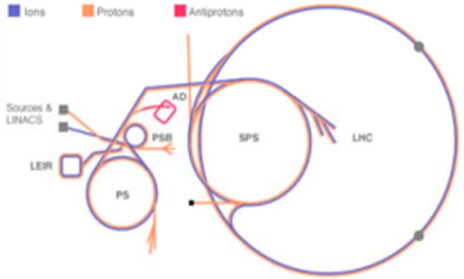
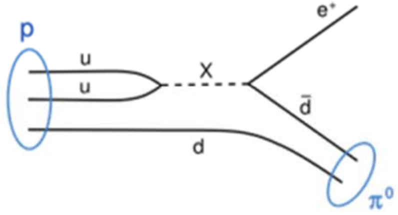
ROCKPLAN

The 15th International Workshop on Next generation Nucleon Decay and Neutrino Detectors (NNN14)

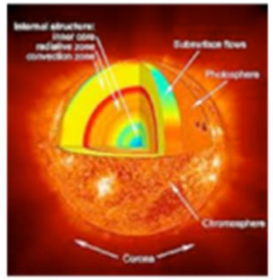
Accelerator



Nucleon decay

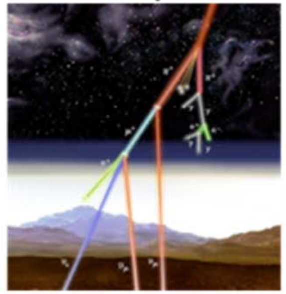


Sun



Dark matter

Atmosphere



Supernova

LARGE UNDERGROUND EXPERIMENTS: ENGINEERING POINT OF VIEW PYHÄSALMI + HOMESTAKE

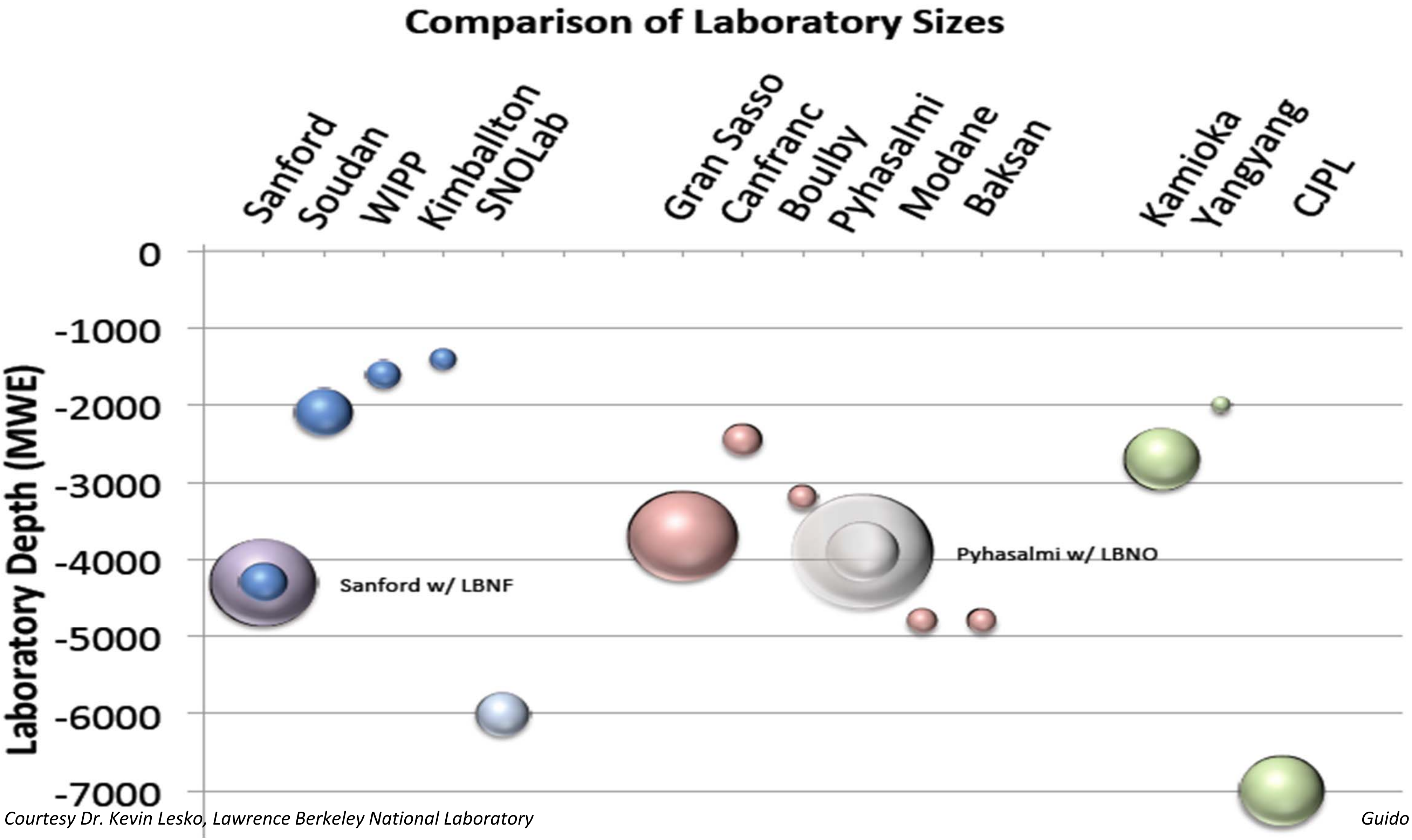
5th of November 2014 PARIS, FRANCE

Guido Nuijten – Rockplan / LBNO-DEMO

PYHÄSALMI + HOMESTAKE

TABLE OF CONTENT

PYHÄSALMI + HOMESTAKE GLOBAL EXISTING AND PROPOSED DEEP SCIENCE LAB CAVERNS AND FACILITIES



Courtesy Dr. Kevin Lesko, Lawrence Berkeley National Laboratory

ROCKPLAN

LAGVNA

PYHÄSALMI + HOMESTAKE
SITE LOCATION

Scientific comparison of long beams (etc.) not part of this engineering presentation

Pyhäsalmi Mine located in Central Finland
450km north from Helsinki (by car)
160km from nearest int. airport (Oulu)

Homestake Mine located in Lead, South Dakota
615km north from Denver (by car)
90km from nearest reg. airport (Rapid City)

PYHÄSALMI + HOMESTAKE MINE INTRODUCTIONS

Pyhäsalmi is an underground copper and zinc mine.

In 1962 the Mine began as an open pit operation. This phase lasted until 1967, the year when Mine operations commenced underground.

In 1975 the open pit was completely worked out. As mining progressed the Mine was gradually deepened.

The latest phase of deepening with a view to exploiting the ore lens below 1050 level was carried out between 1998 and 2001. The resulting new Mine started operation in 2001 and mining is carried out via the new 1440 meter deep Timo Shaft.

Mine due to be closing operation in 2019.

The Homestake Mine was an underground gold mine.

The Mine was one of the early enterprises associated with the Gold Rush of 1876 in the northern Black Hills of what was then Dakota Territory.

Shafts (Yates + Ross) constructed in late ‘30s.

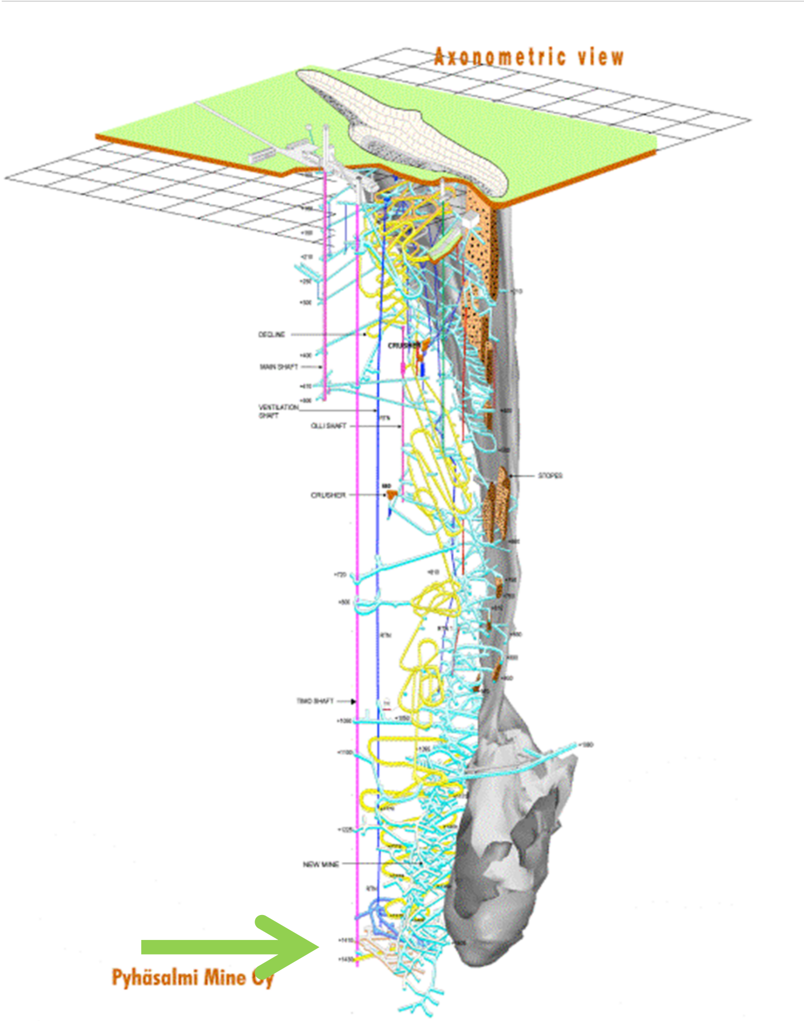
The mine produced more than 40 million ounces (~1.25 million kg) of gold during its lifetime.

In September of 2000 announcement on mine closing. In January of 2002, the Homestake Gold Mine finally shut down after more than 125 years of continuous operation.

Homestake reopened (and dewatered) as an underground laboratory for scientific researches in 2009.

PYHÄSALMI + HOMESTAKE MINES

ROCKPLAN



Pyhäsalmi Mine maximum depth 1450m
LBNO experiment depth 1438m
Access by both decline and shaft/hoist

Homestake Mine maximum depth 8000ft (2440m)
LBNE/LBNF experiment depth 4850ft (1478m)
Access by shaft/hoist only

PYHÄSALMI + HOMESTAKE
ON-SURFACE VIEW



Top: Mine visible from the other side of the lake
Middle: Ore freight transport at the rail yard
Bottom: conveyor belt + old tower at Mine premises


Top: Ross shaft seen from Yates shaft.
In the valley Oro Hondo fans
Bottom: Yates shaft + Sanford Lab

Guido Nuijten

PYHÄSALMI + HOMESTAKE
ON-SURFACE ACCESS

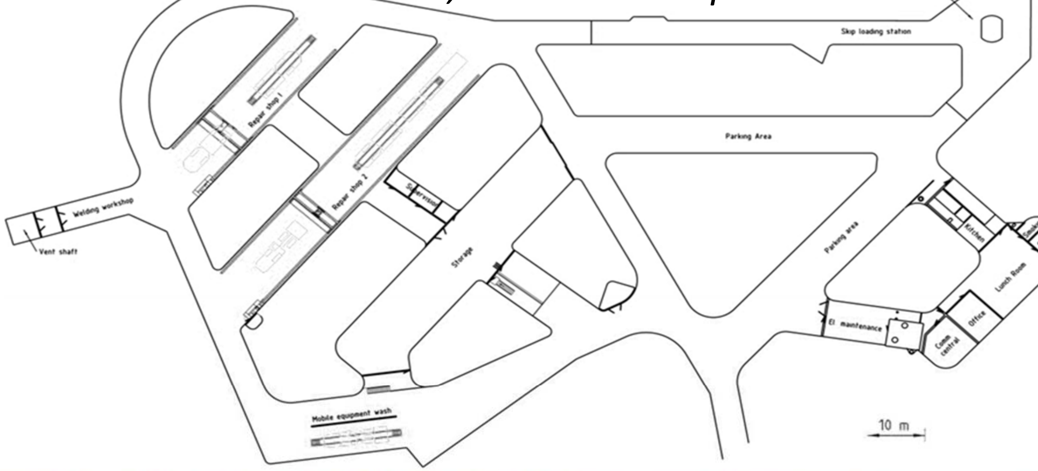

Pyhäsalmi Mine accessible by train (rail yard on site)
Accessible by car + truck directly from National Road
No need to pass the village of Pyhäjärvi

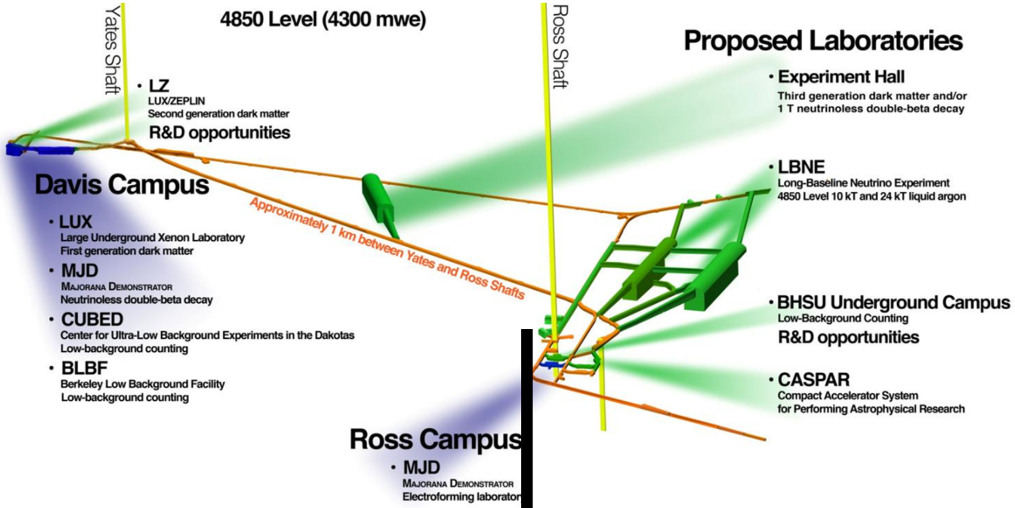
Homestake Mine accessible by road
Road crosses village and partially steep
Signs on picture: Yates shaft to the left / Ross shaft ahead

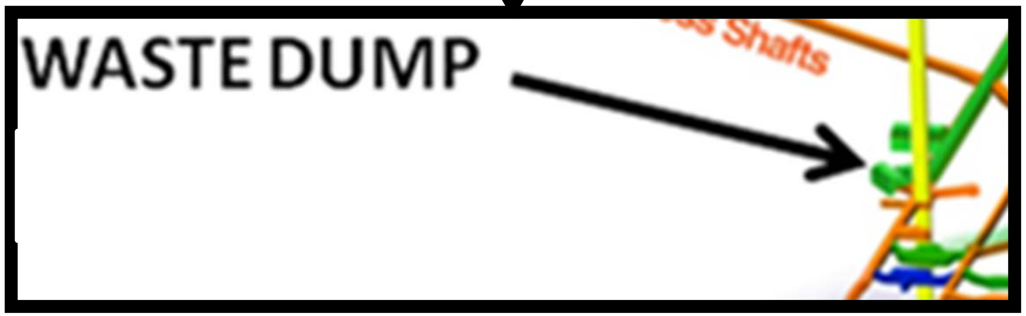
Guido Nuijten

PYHÄSALMI + HOMESTAKE
EXISTING INFRASTRUCTURE AT EXPERIMENT LEVEL

Main level current size 50,000m3 and depth -1415m







Current Infrastructure (available for experiment)

- Crusher (Capacity : over 120 m3/h (= double the hoisting capacity): realised in 14months
- Conveyor belt (connecting crusher and hoist)
- All located very near the future Laguna site

Current Infrastructure (available for experiment)

- No waste rock infrastructure yet available
- Waste rock handling infrastructure foreseen in LBNE excavation extension works immediately next to the Ross Shaft on the 4850L

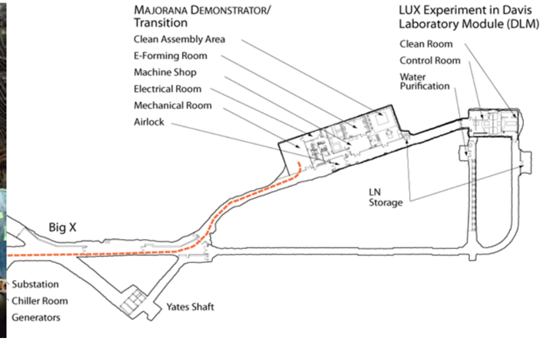
Guido Nuijten

PYHÄSALMI + HOMESTAKE
EXISTING INFRASTRUCTURE AT EXPERIMENT LEVEL




Current Infrastructure (available for experiment)

- maintenance halls for equipment and material
- parking lots for personal vehicles + ambulance stand-by
- parking lots for equipment
- Electricity + mobile U/G network
- electricity repair workshop
- equipment washing lanes (small and big)
- safety area / oxygen supply area,
- intermediate deposits (different levels)
- kitchen, lunch room / meeting room, sauna + showers

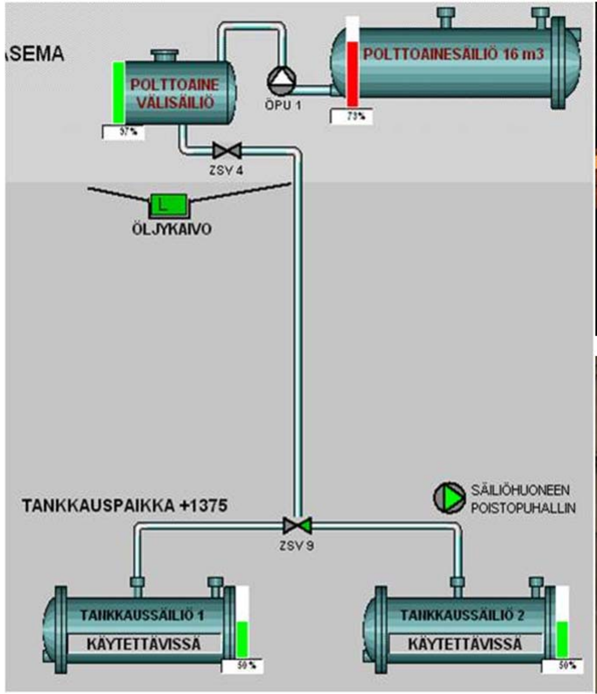

Current Infrastructure (available for experiment)

- railway access
- electricity
- safety area / refuge chamber
- also include clean rooms (as part of current experiments)

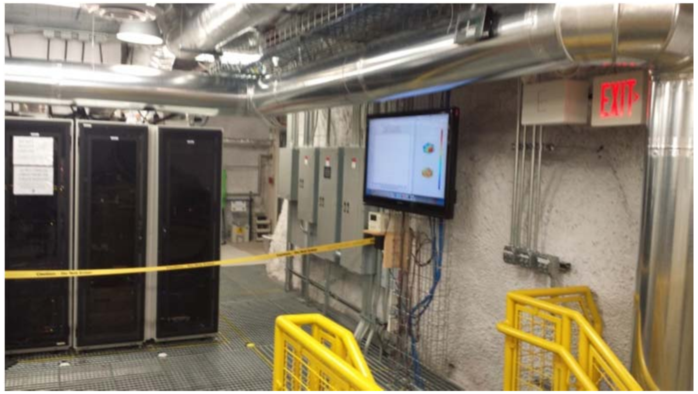
Note. Maximum allowed number of persons working at 4850 limited in line with capacity of the refuge chamber and evacuation strategy via the shaft.

Guido Nuijten

PYHÄSALMI + HOMESTAKE
EXISTING INFRASTRUCTURE (SURFACE CONNECTIONS)




Current Infrastructure (connections to surface)
- electrical connection routes from surface through drill holes to the electrical room + back-up generator
- fuel supply from the surface incl. reservoir and buffer tank plus two fuel fill up stations at the -1375 level
- high speed internet + mobile phone network
- telecommunications + data communication room



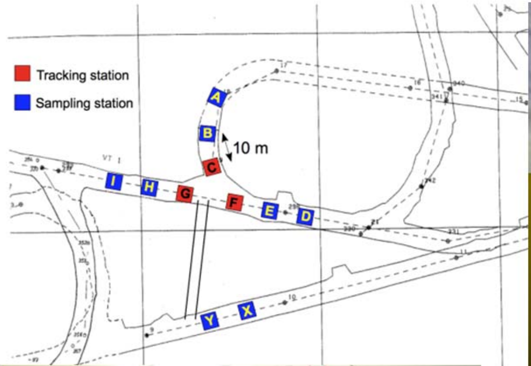
Current Infrastructure (connections to surface)
- telecommunications
- high-speed internet (as part of current experiments)

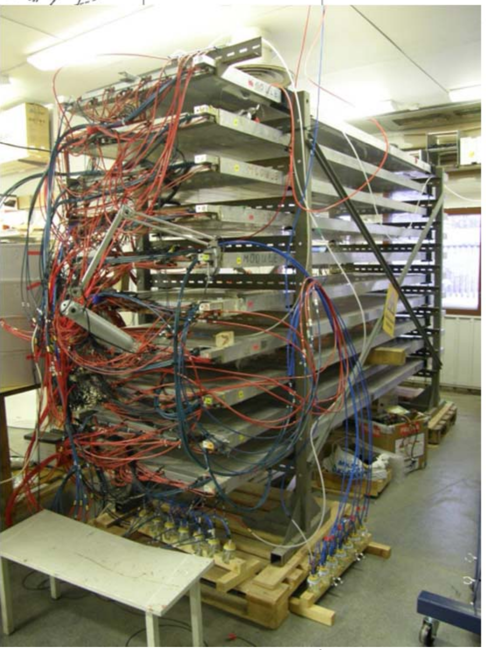
Guido Nuijten

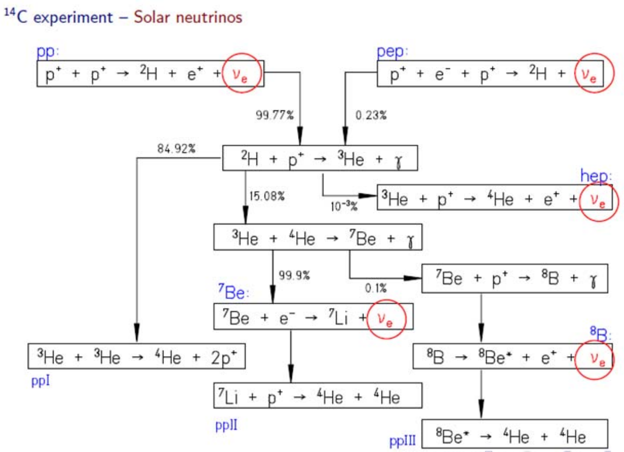
PYHÄSALMI + HOMESTAKE CURRENT EXPERIMENTS

