Karlsruher Institut für Technologie

Entsorgungsforschung

1st Chinese-German Workshop on Radioactive Waste Disposal

Sino-German Science Centre
Beijing, CHINA
May 28 – 31, 2007

A joint workshop organized by

Beijing Research Institute of Uranium Geology, (BRIUG), China
China National Nuclear Corporation (CNNC)
Project Management Agency Karlsruhe (PTKA) - Karlsruhe Institute of Technology, Germany
DBE Technology GmbH, Germany

Ed. W. Steininger

Projektträger Karlsruhe
Wassertechnologie und Entsorgung (PTKA-WTE)

Projektträger für das

Bundesministerium
für Wirtschaft
und Energie

Herausgeber:
Projektträger Karlsruhe
Wassertechnologie und Entsorgung (PTKA-WTE)
Karlsruher Institut für Technologie (KIT)
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Internet: www.ptka.kit.edu

neu zusammengestellt Juli 2017

PTKA
Projektträger Karlsruhe
Karlsruher Institut für Technologie

Der vorliegende Materialienband dient der aktuellen Unterrichtung der auf dem Gebiet der Entsorgung radioaktiver Abfälle arbeitenden Institutionen und der zuständigen Behörden.

Berichte und Publikationen zu
Projektstatusgesprächen, Kolloquien und Fachgesprächen
sind über die Internetseite

www.ptka.kit.edu/wte/171.php

des PTKA zu finden.

中德放射性废物处置研讨会

CHINESE-GERMAN WORKSHOP ON RADIOACTIVE WASTE DISPOSAL

CHINESE-GERMAN SCIENCE CENTRE, BEIJING, CHINA

MAY28－31, 2007

Jointly organized by the

BEIJING RESEARCH INSTITUTE OF URANIUM GEOLOGY,
CHINA NATIONAL NUCLEAR CORPORATION, CHINA
PROJECT MANAGEMENT AGENCY FORSCHUNGSZENTRUM KARLSRUHE &
DBE TECHNOLOGY GmbH, GERMANY

中德放射性废物处置研讨会

CHINESE-GERMAN WORKSHOP ON RADIOACTIVE WASTE DISPOSAL

MAY 28 – 31, 2007

SINO-GERMAN SCIENCE CENTRE，BEIJING, CHINA

Jointly organized by the

BEIJING INSTITUTE FOR URANIUM GEOLOGY, CHINA NATIONAL NUCLEAR CORPORATION
PROJECT MANAGEMENT AGENCY FORSCHUNGSZENTRUM KARLSRUHE and
DBE TECHNOLOGY GmbH, GERMANY

Monday, May 28

09 00 Arrival at the Sino-German Science Center and workshop registration

Opening Ceremony

Chairs: WANG Ju, Walter.Steininger

10 00 Welcome address by Mr. LIN Sen, (China Atomic Energy Authority)
Welcome address by Mr. MA Fei, (BRIUG, China National Nuclear Corporation)
Welcome address by Dr. Walter.Steininger (PTKA-WTE, Germany）
Break: Taking Group Photo

Invited lectures/ National Programs and Activities

Chairs: FAN Zhong, E. Biurrun

10 40 Prof. D. Fuhrmann (PTKA-WTE), Prof. Yun Guichun (INET, Tsinghua University)
Water research – an example of 20 years successful Chinese-German cooperation

11 10 LI Jingying, Director General, Department of Planning, China National Nuclear Corporation
Radioactive Waste Management in the P.R. China

11 40 E. Biurrun, DBE Technology
Development of repository technologies in Germany

12 10 **Lunch**

Technical Sessions

National Program /Decommissioning /Siting / Host rock characterization

Chairs: YANG Chunhe, V. Bräuer

13 30 WANG Ju, BRIUG, CNNC
Geological Disposal of High Level Radioactive Waste in China: latest progress

14 00 Dr. Weigl, FZK:
"Decommissioning of Nuclear Facilities - German R&D"
V. Bräuer, BGR
Clay formations - a possible alternative as host rocks for radioactive waste disposal in Germany ?

15 00 K.-H.Lux, TU Clausthal
Radioactive waste disposal in various host rock formations – Geomechanical aspects (fundamentals)

15 30 Break

16 00 YANG Chunhe, Chinese Academy of Science
Rock Mechanical Research on Granite from Beishan site, Gansu, NW China

H. Shao, BGR

A presentation on German's research on granite讲花岗岩

18 00 **Move to Peking Duck Restaurant (close to the Olympic Game Centre)**

19 00 **Welcome Banquet hosted by BRIUG, CNNC**

Tuesday, May 27

Siting / Host rock characterization

Chairs: LIU Xiaodong, K.-H.Lux

09 00 H. Shao, BGR, Germany

In situ hydro-mechanical characterization of rock formation and coupled HM modeling

CHEN Weiming, BRIUG, CNNC

Geological characterization of Beishan Potential Site for China's High Level Radioactive Waste Repository

10 00 Guo Yonghai, BRIUG, CNNC

Hydrogeological Characterization of Beishan Potential Site for China's High Level Radioactive Waste Repository

SU Rui, BRIUG, CNNC

Hydraulic tests at bore holes at Beishan site, NW China

11 00 **Break**

11 15 O. Czaikowski, TU Clausthal, Germany

Radioactive waste disposal in various host rock formations – Geomechanical aspects (Selected applications)

LIU Yuemiao**,** BRIUG, CNNC

Physical-mechanical property and time- temperature effect of Beishan deep intact granite

12 15 **LUNCH**

Waste forms

Chairs: ZHANG Shendong, R. Odoj

13 30 M. Sailer, Öko-Institut e.V.

Handling of nuclear waste in Germany in the light of final disposal

14 00 B. Kienzler, Forschungszentrum Karlsruhe, Institute for Nuclear Waste Management

Experiences with the performance/behavior of HLW-forms in different host rock media

ZHANG Zhengtao, China Institute of Atomic Energy, CNNC

TMD

15 00 R. Odoj, Forschungszentrum Jülich, Institute for Safety Research and Reactor Technology

Quality control of radioactive waste in Germany

15 30 **Break**

Repository Technology, Engineering and Design

Chairs: YE Weiming, W. Bollingerfehr

16 00 W. Bollingerfehr, DBE Technology

Technical aspects of direct disposal of HLW

LI Tingjun, ZHANG Wei, Beijing Institute of Nuclear Engineering, CNNC

Waste Management Strategy and Design Concept for Geological Disposal of Radioactive Waste in China

WEN Zhijian**,** BRIUG, CNNC

Characteristic of Gaomiaozi Bentonite as potential backfill material for China's HLW repository YE Weiming, Tongji University,China

17 00 Some achievements in study of Gaomiaozi bentonite used as backfill materials

18 00 **Adjourn**

19 00 **Conference Dinner at Xijiao Hotel**

Wednesday, May 30

Repository Technology / Modelling and Safety Assessment

Chairs: SU Rui, W. Brewitz

09 00 B. Haverkamp, DBE Technology

Development of a new Closure Concept for the Richard Repository, Czech Republic – an example for successful international cooperation

W. Brewitz, Gesellschaft für Anlagen-und Reaktorsicherheit (GRS) mbH, Department Final Repository Safety Research

Monitoring and modeling of groundwater parameters as a basis for radionuclide transport modelling

PAN Wei, China Institute for Radiation Protection, CNNC

The experiment research of radionuclide migration in aquifer

10 30 **Break**

10 45 **Discussion on potential cooperation**

Chairs: WANG Ju, W.Steininger

11 30 **Summary of the Workshop**

Outlook, future perspectives for cooperation from the viewpoint of the P.R. China

Outlook, future perspectives for cooperation from the viewpoint of Germany

12 00 **LUNCH**

13 00 **visit to the Great Wall at Mutianyu, Huairou County, Beijing**

Thursday, May 31

09 00 - **Technical visit (Nuclear Research Centre, INET, Tsinghua University)**

End of workshop

Chinese-German Workshop on Radioactive Waste Disposal

Sino-German Science Centre
May 28 - 31, 2007

Water Research - an example of 20 years successful Chinese-German co-operation

Dieter Fuhrmann

Project Management Agency Forschungszentrum Karlsruhe
for Water Technology and Waste Management
acting on behalf of BMBF and BMWi

BMBF:	German Federal Ministry for Education and Research
BMWi:	German Federal Ministry of Economics and Technology

BMBF Program
„FONA“ - Research for Sustainability

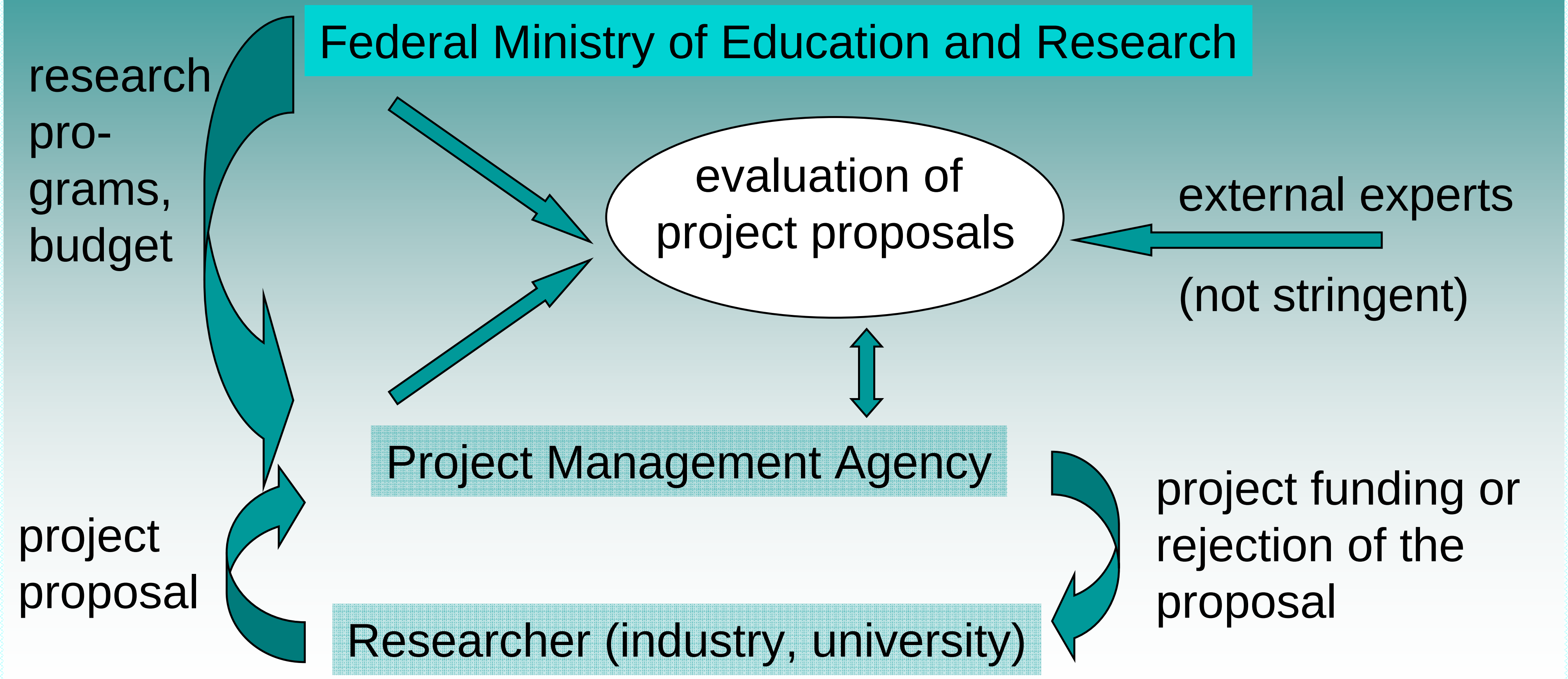
Framework Program of the German
Federal Ministry of Education
and Research (BMBF) for a sustainable,
innovative society (launched 2004)

fields of action:

- **Concepts for sustainability in industry and business**
- **Sustainable use concepts for regions**
- **Concepts for sustainable use of natural resources**
- **Social action geared to sustainability**

www.fona.de **www.fona.de/engl/**

BMBF Research funding



PTKA Annual Budget (2006)

- **PTKA's project funding in the field of water technology:**

  ~ 40 million EUR ~ 450 projects

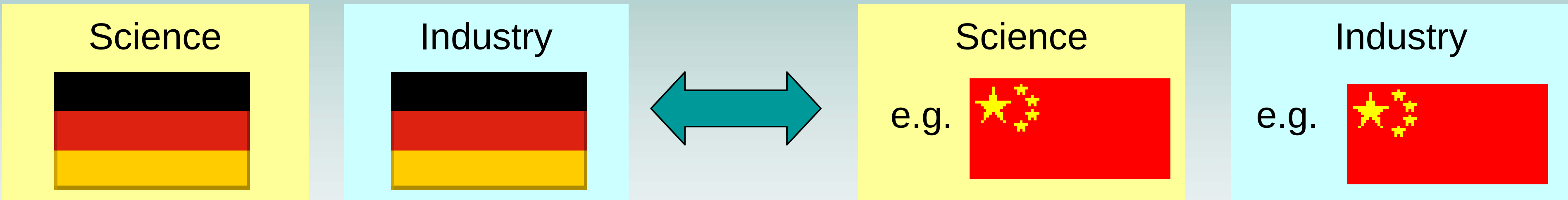
- **PTKA's international projects:**

  ~ 18 million EUR ~ 130 projects

  →funding only for German research institutes, German industry funding of foreign research institutes is not possible (in exceptional cases: grants, consumable materials, equipment)

Preferred Structure of International Co-operations

so-called "2+2 Project"



German funding

foreign funding

Superordinated Targets of BMBF's Water Research

- World Summits of Rio and Johannesburg
- The EU Water Framework Directive ("good status of water bodies")
- Conflicts resulting from the (over-)use of transboundary watersheds
- Sustainability of water supply and sanitation
- Security of the drinking water supply
- Water for agriculture (food production and energy crops)
- Influence of the climate change on water supply
- Germany as a location of high-technology
- Export of German water technology
- Amendment of the German legislation

Overview on Current Activities in the Field of Water Technology

- Decentralized (alternative) water systems
- Adaptation of available water technology to other climate zones, levels of education, and culture
- Integrated water resources management (IWRM)

- Retention and degradation processes to reduce contaminations in ground-water and soil
- Permeable reactive barriers for groundwater remediation
- Prognosis of the entry of noxious substances in ground-water
- Risk-management of extreme flood events
- Phosphorous recovery from sewage sludge

BMBF/PTKA - Bilateral Co-operations in the Field of Water:

Contract for the Scientific Technological Co-operation

between

The Peoples Republic of China

and

The Federal Republic of Germany

signed on

October 9th, 1978

by

State Commission for Science and Technology (SCST)

Federal Ministry of Research and Technology (BMFT)

30th Anniversary of Co-operation in 2008

Fields of Co-operation

- Cultural Heritage
- Production Techniques
- Optical Technologies / Laser Technologies
- Material Research / Nano Technologies
- Marine Research / Geo Sciences
- Biological Research and Technology
- Environmental Technologies and Ecology
- Health Research
- Information and Communication Technologies

Meeting of the Joint Commission for Scientific Technological Cooperation

19th Meeting in April, 2006, Bonn

Meeting of the Steering Committee "Environmental Technology and Ecology"

5th Meeting in February, 2004, Sanya
6th Meeting in March, 2007, Bonn

Bilateral Cooperation with China in the Field of Water

On-going projects:	**since 1988**
Number of projects:	**43 in total; 23 on-going projects**
budget:	**17 million EUR (6,1 million EUR on-going projects)**

Current fields of cooperation:

- **New technologies for industrial waste water treatment**
- **Disinfection of municipal waste water for reuse purposes**
- **Enrichment of groundwater**
- **Management of storm water, utilization of rainwater – Olympic Park 2008**
- **Concepts for the remediation of lake Chao**
- **Decentralized water systems**
- **Drinking water: simultaneous elimination of nitrate and pesticides**

BMBF Program „Decentralized (Alternative) Water Systems“
- Rapidly growing urban areas, China -

New technical solutions (“semi-central approach”) to enable a sustainable supply and disposal of rapidly growing urban areas

partners:

TU Darmstadt and German private companies

Tongji-University Shanghai

Qingdao Tech University

Topics of investigation are:

- **comparison of different ways of gray water treatment**
- **application of ultrasound to clean membranes**
- **production of lactic acid from biomass**

Concepts for the Remediation of Lake Chao

partners:
Technical University of Braunschweig,
Leibnitz Institute for the Ecology of Closed Water Bodies,
University of Göttingen

Anhui Environmental Protection Bureau,
University of Hefei

Lake Chao/Anhui Province
China

Lake Chao Project (concepts for remediation)

Problem:

- **eutrophication of lake Chao (760km²)**
- **seasonal occurrence of blue algae**
- **breakdown of the drinking water supply from the lake water**

Visit to Hefei in June, 2006

Lake Chao:
Concepts for drinking water treatment

Processes close to nature (green liver)

technical solution

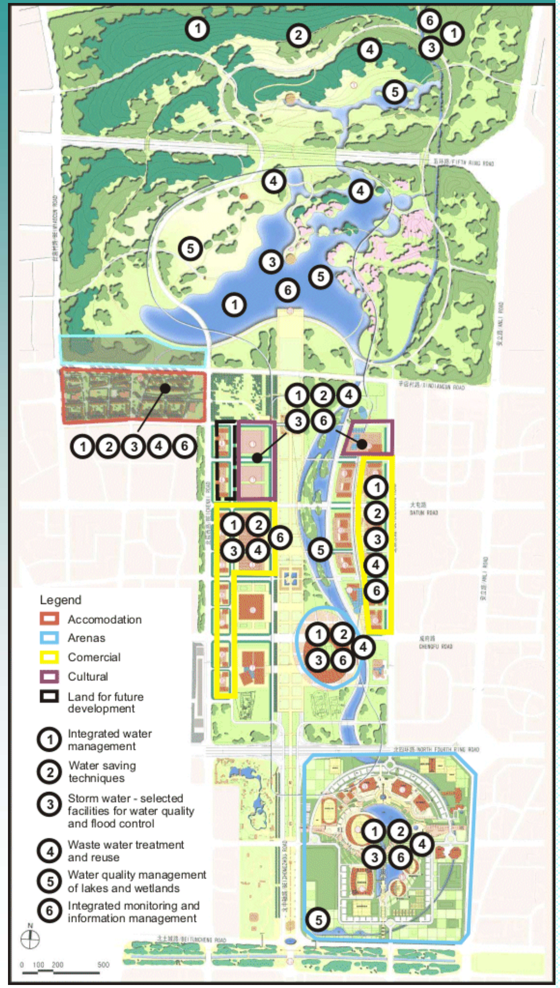
Sustainable Water Concept and its Application for the 2008 Olympic Games in Beijing

WASY Limited, TU Berlin, Geoterra Obermeyer, TU Essen, Institut für Gewässerökologie

Tsinghua University
Beijing Water Authority

Fields of activities:
- integrated water management
- water saving
- rain water resources and flood control
- waste water treatment and reuse
- water quality management of lakes and wetlands
- integrated monitoring and information management

All activities are carried out on the Olympic Park

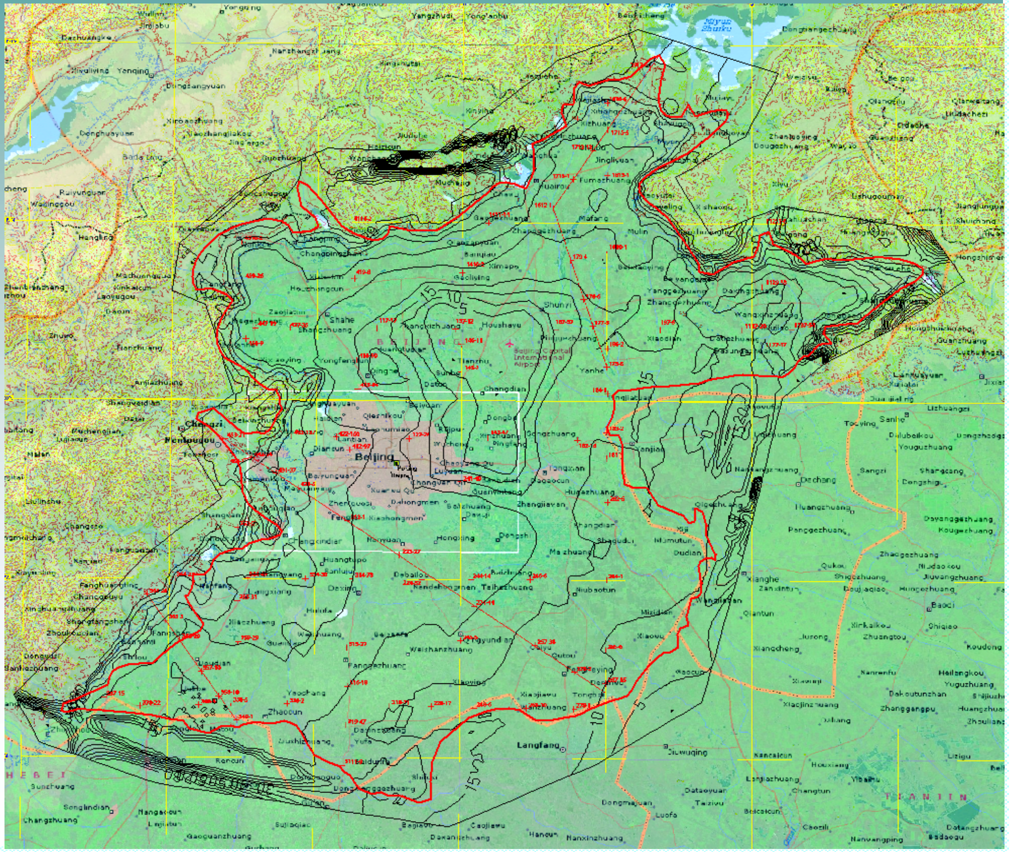


Water Management in Beijing Area

partner:
Fraunhofer Institute
Beijing Water Authority

Development of a decision support system for the water supply of megacities under consideration of

- **the resources (reservoirs, groundwater)**
- **transport (channels, rivers)**
- **water works**
- **consumer**



Establishment of Courses in Environmental Sciences

University of Aachen

Tsinghua University (Beijing) and Sichuan University (Chengdu)

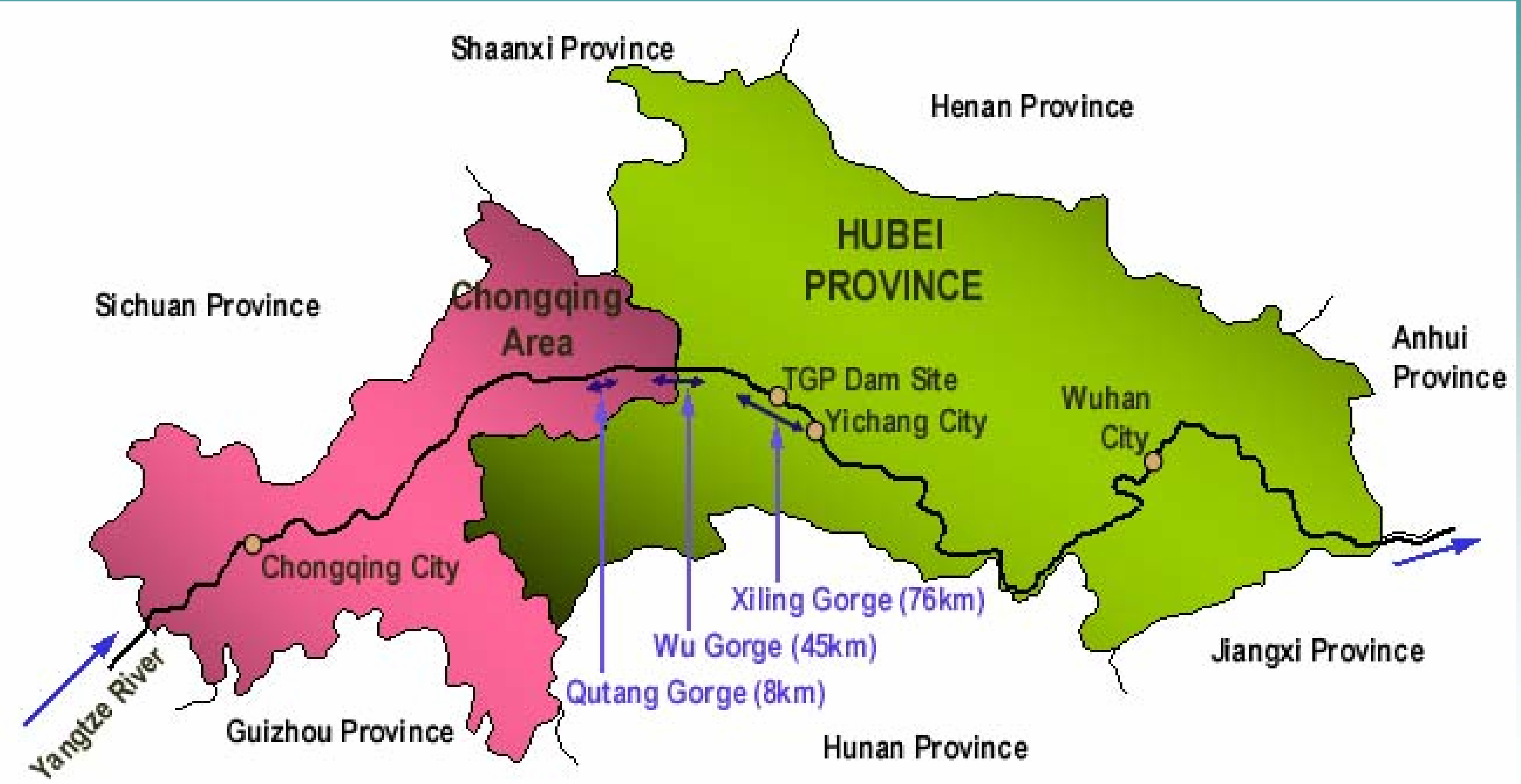
Recently started projects:

- **"Simultaneous elimination of nitrate and pesticides during drinking water treatment in rural areas"**
  partners:
  Forschungszentrum Karlsruhe, Universität of Karlsruhe
  University of Halle
  Tsinghua University Beijing
  and private companies

- **"Different methods of disinfection of waste water for reuse purposes"**
  partners:
  Technical University of Darmstadt
  Tongji-University Shanghai
  private companies

Yangtze River - Three Gorges Dam

Three Gorges Area



Three Gorges Dam Project - Proposed Fields of Co-operation

- Joint Research Projects
- Scientist Exchange Program
- PhD - Students Exchange
- Capacity Building

Proposed Topics for Joint Research Projects

- **Exchange of pollutants between water, suspended matter, and sediment**
  - impact on water quality management
- **Erosion**
  - impact on the stability of banks and slopes
- **Vegetation**
  - impact on plants in the flooded area
- **Climate**
  - impact on the deposition of air pollutants
- **Socio-economic aspects**


Thanks a lot for your attention !!!
Forschungszentrum Karlsruhe - Research Center Karlsruhe

核工业第二研究设计院
BEIJING INSTITUTE OF NUCLEAR ENGINEERING

Introduction of BINE

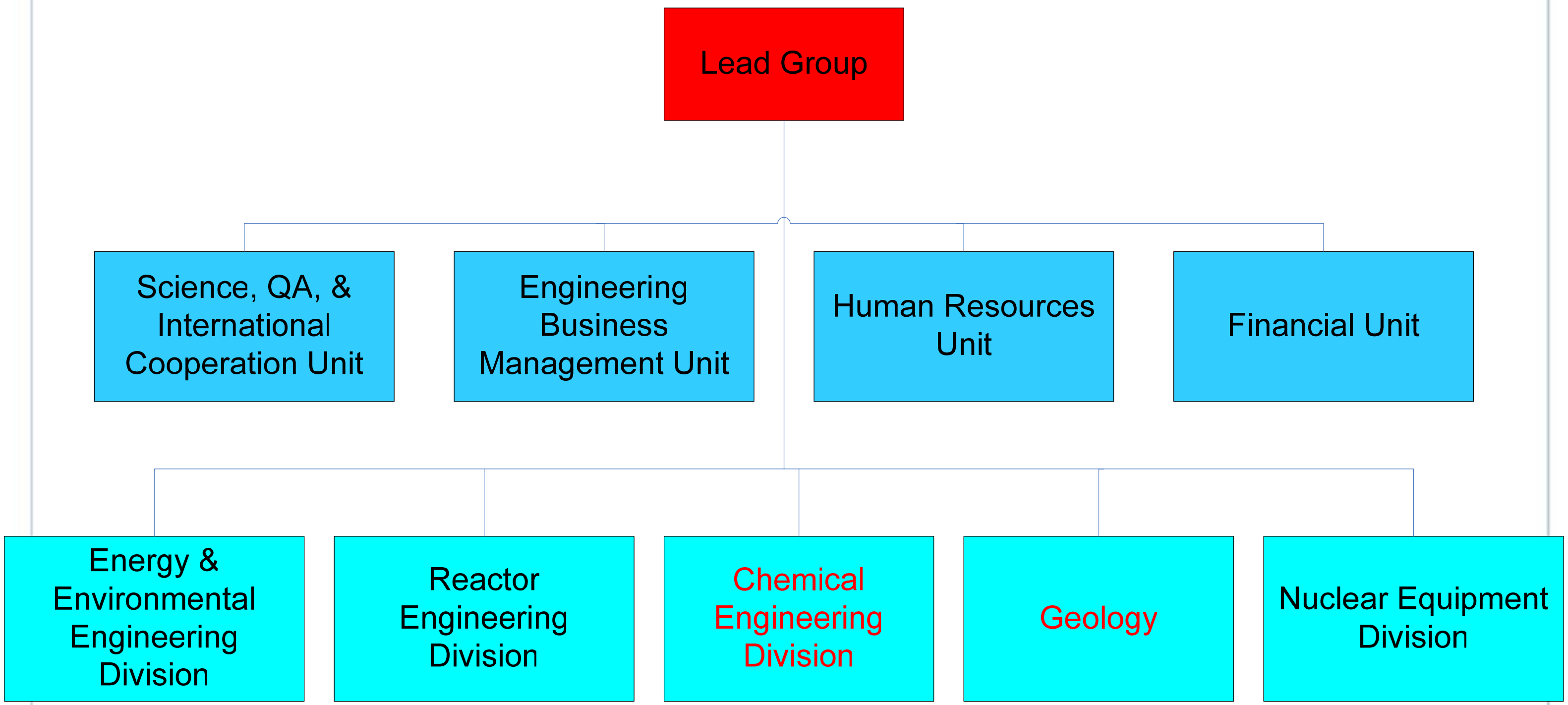
Introduction

Founded on January, 1958.

The first and largest comprehensive institute for nuclear engineering research and design in China.

951 technicians of various specialties , 45 professoriate senior engineers, 301 senior engineers.

