Drilling the Ice from the Past to the Future

★ Vostok

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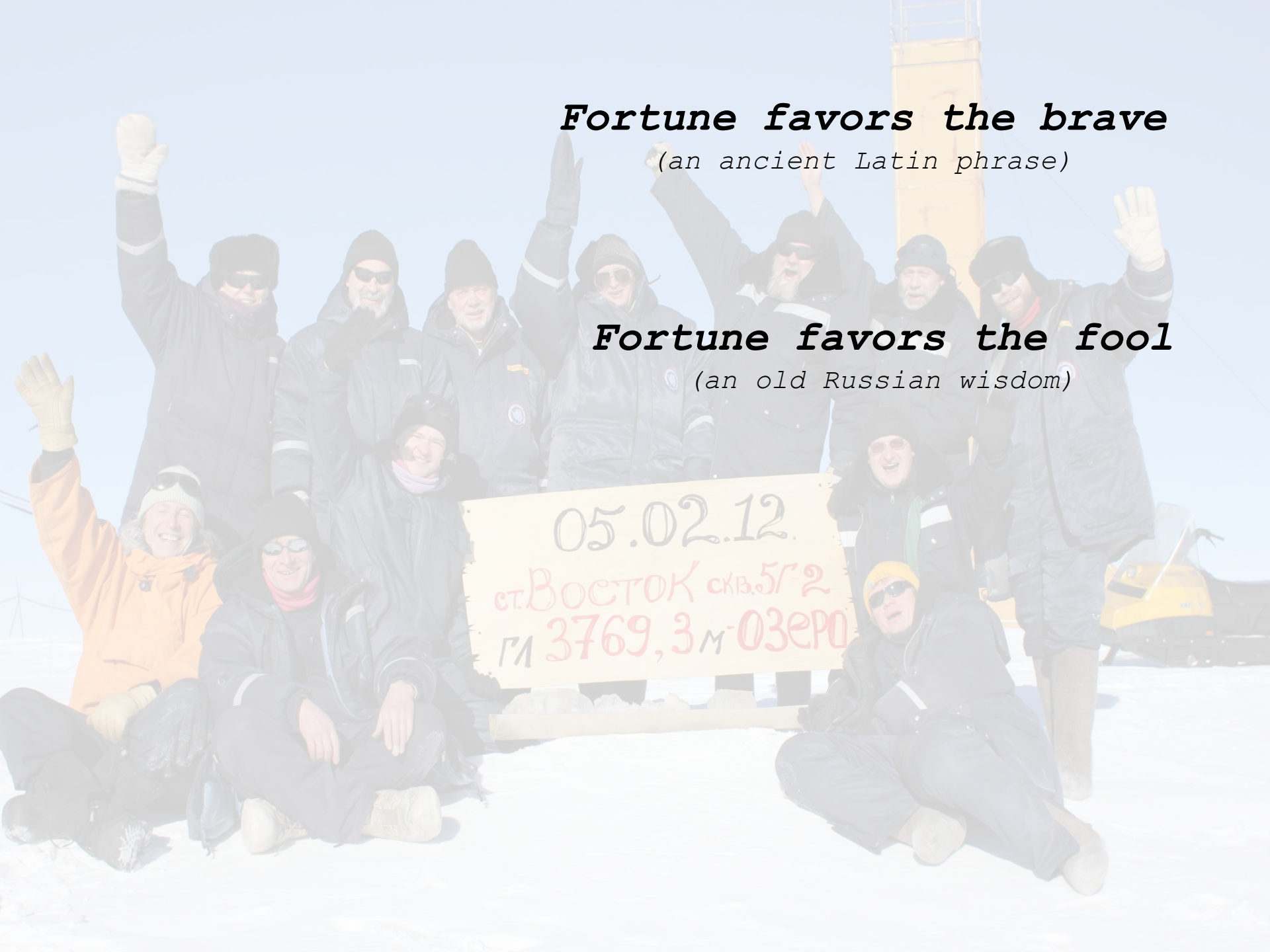


Fortune favors the brave

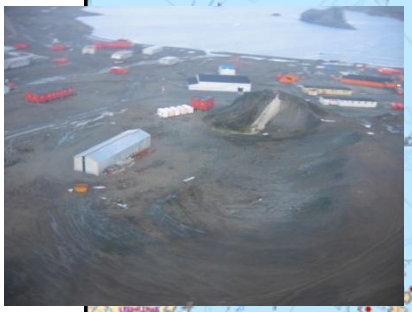
(an ancient Latin phrase)

Fortune favors the fool

(an old Russian wisdom)

Fortune favors the brave

(an ancient Latin phrase)



SOUTH GEORGIA
CROZET ISLAND
SOUTHERN OCEAN
WEDDELL SEA
BELLINGSHAUSEN SEA
AMUNDSEN SEA
DUMONT D'URVILLE SEA
BALLENY ISLANDS
MACQUARIE ISLAND
ENDERBY LAND
KEMP LAND
MAC.ROBERTSON LAND
AMERY ICE SHELF
PRINCESS ELIZABETH LAND
WILHELM II LAND
QUEEN MARY LAND
WILKES LAND
TERRE ADÉLIE
GEORGE V LAND
COATS LAND
MARIE BYRD LAND
ELLSWORTH LAND
PALMER LAND
RONNE ICE SHELF
ORCADAS
SIGNY
PALMER
VERNADSKY
SAN MARTIN
ROTHERA
BELGRANO II
HALLEY
WASA
KONNEN
NOVOLAZAREVSKAYA
SYOWA
DOME FUJI
AMUNDSEN-SCOTT
VOSTOK
CONCORDIA
DUMONT D'URVILLE
DAVIS
MIRNY
CASEY
MAWSON
DRUZHNAYA 4
KING GEORGE ISLAND
INSET
Kilometres
COMANDANTE FERRAZ
VICENTE
MACCHU PICCHU
ARCTOWSKI
ALBANY
KING SEJONG
ARTIGAS
BELLINGSHAUSEN
FREI
GREAT WALL
ESCUDERO
BRANSFIELD STRAIT
INSET
Kilometres
ESPERANZA
O'HIGGINS
MARAMBIO
ARTURO PRAT
MALDONADO
OHRIDSKI
JUAN CARLOS PRIMERO
GABRIEL DE CASTILLA
SOUTH SHETLAND ISLANDS

Vostok

Vostok Station

Altitude: 3490 m a.s.l.

Mean annual temperature: -55.5°C

(coldest place on Earth)

Precipitation rate: 23 mm

(60 times less than in Ljubljana)

Operating as wintering-over station since 16 December 1957

Scientific activity

Meteorological observations

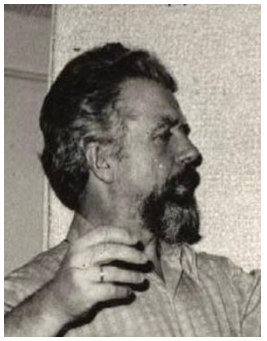
Observations of magnetosphere

Ground glaciological observations

Deep ice coring

Lake Vostok studies

1970: beginning of the deep drilling (nothing to do with the Lake yet)



ГЛАВНОЕ УПРАВЛЕНИЕ ГИДРОМЕТЕОРОЛОГИЧЕСКОЙ СЛУЖБЫ ПРИ СОВЕТЕ МИНИСТРОВ СССР

ОРДЕНА ЛЕНИНА АРКТИЧЕСКИЙ И АНТАРКТИЧЕСКИЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ

ИНФОРМАЦИОННЫЙ БЮЛЛЕТЕНЬ

СОВЕТСКОЙ АНТАРКТИЧЕСКОЙ ЭКСПЕДИЦИИ

90

1975

ГИДРОМЕТЕОИЗДАТ
ЛЕНИНГРАД

БЮЛЛЕТЕНЬ
СОВЕТСКОЙ АНТАРКТИЧЕСКОЙ ЭКСПЕДИЦИИ № 90, 1975

Арктический и антарктический научно-исследовательский институт — *И. И. БАРКОВ*
Московский государственный университет — *Ф. Г. ГОРДИЕНКО*
Арктический и антарктический научно-исследовательский институт — *В. С. КОРОТКЕВИЧ*
Институт географии АН СССР — *В. М. КОТЛЯКОВ*

Изотопно-кислородные исследования 500-метрового ледяного керна из скважины станции Восток

Ледники, как и все природные воды на Земле, состоят из трех изотопных разновидностей воды. При этом более 99,7% приходится на долю H_2O^{16}, около 0,2% на H_2O^{18} и около 0,03% на HDO^{16}. Вода, молекулы которой образованы тяжелыми стабильными изотопами водорода и кислорода (D и O^{18}), отличается от воды H_2O^{16} меньшей насыщающей упругостью водяного пара. Поэтому при испарении и конденсации происходит фракционирование: конденсат обогащается, а водяной пар обедняется тяжелыми изотопами.

По этой причине в атмосферной влаге, а значит и в атмосферных осадках, концентрации D и O^{18} меньше, чем в водах океана, которые являются основным источником атмосферной влаги. Воды океана имеют весьма постоянные концентрации D и O^{18}. Стандартная средняя океаническая вода (SMOW) принимается в этом отношении в качестве эталона. Концентрации D и O^{18} в анализируемых пробах оцениваются в виде отклонений δ относительно их концентрации в SMOW в тысячных долях (‰).

В атмосферной влаге концентрации D и O^{18} убывают с увеличением расстояния от океана и понижением температуры атмосферы. Поэтому осадки, выпадающие в центральных районах Антарктиды, являются наиболее легкими [11, 18]. Зарегистрированы случаи, когда величины δD и δO^{18} в них достигали соответственно −390 и −52‰ относительно SMOW. В связи с сезонными изменениями температуры в атмосфере концентрации D и O^{18} в осадках изменяются по сезонам: зимние осадки беднее тяжелыми изотопами, чем летние [10, 12, 16].

Изложенные особенности атмосферных осадков позволяют по результатам изотопного анализа образцов льда, получаемых в виде керна при бурении скважин, реконструировать палеотемпературные условия, в которых накапливался снег, образовавший толщу

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195 образцов толщиной от 3 до 10 см. Интервалы между ними составляли от 0,1 до 5 м. Результаты анализа показали, что значения δO^{18} в соседних образцах, как правило, изменяются в пределах 5–6‰ при максимальном различии до 12‰ (−47 и −59‰). Небольшие по толщине образцы льда содержат информацию за короткий период времени, что обусловливает значительный разброс значений δO^{18}. Поэтому для палеоклиматической интерпретации полученные результаты сгруппировали по глубине и в каж-

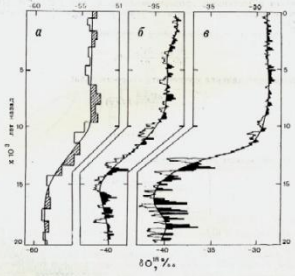

Рис. 3. Вертикальные профили вариаций δO^{18} в ледниковом покрове на станциях Восток (*а*), Бэрд (*б*) и Кемп Сенчури (*в*), охватывающие последние 20 тысяч лет.

дом 20-метровом интервале определили средние величины δO^{18}. С помощью выражения (2) рассчитали возраст льда на различных глубинах и по этим данным построили график (*а*), изображенный на рис. 3.

