MITSUI
KINZOKU

Study on the Excavation of the Hyper-KAMIOKANDE Cavern at Kamioka Mine in Japan

Hiroshi Kurokawa

Mitsui Mining & Smelting Co., Ltd. (MITSUI KINZOKU), Tokyo, Japan

Kamioka Mining & Smelting Co., Ltd. (Kamioka Mine)
is a wholly owned subsidiary of MITSUI KINZOKU.

ANT-11 Philadelphia, USA 10-12 October 2011

MITSUI
KINZOKU

Topics

- Brief Introduction of Kamioka Mine

- Geological Investigation and Conceptual Study on the Excavation of the Megaton Size Hyper-KAMIOKANDE Cavern at Kamioka Mine

Kamioka Mine Location in Japan

MITSUI
KINZOKU

Kamioka Mine Main Office

Kamioka Smelting Plant

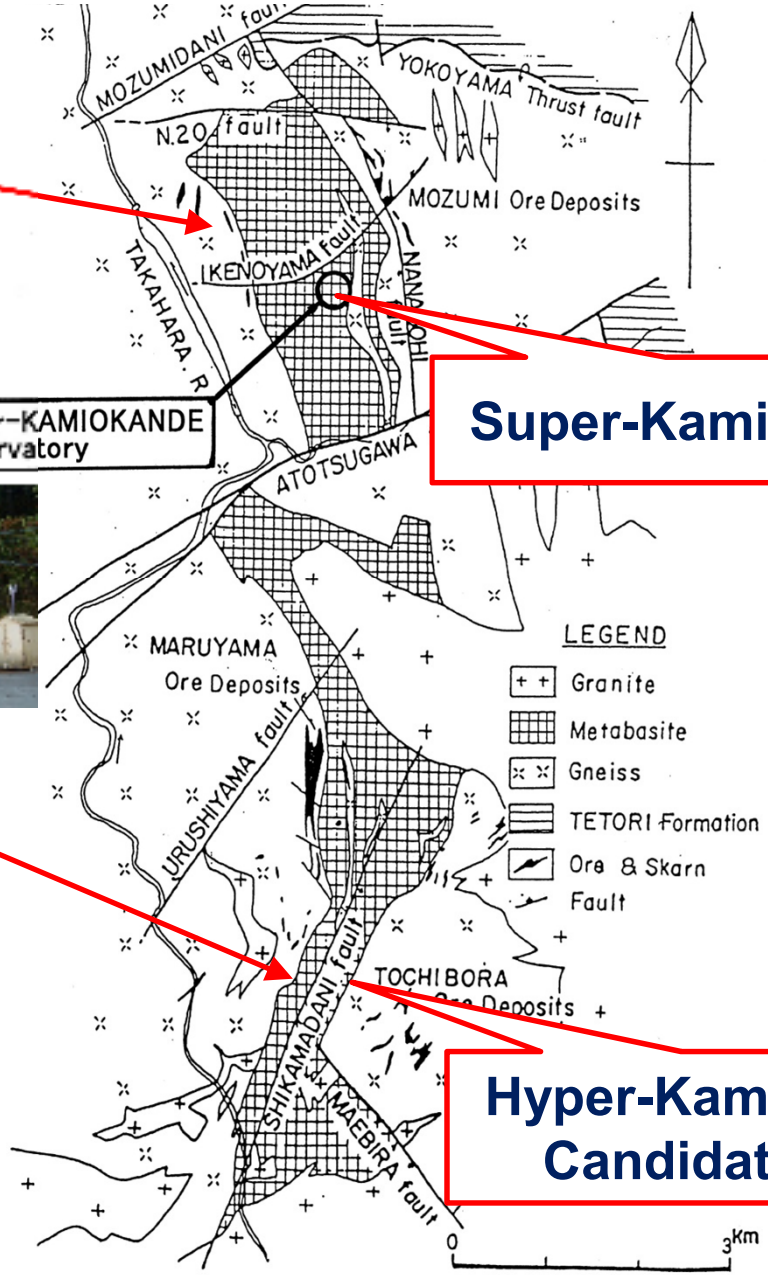
Geological Map of Kamioka Mine

MITSUI KINZOKU

MOZUMI Mine

Atotsu Entrance to Super-K

TOCHIBORA Mine



Super-Kamiokande

Hyper-Kamiokande Candidate Site

Kamioka Pb-Zn-Ag Smelting Plant - Product Line Up -

MITSUI KINZOKU

Zn Smelter

: Zn Conc. Supplied from Overseas Mines

99.99% Zn

Pb Recycling Smelter: Scraps of

- Pb Batteries
- Electronics Devices

99.99% Pb

Hydroelectric Power Generator

: Operated & Owned by Kamioka Mine, attaining Very Low Energy Cost in Smelting & Manufacturing

Precious Metals & Ag Refinery

: Post Process of Pb Recycling Smelter

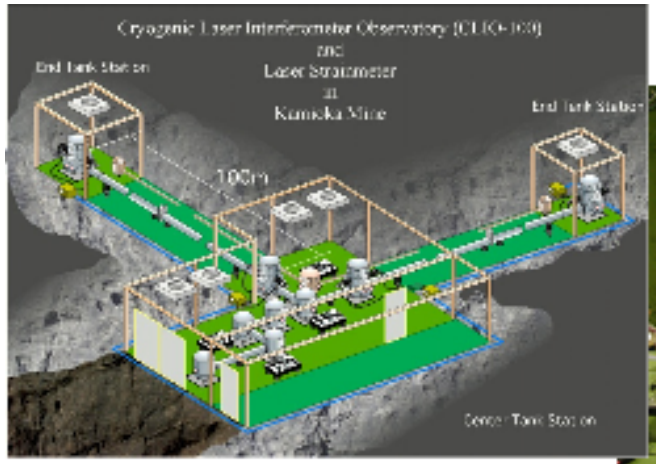
Underground Space Utilization Business at Kamioka Mine

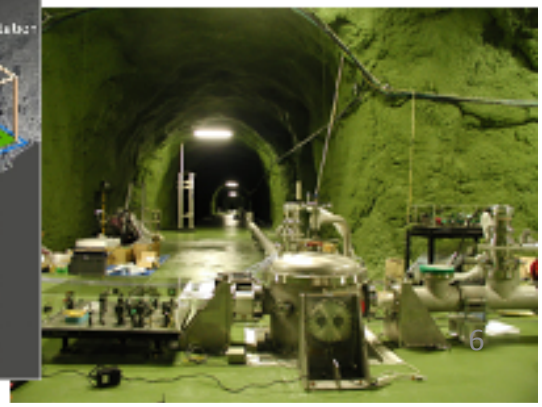
MITSUI KINZOKU

Super-KAMIOKANDE Observatory
(Photo by the Courtesy of ICRR, U-Tokyo)

KAMLAND Observatory
(Photo by the Courtesy of Tohoku Univ.)

Gravitational Wave Observatory
(Photo by the Courtesy of ICRR, U-Tokyo)

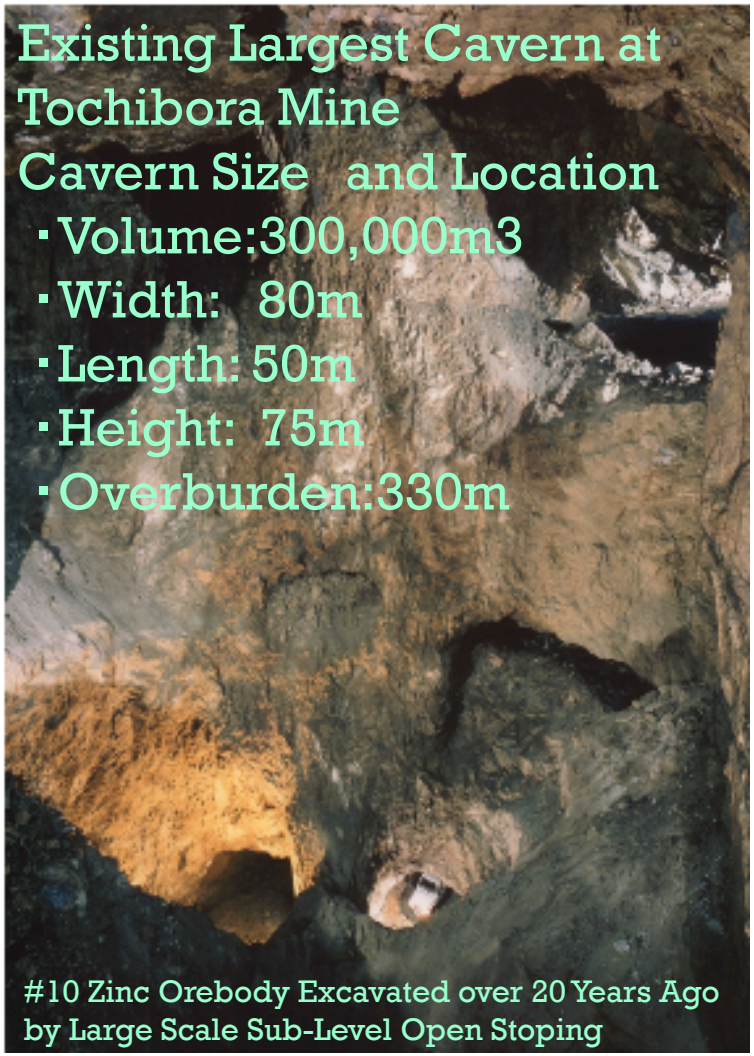




Advantage of Kamioka Mine for Underground Space Utilization

MITSUI KINZOKU

Strong Rock Mass Condition



Various Mining Infrastructures

Geological Investigation and Conceptual Study on the Excavation of the Hyper-KAMIOKANDE Cavern at Tochibora Mine

Former Study of Hyper-K Cavern Construction

Preliminary geological survey and site evaluation had been done from 2002 to October, 2010 at Mozumi & Tochibora mine

History of Geological Survey

Mozumi Mine;

-500mL	Tunnel (130m)	: Geological mapping, Rock class classification (2002)
	Core drill (100m x 2holes)	: Core Logging, Rock class classification (2002)

Tochibora Mine;

-300mL	Core drill (250m x 1hole)	: Core Logging, Rock class classification (2003)
(SL:551m)		: Discontinuity survey by TV camera (2007)
		: Borehole loading tests (2008)
	Core drill (18m x 2holes)	: In-situ stress measurement (2010)
-430mL	Tunnel (500m)	:Geological mapping, Rock class classification (2010)
(SL:424m)		

Result of preliminary site evaluation is that Tochibora mine, in SL:480m~+SL:550m is appropriate location for candidate site with very competent rock mass condition.