BINE Organization

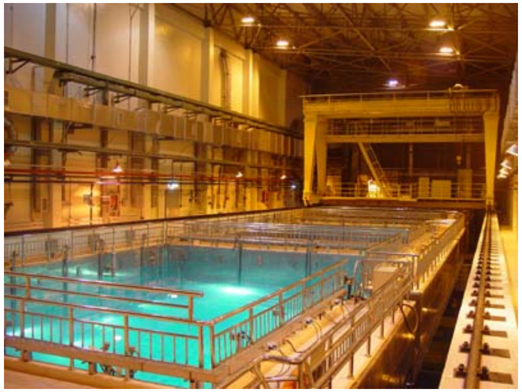


Nuclear Projects

Nuclear Reactor Design and Engineering

- Qin Shan-II PWR NPP
- DaYa Wan PWR NPP
- Ling Ao-I&II PWR NPP
- Tian Wan VVER NPP (Consultancy)
- New NPP (Viability)
- Experimental Faster Breeder Reactor
- Small scale reactor

Nuclear Projects



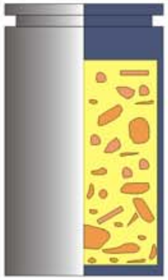
Spent Fuel Reprocessing Design and Engineering

- Spent fuel reprocessing pilot plant with the processing capacity of 300 kgU/d
- Storage pool of the plant with the capacity of 550 tU
- Spent fuel large scale reprocessing plant (Planning)

Nuclear Projects

Decommissioning and Radioactive Waste Management

- Decontamination and decommissioning
- Low and intermediate liquid waste solidification
- Low and intermediate waste conditioning
- Low and intermediate waste near surface disposal
- High level liquid waste evaporation and storage
- Spent source storage



- Organic waste pyrolysis incineration
- Very low level waste disposal
- Alpha bearing waste conditioning
- High level liquid waste vitrification
- High level waste geological disposal

核工业第二研究设计院
BEIJING INSTITUTE OF NUCLEAR ENGINEERING

Design Concept for Geological Disposal of Radioactive Waste

Beijing Institute of Nuclear Engineering

Beijing, China

May 2007

Content

- Nuclear Power Development
- Spent Fuel Management
- Waste Study
- Design Concept of the Repository

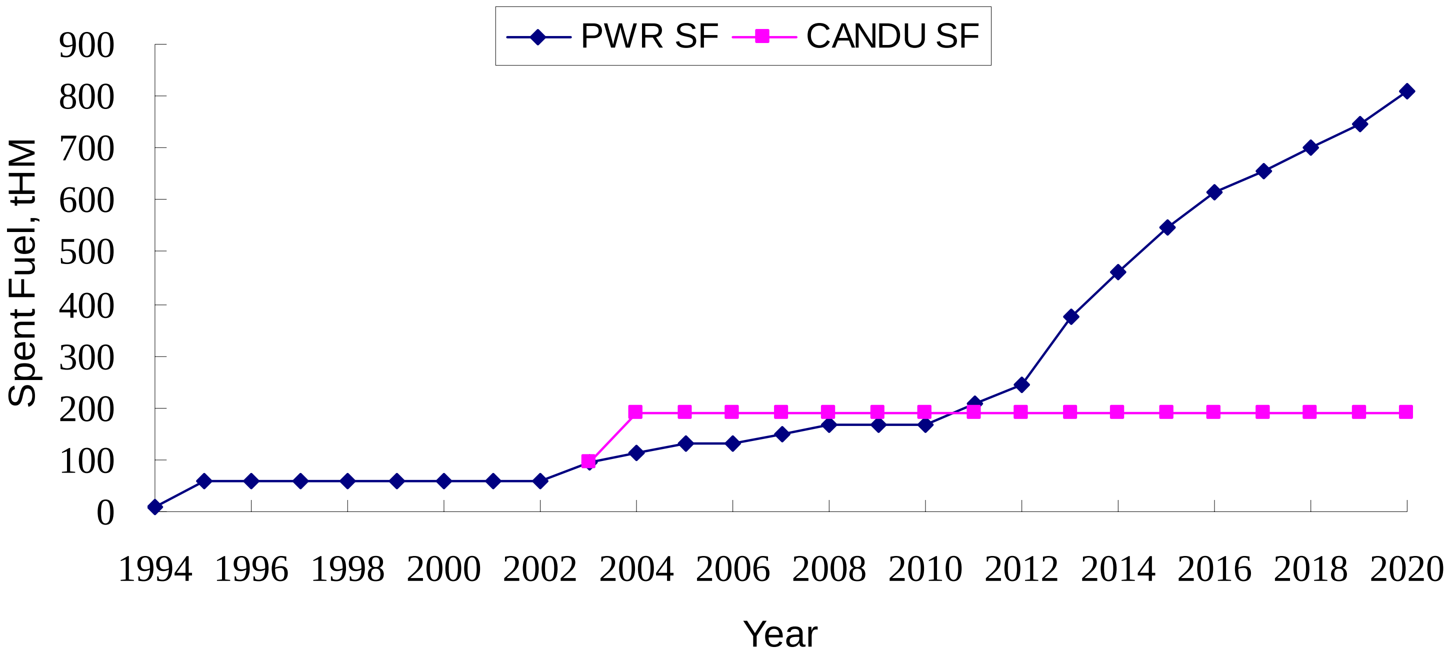
Nuclear Power Development

Ten commercial nuclear power reactors totaling 7,700 MWe are producing electricity.

NPPs in mainland of China

It is scheduled that installed nuclear capacity will be 40 GWe by 2020.

Nuclear Power Development

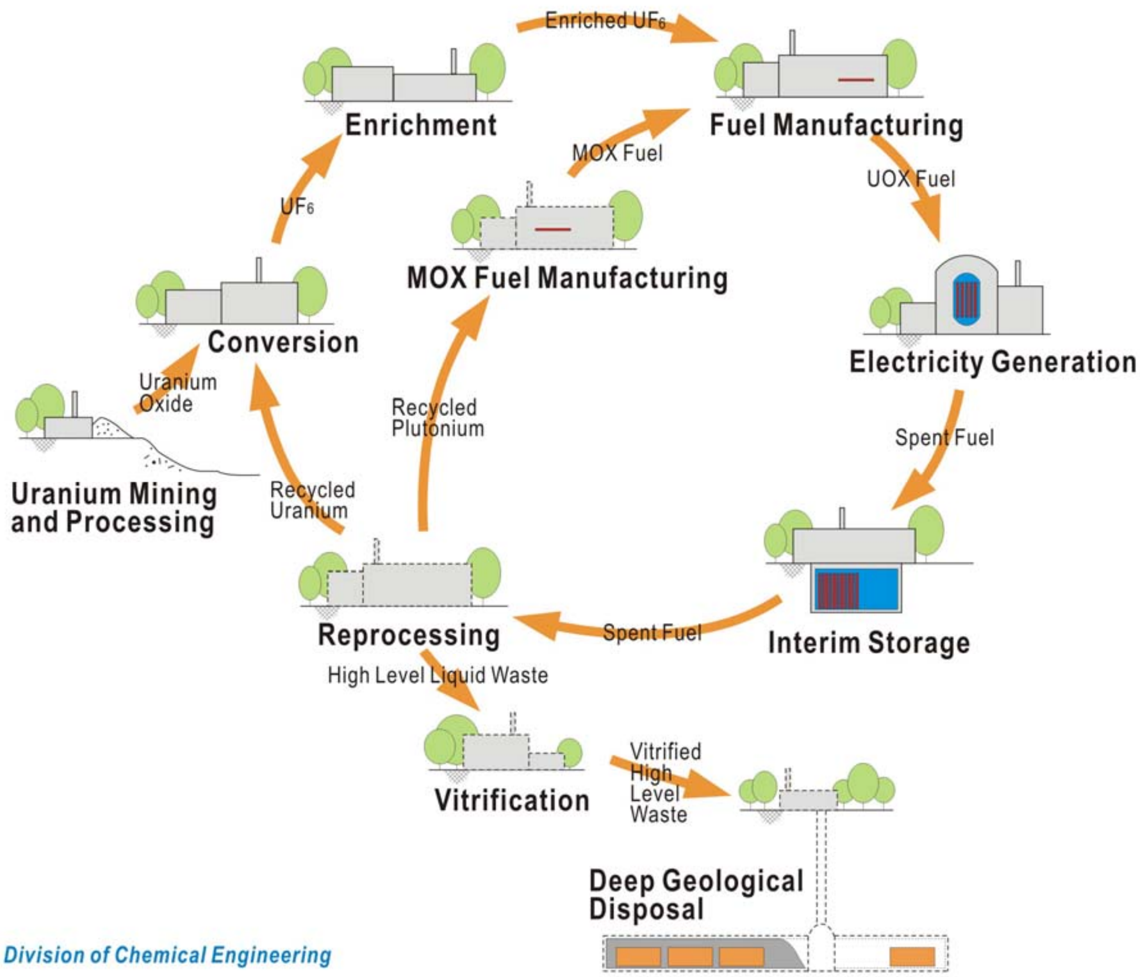


Spent Fuel unloaded annually

(estimated by BINE)

核工业第二研究设计院
BEIJING INSTITUTE OF NUCLEAR ENGINEERING

Spent Fuel Management



Division of Chemical Engineering

BINE

Spent Fuel Management

Currently, Chinese nuclear fuel management is based on a closed fuel cycle strategy.

Spent fuel from nuclear power plants will be reprocessed to recover usable elements which will be recycled into new fuel assembly.

China chooses reprocessing to save amounts of natural resources and minimize radioactive waste.

A pilot reprocessing plant is under commissioning and has accepted PWR spent fuel.

Waste Study

According to “Radioactive Pollution Prevent Law of 2003”, high level radioactive solid waste and alpha bearing solid waste will be disposed in deep geological repositories.

The objective of Chinese HLW geological disposal R&D program is to construct a national HLW repository in the middle of the 21st century.

The waste studied for geological disposal contains vitrified high level glass, other type high level waste, and alpha bearing waste.

Vitrified high level waste

High level liquid waste is immobilized into a stable glass matrix in stainless steel canisters which is called as vitrified high level waste (VHLW).

This waste will be stored in interim storage facilities for several decades until it is suitable for final disposal and the repository is available.

Other type high level waste

Other type high level waste includes fuel structural materials, special devices dismantled from reprocessing line. This waste also give rise to significant heat generation, although to a lesser degree and of shorter duration.

The conditioning technology to convert other type high level waste into suitable waste form to be disposed of in the repository has not been developed.

Alpha bearing waste

Alpha bearing waste in China is defined as single waste package contains more than 4×10^6 Bq/kg of alpha emitting radionuclides with half-lives greater than 30 years.

Alpha bearing waste originates mainly from reprocessing of spent fuel and includes plutonium contaminated equipments, tools and cloth.

The conditioning technology to convert alpha bearing waste into suitable waste form to be disposed of in the repository has not been developed.

Waste Study

In view of waste origin, waste to be disposed of in the geological repository is classified into commercial waste and legacy waste.

Waste Study

- Commercial waste

Most volume, decay heat and radioactivity of the waste to be disposed in the repository will be contributed by commercial waste.

Commercial waste originates from future re-processing of NPP spent fuel. It is foreseen that 10,000-15,000 canisters each containing 150 liters of vitrified waste could be accumulated up to 2050.

- Legacy waste

Legacy waste is stored in the former nuclear facilities and will be generated throughout the decommissioning activities.

Concept Design

With cooperation with BRIUG, CIAE, CIRP and other organizations, BINE carries out her work in respect of radioactive waste geological disposal.

- Characterization for the waste stream of the repository.
- Conceptual design for the underground research laboratory (URL), including surface facility and underground facility.
- Concept making for the HLW geological repository, including surface facility and underground facility.

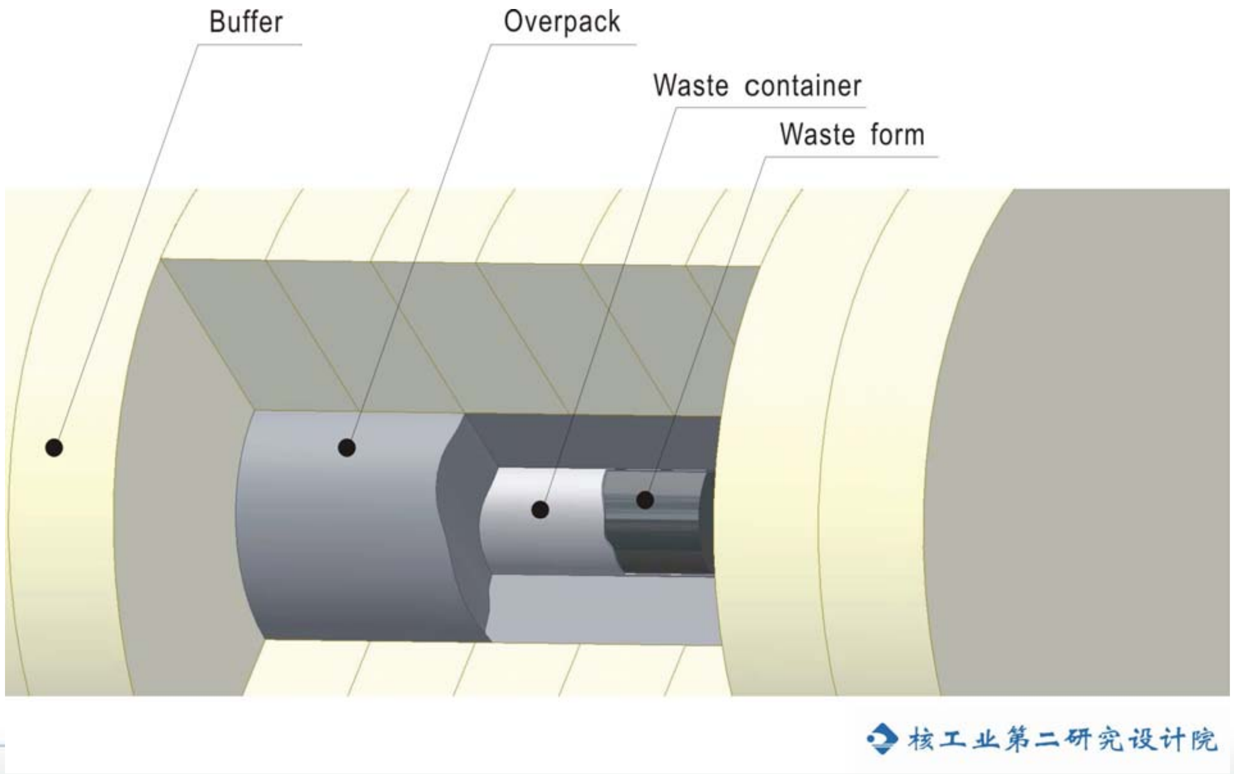
Concept Design

Disposal of radioactive waste in a facility located underground in a stable geological formation is intended to provide long term isolation of the radionuclides in the waste from the biosphere.

The geological disposal system can be defined as a combination of engineered and geological barrier which is generally known as a “multi-barrier” system.

Concept Design

The engineered barrier system (EBS) comprises a variety of sub-systems or components.



Concept Design

Waste package

The waste package is the combination of the waste form and its surrounding container.

Standardization of waste containers for high level waste and alpha bearing waste is under research. Stainless steel containers are preferred to contain high level waste and alpha bearing waste.

The draft of industrial standard of the container for alpha bearing waste and high level solid waste has just been completed by BINE. It will be issued by the end of this year.

Concept Design

Overpack

Overpacks are designed to contribute to the containment function of the EBS. Current study is focused on the overpack for VHLW. Description on the overpack is only narrowed on what is for the VHLW.

Concept Design

Buffer

The purpose of the buffer is to limit and delay any release of radionuclides into the underground environment when the overpack fails.

Bentonite is the main material of the buffer and its properties are investigated.

Compacted bentonite rings could be placed around the overpack or be inserted with the overpack into a large container to form a so called “supper container”.

Thank you!

DEVELOPMENT OF REPOSITORY TECHNOLOGIES IN GERMANY

Nuclear Industry in Germany

- Introduction of Nuclear Power Research in the fifties and sixties
- Commercial Nuclear Power Use since the late sixties
  - 1968 (Obrigheim)
  - 1974 Biblis A
- 17 Power Plants in Operation
- 20,200 MW installed Power (second to France)
- 28% of the Electricity Delivered to the Public Grid is Nuclear

Milestones in Waste Disposal

- 60's: All Waste to go to Deep Geological Repositories

- Asse Experimental Repository 1967 - 1978

  Worldwide First Deep Geological Repository

- 1979 Federal Council Decision on Waste Management:

"Entsorgungsnachweis" a Requirement for NPP Operation

Waste Management Concept

→Interim Storage in NPP Pools (limited capacity)

→Spent Fuel Reprocessing

→Pu Recycling as MOx in LWR

→AFR HLW/SF Interim Storage

→Deep Geological Disposal

Concept Implementation

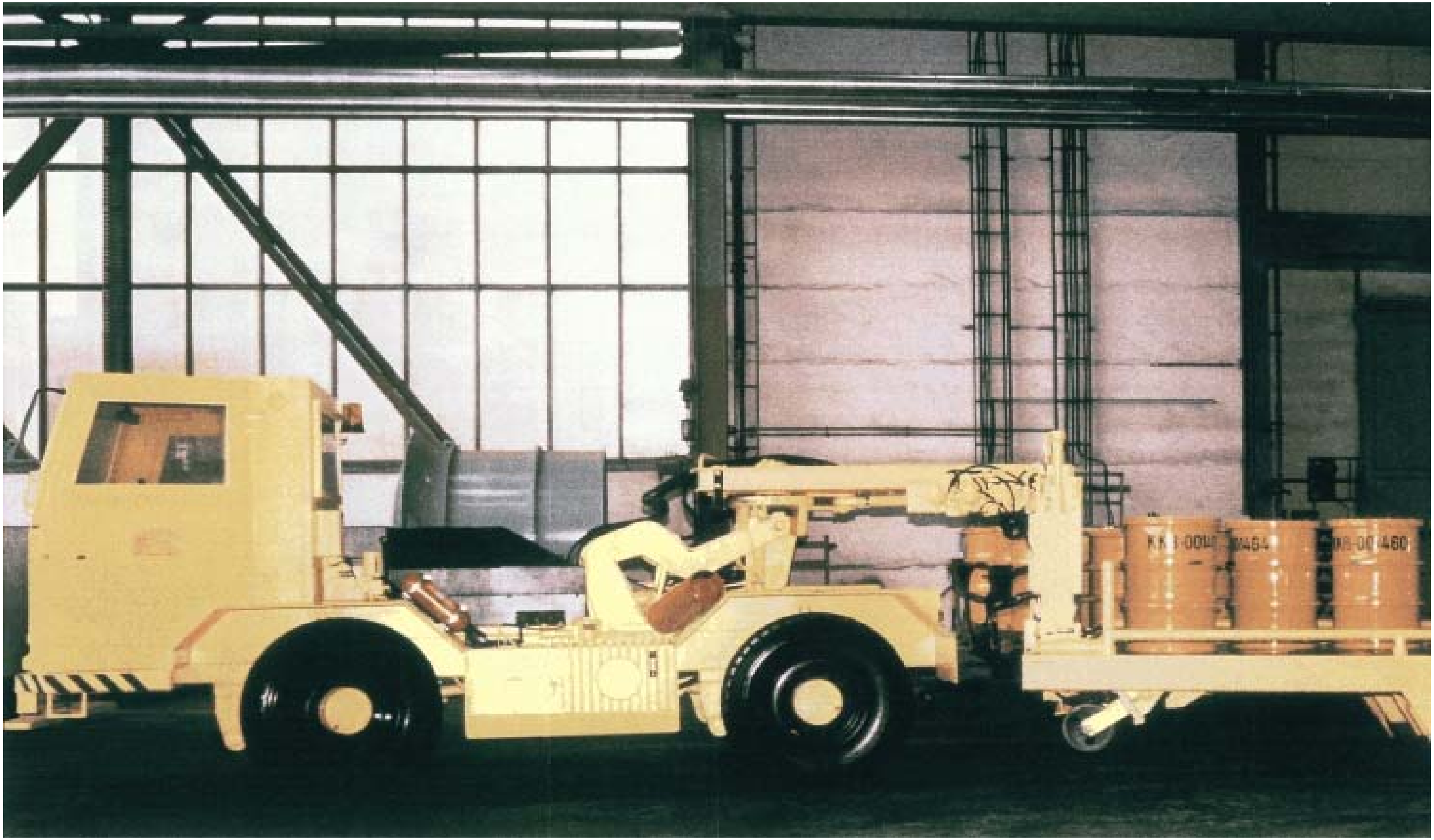
- Gorleben Site Characterization Starts in 1979
- Exploration Mine Starts in 1985
- Konrad Licensing Starts in 1982
- Centralized Interim Storage
- Development of Direct Disposal

Repository Technologies

- Morsleben: Operational Waste (discontinued October 1998)
- Konrad: Non-heat Generating Waste
- Gorleben: Spent Fuel and HLW
- Encapsulation Plant
- AFR Interim Storage: Gorleben / Ahaus

Morsleben Repository

Morsleben Repository



Morsleben Repository

Morsleben Repository

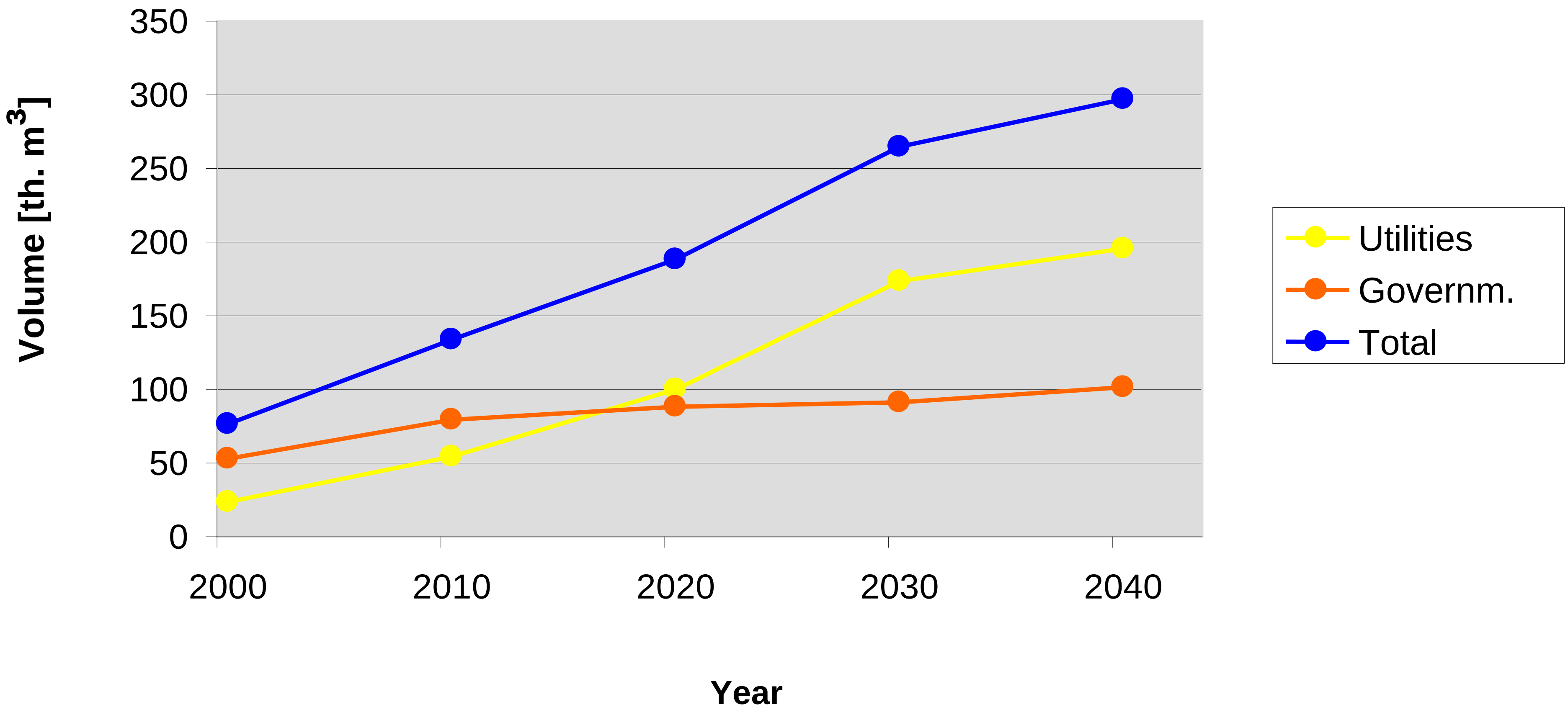
Morsleben Repository

DBE TEC

DBE

Konrad Repository

Waste with Negligible Decay Heat



KONRAD REPOSITORY MILESTONES

- 1933 Konrad iron deposit discovered
- 1957-09 / 1960-01 shaft Konrad 1
  sunk to 1232 m
- 1960 start of iron ore production
- 1976 ore production abandoned

KONRAD REPOSITORY MILESTONES

- 1972 – 1982 site suitability study
- August 31, 1982

  license application submitted

- 1983 – 1990 comprehensive site surv
plan development

DBE TEC

DBE

KONRAD REPOSITORY MILESTONES

- May 22 – July 15, 1991 Konrad plan presented to the public
- 289,387 objections raised
- 1992 – 25 – 09 / 1993 – 03- 06 Konrad hearing (longest ever)
- 1994 – 1996 License Procedure completed...

KONRAD REPOSITORY MILESTONES

- June 14, 2000 Consensus Agreement
  - *Finishing license procedure*
  - *Withdrawal immediate validity*
- July 2000 Immediate Validity cancelled
- **May 22, 2002 NMU grant license**
- 6 Plaintiffs file suit against NMU

KONRAD REPOSITORY MILESTONES

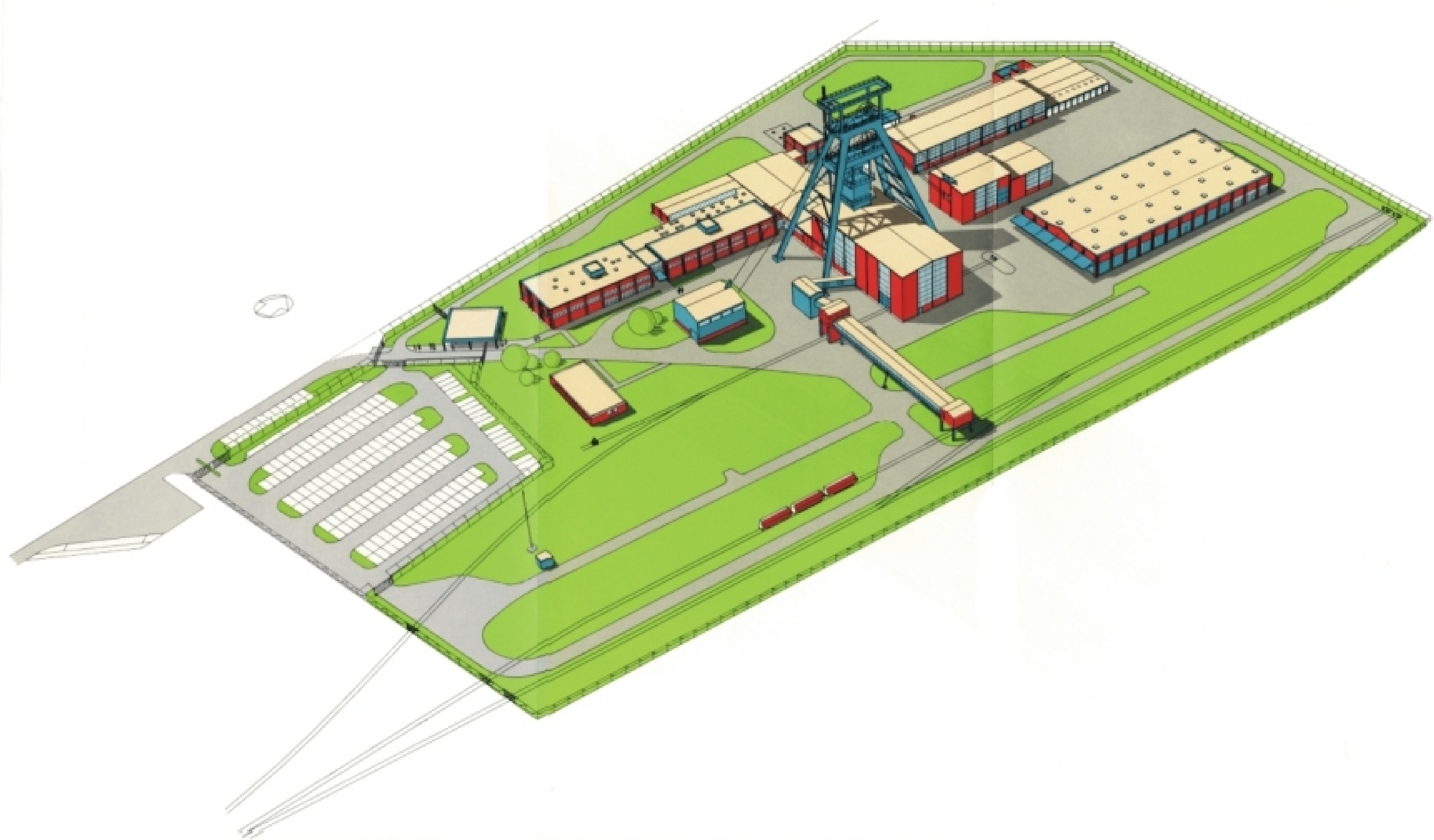
- March 8, 2006 Higher Administrative Court Verdict
  - *Salzgitter, Lengede, Vechelde suits invalid*
  - *Traube family suit unfounded*
  - *Verdict Revision excluded*
- April 2007 final court verdict
- May 21, 2007 construction kick-off by the BMU

KONRAD REPOSITORY MILESTONES

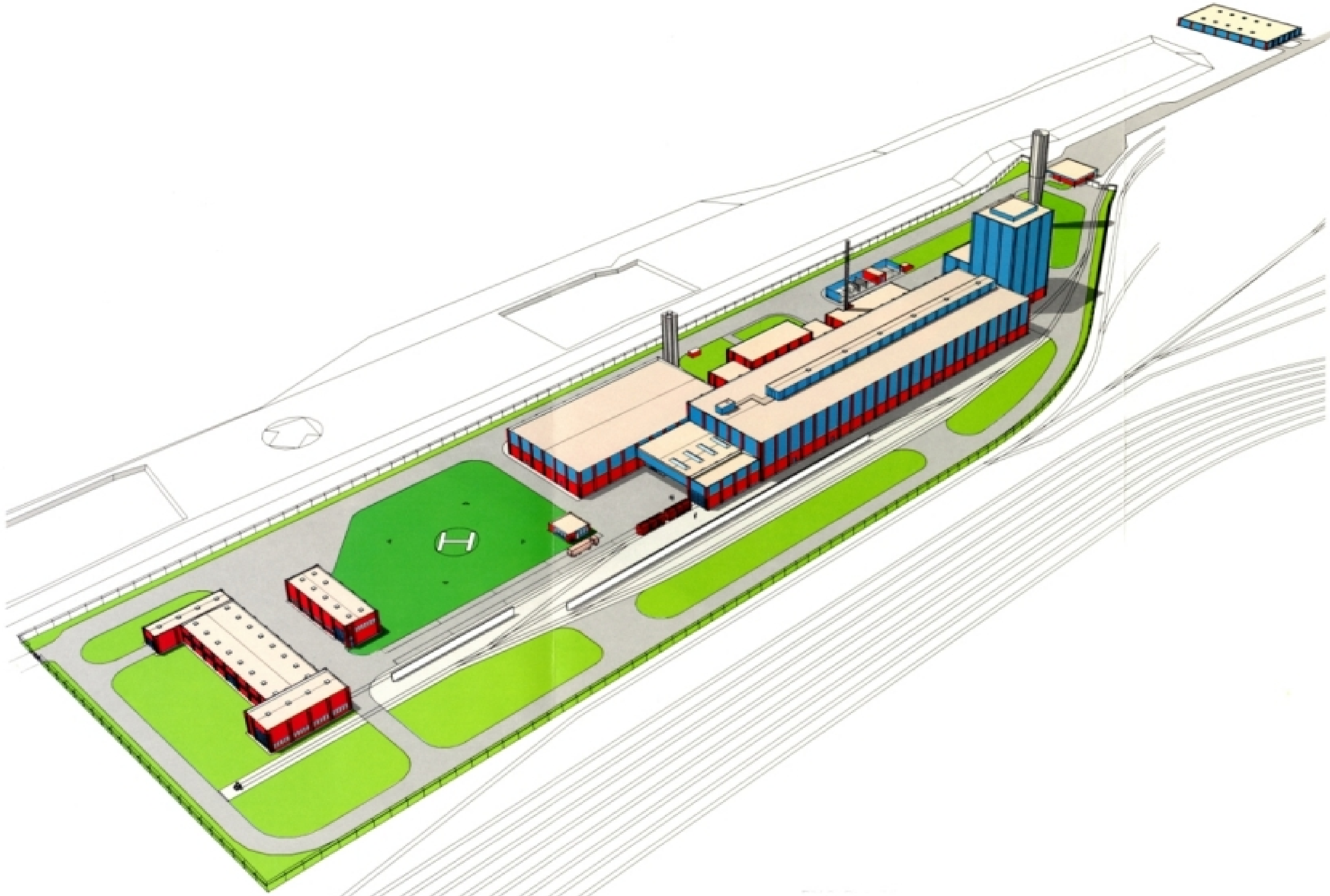
Nr.	ACTIVITY	2007	2008	2009	2010	2011	2012	2013
1	Staff and Organizational Requirements							
2	Mining Licenses							
3	Construction Prerequisites according to License Documents							
4	Preparation of Construction Documents incl. Tendering & Awarding							
5	Adjustment of existing Contracts for Construction Work							
6	Adjustment of planned Rehabilitation Measures incl. Supplementary Technical Equipment for the Conversion							
7	Construction of the Infrastructure for Konrad 1 und Konrad 2							
8	Conversion into a Repository including Operation Start up							
9	Start of Waste Disposal							