Сопоставление изотопного профиля станции Восток с профилями станций Бэрд и Кемп Сенчури [14, 15, 20] показывает, что они весьма сходны между собой. Изменение соотношения изотопов кислорода в атмосферных осадках, некогда образовавших толщи ледников, произошло почти одновременно в Гренландии и в Антарктиде. В районе станции Бэрд и Кемп Сенчури изменения со-

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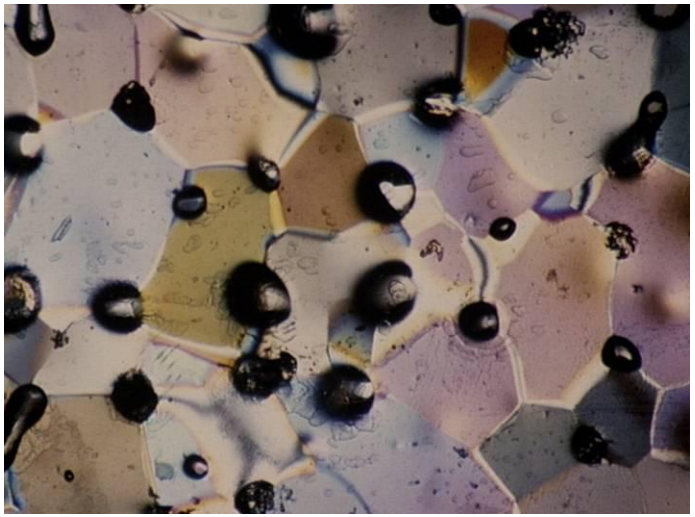
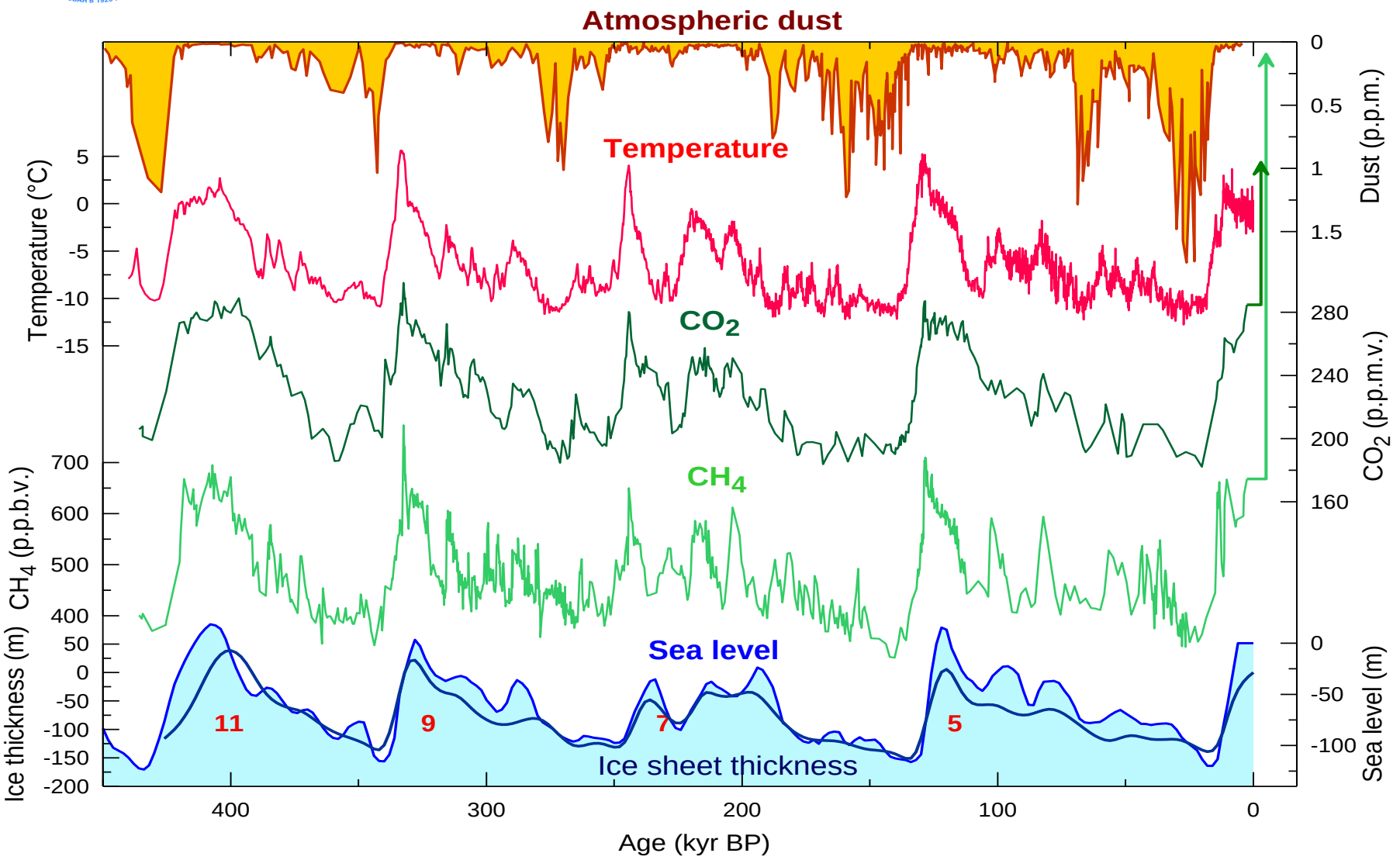
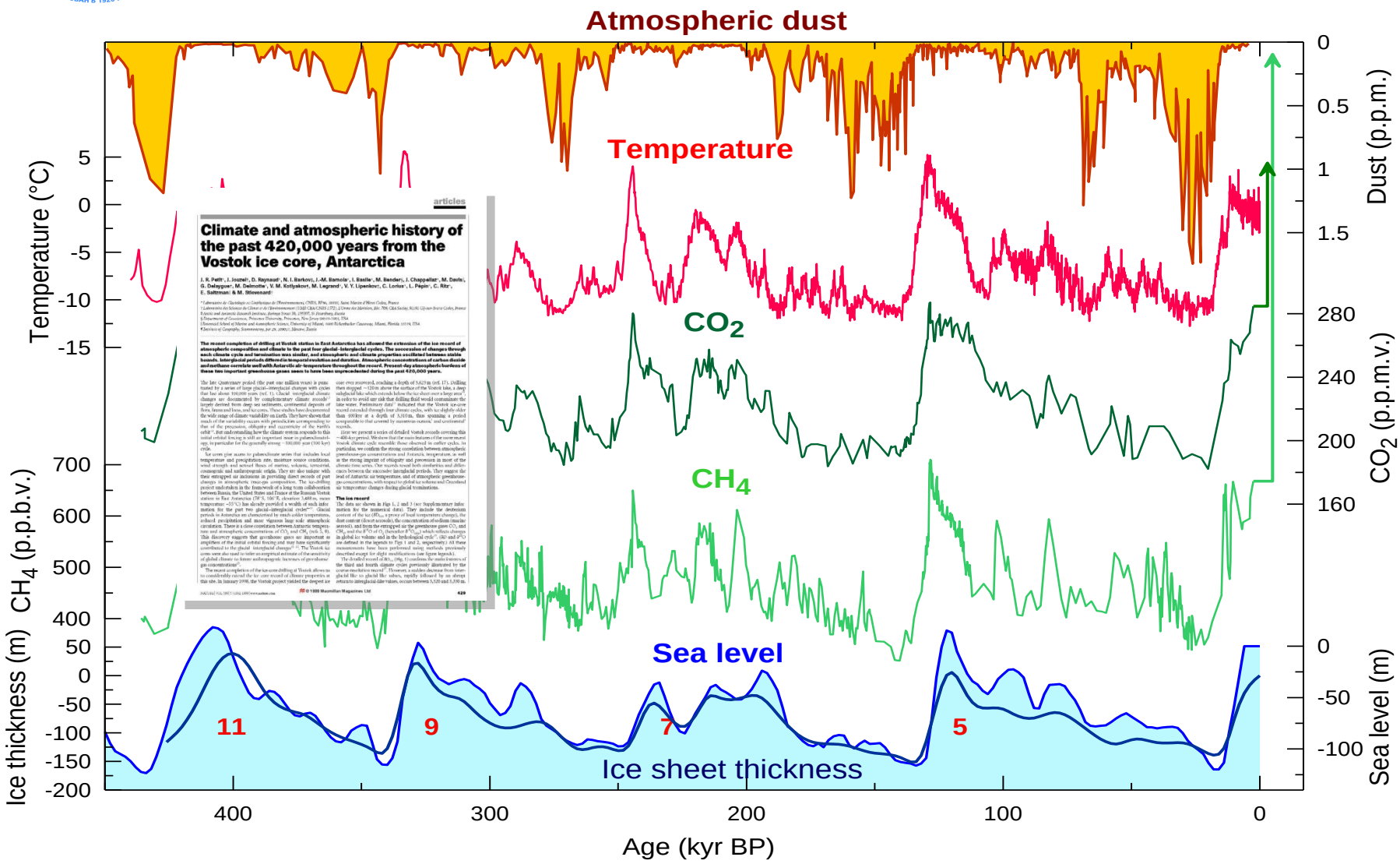
Deep ice drilling to study the remote past

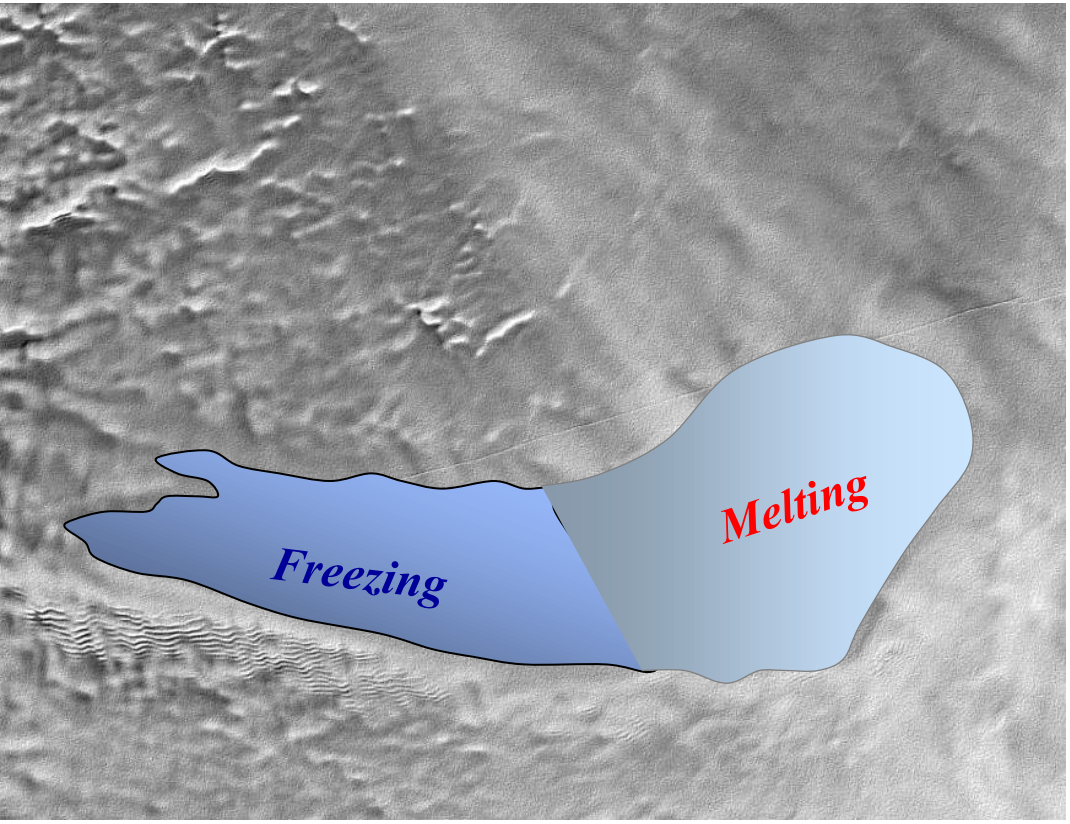


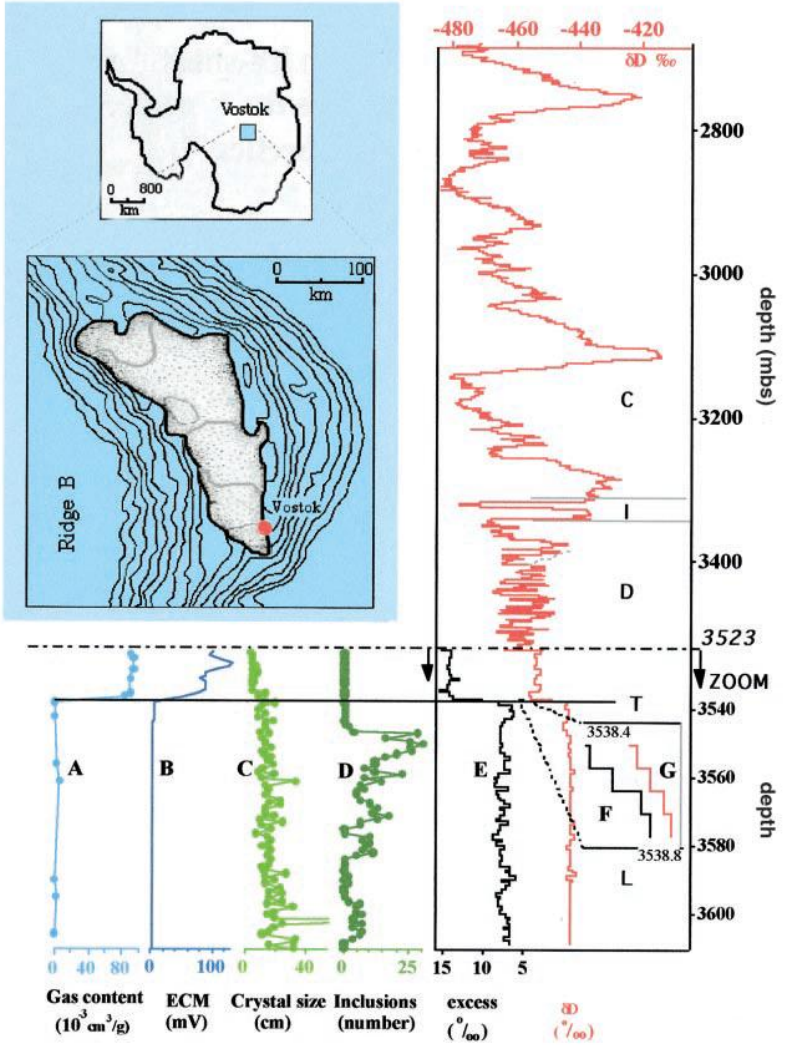
“Cornucopia of paleoclimatic data”