Request of the Conceptual Study of Hyper-K Cavern Construction at Tochibora Mine from ICRR

- **Megaton size cavern**, approx. 20 times larger than Super-K cavern
- More than **500 m of overburden**

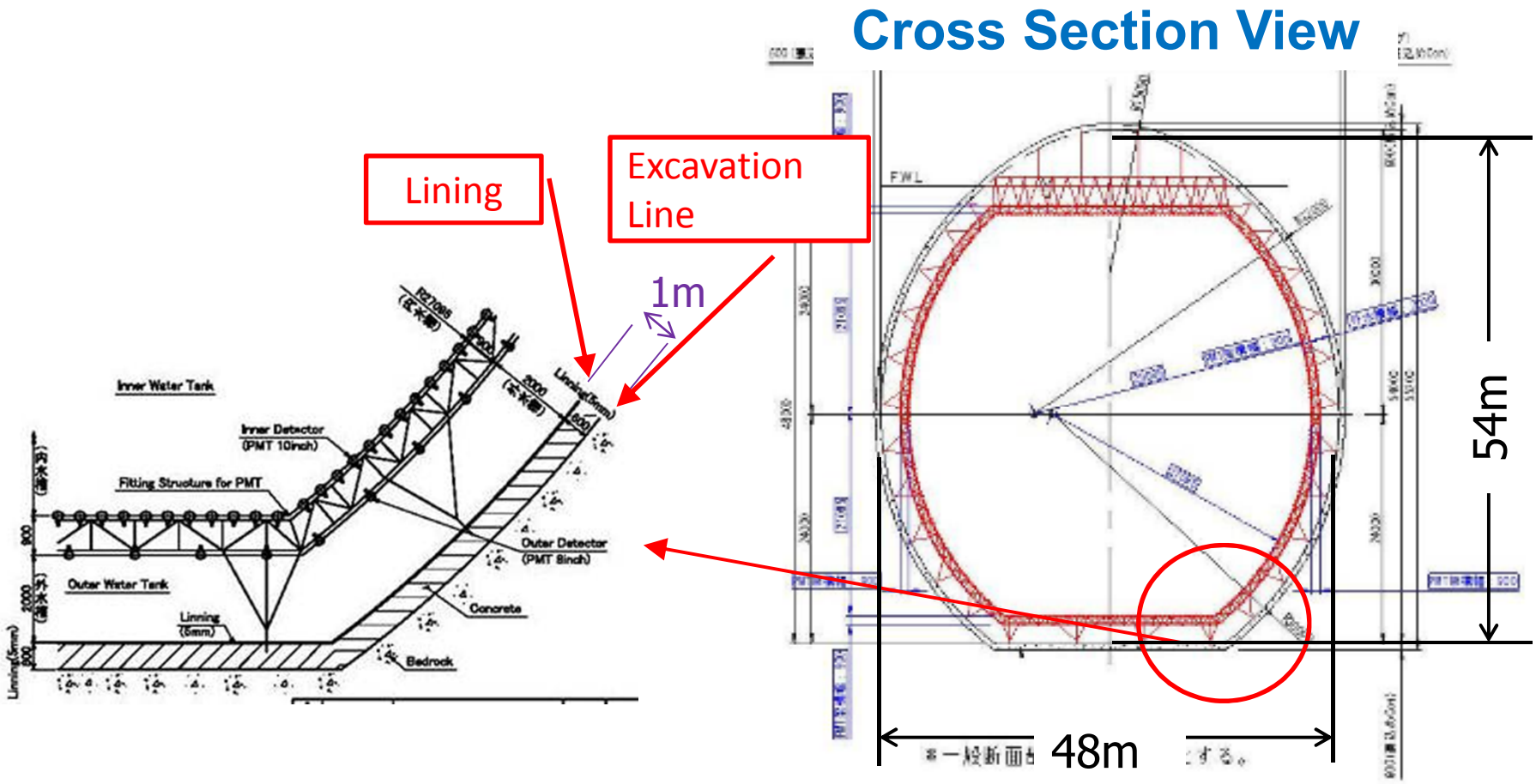
1. Geological survey in the candidate site.
2. Optimum design and layout of the cavern and auxiliary tunnel
3. Engineering of the cavern construction including rock stability analysis, rock support design & construction method

Mitsui mineral development engineering Co., Ltd.(Consulting company) carried out this study from October 2010 to June 2011.

Shape of Hyper-KAMIOKANDE Cavern

Shape of the Hyper-K Tank after Lining

- ➢Cavern Type: Horizontal Tunnel (250m length x 2 caverns in parallel)
- ➢Cross Section Shape: Oval Egg Shaped (48m width and 54m high)



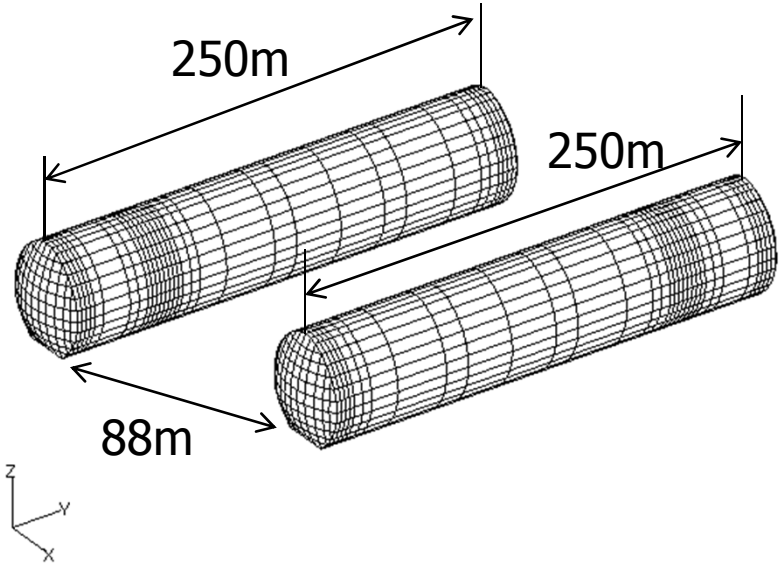
2,077m2

Shape of Hyper-KAMIOKANDE Cavern

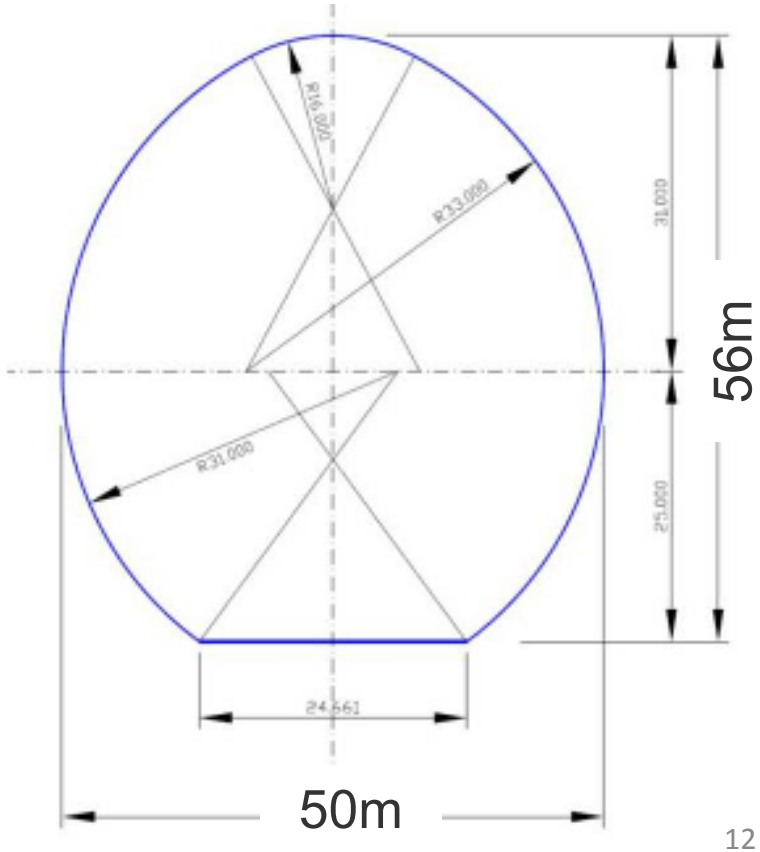
Shape of Cavern for Extraction Design (Excavation Line)

- ➢Cavern Type: Horizontal Tunnel (250m length x 2 caverns in parallel)
- ➢Cross Section Shape: Oval Egg Shaped (50m width and 56m high)
- ➢End Shape: Rounded End