Konrad Shaft 1

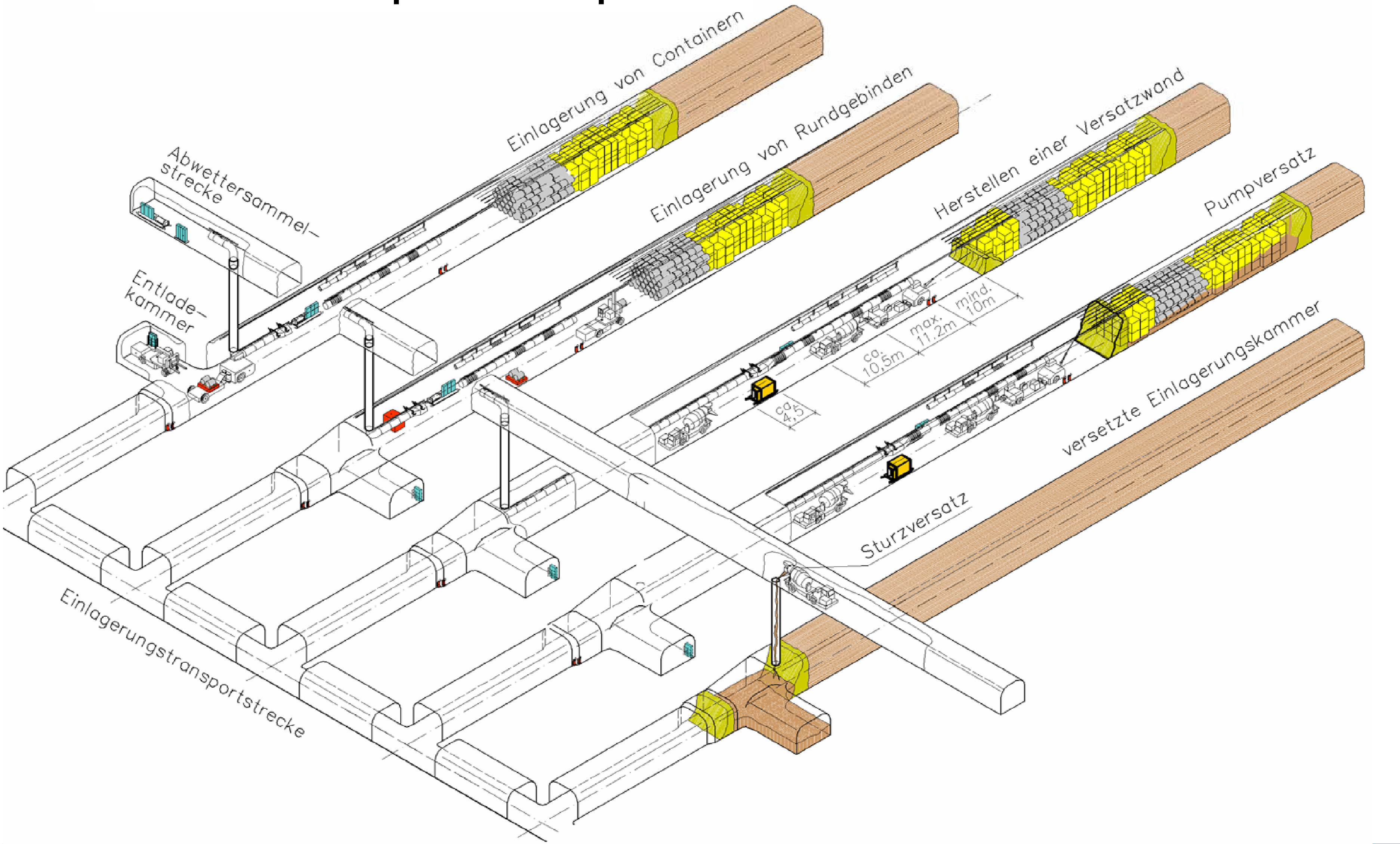
Konrad – Shaft 1 Facilities



Konrad – Shaft 2 Facilities



Konrad – Disposal Sequence



DBE TEC

DBE

Waste disposal at Konrad

Konrad Equipment

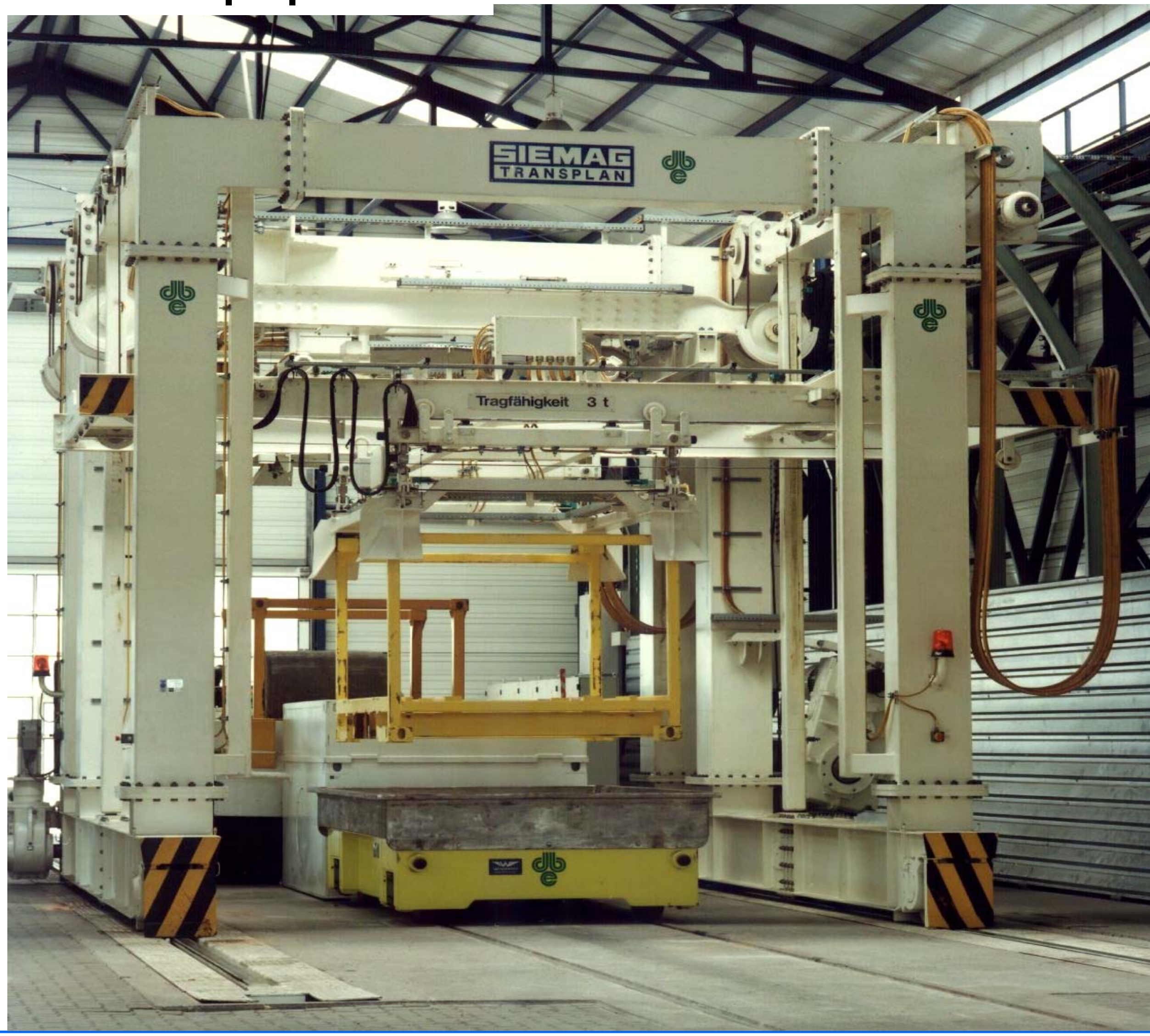
Konrad Equipment

Konrad Equipment

Konrad Equipment

DBE TEC DBE

Konrad Equipment



Konrad Equipment

DBETEC DBE

Konrad Equipment

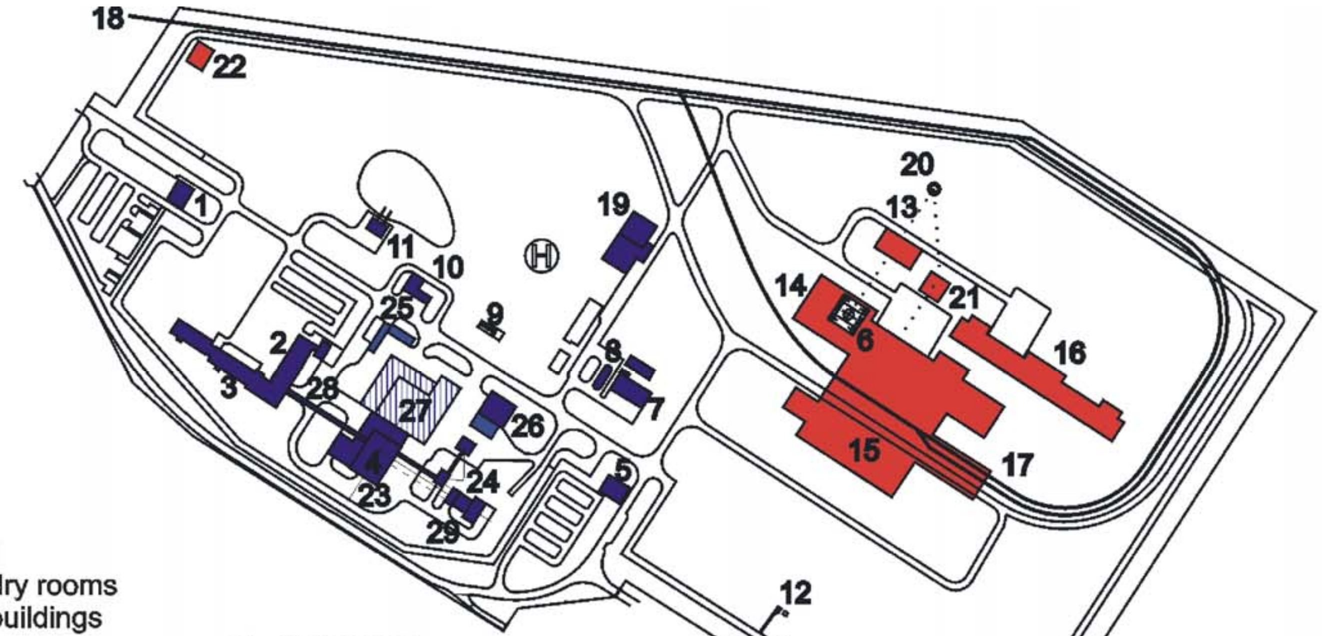
Konrad Repository

DBEtec DBE

Konrad Repository

Gorleben Site Exploration Mine

Gorleben



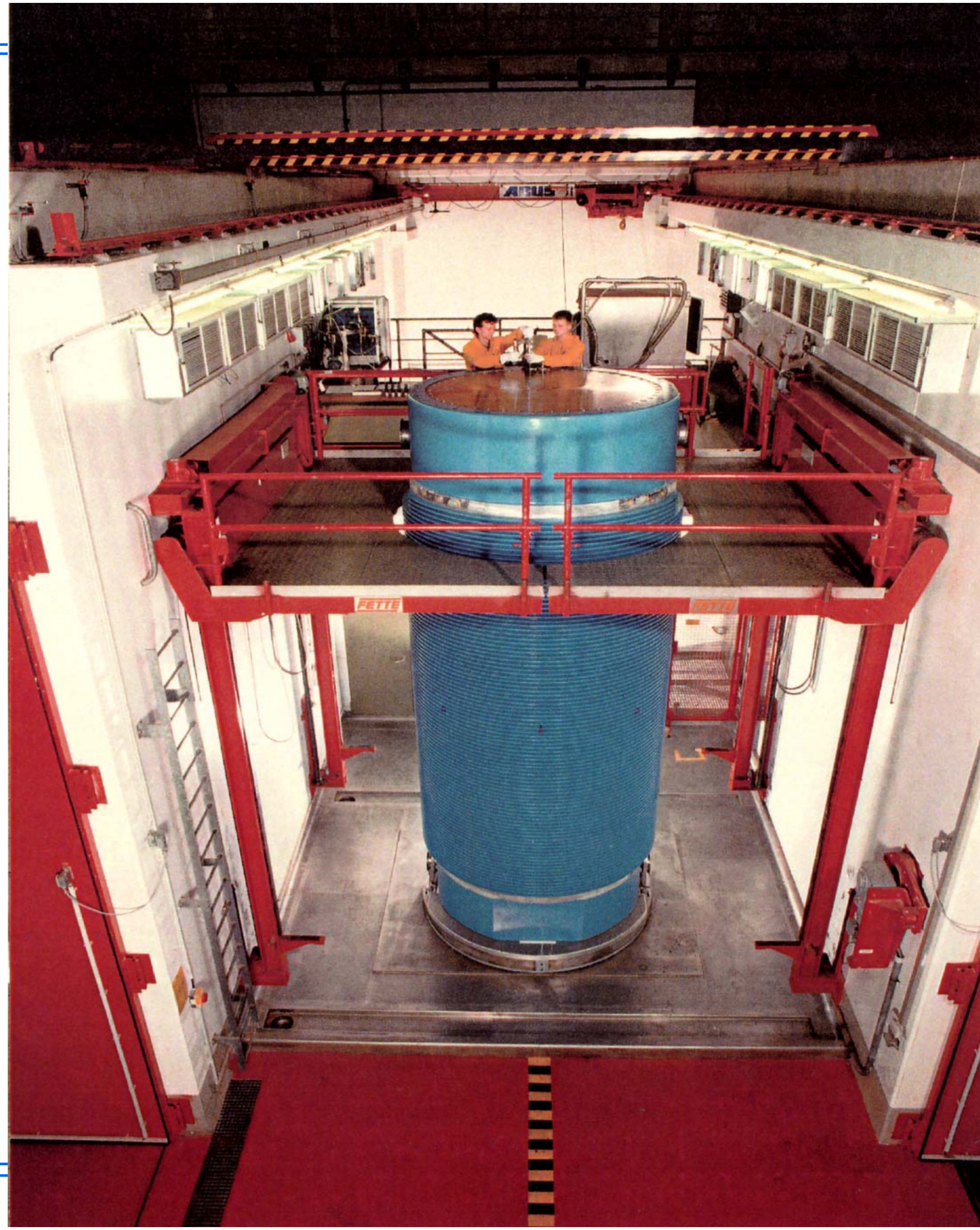
Legend:

1 entrance building 1
2 heating plant and dry rooms
3 offices and social buildings
4 shaft 1
5 entrance building 2
6 shaft 2
7 magazine and equipment storage
8 fuel storage
9 pumping station (fresh and waste water)
10 electric power transmission
11 drain water pumping station
12 weather monitoring station
13 diffusor
14 shaft hall shaft 2
15 shipment - arrival
16 technical offices, laboraties
17 drying hall
18 railway
19 drill core storage
20 chimney
21 exhaust air building surface facilities
22 entrance building 3
23 shaft hall shaft 1
24 salt shipment - departure
25 garages / friction hoist
26 cleaning hall / storage for equipment to pull over new ropes
27 workshop and spareparts
28 gateway - brigde to shaft 1
29 mine ventilation fresh air building