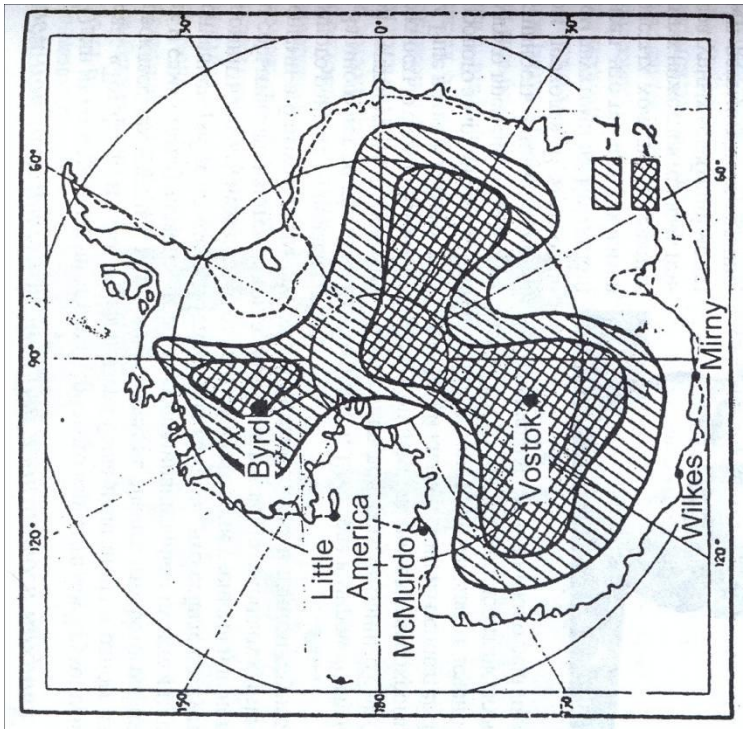
“Cornucopia of paleoclimatic data”




Freezing
Melting


Vostok
0 800
km
0 100
km
Ridge B
Vostok
-480 -460 -440 -420
δD ‰
2800
3000
3200
3400
depth (mbs)
C
I
D
3523
ZOOM
T
3538.4
3538.8
A
B
C
D
E
F
G
L
3540
3560
3580
3600
depth
0 40 80
0 100
0 40
0 25
15 10 5
Gas content
(10^3 cm^3/g)
ECM
(mV)
Crystal size
(cm)
Inclusions
(number)
excess
(°/‰)
δD
(°/‰)

Can melt-water exist under deeply frozen Antarctic glacier?



Igor Zotikov
(1926-2010)

Byrd Station, 2164 m (29 January 1968)

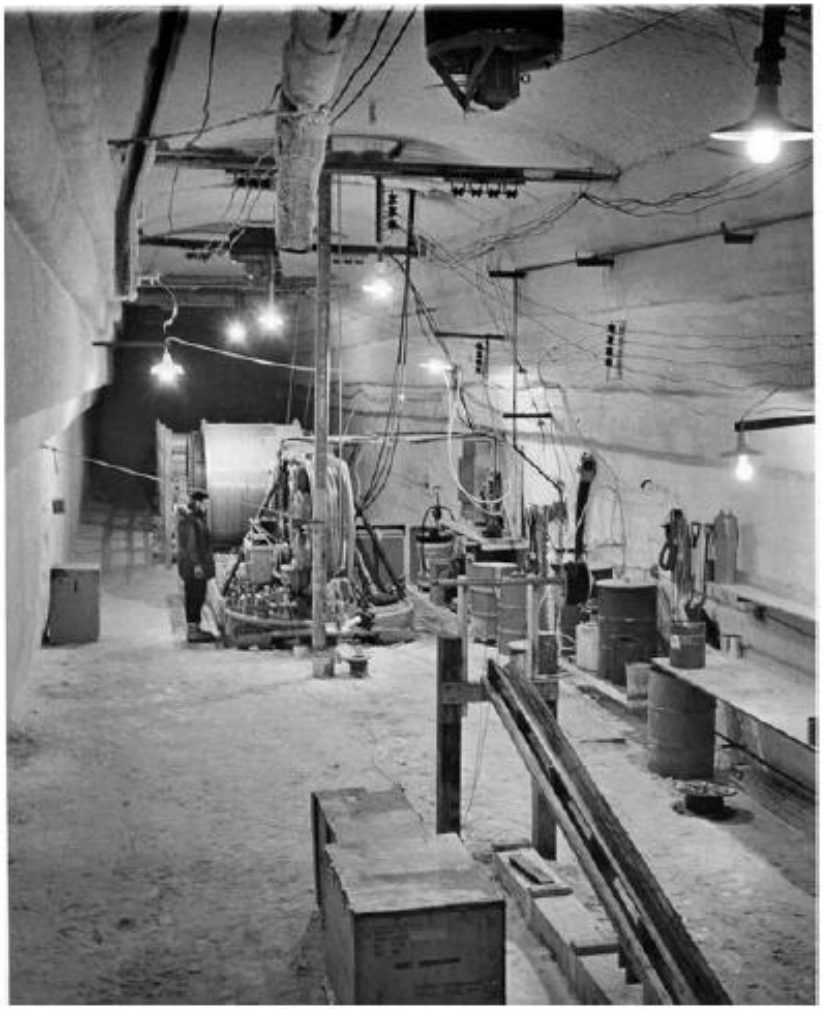


Fig. 2. Winch set-up in main tunnel, 1966.

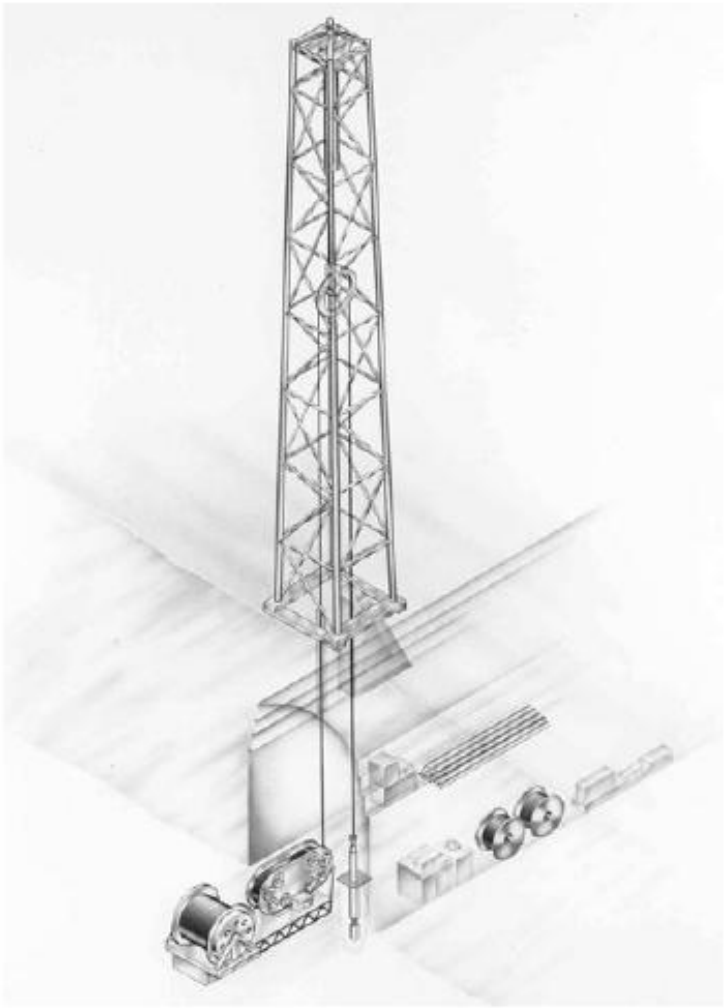


Fig. 3. Overall drilling set-up, Byrd Station, 1966.

Andrey Kapitsa
(1931-2011)

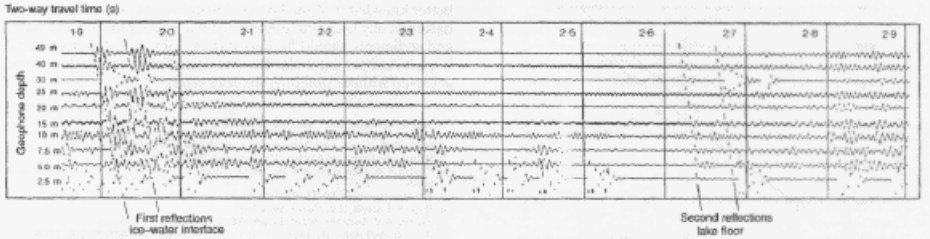


FIG. 2 Section of 24-channel seismic record from Vostok relevant to the sub-ice water layer. This records movement over a vertical line of seismometers from 49 m to 2.5 m depth in a borehole 180 m from the explosion. It covers a period from 1.85 to 2.9 seconds after the explosion of 5 kg of TNT at 39 m depth and 180 m from the vertical seismometer line. A conventional horizontal spread of twelve seismometers at 20-m intervals recorded the same echoes (not shown) at ~1.92 and ~2.65 s against a much higher background noise. The echo from the base of the floating ice reaches the deepest (49 m) seismometer first at ~1.91 s. It then travels up the seismometer line to the surface where it is reflected down to pass the 49-m seismometer ~50 ms later. This has a mean velocity of ~2,200 ms^{-1}, typical of compression (P) waves in the top 50 m of firn in this region[12]. About 45 ms after the first arrival, a second wave train of similar intensity and duration follows as a result of the initial surface reflection of the explosion at 39 m depth. There is no significant return of energy between ~2.00 and ~2.63 s, when a weaker wave train passes up and down the seismometer line at the same velocity. This confirms that they are compressive (P) waves, the only waves that travel through water, and not transverse (PS) waves, which are sometimes recorded from shots on ice shelves.

both likely, our best estimate of the residence time of the lake water is of the order of 50,000 years.

Other features of the water mass can be deduced from the relationship between surface elevation and thickness of floating ice (Fig. 4). The close scatter of points around the freshwater line (Fig. 4) indicates a hydraulic pressure equivalent to a head of water close to 3,140 m above sea level over the whole lake. It also confirms the presence of relatively fresh water in the lake. Any difference between the mean slope of plotted points and the freshwater line could be due to residual effects from boundary stresses, to errors of ice thickness and/or to the effect of limited salinity on water density within a range of 0.00 and 0.05‰.

The decrease of ice thickness of ~500 m from north to south of the lake means that the ice–water contact temperature will be 0.4 °C lower at the north than at the southern end. This may be sufficient to drive slow circulation of sub-ice water and affect basal heat flow distribution over the lake, but not the total heat flux.

Ice cores from Vostok contains micro-organisms[12,13] carried by air to Antarctica on dust particles from low latitudes. Melting of basal ice will release these microorganisms into lake water around one million years after deposition on the ice surface. Sediments on the lake bed may be several million years older, an exceptional environment that should provide useful information to the biological community and to geologists.

