CO
    - CV
    - CK
    - CR
    - CH
    - CB
  - Gewöhnliche Chondrite
    - H
    - L
    - LL
  - Rumuruti-Chondrite
  - Enstatit-Chondrite
    - EH
    - EL

Differenzierte Meteorite

- Achondrite



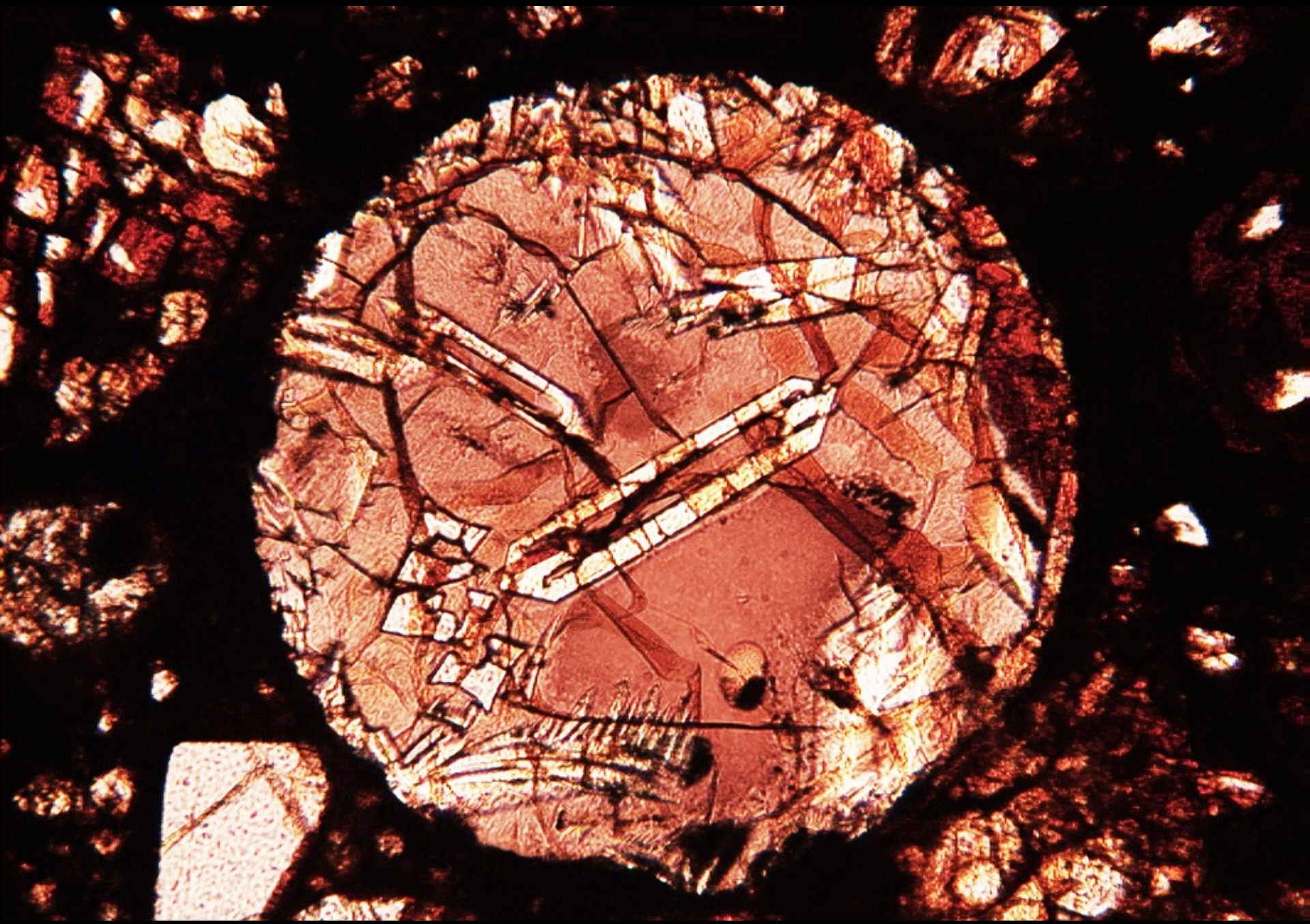
  - Primitive Achondrite:
    - Acapulcoite
    - Winonaite
    - Lodranite
  - Marsmeteorite
  - Brachinite
  - Aubrite
  - Ureilite
  - Angrite
  - HED
    - Howardite
    - Eukrite
    - Diogenite
  - Mondmeteorite
  - SNC
    - Shergottite
    - Nakhlite
    - Chassignite
  - ALH 84001
- Eisenmeteorite
  - IA
  - IIA
  - IIB
  - IIIA
  - IIIB
  - IVA
  - andere

  (Hauptgruppen)
- Steineisenmeteorite
  - Pallasite
  - Mesosiderite

Addi Bischoff (2005)
Inst. f. Planetologie
D - 48149 Münster

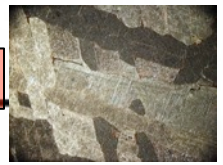
Classification of meteorites: Undifferentiated

Thin section of a chondritic meteorite, Oman (width 37 mm)



Individual chondrule (1 mm)

Klassifikation der Meteorite

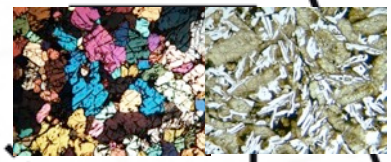


Differenzierte Meteorite

Undifferenzierte Meteorite

Chondrite

Achondrite



Primitive Achondrite:
Acapulcoite
Winonaite
Lodranite

Eisenmeteorite

IA IIA IIB IIIA IIIB IVA andere

(Hauptgruppen)

Kohlige Chondrite
Gewöhnliche Chondrite
Rumuruti-Chondrite
Enstatit-Chondrite

CI CM CO CV CK CR CH CB
H L LL
EH EL

Steineisenmeteorite

Pallasite Mesosiderite

Marsmeteorite Brachinite Aubrite Ureilite Angrite Mondmeteorite

SNC

Shergottite Nakhlite Chassignite

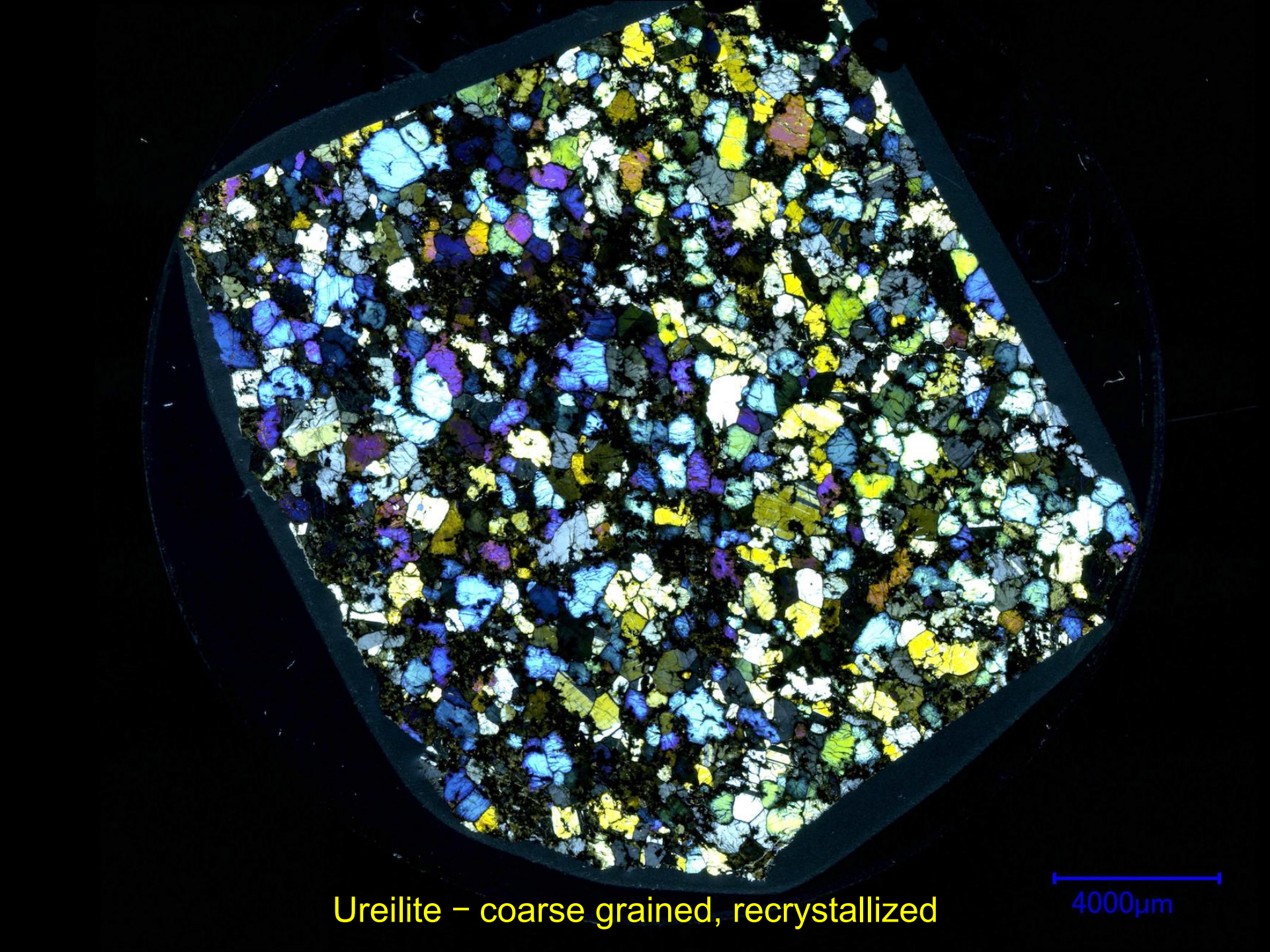
ALH 84001

HED

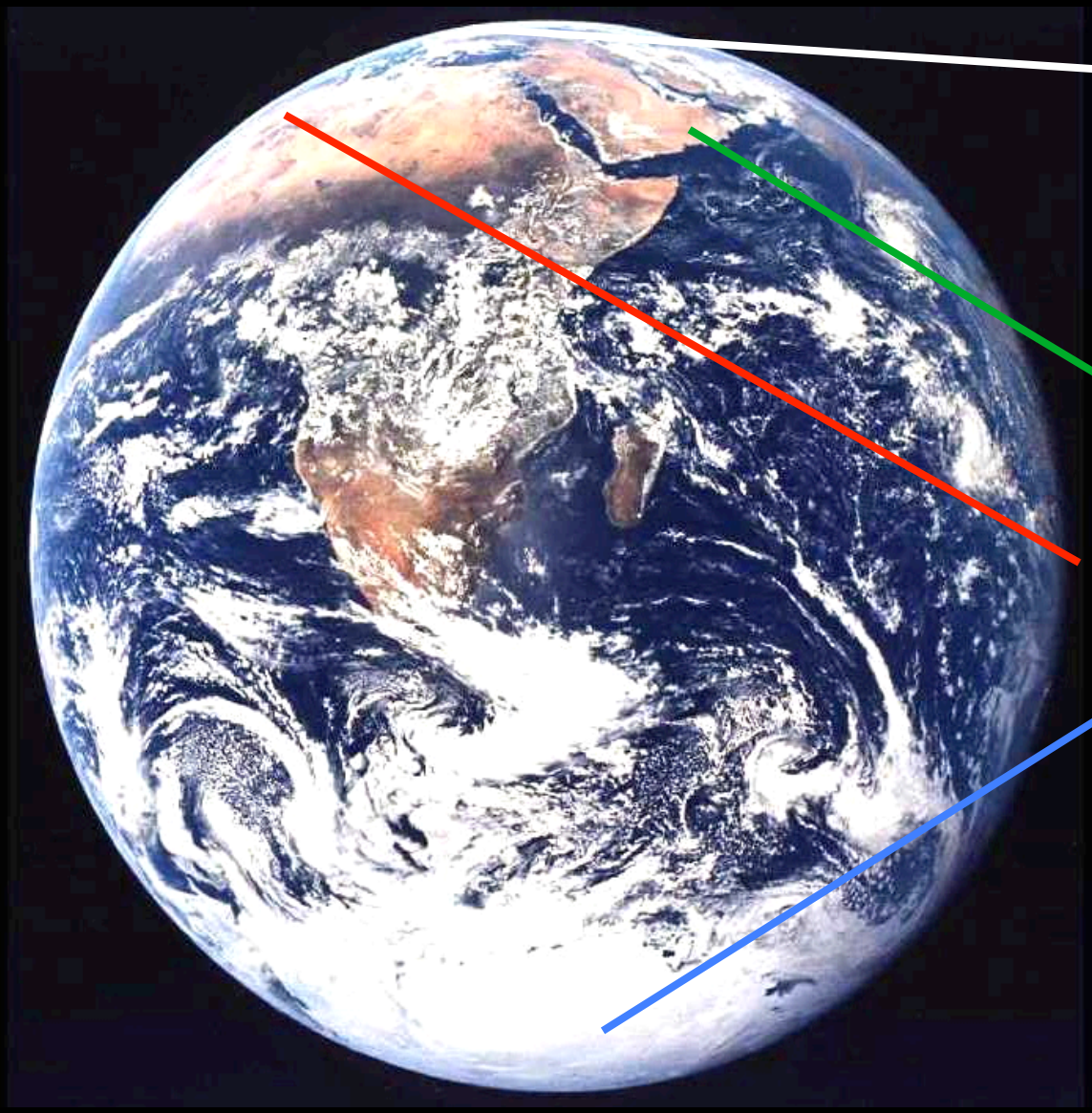
Howardite Eukrite Diogenite

Addi Bischoff (2005)
Inst. f. Planetologie
D - 48149 Münster

Classification of meteorites: Differentiated



Ureilite − coarse grained, recrystallized



Switzerland 11

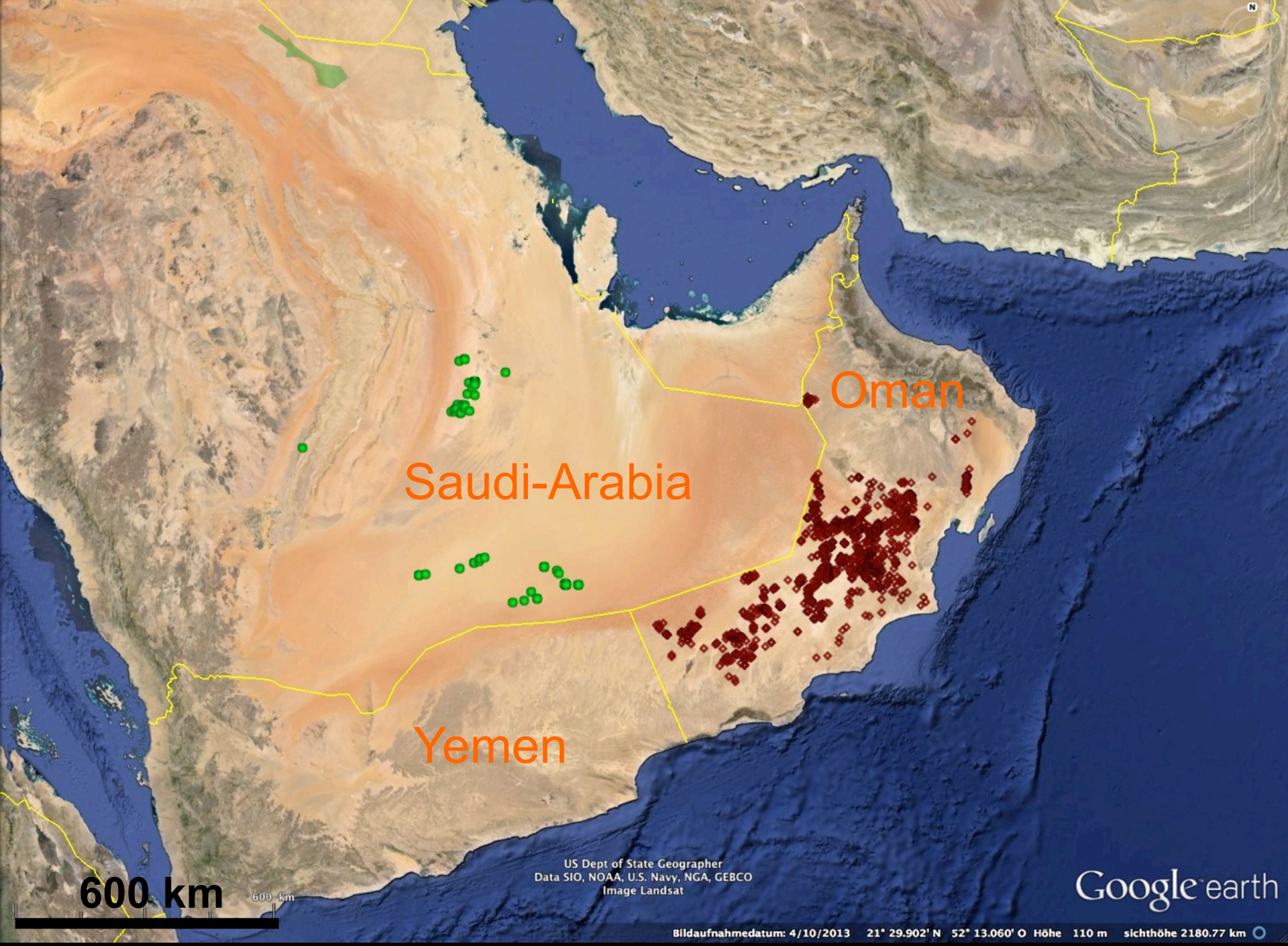
Oman 3’984

Northwest-Africa 9’949

Antarctica 40’752

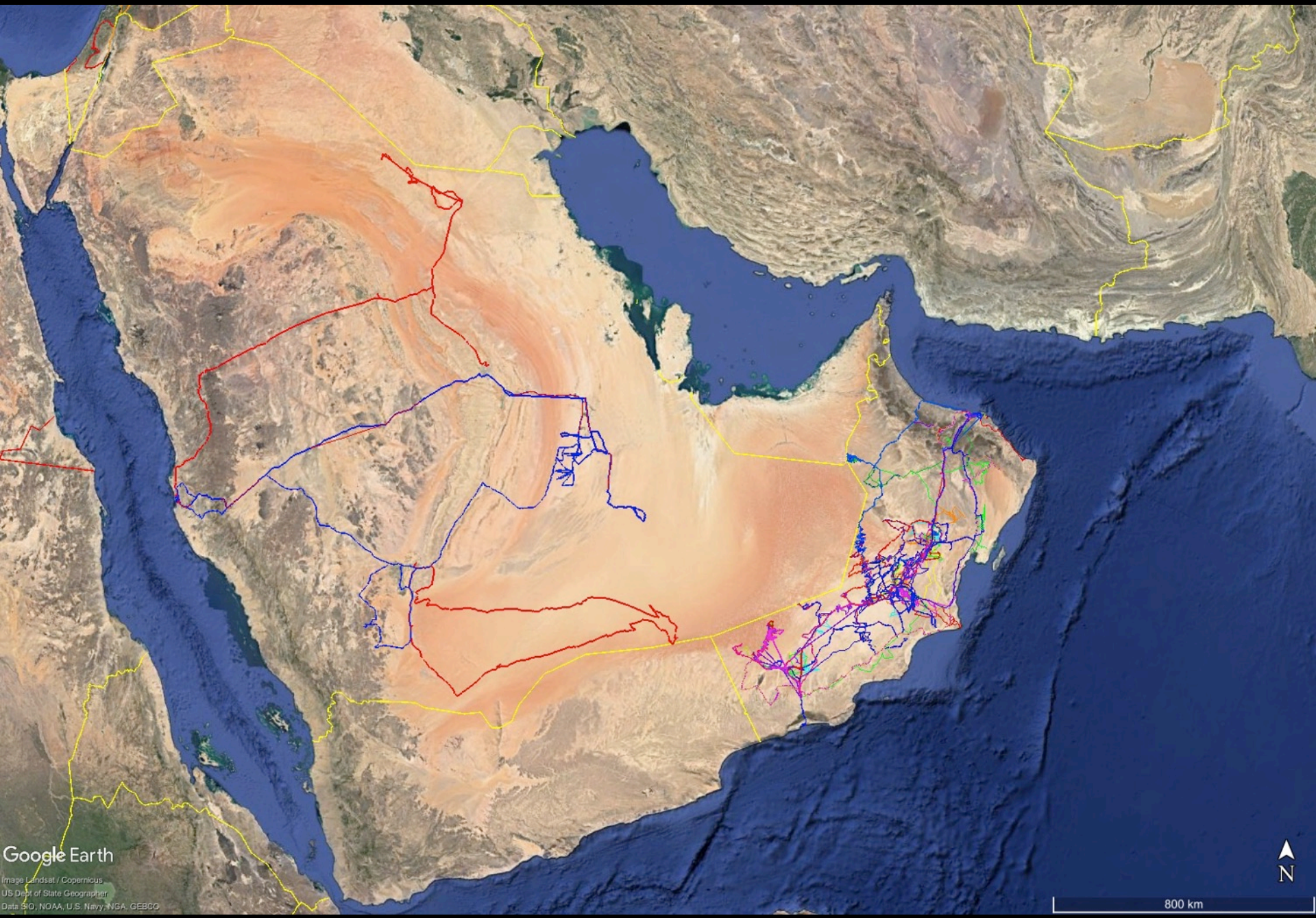
Total 65’503

Officially registred meteorites (Meteoritical Society, April 2021)

