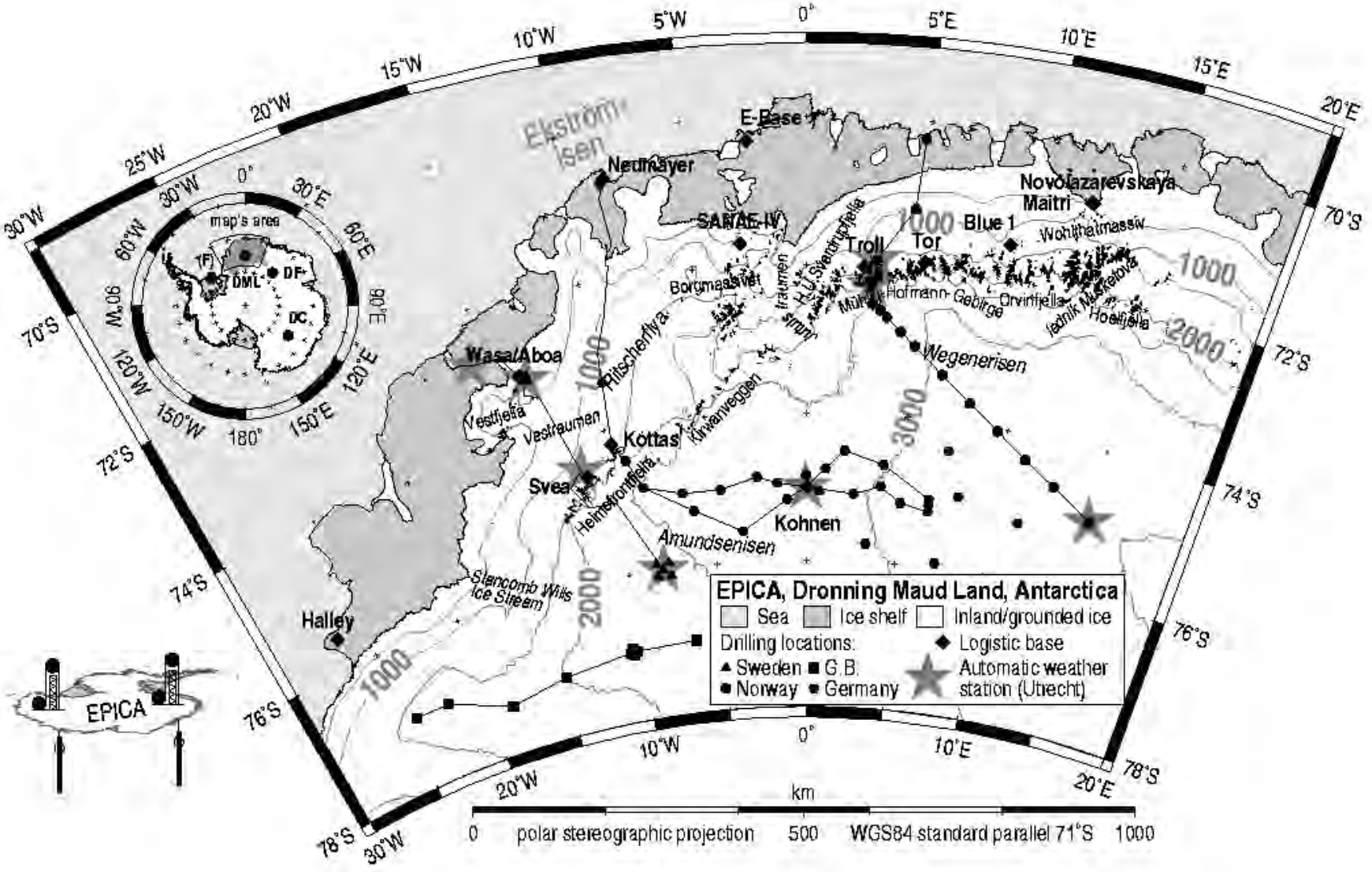
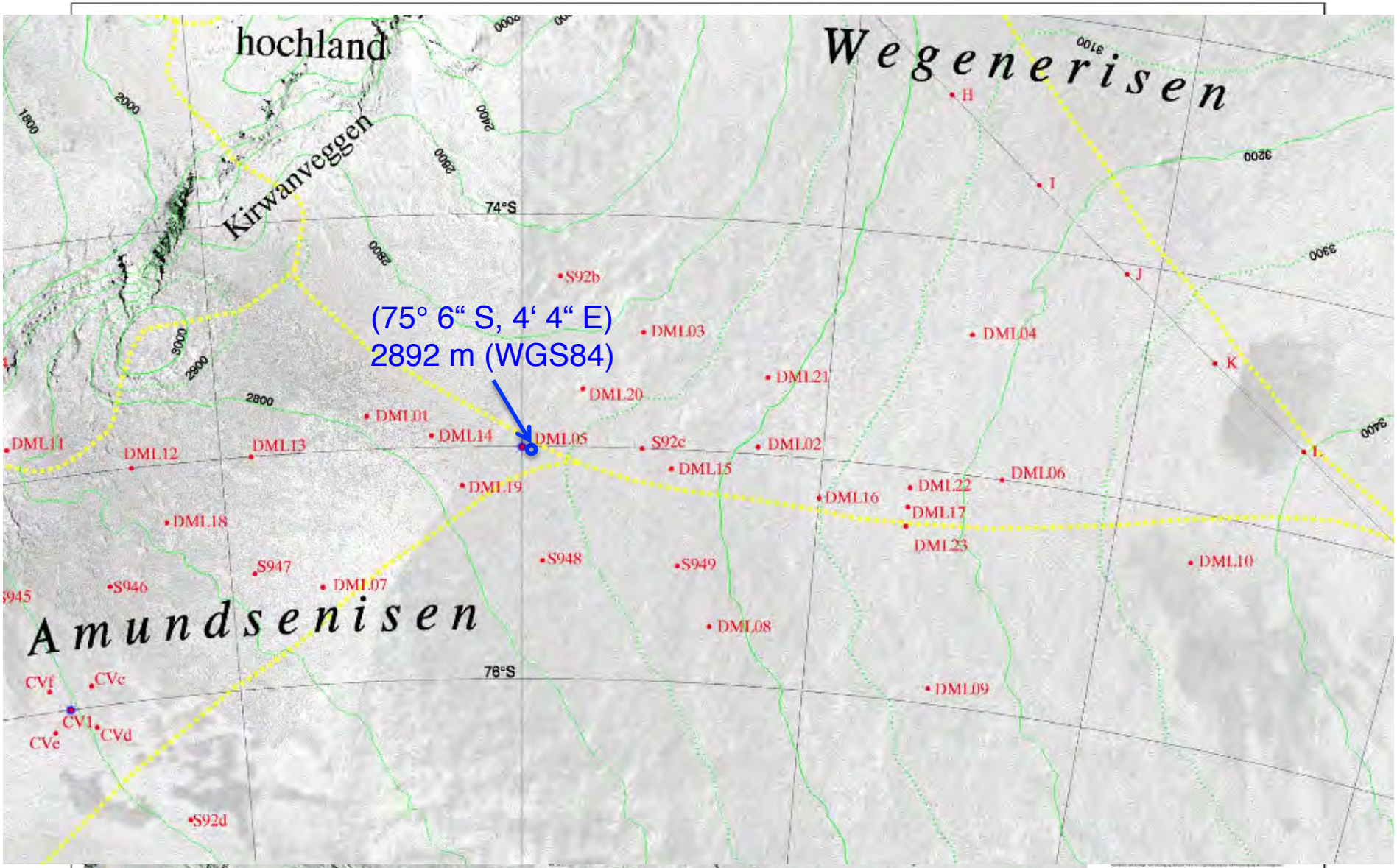
Deep drilling at Base Kohnen, Antarctica: results and future development

F. Wilhelms, D. Fritzsche, S. B. Hansen, S. Æ. Hilmarsson, H. Grobe, A. Karsten, L. Karsten, A. Jaeschke, M. Takata, S. S. Jakobsdottir, G. Lawer, M. Gerasimoff, K. Hörnby, P. Juckschat, I. Schärmeli, A. Frenzel, As. Lambrecht, J. Schmitt, M. Kaczmarska, G, Hoffmann, S. G. Sheldon, M. Trenke, H. Miller, An. Lambrecht, D. Dick, B. Twarloh, F. Valero-Delgado, T. Karlin, P. Kaufmann

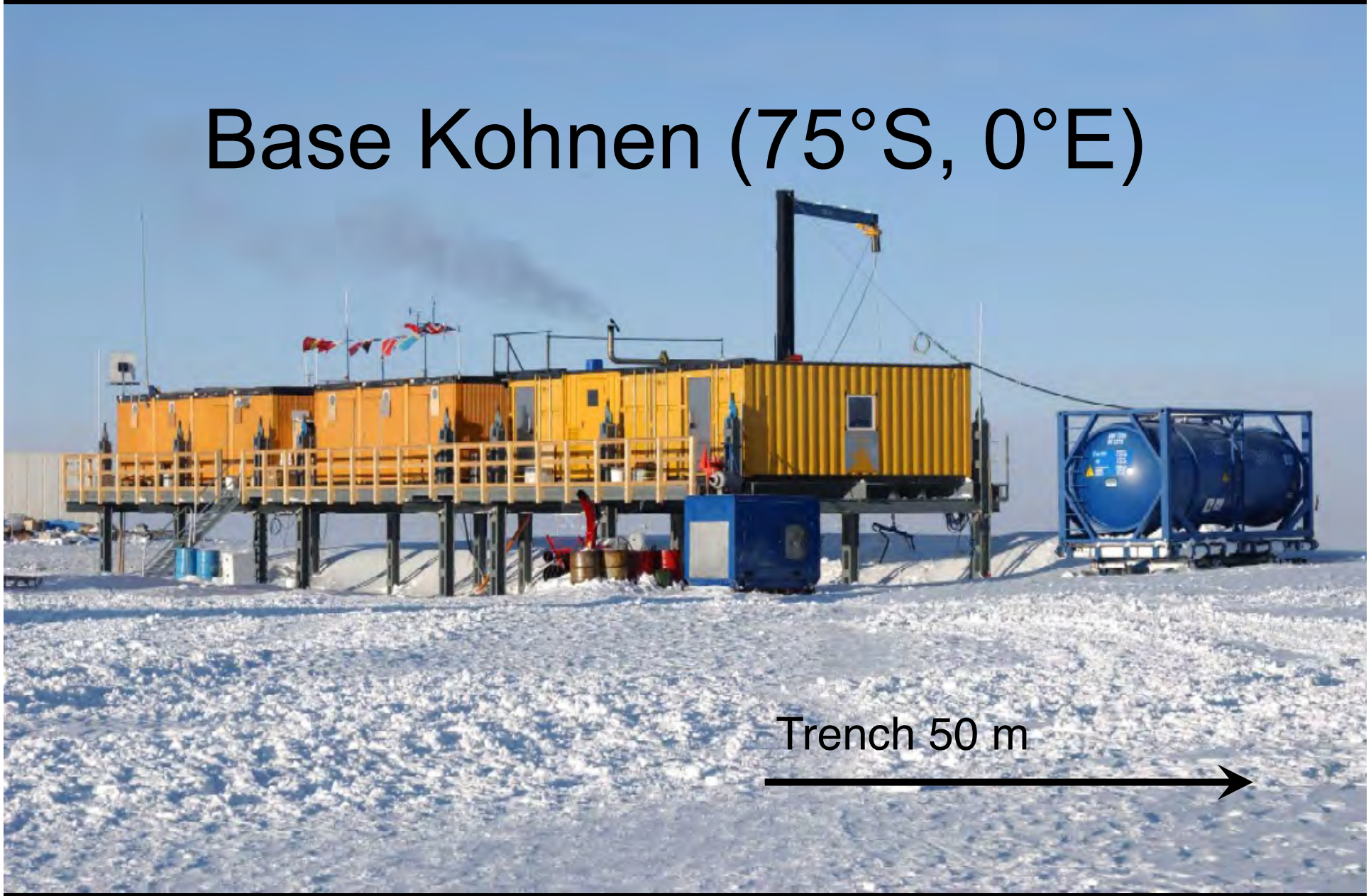
The EDML vicinity



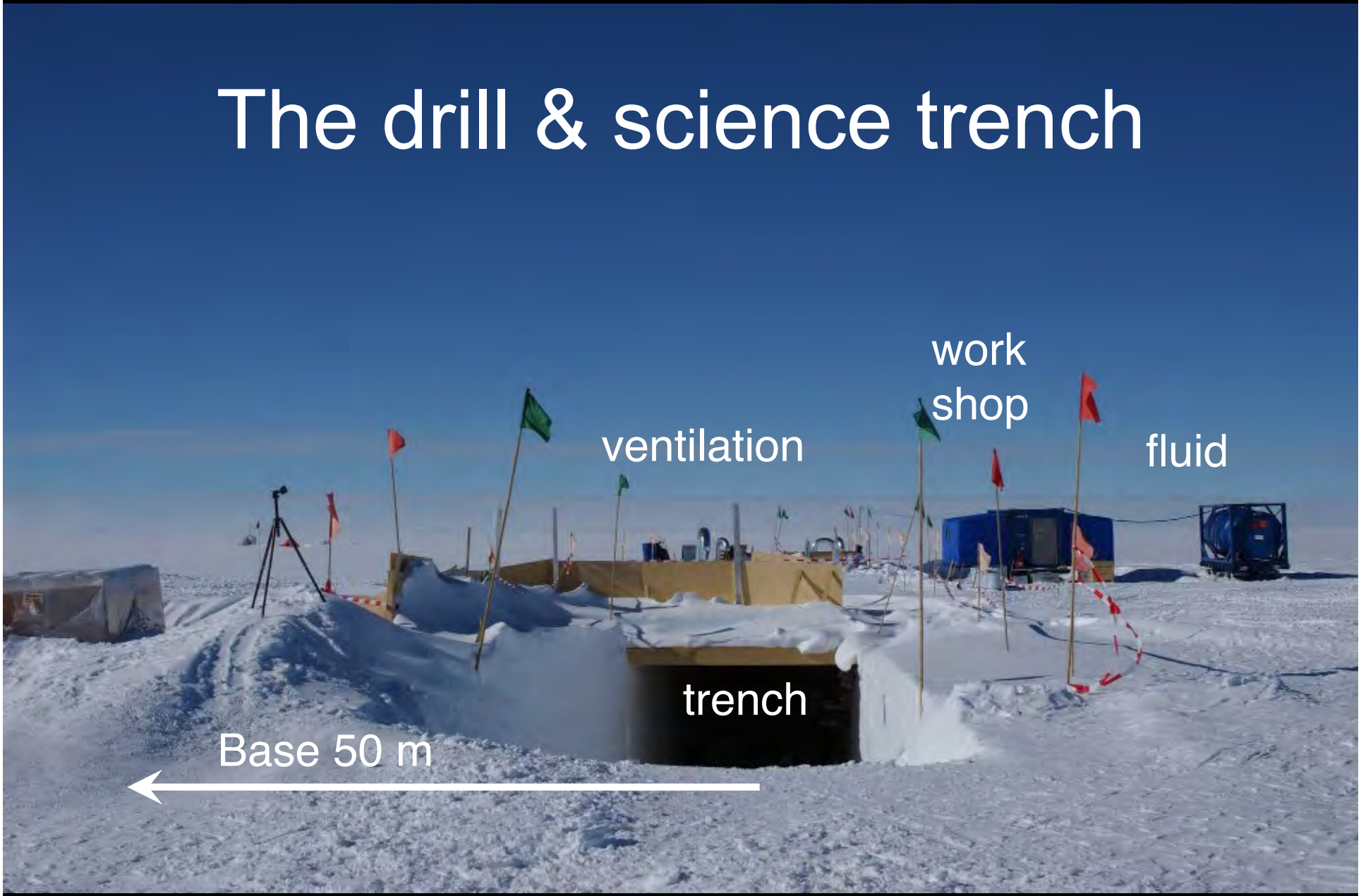
The area


hochland
Wegenerisen
Kirwanveggen
74°S
(75° 6“ S, 4‘ 4“ E)
2892 m (WGS84)
S92b
DML03
DML04
DML21
DML20
DML01
DML14
DML05
S92c
DML02
DML15
DML19
DML16
DML22
DML06
DML17
DML23
DML10
DML18
S947
S948
S949
S946
DML07
DML08
DML09
Amundsenisen
76°S
CVf
CVc
CV1
CVd
CVe
S92d
DML11
DML12
DML13
H
I
J
K
L
Land

Base Kohnen (75°S, 0°E)