The lake occupies the lower part of a basin or rift (Figs 1, 3*b*). Unlike grounded ice, basal drag is negligible over an ice–water

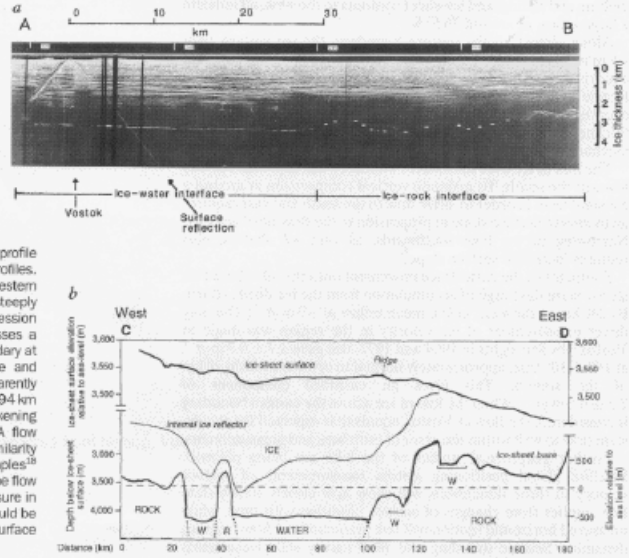
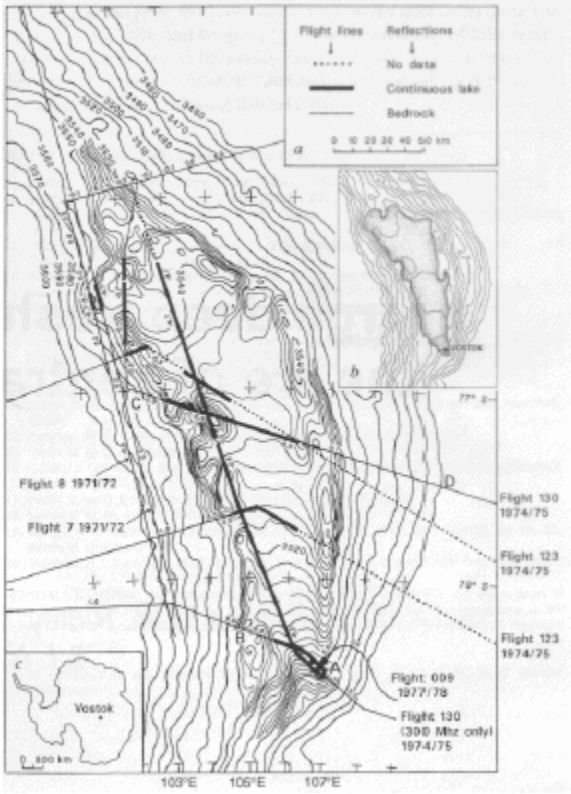
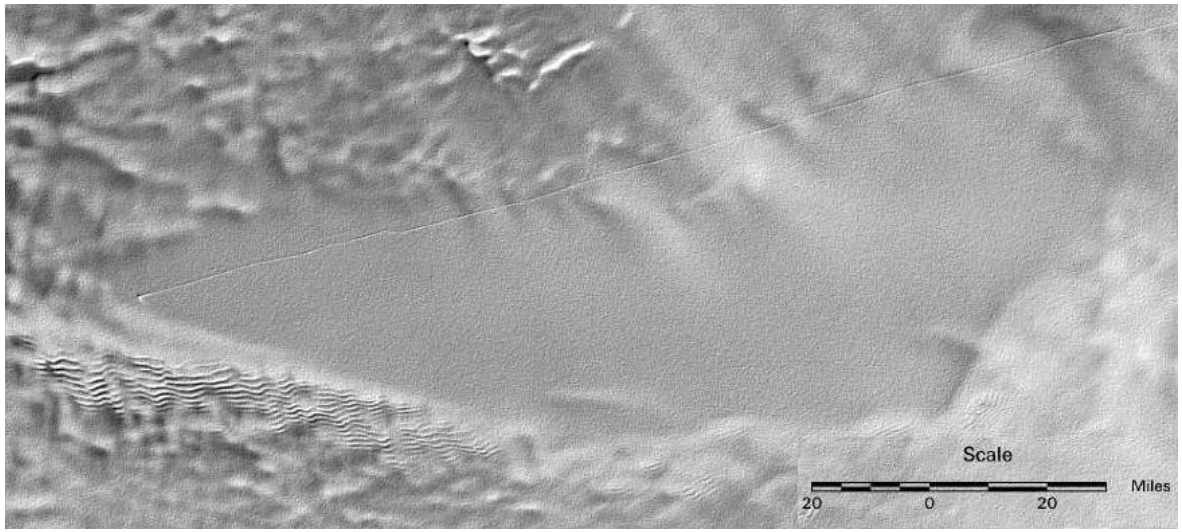


FIG. 3 Two-dimensional vertical profiles. *a*, Continuous RES profile from flight 009, 1977–78, along line A–B in Fig. 1*a*. Strong ice–water reflections beneath Vostok and for ~30 km give way to weaker echoes from ice–bedrock further west. White dots have been added to show the location of weak bedrock echoes where they are not clearly visible. The near-horizontal layering in the upper 2 km is due to higher-conductivity layers of ice resulting from widespread deposition of volcanic material over the ice sheet[17]. Slanting echoes show reflections from surface buildings as the aircraft passed over Vostok. *b*, Cross-section along line C–D in Fig. 1*a*, showing deepest continuous RES layer. The vertical scale of the surface profile is increased to 100 times that of the deep profiles. Surface valleys around 30 and 50 km near the western boundary are due to downslope motion over steeply falling bedrock, opposed by horizontal compression that continues over the lake. After the ice crosses a rock ridge approximately parallel to the lake boundary at 40 km, a deeper valley is formed. The surface and reflecting layer then rise from 50 to 70 km, apparently above faster, southward-moving ice. From 70 to 94 km the surface is almost level, with slight ice thickening probable, until the lake boundary is crossed. A flow component to the east is then indicated by the similarity of the profile in *b* to that across the Doake Ice Rumples[18] (77.7° S, 66.6° W) to the Ronne Ice Shelf. Upslope flow appears to be initiated and driven by vertical pressure in both cases. The alternative to this flow pattern would be an ice divide, with static ice below an almost flat surface for at least 10 km to either side.



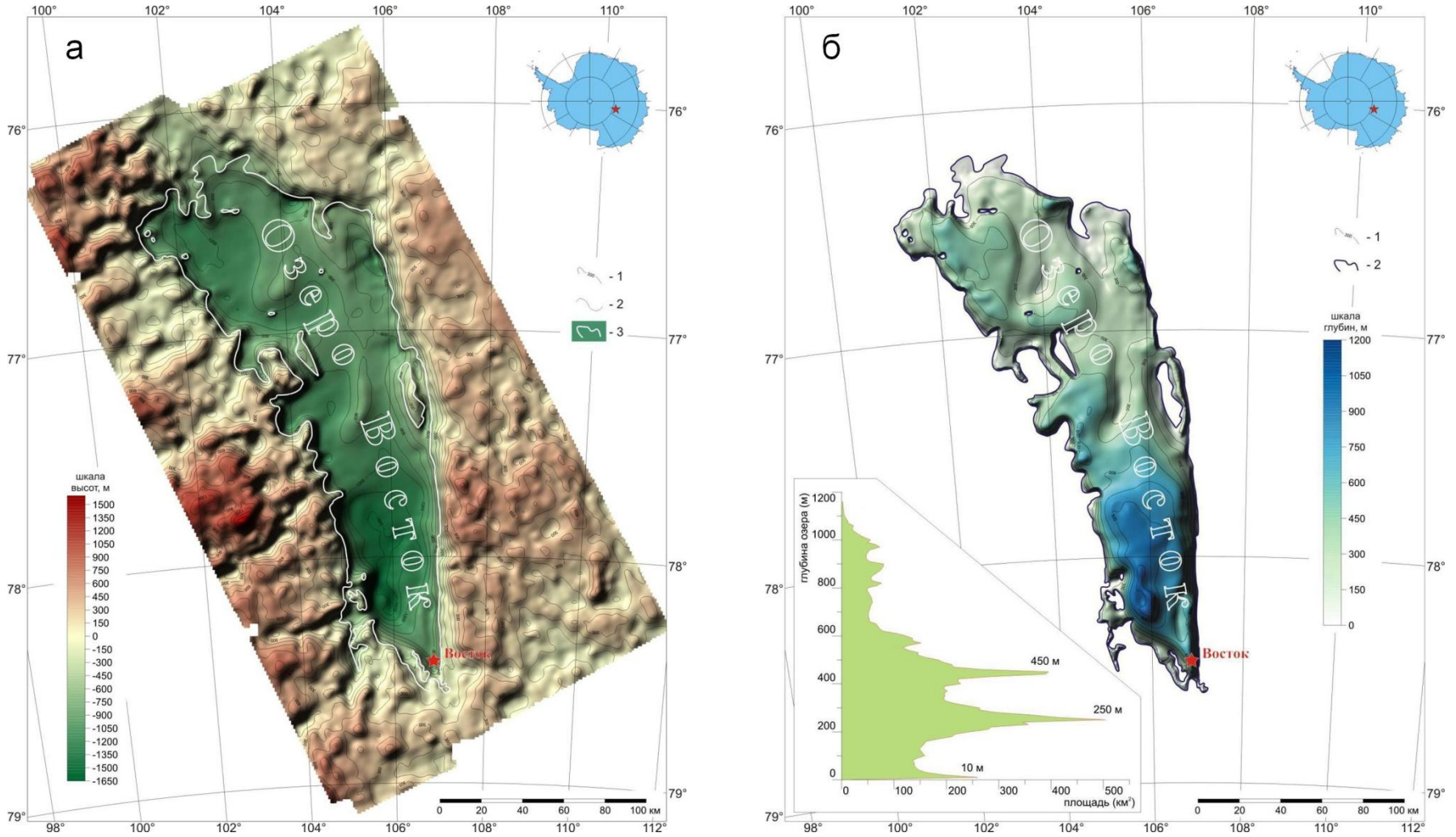
Gordon de Q. Robin, 1970s



Ridley et al., 1993

Lake Vostok:

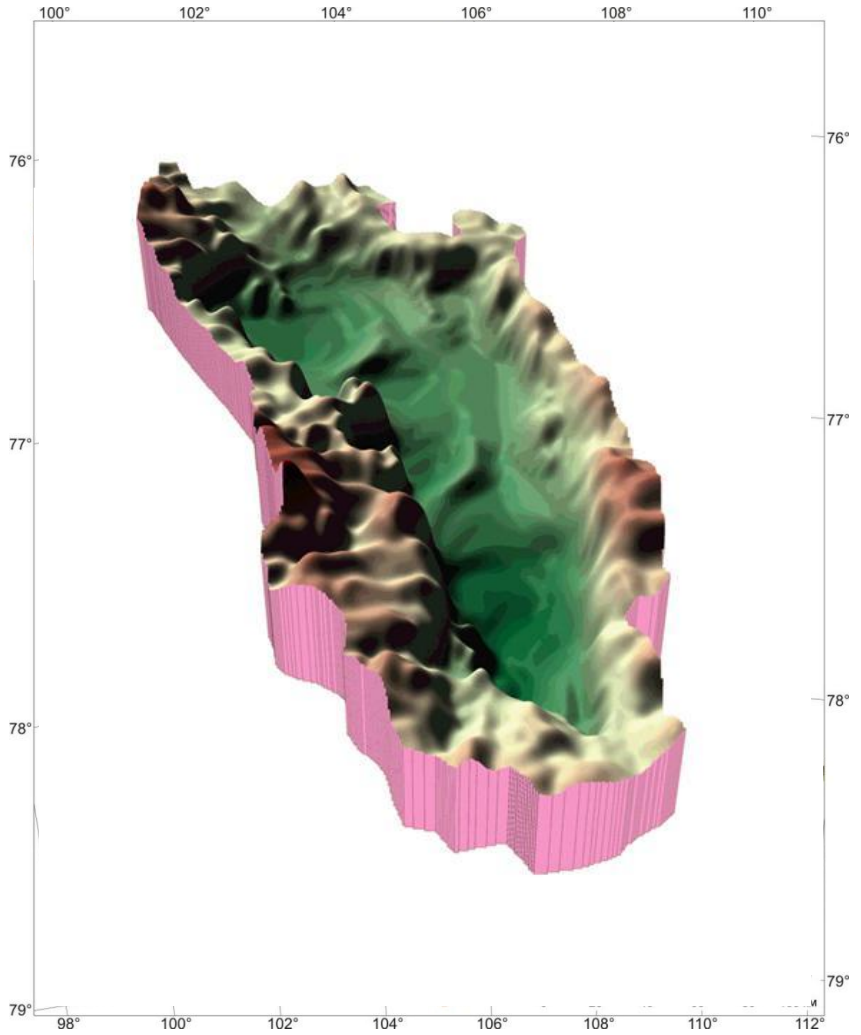
The 5th largest lake in the world!

