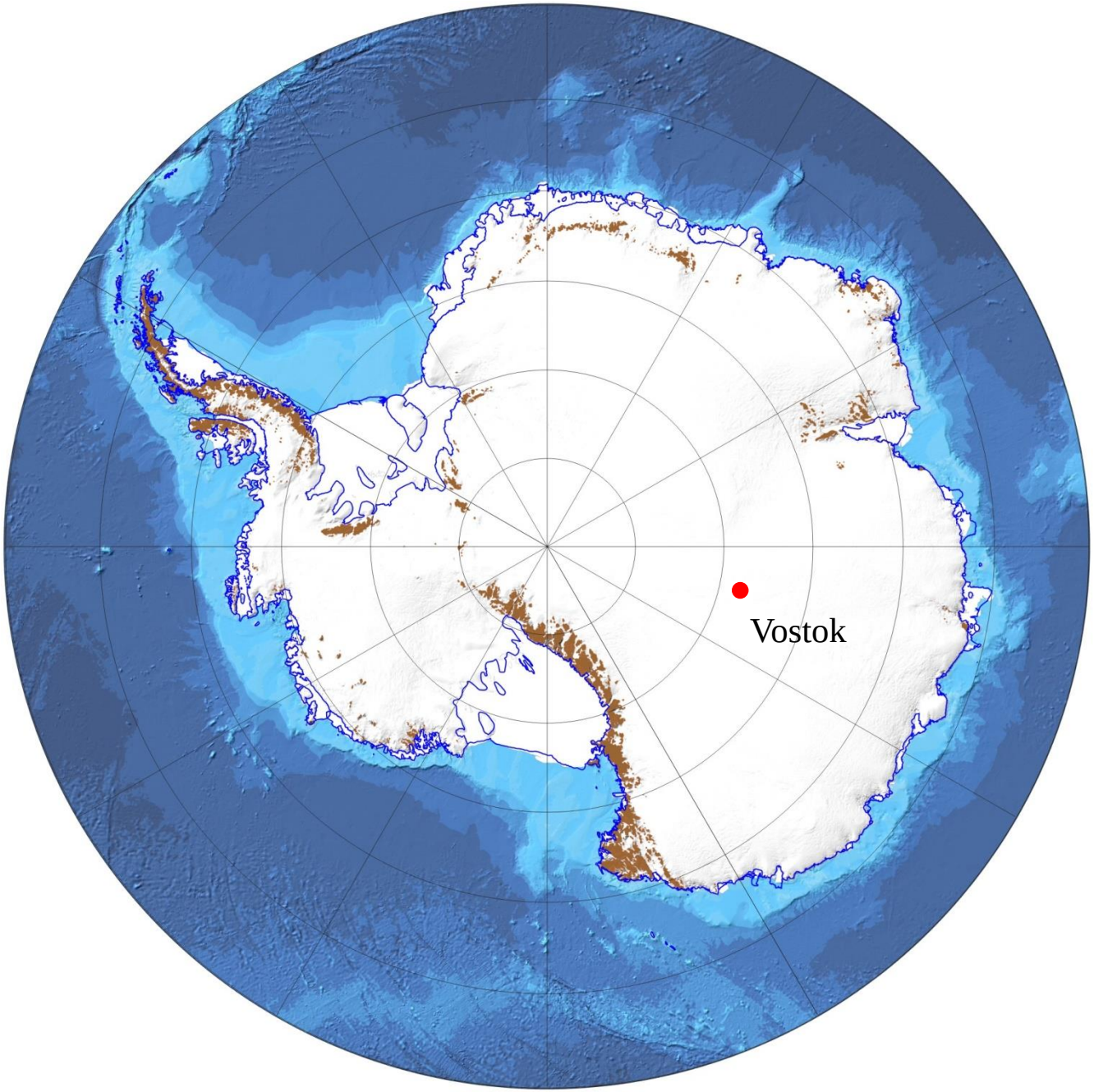
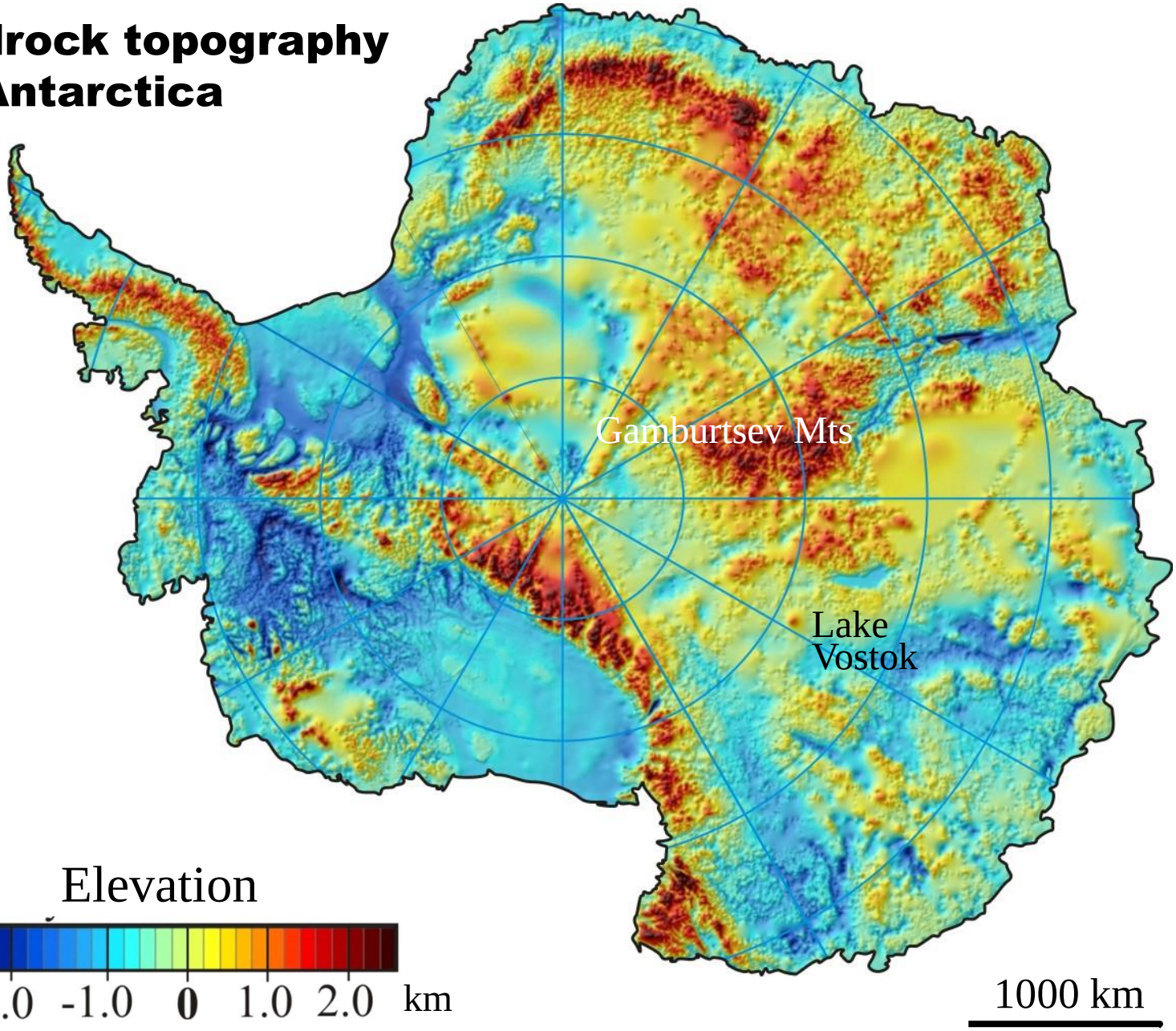
Geology of the Lake Vostok region

German Leitchenkov

Institute for geology and Mineral Resources of the World Ocean, St.-Petersburg

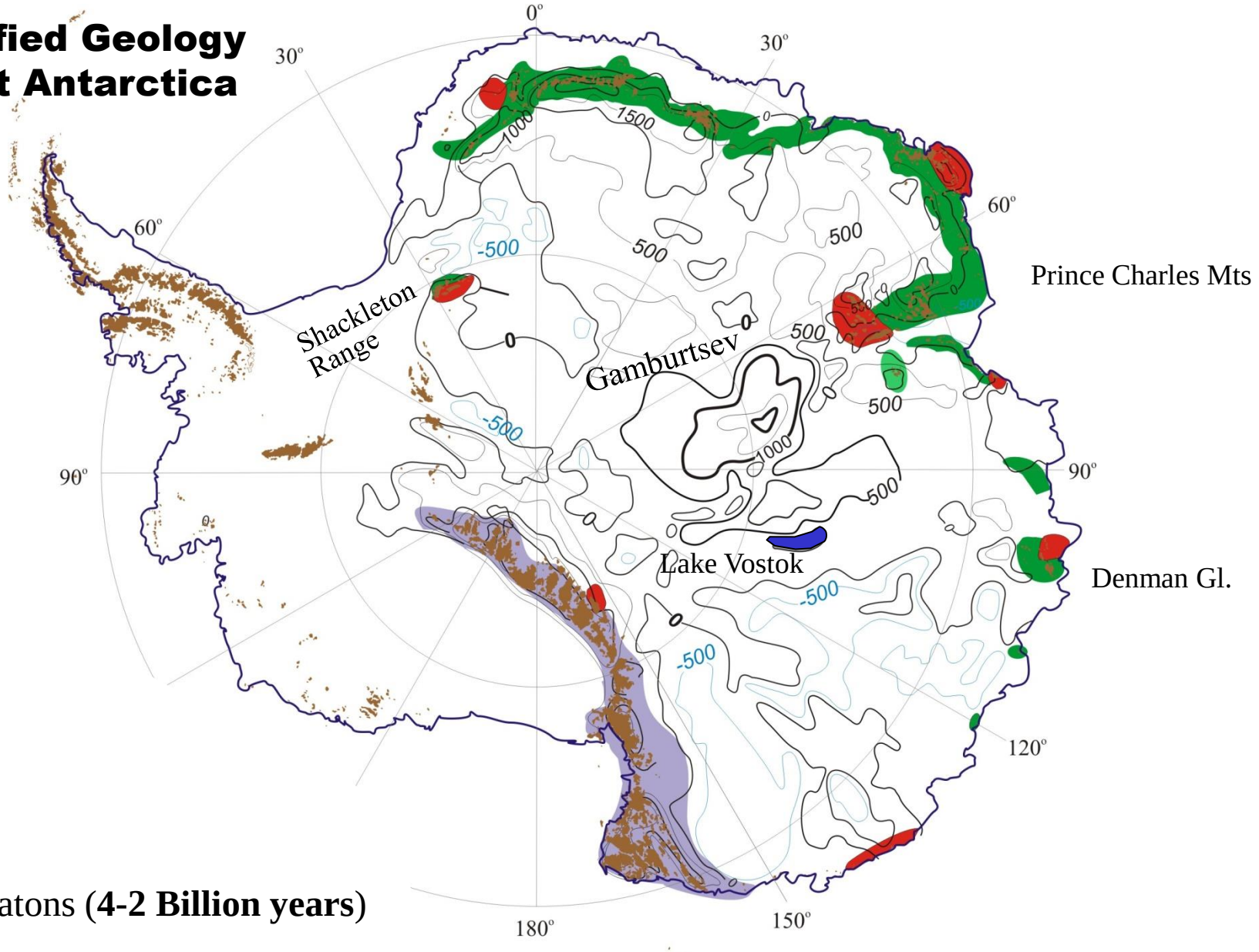

Vostok

Bedrock topography of Antarctica



Geology & Tectonics of East Antarctica

Simplified Geology of East Antarctica



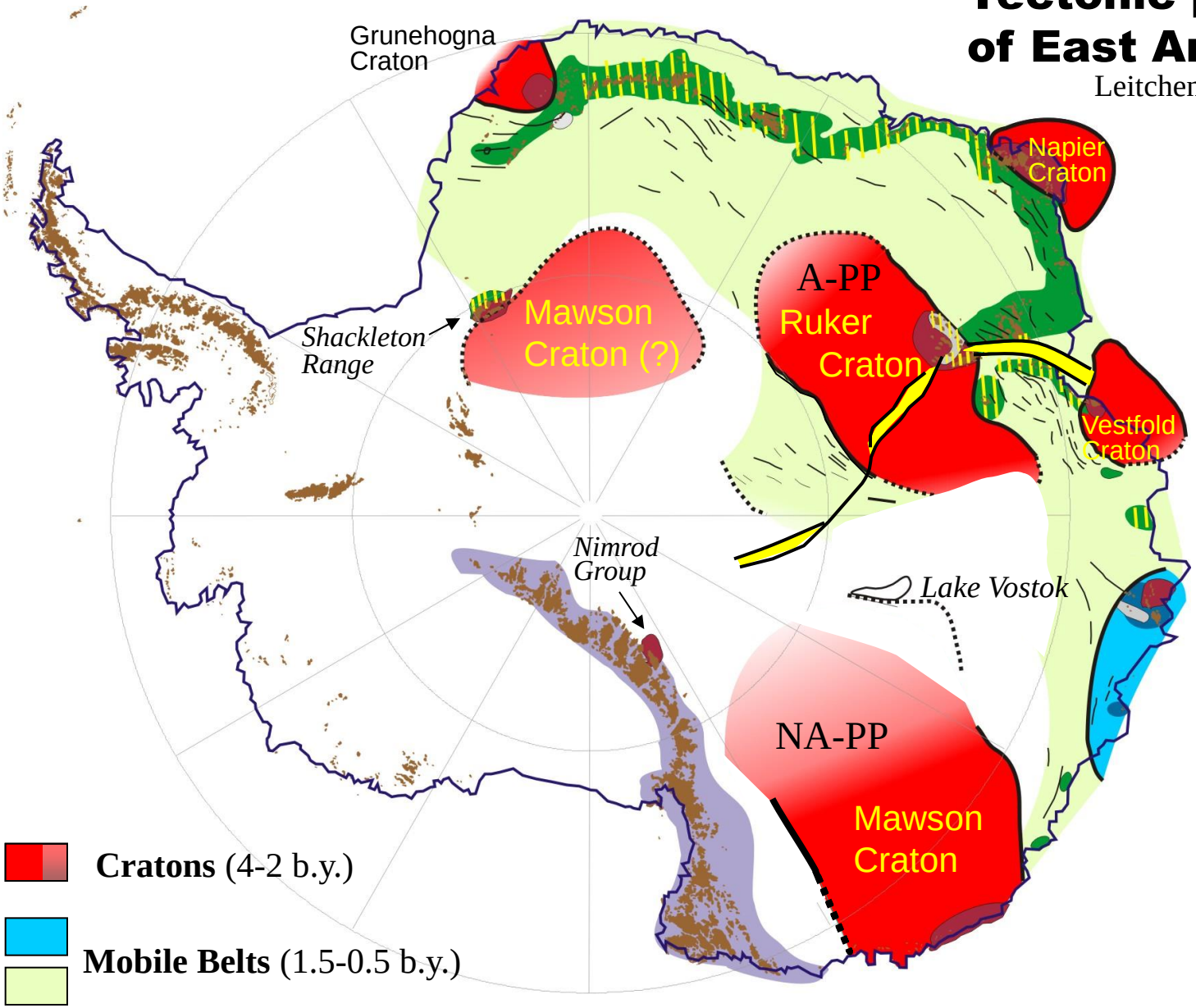
Cratons (**4-2 Billion years**)

Mobile belts (**1.5-0.5 Billion years**)

Pacific (Ross) Orogen **(~ 0.5 Billion years**)

Tectonic provinces of East Antarctica

Leitchenkov et al., 2014, 2015



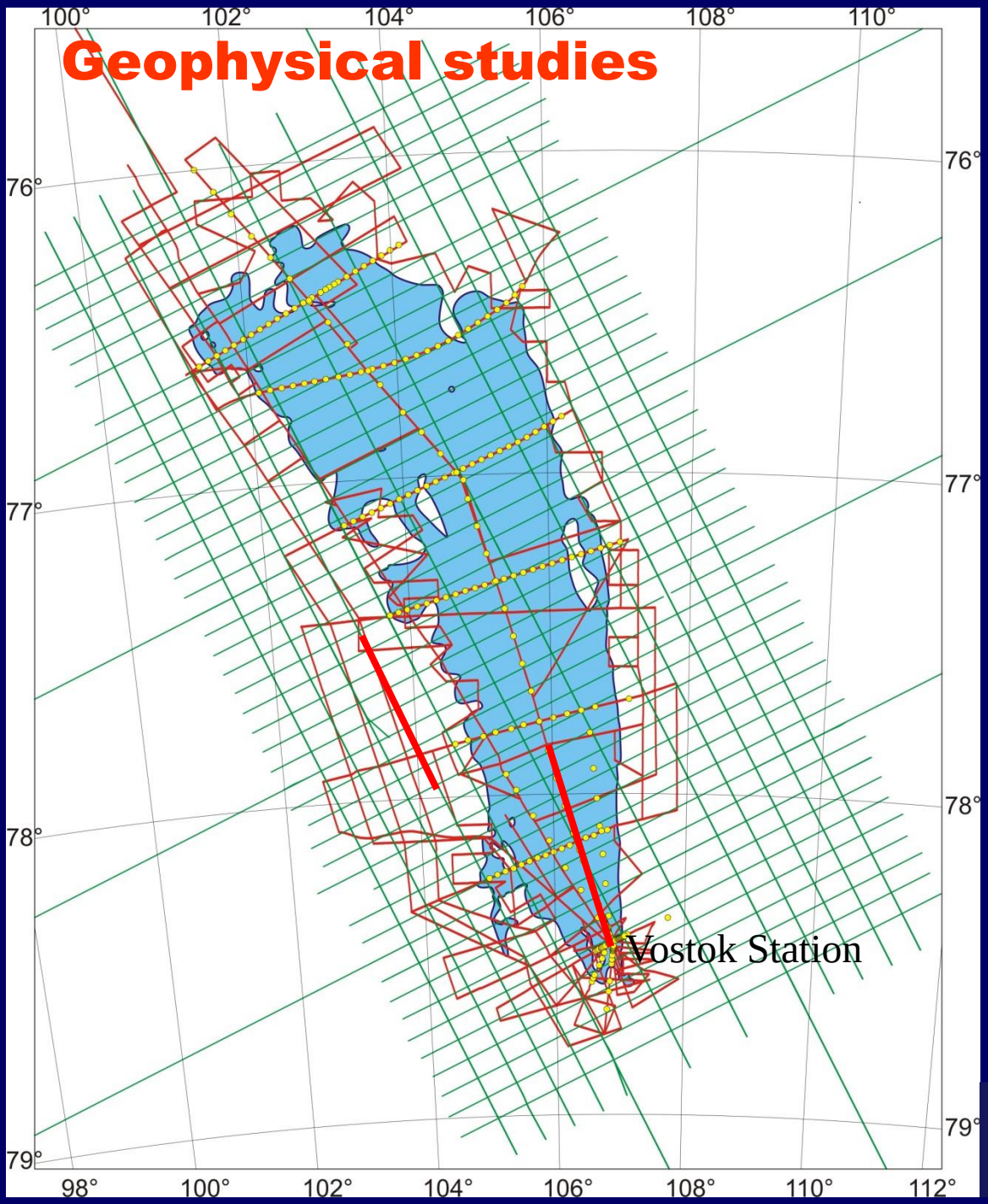
Cratons (4-2 b.y.)

