Drilling of Hot and Fractured Granite at Soultz-sous-Forêts

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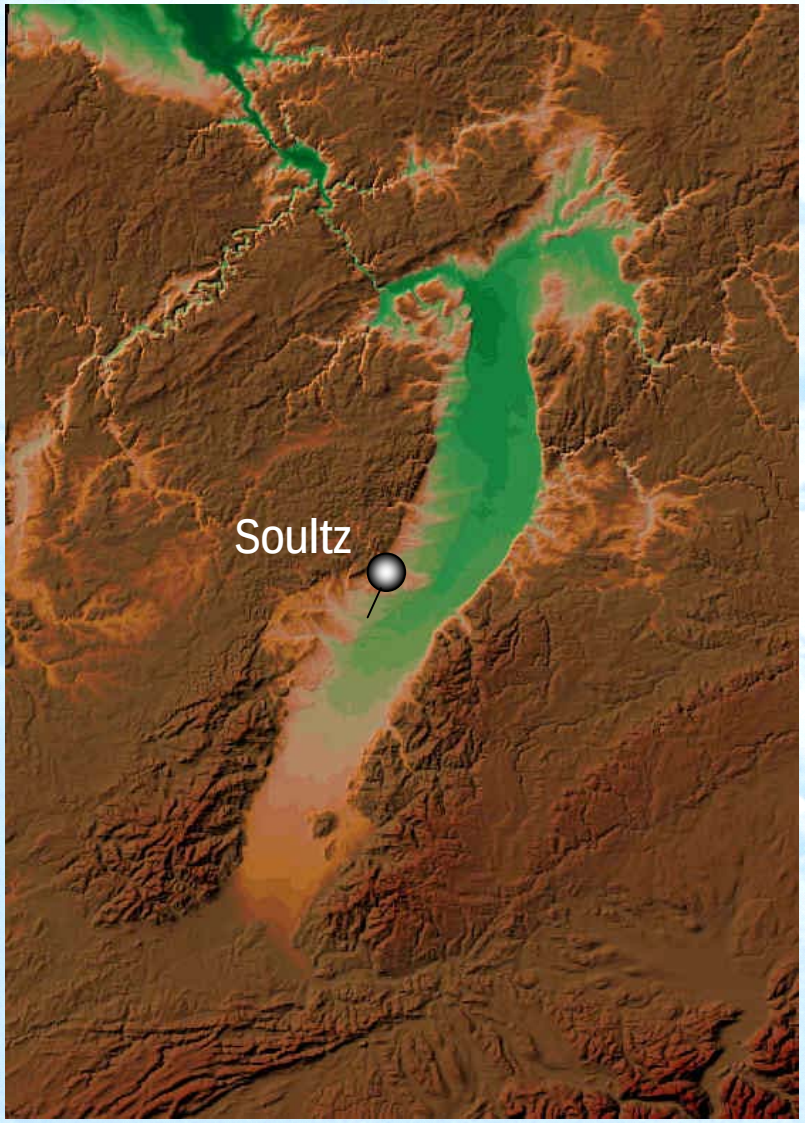
The Project Location