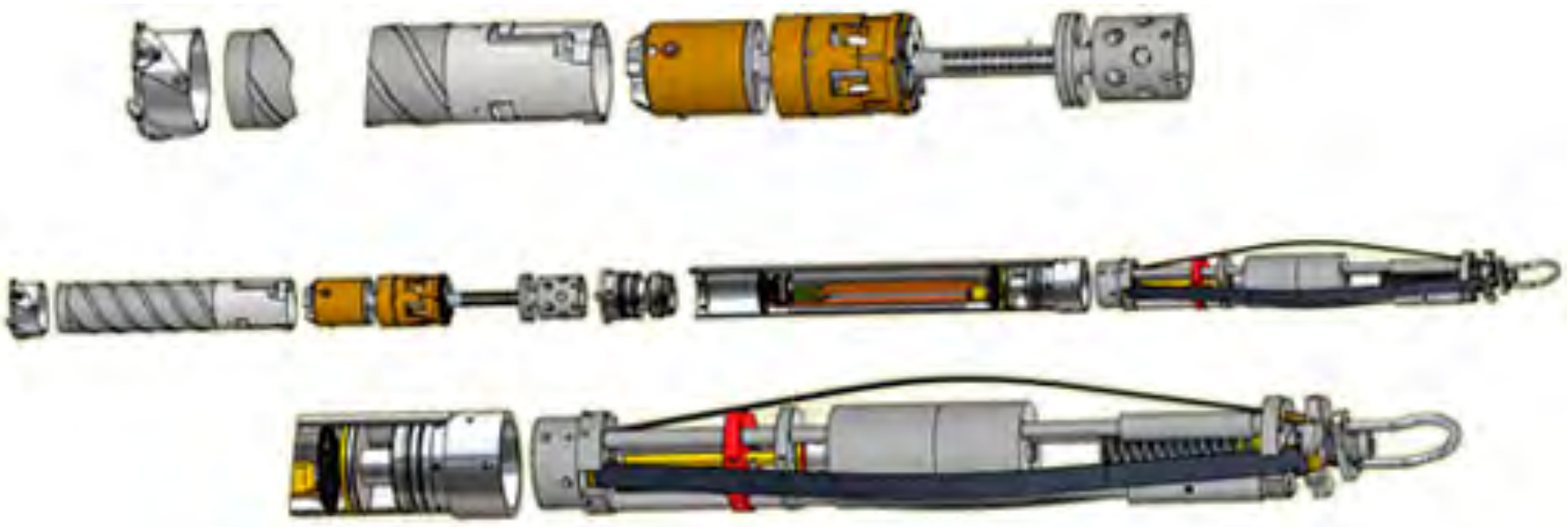


The drill & science trench



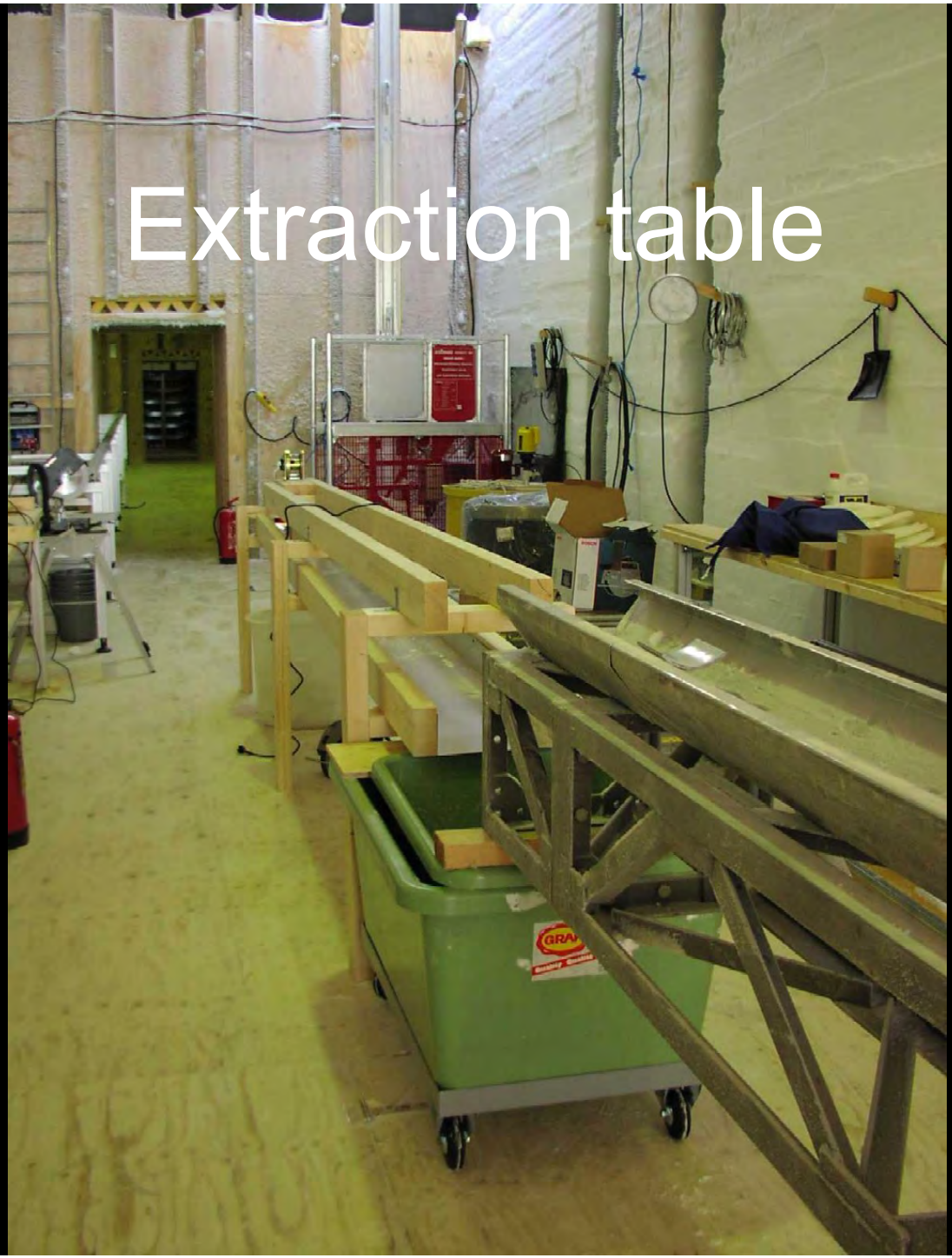

The interior
during
operation

The EPICA/NGRIP drill

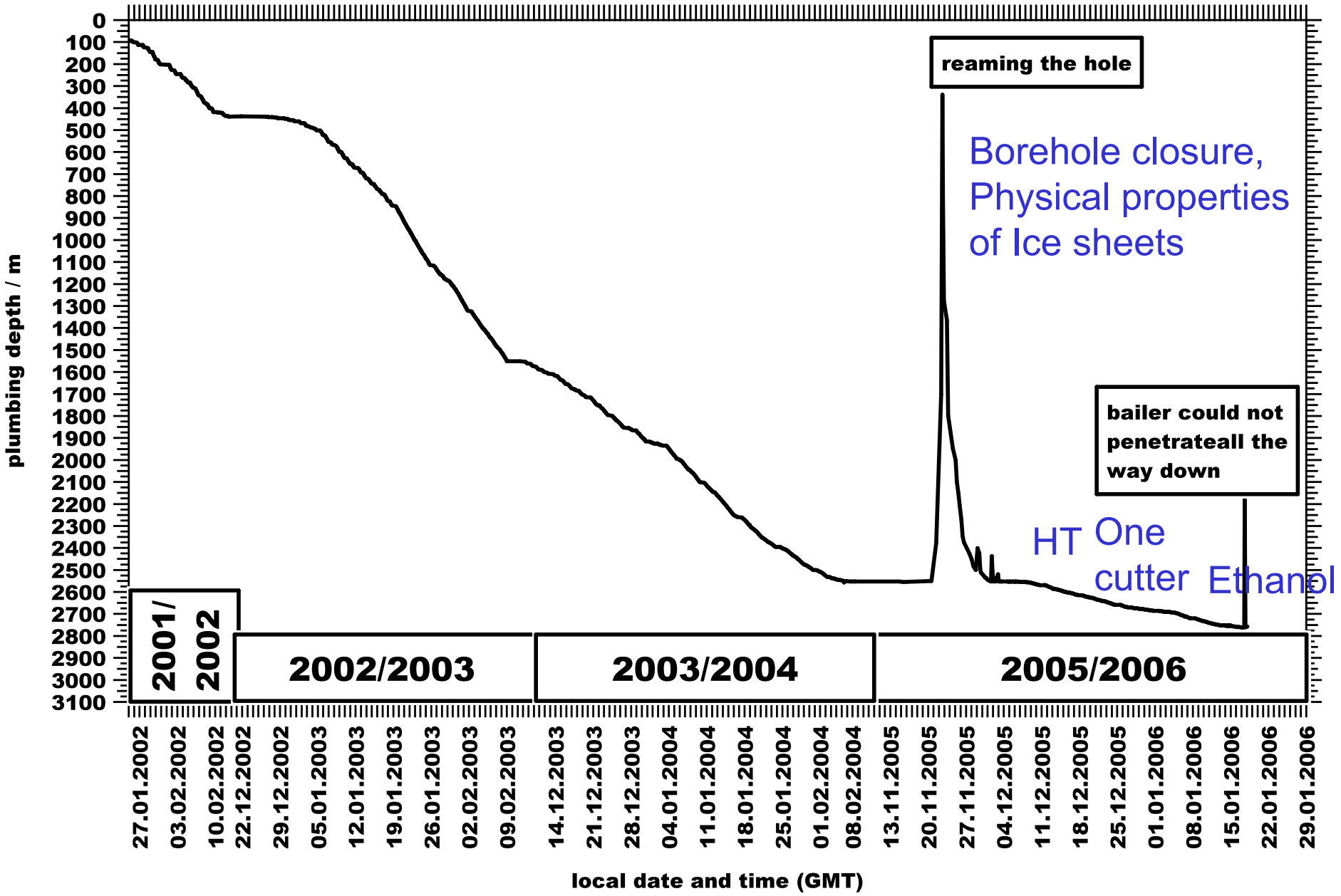


graphics: S.B. Hansen

Extraction table

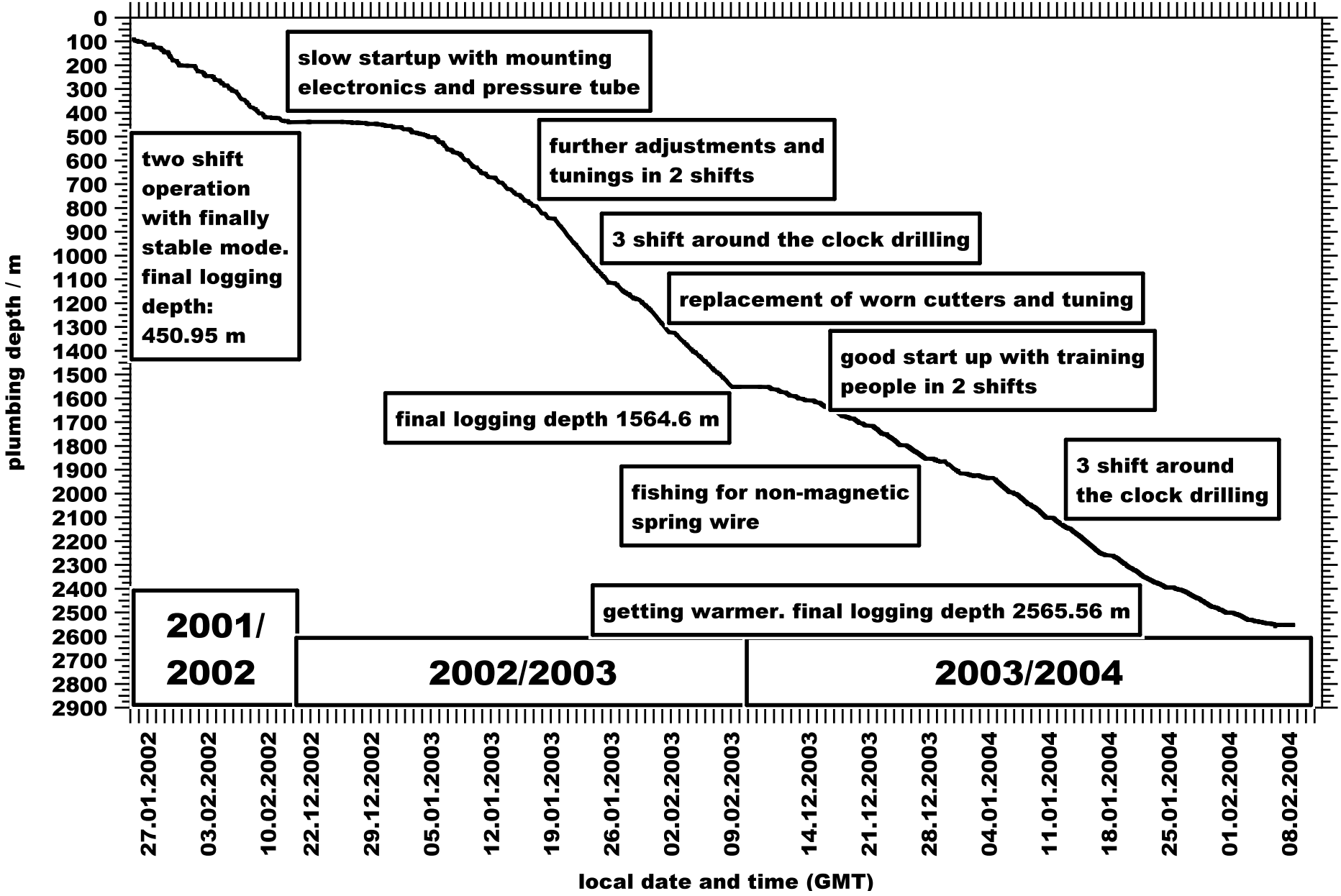


The penetration




At the end of the 3rd season warm ice problems
• bad penetration
• core sticking in the barrel
The one armed bandit

The penetration in the first three seasons



Lessons learnt

1. Don‘t send equipment around between different projects

- Too short maintenance times
- Significant air cargo costs
- A lot of management
- Conclusion: Stress!!!

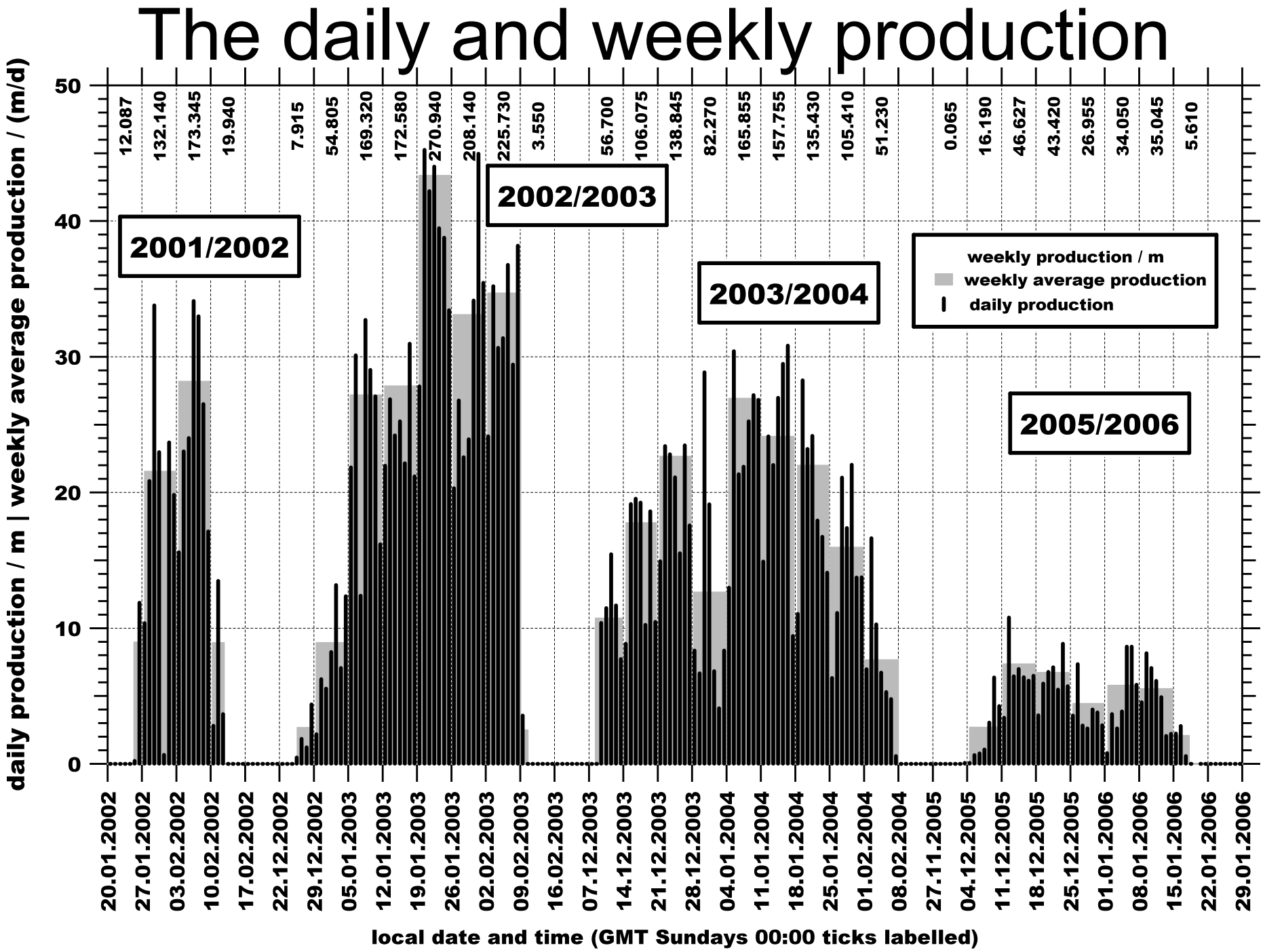
A big thank you to the cooperating people for such a smooth performance: Steff, Laurent, Heiri, Sigfus, Niels, Jakob!!!

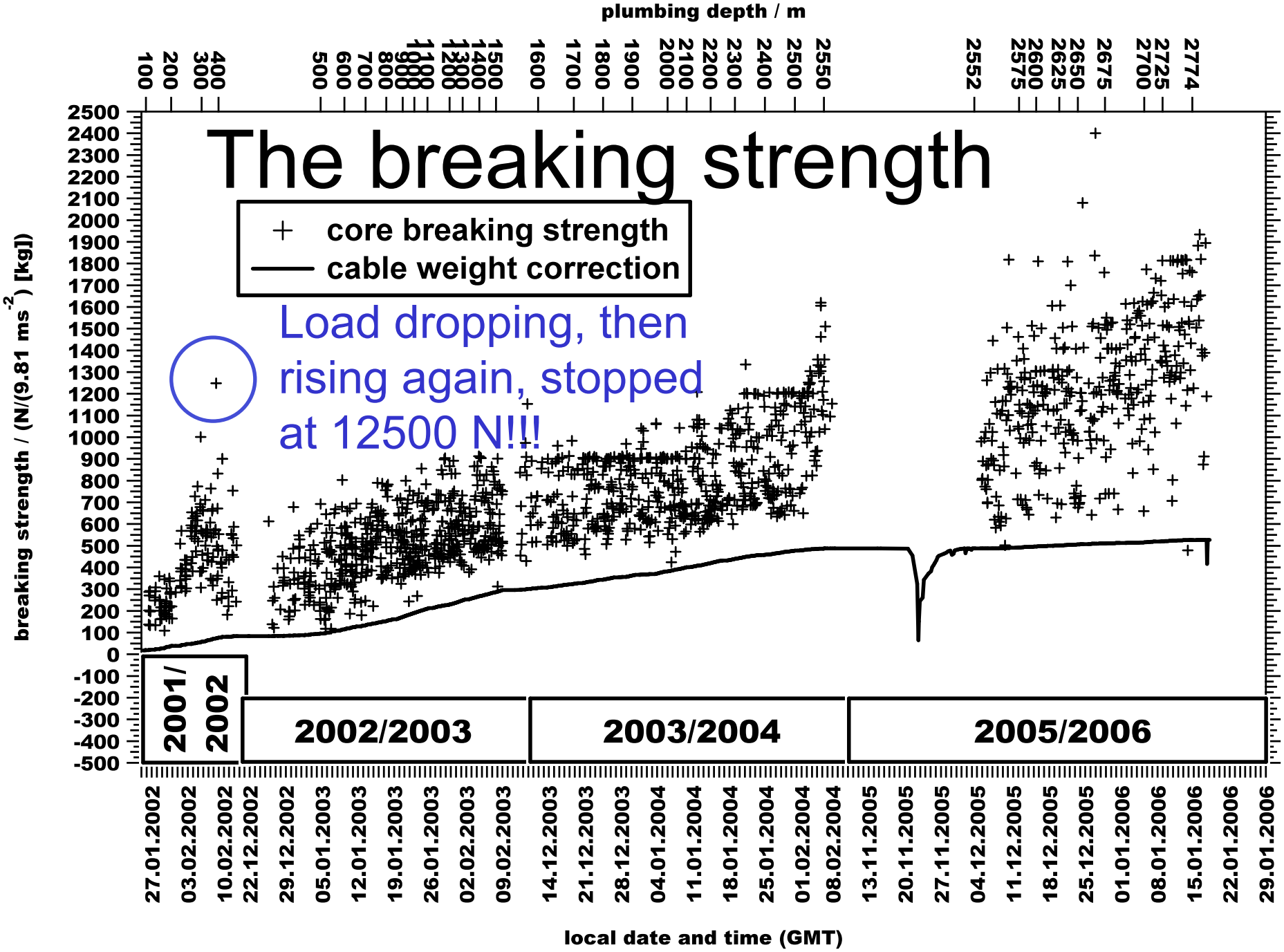
Lessons learnt

2. Never engage in an adventure without sufficient manning

- Train enough drillers and keep them throughout the project
- Get a drill mechanic and have him/her involved in the preparation and operation
- Get an electronics engineer and have him/her involved in the preparation and operation
- Training periods cost you a significant amount of time if you train new people every year

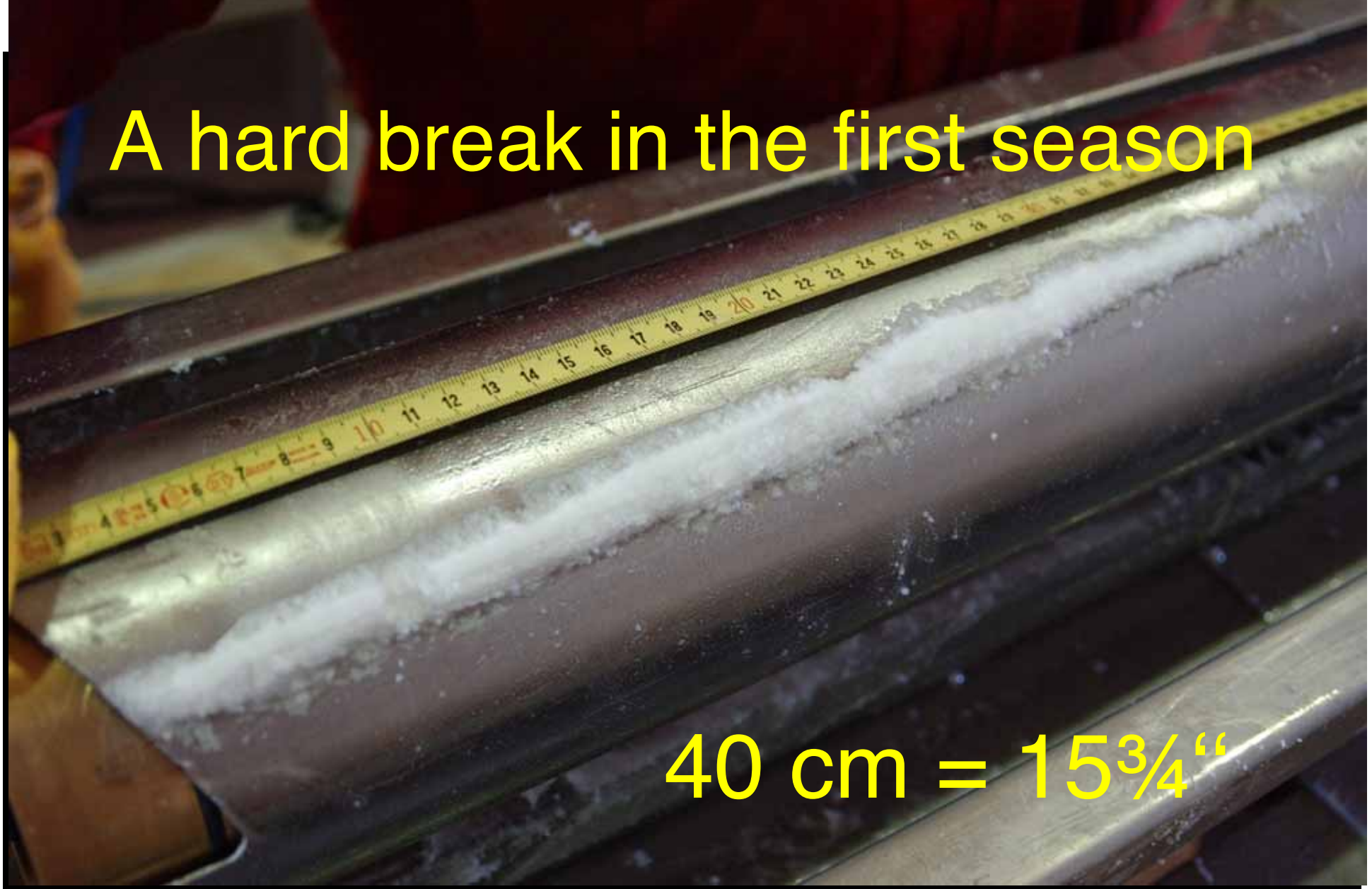
A big thank you to esp. the drillers who joined several years (e.g. Diedrich) and people joining in when needed: Steff!!!


The daily and weekly production
daily production / m | weekly average production / (m/d)
local date and time (GMT Sundays 00:00 ticks labelled)
2001/2002
2002/2003
2003/2004
2005/2006
weekly production / m
weekly average production
daily production
12.087
132.140
173.345
19.940
7.915
54.805
169.320
172.580
270.940
208.140
225.730
3.550
56.700
106.075
138.845
82.270
165.855
157.755
135.430
105.410
51.230
0.065
16.190
46.627
43.420
26.955
34.050
35.045
5.610
0
10
20
30
40
50
20.01.2002
27.01.2002
03.02.2002
10.02.2002
17.02.2002
22.12.2002
29.12.2002
05.01.2003
12.01.2003
19.01.2003
26.01.2003
02.02.2003
09.02.2003
16.02.2003
07.12.2003
14.12.2003
21.12.2003
28.12.2003
04.01.2004
11.01.2004
18.01.2004
25.01.2004
01.02.2004
08.02.2004
27.11.2005
04.12.2005
11.12.2005
18.12.2005
25.12.2005
01.01.2006
08.01.2006
15.01.2006
22.01.2006
29.01.2006


plumbing depth / m
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2550 2552 2575 2600 2625 2650 2675 2700 2725 2774
The breaking strength
core breaking strength
cable weight correction
Load dropping, then rising again, stopped at 12500 N!!!
breaking strength / (N/(9.81 ms^{-2})) [kg]
2500 2400 2300 2200 2100 2000 1900 1800 1700 1600 1500 1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0 -100 -200 -300 -400 -500
2001/2002
2002/2003
2003/2004
2005/2006
27.01.2002 03.02.2002 10.02.2002 22.12.2002 29.12.2002 05.01.2003 12.01.2003 19.01.2003 26.01.2003 02.02.2003 09.02.2003 14.12.2003 21.12.2003 28.12.2003 04.01.2004 11.01.2004 18.01.2004 25.01.2004 01.02.2004 08.02.2004 13.11.2005 20.11.2005 27.11.2005 04.12.2005 11.12.2005 18.12.2005 25.12.2005 01.01.2006 08.01.2006 15.01.2006 22.01.2006 29.01.2006
local date and time (GMT)

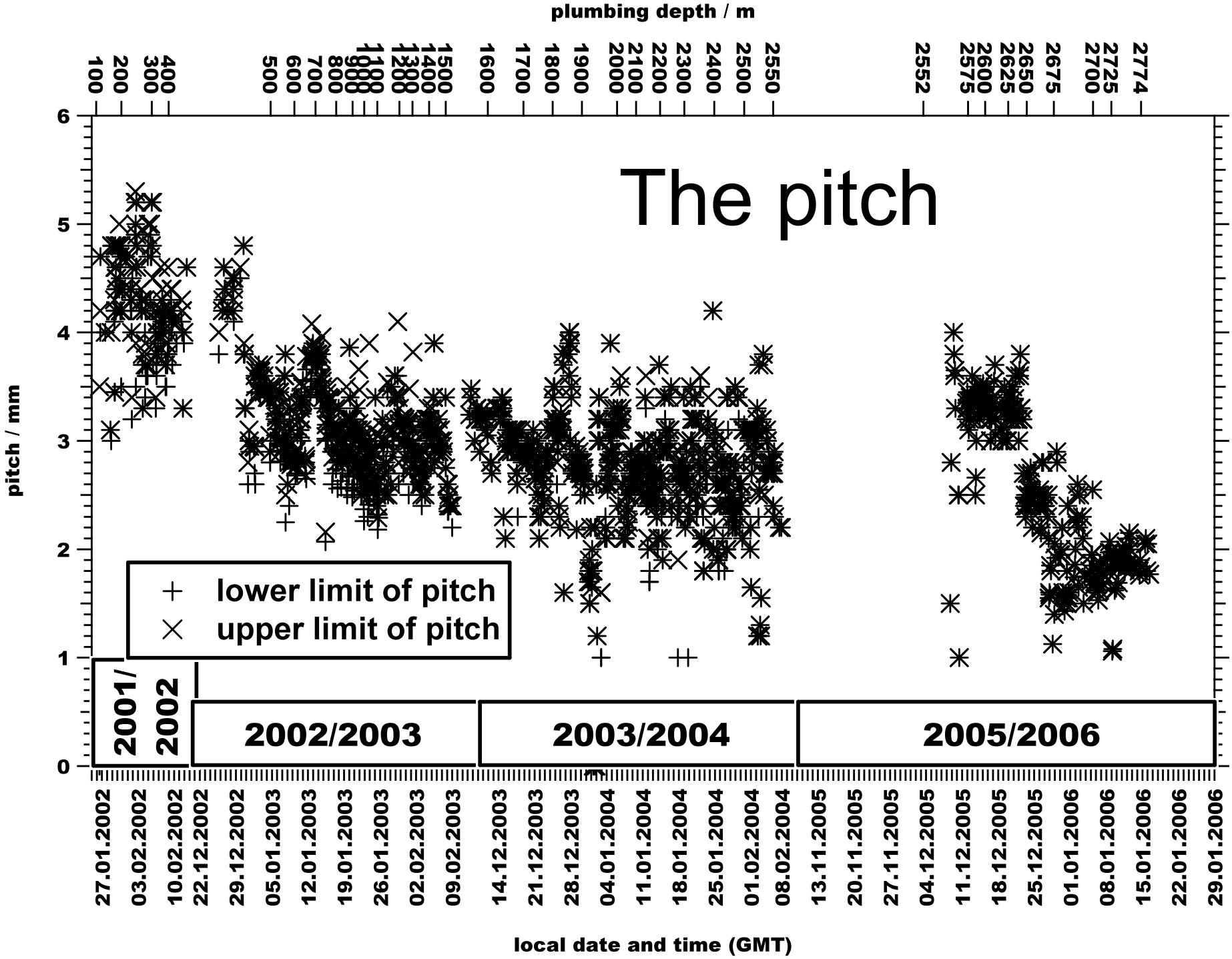
What had happened?

- It was drilled in the usual mode: Stop when power rises
- This one was pressing it very far, the cable load had dropped by 30-40 kg.
- Decision to idle (pump) for some time and then pull up
- Moderate core-break
- When pulling further load came up, stopped it at 12500 N
- Went forth and back, finally put load and rotated
- Got free some time



Very hard scraping with screw driver, no other chance!!!