ROCKPLAN

LAGUNA

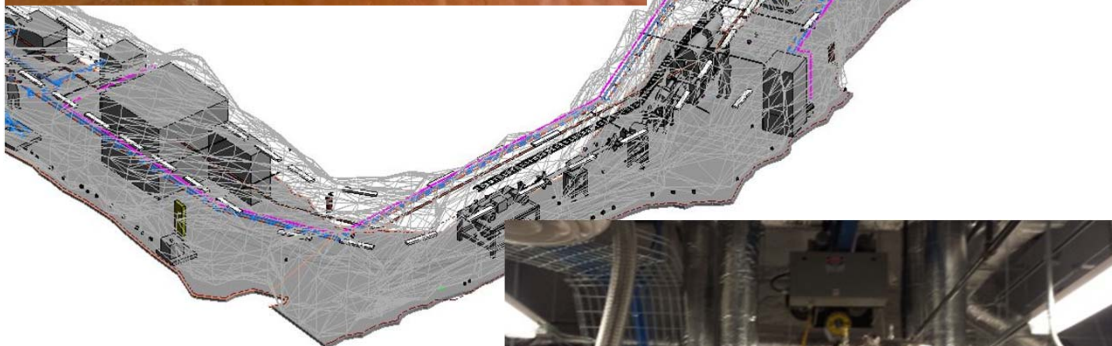






Current experiments

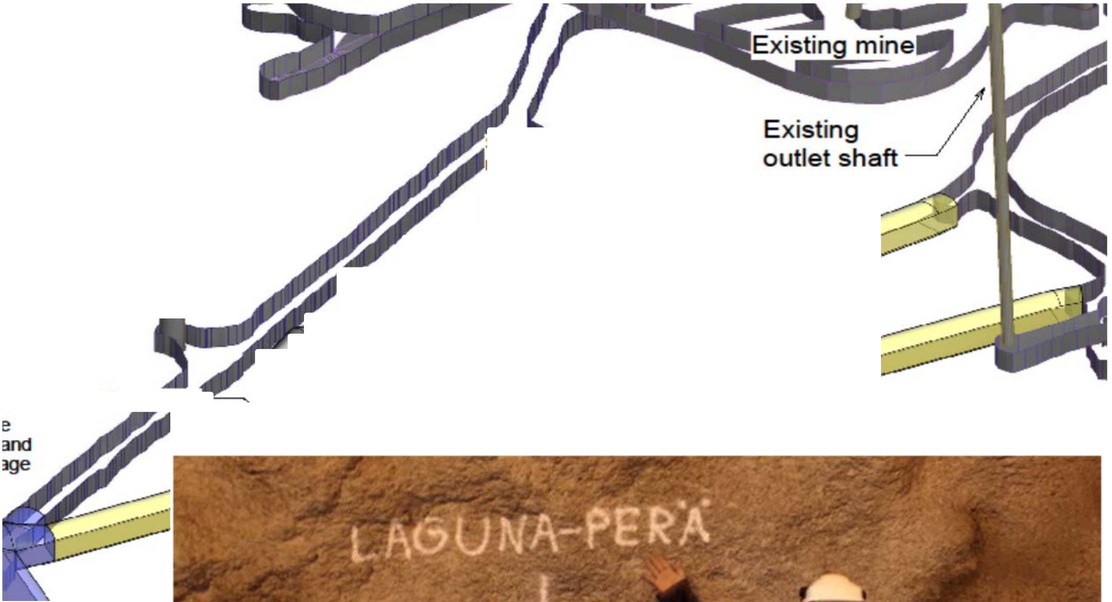
- high-energy cosmic rays (EMMA)
- 14C/12C experiment (solar neutrinos)

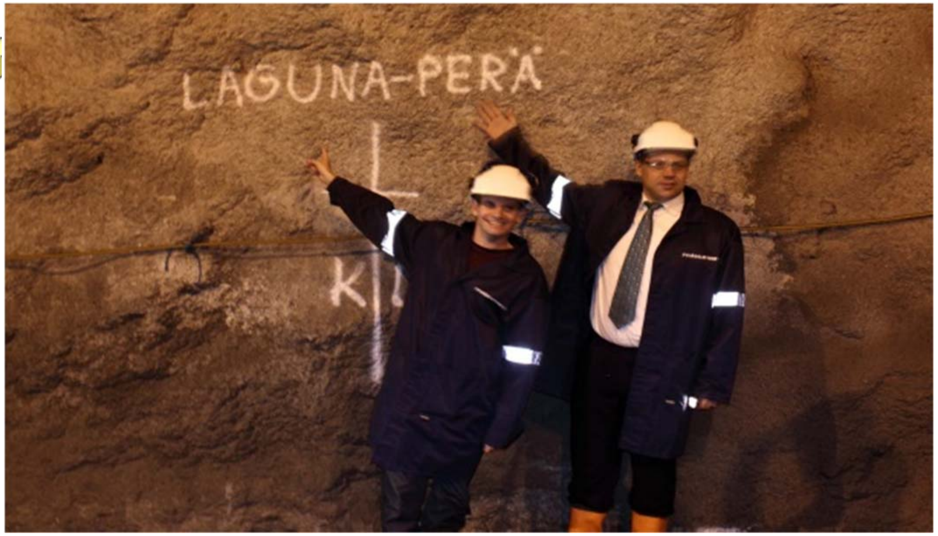


Current experiments at the 4850L

- LUX: dark matter experiment
- MJD Majorana demonstrator
- CASPAR, CUBED and BLBF experiments

PYHÄSALMI + HOMESTAKE
EXISTING INFRASTRUCTURE AT EXPERIMENT LEVEL





Current Infrastructure (available for experiment)

- Complete 250m access drift for experiment (size 5x5 m2 (at end 9x9m)) all the way towards future Laguna cavern locations
- Also other drifts present for multiple face excavation strategy

Current Infrastructure (available for experiment)

- Drifts available nearby designed locating, but all need enlargements (excavation enlargement to 5x6 m2) and removal of present reinforcements
- Enlargement of drifts foreseen in LBNE excavation extension works

ROCKPLAN

LAGVNA

PYHÄSALMI + HOMESTAKE
HORIZONTAL DRIFTS / ACCESSES

Size ~5x5 m2
Access from surface to -1450m (decline 1:7)
Ready for use (only minor enlargements locally)

Size ~3x3 m2
No access from surface, only horizontal from shafts
Needs enlargement (drift expansion to 5x5 m2)

PYHÄSALMI + HOMESTAKE DECLINE

Decline scaled twice a year (operation takes 1 week/time)

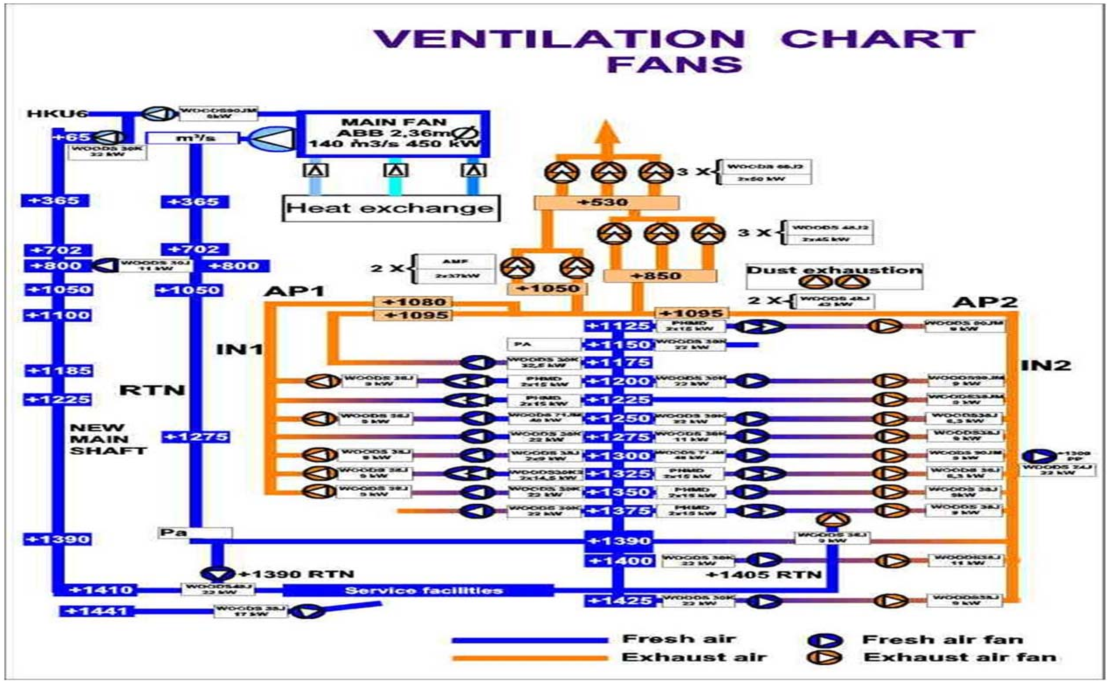
usefulness for transport: suitable for traffic (even heavy such as dumpers or trucks)

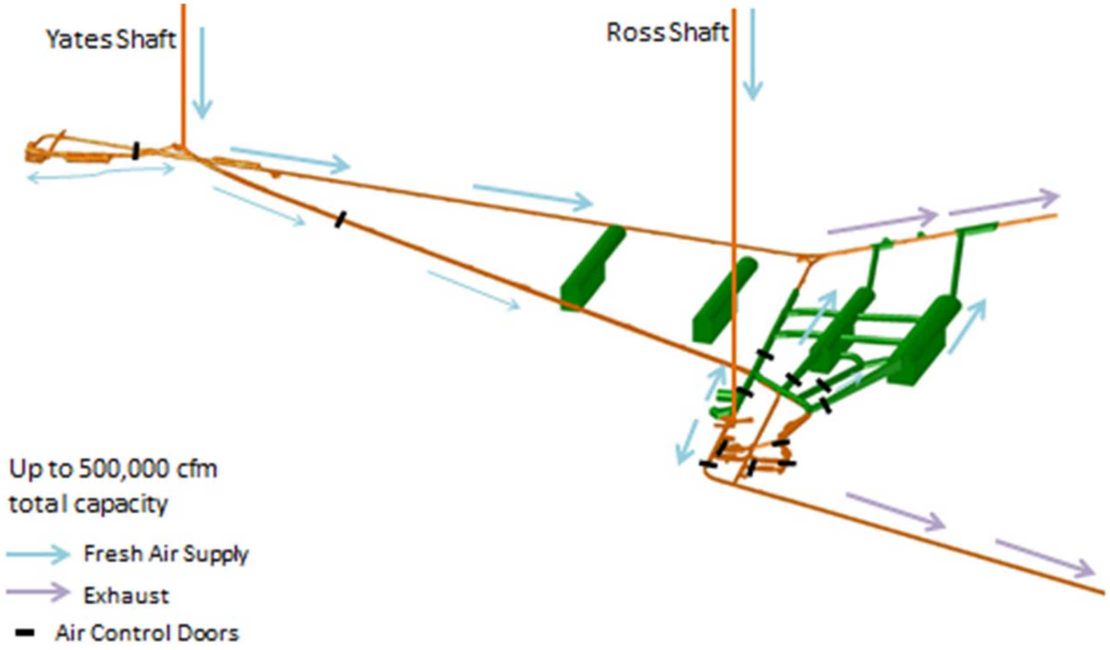
Length 11km, steepness 1:7, conditions good.

No decline present

PYHÄSALMI + HOMESTAKE VENTILATION

ROCKPLAN





Size of inlet shaft (1 fresh air raise): circular with diameter 3.1 m;
Size of outlet shafts (2 exhaust air raises): circular with diameter 2.4 m;

Capacity

137 m3/s (specs),
measured up to 150m3/s,
estimated average 100m3/s

*Demand for ~250,000m3 around 70 m3/s for 1h refresh rate = **OK for both***

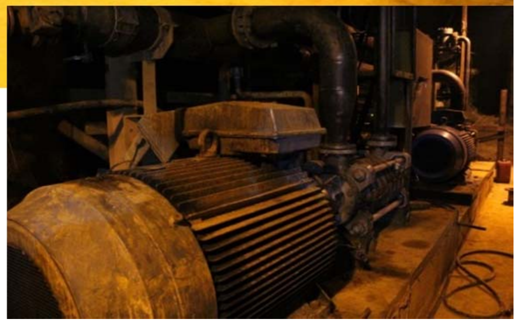
Capacity

500,000 cfm (specs, see above),
equals **236 m3/s**
inlet both via Yates and Ross Shaft
outlet via other shafts (Oro Hondo Fans)

Native rock temperature 25ºC at -1400m, gradient about 1.2ºC/100m, ventilated temperature 22…23ºC

Native rock temperature 35…37ºC at -4850ft, ventilated temperature 15…20ºC

PYHÄSALMI + HOMESTAKE
DEWATERING / DRAINAGE



Dewatering system

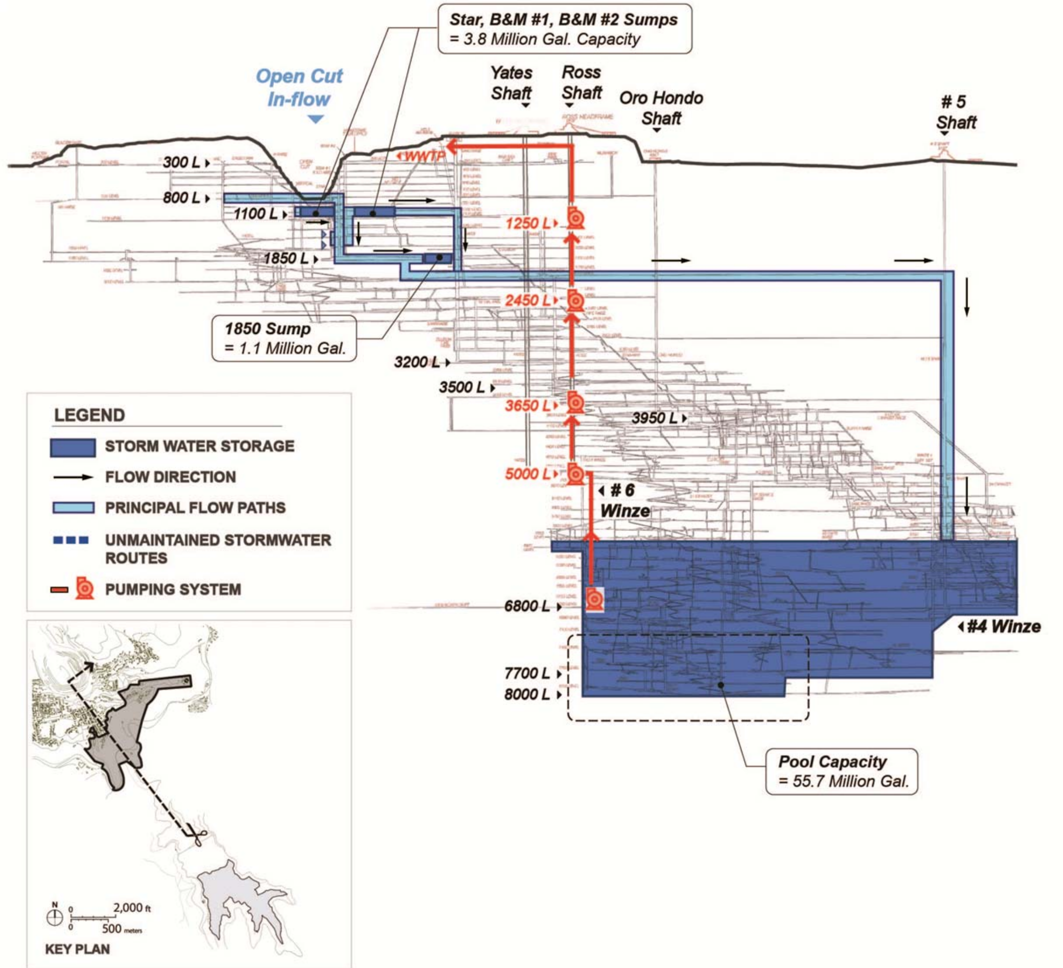
leakage from surface to 650m,

below 650m dry to completely dry

Capacity 130m3/h, avg. 100m3/h

Pumping levels

1444m	submersible pump
1430m	pump svedala, engine 45kW, 2960rpm, 2+2 pcs
1300m	pump svedala, engine 45kW, 2960rpm, 4+4 pcs
970m	pump svedala, engine 45kW, 2960rpm, 4+4 pcs
640m	settling pond, pump Ahlström, engine 355kW, 2 pcs



Normal water flows are captured high and pumped out. Significant precipitation events are controlled using a well defined strategy.

At the proposed site very dry groundwater conditions.

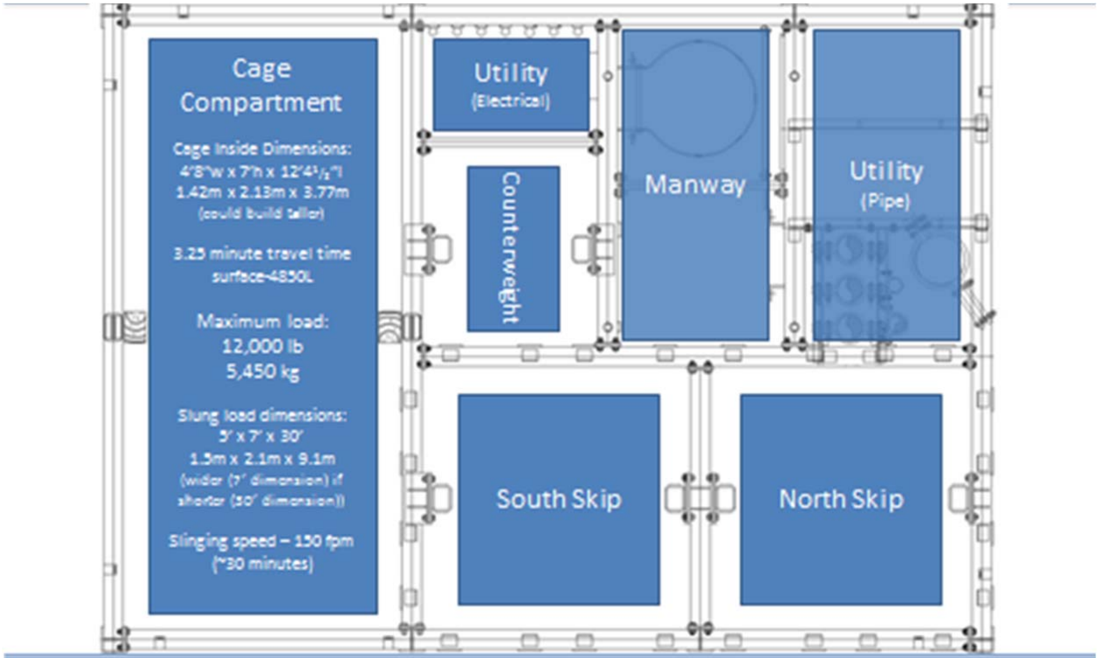
On-surface catchment area 868,500 m2 (9.3Mft2)

Guido Nuijten

PYHÄSALMI + HOMESTAKE HOIST

Timo Shaft: Constructed in 2001 (manufacturer ABB, Installation by Pyhäsalmi Mine)
Automated hoist system: can be switched to manual if necessary

Specs: Rope guided friction hoist: 6 guide ropes, 4 head ropes, 3 balance ropes.
Hoist speed = 12 m/s (man), max. **15.5 m/s** (ore)

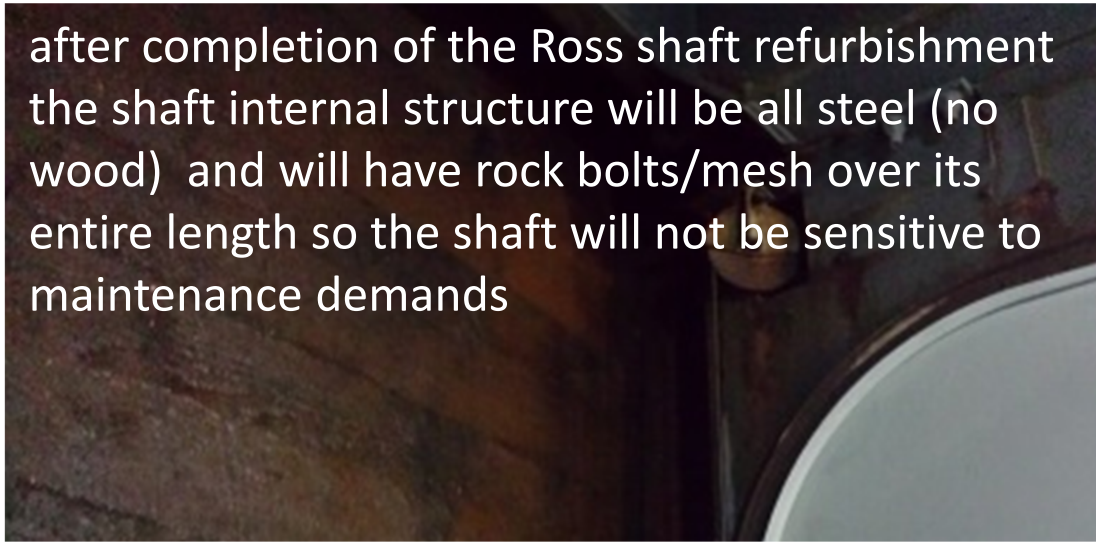


Ross Shaft Constructed in 1939 (75th anniversary now in 2014) Refurbishment finished in 2017.
Refurbished **Hoist speed** 2,500 ft/min = **12.7 m/s**

PYHÄSALMI + HOMESTAKE
SHAFT REINFORCEMENT / LINING

Shaft reinforced by sprayed concrete lining.

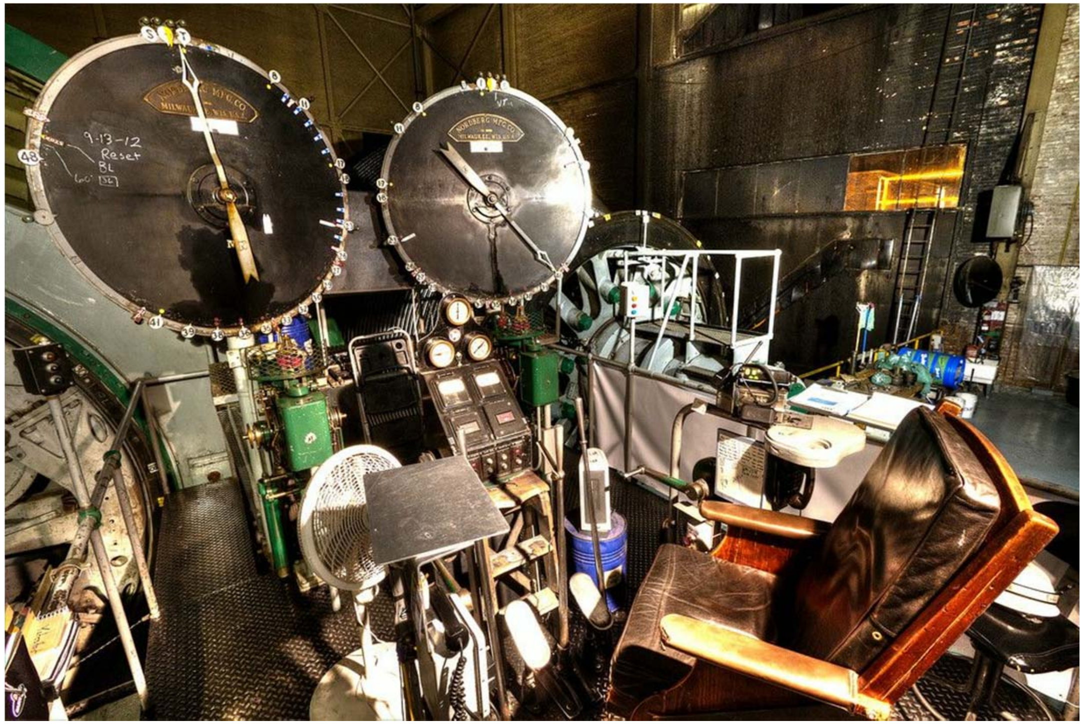
Shotcrete reinforced surface easy to maintain and to keep in good conditions.



after completion of the Ross shaft refurbishment the shaft internal structure will be all steel (no wood) and will have rock bolts/mesh over its entire length so the shaft will not be sensitive to maintenance demands

Shaft reinforced by wood (steel price at that time (WOII) too high)
Due to wood + water combination current shaft very sensitive to maintenance demands

PYHÄSALMI + HOMESTAKE (HOIST) CONTROL ROOM



Separated control room for main Mine activities

Automated hoist system: can be switched to manual if necessary

Hoist control: manual by operator

Not foreseen to change into automatic.

One operator controls the cage and another operator controls the ore skip

Guido Nuijten

PYHÄSALMI + HOMESTAKE
ROCK HOISTING CAPACITY

Timo shaft Hoisting capacity:

Hoisting capacity: 275 ton/hour =
5300 metric ton/day =
Hoisting capacity is about 1902 m3 of rock / day.
(note intact rock volume)

20kT LAr excavation volume = 286,707 m3
Main excavation works take about 2 years.
(i.e. about 520 working days)

Excavation / day average is 551 m3/day.
(= 1535 tonnes) **(=29% of Hoist Capacity**)

When excavation main masses, the production rate may increase significantly

==> Hoist capacity does not restrict cavern excavation !!!