GRABEN TECTONICS

→ Fractured Rocks

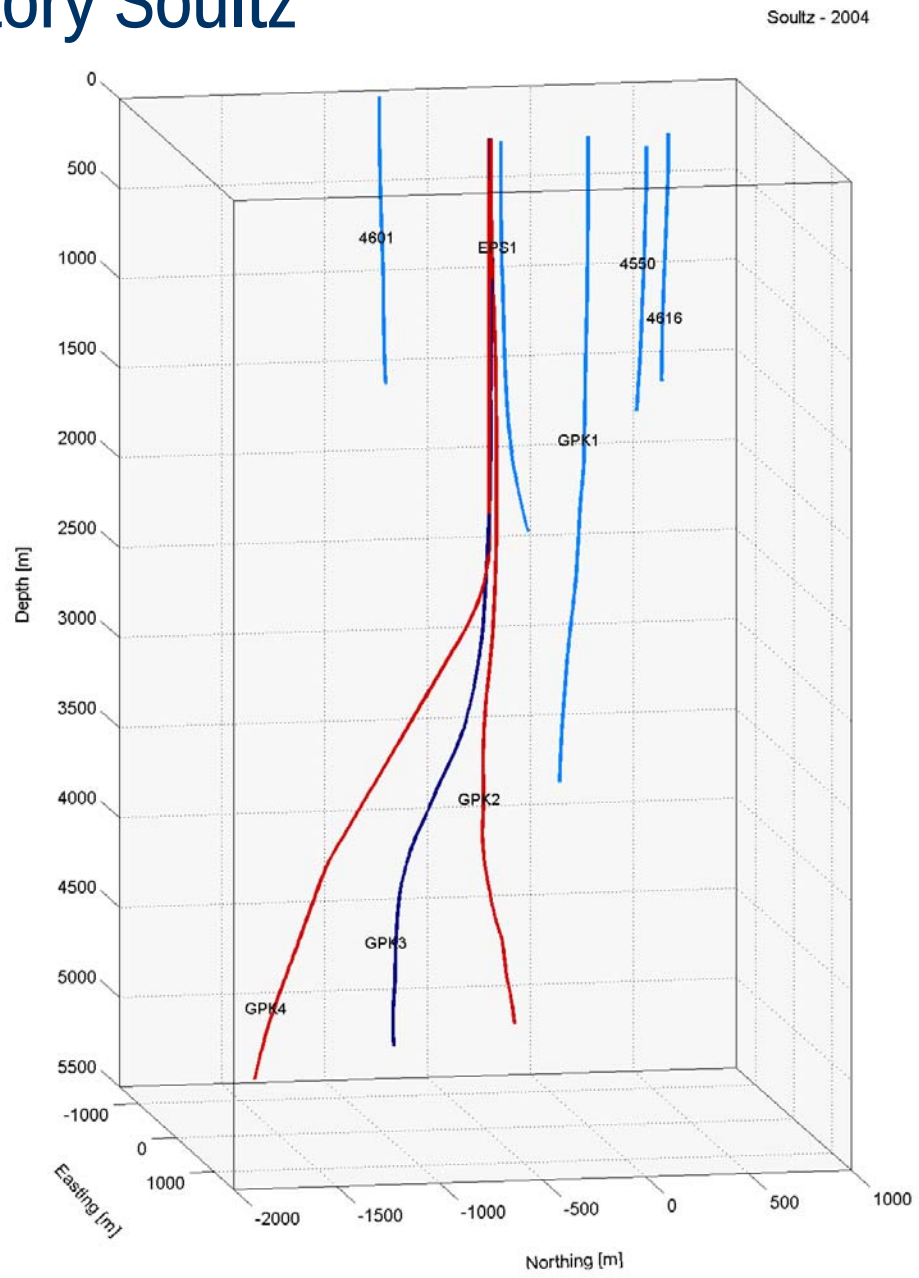
HOT TEMPERATURES

→ 200 °C at 5000 m

GRANITE

→ Rough and Hard Rock below 1500 m

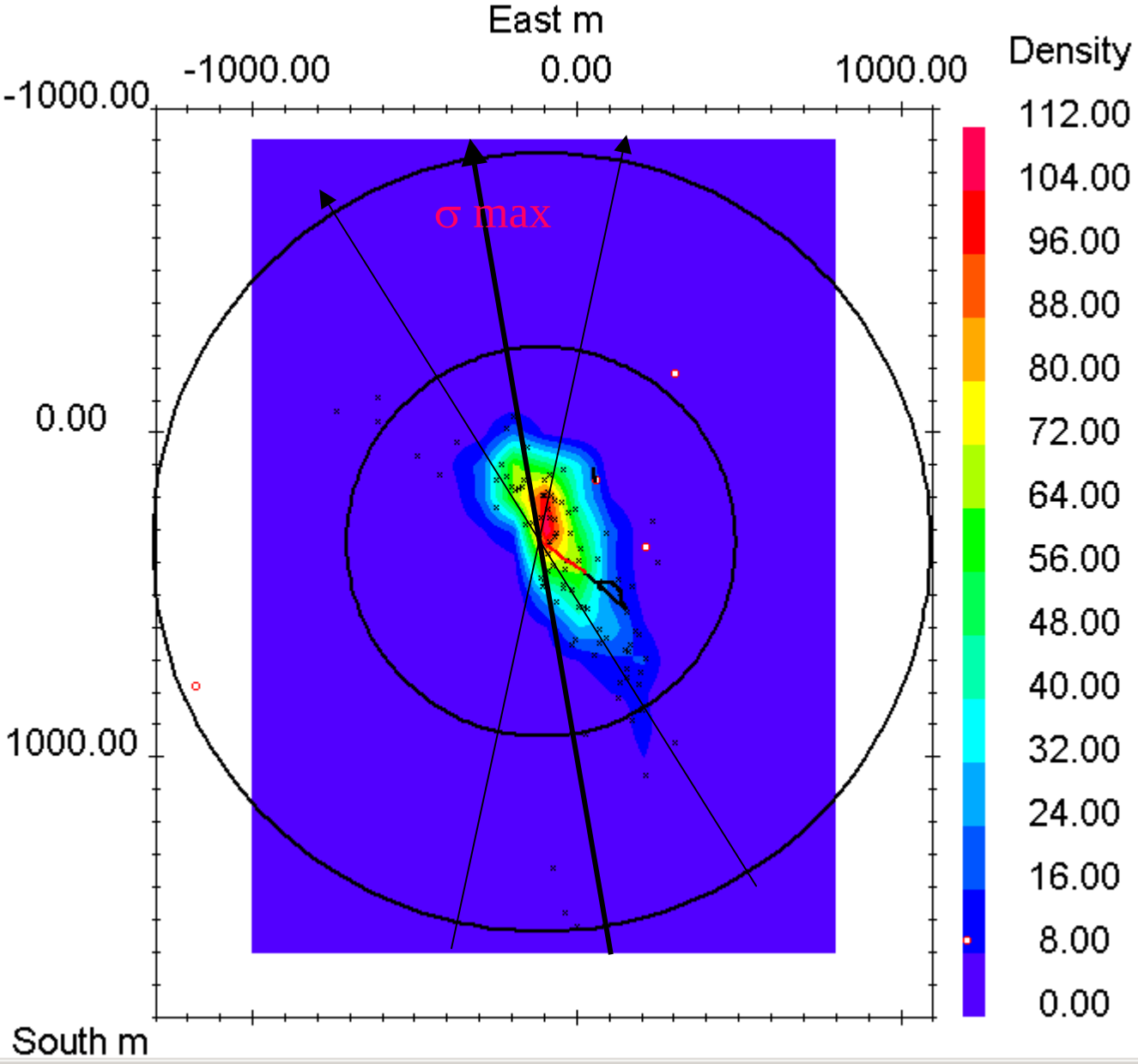
Drilling History Soultz



Target GPK3 – Seismicity 2000

Depth Range:

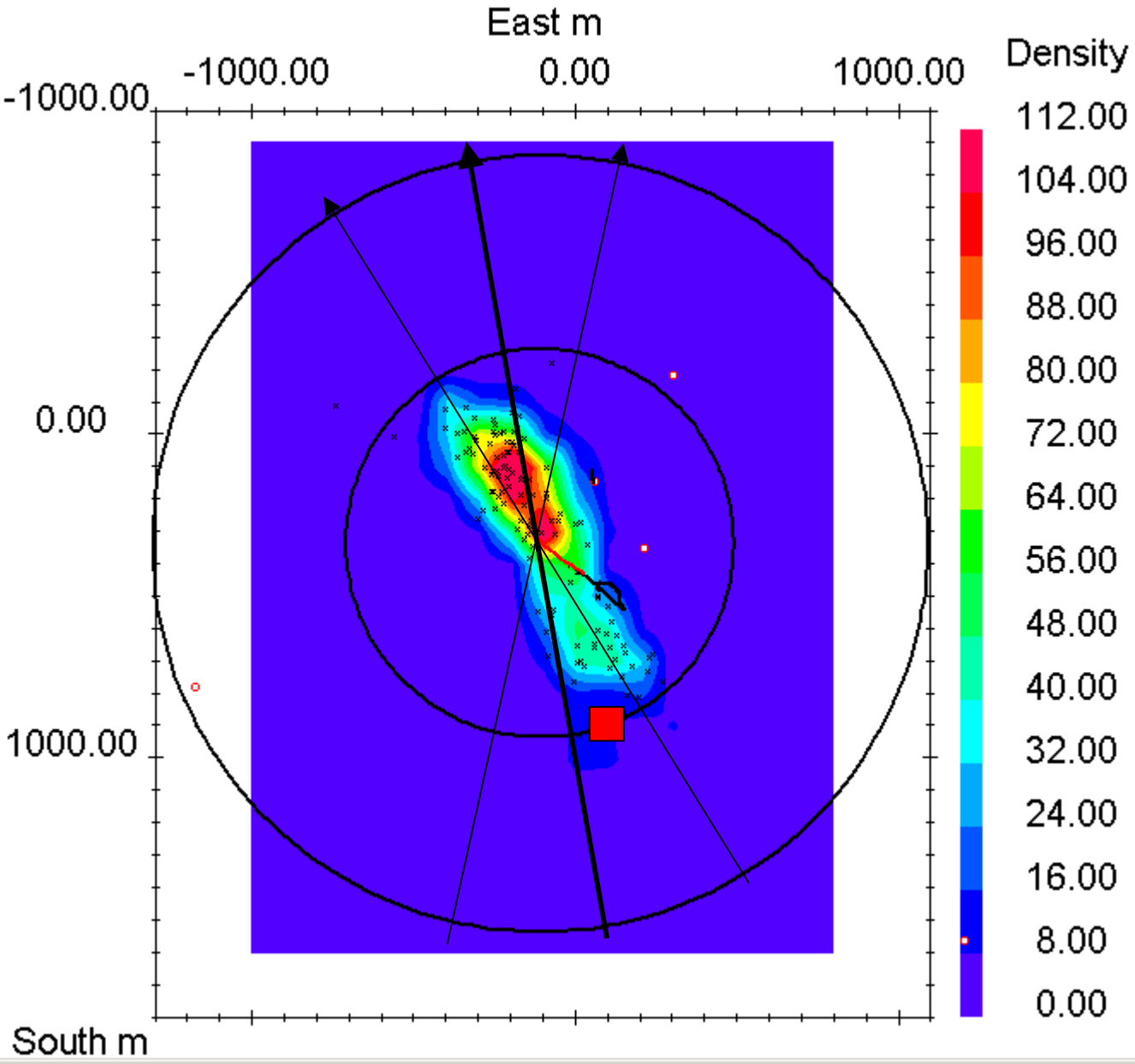
4600 m – 4700 m



Target GPK3 – Seismicity 2000

Depth Range:

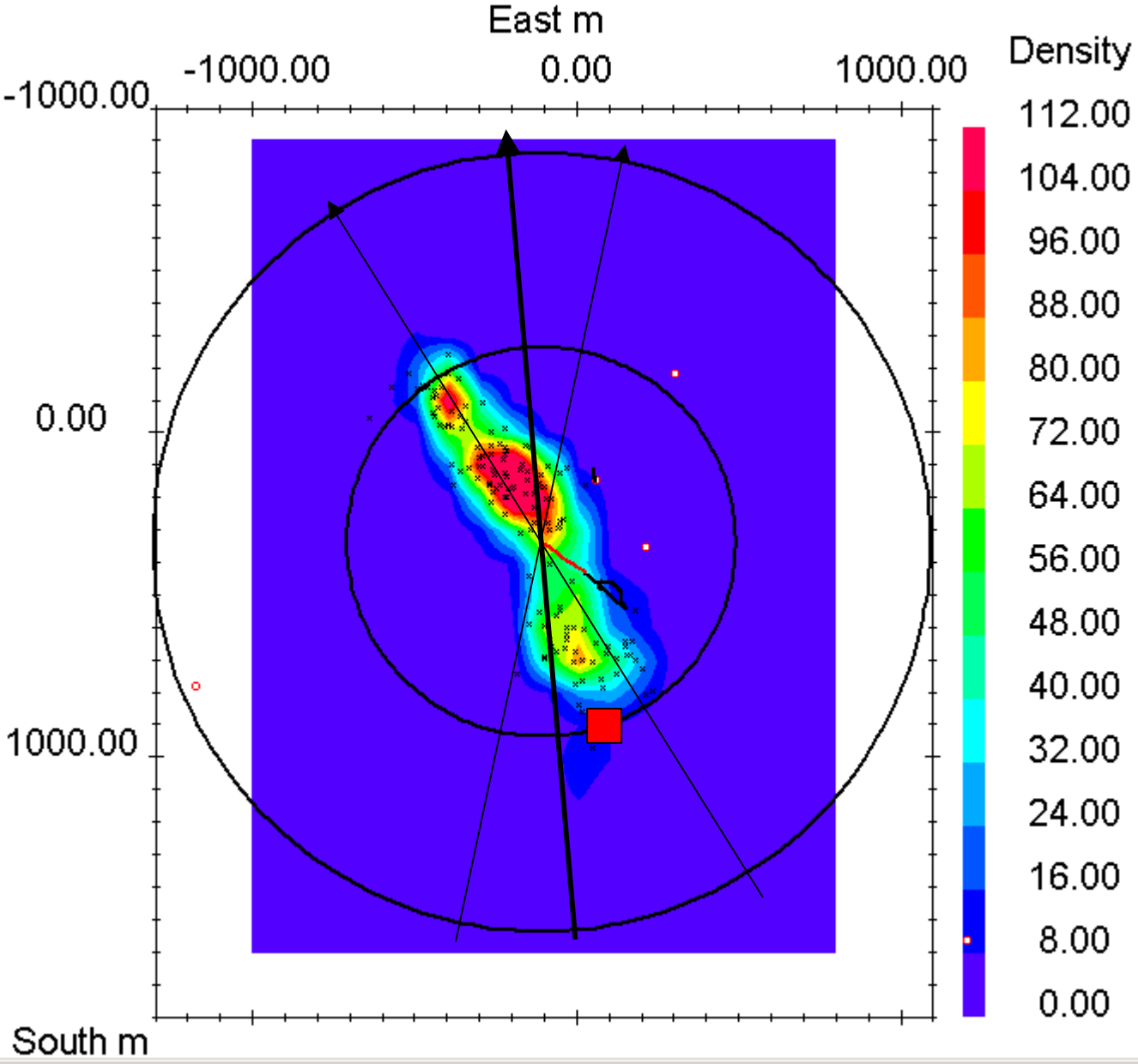
4700 m – 4800 m



Target GPK3 – Seismicity 2000

Depth Range:

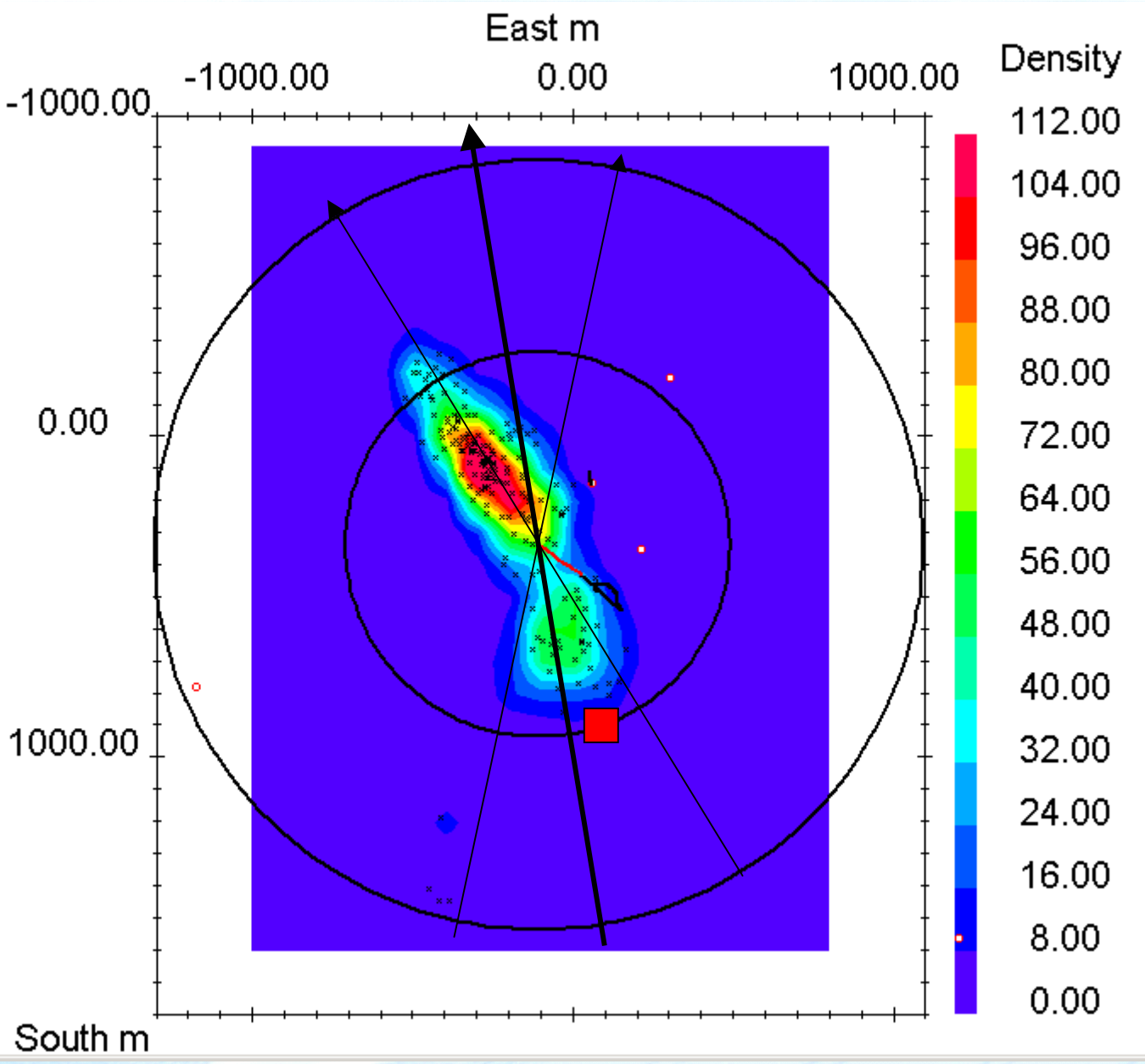
4800 m – 4900 m



Target GPK3 – Seismicity 2000

Depth Range:

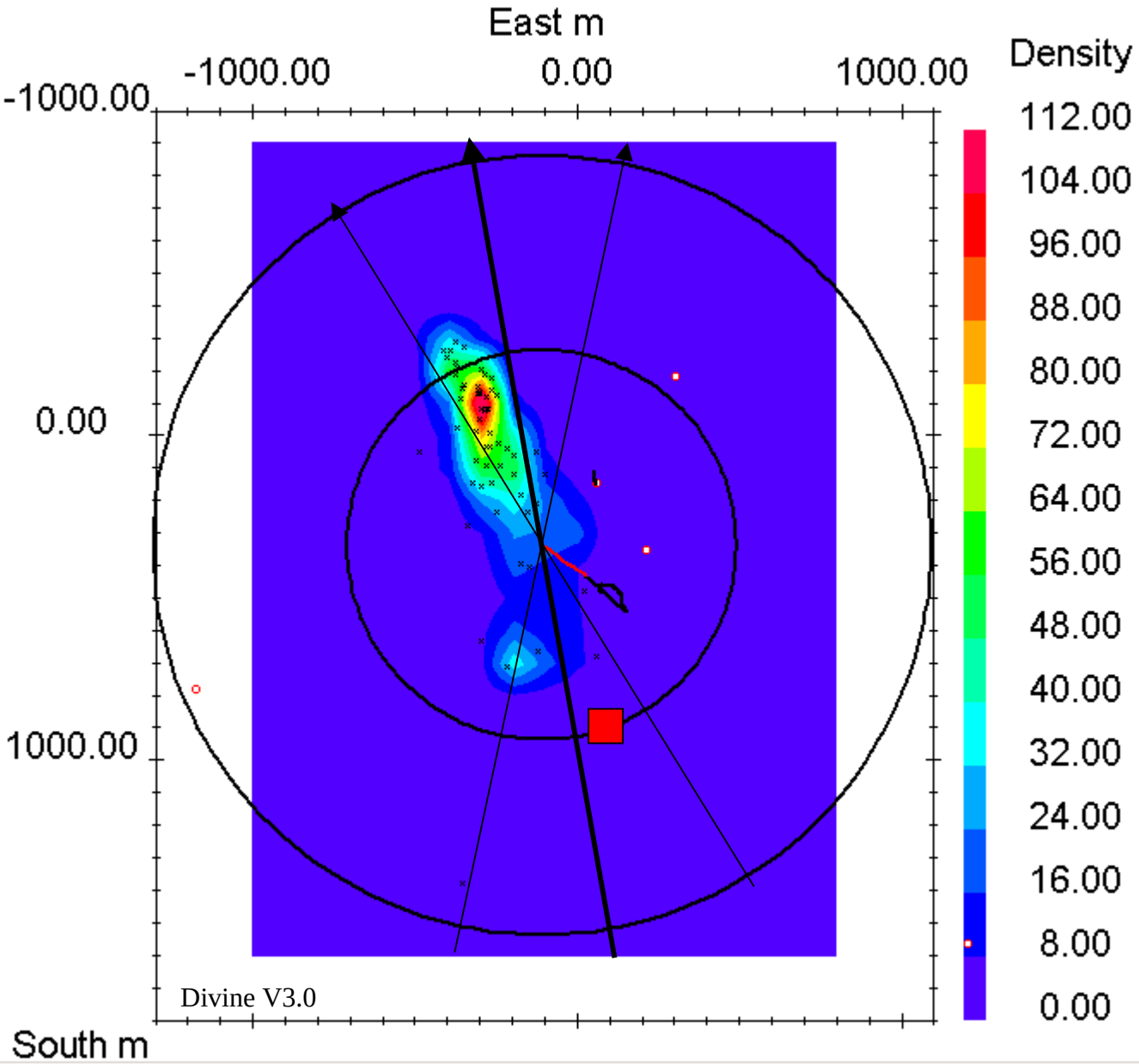
4900 m – 5000 m



Target GPK3 – Seismicity 2000

Depth Range:

5100 m – 5200 m



The Drilling Rig

MAST

Lo-lift "open face" MASSARENTI cantilever mast, 454 tons static hook capacity

SUBSTRUCTURE

MASSARENTI "swing-up" 453 tons casing load and 272 tons setback

DRAWWORKS

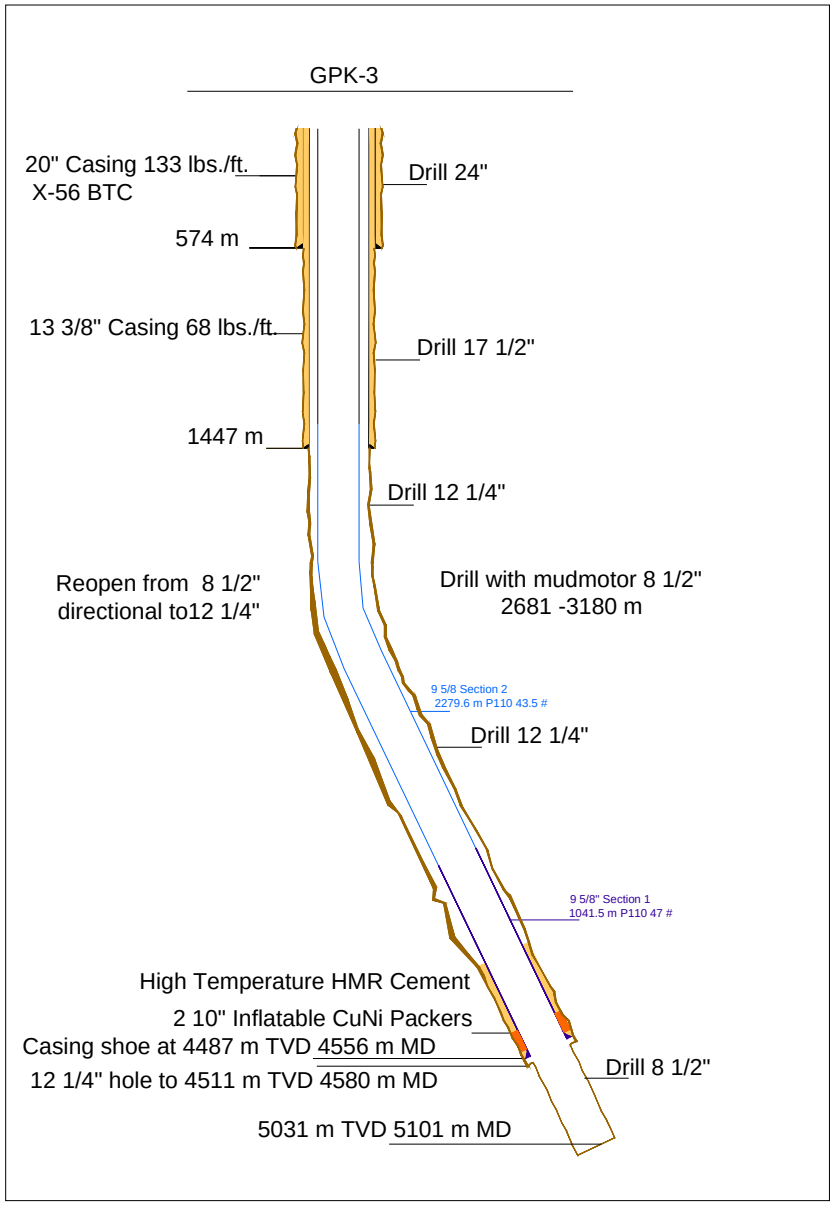
1,700 HP MASSARENTI MAS 6000

PUMPS

Three Emsco FB 1600 mud pumps rated at 1600 HP and 5000 psi

ENEL and their rig MAS 6000E

Drilling of the Injection Well GPK3



24" Drilling, 20" Surface Casing, Cement

17 ½" Drilling, 13 3/8" Intermediate Casing, Cement

12 ¼" Drilling

Kick Off with 8 ½" DHM

Reopening from 8 ½" to 12 ¼"