We closed the windows

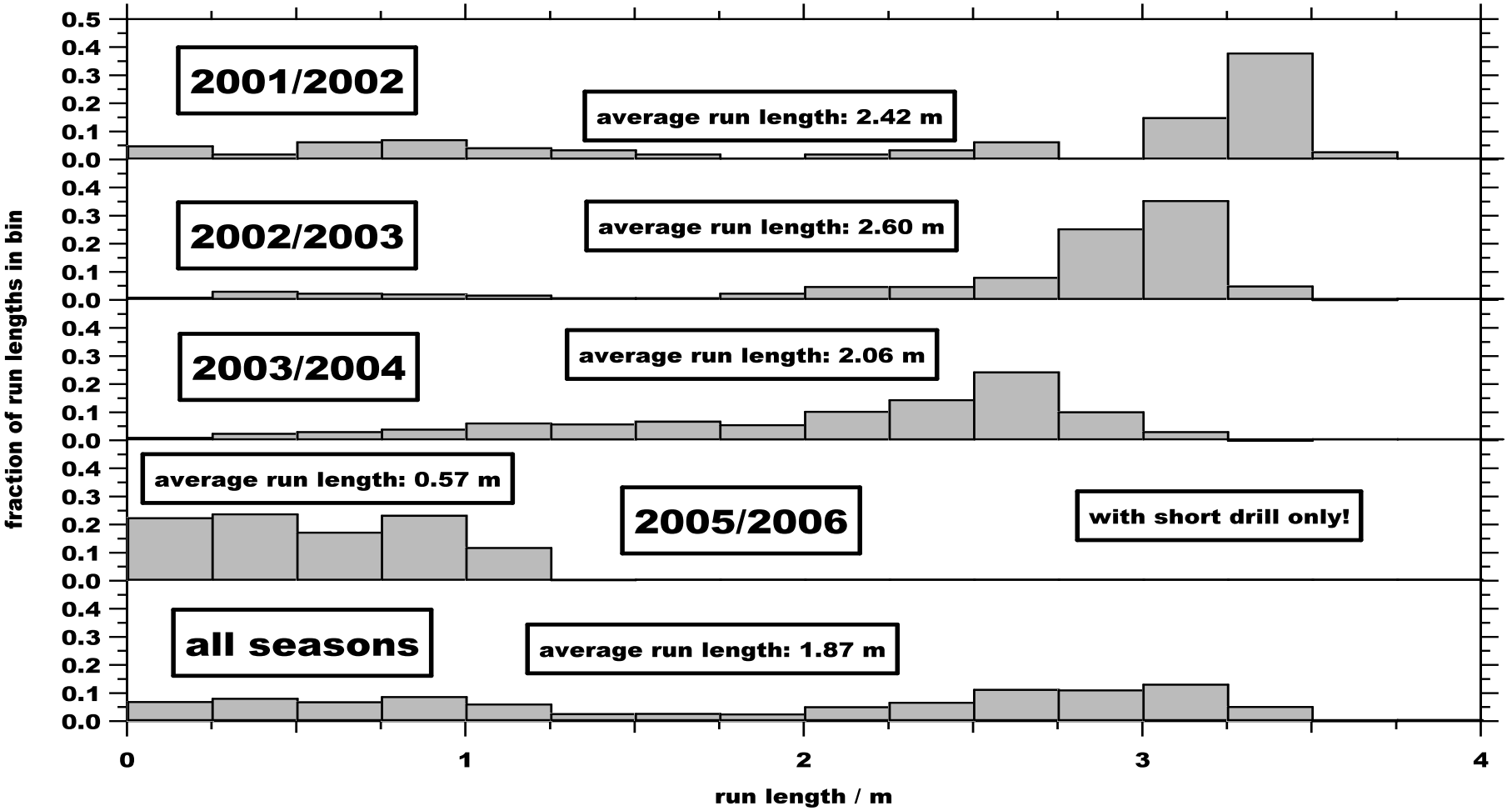

plumbing depth / m
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2550
2552
2575
2600
2625
2650
2675
2700
2725
2774
The pitch
pitch / mm
0
1
2
3
4
5
6
lower limit of pitch
upper limit of pitch
2001/2002
2002/2003
2003/2004
2005/2006
27.01.2002
03.02.2002
10.02.2002
22.12.2002
29.12.2002
05.01.2003
12.01.2003
19.01.2003
26.01.2003
02.02.2003
09.02.2003
14.12.2003
21.12.2003
28.12.2003
04.01.2004
11.01.2004
18.01.2004
25.01.2004
01.02.2004
08.02.2004
13.11.2005
20.11.2005
27.11.2005
04.12.2005
11.12.2005
18.12.2005
25.12.2005
01.01.2006
08.01.2006
15.01.2006
22.01.2006
29.01.2006
local date and time (GMT)

Lessons learnt

3. Drilling mode based on length and power should be changed to judgement on load and power

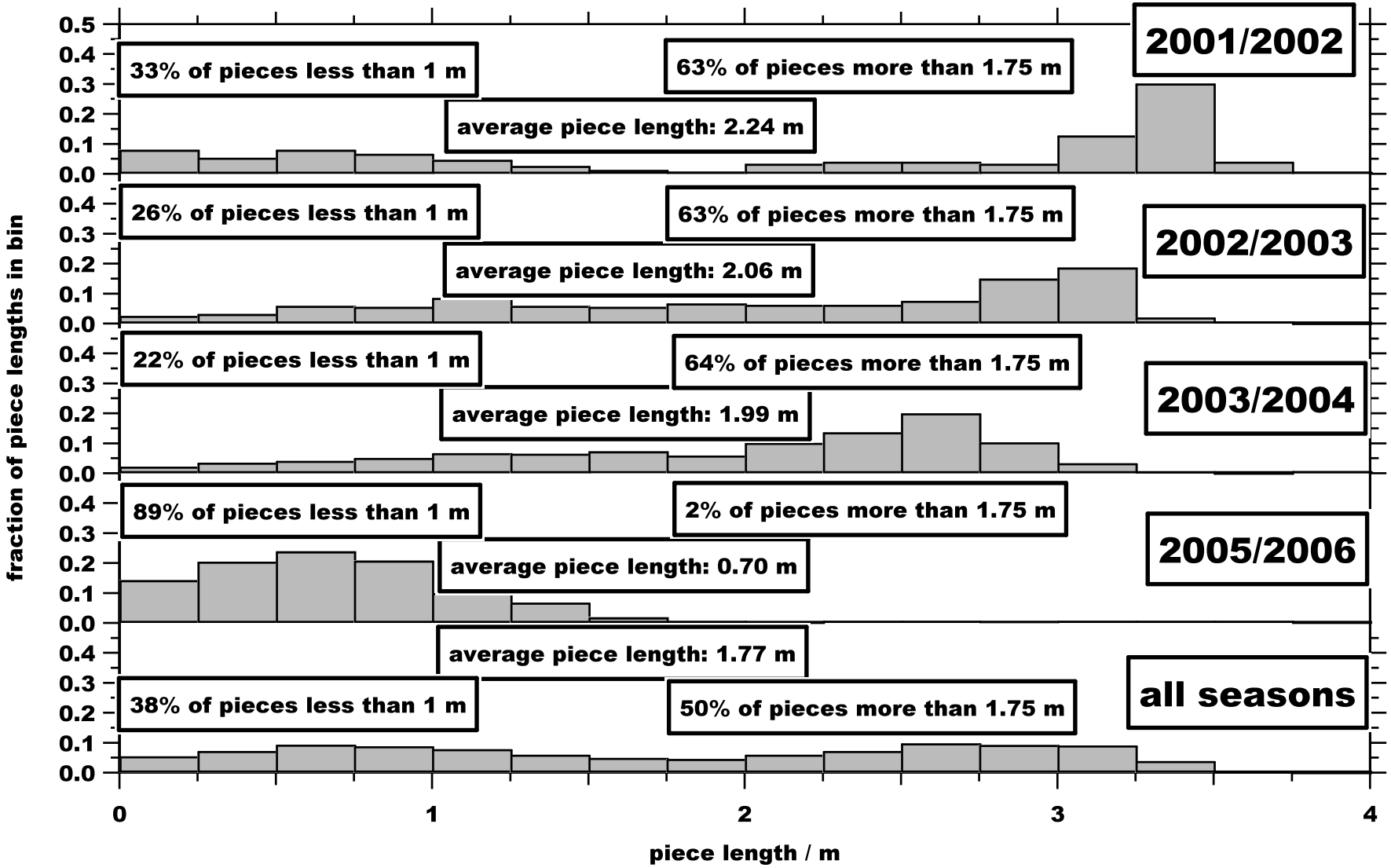
- Drill should not be immersed in chips
- Later we drilled on a judgement to have the load not dropping more than 10 kg, additionally to of course power consumption
- One core break and restart at the utmost!!!

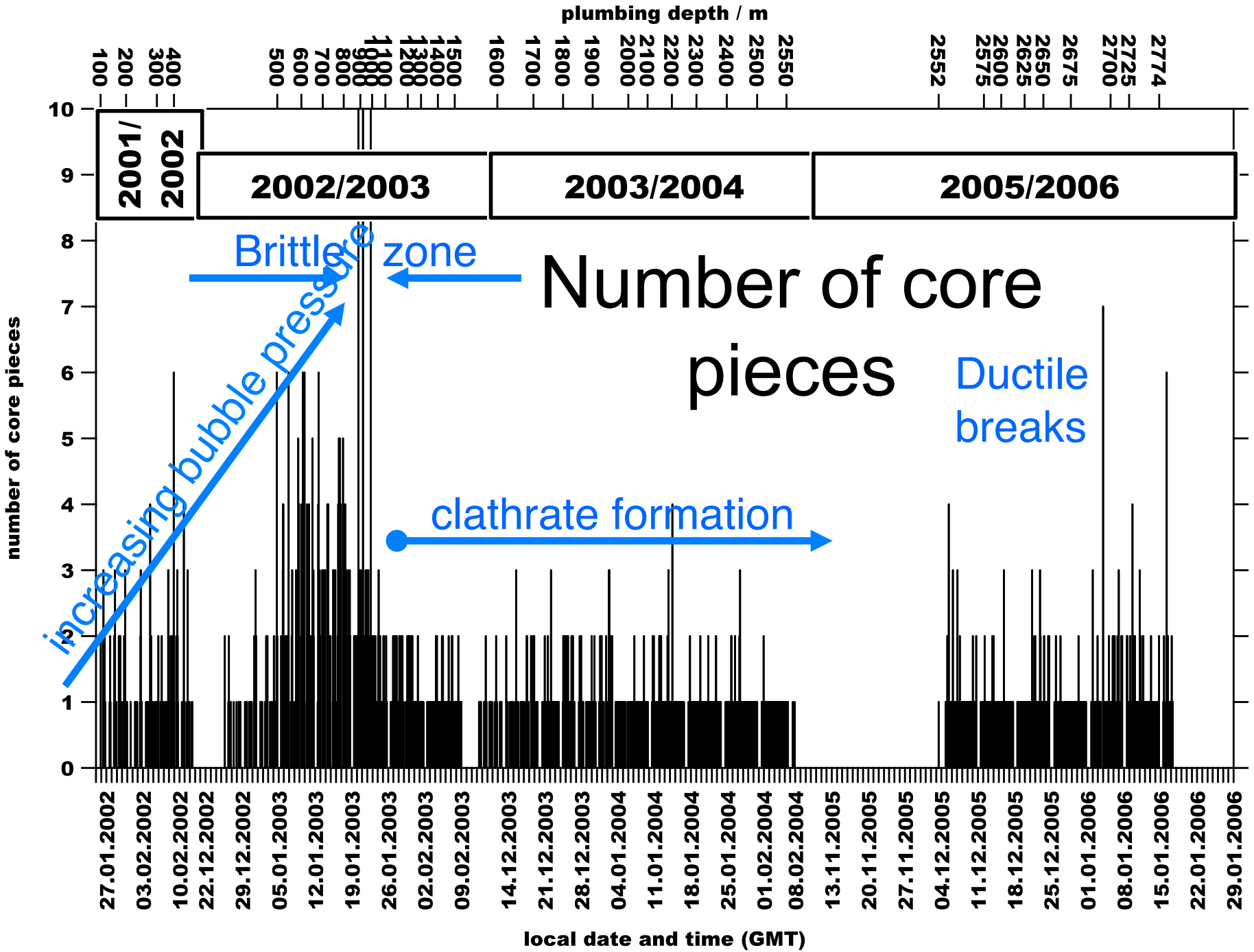
Run length statistics

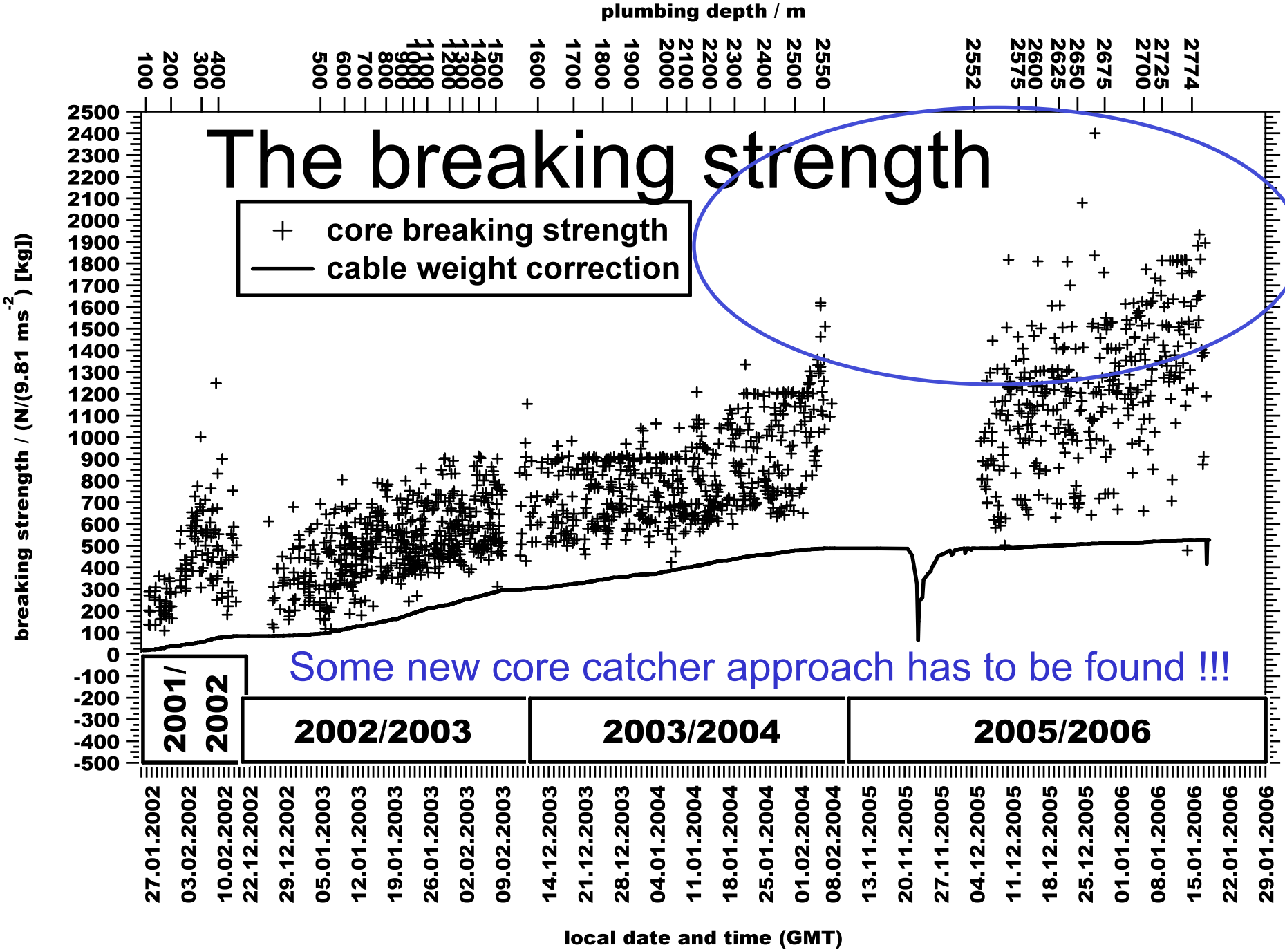


2660 m core production/1457 runs = 1.83 m

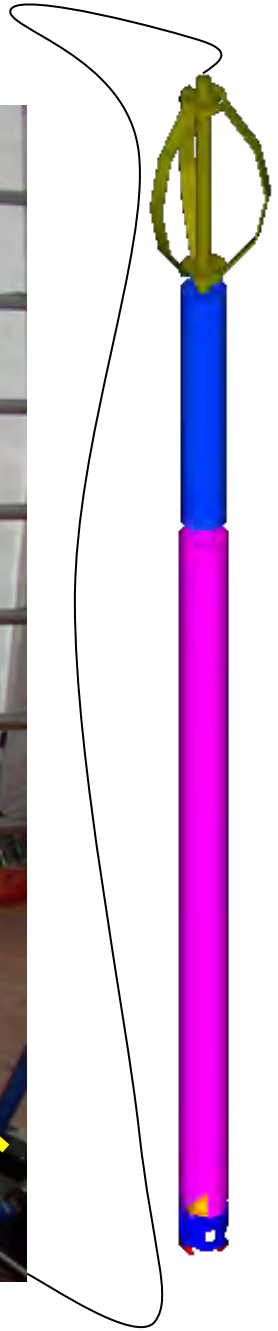
Piece length statistics

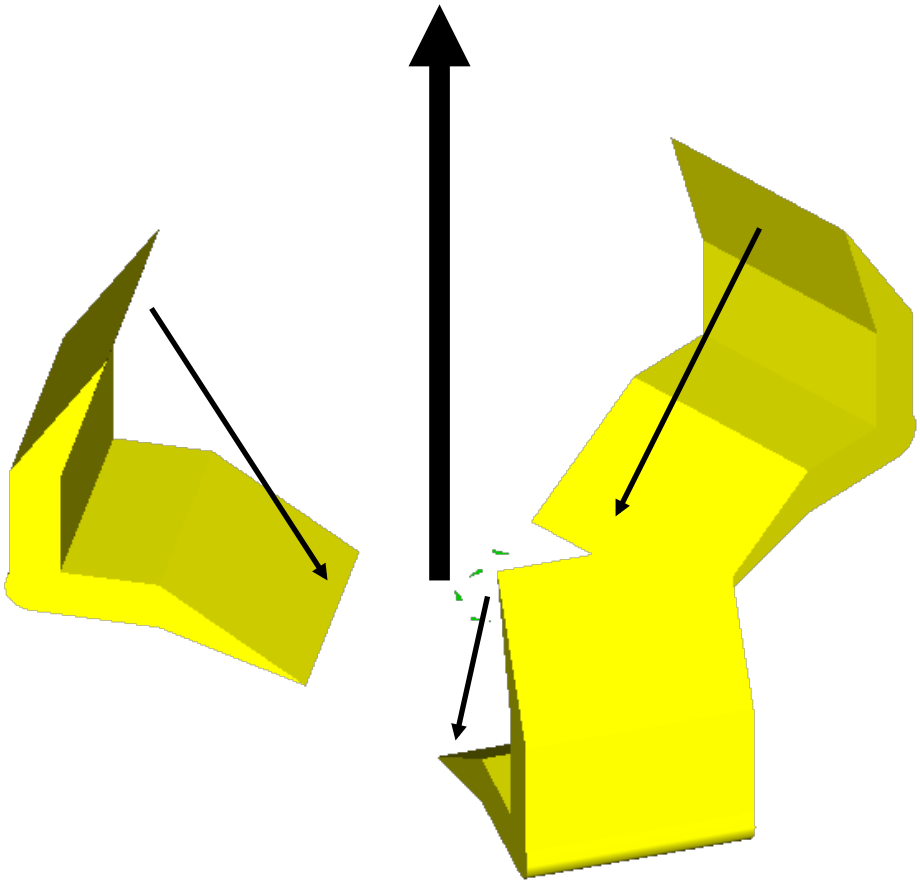


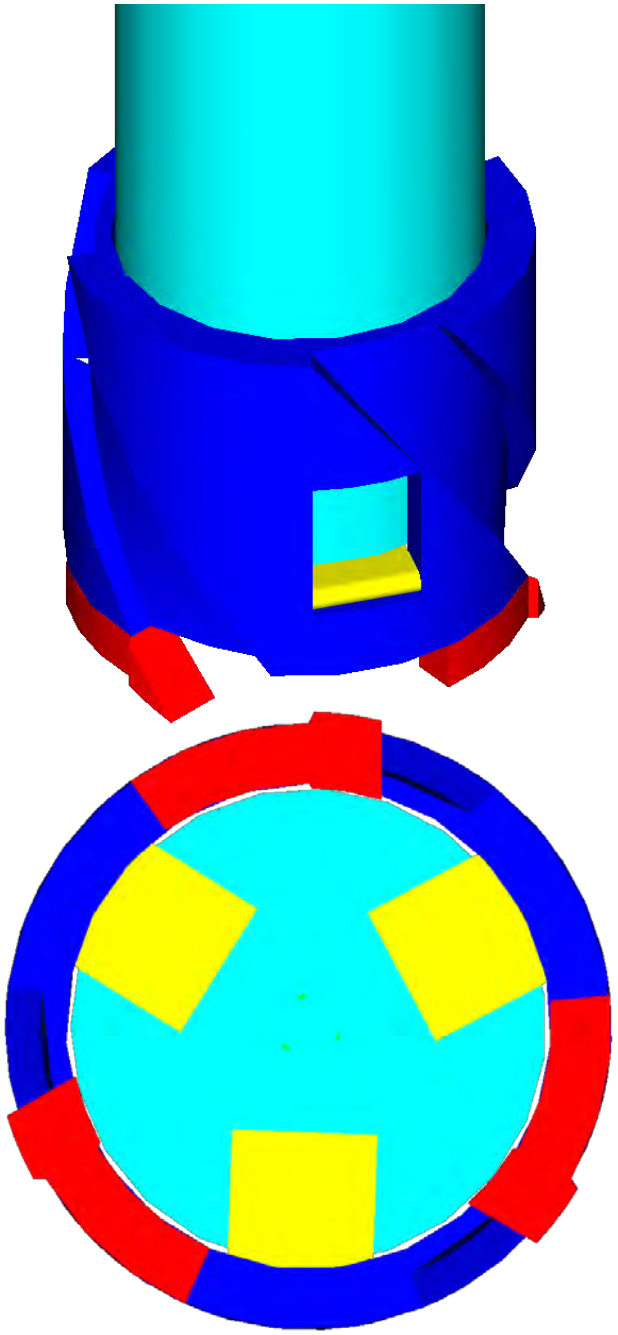

plumbing depth / m
100
200
300
400
500
600
700
800
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2550
2552
2575
2600
2625
2650
2675
2700
2725
2774
2001/ 2002
2002/2003
2003/2004
2005/2006
Brittle zone
Number of core pieces
Ductile breaks
increasing bubble pressure
clathrate formation
number of core pieces
0
1
2
3
4
5
6
7
8
9
10
27.01.2002
03.02.2002
10.02.2002
22.12.2002
29.12.2002
05.01.2003
12.01.2003
19.01.2003
26.01.2003
02.02.2003
09.02.2003
14.12.2003
21.12.2003
28.12.2003
04.01.2004
11.01.2004
18.01.2004
25.01.2004
01.02.2004
08.02.2004
13.11.2005
20.11.2005
27.11.2005
04.12.2005
11.12.2005
18.12.2005
25.12.2005
01.01.2006
08.01.2006
15.01.2006
22.01.2006
29.01.2006
local date and time (GMT)


plumbing depth / m
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2550
2552
2575
2600
2625
2650
2675
2700
2725
2774
The breaking strength
core breaking strength
cable weight correction
breaking strength / (N/(9.81 ms^{-2})) [kg]
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
Some new core catcher approach has to be found !!!
2001/2002
2002/2003
2003/2004
2005/2006
27.01.2002
03.02.2002
10.02.2002
22.12.2002
29.12.2002
05.01.2003
12.01.2003
19.01.2003
26.01.2003
02.02.2003
09.02.2003
14.12.2003
21.12.2003
28.12.2003
04.01.2004
11.01.2004
18.01.2004
25.01.2004
01.02.2004
08.02.2004
13.11.2005
20.11.2005
27.11.2005
04.12.2005
11.12.2005
18.12.2005
25.12.2005
01.01.2006
08.01.2006
15.01.2006
22.01.2006
29.01.2006
local date and time (GMT)

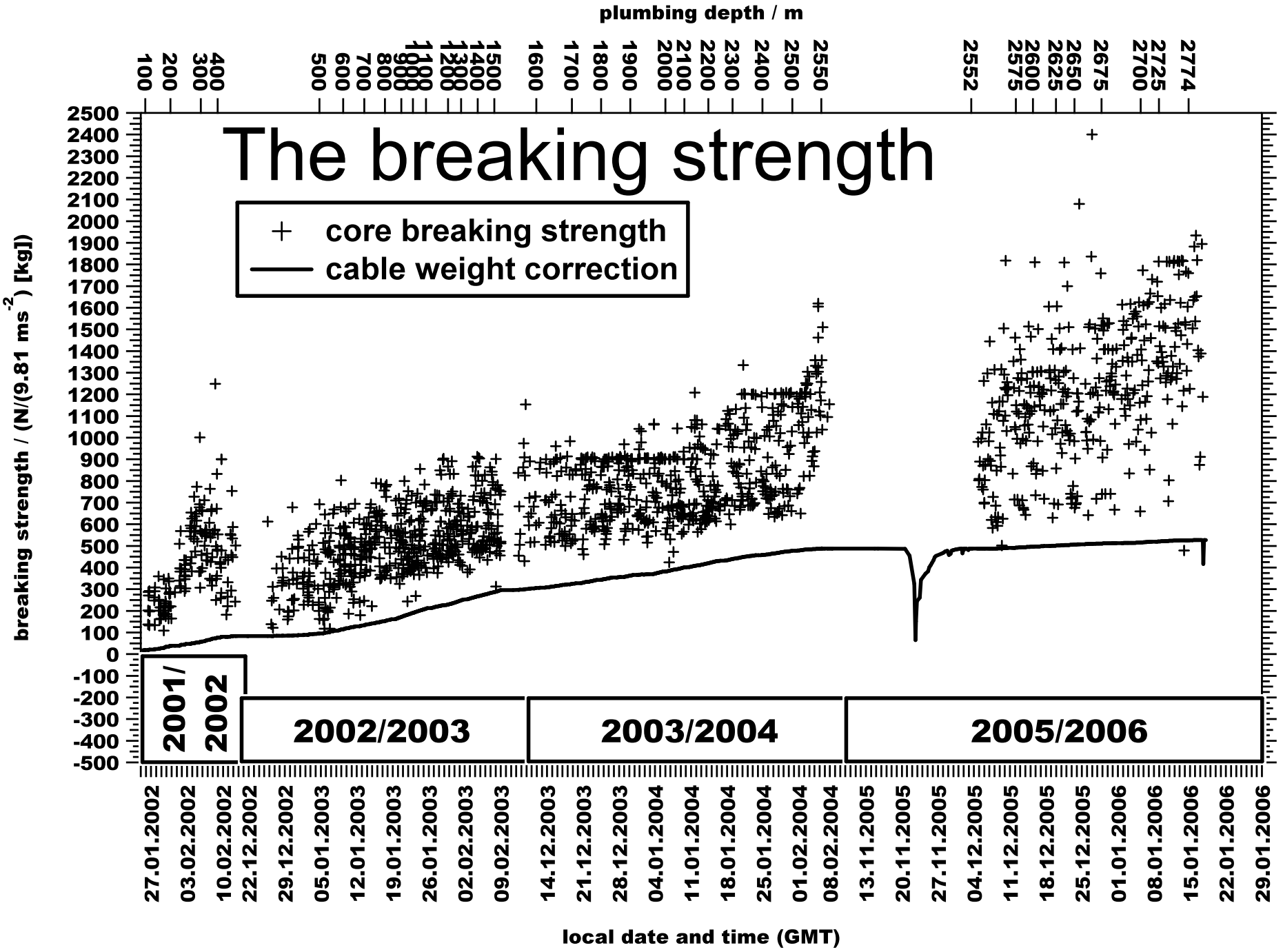
The winch moves the underground unit on a cable