Ross shaft Hoisting capacity:

Hoisting capacity: 3000 short tonnes/day =
2722 metric ton/day =
Hoisting capacity is about 962 m3 of rock / day.
(note intact rock volume)

10+24kT SURF excavation volume= 191,373 m3
Main excavation works take about 2 years.
(i.e. about 520 working days)

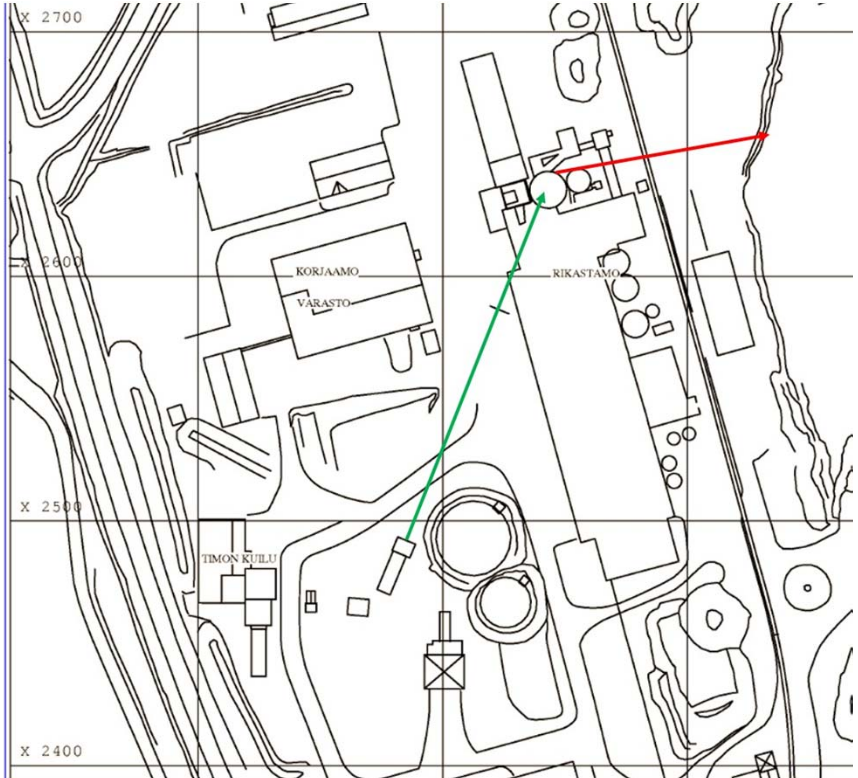
Excavation / day average is 368 m3/day.
(= 1041 tonnes) **(=38% of Hoist Capacity**)

When excavation main masses, the production rate may increase significantly

==> Hoist capacity does not restrict cavern excavation !!!

PYHÄSALMI + HOMESTAKE
ROCK WASTE HANDLING ON SURFACE

All rock can be used for backfill, if excavated before 2019.

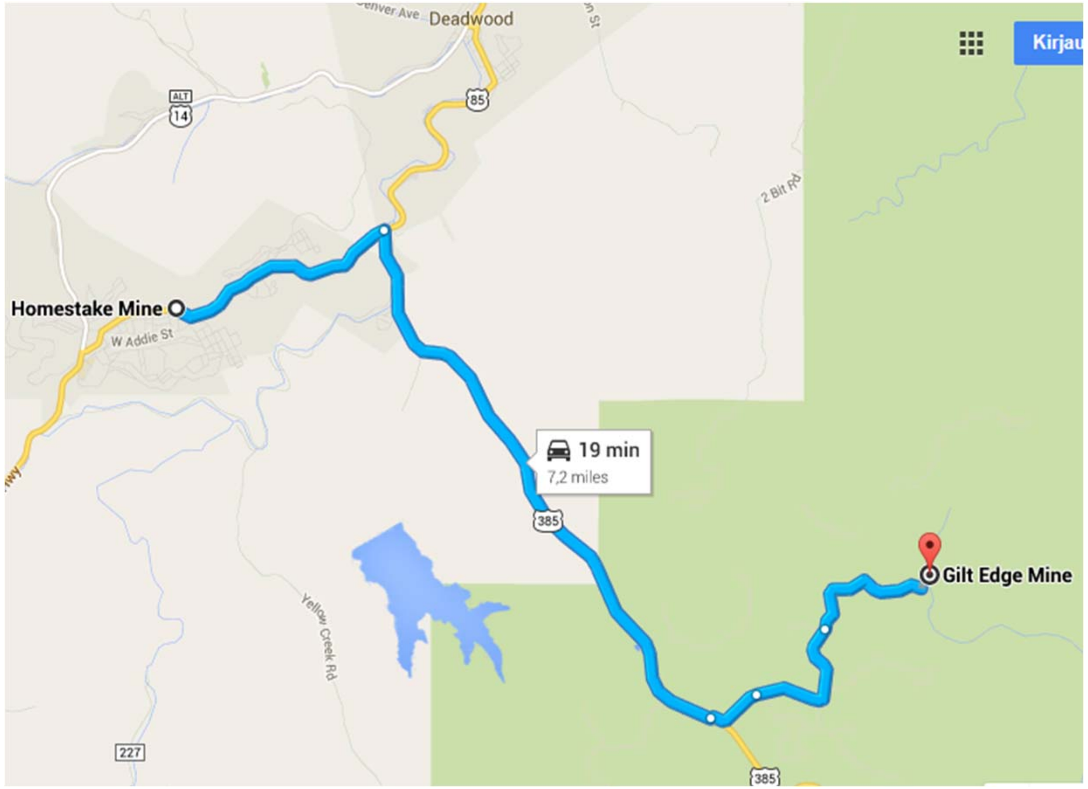


The waste dump is transported only 100m to the Mine Open pit for final disposal.

(if not used for backfill before 2019)

Total transport 287,000m3 * 0.1km =

0.03 Million m3*km



The waste dump is truck transported 11.6 km (7.2 miles) to the Gilt Edge Gold Mine for final disposal.

Total transport 190,000m3 * 11.6km =

2.2 Million m3*km

Guido Nuijten

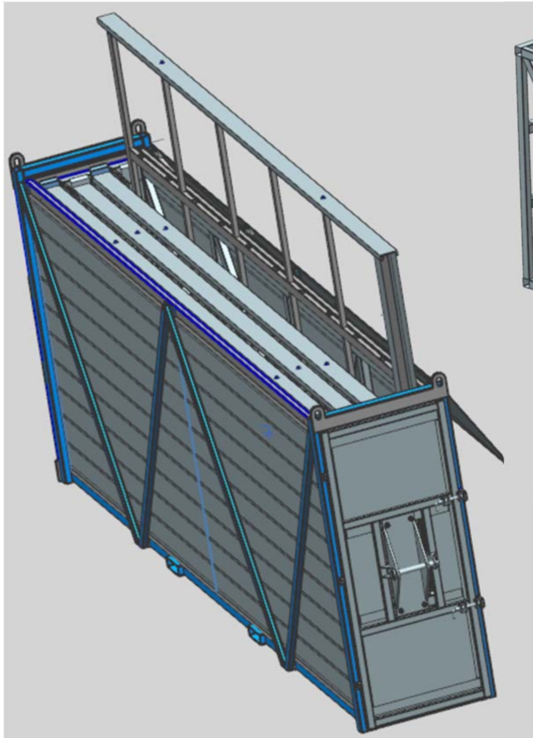
PYHÄSALMI + HOMESTAKE
MATERIAL TRANSPORT

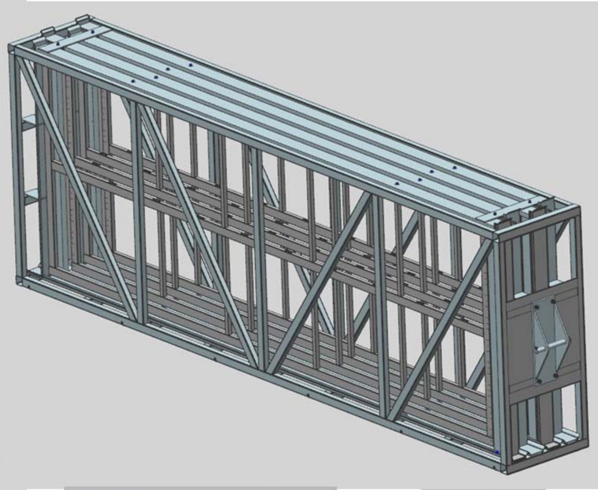
Trucks weigh 20,000 to 30,000 pounds (9,070 to 13,600 kg), and can carry roughly 40,000 pounds (18,100 kg) of concrete. The most common truck capacity is 8 cubic yards (6.1 m^3).

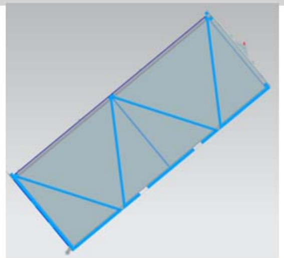
All down via decline.

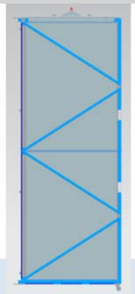
Multiple trucks / containers can be transported per hour down the decline. Travel time down 40min.

20’ Hi Cube Container Dimensions:
8’w x 6’9”h x 20’l = **2.44m x 2.90m x 6.06m**
Maximum load: 50,422 lb = 22,900 kg
(interior container volume 33.0m3)









Removable inner frame can hold 4 APAs. The outer container does not need to be moved into clean areas

One container of APAs is enough for a days work
Less than one hour hoist time for transport

Cage Compartment / Cage Inside Dimensions:
4’8”w x 7’h x 12’41/2”l = **1.42m x 2.13m x 3.77m**
Maximum load: 12,000 lb = 5,450 kg
Slung load dimensions:
5’ x 7’ x 30’ = 1.5m x 2.1m x 9.1m

Guido Nuijten

PYHÄSALMI + HOMESTAKE
CONCRETE MATERIAL TRANSPORT CAPACITY

Concrete (material) transport via Decline

Assuming 2 shifts (16 hours / day)

Transport capacity max. **50 trucks / day** (transport data before Timo Hoist taken into operation):

Pilot + 20kT LAr **concrete volume = 17,389 m3**

- 6,790 m3 fibre shotcrete
- 2,365 m3 cast concrete
- 8,234 m3 post-tensioned concrete

Volume per transport = 6.1 m3

Transport volume per day (max) = 305 m3

Total transport days = 57 days (17,389 / 305)

==> Transport capacity not restricting in construction works / logistics !!!

Concrete (material) transport via skip

Concrete can be delivered via a special conveyance in the skip compartment that will travel at full speed. Assuming 2 minutes to fill and 2 minutes to empty, this could support up to **135 loads / day** .

10+24kT SURF **concrete volume= 15,555 m3**

- 11,280 m3 fibre shotcrete
- 1,001 m3 septum, drifts + floor concrete
- 3,274 m3 detector vessel structure (concrete)

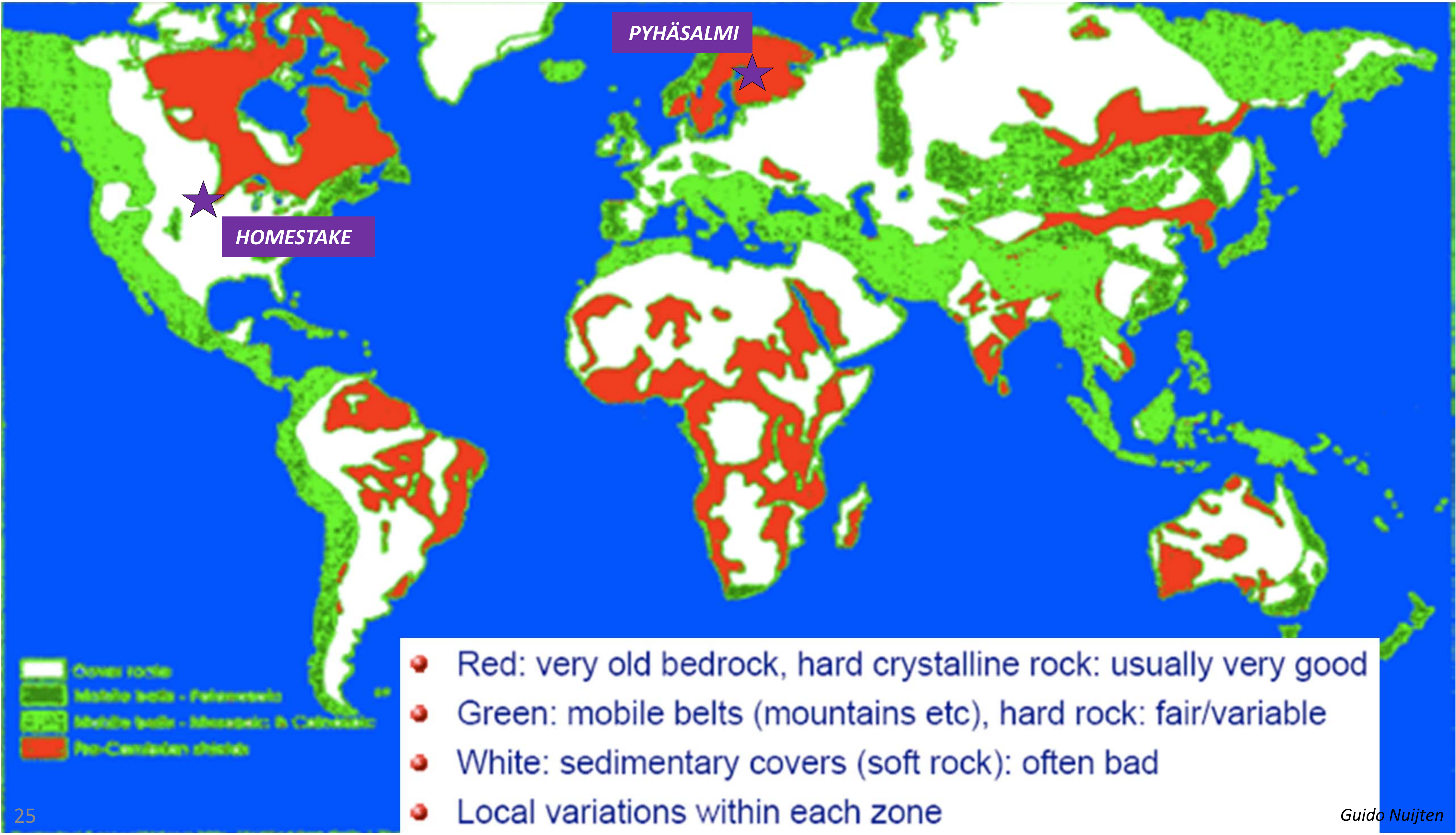
Volume per transport = 2.3 m3 (= 5,450 / 2,400)

Transport volume per day (max) = 297 m3

Total transport days = 52 days (15,555 / 297)

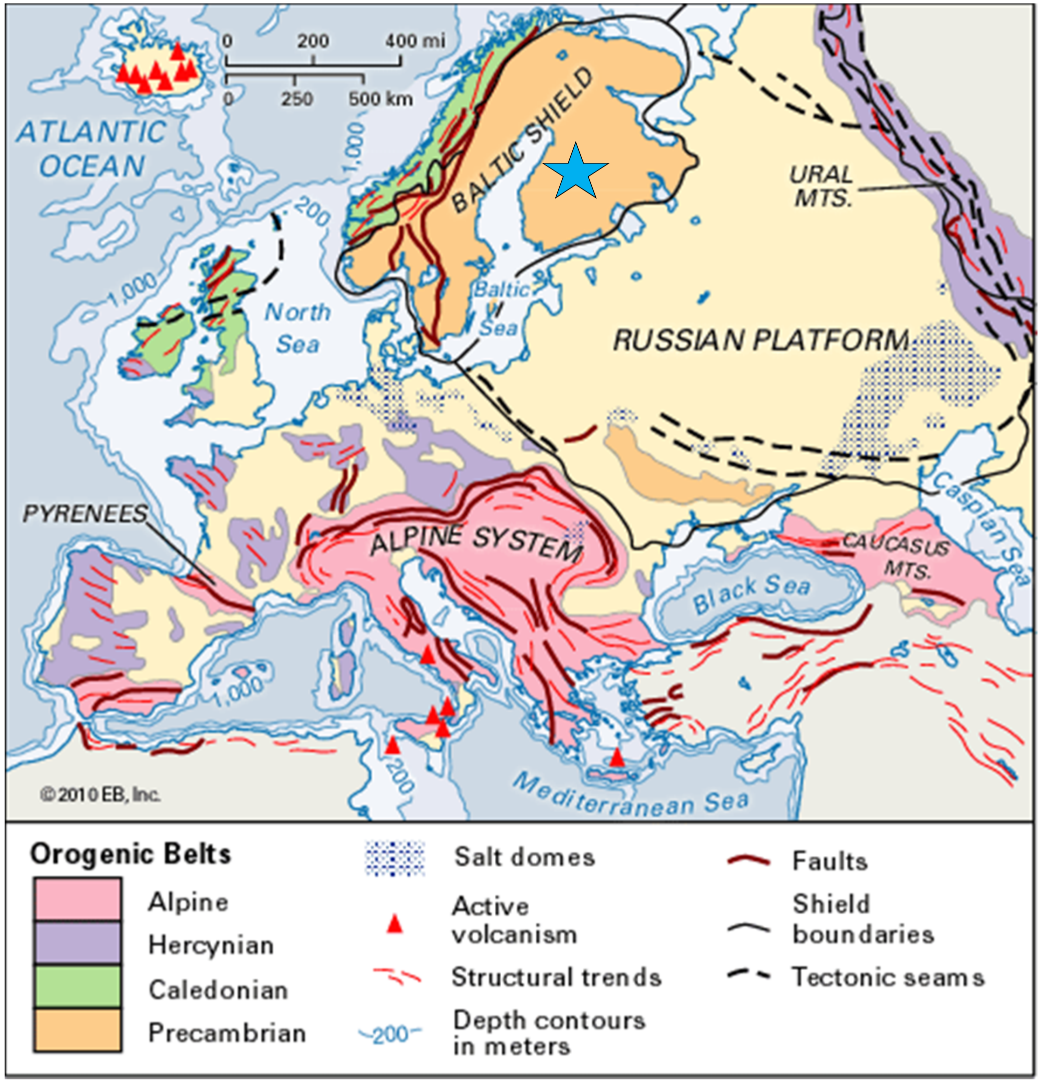
==> Transport capacity not restricting in construction works / logistics !!! (note skip also to be used for rock muck transport)

PYHÄSALMI + HOMESTAKE
GLOBAL GEOLOGY



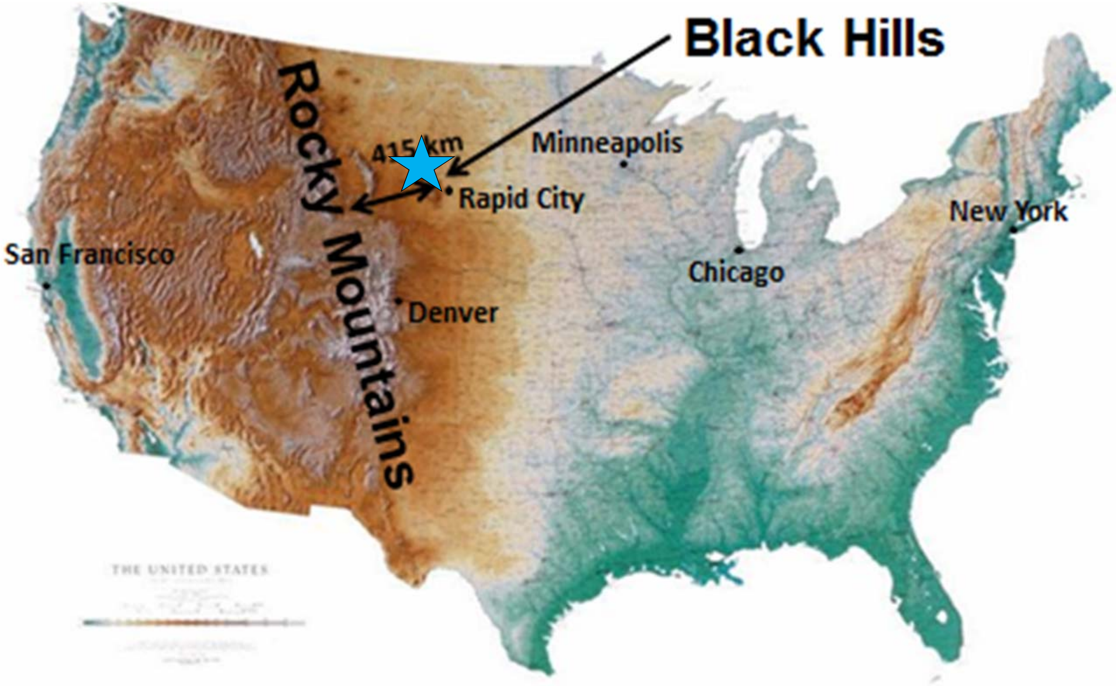
- Red: very old bedrock, hard crystalline rock: usually very good
- Green: mobile belts (mountains etc), hard rock: fair/variable
- White: sedimentary covers (soft rock): often bad
- Local variations within each zone

PYHÄSALMI + HOMESTAKE
CONTINENTAL GEOLOGY



Pyhäsalmi located in the centre of the Baltic Shield, age 2.5 to 3.5 billion years

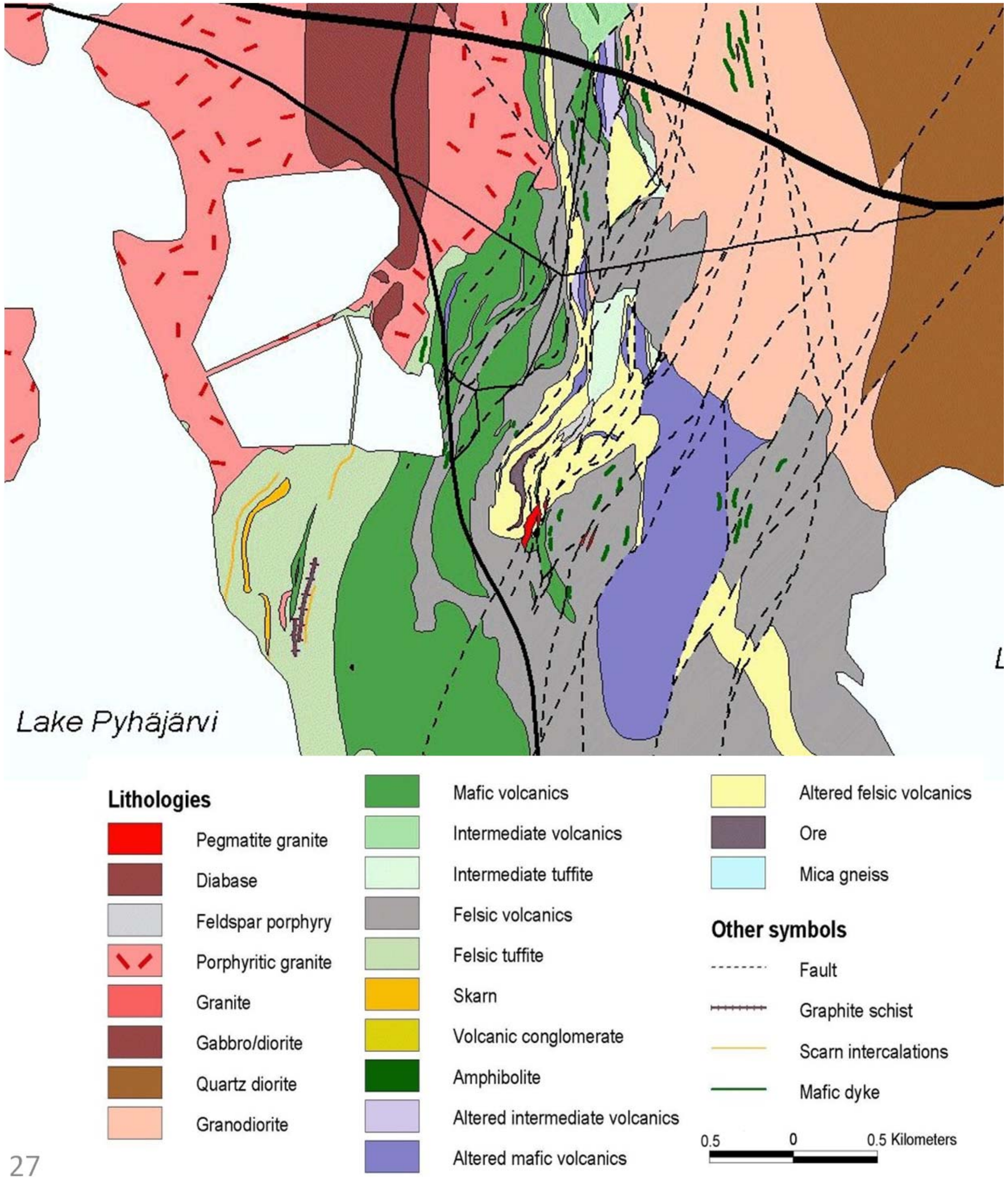
.

