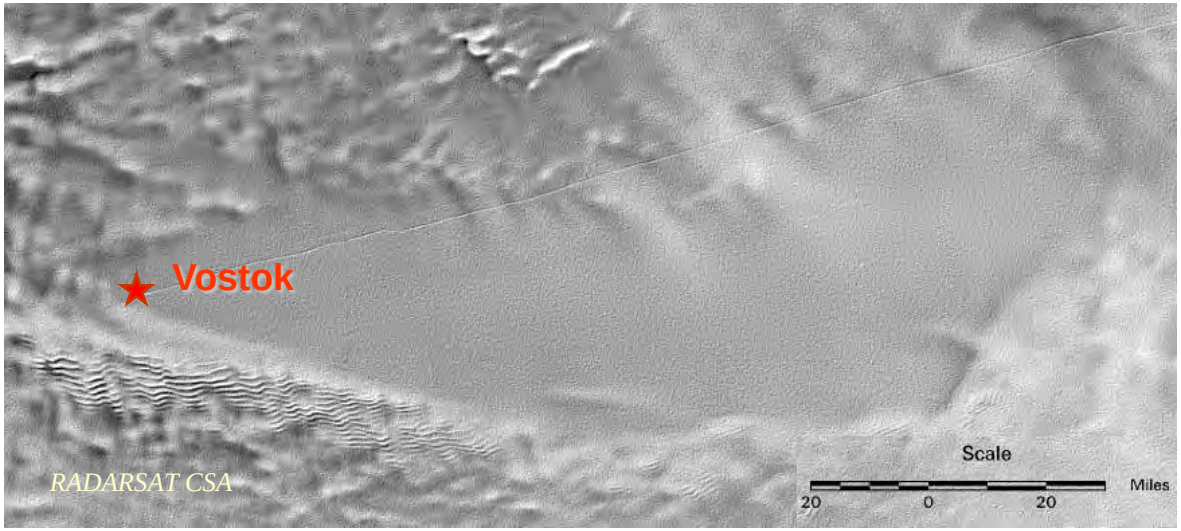
Lake Vostok studies: A review of recent results obtained in the framework of a RSF-supported project



Lipenkov Vladimir, Alekhina Irina, Ekaykin Alexey, Kozachek Anna and Shibaev Yuri

Arctic and Antarctic Research Institute St Petersburg

Grants for Labs
established before January 01 2014

- **1855** proposals
- **161** grants awarded, of them **16** – Earth Sciences

Organizations engagement in grants awarded

Ministry of Natural Resources and Environment of the Russian Federation
Federal Service on Hydrometeorology and Environmental Monitoring

PNPI, NRC "Kurchatov Institute"

Grant RSF No 14-27-00030 for the Climate and Environmental Reseach Laboratory (2014-2016)

Evolution of climate, glaciation and subglacial environments of Antarctica from the deep ice core and Lake Vostok water sample studies

- CERL team – **10** members
- Young researchers (< 39) – **7** members
- Collaboration with the St. Petersburg Mining University

Project aims

1) New methods of analytical investigation of the ice cores and lake water samples with the aim of obtaining qualitative information about past climate changes and the Antarctic ice sheet elevation, about the parameters of the hydrological regime of the sub-glacial Lake Vostok;

2) New and improved data on the past changes of climate and the size of the Antarctic ice sheet over the past 400,000 years, the parameters of Lake Vostok over the past 40,000 years, based on the analyses of the ice cores and lake water samples;

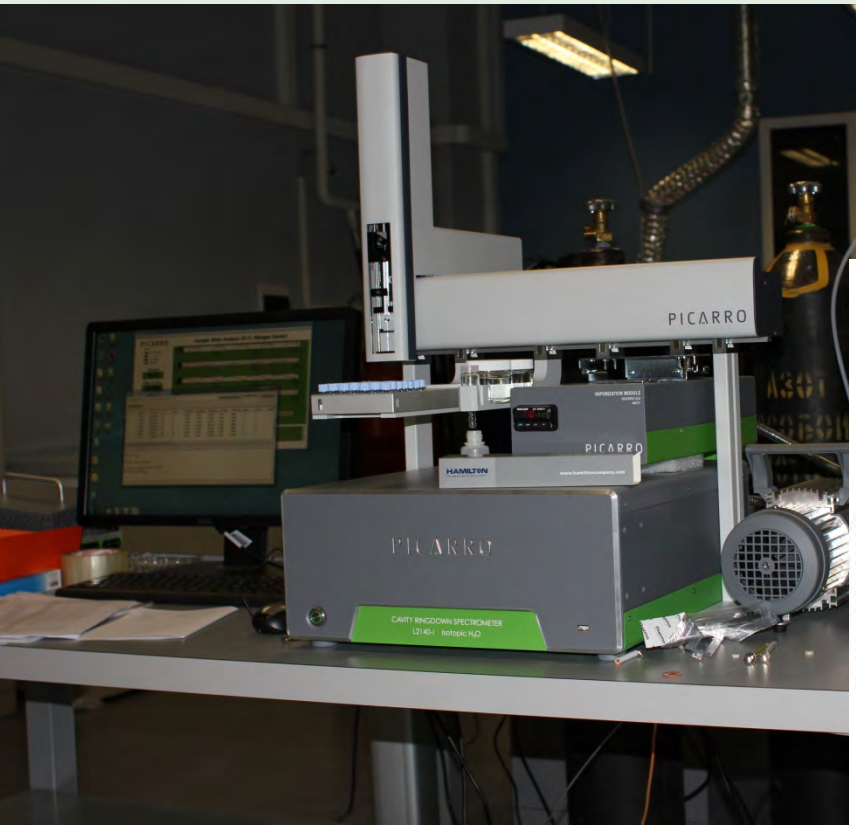
3) New and improved knowledge on the sequence and mechanisms of the global climate changes, on the reaction of the East Antarctic ice sheet, and on the functioning of the "glacier– sub-glacial lake Vostok" system;

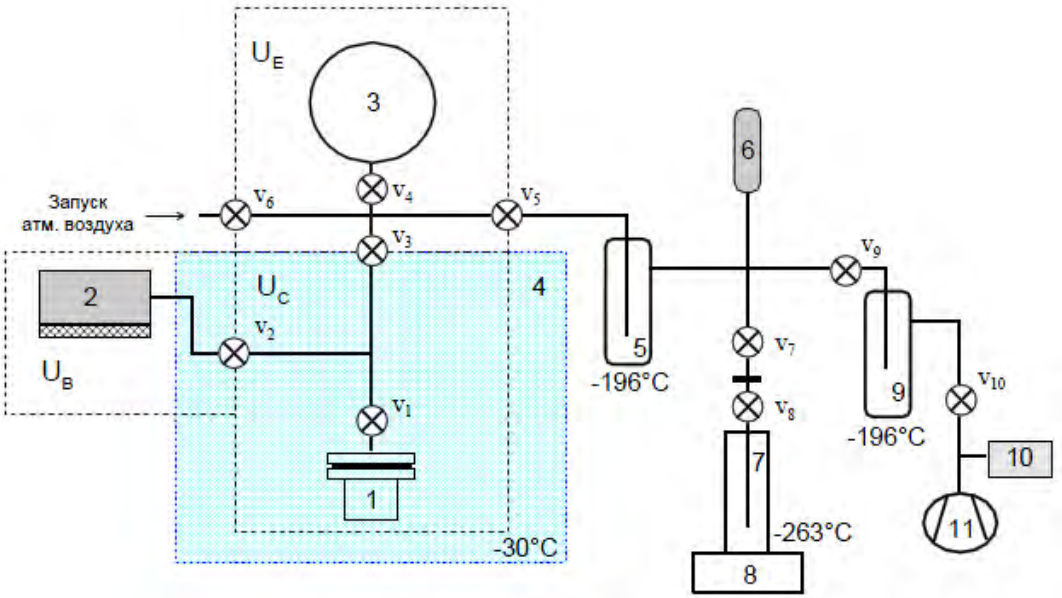
4) The improved technology of deep ice drilling and unsealing of sub-glacial lakes

Upgrading the analytical instrumentation in the CERL

Delta V Plus mass-spectrometer and GasBenchII - measurements of O^{17} , O_2/N_2 ratio, etc…..

