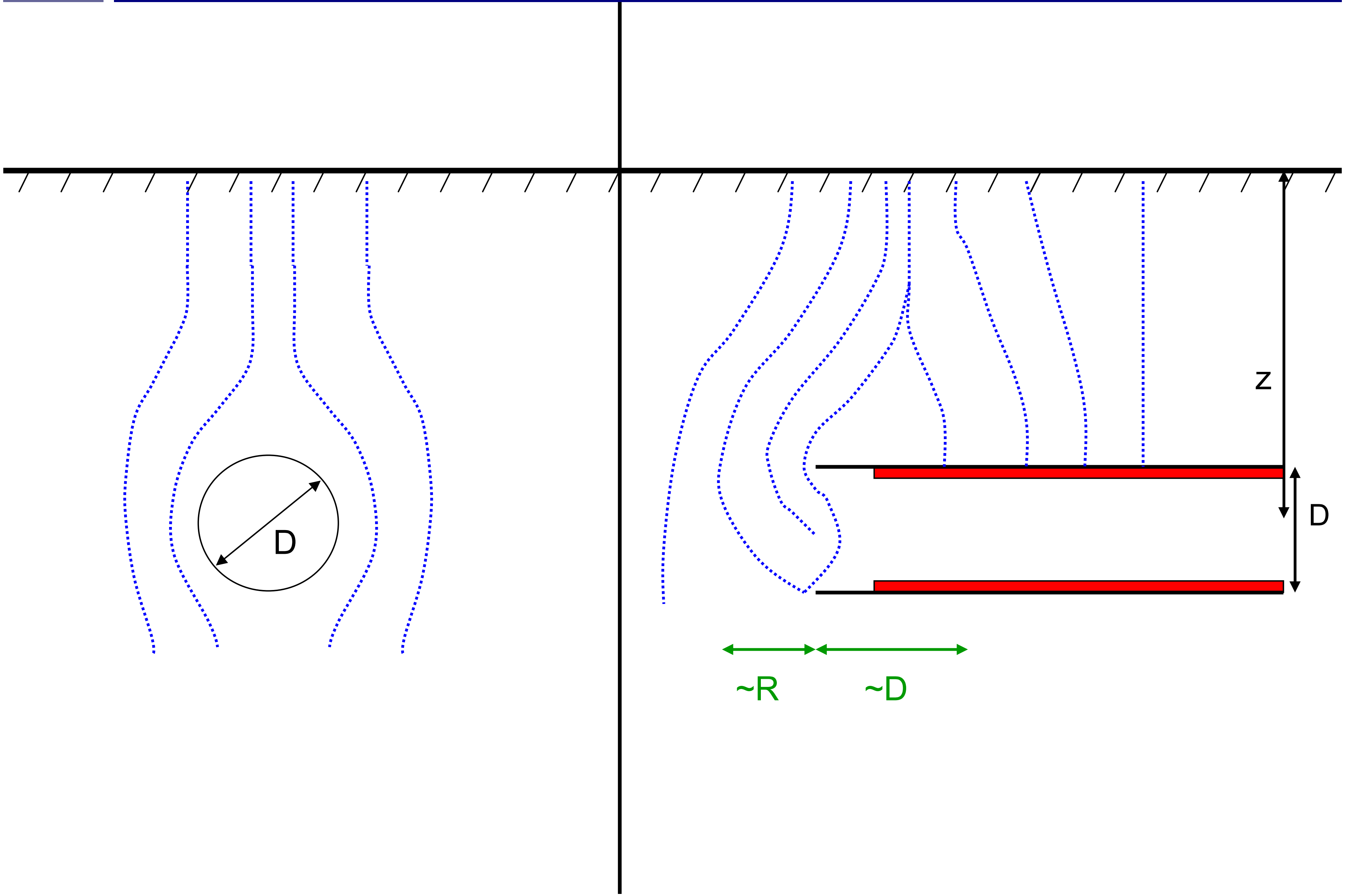
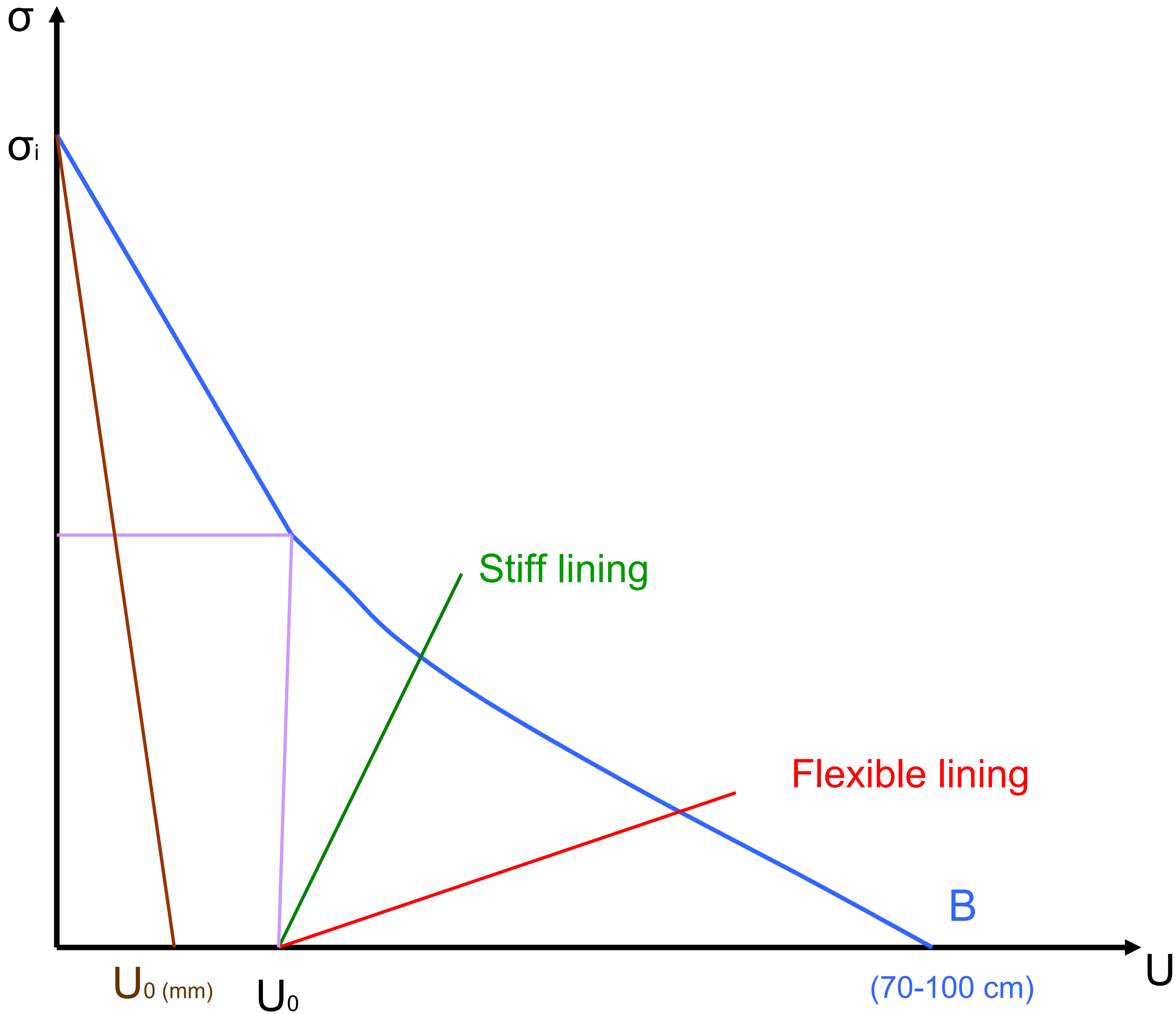
TUNNELING TROUGH DIFFICULT GROUND CONDITIONS IN LOW TO HIGH OVERBURDEN

Athens February 4th 2009

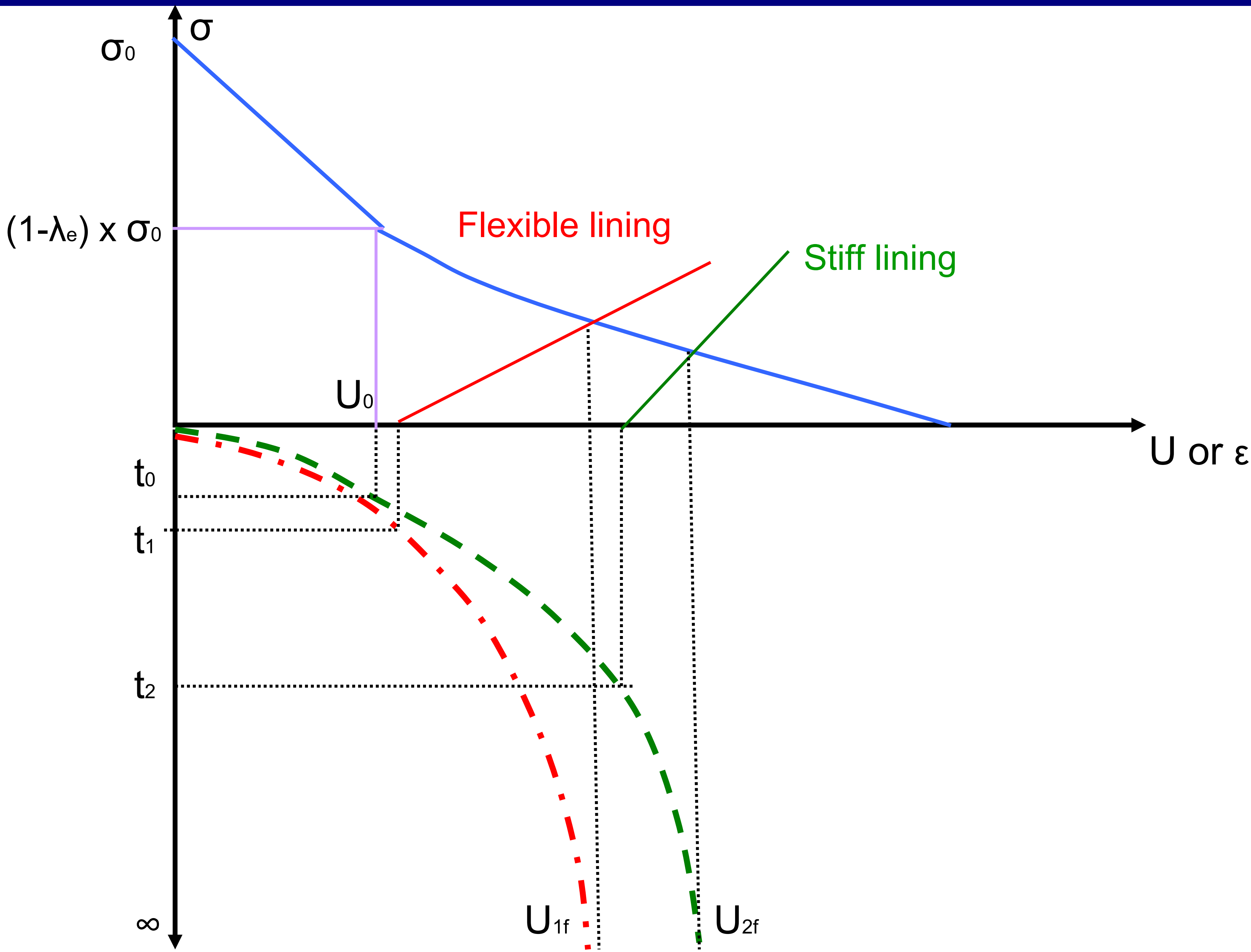
Stress field around a tunnel



Convergence-confining curves



Influence of time on support pressure & movements

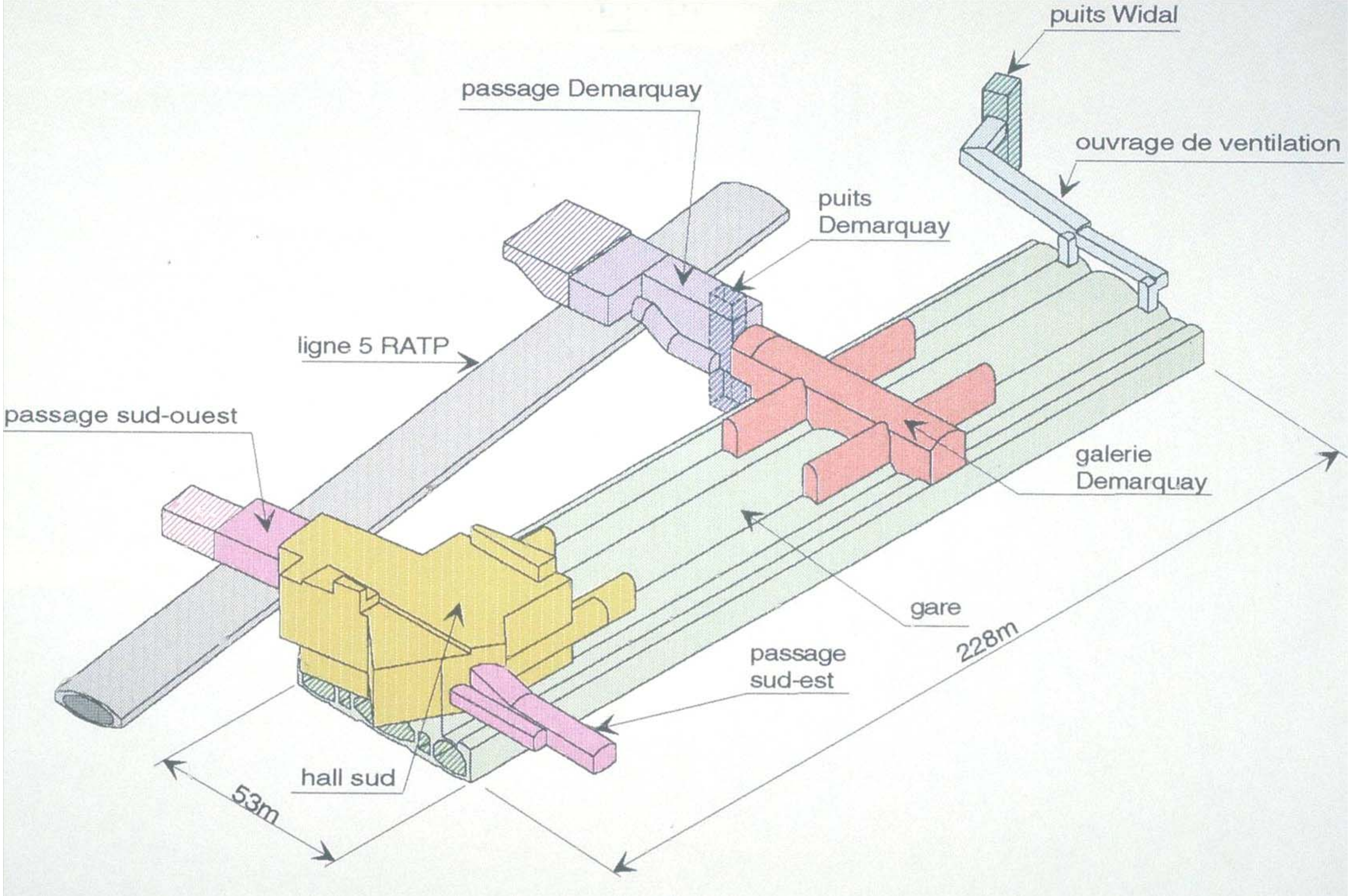


Low overburden

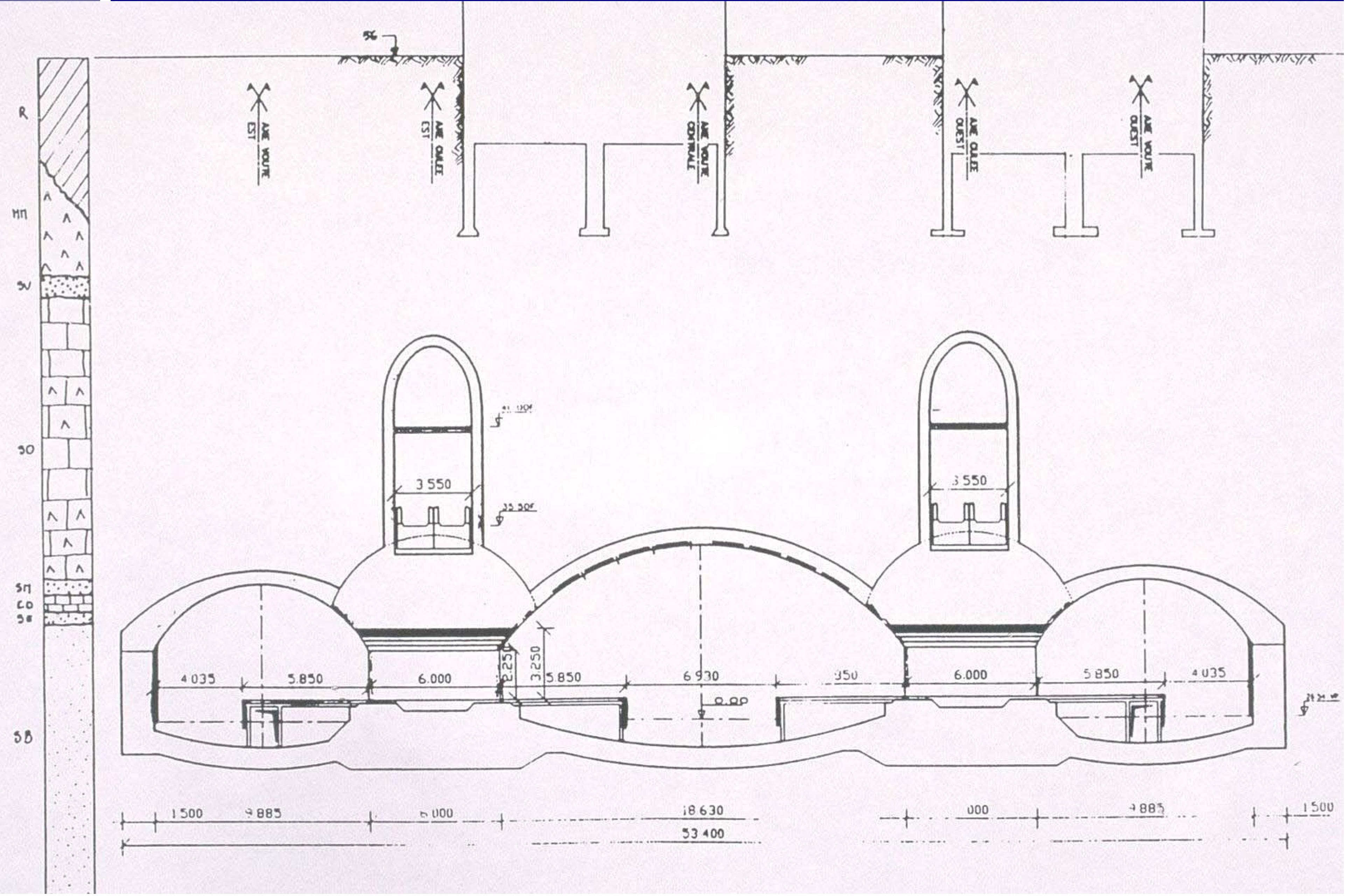
MAGENTA STATION-PARIS:

- St Ouen limestone=Alternate layers of marl and limestone
- RMR: 15-45 ;σci=10MPa
- Beauchamp Sand: very dense clayey sand
- Limit pressure: pl=4.8MPa
- E_m=60MPa