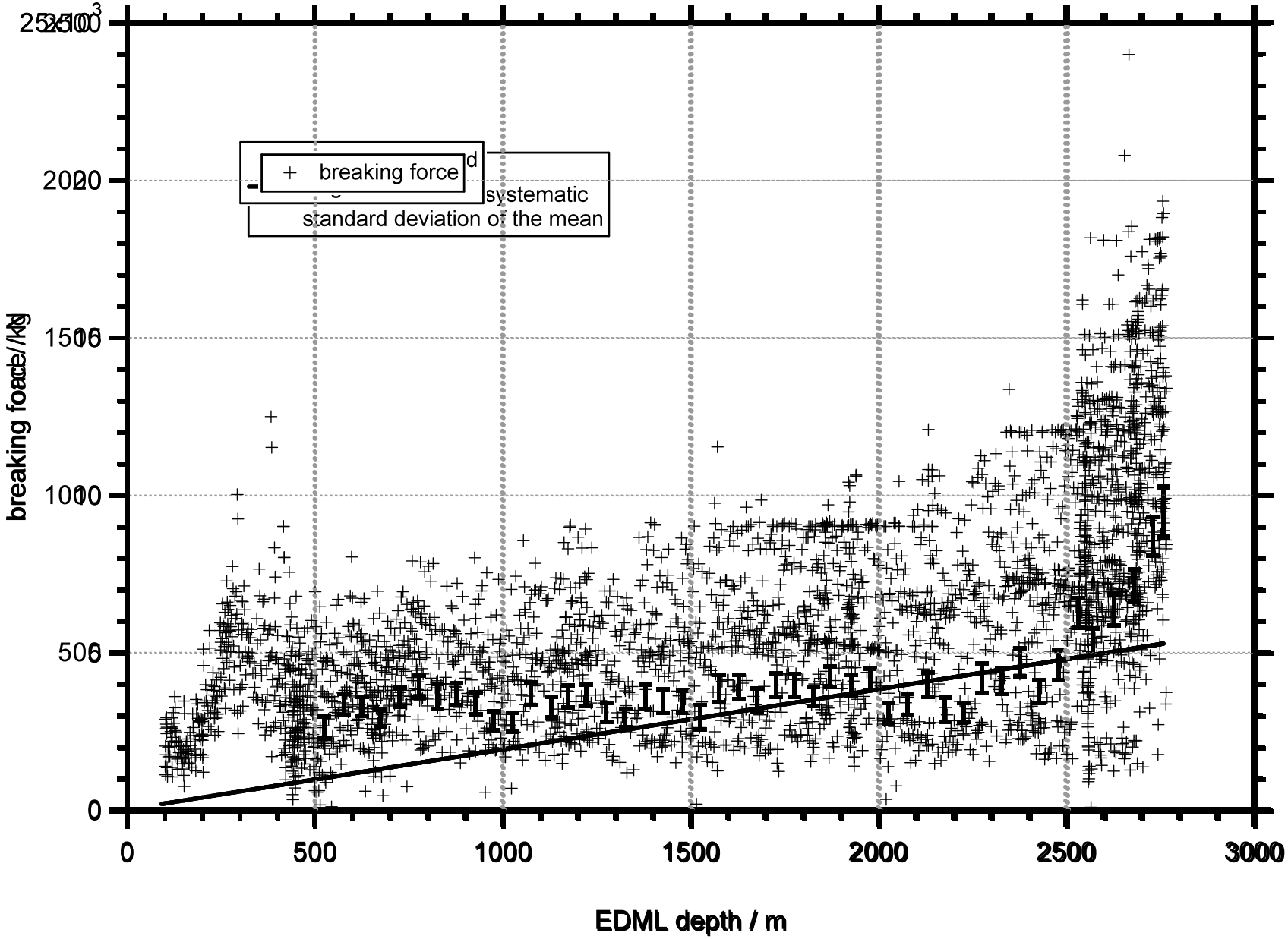


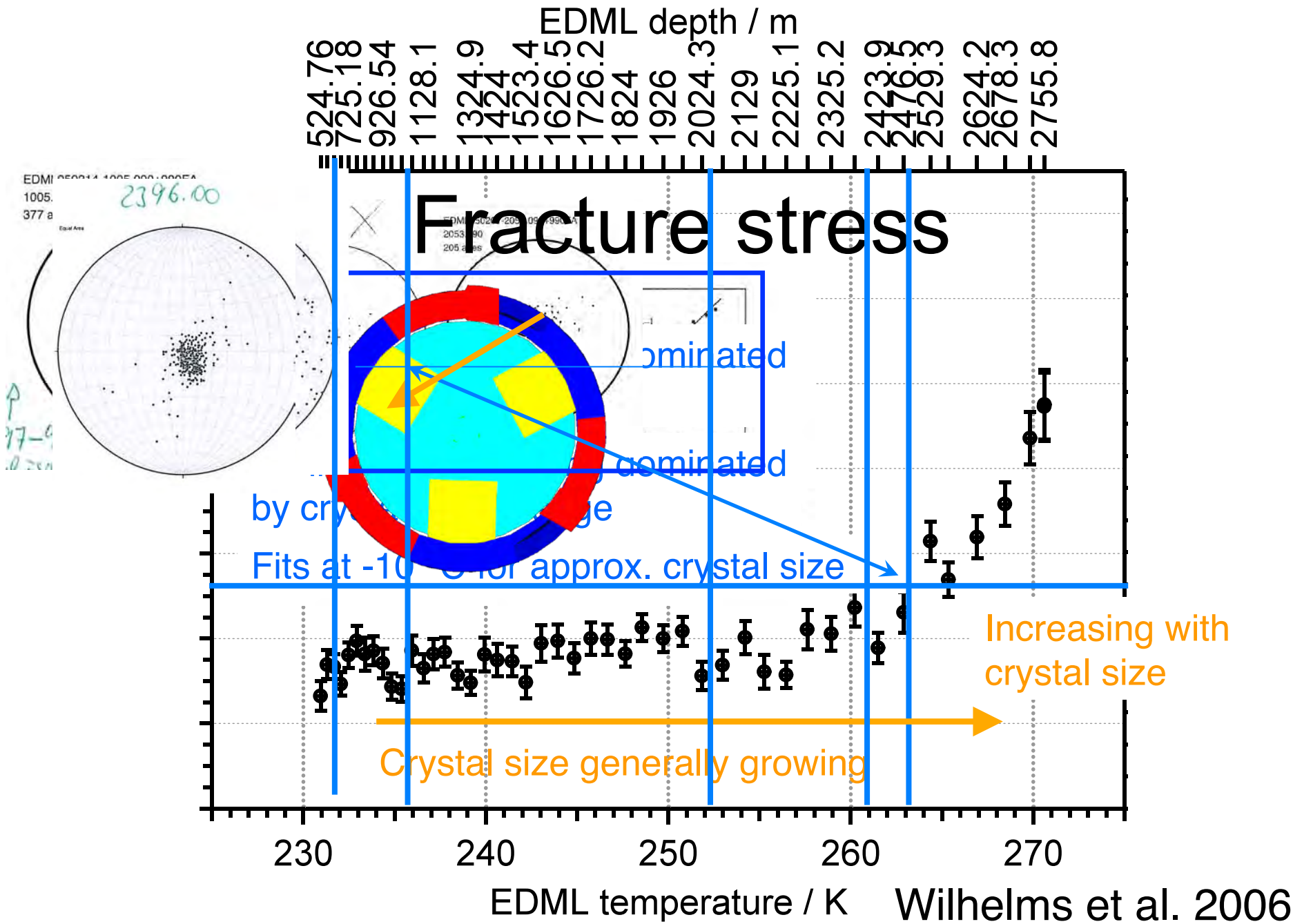


By pulling they are forced into the core, break and hold it (in reality they are much smaller compared to the core


plumbing depth / m
100
200
300
400
500
600
700
800
888
1180
1288
1388
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2550
2552
2575
2600
2625
2650
2675
2700
2725
2774
The breaking strength
core breaking strength
cable weight correction
breaking strength / (N/(9.81 ms^{-2})) [kg])
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
2001/ 2002
2002/2003
2003/2004
2005/2006
27.01.2002
03.02.2002
10.02.2002
22.12.2002
29.12.2002
05.01.2003
12.01.2003
19.01.2003
26.01.2003
02.02.2003
09.02.2003
14.12.2003
21.12.2003
28.12.2003
04.01.2004
11.01.2004
18.01.2004
25.01.2004
01.02.2004
08.02.2004
13.11.2005
20.11.2005
27.11.2005
04.12.2005
11.12.2005
18.12.2005
25.12.2005
01.01.2006
08.01.2006
15.01.2006
22.01.2006
29.01.2006
local date and time (GMT)

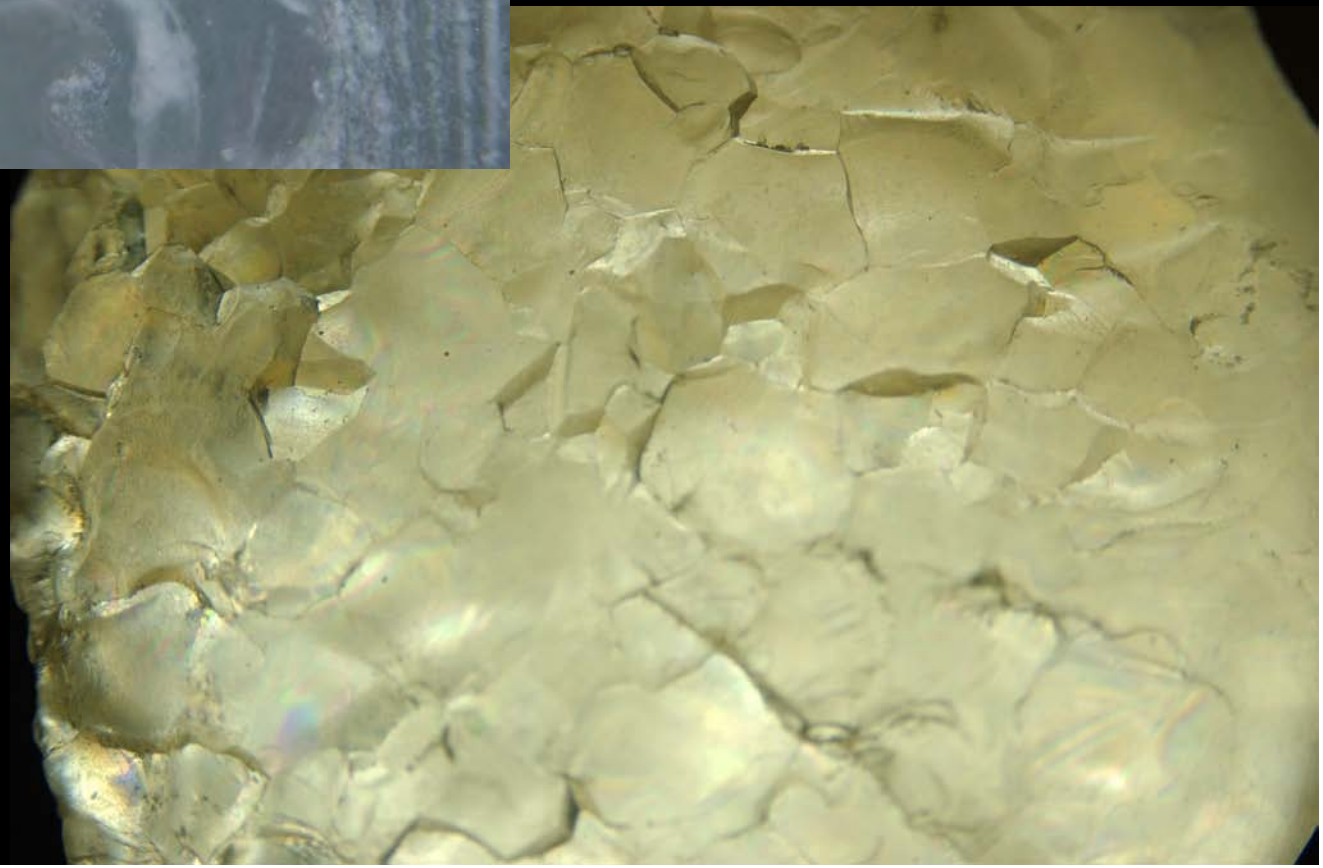
The breaking force




EDML depth / m
524.76
725.18
926.54
1128.1
1324.9
1423.4
1523.4
1626.5
1726.2
1824
1926
2024.3
2129
2225.1
2325.2
2423.9
2476.5
2529.3
2624.2
2678.3
2755.8
Fracture stress
2396.00
dominated
dominated
by cry ge
Fits at -10 °C for approx. crystal size
Increasing with
crystal size
Crystal size generally growing
230
240
250
260
270
EDML temperature / K
Wilhelms et al. 2006

This fits my practical experience of changing from brittle …

…. to ductile



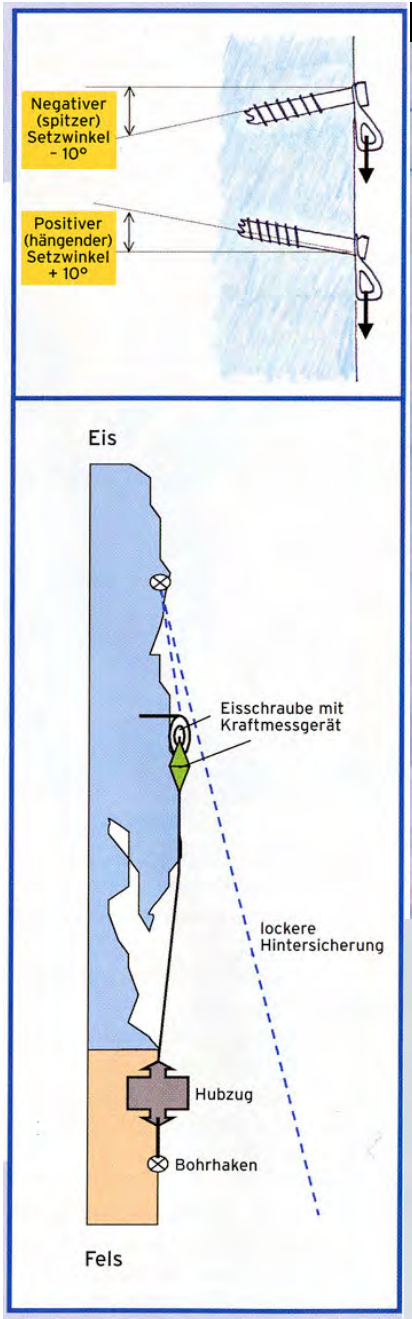


Abb. 3: Der Versuchsaufbau: Mit dem Hubzug ließen sich maximal etwa 20 kN(= 2 Tonnen) erreichen

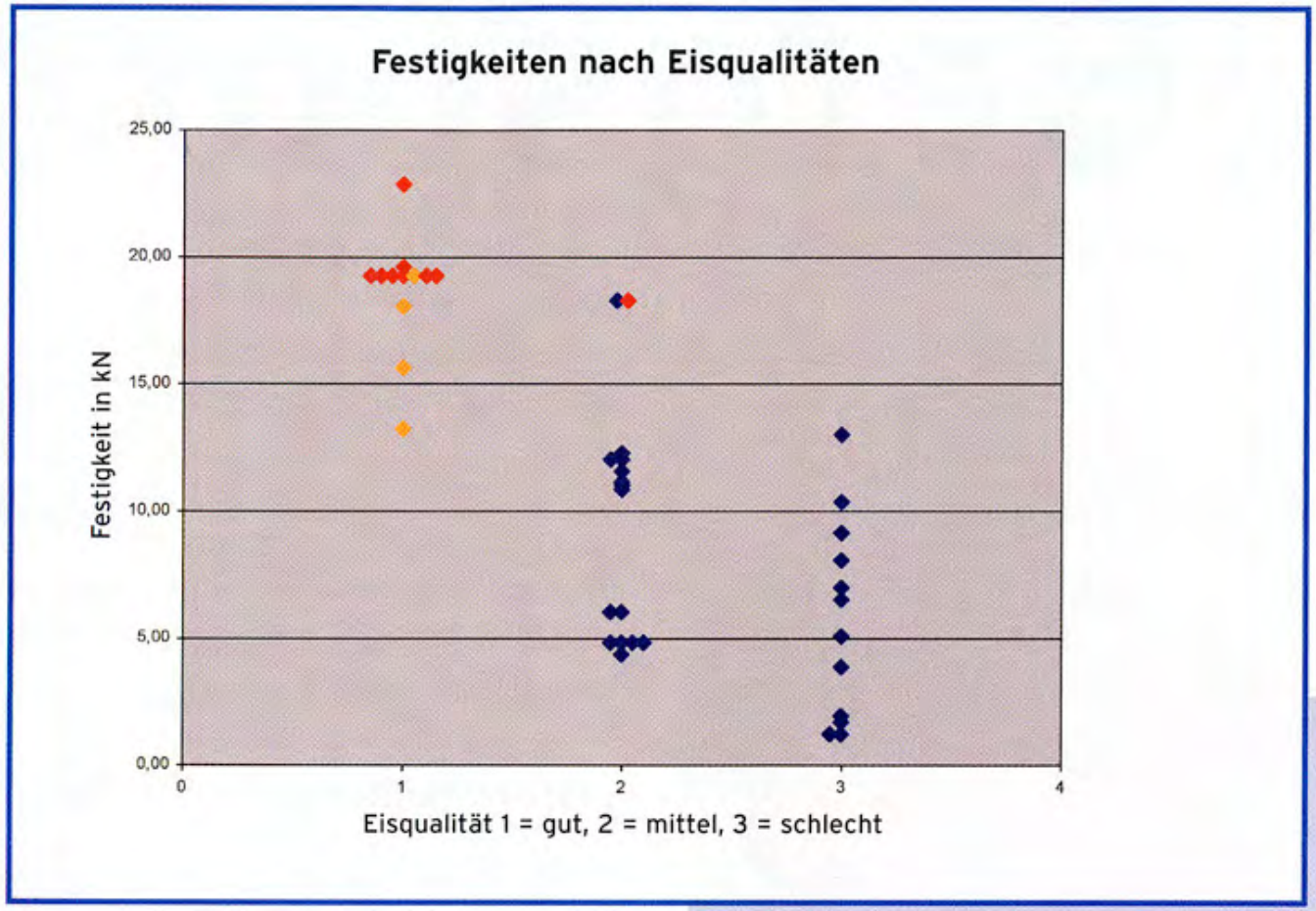


Diagramm 1: Rot: Versuch abgebrochen; gelb: Schraube gebrochen; blau: Eisausbruch.

Diagramm 2: Optimal gesetzte Schrauben halten etwa dreimal so viel wie optimal gesetzte Sanas

Zukunft schützen DAV
PANORAMA
Mitteilungen des Deutschen Alpenv

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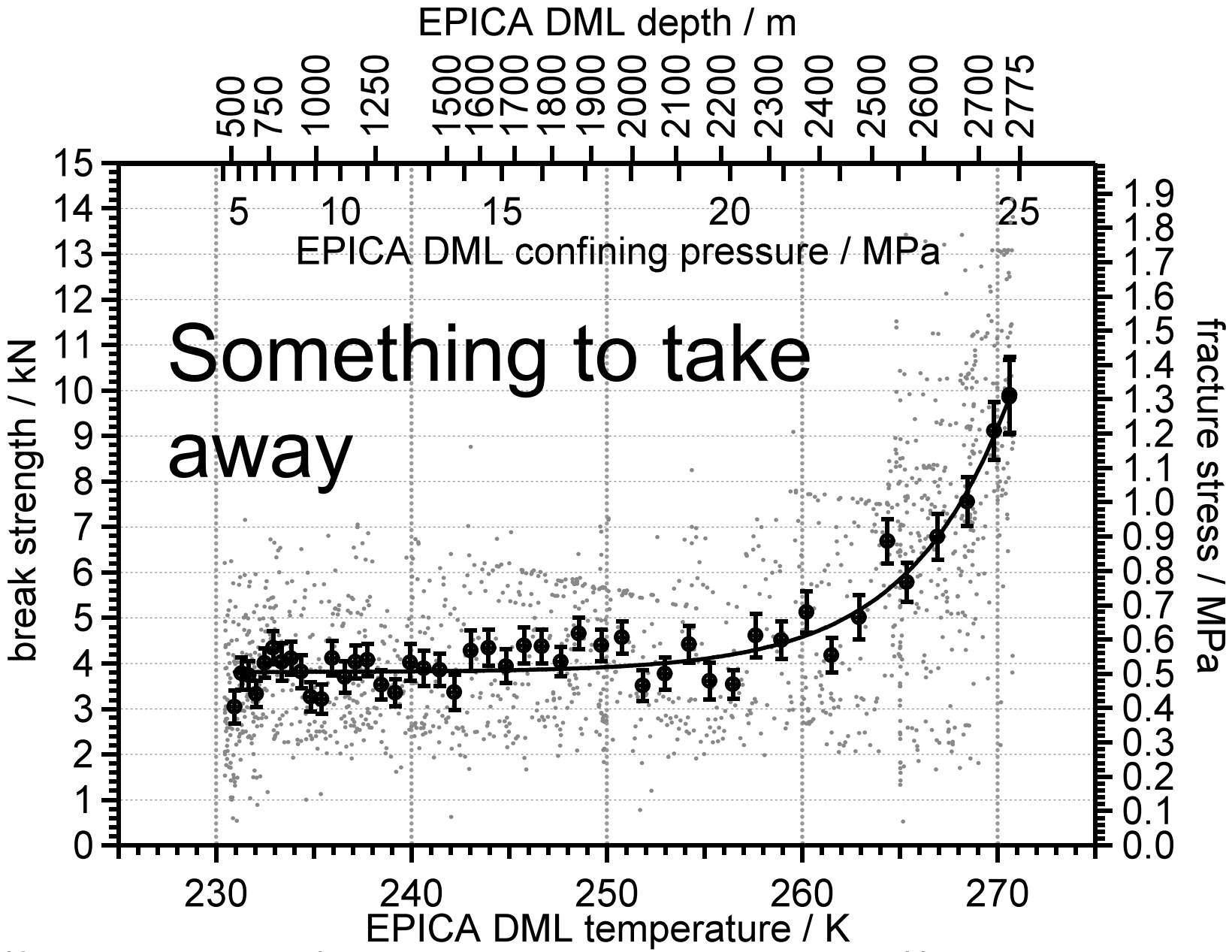
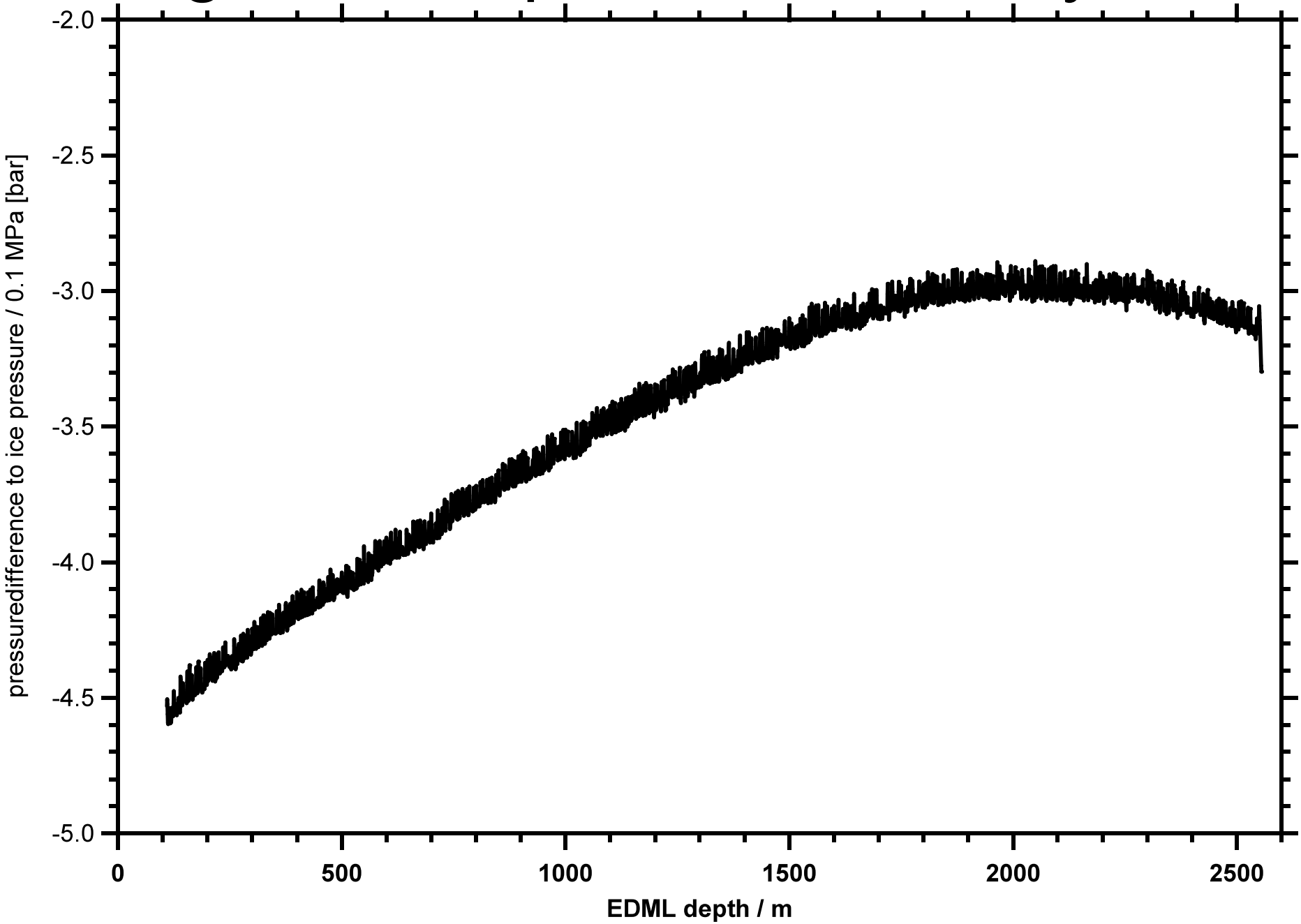
Internet: www.dav-panorama.de