Mobile Belts (1.5-0.5 b.y.)

Rifts (260 – 130 million years)

Leitchenkov G., Antonov A., Luneov P., Lipenkov V. Geology and environments of subglacial Lake Vostok . Phil. Trans. R. Soc. A. 2015. Vol. 373,. In press

Geophysical studies over Lake Vostok



USA

Airborne survey, 2000

RUSSIA

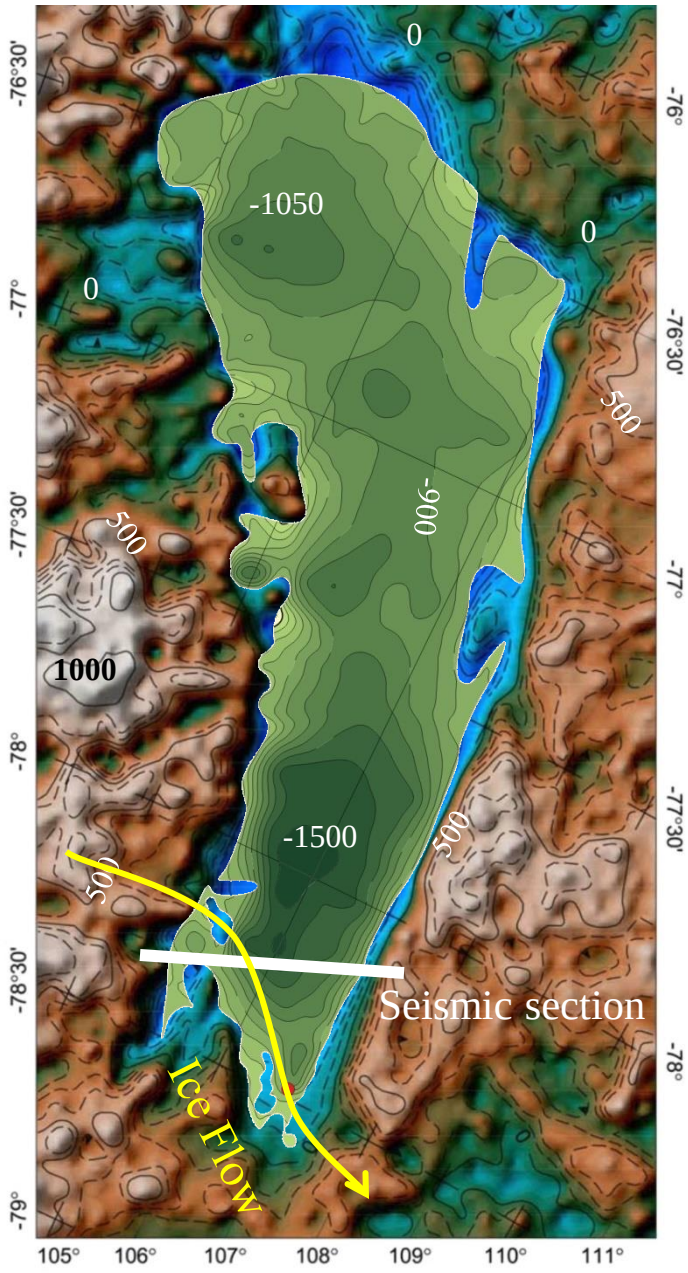
On-land Radio-Echo Soundings 1996-2008

Reflection Seismics 1996 - 2008

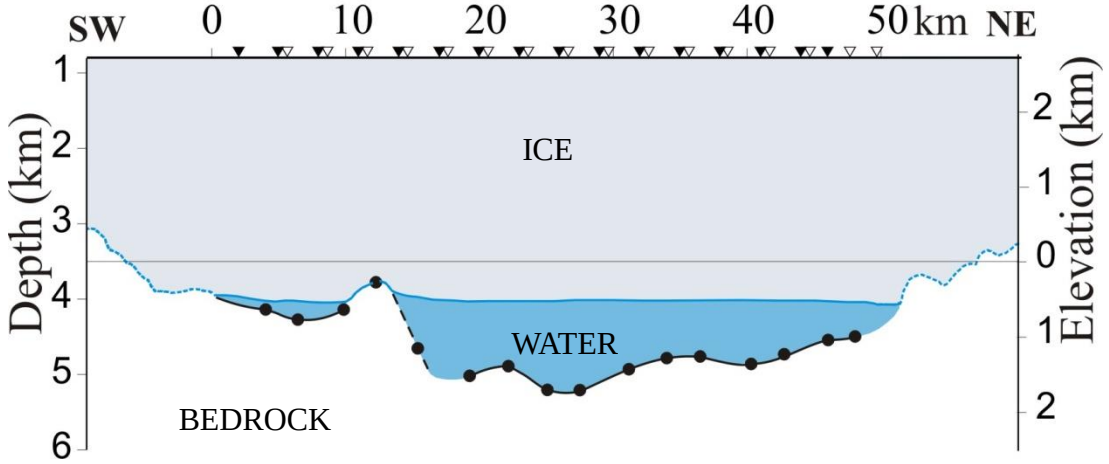
Refraction Seismics 2009 - 2013

Bedrock topography

Studinger et al., 2003; *Popkov et al., 2009*



Seismic Section



Length: 250 km

Width: 50-80 km

Morphology of the depression shows resemblance with rift-related lakes

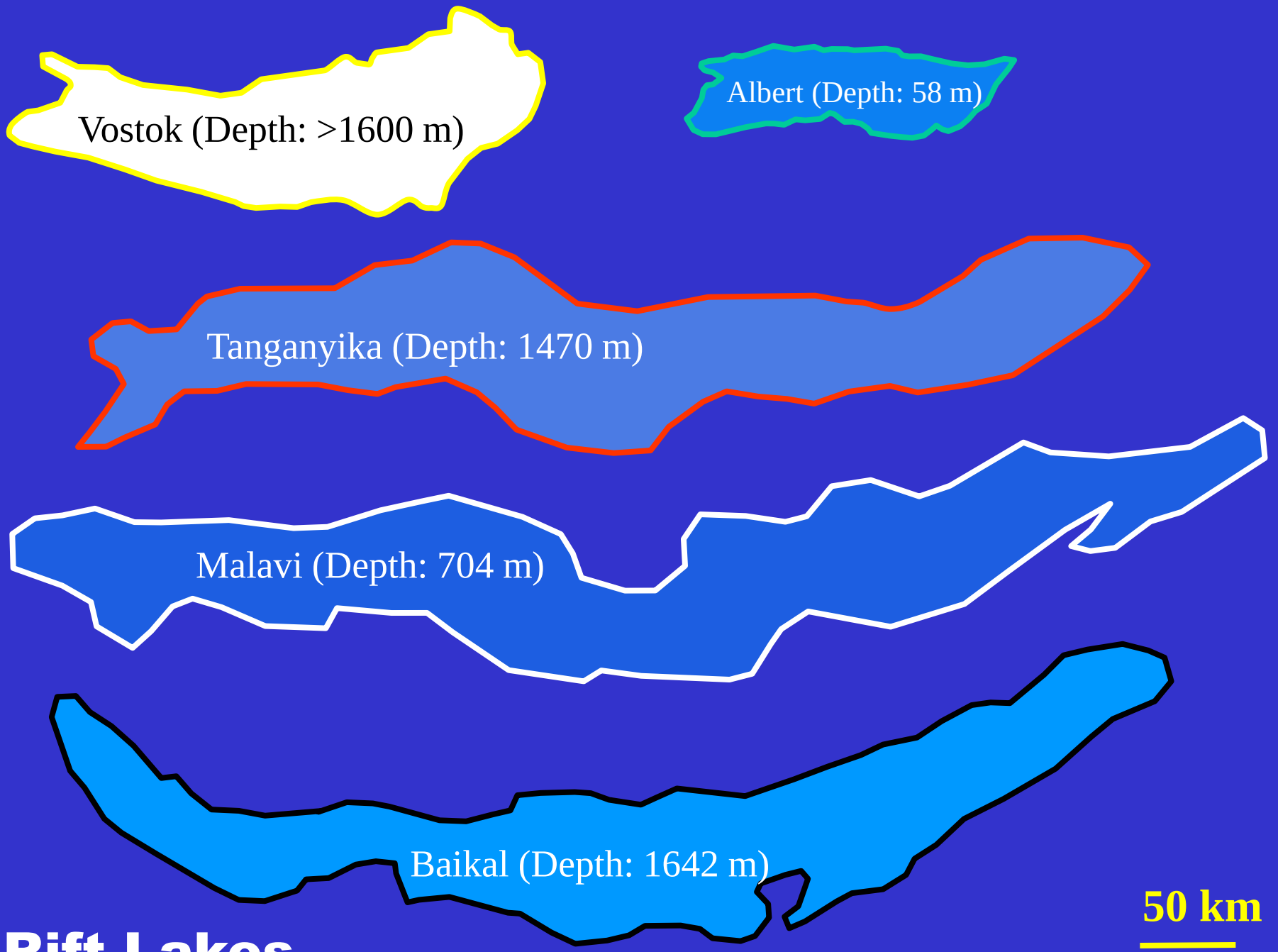
Maximum Depths:

~1600 m below sea level

~1200 m below ice base → 2-nd in the World

Surface are: ~16 000 km^2 → 17-th in the World

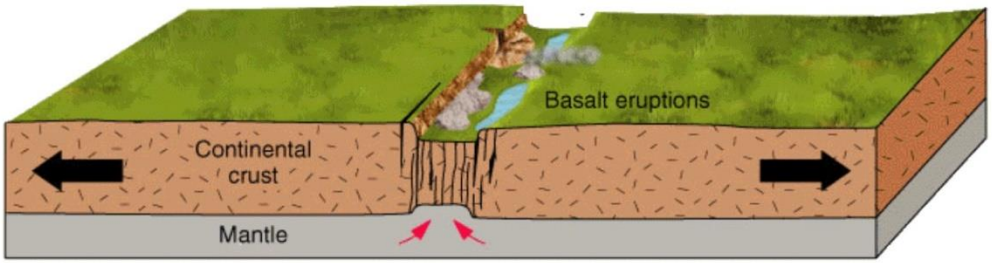
Water volume: ~ 6000 km^3 → 5-th in the World

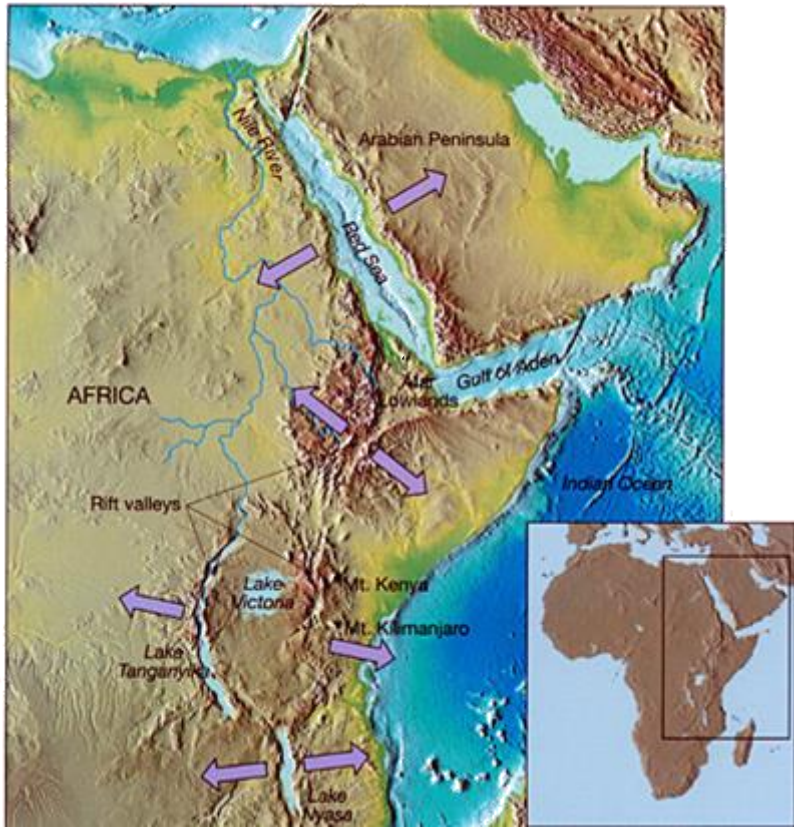

Vostok (Depth: >1600 m)
Albert (Depth: 58 m)
Tanganyika (Depth: 1470 m)
Malavi (Depth: 704 m)
Baikal (Depth: 1642 m)
50 km