Upgrading the analytical instrumentation in the CERL

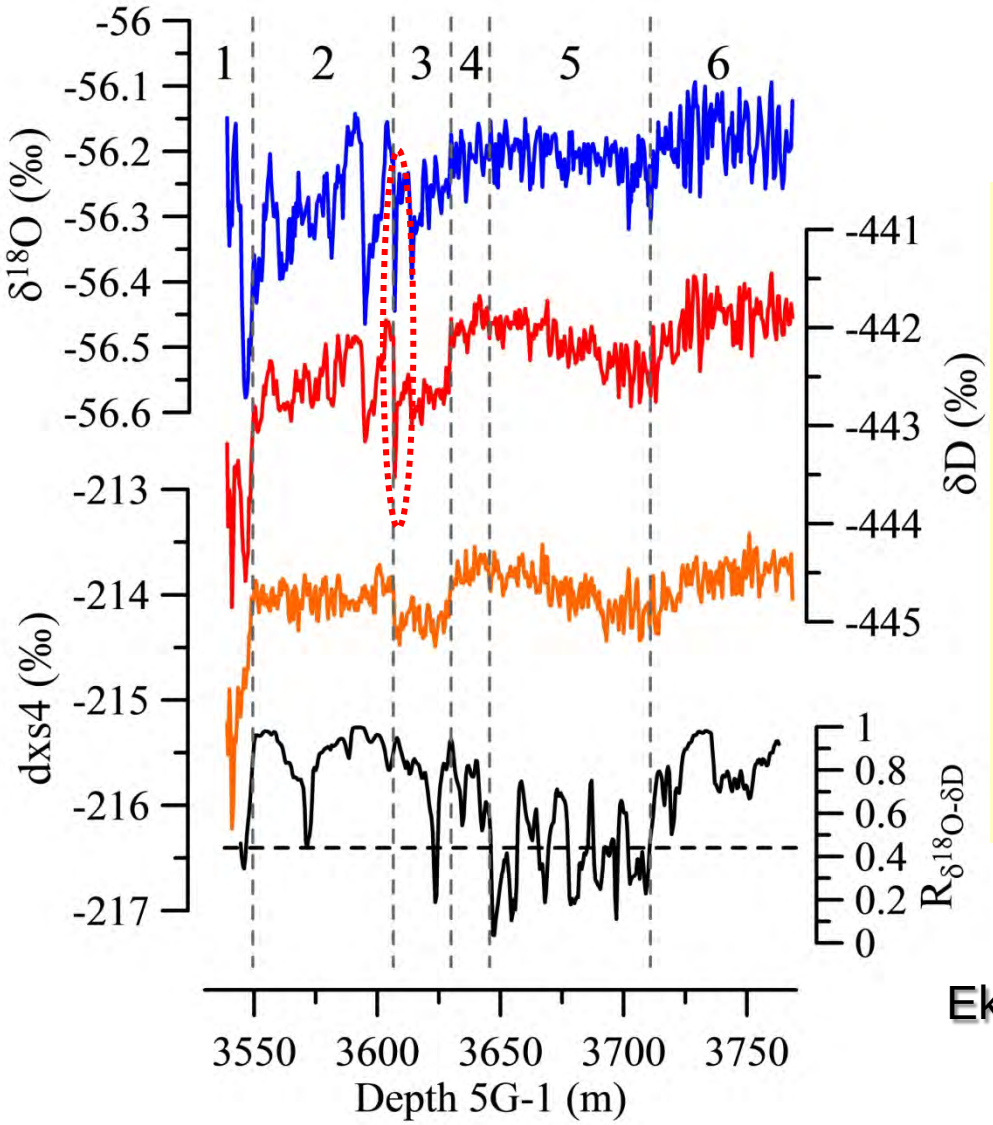




New generation laser analyser Picarro L-2140i

Gas analytical device STAN-2

Isotope content: Results



Robust signal in the three replicate cores of Lake Vostok accreted ice

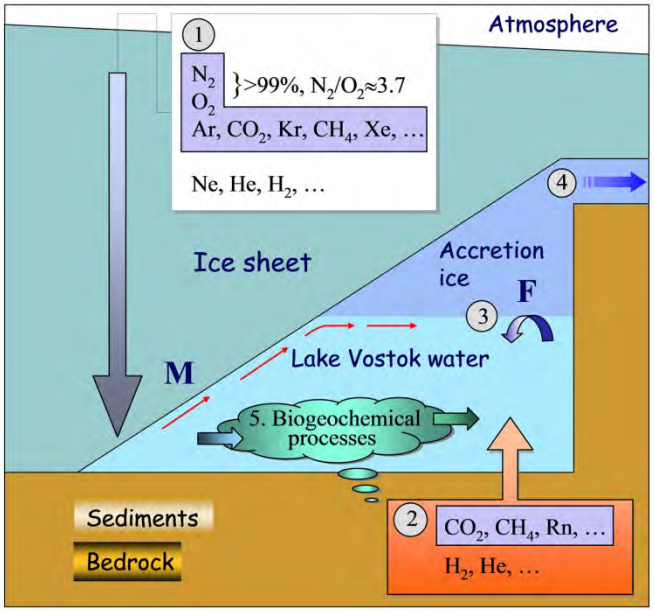
1. Large variations of dxs4 (isotope composition of water)
2. Significant changes in ice formation mechanism
3. Transition between lake ice 1 and 2 downstream of island

4-5-6 Slow freezing on at equilibrium conditions (5 – with considerable contribution of hydrothermal waters (*insufficient data accuracy?*)

Ekaykin Alexey' talk – Stable water isotopes studies ….