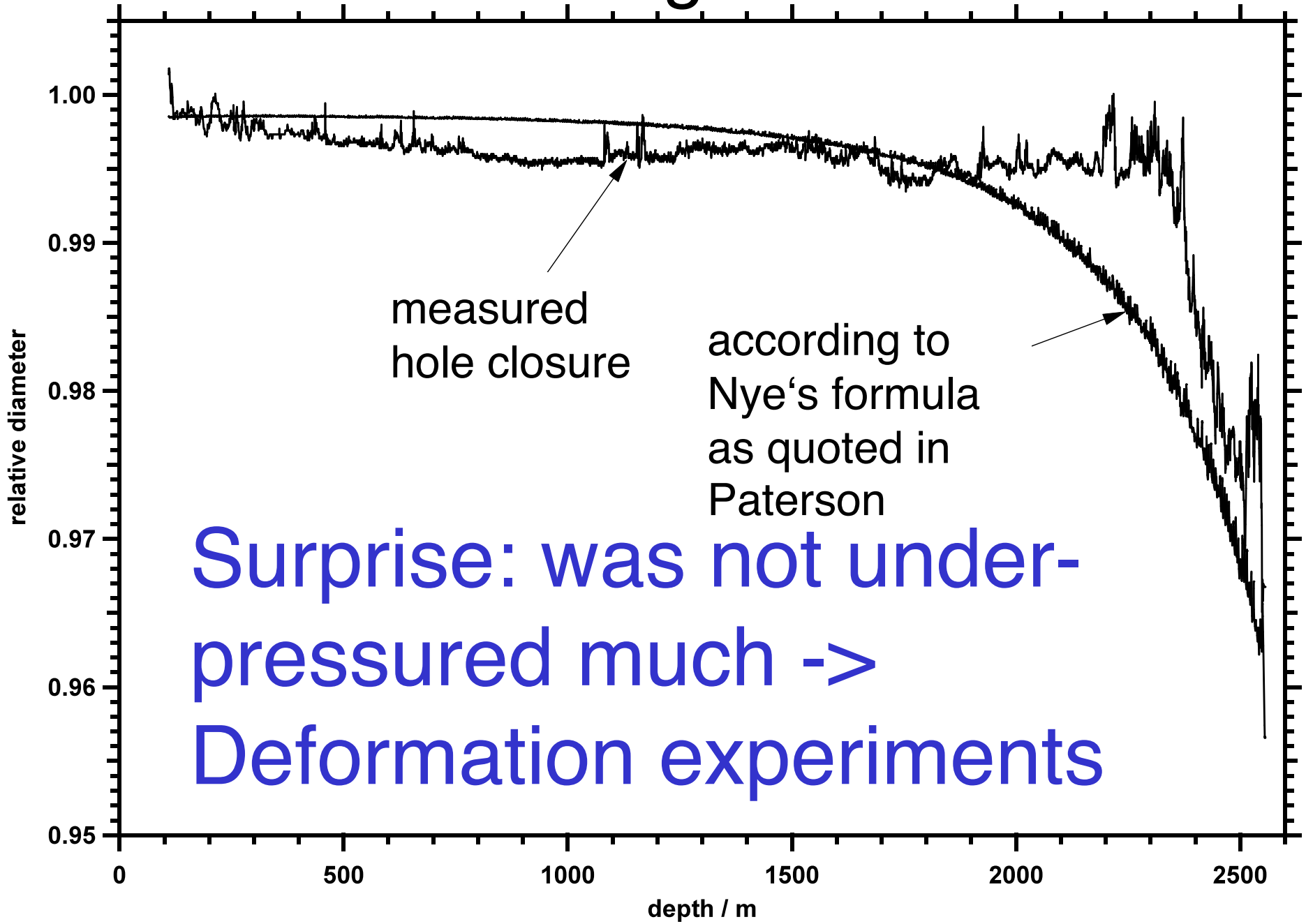


(fracture stress)/kPa = 505 + 1.4E–20*exp((absolute temperature)/5.17 K)

Slight under-pressure over 2 years

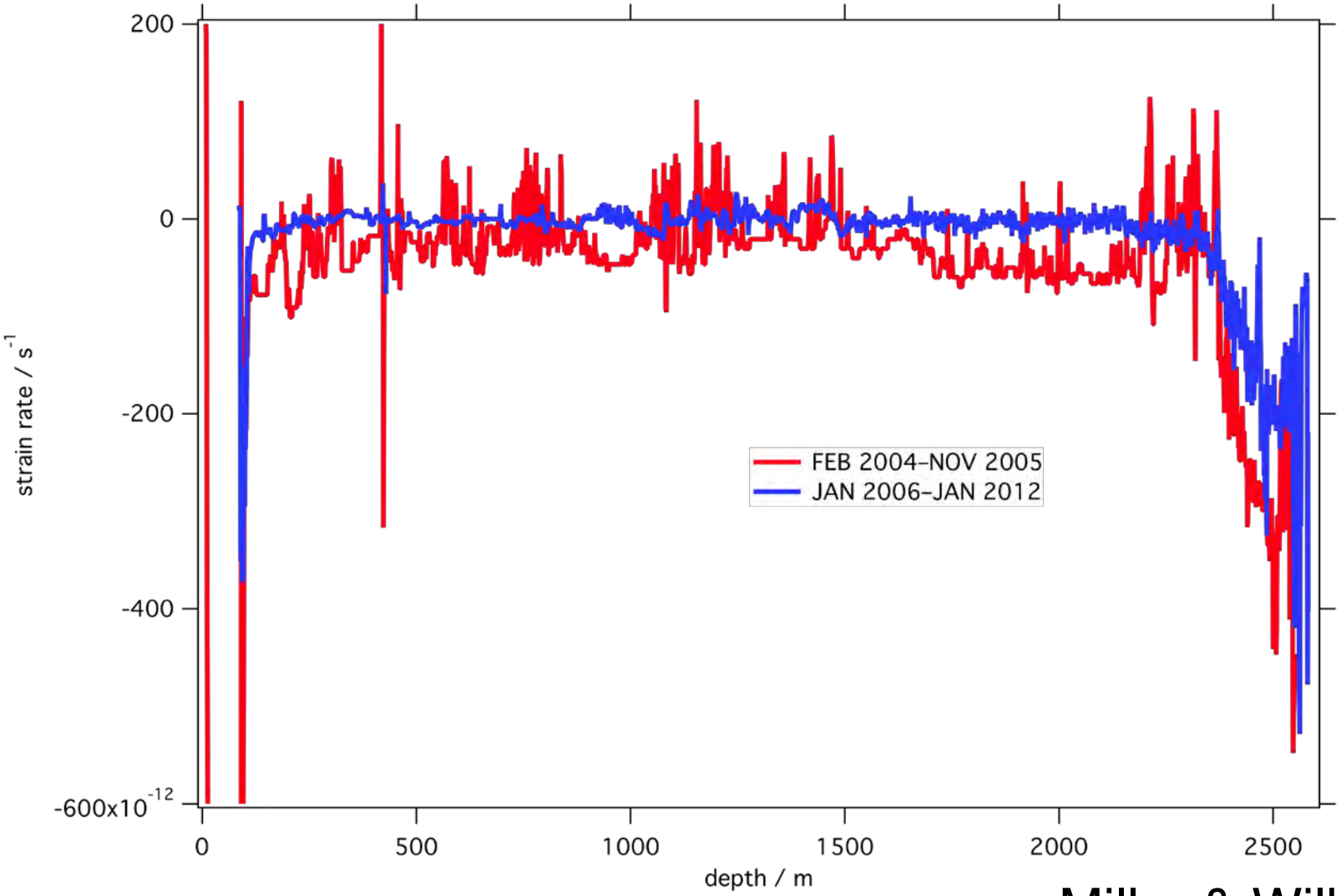


First log the hole



Surprise: was not under-pressured much ->
Deformation experiments

recent bore-hole log

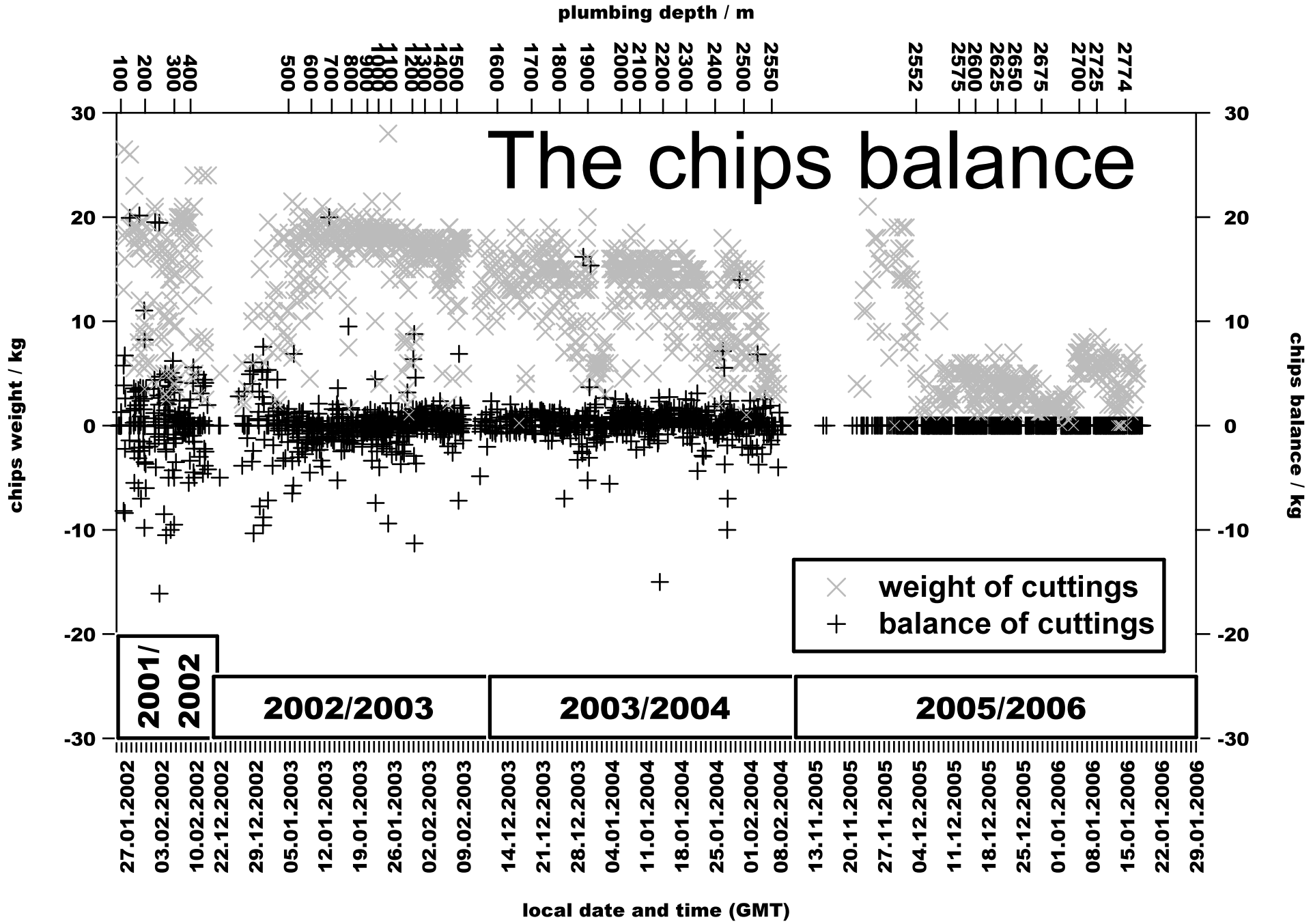


Miller & Wilhelms

Conclusions

- Ice Drilling Community: log as much of the parameters as possible: any core break is a stress test, any unbalanced hole is a flow test
- Physical Properties of Ice Community: discuss mechanical design to get maybe even better defined experimental set-up
- Use boreholes for ice flow deformation tests.

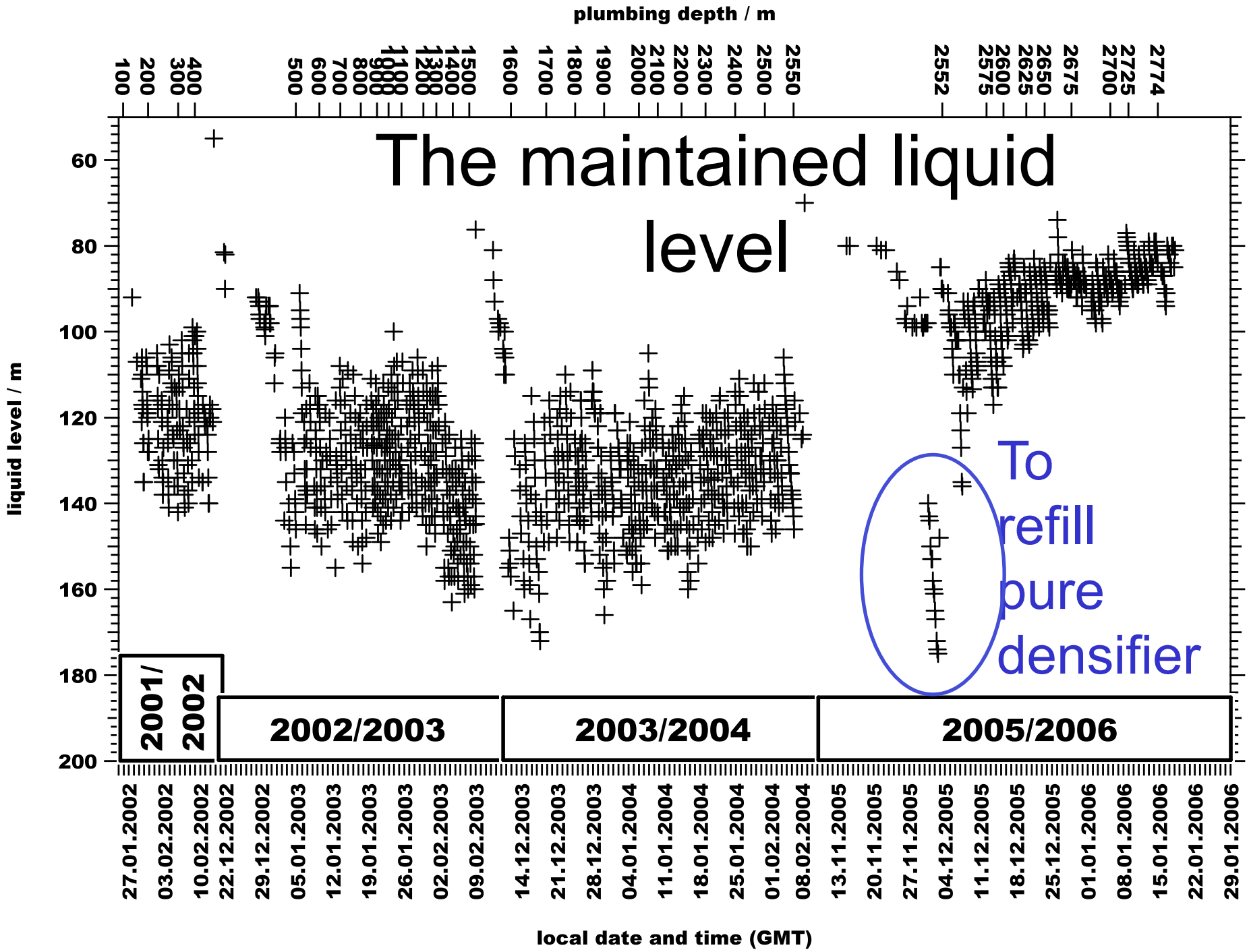

The chips


plumbing depth / m
100
200
300
400
500
600
700
800
1080
1100
1300
1400
1500
1690
1700
1800
1900
2000
2100
2200
2300
2400
2500
2550
2552
2575
2600
2625
2650
2675
2700
2725
2774
The chips balance
chips weight / kg
chips balance / kg
30
20
10
0
-10
-20
-30
weight of cuttings
balance of cuttings
2001/
2002
2002/2003
2003/2004
2005/2006
27.01.2002
03.02.2002
10.02.2002
22.12.2002
29.12.2002
05.01.2003
12.01.2003
19.01.2003
26.01.2003
02.02.2003
09.02.2003
14.12.2003
21.12.2003
28.12.2003
04.01.2004
11.01.2004
18.01.2004
25.01.2004
01.02.2004
08.02.2004
13.11.2005
20.11.2005
27.11.2005
04.12.2005
11.12.2005
18.12.2005
25.12.2005
01.01.2006
08.01.2006
15.01.2006
22.01.2006
29.01.2006
local date and time (GMT)

Lessons learnt

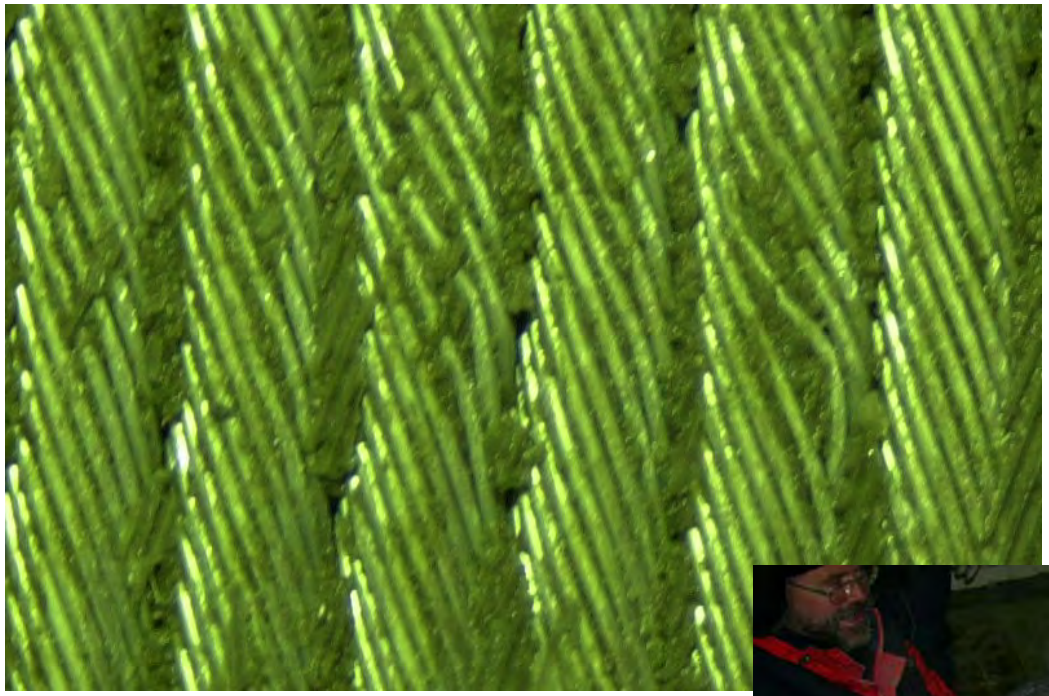
4. Drilling mode based on length and power saved filtering time

- We had a really clean hole
- Typically one filter-run per week for check from top to bottom with relatively high speed
- During the first season we did several runs to filter the hole once and sieved a significantly bigger amount of cuttings in the much shorter hole


plumbing depth / m
100
200
400
500
600
700
800
1000
1100
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2550
2552
2575
2600
2625
2650
2675
2700
2725
2774
The maintained liquid level
To refill pure densifier
liquid level / m
60
80
100
120
140
160
180
200
2001/2002
2002/2003
2003/2004
2005/2006
27.01.2002
03.02.2002
10.02.2002
22.12.2002
29.12.2002
05.01.2003
12.01.2003
19.01.2003
26.01.2003
02.02.2003
09.02.2003
14.12.2003
21.12.2003
28.12.2003
04.01.2004
11.01.2004
18.01.2004
25.01.2004
01.02.2004
08.02.2004
13.11.2005
20.11.2005
27.11.2005
04.12.2005
11.12.2005
18.12.2005
25.12.2005
01.01.2006
08.01.2006
15.01.2006
22.01.2006
29.01.2006
local date and time (GMT)

Liquid consumption for third season

- total D40 consumption +10.5 m^3
- total HCFC F141b consumption +5.6 m^3
- geometrically to fill the hole: -13.2 m^3
- lost -2.9 m^3:
  - -0.65 m^3 with the chips
  - -0.60 m^3 to raise liquid level in casing 82 m to 70 m
  - -1.40 m^3 collected under the winch drum and brought home as waste
  - -0.25 m^3 evaporation and spray