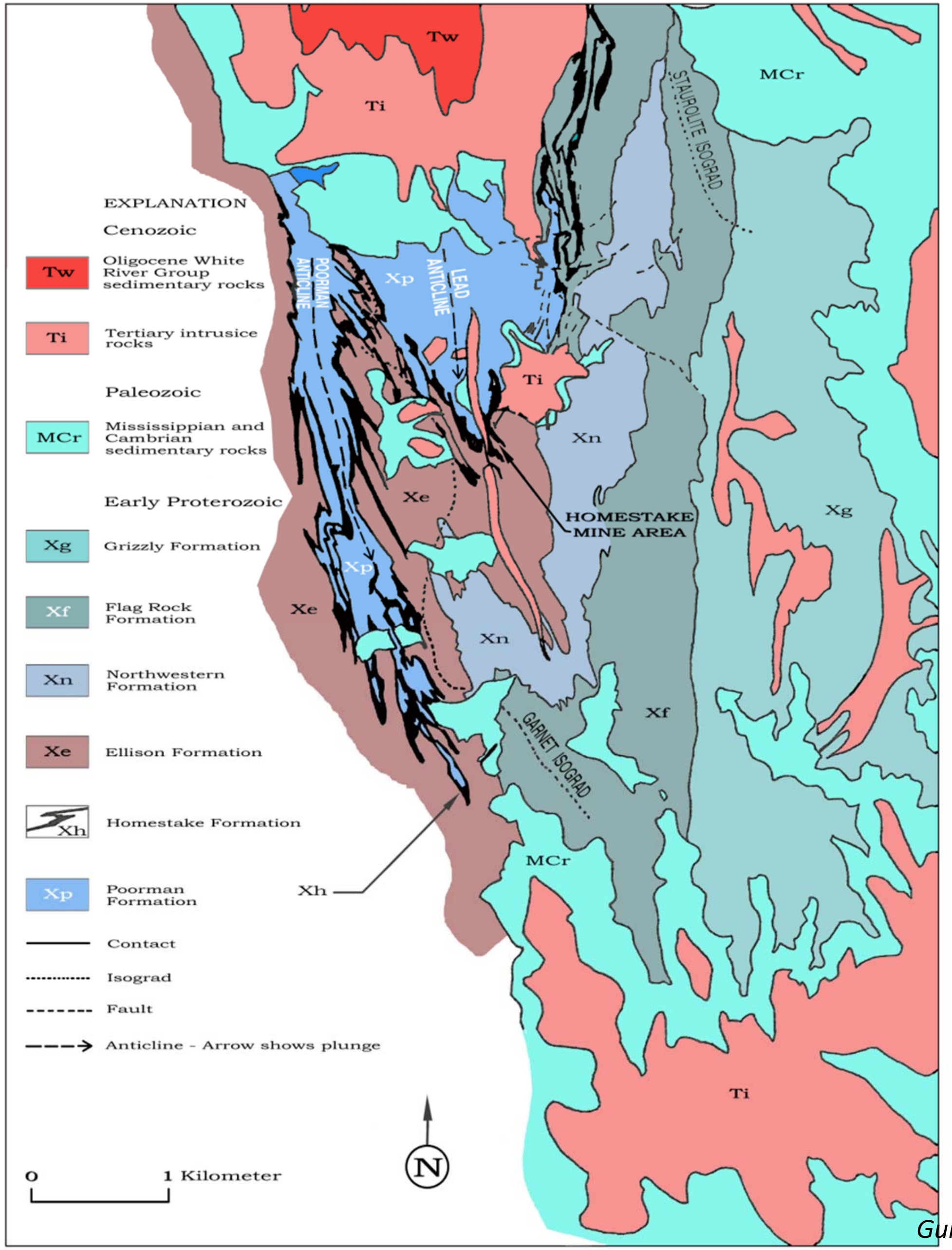


Homestake located some 260 miles east of the Rocky Mountains, part of the Black Hills

Guido Nuijten

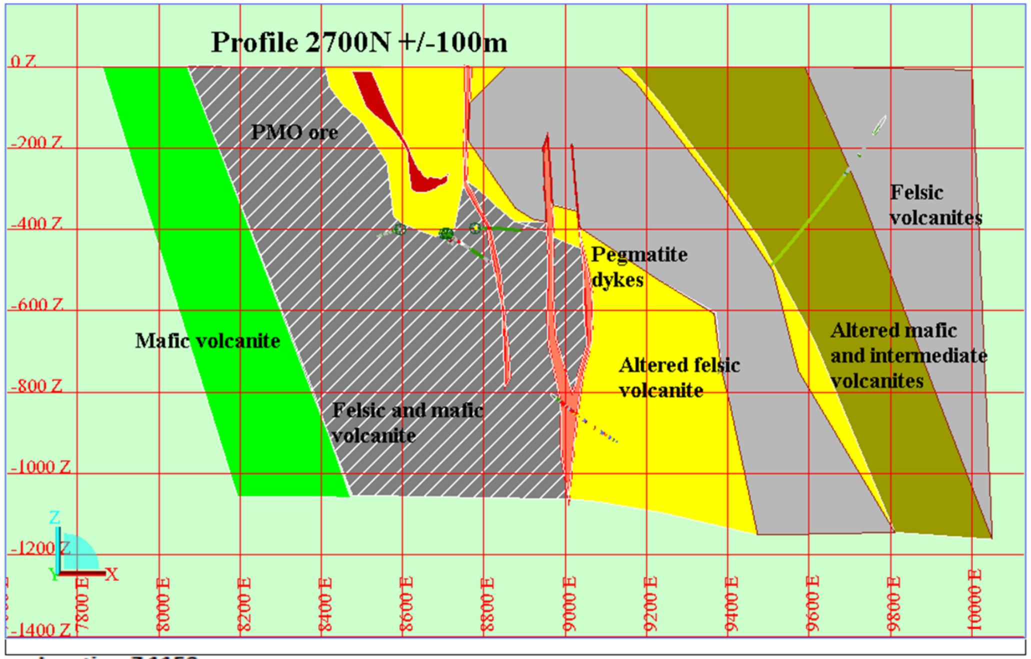
PYHÄSALMI + HOMESTAKE REGIONAL GEOLOGY

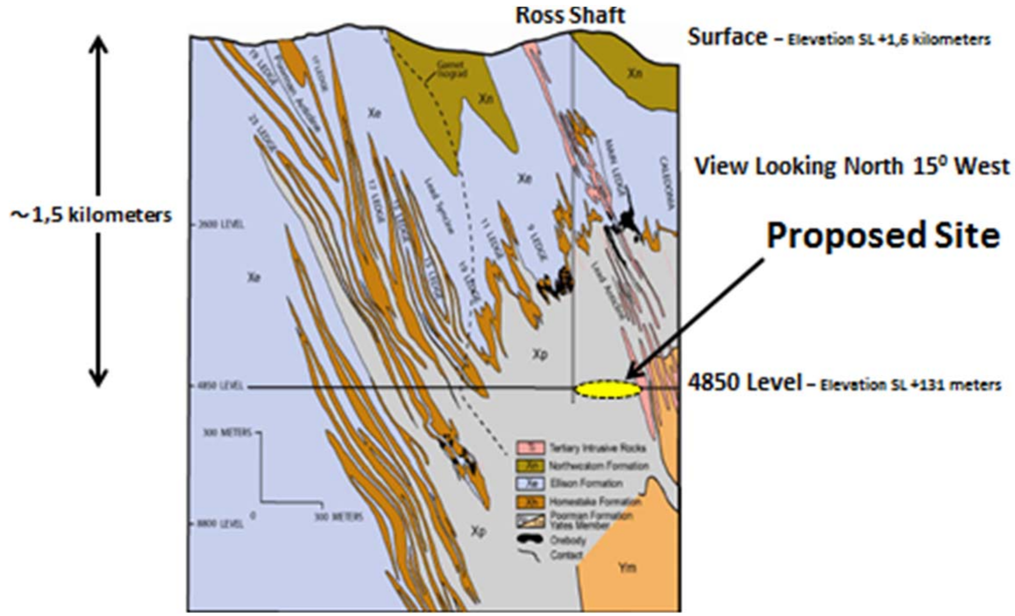




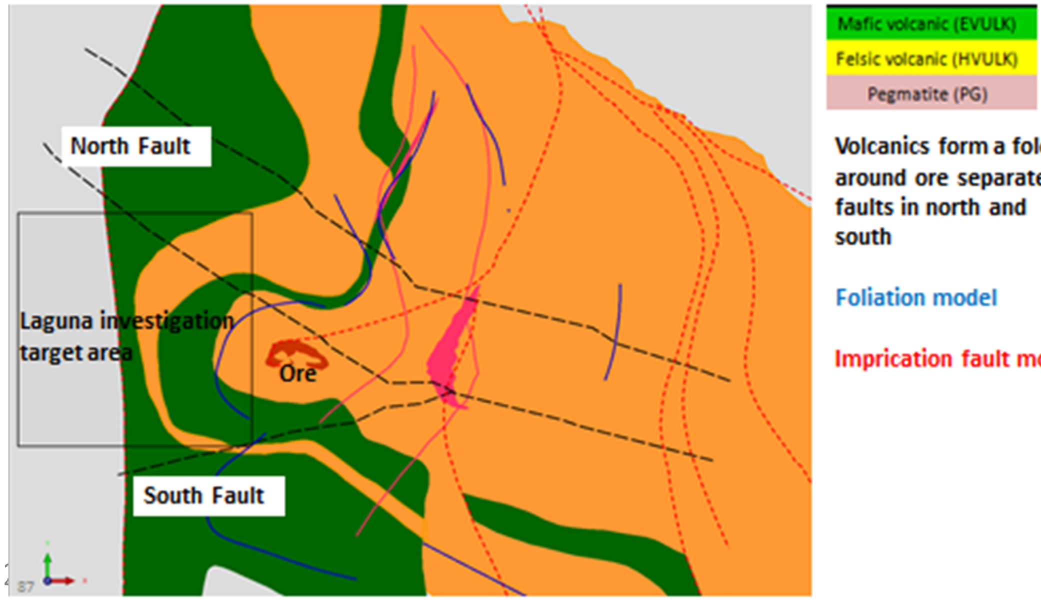
Guido Nuijten

PYHÄSALMI + HOMESTAKE DISTRICT GEOLOGY





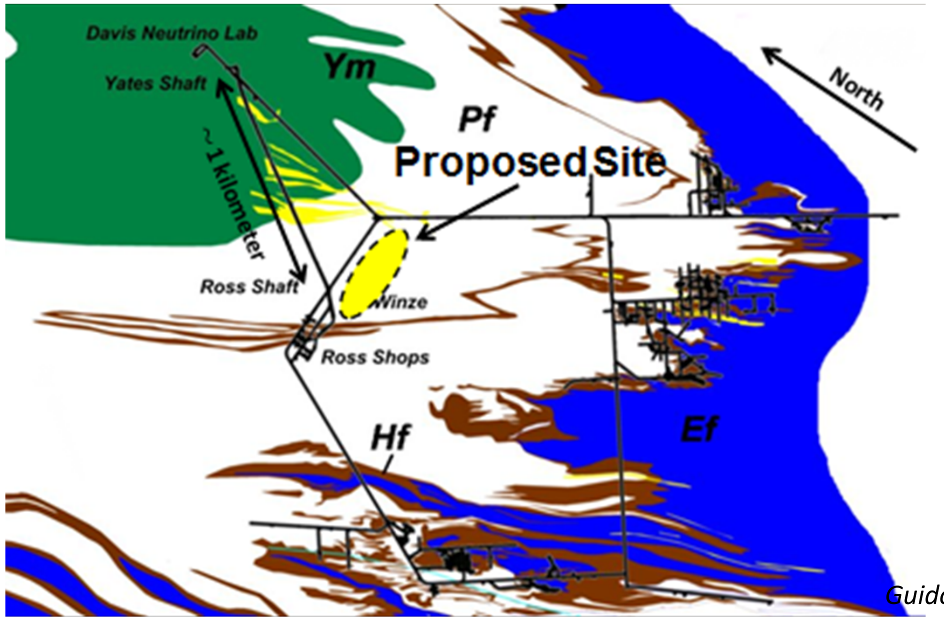
Level section Z 1150



Volcanics form a fold around ore separated by faults in north and south

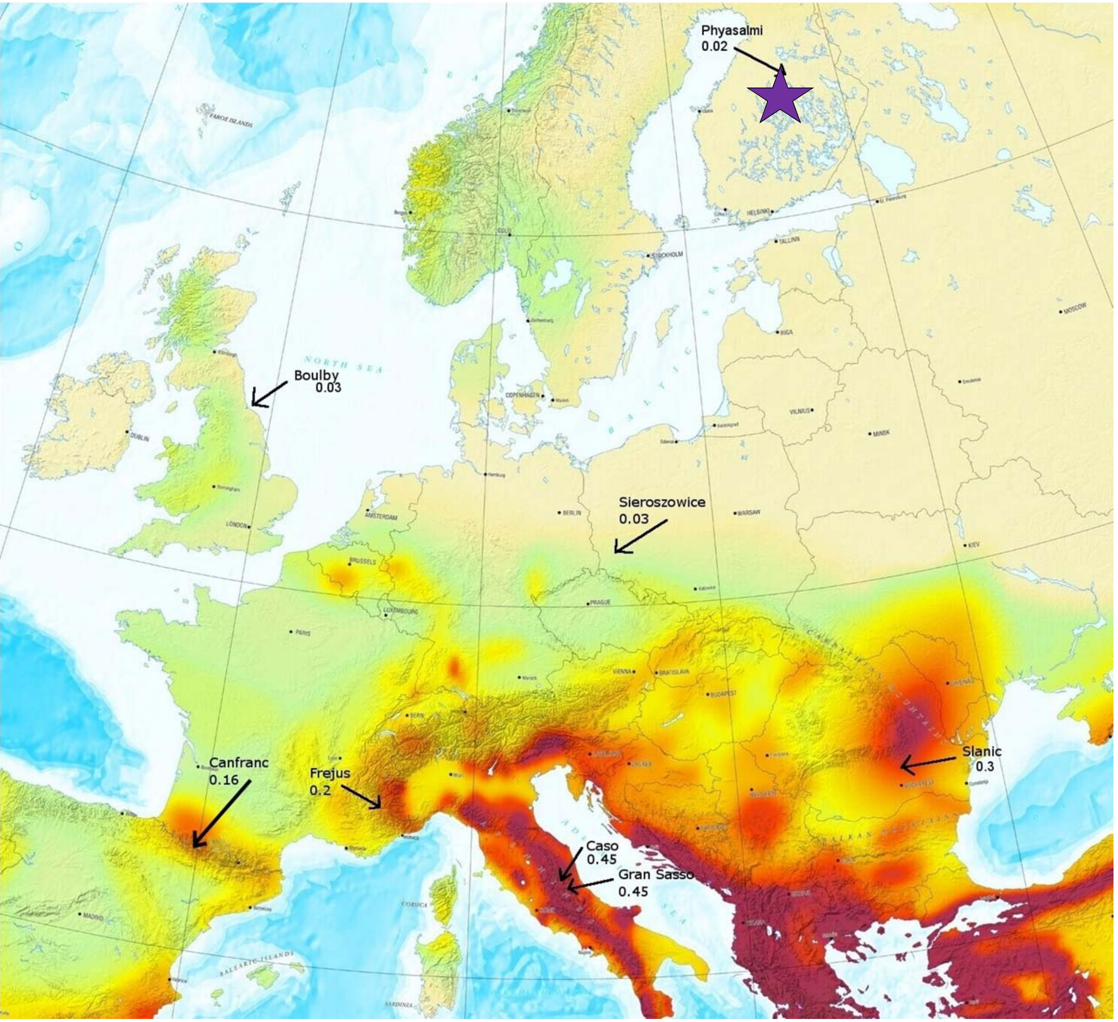
Foliation model

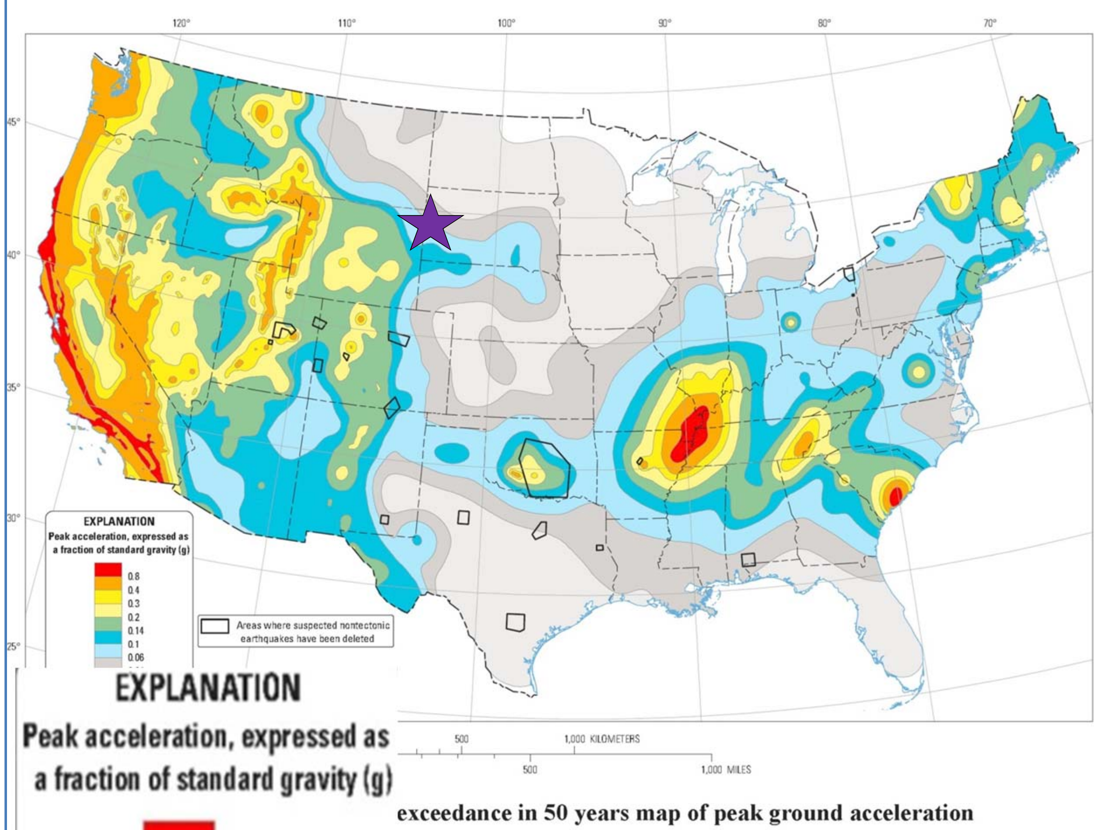
Imprication fault model

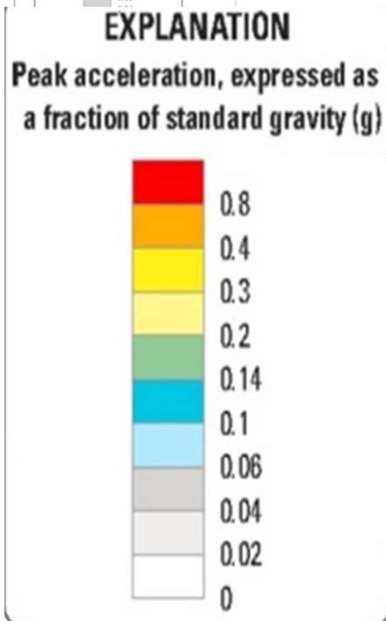


Guido Nuijten

PYHÄSALMI + HOMESTAKE
SITE SEISMICITY







Pyhäsalmi vibration accelerations at 500m from source:

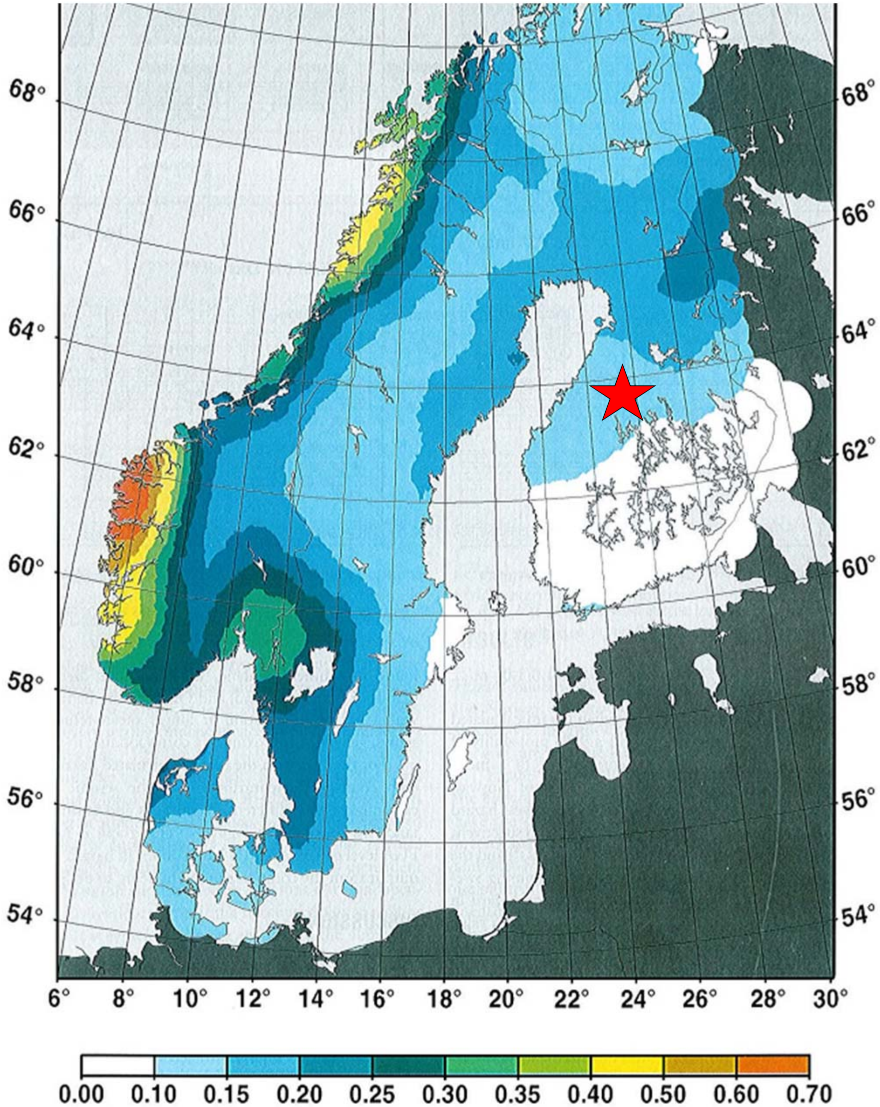
0,013g (due to earthquakes)

0,020g (due to blasting activities)

Homestake peak acceleration
~0.060g

Guido Nuijten

PYHÄSALMI + HOMESTAKE
SITE SEISMICITY



At the end of 2007 an earthquake was measured with a **magnitude of 2.1** on the Richter scale.