Gas content: Model

In lake water

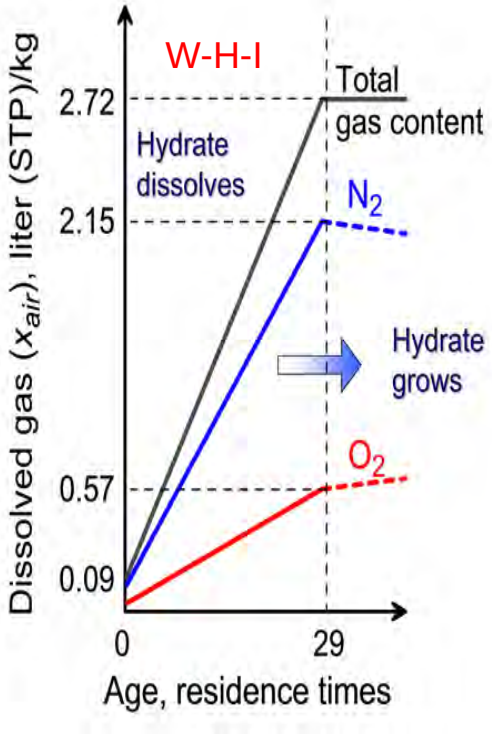


$\tau = t/t_R$

$C_{LV} = C_{met.\ ice} * (1+\tau)$

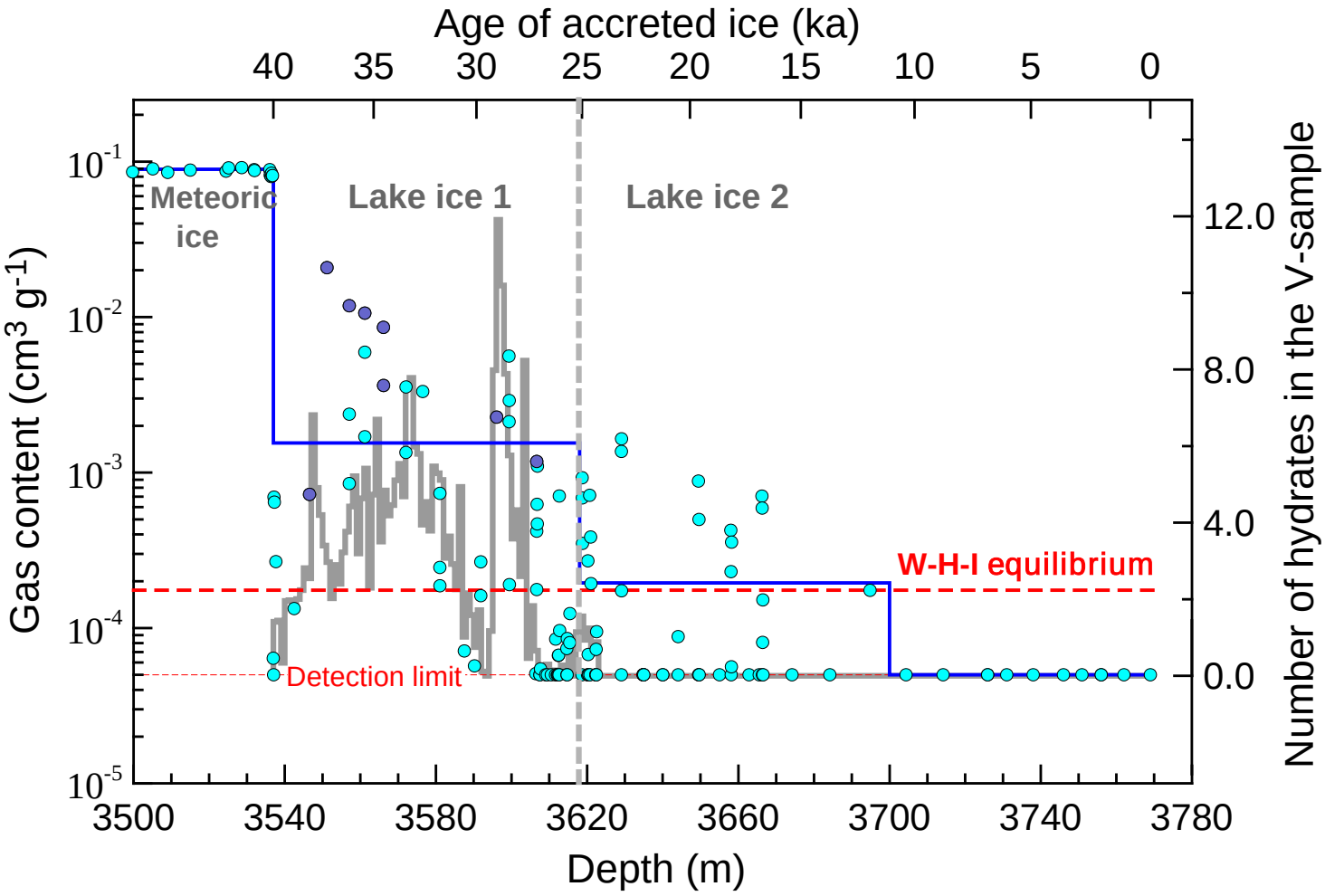
$N_2/O_2 = 3.7$ at $\tau \leq \tau_{eq.}$

$x_{O2} = X_{O2}$ at $\tau = \tau_{eq.}$



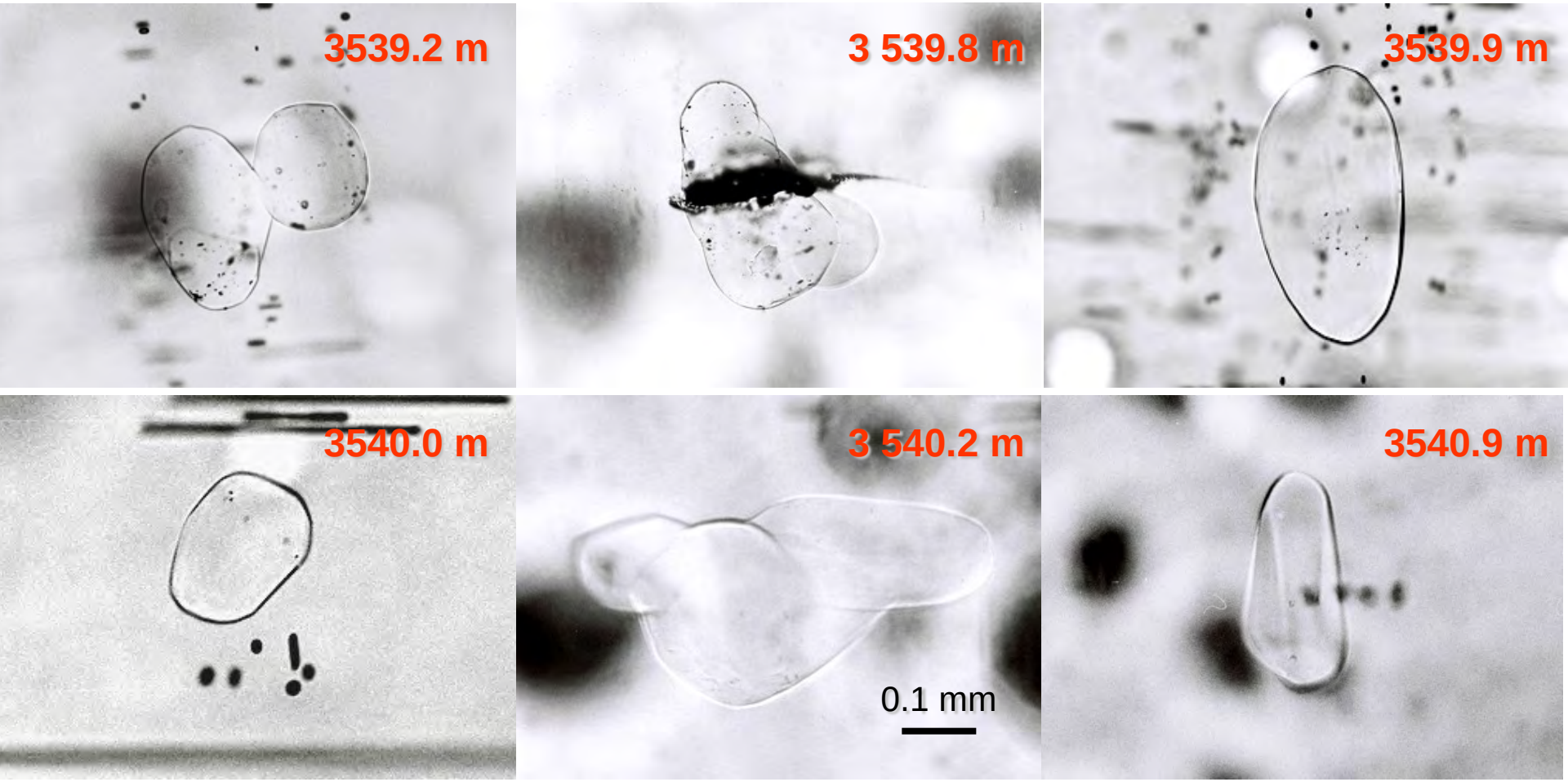
Models predict that about 30 water residence times are required to reach the upper bounds of concentrations of nitrogen and oxygen dissolved in lake water, which correspond to equilibrium between gases in solution and those in a hydrate phase.