Magenta station - Paris MRT

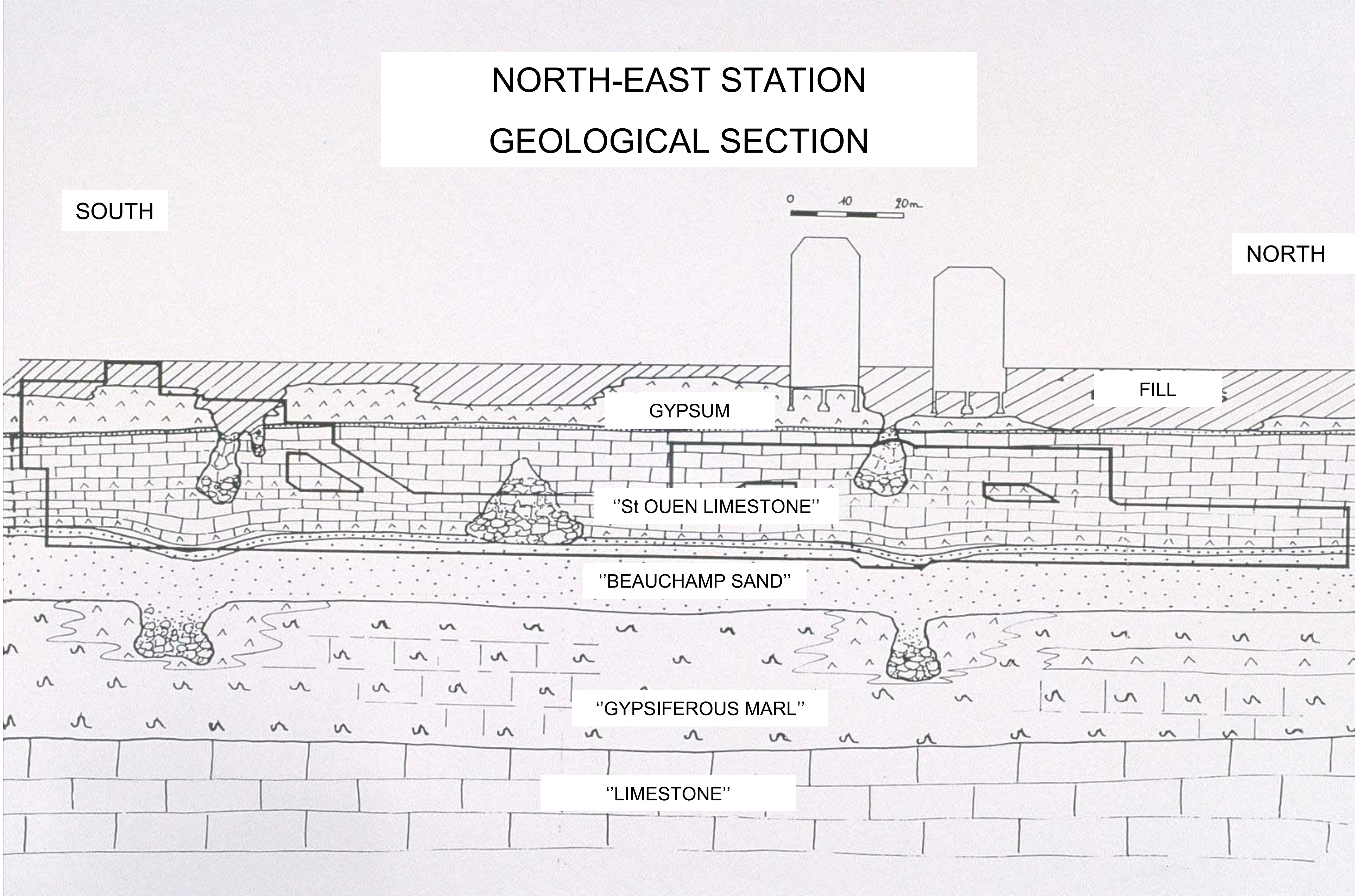


Station Final Cross Section

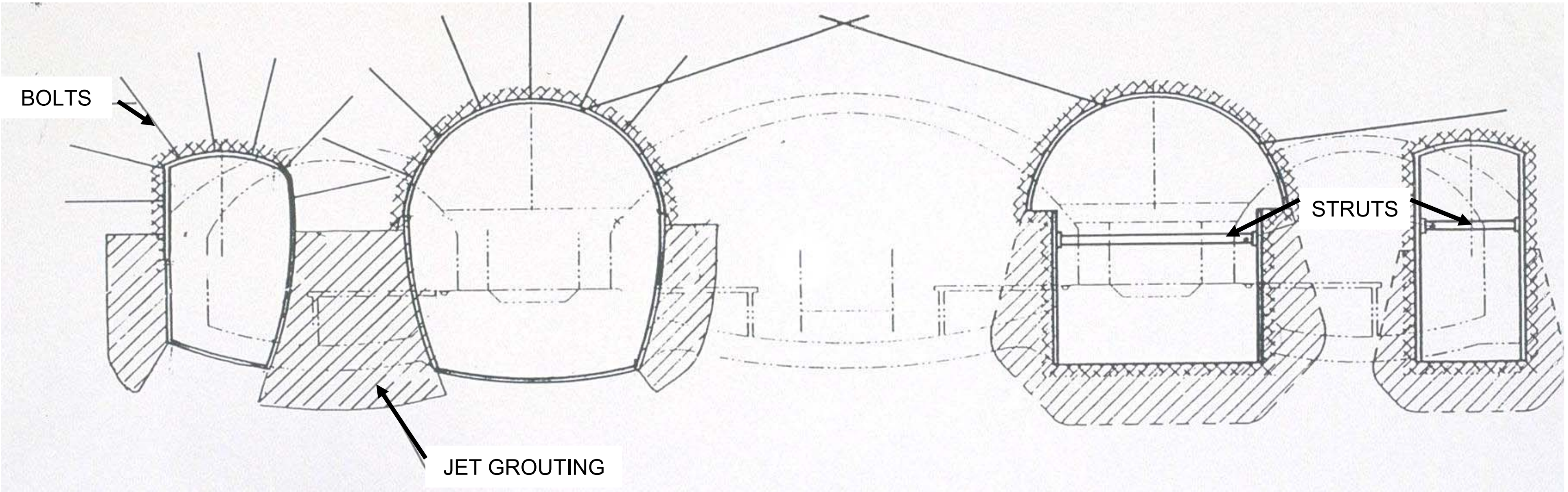


Typical Housing above the Station

Longitudinal Geological Section



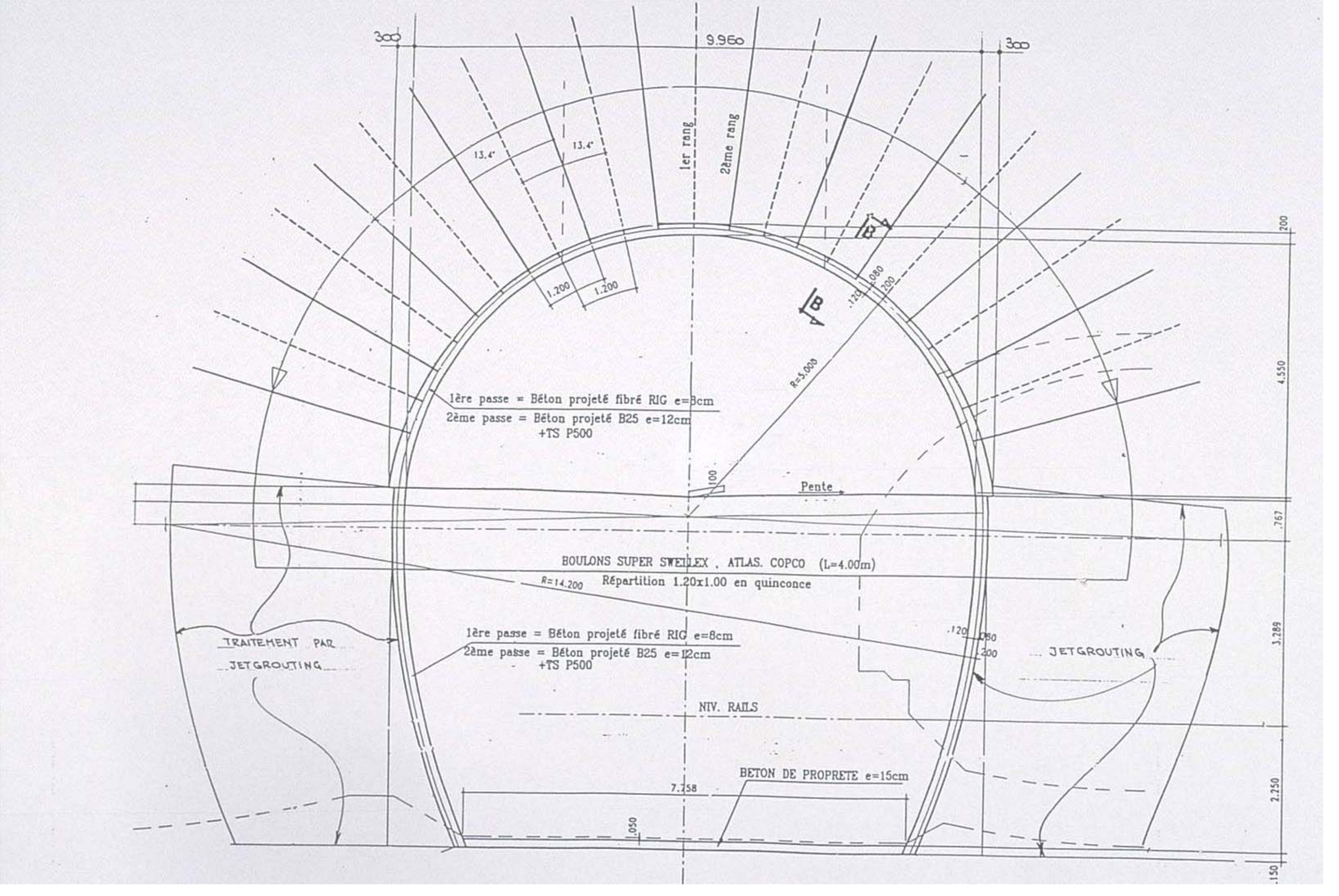
Temporary Excavation Sections



ALTERNATE DESIGN

TENDER DESIGN

Main Gallery Outer Lining Design

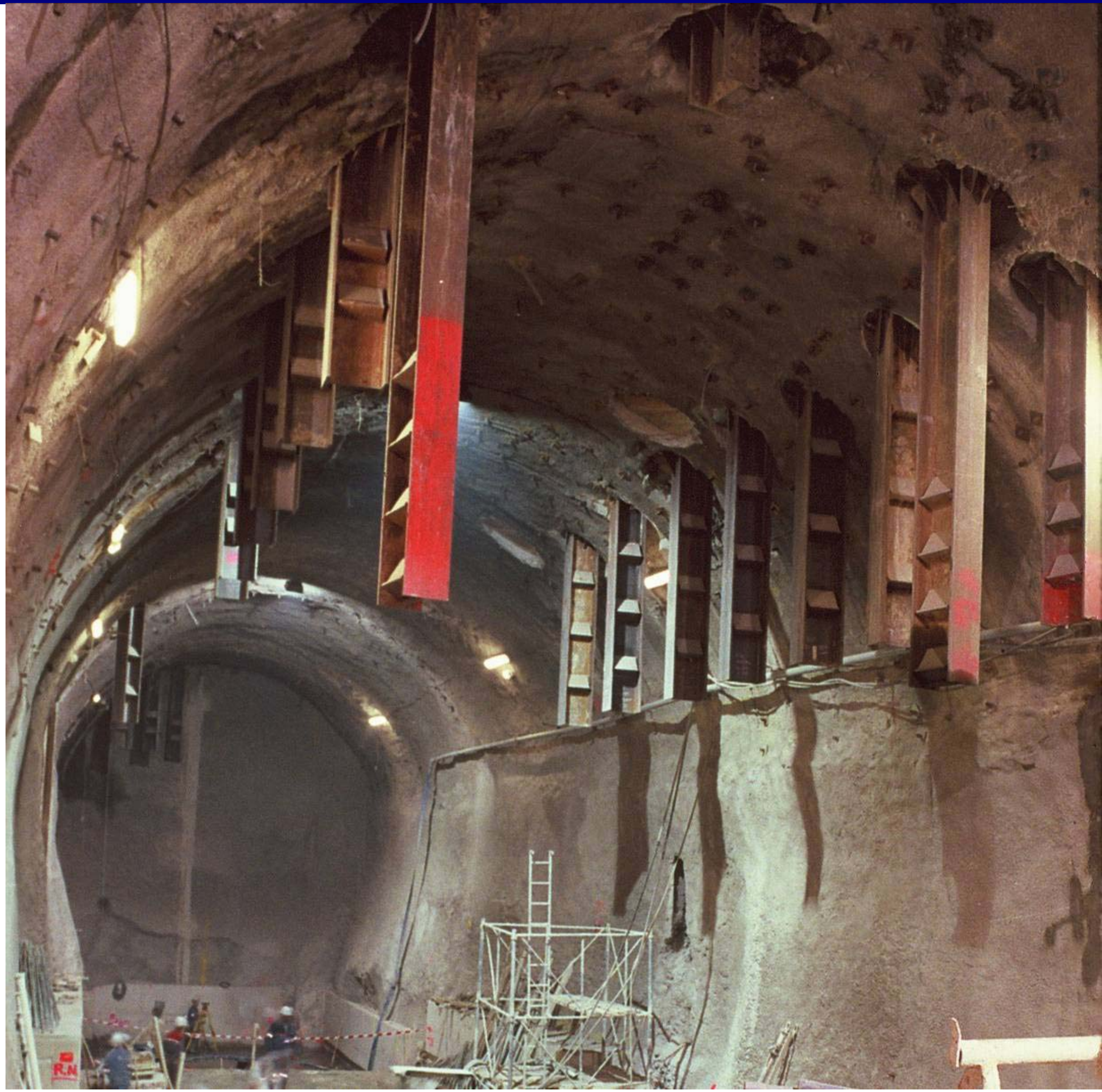


Main Gallery Top Heading Excavation Stage

Main Gallery Bench Excavation

Main Gallery Bench Excavation

Main Gallery Final Excavation

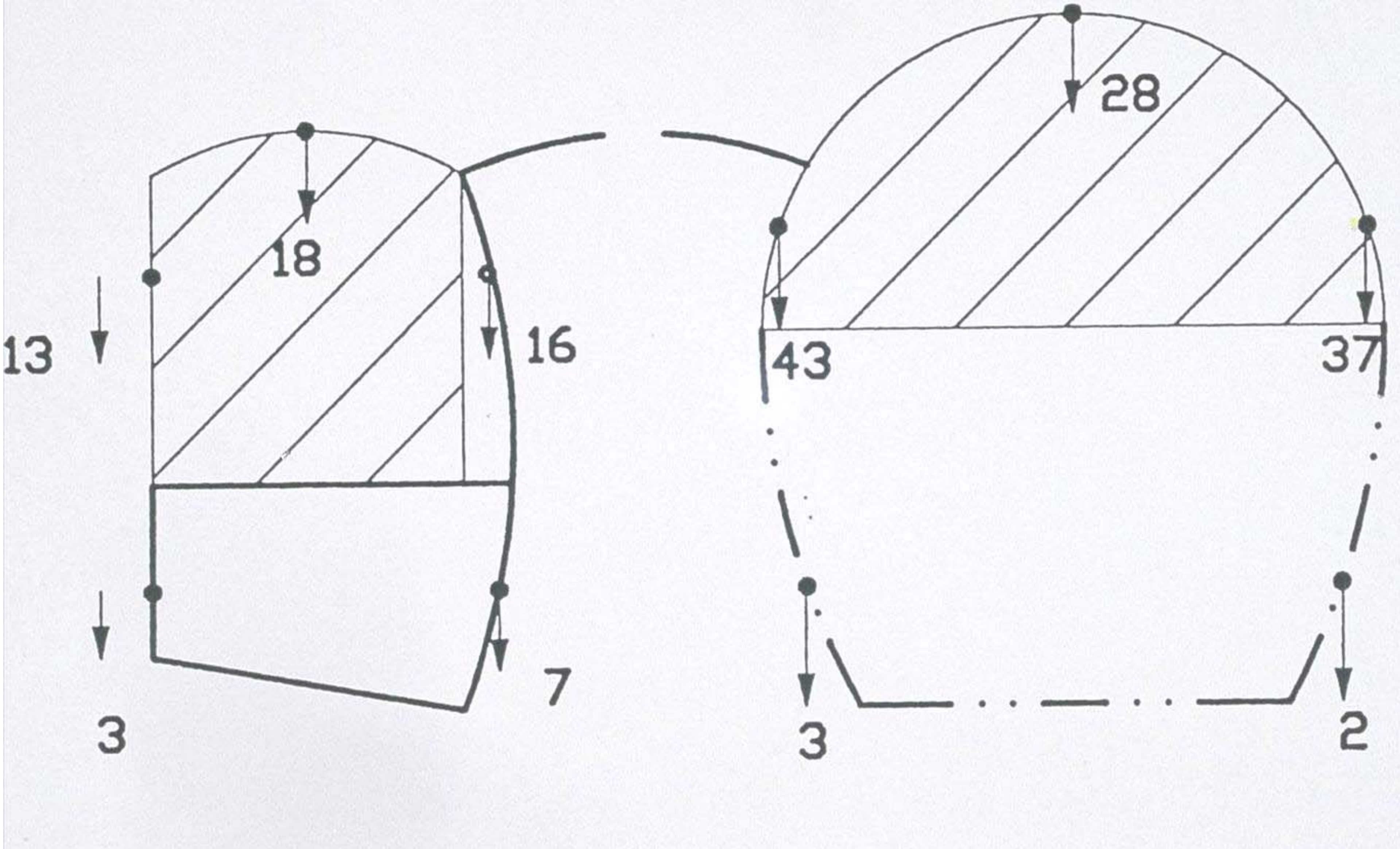


Side Gallery Final Excavation

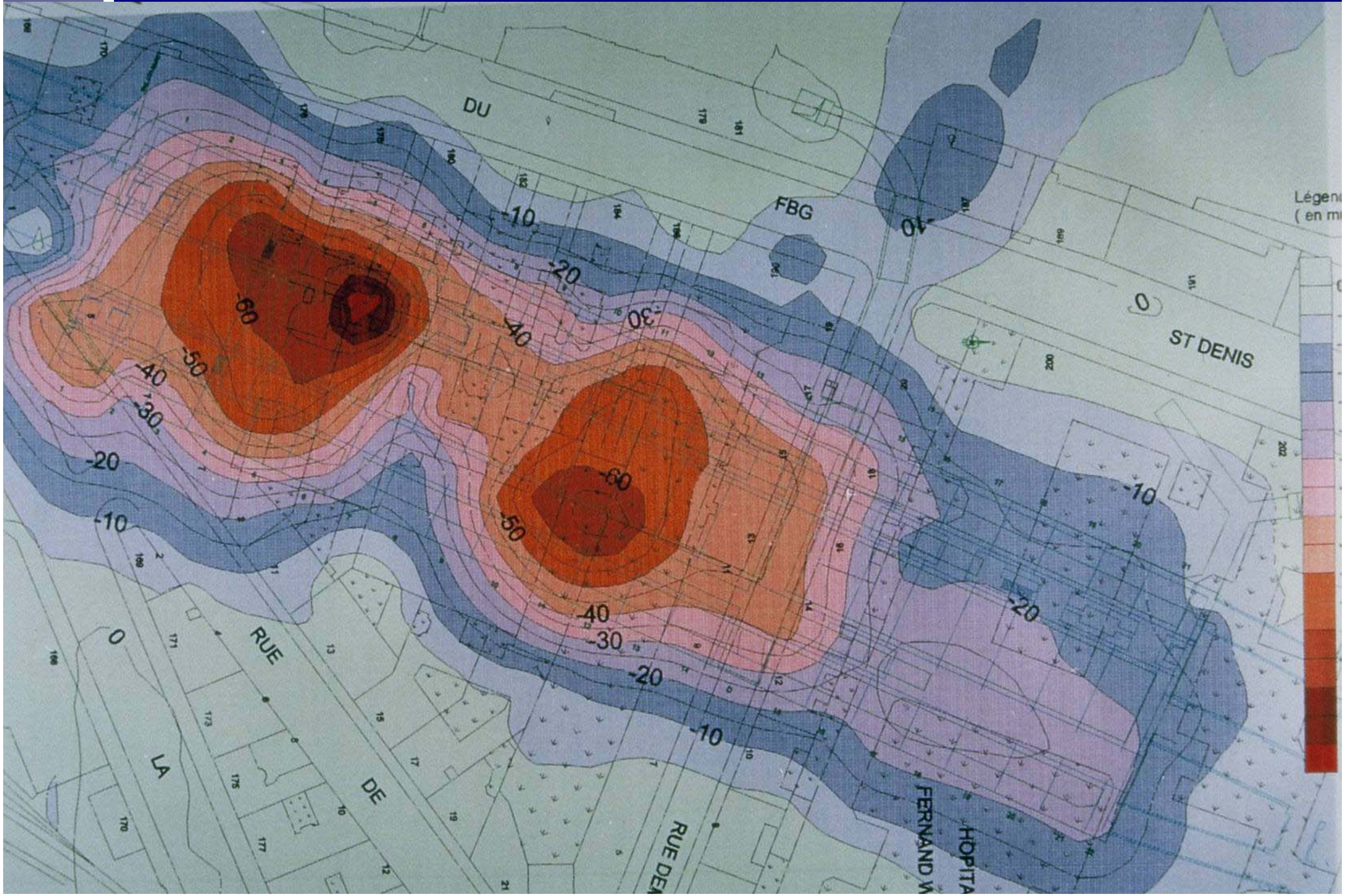
Removal of Central Pillar

Removal of Central Pillar

Tilting of the Galleries



Surface Settlements Contours(mm)