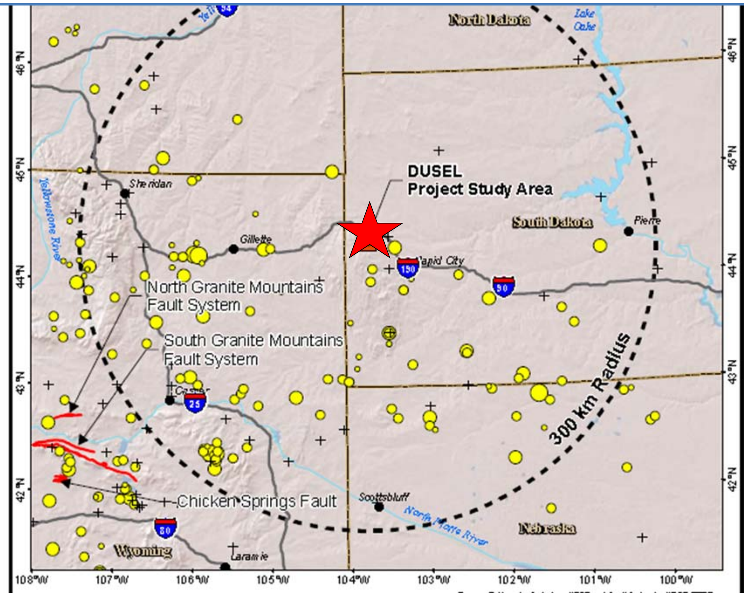


TABLE 2.1: HISTORIC EARTHQUAKE EPICENTERS LOCATED WITHIN 62 MILES (100 KM) OF THE DUSEL PROJECT SITE

Year	Month	Day[1]	Latitude (degrees N)	Longitude (degrees W)	Depth (km)[2]	Magnitude[3]	Approx. Distance from DUSEL (km)[4]
1895	10	11	43.9	103.3	-	3.8	61
1895	10	12	43.9	103.3	-	3.8	61
1924	12	30	43.5	103.5	-	4	96
1928	11	16	44.1	103.7	-	3.7	28
1941	5	25	43.5	103.5	-	4.1	96
1964	3	24	43.5	103.5	-	3.7	96
1966	6	26	44.29	103.42	2	3.1	27
1991	11	5	44.35	103.75	0	2.5	0
1993	9	5	44.4	103.8	5	2.7	6
1996	2	6	43.98	103.72	5	3.7	40
2004	1	5	43.59	103.99	5	2.8	85
2004	1	24	44	103.2	5	2.5	59
2009	9	25	45.02	104.21	4	4.2	82

In autumn of 2009 an earthquake was measured with a **magnitude of 4.2** on the Richter scale.

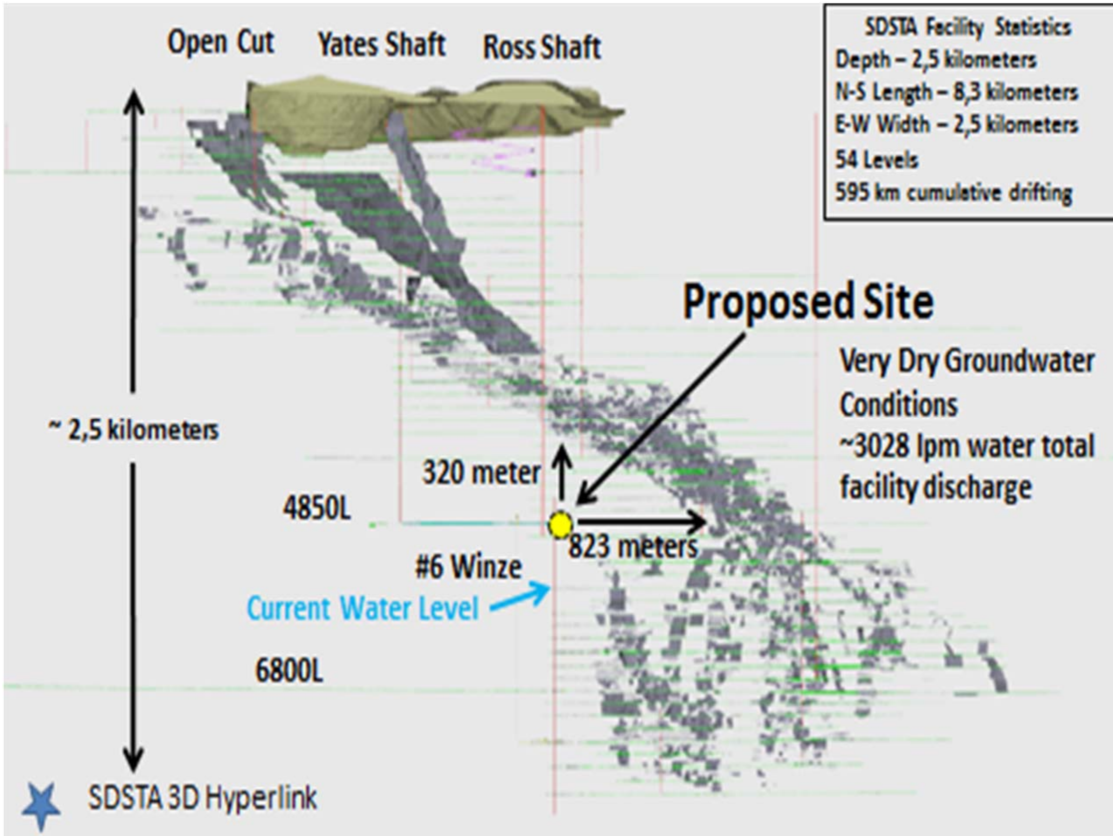
Guido Nuijten

PYHÄSALMI + HOMESTAKE HYDROLOGY

The rock investigated is very dry in the LAGUNA cavern area, thus at the proposed site very dry groundwater conditions to be expected

Some water is found in other locations:

- Containing chloride
- pH is neutral
- Sulfate same level as e.g. in Helsinki-Espoo region

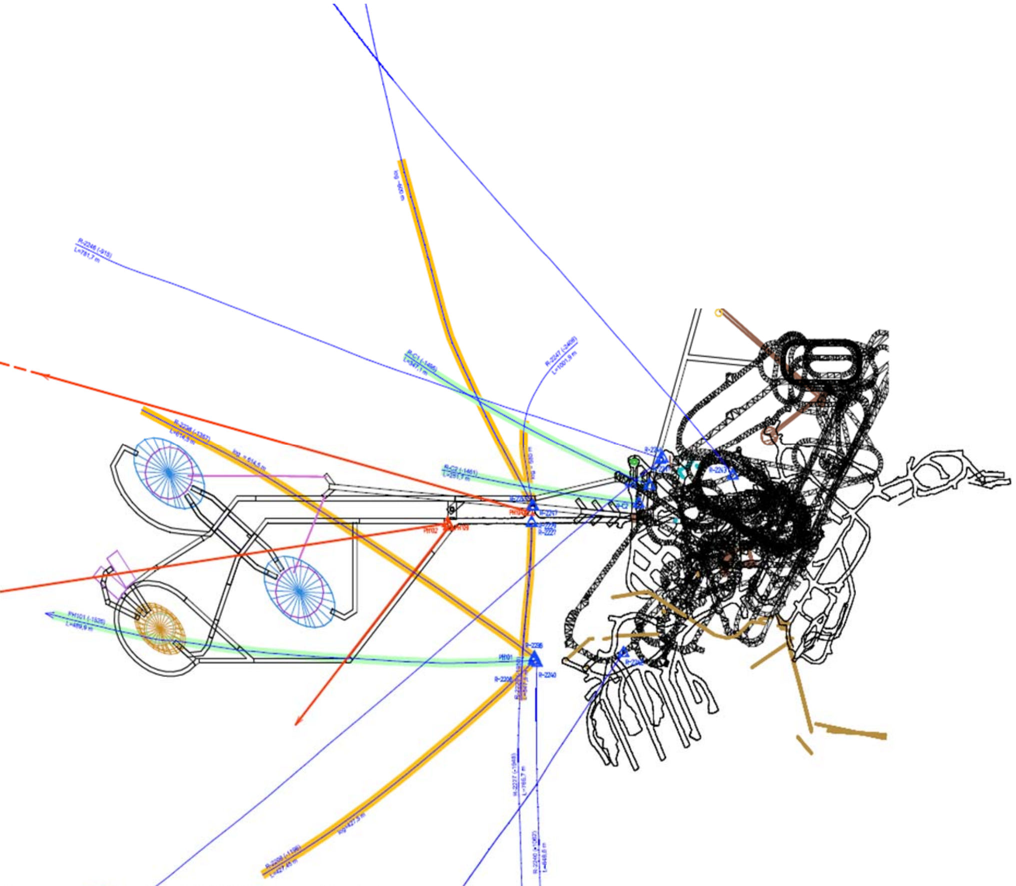


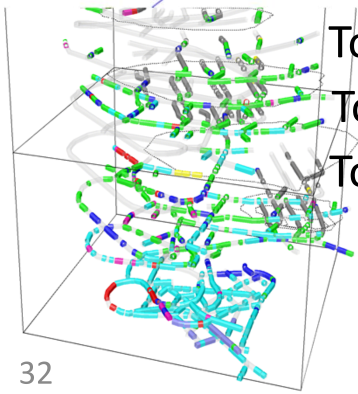
At the proposed site very dry groundwater conditions

Current shaft kept wet for fire safety

Current water level well below site

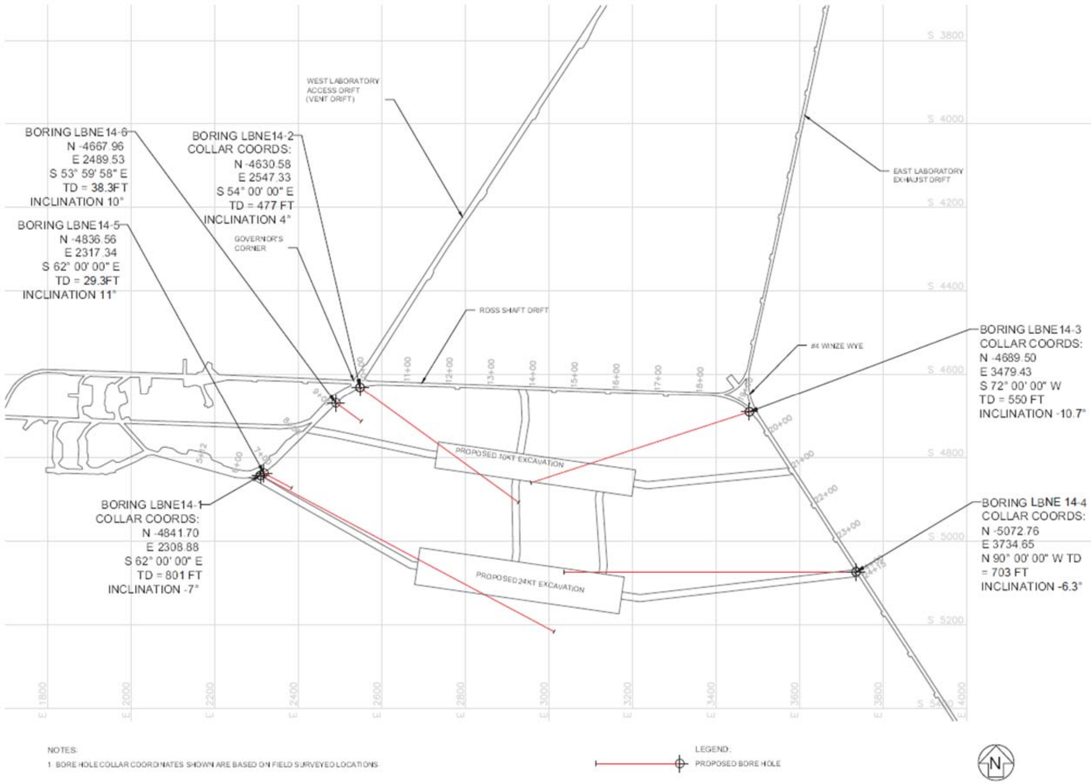
PYHÄSALMI + HOMESTAKE
SITE INVESTIGATIONS





Total amount new holes drilled 3.5 km
Total existing holes core logged 2.9 km
Total amount holes core logged 6.4 km

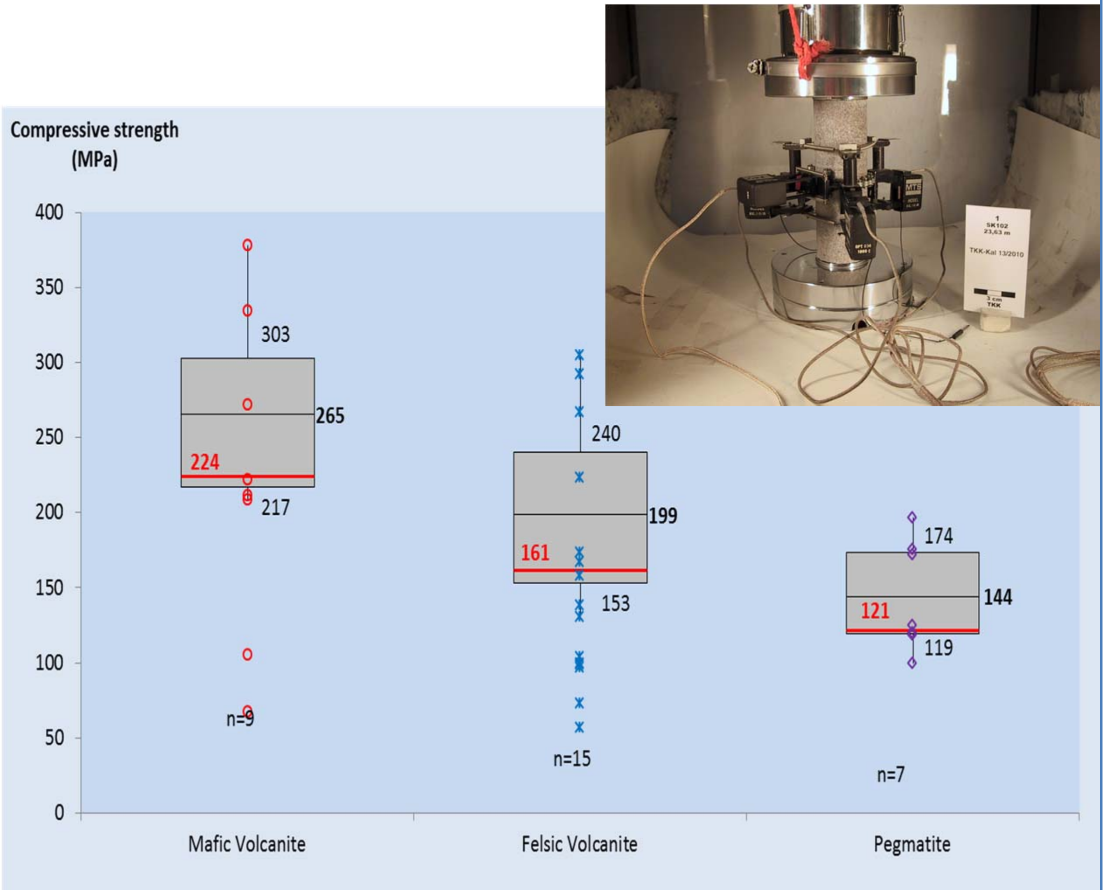
Multiple kilometres of drift and decline mapped.

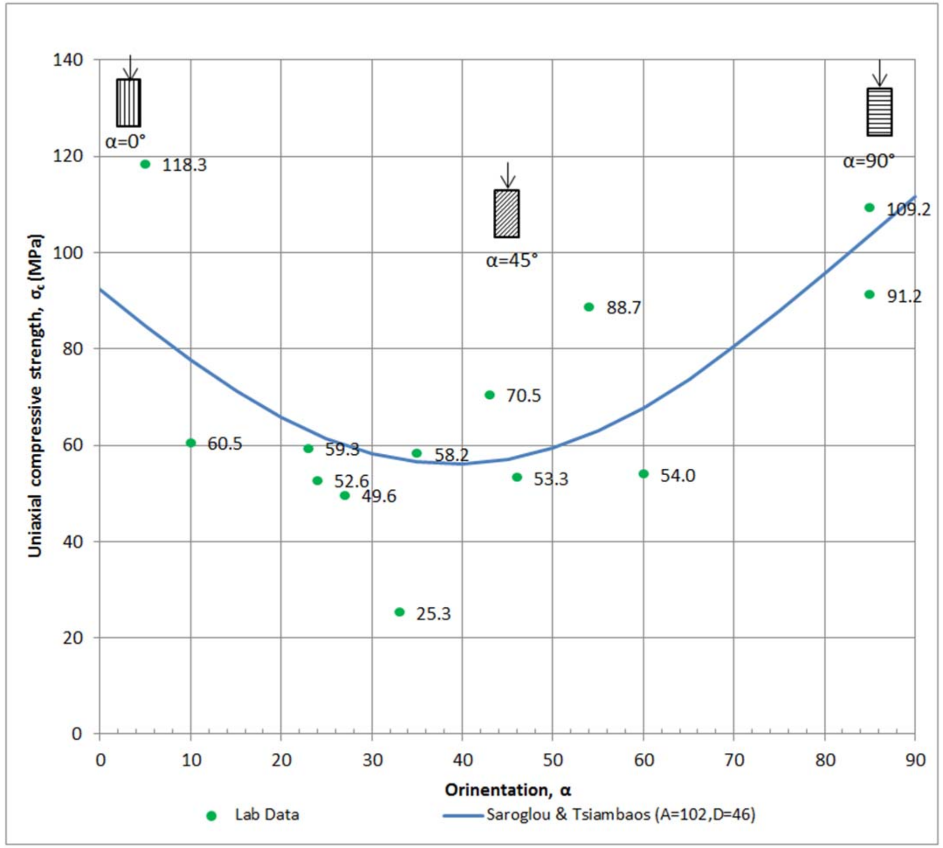


Drilling and Core Logging (5400 ft) = 1.6km
Drift Mapping (4300 ft) = 1.3 km

Guido Nuijten

PYHÄSALMI + HOMESTAKE
INTACT ROCK STRENGTH





*In **green** chosen formation for Main Detector Cavern(s)*
Note: schistosity etc. substantial impact on rock mass compressive strength

Average values:

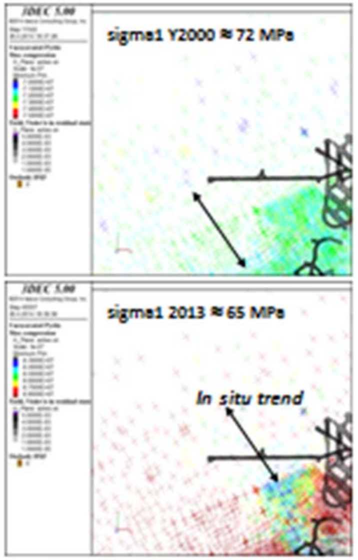
Mafic Volcanites σucs = 265 MPa (= 38,435 psi)
Felsic Volcanites σucs = 199 MPa (= 28,863 psi)
Pegmatite dikes σucs = 144 MPa (= 20,885 psi)

Average values:

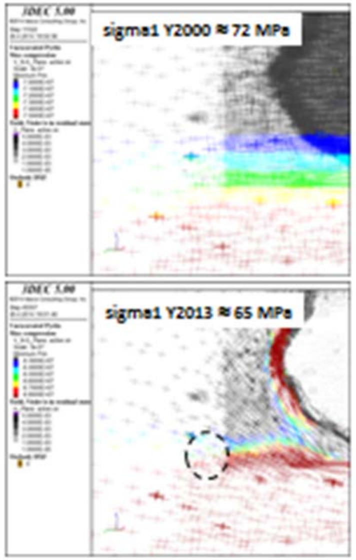
Yates amphibolite σucs = 150 MPa (= 21,756 psi)
Poorman formation σucs = 106 MPa (= 15,374 psi)
Rhyolite dikes σucs = 142 MPa (= 20,595 psi)

PYHÄSALMI + HOMESTAKE ROCK STRESSES

LVDT-cell measurement – Effect of mining

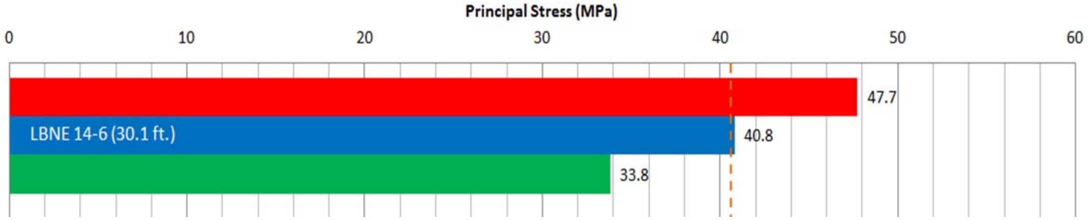


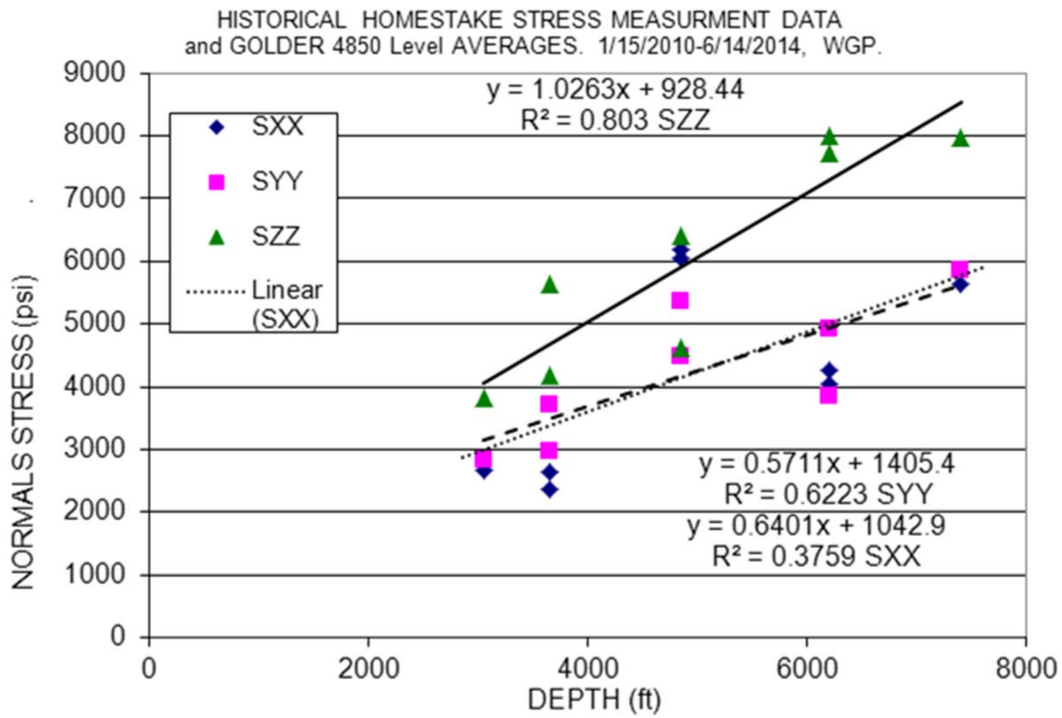
- Magnitude underestimated max -7 MPa
- trend; max ± 10°
- plunge; max 15° down towards orebody



	Mean (MPa)	Upper (MPa)	Trend
Major horizontal stress, MPa	54	72	280°-311°
Minor horizontal stress, MPa	39	44	
Vertical stress, MPa	39	43	

In situ Stress Magnitudes as Determined From LBNE Overcoring

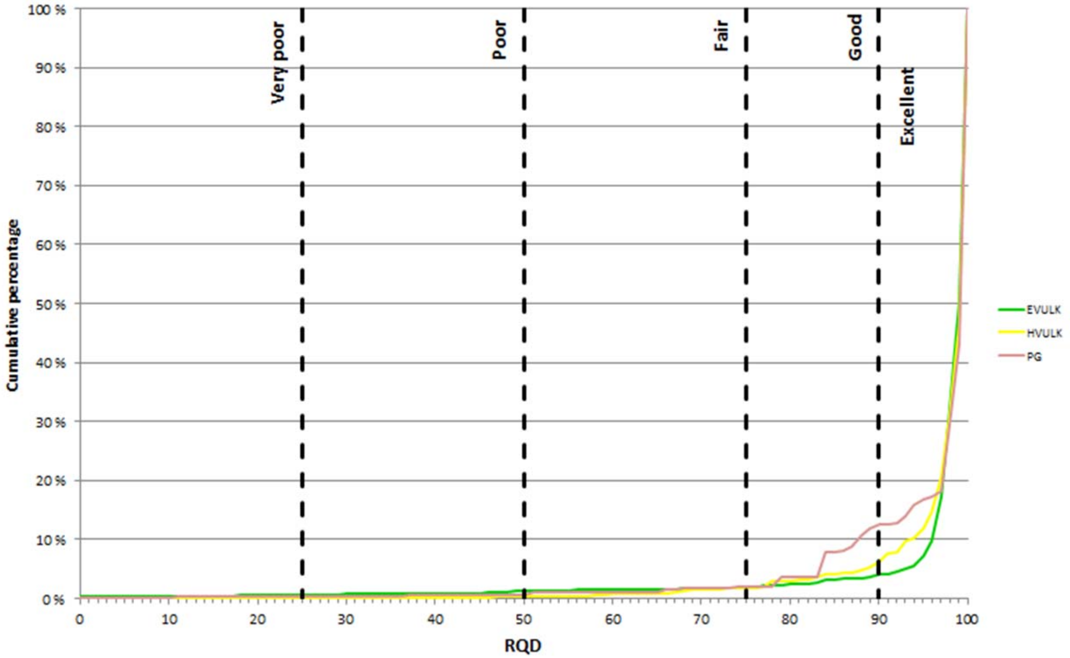




Major Stress (Vertical) Mean Value 5,906 psi = 41 MPa
Horizontal σxx Mean Value 4,175 psi = 29 MPa
Horizontal σyy Mean Value 4,147 psi = 29 MPa

Guido Nuijten

PYHÄSALMI + HOMESTAKE
ROCK QUALITY DESIGNATION (RQD)



RQD generally well above 90% = excellent

Amount of fractures on average less than 1 per meter. Mafic volcanites almost completely intact rock.

