

Application of MIXE analyses in meteoritics

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





Twannberg meteorite
Switzerland



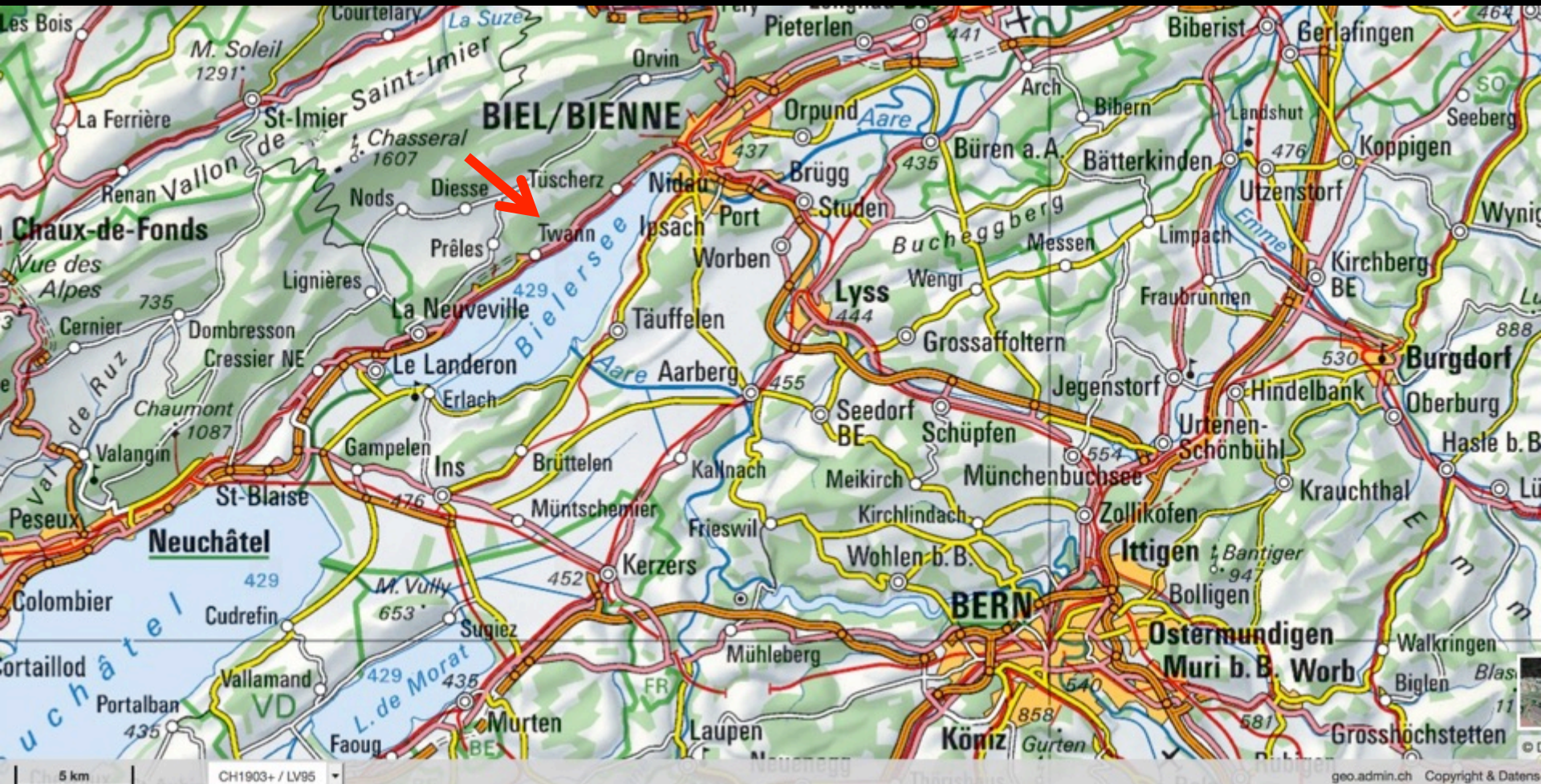
Meteoritic artefact



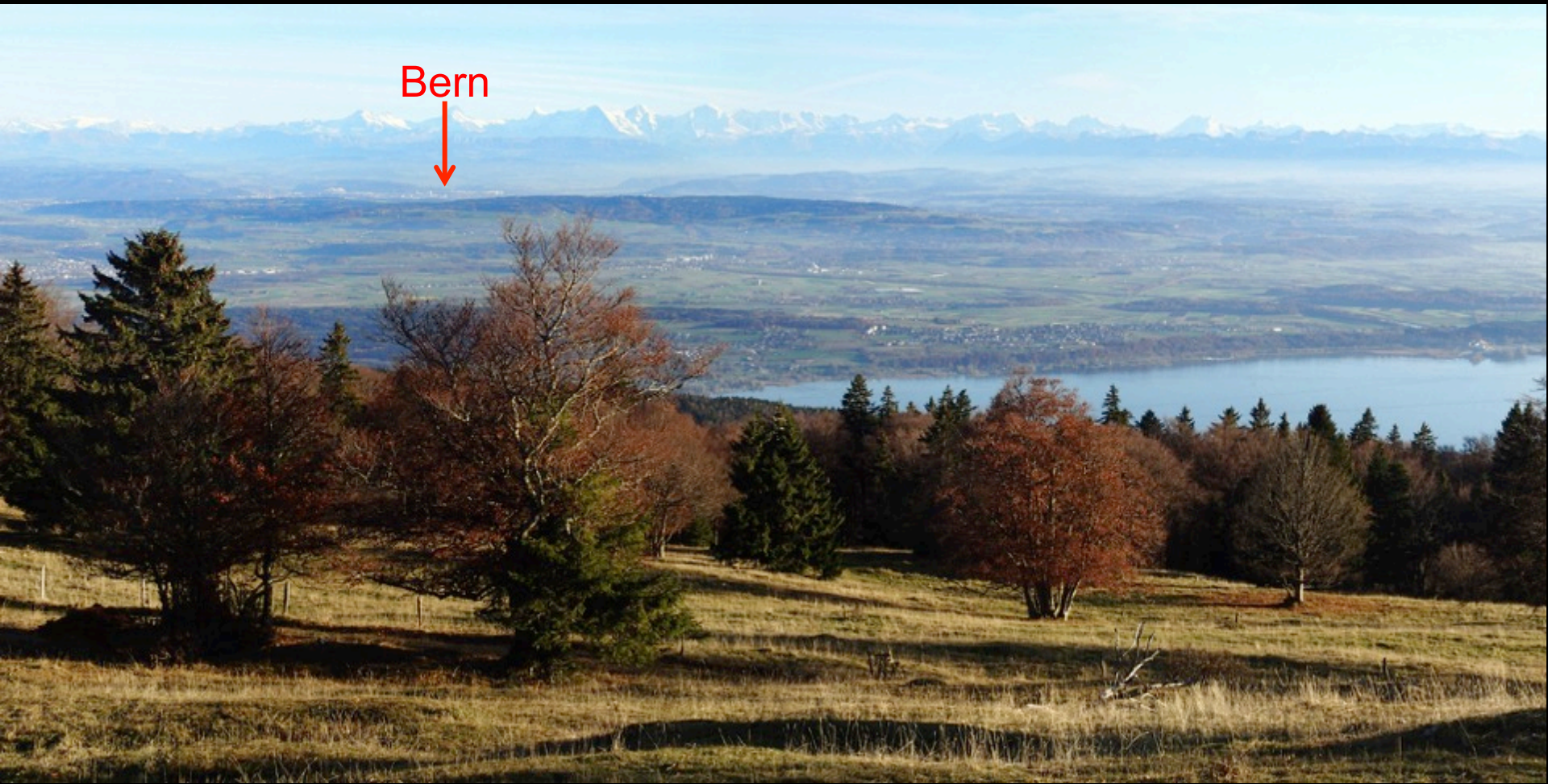
Meteorites from the Omani desert



1984: Find of the still largest Twannberg mass of 15.9 kg by Margrit Christen



Twannberg: The only meteorite strewn field in Switzerland
30 km NW of Bern



Bern

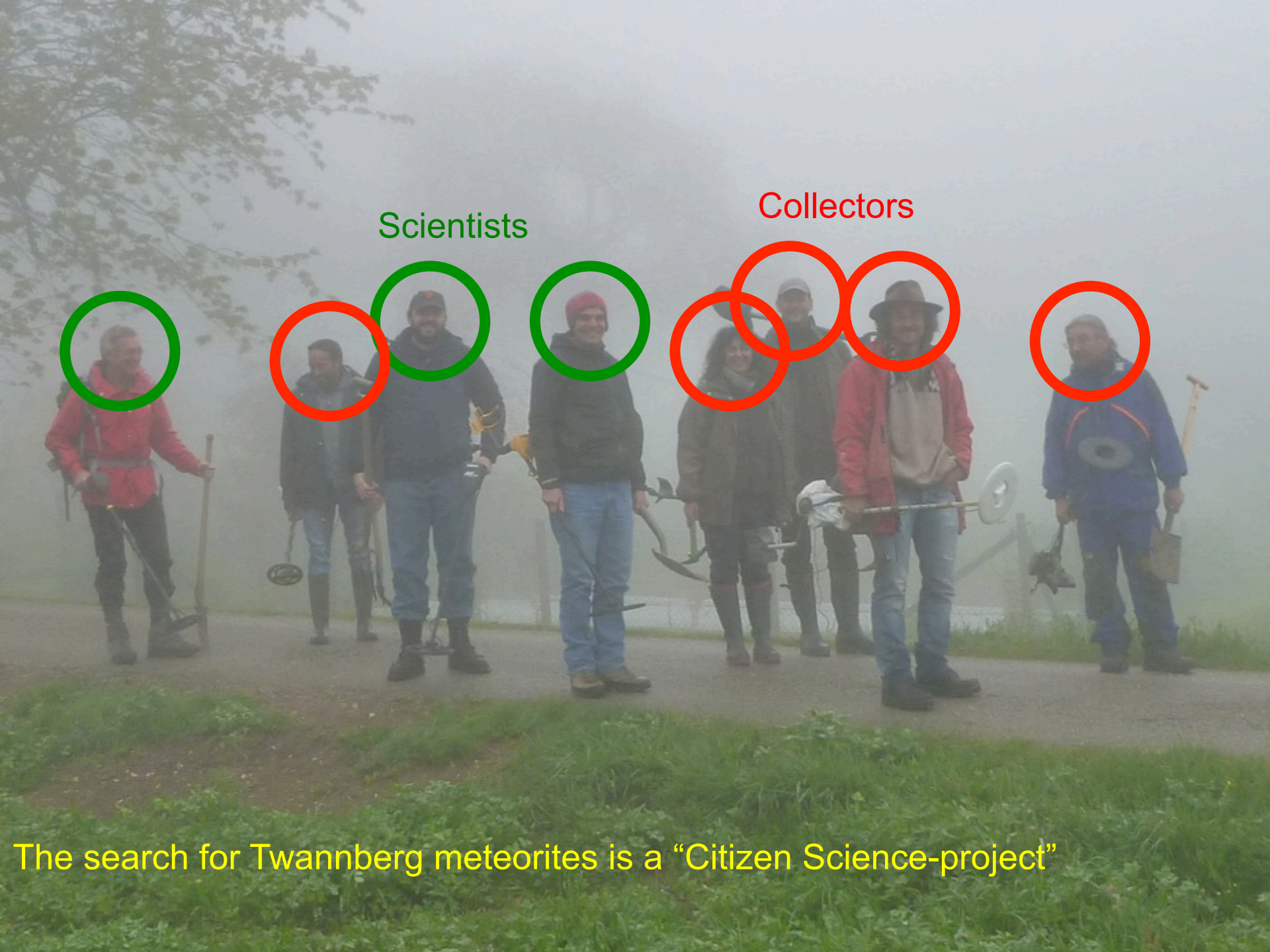


On Mont Sujet, Twannberg strewn field



Twannberg mass TW1 (~25 cm)
Iron (kamacite) with 4.5% nickel and schreibersite $(\text{Fe,Ni})_3\text{P}$





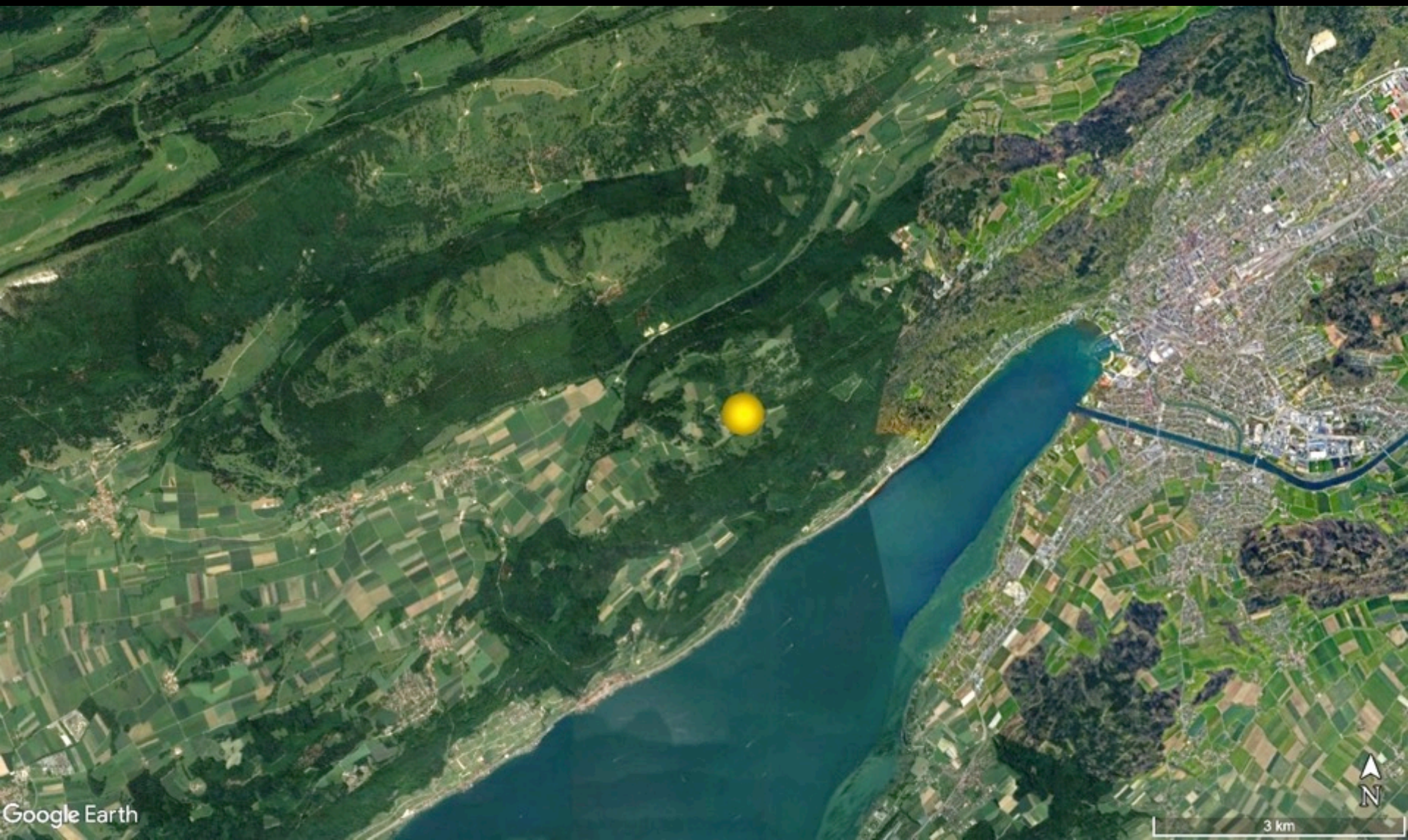
Scientists

Collectors

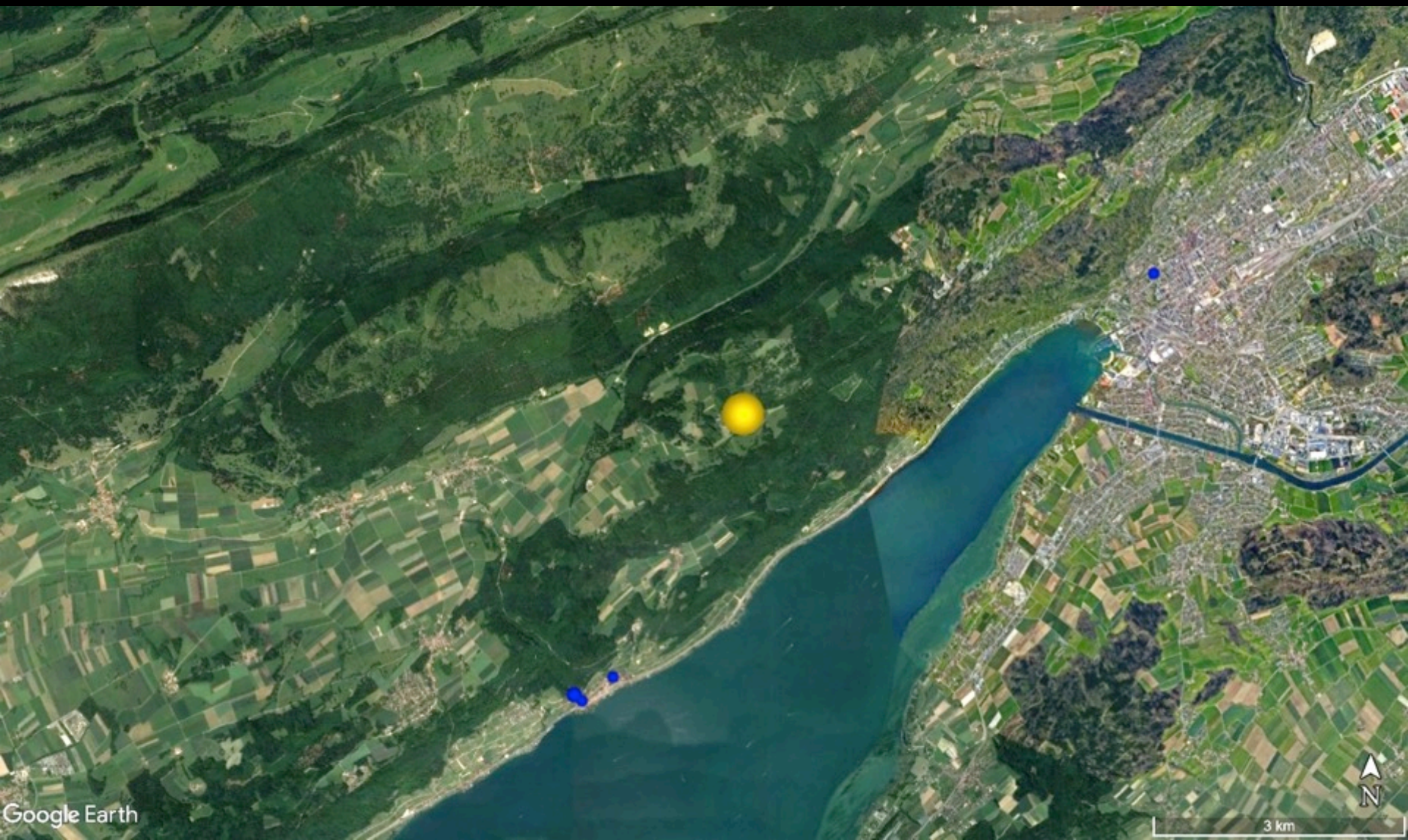


The search for Twannberg meteorites is a "Citizen Science-project"