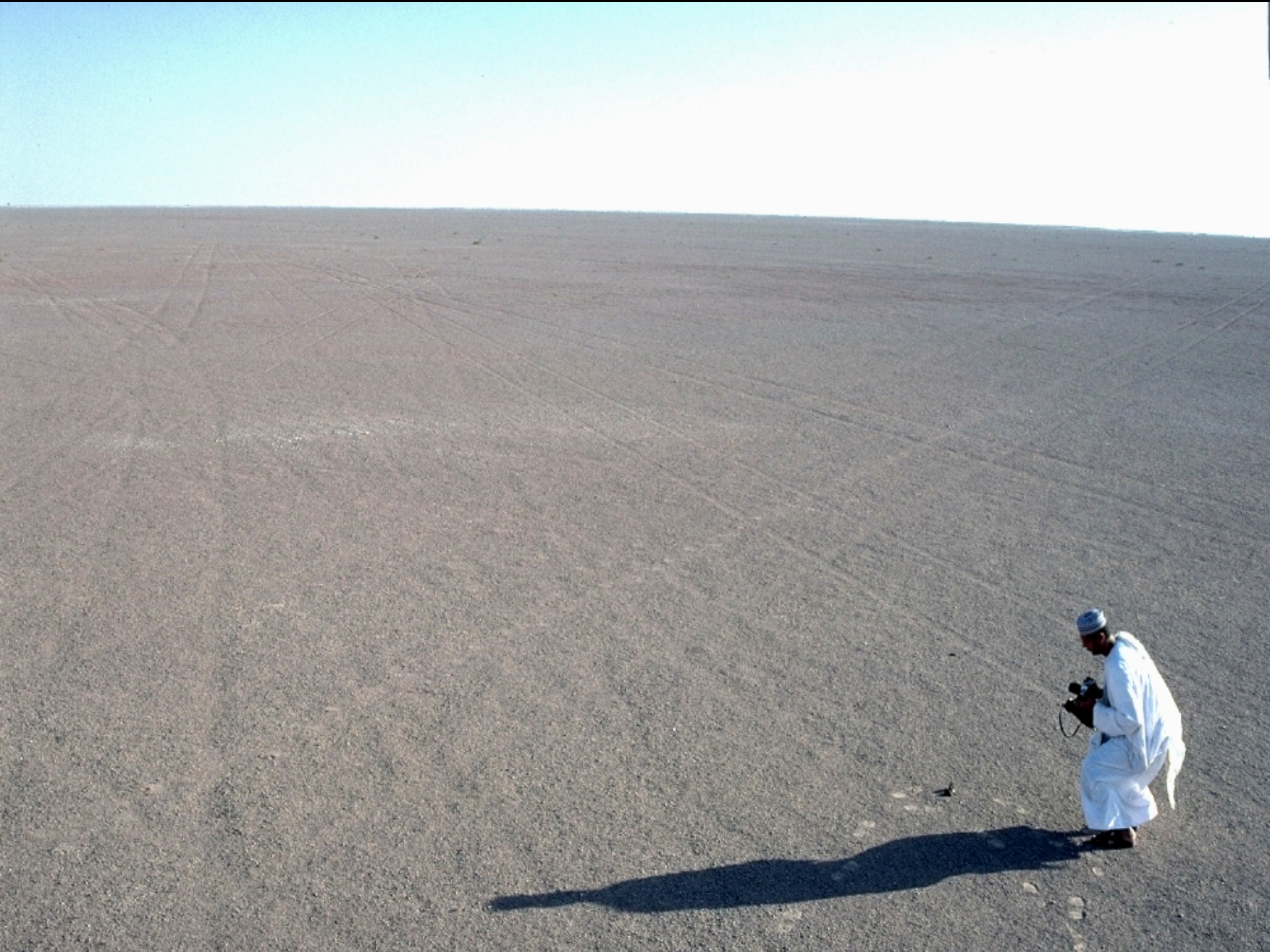

Oman
Saudi-Arabia
Yemen
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat
600 km
600 km
Google earth
Bildaufnahmedatum: 4/10/2013 21° 29.902' N 52° 13.060' O Höhe 110 m sichthöhe 2180.77 km

2001-2020
19 campaigns in Oman
~56 persons involved
Switzerland 48
Oman 8

4 campaigns in
Saudi Arabia

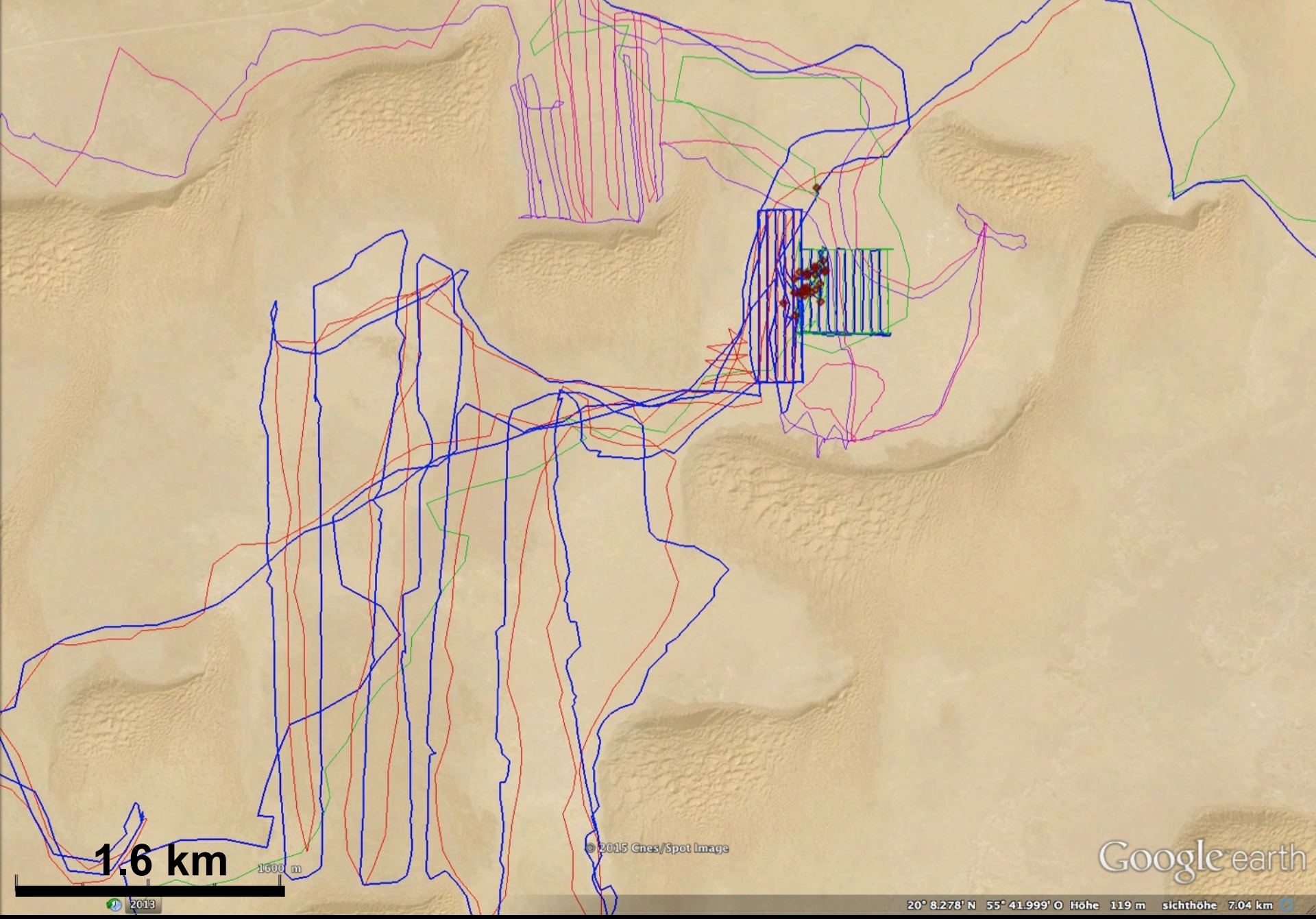


Tracks of the search campaigns in Oman and Saudi Arabia



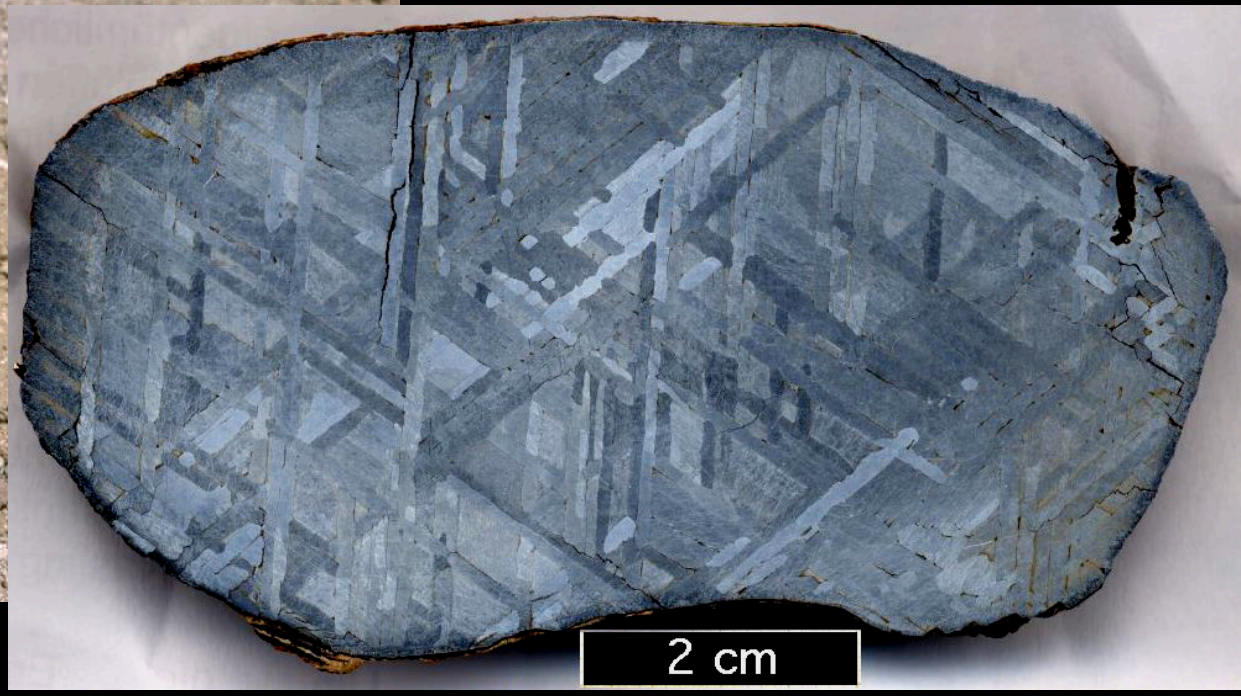

Omani-Swiss Meteorite Search 2014
1402-014

Typical find density is 0.5 to 5 meteorites/km^2



GPS tracks: 5 different meteorites on 50’000 m^2 -> a first “hot spot”


Canon



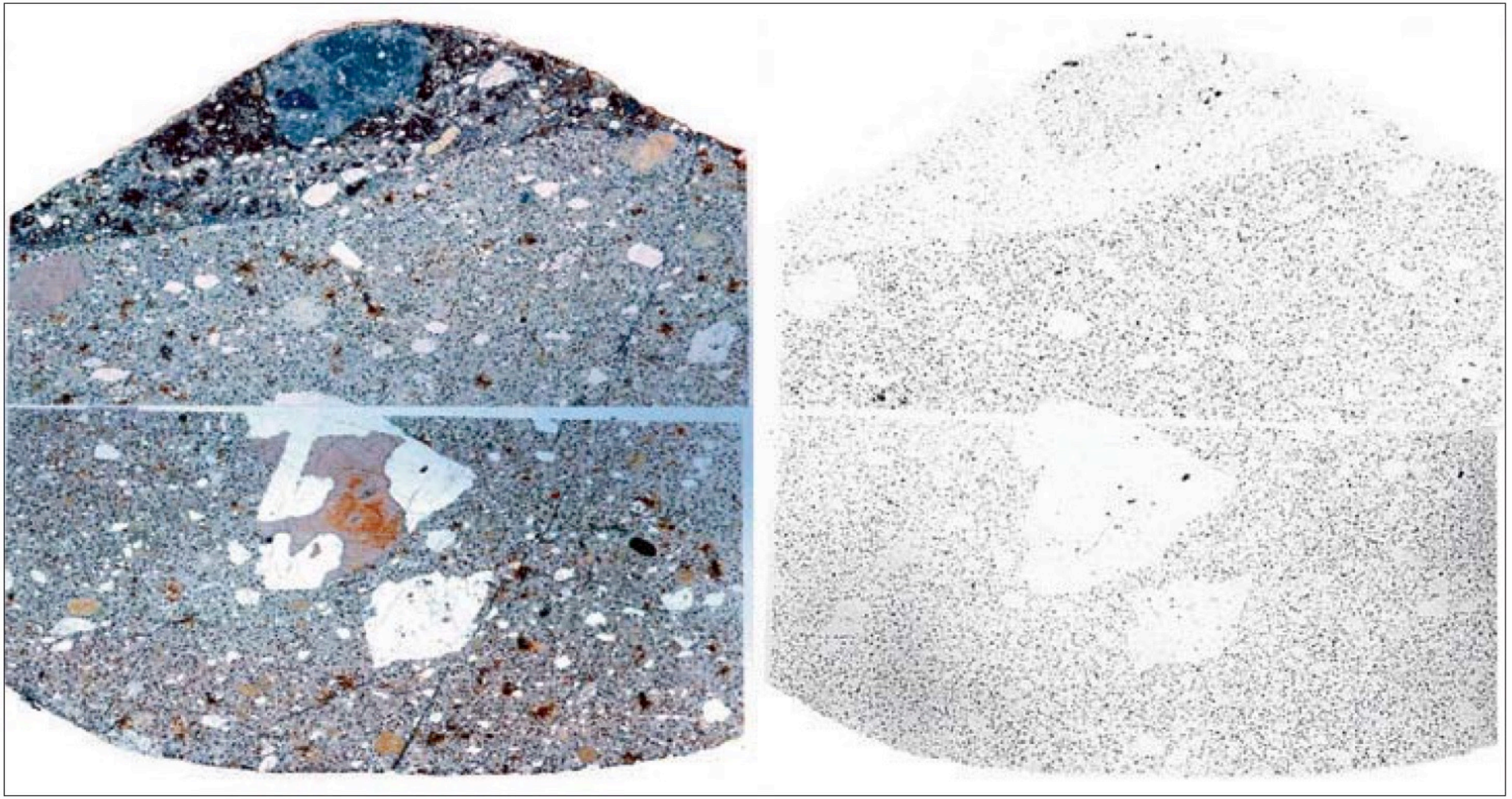
Iron meteorite Shisr 043 (IIIAB), found 2003: The only unoxidized iron meteorite from Oman

Abundance of iron meteorites

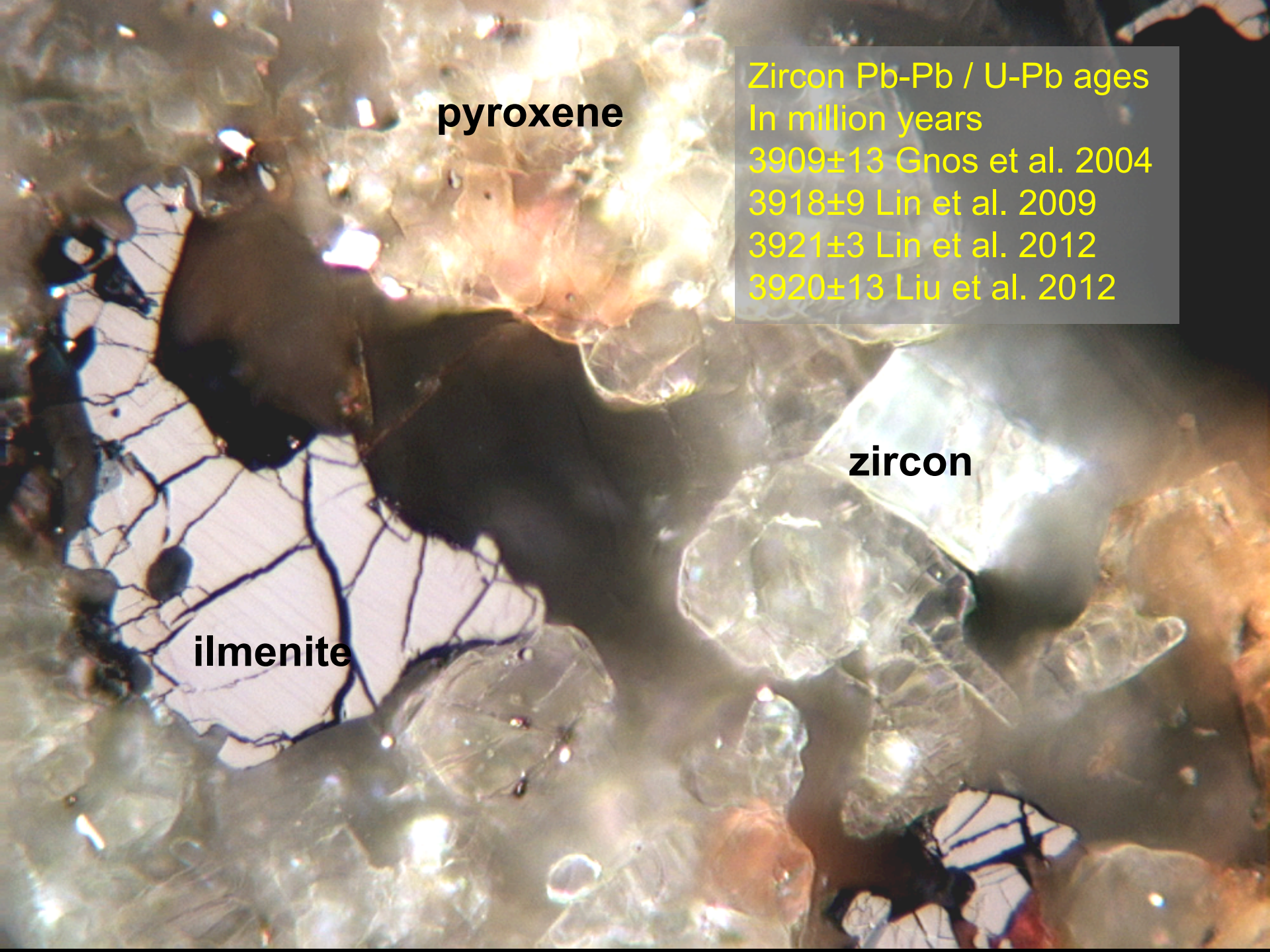
Observed falls: 5.0 %
Antarctica: 0.4%
Oman: <0.1 %

Lunar meteorite SaU 169, found in January 2002 (7 cm − 206 g)