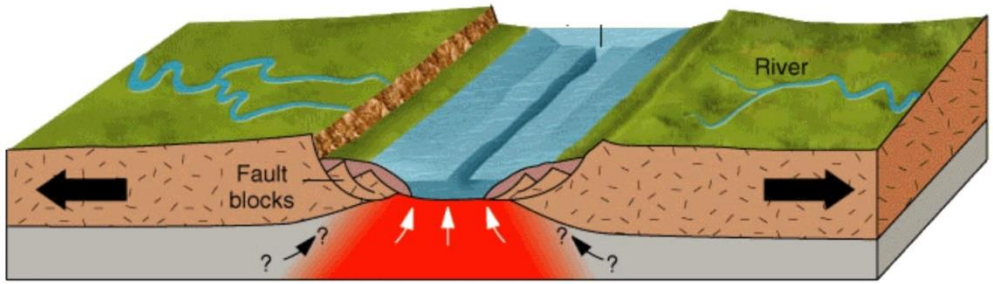
Rift Lakes

TECTONIC SETTING OF LAKE VOSTOK

Type structure of continental rift

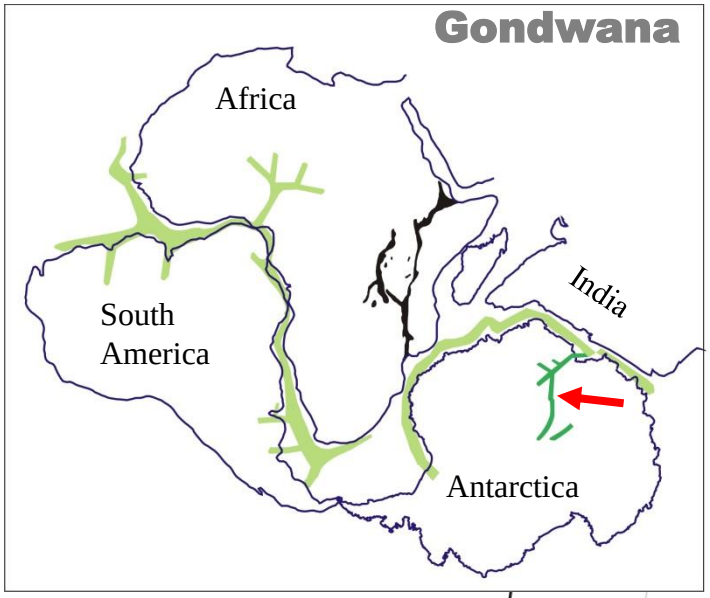






Rifts are formed due to crustal extension

Antarctic Rift System



Mesozoic Failed Rifts

Late Cenozoic East African Rift

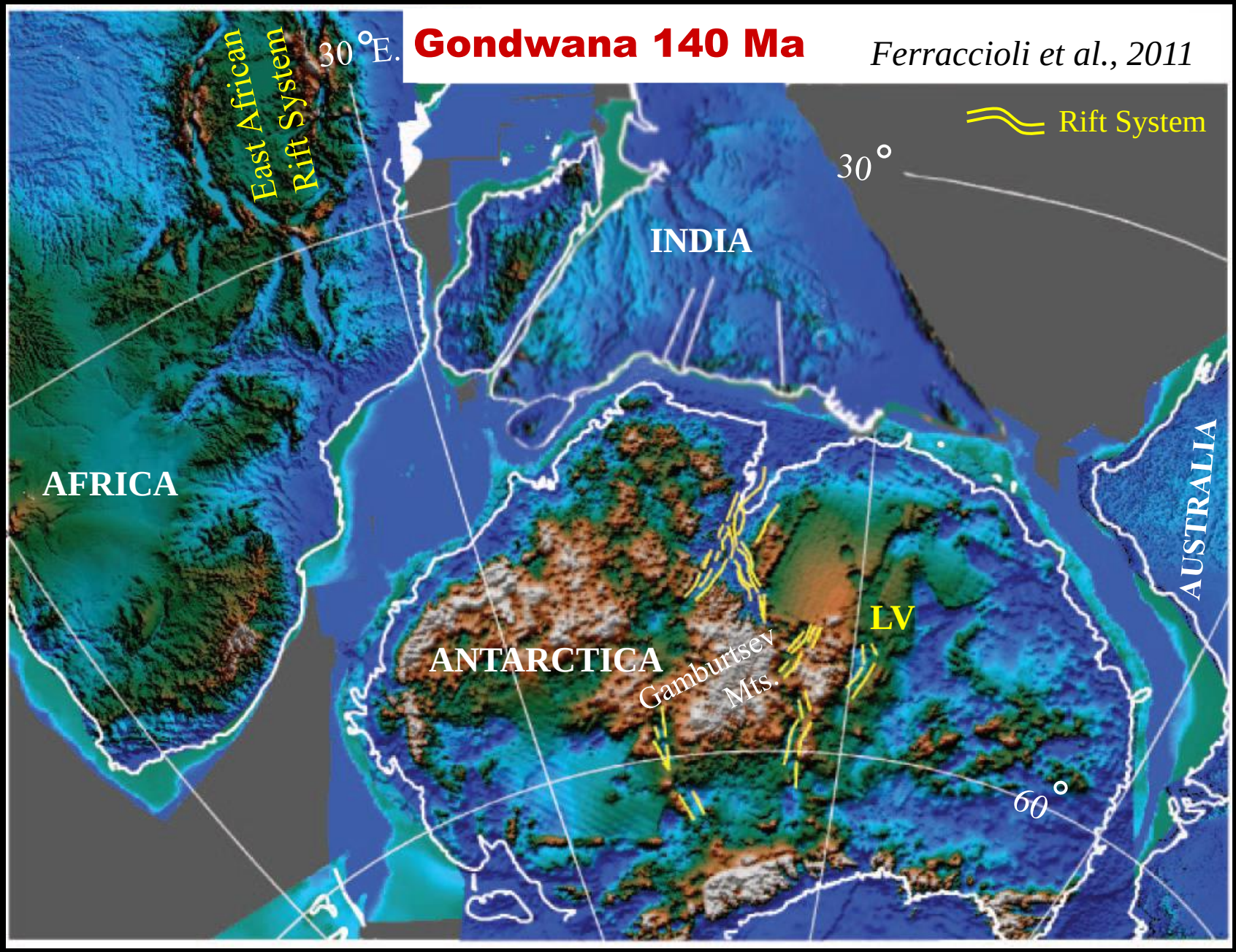
Gamburtsev Mts.

Lambert Rift

Vostok

>500 м

Leychenkov et al., 1998 (AARI meeting), 2003 (EGU meeting), (2004 MGI Paper)

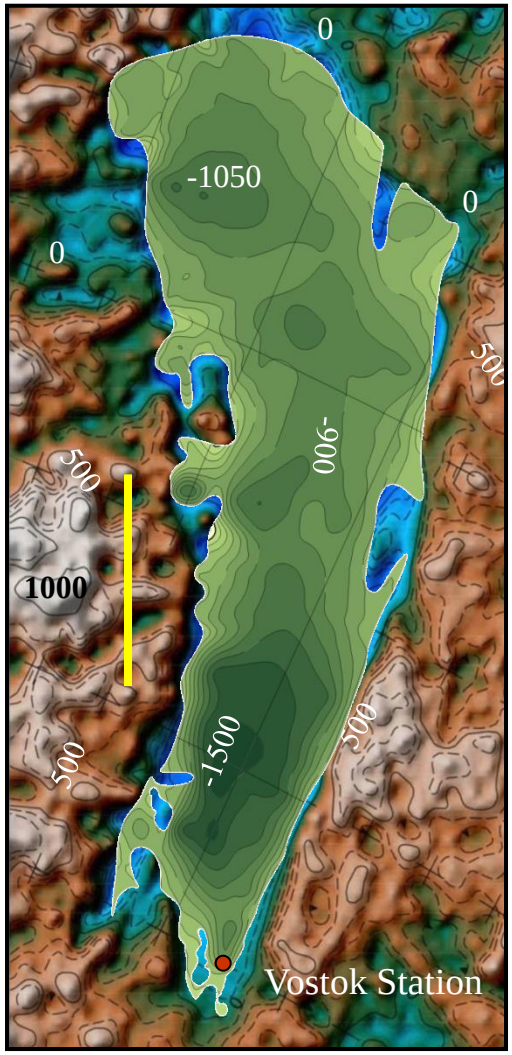

Gondwana 140 Ma
Ferraccioli et al., 2011
Rift System
East African Rift System
30 °E.
30 °
60 °
INDIA
AFRICA
ANTARCTICA
AUSTRALIA
LV
Gamburtsev Mts.

Seismic Refraction Experiments

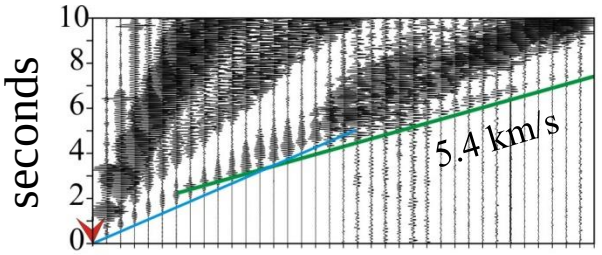
Seismic refraction Experiment

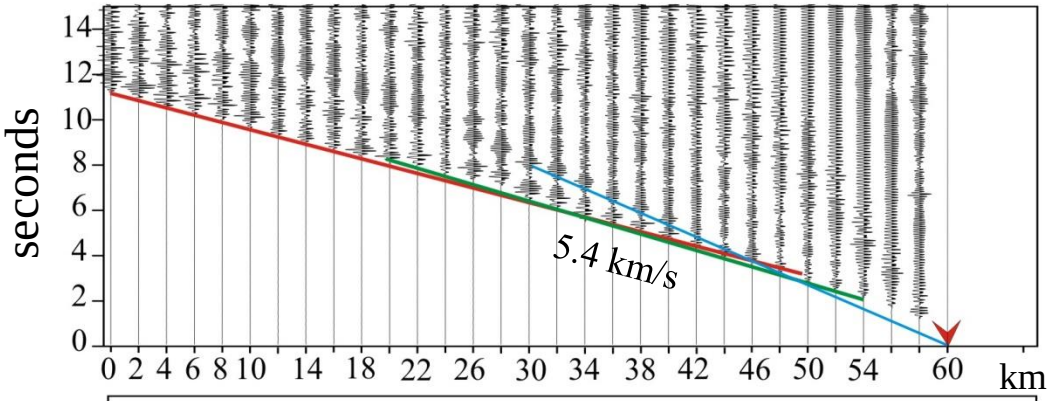
Technology:

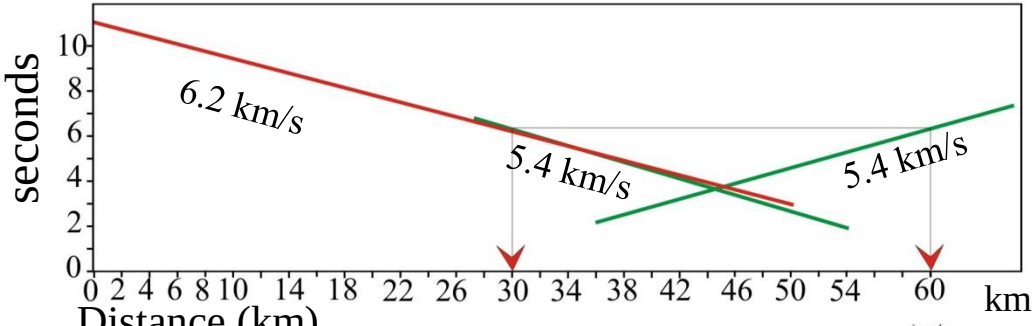
Two reversed lines; 1 and 2 km between receivers;
Shot points: 25-500 kg of TNT



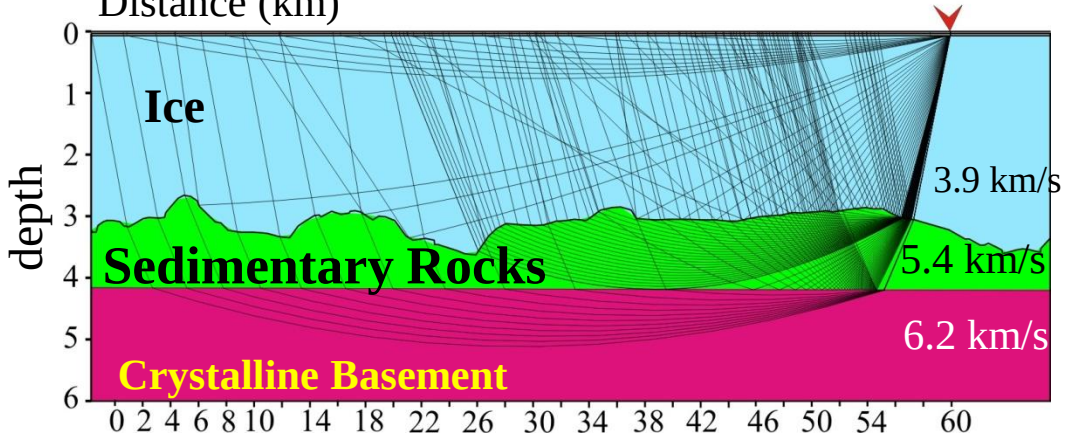
sediments



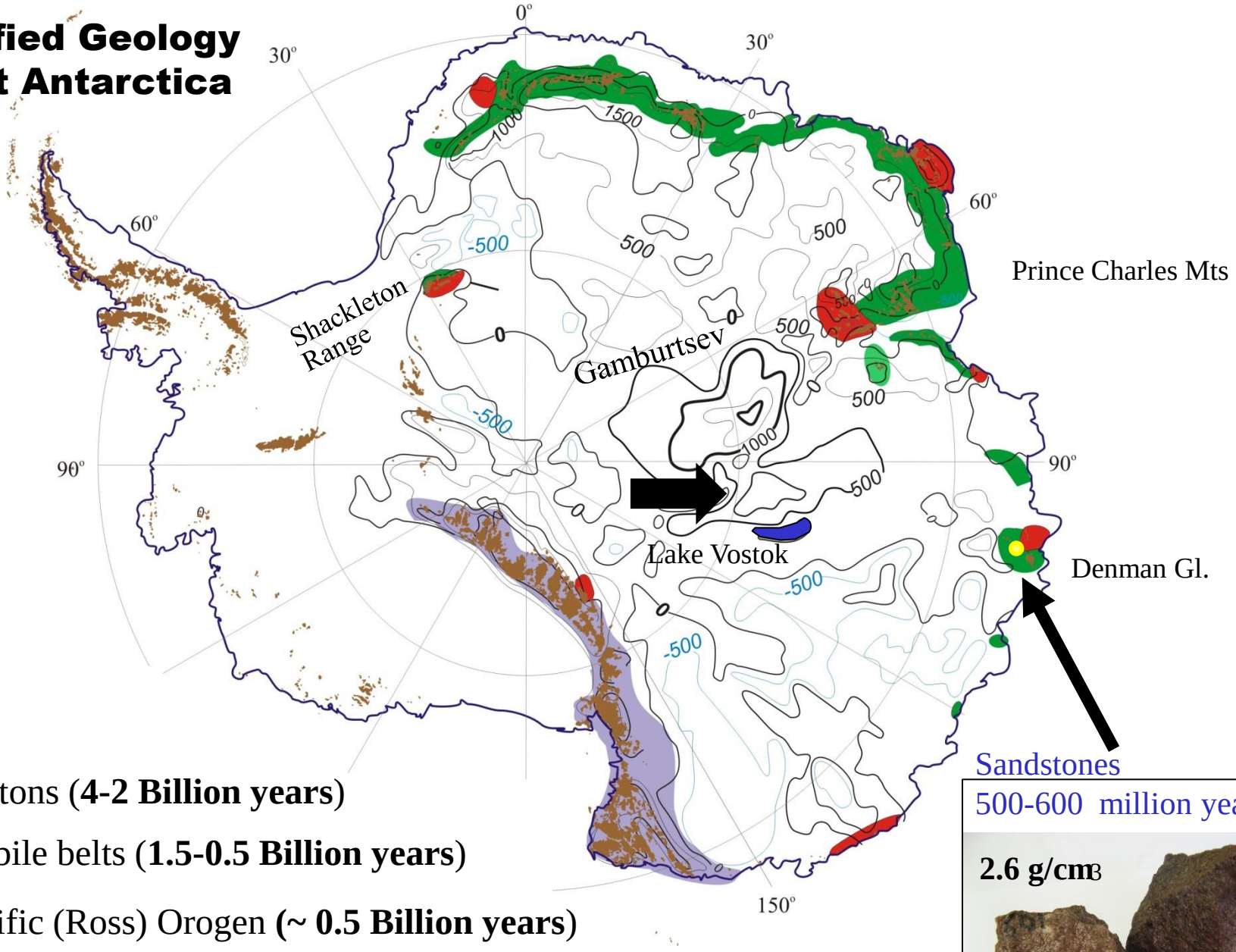




Distance (km)



Simplified Geology of East Antarctica



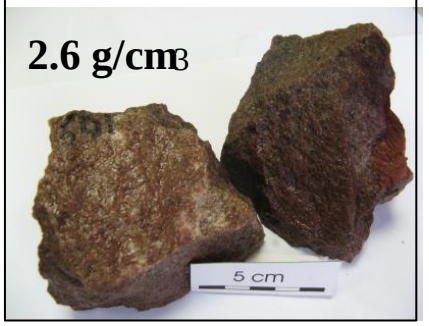
Cratons (**4-2 Billion years**)

Mobile belts (**1.5-0.5 Billion years**)

Pacific (Ross) Orogen **(~ 0.5 Billion years**)