1984



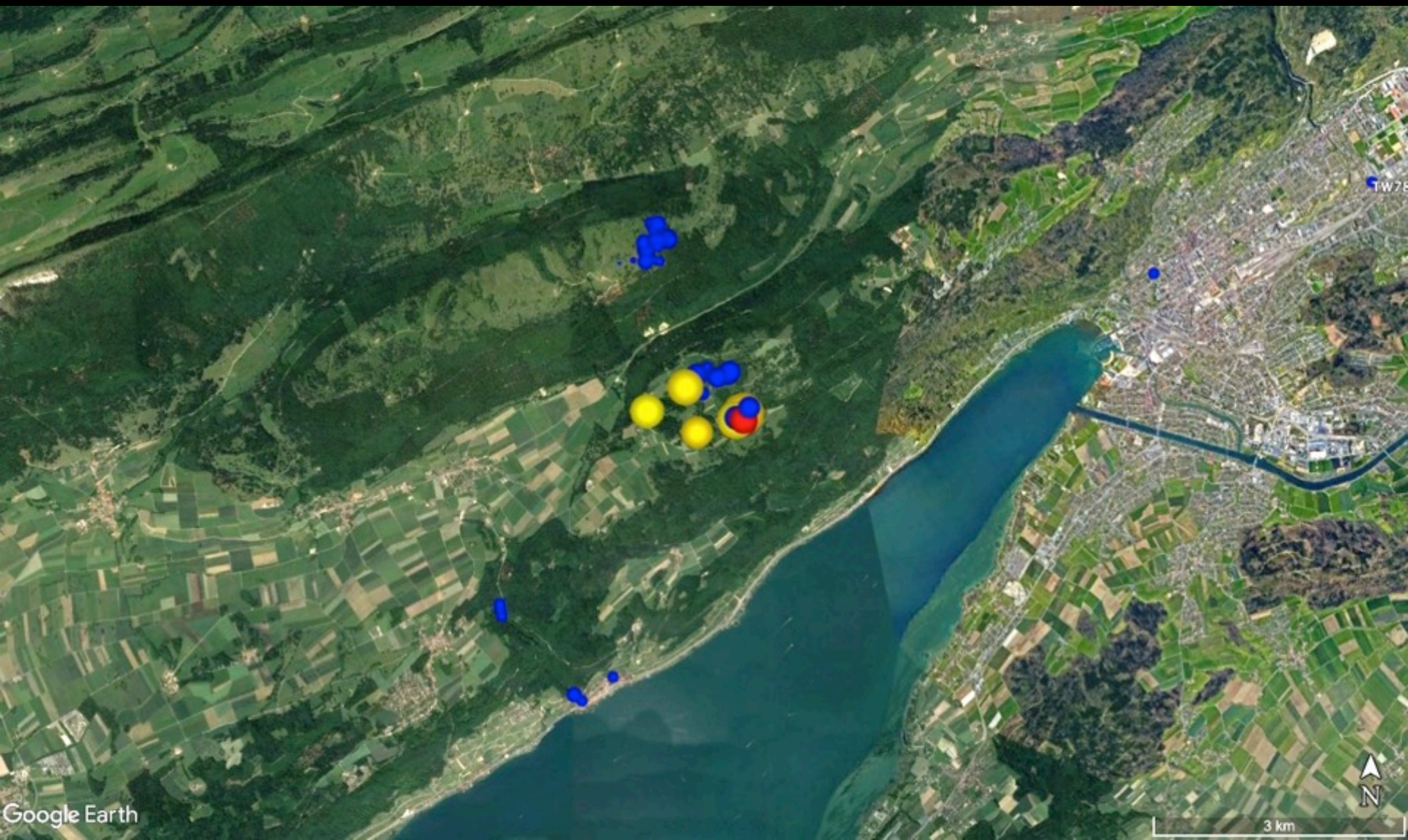
2006



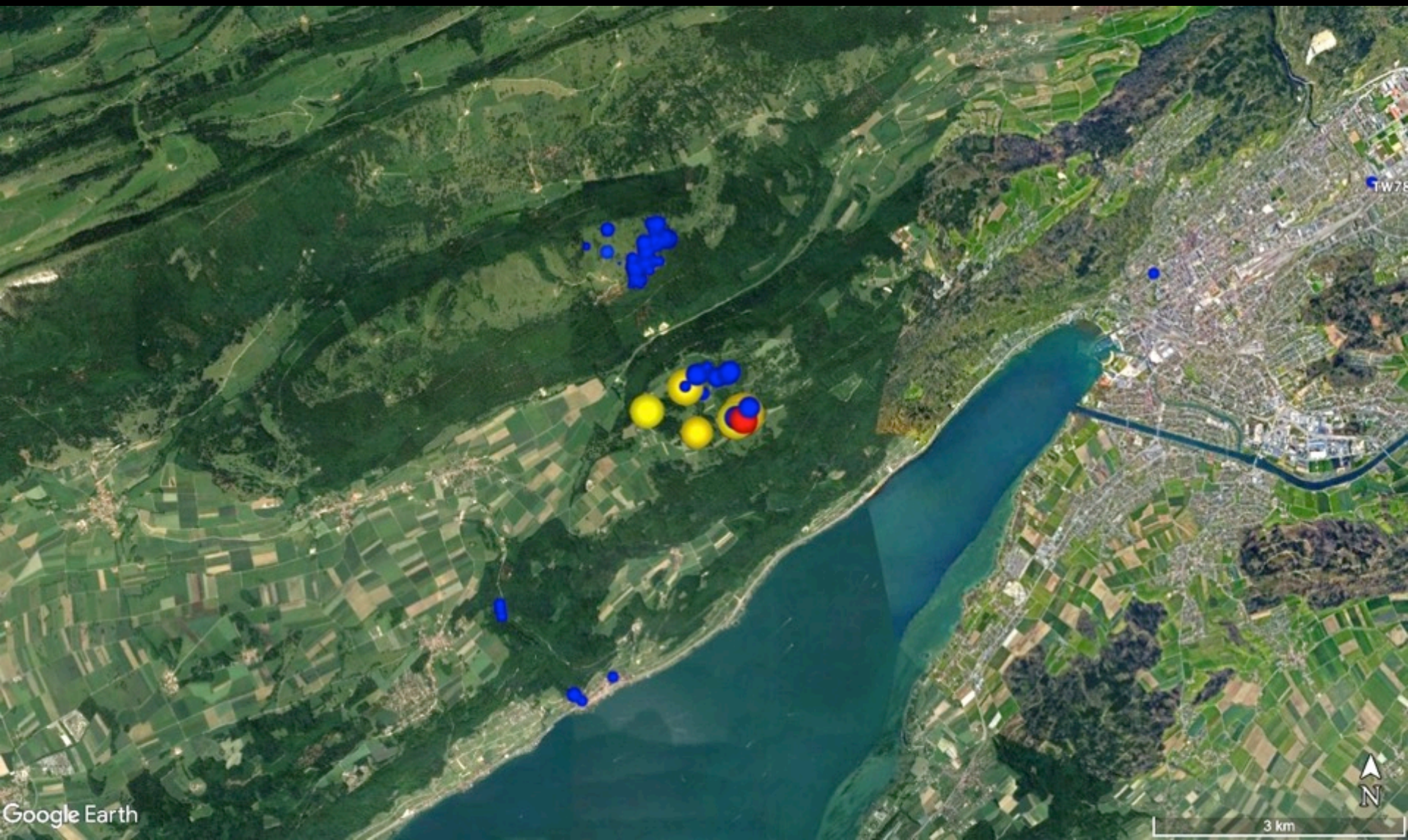
2014



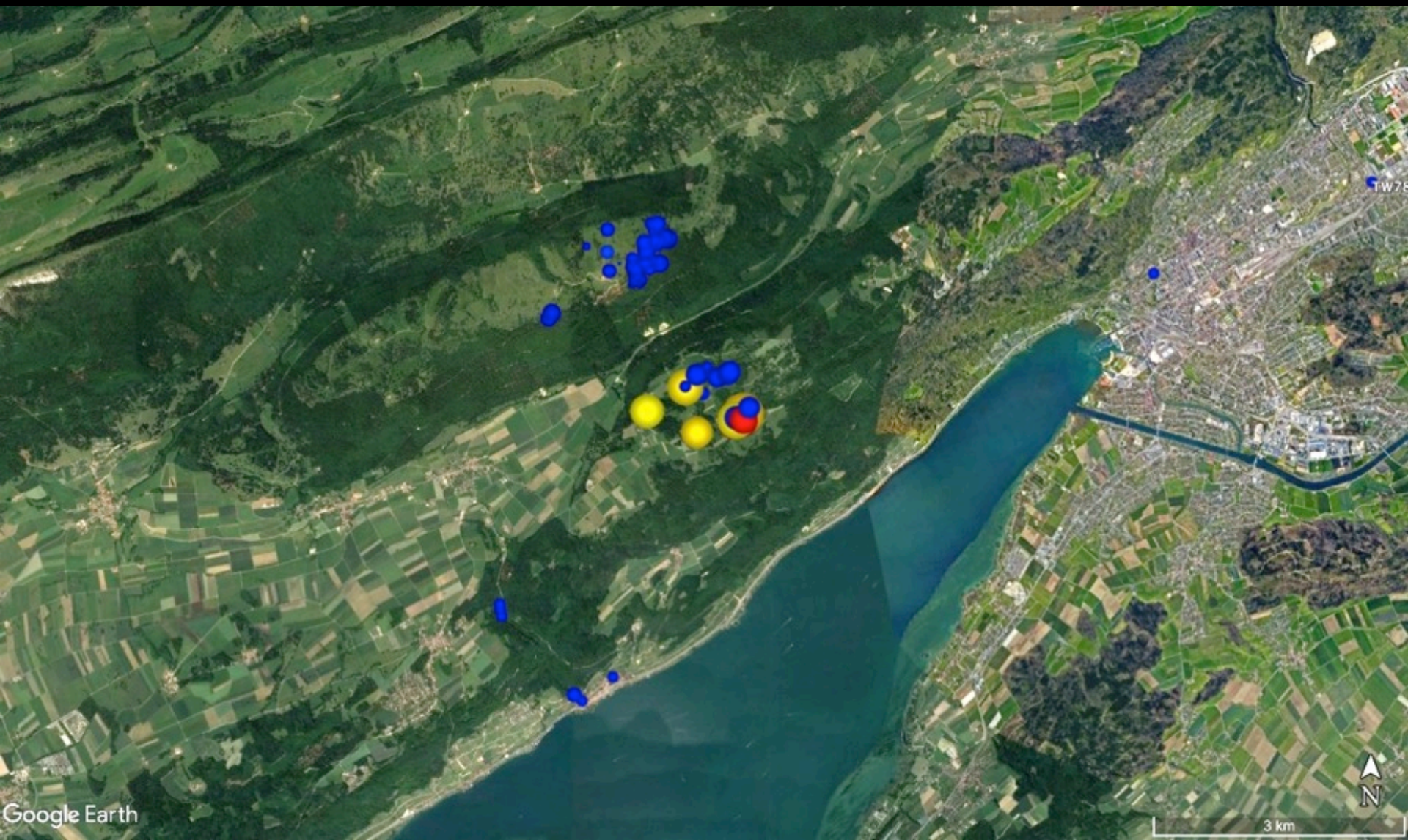
2015



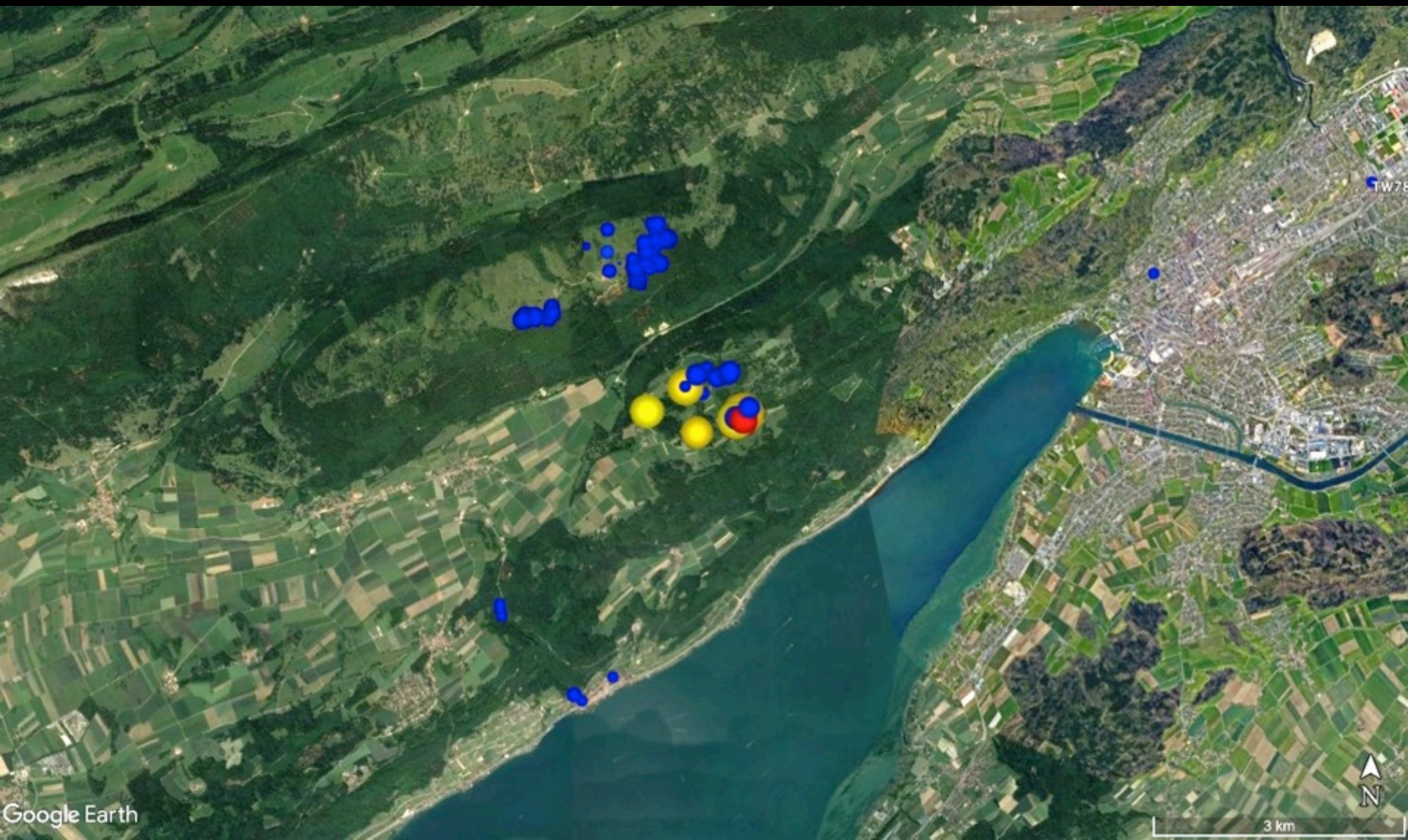
2015



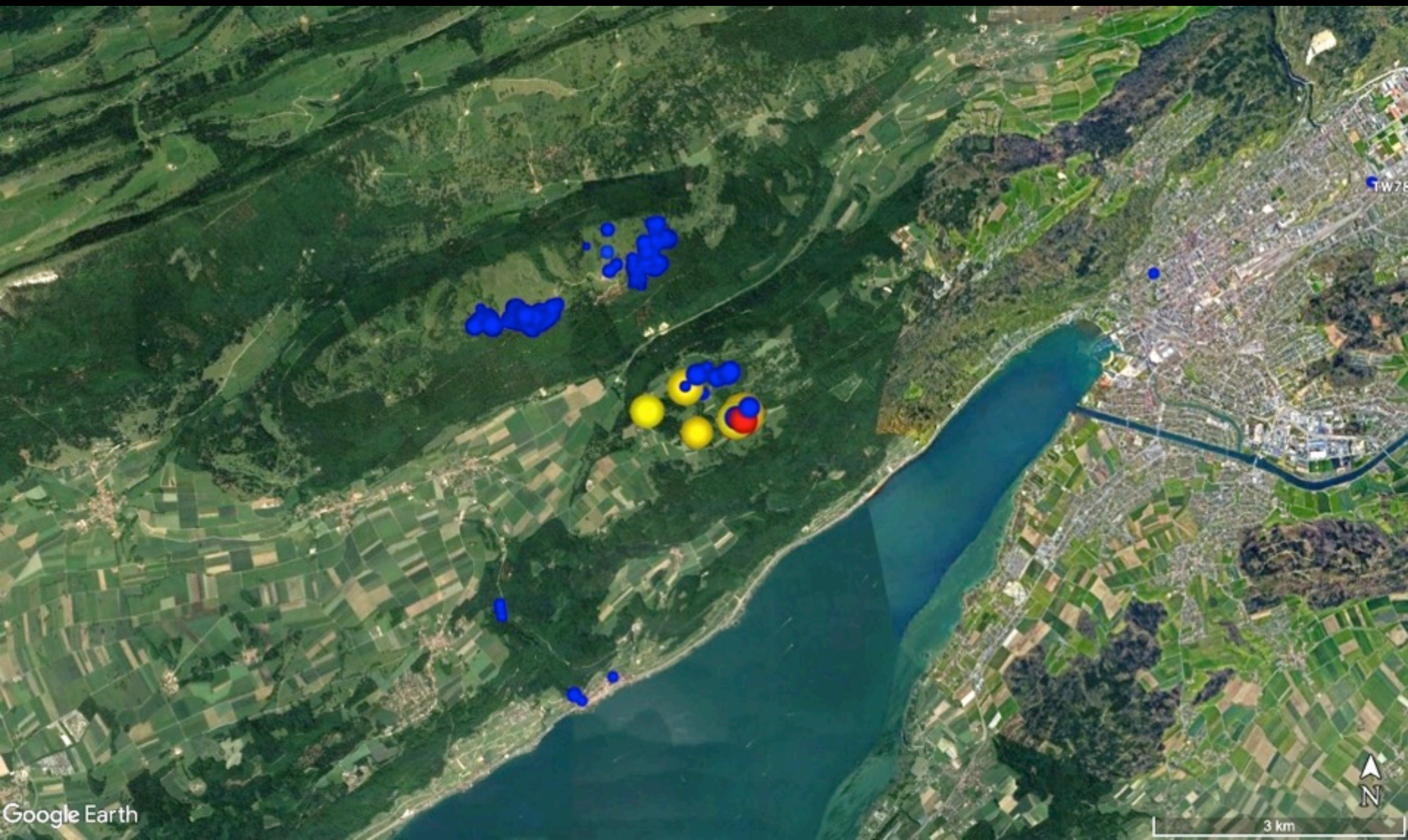
2015



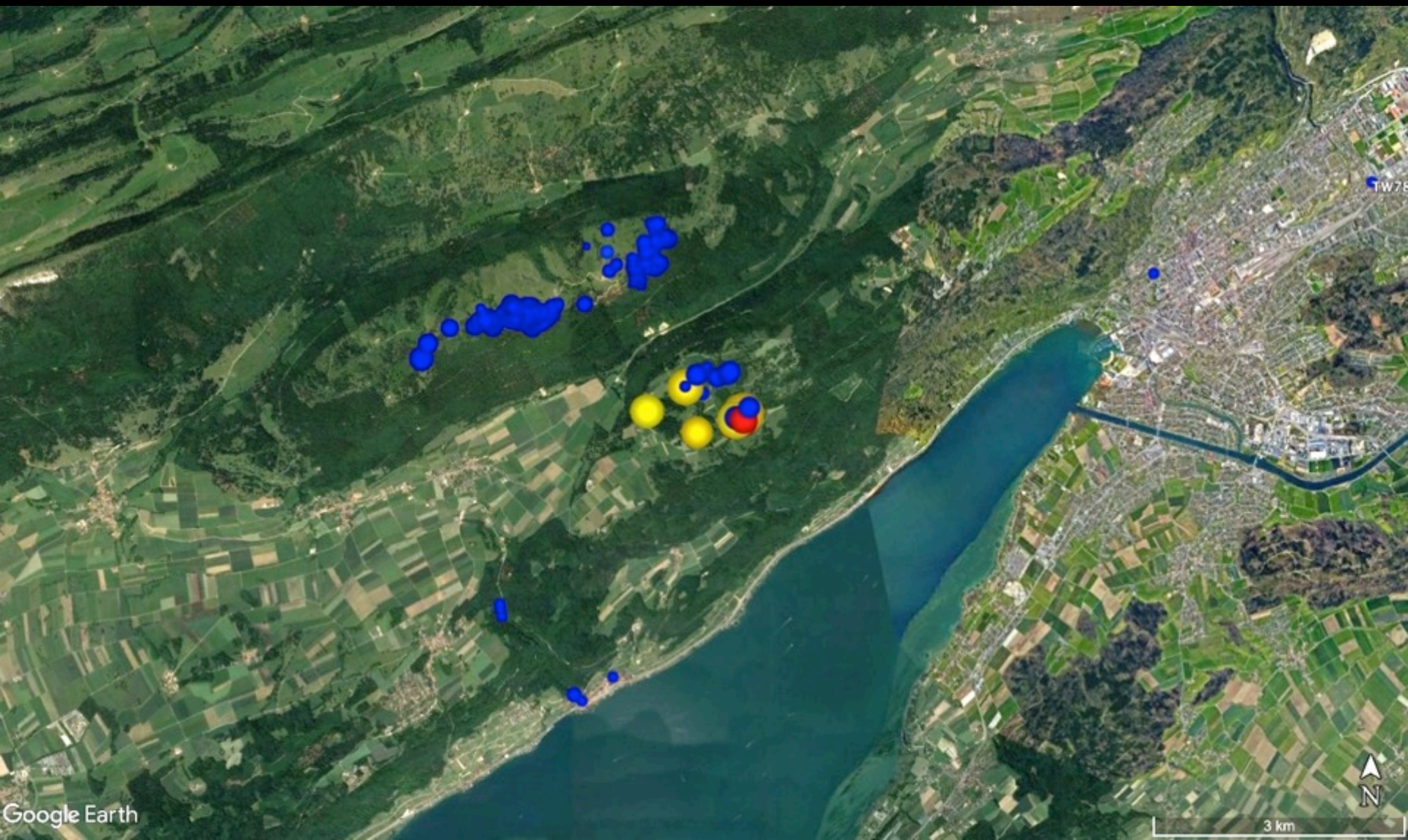
2015



2015

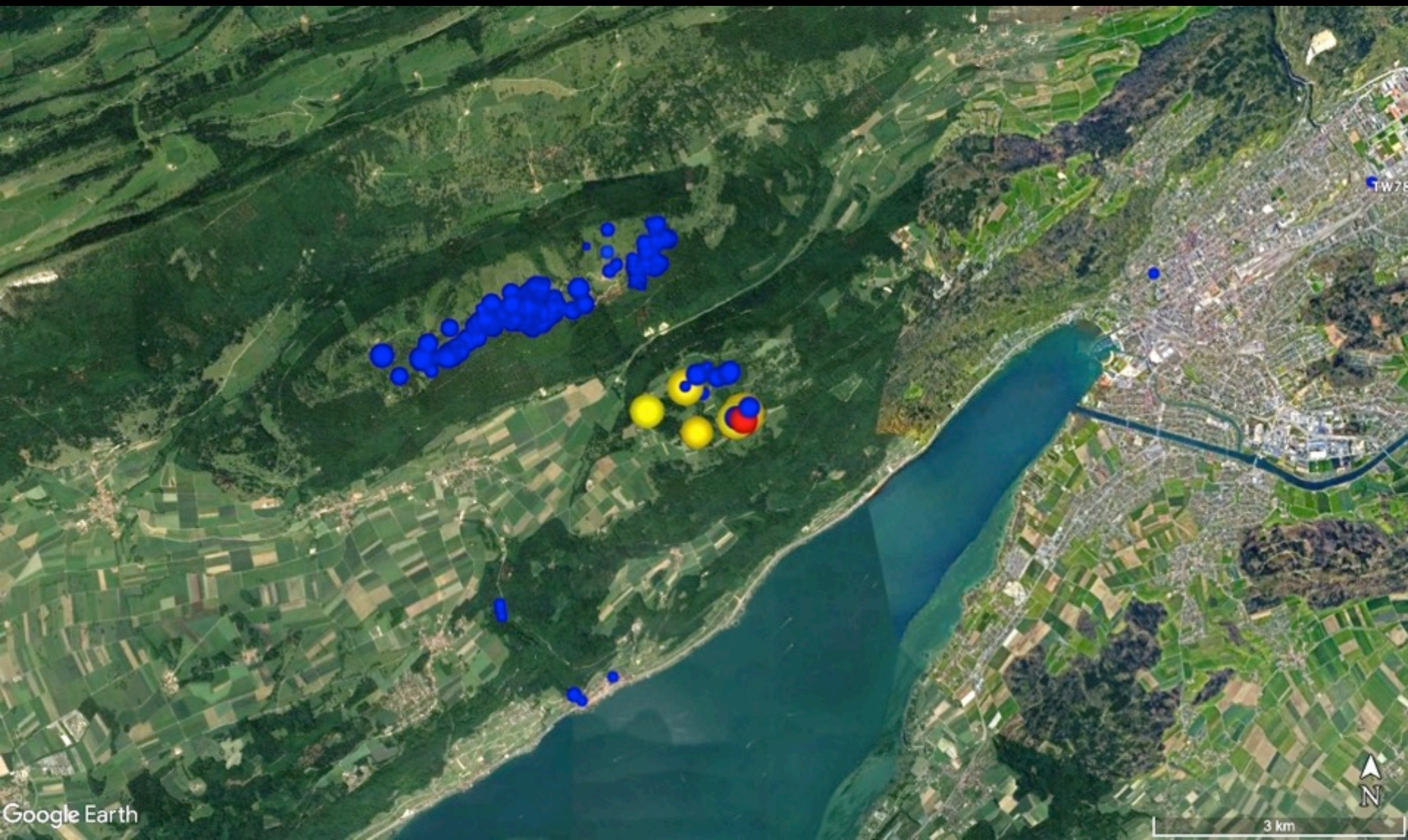