LOW OVERBURDEN

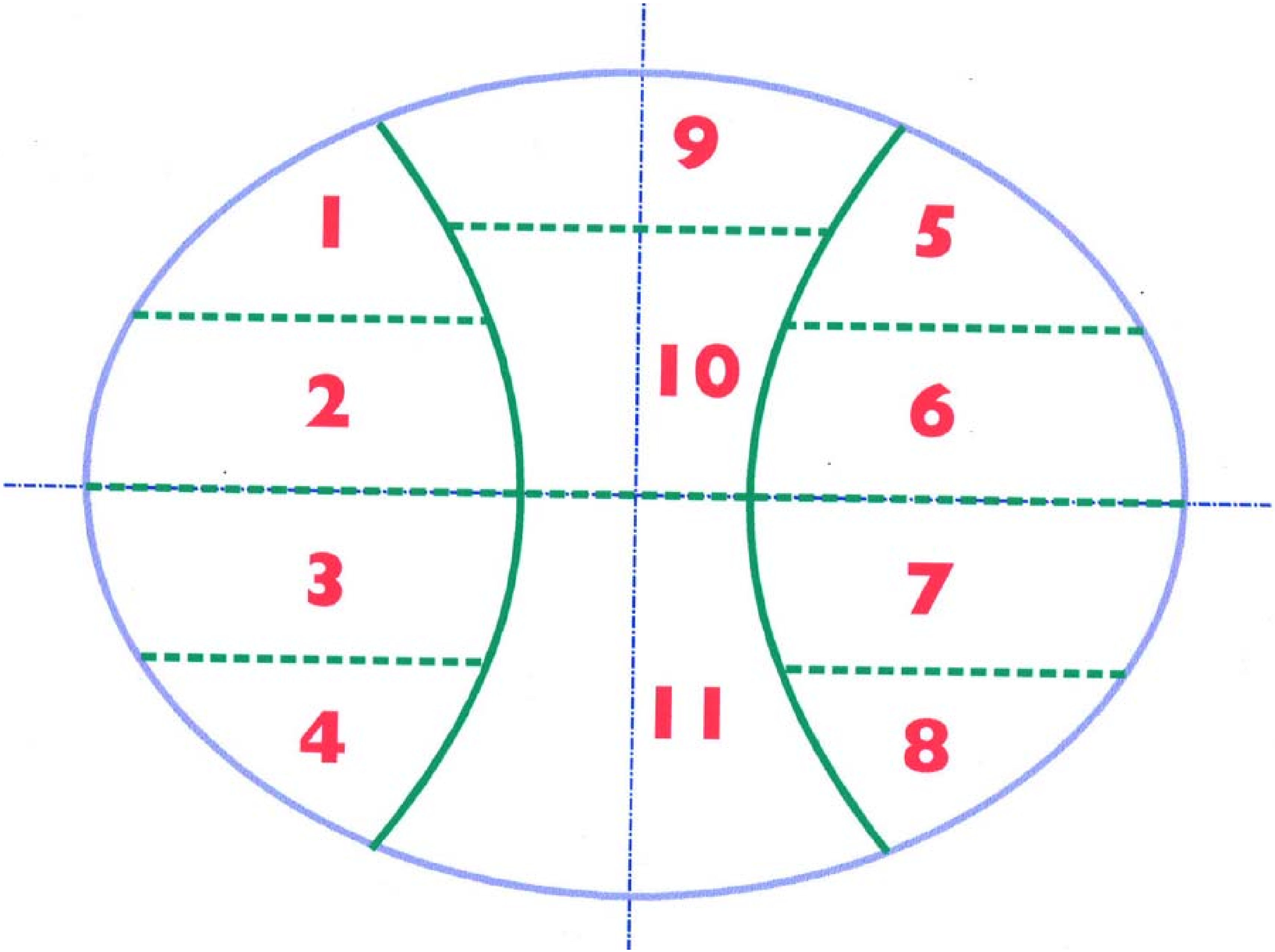
ATHENS METRO

- VARIOUS EXCAVATION APPROACHES

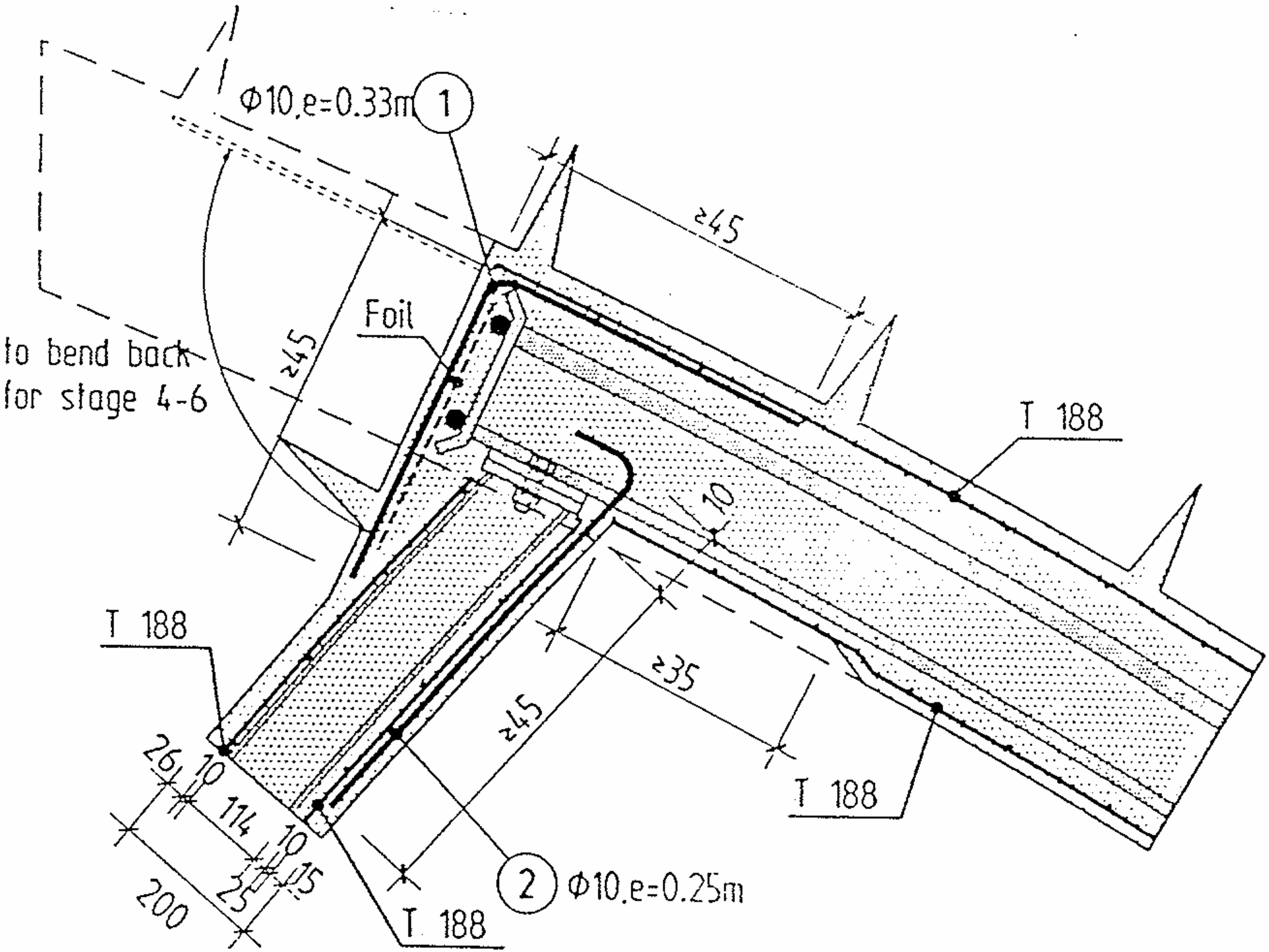
SIDE GALLERIES METHOD

STIFF SUPPORT

Side Galleries Excavation Stages



Details of Reinforcement Connections



Side Gallerry-Stage1

Side Gallery-Stage 2

Side gallery-Stage 2

Side Gallery-Stage 3

Side Galleries Completed

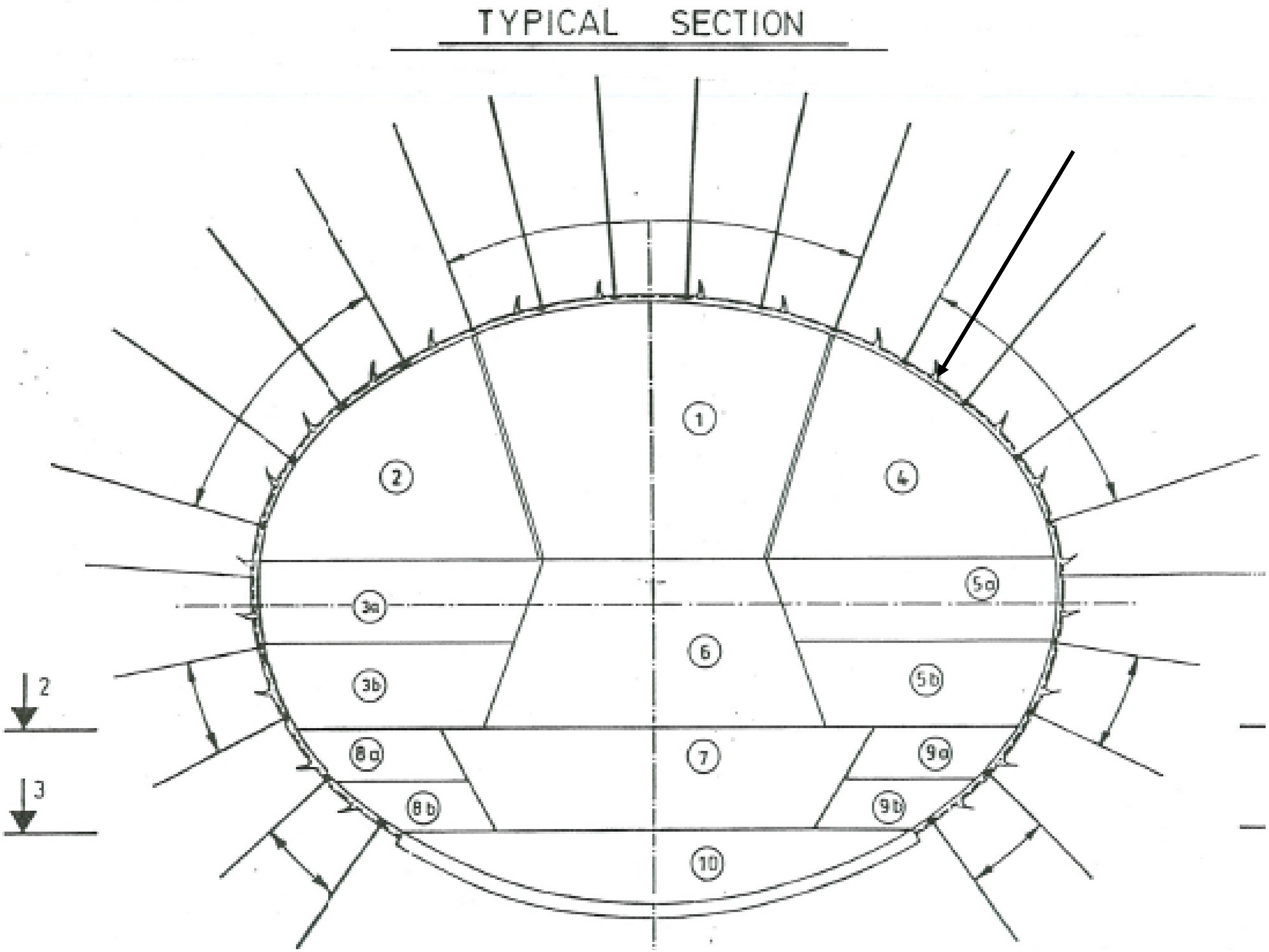
Central Top Heading-Stage 9

Central Pillar Removal- Stage 10

HYDRO-POWER CAVERN OR CENTRAL METHOD

FLEXIBLE SUPPORT

Excavation Stages



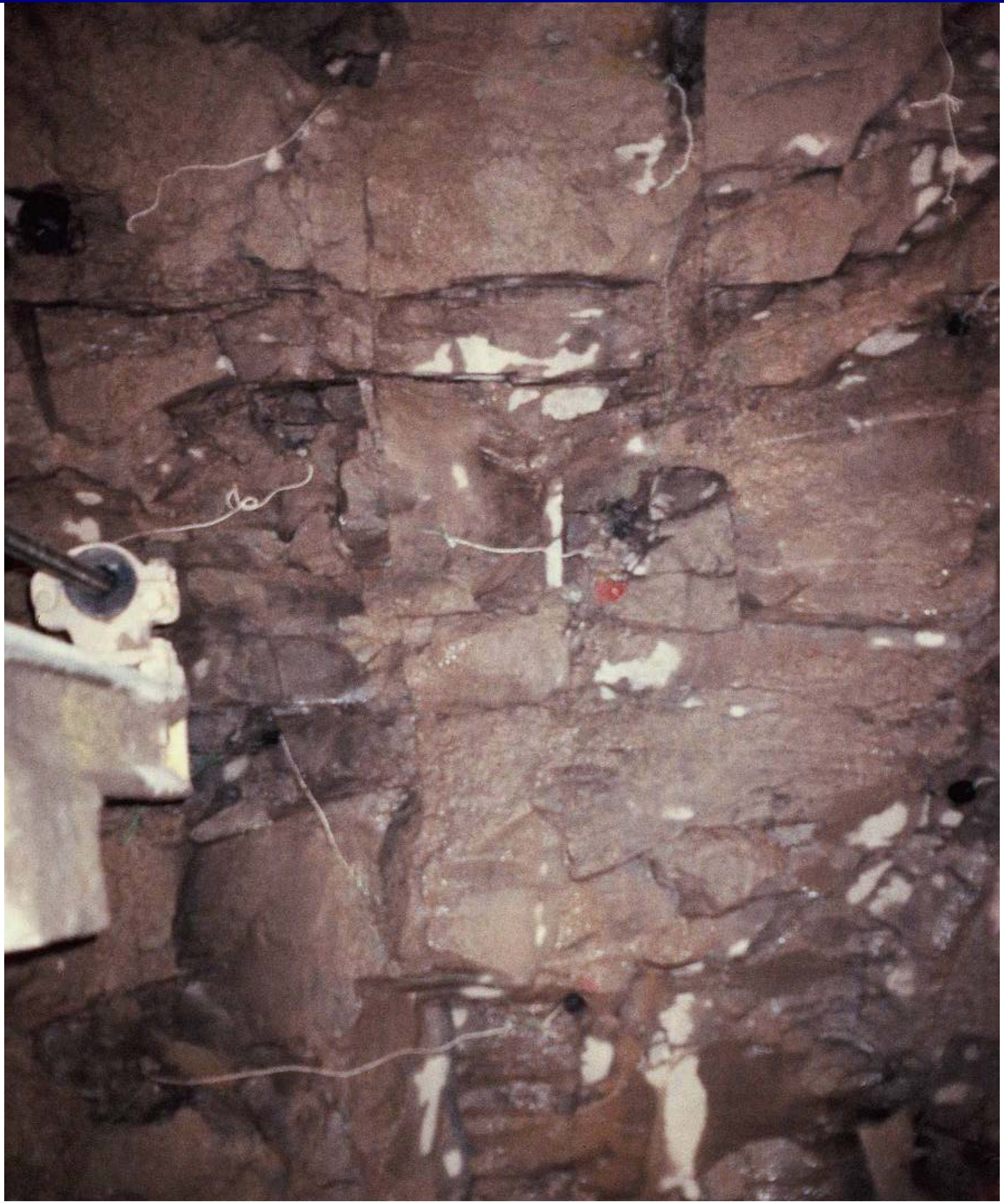
Outer Lining

Section type	RMR	Shotcrete thickness	Anchor bolt		
			Length	Mesh	Pattern
A	40 - 50	15 cm	4.5 m	2.25 m^2	1.5m x 1.5m
B	30 - 40	15 cm	4.5 m	2.00 m^2	1.22m x 1.22m
C	20 - 30	15 cm	5 m	1.00 m^2	1.0m x 1.0m
D	15 - 20	20 cm	6 m	1.00 m^2	1.0m x 1.0 m