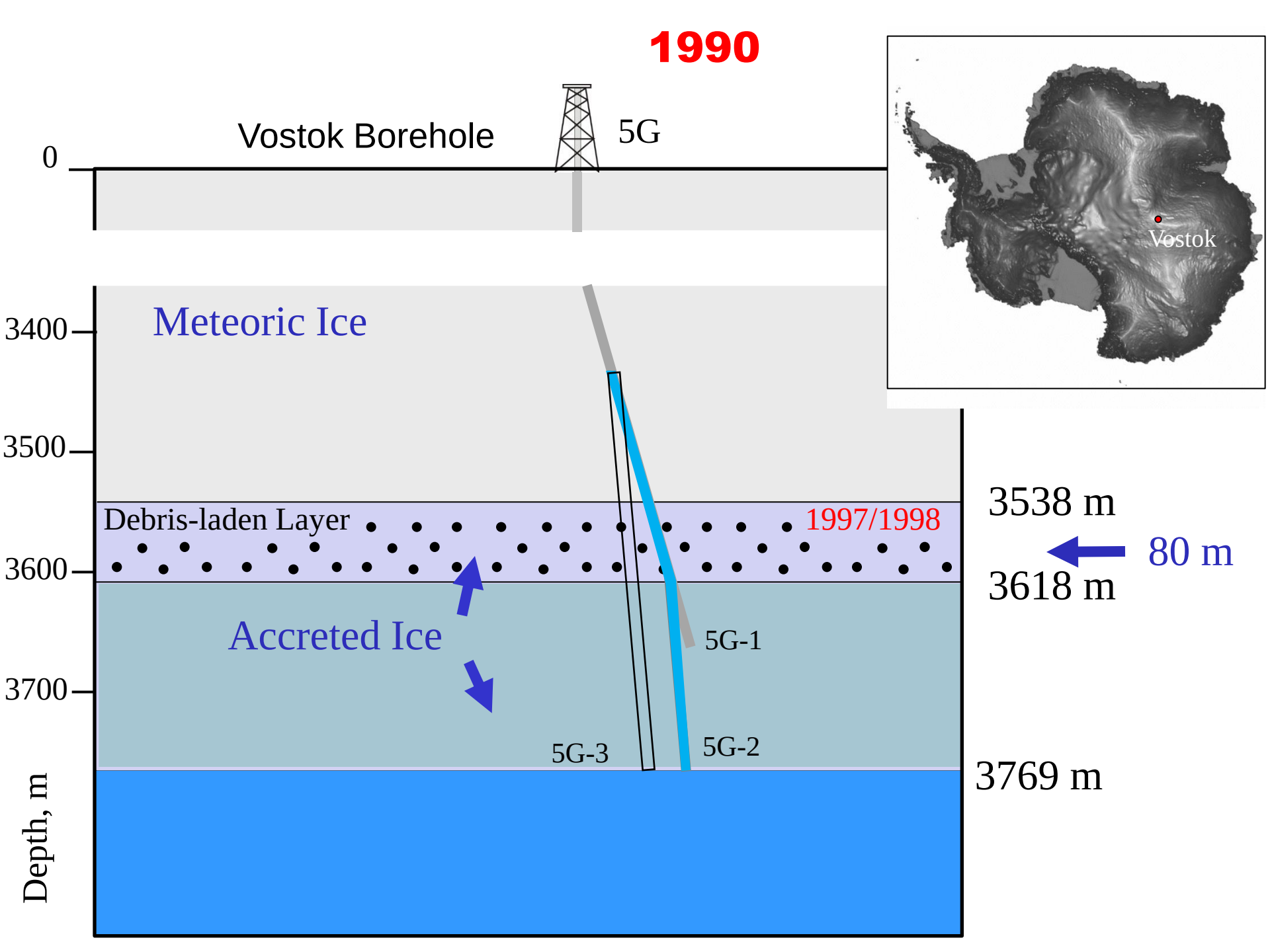
Sandstones

500-600 million years

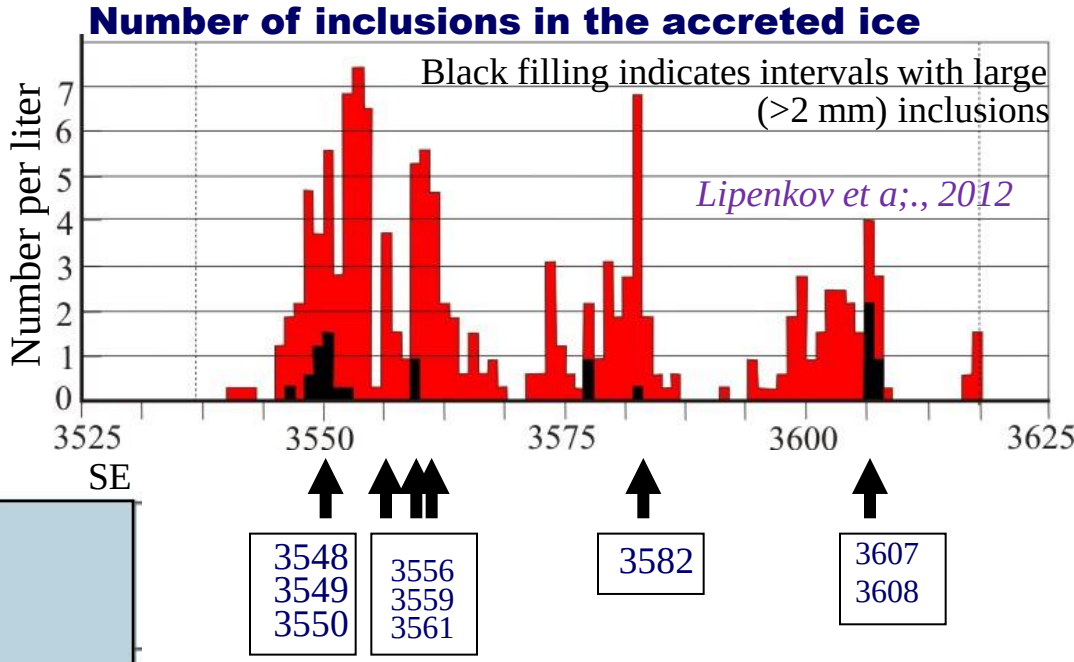


Density 2.6 g/cm → Velocity 5/4 km/s

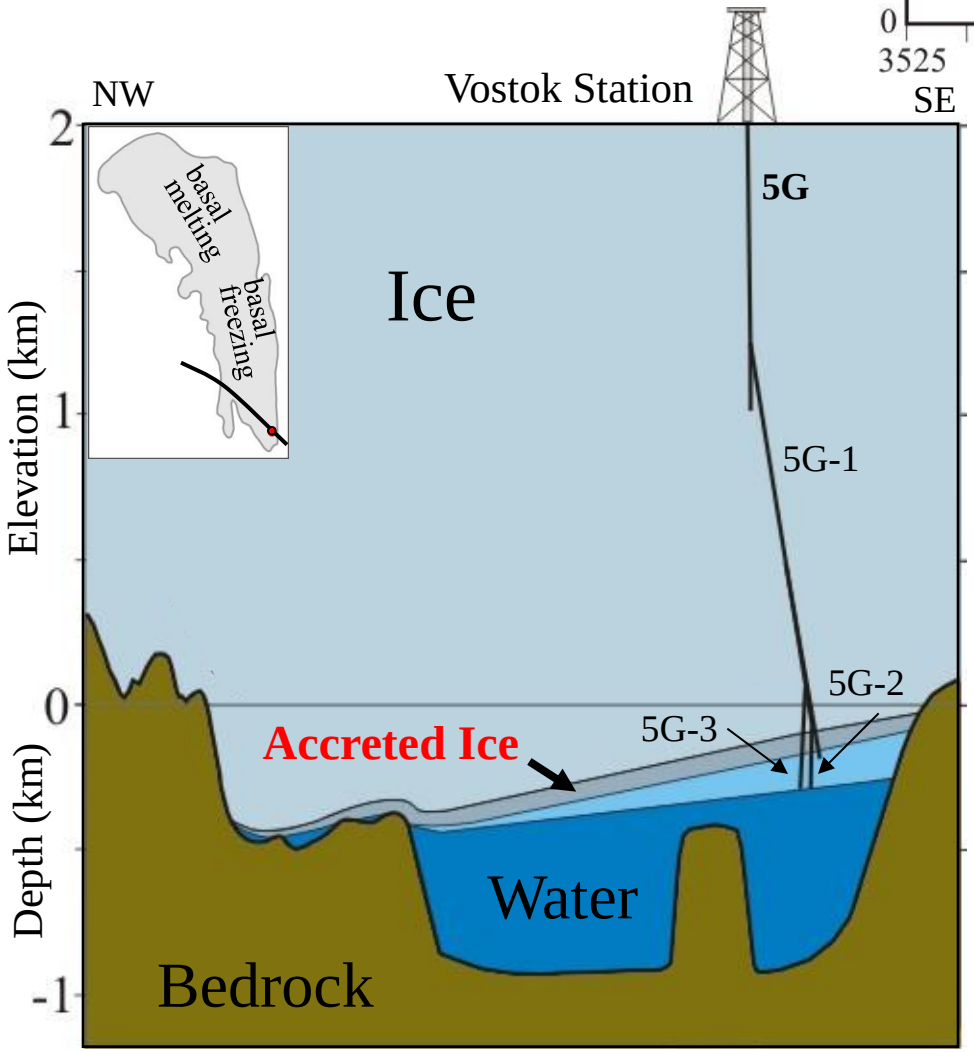
Study of Mineral Inclusions in Debris-laden Basal Ice

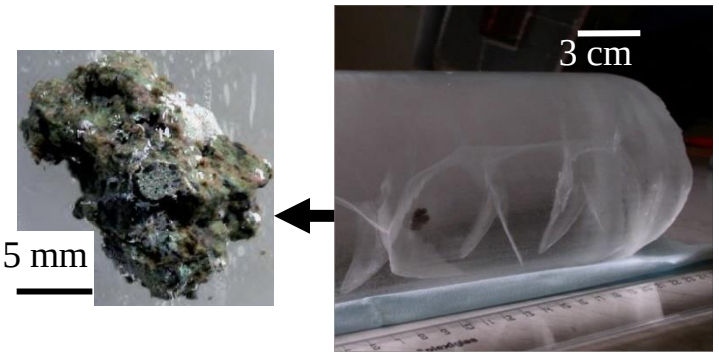

1990
Vostok Borehole
5G
0
Vostok
Meteoric Ice
3400
3500
Debris-laden Layer
1997/1998
3600
Accreted Ice
3700
5G-1
5G-3
5G-2
3538 m
80 m
3618 m
3769 m
Depth, m

Ice-Water-Bedrock section across Lake Vostok



Studied inclusions (core depths in meters)

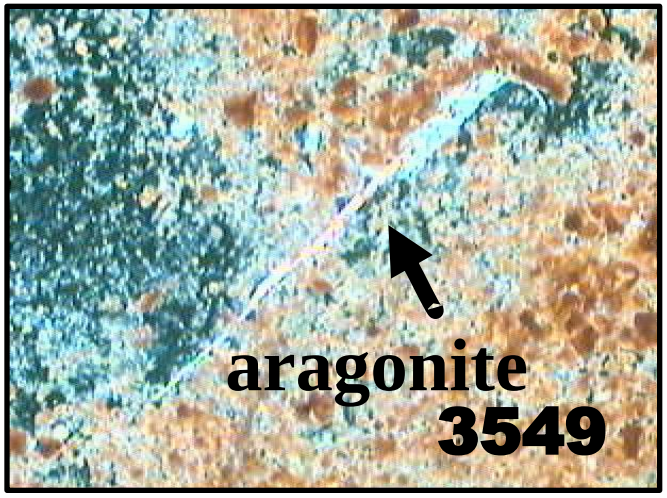




Inclusions are soft aggregates consisting mainly of clay-mica minerals and quartz clasts

Study of mineral inclusions

depth (m)	Size	Identified minerals
3549	1.2 mm	Clay-mica and accessory minerals including **Aragonite ($CaCO_3$)**
3550	>1.0 mm	Clay-mica and accessory (50-100 μm) minerals including **Pyrite (FeS_2)** and **Dolomite - $CaMg(CO_3)_2$**
3556	1.0 mm	Mostly mica minerals (group of biotite)
3561	1.0 mm	Mostly mica minerals (group of biotite) + chlorite & **Calcite ($CaCO_3$)**
3559	2-5 μn	**Sphalerites (ZnFeS), Molibdenite (MoS_2)**
3608	1.5-2.0 mm	40% – Clay-mica minerals; 20% – rock clasts (pelites, aleurolites) 35% – biotite; **Aragonite (3 crystals, 0.5-1.0 mm long)**

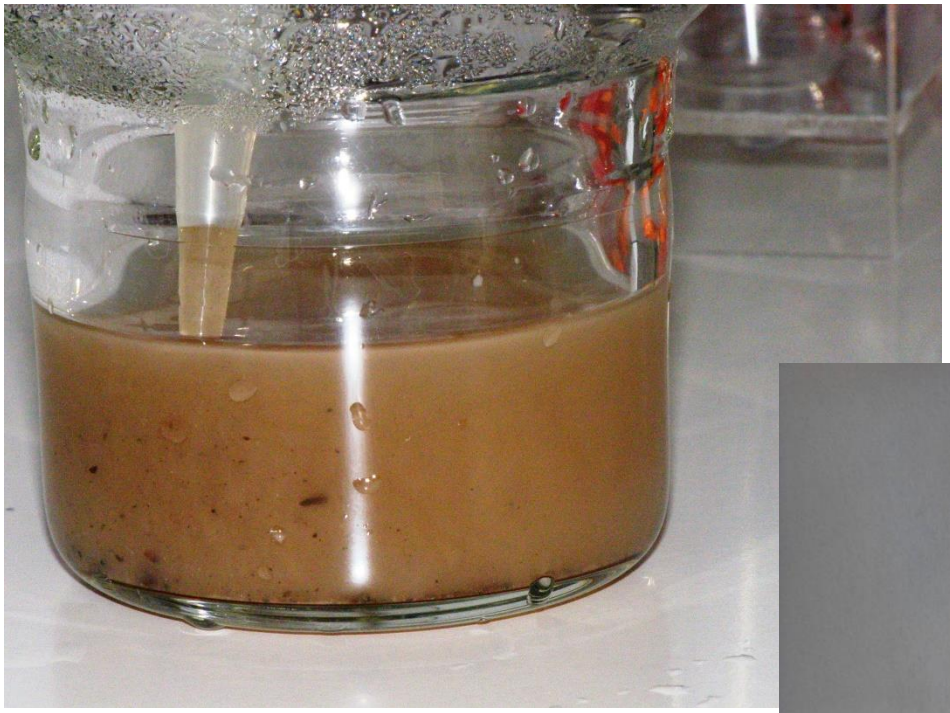


1 mm

0,3 mm

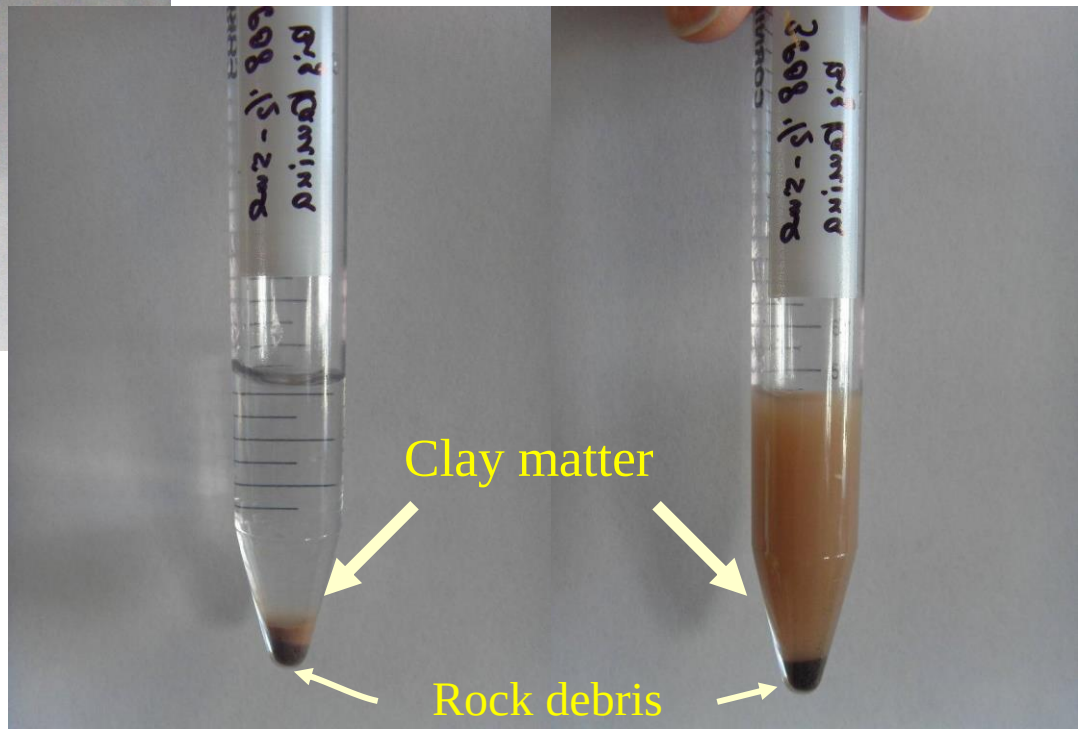
- Aragonite, calcite and sulfides found in sediment inclusions support idea about hydrothermal activity in Lake Vostok

The chemical precipitation of aragonite requires the parent water to be saturated in $CaCO_3$



3608 m

after shaking



Study of clay minerals

-
- *VNNIOkeanheologia*

Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, RAN

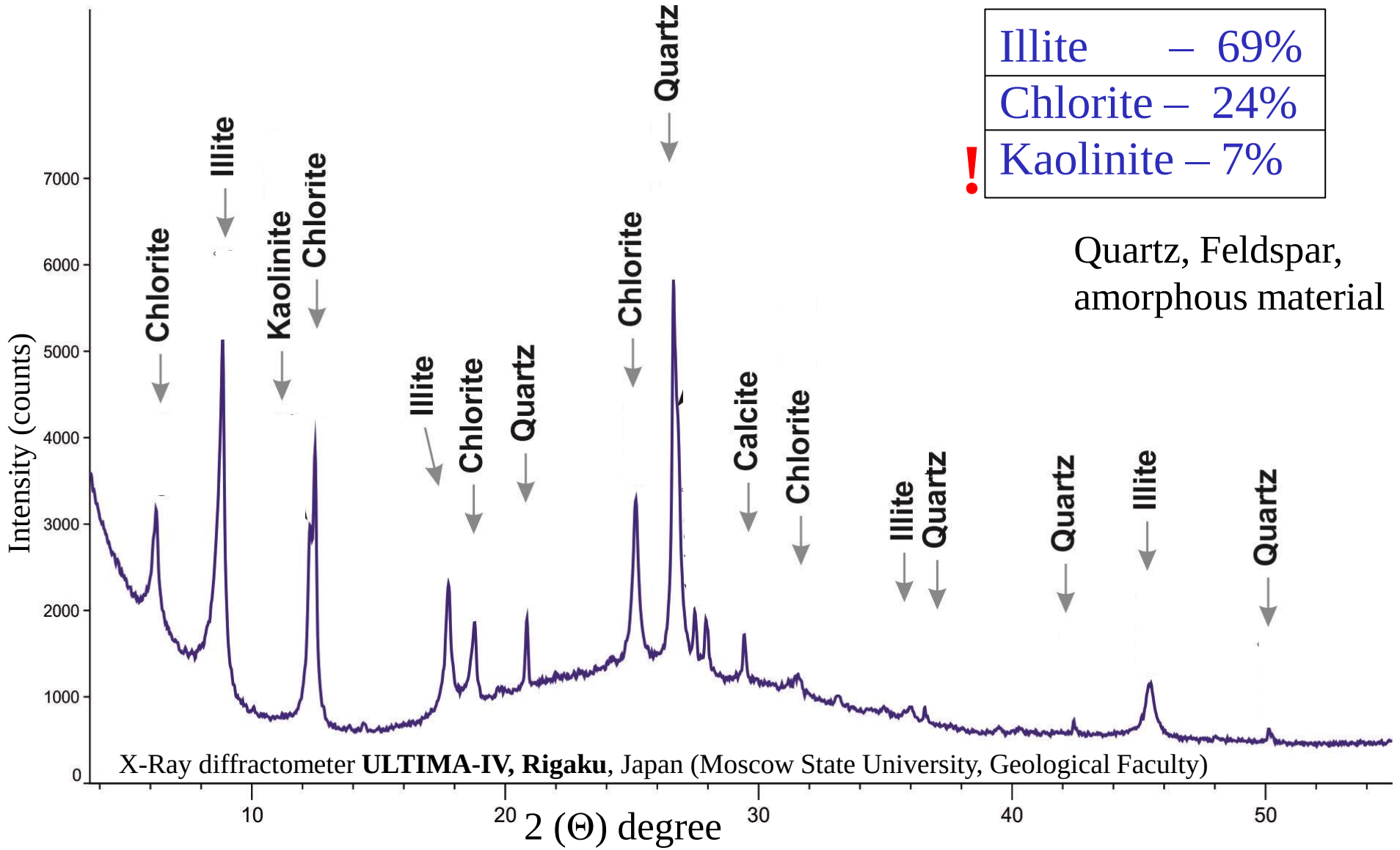
Mineral composition

X-Ray diffraction spectra (oriented samples)