0 m 100 m

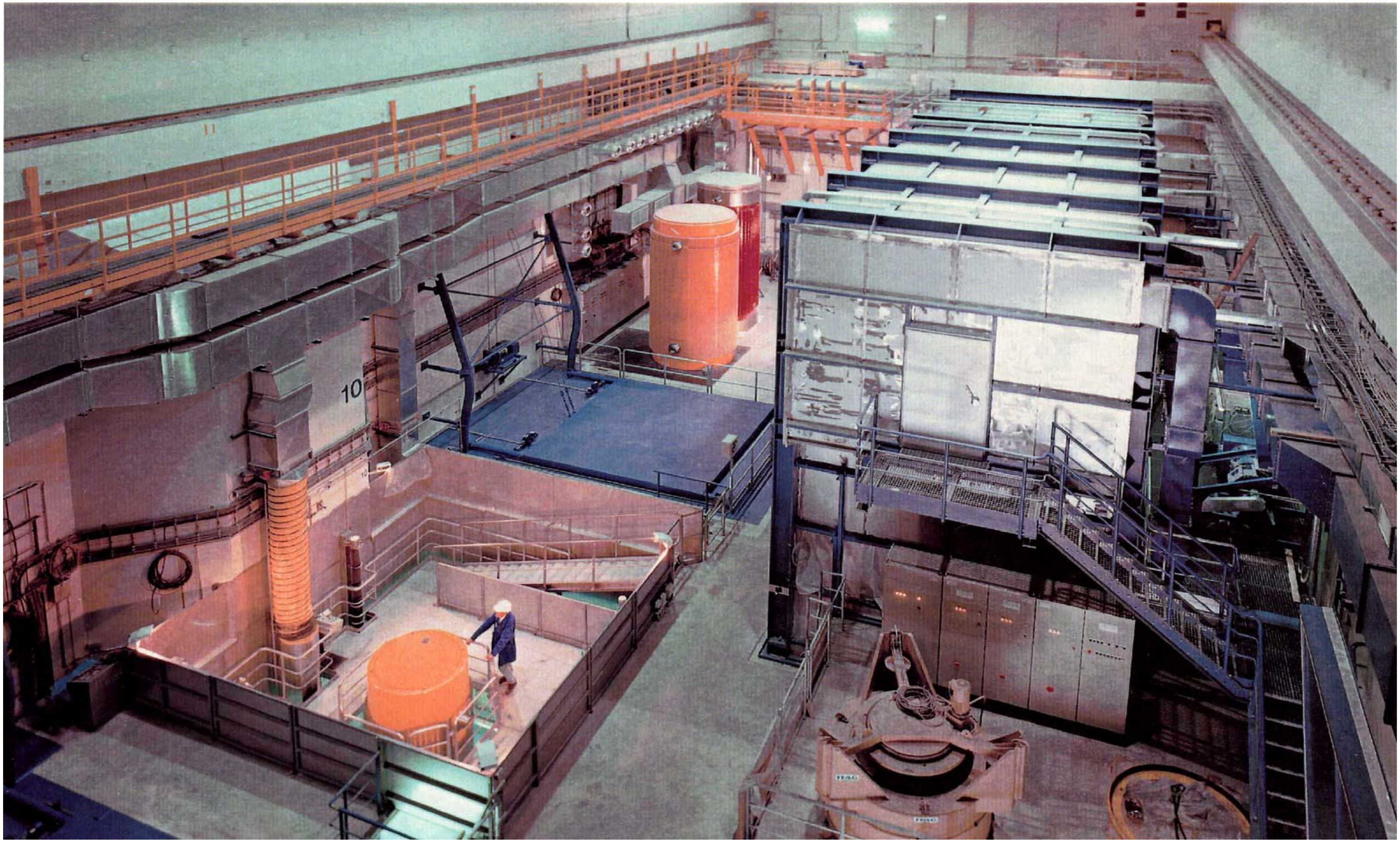
existing
new
planed while exploration

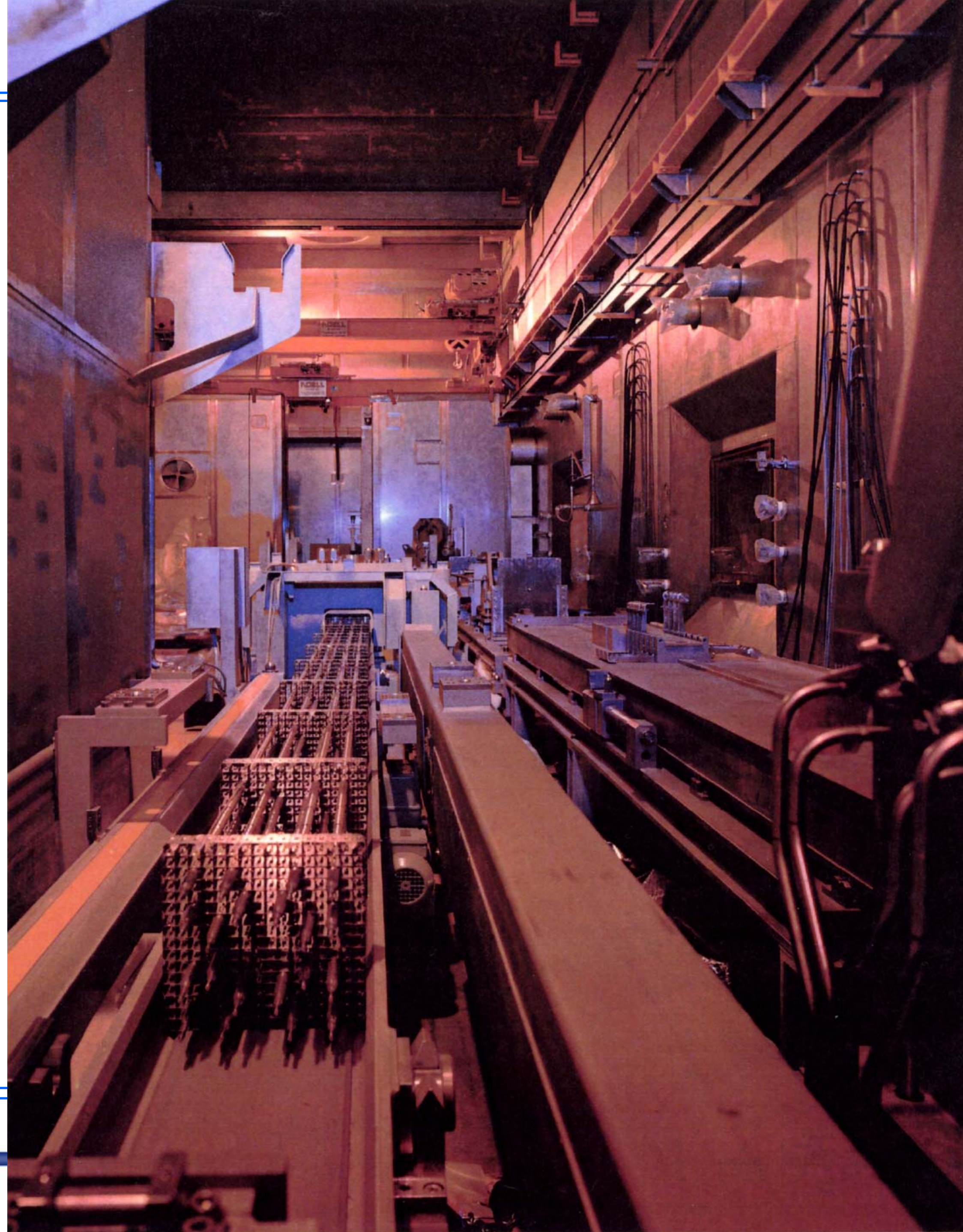
Gorleben


ABUS
FETTE
FETTE

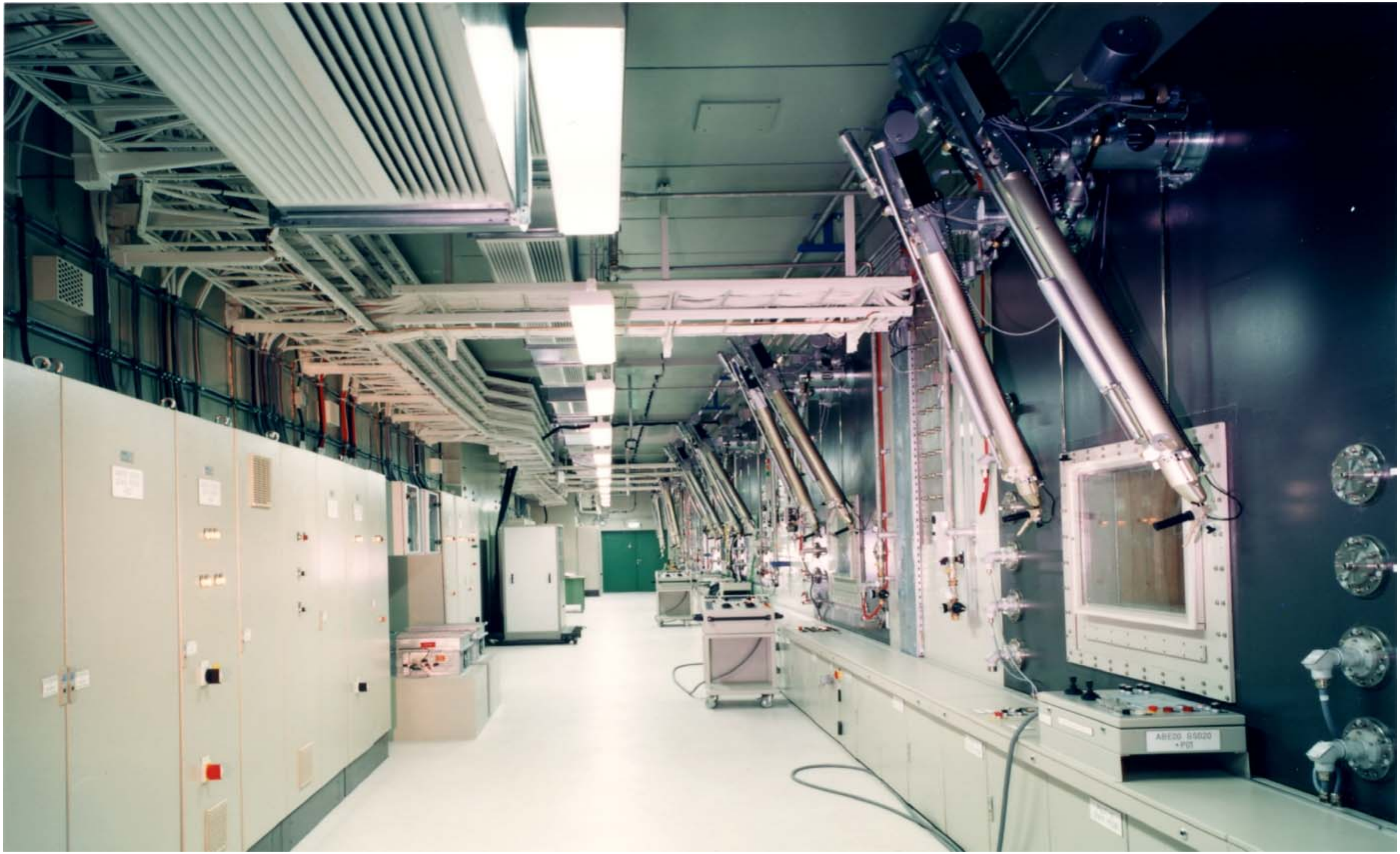
Gorleben

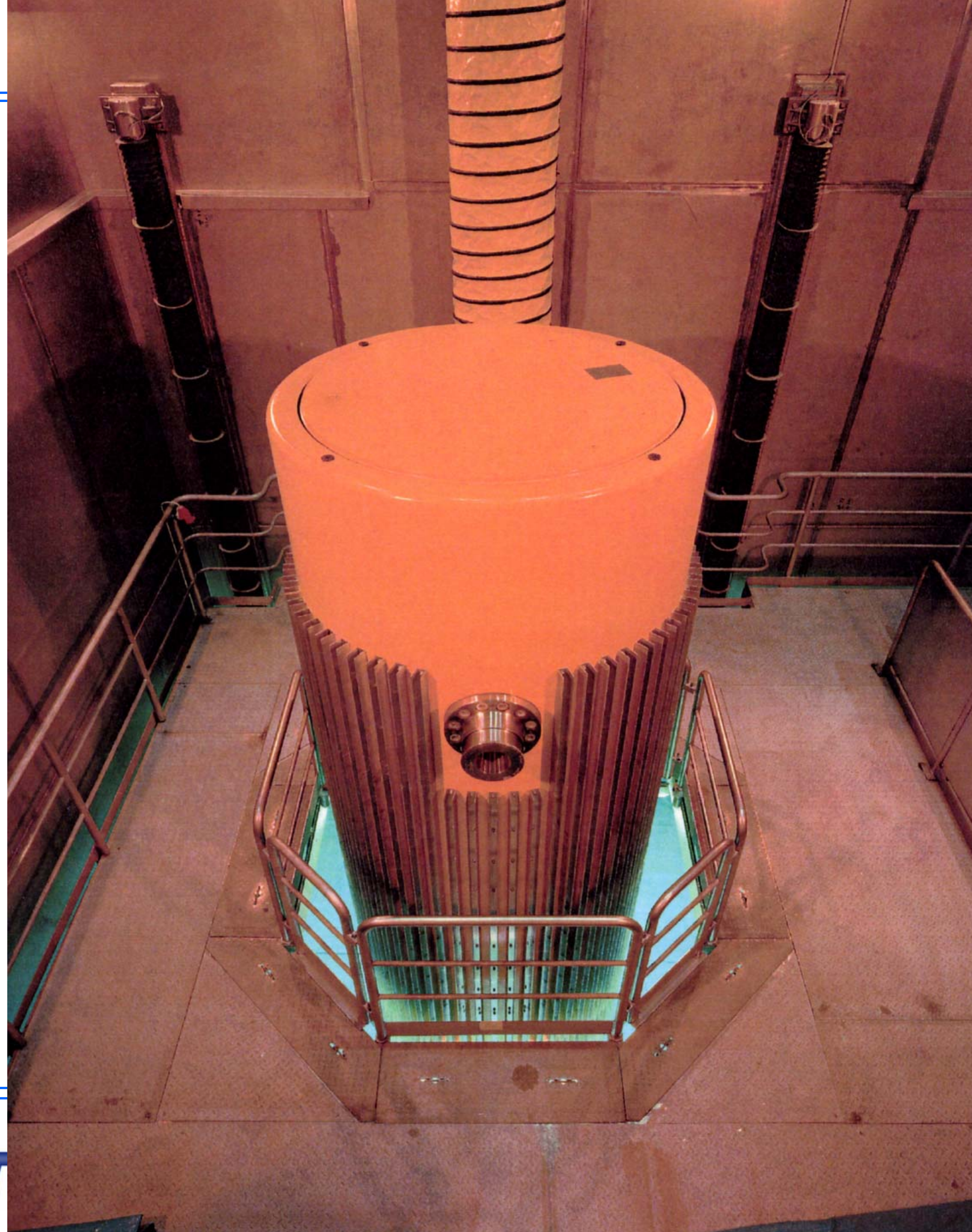
Gorleben





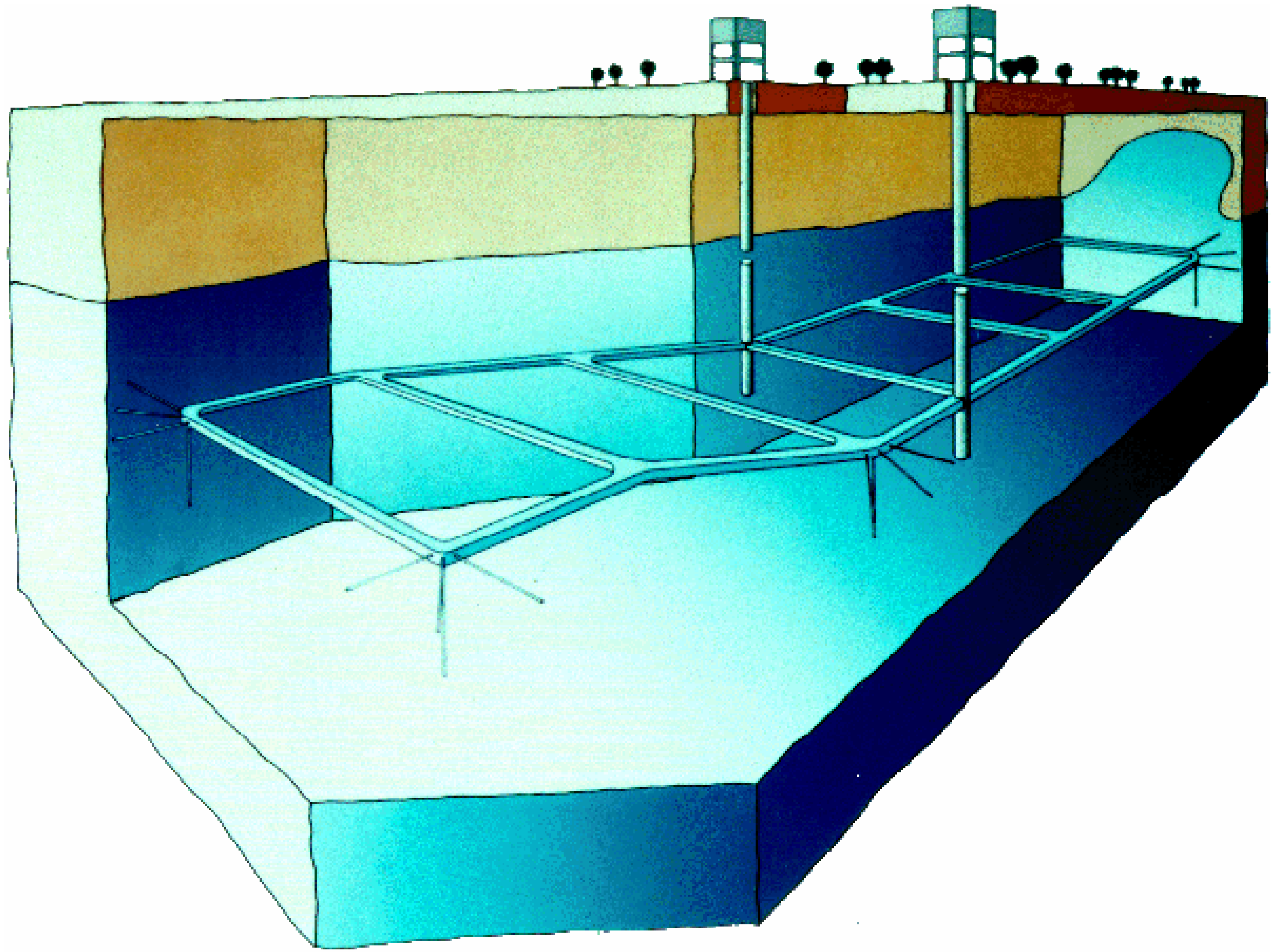
Gorleben



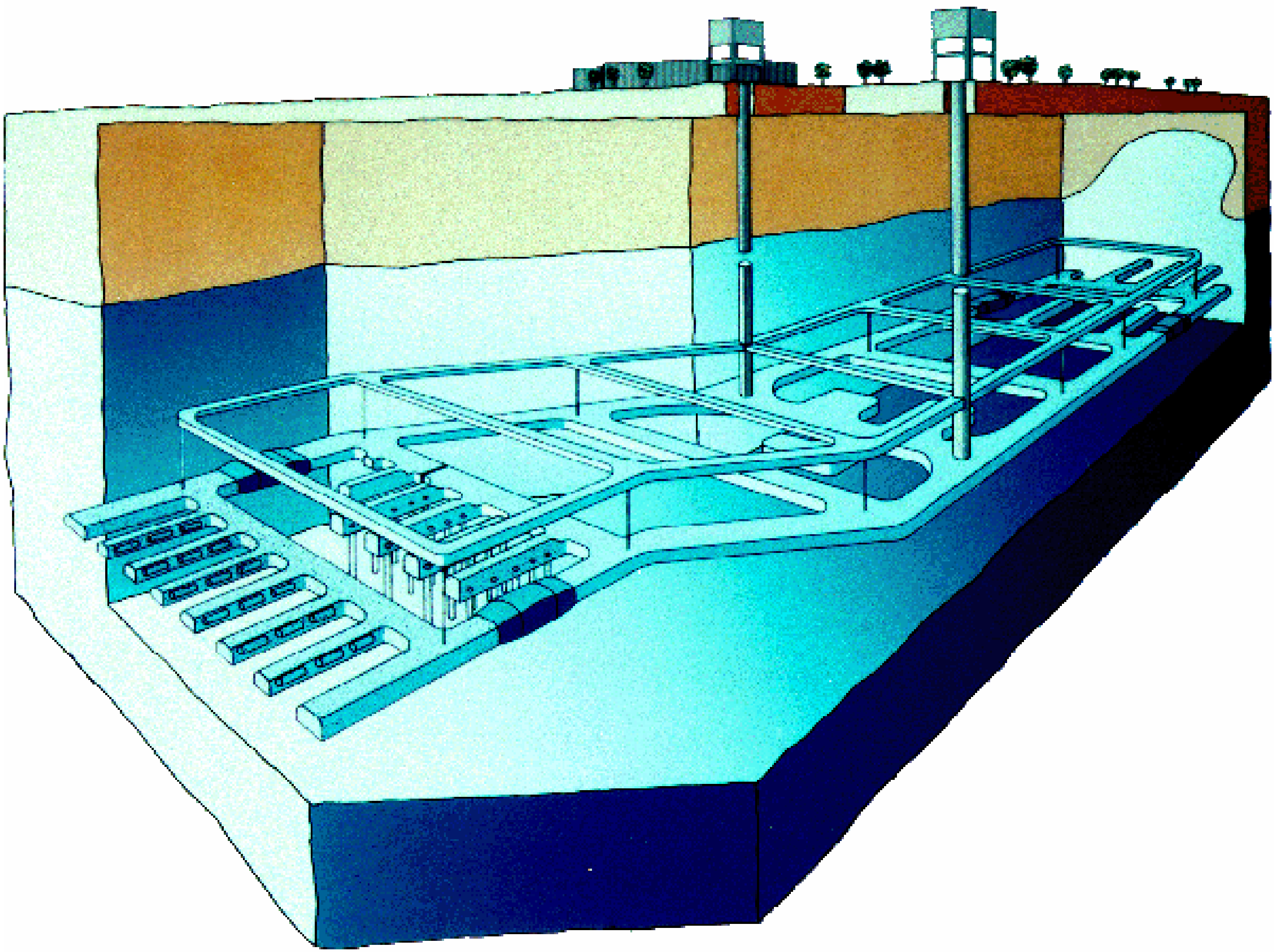


Gorleben

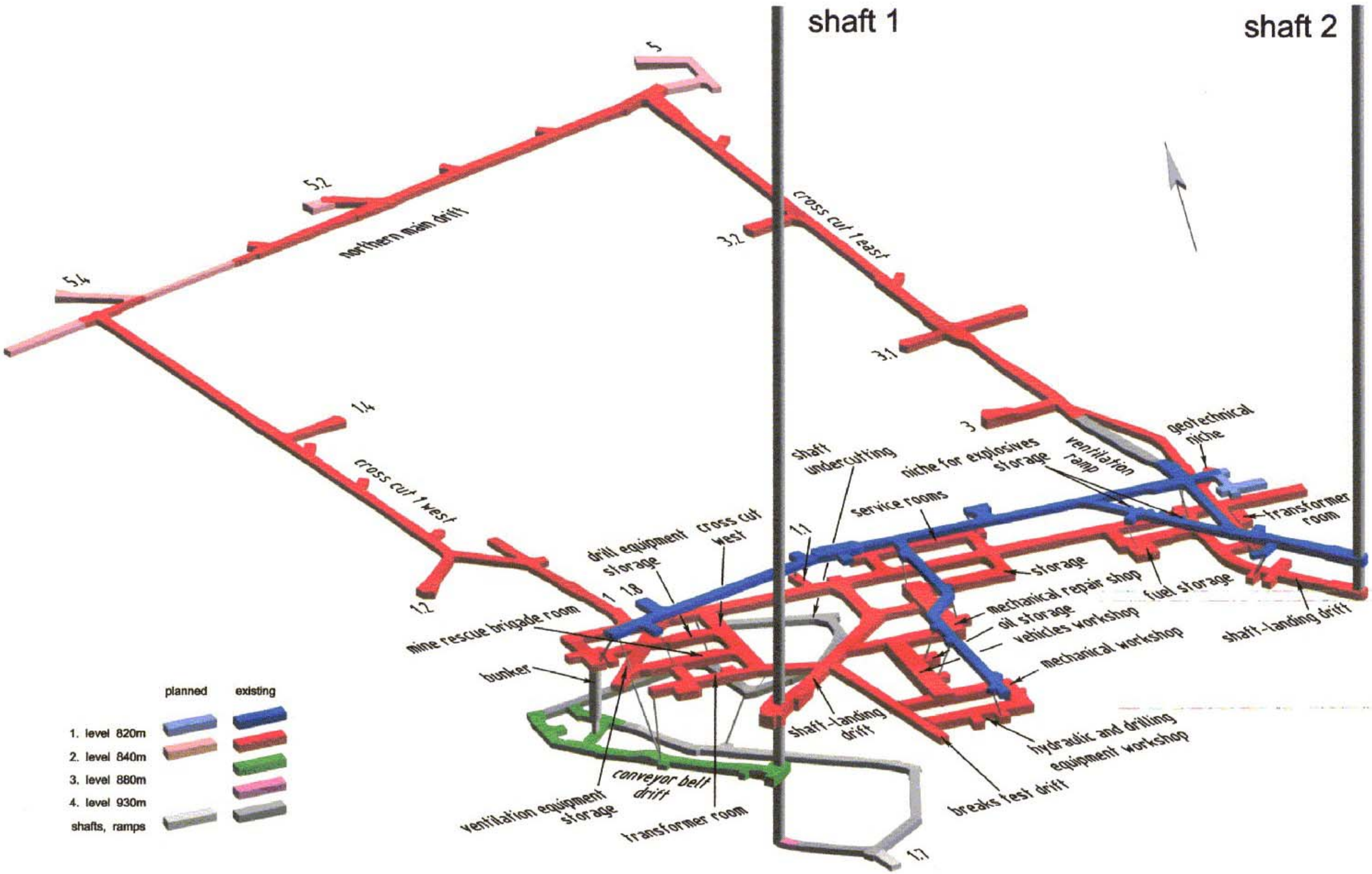
Gorleben



Gorleben

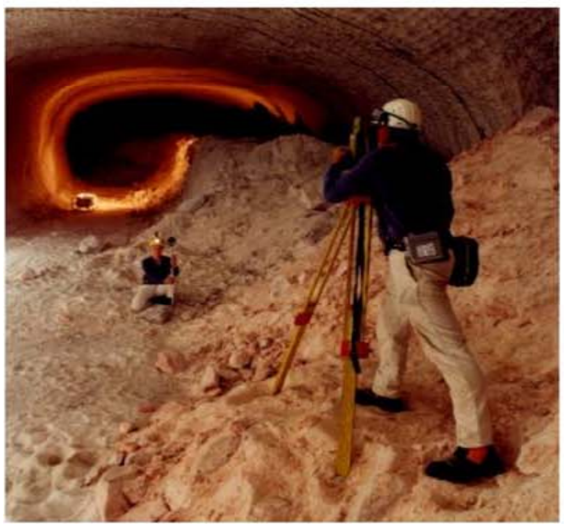


Gorleben



shaft 1
shaft 2
5
5.2
5.4
northern main drift
cross cut 1 east
3.2
3.1
3
1.4
cross cut 1 west
1.2
geotechnical niche
ventilation ramp
niche for explosives storage
shaft undercutting
service rooms
transformer room
1.1
drill equipment storage
cross cut west
1.8
1
storage
mechanical repair shop
fuel storage
oil storage
vehicles workshop
mechanical workshop
shaft-landing drift
mine rescue brigade room
bunker
shaft-landing drift
hydraulic and drilling equipment workshop
breaks test drift
conveyor belt drift
ventilation equipment storage
transformer room
1.7
planned
existing
1. level 820m
2. level 840m
3. level 880m
4. level 930m
shafts, ramps

Gorleben



Gorleben

Gorleben

Gorleben

Gorleben

Gorleben

Peine Headquarters

DBE TEC

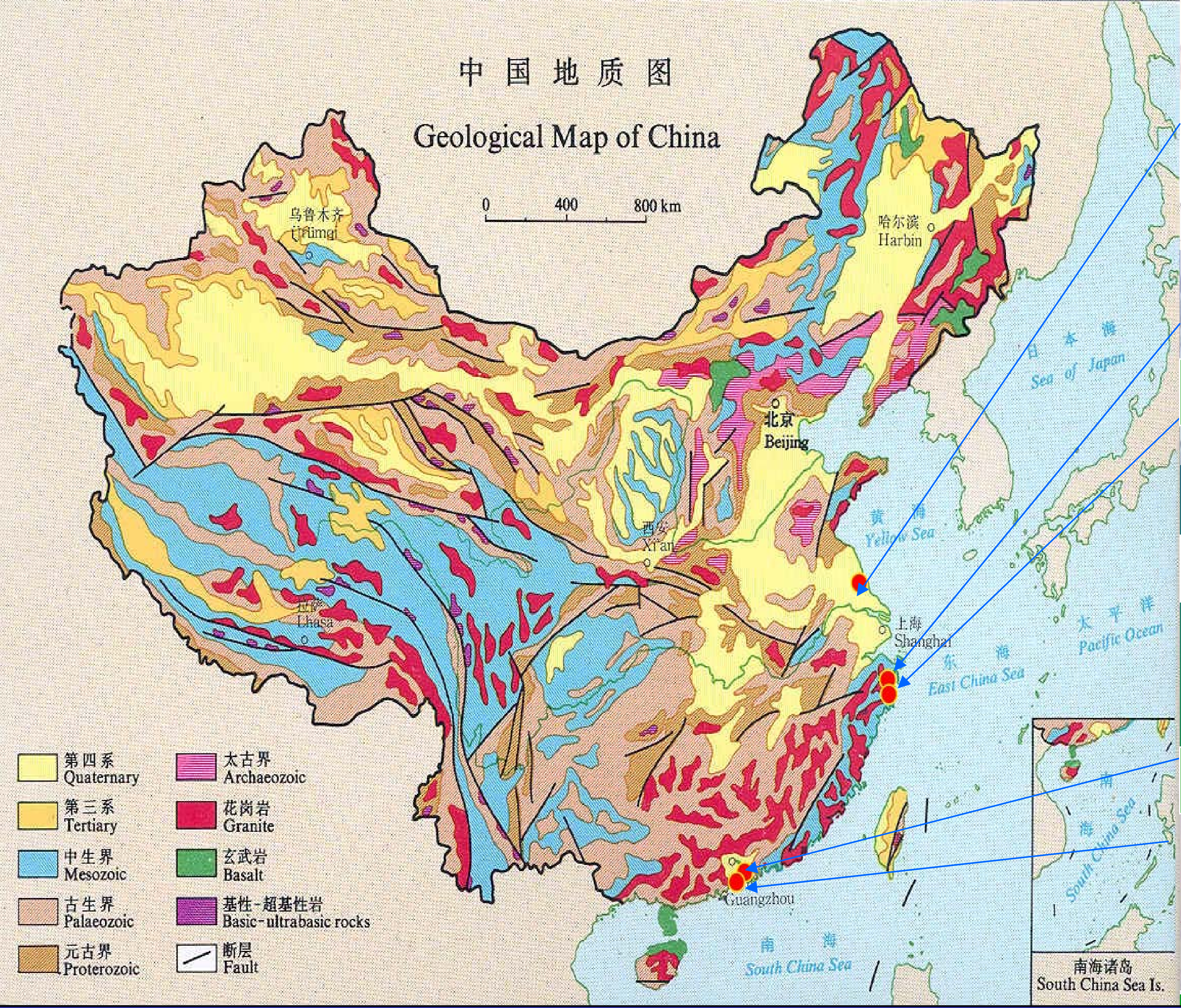
DBE

Deep Geological Disposal of High Level Radioactive Waste in China:

Latest Progress by 2007

WANG, Ju (王 驹)

Beijing Research Institute of Uranium Geology,
China National Nuclear Corporation



Tianwan

Qinshan 3

Qinshan1, 2

Lin'ao

Daya Bay

Nuclear power plants in Chinese Mainland in 2006:
10 reactors in operation, 1 in test operation, 4 under construction

By 2020

- **Installed capacity of NPP: 40 GW**

  18 GW under construction
- **30 more 1000 MW NPPs will be built in Chinese Main Land**
- **Cost: 50 billion USD**
- **Right now, Sanmen NPP, Lin'ao (2nd phase), and Qinshan Phase 2 (2 new reactors) are under construction**

Spent Fuel Accumulation from Light Water Reactor

- By 2010 1,000 MTU from PWR
- By 2020 10,300 MTU (7000 from PWR, 3300 from CANDU)
- After 2020 1,000 MTU/year

based on that the installed nuclear power capacity in China will be

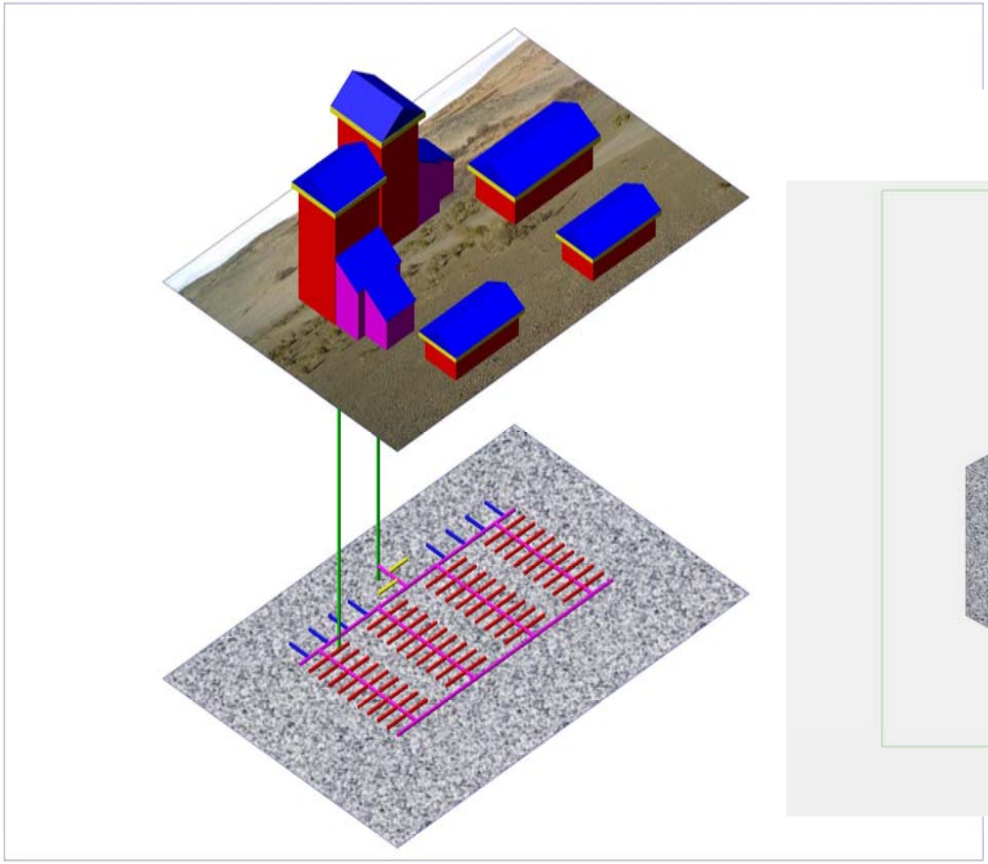
20,000 MW in 2010

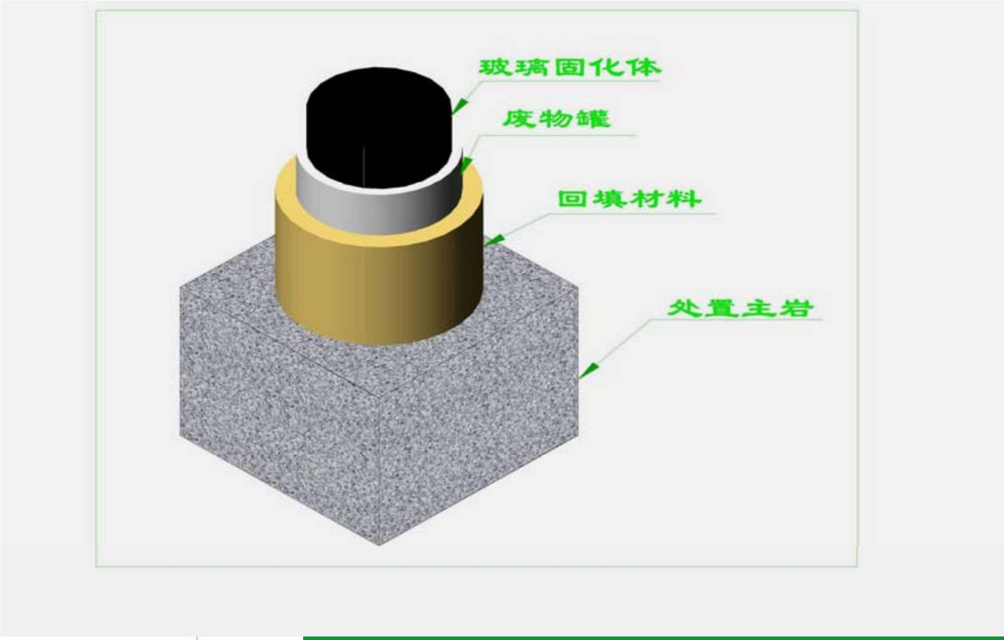
40,000 MW in 2020

Basic Policy for HLW Disposal

- spent fuel should be reprocessed
- waste form: vitrified waste, CANDU SF
- deep geological repository
- host rock: granite
- repository concept: shaft--tunnel-disposal hole, located in saturated zone

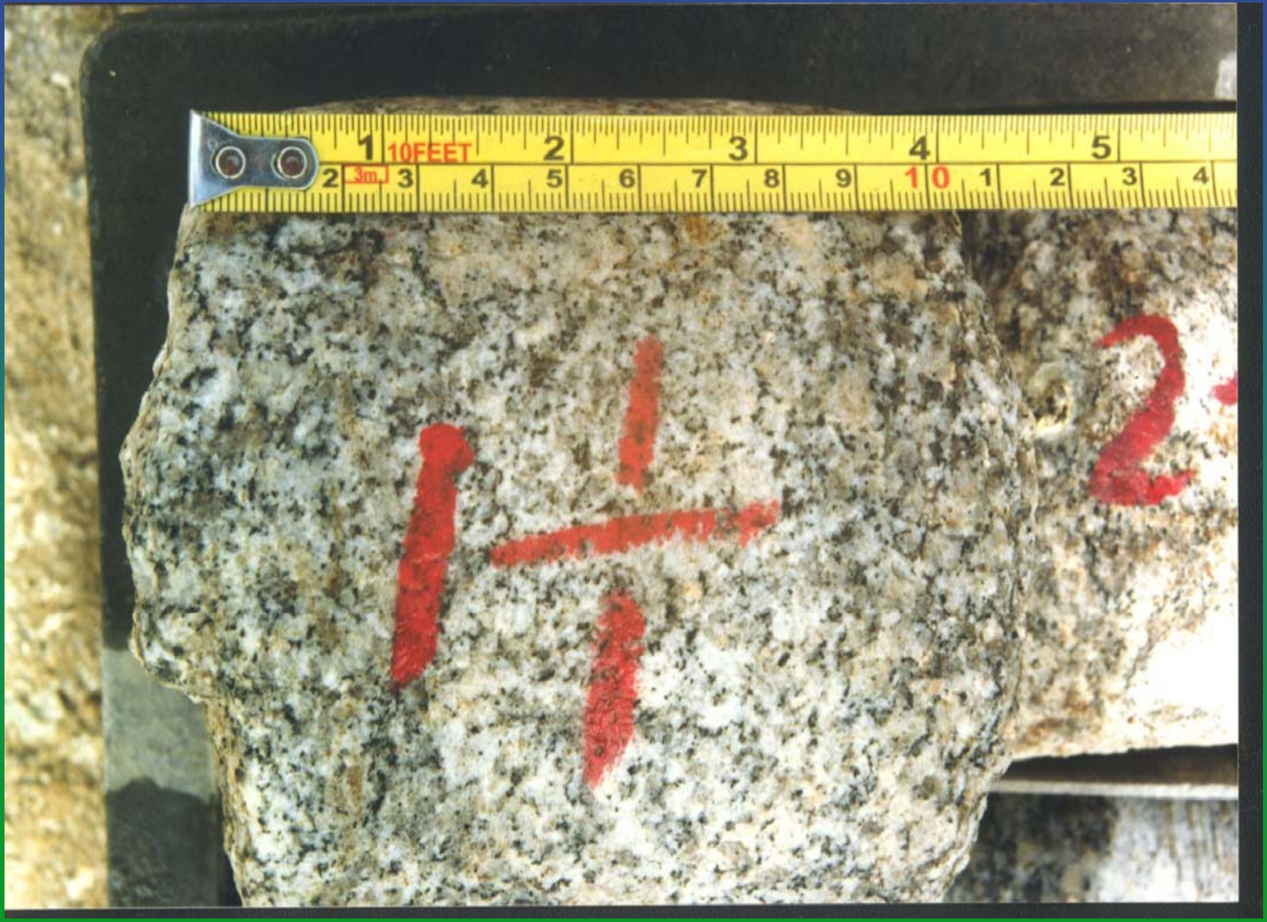
Preliminary Concept of Chinese HLW Repository





Host rock for China's HLW

granite



国家环境保护总局
国家核安全局

Regulatory body

国家原子能机构

Project and fund control

State Environment Protection Admin. (SEPA)

National Nuclear Safety Admin. (NNSA)

China Atomic Energy Authority (CAEA)

↓

China National Nuclear Corporation (CNNC)
-- possible implementation body

中国核工业集团公司

Institutes Involved in HLW Disposal Research

4 Lead Institutes

- Beijing Research Institute of Uranium Geology (BRIUG)
- China Institute of Atomic Energy
- China Institute for Radiation Protection
- Beijing Institute of Nuclear Engineering

- other institutes and Universities

October 1, 2003

The Law of Prevention of Radioactive Pollution entered into force:

" the high level radioactive waste and alpha-bearing waste should be disposed of in centralized deep geological repositories"

R&D Guidelines for Geological Disposal

- jointly published by China Atomic Energy Authority Ministry of Sci&Tech., State Environment Protection Administration
- published in Feb. 2006
- First government document on HLW disposal
- the R&D on HLW in China entered into a new stage

Objectives of HLW disposal Program

- To select an site with stable geological and suitable social-economical conditions
- To build a geological repository in the middle of 21st century
- To protect the public health and the environment from the unacceptable harm from HLW through the containment, retardation by engineered and natural barriers.