Core disking observed in some core drilled holes: risk of some spalling.

Table 5.1: Summary of lower quality RQD values encountered in coreholes

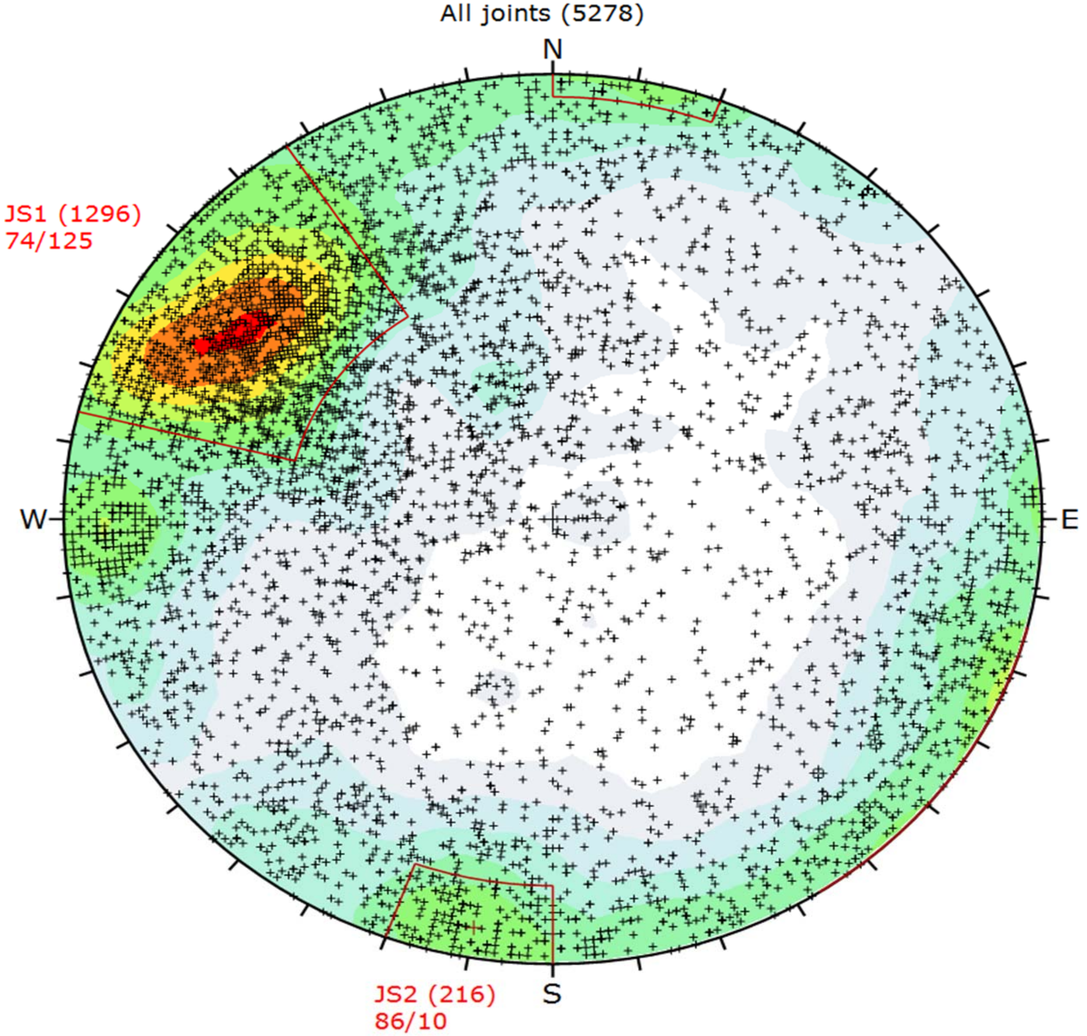
Corehole	Depth (ft.)		Lithology	RQD[1]	Comment
	Start	End			
LBNE 14-3	200.0	205.0	Graphitic SCHIST	87	Mod. fractured, intensely foliated.
LBNE 14-3	480.0	485.0	SCQ SCHIST	87	Mod. to highly fractured, planar to contorted foliation
LBNE 14-3	525.0	530.0	SCQ SCHIST	82	Highly fractured, brecciated zone, porous with vugs
LBNE 14-4	153.0	158.0	RHYOLITE	73	Mod. to highly fractured, sl. rough planar joints
LBNE 14-4	303.0	306.8	Graphitic SCHIST	80	Highly fractured, contorted foliation

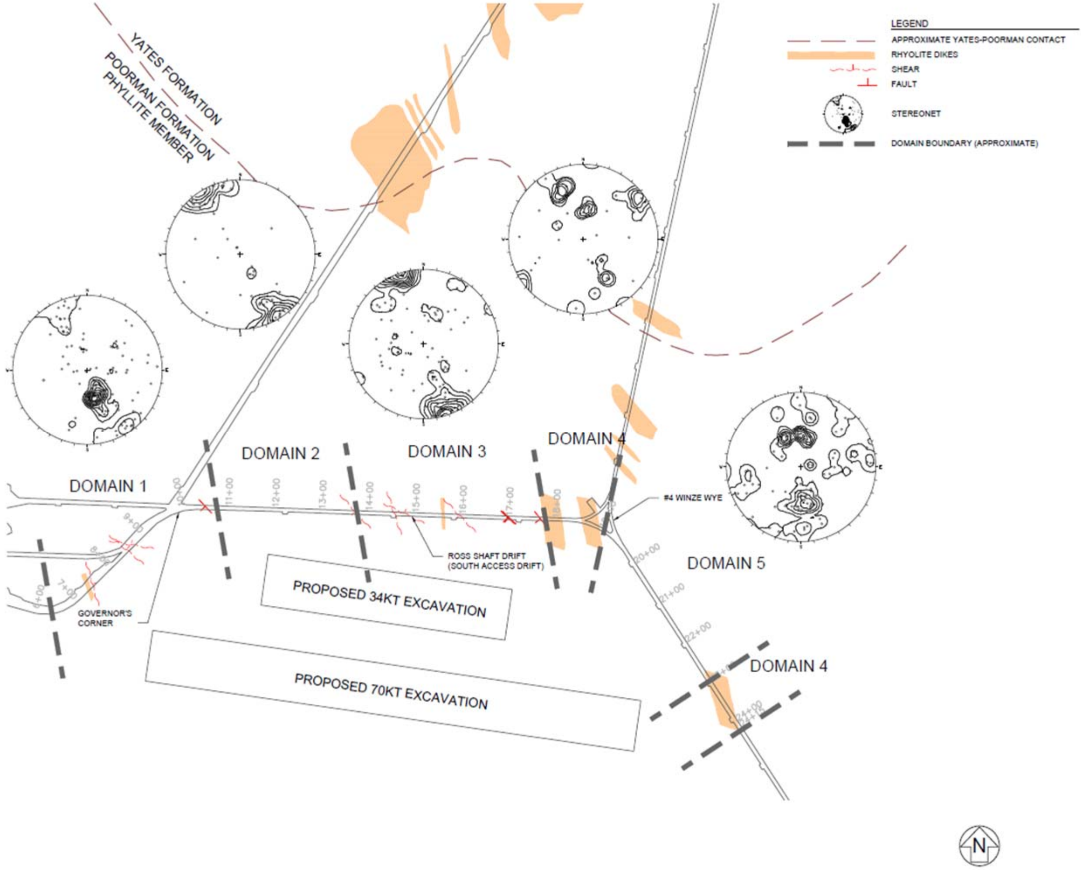
RQD generally 90-100% or "excellent"

Exceptions noted above (1% of drilled length)

"Disking" of core, which was observed in Poorman Formation Yates lithology and rhyolites/quartz veins, not observed in this investigation in Poorman Formation schist. Indicative of rock "brittleness" – no disking is a favorable observation

PYHÄSALMI + HOMESTAKE
ROCK FRACTURING / JOINT ORIENTATION



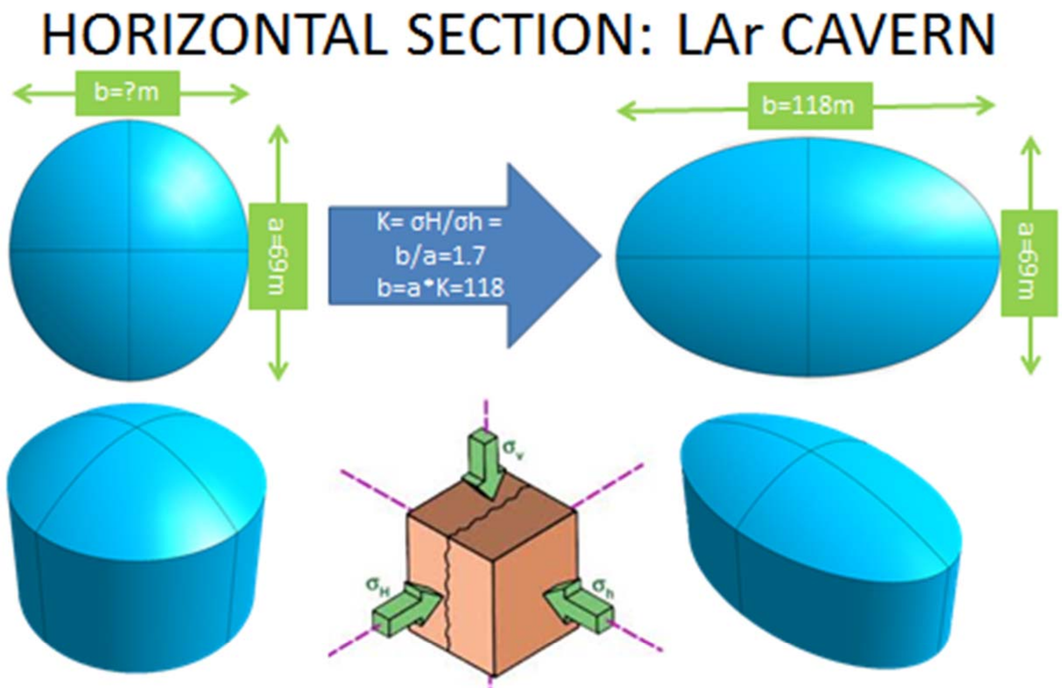


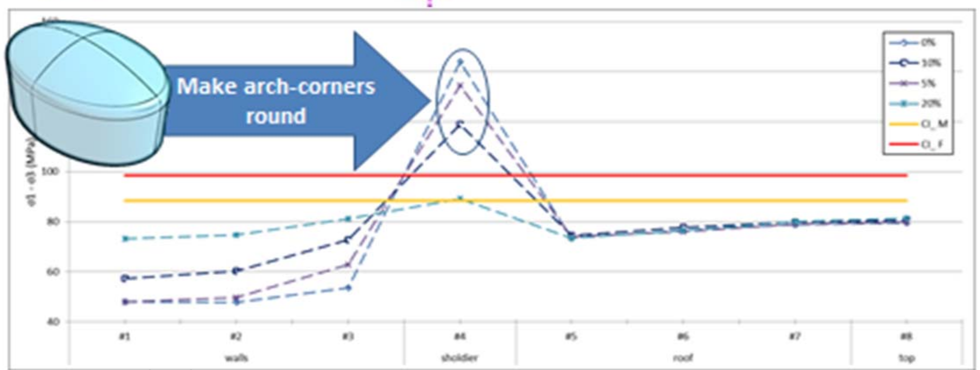
In general joint directions in major rock types show more or less the same orientations as in all fractures combined: **only 2 joint sets**

Qualitative differentiation of rock mass fabric / structure, area divided in 5 domains.
Some domains challenging (**>2 joint sets**)

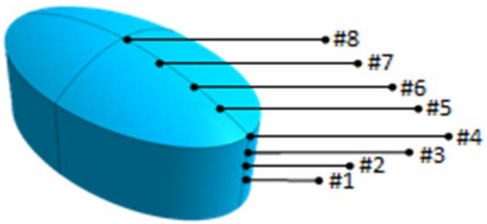
Guido Nuijten

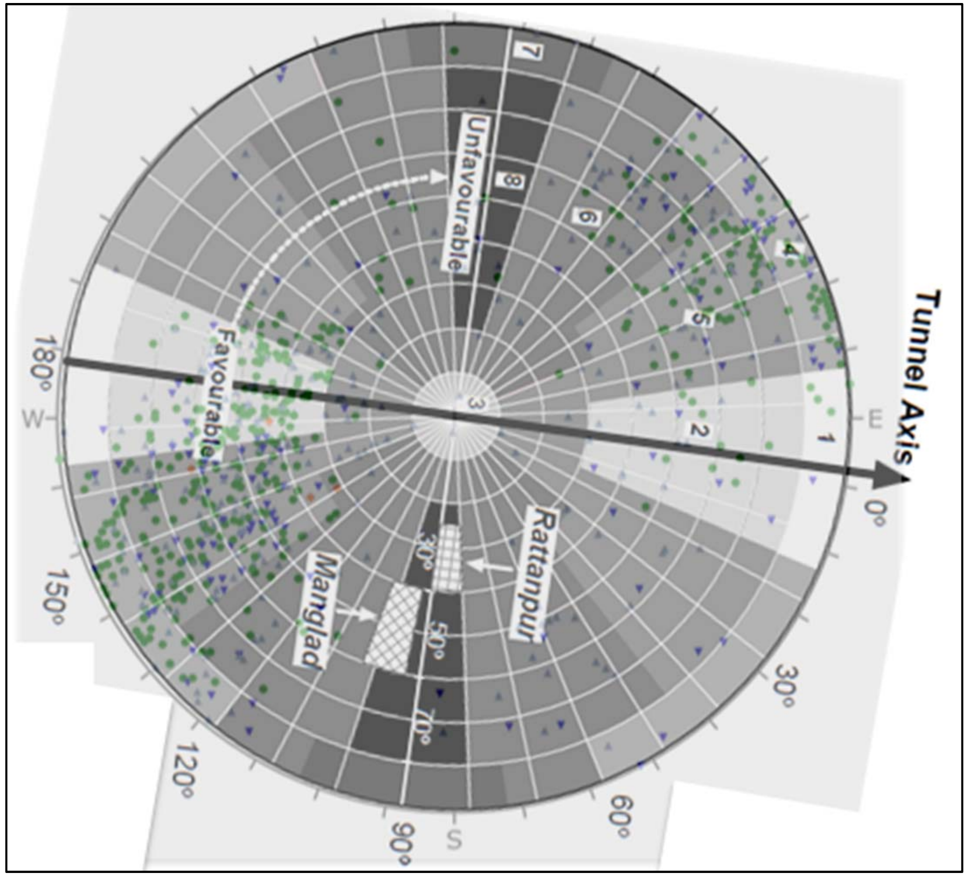
PYHÄSALMI + HOMESTAKE
OPTIMUM CAVERN SHAPE





Optimal shape elliptical due to major horizontal stress in SE-NW direction





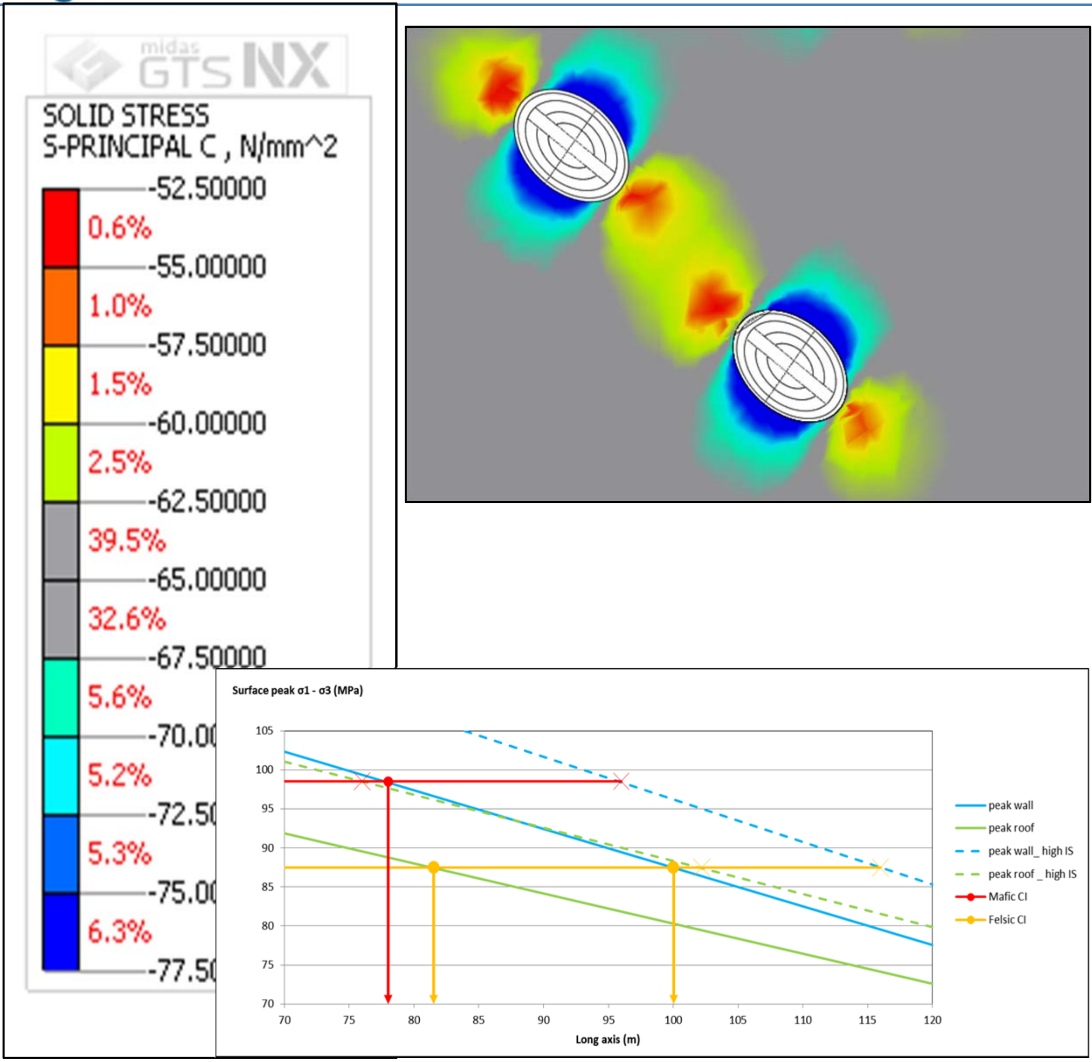
Comparatively stress friendly conditions.

Previous study carried out in Yates member amphibolite

Considered mailbox and upright cylinder

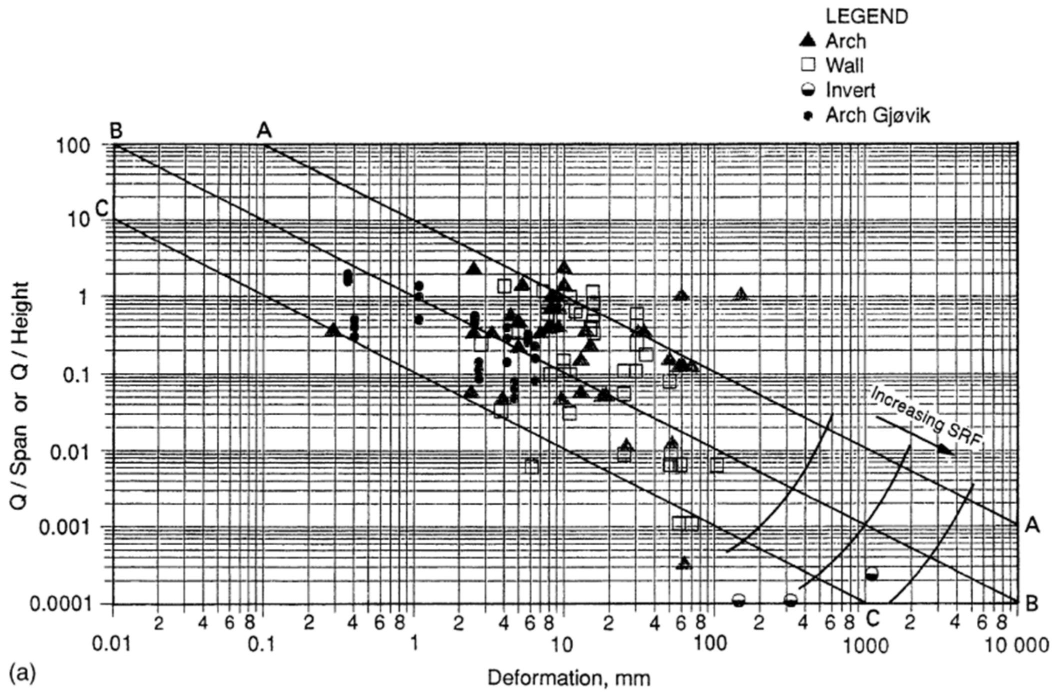
Concluded: mailbox gave higher sidewall deformations for every case, and similar crown deformation

PYHÄSALMI + HOMESTAKE
MAX. CAVERN SIZE



Based on the analysis results, the recommended cavern circumference shapes are elliptical and the major axis is orientated along the major horizontal *in situ* stress component.

LAr cavern dimensions are 100m x 69m.



From conceptual standpoint, an elastic (immediate) deformation of 75mm would be reasonable (Δ / span = 0.25% strain) for GSI ≥ 70

Span limit: 125 ft. (38m)

For increase to 150 ft. (45.7m), deformation = 100mm

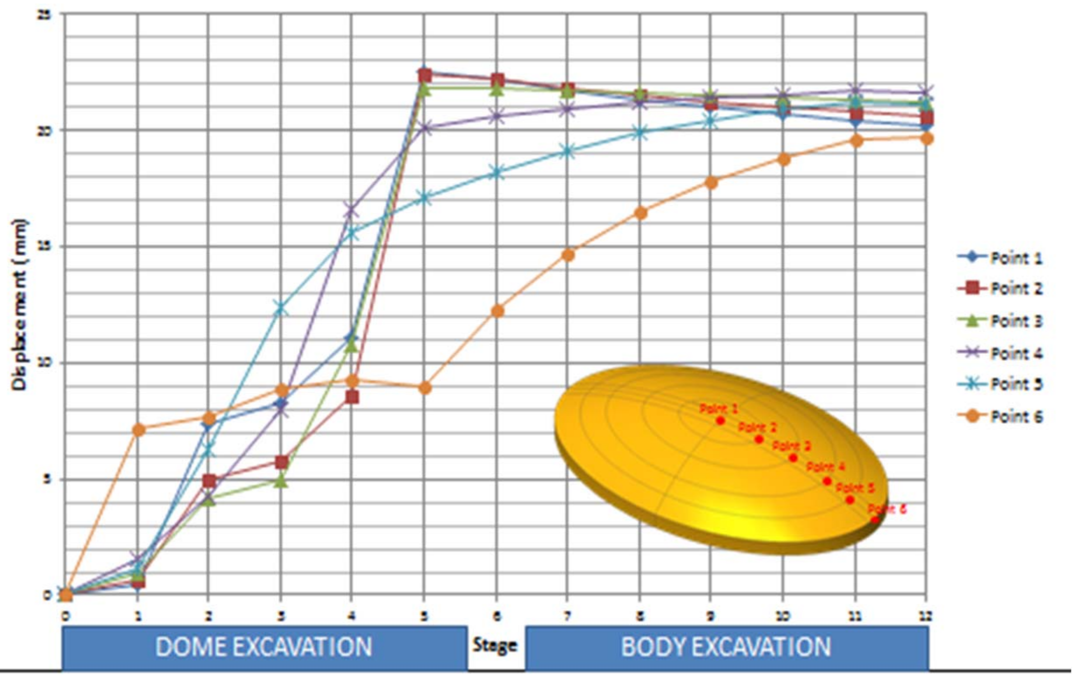
Further study foreseen.