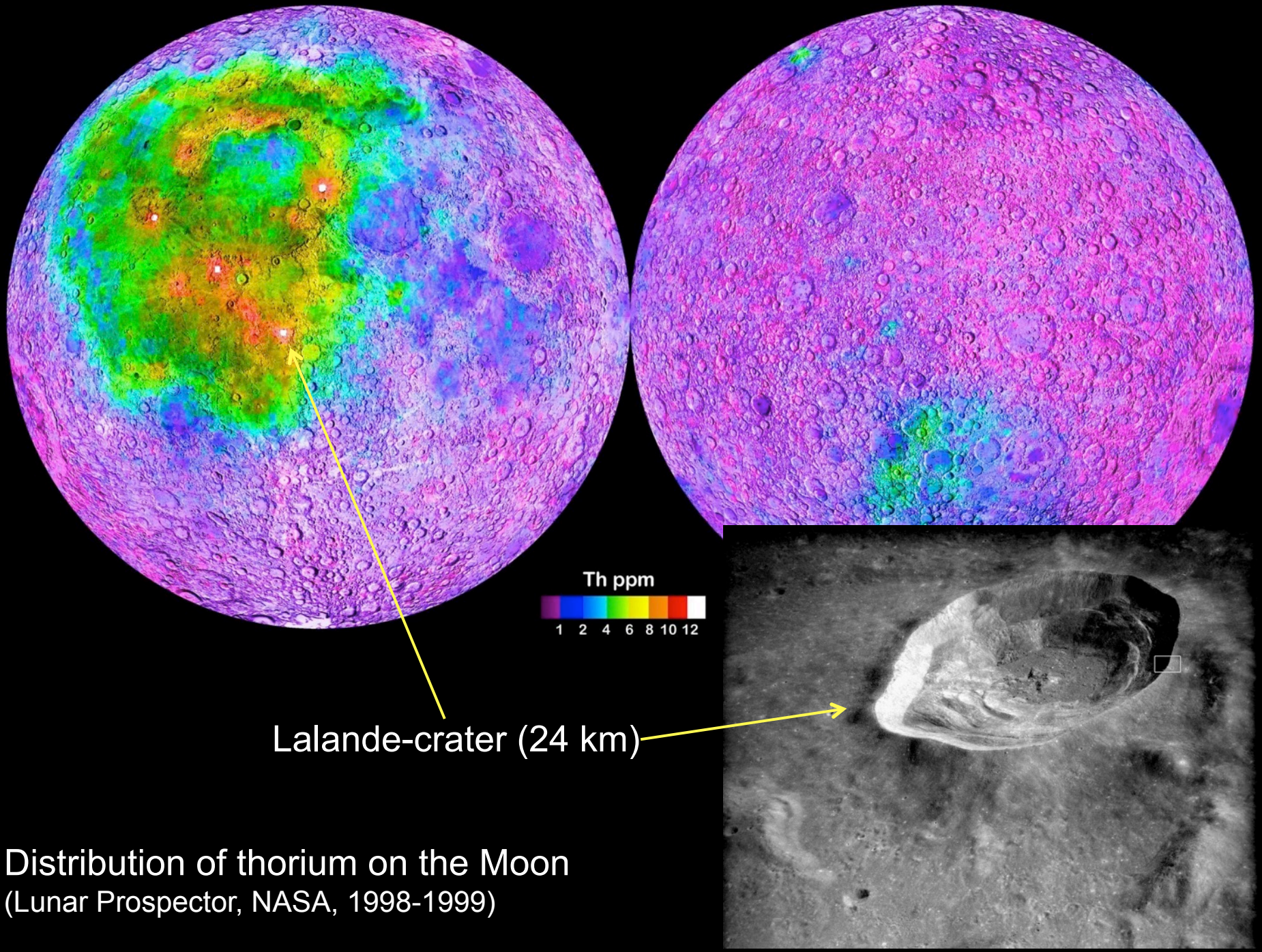
SaU 169: Highly enriched in uranium and thorium (U: 9 ppm, Th: 32 ppm)



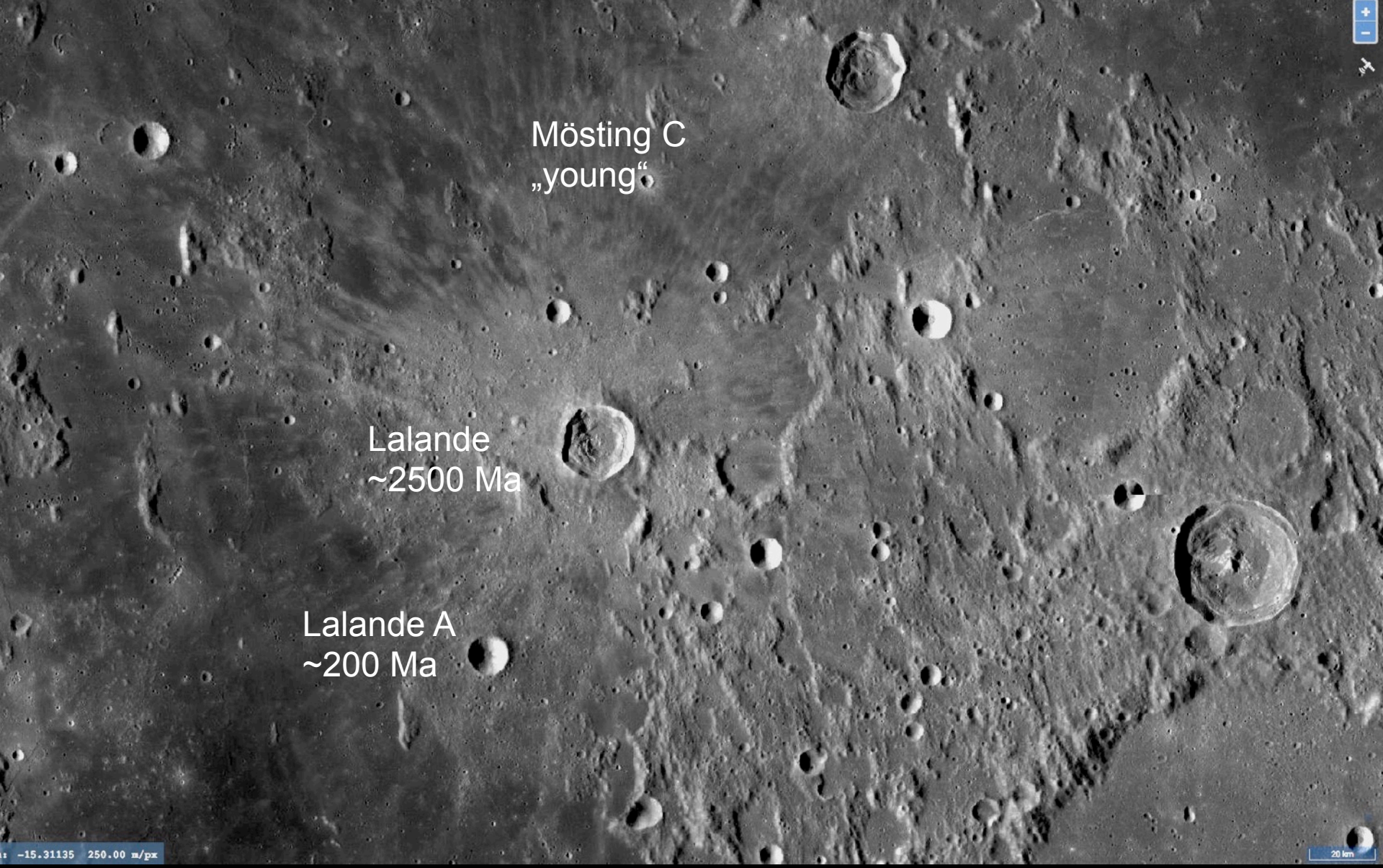
α-autoradiograph of SaU 169 shows enrichment of U, Th in the matrix of the melt breccia lithology.



Zircon Pb-Pb / U-Pb ages
In million years
3909±13 Gnos et al. 2004
3918±9 Lin et al. 2009
3921±3 Lin et al. 2012
3920±13 Liu et al. 2012

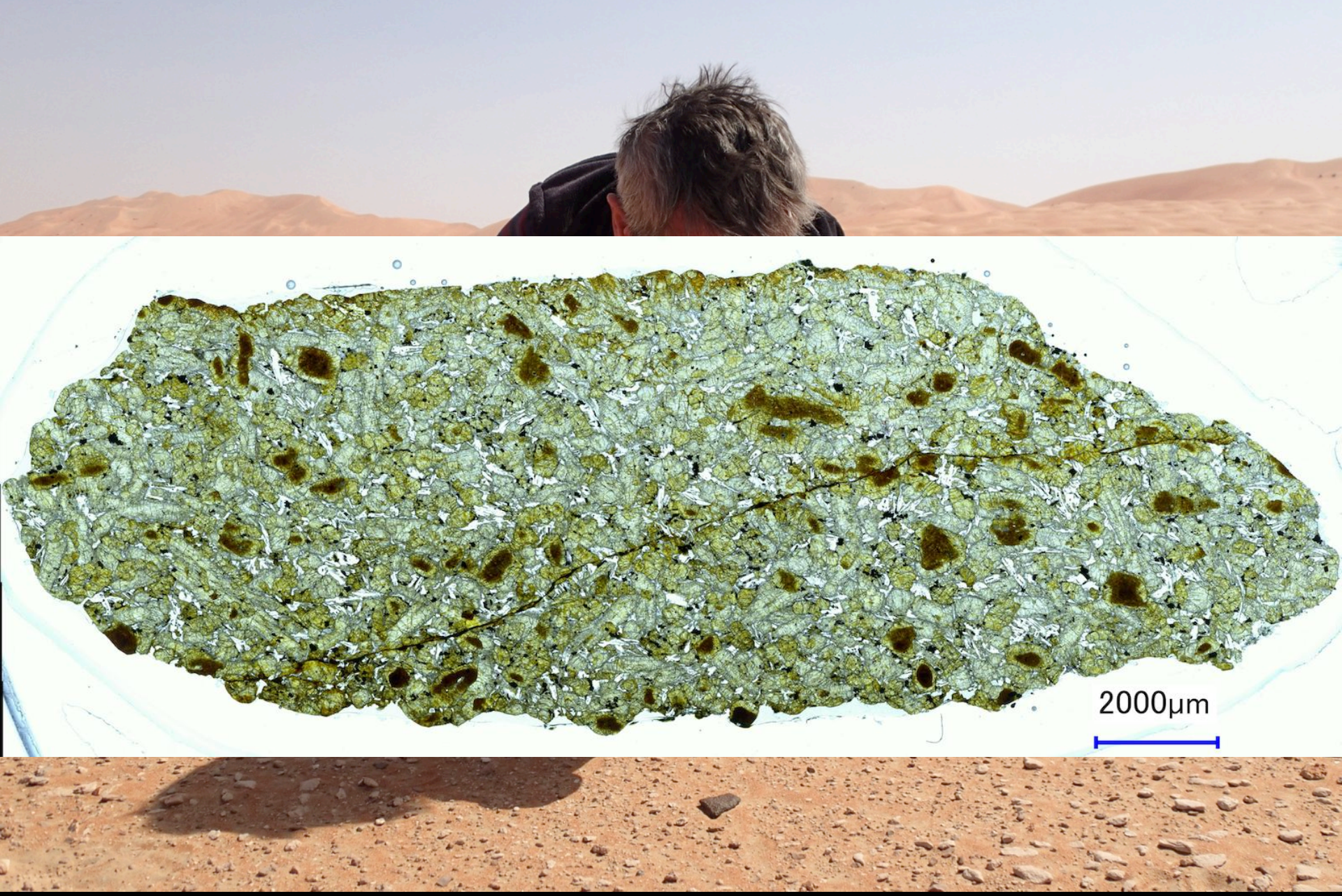


Distribution of thorium on the Moon
(Lunar Prospector, NASA, 1998-1999)

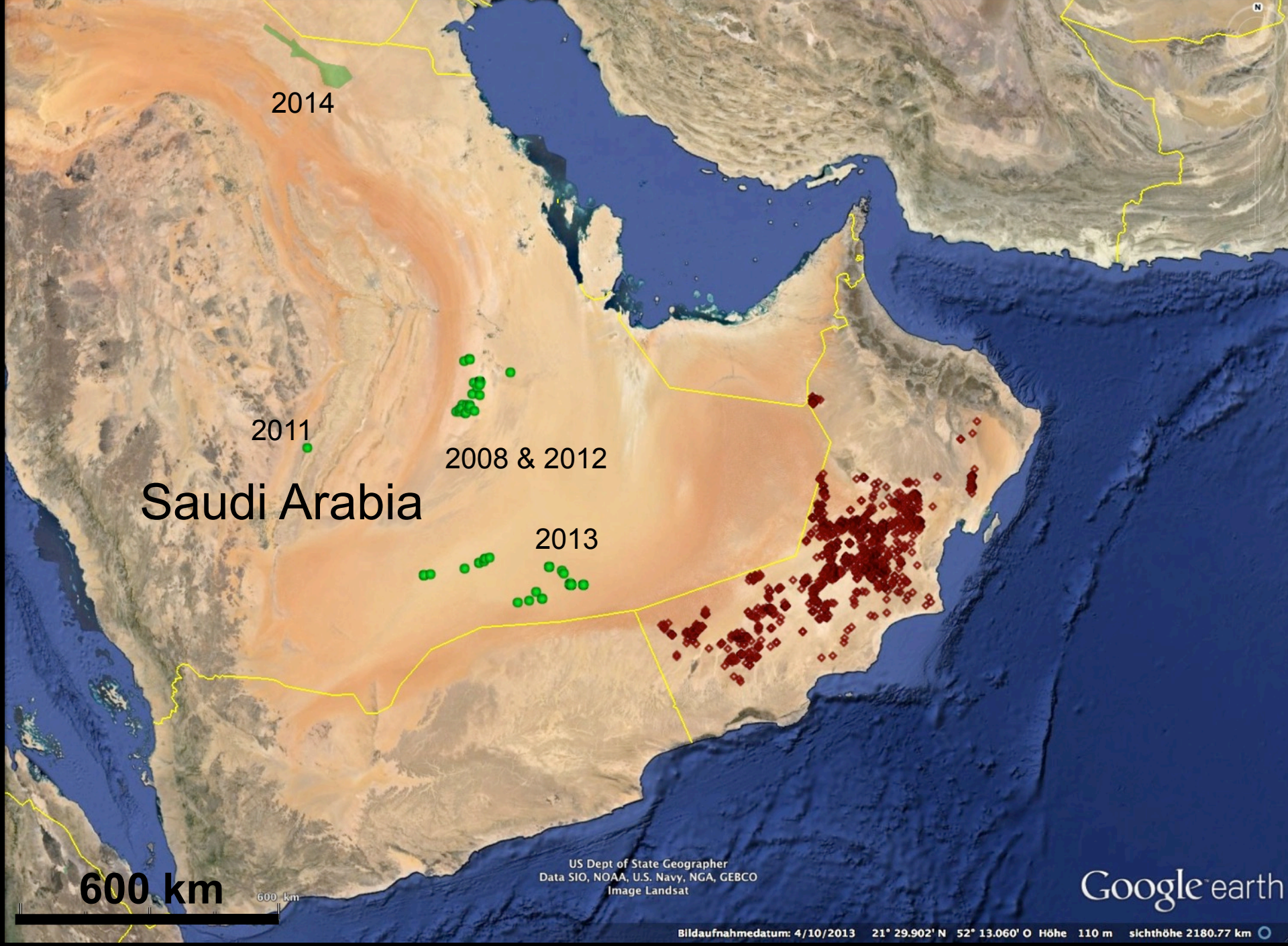


In addition to the 3900 Ma crystallization age, SaU 169 shows ages of ~2500 Ma (shock event), 200 Ma (placement in soil at depth of a few decimeters), <0.34 Ma (ejection from the Moon) and 9.7±1.3 ka (fall on Earth).