Gas content: Data



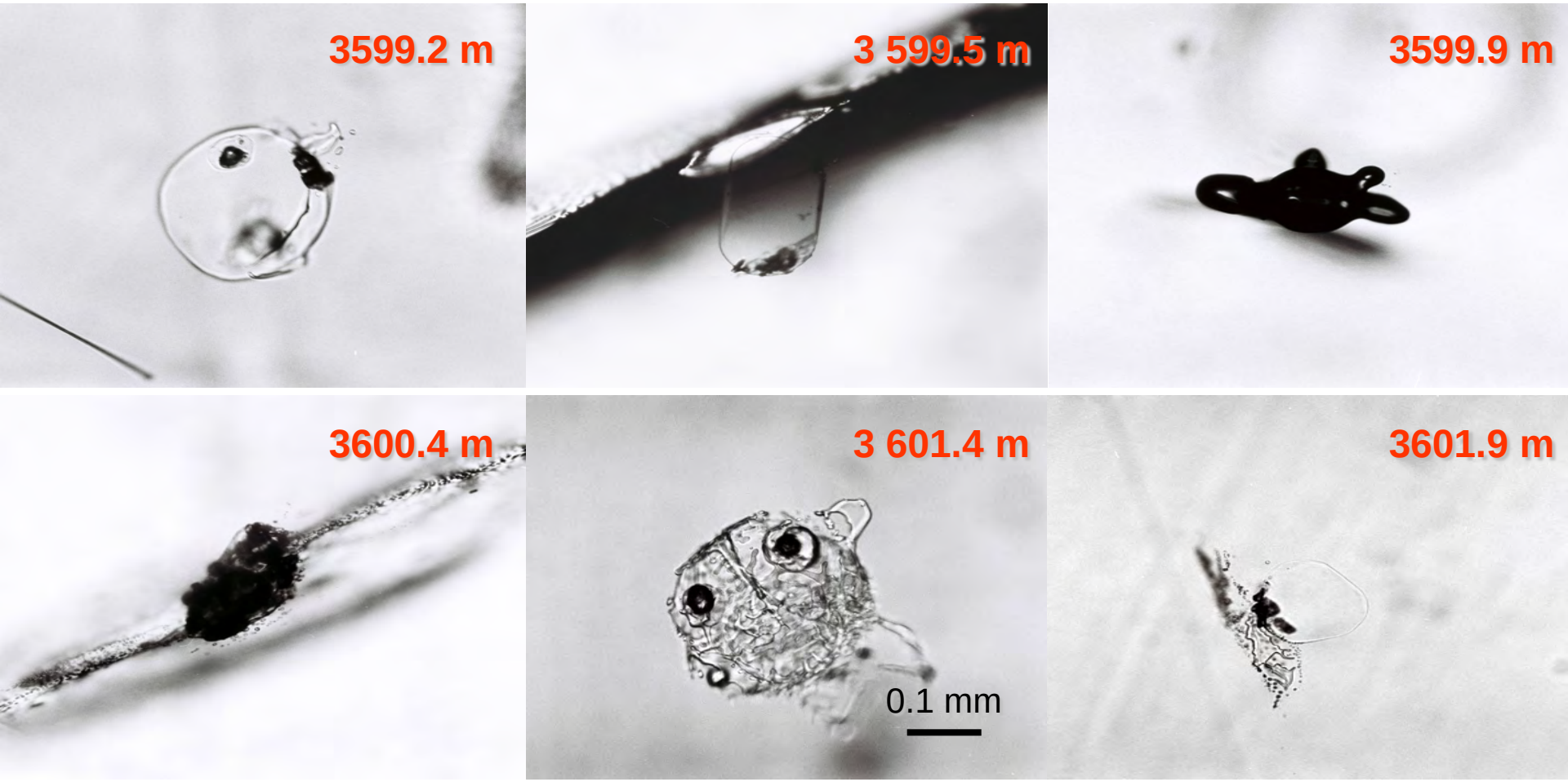
Our precise air content measurements show that Lake Ice 2 formed in the vicinity of Vostok Station, and now bedded below 3700 m, was accreted from the water in which the concentration of dissolved gases was far below the uppermost level determined by equilibrium with a hydrate phase

Gas inclusions = Gas hydrates = ‘Water pockets’?



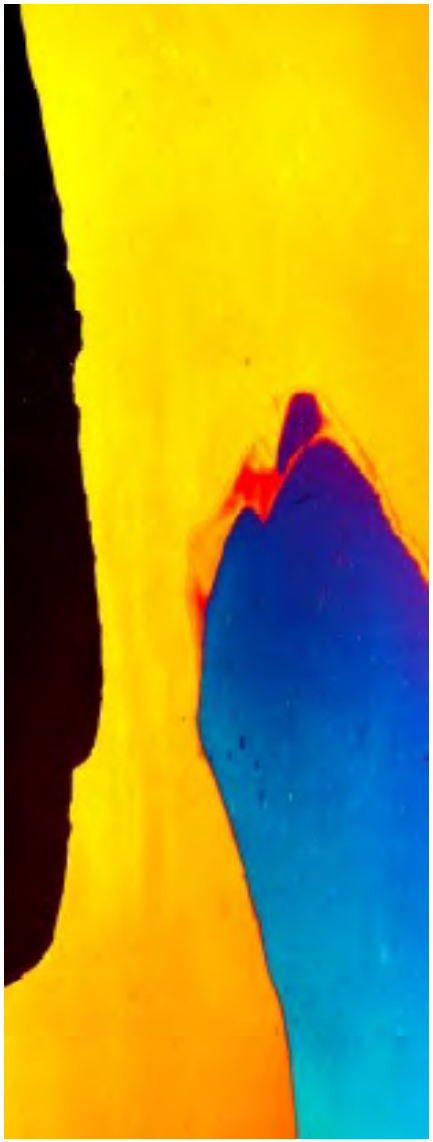
Gas hydrates in accreted ice 1

Gas inclusions = Gas hydrates = ‘Water pockets’?

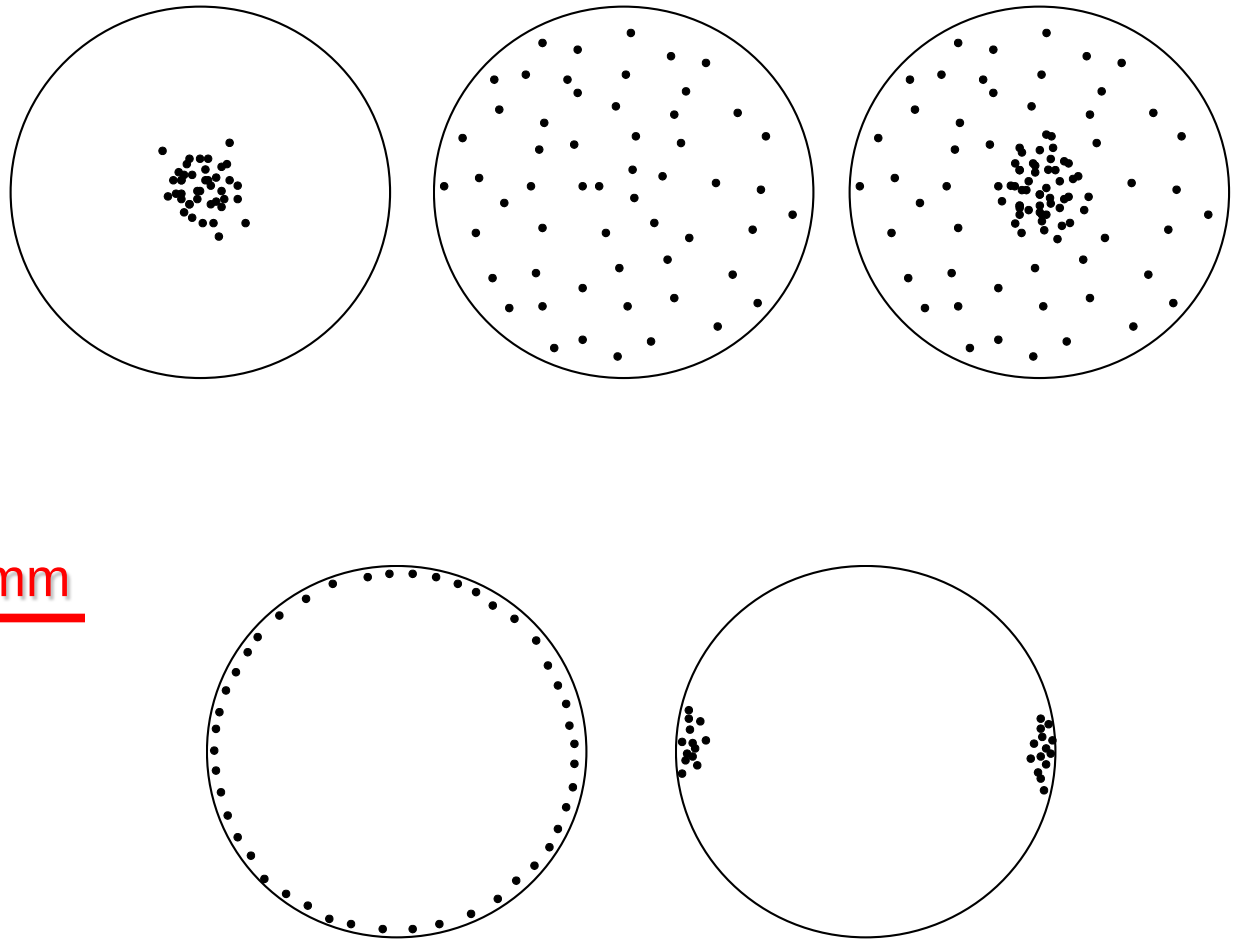


Gas hydrates and air cavities in accreted ice 2

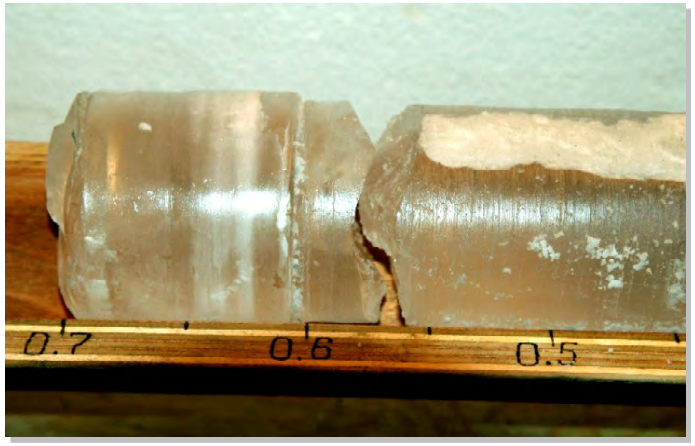
Ice texture and fabric: Problem 1 - large crystals