Central Top Heading-Stage 1

Top Heading-Stage 1

Best Rock Mass Conditions

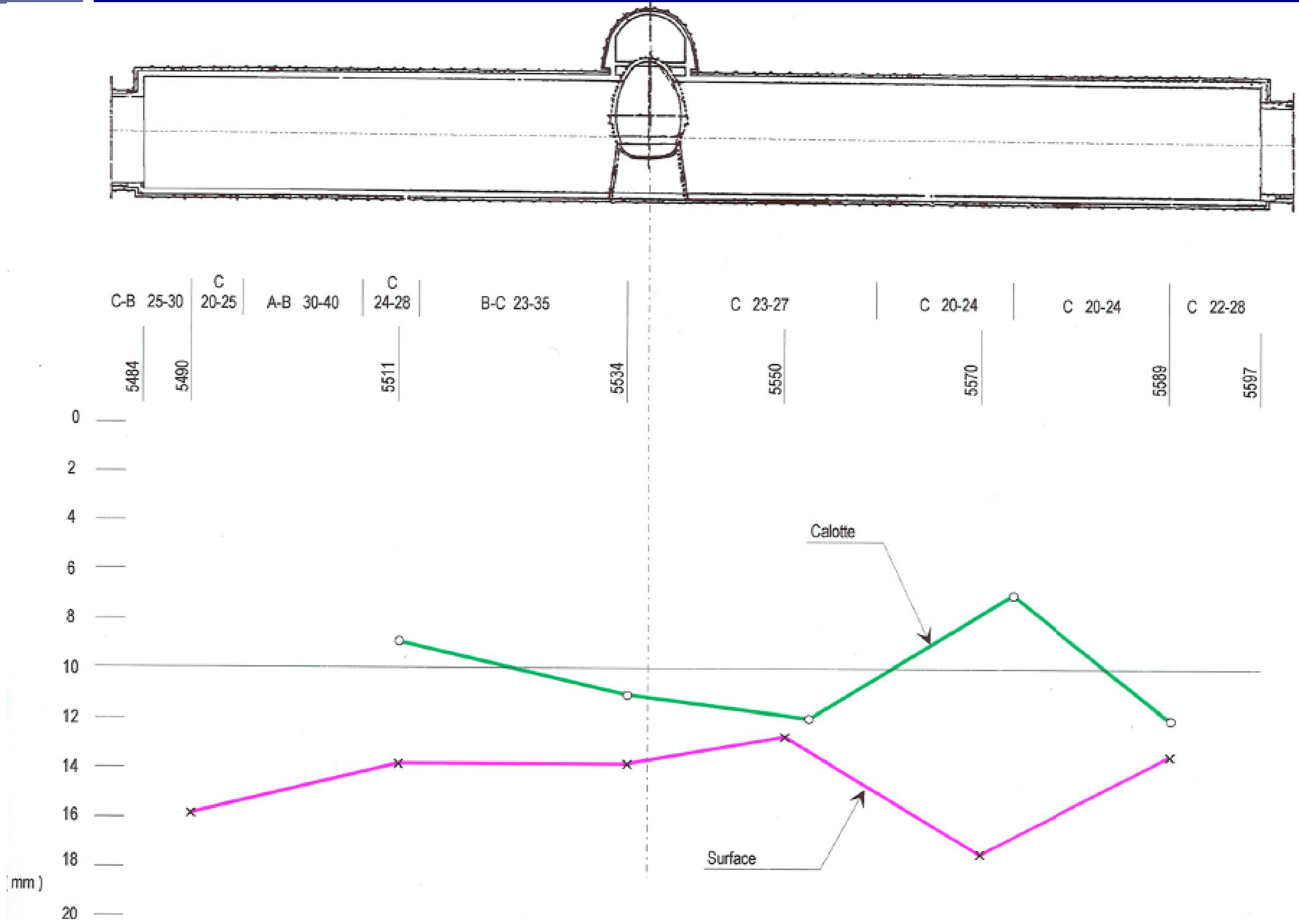


Top Heading –Stage 2

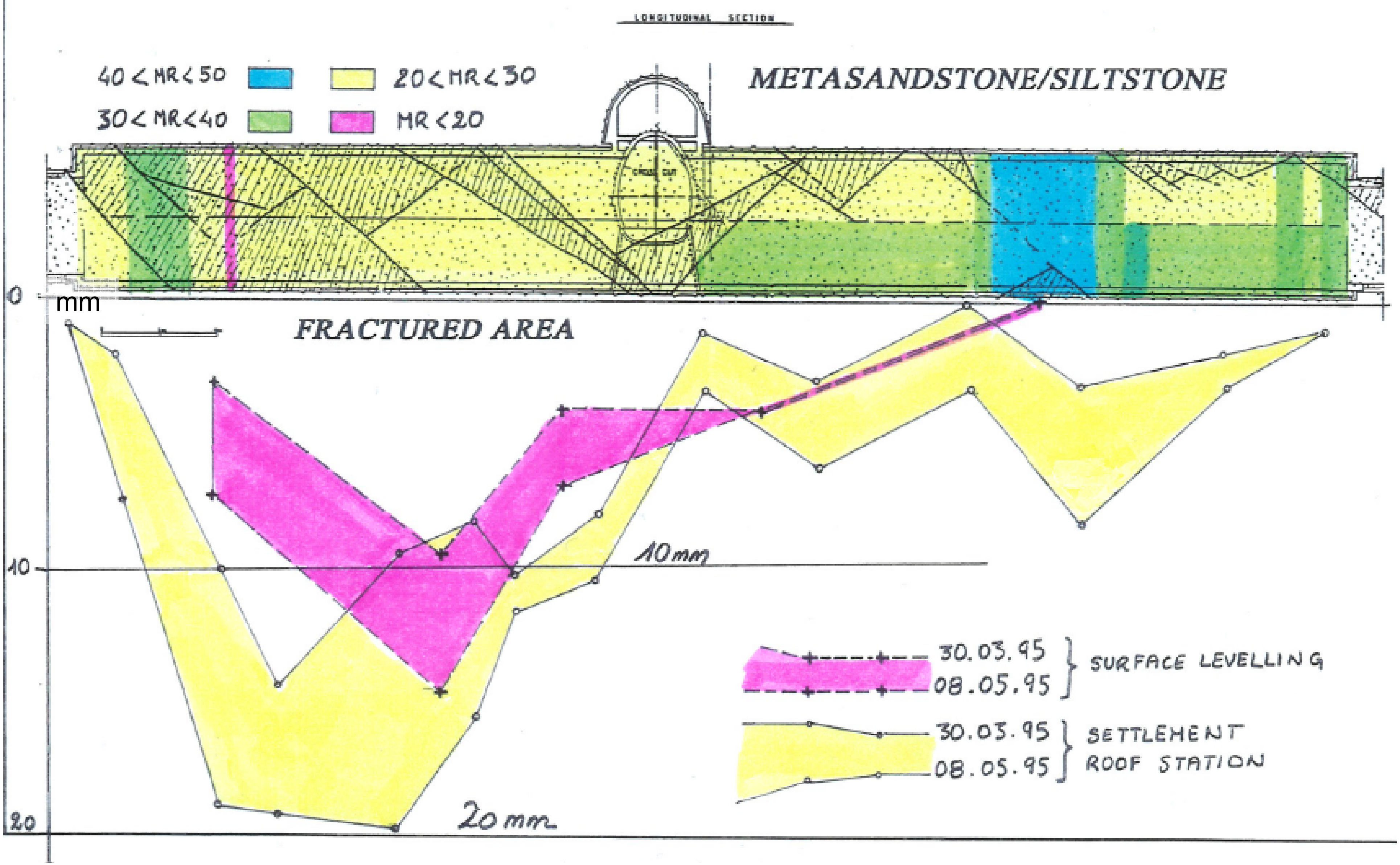
Top Heading –Stage 2

Stross Excavation-Stage 3

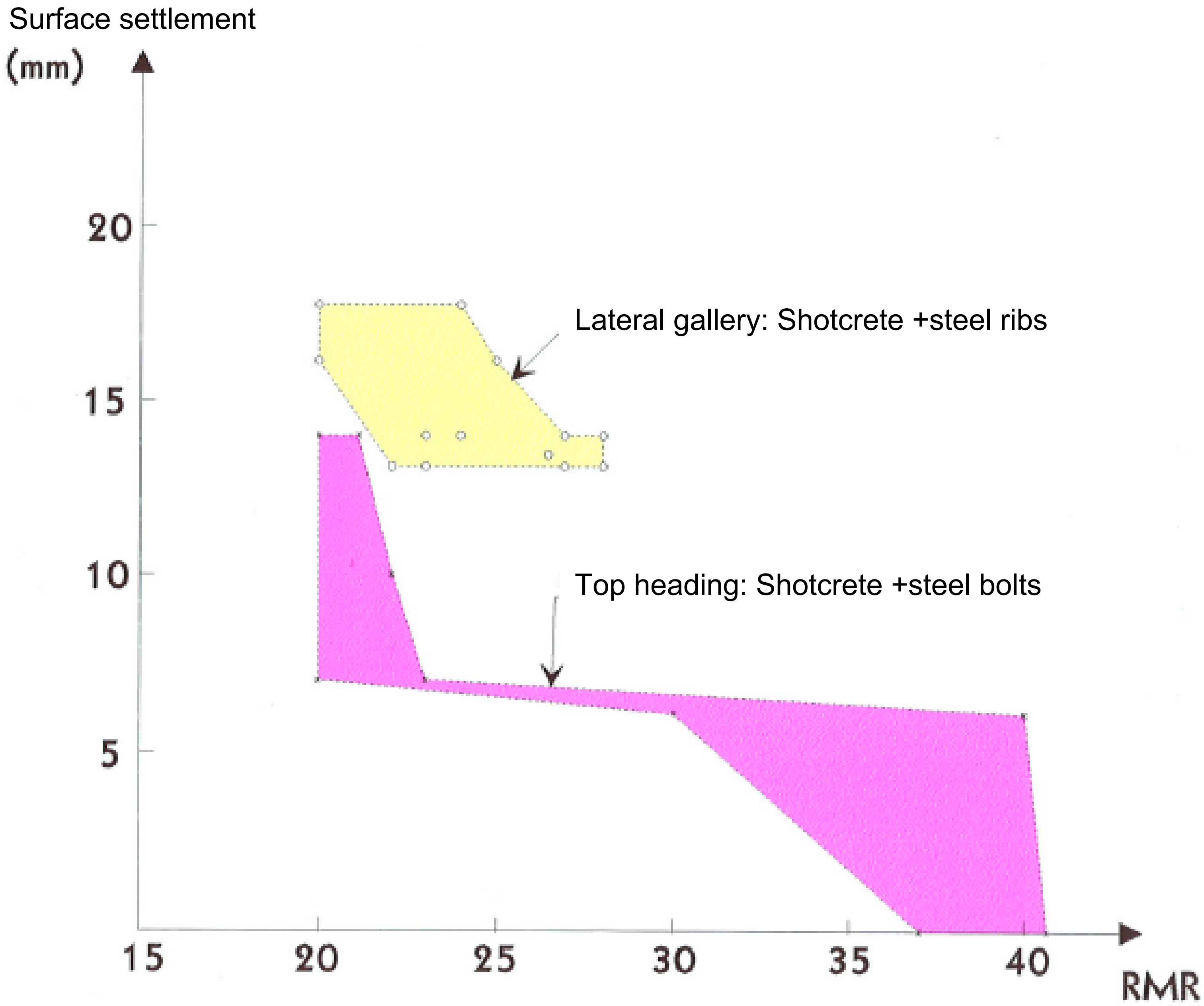
Stiff Lining - Settlements



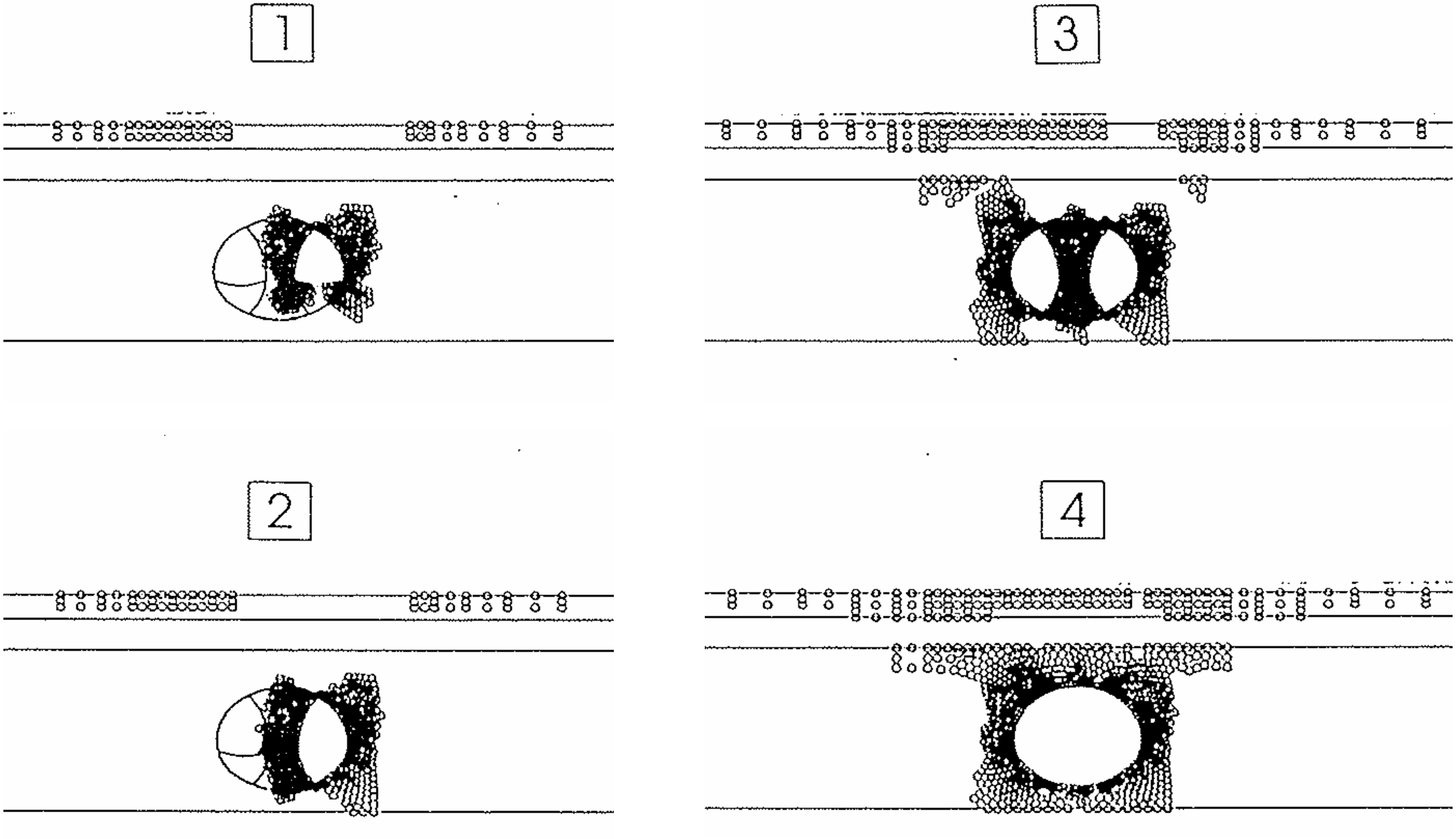
Flexible Lining- Settlements



Surface Settlements versus RMR

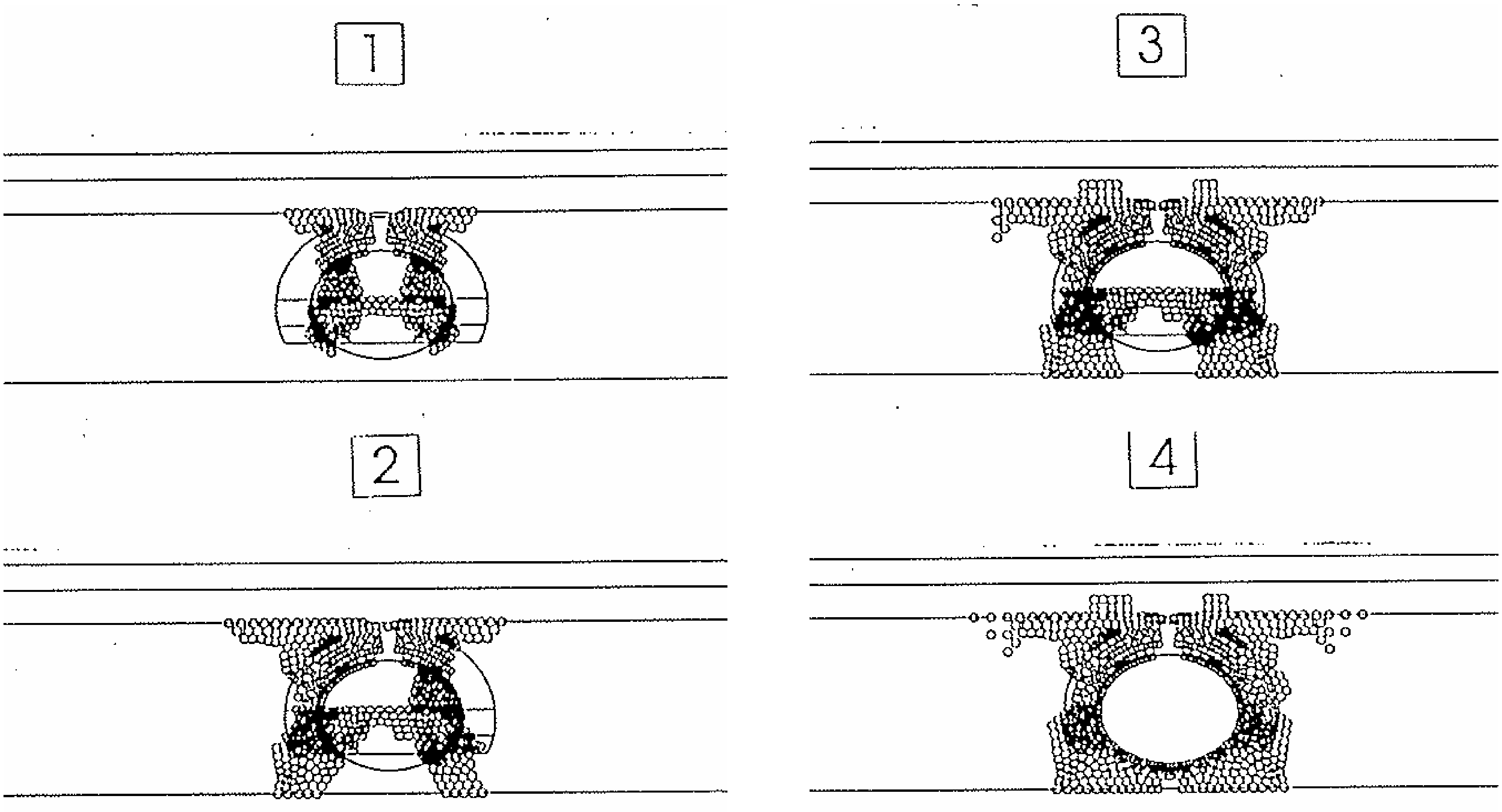


Stiff Lining – FEM Modeling Results



S.C.L – Plastified Zone during Excavation Stages

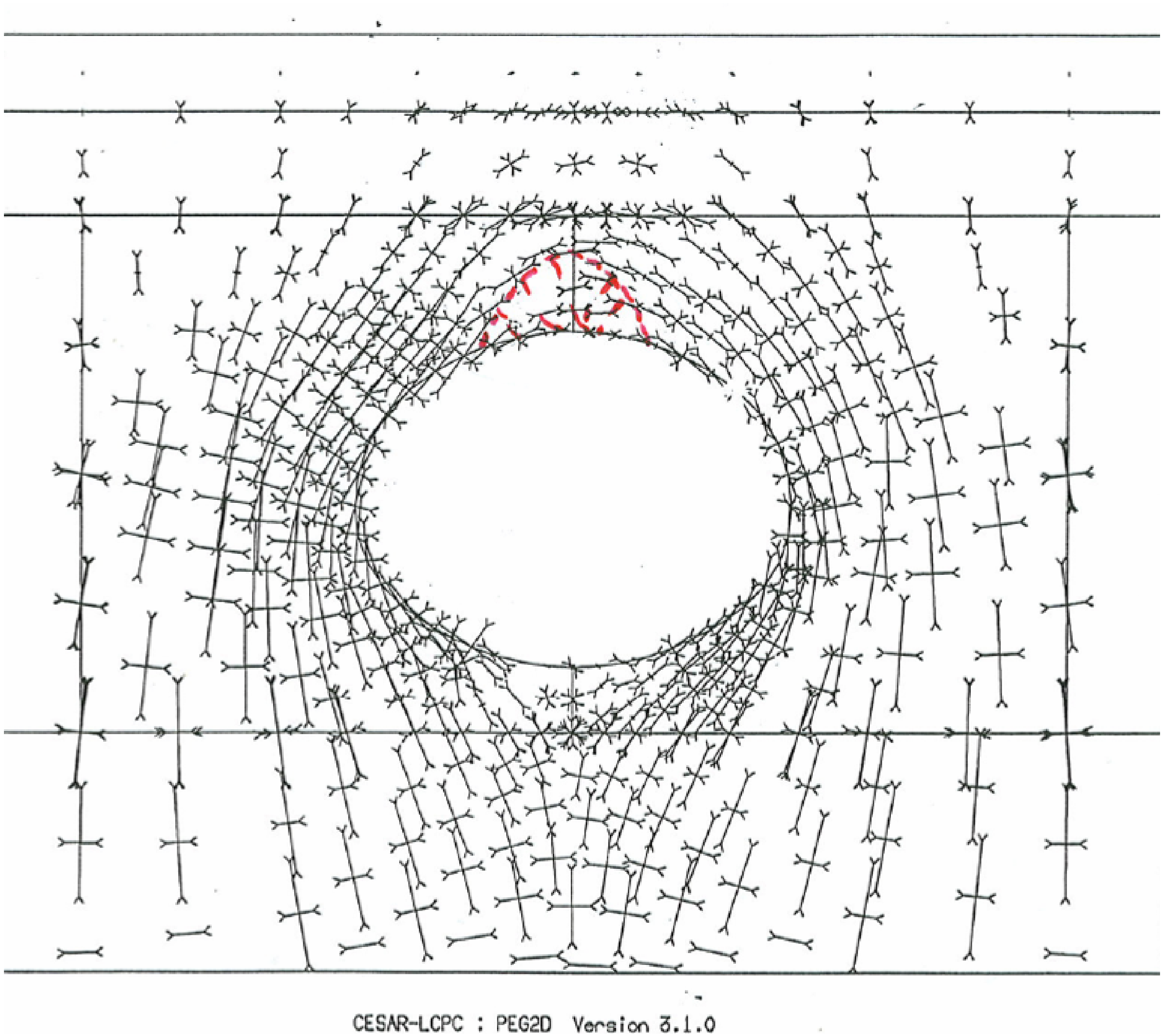
Flexible Lining- FEM Modeling Results



N.A.T.M – Plastified Zone during Excavation Stages

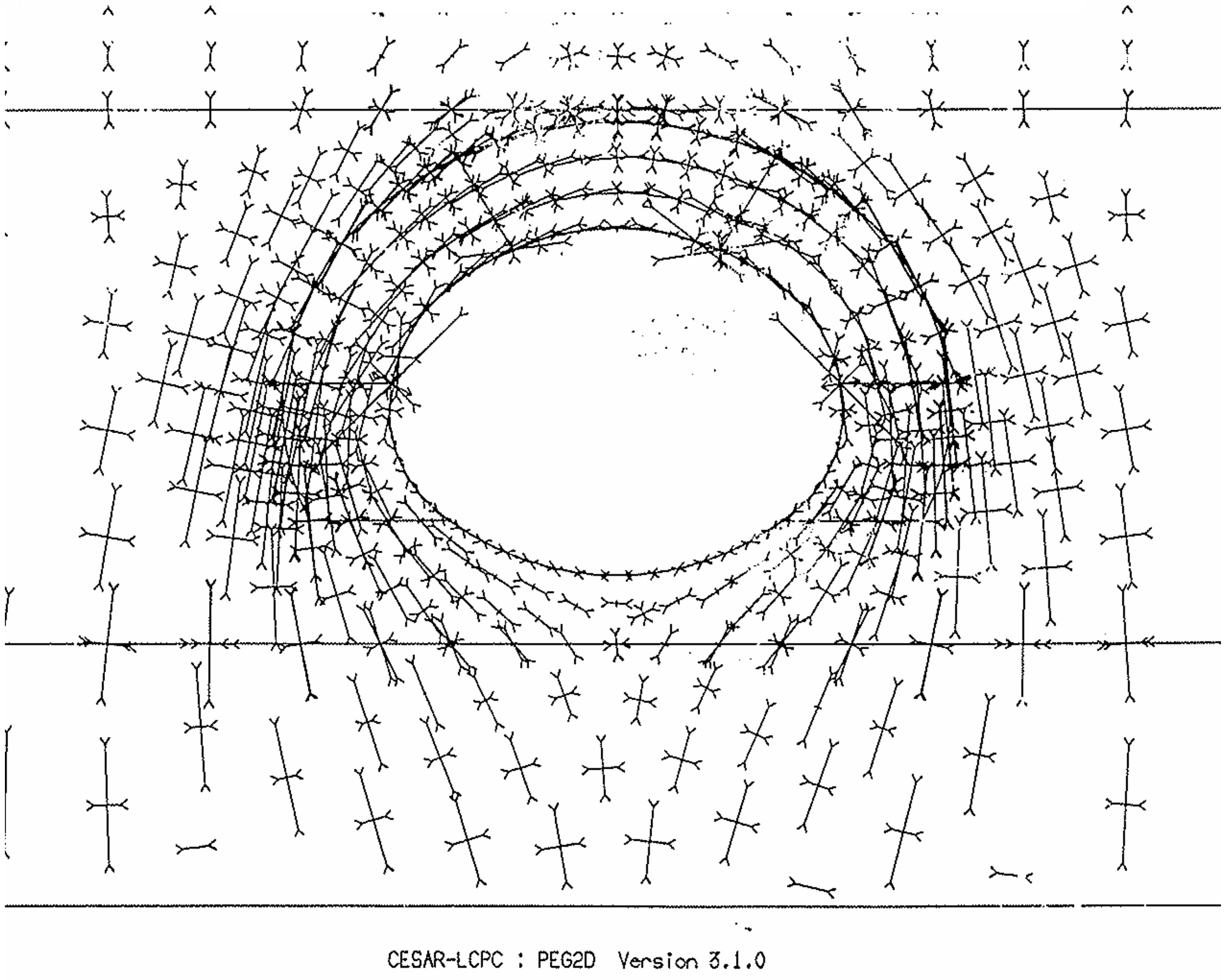
Stiff Lining- Stress Field

S.C.L: Shotcrete + steel ribs



Flexible Lining –Stress Field

Shotcrete+ bolts

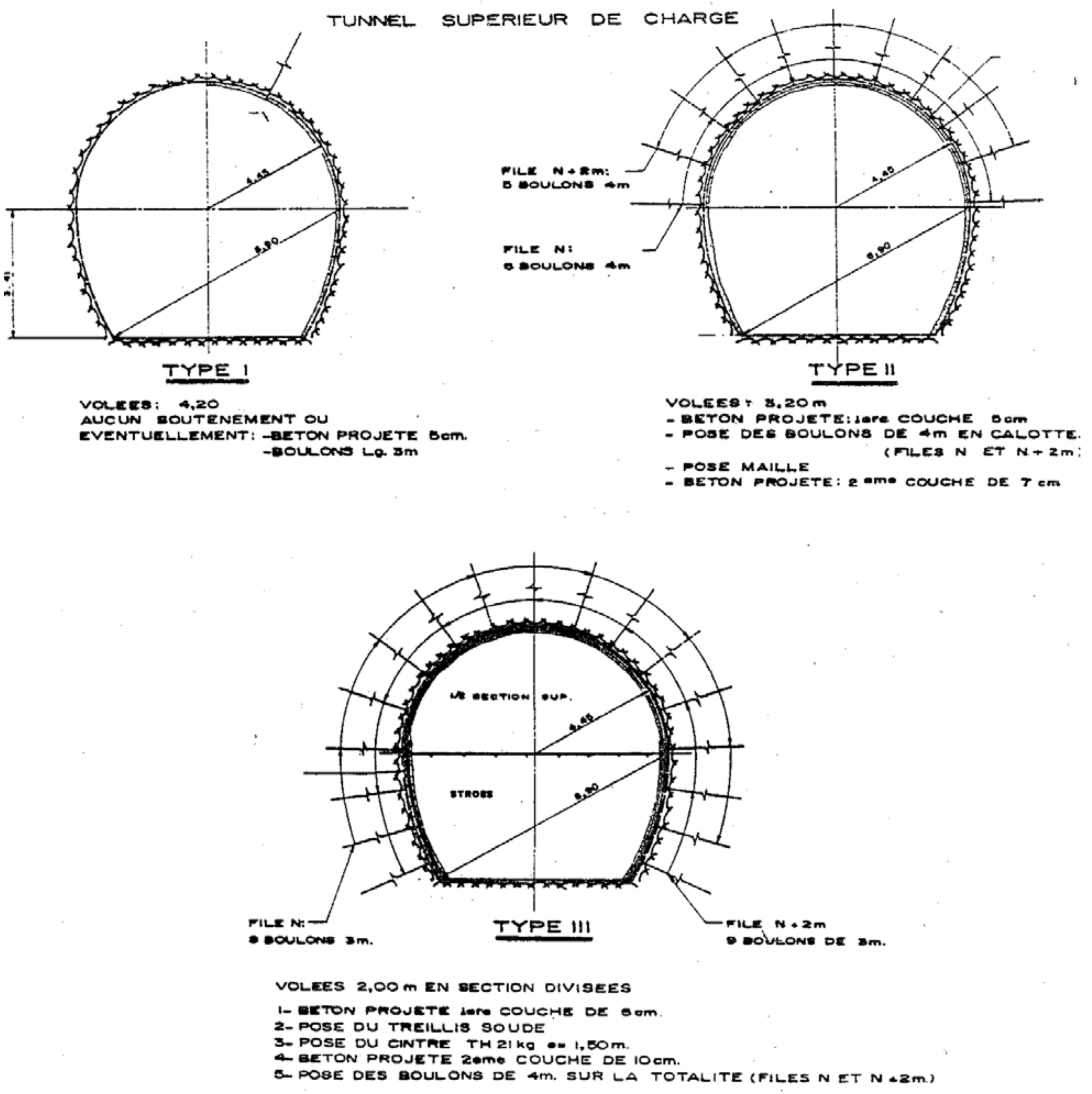


HIGH OVERBURDEN

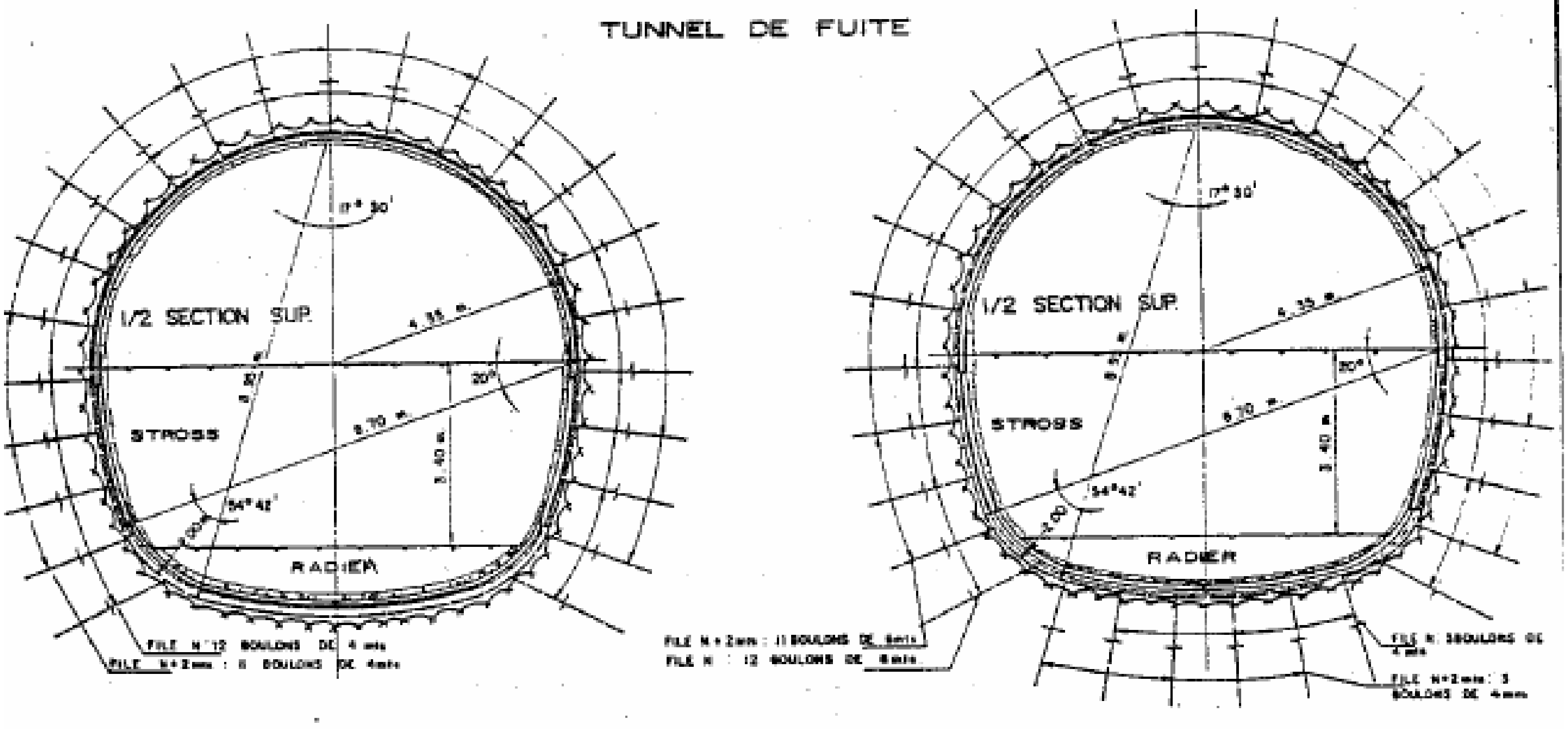
Guavio Hydro Power Project, Columbia

- 1600MW Underground Power Cavern
- 13km Headrace Tunnel(60 m²)
- 3km Lower Headrace Tunnel (60 m²)
- 5 km Tailrace Tunnel(60 m²)
- 4km Acces Tunnel
- 4x500m 4.6 to 7.1m diam Vertical Shafts

Headrace Tunnel -Supports



Tailrace Tunnel -Supports



. TYPE IV .

VOLÉES : 1.50 m. EN SECTIONS DIVISEÉS

- BÉTON PROJETÉ 1ère COUCHE DE 5 Cms.
- POSE DU TREILLIS SOUDE
- POSE CINTRE TH 21 Kg e= 1.00 m.
- BÉTON PROJETÈ 2e COUCHE DE 10 Cms
- POSE DES BOULONS DE 4 m. (file N et N+2 m.)
- BÉTON PROJETÉ DE 5 à 10 Cms.