Clay Minerals:

Illite	– 69%
Chlorite	– 24%
! Kaolinite	– 7%

Quartz, Feldspar, amorphous material



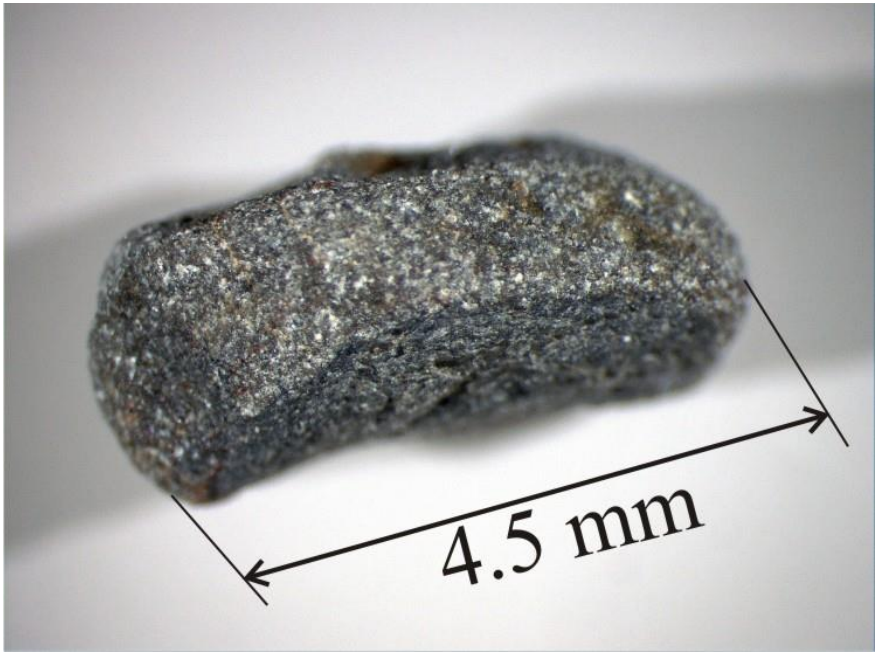
X-Ray diffractometer **ULTIMA-IV, Rigaku**, Japan (Moscow State University, Geological Faculty)

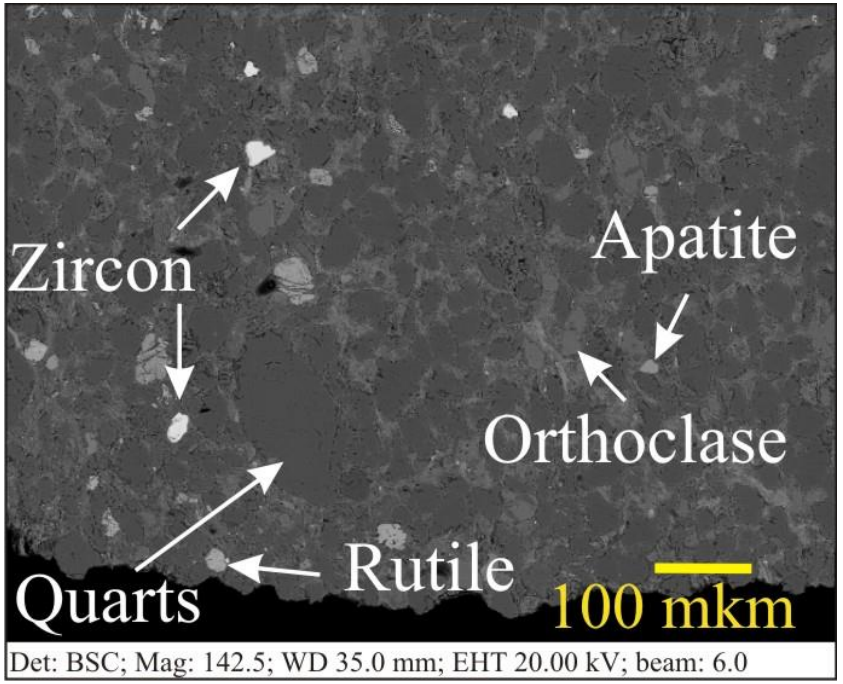
Rock Clasts

Rick clasts

5G1

3607 м

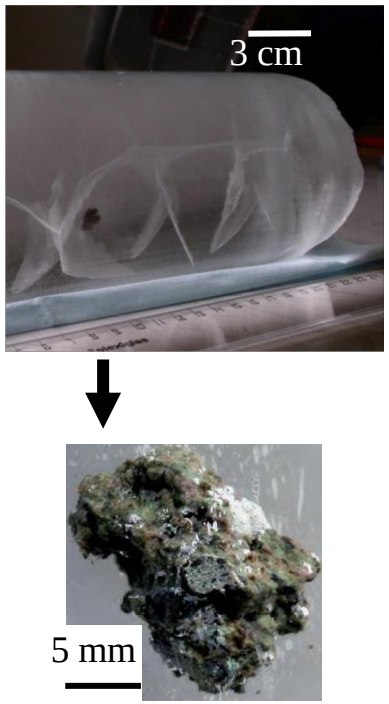


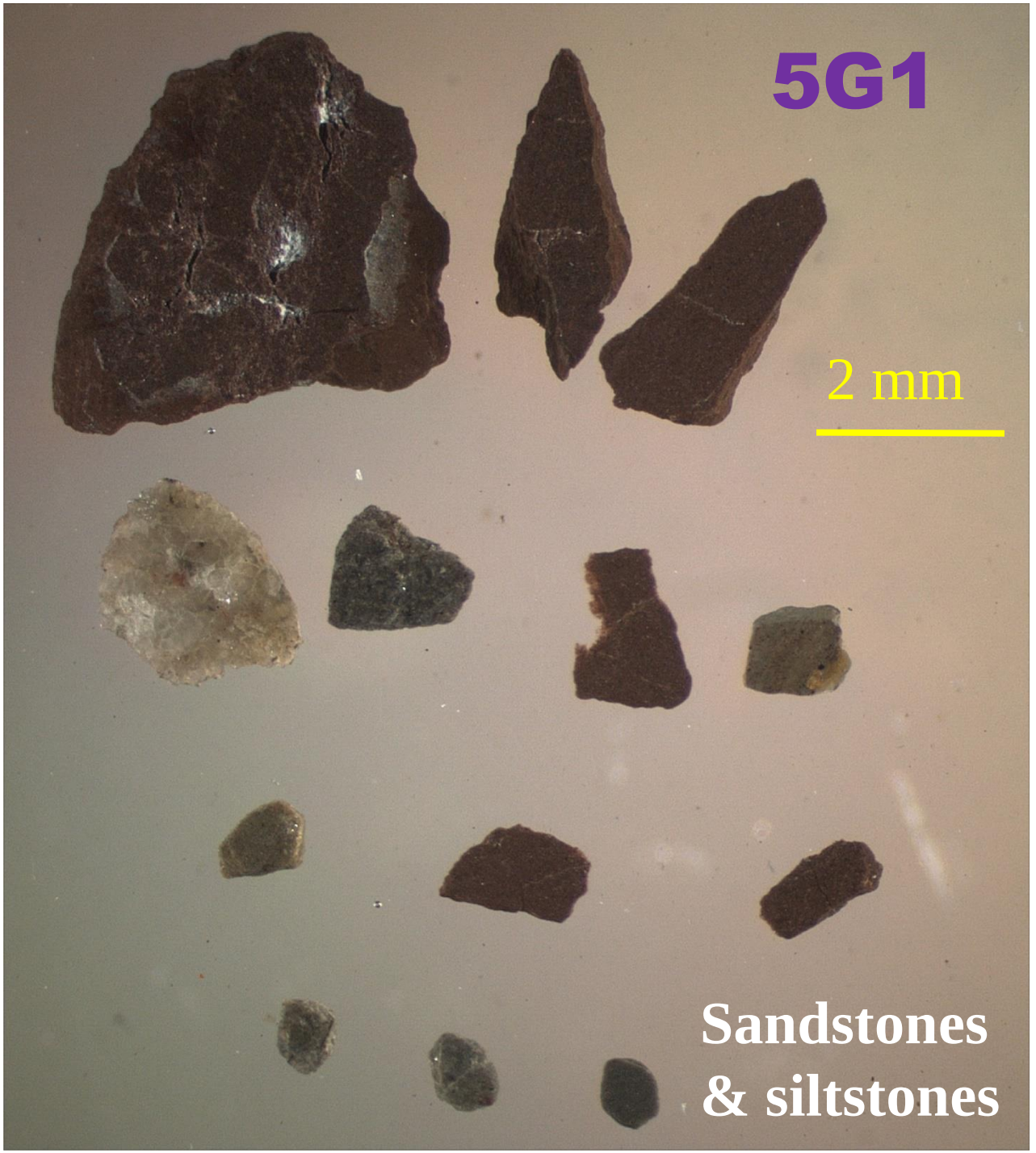


Scanning Electron Microscope (SEM) Image

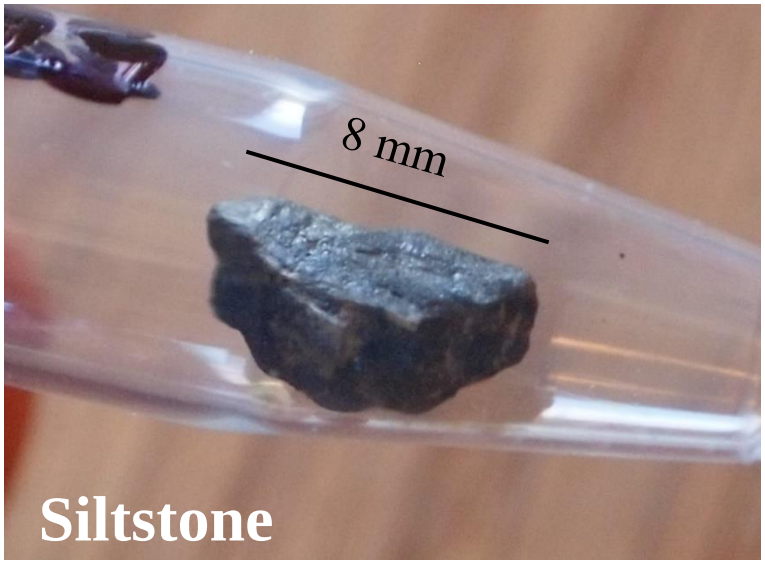
SANDSTONE

3608 м

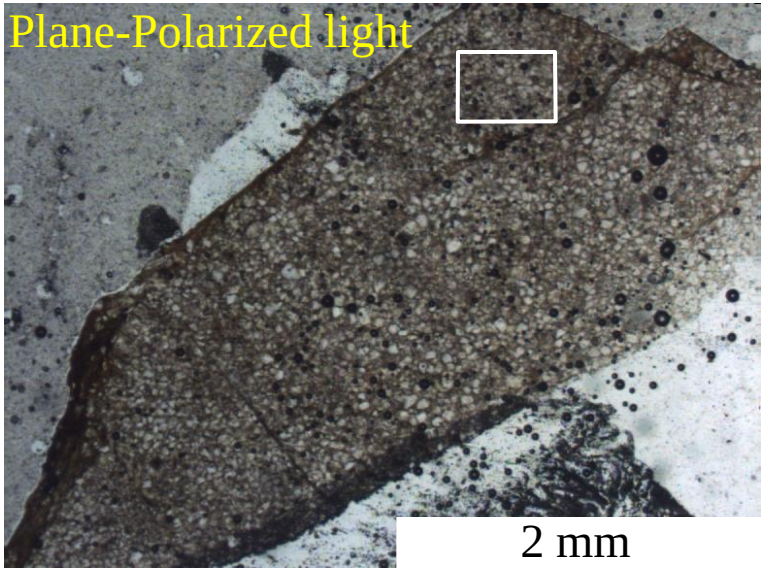


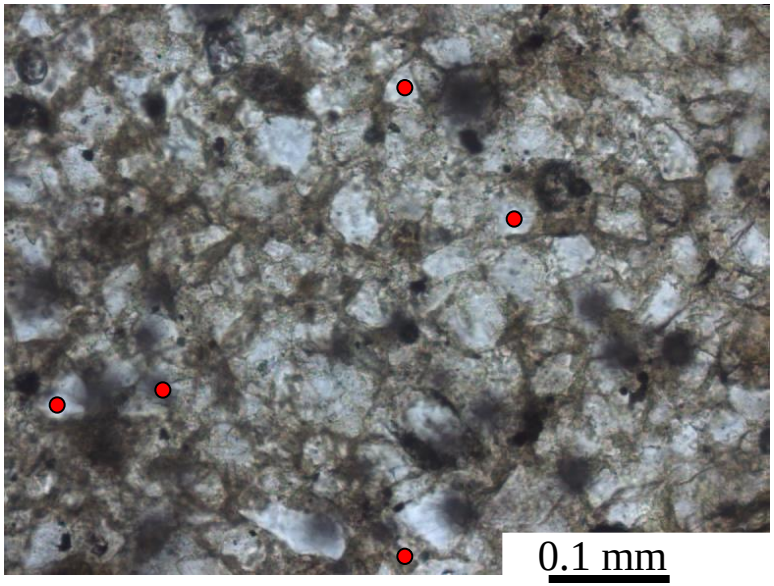


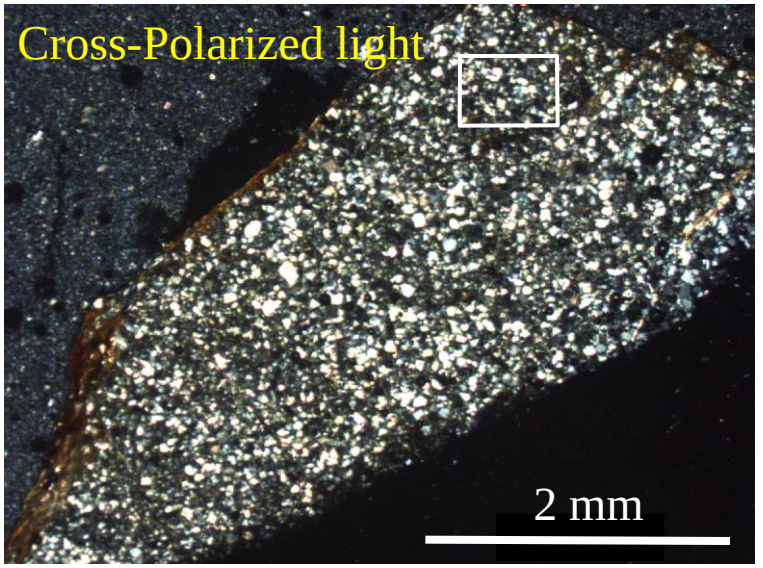
Biggest rock clast from 5G-3 (3608 m)