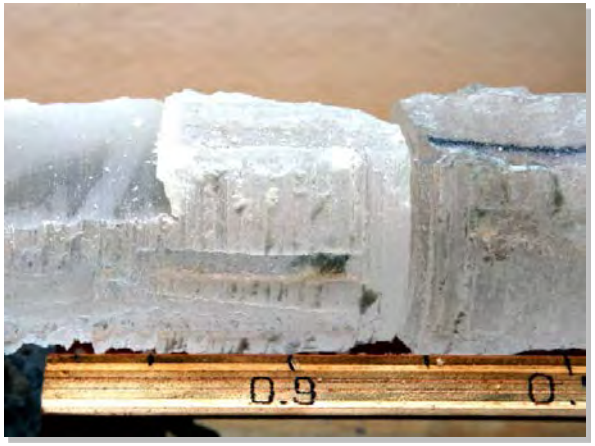


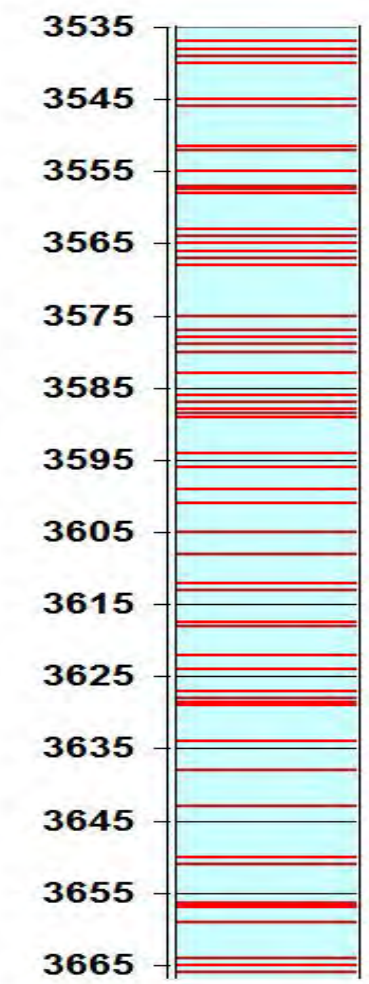
20 mm



Ice texture and fabric: Problem 2 – ice core orientation





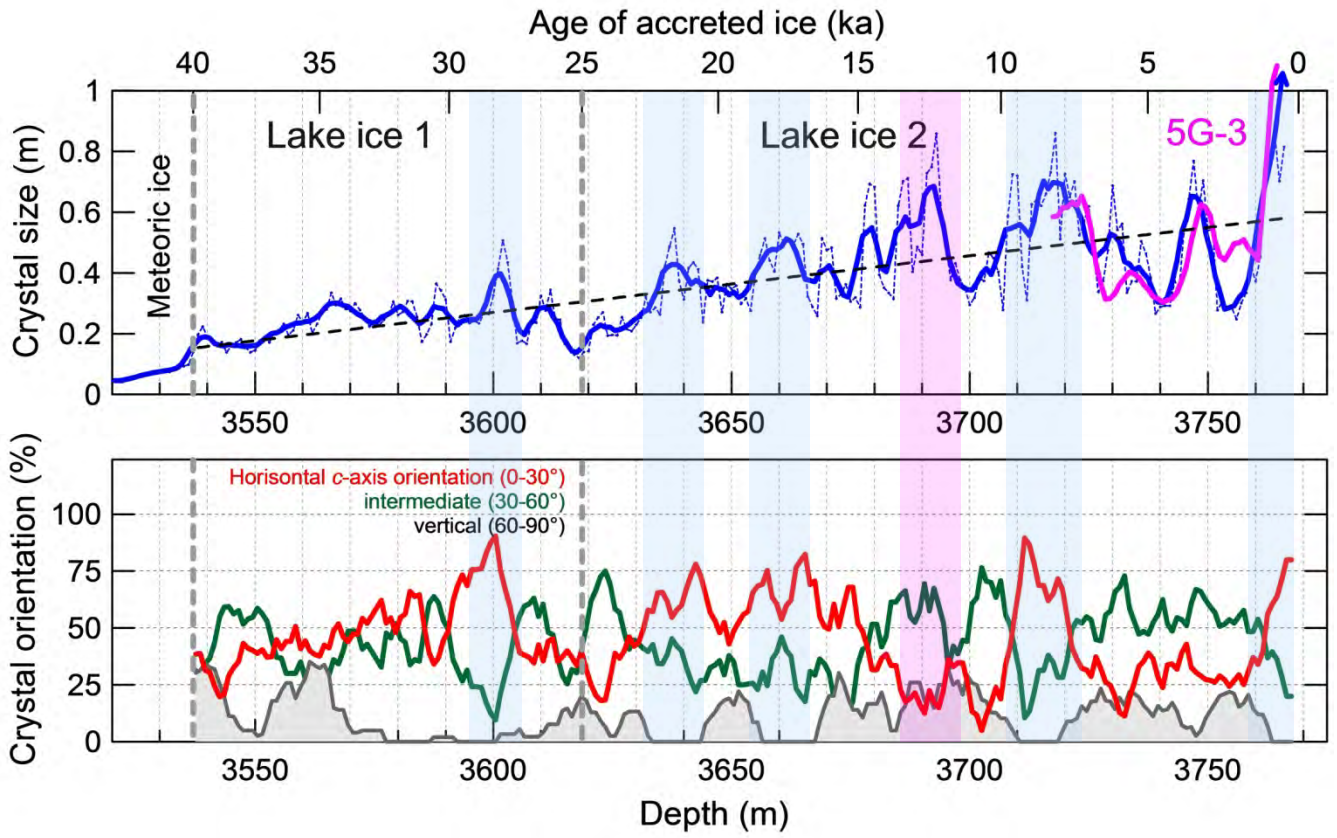


Correcting angle between two adjacent cores:

$$\Delta X = (\arccos(\frac{b_2}{\sqrt{a_2^2 + b_2^2}}) \cdot sign(a_2) - 90 \cdot sign(c_2)) - (\arccos(\frac{b_1}{\sqrt{a_1^2 + b_1^2}}) \cdot sign(a_1) - 90 \cdot sign(c_1))$$