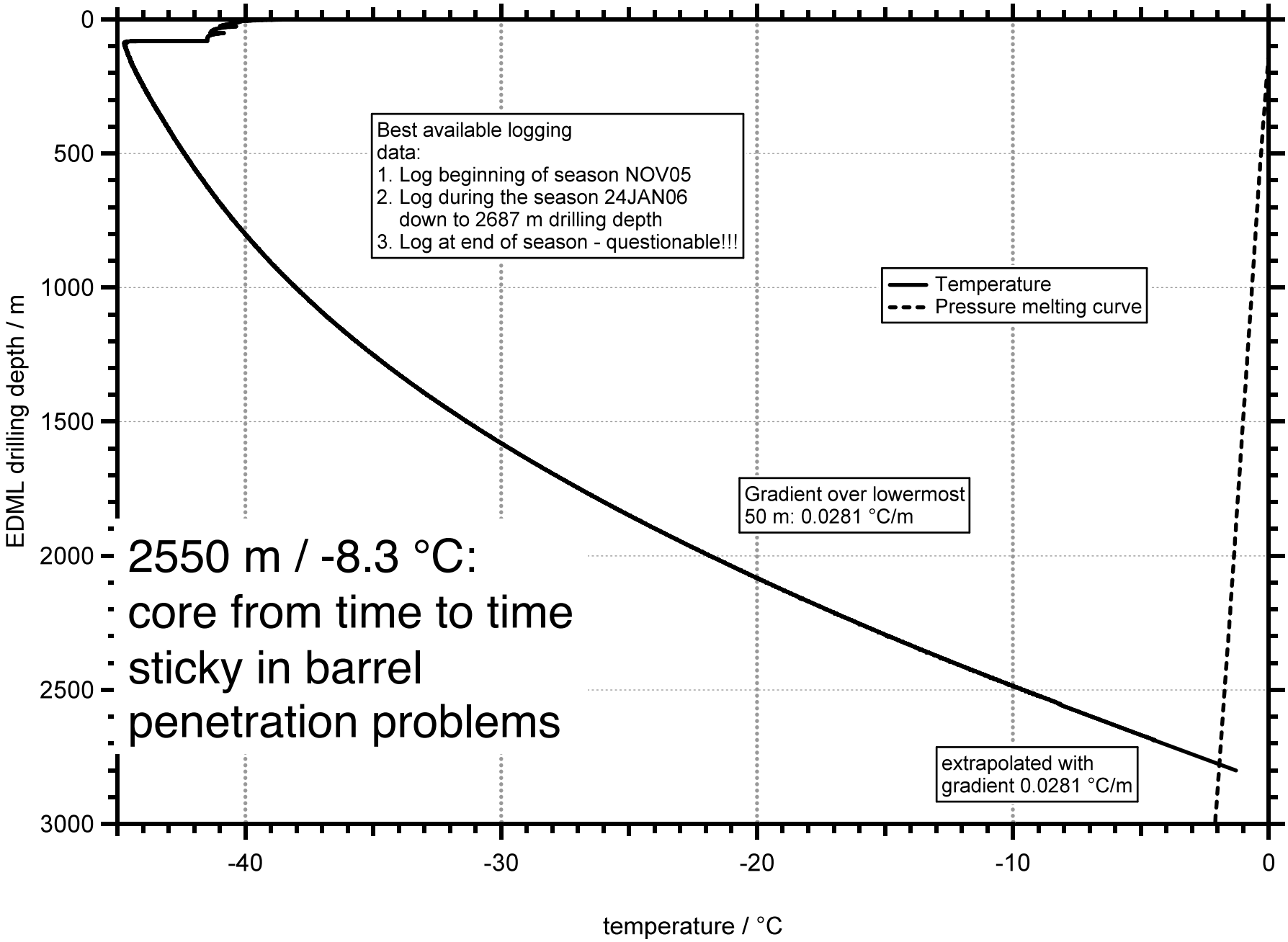
Winch games

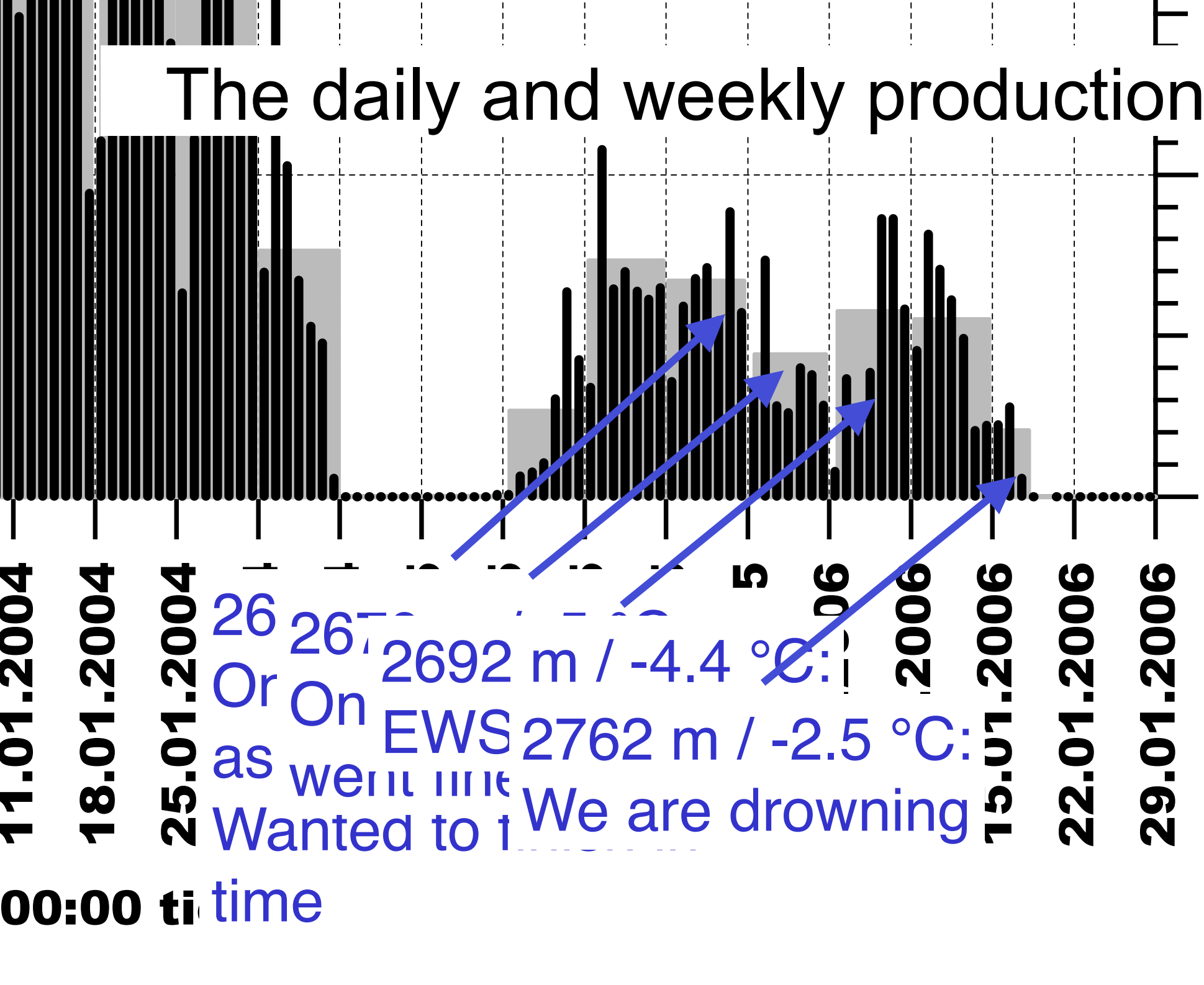
Lessons learnt

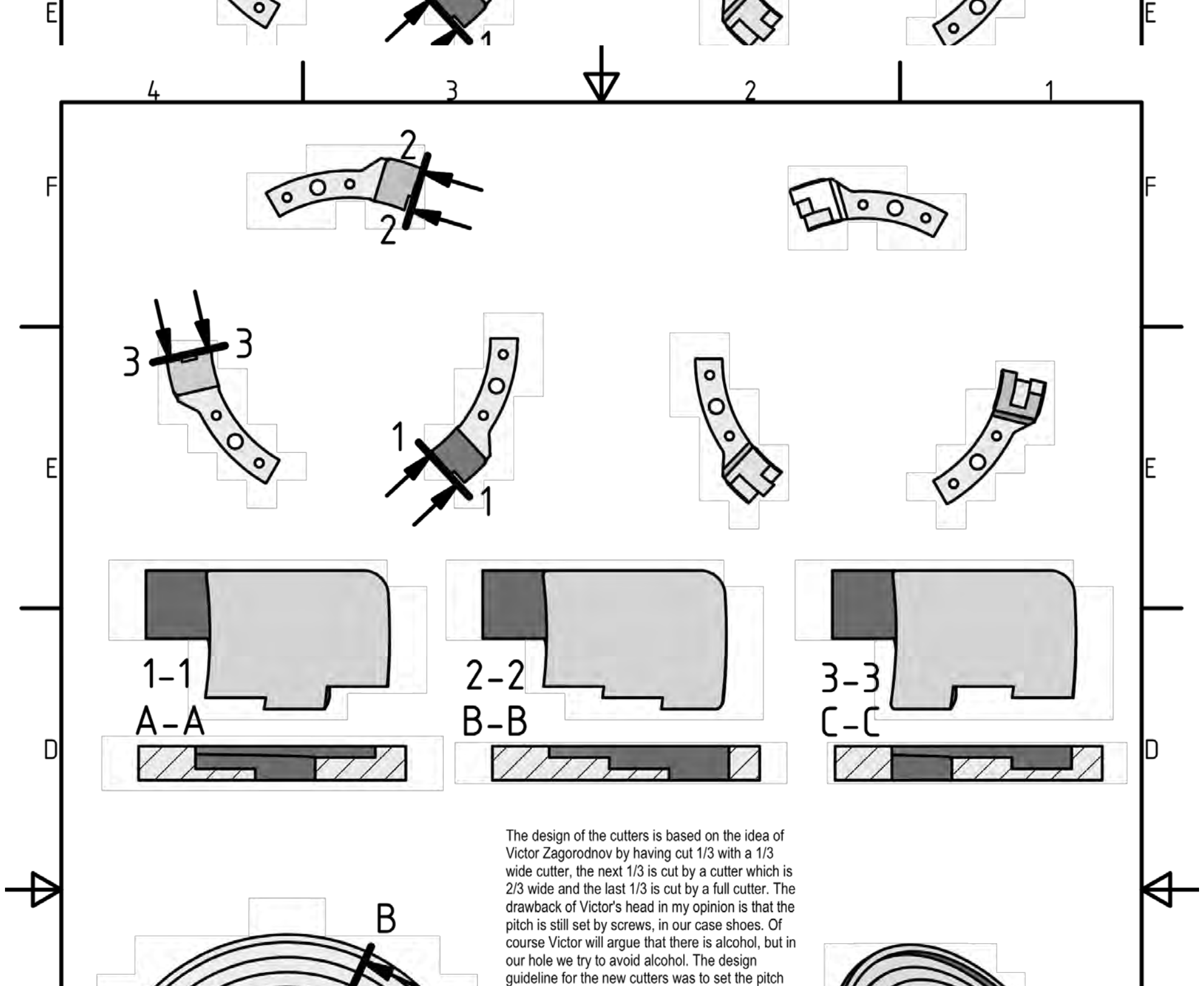
5. Spooling errors on the winch drum

- Persistent spooling errors for two seasons
- Icing and plastic liners for filling gaps; finally cable squeezed
- Re-tensioned cable with custom made capstan. Capstan with 8 grooves not enough friction and brake too small
- Reason for spooling error: Loose bolts on the winch drum, about ½ cable too wide!!!
- Cable stretched again and no squeeze visible anymore

Logging temperature

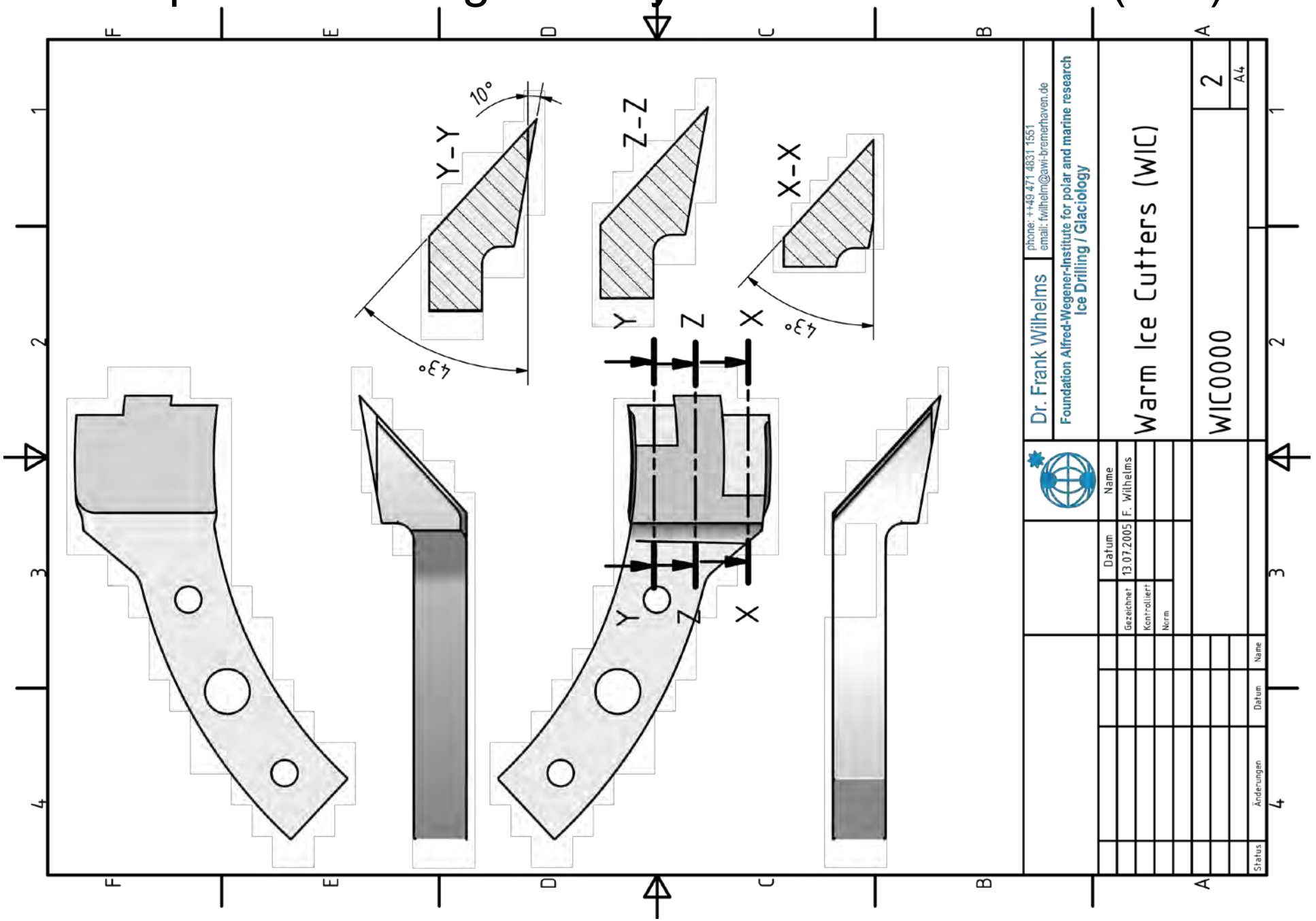



The daily and weekly production
11.01.2004
18.01.2004
25.01.2004
2006
15.01.2006
22.01.2006
29.01.2006
26
Or
as
Wanted to
2692 m / -4.4 °C:
On
EWS
2762 m / -2.5 °C:
We are drowning
00:00 ti
time

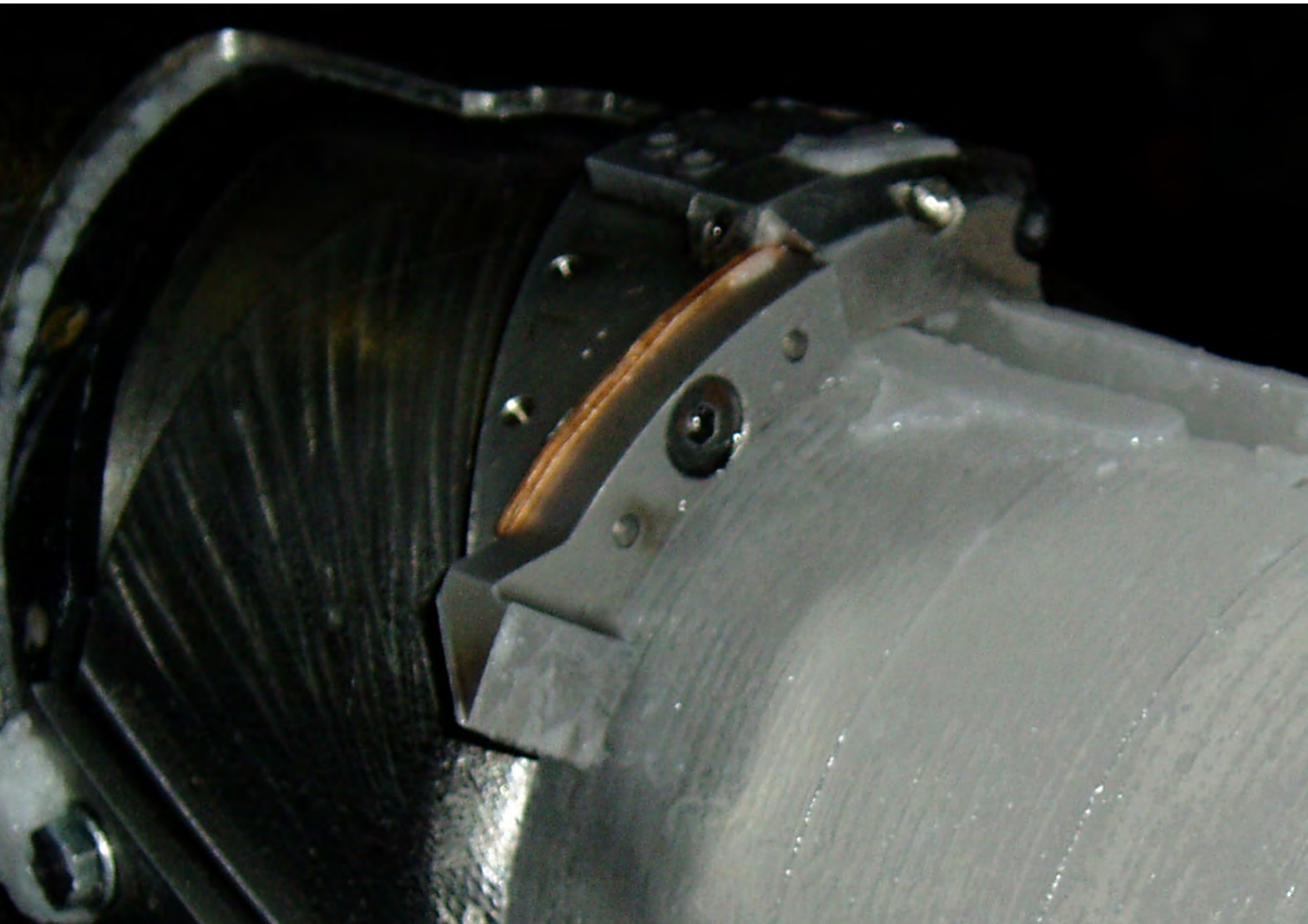


The design of the cutters is based on the idea of Victor Zagorodnov by having cut 1/3 with a 1/3 wide cutter, the next 1/3 is cut by a cutter which is 2/3 wide and the last 1/3 is cut by a full cutter. The drawback of Victor's head in my opinion is that the pitch is still set by screws, in our case shoes. Of course Victor will argue that there is alcohol, but in our hole we try to avoid alcohol. The design guideline for the new cutters was to set the pitch

Proposed cutter geometry before the season (ctd.)