Strategy for repository development

3-step strategy （“三部曲”战略）

SITE — Basic study,Site selection and site Characterization

↓

URL — Might be a Site-specific URL in the potential HLW repository area

↓

REPOSITORY — final repository constructed based on URL

Long term plan for HLW disposal

- 2006--2020：
  Basic Study and Site Selection
- 2020--2040
  Underground Research Laboratory
- 2040--middle of 21^{st} Century
  Repository

Major Research Activities between 2006-2020

- Strategies, planning and management
- Engineering Design
- Site selection and site characterization
- Radiochemical studies for disposal
- Safety assessment

Major activities 2006-2010—(1)

Studies on strategy, regulation, plan and standards

- studies on disposal strategies
- establishment of framework of standards
- compilation of R&D network
- framework for management system
- comparison among geological disposal, P&T and long-term storage

Major activities 2006-2010—(2)

Studies on site selection and site evaluation

- deep geological environment of Beishan site
- regional geology of Beishan site
- hydrogeology of Beishan site
- geophysical survey
- another pre-selected region
- technologies for site evaluation
- digital geoscience database
- facility establishment for site evaluation

Focus: Beishan granite site

Major activities 2006-2010—(3)

Studies on Engineering design

- conceptual design of URL,
- conception design of repository
- engineered barrier system study
- bentonite study
- facility establishment for engineering design

Major activities 2006-2010—(4)

Radiochemical studies for disposal

- performance of glasses, containers
- chemical behavior of radionuclides under simulated repository conditions
- migration behavior of radionuclides
- database for radionuclide migration
- facility construction for radionuclide migration study

Major activities 2006-2010—(5)

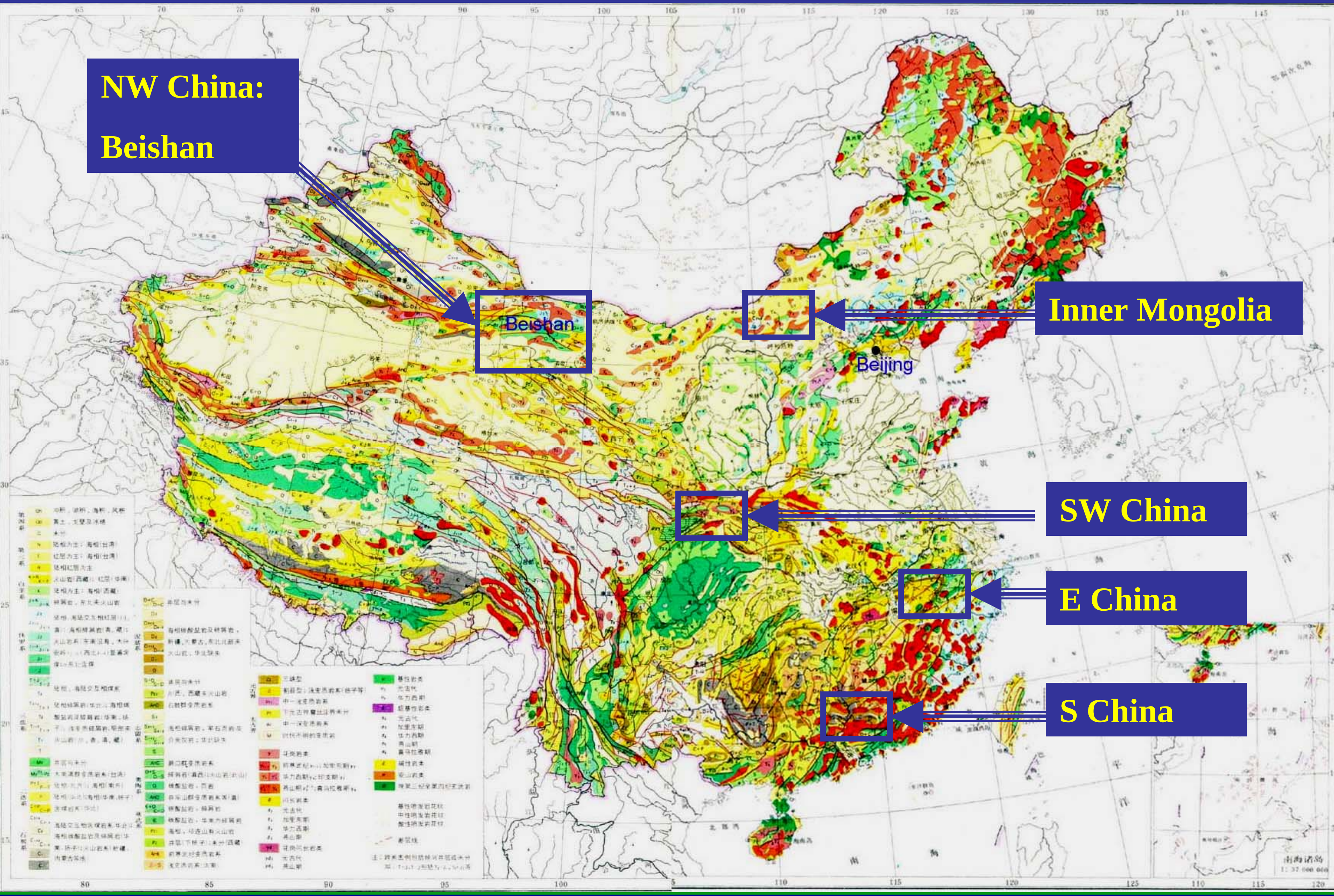
Studies on safety assessment

- methodologies for safety assessment
- study on safety standards
- safety cases
- studies of computer codes for SA
- study platform for SA

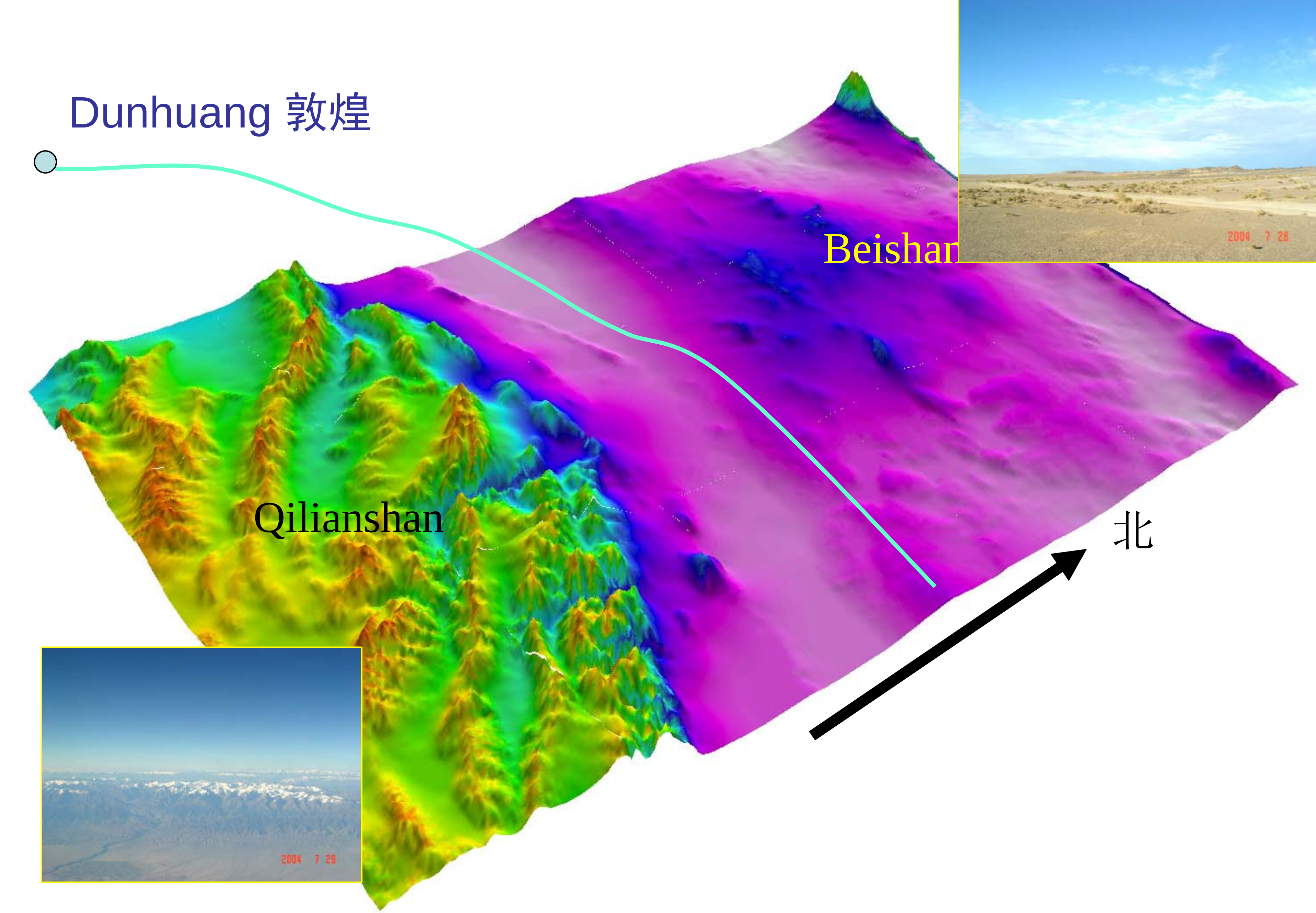
Major progress of HLW Program

- Site selection and Site characterization: since 1986
- Backfill material study: Bentonite from Inner Mongolia
- migration behavior of radionuclide
- Natural analogue

Major activities: Site selection and site characterization



5 Pre-selected regions for China's HLW repository since 1986



3-D DEM of Beishan and Qilianshan

Beishan site 北山场址

- in Gansu （甘肃）province, NW China
- the most potential area for China’s repository
- Gobi desert area
- low population density
- low precipitation : 60--80 mm/a
- high evaporation: 2900-3200 mm/a
- no economical prospect
- no important mineral resources
- convenient transportation
- stable crust
- favorable hydrogeological conditions
- host rock: granite and diorite

Beishan site 北山场址

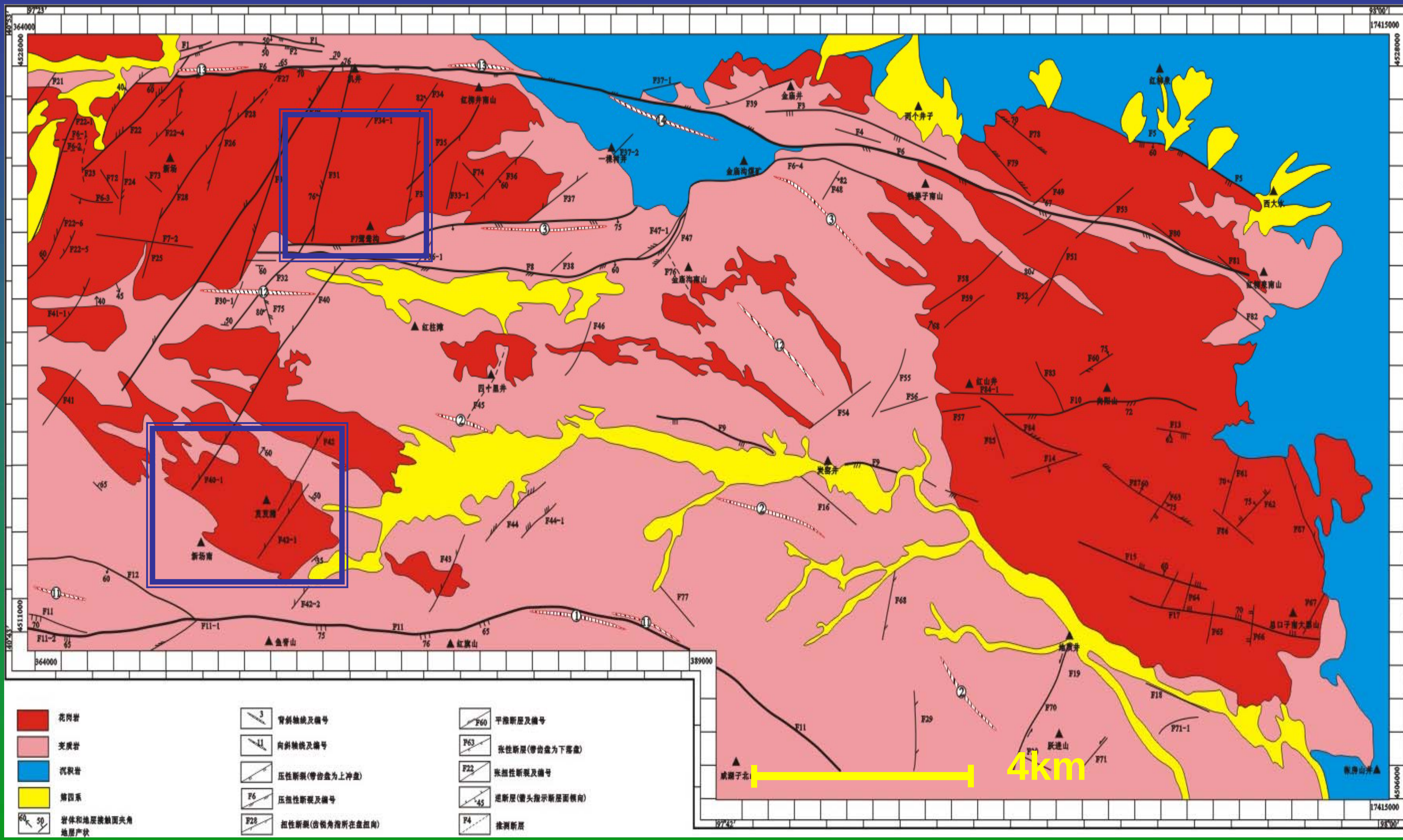
Landscape of Beishan site

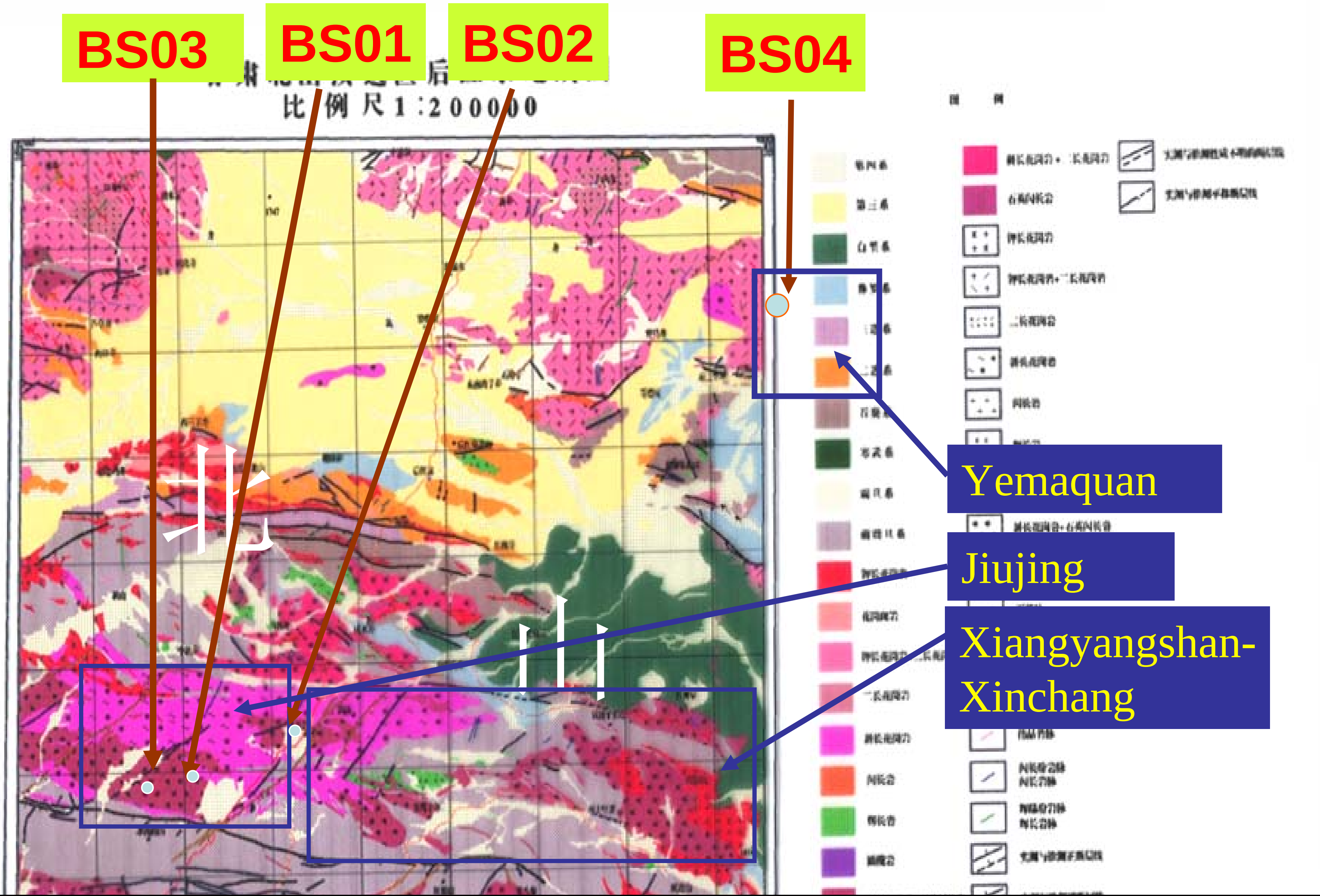
Outcrops of granite

Major Activities 2000--2007

- surface geological, hydrogeological and survey at Jiujing, Yemaquan and Xinchang-xiangyangshan sections
- bore hole drilling for BS01, 02, 03, 04
- geophysical survey
- in situ tests in bore holes
- application of remote sensing technology
- Regional crust stability study
- evaluation of site suitability

Geological map of Xinchang-Xiangyangshan section



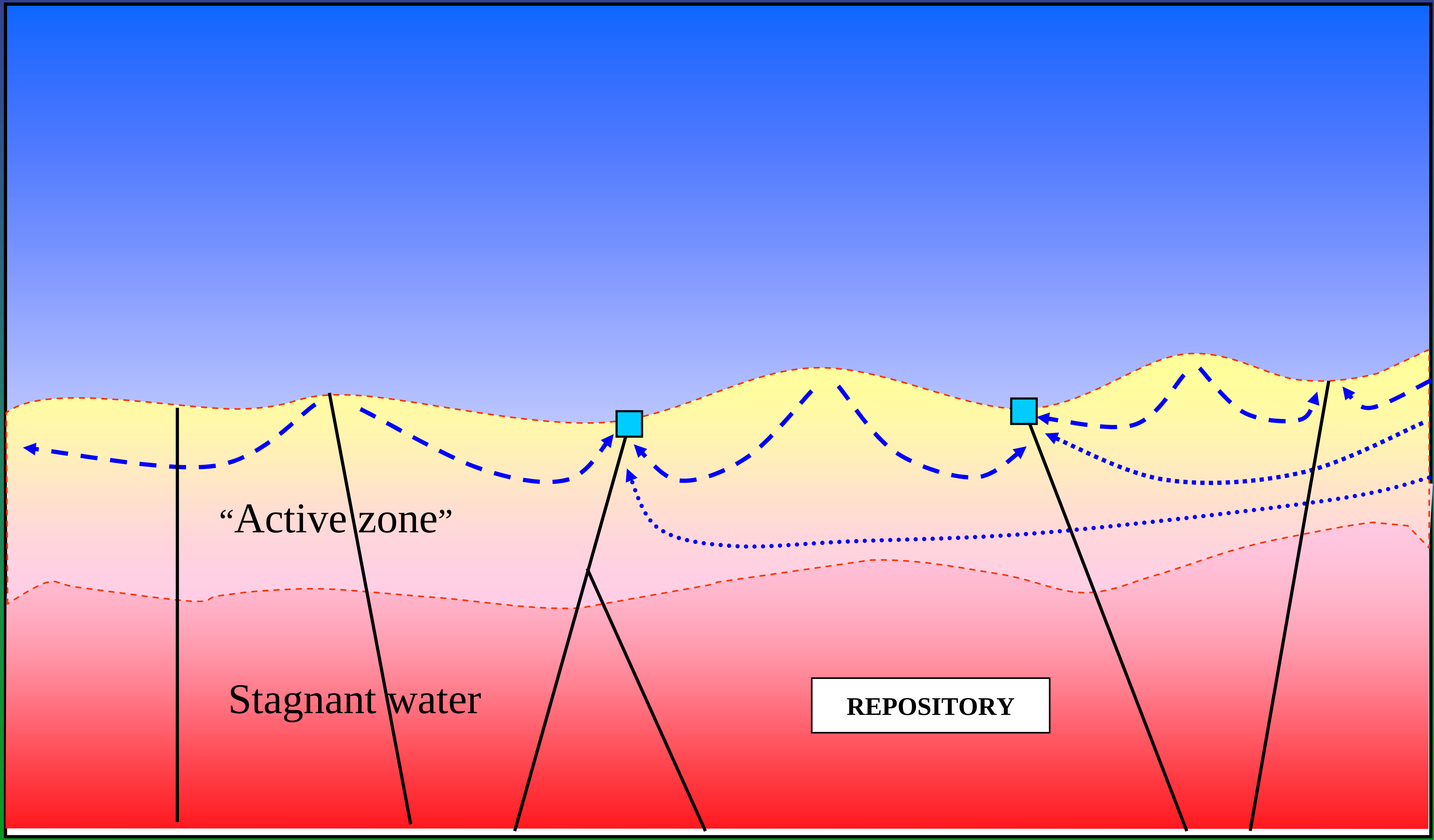


4 bore hole completed

drilling sites at BS01, BS02, BS03, BS04 boreholes

BRIUG

Conceptual model of the groundwater flow



Dynamics of deep groundwater

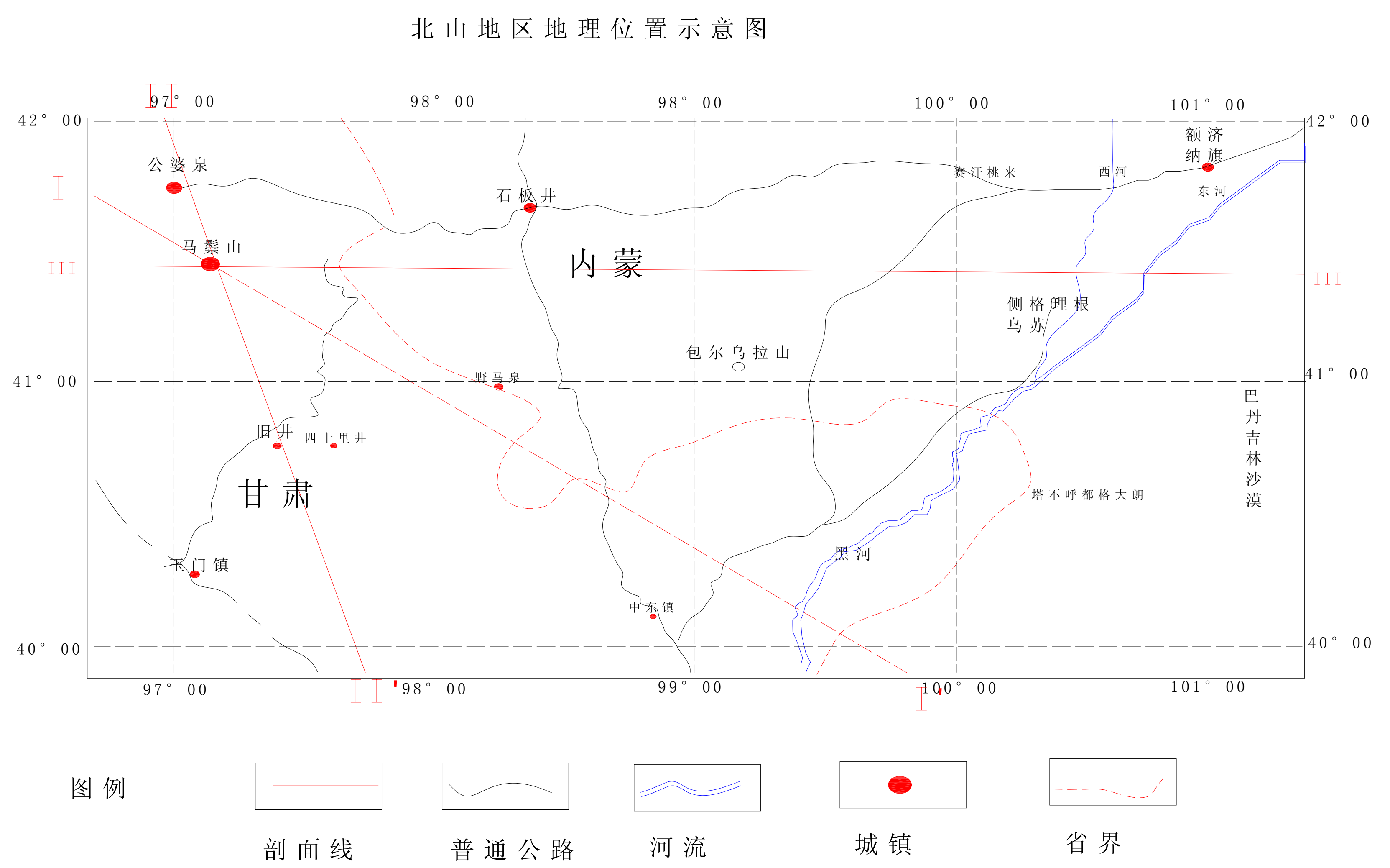
- **low water outflow 弱含水性**
- **low permeability 低渗透性**
- **low velocity 低流速性**

Chemistry of deep groundwater

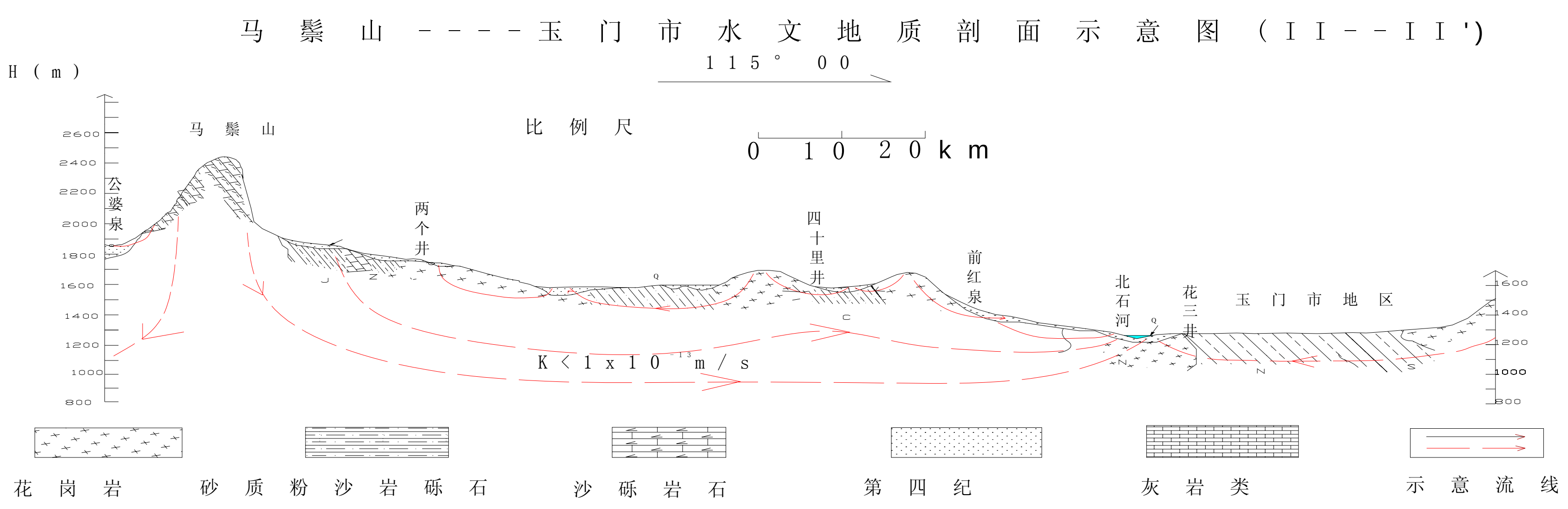
- **High salinity 高矿化性,**
- **slight-alkaline 偏碱性,**
- **reducing 还原状态**