3D View

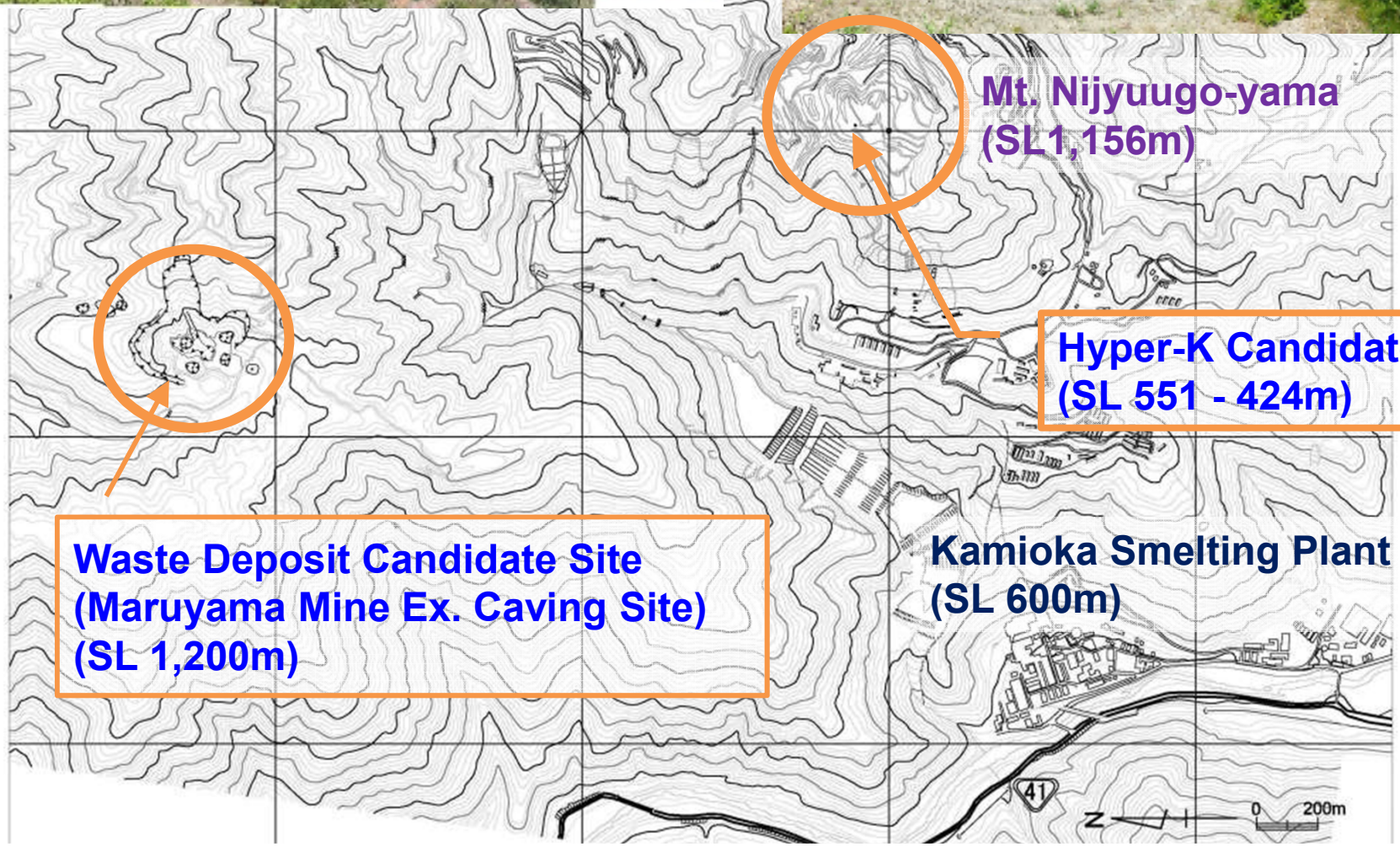


Cross Section View



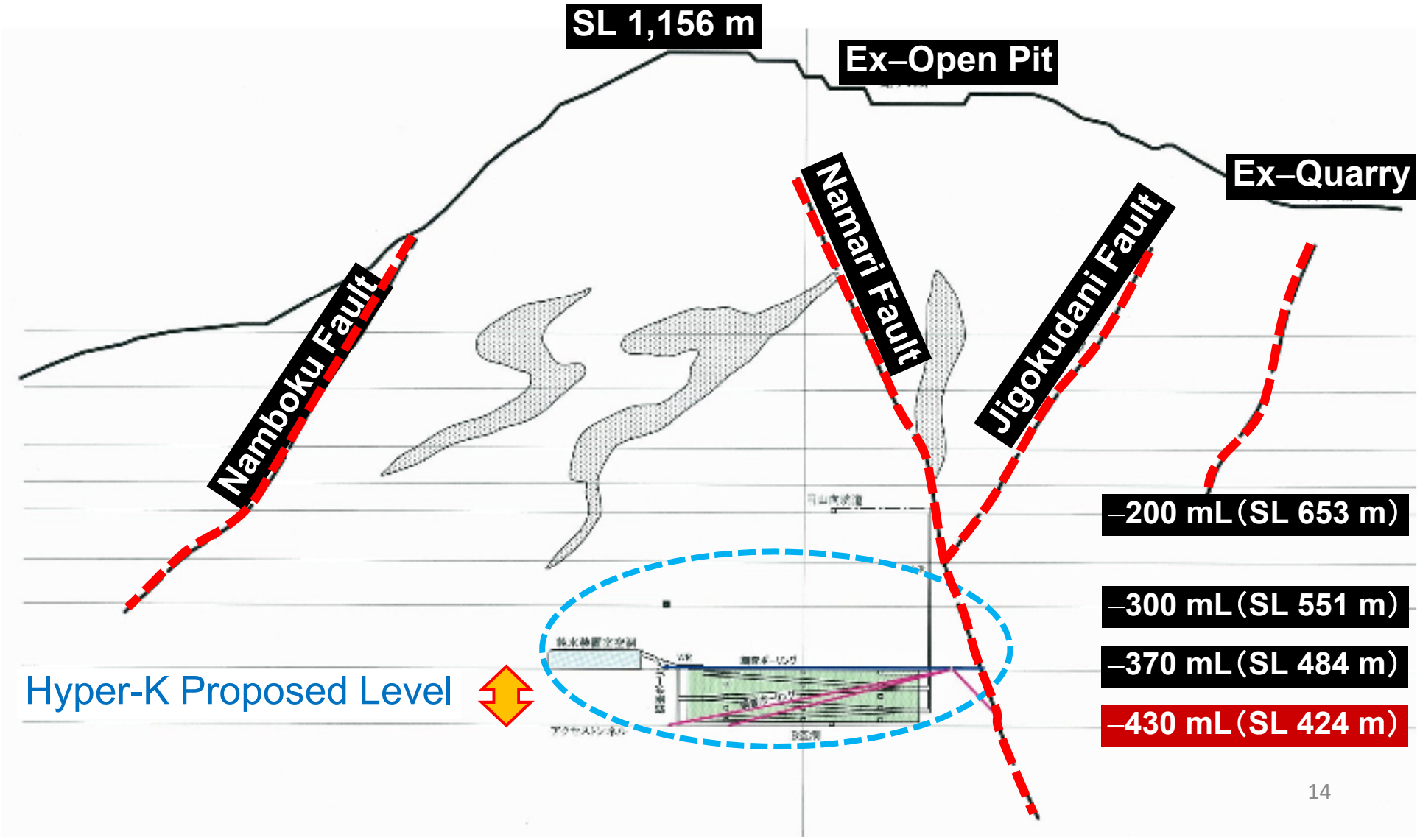
Total 1.2 Mm3

Candidate Site of Hyper-K at Tochibora Mine



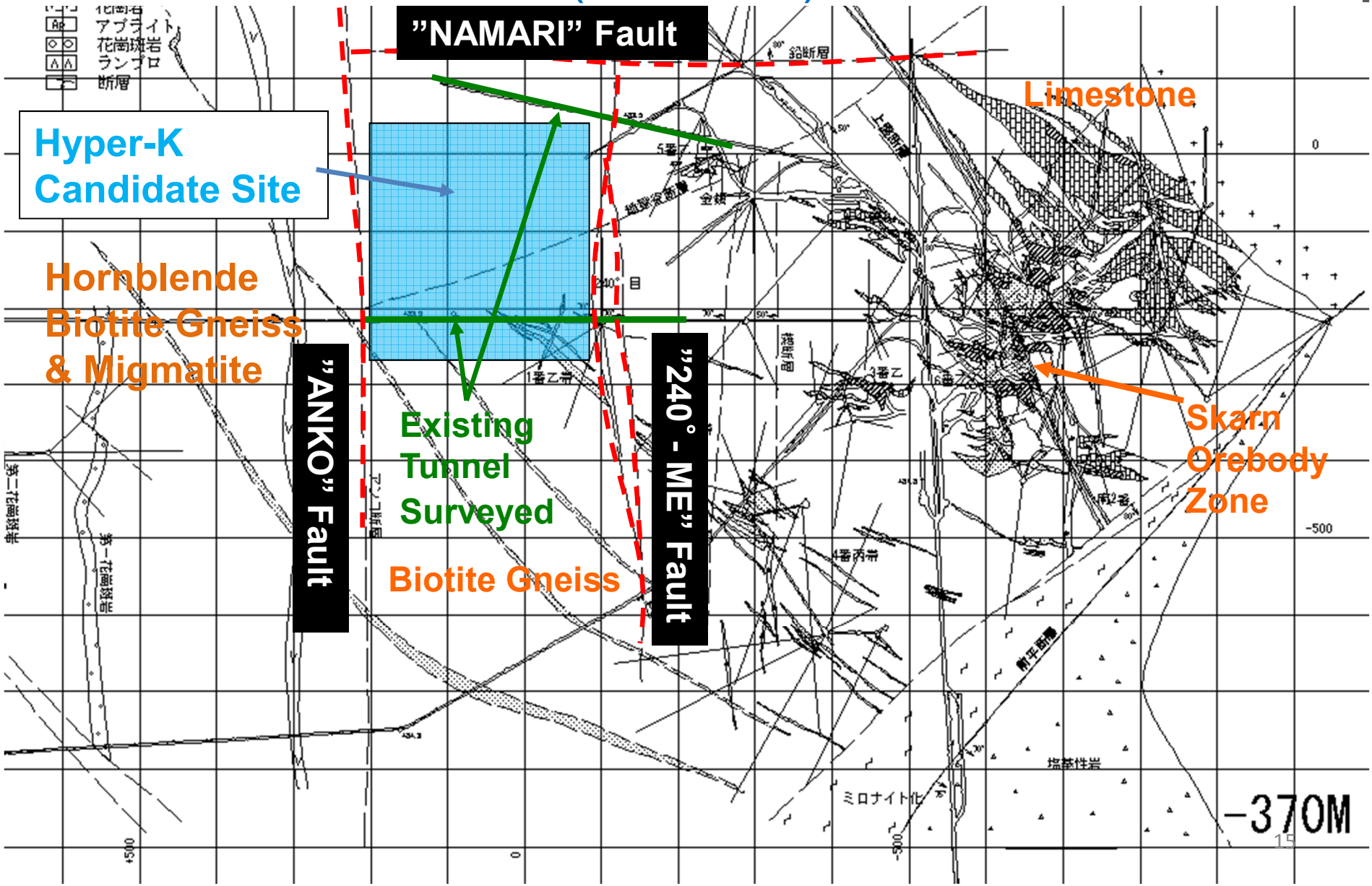
Candidate Site of Hyper-K at Tochibora Mine

The main drainage level of Tochibora Mine (–430 mL) limits the available rock mass thickness to 500～700 m.



Geological Map of Candidate Site at Tochibora mine

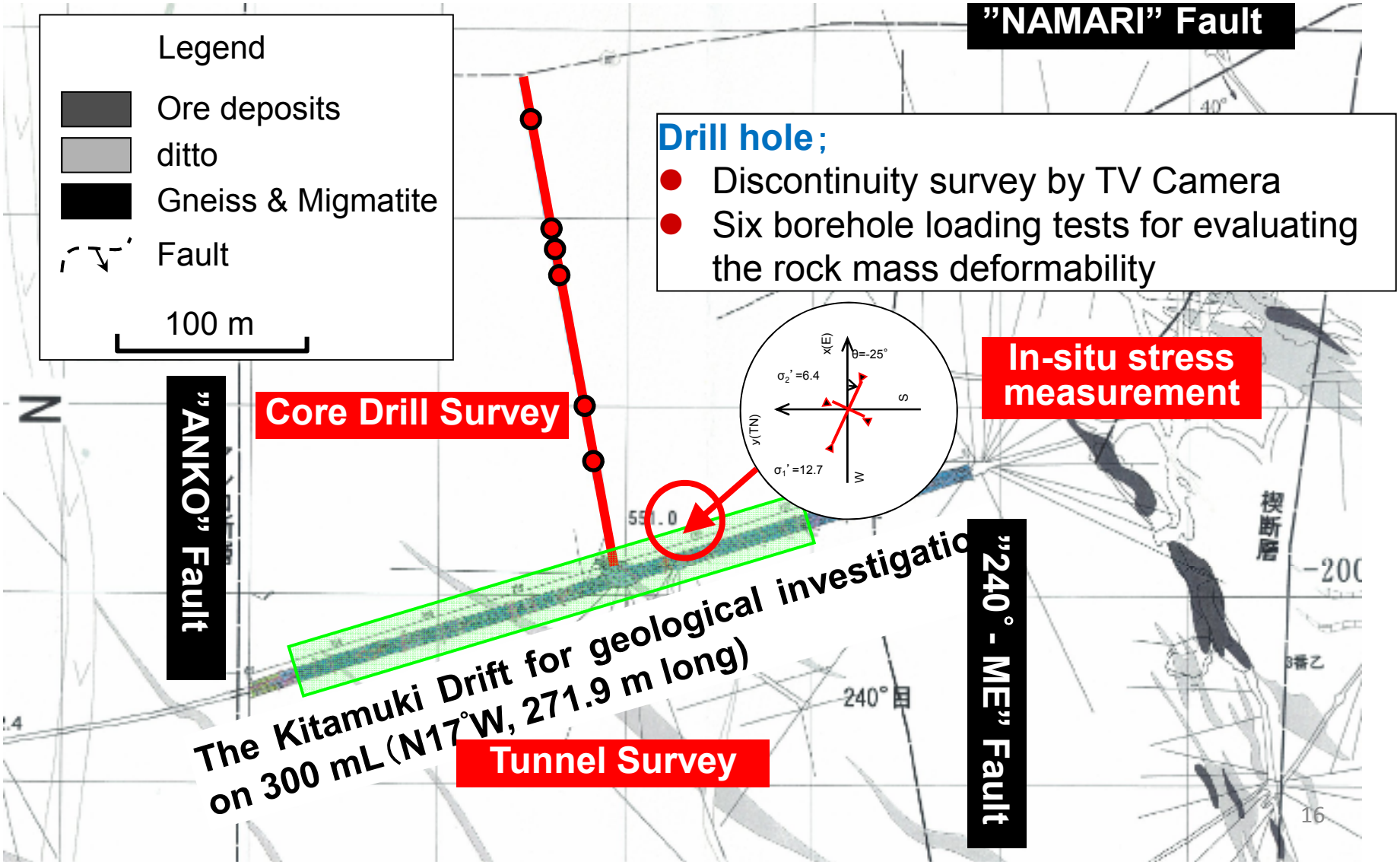
Plan View of -370mL (SL:484m)



Geological Survey in 2003-2010

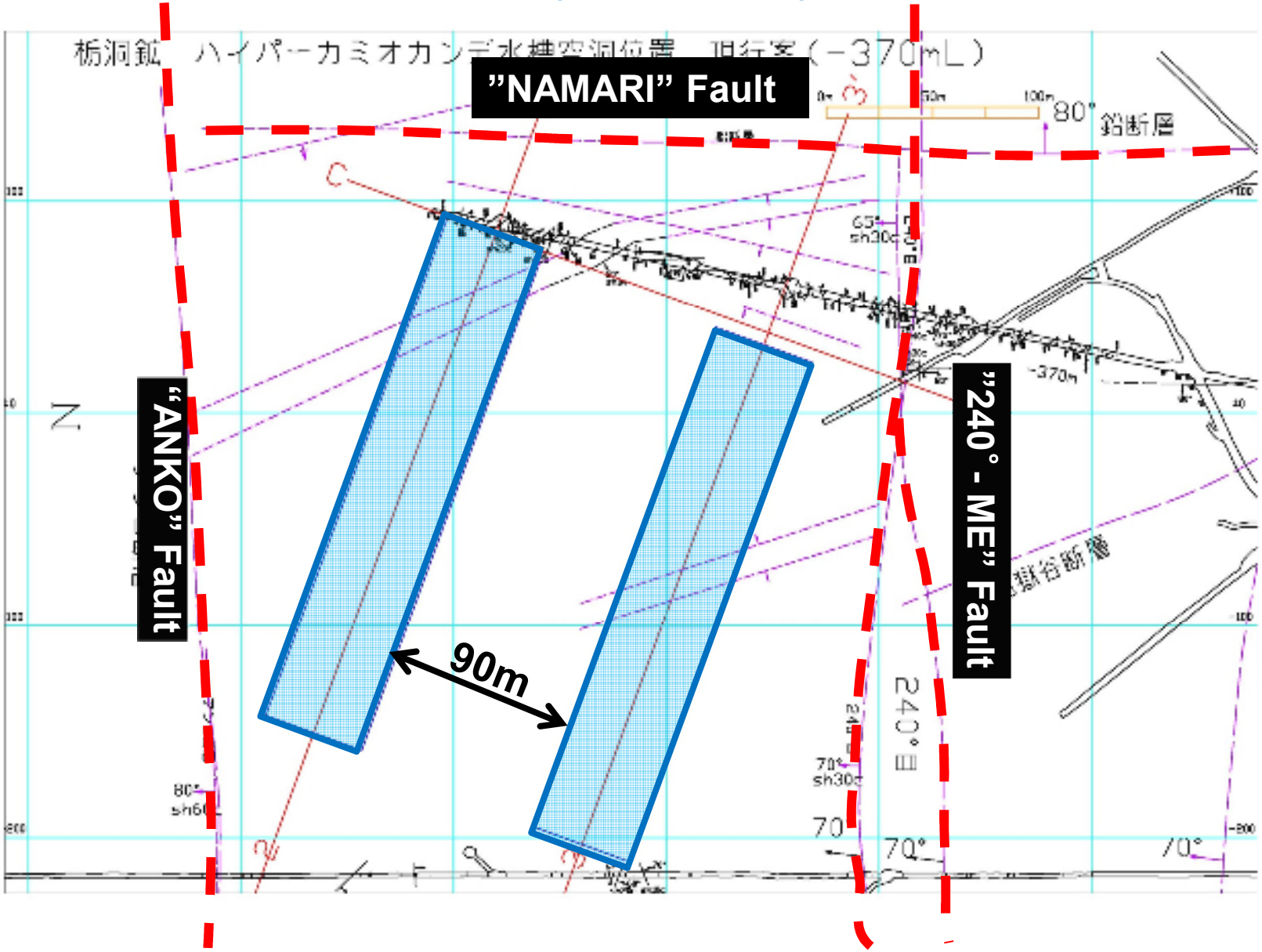
Plan View of -300mL (SL 551m)