Thin Sections

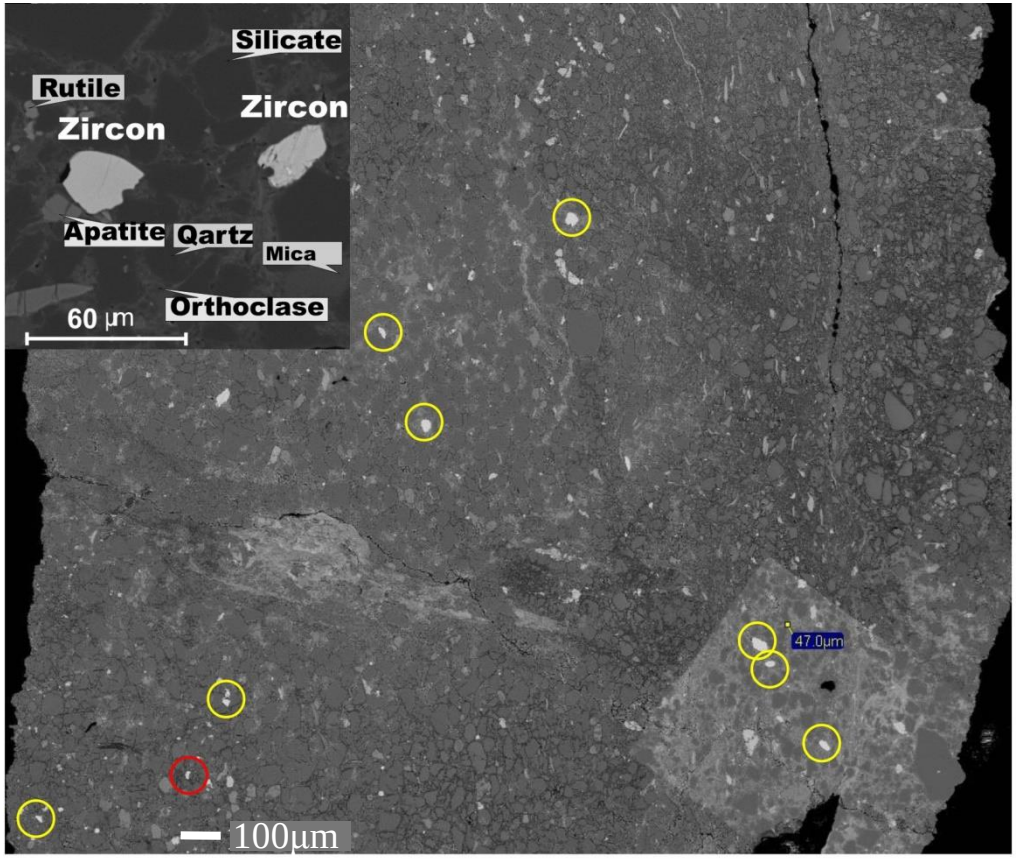


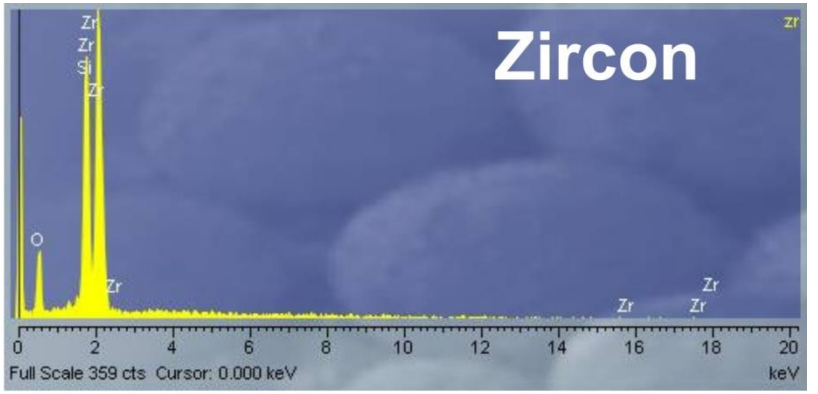


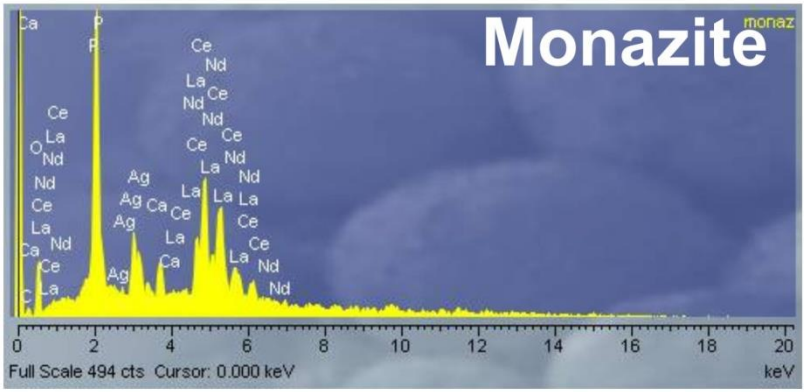


- Feldspars

Other detritus are predominantly quartz





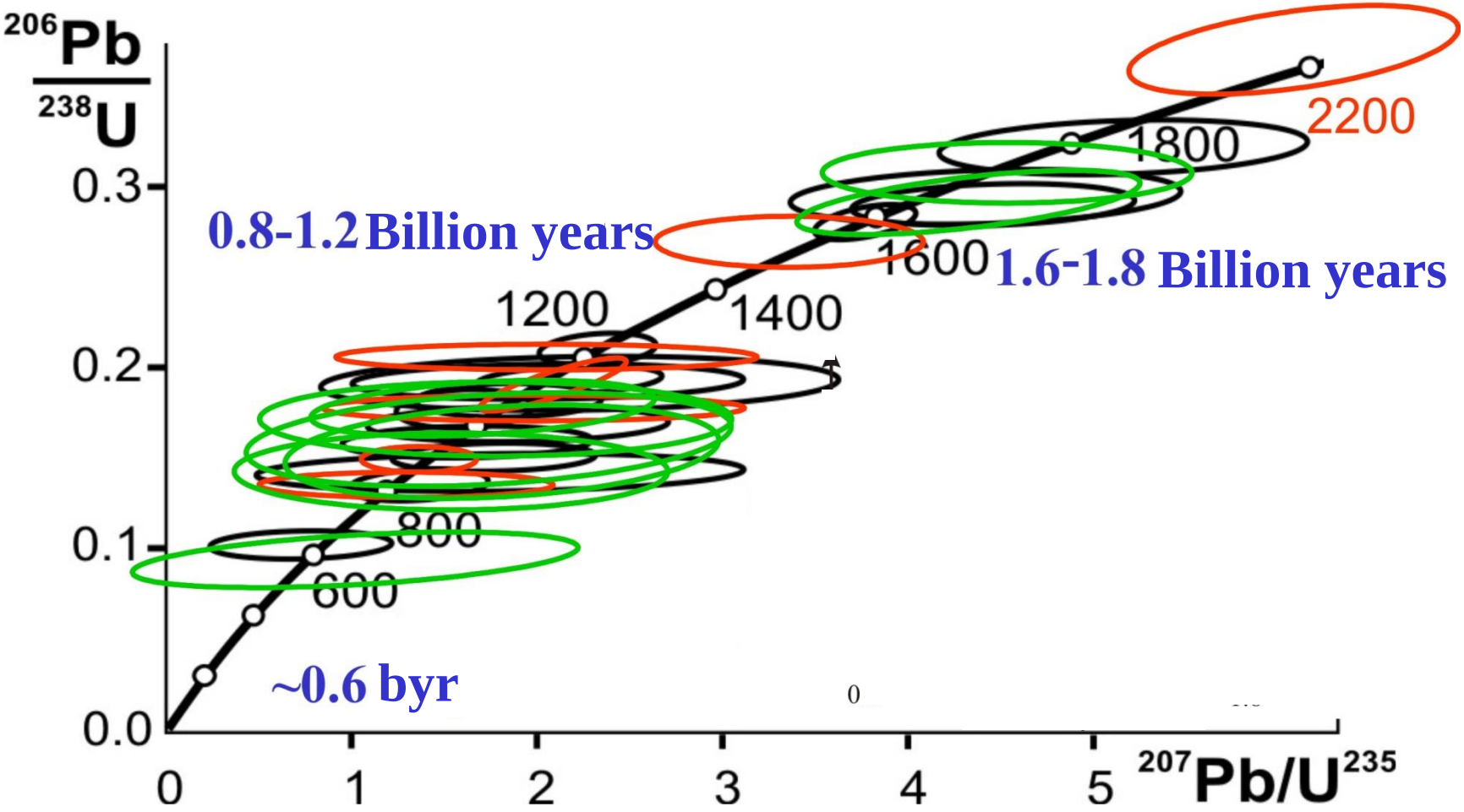


X-Ray detector

Zircons
Monozites

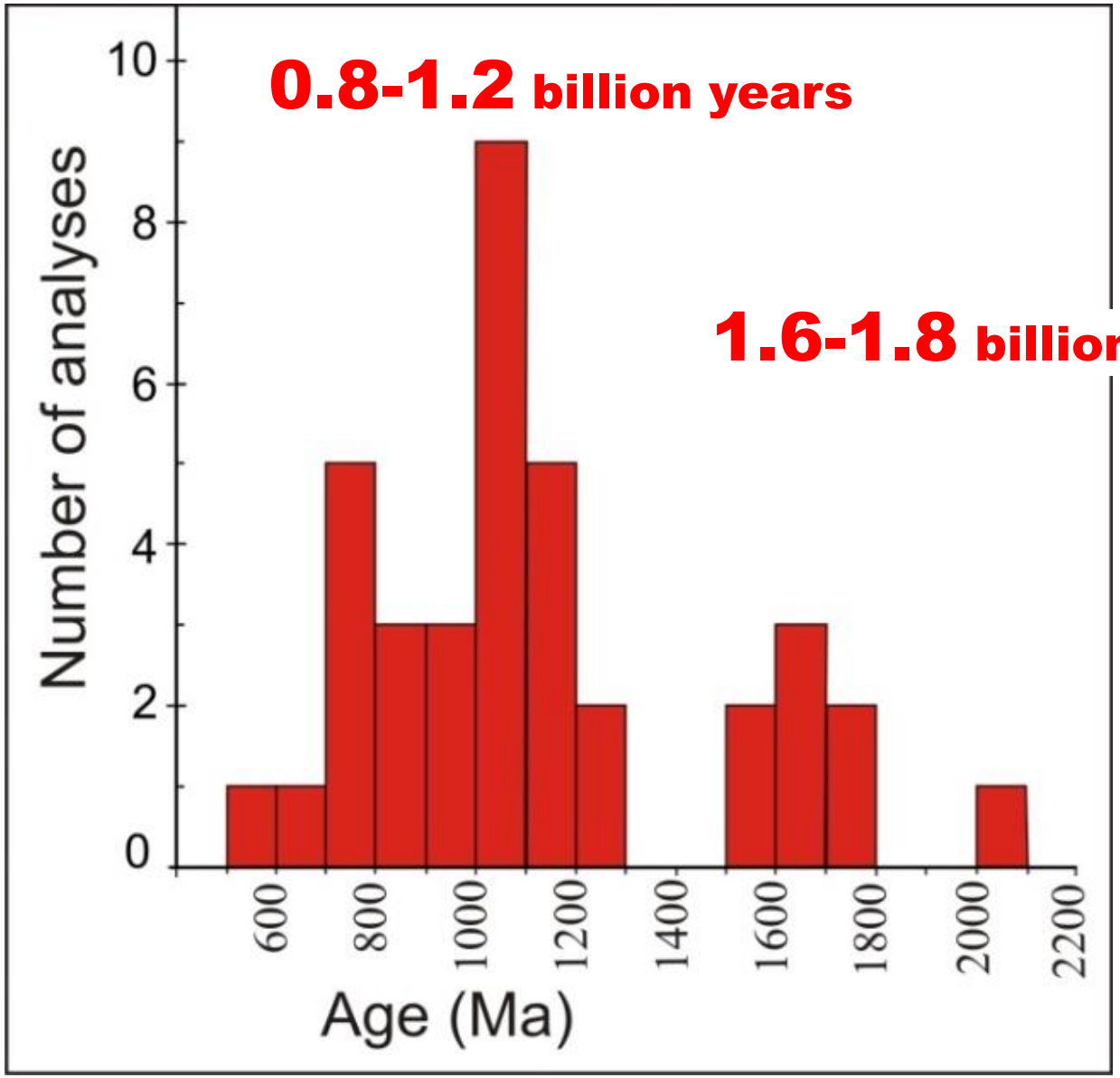
Totally, 31 Zircone and 5 monazite grains have been identified

Zircon/monozite ages



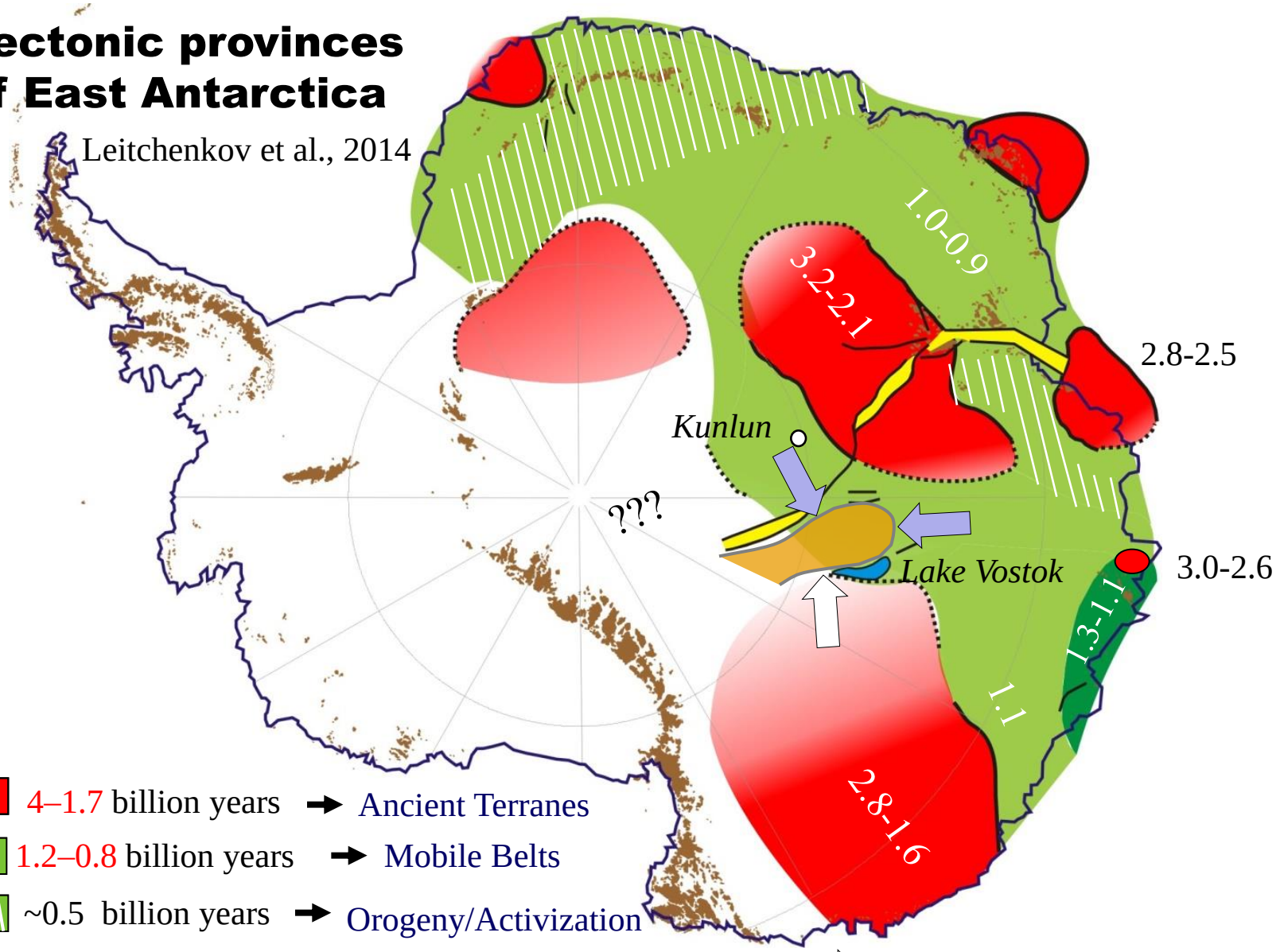
U-Pb concordia diagram for studied zircons

Zircon ages


0.8-1.2 billion years
1.6-1.8 billion years
Number of analyses
0
2
4
6
8
10
600
800
1000
1200
1400
1600
1800
2000
2200
Age (Ma)

Tectonic provinces of East Antarctica

Leitchenkov et al., 2014



4–1.7 billion years ➔ Ancient Terranes

1.2–0.8 billion years ➔ Mobile Belts

~0.5 billion years ➔ Orogeny/Activization

210-130 million years ➔ Rifts

Late Neoproterozoic Basin (< 600 Ma)

Arrival of 1.8-1.6 billion years zircons

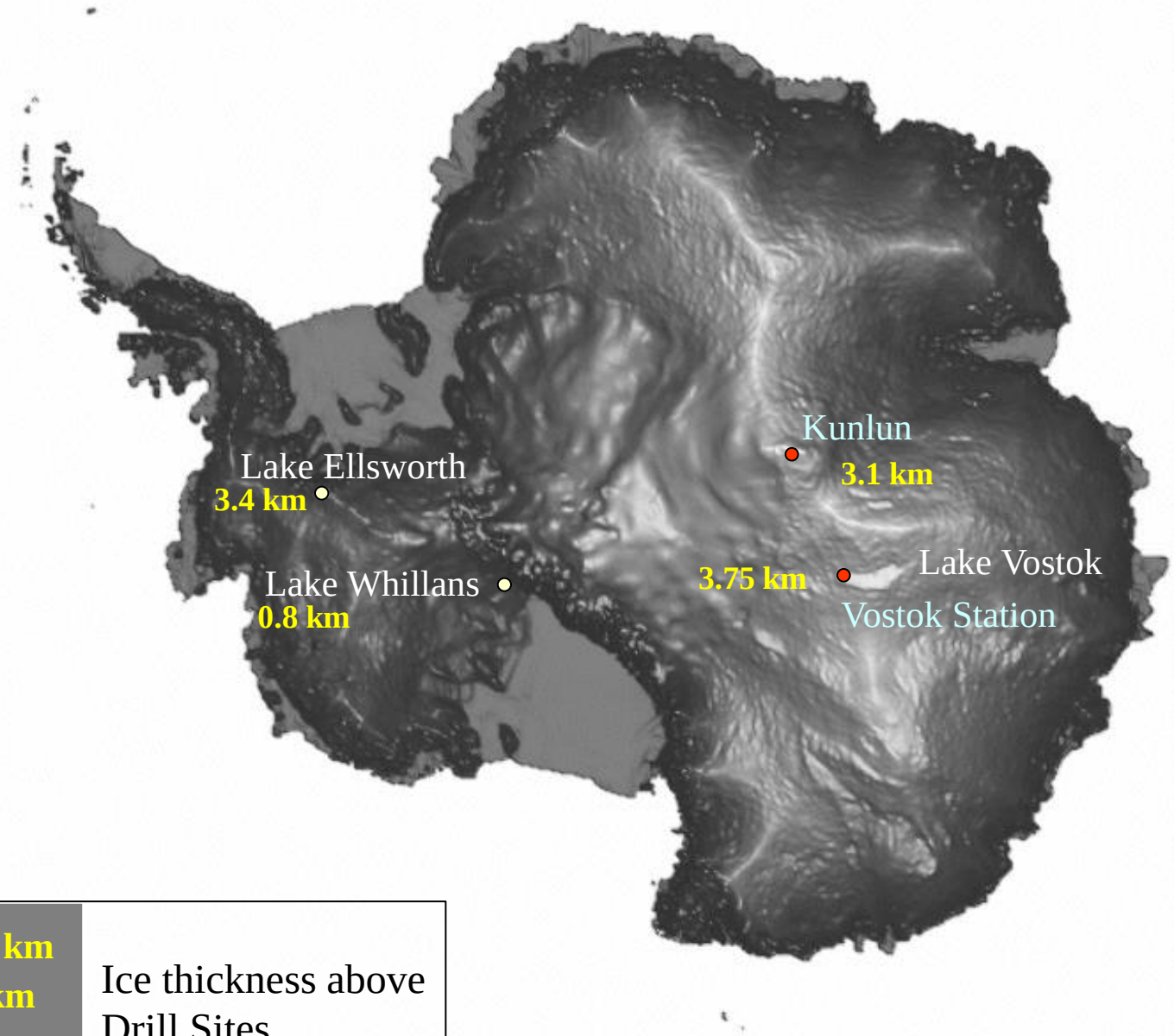
Arrival of 1.2-0.8 billion years zircons