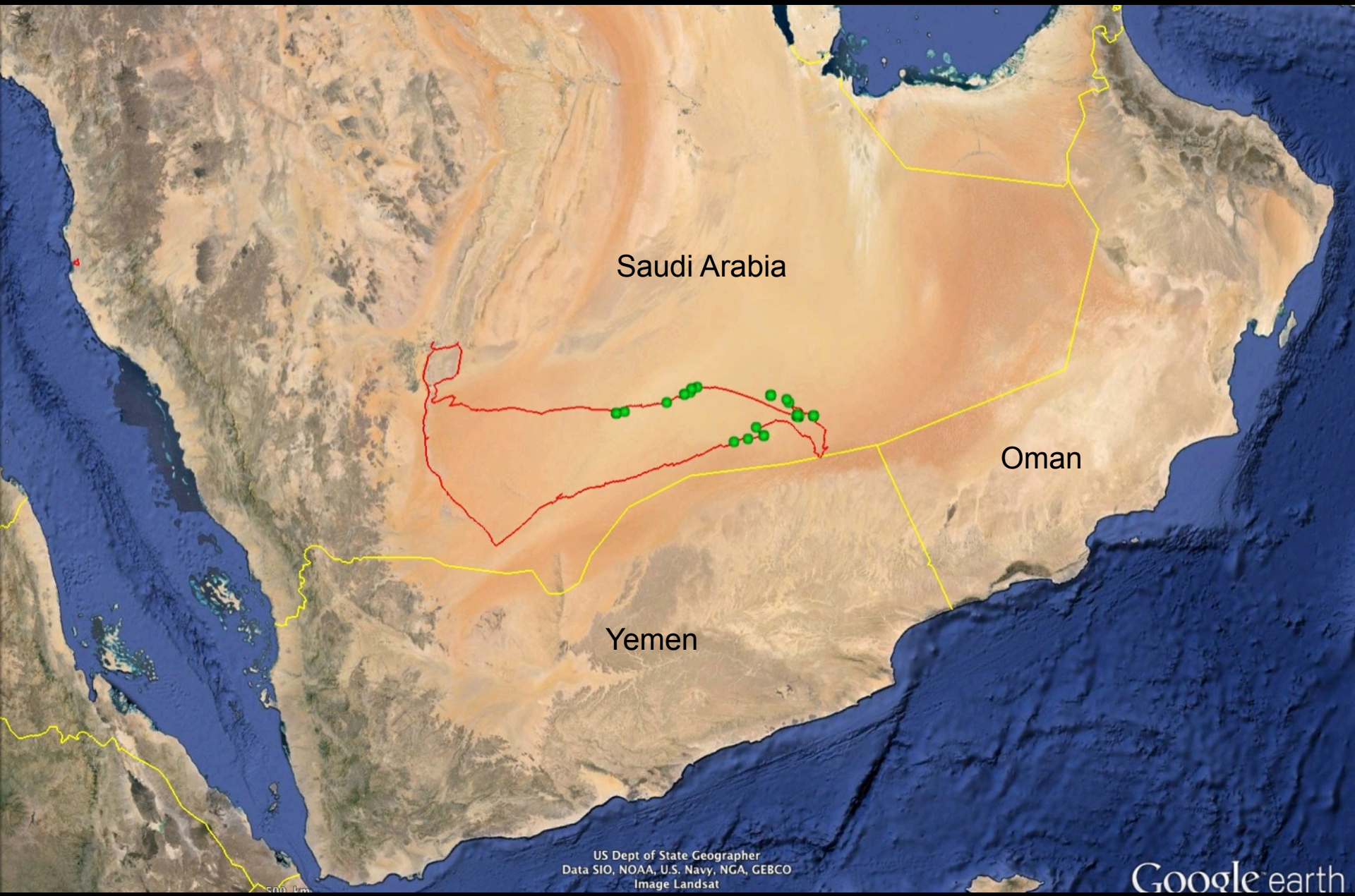
Shergottite (Mars basalt) found 2016



Shergottite (Mars basalt) found 2016

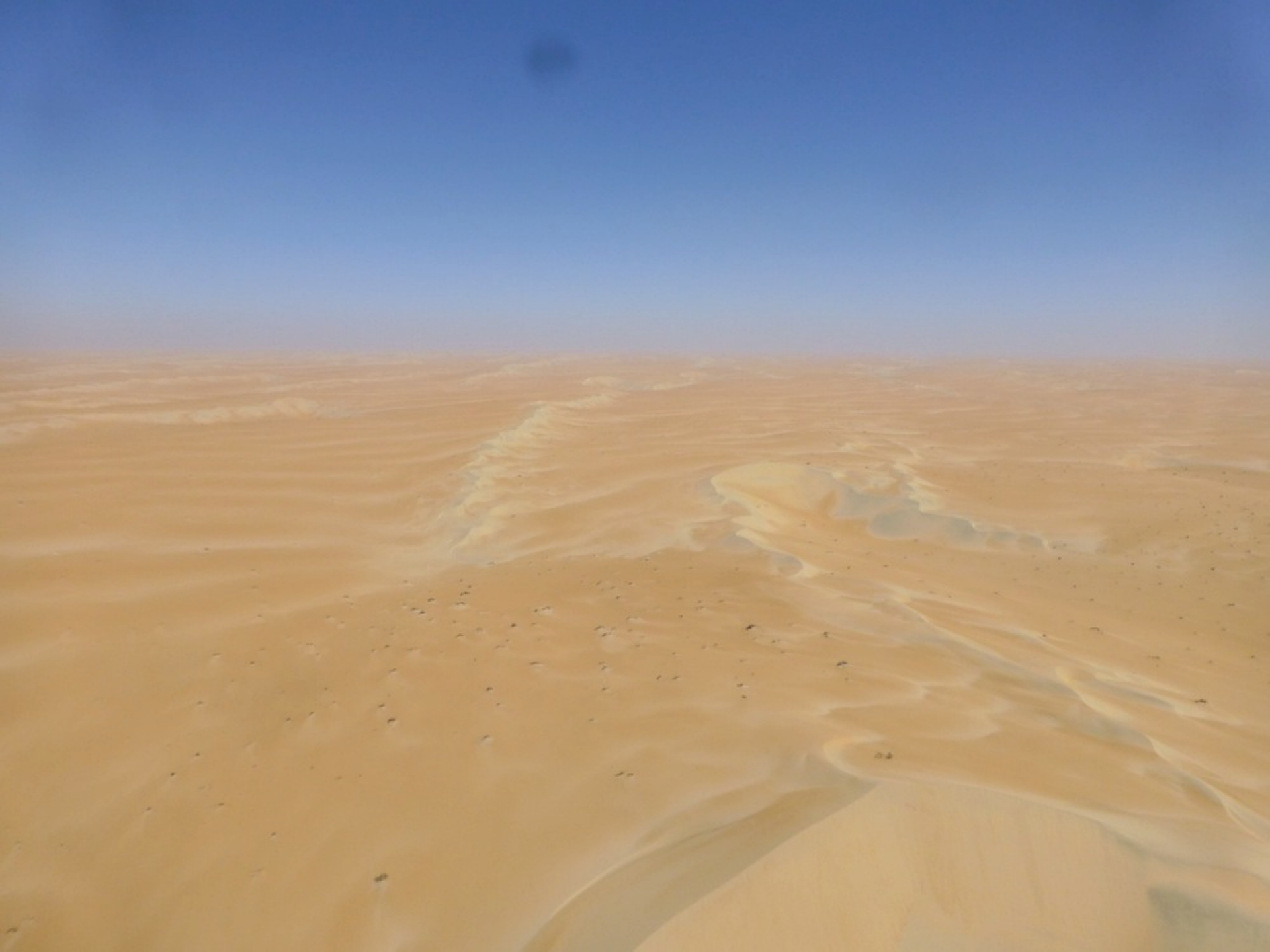

2014
2011
2008 & 2012
Saudi Arabia
2013
600 km
600 km
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat
Google earth
Bildaufnahmedatum: 4/10/2013 21° 29.902' N 52° 13.060' O Höhe 110 m sichthöhe 2180.77 km

Rub‘ al-Khali expedition, Saudi Geological Survey, 2013



Rub‘ al-Khali Expedition, Saudi Geological Survey, 2013 (2000 km track)

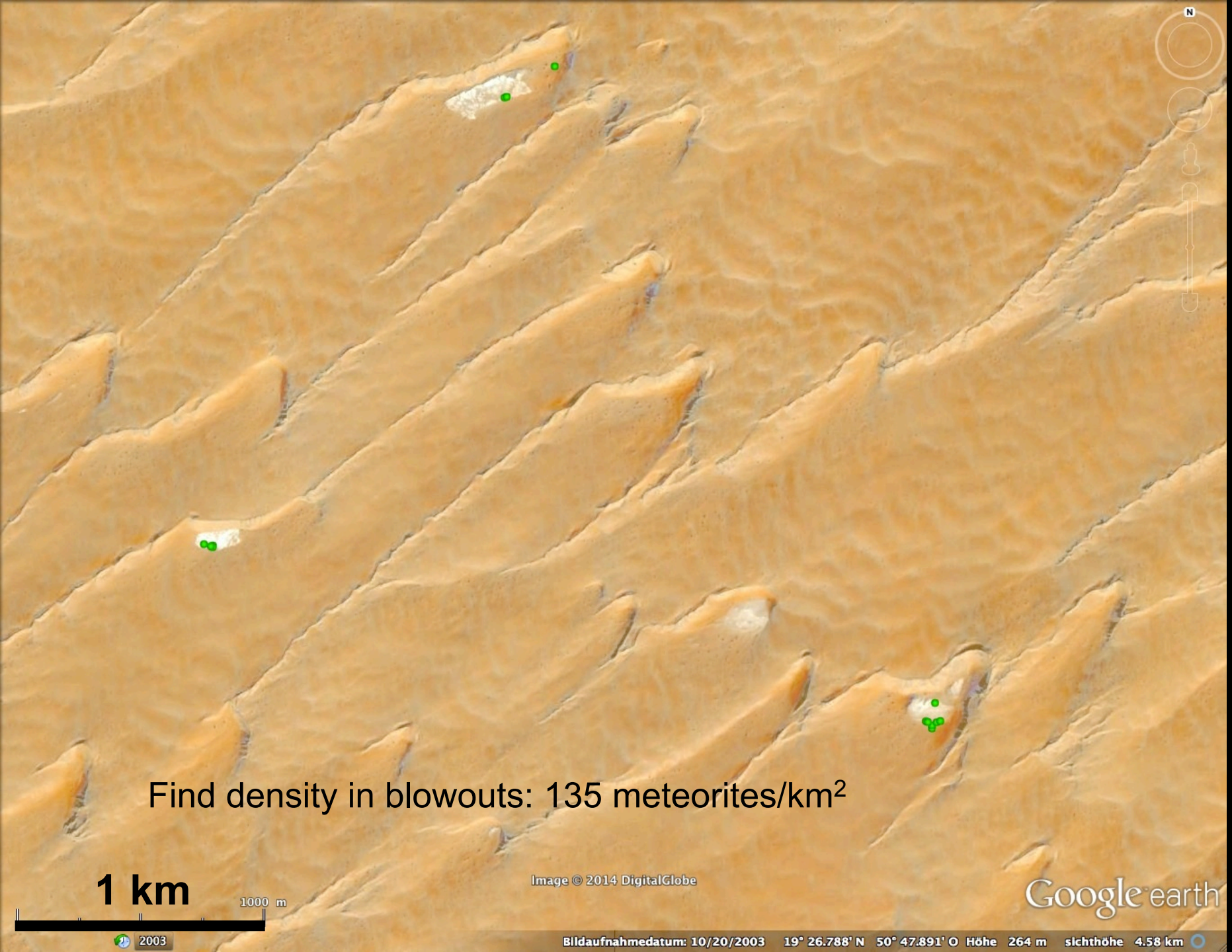

Estimated find density on open areas: 2.8 meteorites/km^2



Lake deposits from humid climate intervals, 70 − 125 ka (Matter et al. 2015)

Lake deposits from humid climate intervals, 70 − 125 ka (Matter et al. 2015)


Saudi-Swiss Meteorite Search 2013
S13-018


Find density in blowouts: 135 meteorites/km^2
1 km
1000 m
Image © 2014 DigitalGlobe
Google earth
2003
Bildaufnahmedatum: 10/20/2003 19° 26.788' N 50° 47.891' O Höhe 264 m sichthöhe 4.58 km

2001 – 2017 open areas searched ~1390 km^2 ~1140 fall events
Search by car: 1.0 met/km^2; syst. search by foot: 7.1 met/km^2

2 falls during last 20 years
-> 72 falls per 10^6 km^2*year (Halliday 1989: 80*10^6 km^2*year)

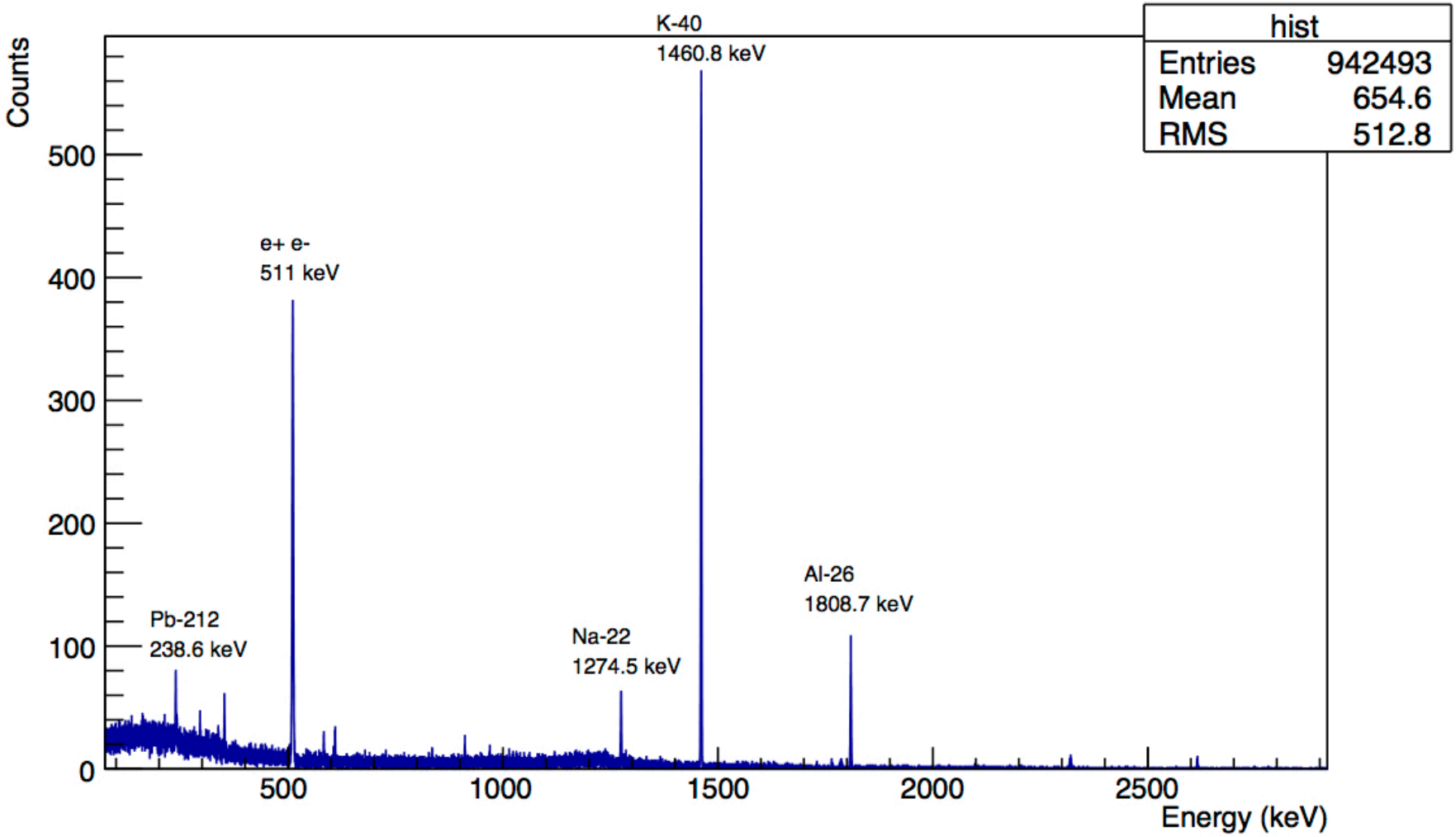
Going back to Oman with the Saudi experience..!

2016 - 2020: 254 „blowouts“ searched (13.1 km^2)

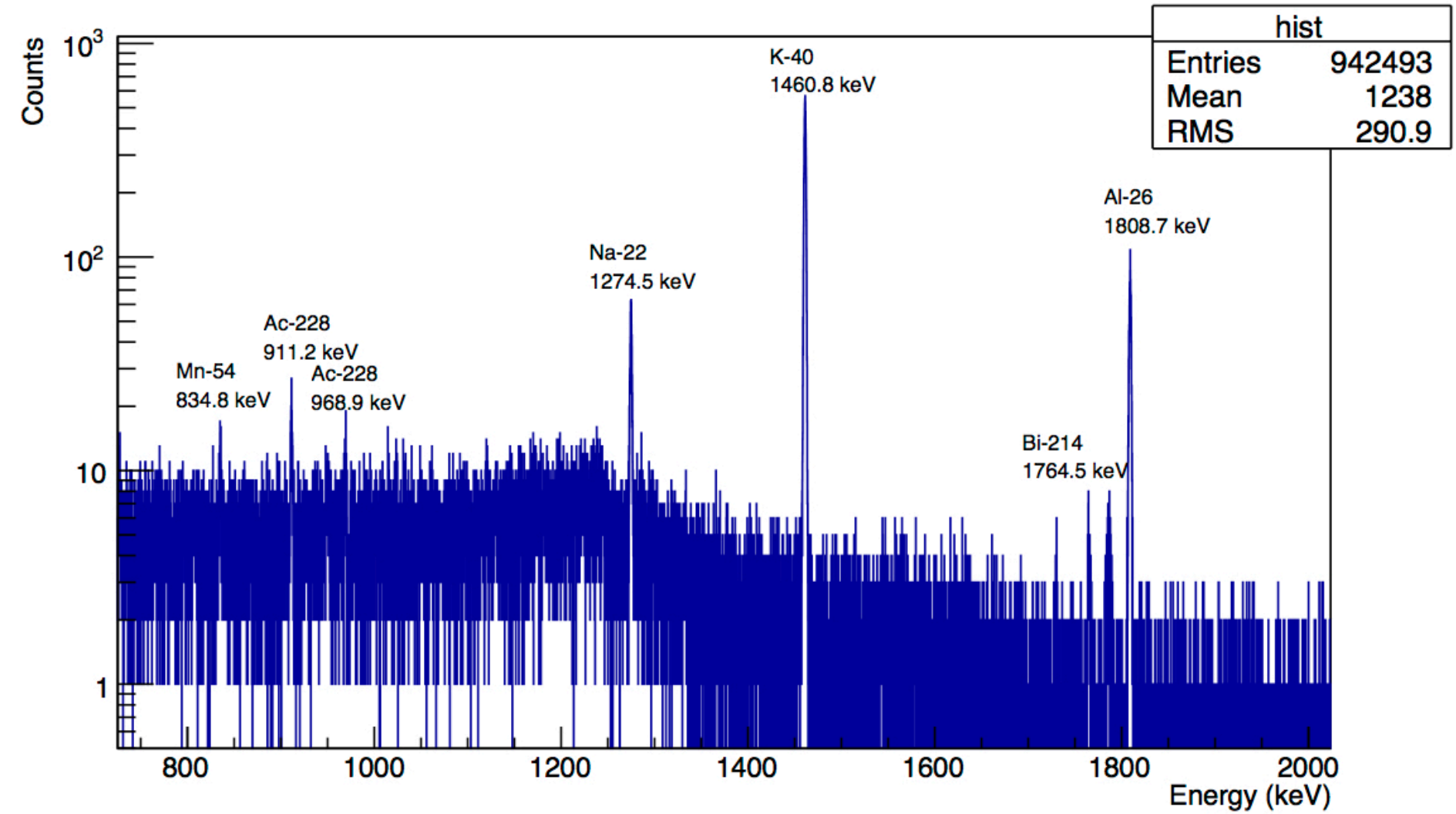
-> 408 meteorites

-> 31 meteorites/km^2 (fall rate 80/10^6 km^2*a -> ~400‘000 a accumulation)

Very fresh (unweathered) chondrite, found February 12, 2017

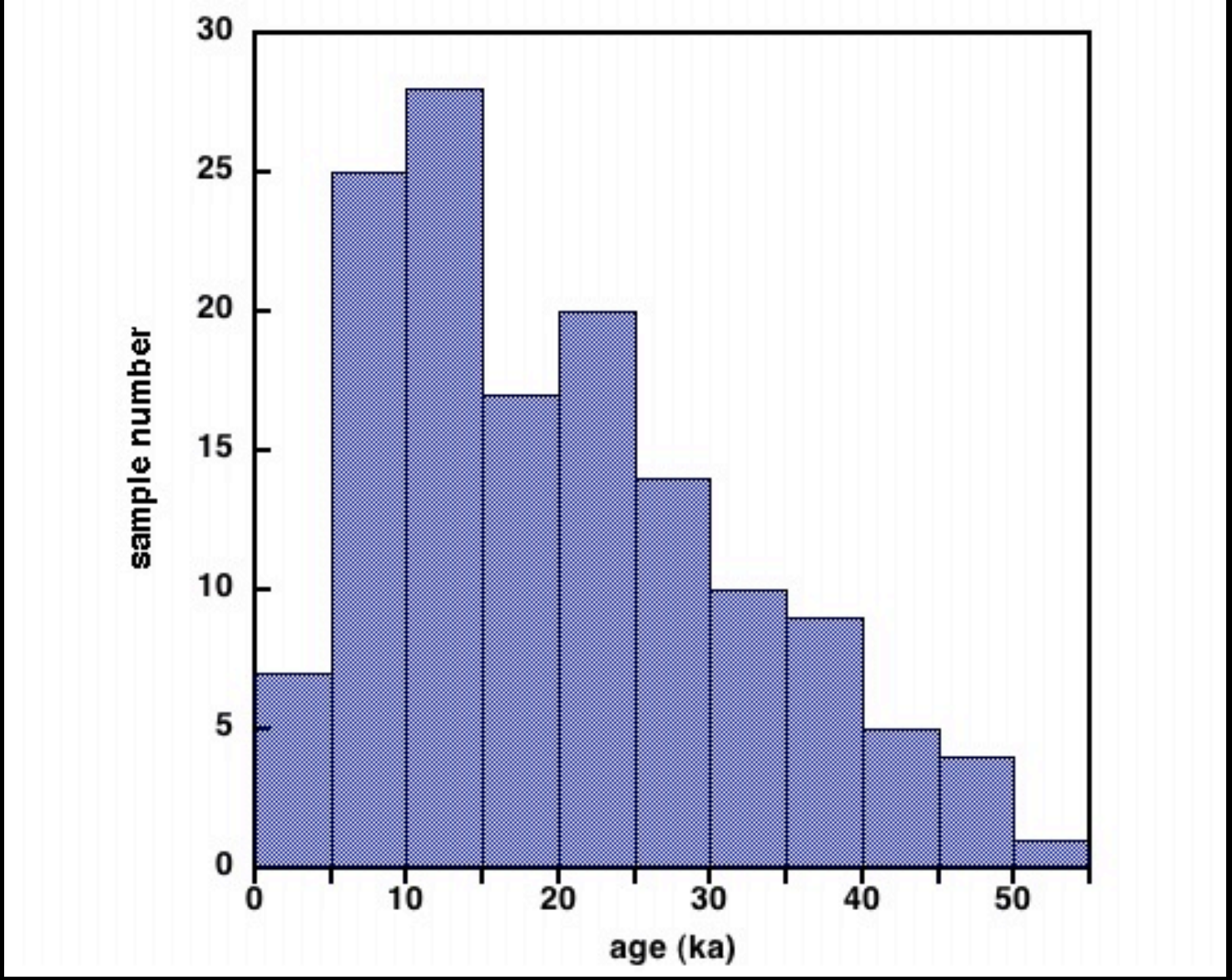


Gamma spectrum of fresh find (GeMSE facility, Åke Rosén)