➢ Very competent rock mass condition



Preliminary Layout of Hyper-K

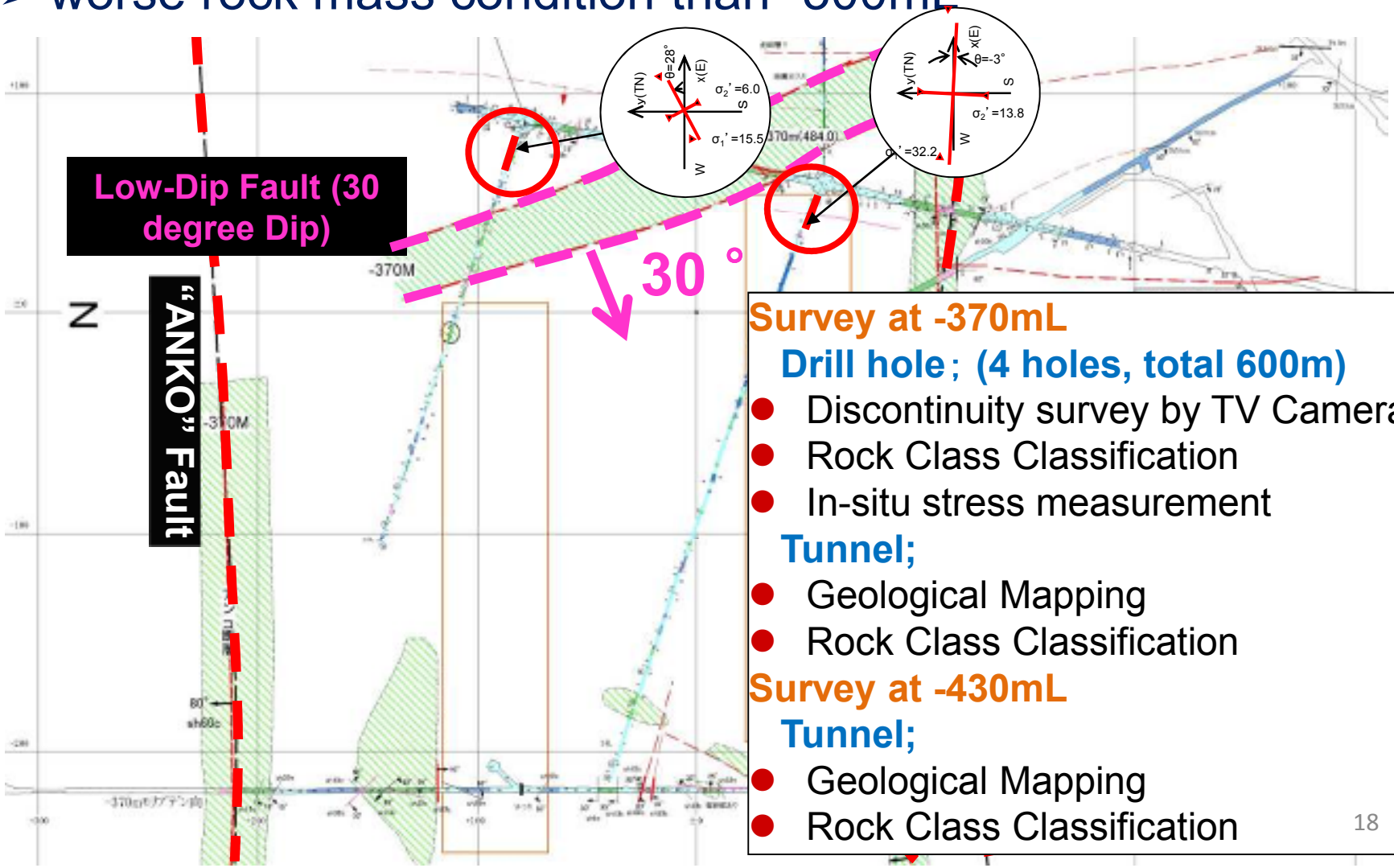
Plan View of -370mL (SL 484m)



Geological Survey in 2010-2011

Plan View of -370mL (SL 484m)

- ➢New fault was found
- ➢worse rock mass condition than -300mL



Survey at -370mL

Drill hole; (4 holes, total 600m)

- Discontinuity survey by TV Camera
- Rock Class Classification
- In-situ stress measurement

Tunnel;

- Geological Mapping
- Rock Class Classification

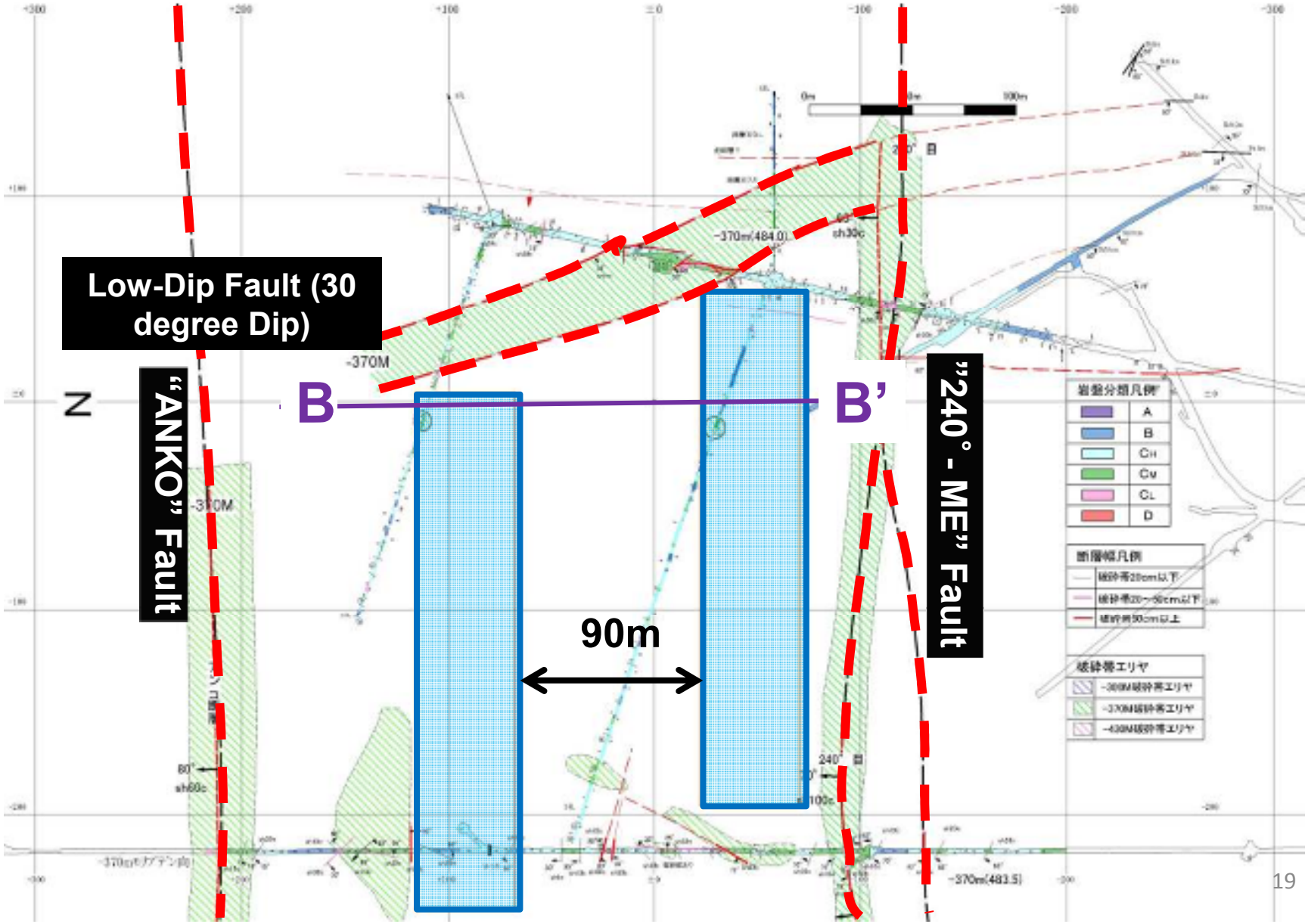
Survey at -430mL

Tunnel;

- Geological Mapping
- Rock Class Classification

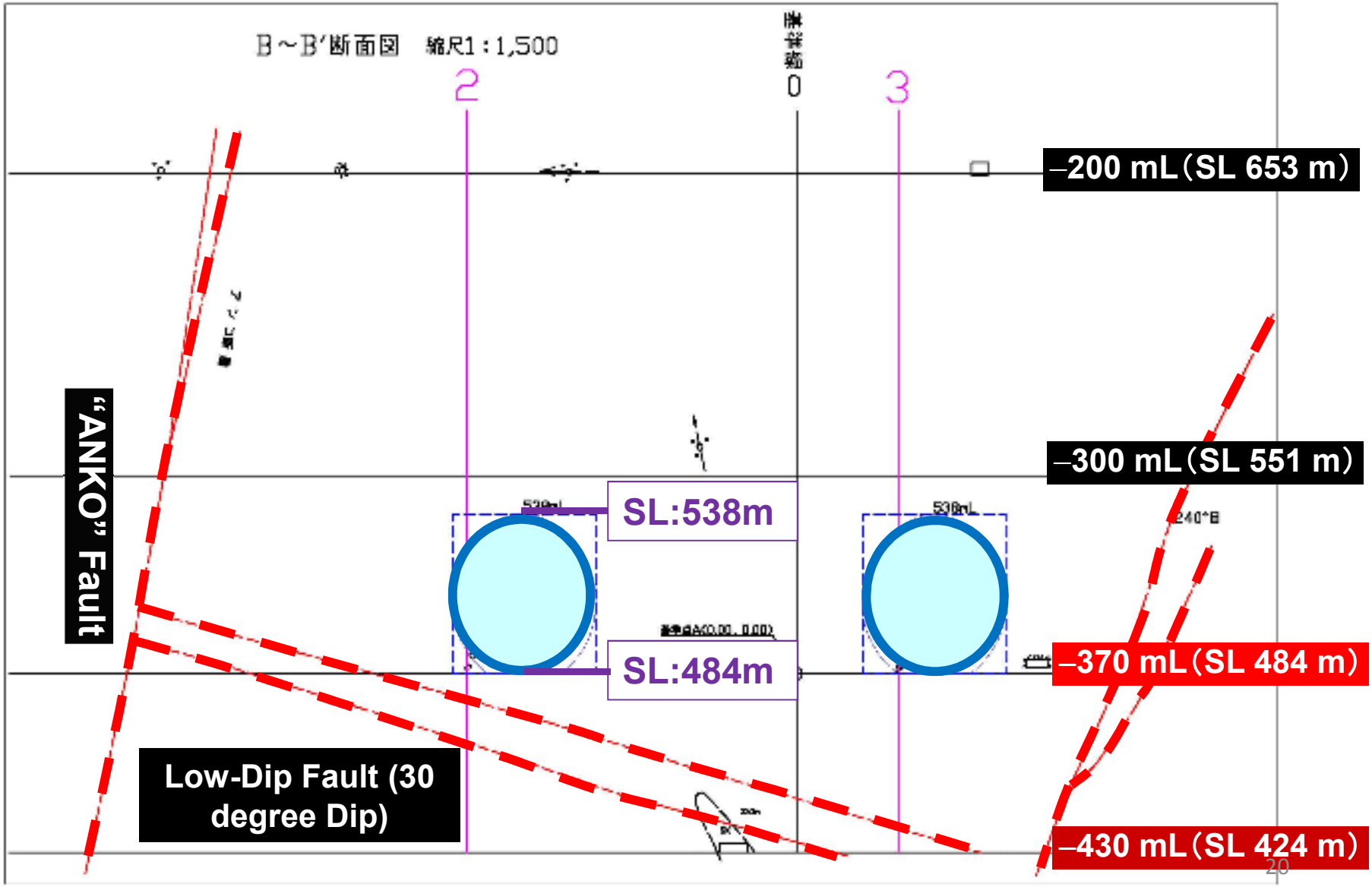
Layout of Hyper-K for Conceptual Study in 2011