Geology of Lake Vostok

Subbottom sediments &

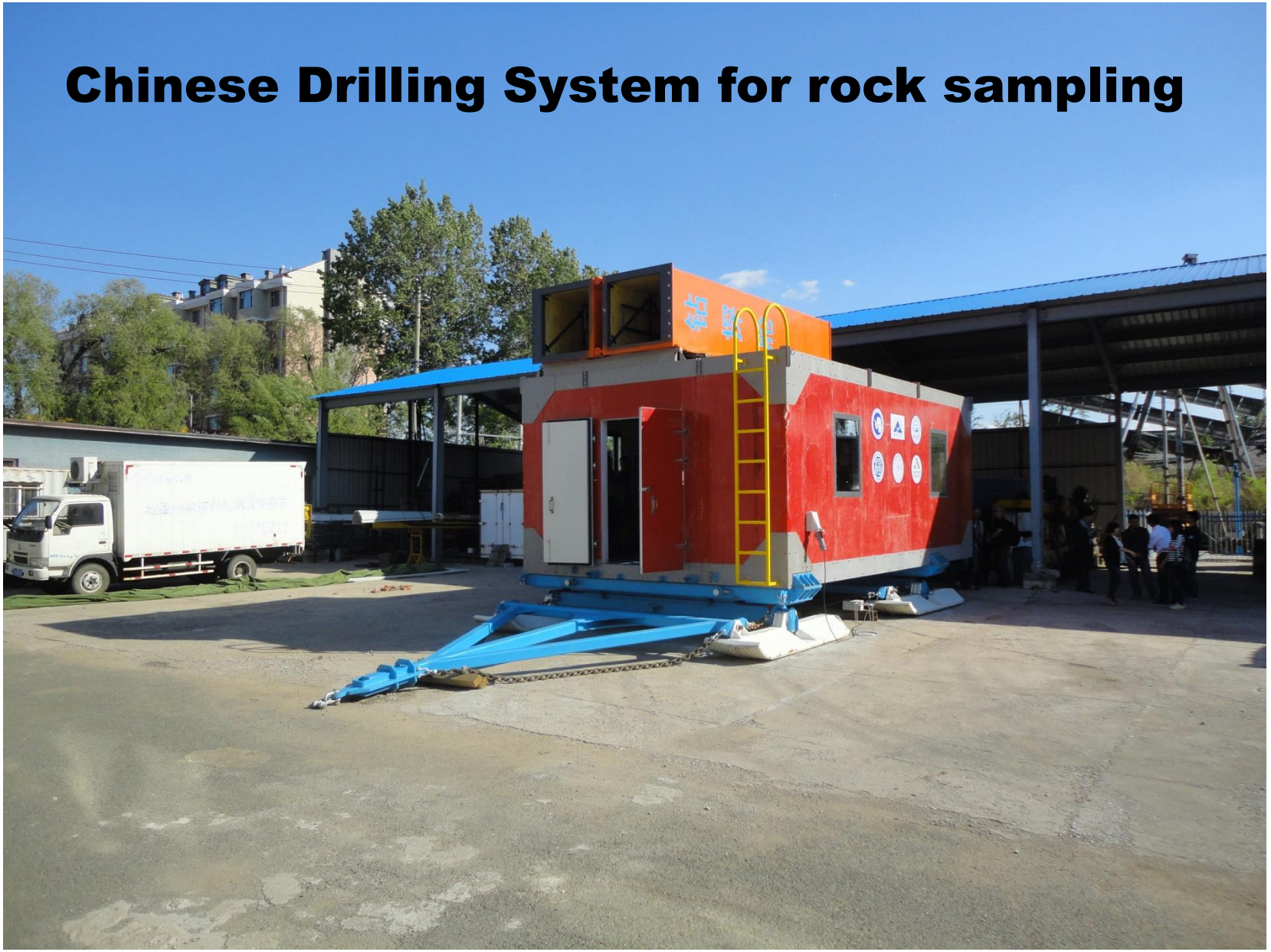
Challenge for Drilling

Current and proposed Over-ice drill sites with rock sampling



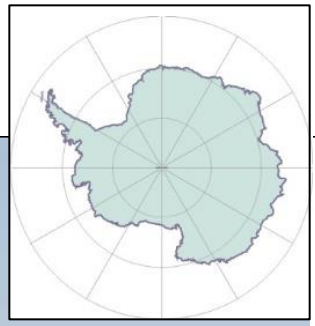
3.75 km 3.4 km 0.8 km	Ice thickness above Drill Sites

Chinese Drilling System for rock sampling



New US Project for drilling on Antarctic continent

(Fast Drilling trough ice with bedrock sampling)

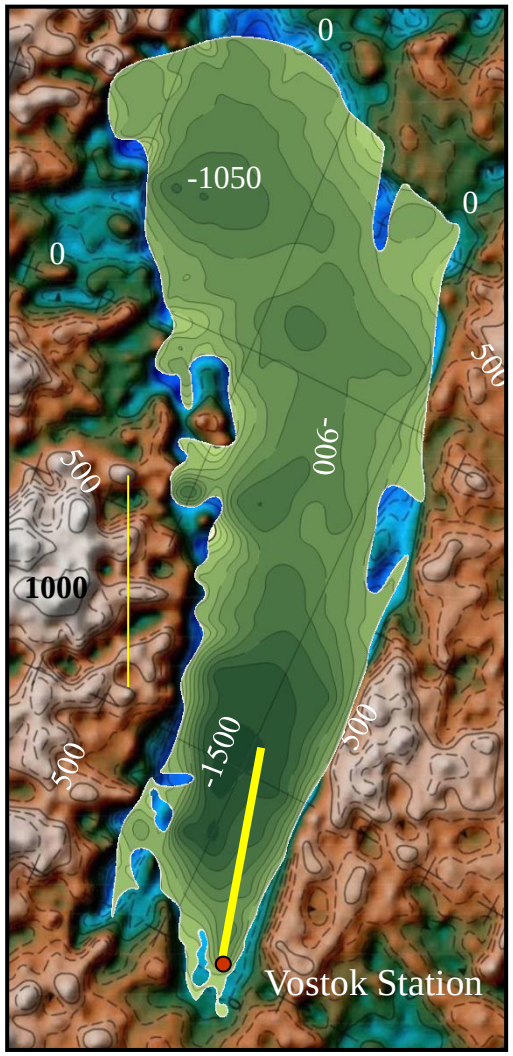


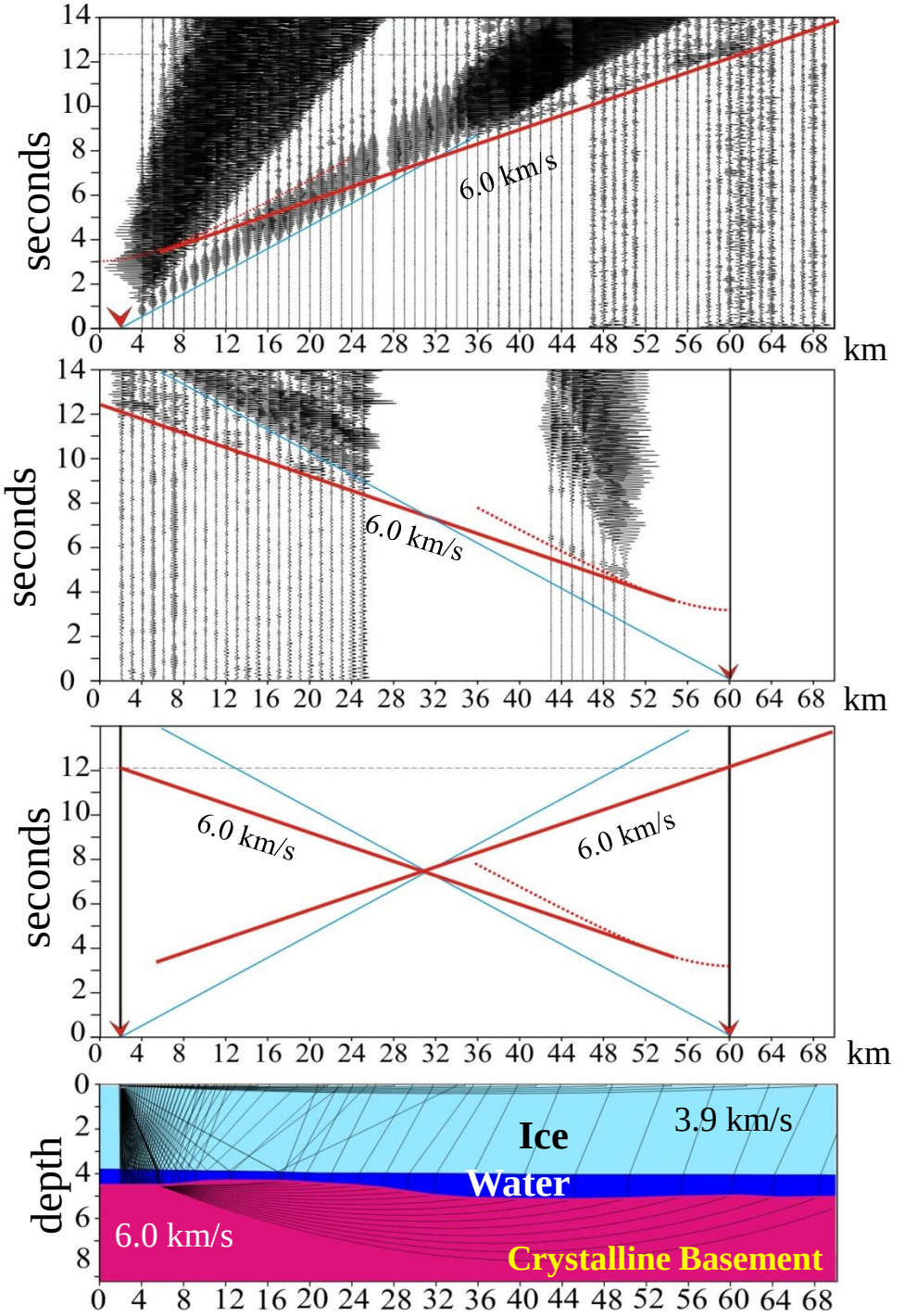
RAID – Rapid Access Ice Core

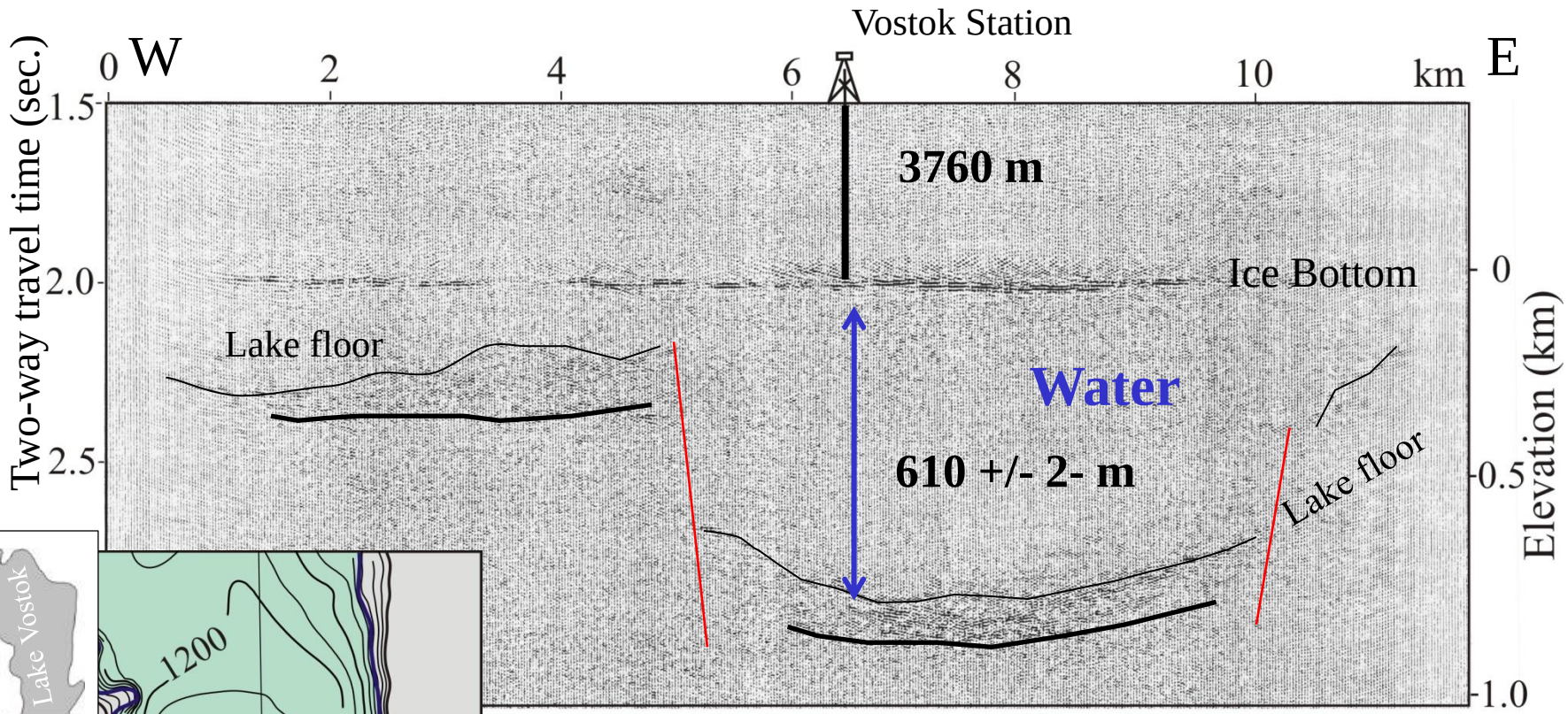
RAID is designed to penetrate up to 3,3 km of ice **1 week**