2015

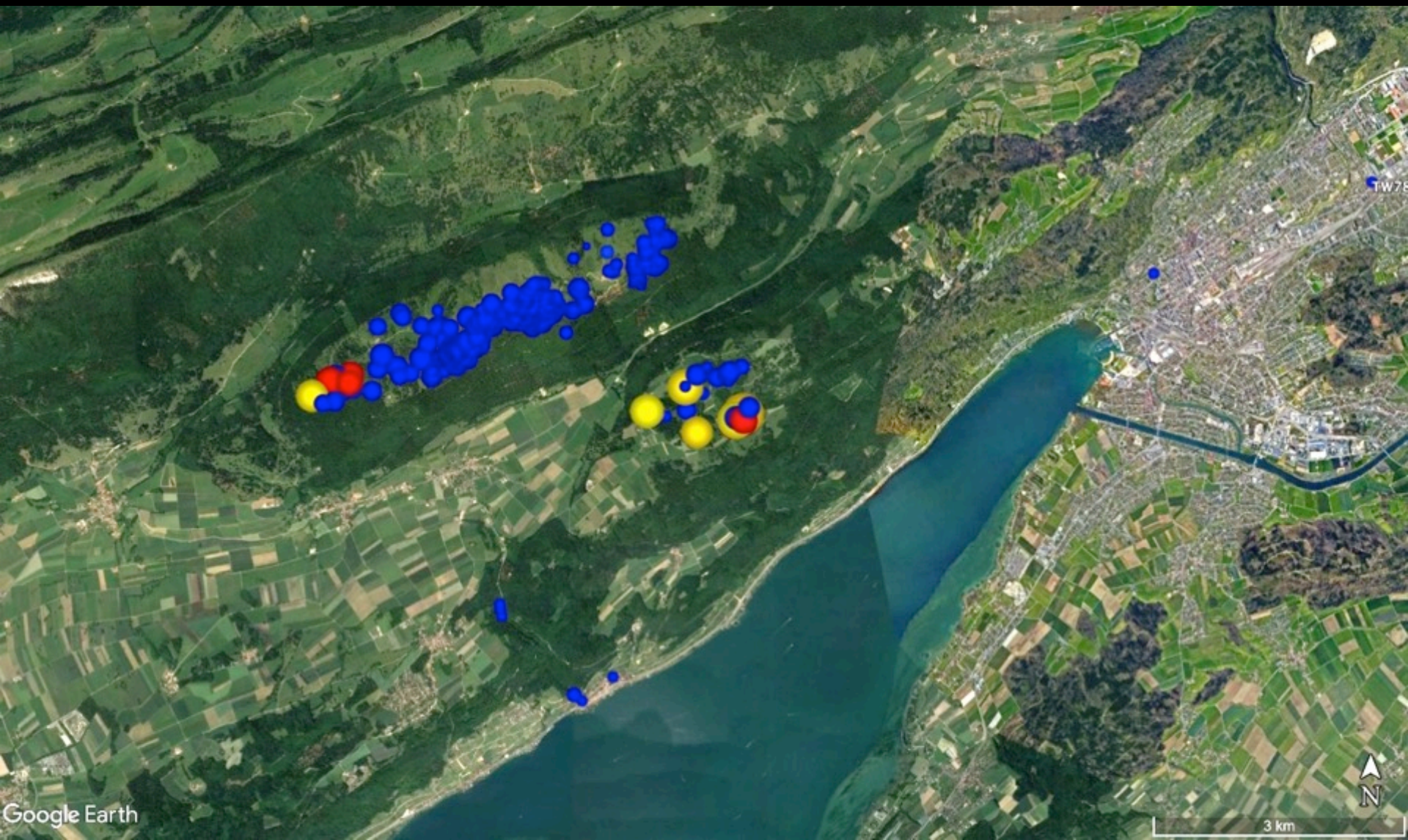


Google Earth

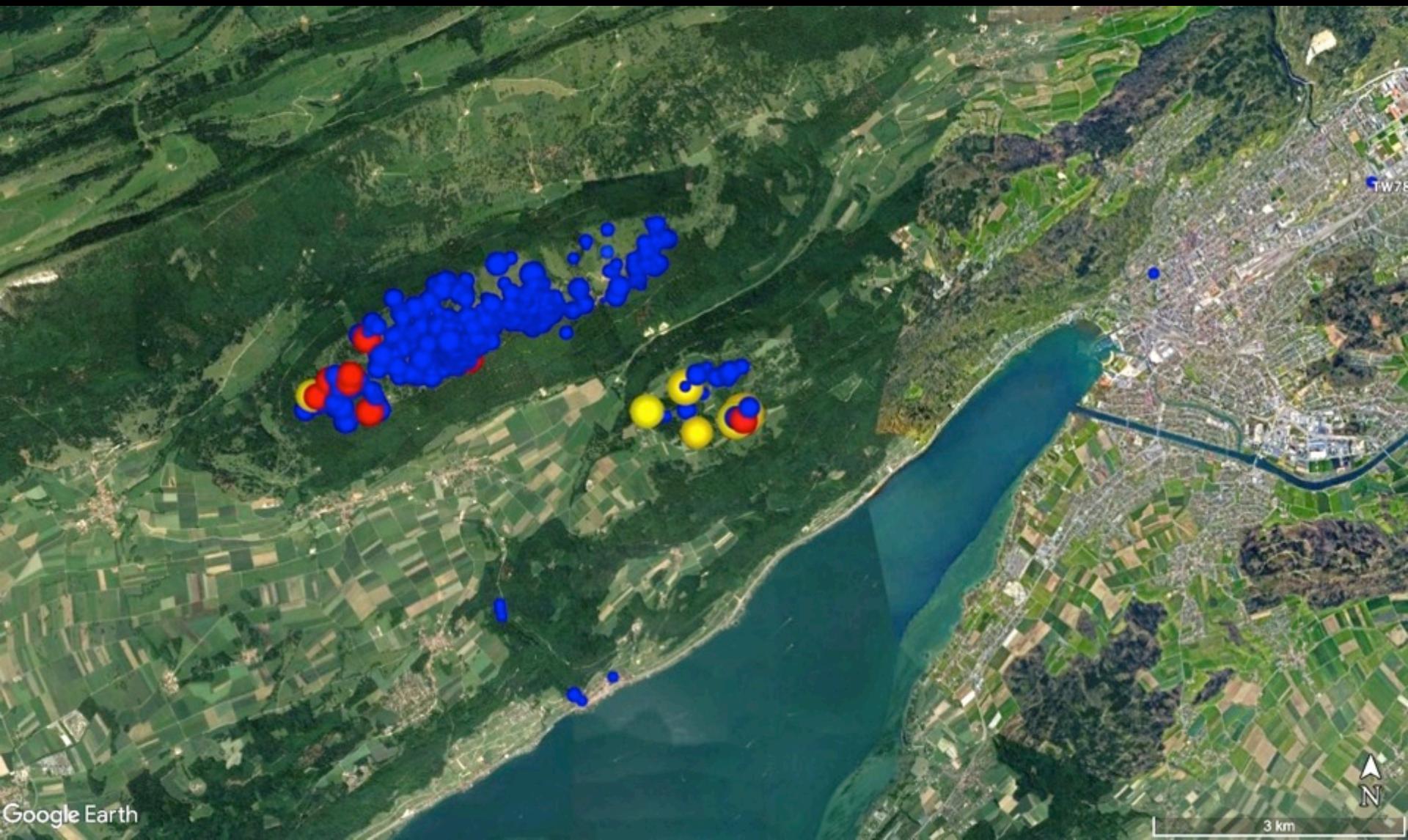
2015



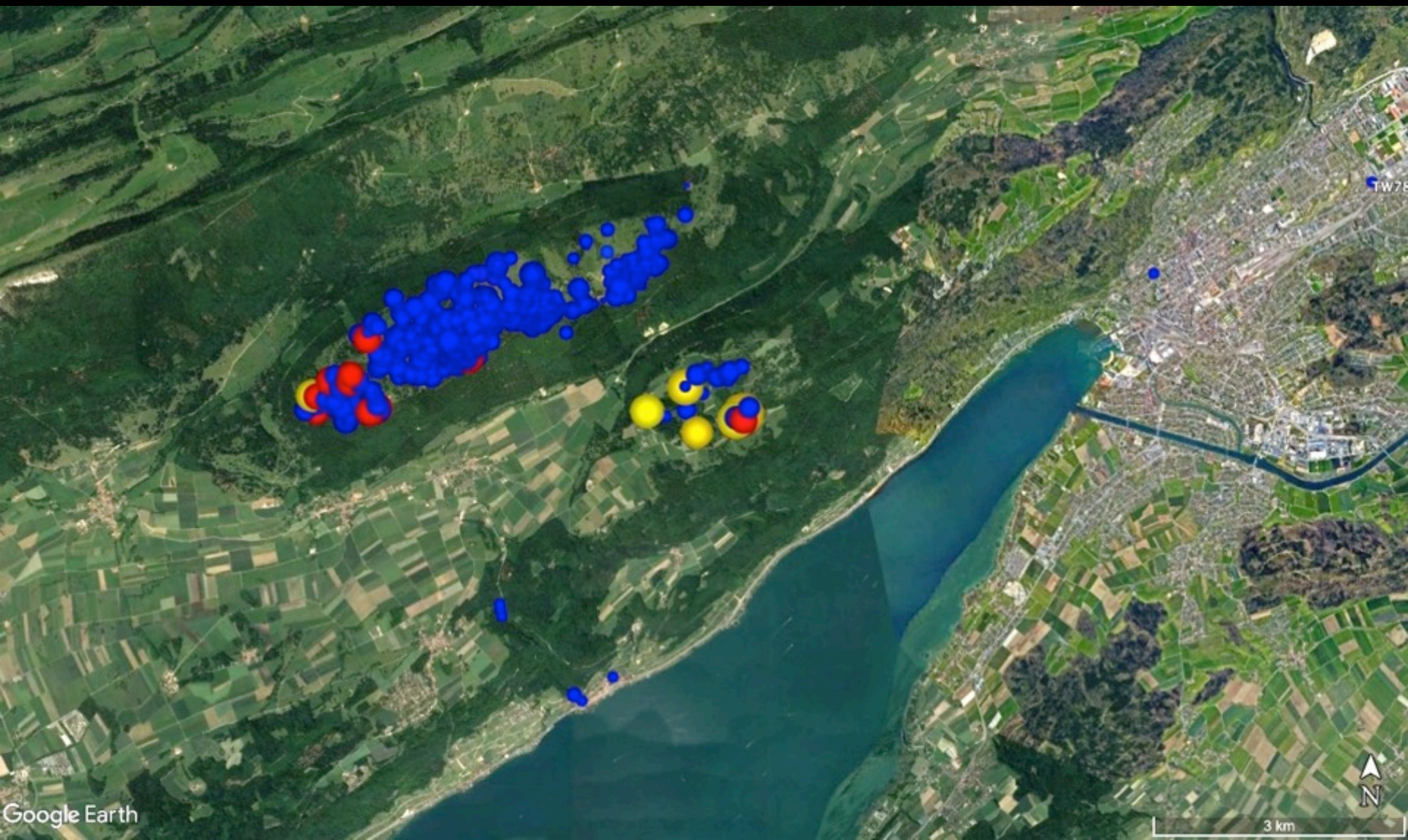
2015



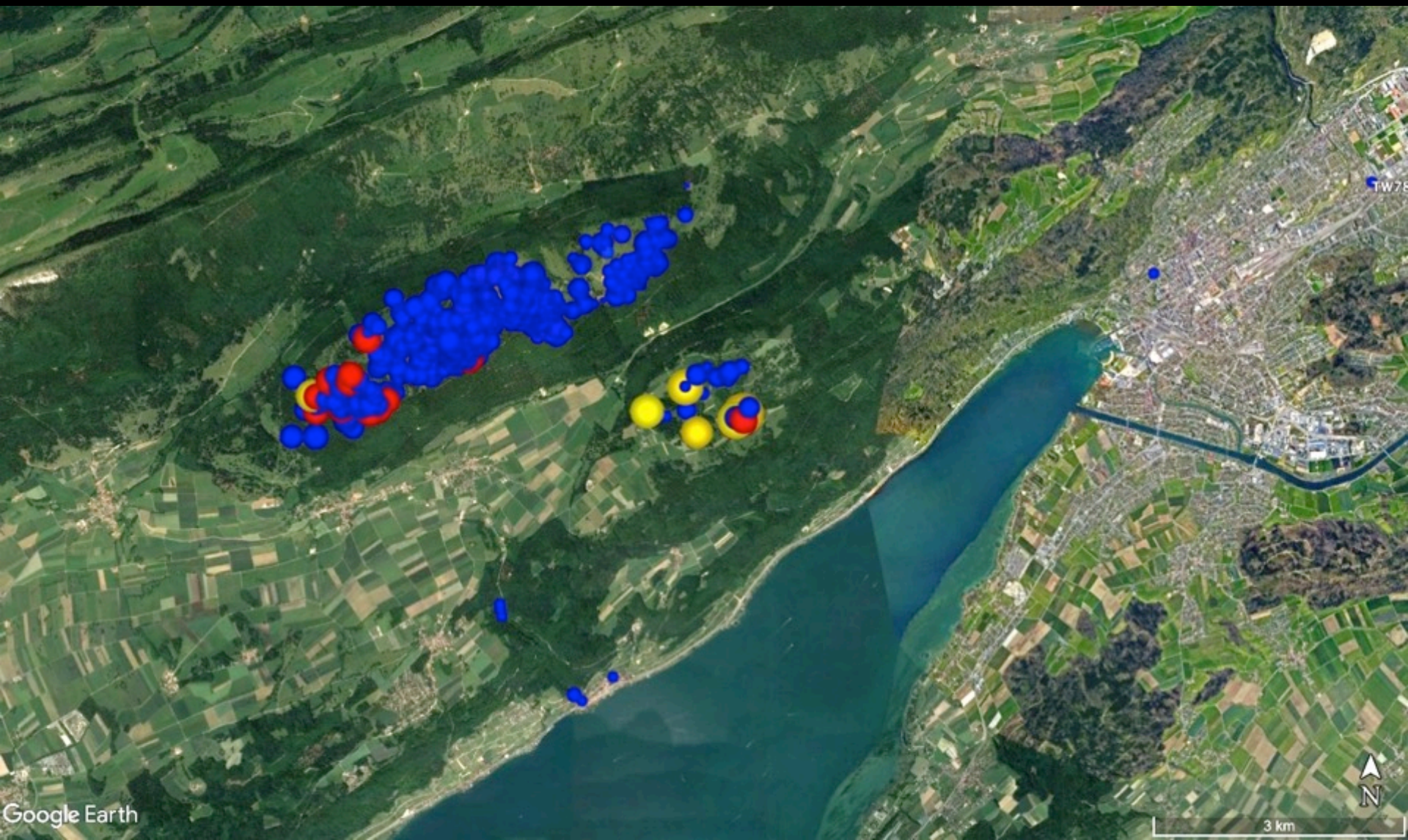
2016



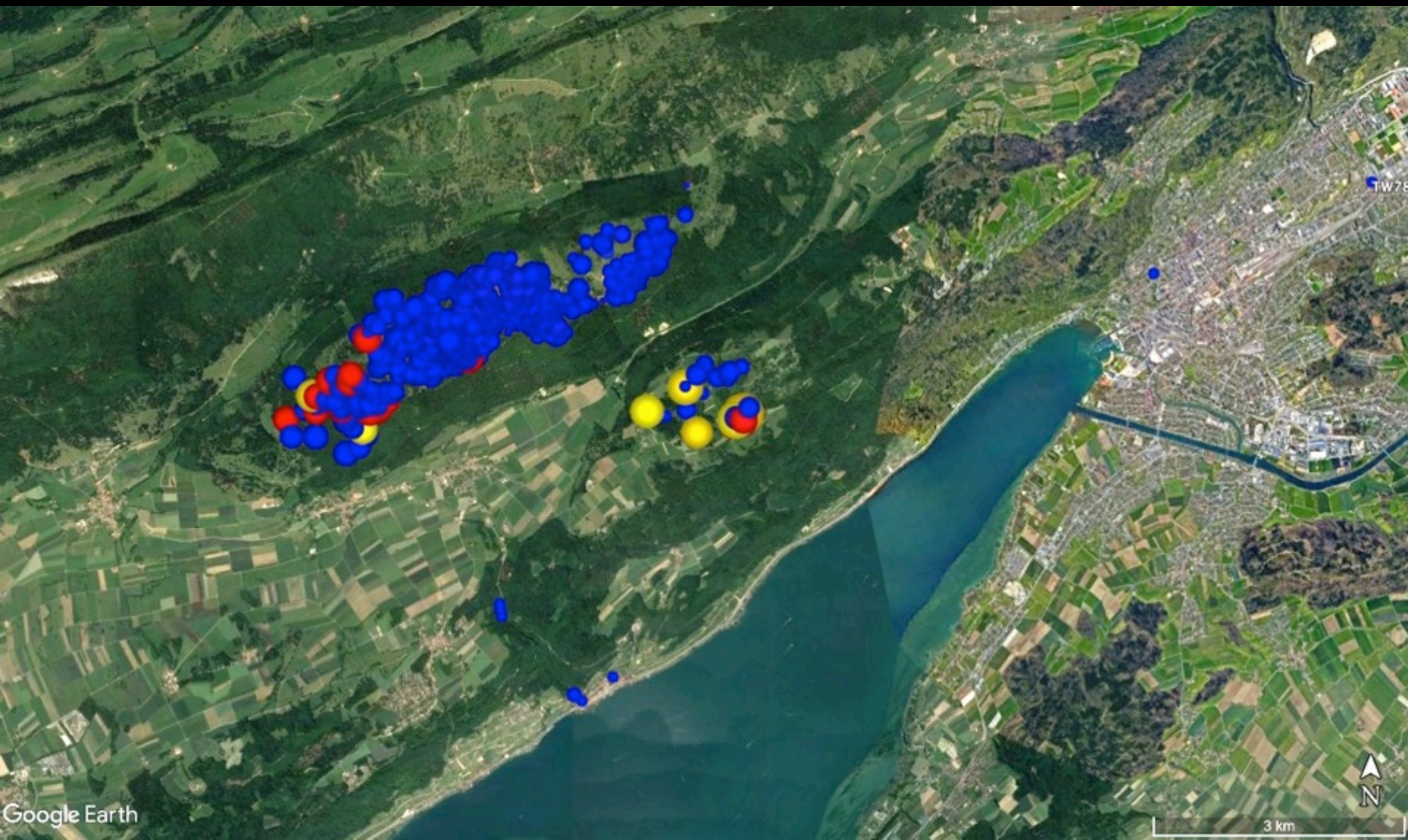
2016



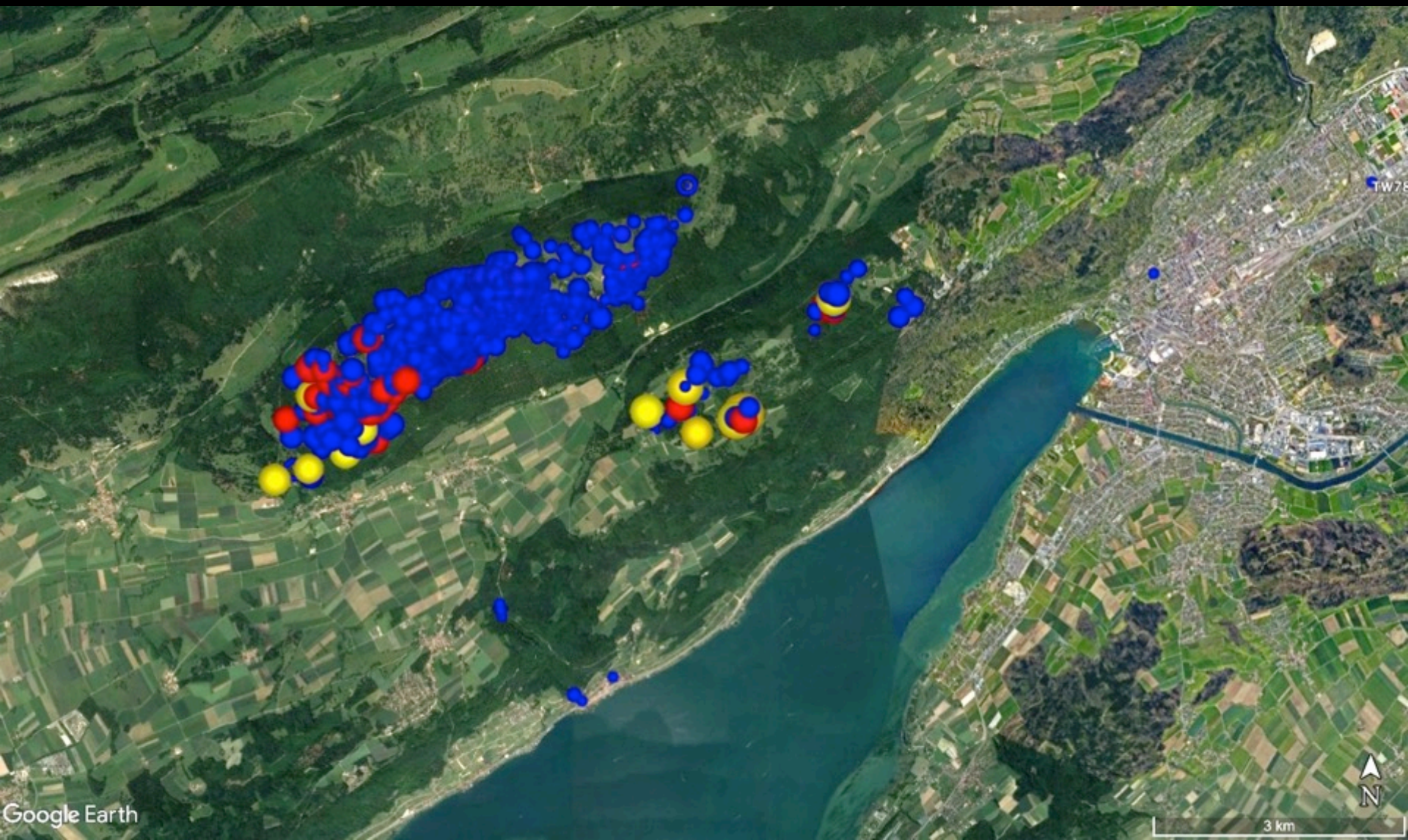
2016