Plan View of -370mL



Layout of Hyper-K for Conceptual Study in 2011

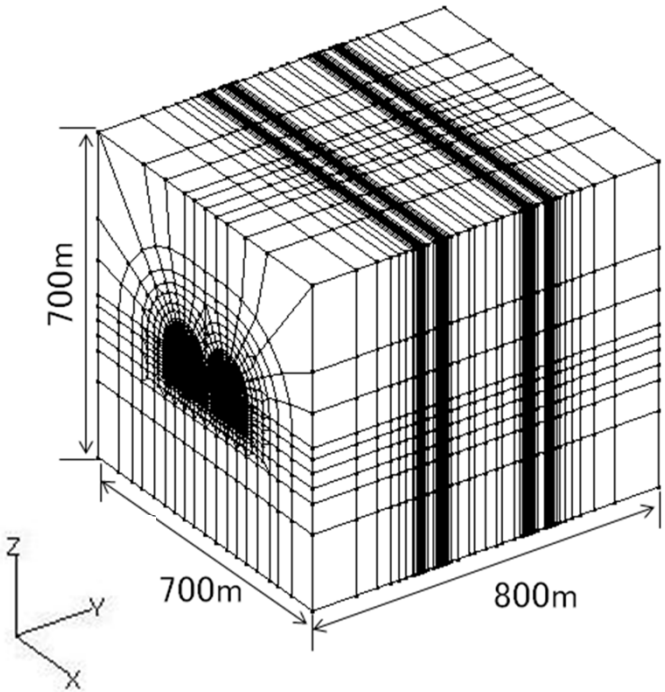
Section (B-B') View



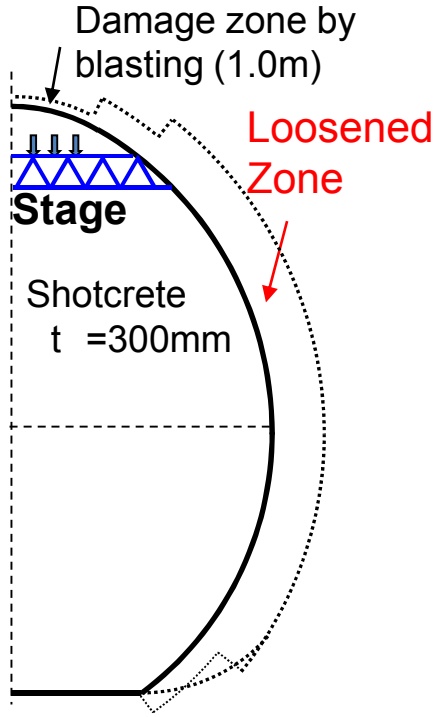
Flow of Rock Stability Analysis and Rock Support Design

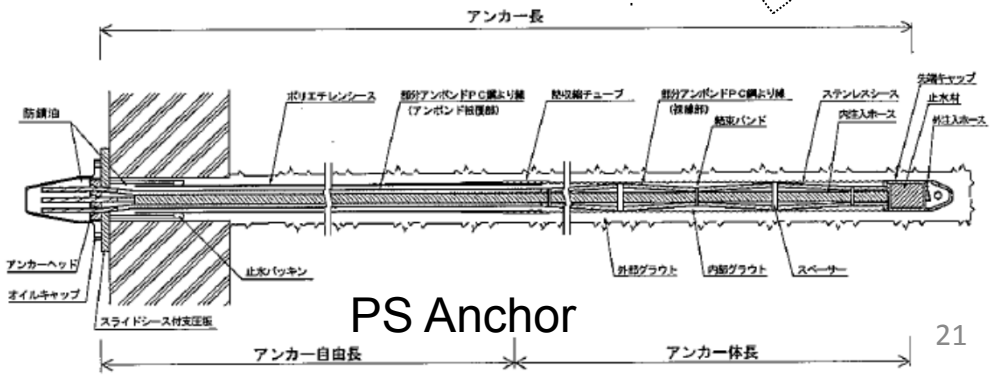
Stability Analysis of Cavern → **Stability Analysis of Rock Support** → **Support Design**

☆Finite Element Method（FEM）
→Rock Class Model: B, CH, CM
☆Mohr-Coulomb failure criterion
Loosened Zone：
Factor of Safety＜1.0
☆Principal Stress is considered



☆Load
self-weight of Loosened Zone
self-weight of Shotcrete
Load of Stage (210kN/m)
☆Rock Support
PS（Pre-Stress）Anchor for supporting Loosened zone.
Decision of tension, length, and spacing of PS Anchor.



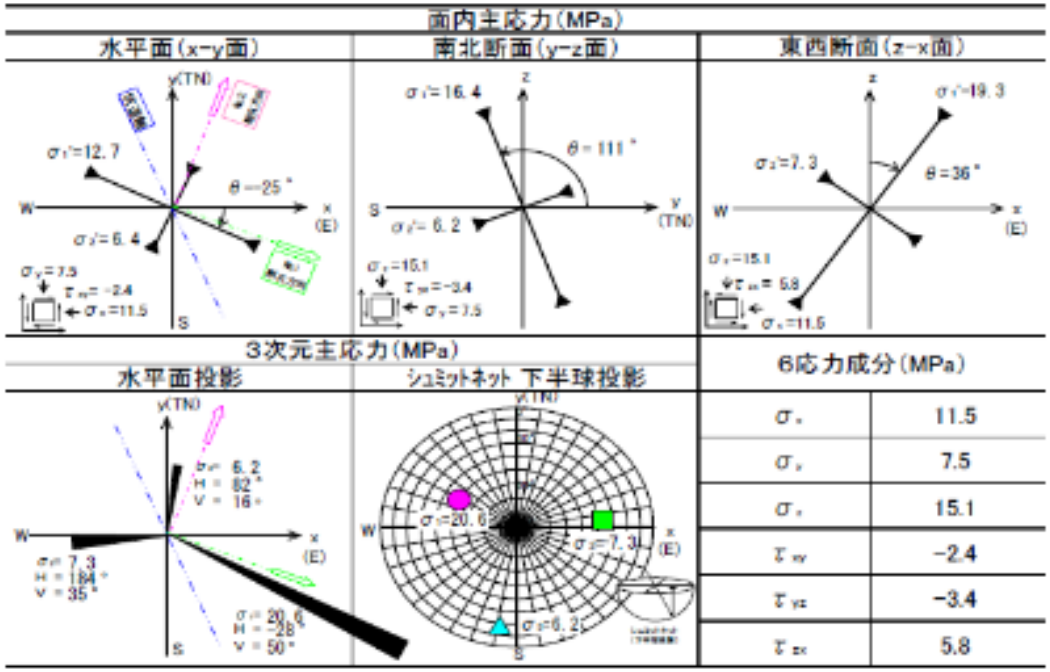


PS Anchor

Rock Stability Analysis of Cavern（Analysis Condition）

In-situ stress measurement (-300mL) → **In-situ stress for Stability Analysis**

x1.08 **(Depth Compensation as-370mL)**



Principal Stress (MPa)

NS-Coordinate		Adjusted to the axis of Cavern (90° rotation in clockwise)
σ_x	12.42	8.10
σ_y	8.10	12.42
σ_z	16.31	16.31
τ_{xy}	-2.59	2.59
τ_{yz}	-3.67	6.26
τ_{zx}	6.26	3.67

Rock Mass Property for Rock Stability Analysis

Assumed Rock Class (Japanese)	B	CH	CM
Young's Modulus(kN/mm^2)	10.10	3.43	1.22
Poisson's Ratio	0.25	0.25	0.25
Cohesion(N/mm^2)	4.90	2.40	1.40
Angle of Internal Friction (deg.)	60.00	50.00	45.00
Tensile Strength(N/mm^2)	0.00	0.00	0.00

Rock Mass Property in Loosened Zone for Rock Support Analysis

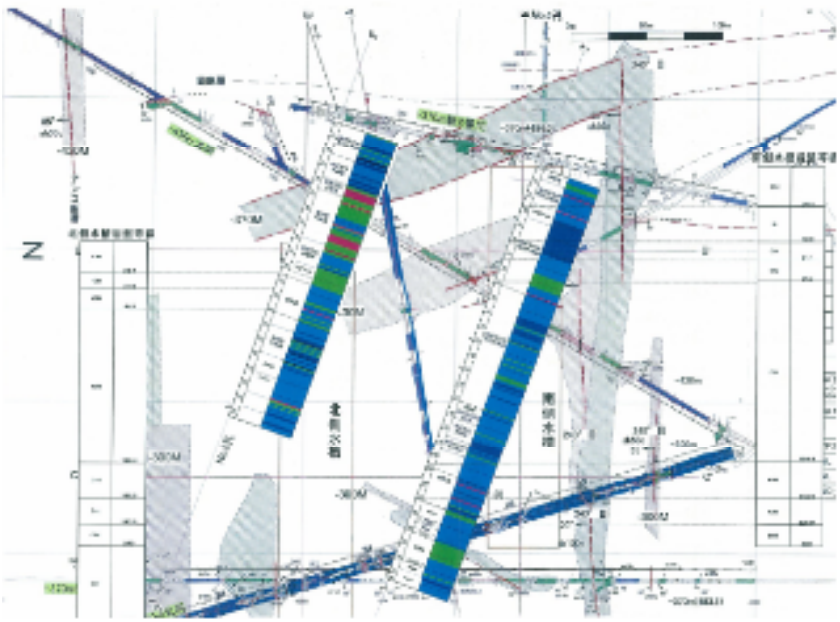
Assumed Rock Class (Japanese)	B	CH	CM
Cohesion (N/mm^2)	0.1	0.1	0.1
Angle of Internal Friction (deg.)	50.00	45.00	35.00