which is not favorable for the transportation of radionuclide

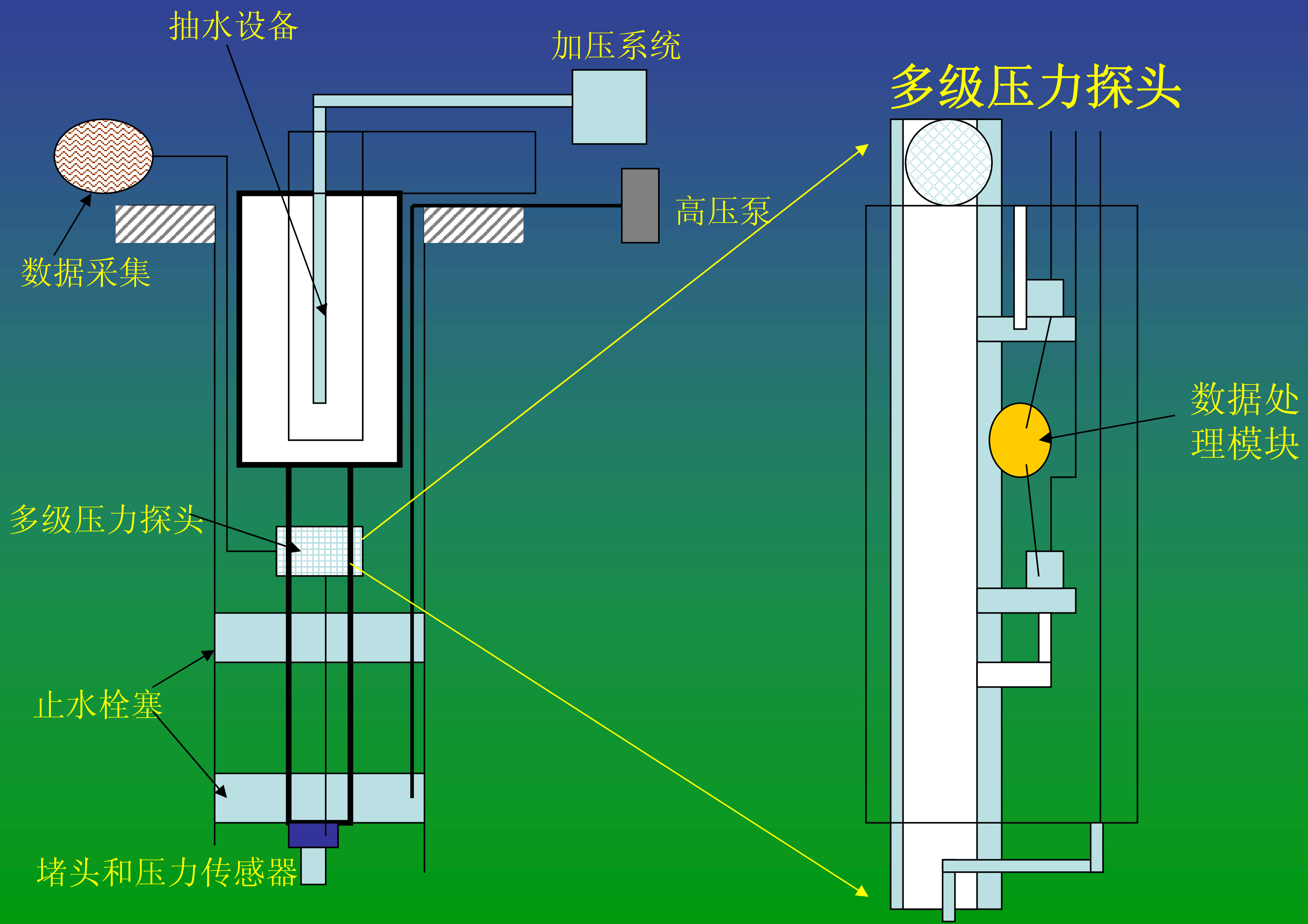
Regional Hydrogeological profile



Hydrogeological profile



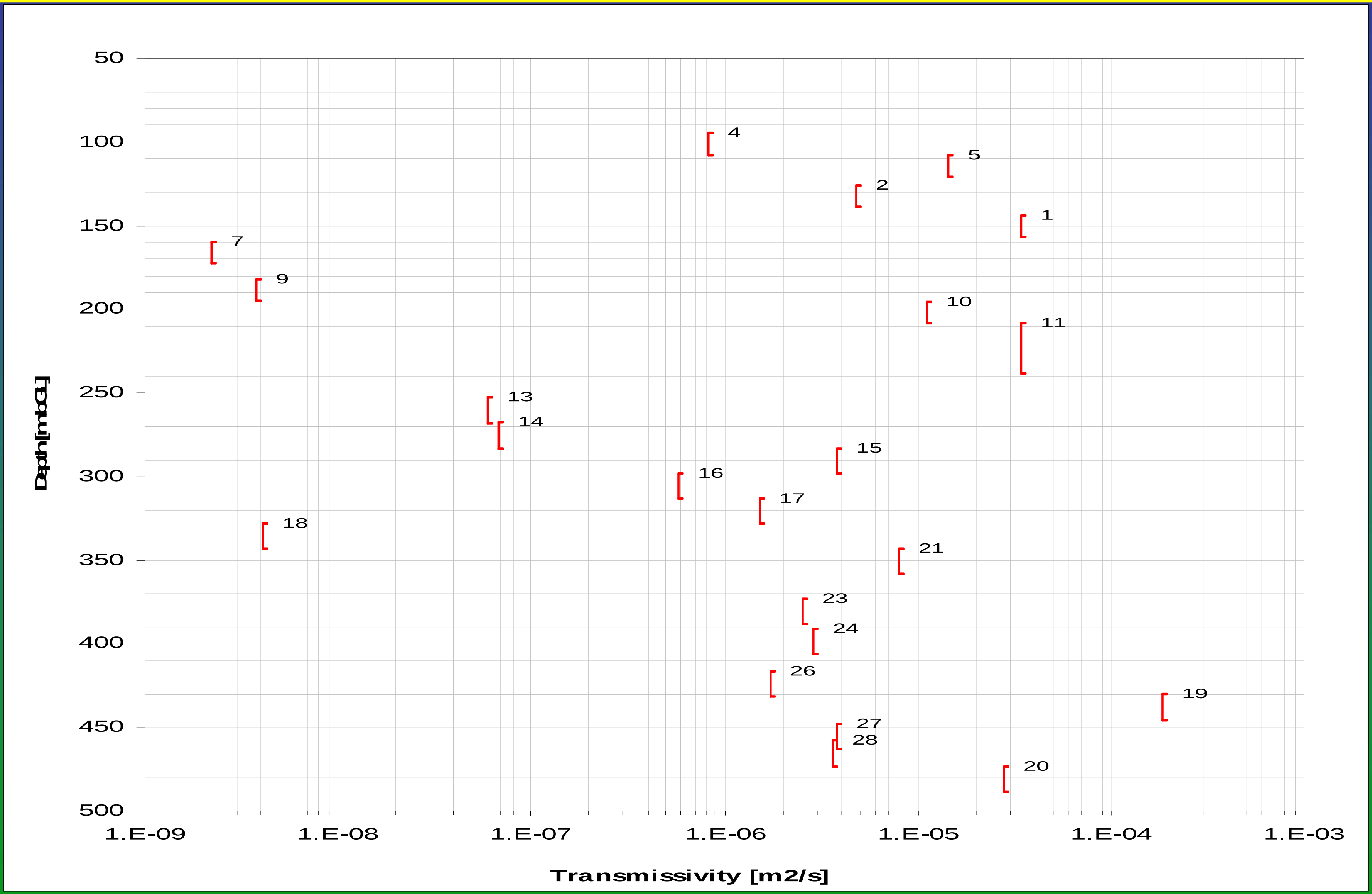
Double packer system



Double packer test at BS03 in 2005

Double packer system

Transitivity Profile in BS03: 95m-489m,

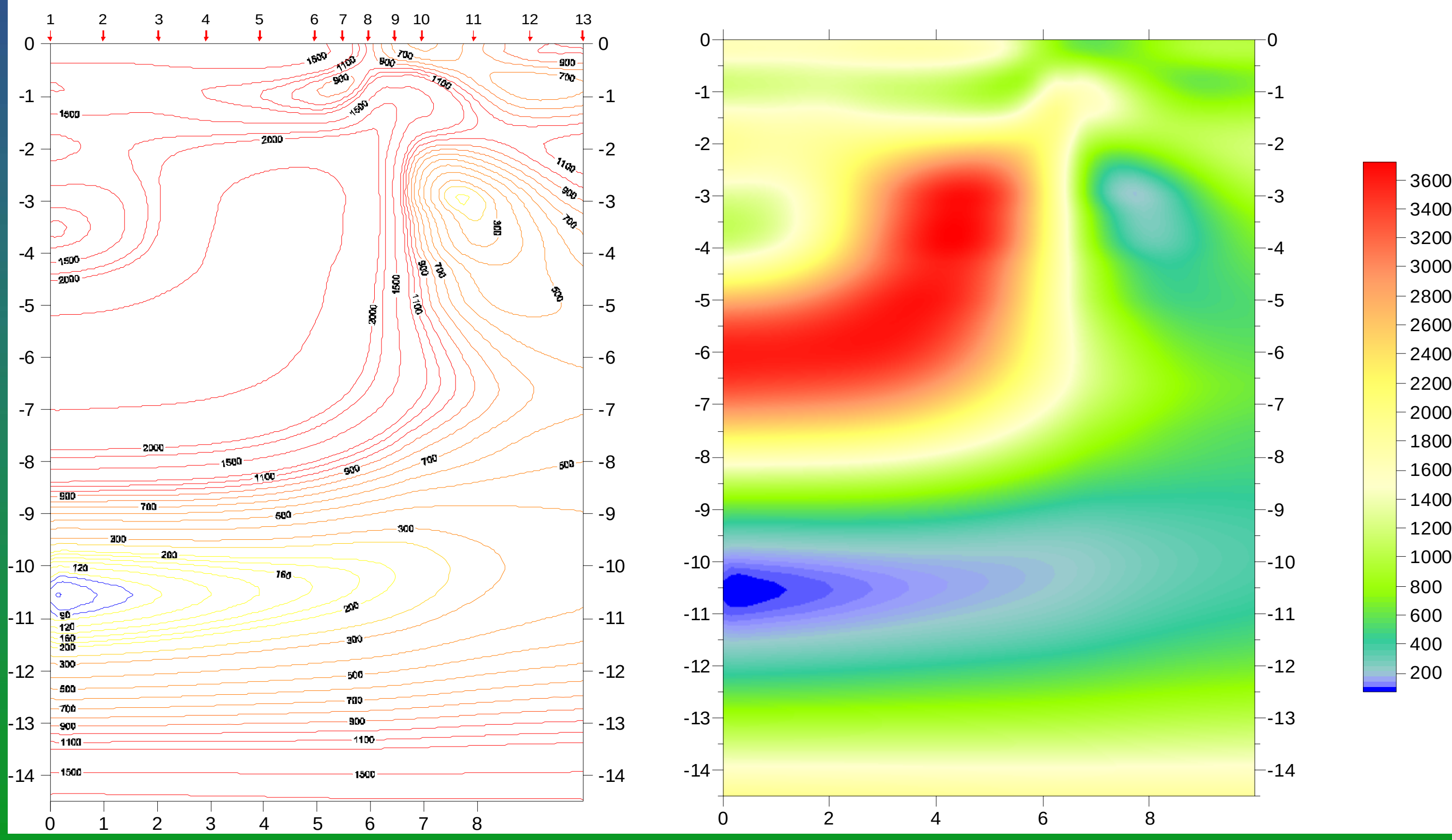


Major geophysical activities

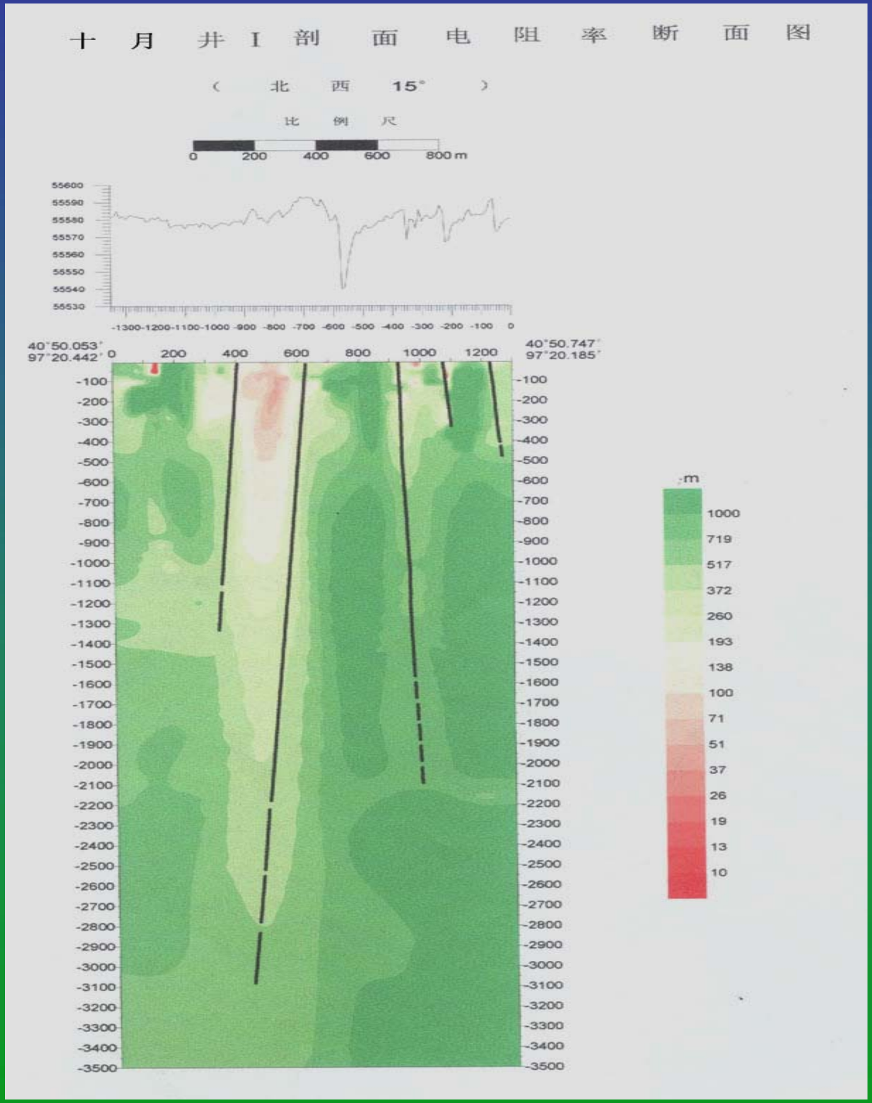
1 Electromagnetic measurement: EH4
2 high-resolution magnetic survey
3 Magnetotelluric survey: MT-1
4 bore hole geophysical logging:
dipole, resistivity, potential, temperature, gamma etc.

MT survey in Caishichang

采石场岩体MT结果



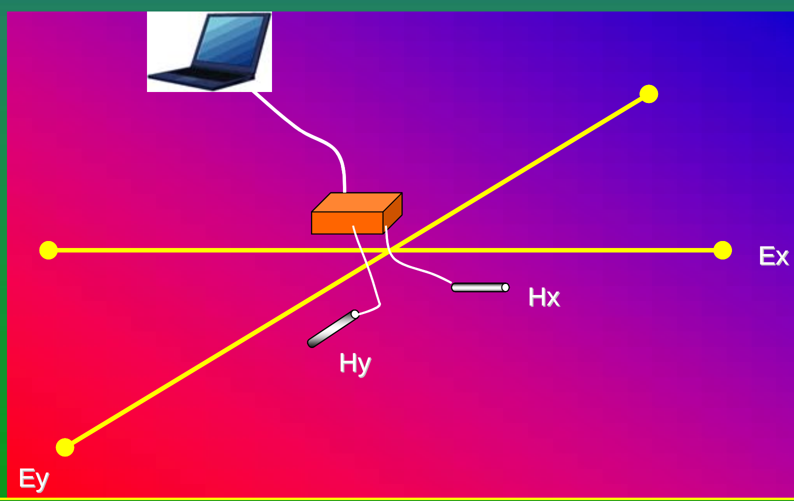
EH4 survey in Shiyuejing

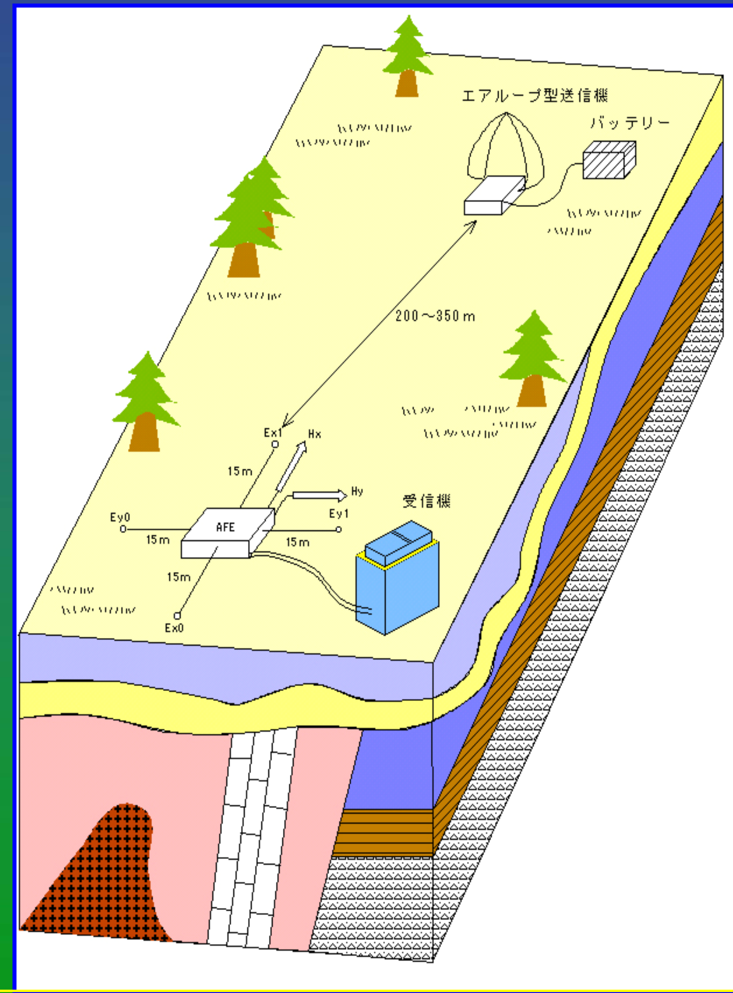


3D Electromagnetic Imaging in Beishan

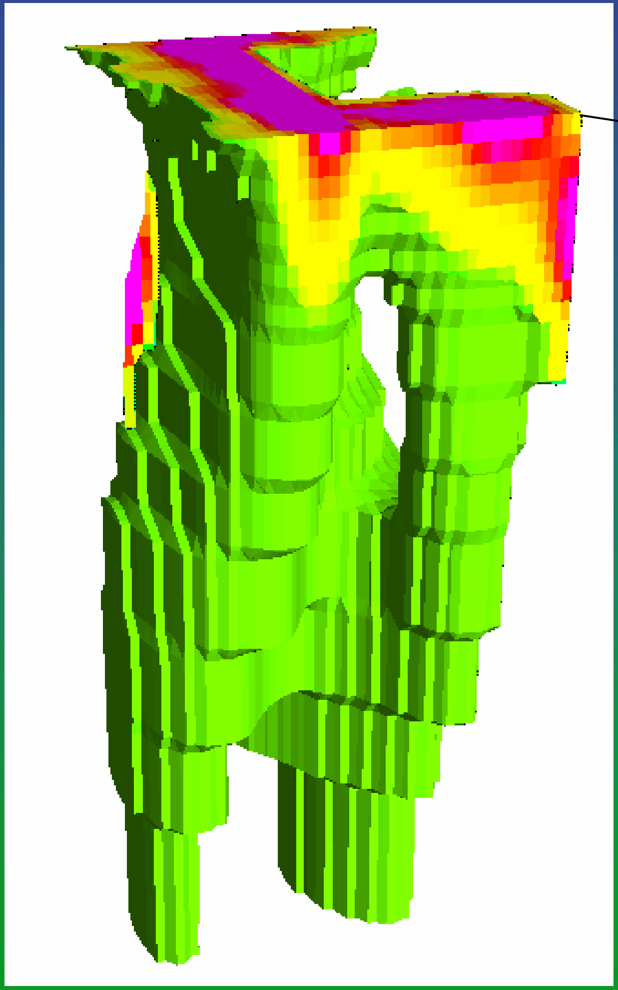
Survey Specification (Sino-Japan cooperation)

- Components
  - Ex,Ey (=30m)
  - Hx,Hy
- Frequency
  - 100k – 1k Hz : CSMT
  - 1k —10 Hz : MT





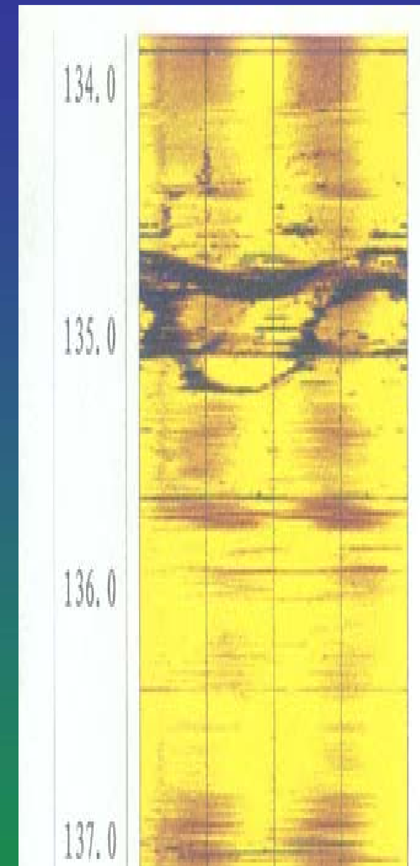
3-D Inversion Results



Blocks with less than 700 Ω · m

Major bore hole survey

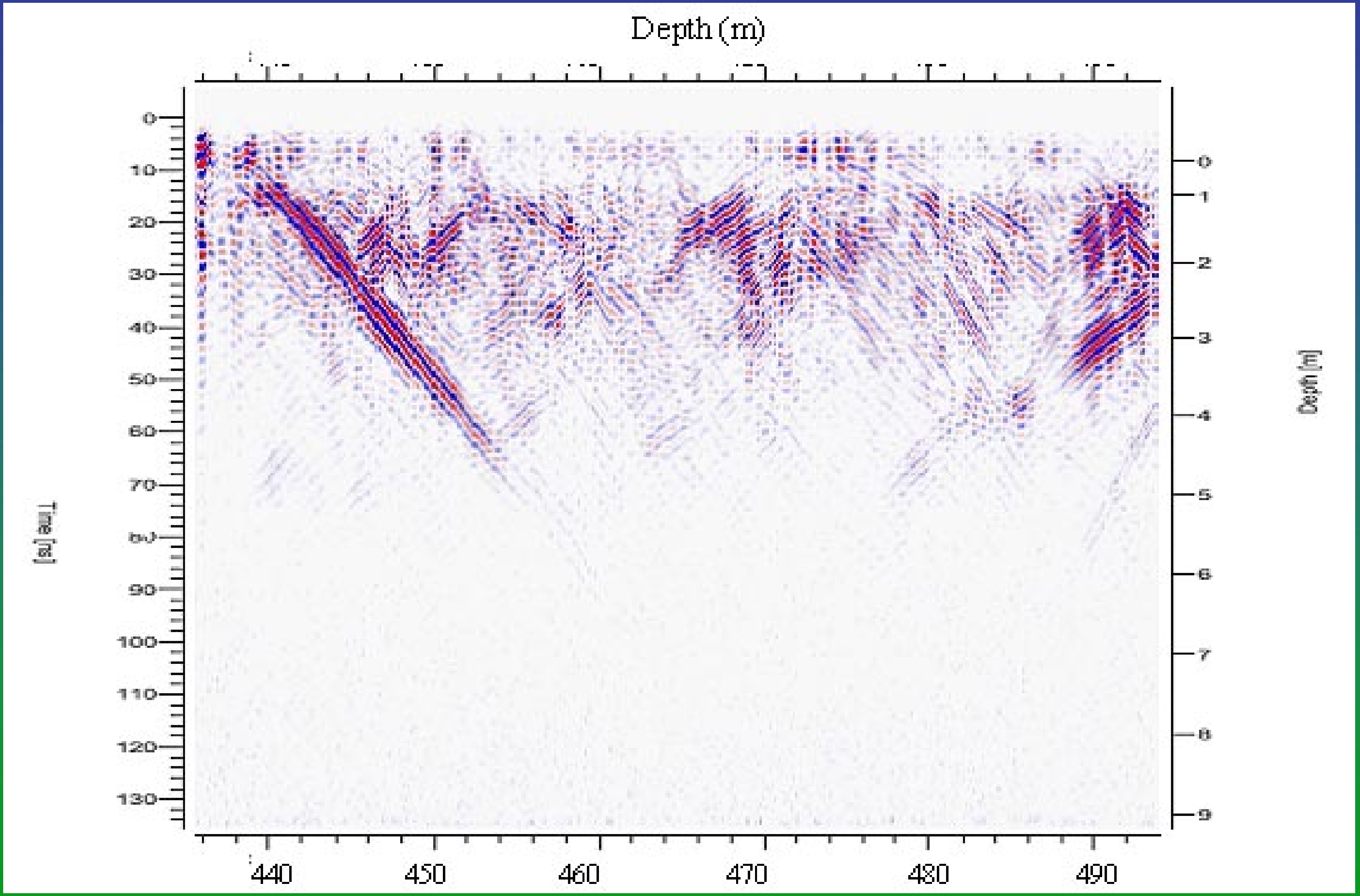
- Bore hole optical camera
- Bore hole acoustic televiewer
- Bore hole hydrogeochemical logging
- Bore hole radar survey
- Bore hole geostress measurement
- Vertical seismic profile



bore hole televiewer survey

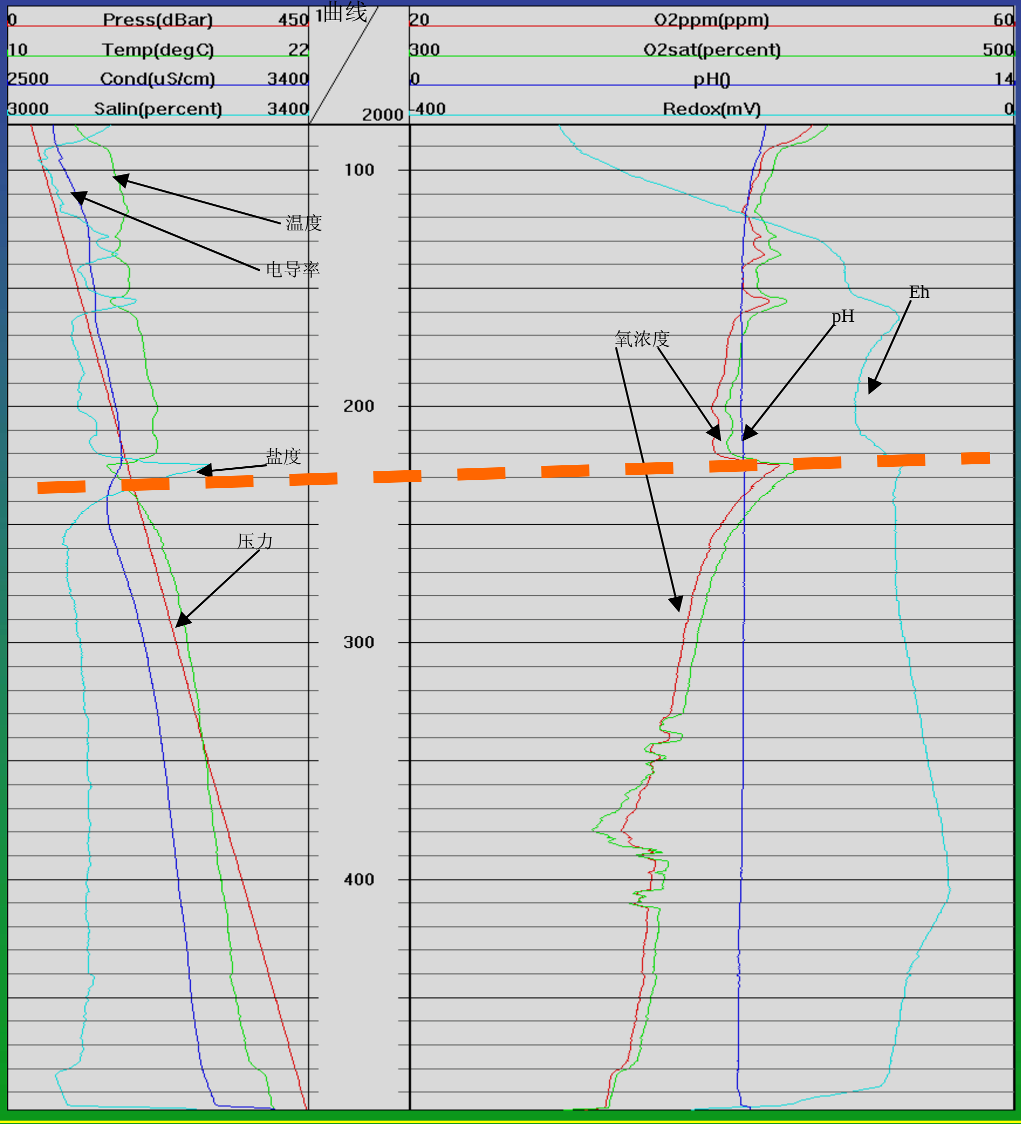
钻孔电视测量

Image of bore hole radar measurement, BS03

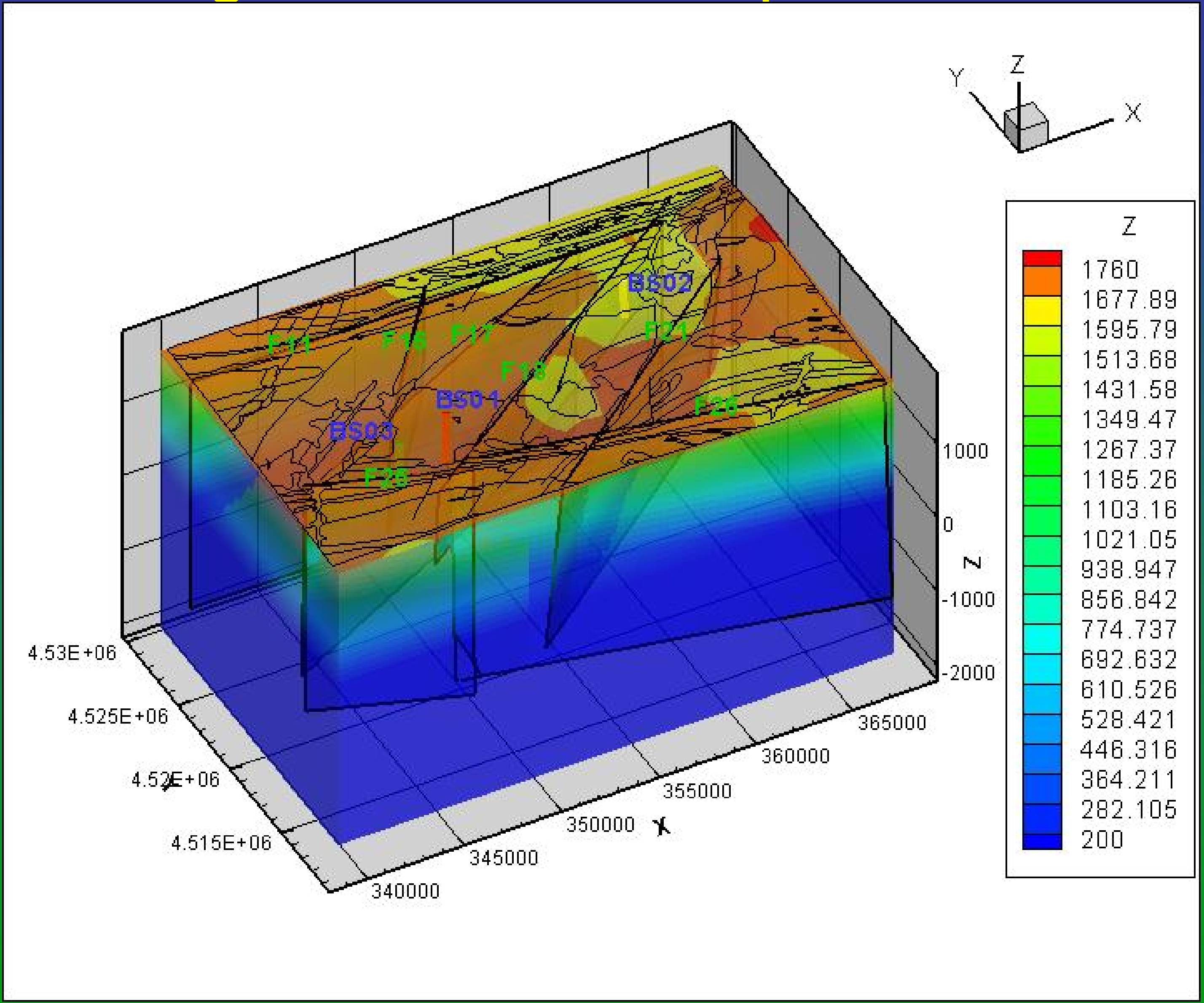


Fluid logging for BS03

图11-2 BS03多参数水质测量曲线



3D Geological model—cooperation with BGR



Rock mechanical study

BS01, 深度 556-676m, 总长度 19.54m

BS03, 深度 411-420m, 总长度 2.95m

Rock mechanical test :samples before test

直径

---- 5cm

长度

---- 10cm

Rock mechanical test: samples after test

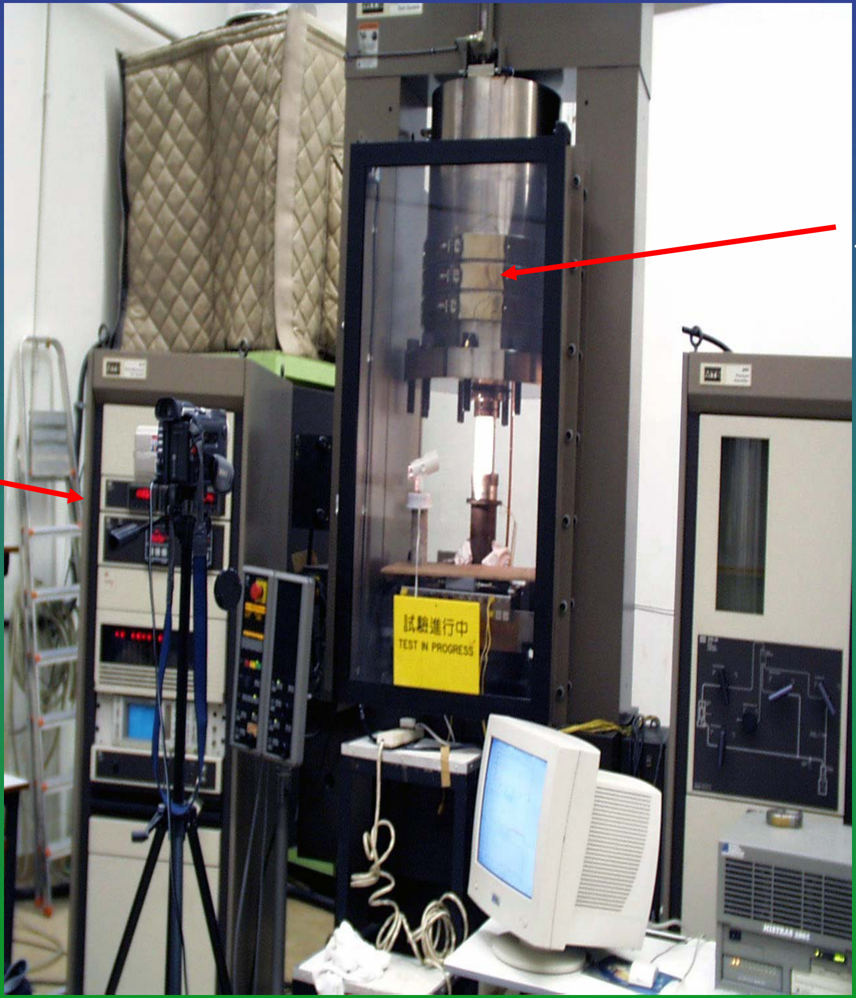
脆性
破坏

MTS 815 岩石力学试验机

高温条件下的试验

加热条带

温度控制面板



样品破坏—sample broken

Φ50Ⅹ125 mm，90℃， 恒载223KN,

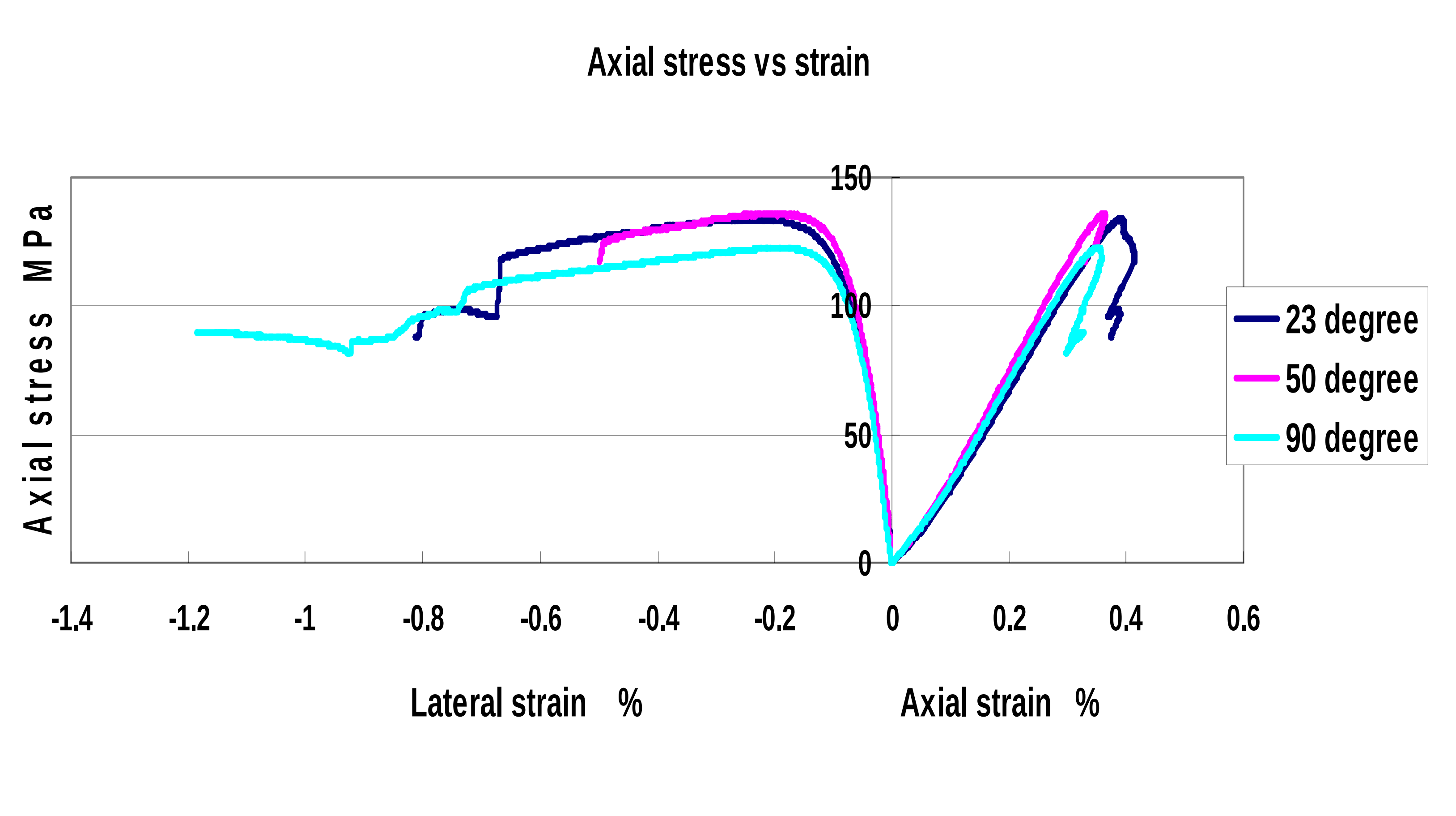
破坏时响声很大,岩样分为两大块

2004.07.2—07.20

Study completed—rock mechanics

- Uniaxial stress-strain tests under room temperature,50、90
- Uniaxial long-tern loading test under room temperature, 50, 90
- Triaxial stress-strain tests, long term loading tests

Stress-strain test at elevated temperature



- 室温至60度，强度无明显变化
- 60度后，强度明显降低，塑性增大

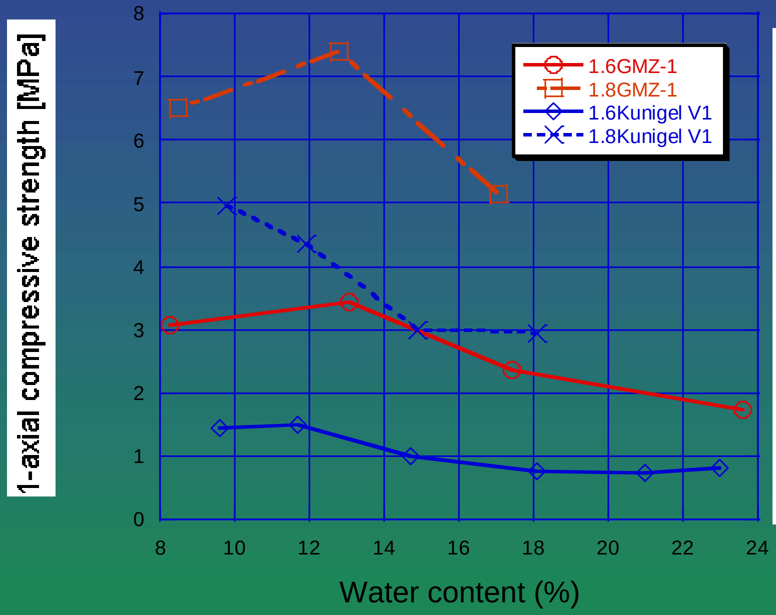
Geological features

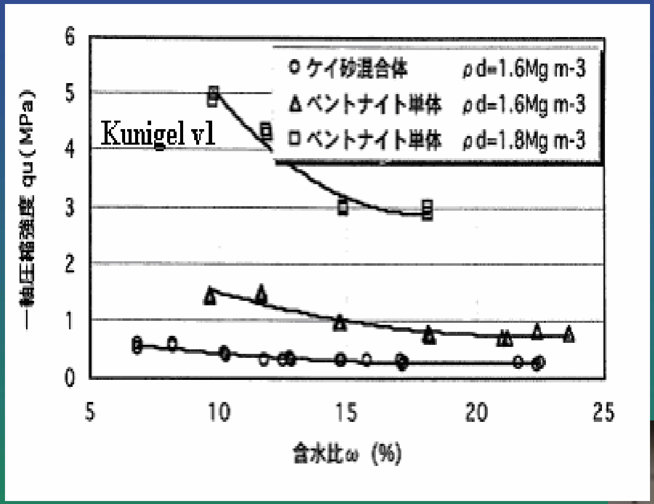
The GMZ bentonite deposit is a large-scale deposit. In China, the proved reserves of GMZ deposit ranks the third of its kind and the reserves of sodium bentonite ranks the second.