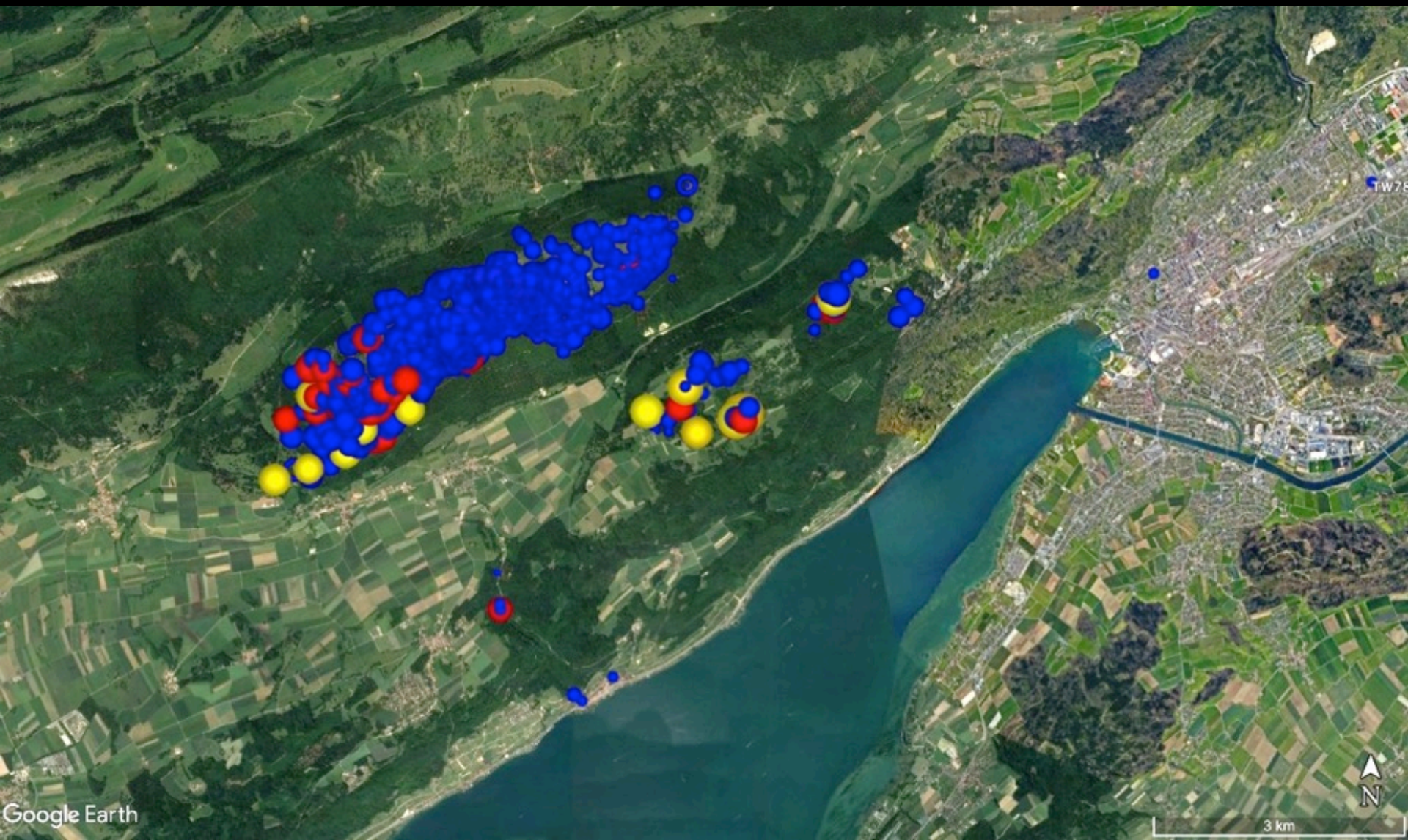
2016



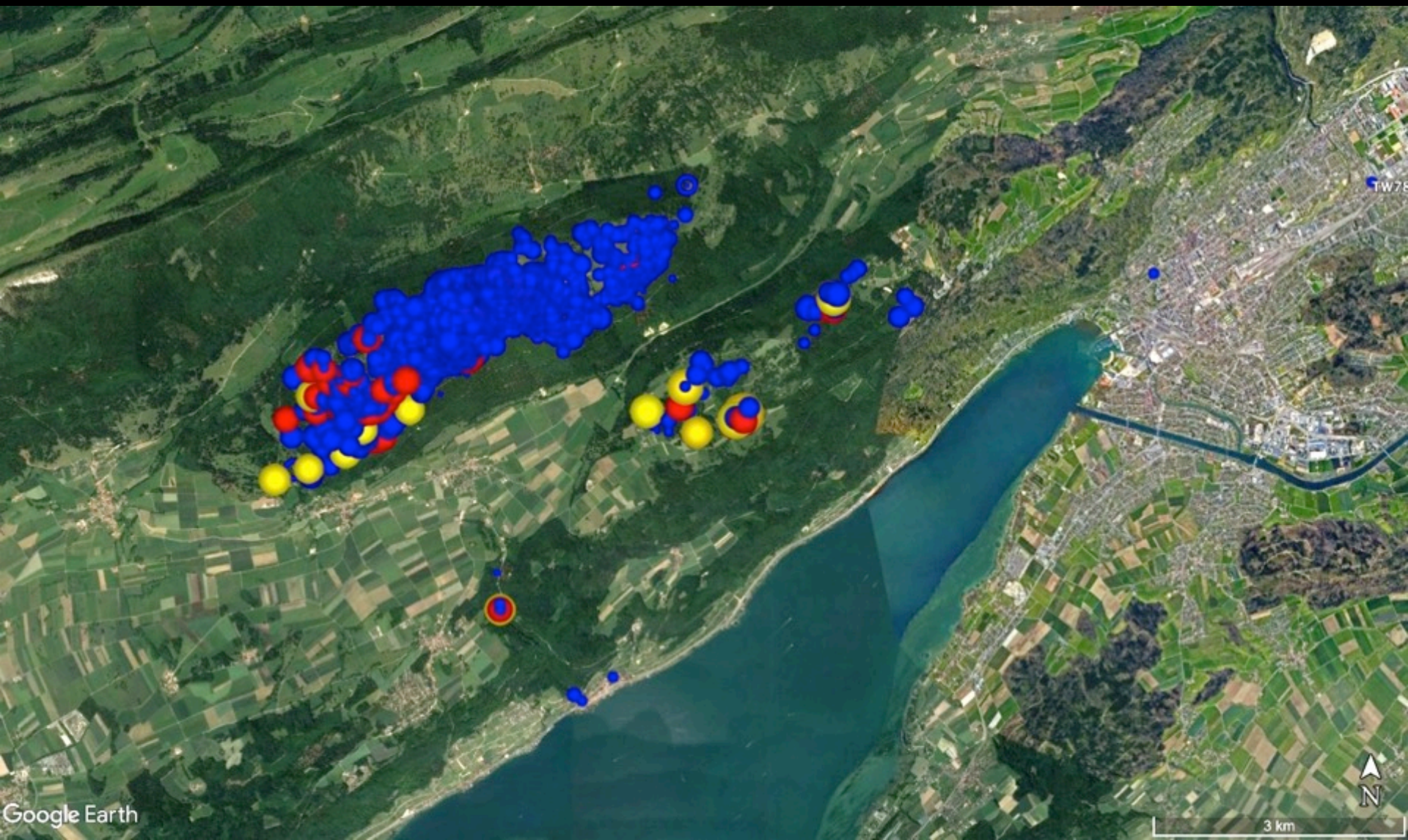
December 2016



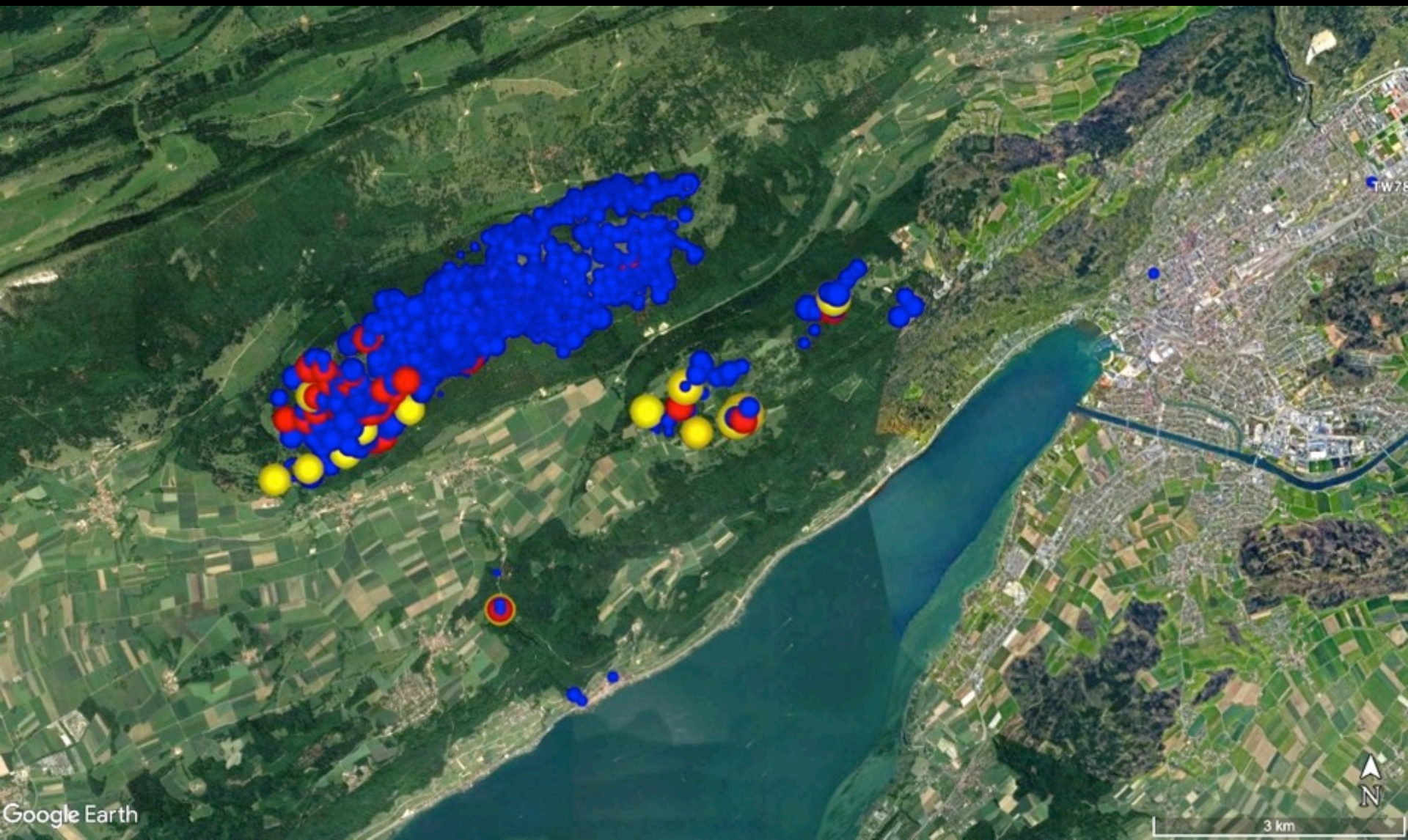
December 2017



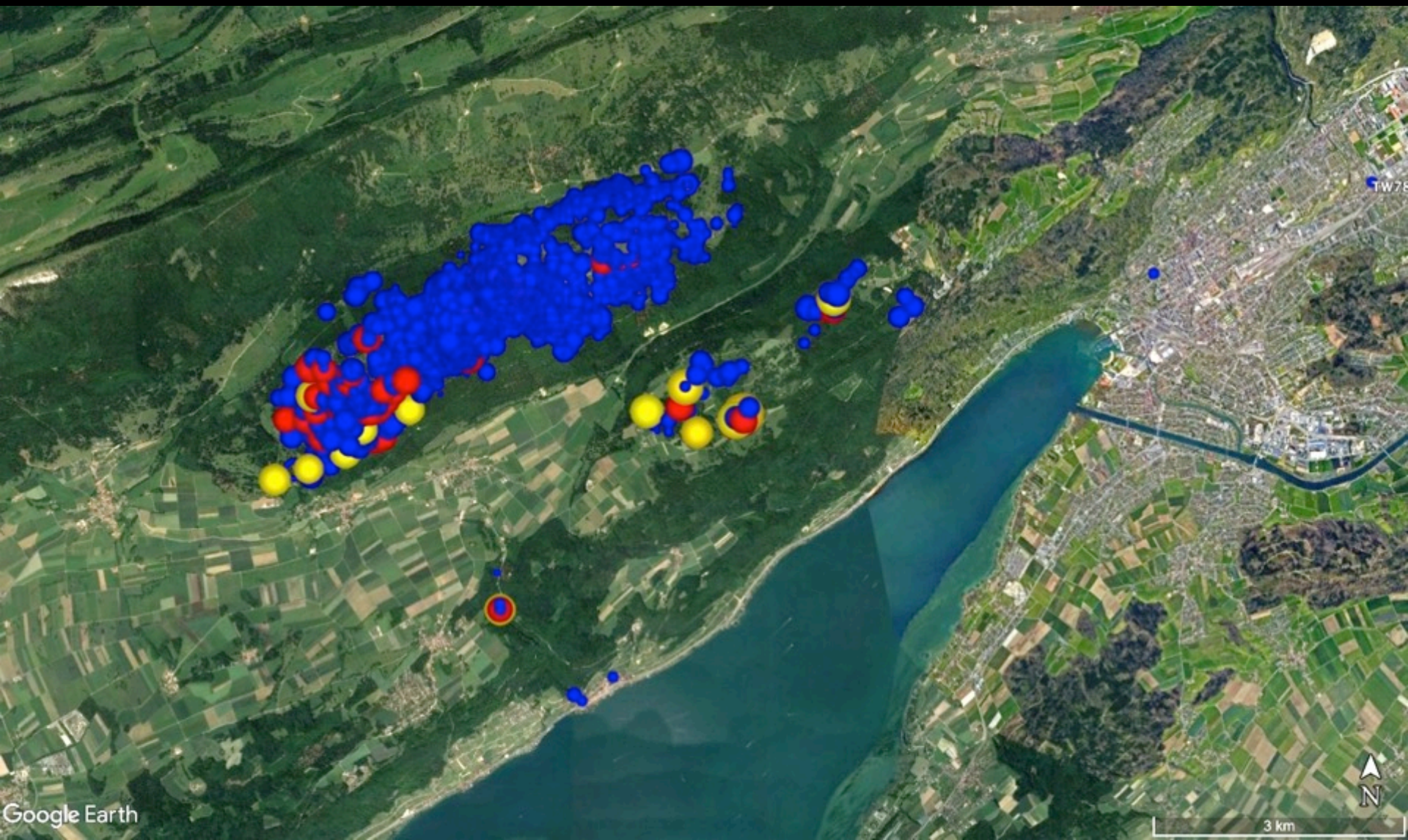
December 2018



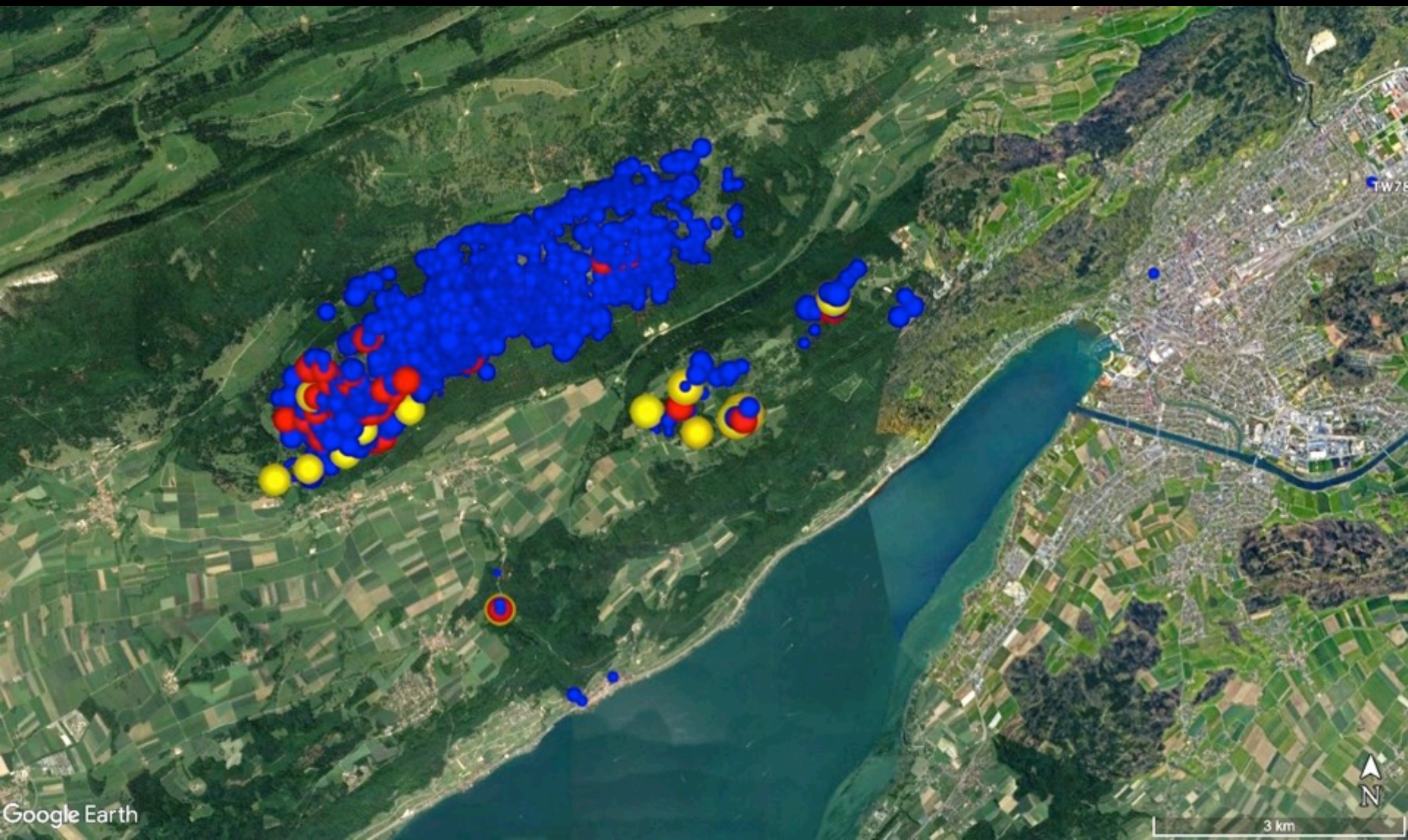
December 2019



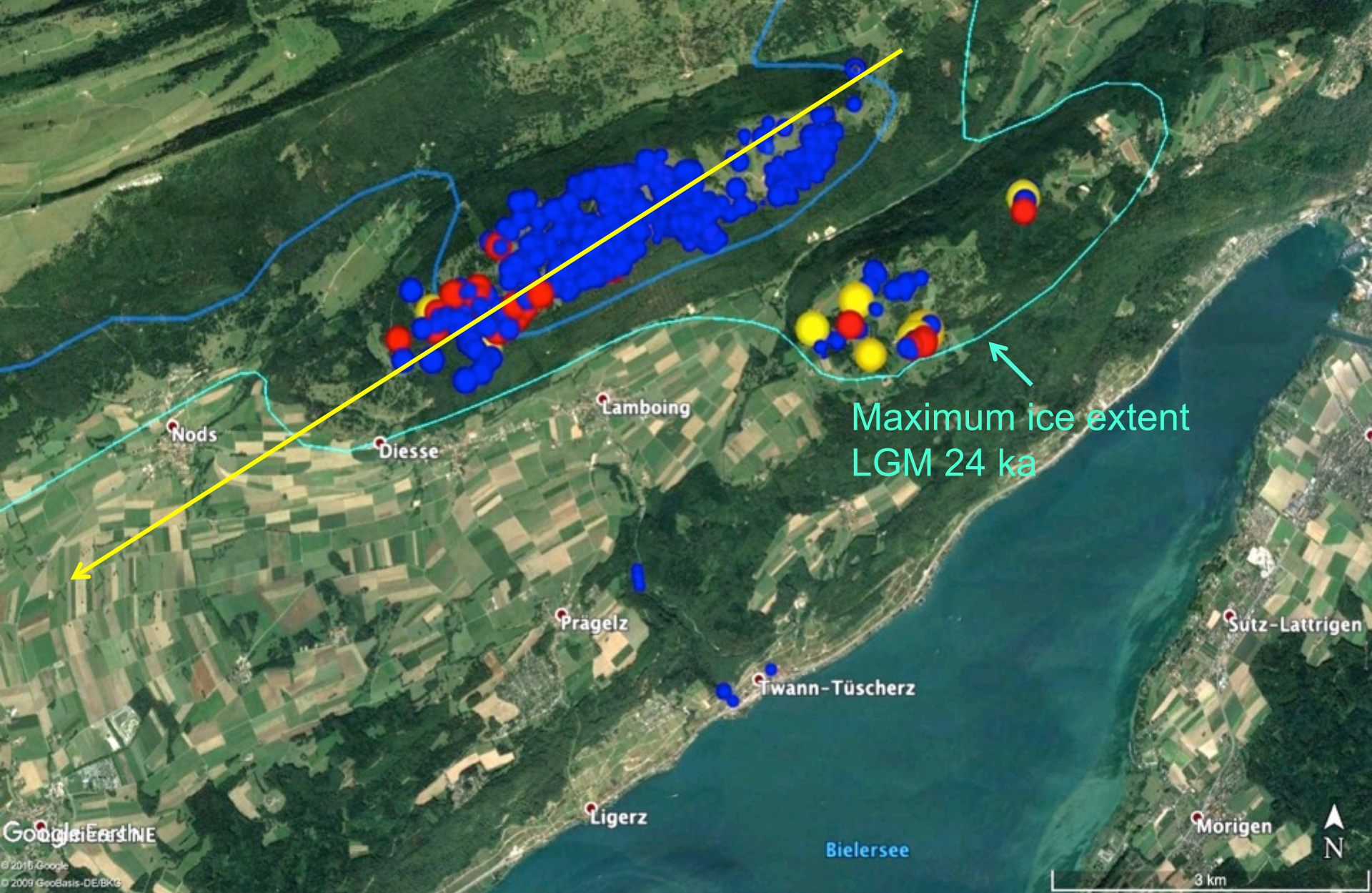