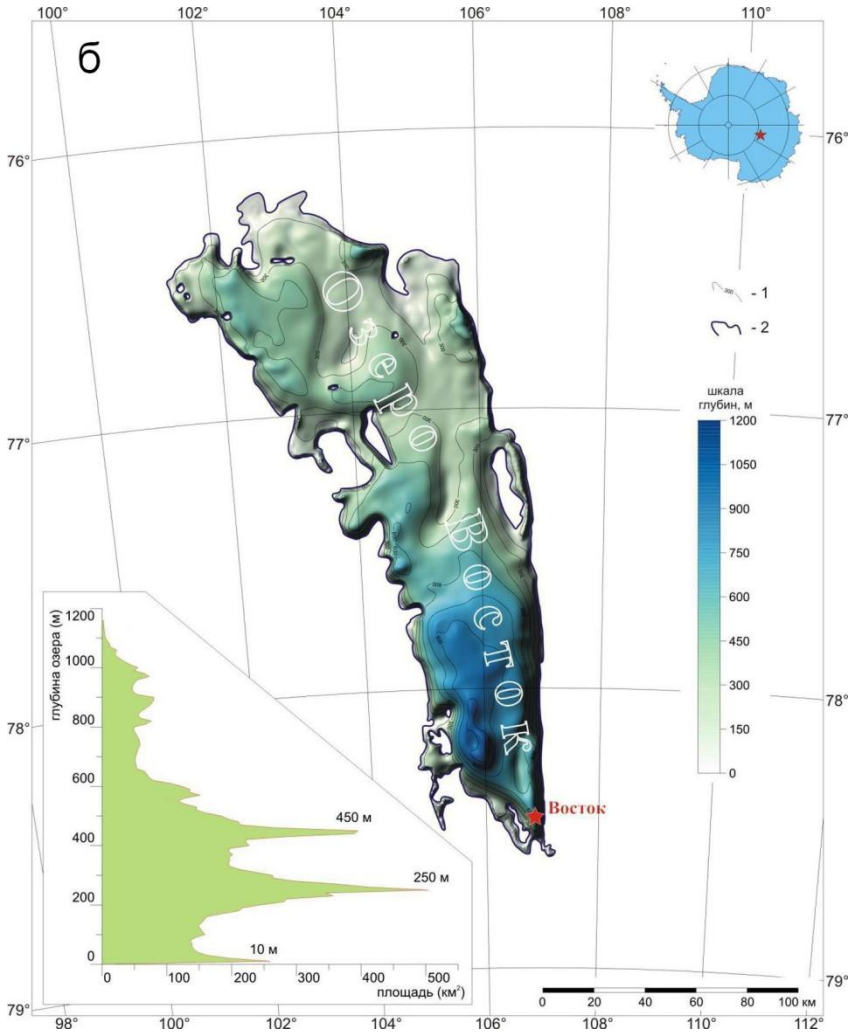


Popov et al., 2011

Lake Vostok:

The 5th largest lake in the world!



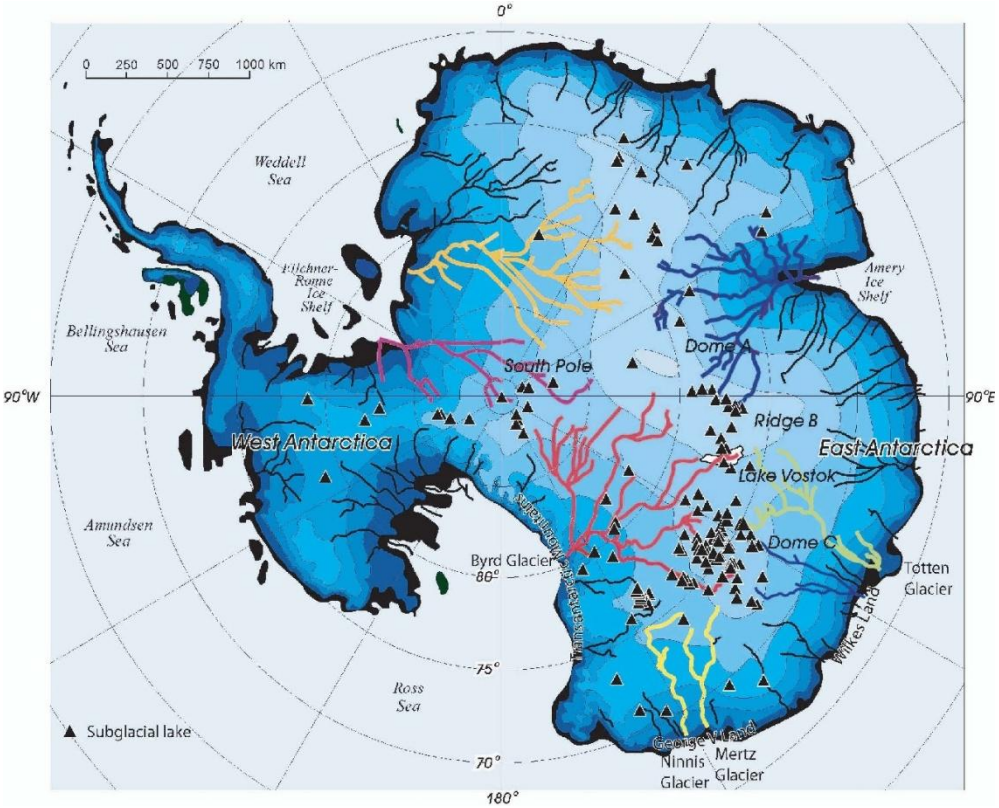


Popov et al., 2011

Aquatic environments beneath the Antarctic ice sheet

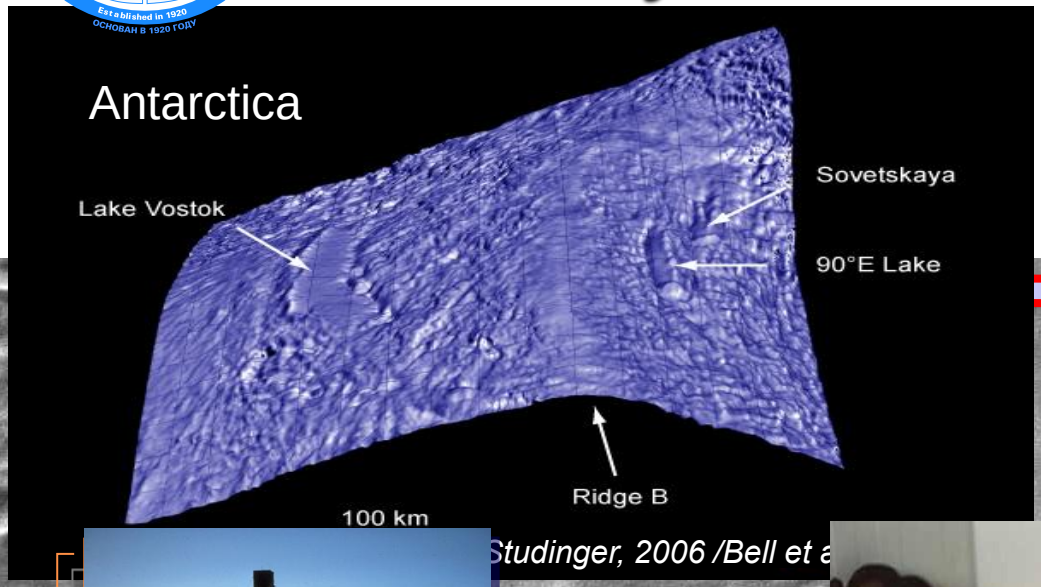
>22,000 km^3 of water in >145 sub-ice lakes:

- Affect ice sheet and ice stream dynamics
- Control drainage of the EAIS and contribute to see level rise
- Provide a “Natural laboratory for ecological experiments”, and
- Earth-bound analogues for extraterrestrial ice worlds

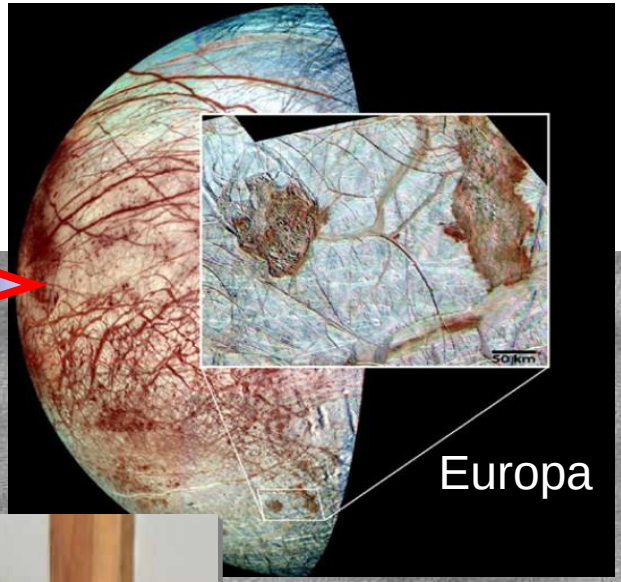


Subglacial lakes and major drainage routines from Siegert et al., 2007

Why Lake Vostok?



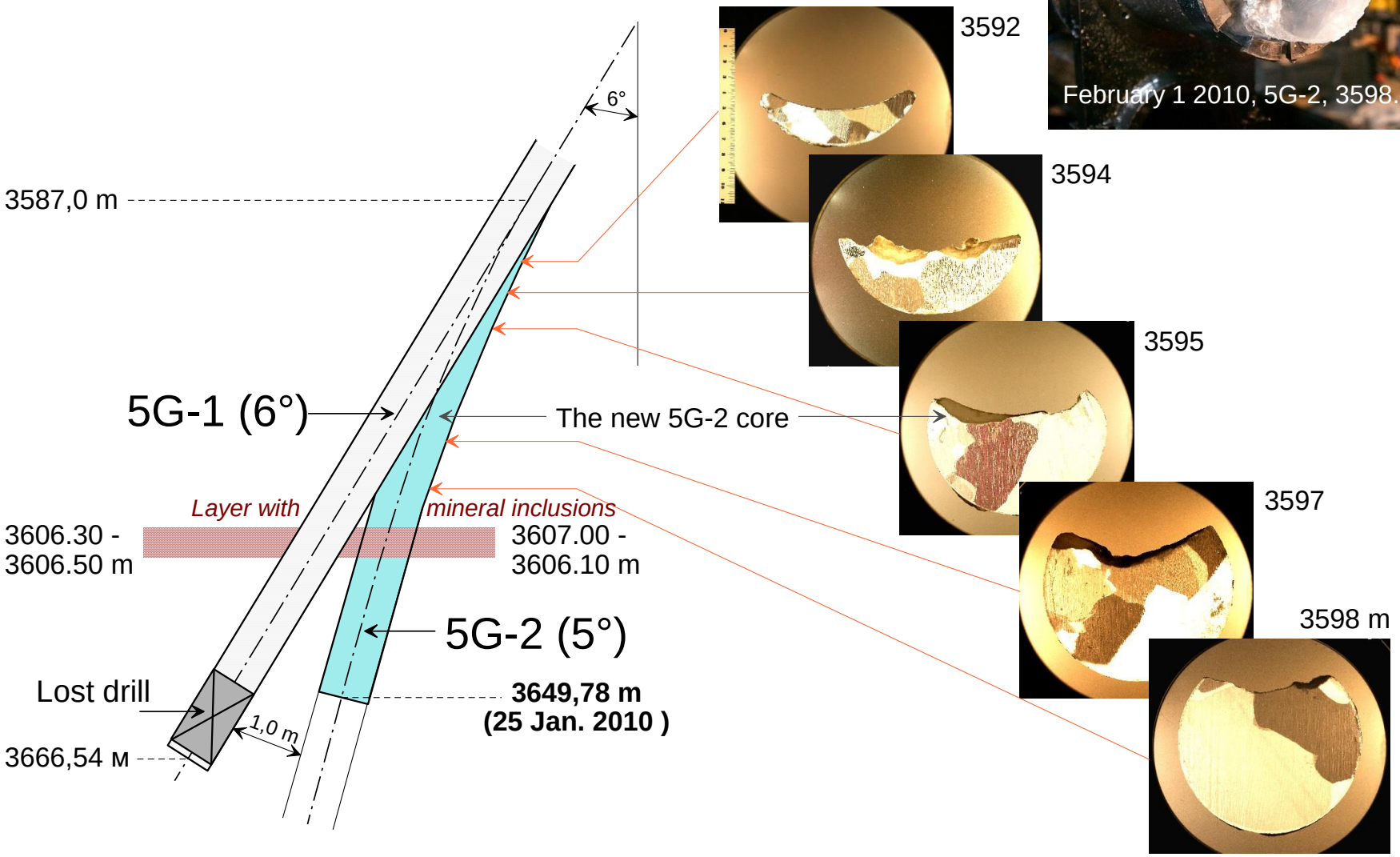
Studinger, 2006 /Bell et a



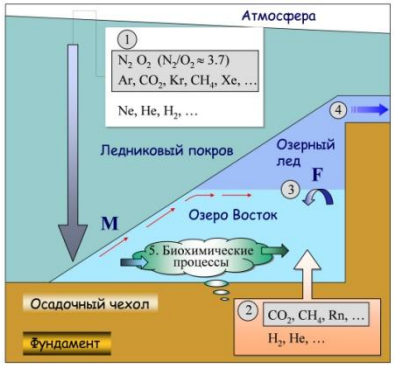
Восток

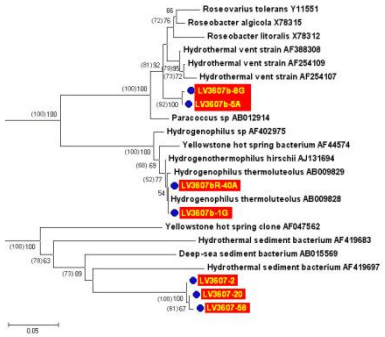
230 m of accreted lake ice

From 5G-1 to 5G-2

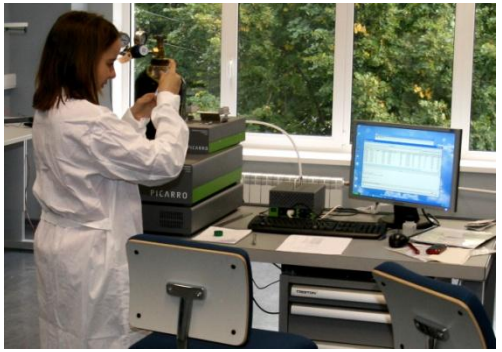


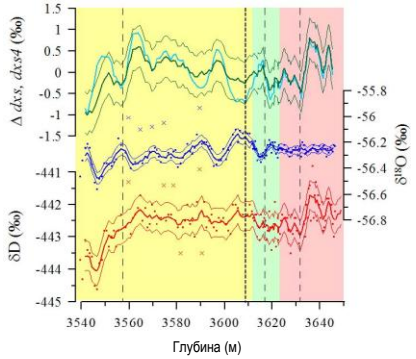
What do we know about the Lake Vostok?