Guido Nuijten

ROCKPLAN

PYHÄSALMI + HOMESTAKE
DEFORMATIONS + LONG TERM BEHAVIOUR

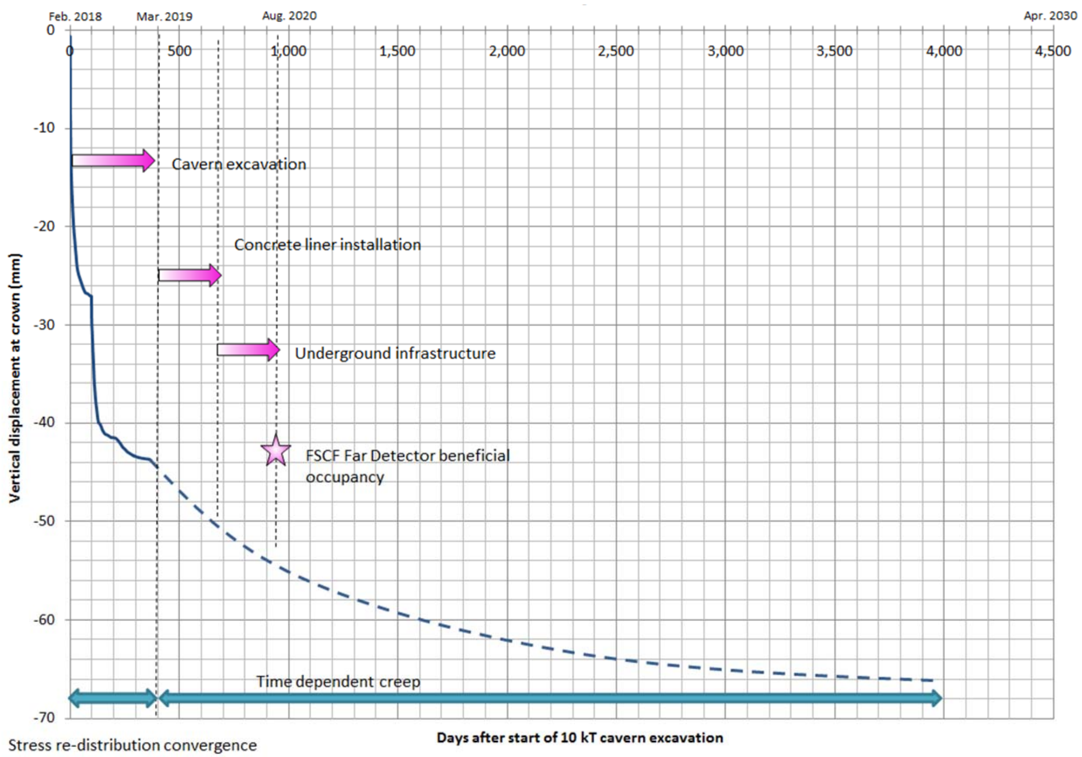
LAGUNA



Maximum **absolute deformation 23mm** (for a 64 by 102 m span elliptical cavern

Lowering cavern (bench excavation) introduces a decrease of deformation by 2…3mm

Pyhäsalmi Mine has no rock formations, that show time related deformations (like creep of salt or anhydrite)

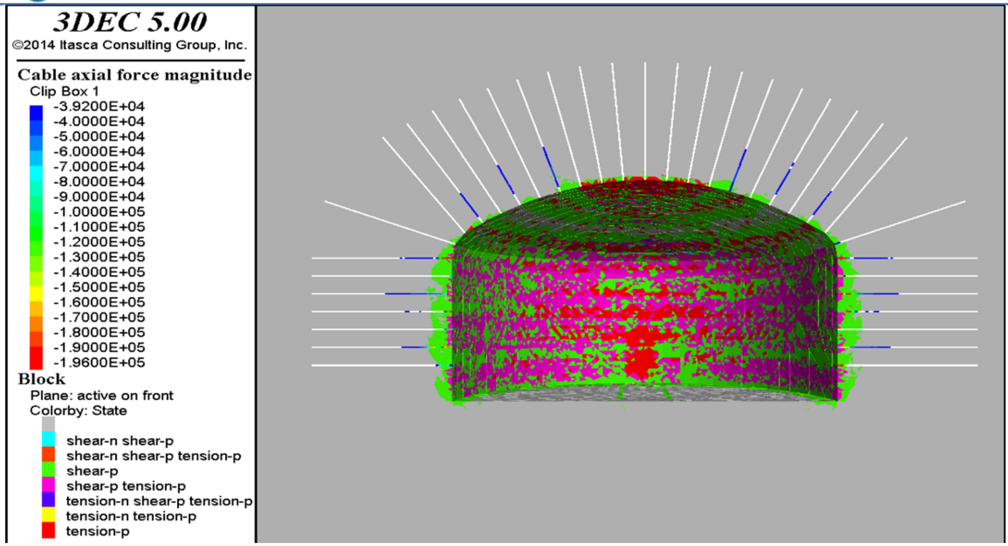


Maximum **absolute deformation 45mm** (for a 27 m span mailbox cavern (excl. creep)

Lowering cavern (bench excavation) increases deformation from 27mm to 45mm

Insufficient data to produce constitutive law
Summed up (lateral) creep strain 22.7mm (assumes no support pressure at boundary) over 10 years. More investigations planned.

PYHÄSALMI + HOMESTAKE
REINFORCEMENT ANALYSIS + DESIGN



Based on the stress induced damage extent, the bolt loading pattern and the block analyses, a bolting pattern with **bolt spacing of 2 meters** and alternating between **6 meter rebar anchor** bolts and **12 meter cable bolts** can be recommended at this stage for the dome and the walls. A number of the bolts should be equipped with strain gauges to verify the predicted behaviour.

Wiremesh is recommended over shotcrete **for immediate support** due to better load distribution and deformation properties. The final shotcrete should be fibre reinforced. The required shotcrete thickness varies, but based on the damage extend and the block analyses, a prediction of a final **shotcrete thickness of 100-200 mm** can be considered (C35/K45-1)

There is not yet a preliminary design for the 10kT & 24kT baseline design and so **quantities are basic extrapolations** from prior consultant-based designs, especially for calculation of the ground support. A pre-conceptual bolting pattern from a 34kT design is used developed by Golder Associates and extrapolated this to the 10kT & 24kT drifts and caverns.

The concrete and shotcrete quantities include concrete inverts and wall shotcrete for every drift and cavern including waste allowances. Mesh is the surface area of all drifts and caverns and does not account for overlap, therefore may be 25% more in reality.

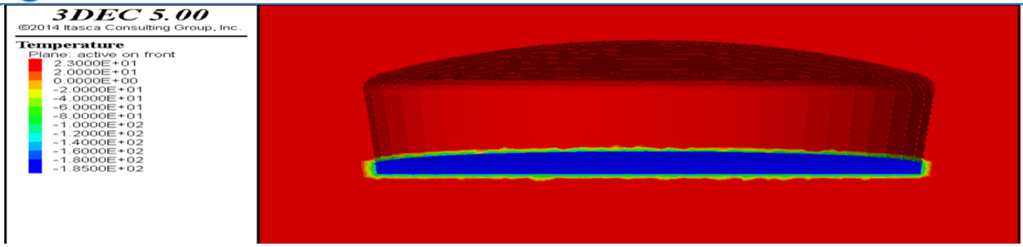
PYHÄSALMI + HOMESTAKE
BILL OF QUANTITIES

	Pyhäsalmi Pilot (2*2.5kT)	Circular 20kT+MIND or 50kT	SURF - SDSTA 10kT & 24kT
Excavation	87,750 m^3	286,707 m^3	146,403 m^3 Caverns 44,970 m^3 Access Drifts
Reinforcements			
Rock bolts	24,171 m	80,076 m	112,442 m Caverns (rigid & cable) 161,647 m Access Drifts (rigid only)
Fibre shotcrete	1,980 m^3	4,810 m^3	2,896 m^3 Caverns 8,384 m^3 Access Drifts
Wire mesh	7,393 m^2	20,541 m^2	20,562 m^2 Caverns 47,497 m^2 Access Drifts

There will be stress induced damages but they are in acceptable scale and can be managed with conventional reinforcement methods. Cavern and reinforcement behaviour should be monitored during and after excavation in several locations.

Note all LAr masses are fiducial masses.
- *2.4kT fiducial equals 4kT total mass*
- *10+24 kT fiducial equals 44kT total mass*
- *20kT circular fiducial equals 33kT total mass*
- *50kT circular fiducial equals 73kT total mass*

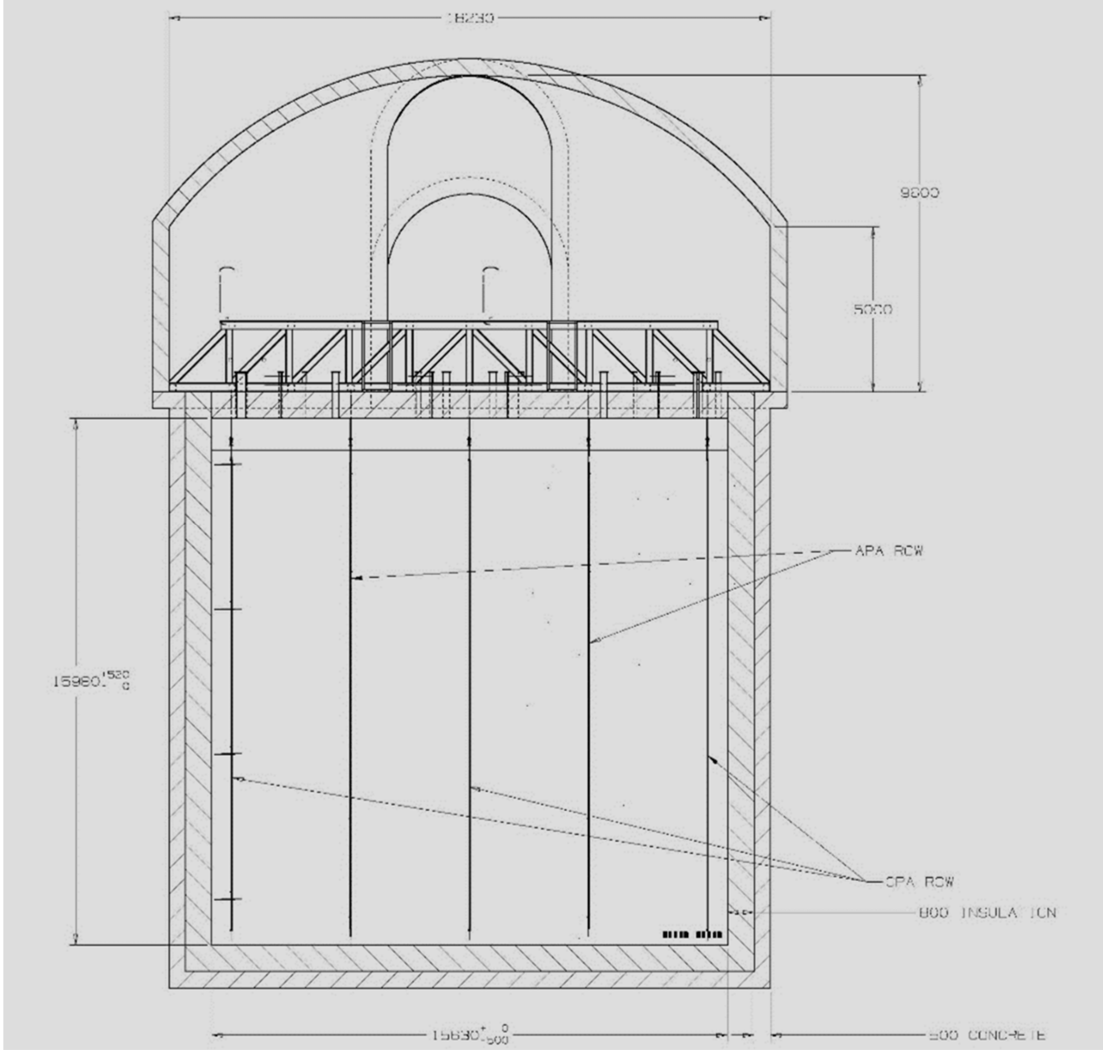
PYHÄSALMI + HOMESTAKE
LIQUID SPILL, RISK ASSESSMENT



The thermal impact of the argon leaks doesn't threat the overall stability of the cavern. The thermal impact will nevertheless severely damage the reinforcement structures and the rock at the cavern boundary. This will require more or less extensive maintenance work to be done to repair damaged reinforcement structures. Due to the existing structures and the big dimensions of the cavern, this will be technically very challenging.

For this reason it is recommended to make all the effort to prevent a scenario, where the whole cavern is exposed to very cold substances. Local exposure, especially at the bottom of the cavern can be handled more easily.

Additionally the cavern and tank construction should be disconnected to allow for ventilation, continuous and visual monitoring of leakages and direct measures in case any leakage is to happen (note. LAr spill starts at the cavern bottom) + rock wall surface inspections.



Risk of LAr leakage considered very low.

Cryogenic completely embedded in rock (saves excavation volumes)

Guido Nuijten

PYHÄSALMI + HOMESTAKE DYNAMIC ANALYSIS, RISK ASSESSMENT

ROCKPLAN

LAGUNA

Displacements created by the wave are less than one millimetre and are not sufficient to develop any perceptible change on the cavern surface, plastic areas, sprayed concrete or bolts. Without taking the damping into consideration, the biggest motion takes place on the northern part of the cavern minor axis with values of 4.4mm/s and 0.48m/s2.

With an assumed minimum distance of 100 meters between the existing caverns and new excavations, efficient excavation can be reached from blasting vibrations point of view. This requires that the boundaries of the existing caverns have been excavated carefully and all sensitive equipment have been separated from vibration sources or damped.

The modelled 2.5 magnitude earthquake does not have a significant effect to the cavern or the reinforcement structures. More detailed studies with various seismic sources and a larger scale of inputs is still recommended (esp. for hanging detector eigen state / eigen frequence)

4.0 CONCLUSIONS

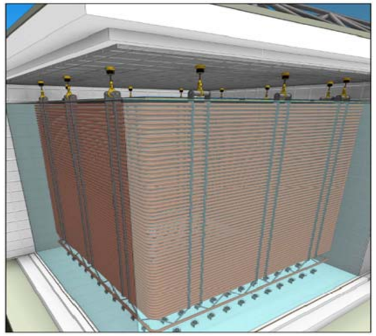
- The DUSEL site is located within the western part of the North American craton away from known areas of historic large earthquakes and active tectonic deformation with Quaternary-active faults and folds. Although the DUSEL site is located in a tectonically uplifted area, the regional geologic history of the initiation, growth and uplift of the Black Hills indicates that the area has probably remained tectonically stable over at least the Quaternary Era (about 2 million years) and probably for much longer.
- Historic earthquake activity within about 188 miles (300 km) of the DUSEL site is low. Of the 71 known epicenters with recorded magnitudes within about 188 miles (300 km) of the study area, there are only three (3) earthquakes of magnitude (M) 5.0 to M 5.5 in about the last 120 years. These larger earthquakes occurred in 1984 and are located about 100 to 156 miles (170 to 270 km) west of the DUSEL site in eastern Wyoming. Only 13 of the earthquakes with assigned magnitudes have epicenters located within 62 miles (100 km) of the DUSEL site. These local earthquakes are of low to moderate magnitude, and occur typically at shallow hypocentral depths (less than about 9 miles [15 km]).
- The five records of felt earthquakes in Lead, South Dakota since 1928 indicate that only infrequent, low intensity earthquake shaking has been experienced. Earthquakes generating these MMI are small (≤ M 4), shallow earthquakes less than 30 km from Lead, or moderate earthquakes (M 5 to 5.5) occurring at a great distance (≥ 200 km).
- Quaternary faults in northeastern Montana and central Wyoming show some evidence of surface fault rupture on several occasions during the last two million years (Quaternary). These faults are more than 500 km and 300 km from the DUSEL site, respectively. Ground shaking associated with any future earthquakes on these fault zones is likely to have a low intensity at the DUSEL site.
- The 2,475-year return period PGA and spectral accelerations at 0.2 seconds (S_S) and 1.0 seconds (S_1) used as the maximum considered earthquake in the 2009 IBC-ASCE 7-05

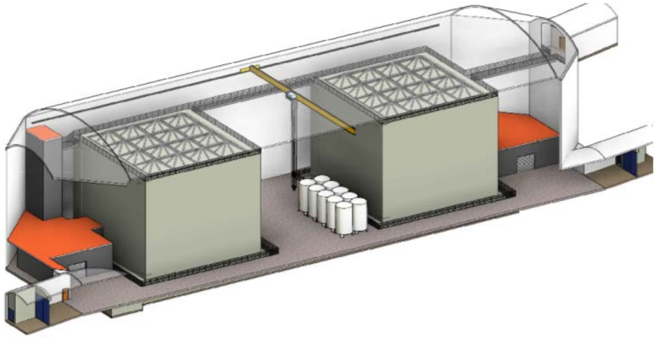
procedures are 0.160 g and 0.044 g, respectively at the DUSEL site. These spectral acceleration values are relatively low when compared to most other regions of the USA, and are similar to seismically inactive areas such as Florida and the Gulf of Mexico coast, and the Great Lakes regions.

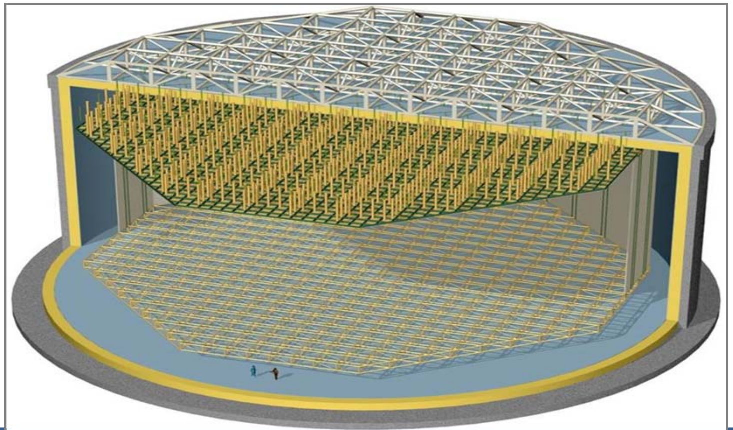
- The 2008 update of the USGS national seismic hazard model results in slightly lower S_S and S_1 values of 0.121 g and 0.037 g, respectively. These revised values could be applied as site-specific values for application of the procedures as set out in Chapter 21 of ASCE 7-05, and may result in a site-specific response spectrum slightly lower than that derived from non-site-specific 2009 IBC/ASCE 7-05 code procedures.
- The recent tectonic geologic history, historic seismicity and seismic hazard mapping are consistent with a relatively low seismic hazard at the DUSEL site.

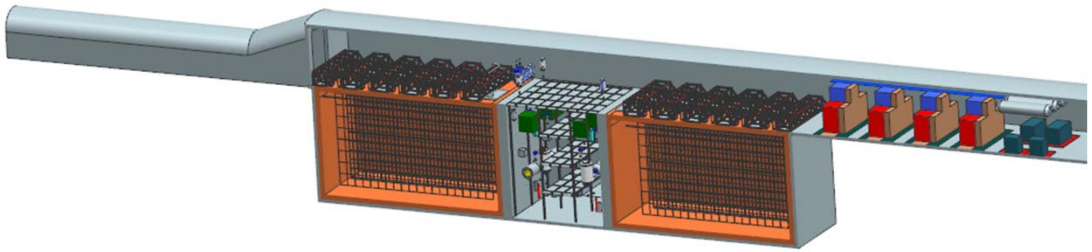
Conclusions = ***OK for both, but verification recommended for hanging detectors***

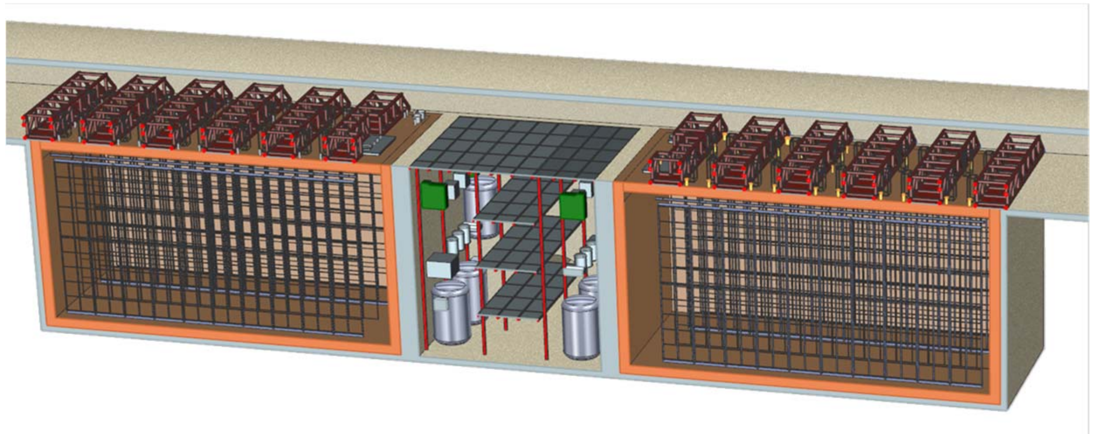
PYHÄSALMI + HOMESTAKE EXPERIMENT











Tank, Detector, Cryogenics, Clean Rooms etc. (Construction and Installation sequences) comparison not part of this engineering presentation

PYHÄSALMI + HOMESTAKE
STATUS OF DESIGN

ROCKPLAN

LAGUNA

First conceptual designs 2002…2007 + 6 years of Design Study (2008…2014): 17 M€

Technical Reports (8 Deliverables) 4,233 pages
Reports on extended Site Investigation and analysis 2,358 pages. ALL COMPLETED

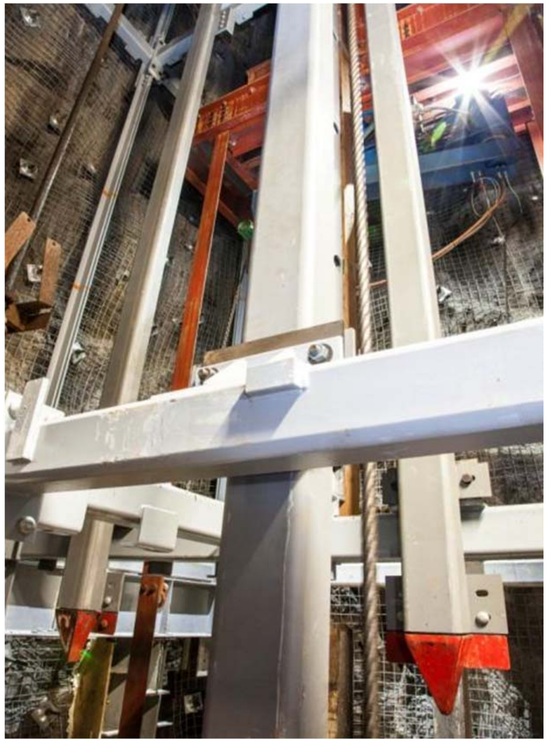
Near future: Overall general design + Final Layout + Infra Executive design
(cost estimate 4.7 M€)

Golder Associates DVS design (Sept. 2011) + the 4850L LAr design (Nov. 2011) developed as a pre-conceptual design of the initial 34kT LAr cavern on the 4850L. These documents + the then CM independent design and cost estimate provided guidance for the current 10kT & 24kT LAr design

Near future: Conceptual design beyond CD-1, Preliminary design and Final Design
(cost estimate 33M$ = 26 M€)

Guido Nuijten

PYHÄSALMI + HOMESTAKE
PREPARATION WORKS AND COSTS



No preparations needed
Work can start tomorrow (technically)
.