December 2020



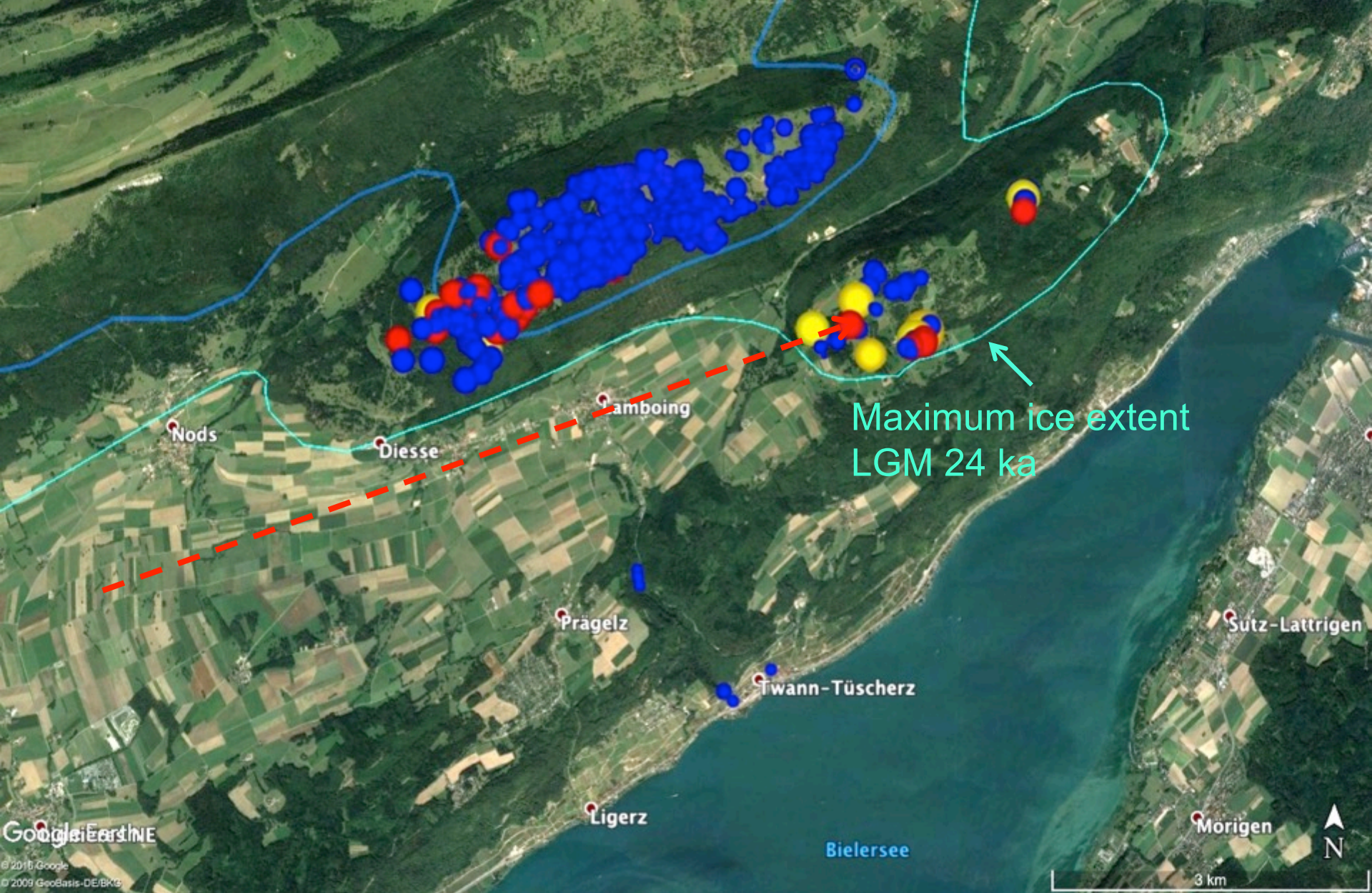
December 2021



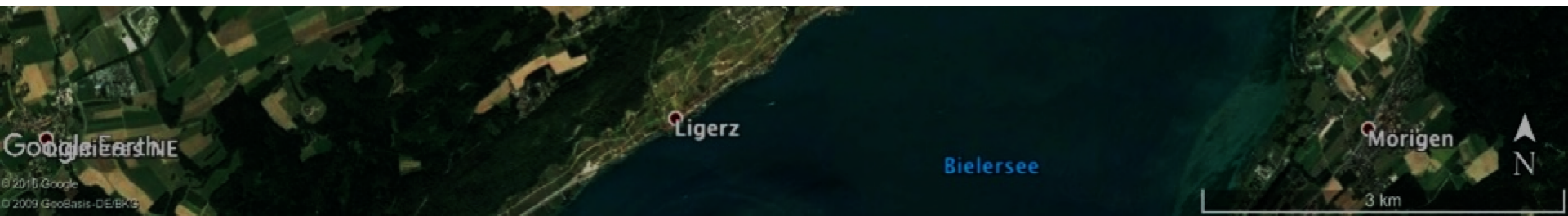
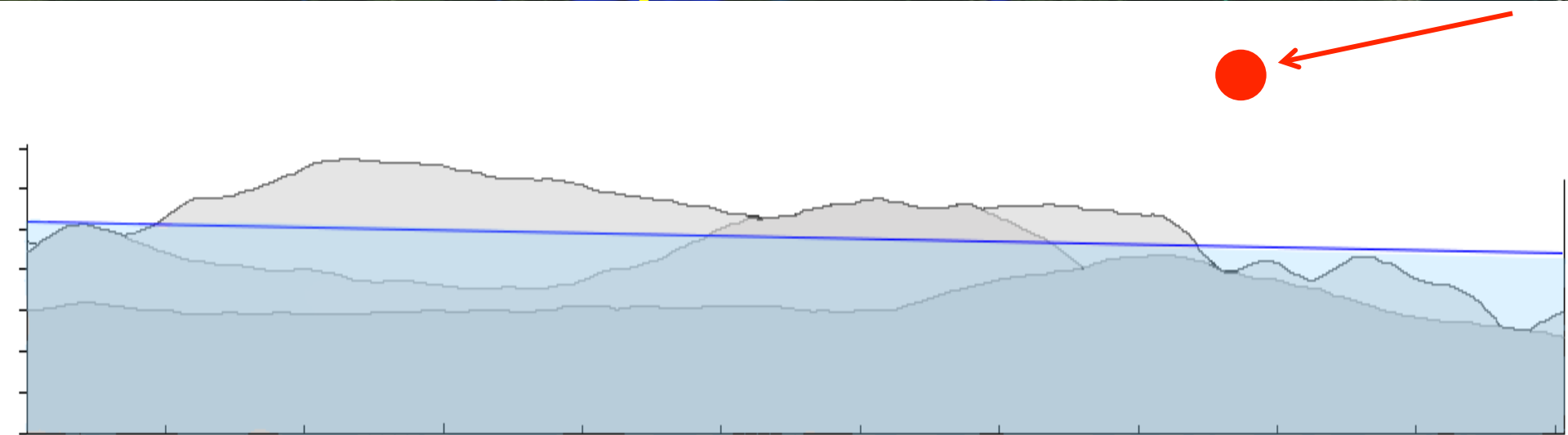
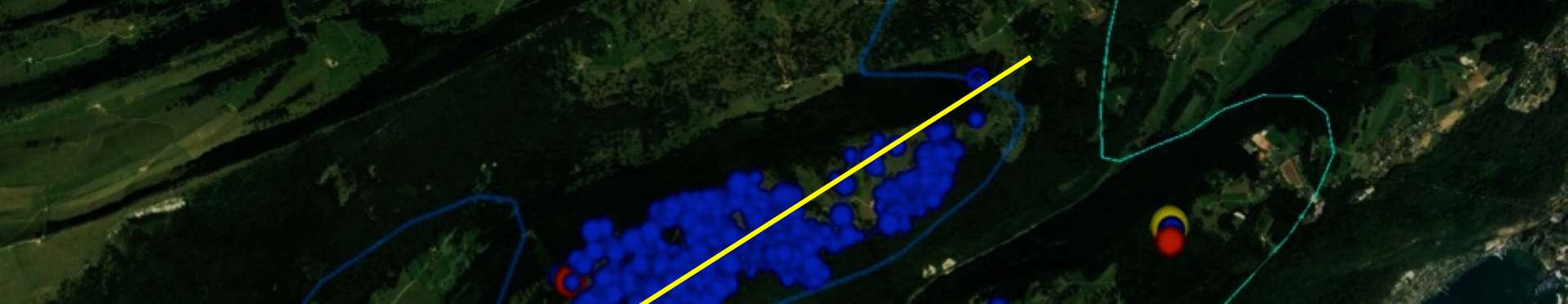
November 2022

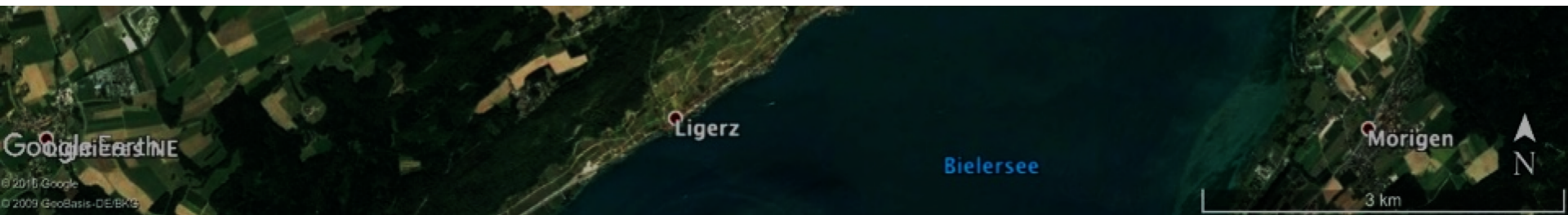
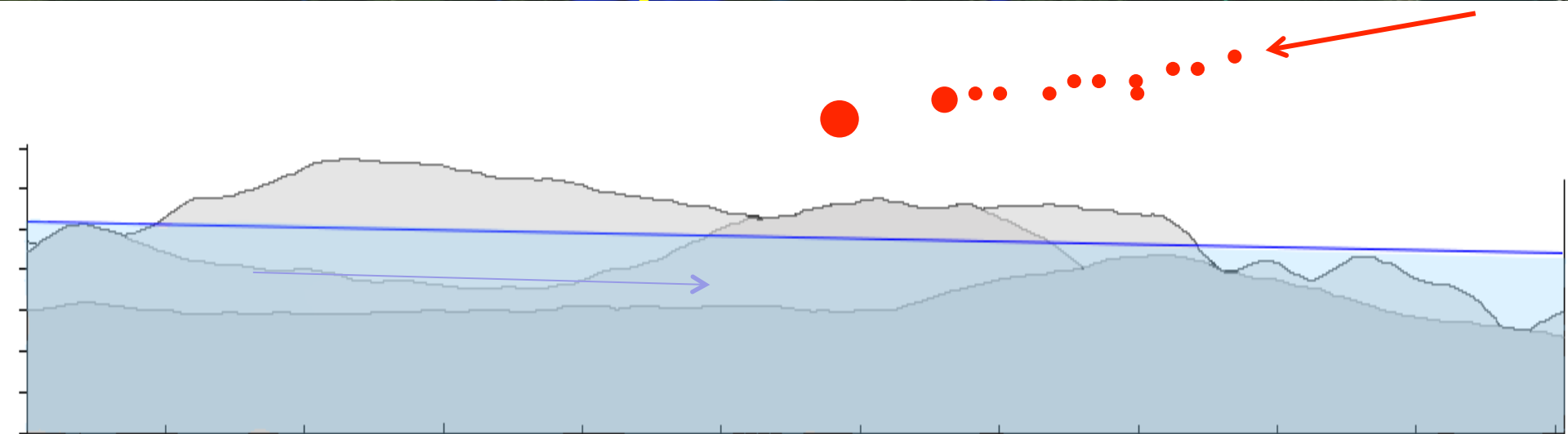
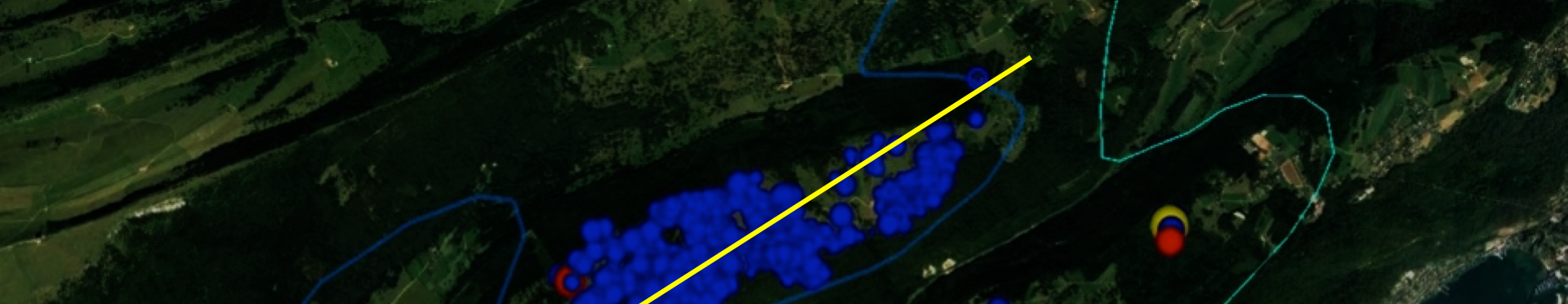