Rock Stability Analysis of Cavern（Analysis Condition）

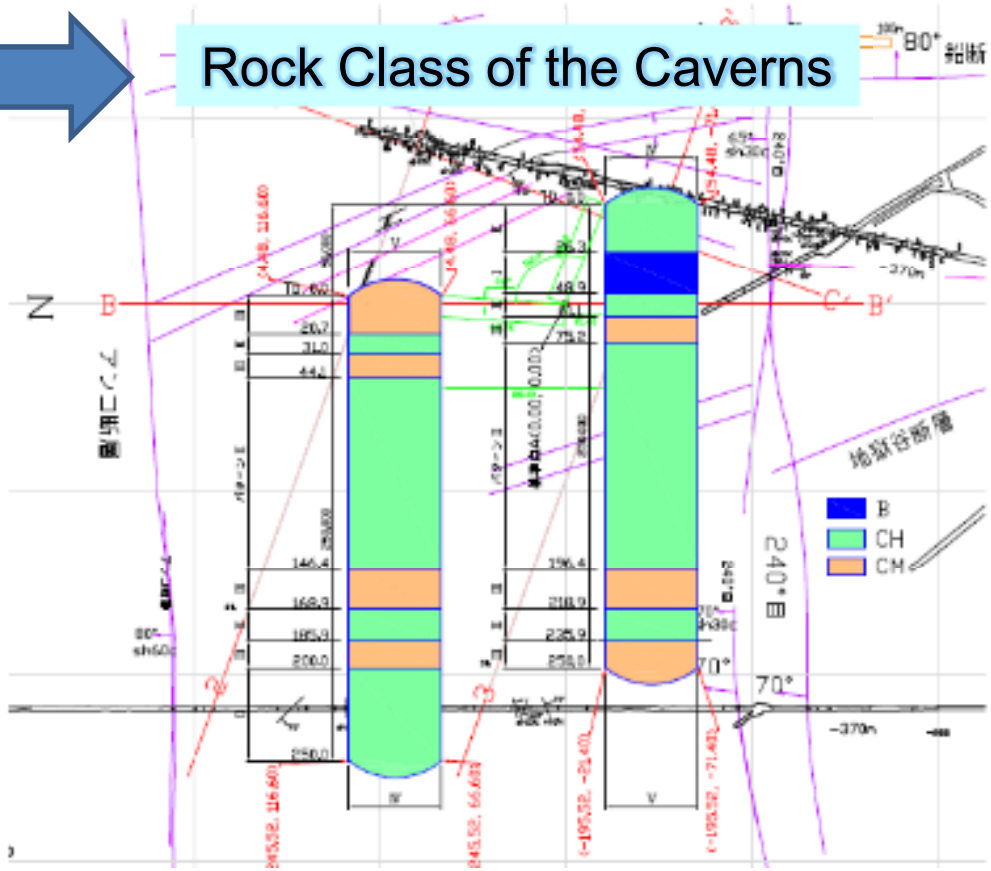
Distribution of Rock Class Classification on the Cavern

It was assumed rock class applying the nearest result of boring core data.

Rock Class of Boring Core

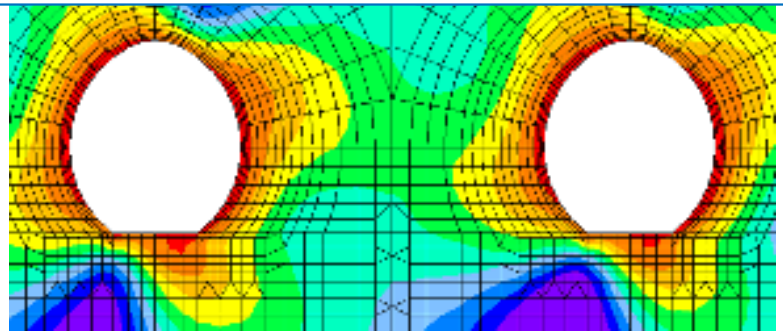


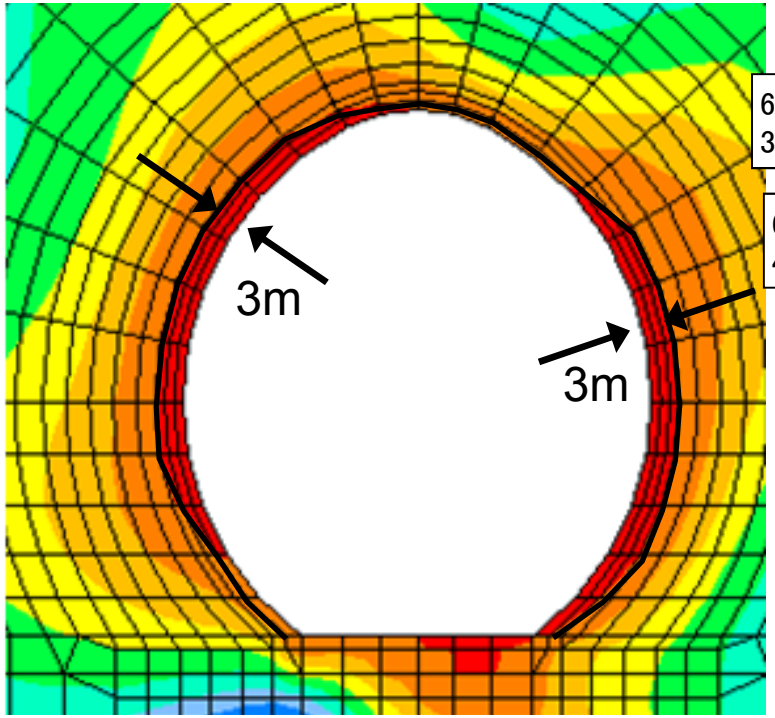
Rock Class of the Caverns



Result of Rock Stability and Rock Support Analysis

Distribution of Factor of Safety
(Ex. Rock Class: CH)

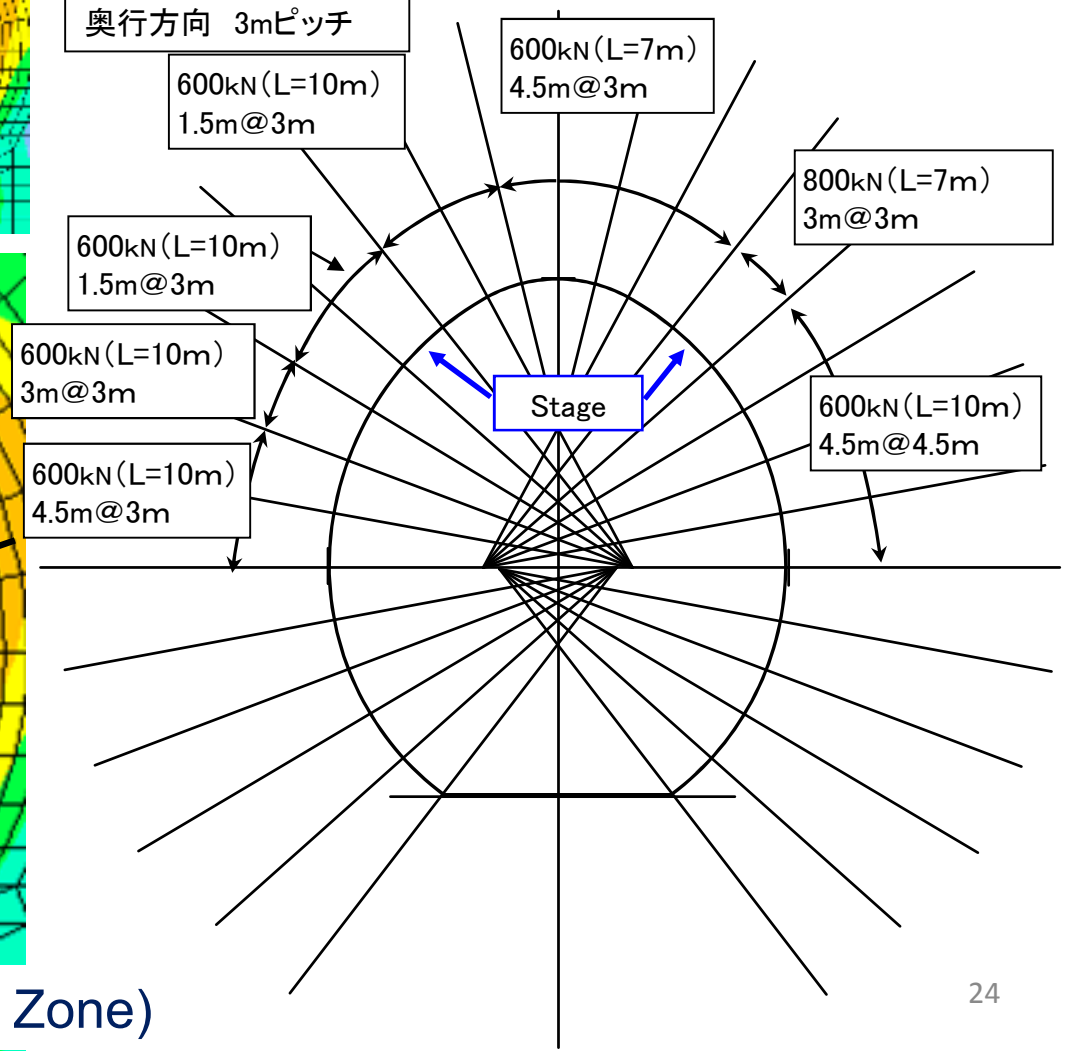




(Section G：3m of Max Loosened Zone)

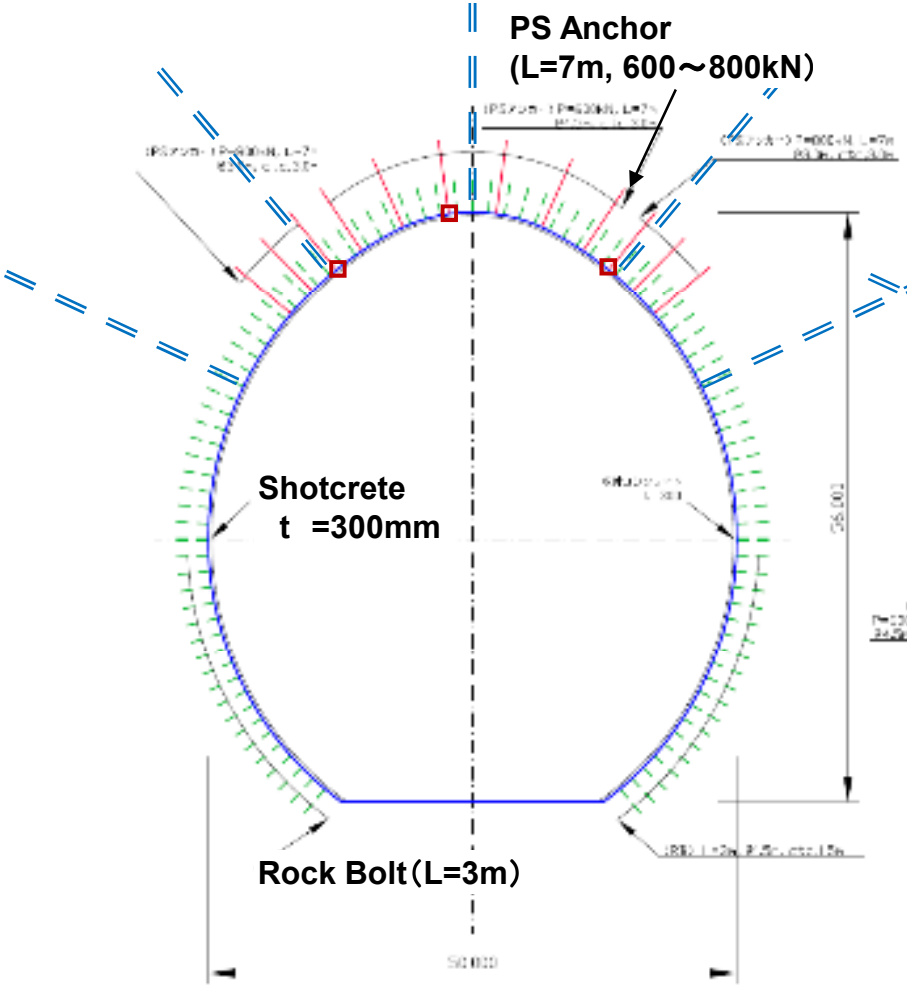
Rock Support Design (PS Anchor)