12 ¼" Drilling

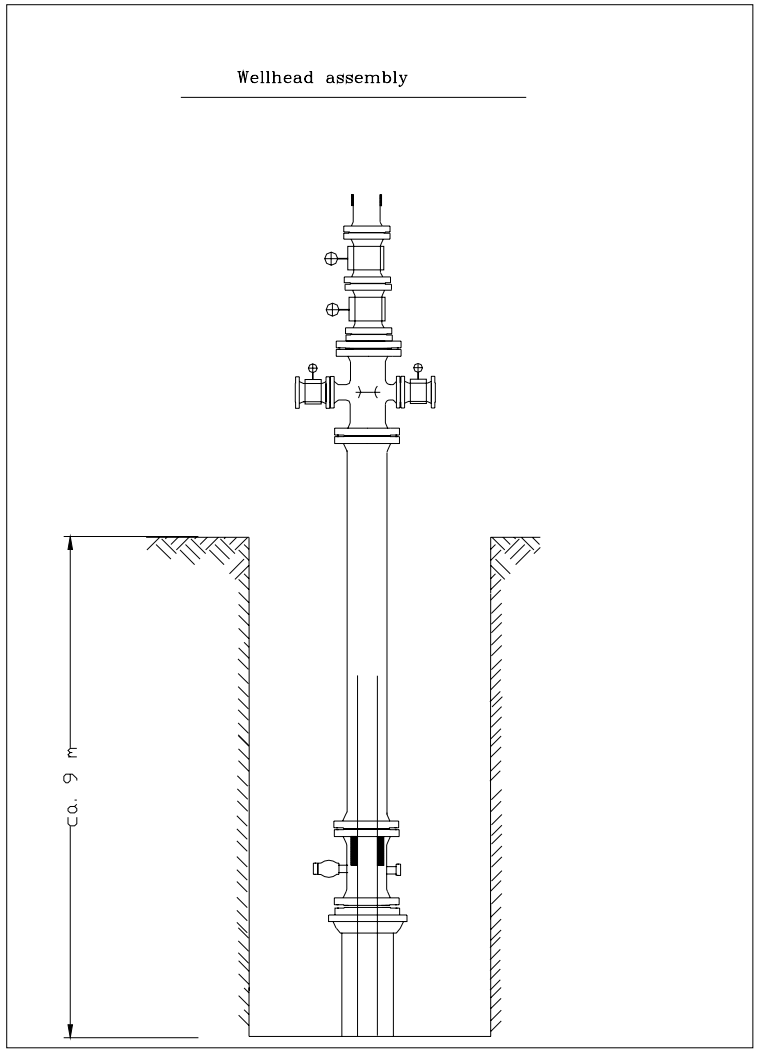
8 ½" Drilling, Sand

Set the 'free' 9 5/8" Casing, HMR-Cementation, Set CuNi Packers

Clean Open Hole

Wellhead Packing of the free floating casing

‘Free’ 9 5/8" Casing

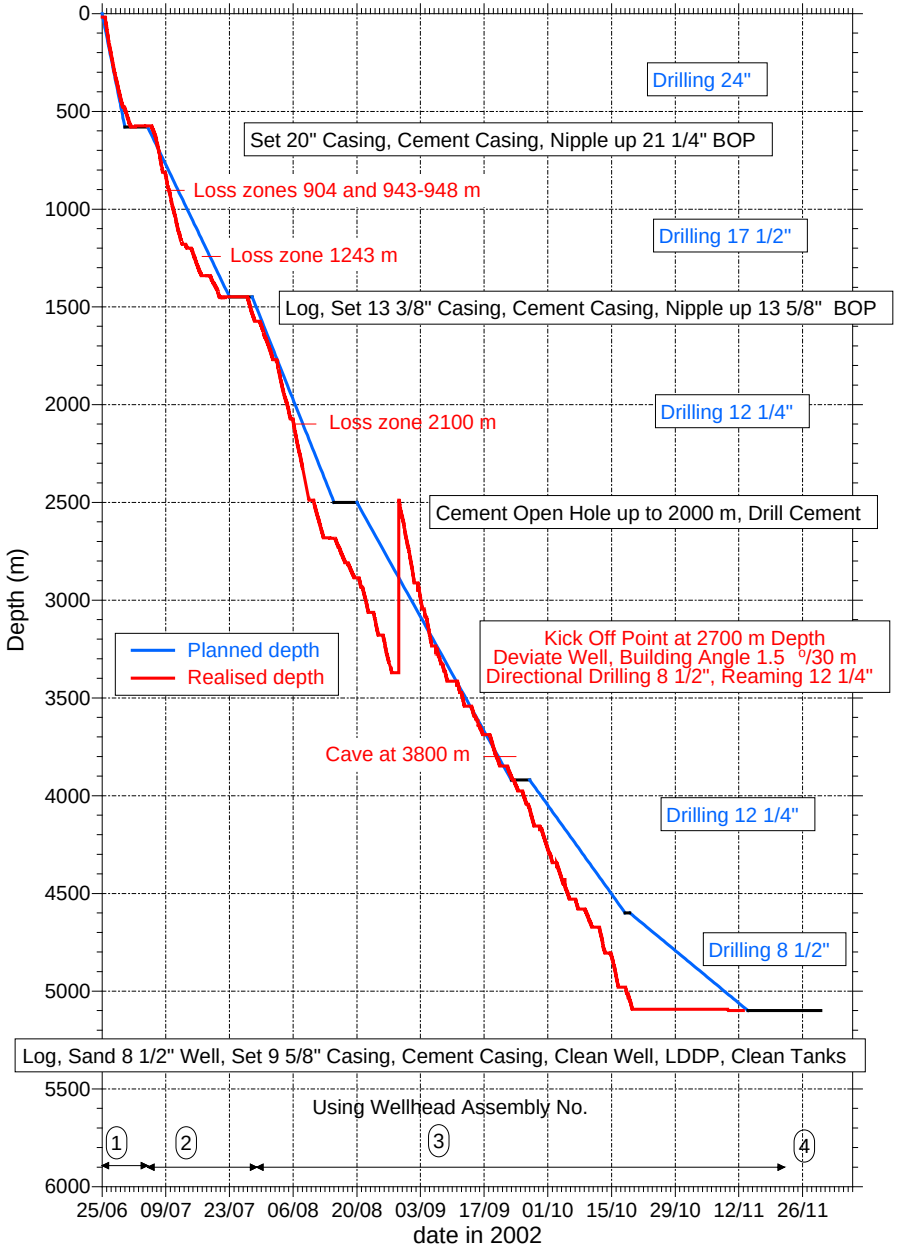


Valves

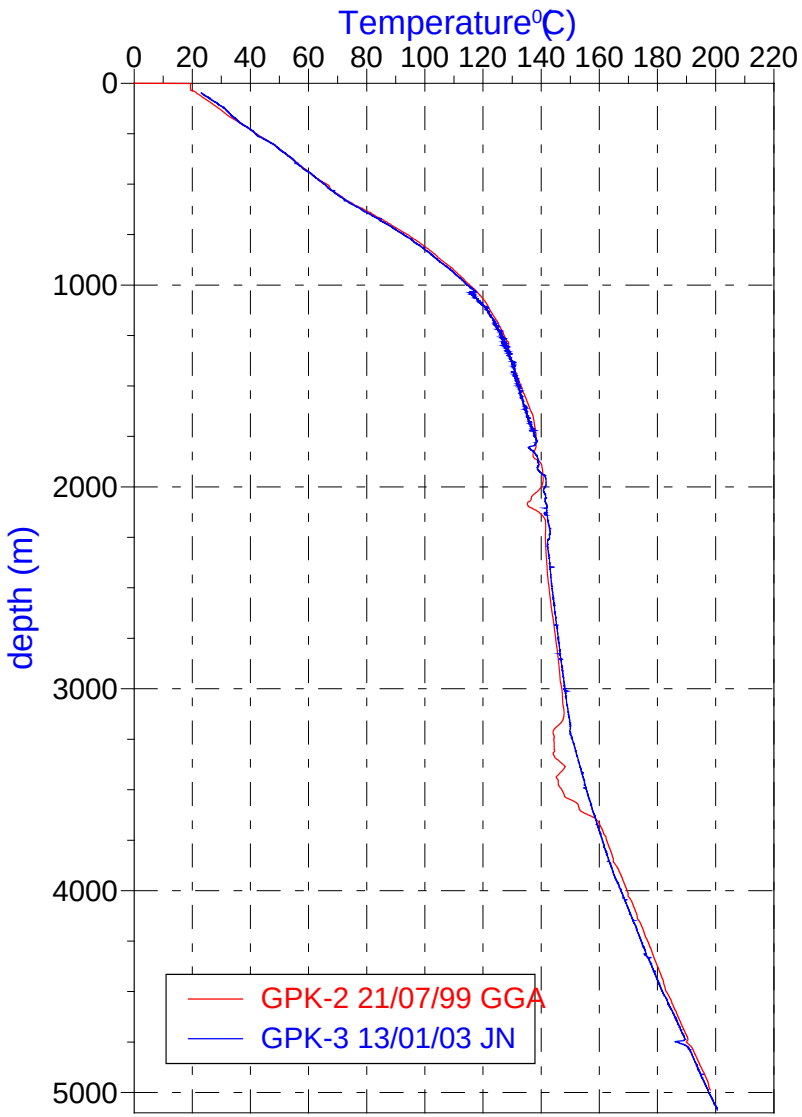
Riser

Cellar

Drilling Progress GPK3 – 142 days



Temperature Profile GPK3



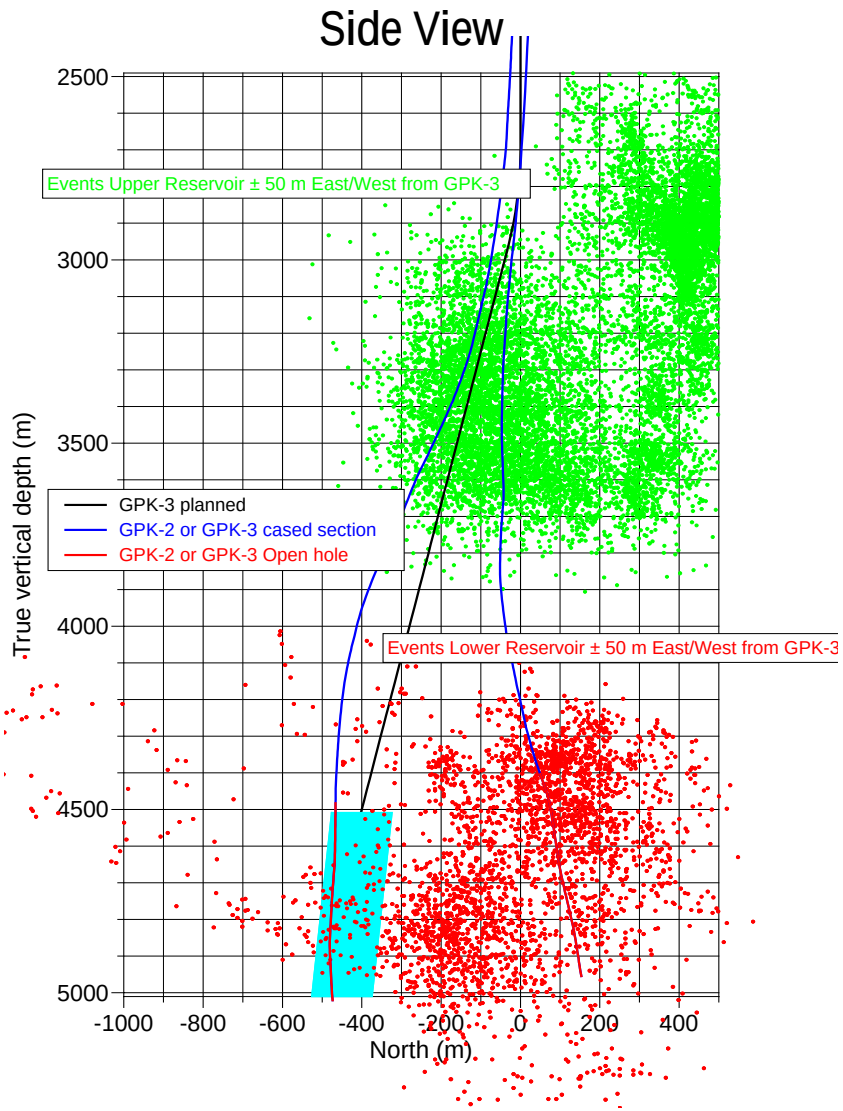
High Gradient

Loss Zone in 2100 m

Upper reservoir

Total Losses at 4756 m

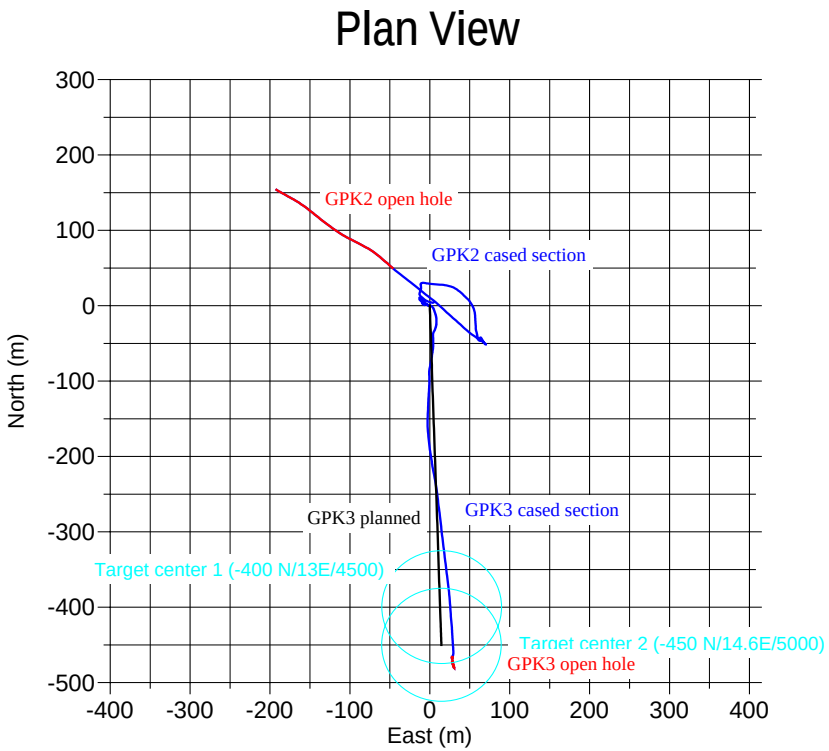