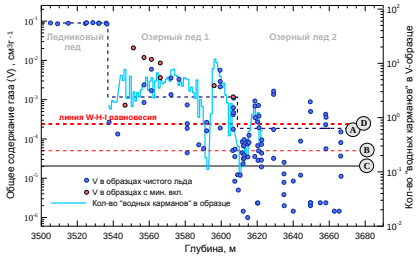




- Accumulation of impurities coming to the lake due to glacier ice melting
- Hydrothermal activity at the lake bottom
- High concentration of gases including oxygen!
- Not perfect mixing of melt water with the resident lake water
- Ultra-oligotrophic environment
- Expected micro-organisms: oxygenophilic chemoautotrophs







ARCTIC AND ANTARCTIC RESEARCH INSTITUTE
Established in 1920
2 January – 5 February 2012

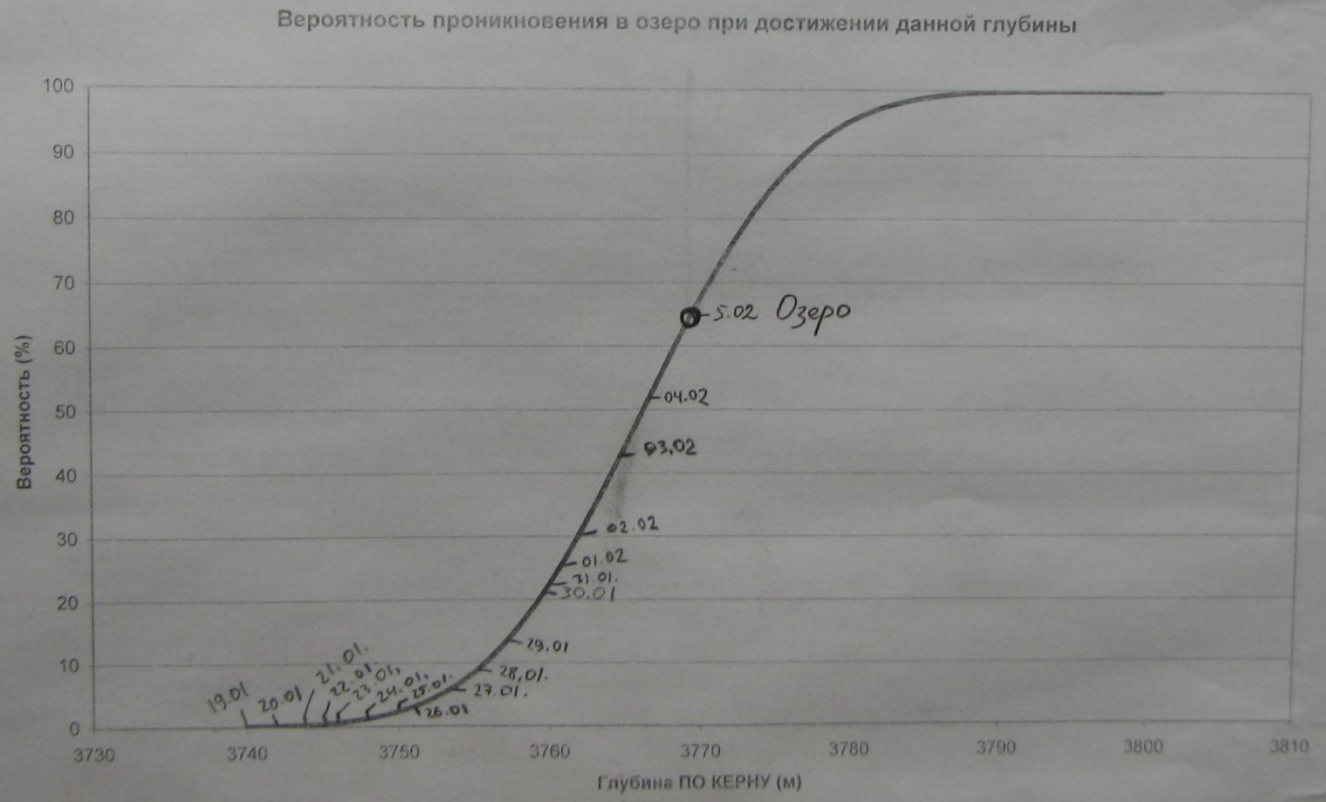
Show must go on, Alexey

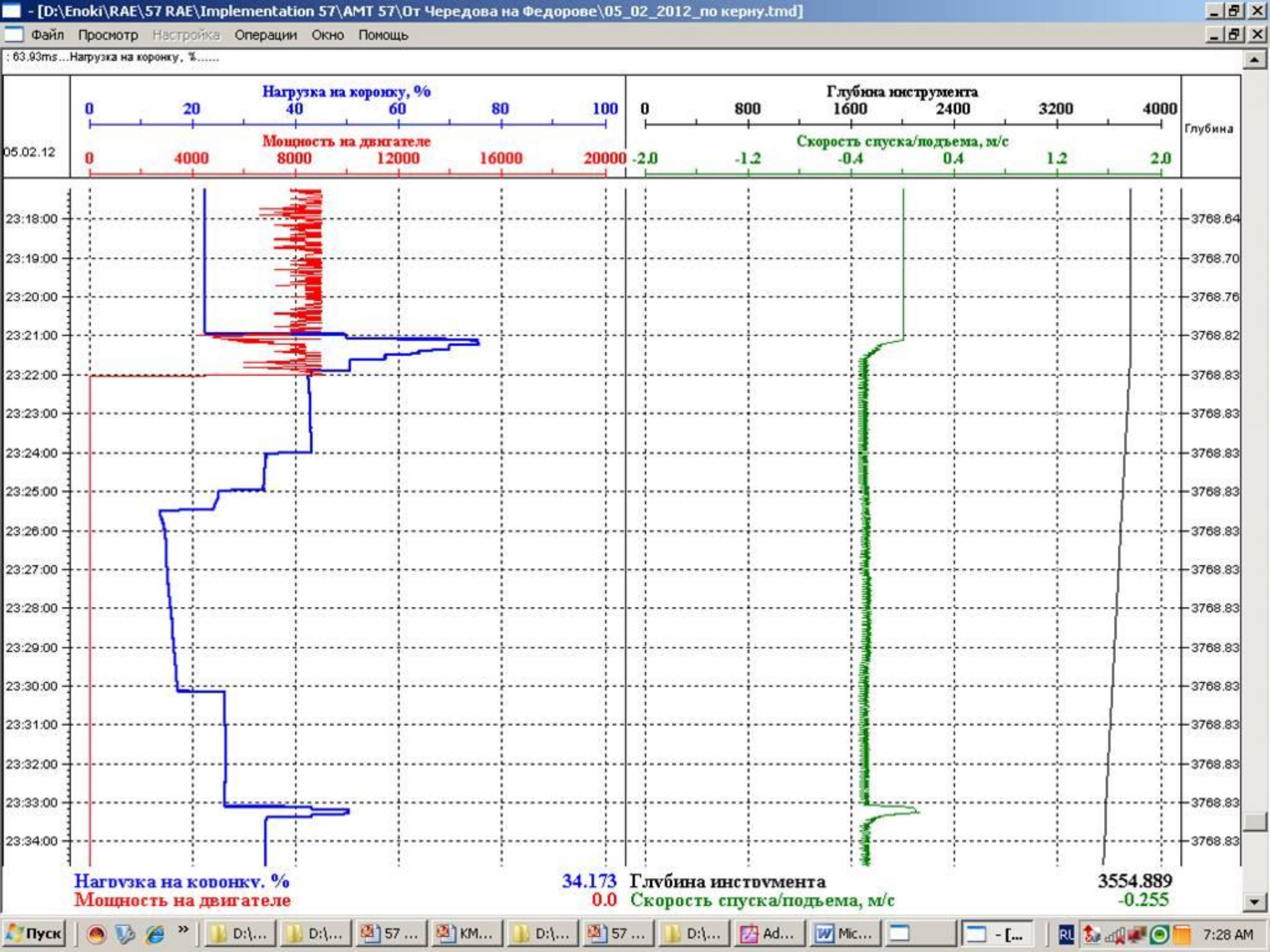
Now the time for some pictures

Bio
time

Bistro
SAVAGE
Набор для вина 2 шт.