. TYPE V .

VOLÉES : 1.20 EN SECTIONS DIVISEÉS

- BÉTON PROJETÉ 1ère COUCHE DE 5 Cms.
- POSE DU TREILLIS SOUDE.
- POSE CINTRE TH 21 Kg e= 0.75 m.
- BÉTON PROJETÈ 2e COUCHE DE 10 Cms
- POSE DES BOULONS DE 6 m. (file N et N+2 m.)
- POSE DES BOULONS DE 4 m (file N et N+2m. Xa...)
- BÉTON PROJETÉ 3e COUCHE DE 5 à 10 Cms

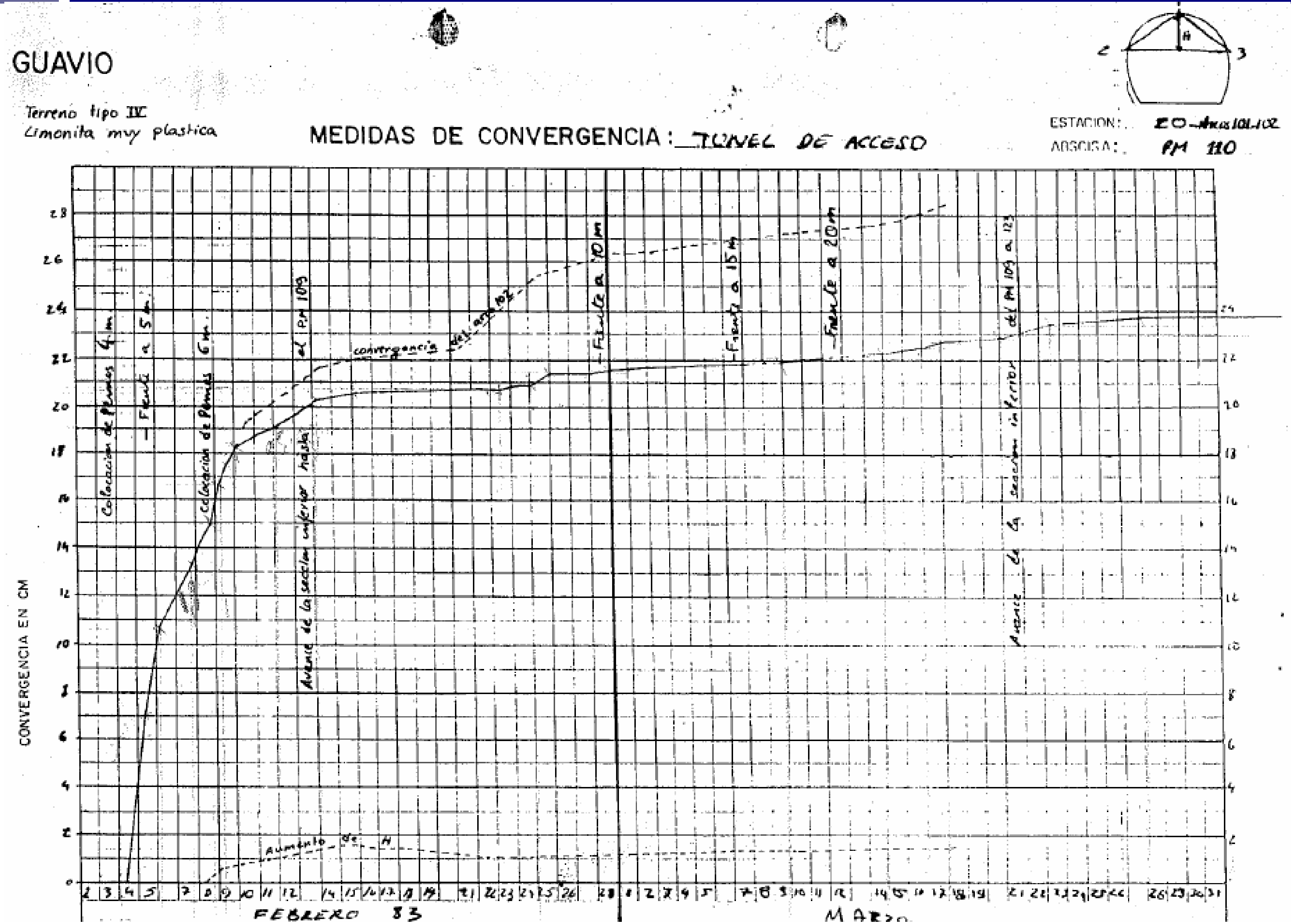
Access Tunnel – Santa Marta Fault

Santa Marta Fault in Lutita

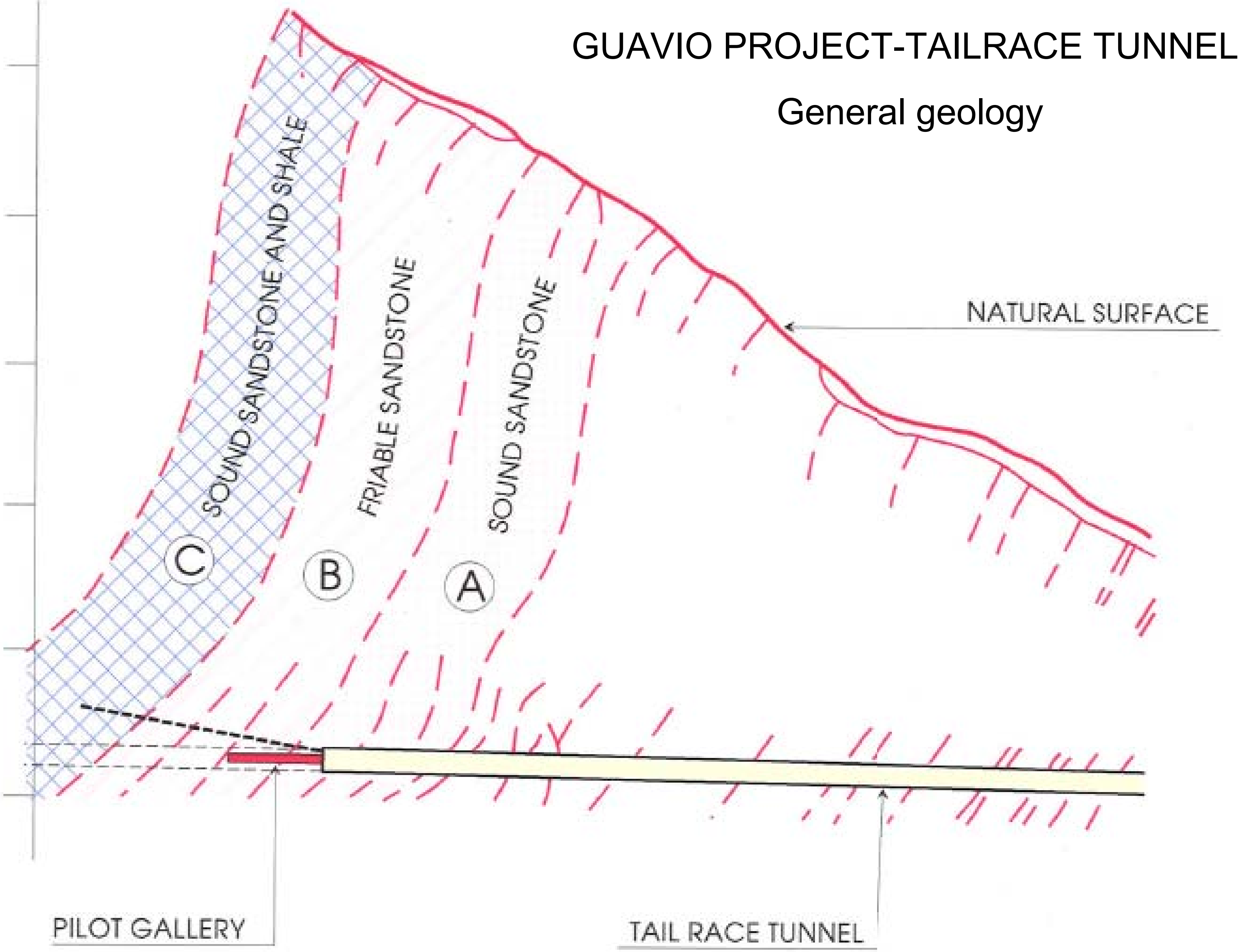
Santa Marta Fault

Santa Marta Fault -Forepoling and Drainage

Santa Marta Fault-Convergence



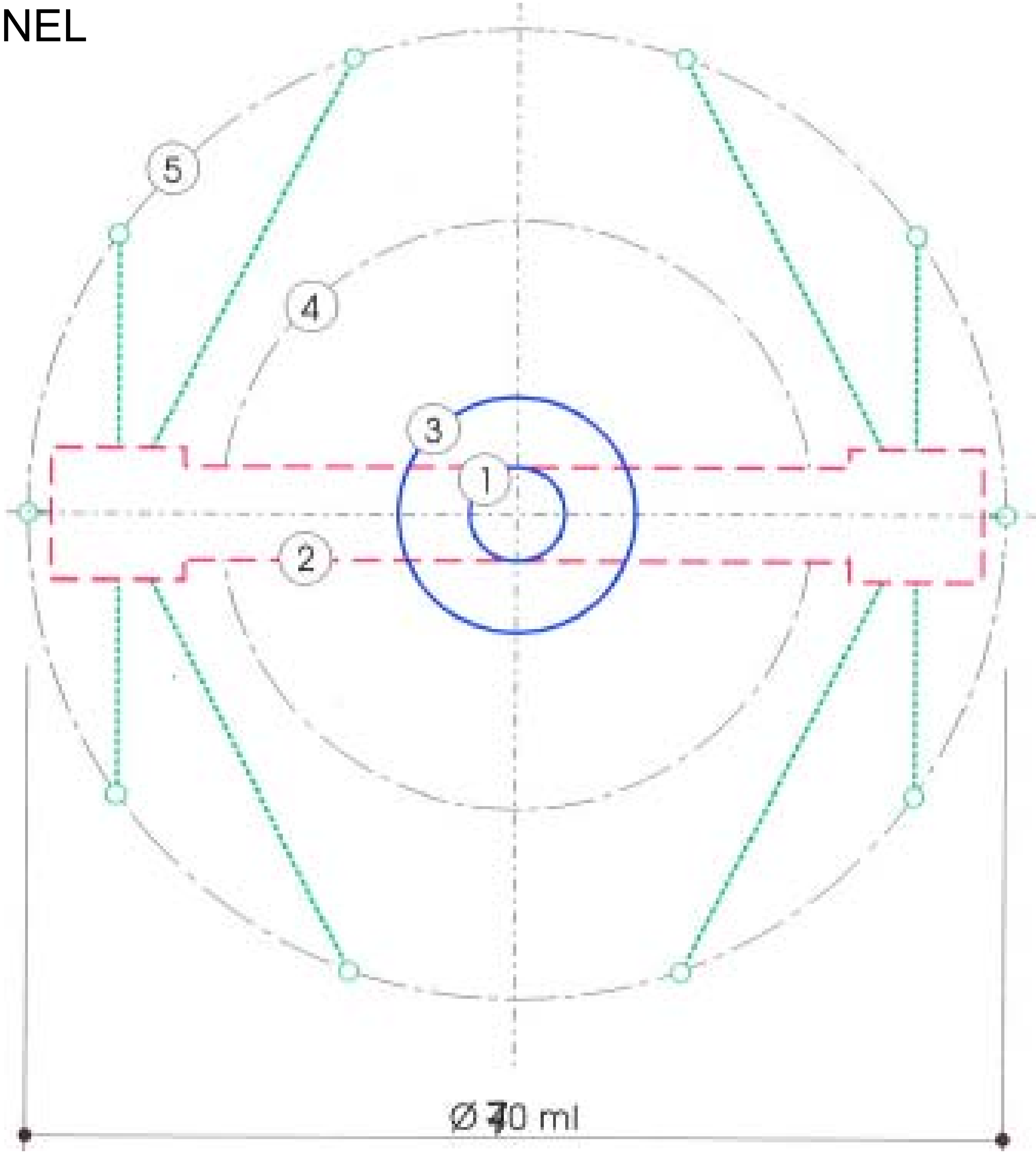
Tailrace tunnel –Main Collapse Area



Treatment Layout

GUAVIO PROJECT-TAILRACE TUNNEL

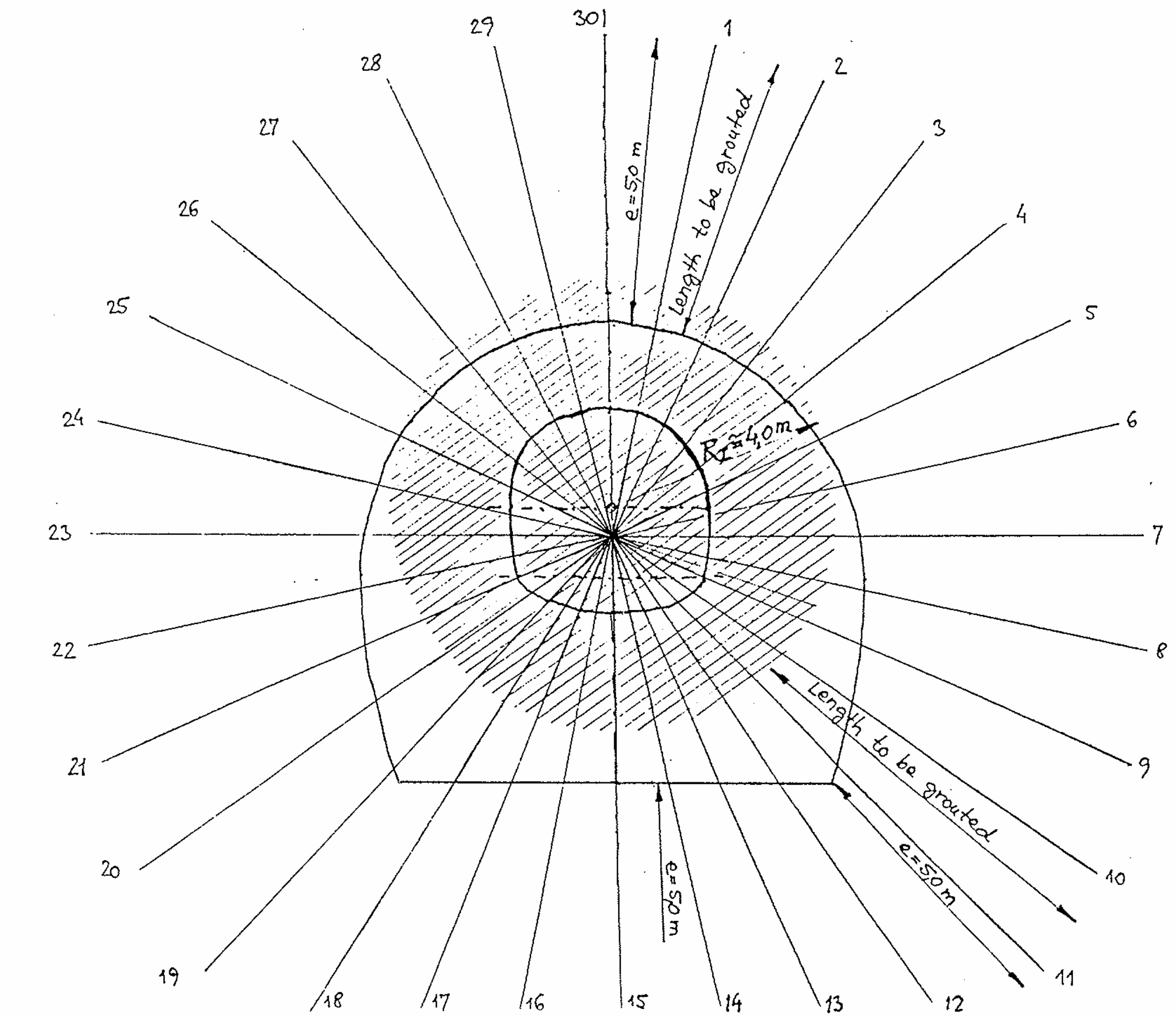
Drainage treatment works



1. Pilot tunnel Ø 4m
2. Drainage recess Ø 4m
3. Widen tunnel to Ø 10m
4. Treated ring Øext 10m
5. Average distribution of the drains from the working recess