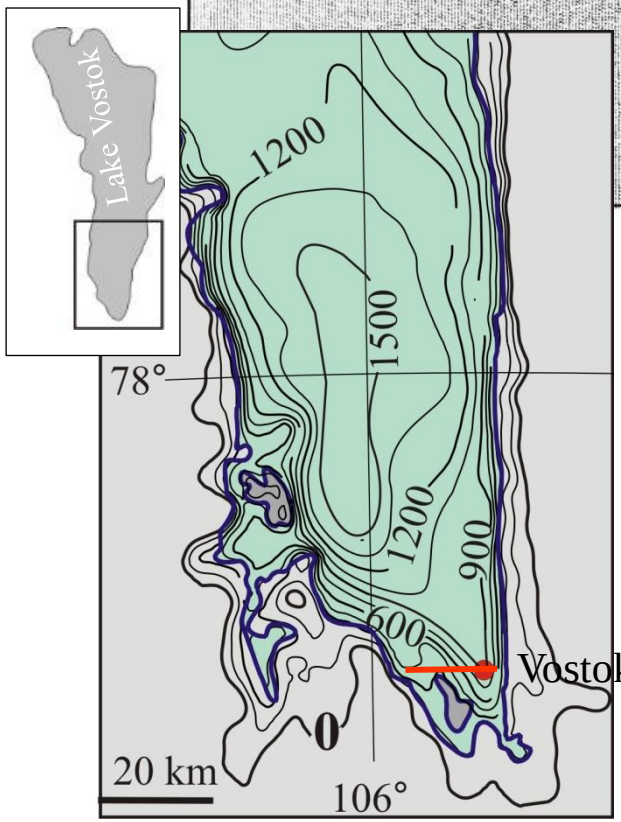
Seismic Studies of the Lake Bottom

Seismic refraction Experiment





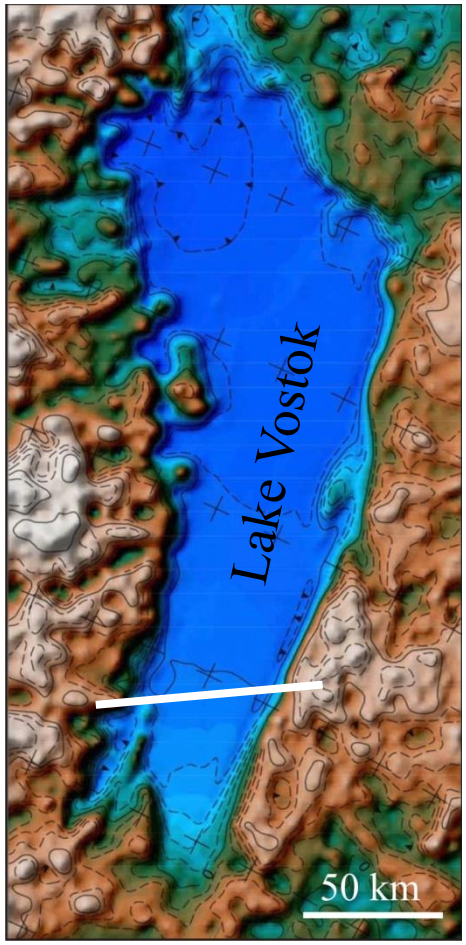




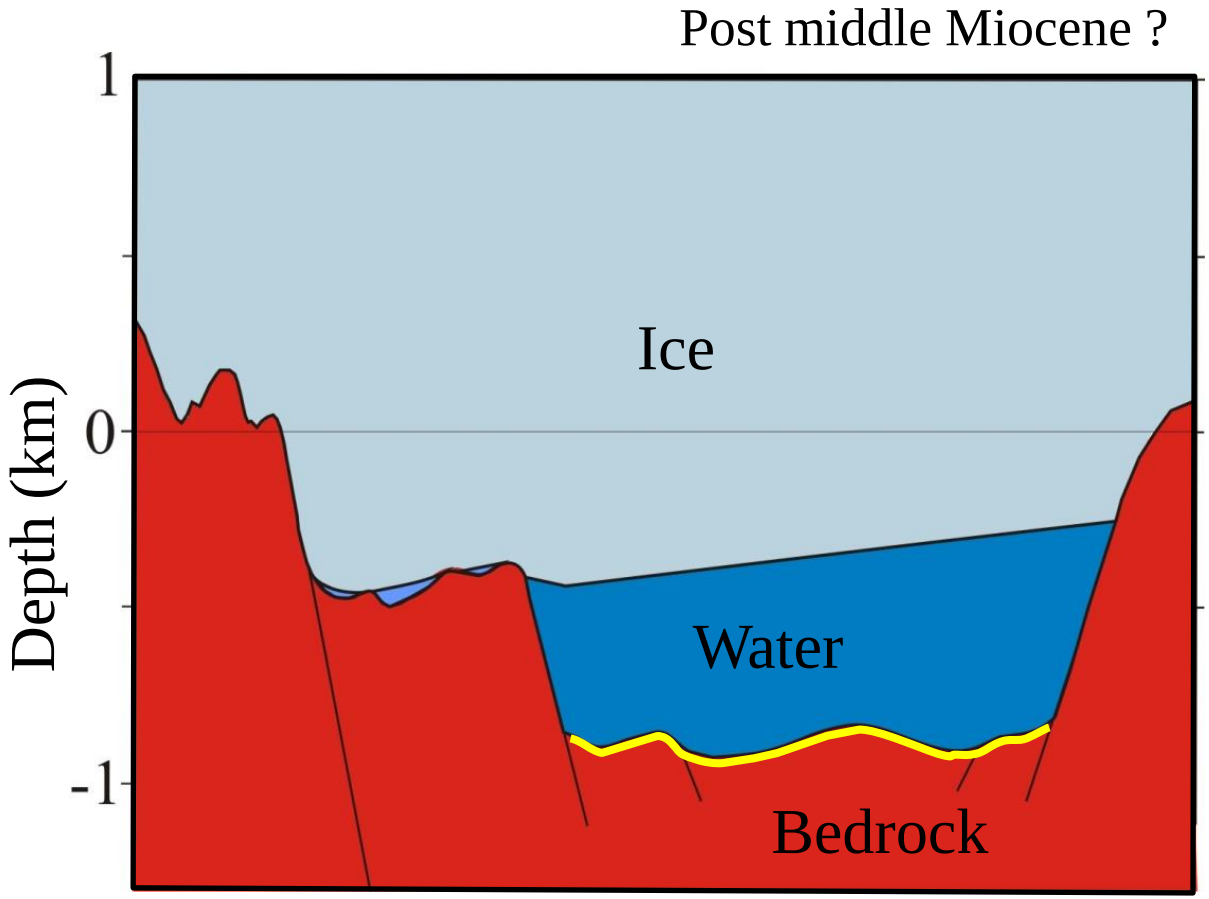
Seismic section across southern Lake Vostok

Sediments: 200-300 m

Thin sedimentary infill in Lake Vostok suggests the low rate of deposition and relatively young age of sediments and lake depression



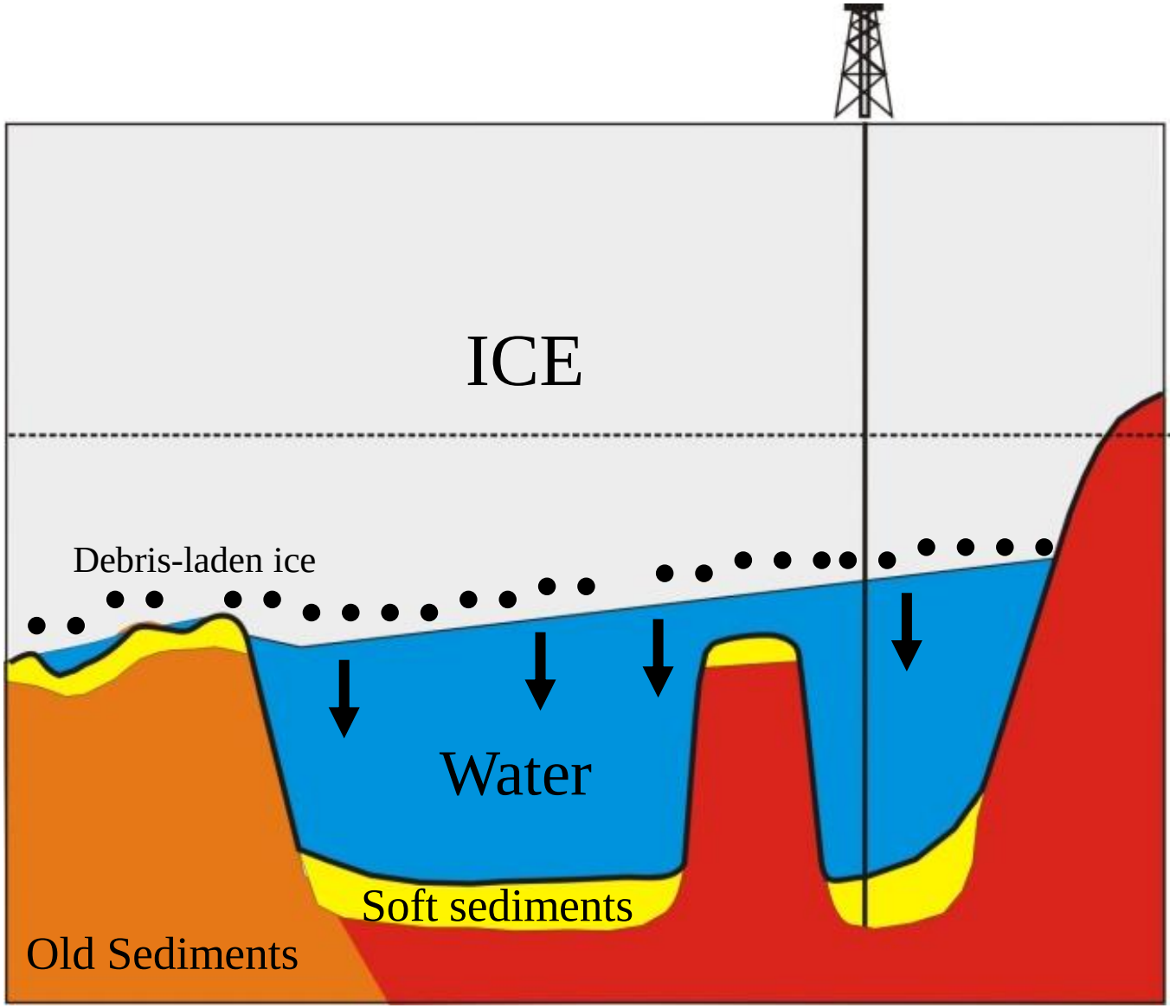
Studinger et al., 2002



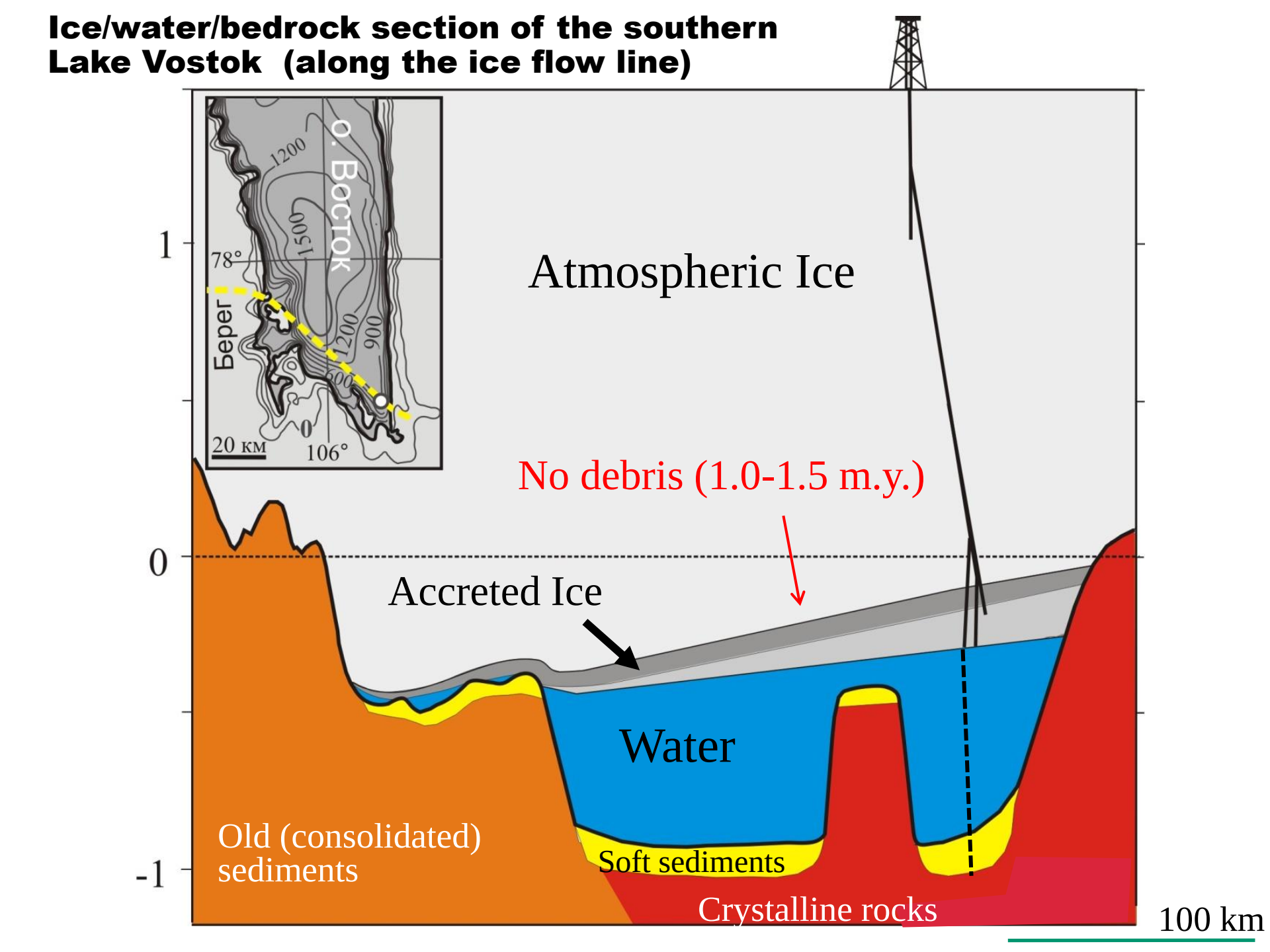
What geodynamic processes have led to formation of the deep Lake Depression ?

Age and composition of Lake Vostok Sediments

Glacial sedimentation



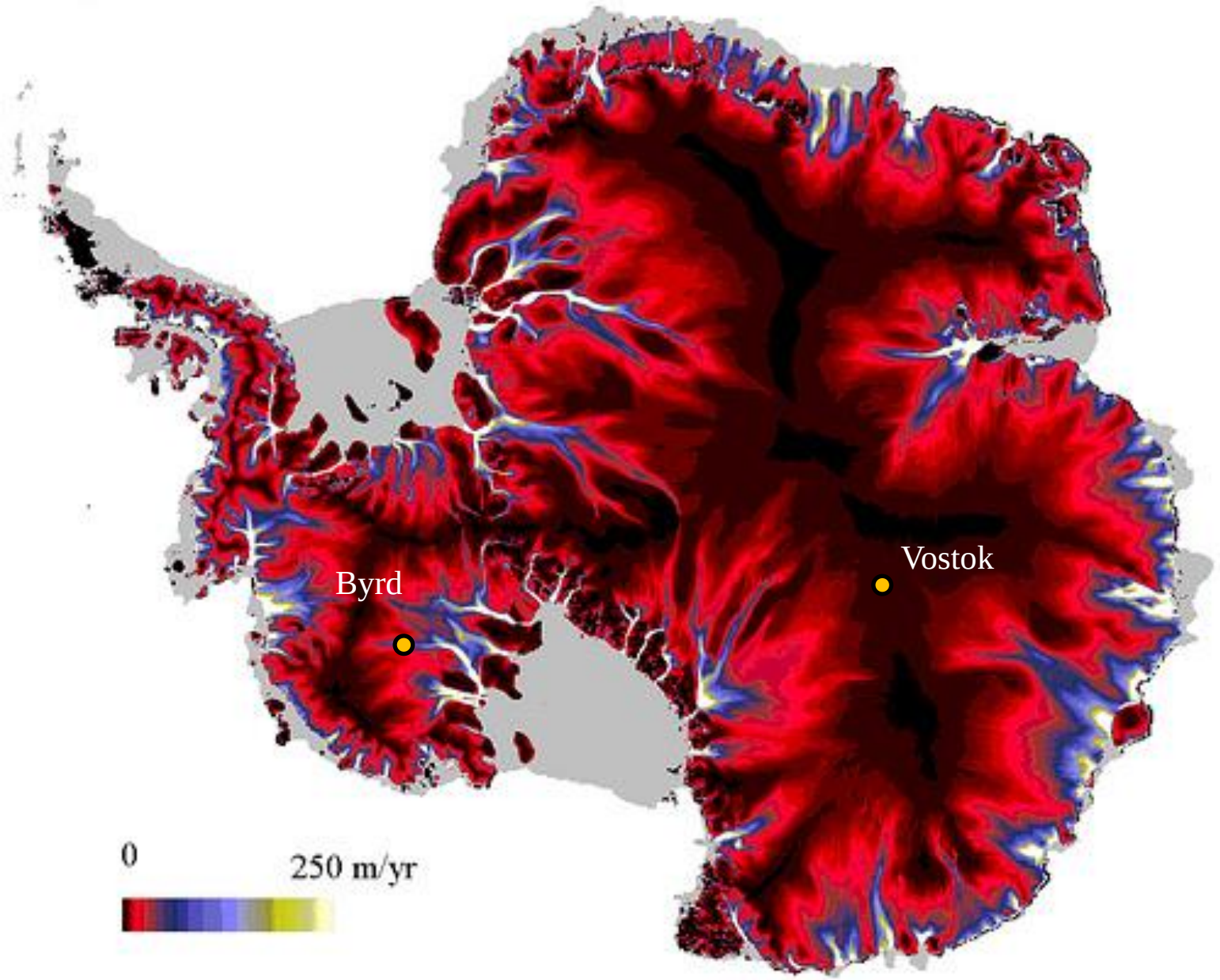
Ice/water/bedrock section of the southern Lake Vostok (along the ice flow line)



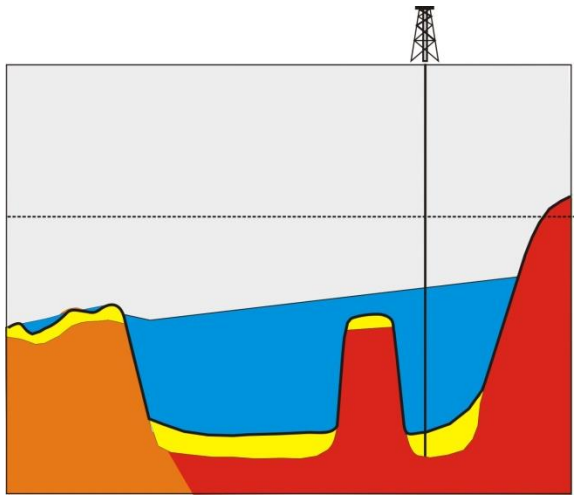
Basal Ice at the Byrd Station

Gow and Meese, 1996

Ice flow velocities



Predictable Geological Section



Million years

Modern clay/silt

0m

3m

млн. лет

3,3-3,0
6,4-5,9
10,5-8,5
17-15
22-18
24-23
32-30
42-34 ?

диамиктиты

100 м

диамиктиты

200 м

hiatus

перерывы в накоплении осадков

Million years

0
10
20
30
40
50
60
65

Плейстоцен - квартер
Плиоцен
Миоцен
Олигоцен
Эоцен
Палеоцен
Мел

Start of glaciation

0° 2° 4° t°

Earth's mean Temperature

Warming periods

New Challenge

Bottom sediments contains exceptionally unique information about Environmental changes and geology of Central Antarctica as well as about extreme life, so the sampling of these sediments is **the extremely important task of the Future!!!**

SCIENTIFIC ISSUES

CORE (1-3 m long):

- Record of EAIS evolution (last 14-12 m.y.)
  - Transition from temperate to full ice sheet conditions (~14 Ma)
  - Oscillations of EAIS
- Lake environments
  - Variations in lake environments
    (lake survival, water temperatures, pH, Redox)
- Geology
  - Sediment flux, Provenance (sources of minerals)
  - Crustal conditions (tectonic activity, hydrothermal activity)
- Biology
  - Fossil microorganisms

MAJOR CONCLUSIONS

1. Vostok Subglacial Highlands (VSH) are underlain by 500-600 m.y. old sediments

2. The Antarctic Earth's Crust surrounding LV and VSH is mostly composed of **Ancient (1.6-1.8 & 0.8-1.2 billion years) Terranes**

3. Lake Vostok (LV) is a deep depression filled with thin depositional unit.

The Lake Vostok Depression was formed during the time of Antarctic Glaciation **(it is not older than 34 million years).**


3608 m
Lake Vostok sediments
1 mm
Thank you !!!