GMZ deposit

The reserves in GMZ is about 160 million tons with 120 million tons Na-bentonite reserves.

Mechanical characteristics of Gaomiaozi bentonite



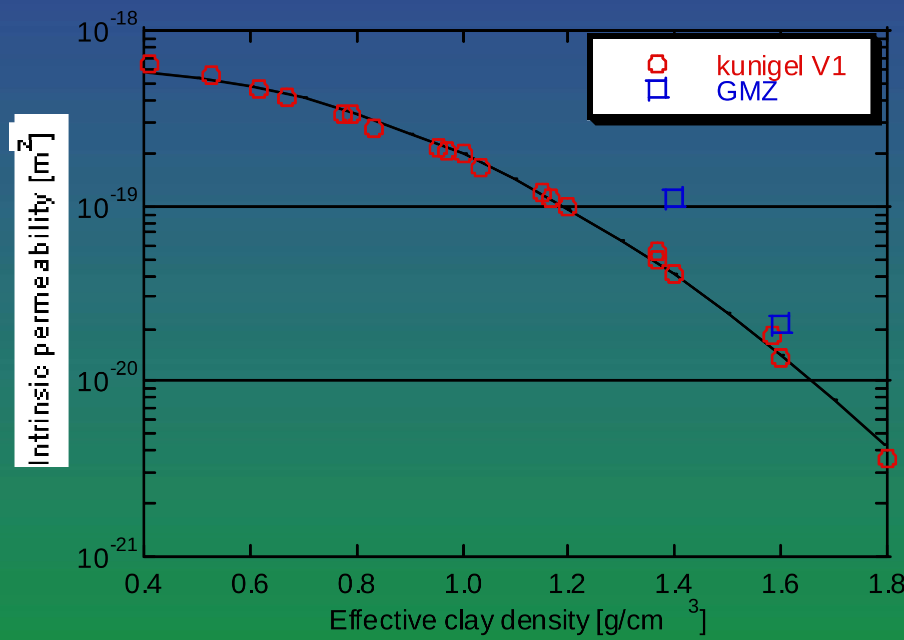


GMZ-1: 2 times of Kunigel V1(1.6g/cm3);

50% higher than Kunigel V1 (1.8g/cm3);

The trend of change for GMZ-1 is a little different from that of Kunigel V1. There is a peak point of GMZ-1 curve for both densities.

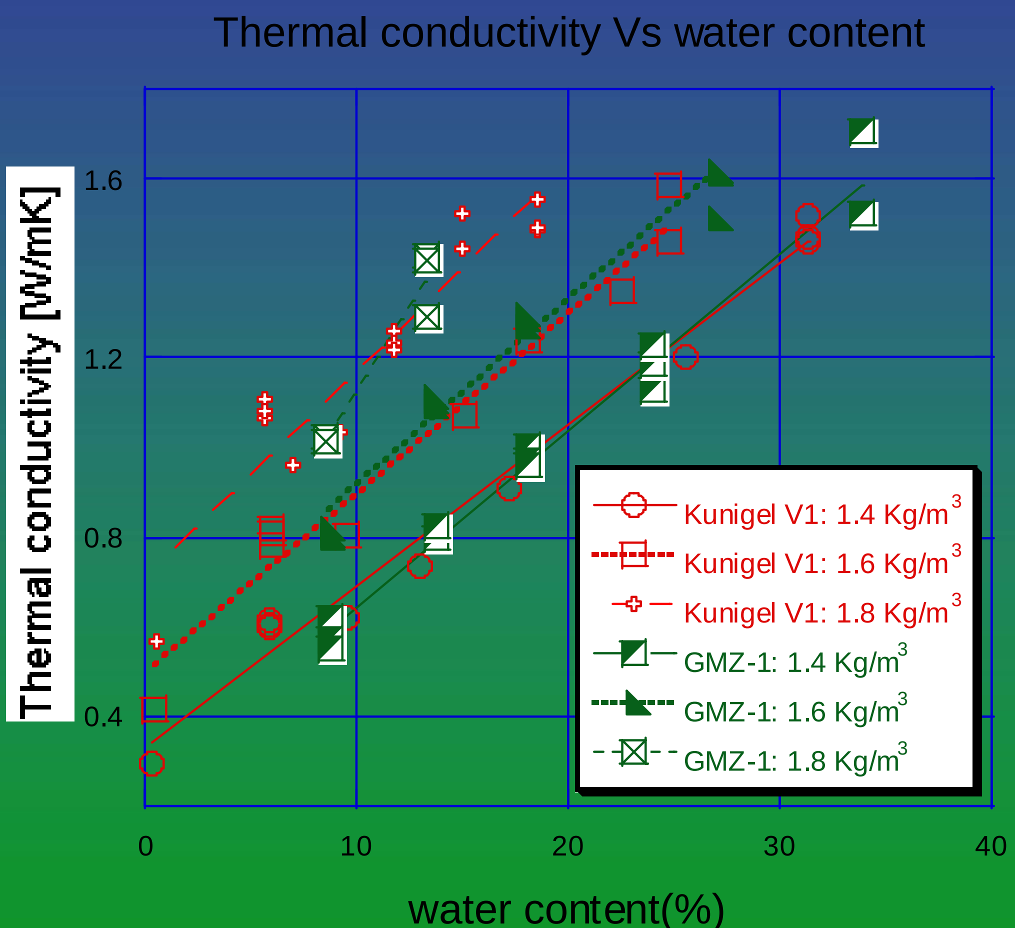
Hydraulic property of Gaomiaozi bentonite

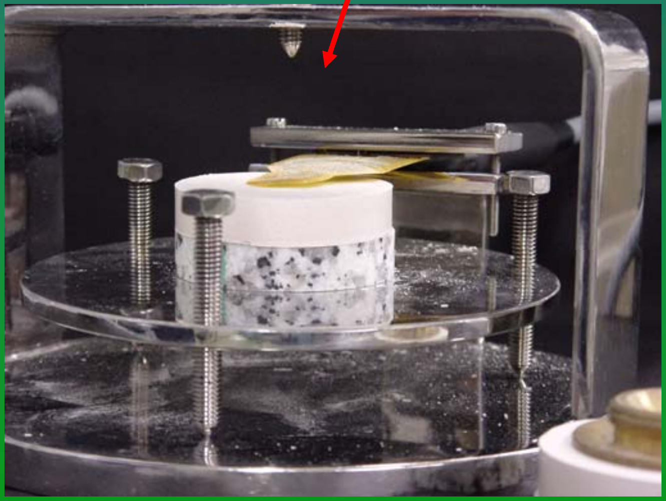


The intrinsic permeability: GMZ-1 > Kunigel V1. higher content of Na-montmorrillonite in Kunigel V1.

Due to a little difference of experimental condition (i.e. pressure of compressed air), it is possible that data obtained to some extent didn't reveal the fact of difference.

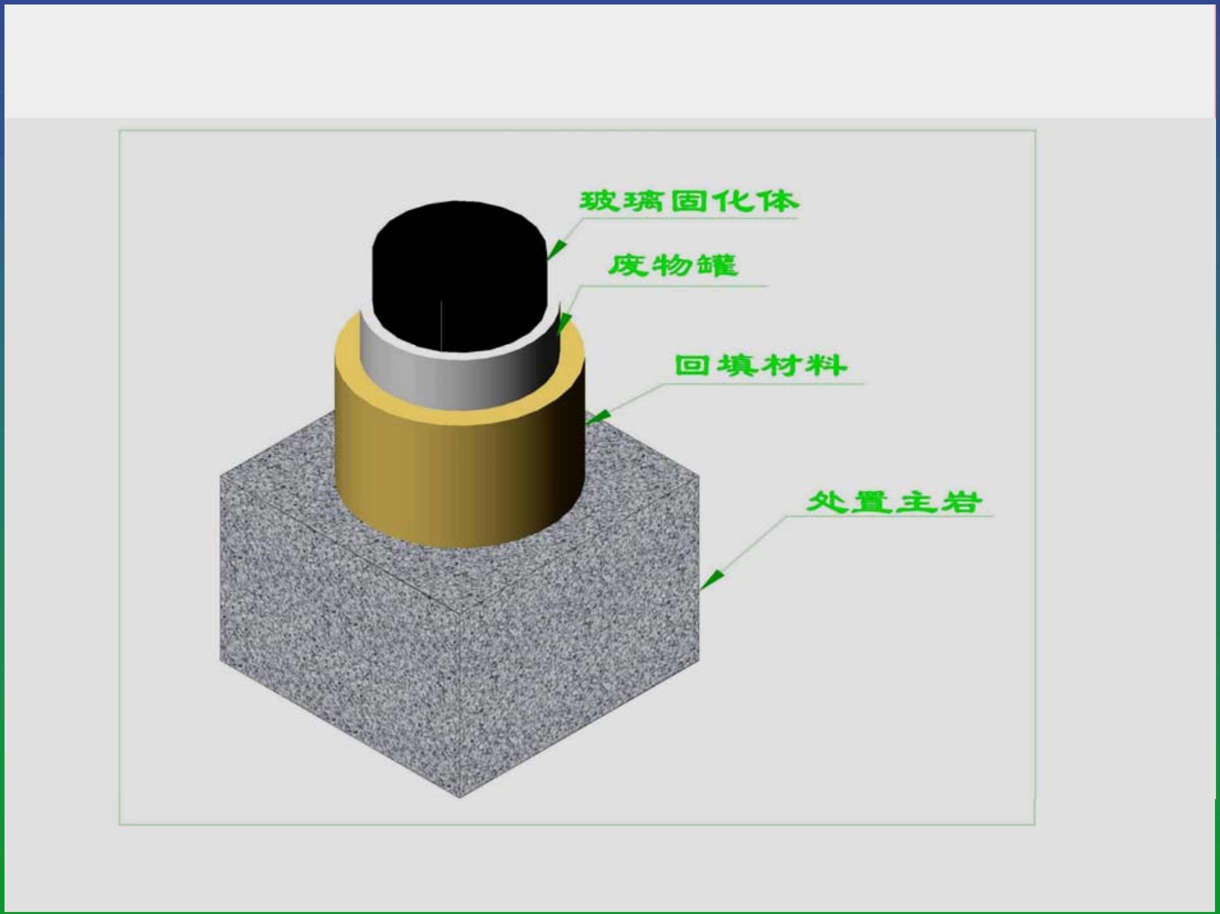
Thermal property of Gaomiaozi bentonite





Thermal conductivity : no significant difference

Study on radionuclide migration



Radionuclide used

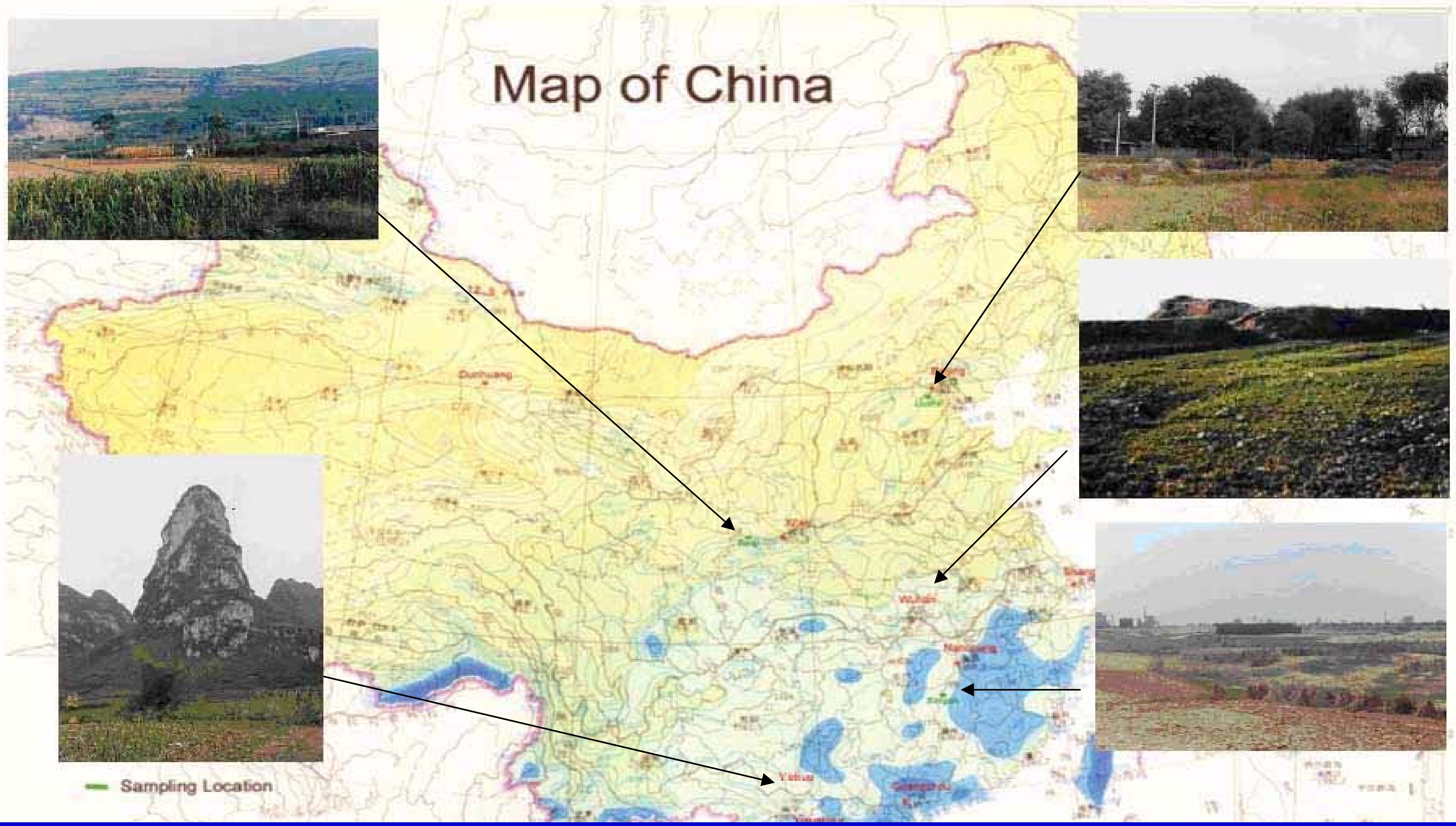
Np-237,
Pu-239,
Tc-99,
Am-241
Sr-85, 89, 90
Cs-134,
I-129 等,

Study on radionuclide migration

Media used:

- Bentonite-膨润土
- Stibnite 辉锑矿
- Active carbone of apricot shell杏壳活性炭
- Granite, Beishan granite
- Altered granite
- fracture

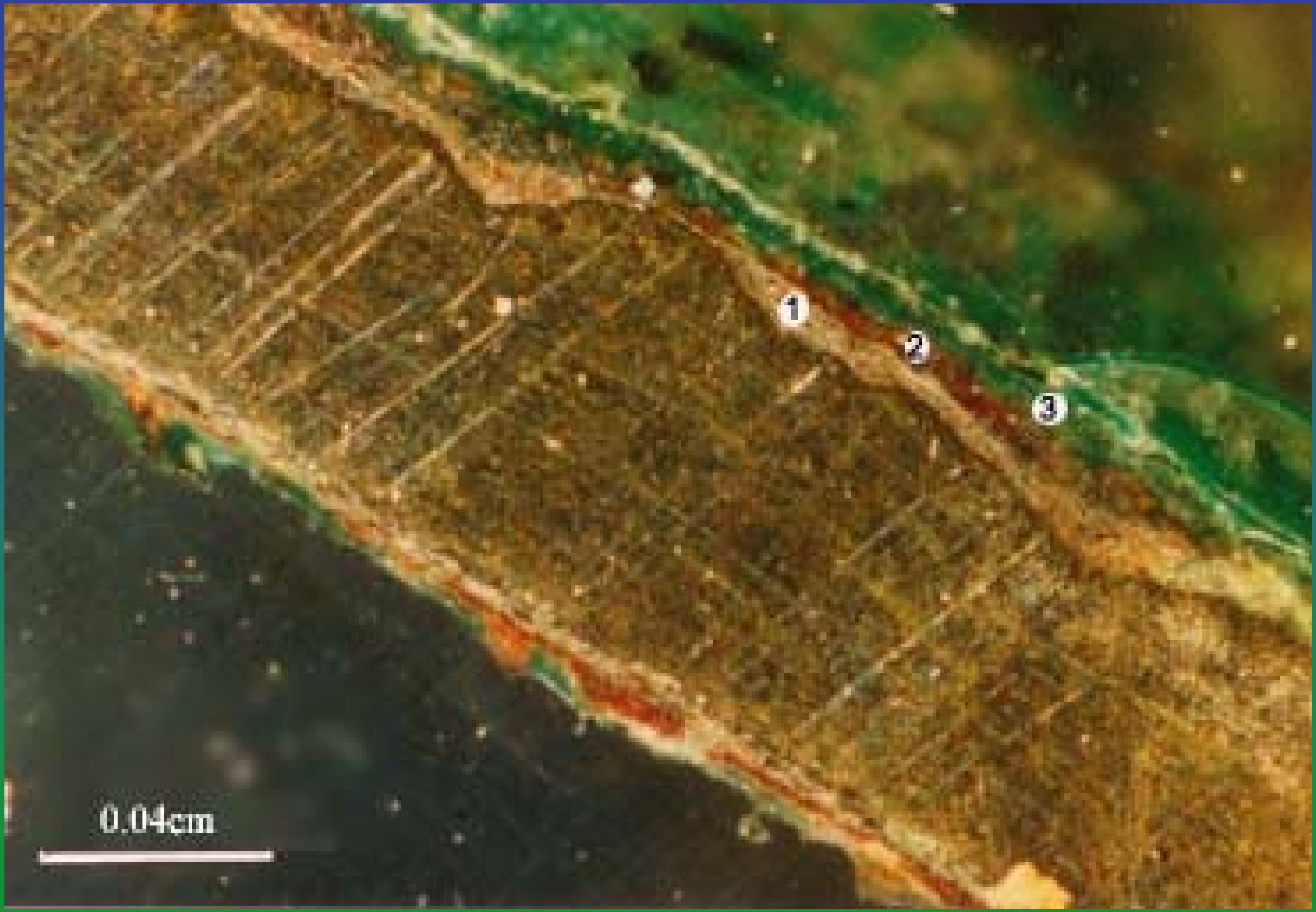
Major Activities: analog study



Location of bronze relics as natural analog

Bronze wares at Liulihe site and Wuhan site

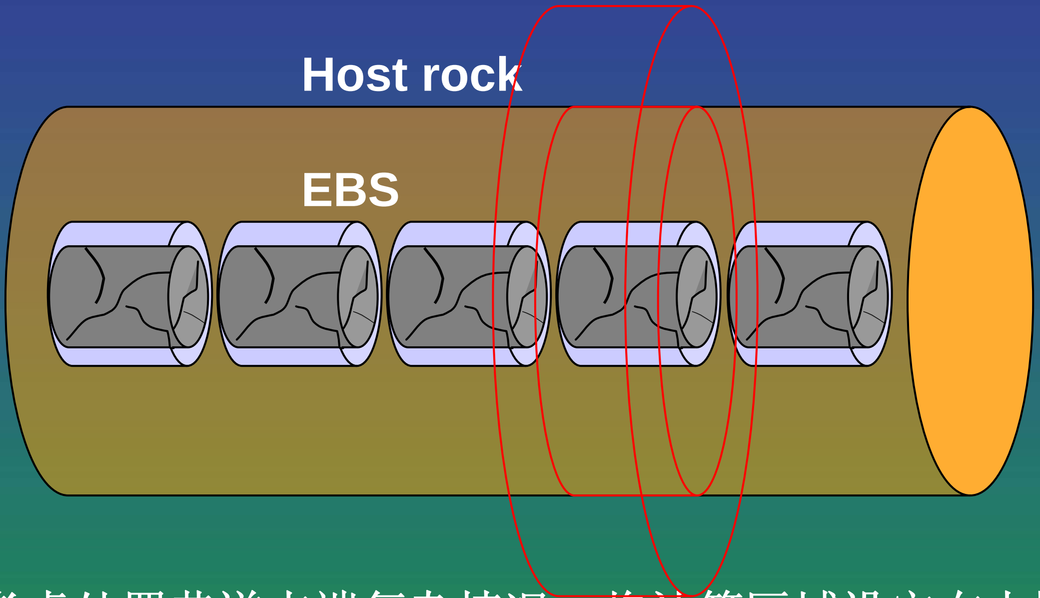
Corrosion of bronze ware



① - 疏松亚层；② - Cu氧化物亚层； ③ - Cu碳酸盐亚层

PA calculation for glass-canister-bentonite system

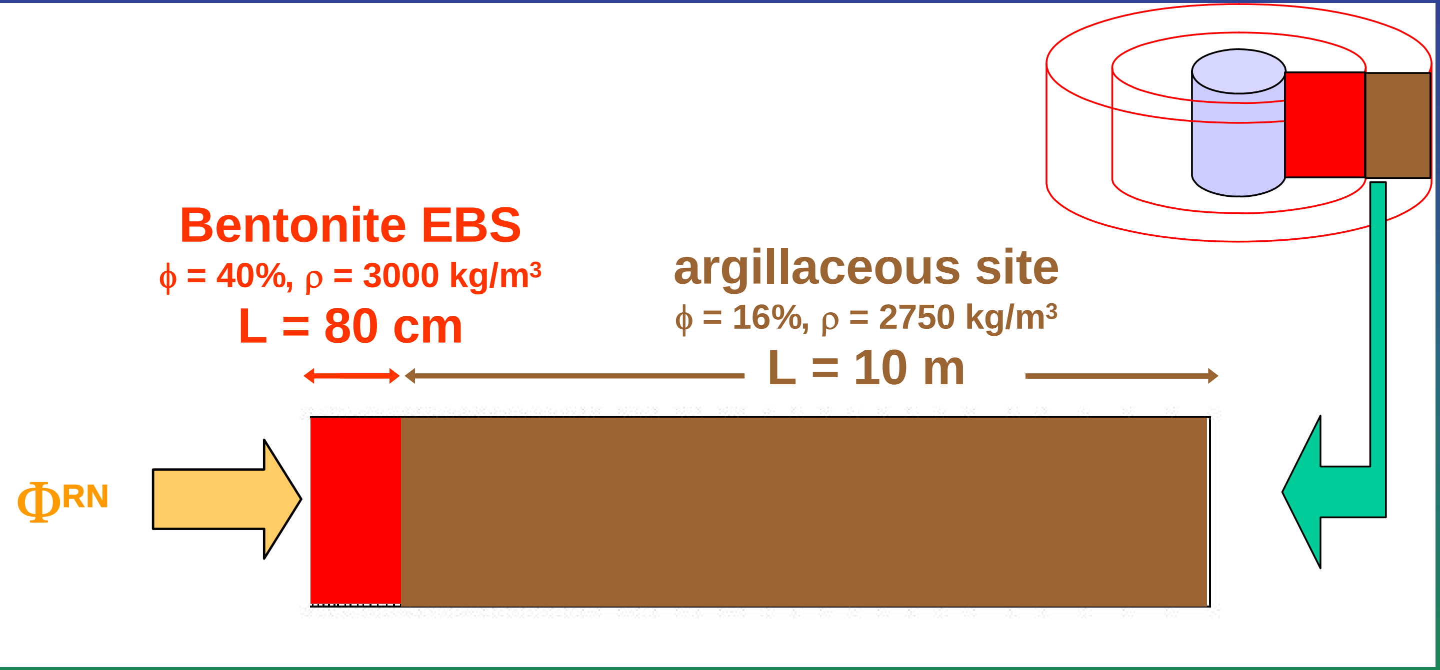
Concept:



本次计算不考虑处置巷道末端复杂情况，将计算区域设定在上图的红色圆柱体区域。考虑该概念模型为对称结构，特将模型简化为1维环状模型

- 最内层为玻璃固化体，内径为0.3米，高1.1m
- 外层为0.07m厚废物罐
- 0.8m 的回填材料
- 10m厚的处置

2. Recent progress in HLW disposal--PA

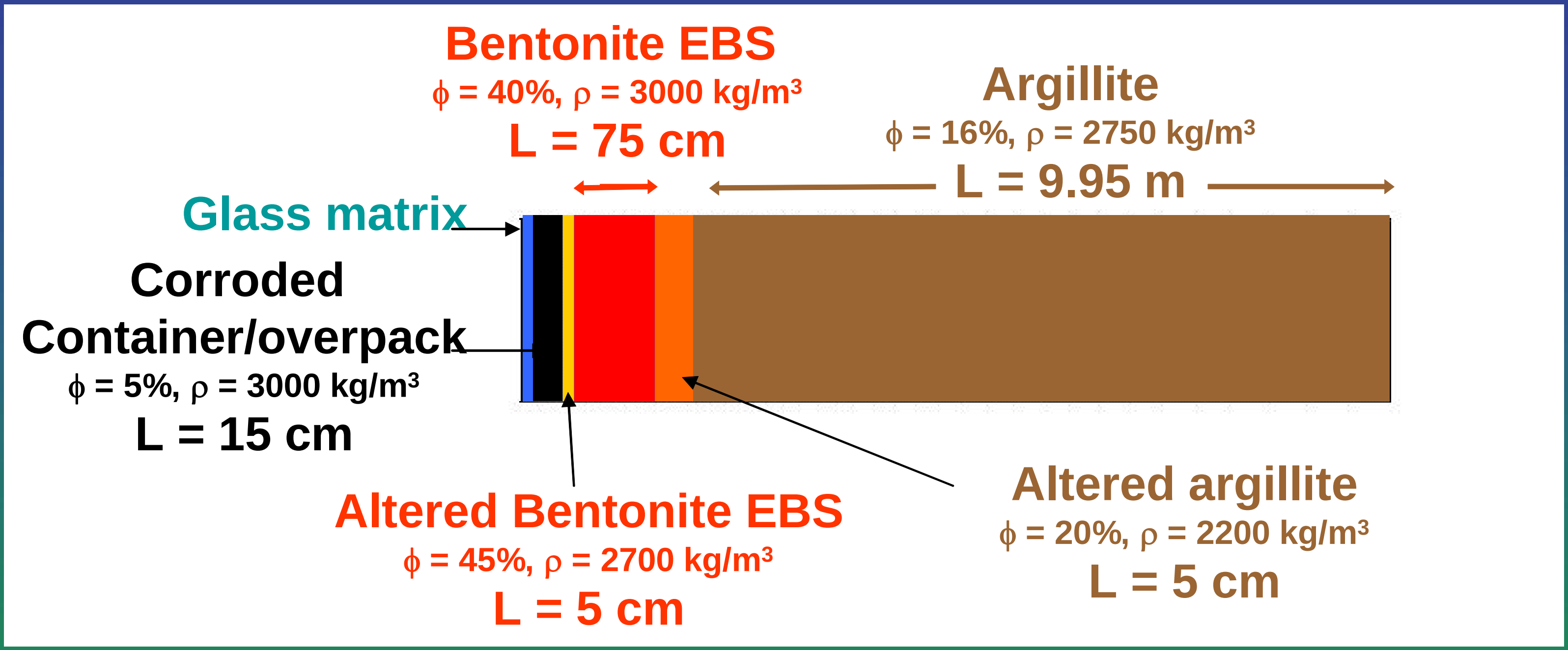


Scenario1 Cylindrical computational domain for RN migration in reference case.

The system comprises only the **unaltered, initial bentonite based EBS argilleous EDZ.**

The density and effective porosity are 3000 kg/m3 and 40% for the EBS, and 2750 kg/ m3 and 16% for EDZ.