Pilot Gallery-Treatment

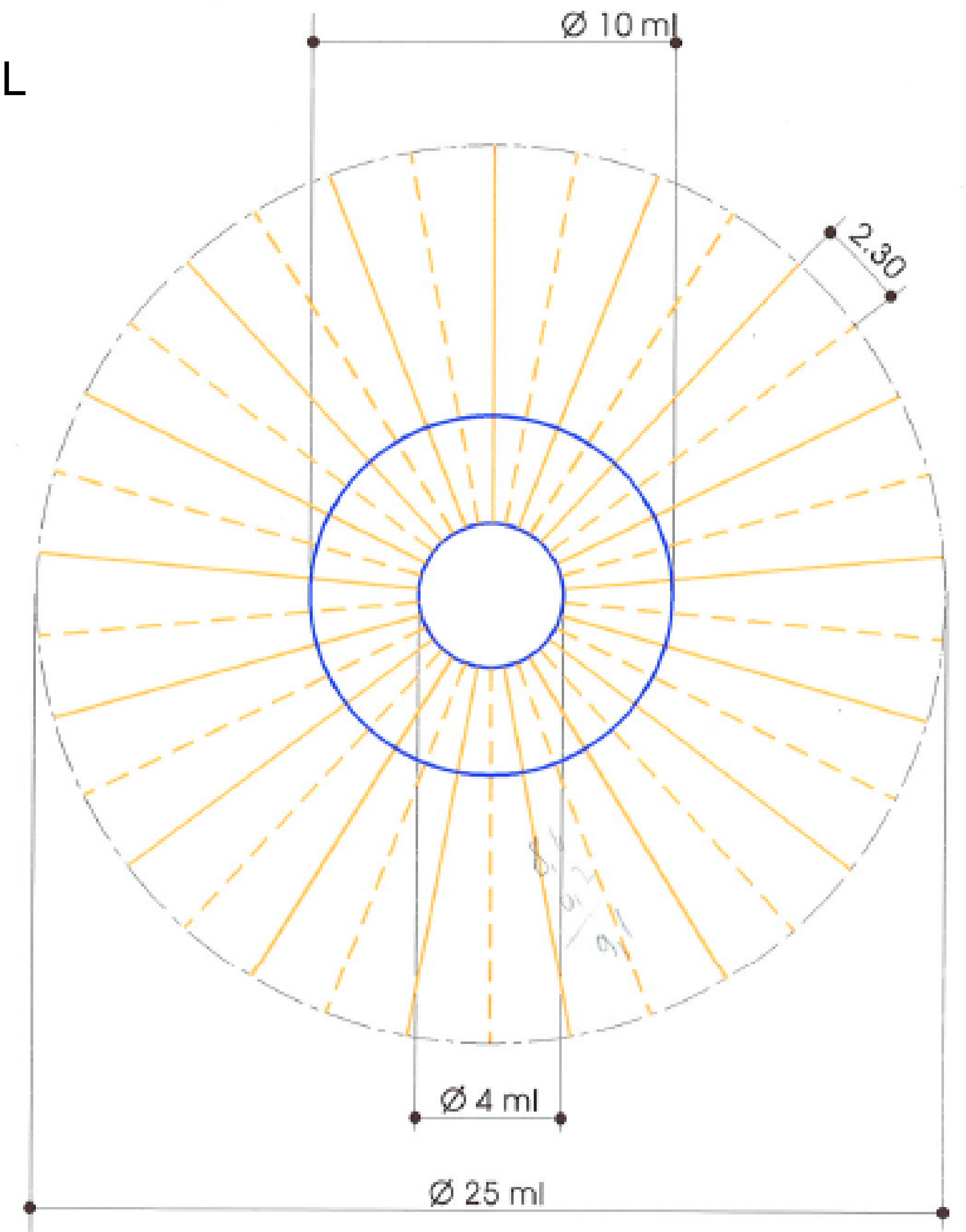
Radial grouting for section tunnel



Pilot Gallery- Grouting Works

GUAVIO PROJECT-TAILRACE TUNNEL

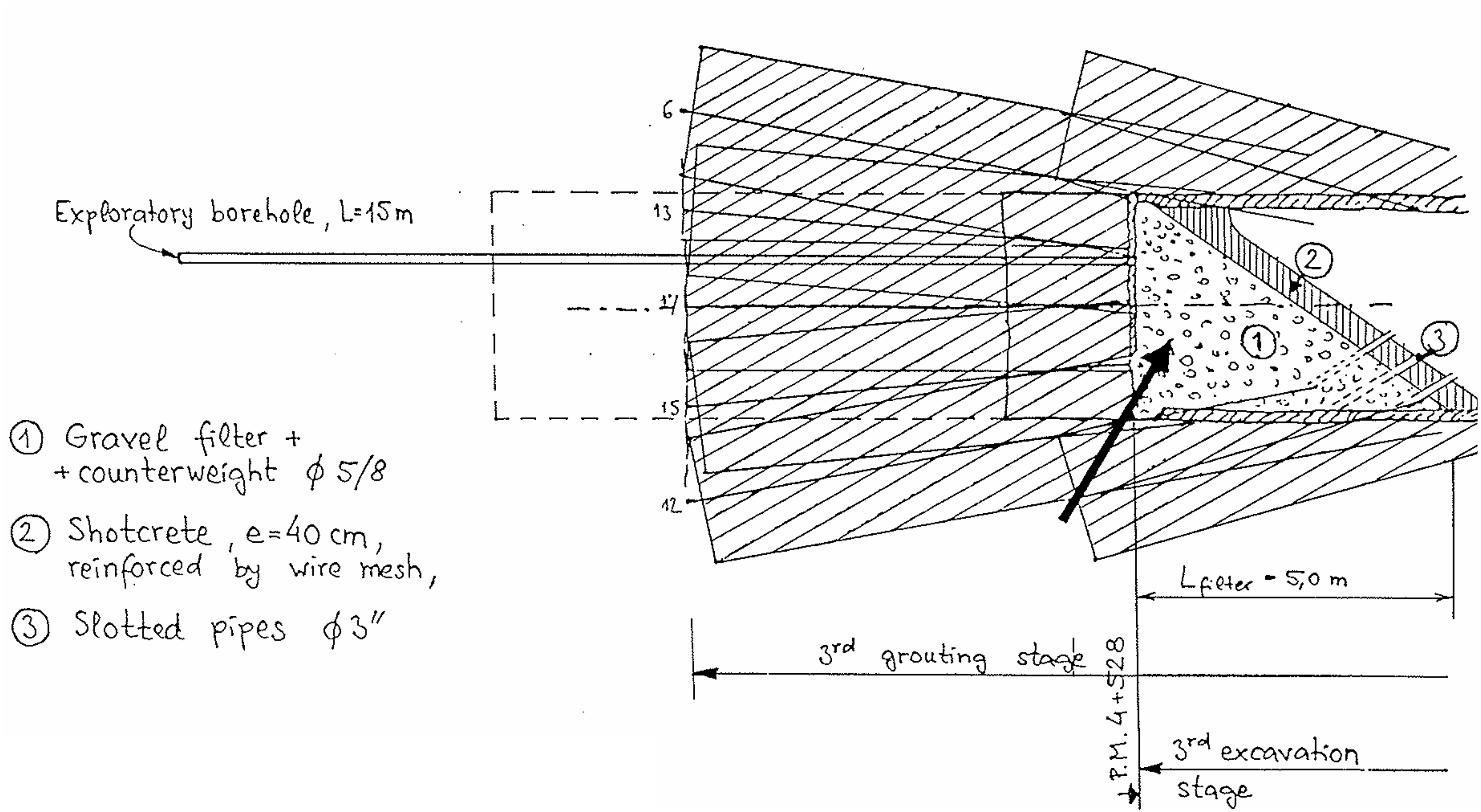
Grouting works



Pilot Gallery-Face Grouting

Proposed immediate measures

Longitudinal section



Pilot Gallery

Pilot Gallery- Grouting Tubes

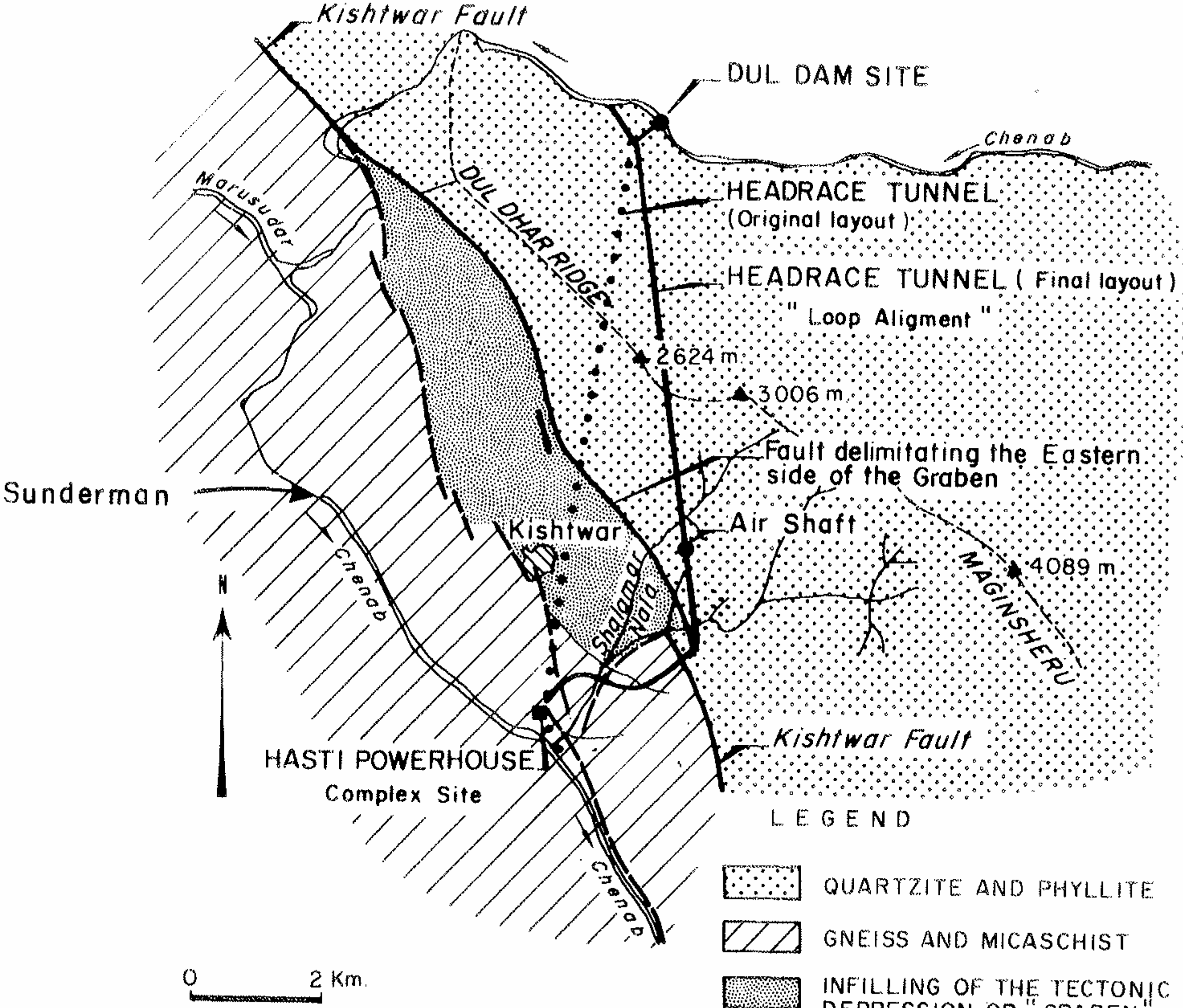
Completed Pilot Gallery

HIGH OVERBURDEN

Dul Hasti Hydro Power Project, India-Cashmir

- 390MW Underground Cavern
- 10.6km long 7.7m inner diameter Headrace tunnel
- 1020m Tailrace Tunnel

Project Layout



Original Geological Profile

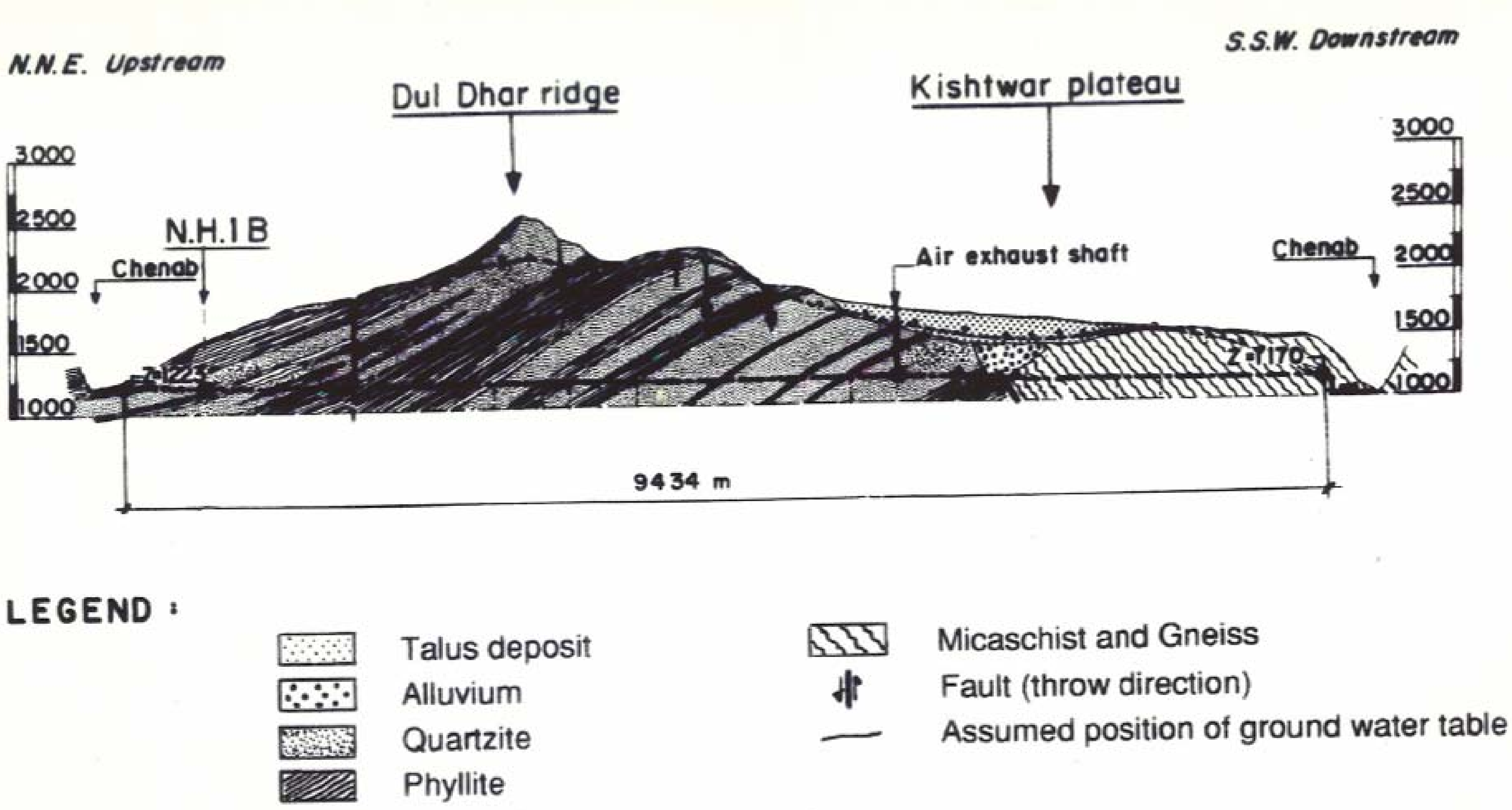
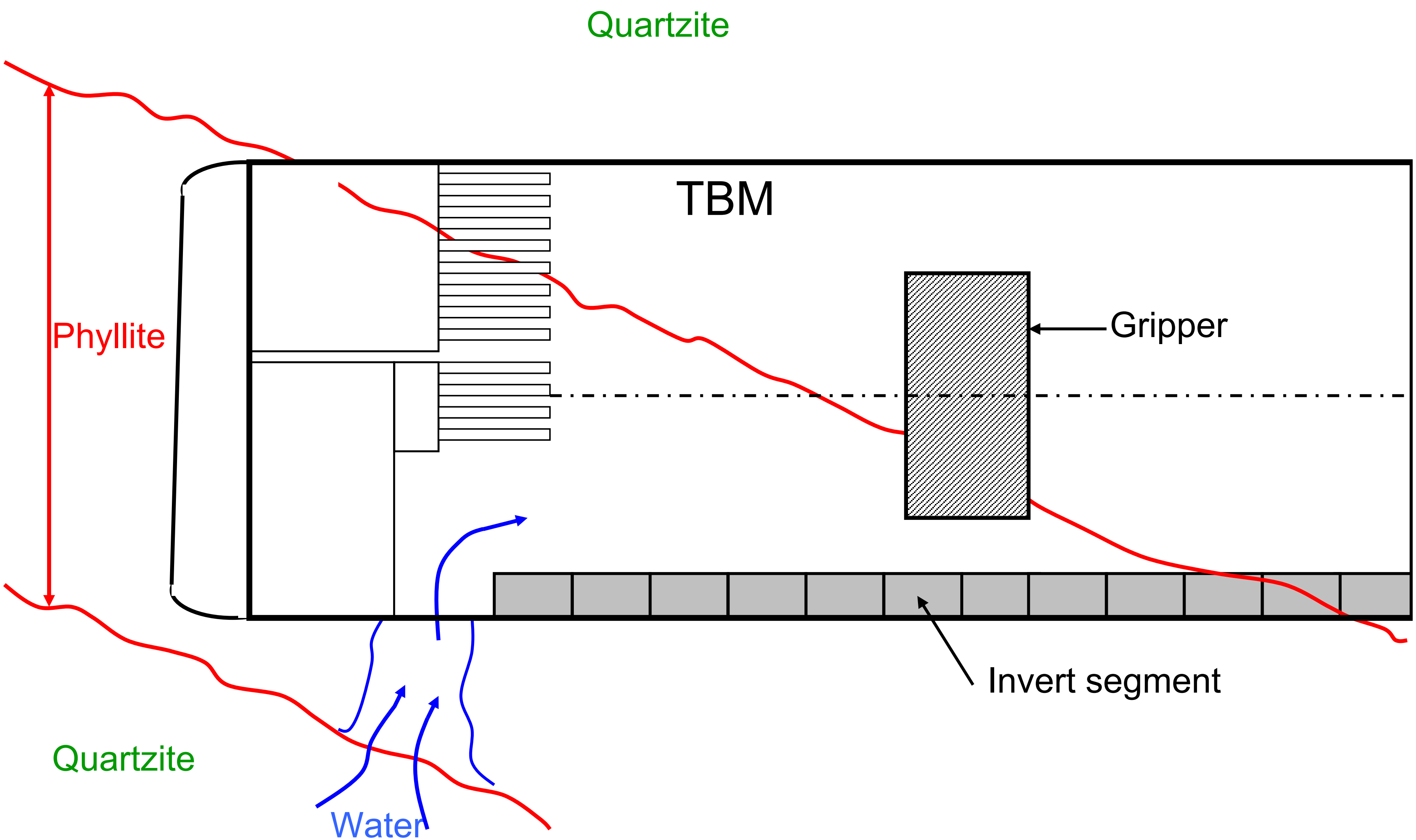
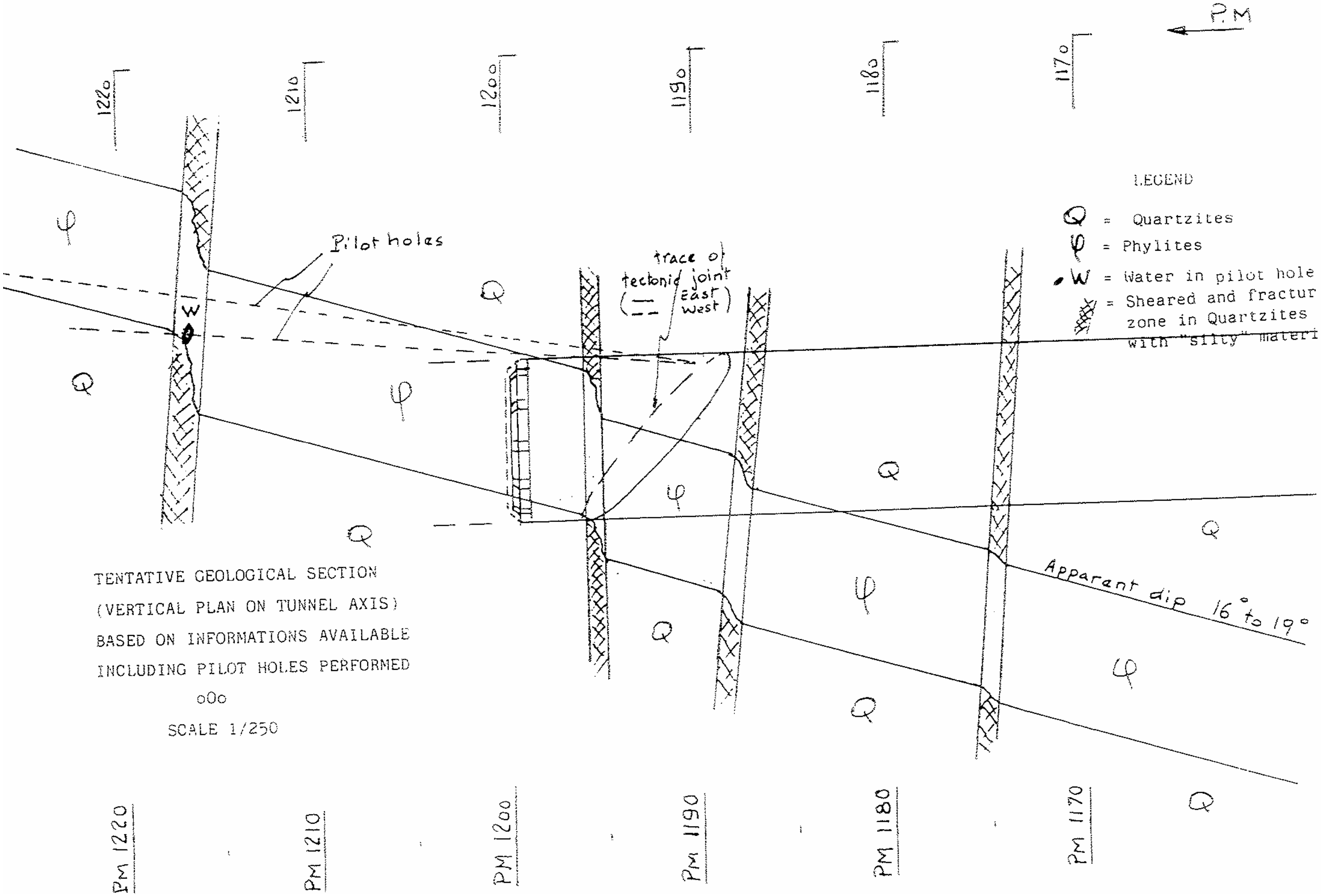


Fig. 4. Geological cross-section along the initial straight alignment of the tunnel, as known in September 1989.

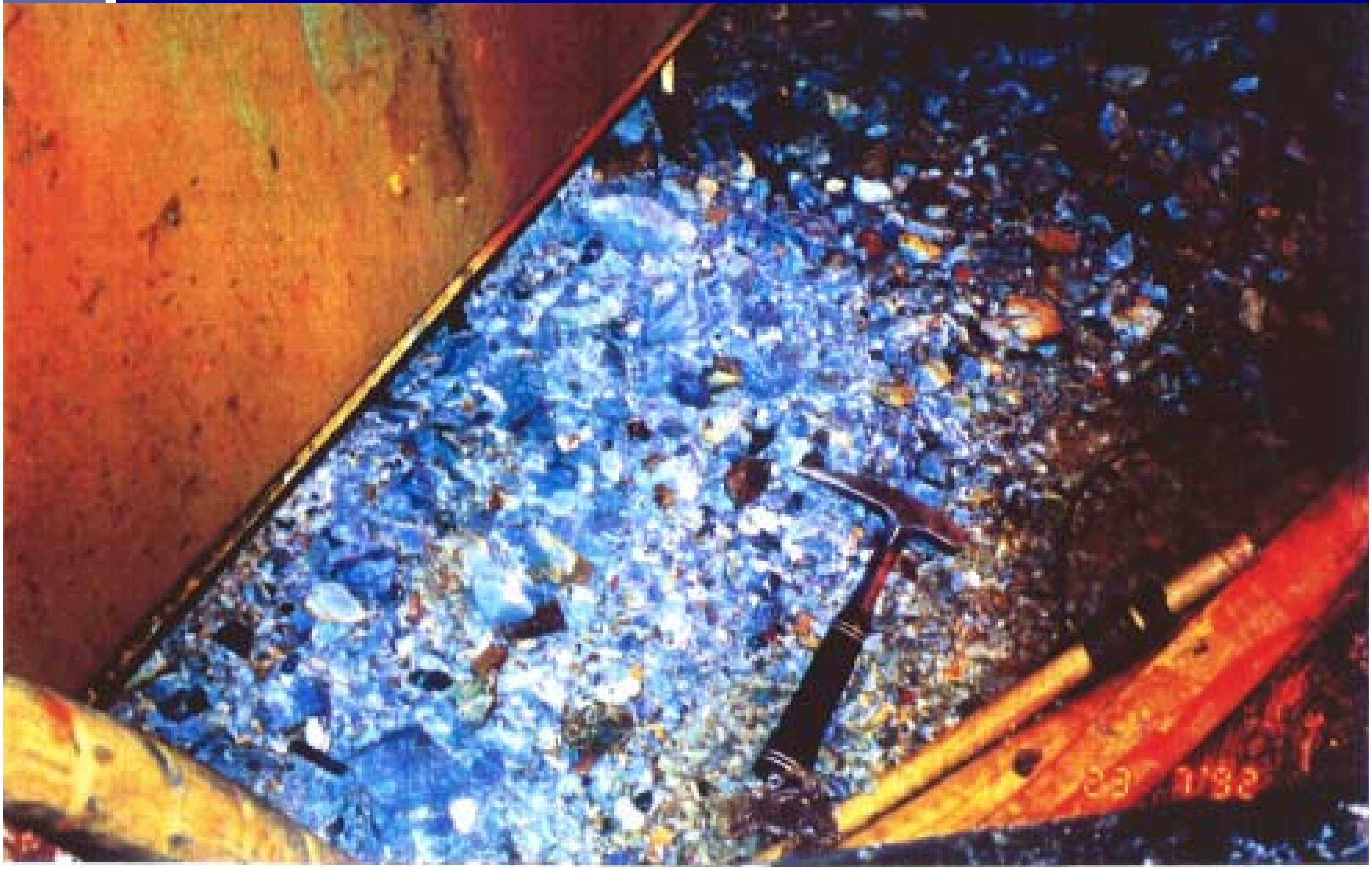
Location of Water Inflow



Estimated Geological Conditions



Rock Pieces Coming With Water Inflow

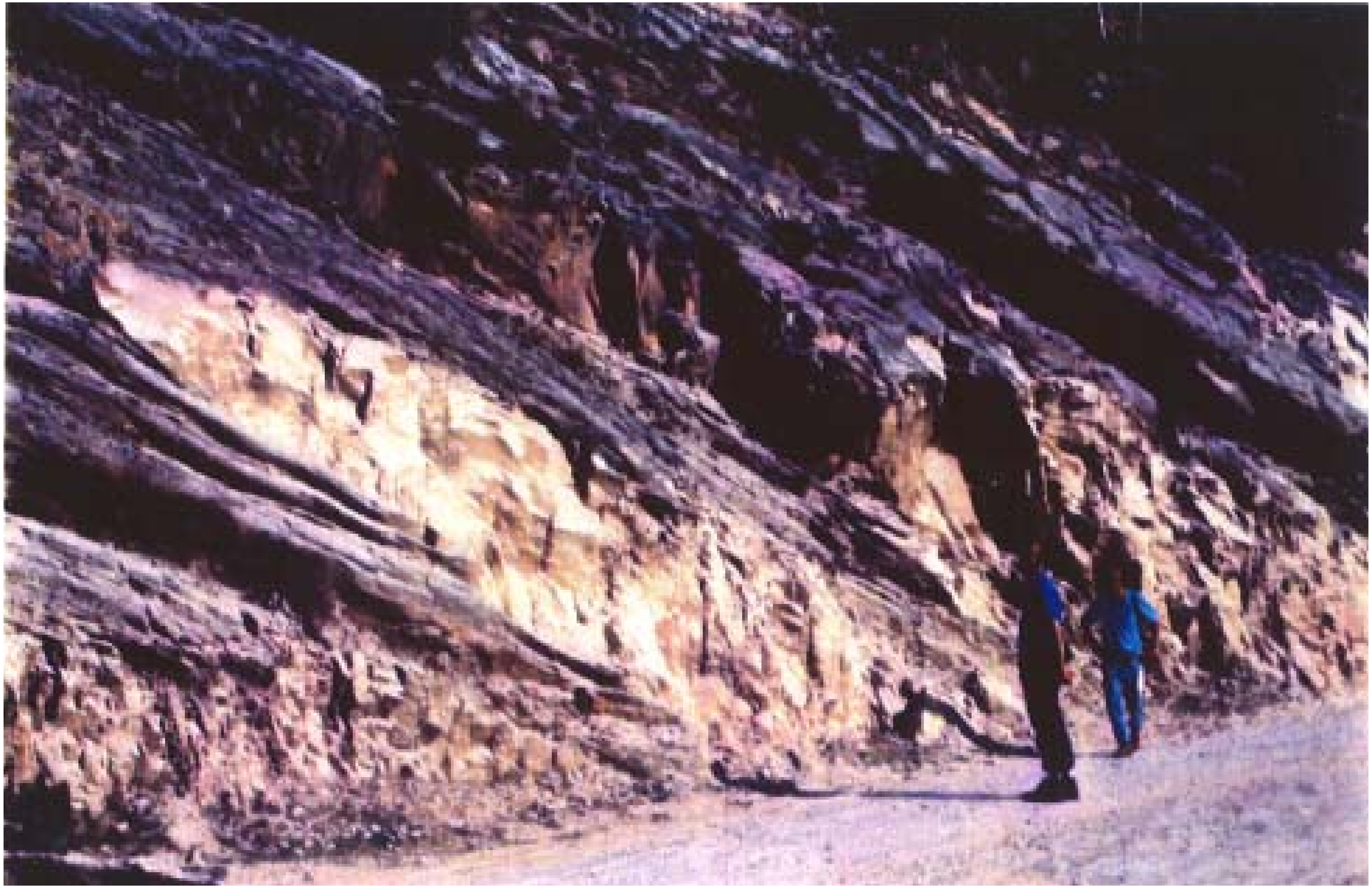


Angular pieces of quartzite and phyllite ejected from the HRT spring at chainage 1194