63 ice core pieces have been aligned in 5G-1 core

Ice texture and fabric: Results



Gradual orthotropic grain growth

+

supercooled water supply to the crystallization front

⇓

development of horizontal c-axis orientation

or

Stratified water column

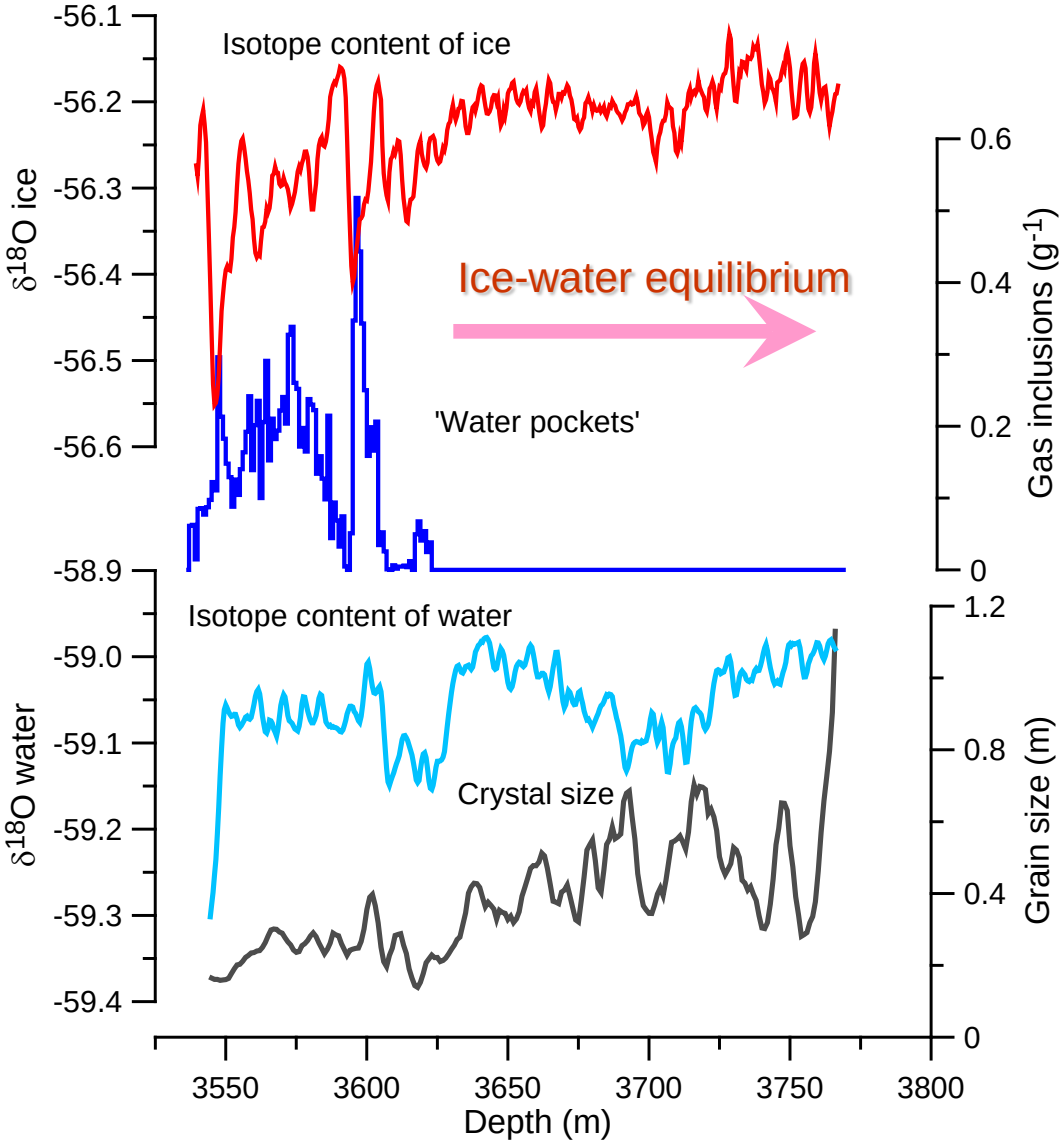
⇓

vertical c-axis orientation

Preliminary conclusion

1. Accreted ice texture and fabric data denotes spatial and/or temporal variability of melt water inflow to the lake ice formation site
2. Lake ice 2 forms by slow (orthotropic) growth in equilibrium with lake water

Conclusion



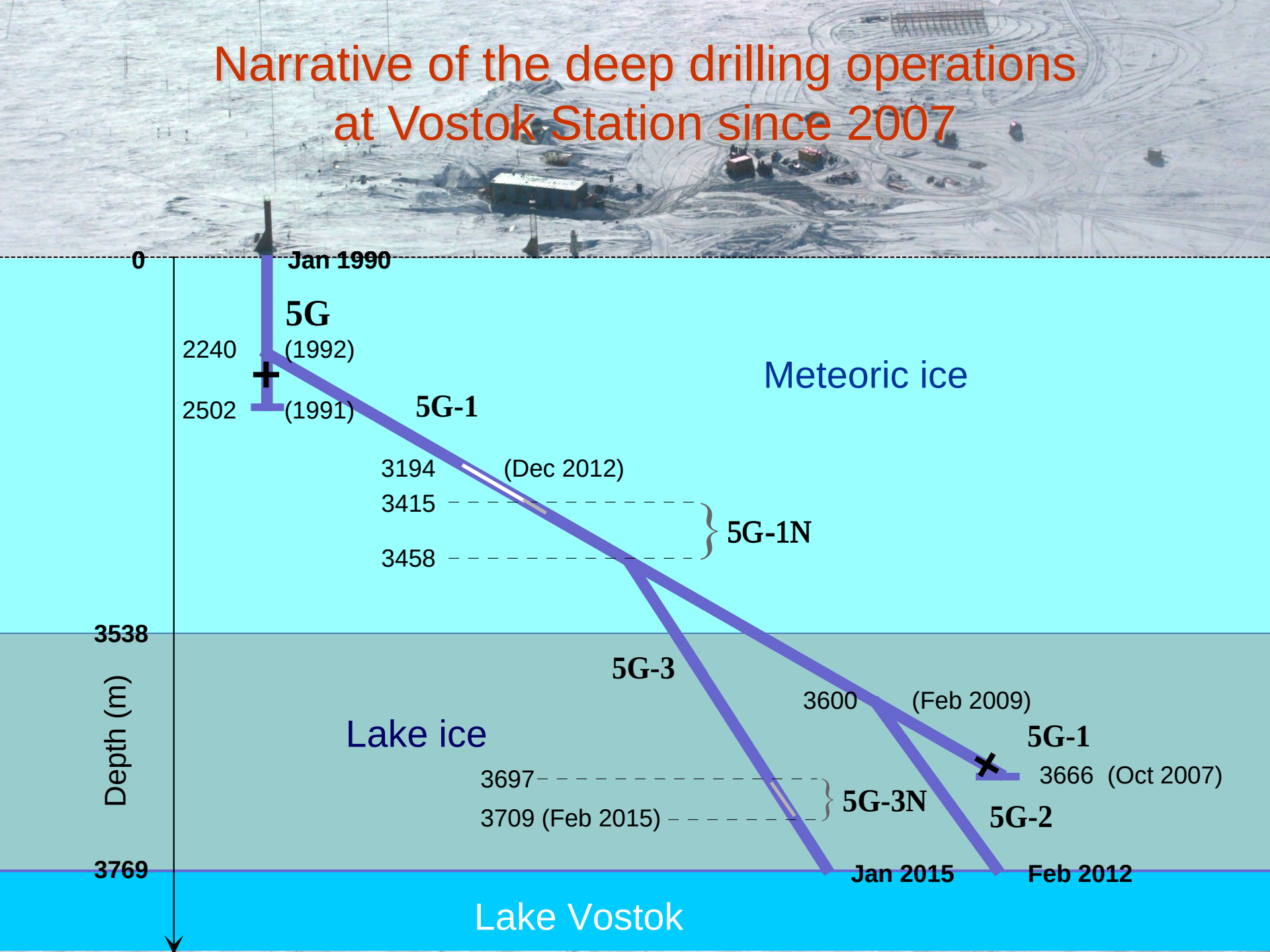
The three independent data sets indicate that

(a) lake ice 2 was formed in equilibrium with lake water,

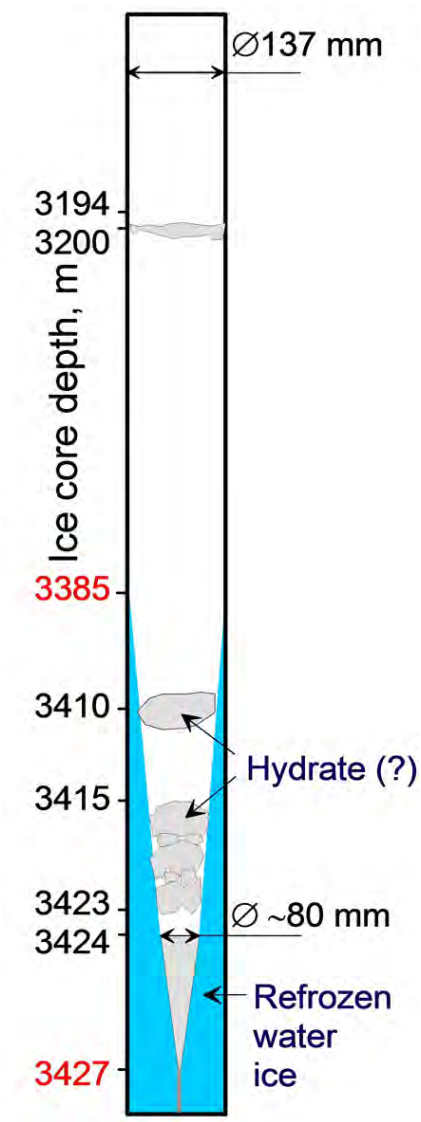
(b) the gas and isotopic properties of lake water vary significantly in space/time due to fluctuations of the melt and hydrothermal water inflow to the ice formation site