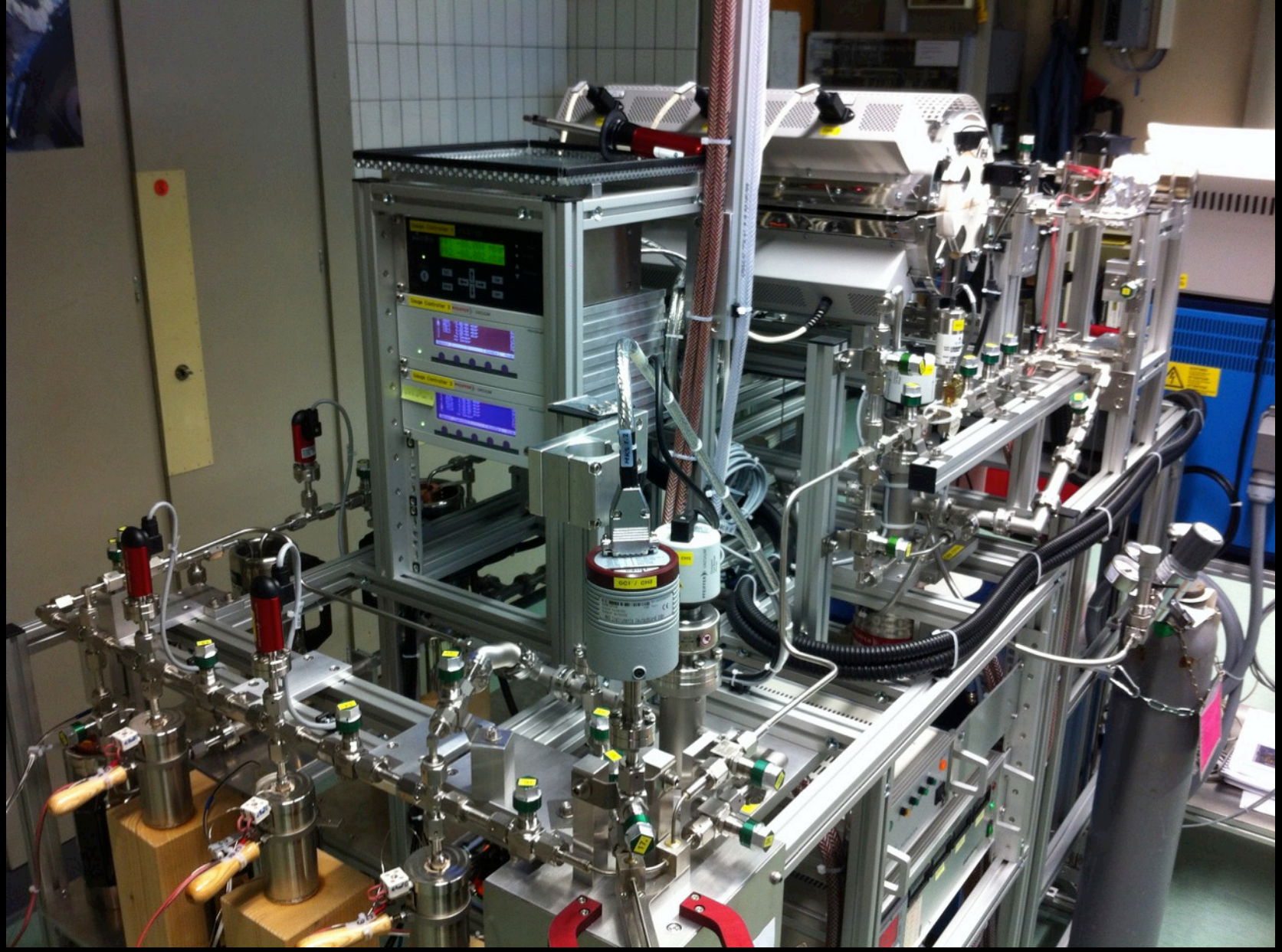


Gamma spectrum of fresh find (GeMSE facility, Åke Rosén): ^{22}Na ($t_{1/2}$ 2.6 a) and ^{54}Mn ($t_{1/2}$ 0.85 a) prove that it is a young fall (summer 2012)

Analysis of all candidates for recent falls among ~1300 fall events
-> 2 falls younger than ~20 years -> recovered meteorites represent ~13‘000 years of falls.



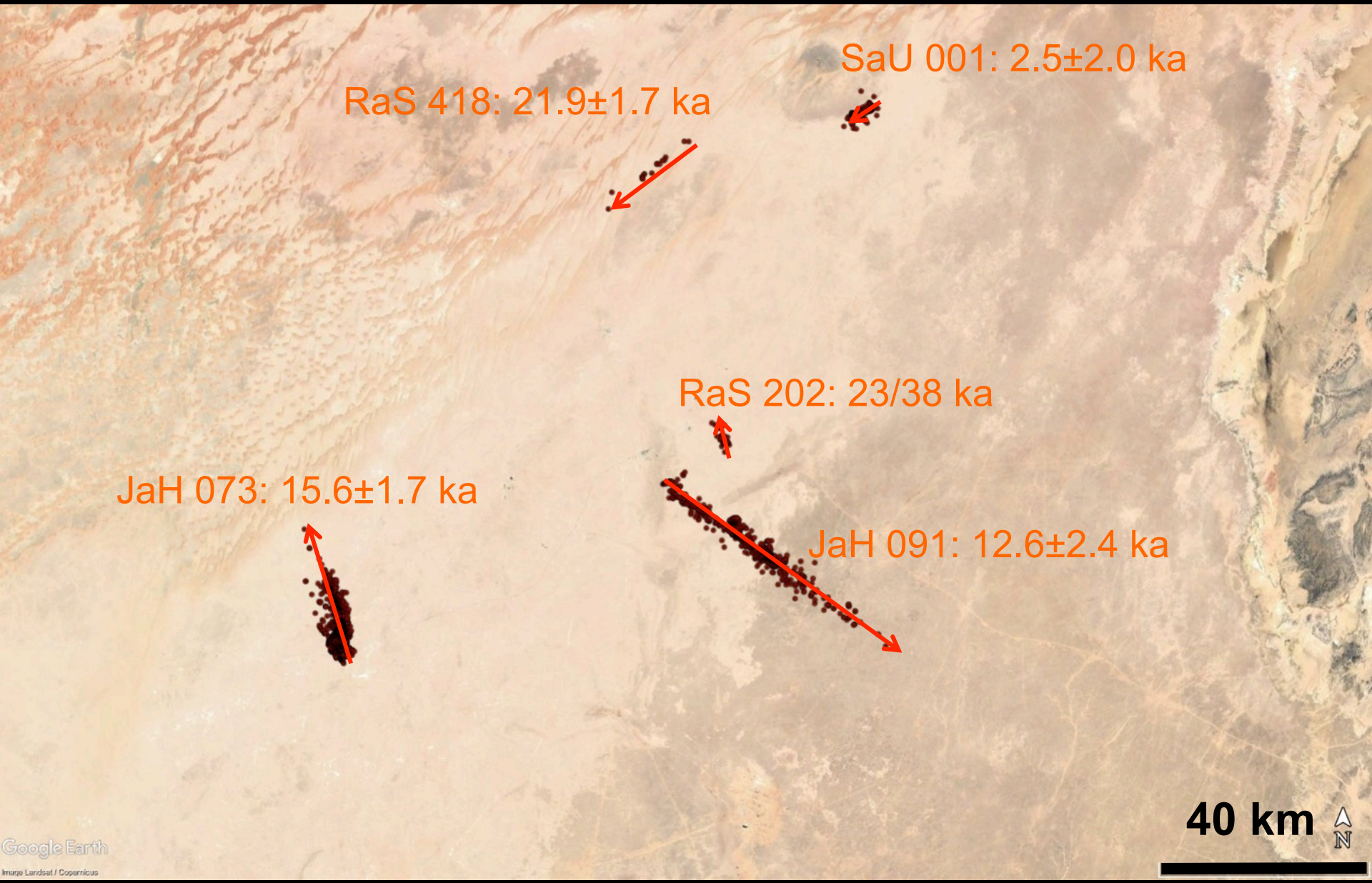
^{14}C –terrestrial ages (Tim Jull, University of Arizona): Mean age ~20‘000 years, lack of young meteorites

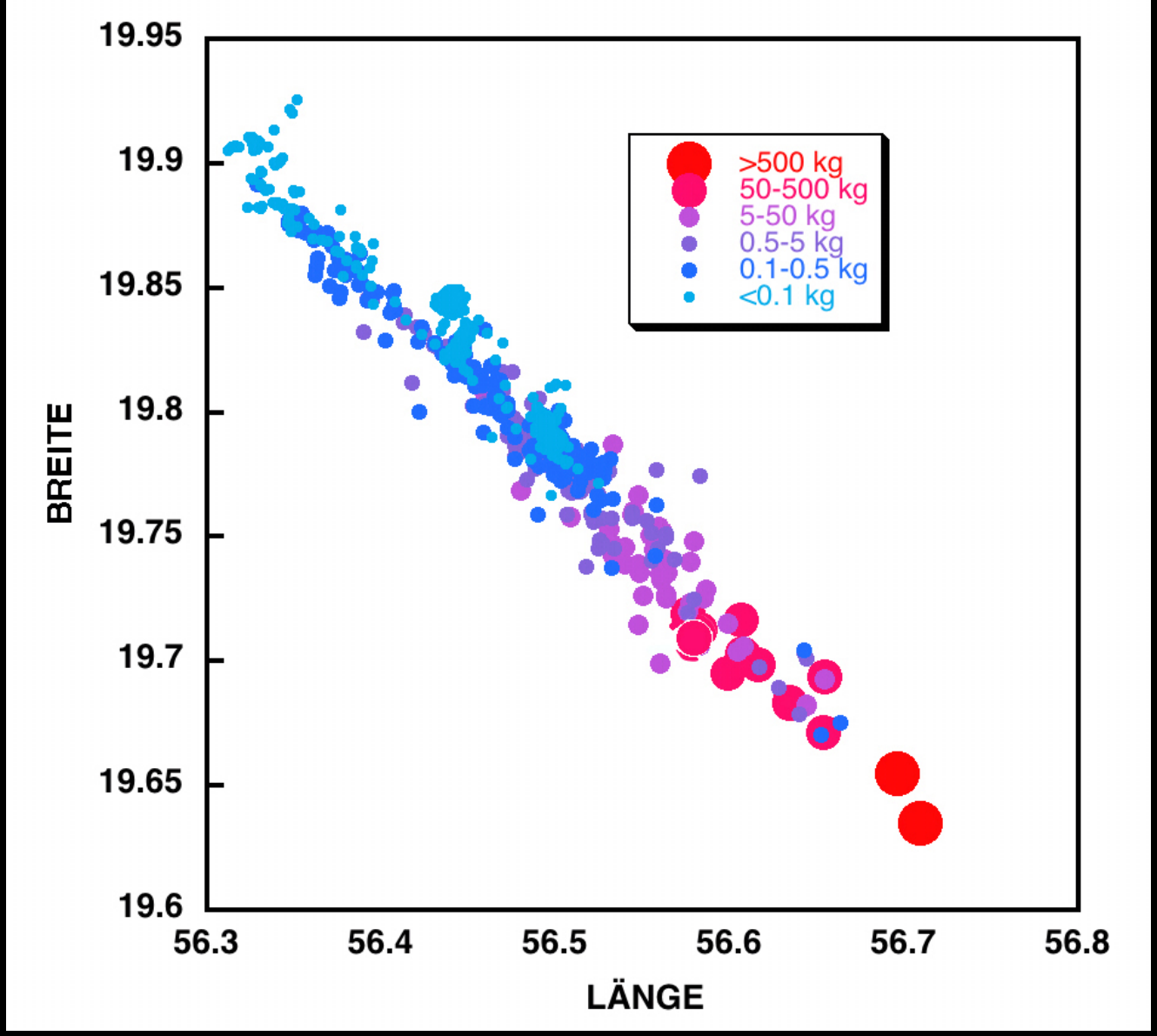


^{14}C extraction line for meteorites, Physics Institute, University of Bern
Prof. Ingo Leya, PhD project Malgorzata Sliz 2016-2020


40 km
N
Google Earth
Image Landsat / Copernicus


40 km
N
Google Earth
Image Landsat / Copernicus


SaU 001: 2.5±2.0 ka
RaS 418: 21.9±1.7 ka
RaS 202: 23/38 ka
JaH 073: 15.6±1.7 ka
JaH 091: 12.6±2.4 ka
40 km
N
Google Earth
Image Landsat / Copernicus

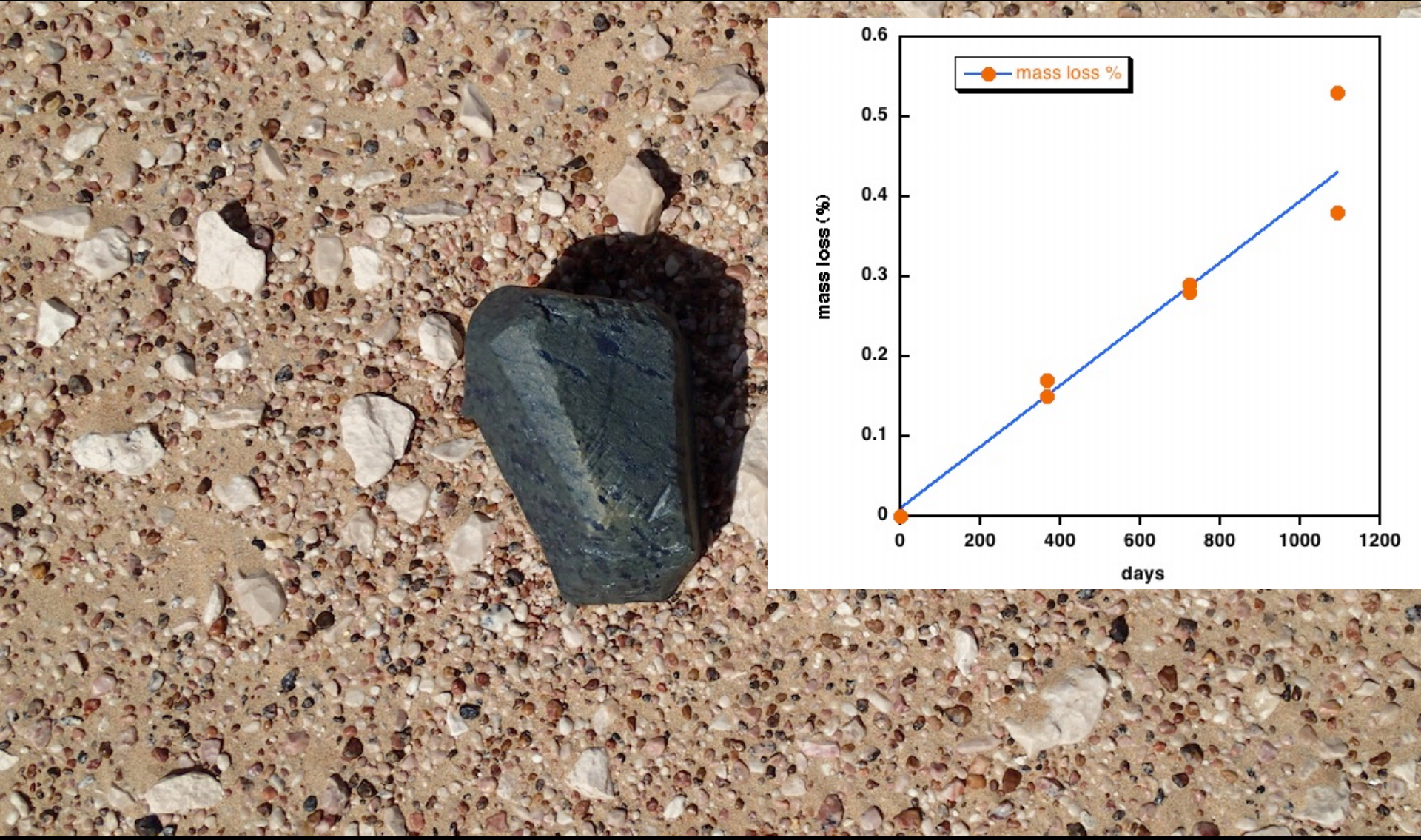


Jiddat al Harasis 091 (L5): The largest strewn field in Oman
Length: 52 km, 703 meteorites, 4600 kg total mass
(~14-30 t pre-atmospheric mass)


What is the main process removing meteorites from the desert?


What is the main process removing meteorites from the desert?

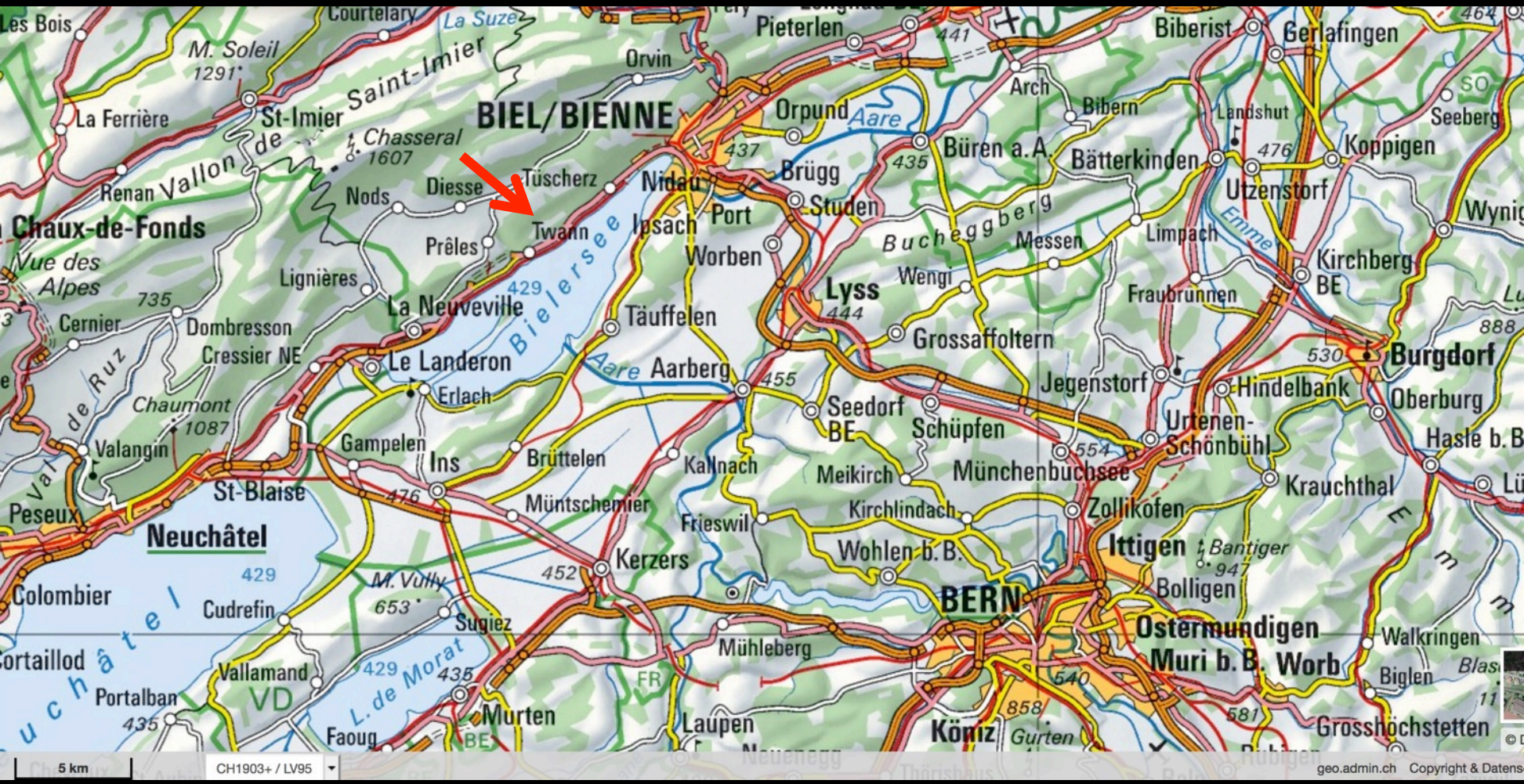
What is the main process removing meteorites from the desert?