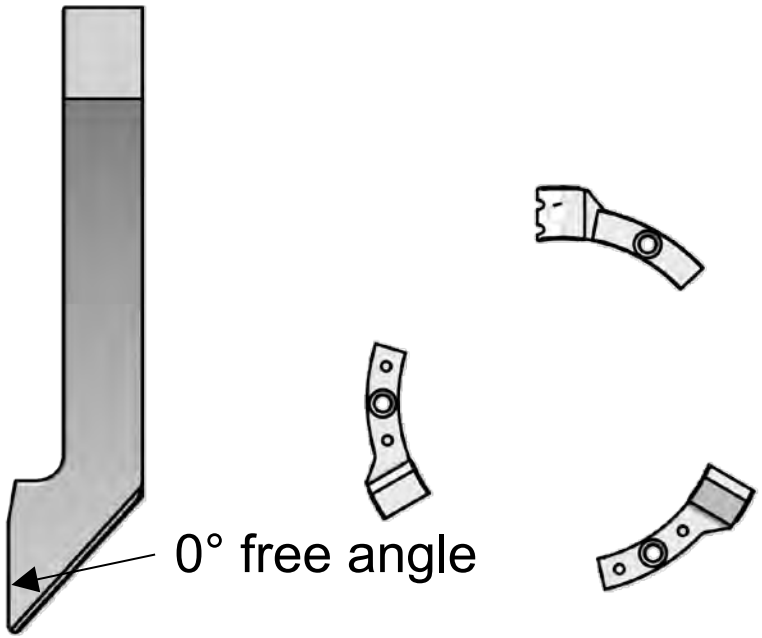


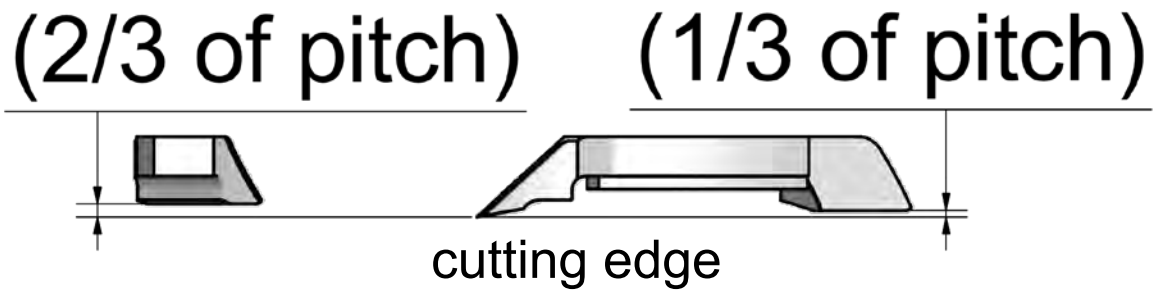

Handmade Shoes

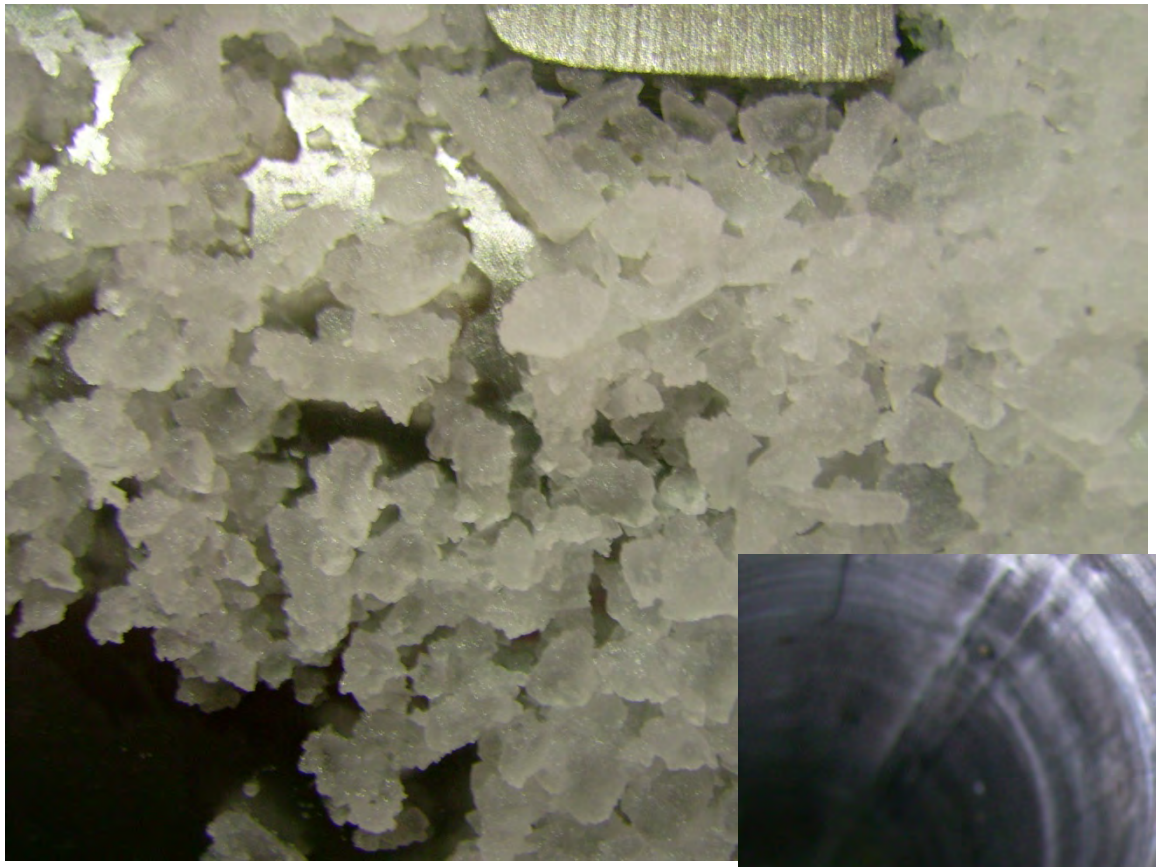


One armed bandit

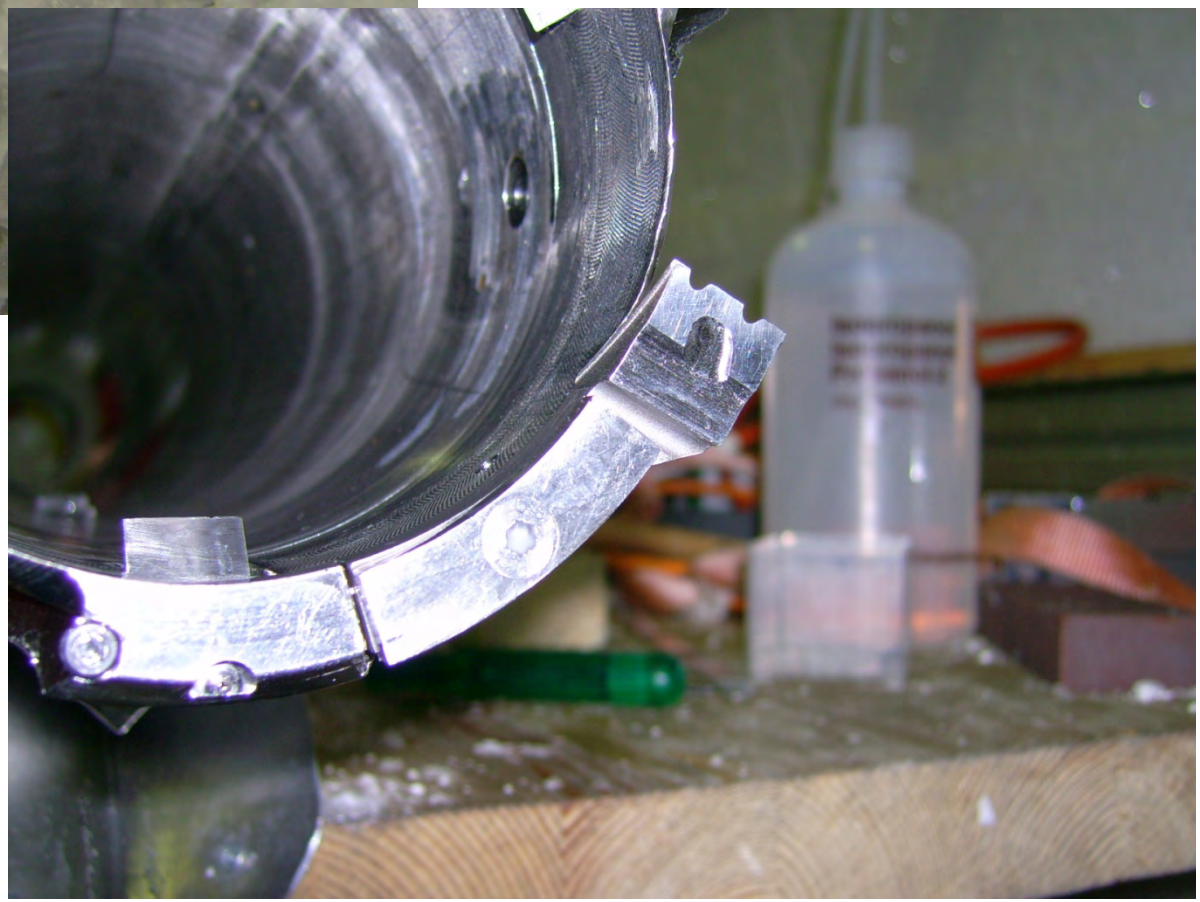
Two cutters as shoes

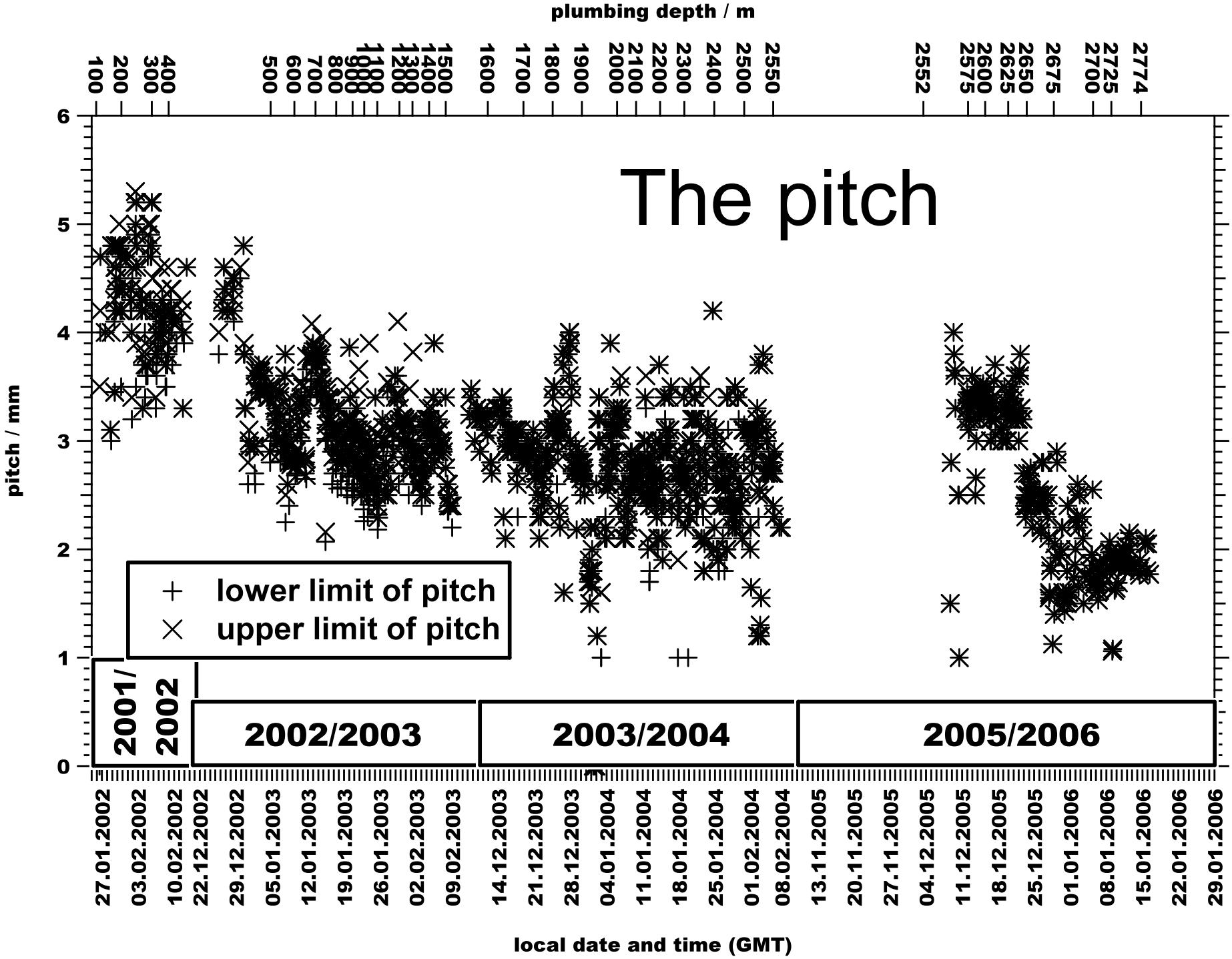




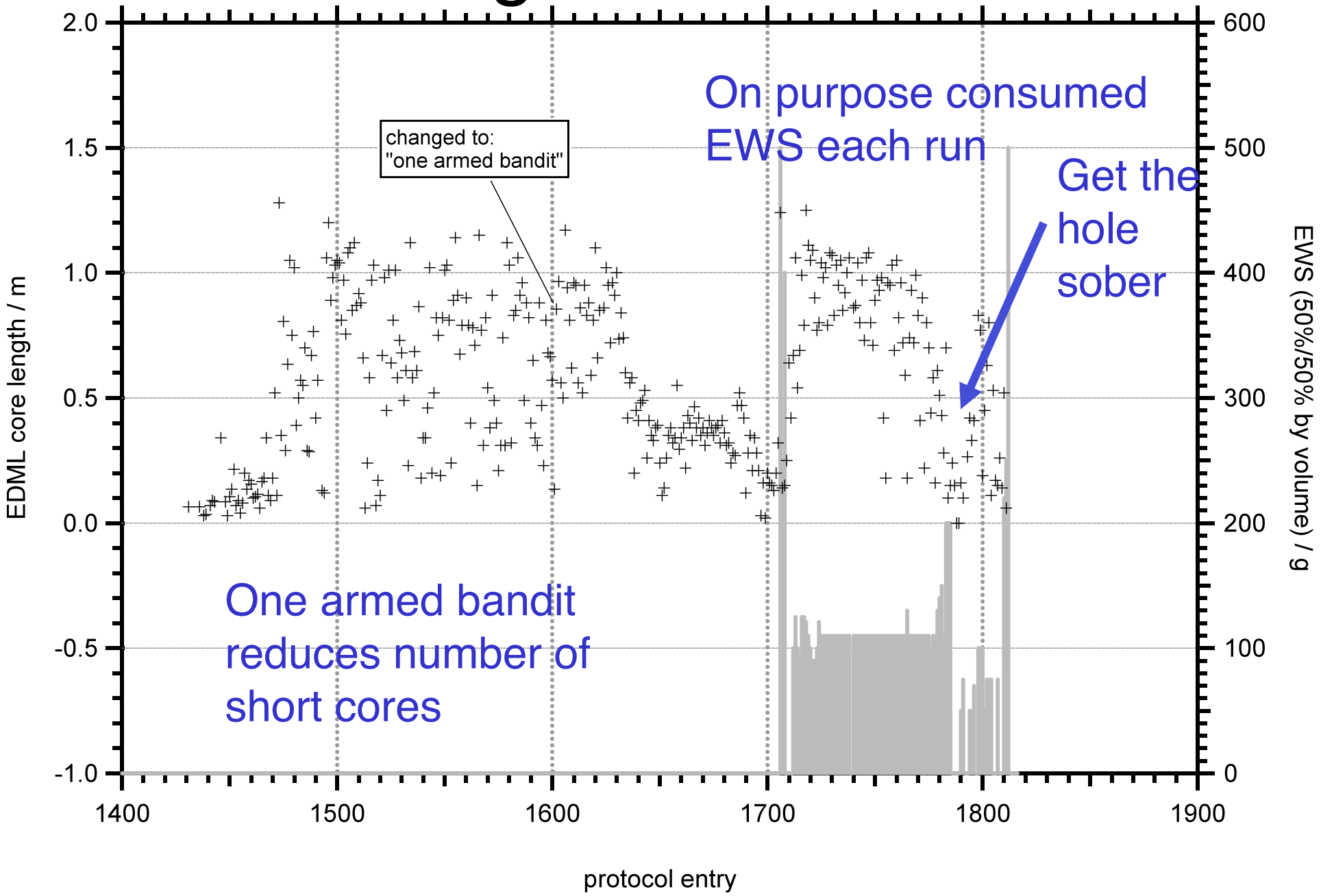


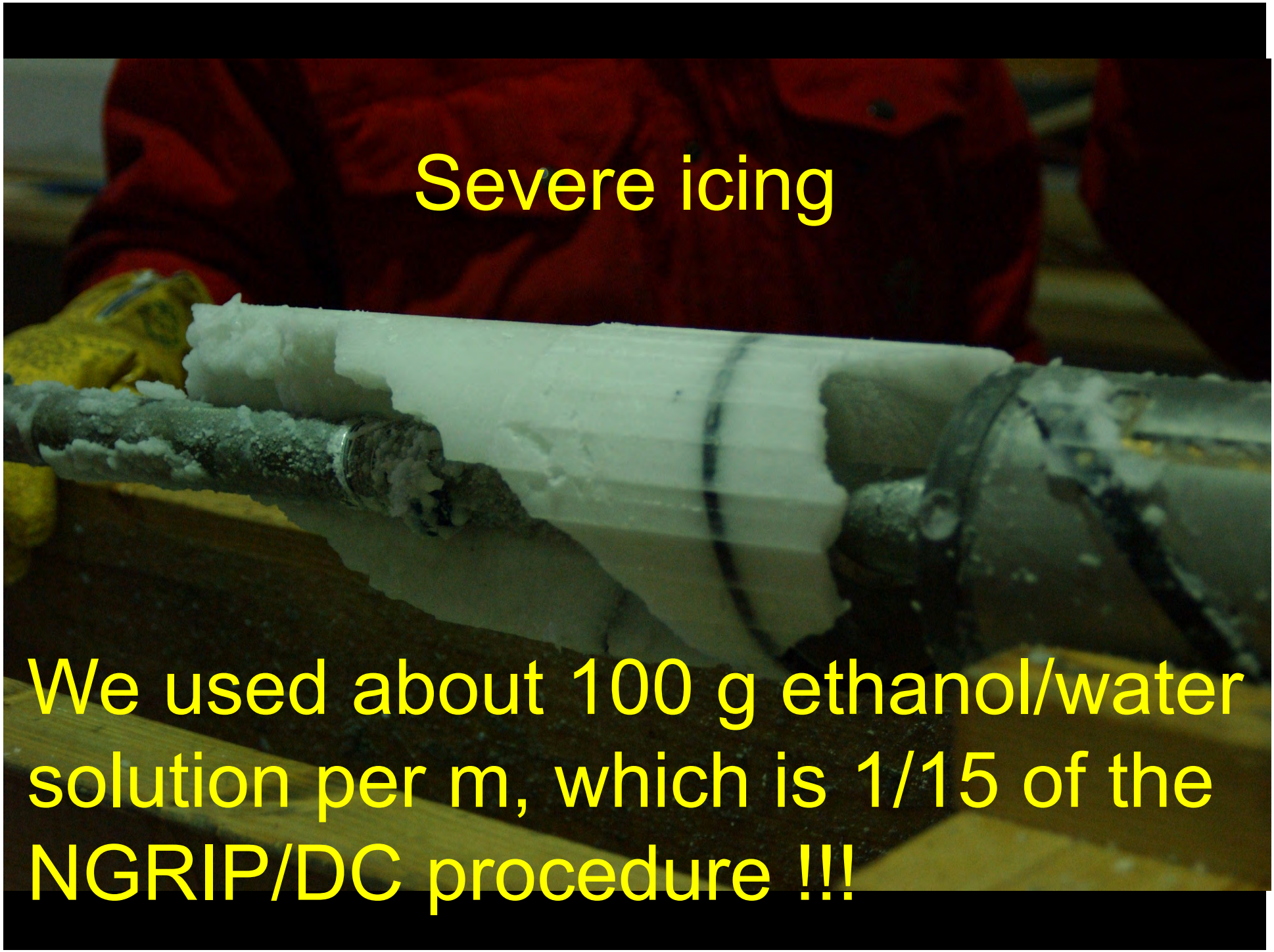
Coarser chips




plumbing depth / m
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2550
2552
2575
2600
2625
2650
2675
2700
2725
2774
The pitch
pitch / mm
0
1
2
3
4
5
6
lower limit of pitch
upper limit of pitch
2001/2002
2002/2003
2003/2004
2005/2006
27.01.2002
03.02.2002
10.02.2002
22.12.2002
29.12.2002
05.01.2003
12.01.2003
19.01.2003
26.01.2003
02.02.2003
09.02.2003
14.12.2003
21.12.2003
28.12.2003
04.01.2004
11.01.2004
18.01.2004
25.01.2004
01.02.2004
08.02.2004
13.11.2005
20.11.2005
27.11.2005
04.12.2005
11.12.2005
18.12.2005
25.12.2005
01.01.2006
08.01.2006
15.01.2006
22.01.2006
29.01.2006
local date and time (GMT)

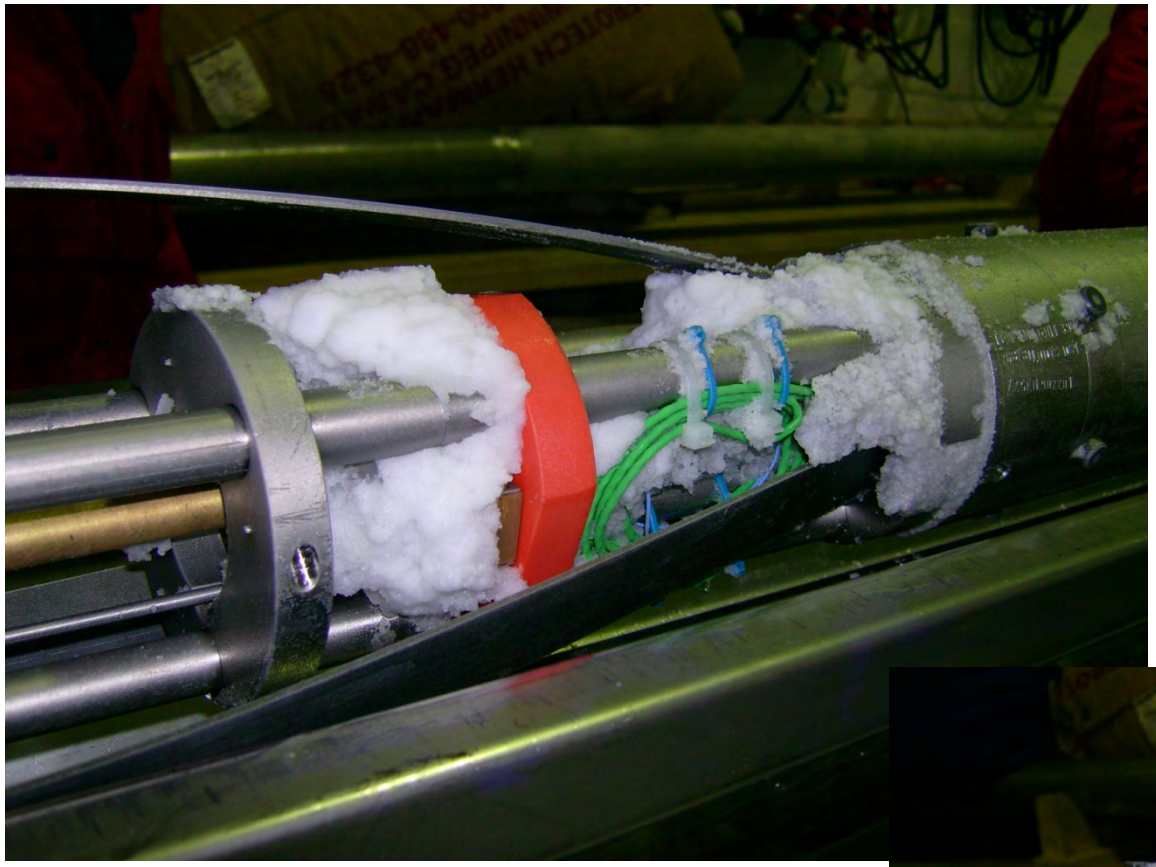
Core length – OAB – EWS



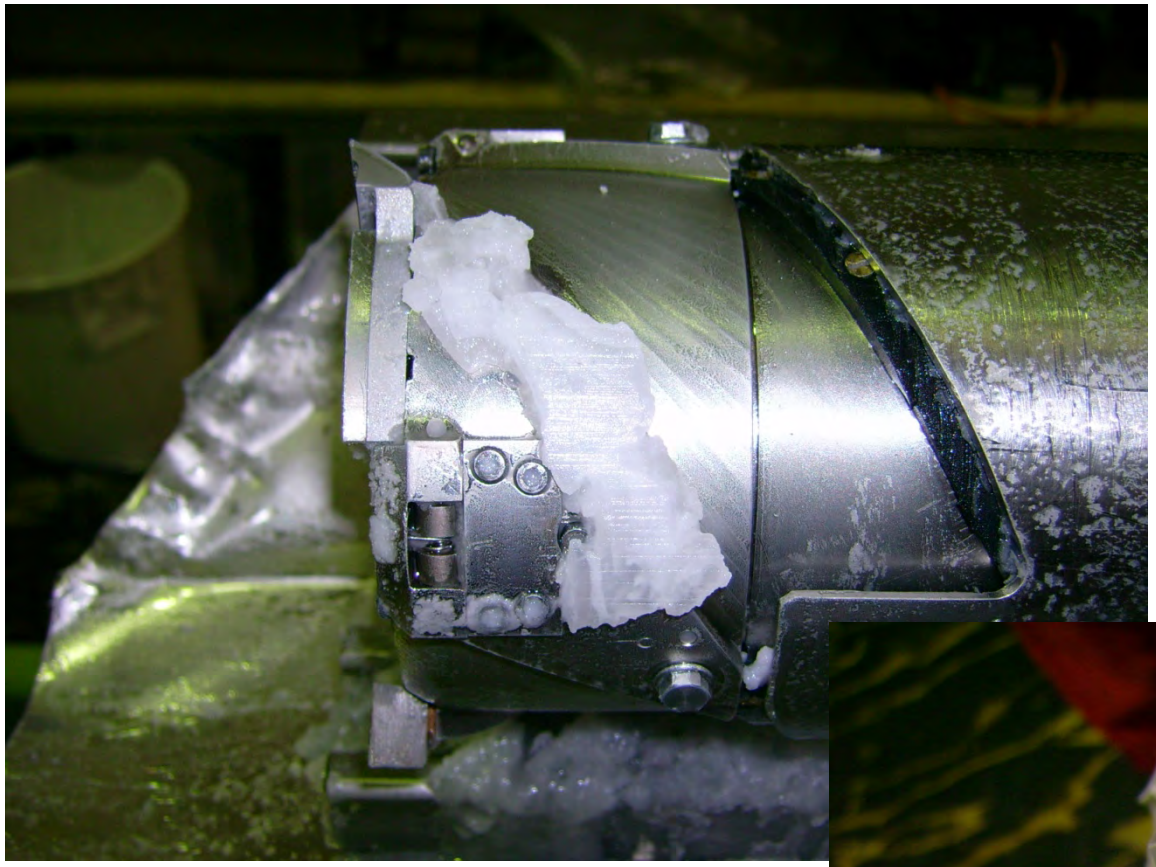

Severe icing
We used about 100 g ethanol/water solution per m, which is 1/15 of the NGRIP/DC procedure !!!

One armed bandit - Conclusions

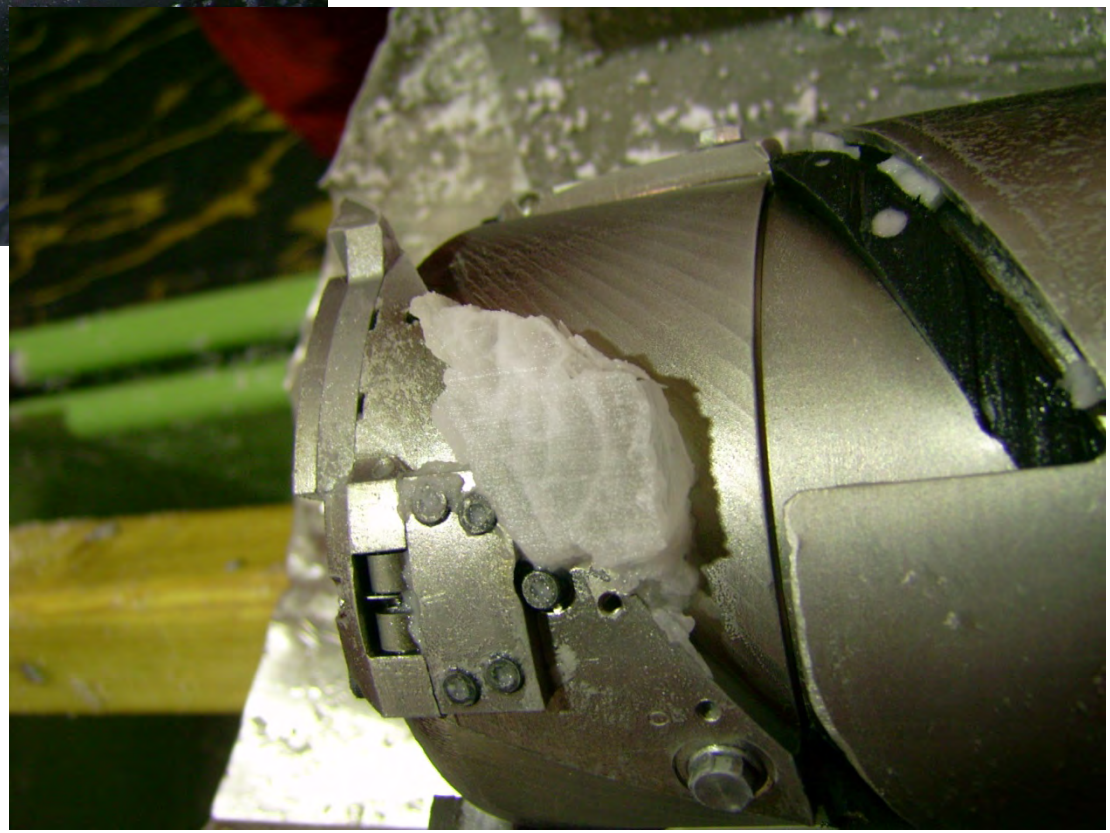
- To -5 °C with good penetration properties
- Managed with significantly less EWS, 1/15 th!
- Core would easily move out of barrel!
- Good for testing purpose, you only have to modify and sharpen one cutter
- Swarf breaking grooves helped, as swarfs are expected to be bigger
- Dome F small edge design helped
- Inclination decreased, we stopped with less than 1°



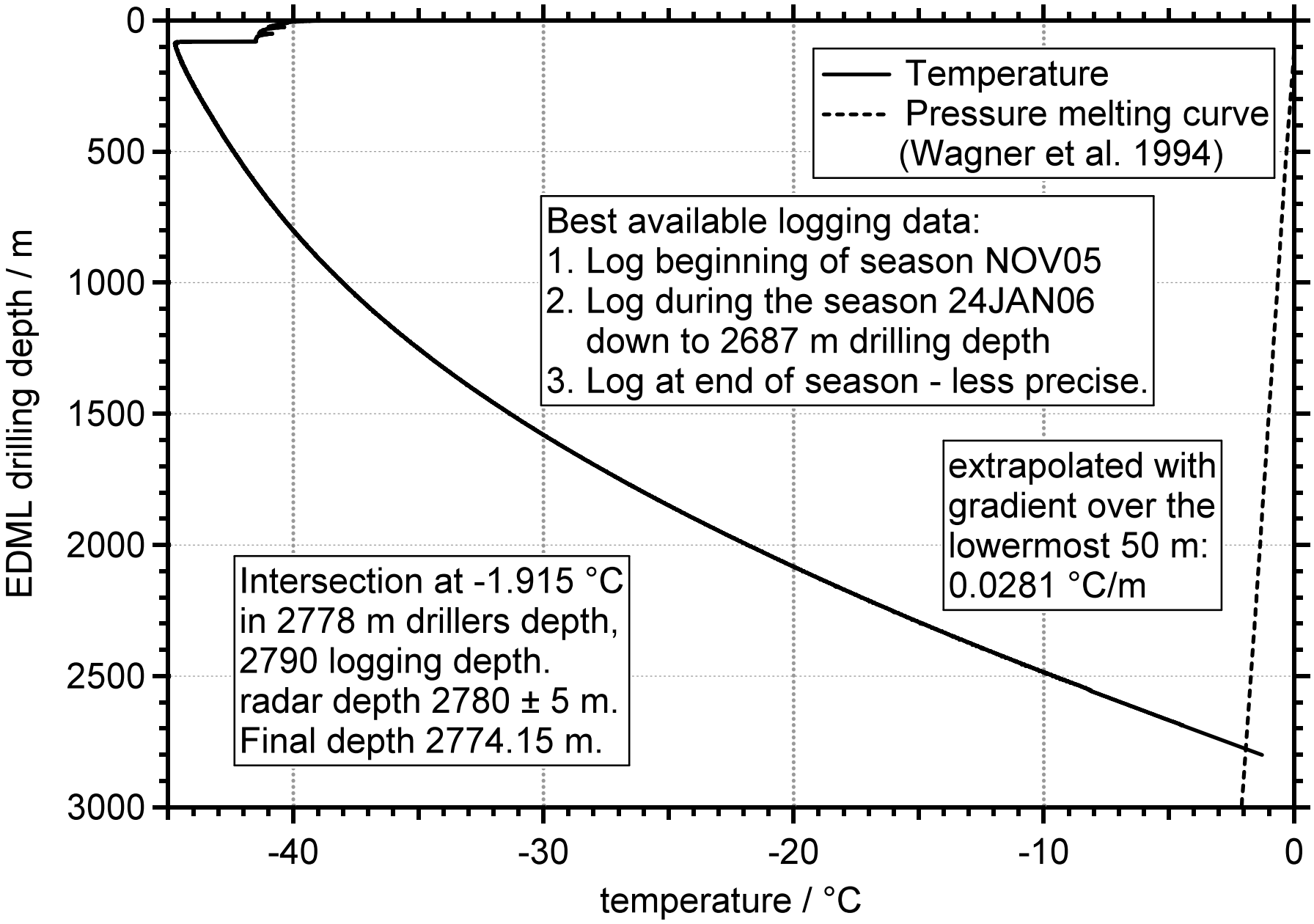
Drown it!!!