Trajectory GPK3



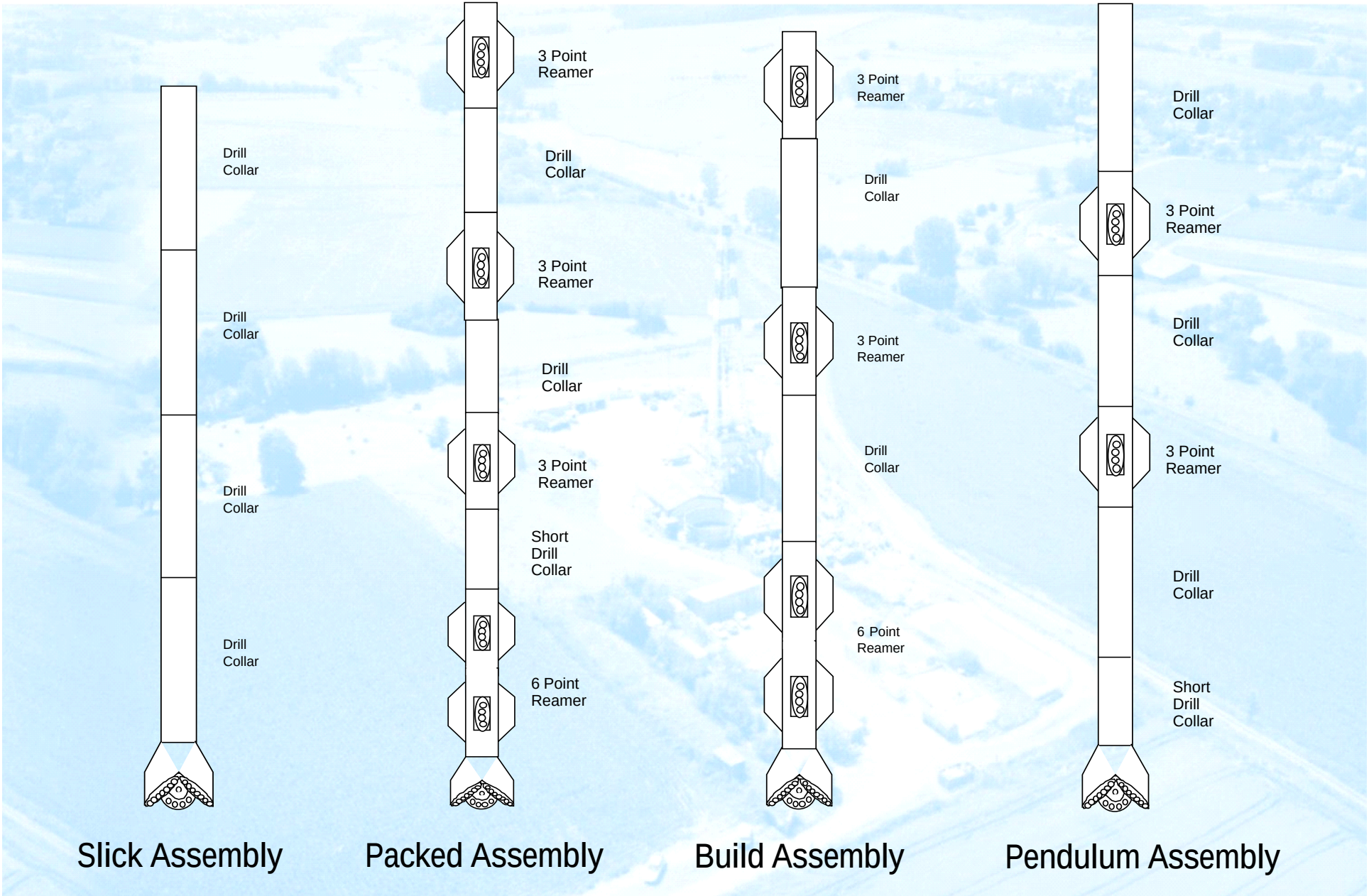
Rotary Drilling to 2681 m

Directional Drilling with Downhole Motor from 2681 m to 3180 m

Rotary drilling to 5101 m



Bottom Hole Assemblies



Slick Assembly | Packed Assembly | Build Assembly | Pendulum Assembly

Surveying and Surveying Methods GPK3

- Gyro surveys at kickoff point and when confirmation of trajectory was required.

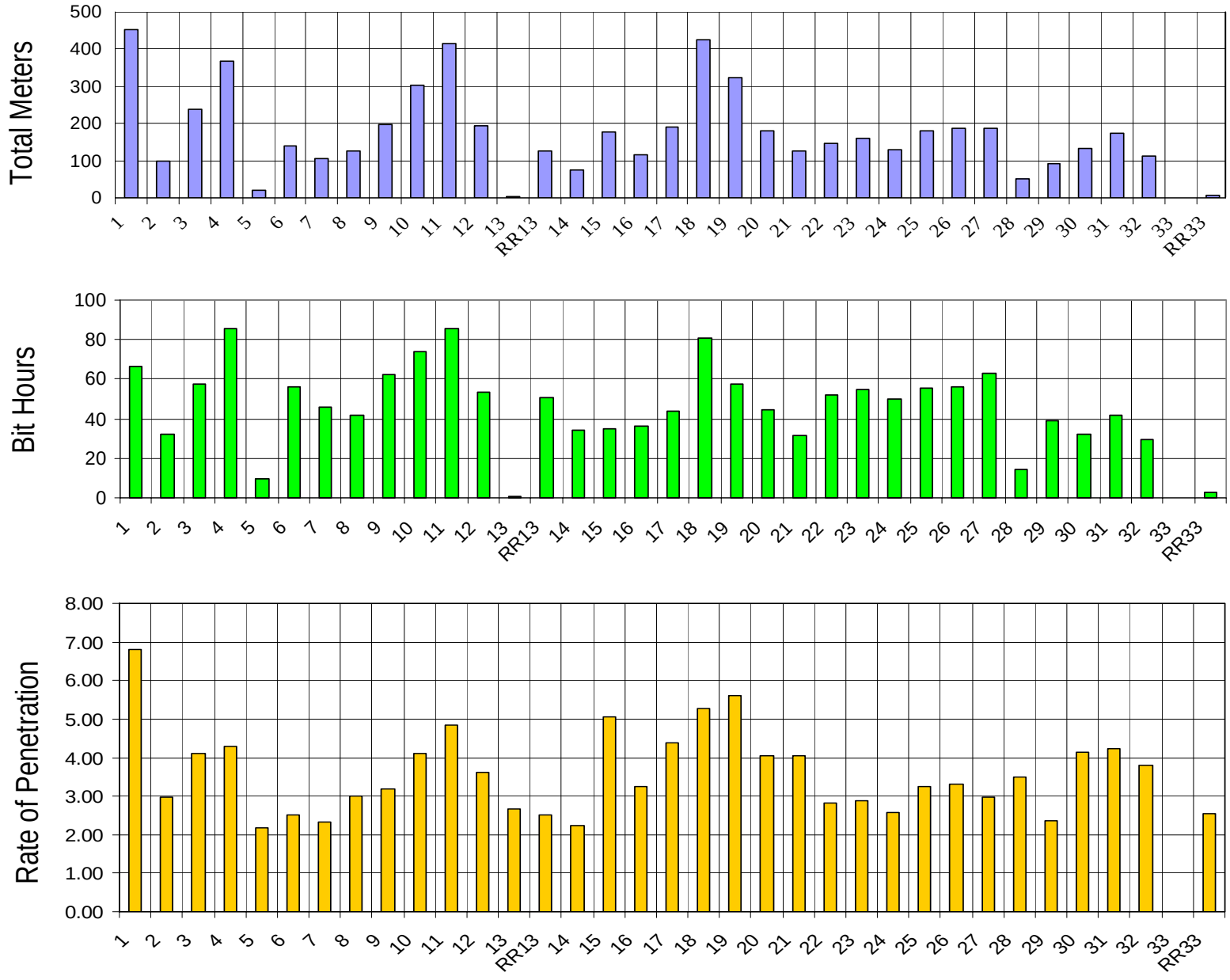
- MWD system while directional drilling and rotary drilling after motor run to monitor trajectory at early stages of kickoff.