Angle of Internal Friction＝45°
Cohesion＝0.1N/mm^2



Rock Support Design of Cavern

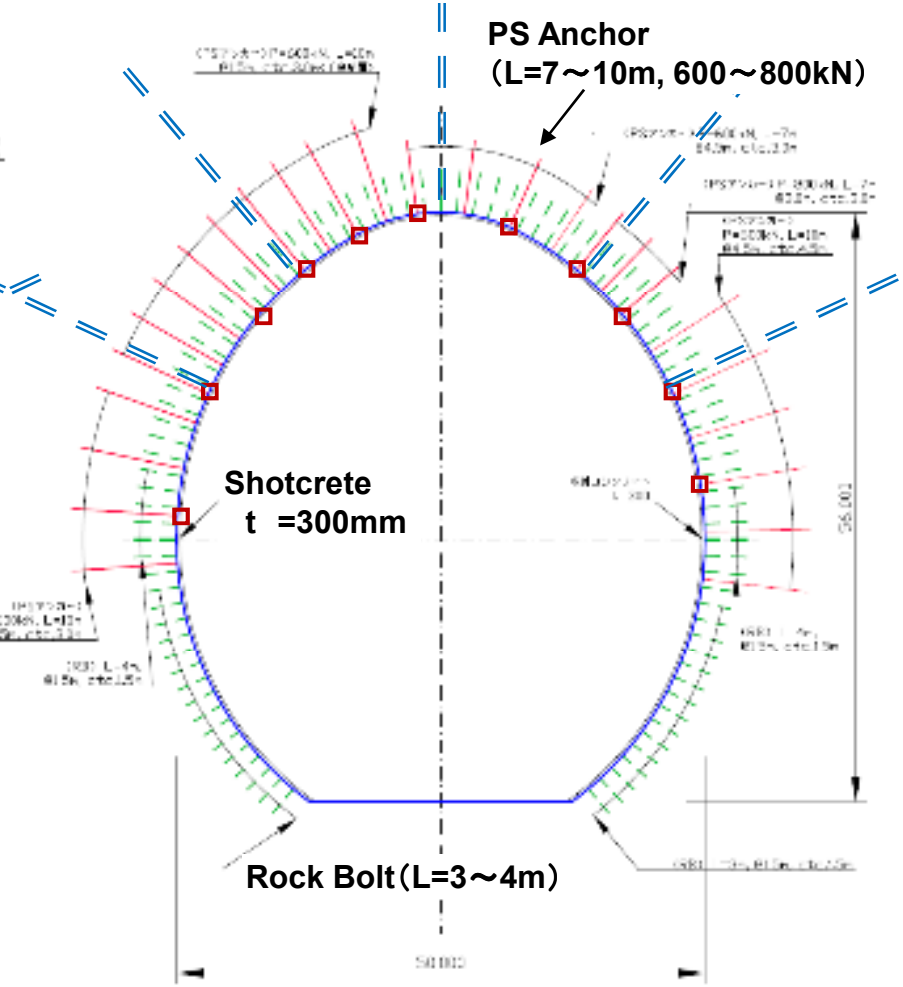
Pattern I (Rock Class: B)



Load Cell (1MN): 3

Extensometer (L=25m): 5 holes (6points@2,5,10,15,20,25m)

Pattern II (Rock Class: CH)

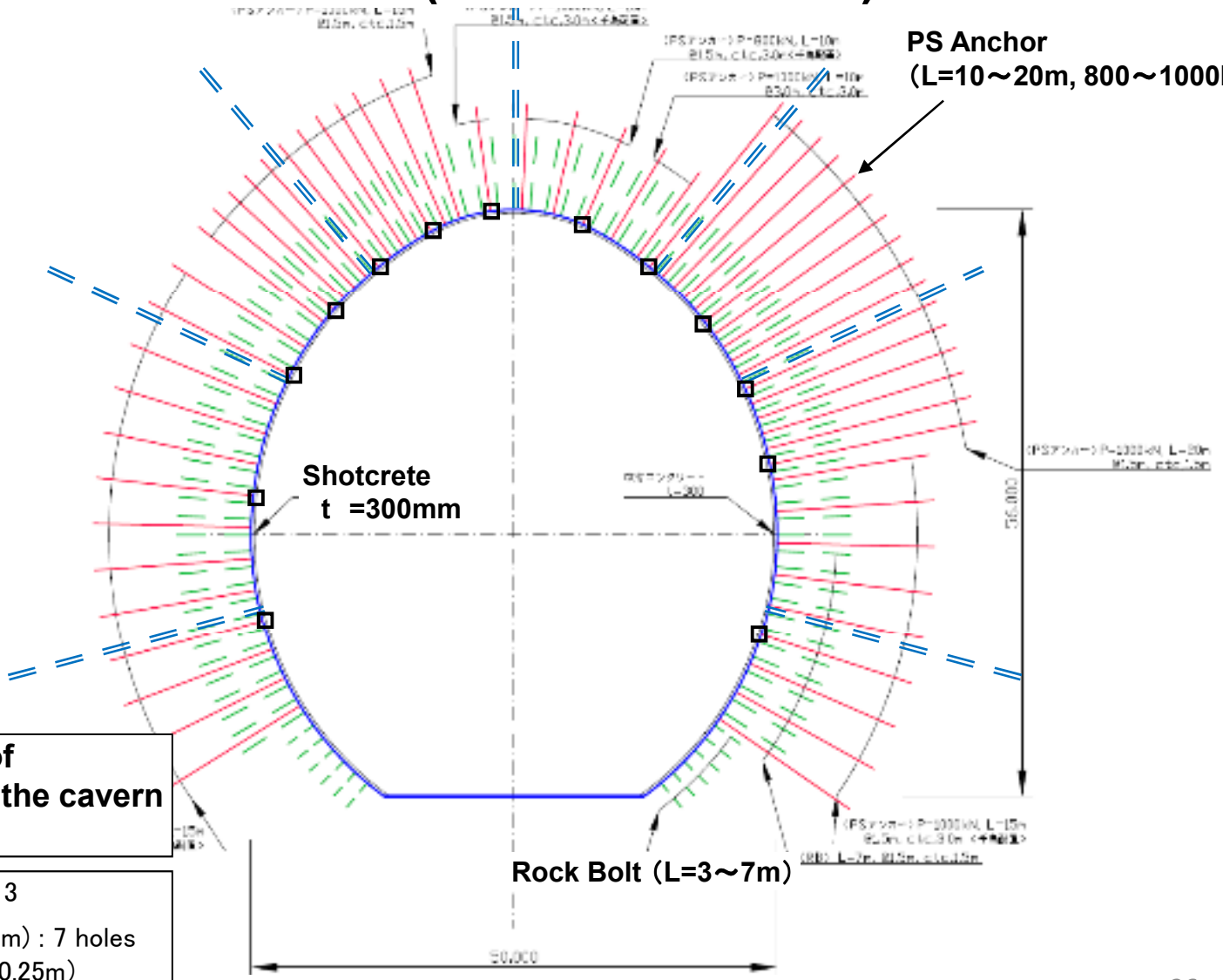


Load Cell (1MN): 11

Extensometer (L=25m): 5holes (6points@2,5,10,15,20,25m)

Rock Support Design of Cavern

Pattern III (Rock Class: CM)



On-time Monitoring of displacement during the cavern Excavation

Load Cell（1.5MN）: 13

Extensometer（L=25m）: 7 holes
（6points@2,5,10,15,20,25m）

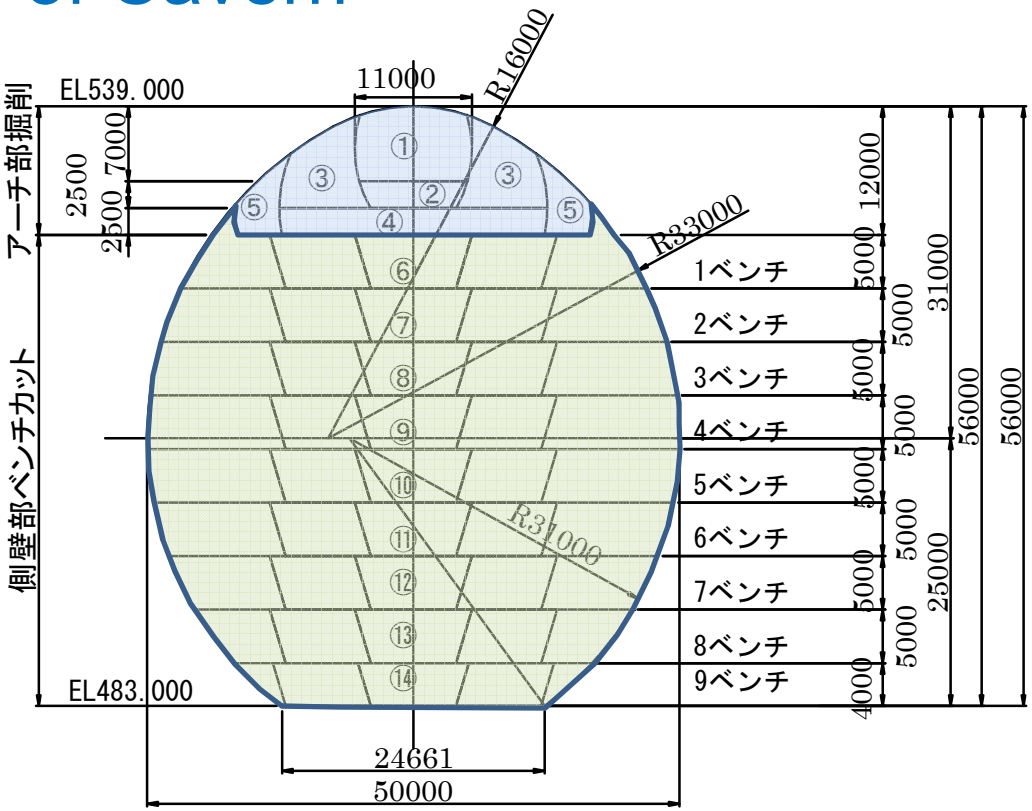
Construction of Hyper-K Cavern

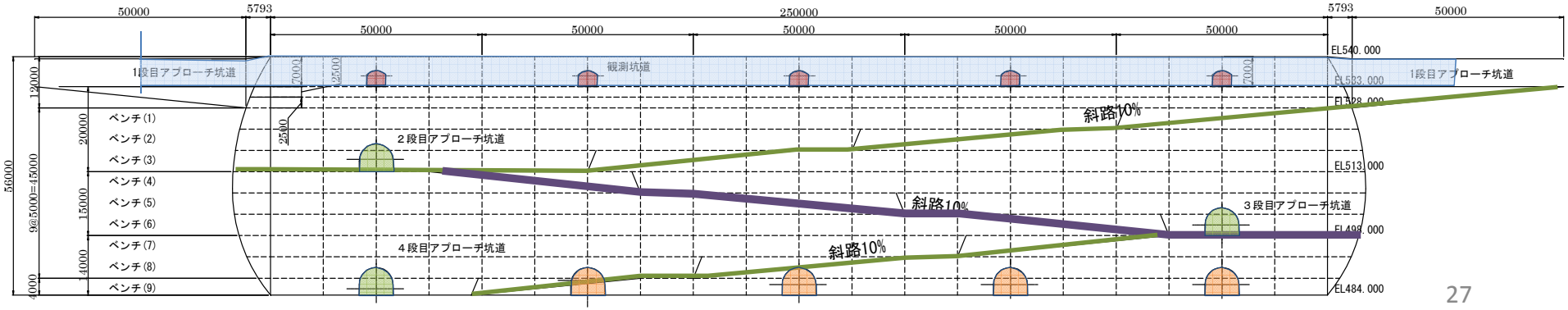
Construction Scheme of Cavern

Excavation Sequence with Bench Cut Method

Equipment
- -3 Boom Jumbo
- -3.0m3 Side Shovel
- -22 ton Dump Truck
- -Shotcreter