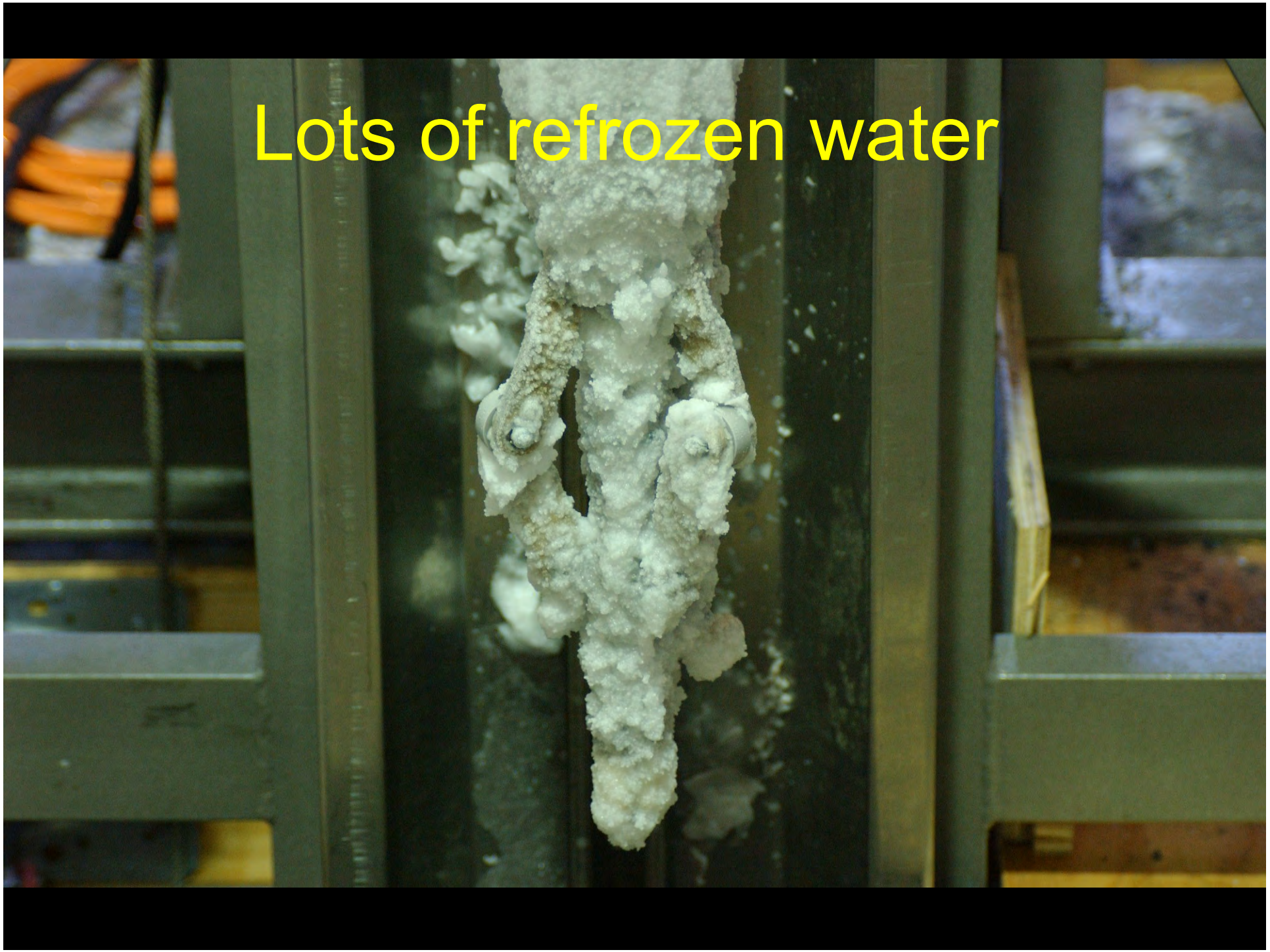
Icing Chips cannot enter barrel!!!



Refreezing on the drill

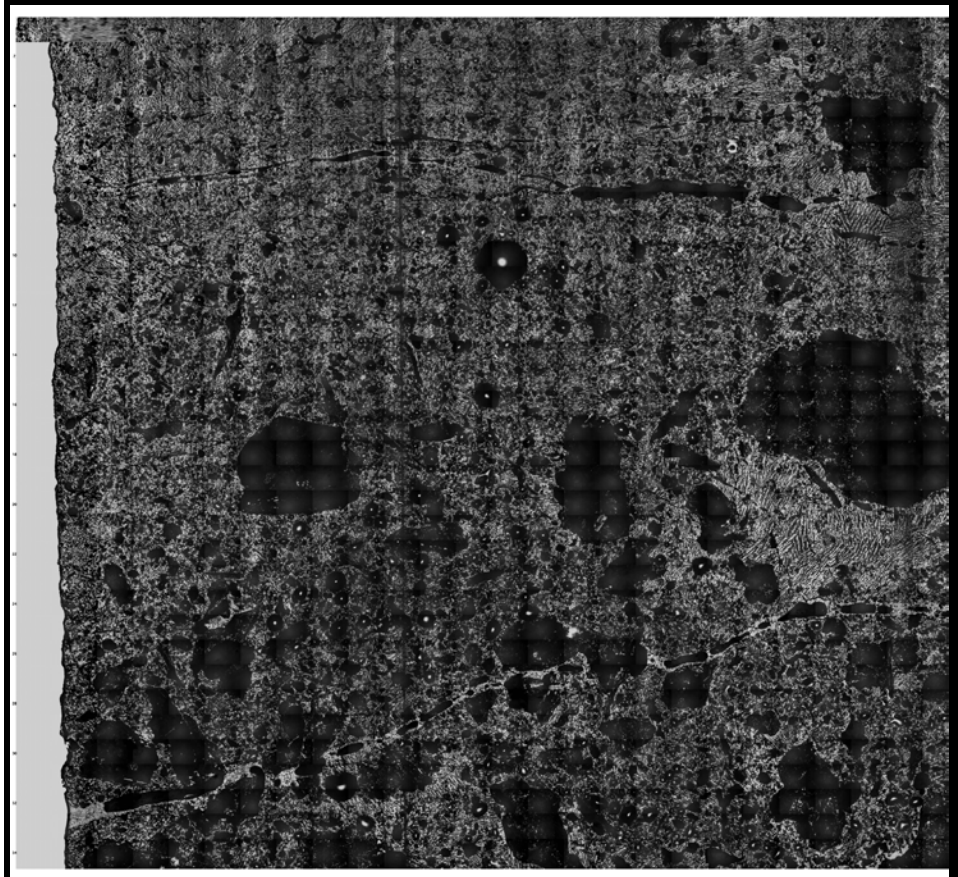

Logging temperature
EDML drilling depth / m
0
500
1000
1500
2000
2500
3000
-40
-30
-20
-10
0
temperature / °C
Temperature
Pressure melting curve
(Wagner et al. 1994)
Best available logging data:
1. Log beginning of season NOV05
2. Log during the season 24JAN06
down to 2687 m drilling depth
3. Log at end of season - less precise.
extrapolated with
gradient over the
lowermost 50 m:
0.0281 °C/m
Intersection at -1.915 °C
in 2778 m drillers depth,
2790 logging depth.
radar depth 2780 ± 5 m.
Final depth 2774.15 m.

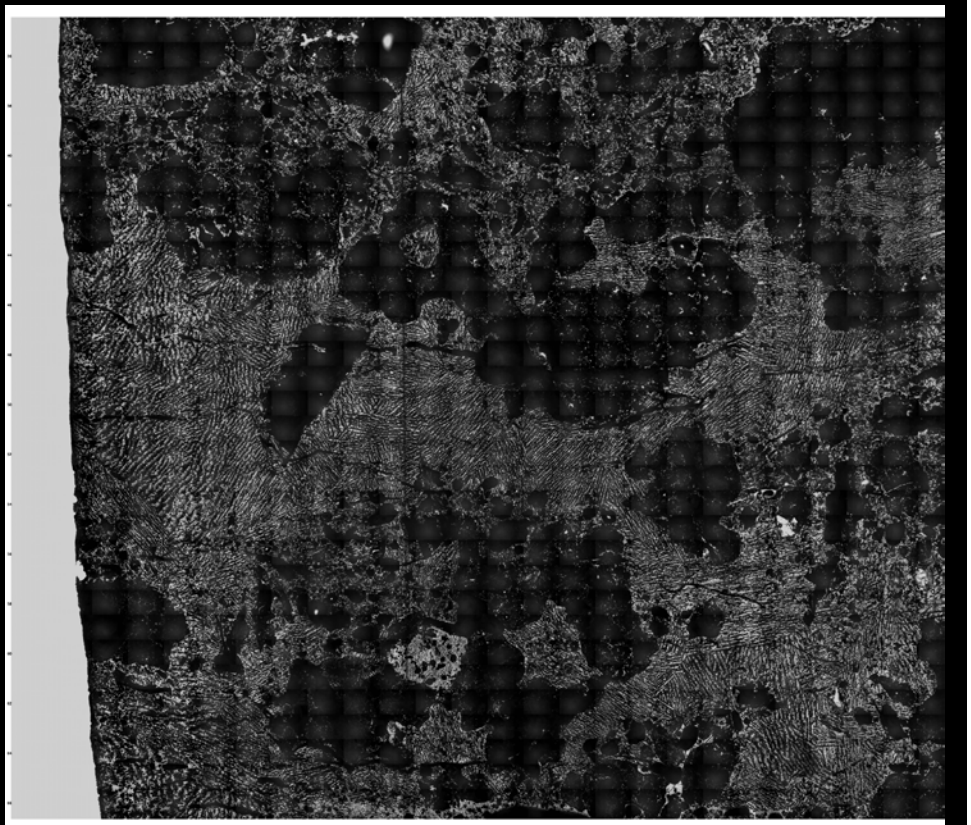

EUROPEAN PROJECT FOR ICE CORING IN ANTARCTICA
EPICA
bottom
2774.15 m
17.01.2006
Dronning Maud Land
DOME CONCORDIA
DRONNING MAUD LAND


Lots of refrozen water

Ice Coring goes arts!

The white color from inclusions





HCFC-141b forms clathrate

Annals of Glaciology 47 2007

The role of hydrochlorofluorocarbon densifiers in the formation of clathrate hydrates in deep boreholes and subglacial environments

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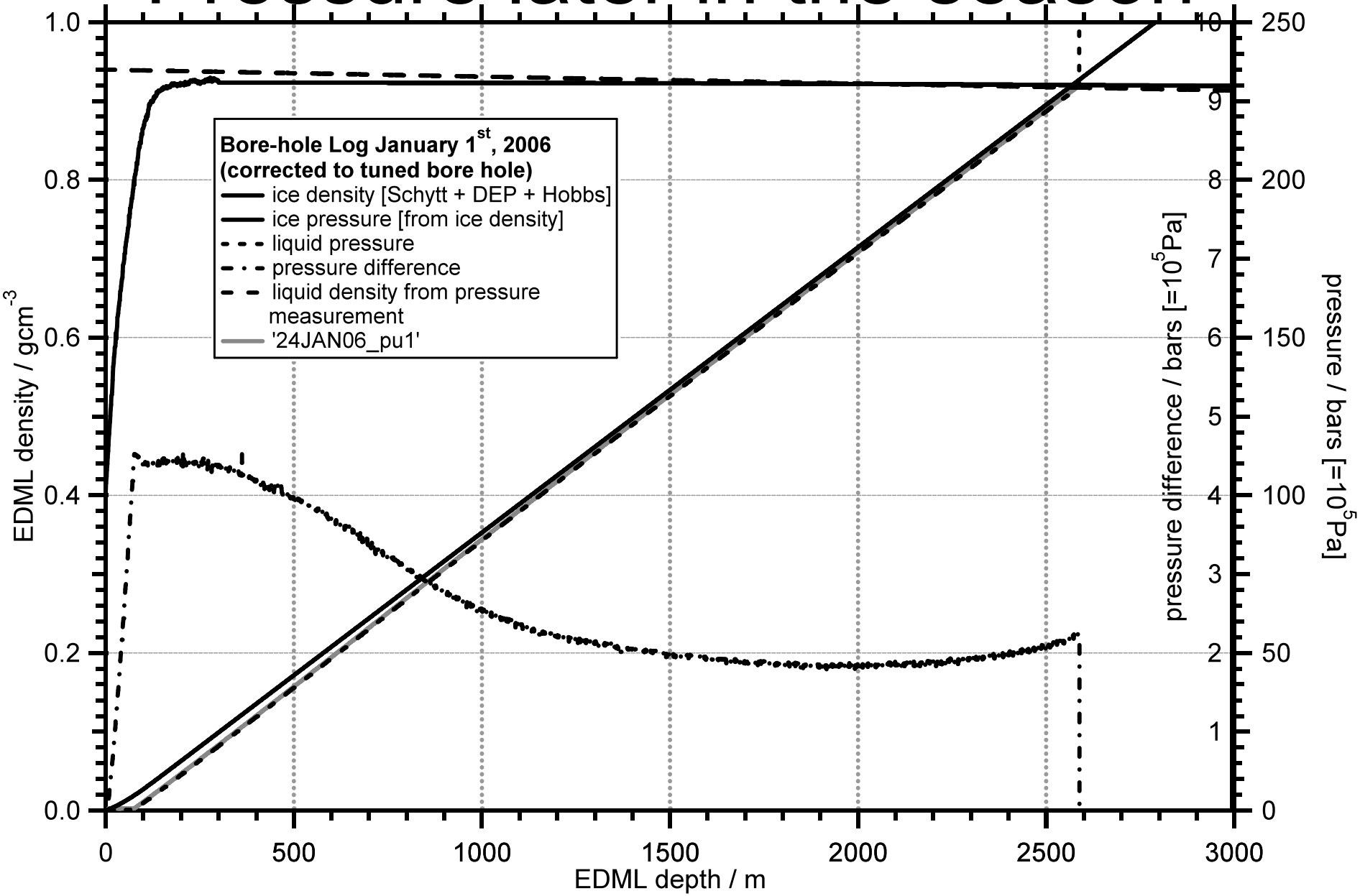
ABSTRACT. Clear evidence for the formation of mixed clathrate hydrates of air and hydrochlorofluorocarbon densifier (known as HCFC-141b, sometimes also called R-141b) is found by means of synchrotron X-ray diffraction and Raman spectroscopy on a sample recovered from the bottom of the EPICA Dronning Maud Land deep borehole in Antarctica. Subglacial water (SGW) appears to have reacted with the drilling liquid to build a large lump of clathrate hydrate. The hydrate growth may well have been accelerated by the stirring of the SGW–densifier mixture during drilling. Moreover, dissolved air in the SGW appears to have participated in the formation of mixed hydrates of air and HCFC-141b as evidenced by the concomitant appearance of Raman signals from both constituents. Our findings elucidate to some extent the meaning of earlier accounts of the formation of 'heavy chips' that may sink to the bottom of the borehole, possibly affecting or even impeding the drilling advance. These observations raise concerns with respect to the use of HCFC-141b densifiers in ice-core drilling liquids under warm ice conditions.

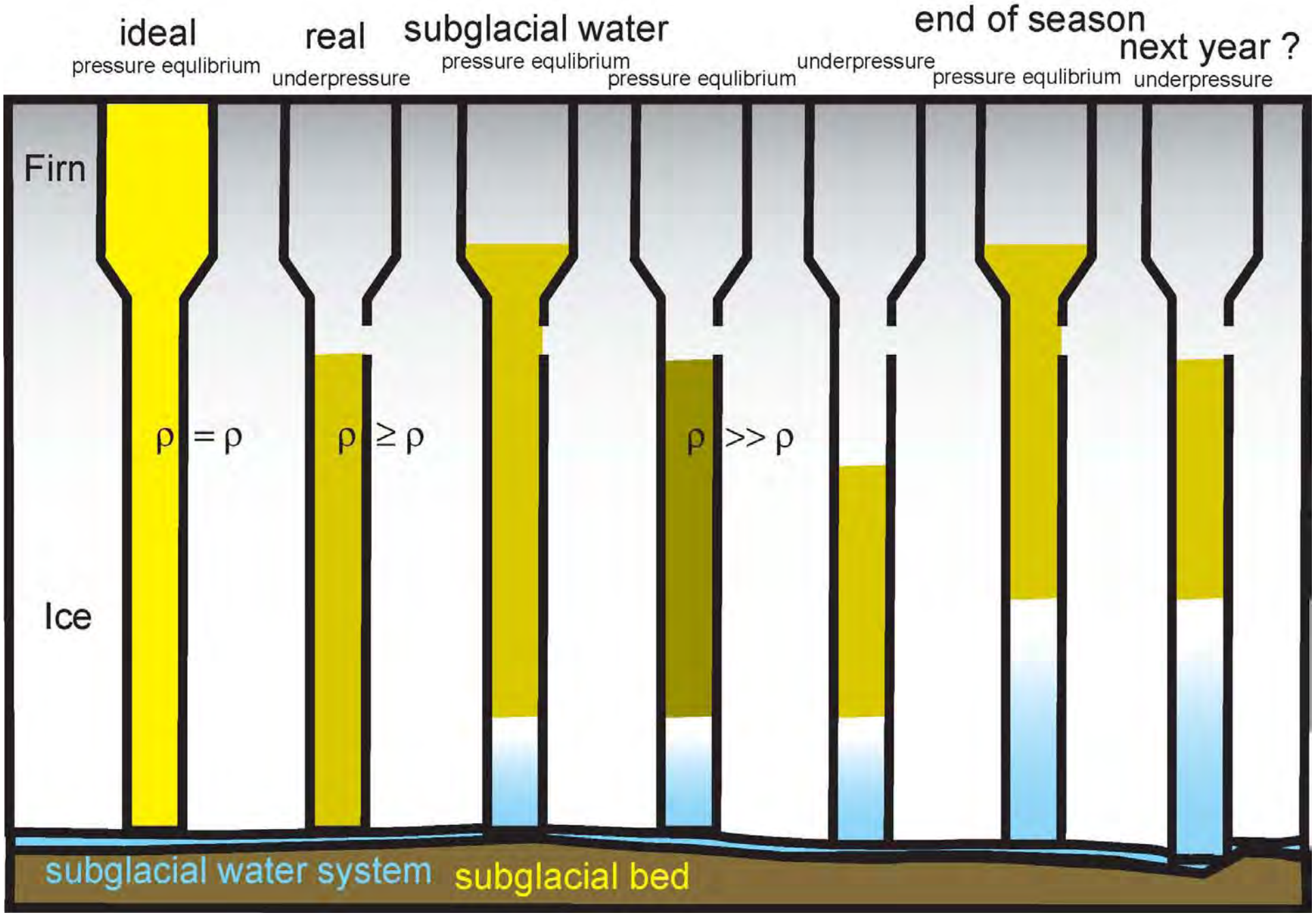
What we have

- approx. 13 kg white material with drill liquid from core barrel
- approx. 13 kg water from bailer not melted and refrozen
- approx. 10 kg water from bailer melted and refrozen in slabs
- lower 163 m of hole filled with refrozen subglacial water

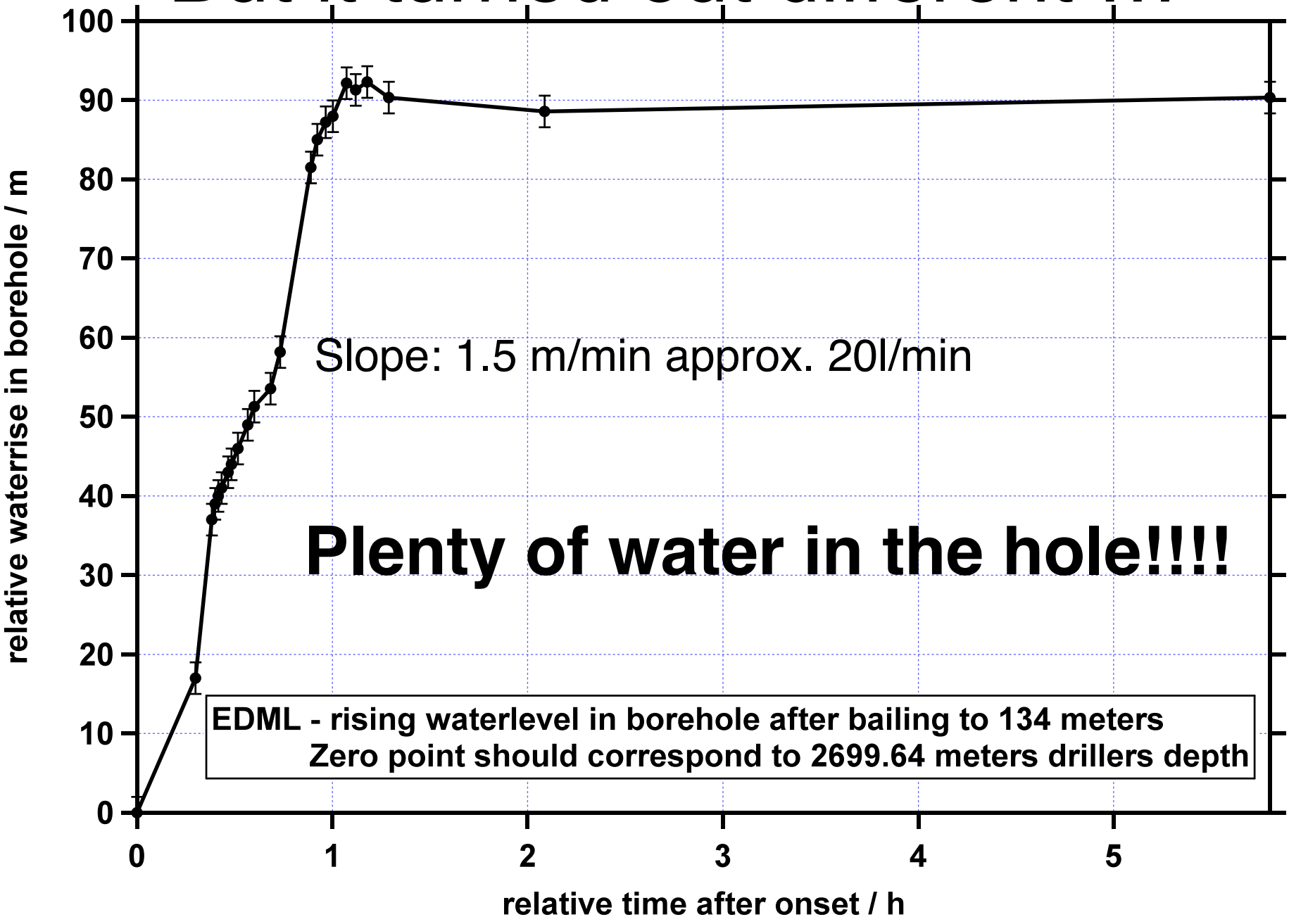
Pressure later in the season



The casing and what happened?

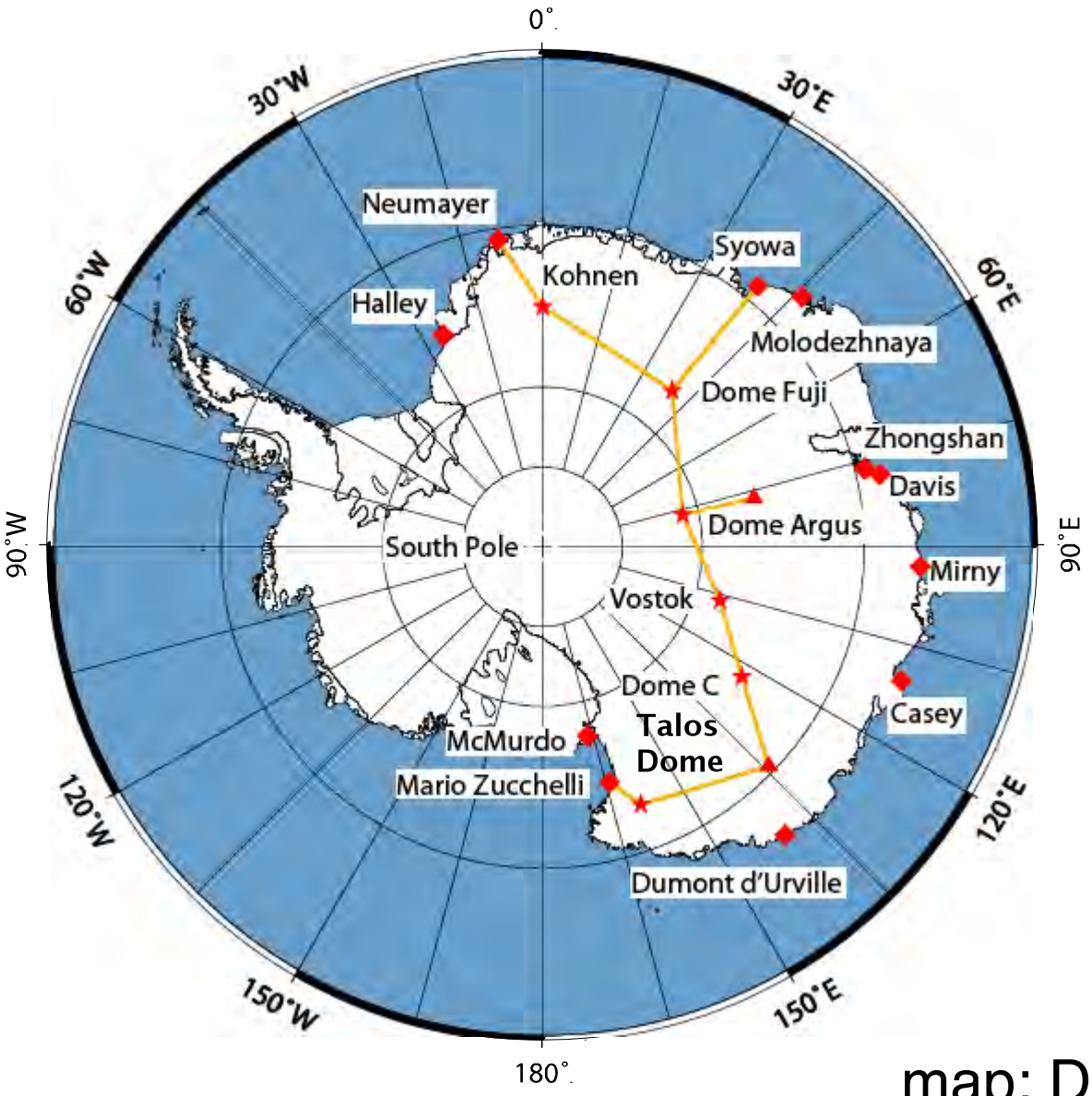


But it turned out different …



Conclusions

- Smooth operation in 4 seasons deep drilling
- Roughly 25 weeks of drilling for the 2660 m of core production, which is an average of more than 100 m/week
- We drilled very cautious and saved more time than we lost
- The equipment was far from being ideal, but it did the job!
- More replicate units to just kick on
- Shift leaders, mechanic, electronics engineer for the entire project
- Drillers helpers can be changed every season



Linking Ice Cores and surveys in East Antarctica

map: Daniel Steinhage
Data: Antarctic Digital Database

Thank you!

bedrock reception

A special thank you to:
Steffen Bo Hansen, Henry Rufli, Laurent Augustin