- Gyro surveys for confirmation and permanent records.

Twelve gyro surveys were ran to confirm that the drilling operation was following the required trajectory to intersect the target.

Some temperature associated problems occurred with both utilization on a single shot or MWD tool. So surveying was modified to minimize time in well and number of surveys run.

Bit Performance – 33 Tricone Bits



Mud Program GPK3

Objectives:

-**Provide an adequate means to transport cuttings to the surface.**

-**Control the flow from the active zones in the wellbore and thus provide a stable wellbore.**

-**Provide cost effective mechanism for controlling fluid losses to the wellbore.**

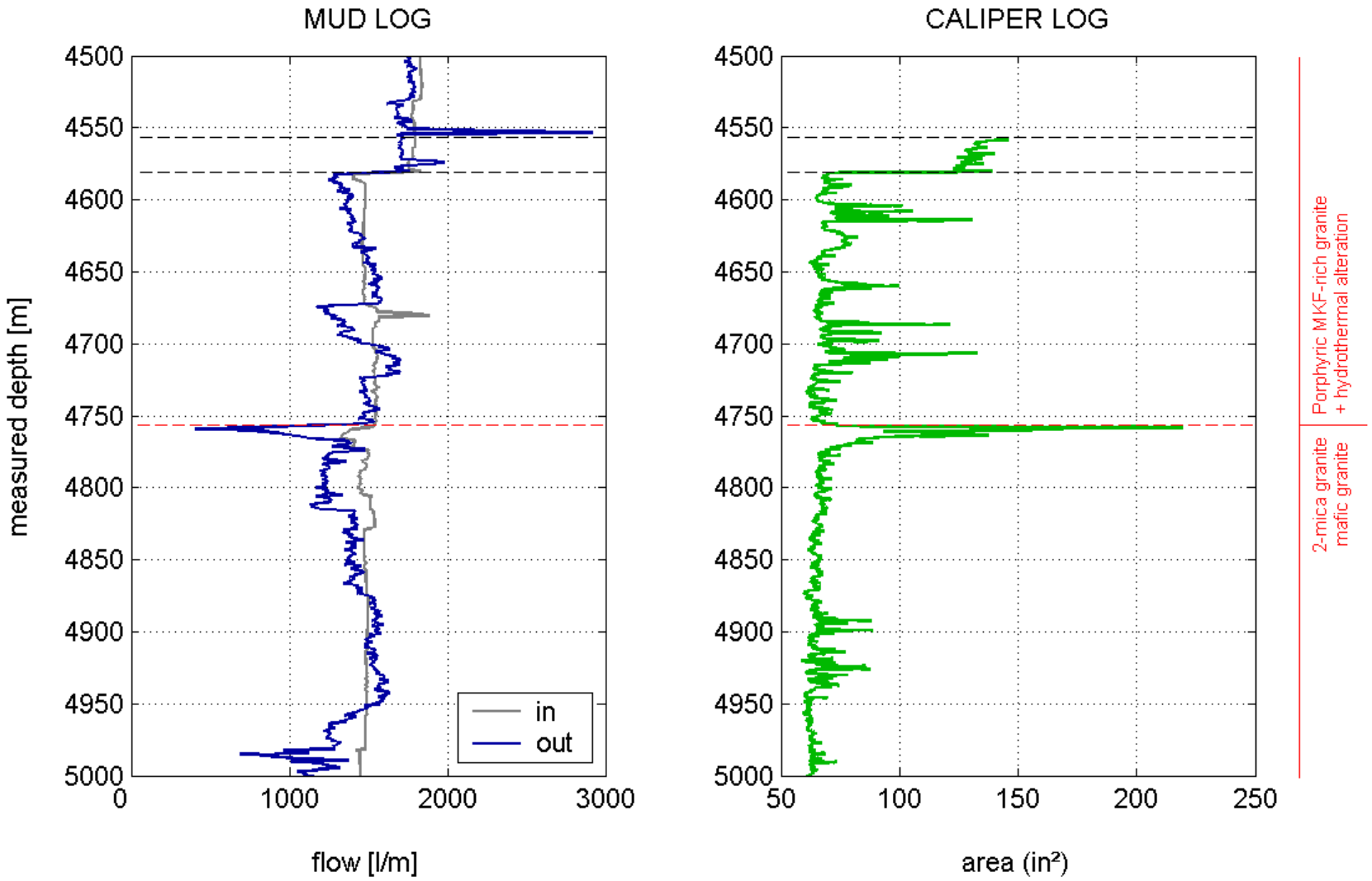
-**Minimize damage to the drillstring via chemical corrosion (oxidation) and mechanical abrasion on the wellbore walls.**

-**Reduce or eliminate environmentally sensitive materials from use (minimize disposal costs).**

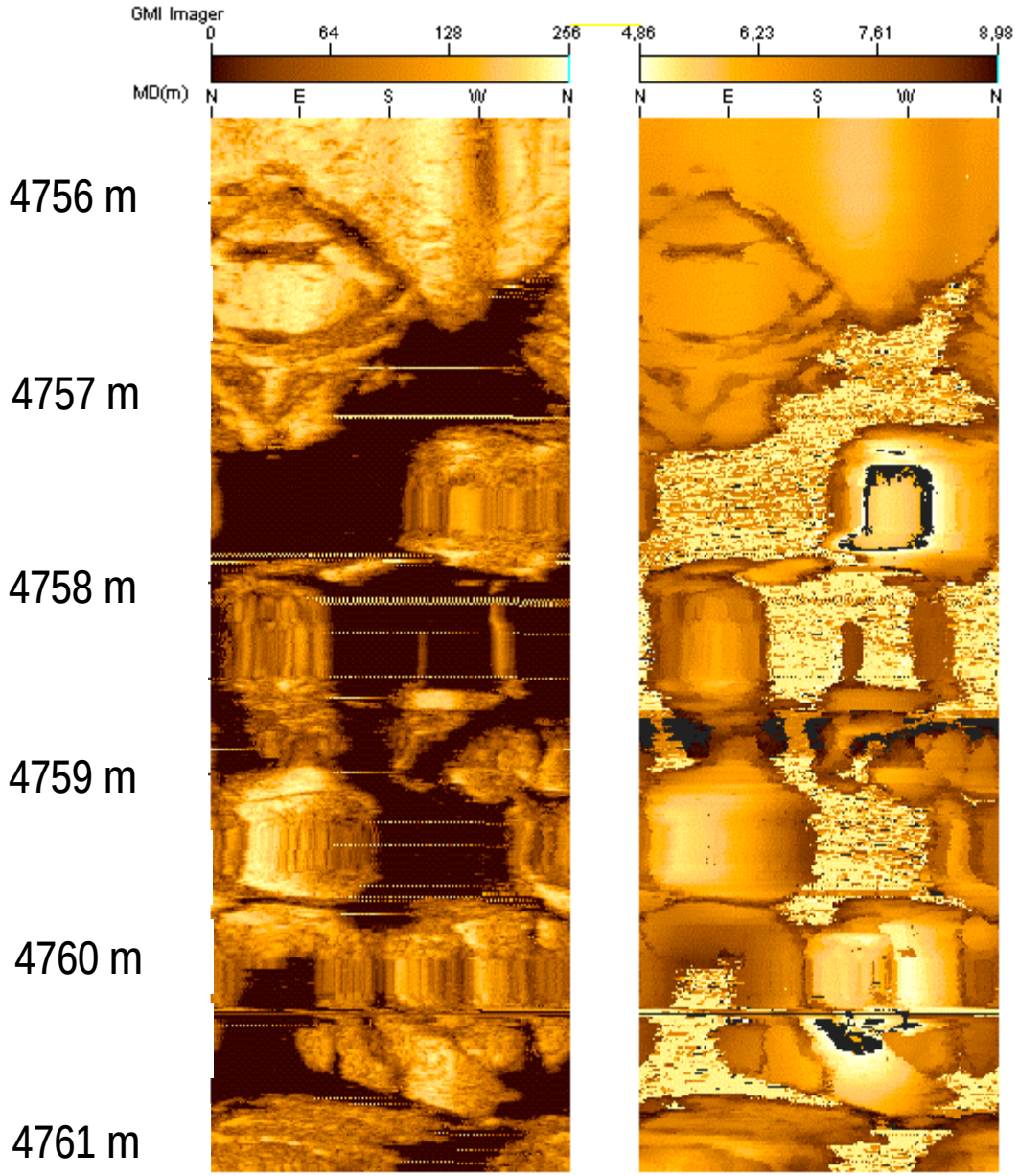
It was first determined to use natural salt (sodium chloride) as the weighting agent as long as the well could be controlled by this manner. This medium provided an inexpensive weighting agent that was easily soluble and non-toxic.