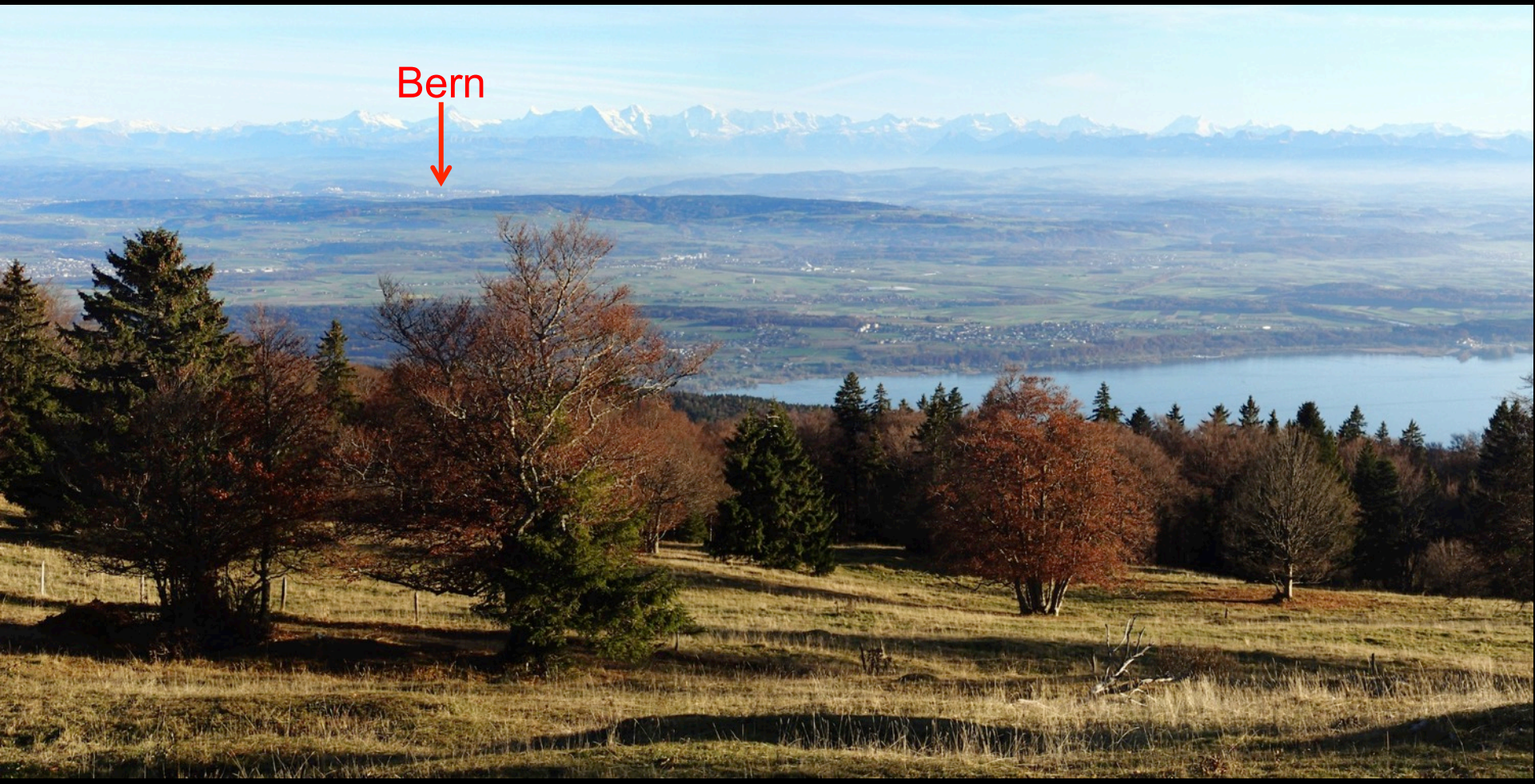
Field experiment with peridotite samples (meteorite-like mineralogy) with exposure times of 4 weeks to 3 years -> significant mass loss, estimated survival time of kg-sized meteorite just a few 1000 years.

Searching for meteorites in Switzerland

11 meteorites are known from Switzerland



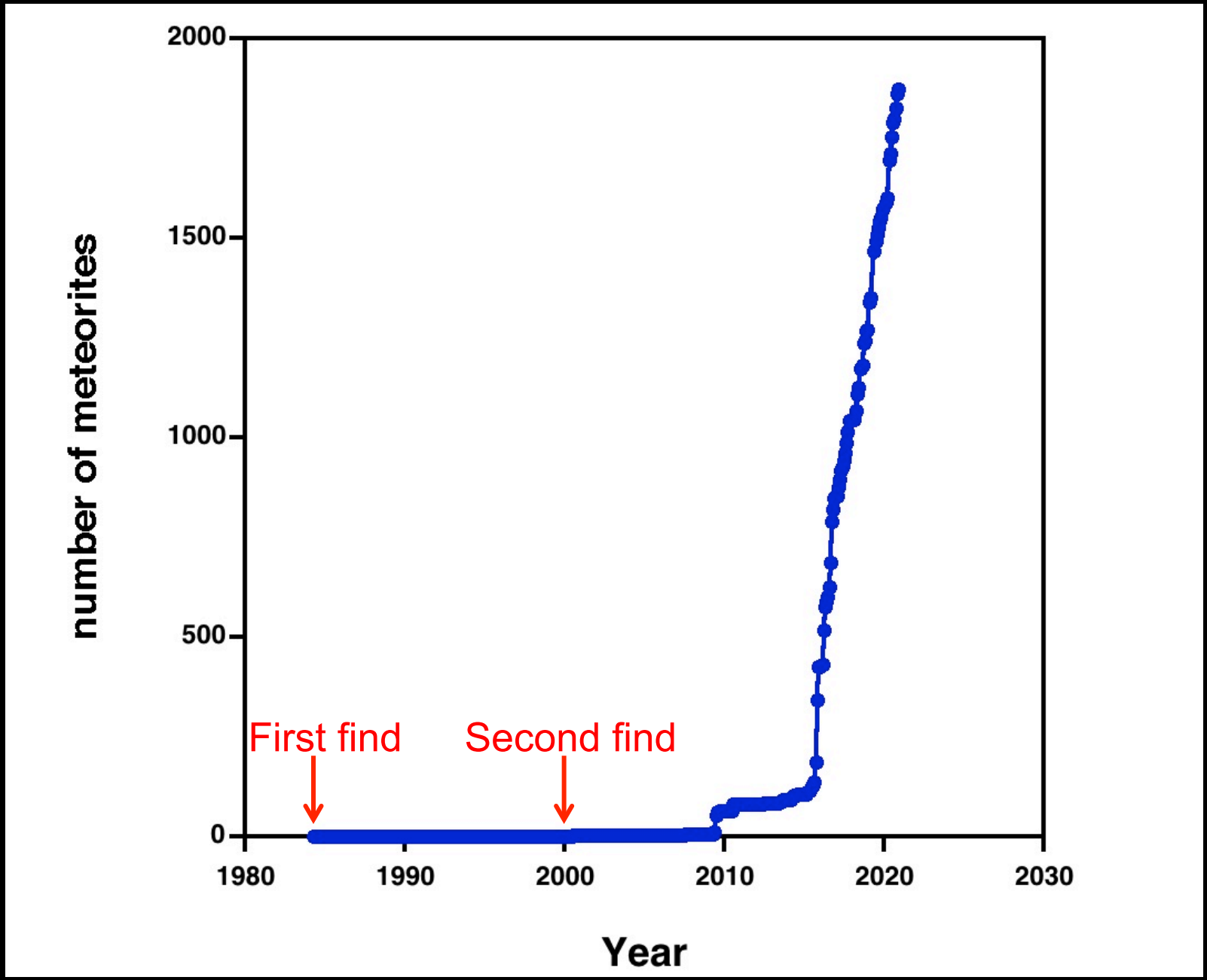
Twannberg is the only strewn field: just 30 km NW of Bern



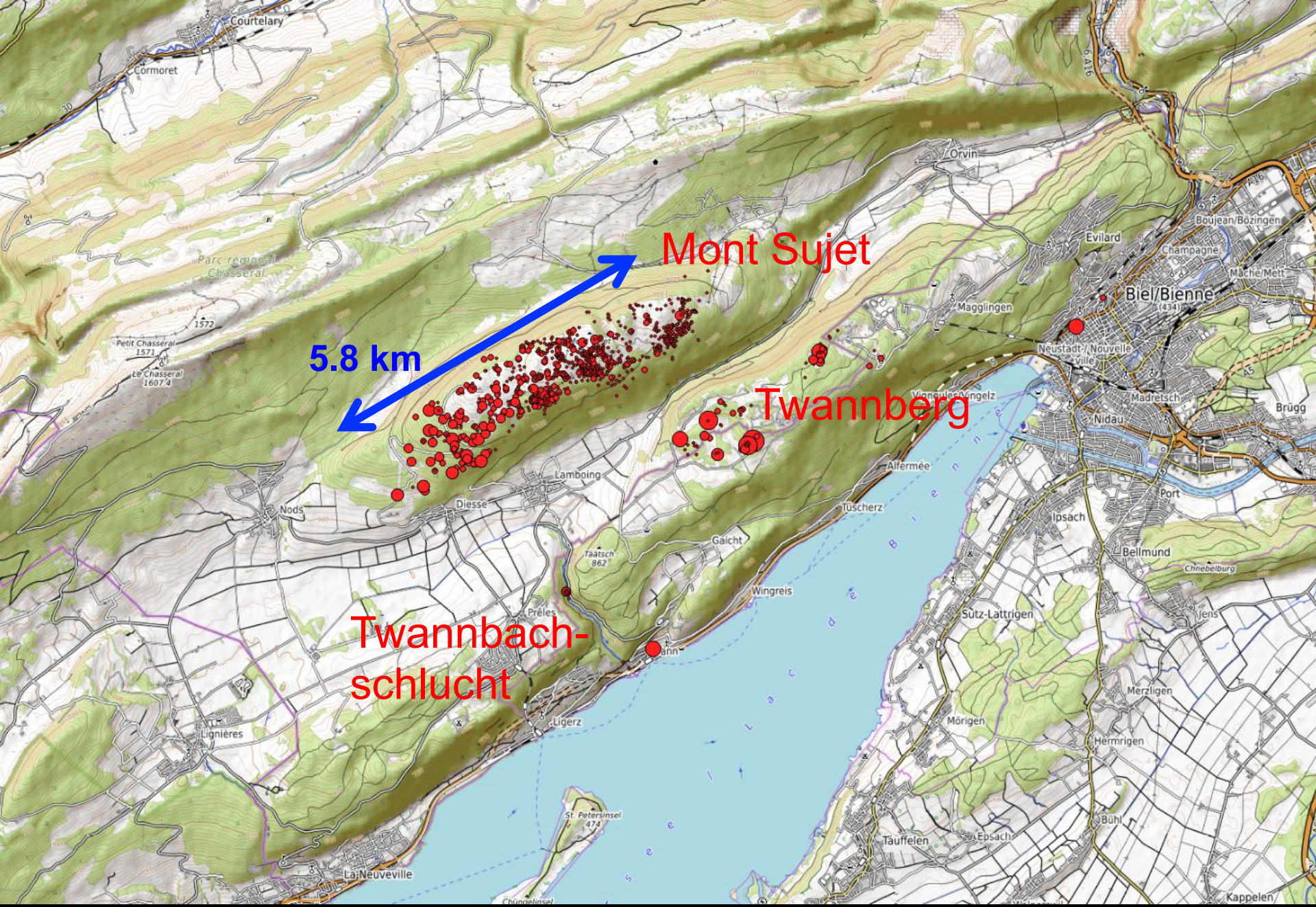
On Mont Sujet in the Twannberg strewn field, looking south

First and still largest mass of Twannberg (15.9 kg) found 1984 by Margrit Christen
Rare type IIG − iron meteorite

Twannberg mass1 (~25 cm) iron (4.5% Ni) and schreibersite $(Fe,Ni)_3P$



Many finds of Twannberg meteorites since 2015 !

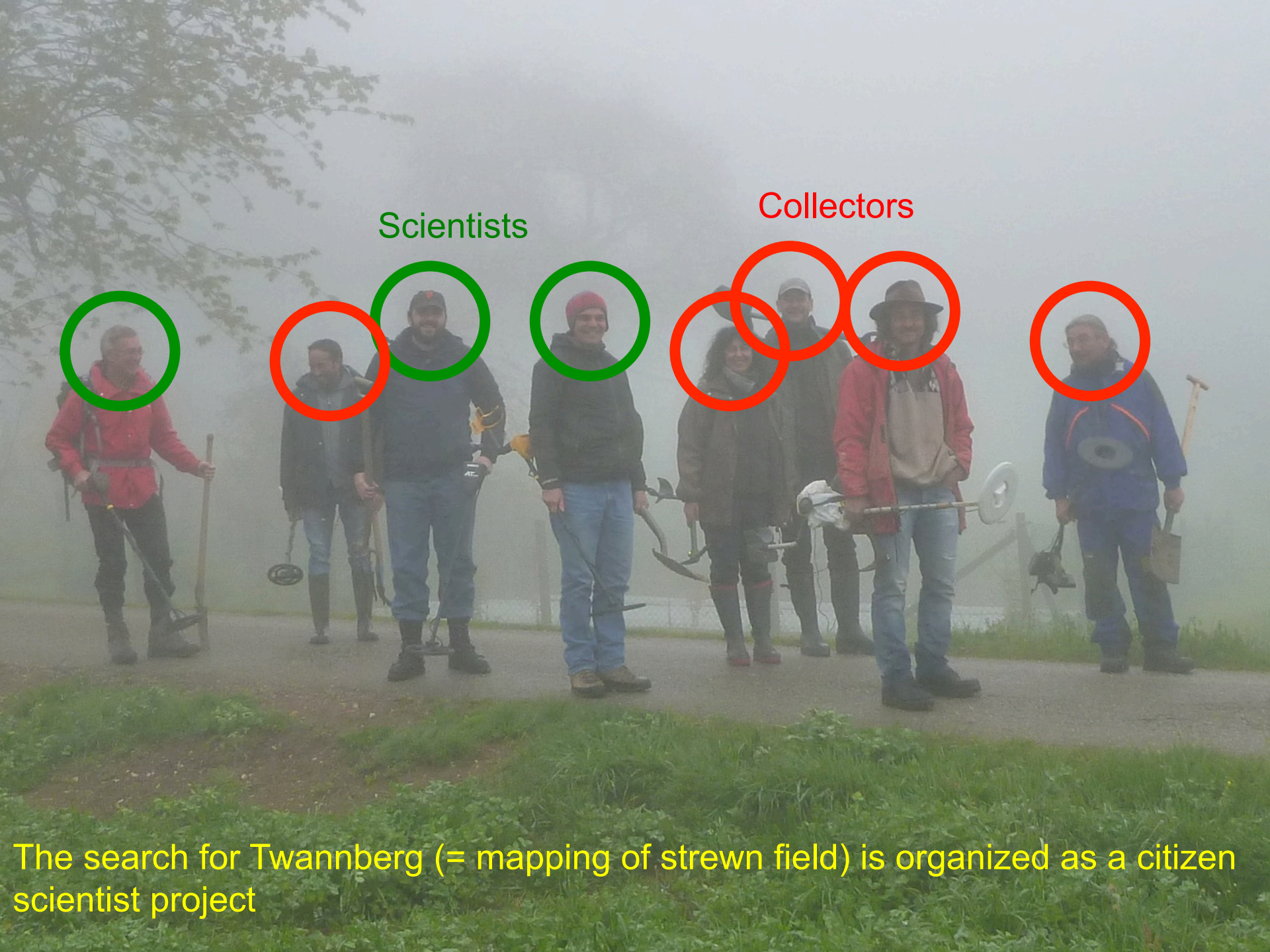


Three find areas of Twannberg meteorites northwest of the Lake of Biel

Twannberg - Meteorites, Mont Sujet


Well-preserved fusion crust with flow lines)
1000µm


Well-preserved fusion crust with flow lines and “ripples” (2 cm)



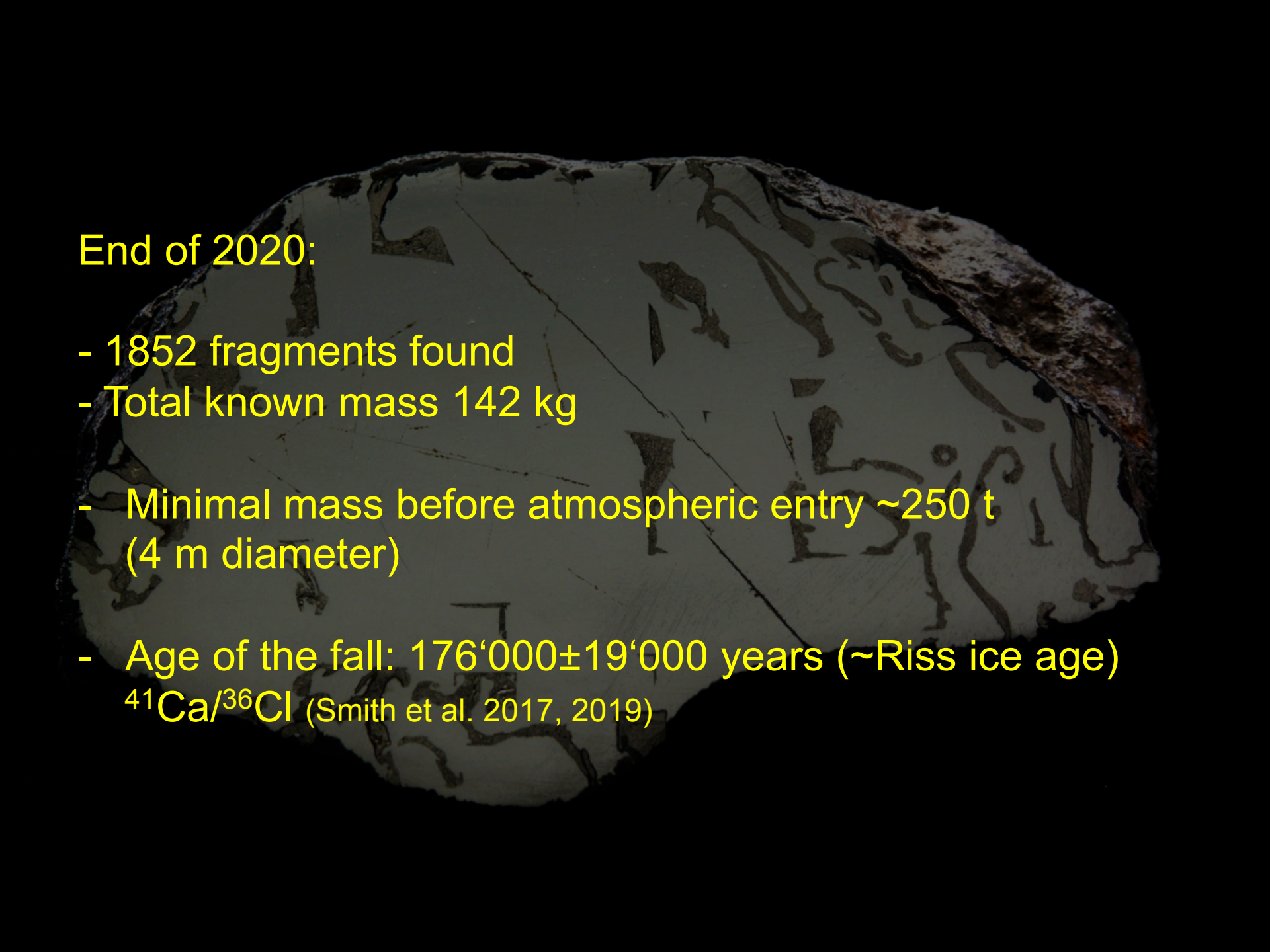
The search for Twannberg (= mapping of strewn field) is organized as a citizen scientist project

Permissions are required for the use of metal detectors (Archaeological Survey, canton's responsibility), limited number of permissions (from 30 down to 15)

Permissions are required for the use of metal detectors (Archaeological Survey, canton's responsibility), limited number of permissions (from 30 down to 15)

Permissions are required for the use of metal detectors (Archaeological Survey, canton's responsibility), limited number of permissions (from 30 down to 15)

Ordinary chondrite meteorite « Mont Sujet », independent find in the Twannberg strewn field, found 2017 by Bruno Meier