The gas and isotopic properties of lake water can be deduced from lake ice 2 analyses

Narrative of the deep drilling operations at Vostok Station since 2007



Redrilling of frozen water after first lake unsealing



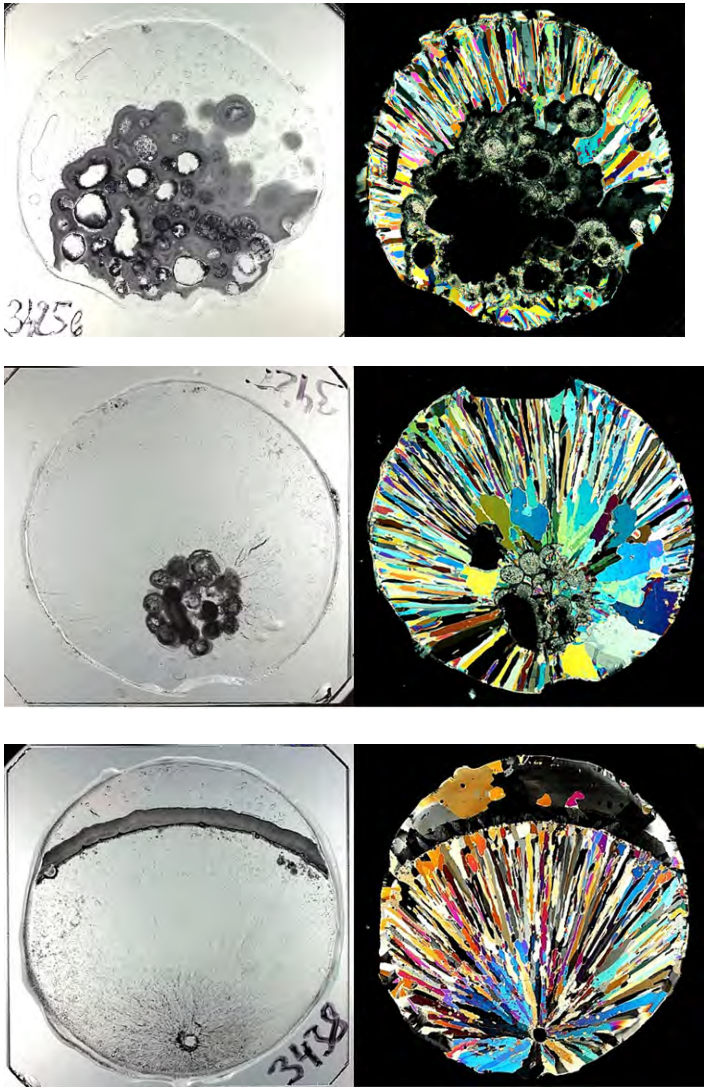
3194 m – beginning of hole reaming (575 m above the lake)

3200 m – first cork of bright white hard material

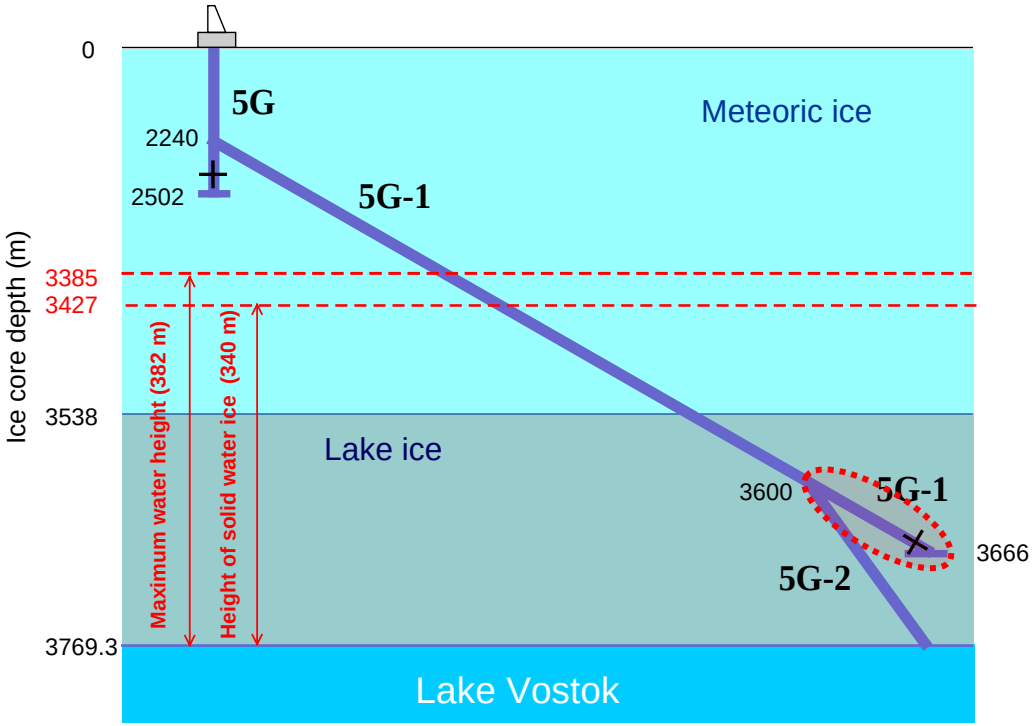
3385 m – first crescent-shaped fragments of refrozen water ice

3415-3427 m – mixed clathrate hydrate of hydrochloroflurocarbon densifier (HCFC-141b) filling ~ 30% of the hole volume

3427-3458 m – frozen lake water (glacial ice gradually replace the water ice in the core as the new hole deviates from the initial hole 5G-1)



Lessons from the first LV unsealing



Hydrostatic imbalance, if exists, is lower than uncertainties of the drilling fluid pressure measurements (± 1 bar)

A series of reactions occurs between subgalcial water rising in the hole and different components of the drilling fluid

The unexpectedly high water rise and fluctuations of the water level in the hole can be explained by:

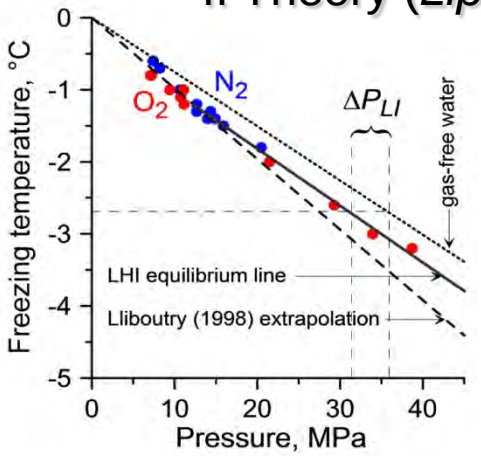
a) suction effect during the drill hoisting;

b) high initial level of the drilling fluid in the casing column;

c) the role of abandoned section of 5G-1 hole in generating slug flow in the rising water-drilling fluid mixture.

The pressure melting temperature of ice and concentration of gases in lake water

I. Theory (*Lipenkov & Istomin, 2001*)

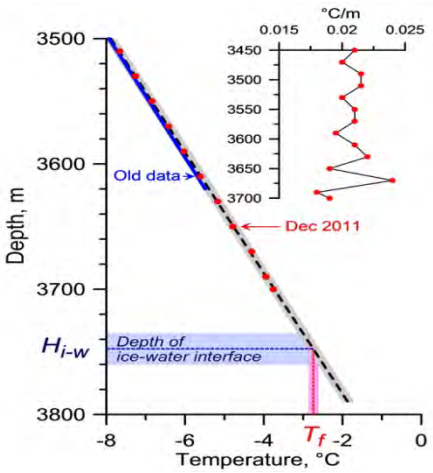


$$T_f(S,P) = T_f(S,0) - 7.53 \cdot 10^{-2} P(\text{MPa})$$

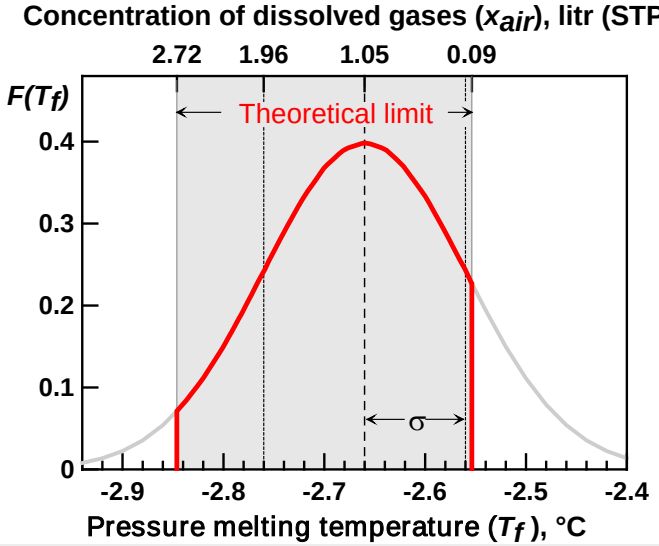
$$P(\text{MPa}) = P_{atm} + g\rho_i H_{i.e.} \approx 9.049 \cdot 10^{-3}\left[H_{real}(\text{m}) - 32\right]$$

$$\Delta P_{LI} = P_{LI}(0) - P_{LI}(x_{air}) \approx \frac{RT_f x_{air}}{\Delta V_w}$$