Typical Twisted Rock Layers

Quartzitic Mylonite(white) and Grey Phyllite

Twisted Beds



Mylonite quartzitic (white color) – phyllite (grey color) contact. DUL road, PK10

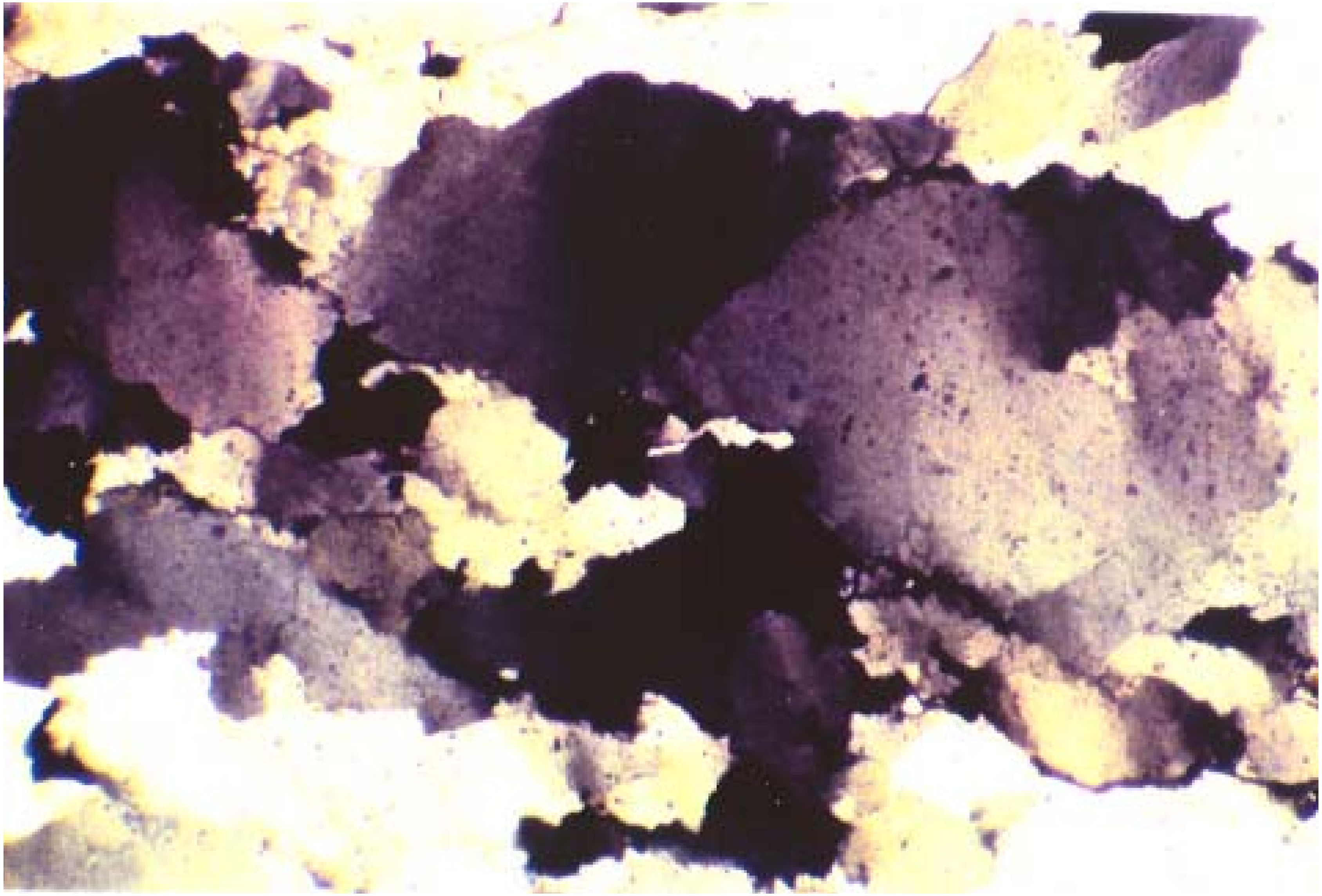
Folded Phyllite Insert in a Rock Core

SYNFODIAL FOLD

A thin phyllitic bed in quartzitic mylonite, showing the shear deformation related to mylonitisation phenomena (gallery core, PM373)

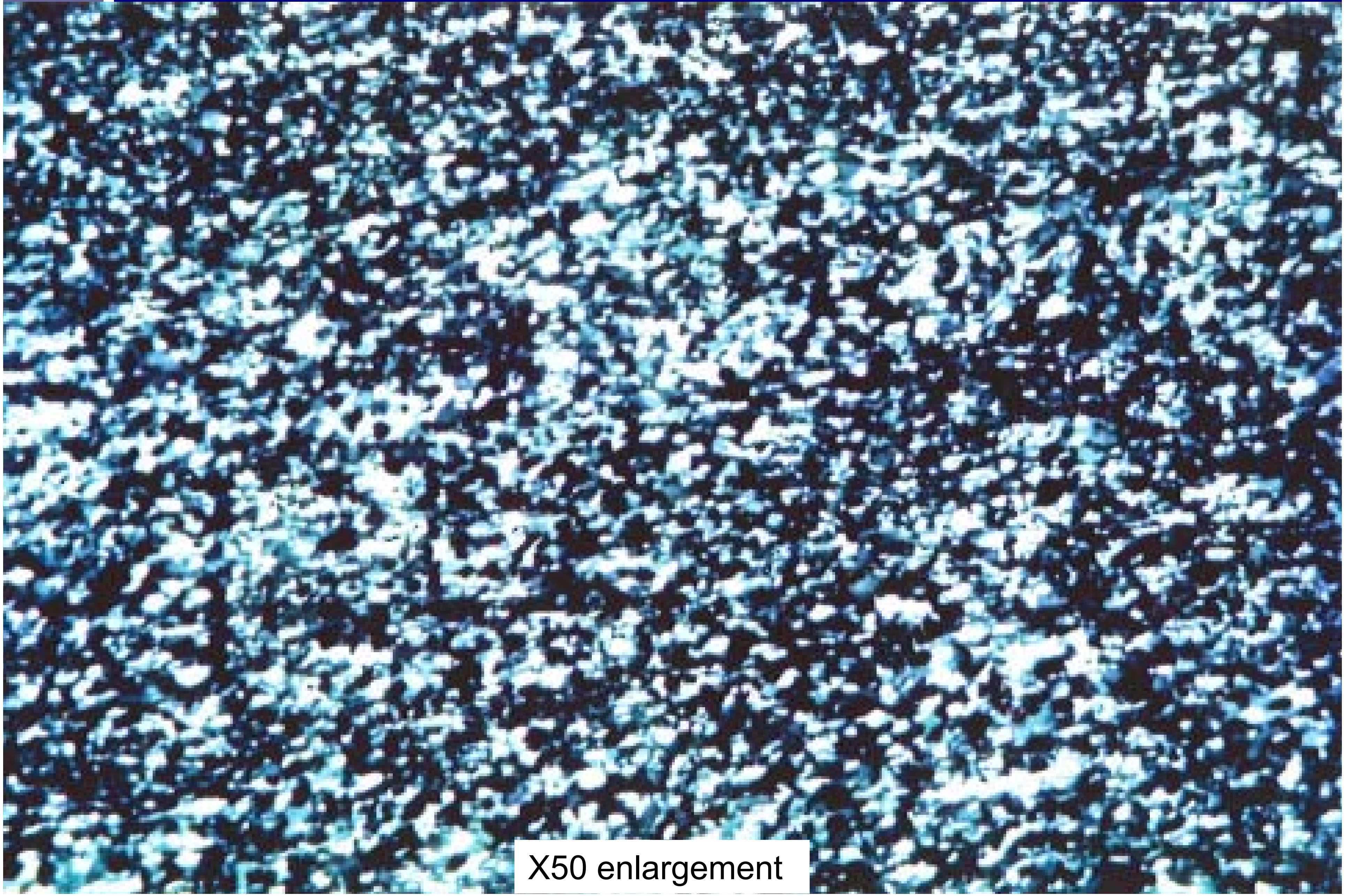
Normal Quartzite Grains

Non mylonised epimetamorphic quartzite from Cevennes (France)



X50 enlargement

Mylonized Quartzite Grains at Dul Hasti



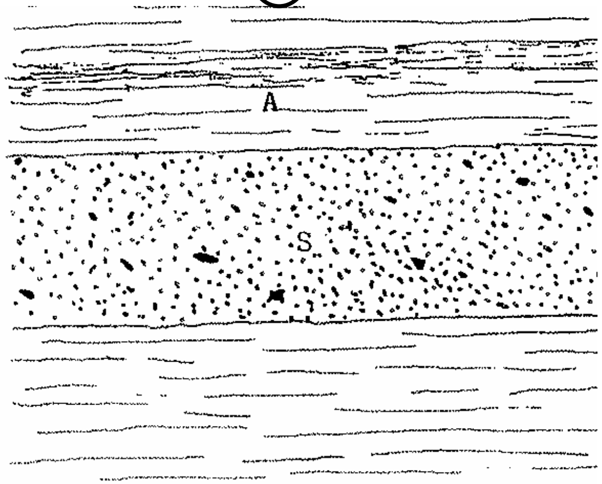
X50 enlargement

Dul Hasti Rock Mass Genesis

Massif genesis diagrams

(without scale)

1



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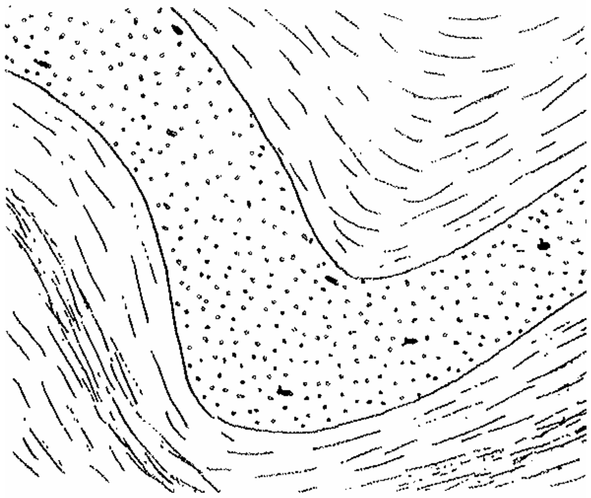

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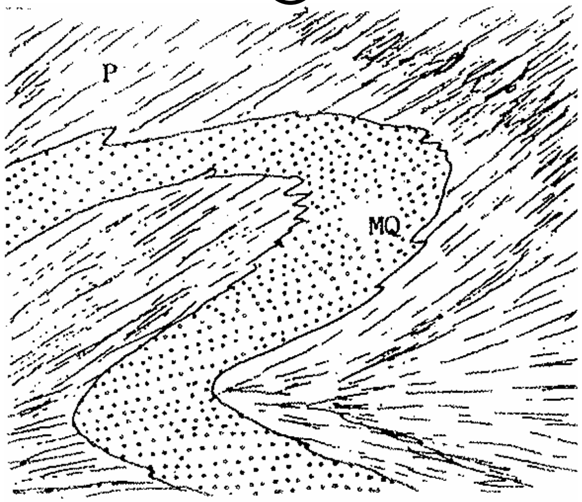

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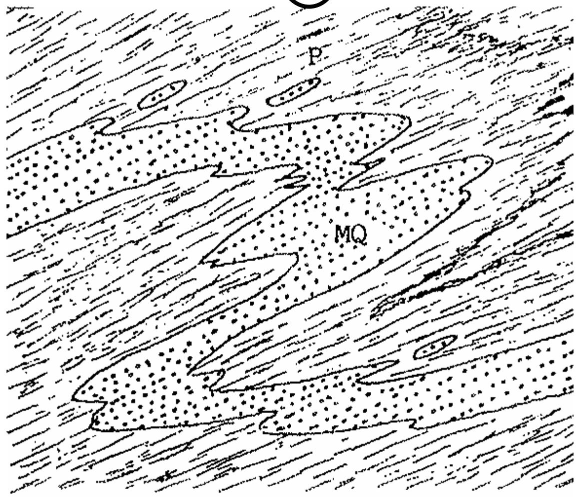

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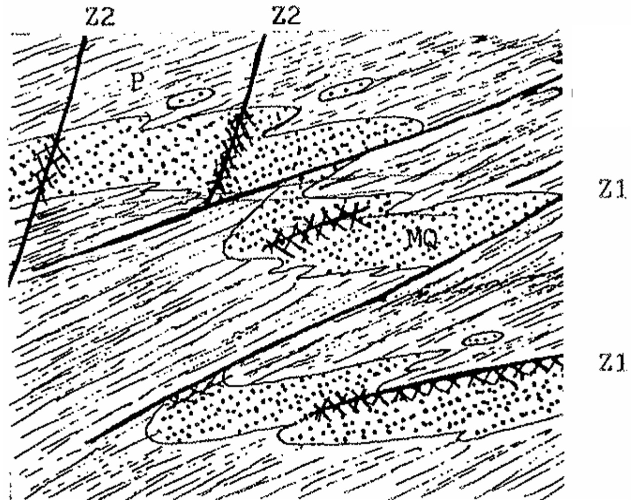


Legend

S: Sand — A : Clay

P: Phyllite — MQ : Mylonite quartzitic

Z1-Z2 : Late fractures — ⌗ : Brecciated mylonite

Revised Geological Profile

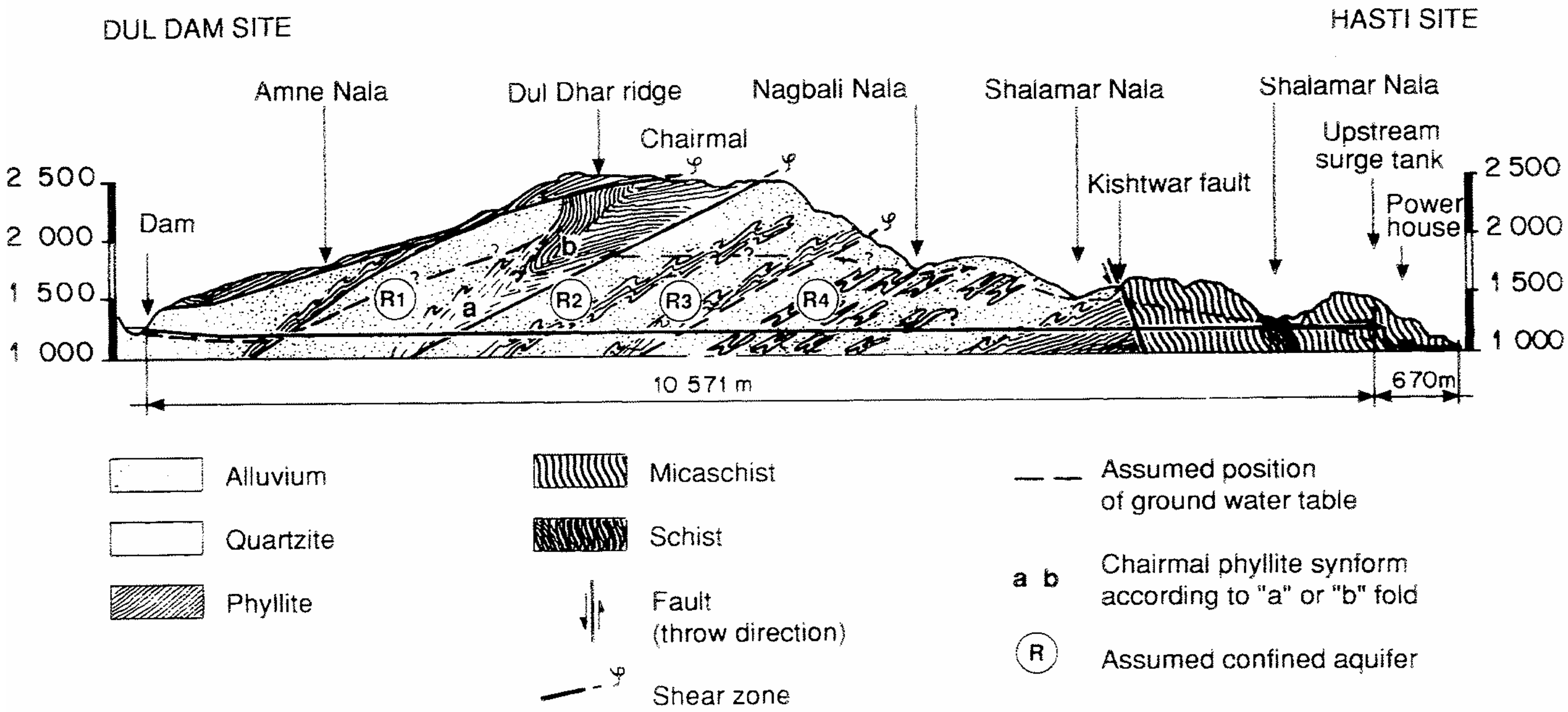
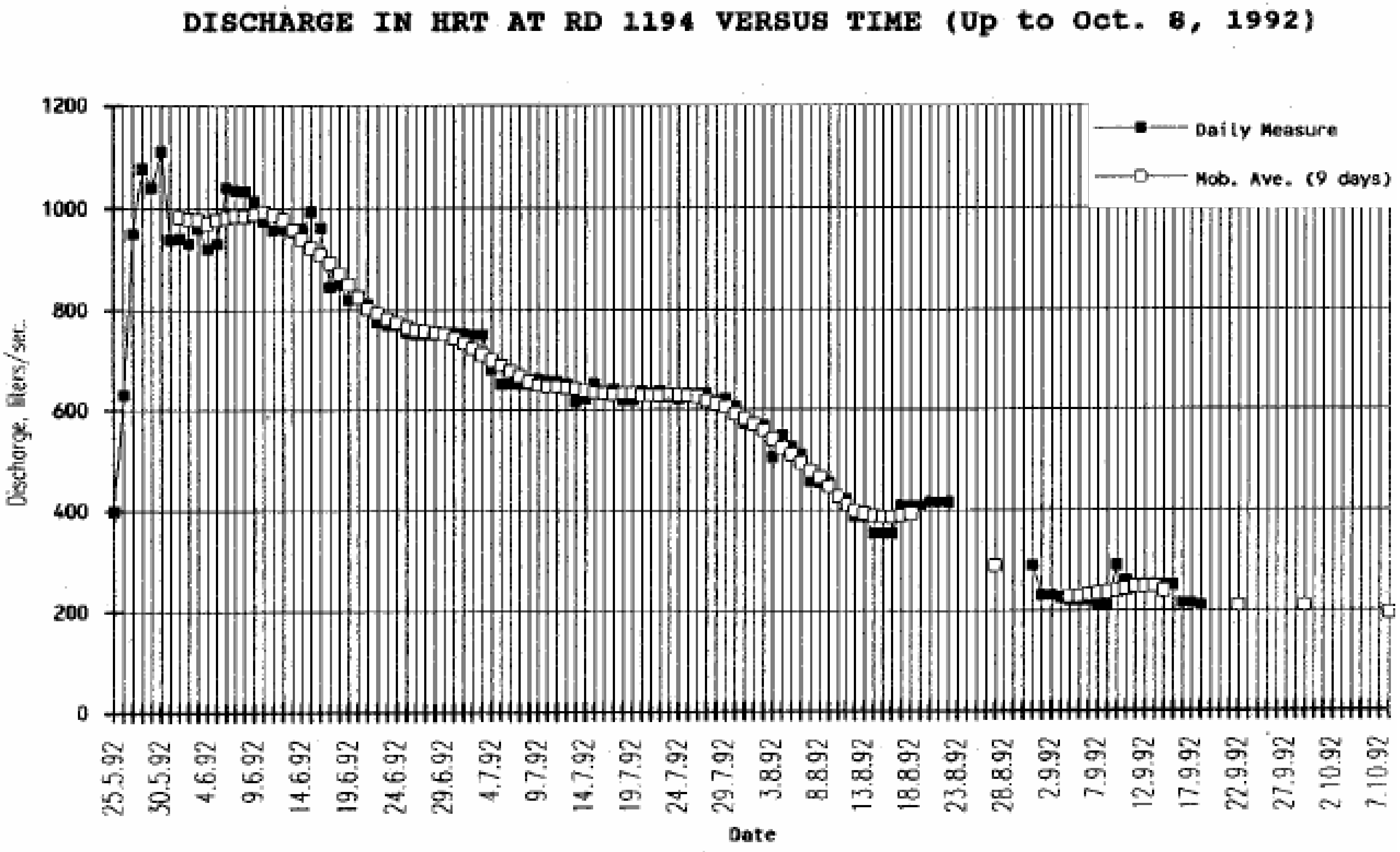


Fig. 16. Probable schematic geological cross-section along the final headrace tunnel route (“loop alignment”).