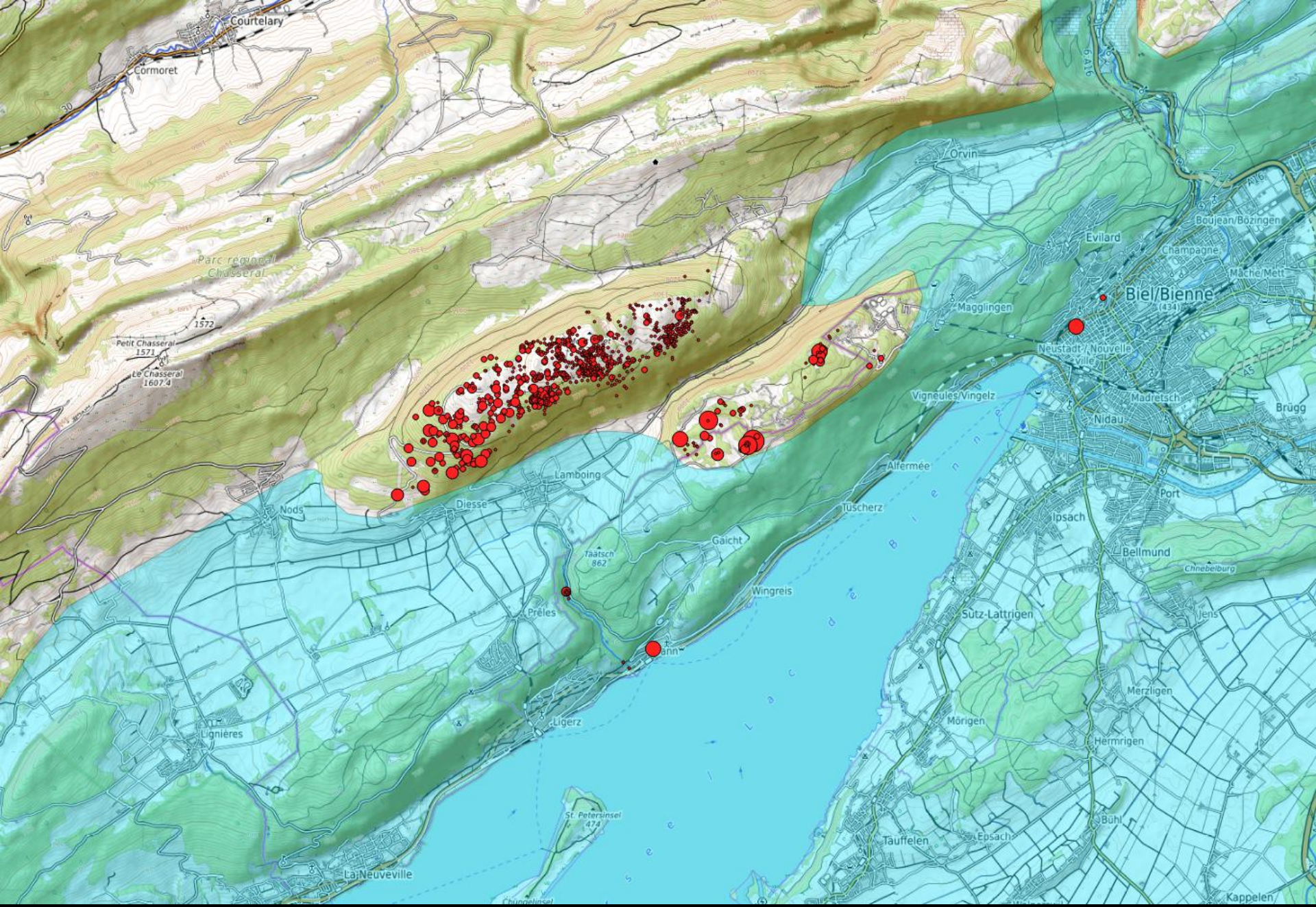


End of 2020:

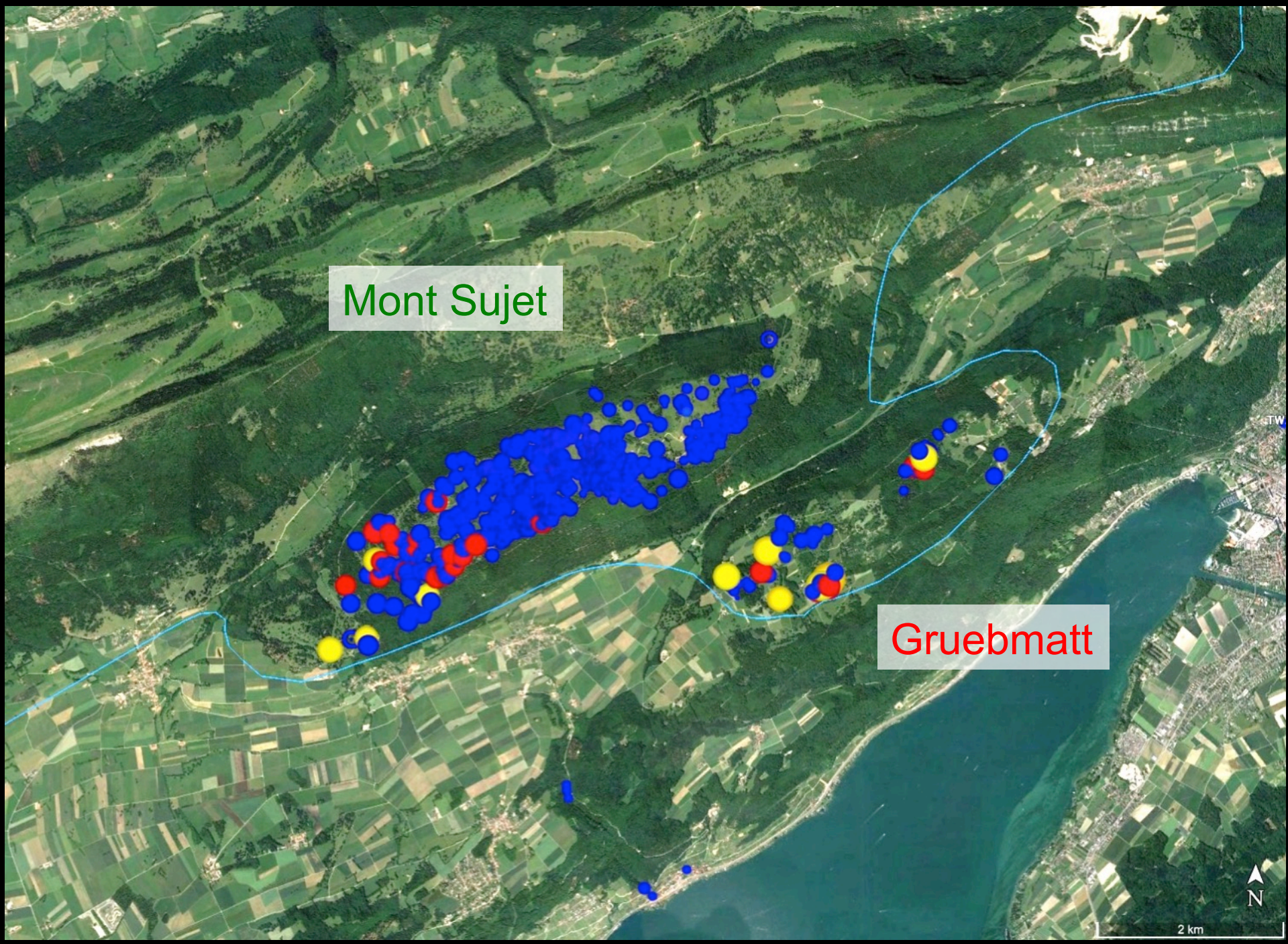
- 1852 fragments found
- Total known mass 142 kg

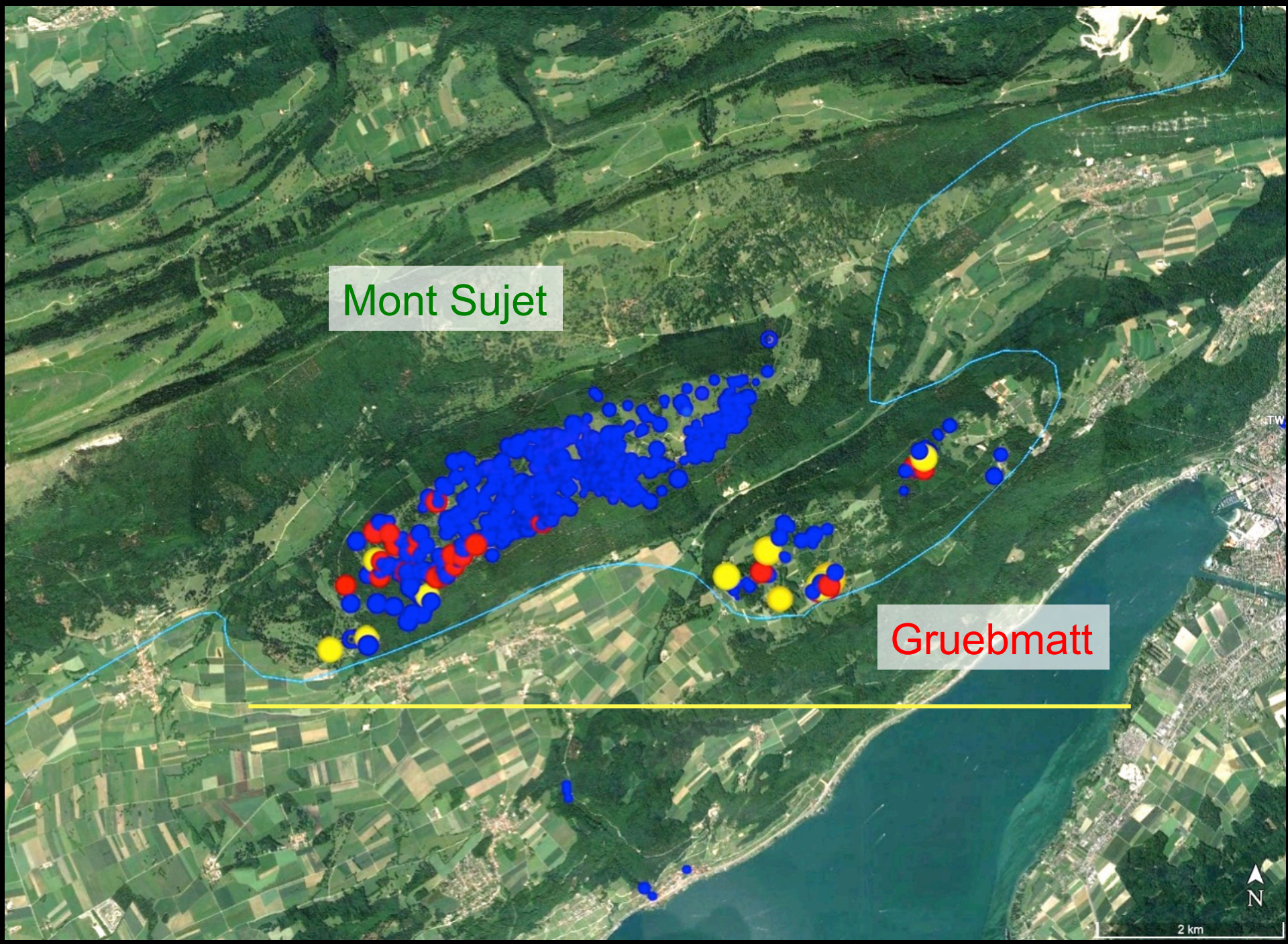
- Minimal mass before atmospheric entry ~250 t (4 m diameter)

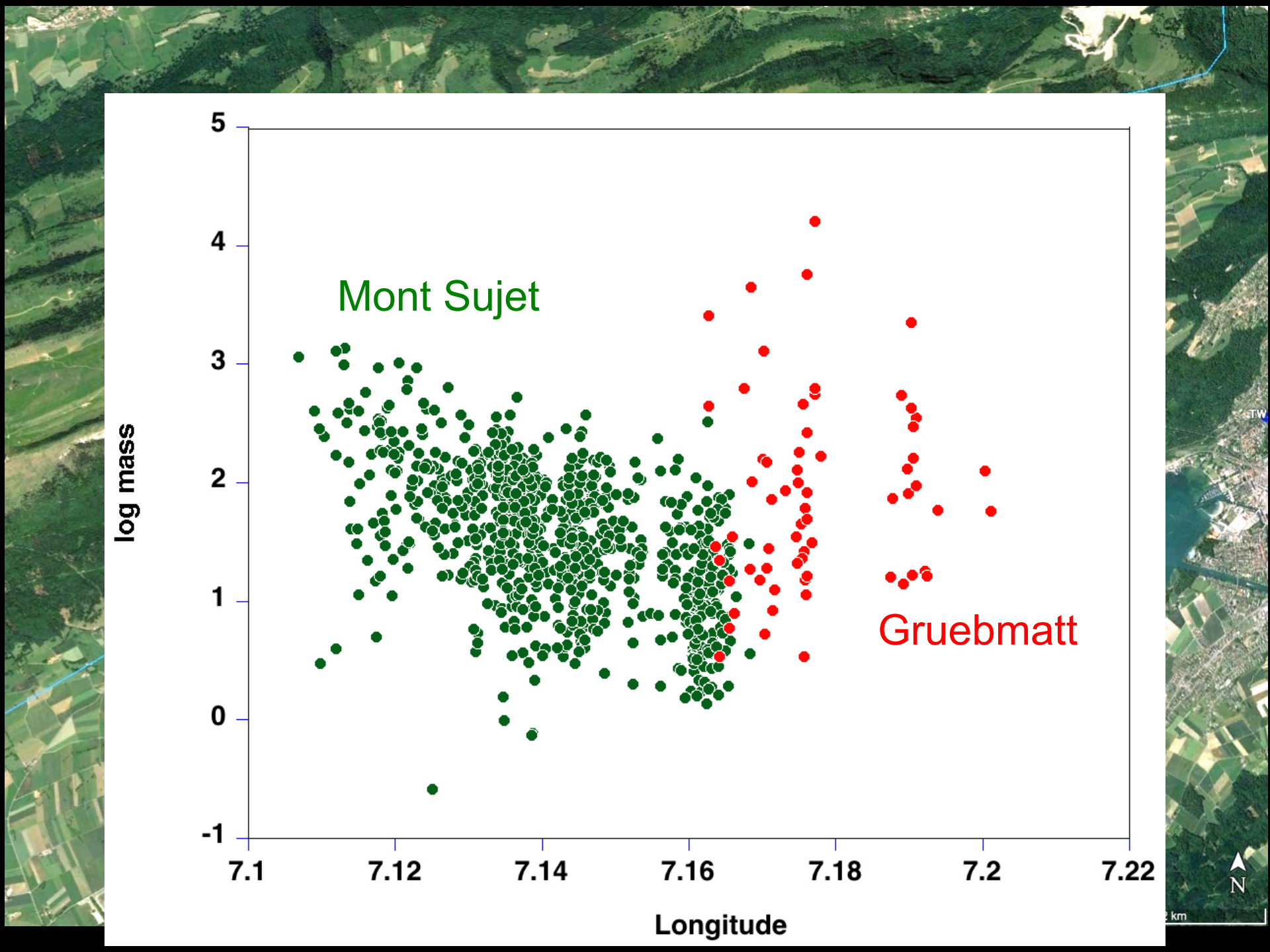
- Age of the fall: 176‘000±19‘000 years (~Riss ice age) $^{41}Ca/^{36}Cl$ (Smith et al. 2017, 2019)



Twannberg-meteorites: Find localities and extent of ice during last glacial period


Mont Sujet
Gruebmatt
N
2 km


Mont Sujet
Gruebmatt
N
2 km

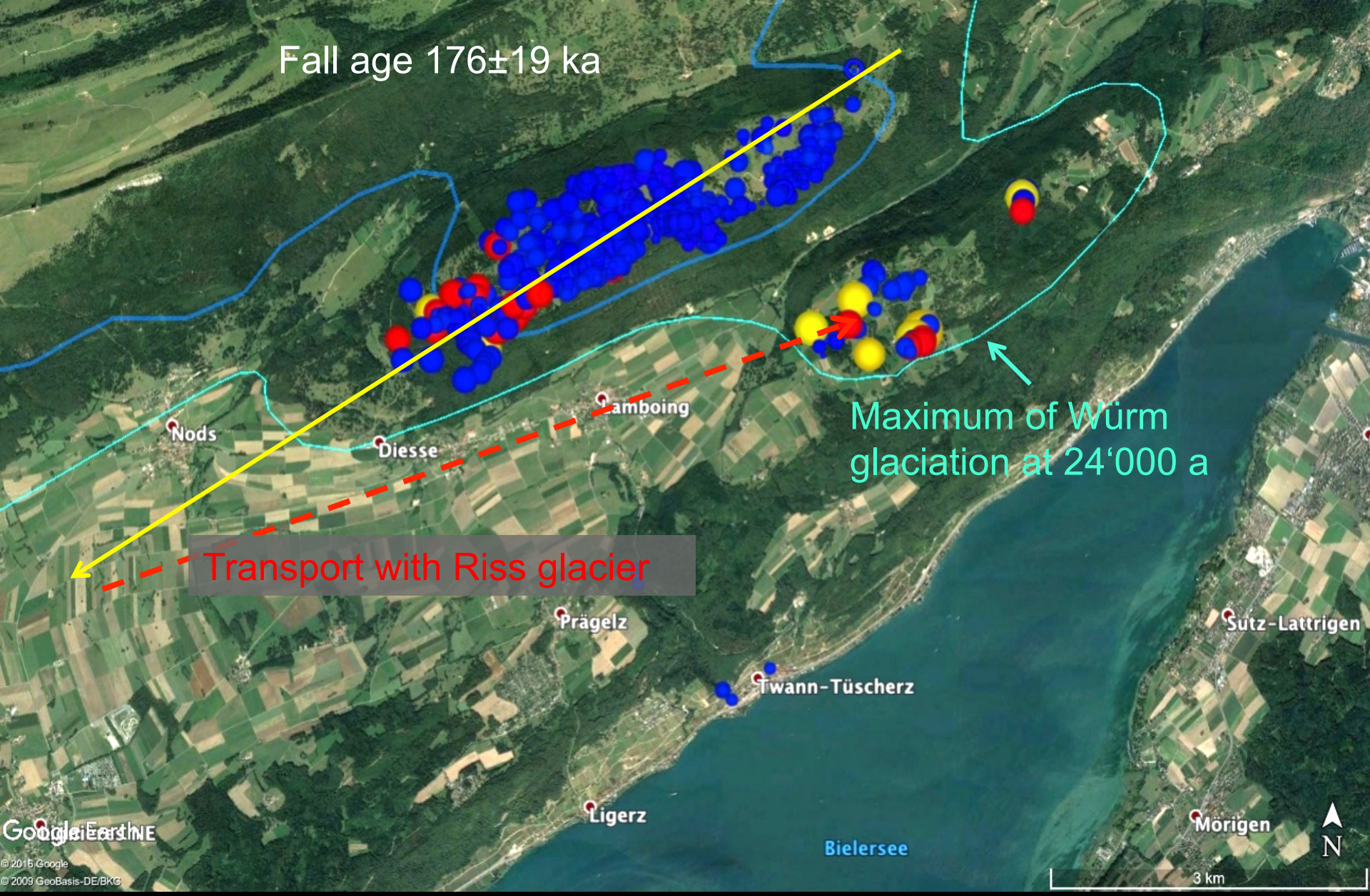

Mont Sujet
Gruebmatt
log mass
Longitude
5
4
3
2
1
0
-1
7.1
7.12
7.14
7.16
7.18
7.2
7.22
N

Twannberg-meteorite with adhering glacial till (field of view 10 cm)