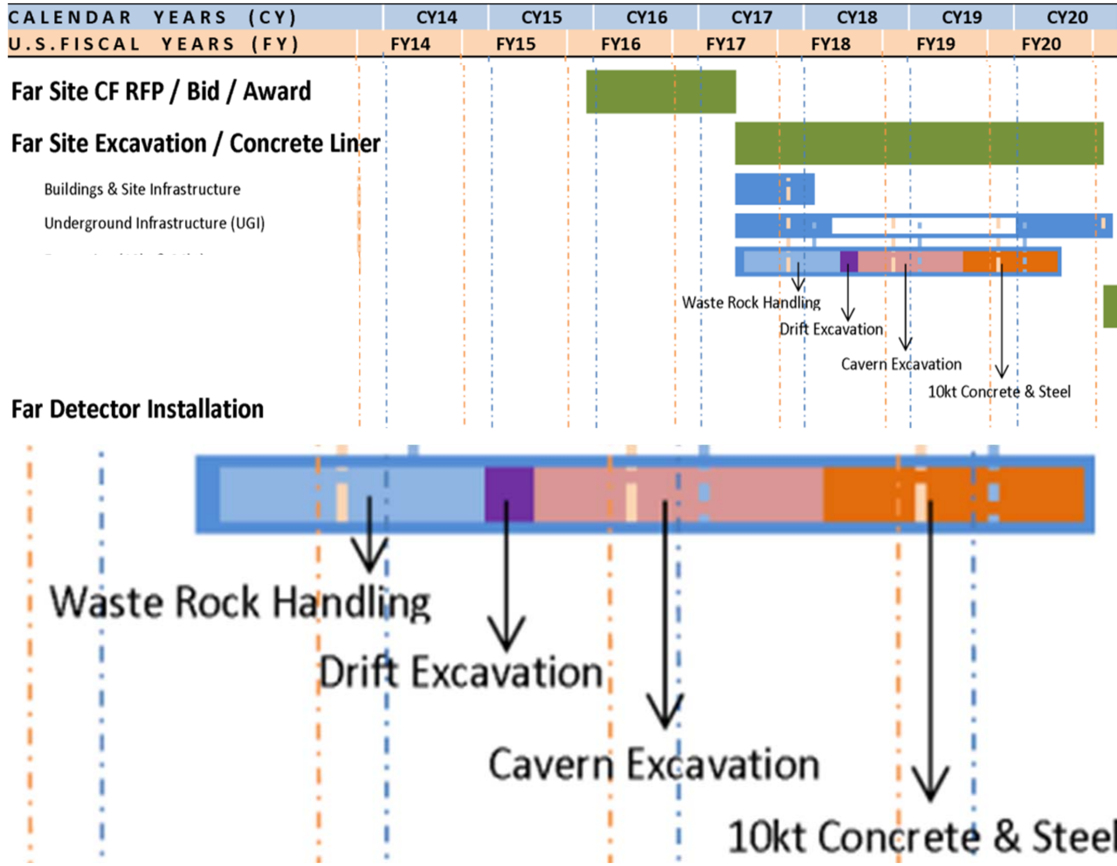
Refurbishment of shaft (~35% complete)
Costs $25.5M (to date)
Due to be finished in 2017 (critical path)

Guido Nuijten

PYHÄSALMI + HOMESTAKE
INFRASTRUCTURE CONSTRUCTION PROGRAMME

WA105 · Lagvna · ROCKPLAN

LAGUNA-LBNO, LAr 20kT @ PYHÄSALMI	year 1				year 2				year 3				year 4				year 5				year 6			
INFRASTRUCTURE REALISATION																								
-enabling works at site	X	X	X																					
-auxiliary infrastructure excavation			X	X	X	X	X																	
-shaft infrastructure raises				X	X	X	X	X	X	X	X	X	X	X										
-main detector cavern no. 1 excavation				X	X	X	X	X	X	X	X													
-civil works (floors, HVAC, etc.)			X	X								X	X											
20KT LAR TANK CONSTRUCTION																								
-mobilisation + preparation													X	X										
-20kT tank + hydrotest														X	X	X	X	X						
-20kT deck (incl. off site fabrication)														X	X	X	X	X	X	X	X			
-20kT membrane liner + test																						X	X	X



5 years reserved for infrastructure + tank (excl. membrane) realisation of which

3 years reserved for infrastructure excavation of which

excavation + reinforcement of the Main Detector Cavern take 2 years

Clarification on programme (Jim Strait):

The cavern excavation and installation of the concrete liner and infrastructure is 3 years.

The tank installation is an additional 1.5 years.

ROCKPLAN

PYHÄSALMI + HOMESTAKE
COSTS REFERENCES (not for 1:1 comparison)

The New Mine in Pyhäsalmi Mine is developed between 1998 and 2001. It considered the extension of the Mine from the 1050 level down to the 1430 level. Part of this development was the construction of a new shaft as well extension of the decline (road tunnel) from the 1100 level down at a 1:7 steepness. The works contained:

•decline and drifting (size 5x5 m2)	8,400 m
•shaft sinking (raising method)	1,400 m
•raise boring	5,000 m
•total excavation	250,000 m^3
•cemented rebar bolts	70,000 pcs
•shotcrete	15,000 m^3
•steel structures	870,000 kg

COST BREAKDOWN at the Pyhäsalmi Mine.

decline and research drifts	*3 M€*
shaft	*8 M€*
hoisting sinking	*8 M€*
crusher and ore passes	*5 M€*
ore bins and conveyors	*5 M€*
ventilation	*5 M€*
other infrastructure	*9 M€*
underground mobile equipment	*7 M€*
other expenses	*2 M€*
miscellaneous	*2 M€*
Total costs	***54 M€***

South Dakota as a state has invested over $130M to the facility and current experiments.

Expenses breakdown (situation 28.10.2014)

General facility infrastructure improvements	$60.3M
Ross Shaft rehabilitation (to date)	$25.5M
Davis Campus construction	$16.5M
Reserved funds for liability management	$11.5M
Education and Outreach facilities	$10.2M
Experiment construction and experiment facilities	$ 6.0M

$130M ~ 103M€

ROCKPLAN

LAGUNA

PYHÄSALMI + HOMESTAKE
INFRASTRUCTURE COSTS (SITE PREPARATION)

Excavation underground infrastructure	**38.7 M€**
Project Management costs, Legal Fees etc.	5.2 M€
Overall general design + Final Layout	2.5 M€
Executive rock engineering design	1.7 M€
Additional site investigations (mainly for shaft)	0.9 M€
MDC Cavern and U/G infra Excavation costs	11.7 M€
MDC Cavern and U/G infra Reinforcement costs	9.0 M€
Shaft infrastructure realization costs (raise bore)	7.7 M€

Civil Works construction U/G infra.	**9.4 M€**
Project Management costs, Legal Fees etc.	1.2 M€
Executive civil works design	0.5 M€
Enabling Works (HVAC etc.)	3.3 M€
Auxiliary Room Constructions	4.1 M€
Tank deck accesses	0.3 M€

Contingency *(15.3% of total)*	**8.7 M€**
Contingency costs for a 20kT excavation works	5.2 M€
Contingency costs for shaft infrastructure	1.2 M€
Contingency costs for civil works	2.3 M€

TOTAL EXCAVATION + CIVIL WORKS 57 M€

For hoisting a 20kT LAr detector + possible MIND

or hoisting a 50kT LAr detector

Excavation underground infrastructure	**248 M$**
Project Management and concept through CD1	4 M$
Conceptual design beyond CD-1	5 M$
Preliminary design	9 M$
Final Design	19 M$
Construction Management	30 M$
MDC Cavern and U/G infra Reinforcement costs	230 M$

Site infra, buildings, U/G infrastructure 42 M$

Contingency *(10.5% of total)* **34 M$**

TOTAL CONVENTIONAL FACILITIES 324 M$

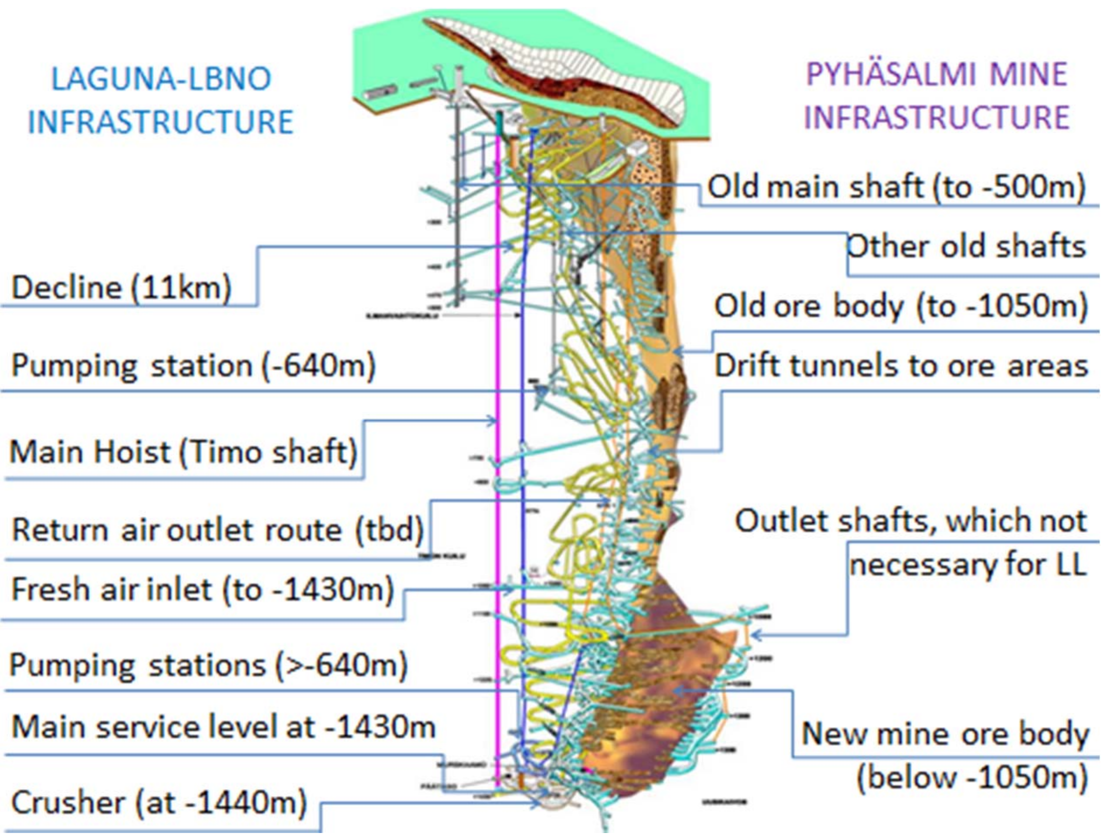
For hoisting a 10+24kT LAr detector

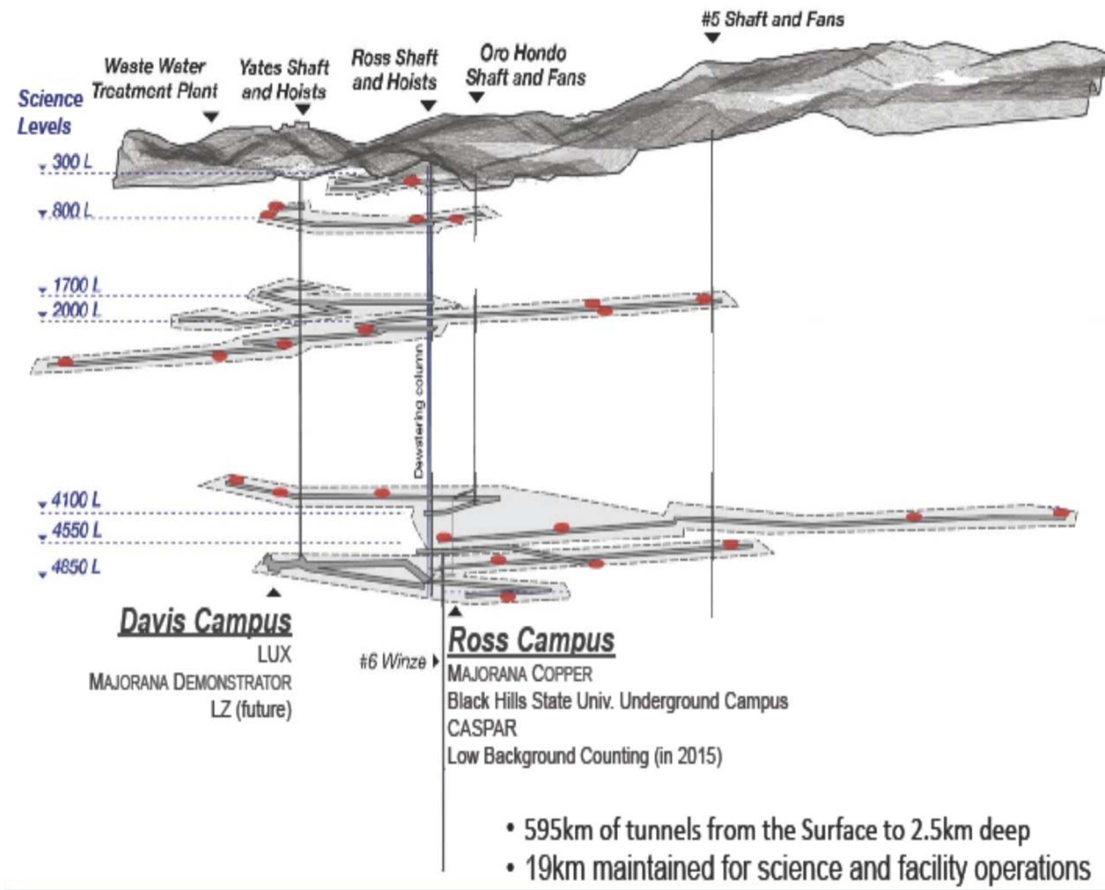
1 US$ = 0.789 € (25.10.2014)

TOTAL CONVENTIONAL FACILITIES 256 M€

For hoisting a 10+24kT LAr detector

PYHÄSALMI + HOMESTAKE MINE TRANSFER ISSUES





Real Estate Company established (Oct. 2014)

Company responsible for transferring Mine into U/G Research Infrastructure

Only parts needed for LBNO rented from Real Estate Company

Already hosting Emma + 14C/12C experiment

Complete Mine part of Homestake Sanford Underground Research Laboratory (SDSTA)

Already hosting:

- LUX anatomy experiment
- MJD Majorana demonstrator

and coming CASPAR, CUBED + BLBF experiments

PYHÄSALMI + HOMESTAKE OPERATIONAL COSTS

Operation subject	4) Operational of science
Decline operation and maintenance	100 000,00 €
Main hoist (operational costs) incl. crusher	400 000,00 €
Water pumping and operational costs	200 000,00 €
Ventilation arrangements and operational costs	100 000,00 €
Main service level (-1400m) maintenance and operation	70 000,00 €
Other operational costs (social spaces, ITC, electricity, rail yard)	320 000,00 €
Rock mechanical monitoring and analyzing costs	55 000,00 €
TOTAL OPERATIONAL COSTS	**1 245 000,00 €**

TOTAL OPERATIONAL COSTS (estimate) 1.25M€

Excavation underground infrastructure 3.4 M$

Lab. Management	659 k$
Business services	105 k$
EHS	1,360 k$
Engineering	815 k$
Science support	473 k$

Infrastructure preservation 3.5 M$

Dewatering activities 3.7 M$

Early Science 2.8 M$

TOTAL CONVENTIONAL FACILITIES 13.4 M$

1 US$ = 0.789 € (25.10.2014)

TOTAL OPERATIONAL COSTS (FY2014) 10.6M€

PYHÄSALMI + HOMESTAKE
COURTESY & THANKS

Kimmo Luukkonen – Pyhäsalmi Mine
Jesse Ström – Rockplan
Juha Salmelainen – Rockplan
Sergio Cristía Abad – Rockplan
Gustav Westerlund – Rockplan
Petteri Somervuori – WSP
Matti Hakala – SMC

David Vardiman – SDSTA
Joshua White – SDSTA
Mike Headley – SDSTA
Seth Polak – ARUP
John Powell – ARUP
Tracy Lundin – FNAL
Kevin Lesko – LBNL

PYHÄSALMI + HOMESTAKE CONCLUSIONS

ROCKPLAN

LAGUNA

Aug. 31st conclusions of EC FP7 LL DS:

After several years of R&D and very detailed EC funded studies (a total of around 17M€ investment), there is a clear end-to-end path solution for LBNO, a liquid argon LAr TPC based experiment at Pyhäsalmi.

A full Conceptual Design Report is available, developed in collaboration with Industrial Partners illustrating the underground facility, construction sequences and programmes, well defined costs, extensively evaluated and quantified risks and contingency for deployment within Europe.

Oct. 20th 2014 conclusions to iiEB:

We could not find any indications that LAr detectors of either LBNE or LBNO styles (or a combination of the two) could not be constructed at SURF with a sufficiently large investment.

However, further studies are required to support this statement, in particular in view of a timely and affordable realization of LBNF.

For LBNO-type, the feasibility and cost of larger-span caverns must be assessed.

Guido Nuijten

Back-up slides

(the personal opinion of the author only)

PYHÄSALMI CONCLUSIONS

GOOD, NEUTRAL, CHALLENGING or PROBLEMATIC

ROCKPLAN

LAGUNA

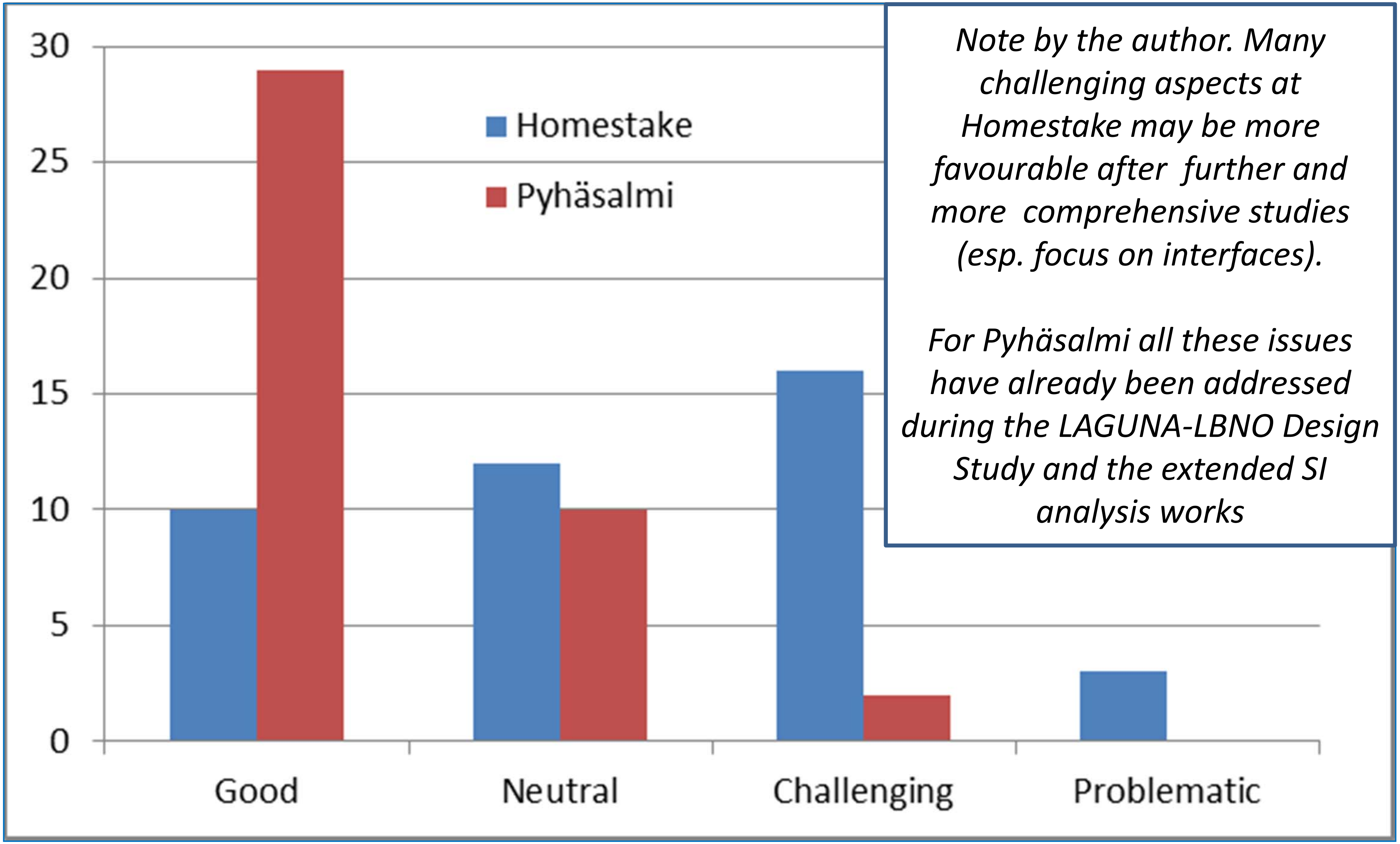
1. Global deep science lab caverns and facilities
2. Site Location
3. Mine introductions
4. On-surface access
5. Existing infrastructure at experiment level
6. Horizontal drifts / accesses
7. Decline
8. Ventilation
9. Dewatering / drainage
10. Hoist
11. Shaft reinforcement / lining
12. (Hoist) Control room
13. Rock hoisting capacity
14. Rock waste handling on surface
15. Material transport
16. Concrete (material) transport capacity
17. Global / continental geology
18. Regional geology
19. District geology
20. Site seismicity
21. Hydrology at -1400m
22. Site Investigations
23. Intact rock strength
24. Rock stresses
25. Rock Quality Designation (RQD)
26. Rock fracturing / joint orientation
27. Optimum cavern shape
28. Max. cavern size
29. Deformation / long term rock behaviour
30. Reinforcements analysis + design
31. Bill of Quantities
32. Liquid spill / risk assessment
33. Dynamic analysis / risk assessment
34. Experiment (not addressed)
35. Status of design
36. Preparation works and costs
37. Infrastructure construction programme
38. Cost references
39. Infrastructure costs (site preparation)
40. Mine transfer issues
41. Operational costs

HOMESTAKE CONCLUSIONS

GOOD, NEUTRAL, CHALLENGING or PROBLEMATIC

1. Global deep science lab caverns and facilities
2. Site Location
3. Mine introductions
4. On-surface access
5. Existing infrastructure at experiment level
6. Horizontal drifts / accesses
7. Decline (not present)
8. Ventilation
9. Dewatering / drainage
10. Hoist, when refurbished
11. Shaft reinforcement / lining
12. (Hoist) Control room
13. Rock hoisting capacity
14. Rock waste handling on surface
15. Material transport
16. Concrete (material) transport capacity
17. Global / continental geology
18. Regional geology
19. District geology
20. Site seismicity
21. Hydrology at -4850ft
22. Site Investigations
23. Intact rock strength
24. Rock stresses
25. Rock Quality Designation (RQD)
26. Rock fracturing / joint orientation
27. Optimum cavern shape
28. Max. cavern size
29. Deformation / long term rock behaviour
30. Reinforcements analysis + design
31. Bill of Quantities
32. Liquid spill / risk assessment
33. Dynamic analysis / risk assessment
34. Experiment (not addressed)
35. Status of design
36. Preparation works and costs
37. Infrastructure construction programme (??)
38. Cost references
39. Infrastructure costs (site preparation)
40. Mine transfer issues
41. Operational costs

PYHÄSALMI + HOMESTAKE
AUTHOR'S CONCLUSIONS SUMMARY



Note by the author. Many challenging aspects at Homestake may be more favourable after further and more comprehensive studies (esp. focus on interfaces).

For Pyhäsalmi all these issues have already been addressed during the LAGUNA-LBNO Design Study and the extended SI analysis works

Guido Nuijten