График нарастания интриги




- [D:\Enoki\RAE\57 RAE\Implementation 57\AMT 57\От Чередова на Федорове\05_02_2012_по керну.tmd]
Файл Просмотр Настройка Операции Окно Помощь
: 63.93ms...Нагрузка на коронку, %.....
Нагрузка на коронку, %
0 20 40 60 80 100
Мощность на двигателе
0 4000 8000 12000 16000 20000
Глубина инструмента
0 800 1600 2400 3200 4000
Скорость спуска/подъема, м/с
-2.0 -1.2 -0.4 0.4 1.2 2.0
Глубина
05.02.12
23:18:00
23:19:00
23:20:00
23:21:00
23:22:00
23:23:00
23:24:00
23:25:00
23:26:00
23:27:00
23:28:00
23:29:00
23:30:00
23:31:00
23:32:00
23:33:00
23:34:00
3768.64
3768.70
3768.76
3768.82
3768.83
Нагрузка на коронку, %
34.173
Глубина инструмента
3554.889
Мощность на двигателе
0.0
Скорость спуска/подъема, м/с
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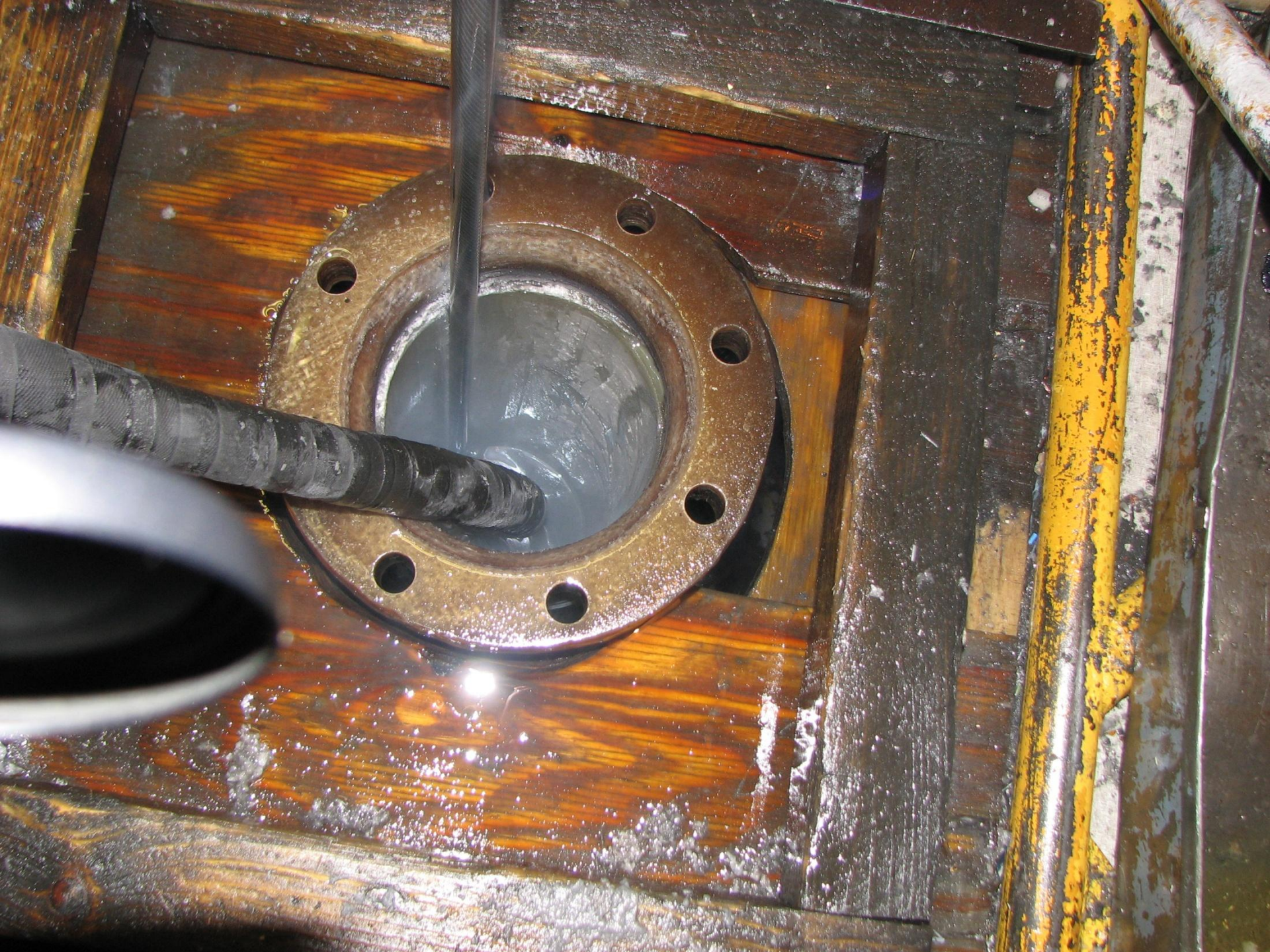
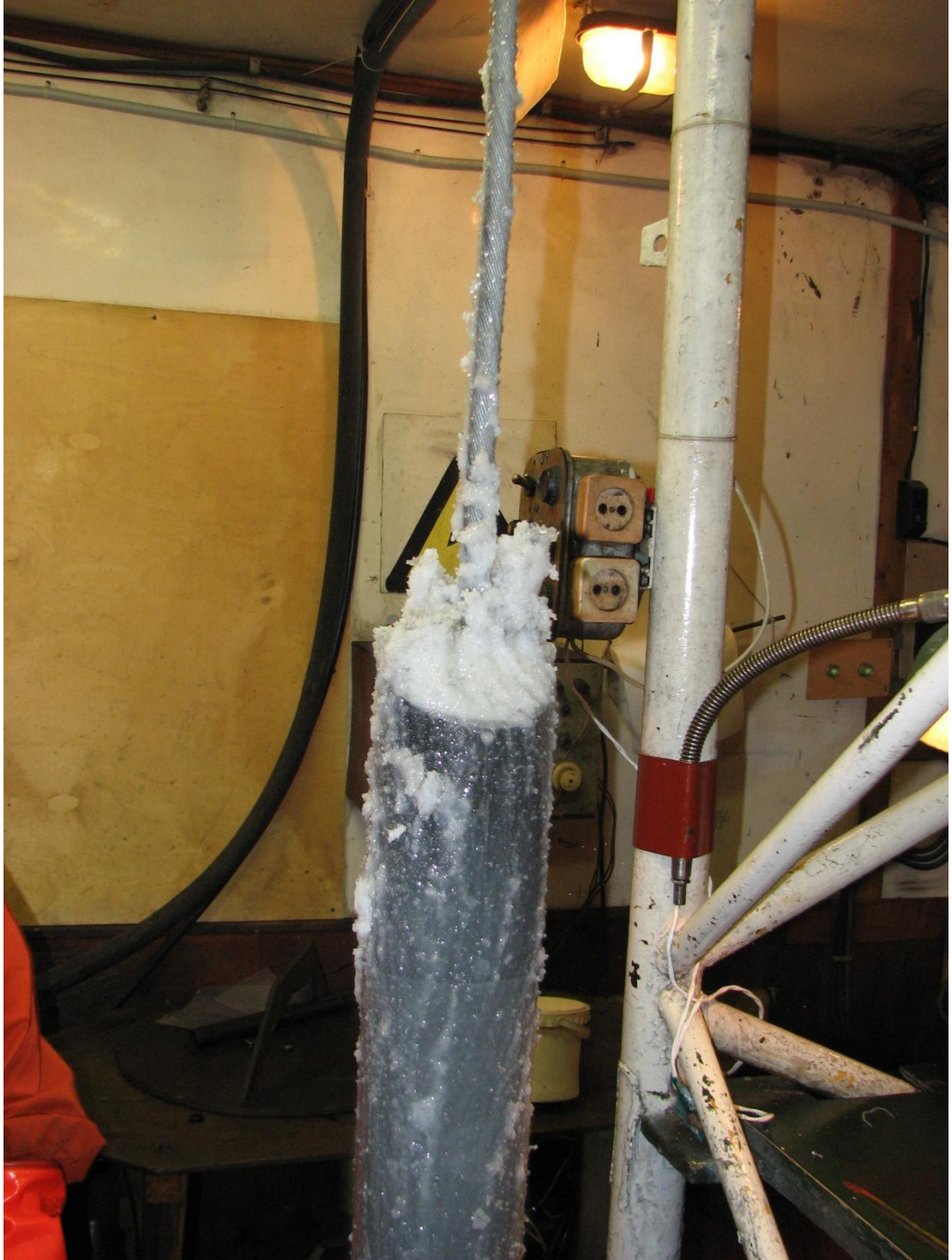
Пуск
7:28 AM

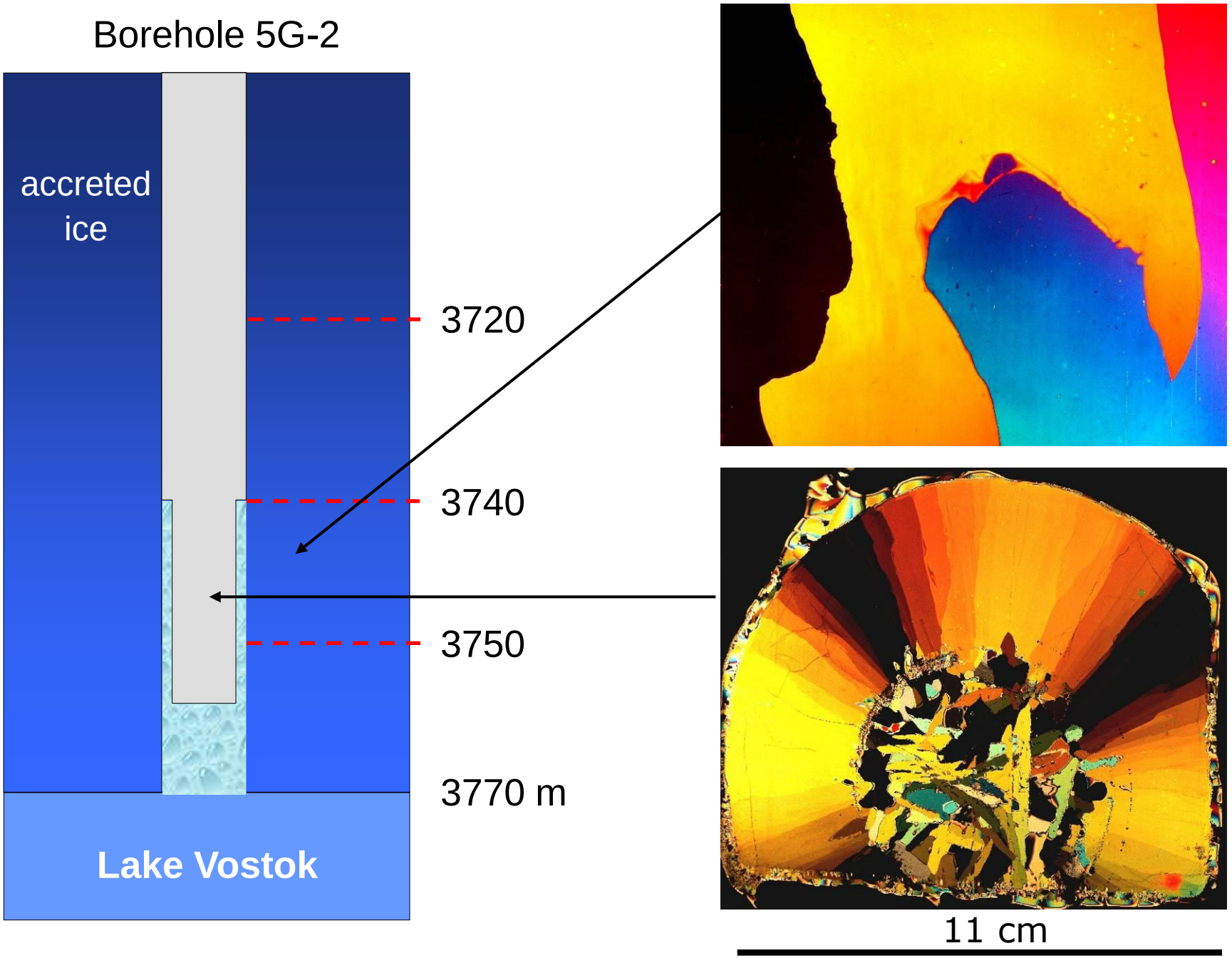


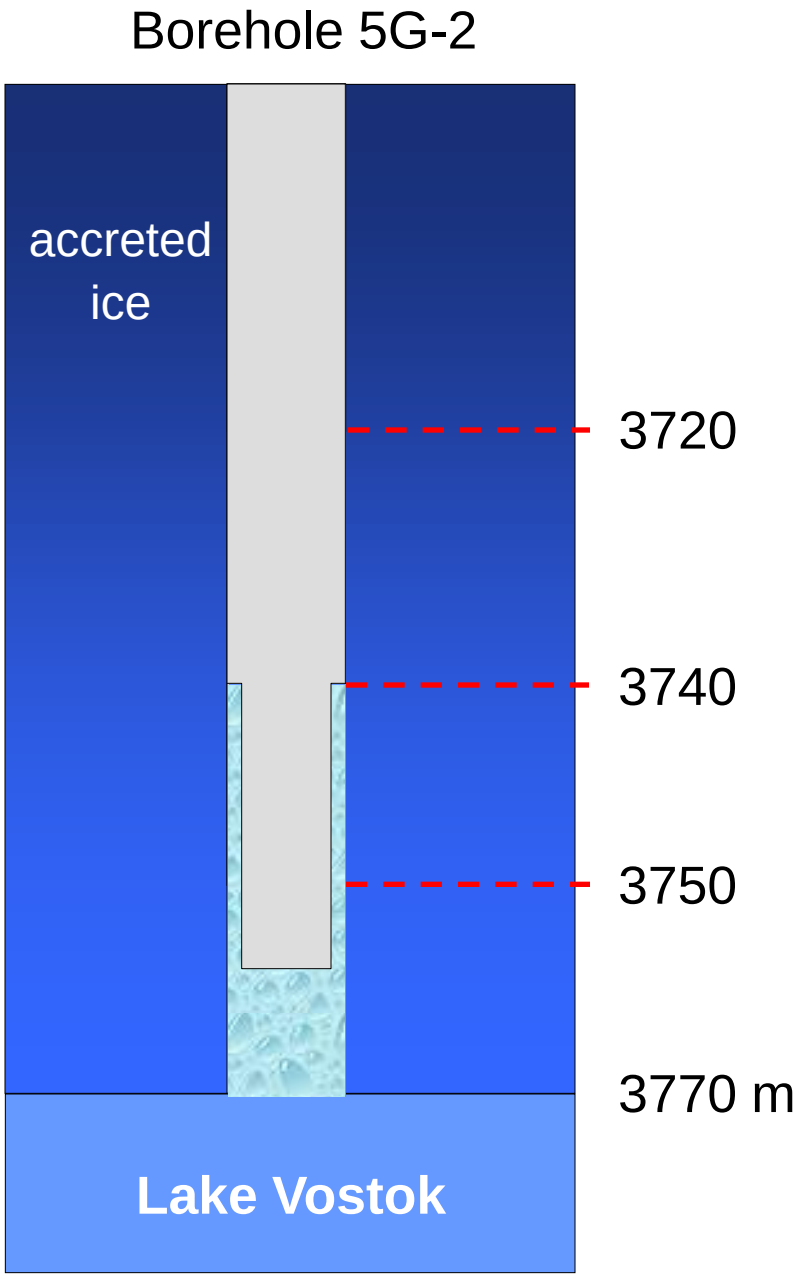


elf

3722
3723
3724
57 РАЭ
5Г-2
3745
57 РАЭ
5Г-2
3746
57 РАЭ
5Г-2
3747
57 РАЭ
5Г-2
3768
57 РАЭ
5Г-2
3769

3700
21.01.2011
Озеро
05.02.2012
5Г-2
3598,6
02.02.2008
29.01.98
623
22.01.98
3600
3540
08.01.98
Первый камень в сердце ВОСТОКА