Caustic soda was used to raise the pH levels to minimize corrosion damage and bentonite was used as a viscosifying agent for cuttings transport, if required.

Open Hole Caliper Log and Flow Losses in GPK3

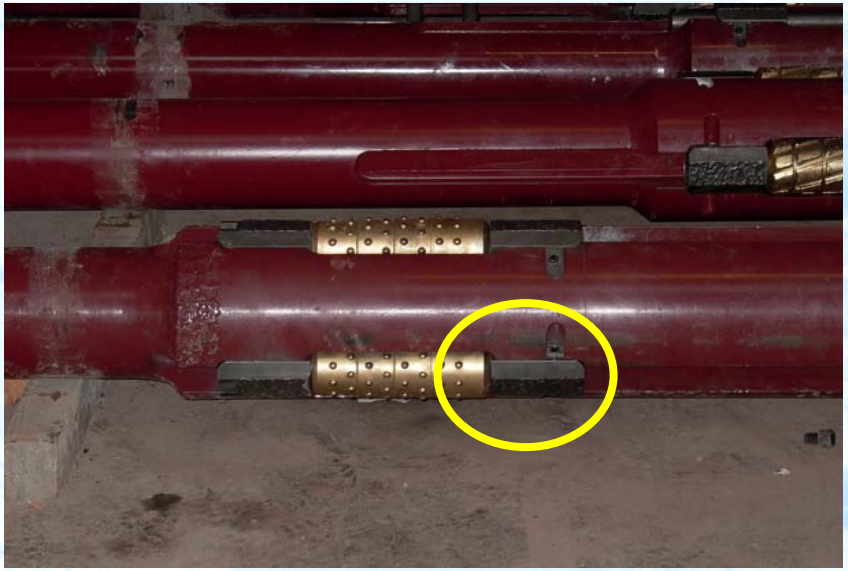


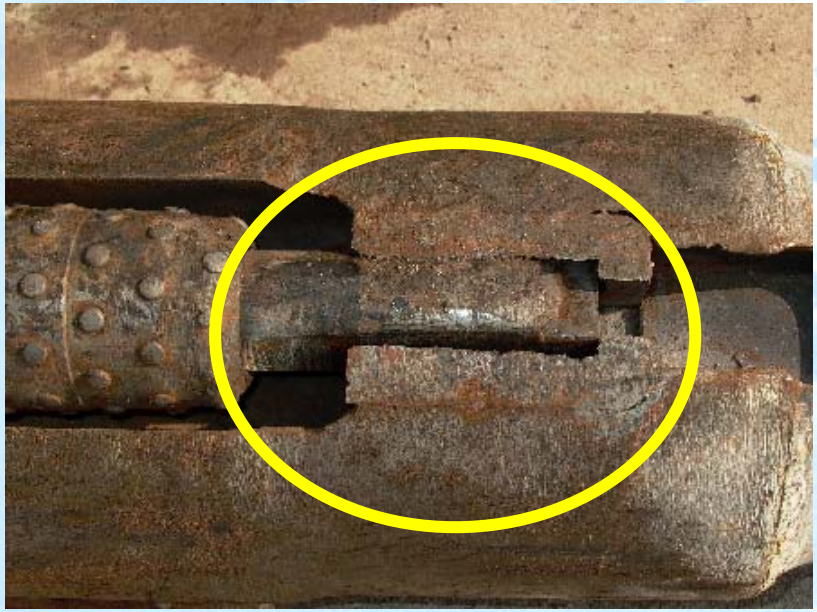
UBI Log GPK3 – Fracture Zone and Loss Zone at 4756 m



Reamer Wear

before …

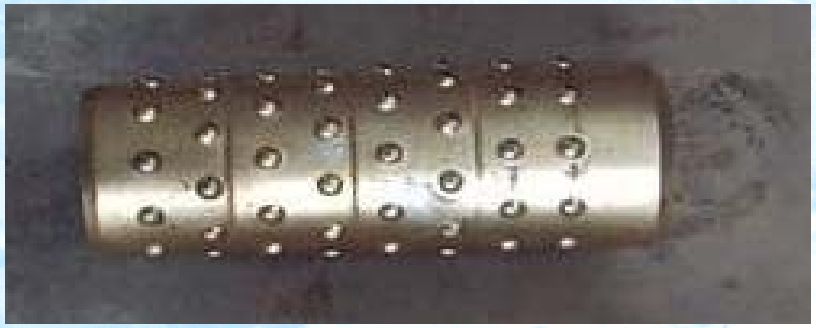




… after

Reamer Wear

before…



old design

after…

old design

new design

new design

Reamer Wear

Drillpipe Wear – Fatigue Fracture

Drillpipe Wear – Wash Out

It sometimes has its moments!

What did we learn?

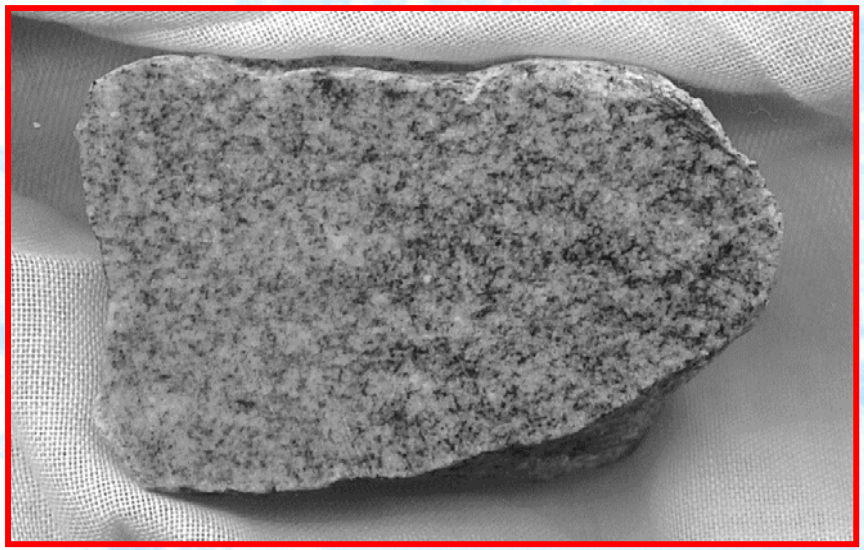
1. Borehole breakouts are observed below a depth of 4000 m – critical stress regime !

2. The service industry is not really adapted to high in situ temperatures (low porosity crystalline rocks cannot be really cooled off for longer periods of time with the means of a drilling rig !!!)

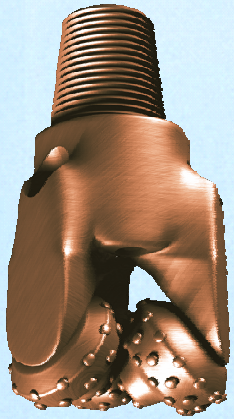
3. Drilling in crystalline rocks is not a "rocket sience". However, numerous adaptations have to be integrated in the drilling procedures (stabilisation, tools, mud systems (no wall cake !!) ……). For these, Soultz, was a unique experience.

>>> don't forget crystalline rocks may very a lot in their composition !!!!

Soultz shallow reservoir



Soultz deep reservoir



Thank you for your attention !