II. Measurements (2012-2015)



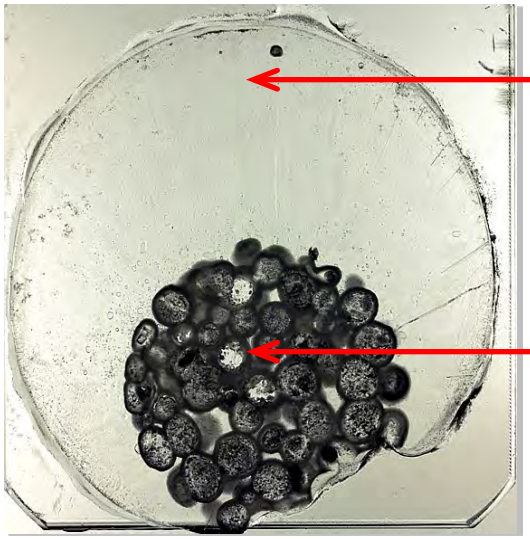
III. Interpretation



H = 3758.6 3 m
P = 33.78 0.005 MPa
T_f = -2.66 0.10 ºC
x_{air} = 1.35 g/l
x_{O2} = 0.32 g/l

Drilling fluid components in the frozen water core

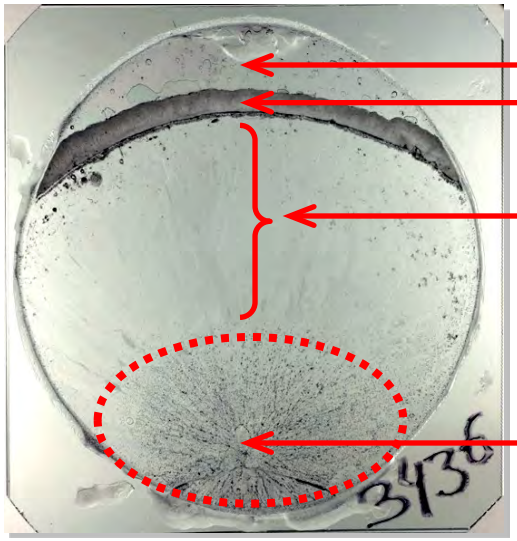
3426 m



Refrozen water ice:
concentration of DF components ~5-10%

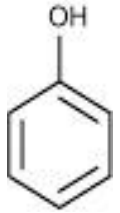
Hydrate core:
DF components ~15%, but HCFC-141b is increased by factor of 2

3436 m



Meteoric ice
Hydrate layer

Refrozen water ice:
Concentration of DF components ~16 mg/l



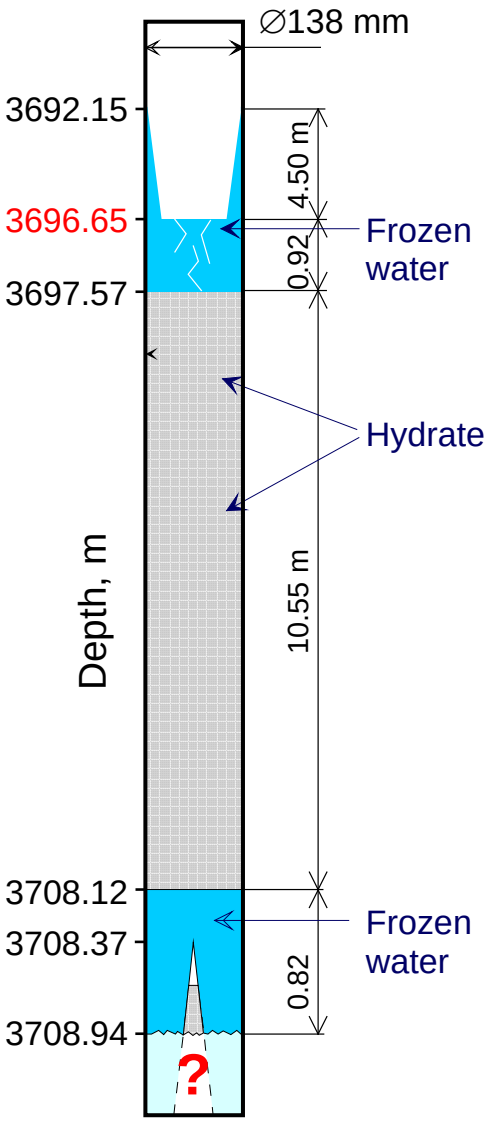
Central channel:
HCFC-141b ~15 mg/l
Phenol congeners ~35 mg/l
And NO KEROSENE!

Drilling technology – Mining Institute' input

- Further development of the technology of deep drilling in the proximity of subglacial lakes and introduced corresponding changes in the design of the drill

- Design of a process for maintaining the borehole in close proximity to the subglacial water in running order for performing direct investigations of the Lake Vostok water body, which will be carried out through filled with drilling fluid borehole 5G-3.

Redrilling of frozen water after second lake unsealing

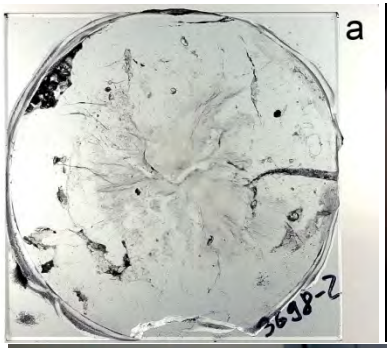


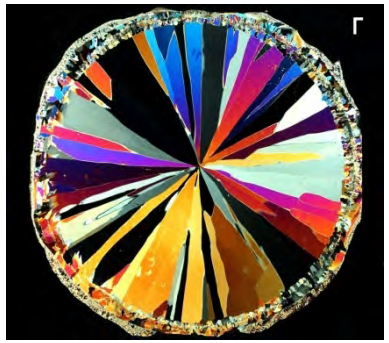
3692 m – tight section of hole starts (77 m above the lake)

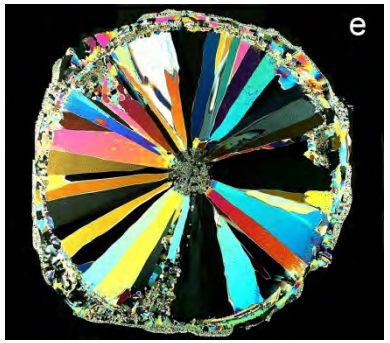
3696.65-3697.57 m – frozen water

3697.57-3708.12 m – white solid substance – mixture of ice (18%) with HCFC-141b hydrate (38%) saturated with kerosene (44%)

From 3708.12 m – frozen lake water (61 m above the lake)







Main problems of using the existing hole for LV exploration

1. Fluctuation of level of the drilling fluid and water in the hole during round-trip of drilling-tool and sampling devices

2. Reaction between drilling fluid and subglacial water

Clear evidence for the formation of mixed clathrate hydrates of air and hydrochlorofluorocarbon densifier (HCFC-141b=R-141b) is found on a sample recovered from the bottom of the Vostok deep borehole. Subglacial water (SGW) appears to have reacted with the drilling liquid to build a large lump of clathrate hydrate. Moreover, dissolved air in the SGW appears to have participated in the formation of mixed hydrates of air and HCFC-141b. These observations raise concerns with respect to the use of HCFC-141b densifiers.