Water Inflow vs Time



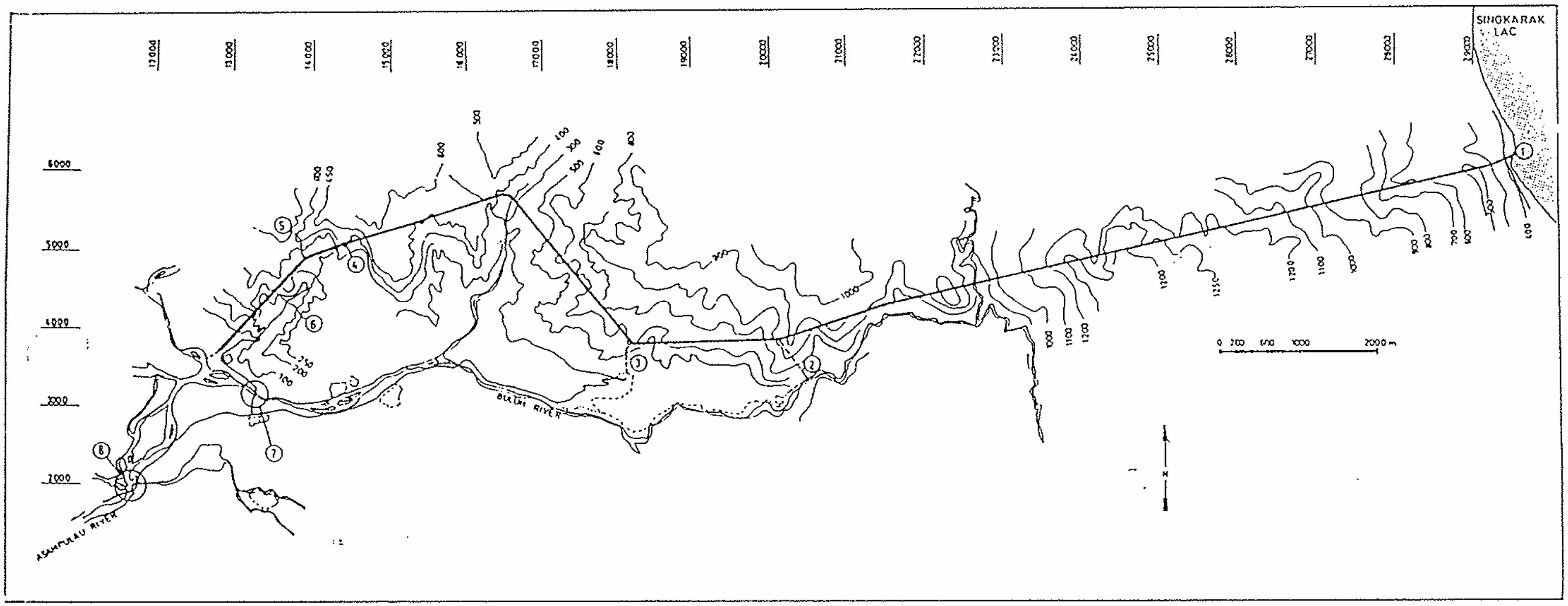
HIGH OVERBURDEN

Syngkarak Hydro Power Project,

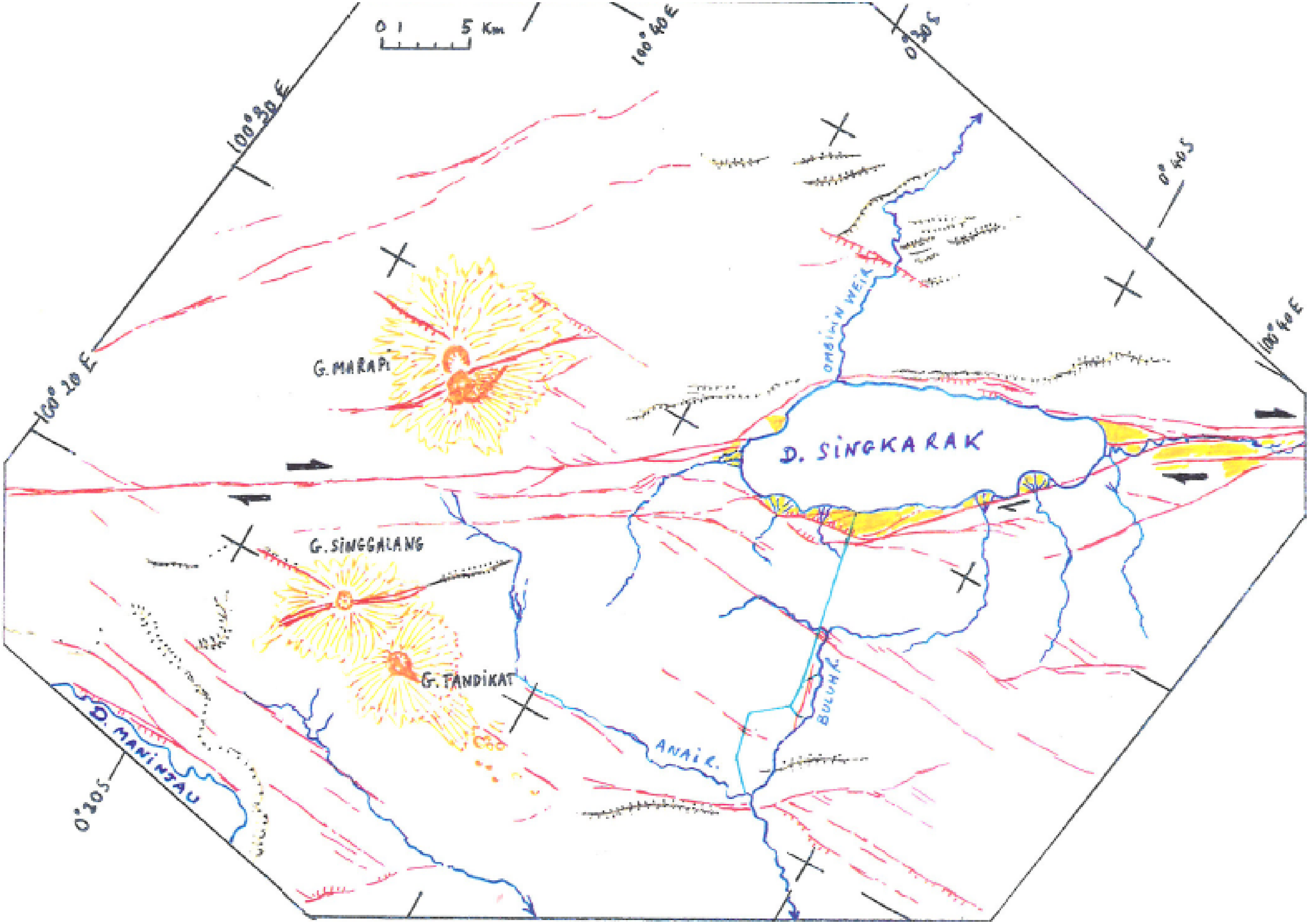
Indonesia-Sumatra

- 700MW Underground Cavern
- 16.5km long 5.0m inner diameter Headrace Tunnel

Syngkarak-General Layout

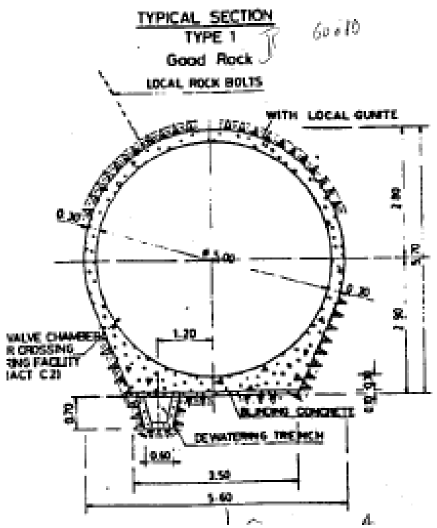


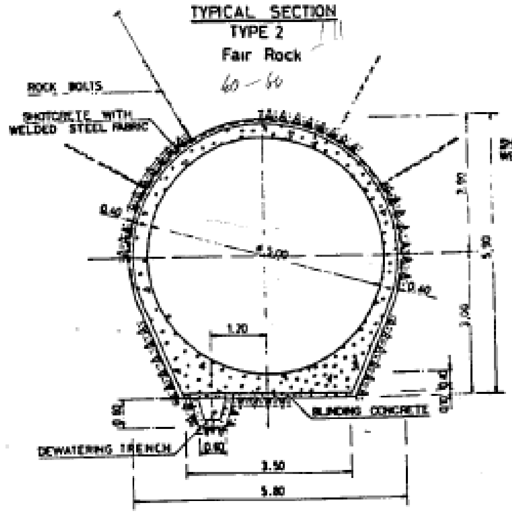
Layout of the Main Sumatra Active Fault

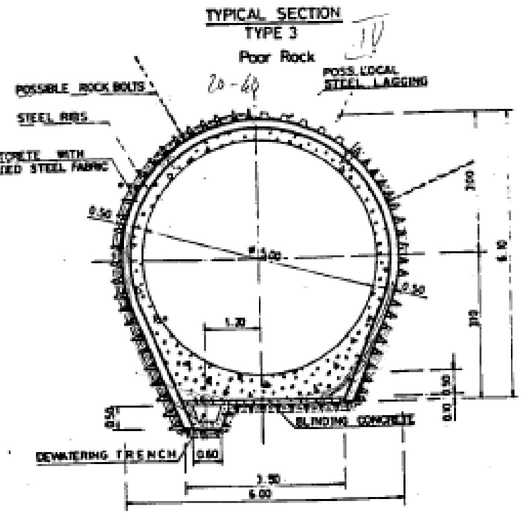


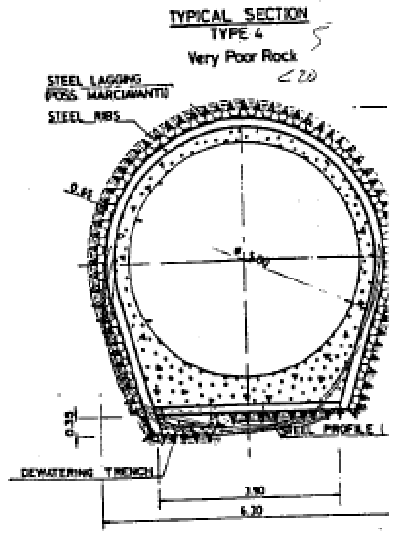
Headrace Tunnel-Typical Sections

Conventional excavation



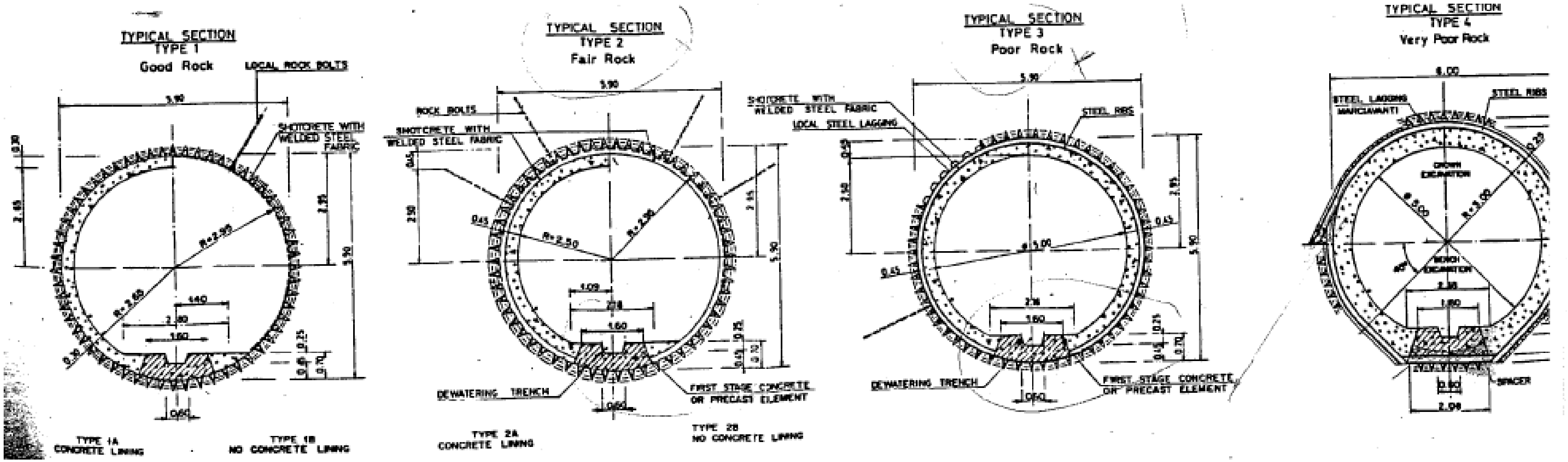




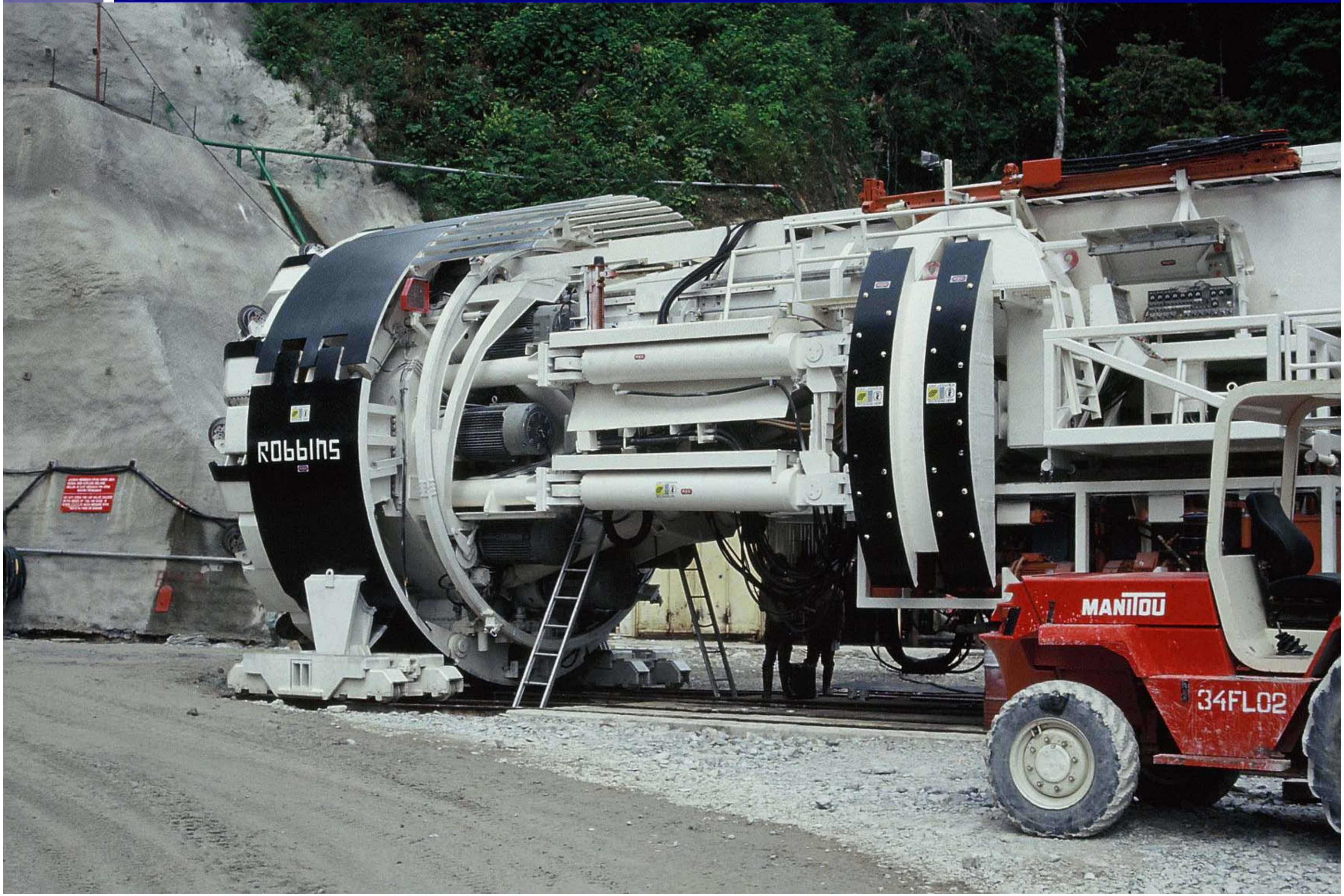


Headrace Tunnel-Typical Sections

Tunnel boring machine excavation



Hard Rock TBM



TBM Back-Up

Distorted Ribs in Squeezing Rock Calcarous Schist

Distorted Ribs in Calcareous Schist

By-pass Gallery-Grouting Works

By-pass Gallery-Grouting Works

D&B Heading

Heading in Phyllite

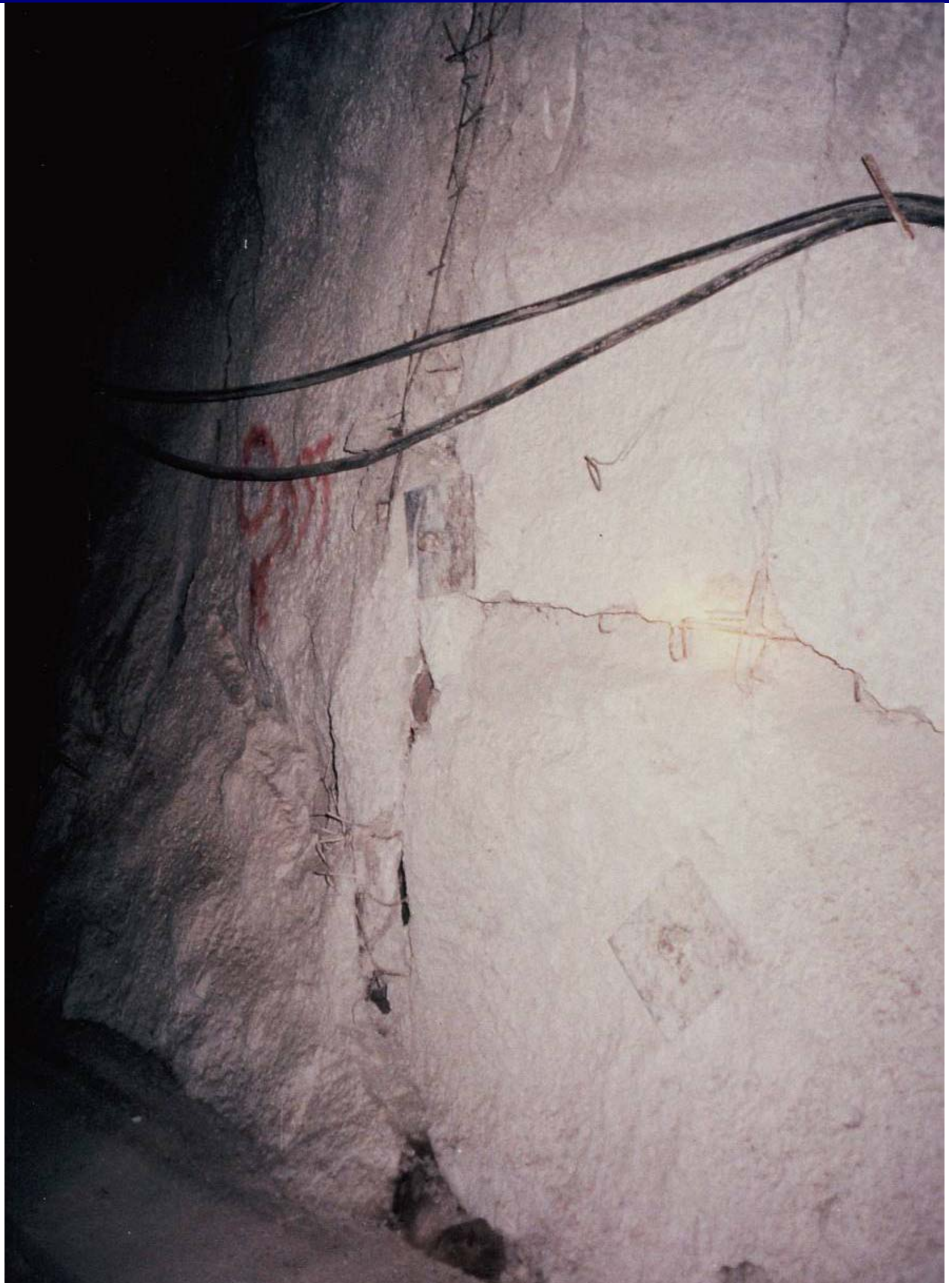
Phyllite Excavation

Phyllite Excavation

Sheared Shotcrete and Buckled Ribs Phyllite

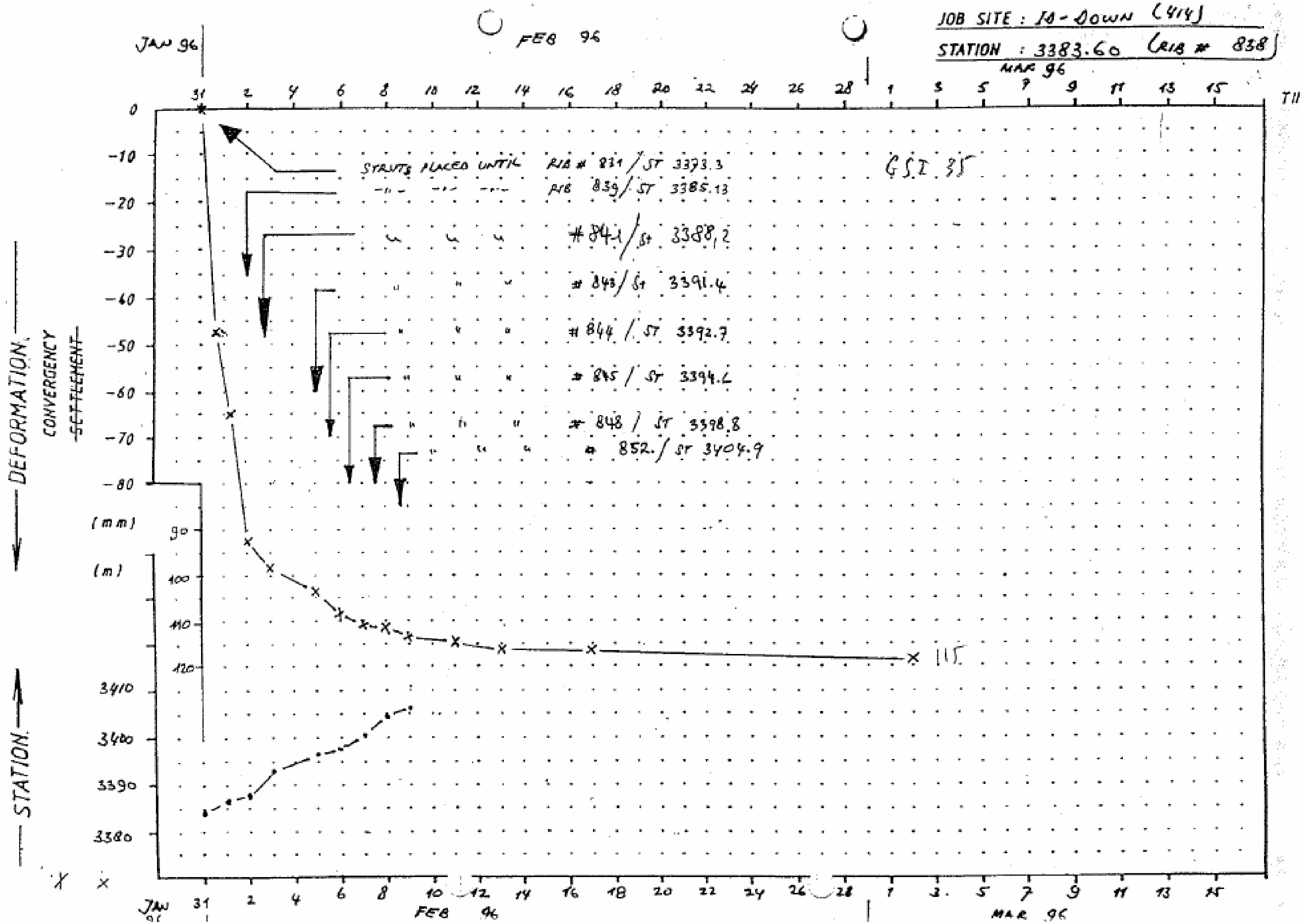
Sheared Shotcrete and Buckled Ribs Phyllite

Sheared Shotcrete- Upward Movement of Invert



Buckling of Invert- High Lateral Stress

Sidewalls Convergences in Phyllite



CONCLUSIONS

- Geological and geotechnical prognosis are hazardous works.
- Engineer’s ingenuity must always be ready to accept the soil/rock challenge
- Flexibility in terms of solving problems as well as in structural supports must always be part of tunneling practice
- Measurements and their follow-up are the « safety »of tunnel works
- Back analysis is the development of tunnel’s work understanding and future design approaches