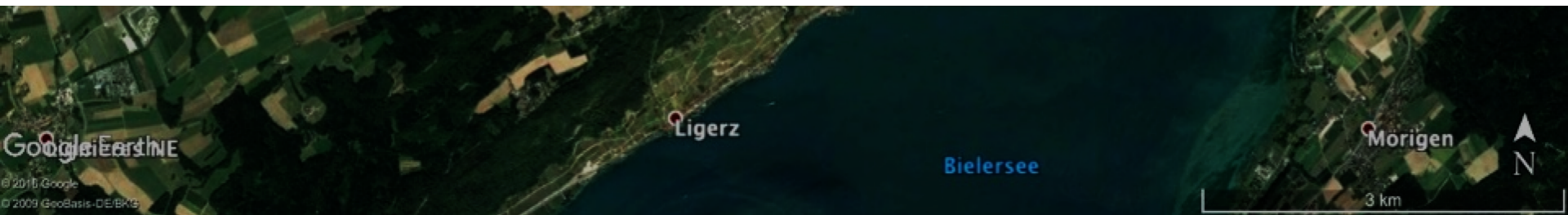
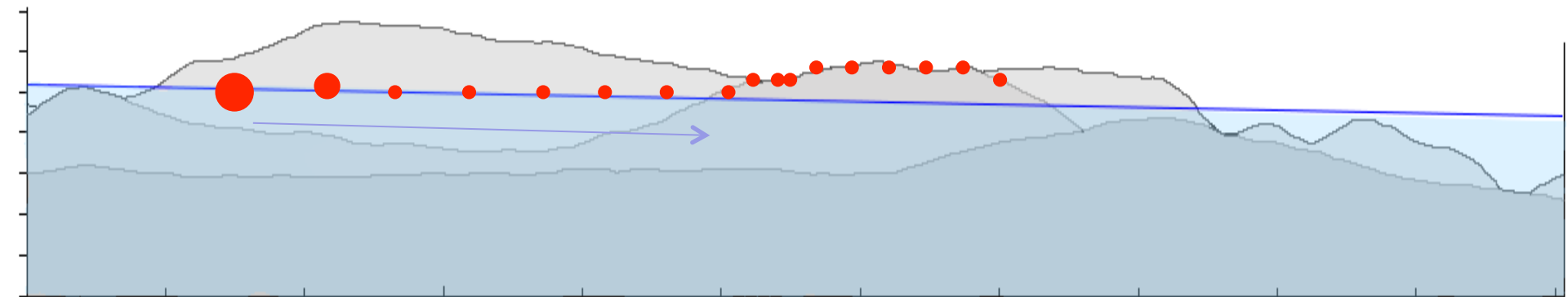
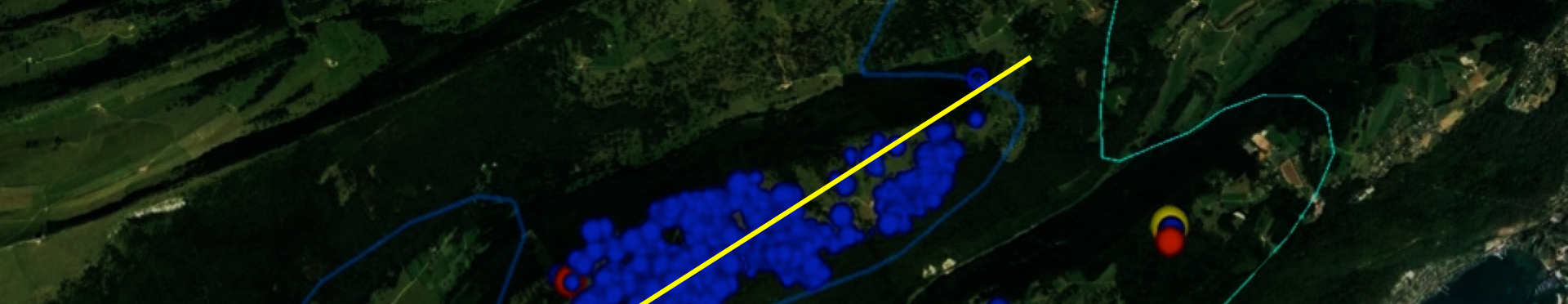
Direction of fall 176 ± 19 ka

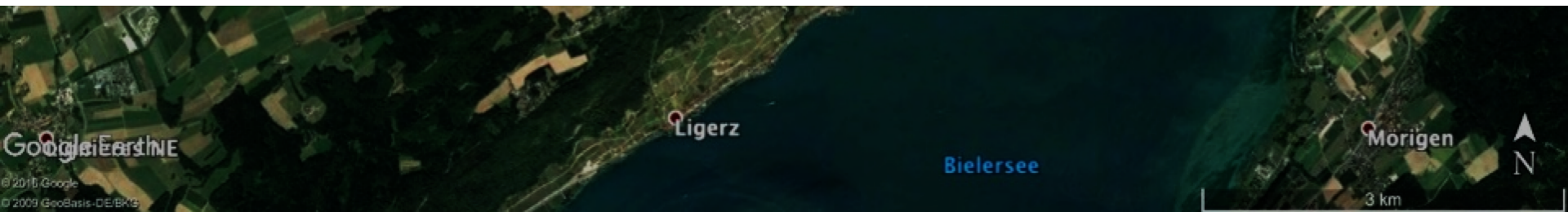
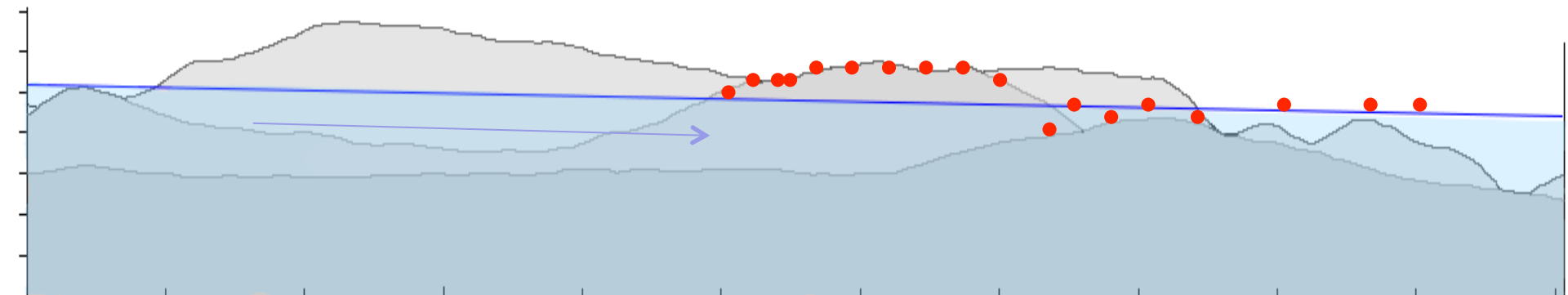
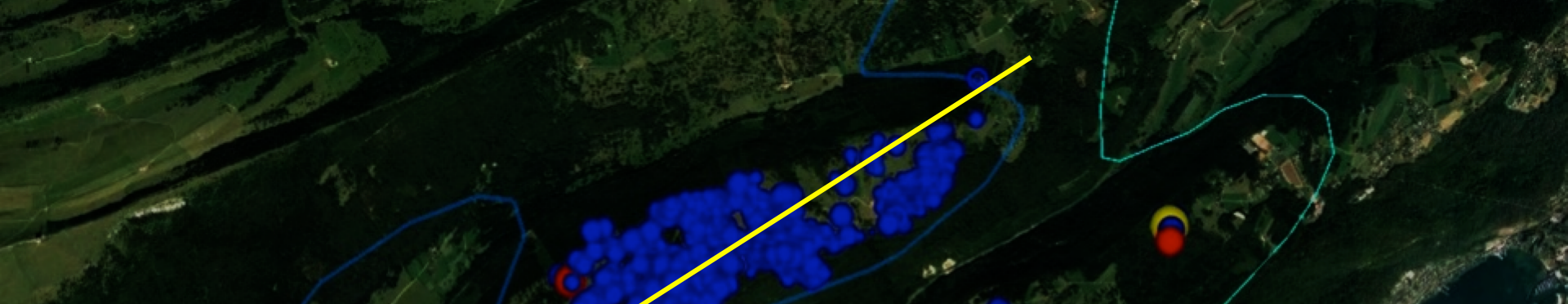


Assumed glacial transport of Twannberg meteorites (Riss/MIS6, 191-130 ka)











Age 2'800 years

Age 176'000 years



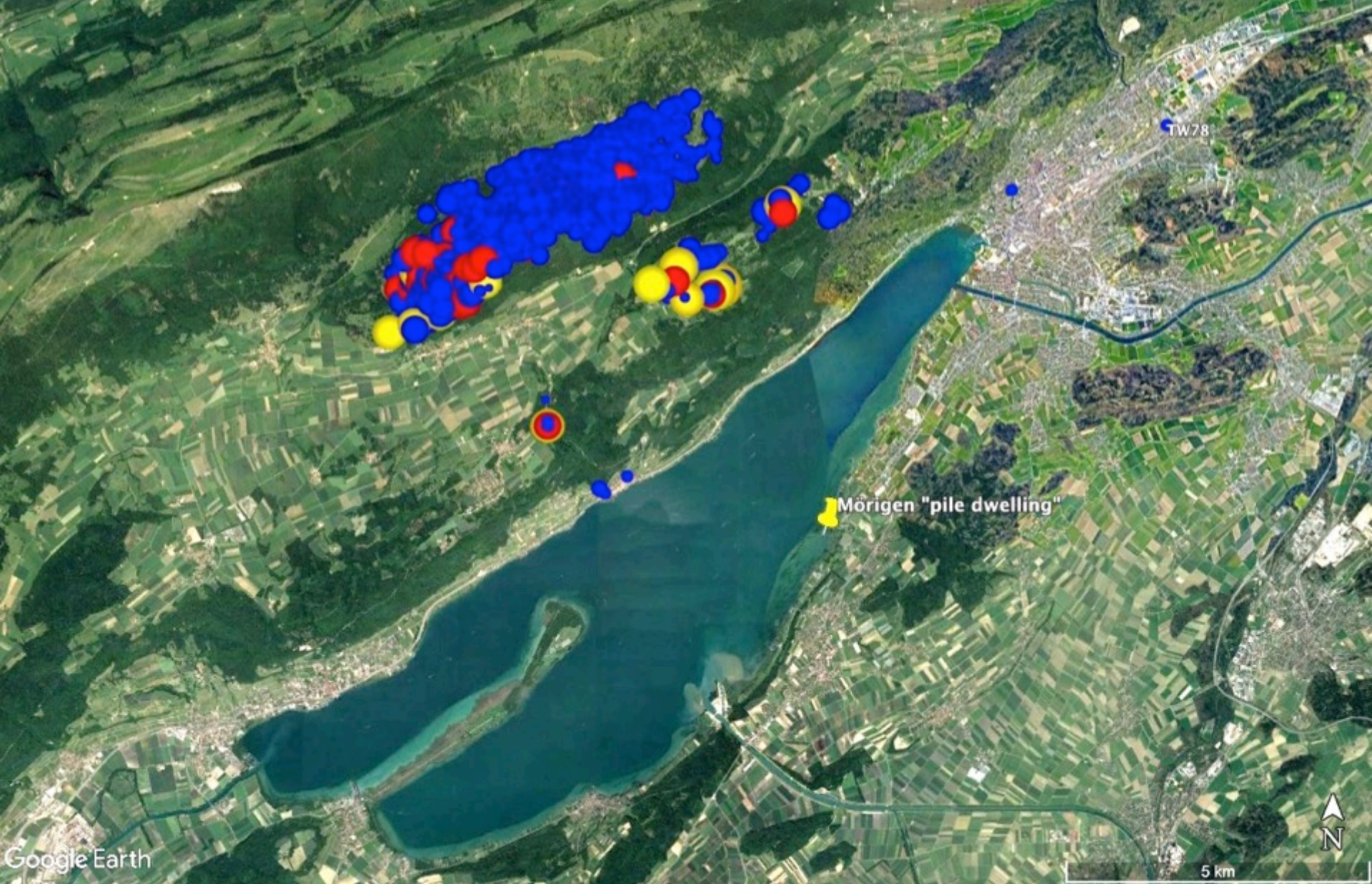
Bronze age sickle and meteorites from Twannberg (not find-connected!)



Late Bronze age arm ring made of copper with inlays of bronze and iron
Mörigen, Lake of Biel (Historisches Museum Bern, 19th century find)



Late Bronze arrowhead made of iron
Mörigen, Lake of Biel (Historisches Museum Bern, 19th century find)



Late Bronze arrowhead made of iron
Mörigen, Lake of Biel (Historisches Museum Bern, 19th century find)

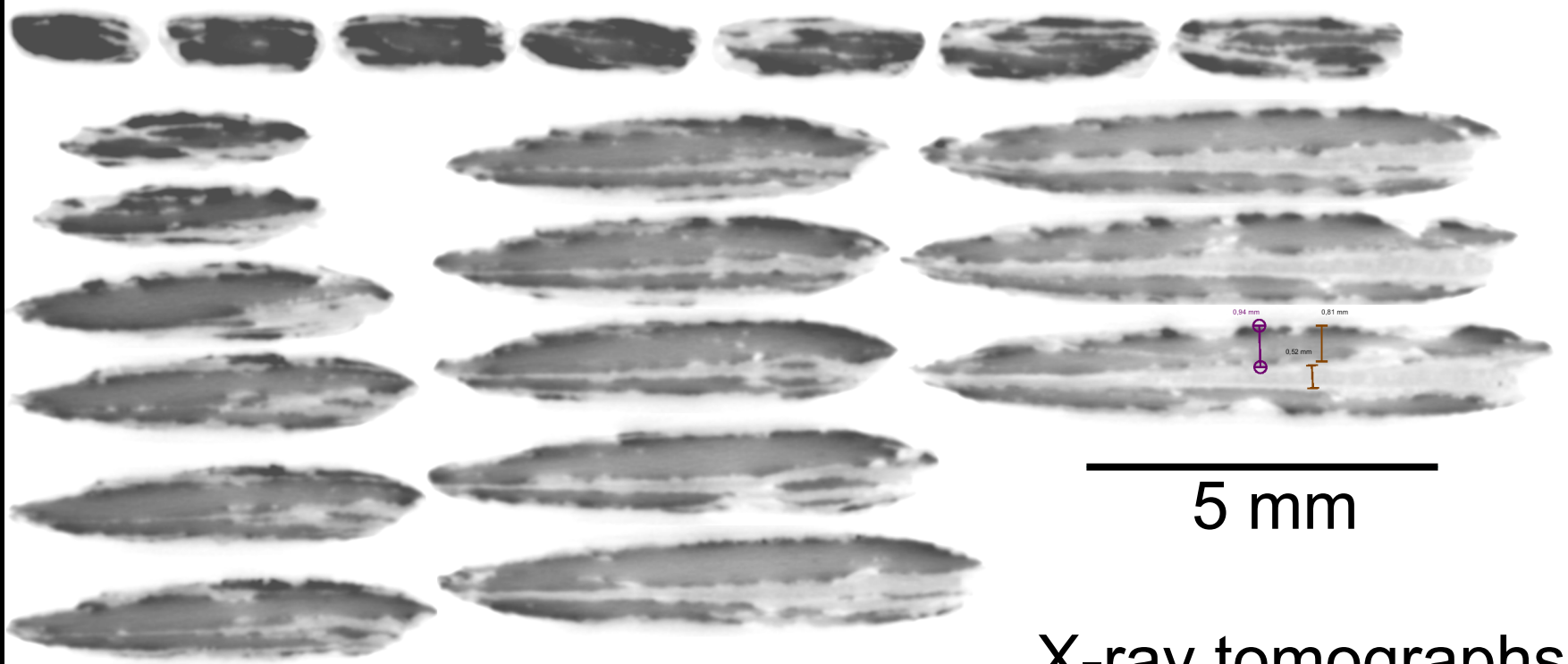
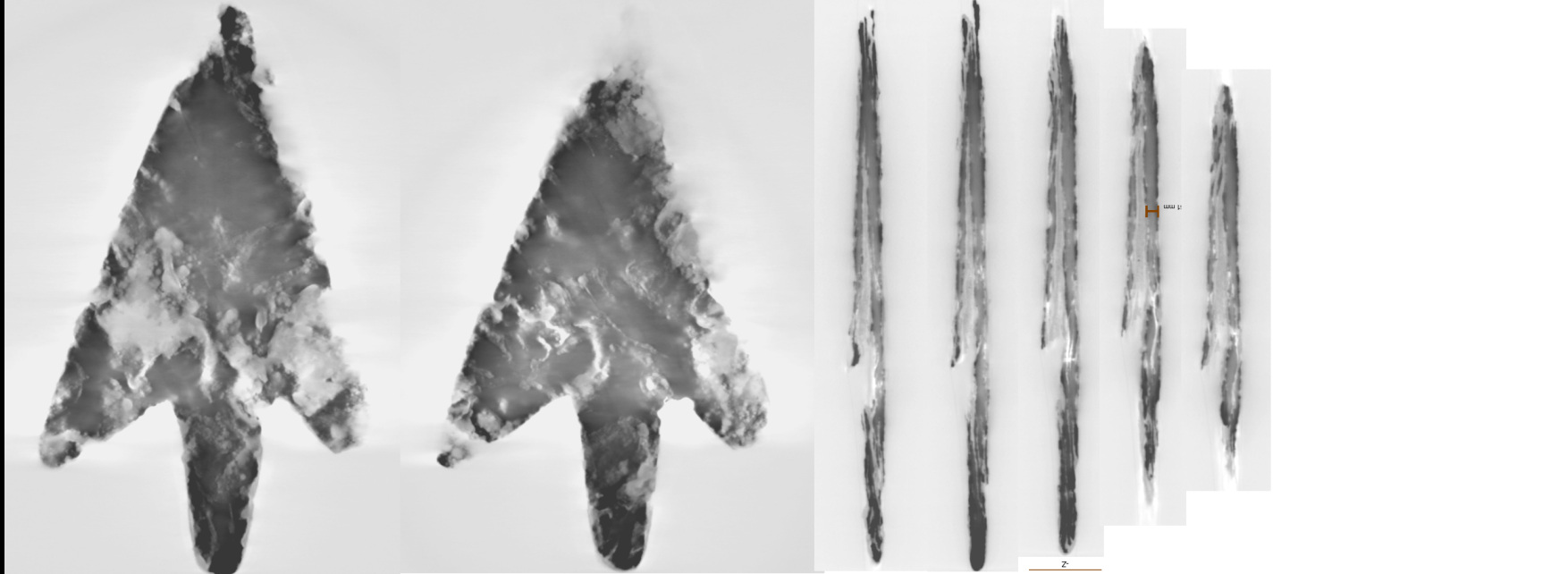