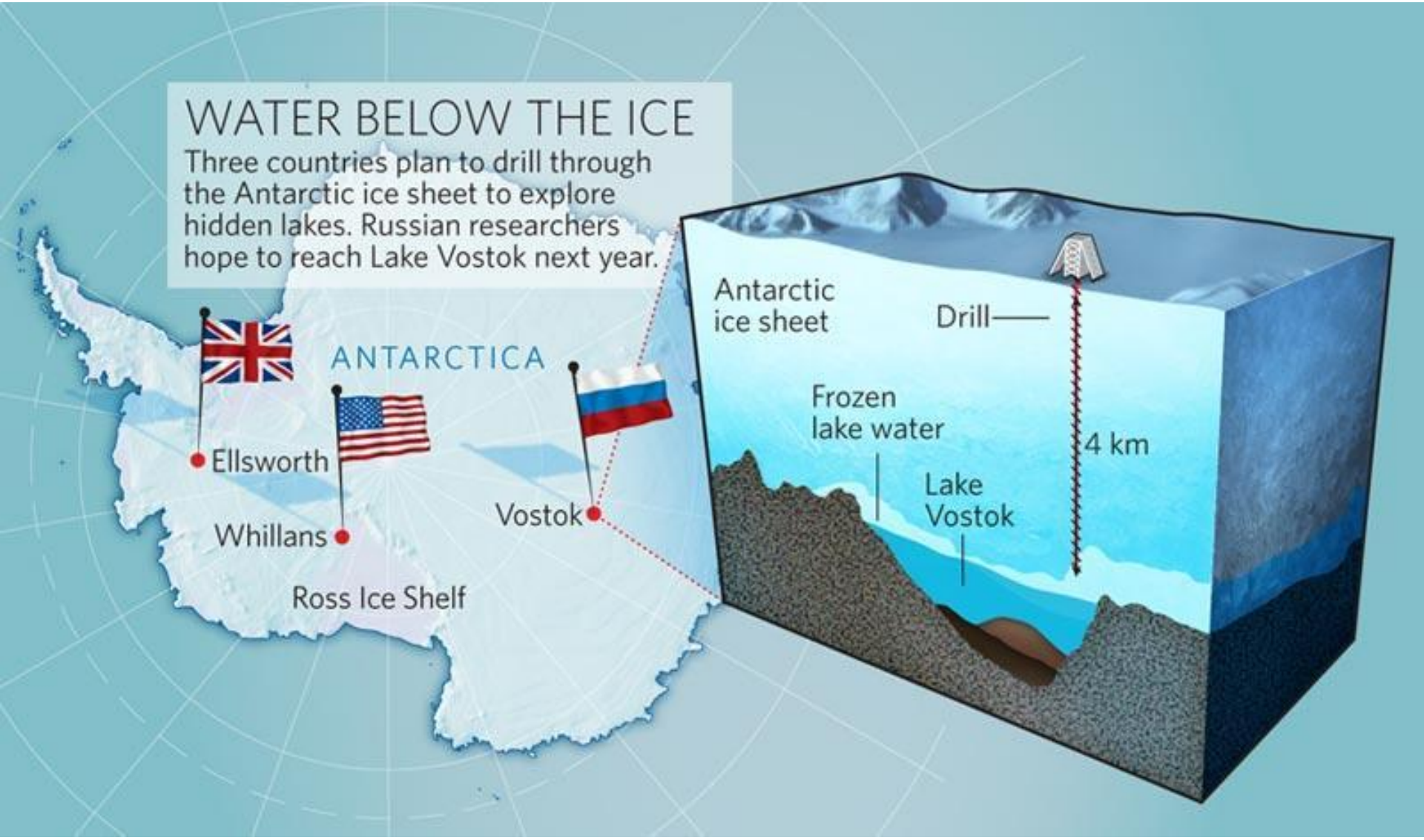

Borehole 5G-2
accreted ice
3720
3740
3750
3770 m
Lake Vostok
11 cm



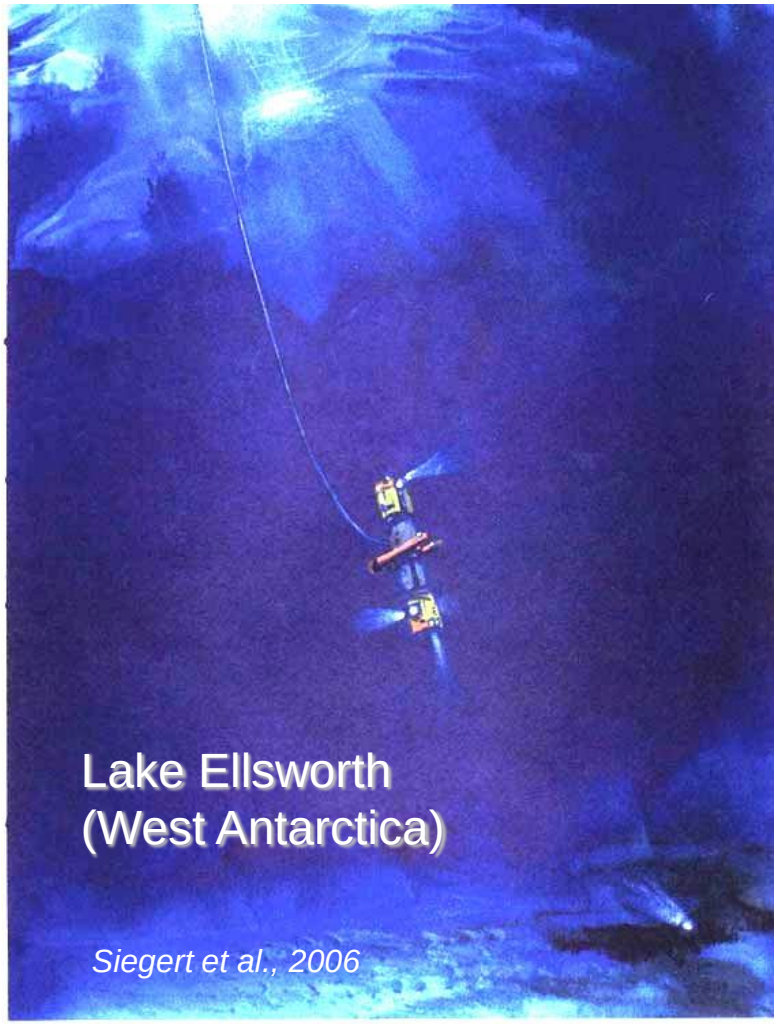
What next?

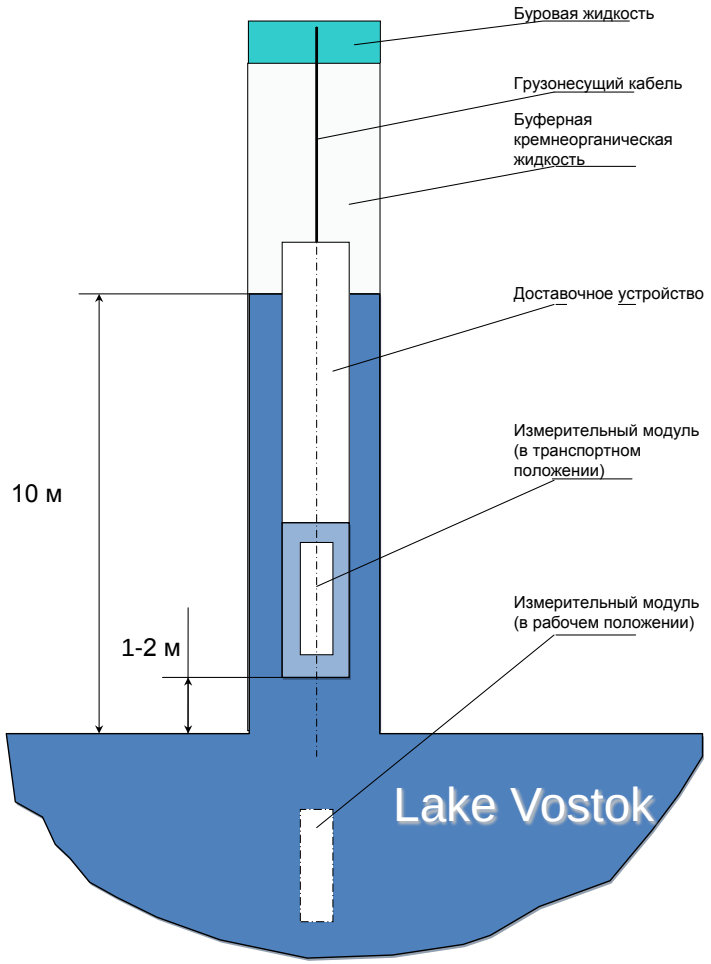
2011/12
Antarctic season:
Drilling of the frozen lake water

“Teams set for first taste of Antarctic lakes”, Nature, 2010



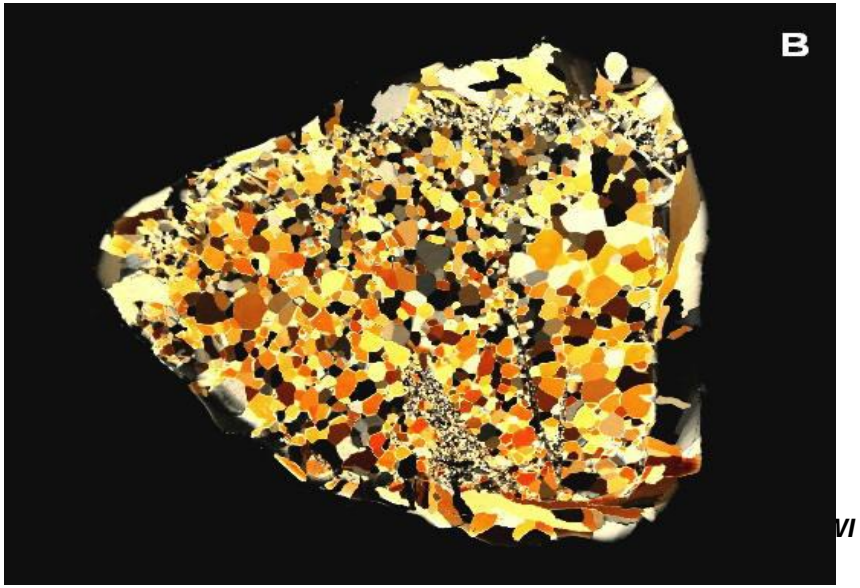
“Second penetration” to LV: direct measurements and water sampling

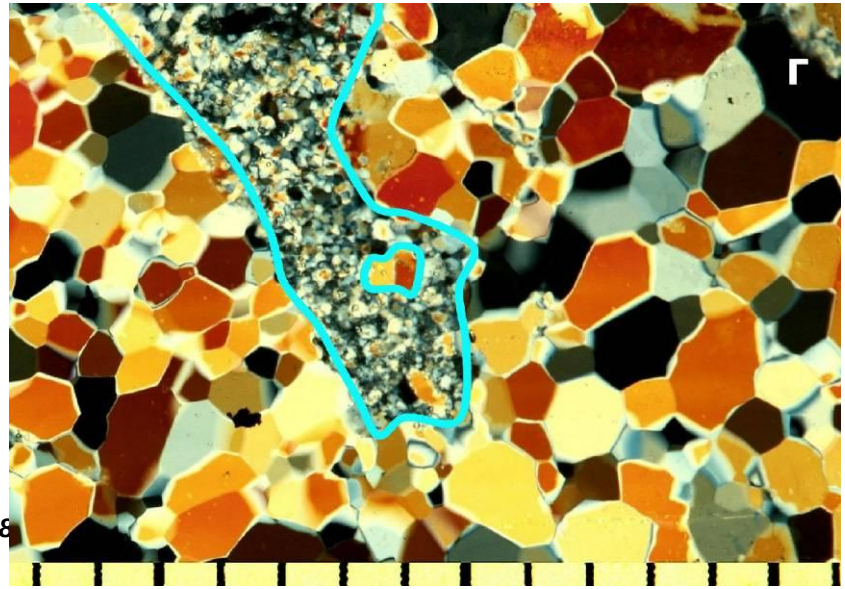




Thank you!

Problem N1: “The warm ice”





Problem N2: big ice crystals make the core breakoff difficult