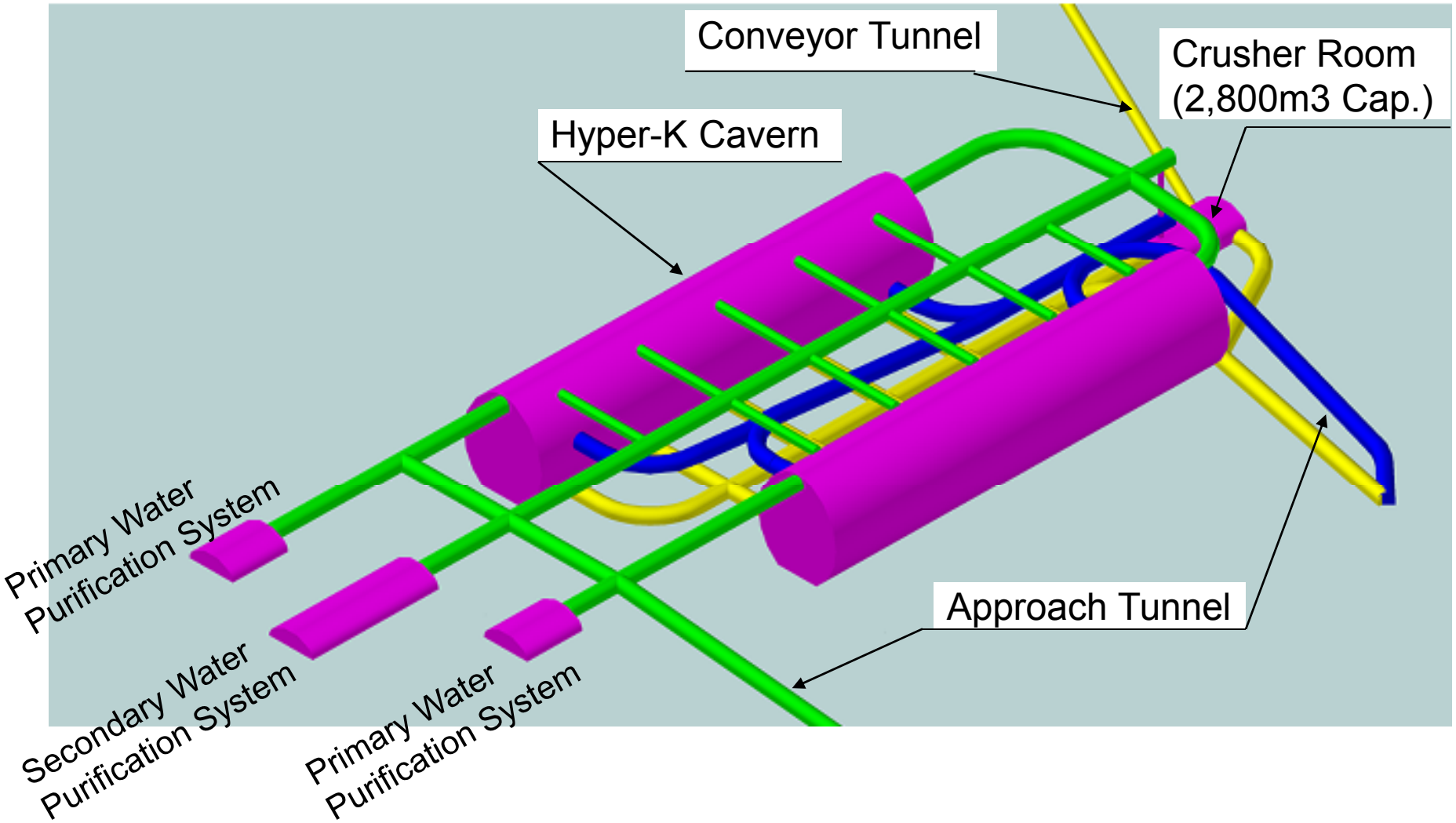
Approach Tunnel design for Access to Each Excavation Level





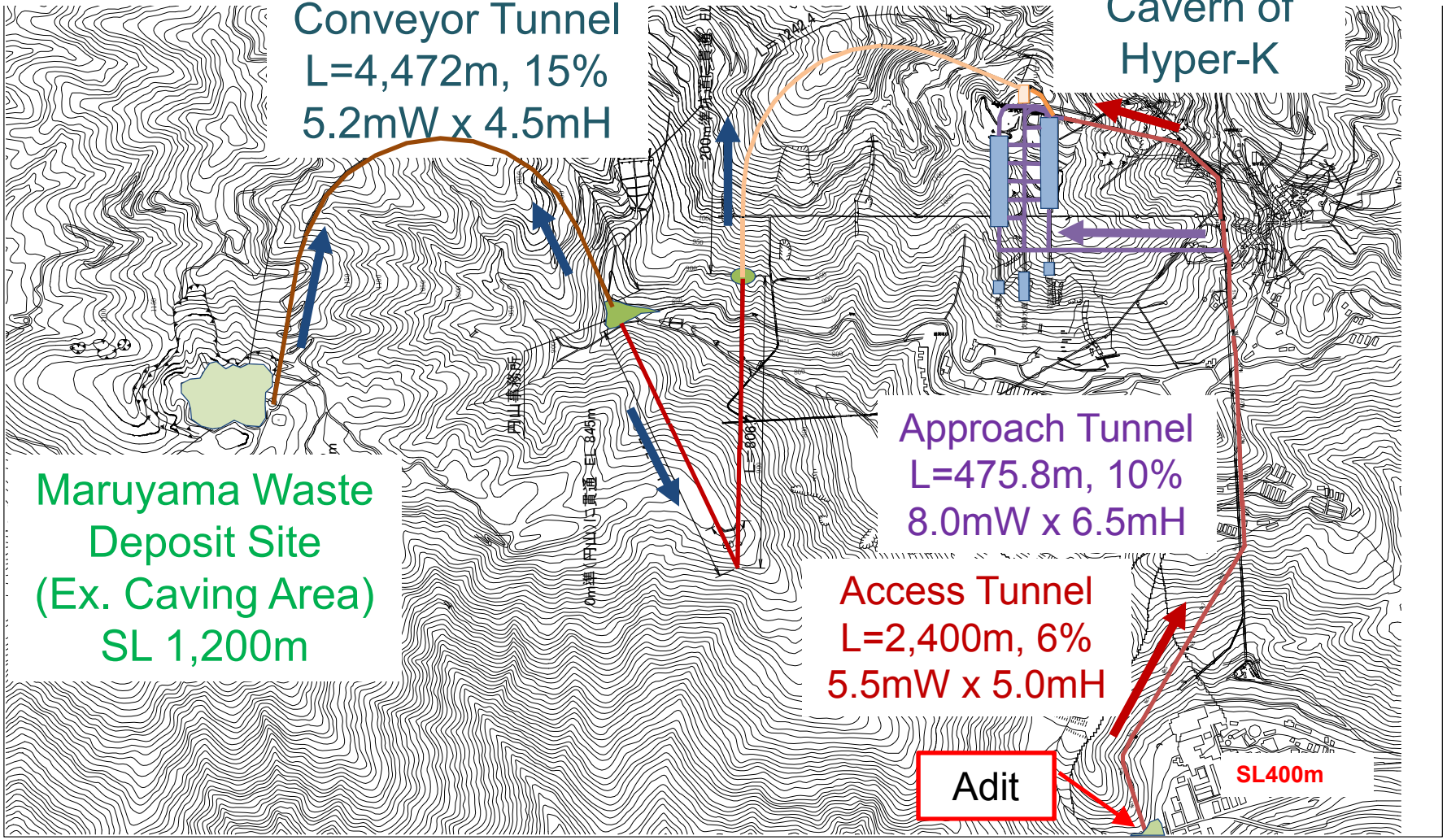
Construction of Hyper-K Cavern

Layout of Hyper-K Cavern and Tunnels



Construction of Hyper-K Cavern

Layout of Hyper-K Cavern and Tunnels

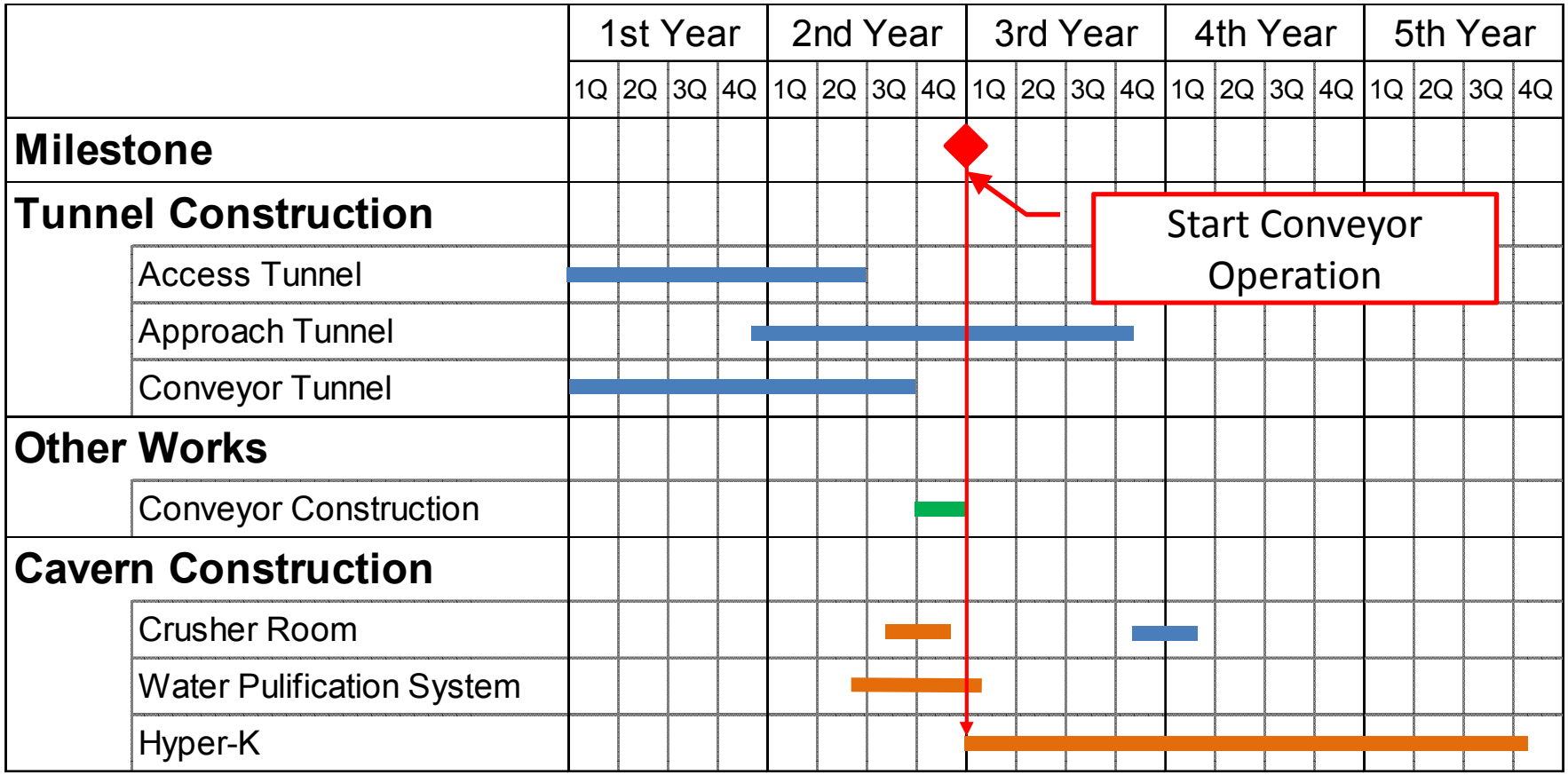


Construction of Hyper-K Cavern

Construction Schedule

About 5 years for construction of Tunnels and Caverns

- Excavated Rock: 1.6Mm3 (1.3Mm3 by conveyor)
- Excavation rate: 4,000m3/day (max)



Summary (1/2)

Result of the Conceptual Study of the Hyper-K Cavern Construction:

*Site & Layout :

-Geological survey was carried out at -370mL around the candidate site of Hyper-K.

-Site and Layout of the Cavern for this study were decided, avoiding the fractured zone, keeping more than 500m of overburden.

-Rock stability analysis and rock support design were carried out applying calculated parameters and empirical values of rock mass property.

*Cavern Excavation :

-Bench cut excavation and underground crushing / conveyor system to the Maruyama waste rock deposit site are optimum method.

-5 years is required for the Cavern construction including the tunnels.

Summary (2/2)

Themes of our Major Concerns :

Required further geological survey and rock engineering study

*Site & Layout of the Cavern should be reviewed doing further geological surveys and rock engineering studies.

*Rock Stability Analysis & Rock Support Design should be required further engineering studies, getting in-situ geotechnical parameters on the candidate site of Hyper-K.

*Waste Rock Haulage Tunnel - Case Study on the construction by TBM.

*Cavern Shape - Optimum shape of cross section and end shape.

*Waste Deposit Site should be needed further engineering.

*Clean Water Resource & Supply at TOCHIBORA Mine should be precisely planned and estimated.

*Construction Scheduling & Cost Estimation should be reviewed when further engineering studies will be done.