Several wt.% of Ni indicated meteoritic origin

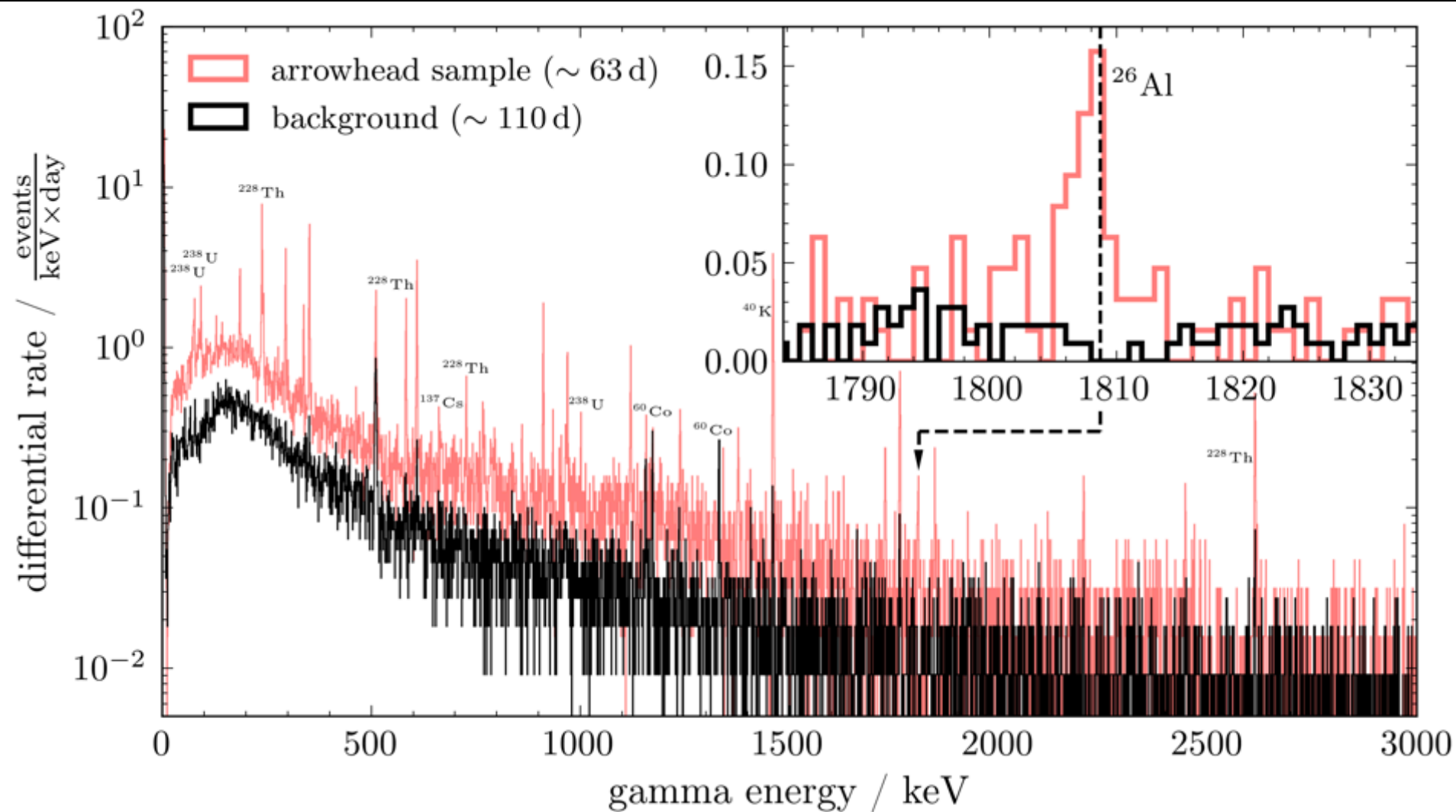
Late Bronze arrowhead made of iron (39 mm)
Mörigen, Lake of Biel (Historisches Museum Bern, 19th century find)



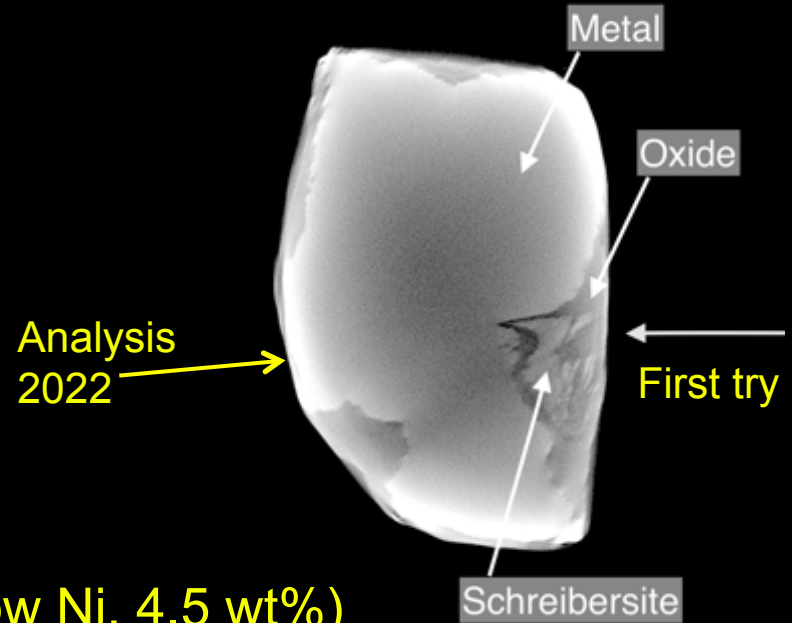
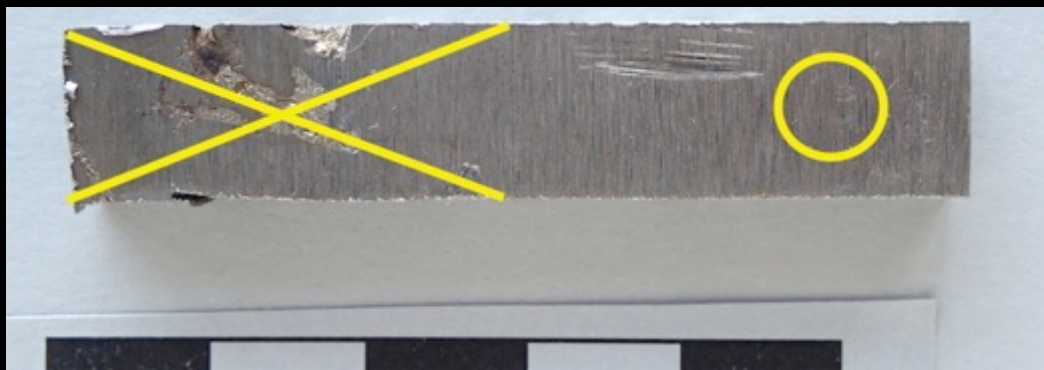
Late Bronze arrowhead made of iron (39 mm, 2.9 g)
Mörigen, Lake of Biel (Historisches Museum Bern, 19th century find)



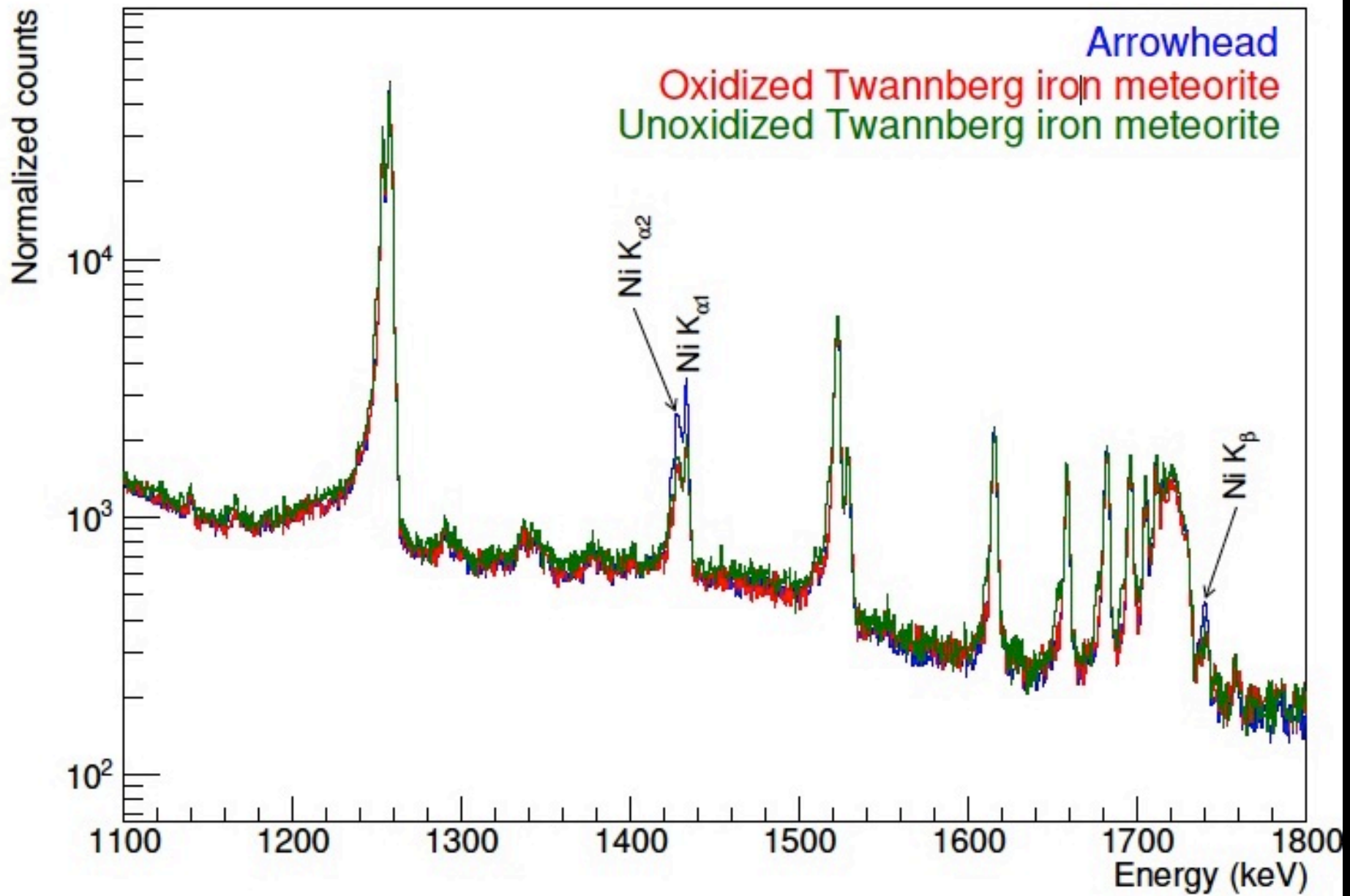
X-ray tomographs



Presence of cosmogenic ^{26}Al (~ 1 dpm/kg) proves meteoritic origin
 (gamma spectrometry, GeMSE lab) ~ 260 decays in 63 days!



MIXE application for Twannberg analyses:
Nondestructive verification of meteorite type (low Ni, 4.5 wt%)



MIXE data show a significantly higher Ni concentration in arrowhead compared with Twannberg

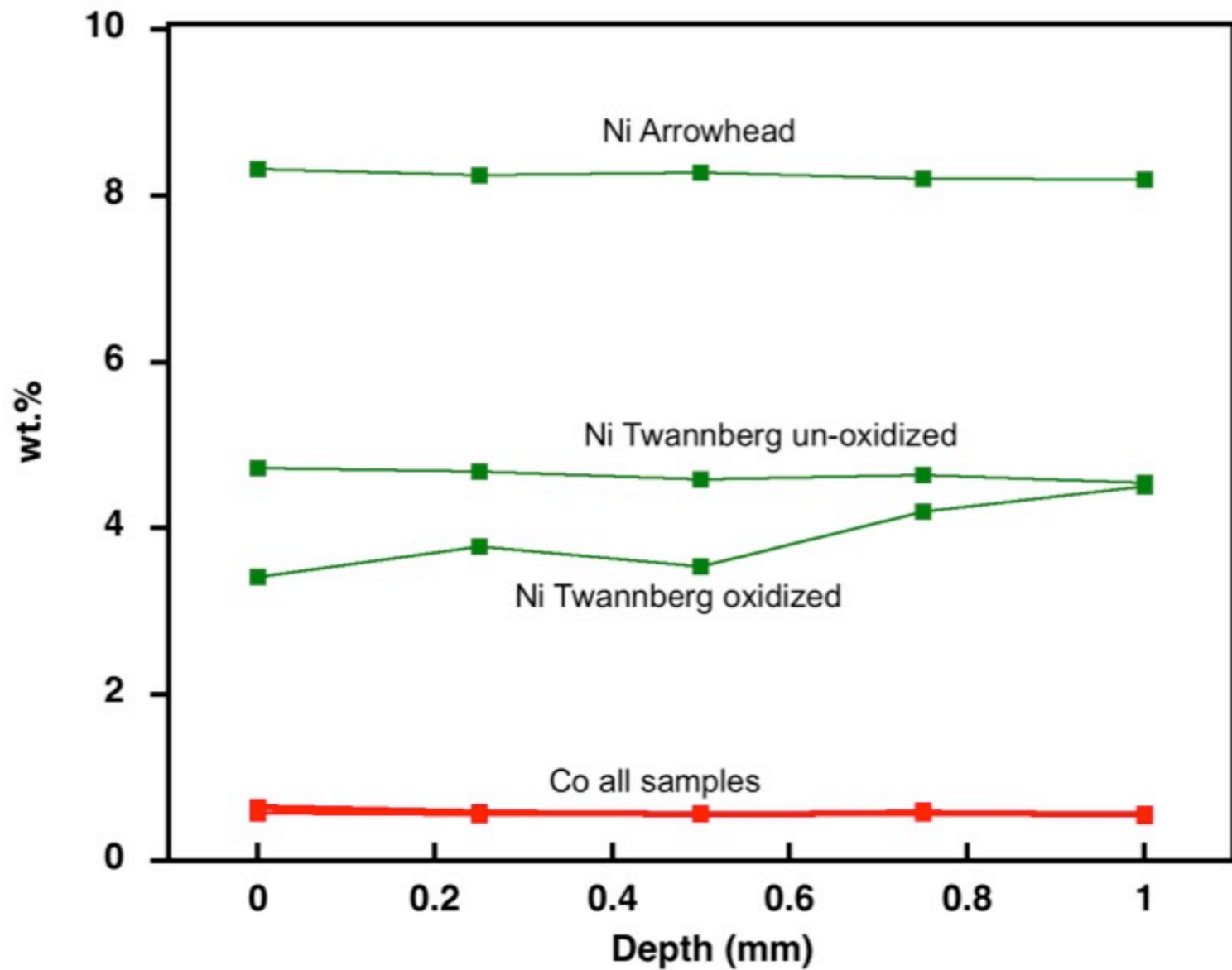
Unoxidized Twannberg meteorite

| Depth (mm) | 0.00 | 0.25 | 0.50 | 0.75 | 1.00 | av. | stdev. | TW* |
|------------|-------|-------|-------|-------|-------|-------|--------|-------|
| Fe wt. % | 94.62 | 94.72 | 94.84 | 94.78 | 94.88 | 94.77 | 0.10 | 94.96 |
| Ni wt. % | 4.73 | 4.69 | 4.59 | 4.64 | 4.55 | 4.64 | 0.07 | 4.52 |
| Co wt. % | 0.65 | 0.59 | 0.57 | 0.58 | 0.57 | 0.59 | 0.04 | 0.52 |

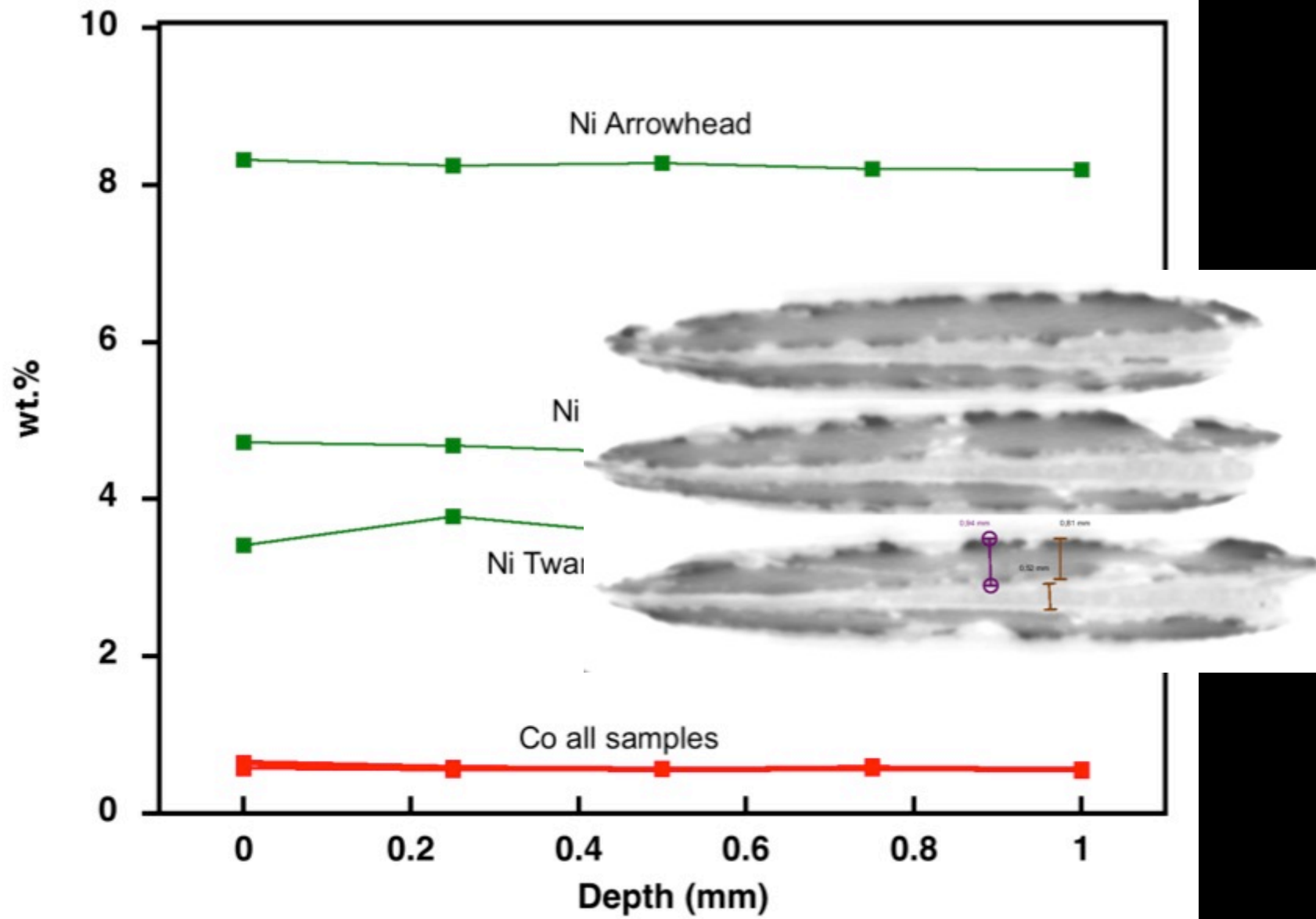
Assuming Fe+Ni+Co = 100% (very close for iron meteorites)

* From Hofmann et al. (2009), based on combined INAA and ICP-MS analyses, Fe by difference