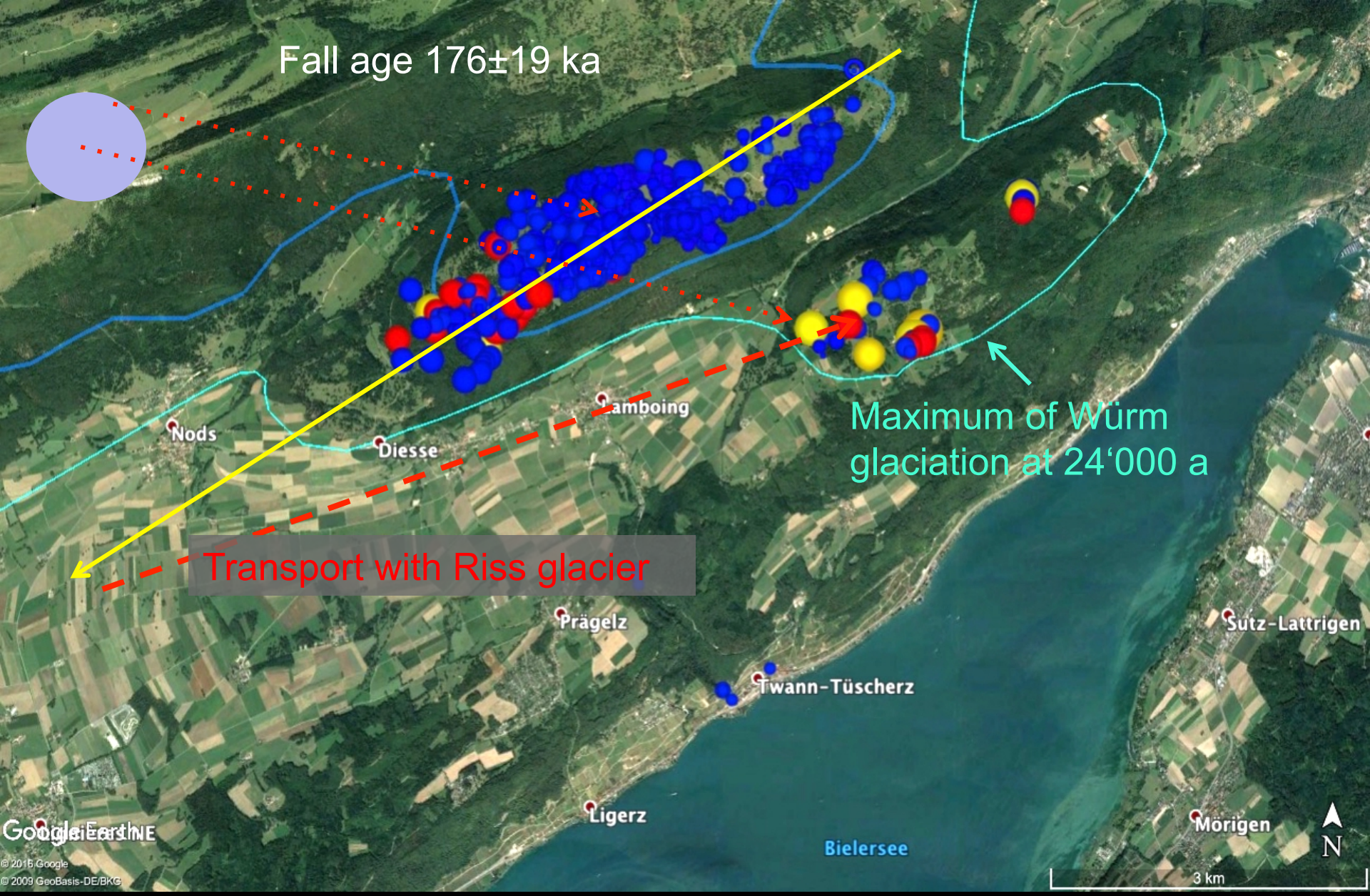
Twannberg-meteorite TW934 with till remains (coarse quartz) and fusion crust -> transport on the glacier (not at base)

Twannberg-meteorite TW934 with till remains (coarse quartz) and fusion crust -> transport on the glacier (not at base)

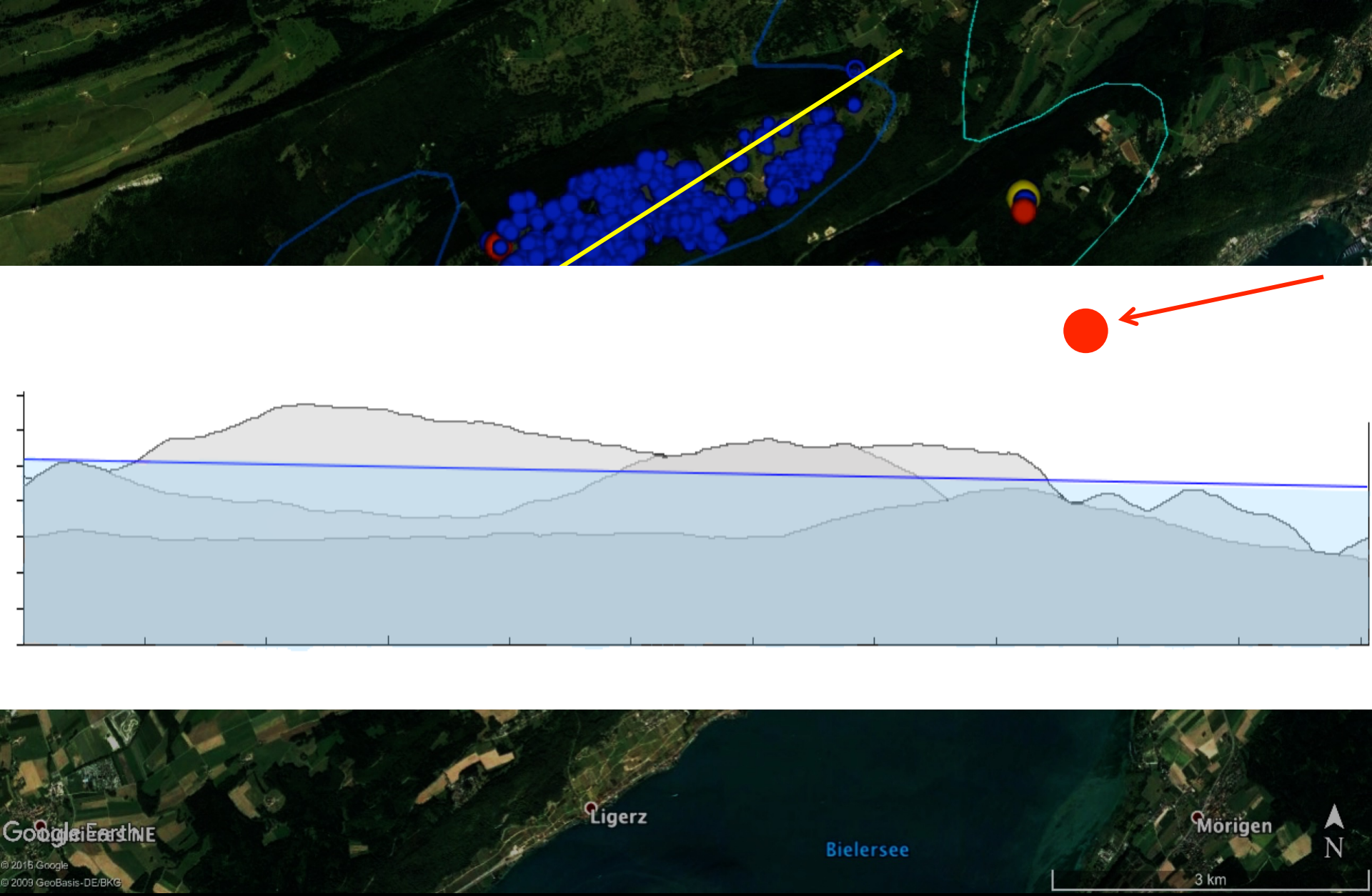
Highest glacial boulder in Twannberg area at Ferme Jobert, 1300 m
Axposure age dating using ^{10}Be and ^{26}Al : 66±2 ka (Naki Akçar)

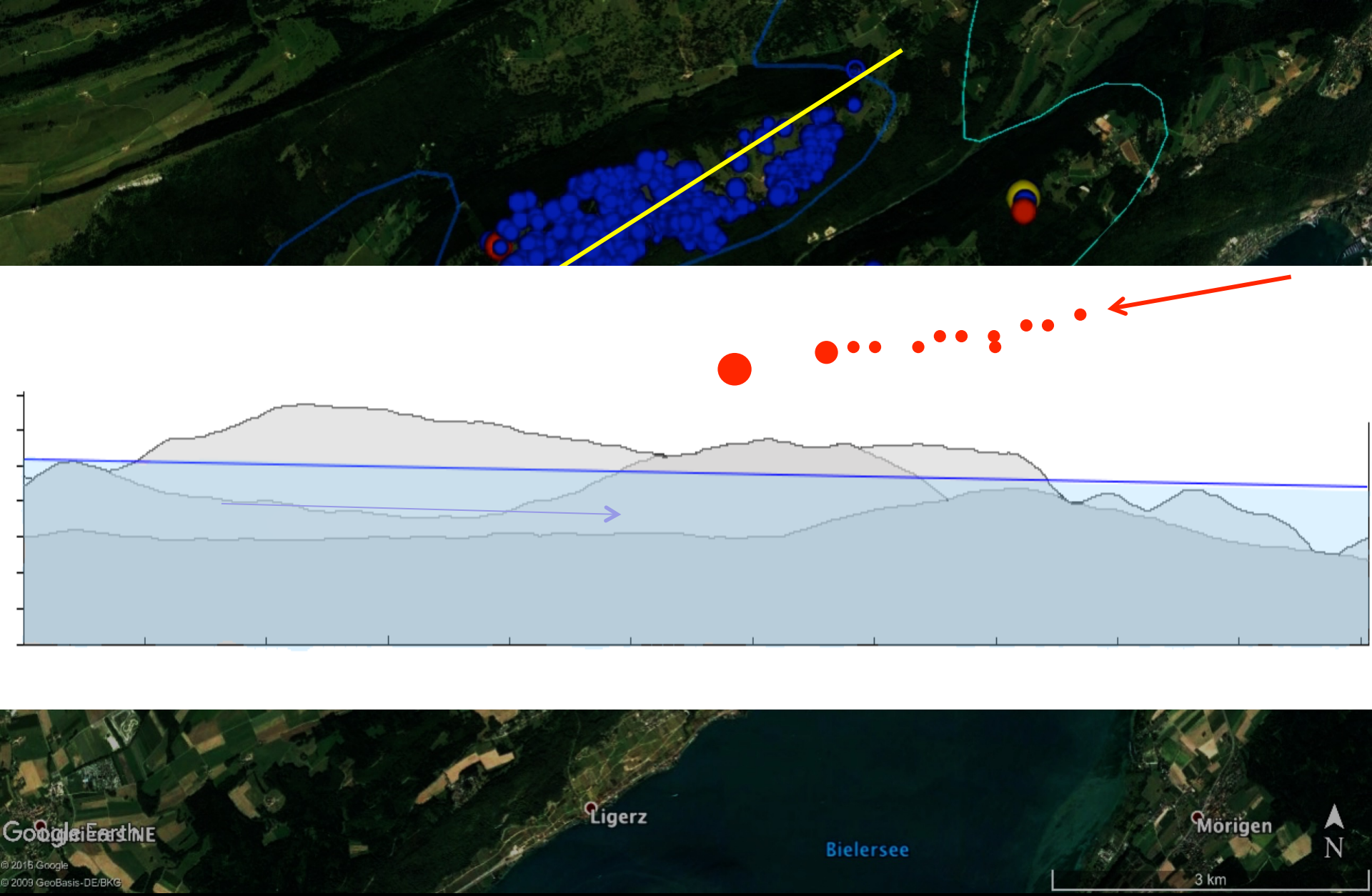


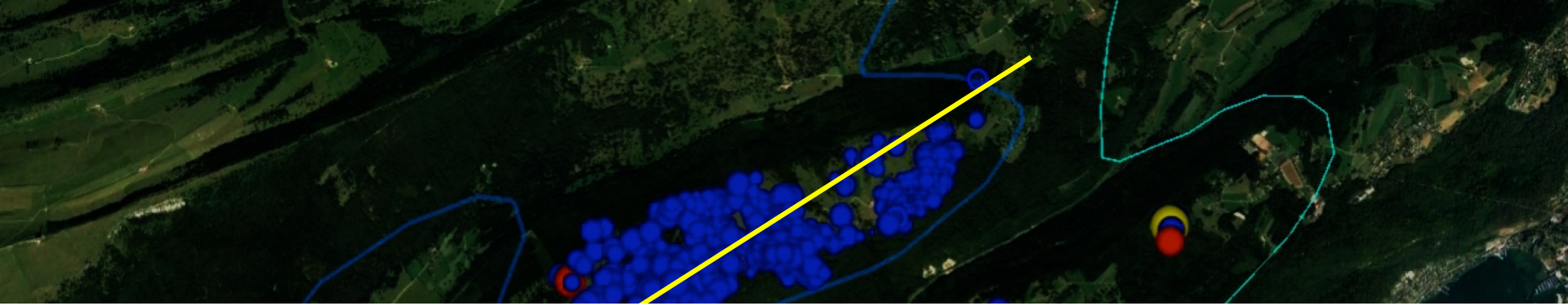
Suspected meteorite transport on ice during Riss ice age (MIS 6)

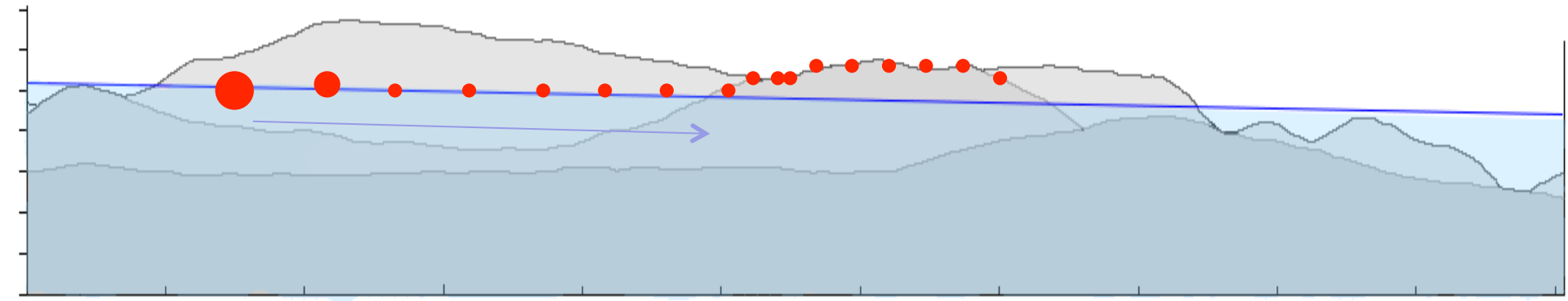


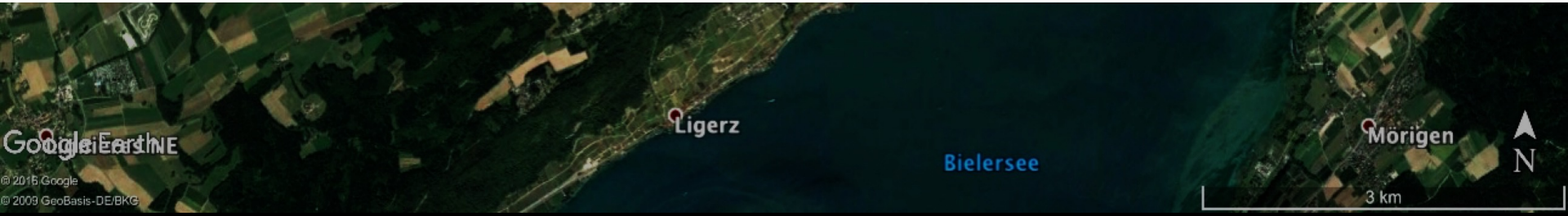
Suspected meteorite transport on ice during Riss ice age (MIS 6)

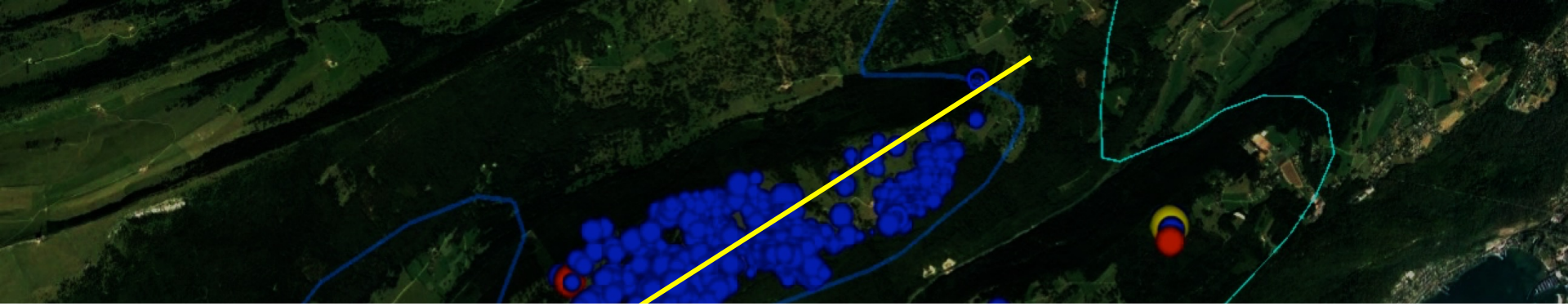

Ligerz
Bielersee
Mörigen
N
3 km
Google Earth
© 2015 Google
© 2009 GeoBasis-DE/BKG

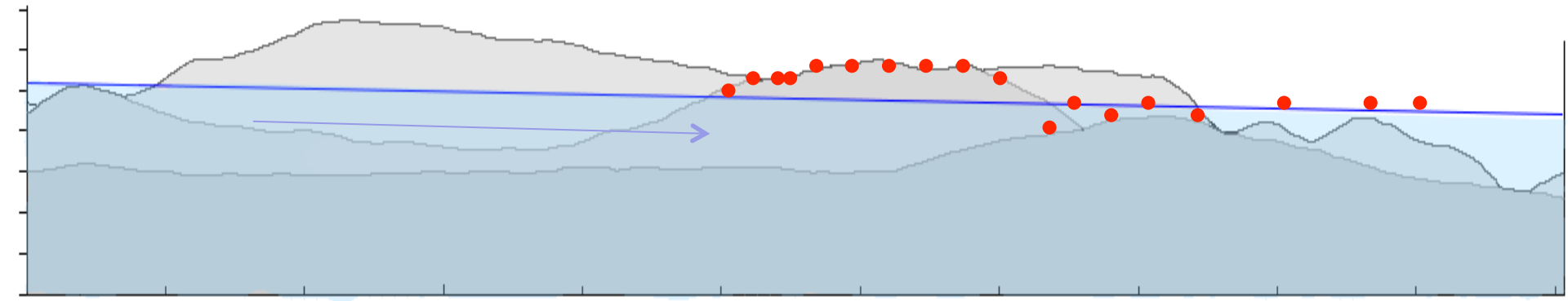

Ligerz
Bielersee
Mörigen
N
3 km
© 2015 Google
© 2009 GeoBasis-DE/BKG

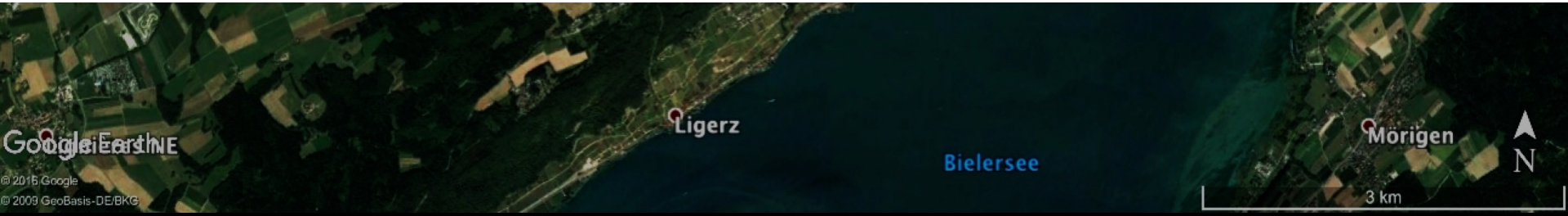





Ligerz
Bielersee
Mörigen
N
3 km
© 2015 Google
© 2009 GeoBasis-DE/BKG






Ligerz
Bielersee
Mörigen
N
3 km
© 2015 Google
© 2009 GeoBasis-DE/BKG

Twannberg project is only possible thanks to the work of all participating collectors = citizen scientists!

Open questions:

Oman/Arabia:

- Modelling accumulation over time using estimated terrestrial ages of all finds
- Finalizing the statistics of the Oman meteorite population (after pairing)
- Fall rate of small meteorites using camera network (to be installed in 2021)

Twannberg/Switzerland:

- Constraining the size of the strewn field
- Understanding effect of ice transport
- Using meteorite fall age to estimate ice level during second last ice age
- Were Twannberg meteorites recognized and used long before?
  -> Search for meteoritic iron in archaeological collections


Thank you!