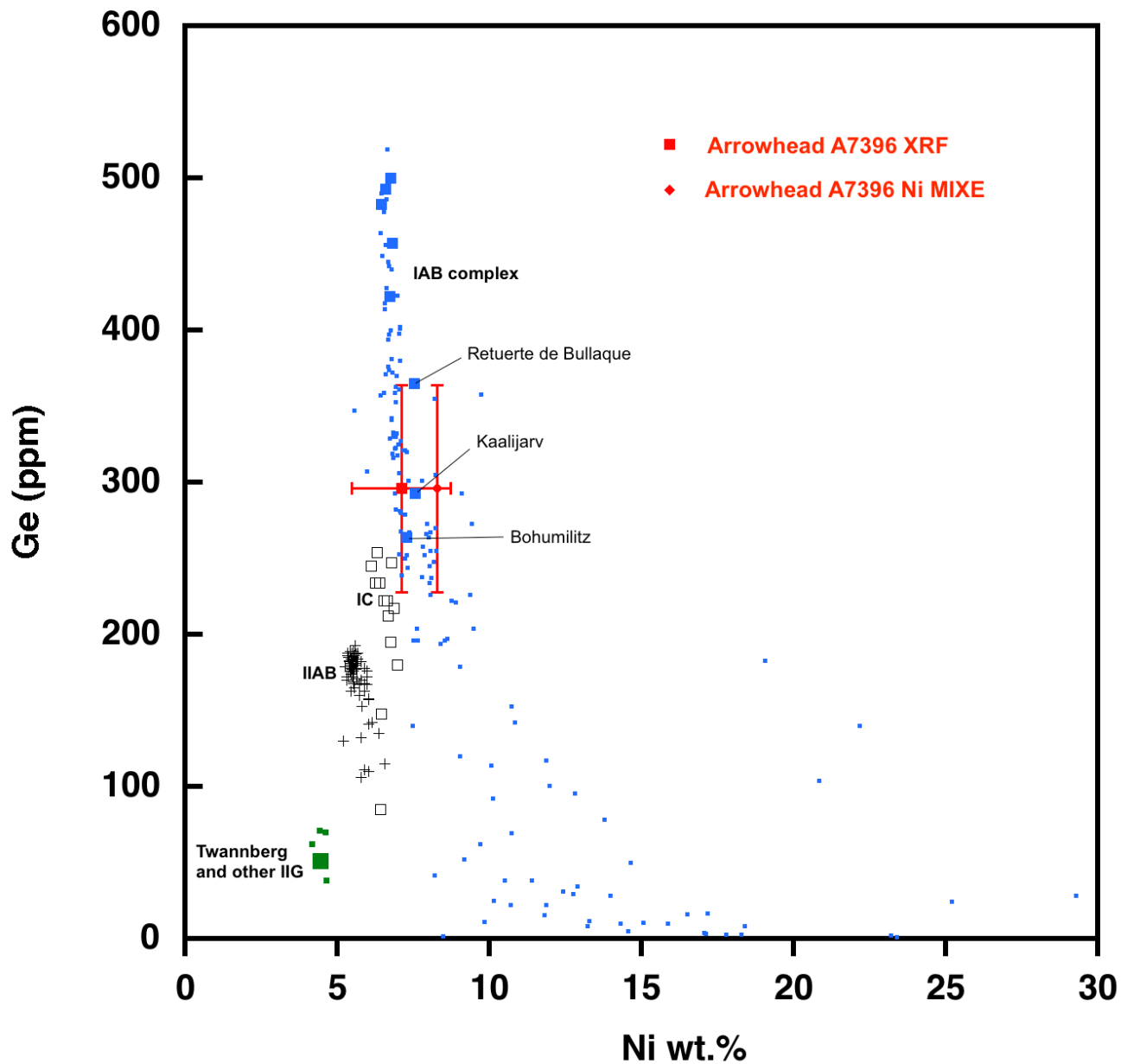
MIXE depth profiles



MIXE depth profiles: MIXE data for Fe, Ni, Co very close to conventional data at depths of 0-1 mm, determination of primary Ni below rust works.



MIXE depth profiles: Arrowhead shows no Ni-depletion at surface, probably due to thin oxidation layer.



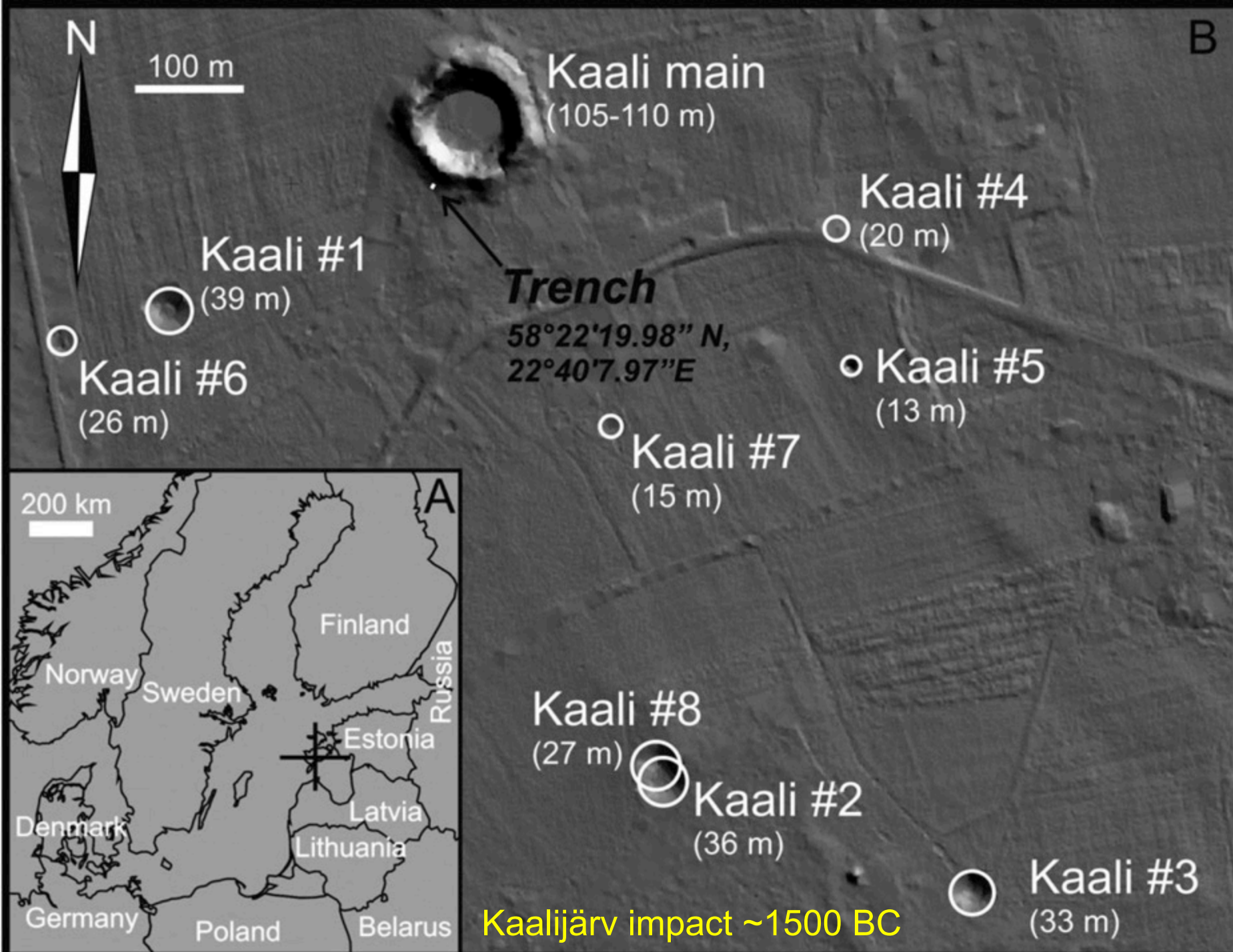
Mörigen arrowhead compared with iron meteorites



Google Earth

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Image IBCAQ

Known pre-iron age meteoritic artefacts





A C E G J M

Abb. 4 Ein weiterer Weggefährte Carters, der Fotograf Harry Burton vom Metropolitan Museum in New York, für die Arbeiten im Tal der Könige freigestellt, fotografierte exemplarisch lediglich sechs der zierlichen Werkzeuge. M. 1:2.

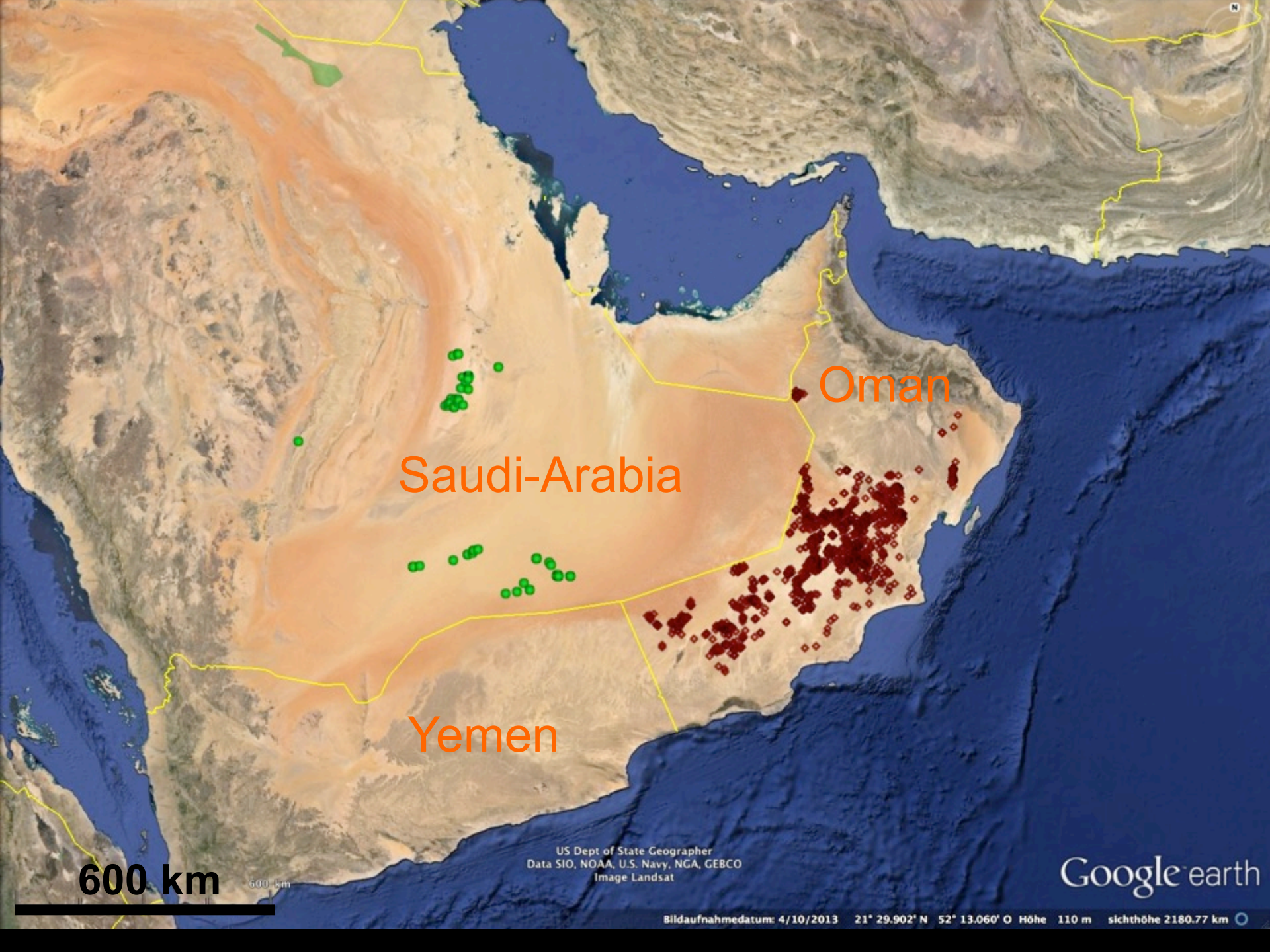


Abb. 5 Einer der 16 Meißel mit fast neuwertig erscheinendem Griff aus Koniferenholz. M. ca. 1:1.

Dagger, headrest, amulet + 16 meteoritic tools from the grave of Tutankhamun (1341-1323 BC) (Broschat et al. 2018)



Meteorite searches in Oman 2001 – 2022:
7276 meteorite samples representing ~1300 fall events



Saudi-Arabia

Oman

Yemen

600 km

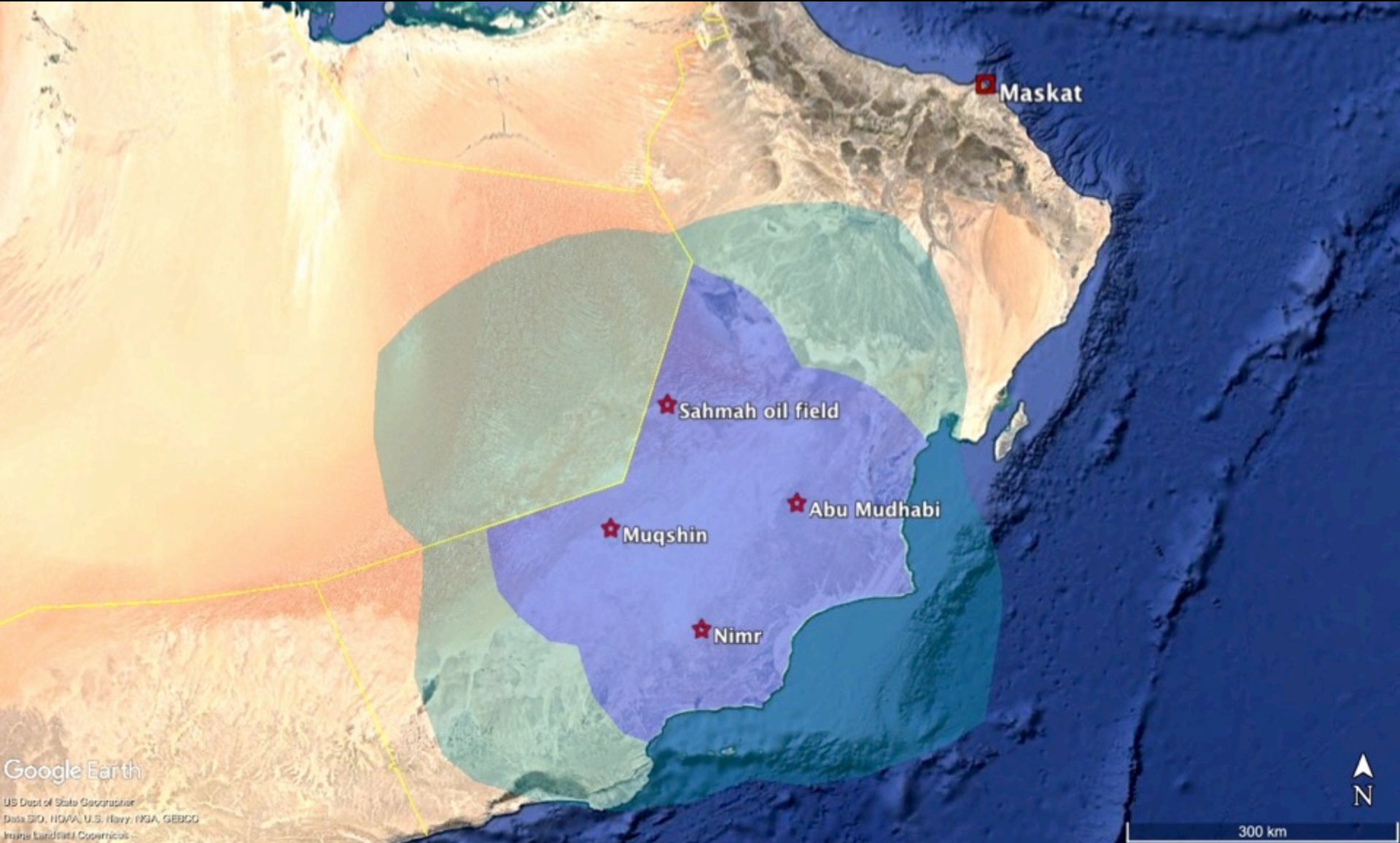
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat

Google earth

Bildaufnahmedatum: 4/10/2013 21° 29.902' N 52° 13.060' O Höhe 110 m slichthöhe 2180.77 km



Chondrit, found February 12, 2017 -> fallen in summer 2012



Four installed cameras observe ~ 115'000 km² in Oman
-> 9 fall events/year >10 g

PARTNERS



„Oman Meteorites Monitoring Project“ is part of the Global Fireball Observatory
Oman (Ministry of Heritage and Tourism) – CH – Curtin University (Perth)

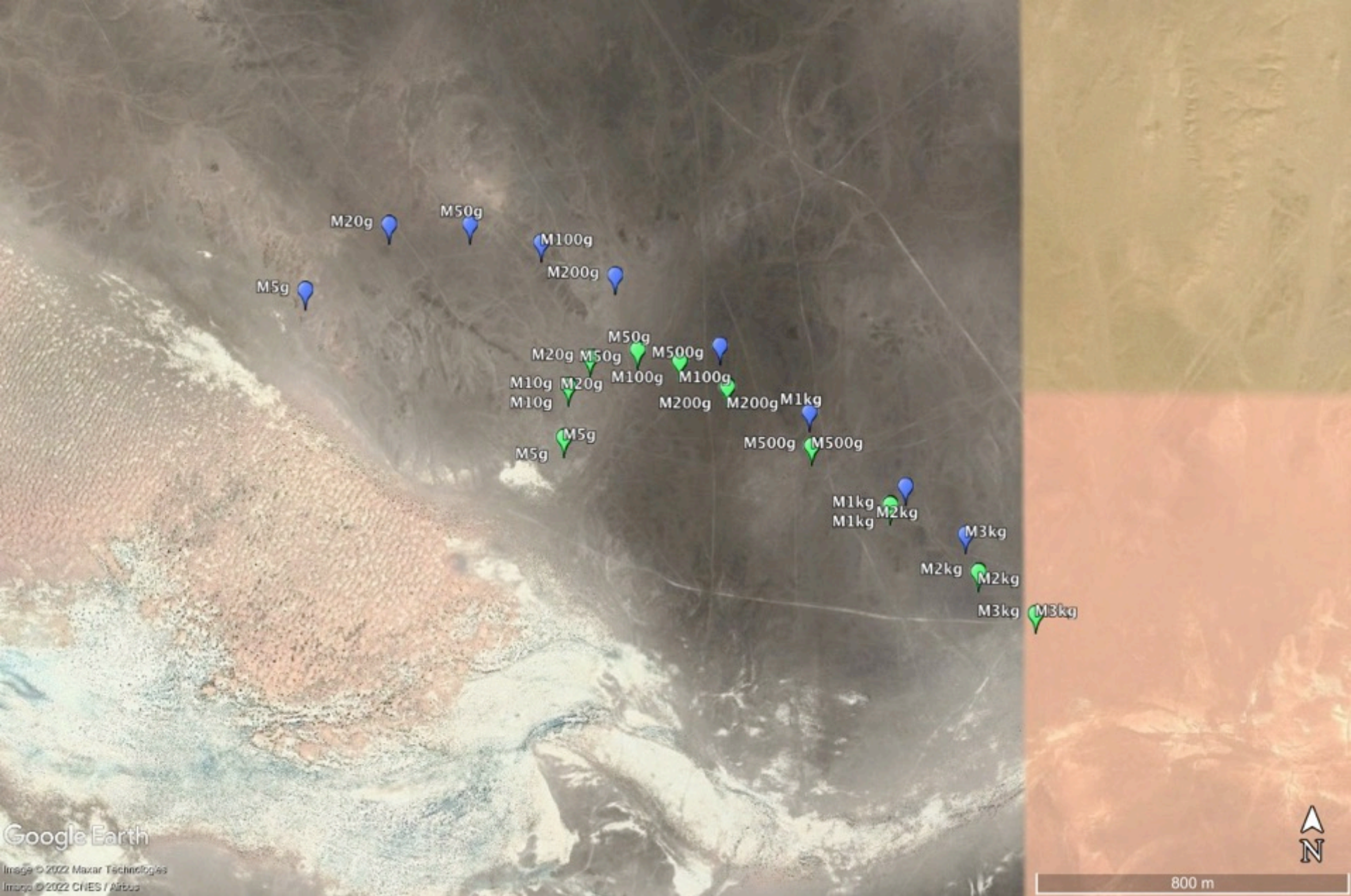




Sahama filed, DFNEXT047, March 14, 2022
Hussain Al-Ghafri, Ministry of Heritage & Tourism







Example of target with two independent calculations from raw data

Vereinigte Arabische Emirate



Sahmah oil field

Oman

Muqshin

Abu Mudhabi

Nimr

Google Earth

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

200 km

N

Options for future MIXE meteorite analyses:

- Fresh meteorite fall from Oman, analysis through fusion crust
main elements including C, O, S
- Any other artefacts made of meteoritic iron
(maybe from Egypt – link with arrowhead?)
- Twannberg sample with rust layer
non-destructive test of sample in private collection