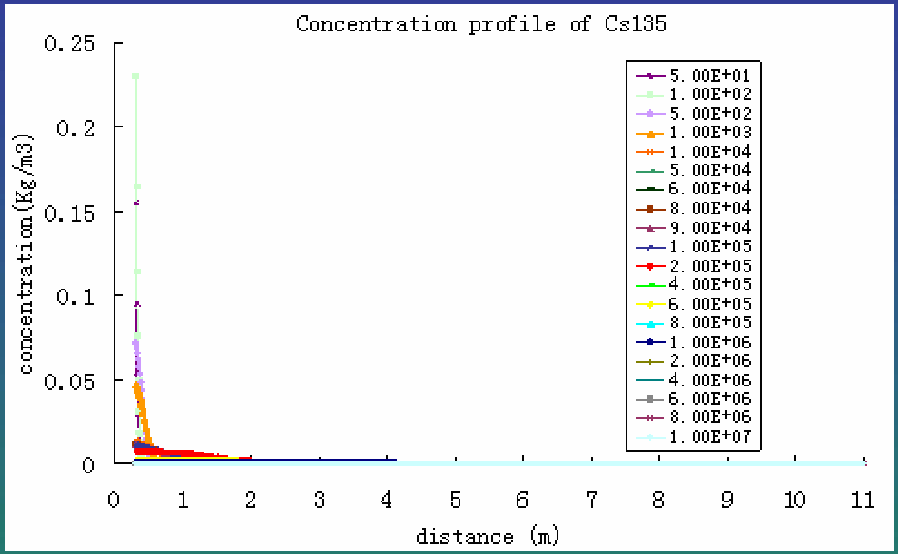
2. Recent progress in HLW disposal--PA

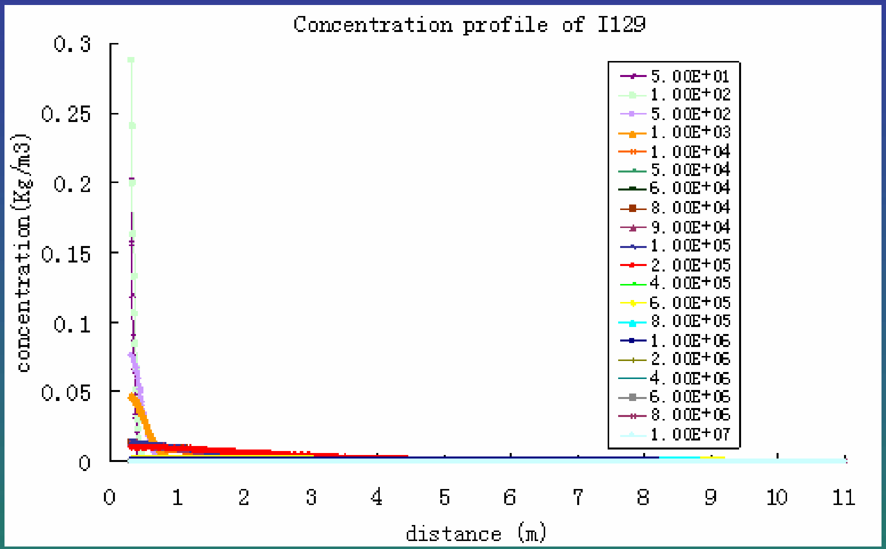


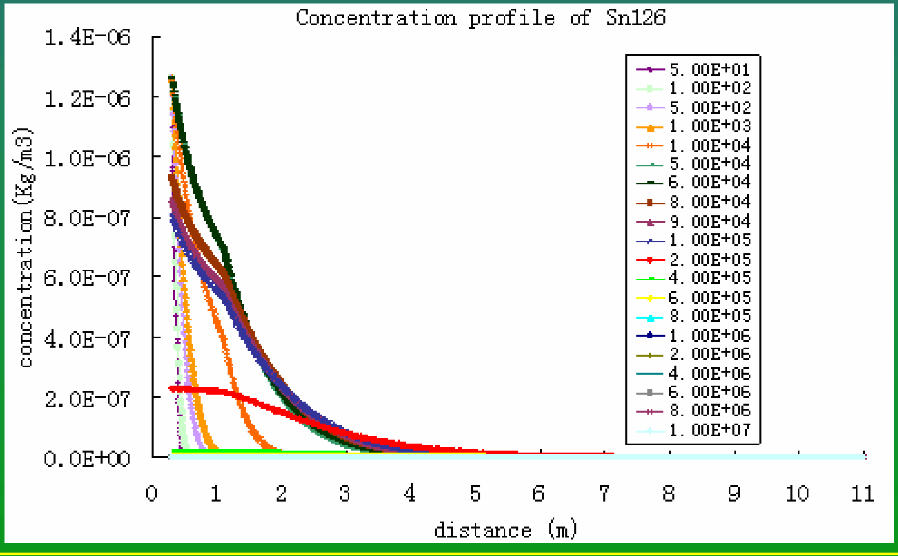
Scenario2 Cylindrical computational domain for RN migration in altered case.

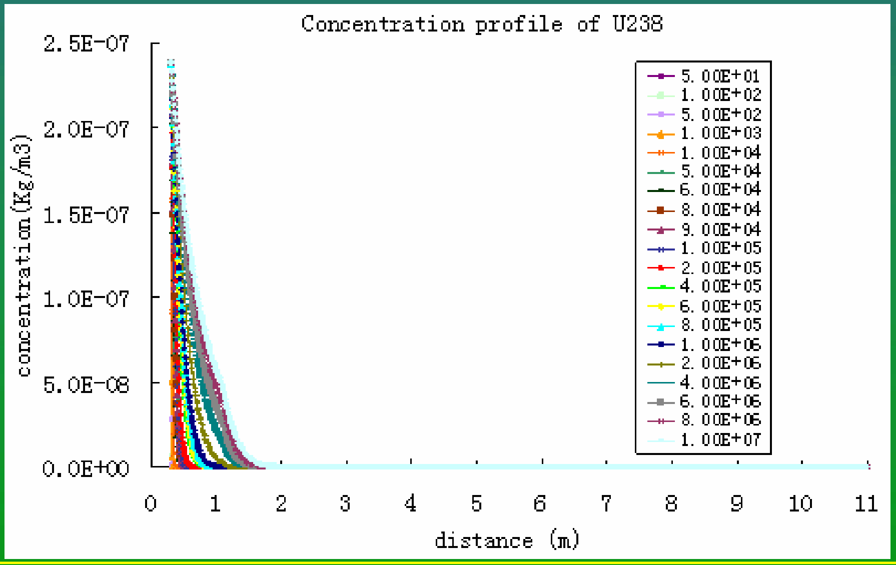
As a result of canister/overpack corrosion,
additional domains are created by the corrosion products and the argillite and/or EBS are altered

模拟计算结果-(1) 参考情景的浓度变化剖面

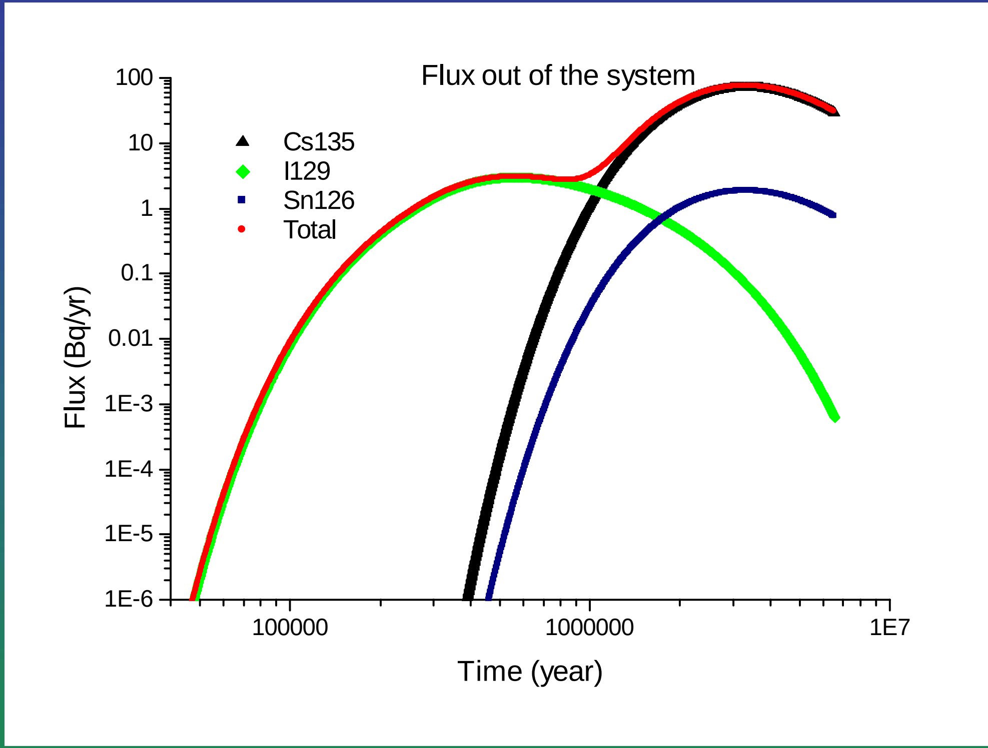








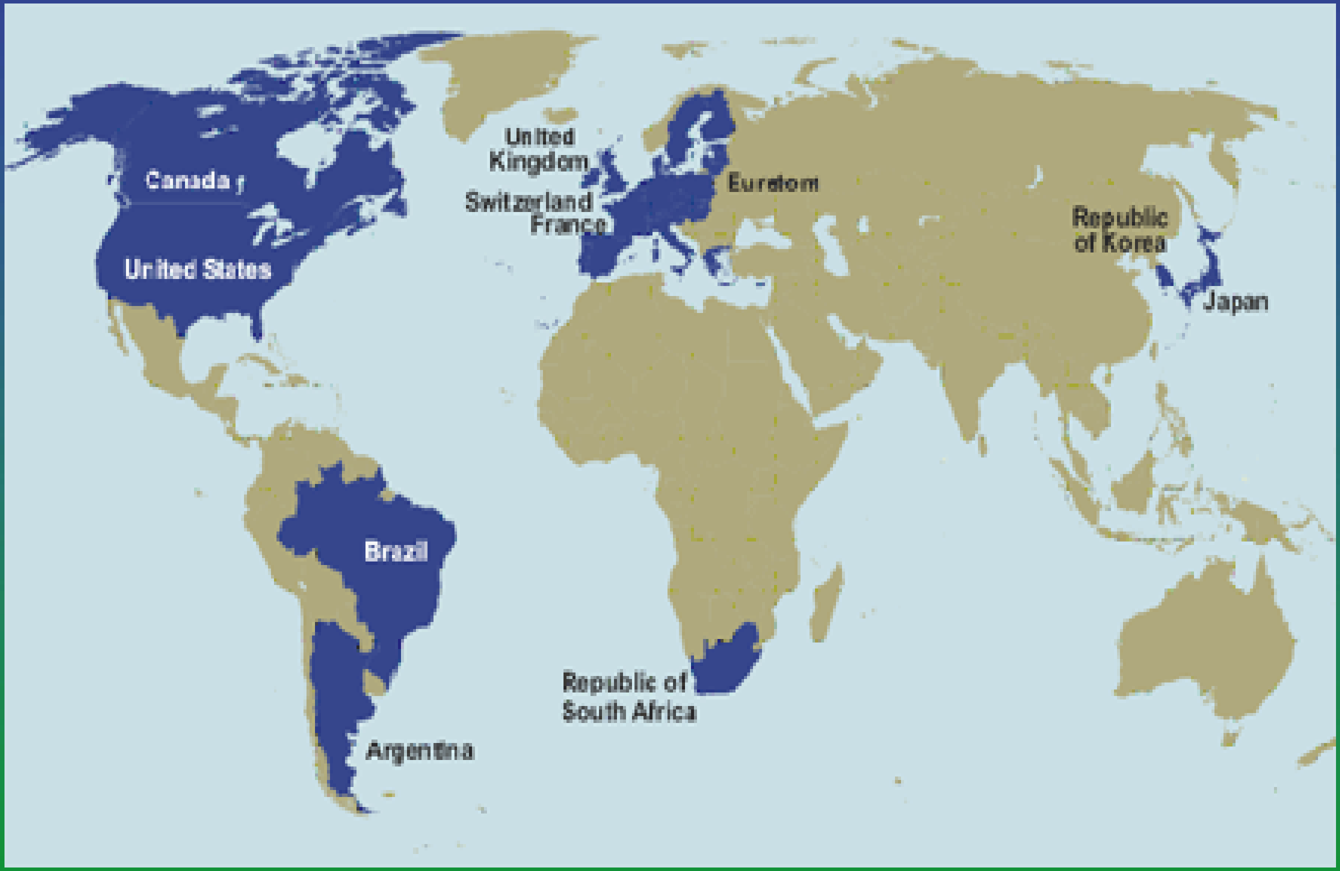
模拟计算结果-(3) 核素迁移出系统的量（参考情景）



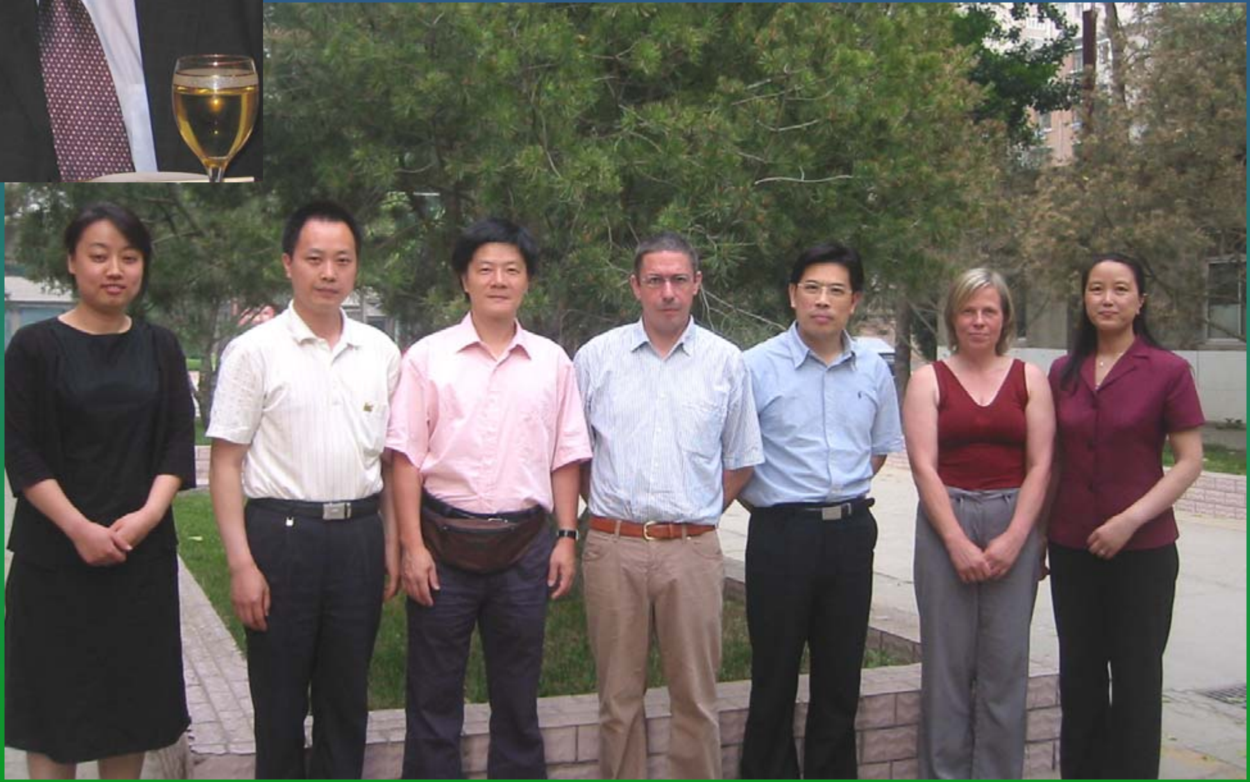
1. ^{238}U(*T1/2*=4.47×10^{9} years) , ^{239}Pu(*T1/2*=2.41×10^{4} years) and ^{243}Am(*T1/2*=7.73×10^{3} years) did not come out of the system,
2. ^{135}Cs(*T1/2*= 2.30×10^{6}years), 129I(*T1/2*= 1.57×10^{7}years) and ^{126}Sn(*T1/2*=1.0×105 years) contribute the release rates,
3. ^{129}I is the first one come out of the system due to no sorption,
4. ^{135}Cs contribute 50 times more to the total release rate with the value 100Bq/a than ^{129}I , ^{126}Sn.

International cooperation

- Germany
- Finland
- Korea
- Japan
- France,
- Sweden,
- Canada,
- Switzerland,
- USA
- IAEA



Experts from BGR visit Beishan, April, 2002



Experts from BGR, GRS visit BRIUG, 2006

China-Germany meeting, May 2005

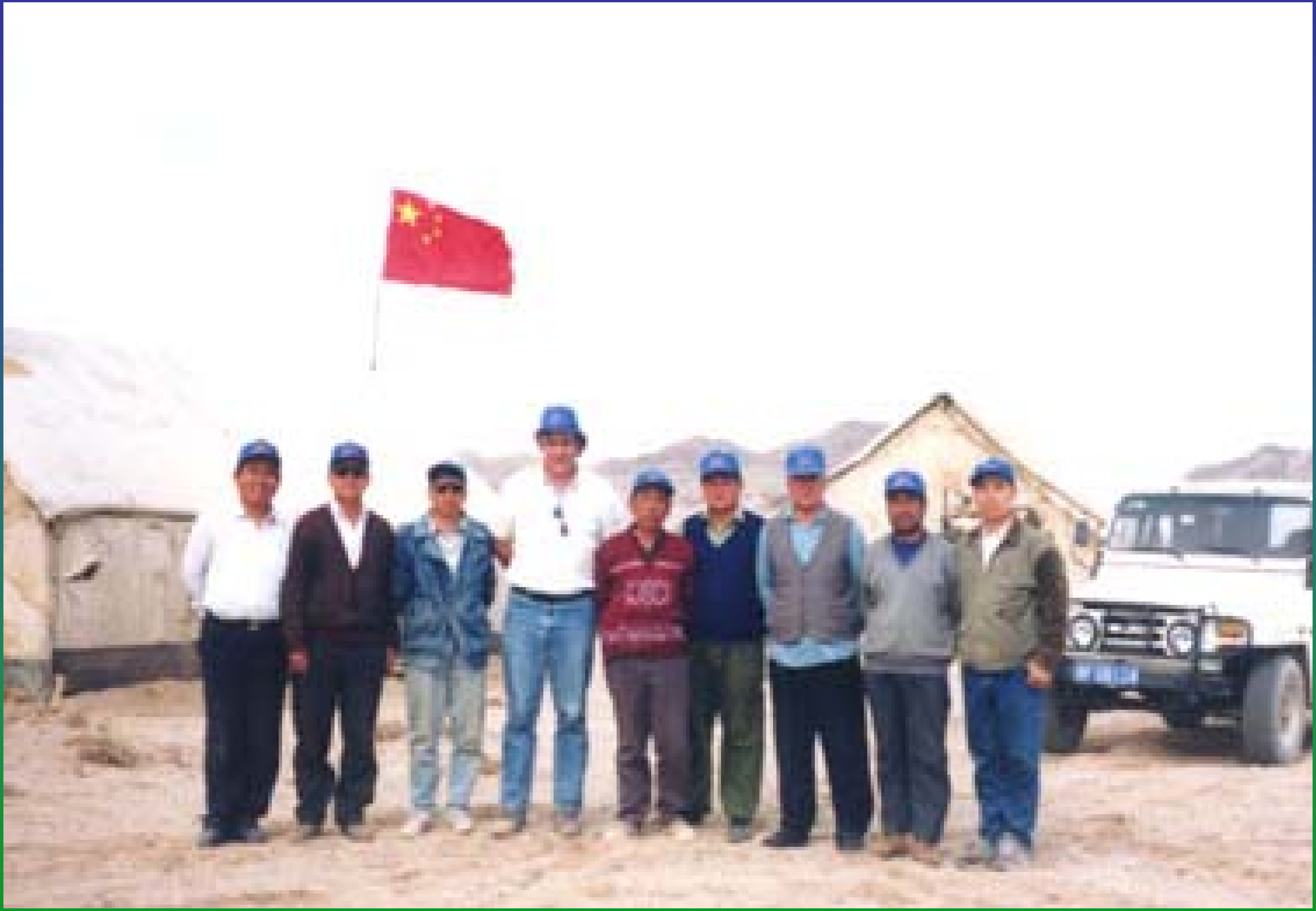
Experts from US NWTRB visit Beishan, Oct. 1999

Experts from Canada, Korea, France, Switzerland and USA visited Beishan site on June 3, 2002

IAEA workshop on HLW disposal,
May 27--June 4, Beijing, China

日本核燃料循环研究所(原动燃团,PNC) 访问北山(1999.6.10)

JNC experts visit Beishan site, June 10, 1999



IAEA expert visit Beishan site, May 2000

Experts from France, Switzerland dispatched by IAEA
Working at Beishan site in September 2003

Experts from US DOE, EPA, NRC visit Beishan site in June 2005

IAEA Officer, B. Neerdael Visits Beishan site, April 16, 2007


Thank you
北山日出 Sun Rising in Beishan

Bundesministerium
für Bildung
und Forschung

Decommissioning of Nuclear Facilities: German R&D

Michael Weigl

CHINESE-GERMAN WORKSHOP ON RADIOACTIVE WASTE DISPOSAL

MAY 28 – 31, 2007

Sino-German Science Centre, Beijing

Ideen zünden!

Bundesministerium
für Bildung
und Forschung

Federal Ministry of Education and Research

Division 713: Decommissioning of Experimental Nuclear Installations and Waste Management

Head of Division: Dr. Komorowski

Building of the Ministry in Bonn

Project Management Agency Forschungszentrum Karlsruhe

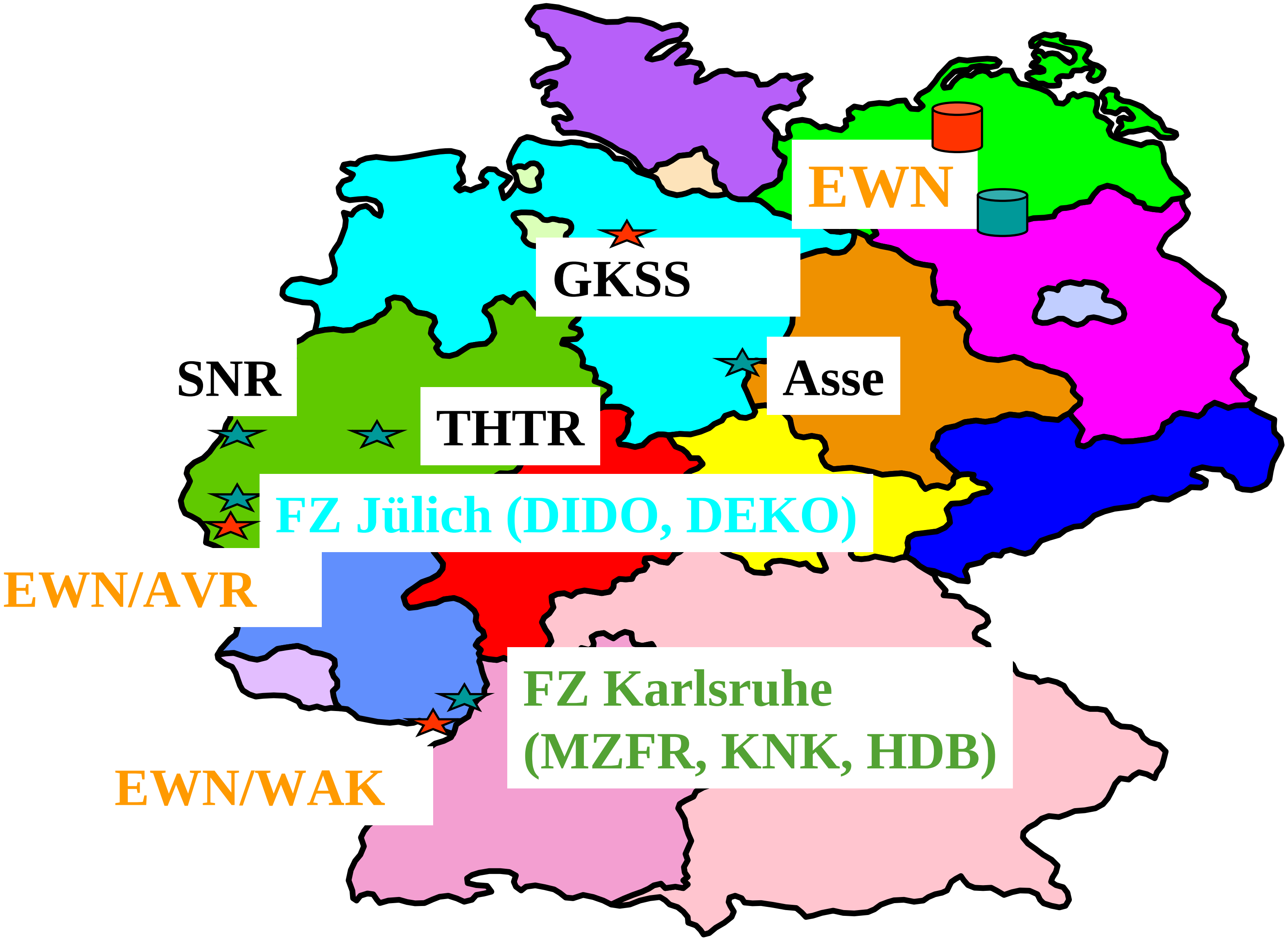
Water Technology and Waste Management Division

Research Center Karlsruhe

Outline

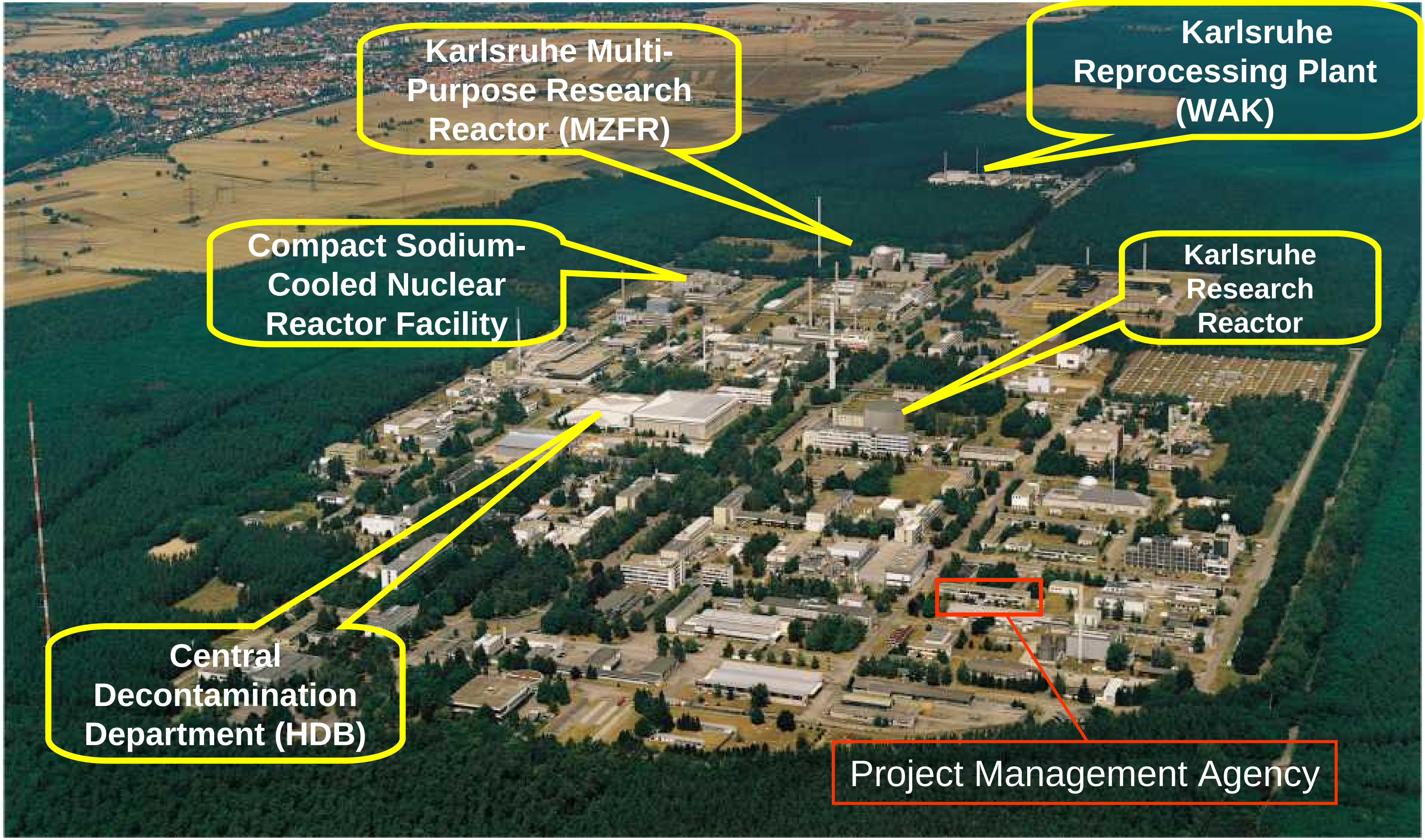
- Decommissioning of Experimental Nuclear Installations in Germany – Past, Present and Future
- R & D Projects in the field of Decommissioning and Dismantling of Nuclear Facilities (founded by the Federal Ministry of Education and Research)
- Decommissioning of the MZFR: An example for the application of new technologies
- Outlook

Decommissioning Projects of the Federal Ministry of Education and Research



Bundesministerium für Bildung und Forschung

Decommissioning Projects at the Forschungszentrum Karlsruhe



Bundesministerium
für Bildung
und Forschung

Tasks already finished

- Niederaichbach Nuclear Power Plant (KKN)

- Karlstein Superheated Steam Reactor (HDR)

- Karlsruhe Research Reactor (FR2) (Safe storage)
- Thorium High temperature reactor THTR (Safe storage)
- TRIGA II Heidelberg (decommissioning completed)

Present and Future Tasks

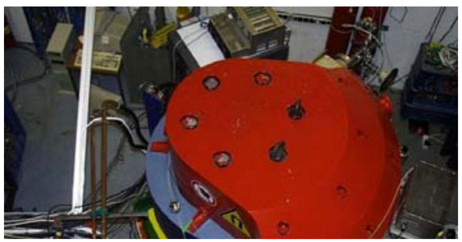
- DIDO (Research Center Jülich)
- FRG1 u. 2 (Research Center Geesthacht) decommissioning starts in 2009
- HAWC-Vitrification: VEK (Vitrification Plant Karlsruhe)
- Closing of the Asse Research Mine
- Start of Operation of Konrad repository (LAW, MAW)

Bundesministerium
für Bildung
und Forschung

R & D Projects

Applied
Radio Chemistry

Cutting technologies

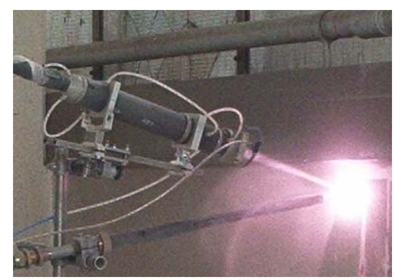


New Analytic Methods

Decontamination

Radiation Research

Biological
dump recultivation



Remote-controlled
techniques

Bundesministerium
für Bildung
und Forschung

1. Decontamination Technology

Ideen zünden!

TECHNISCHE UNIVERSITÄT DRESDEN

Decontamination of concrete surfaces using Laser ablation and simultaneous conditioning

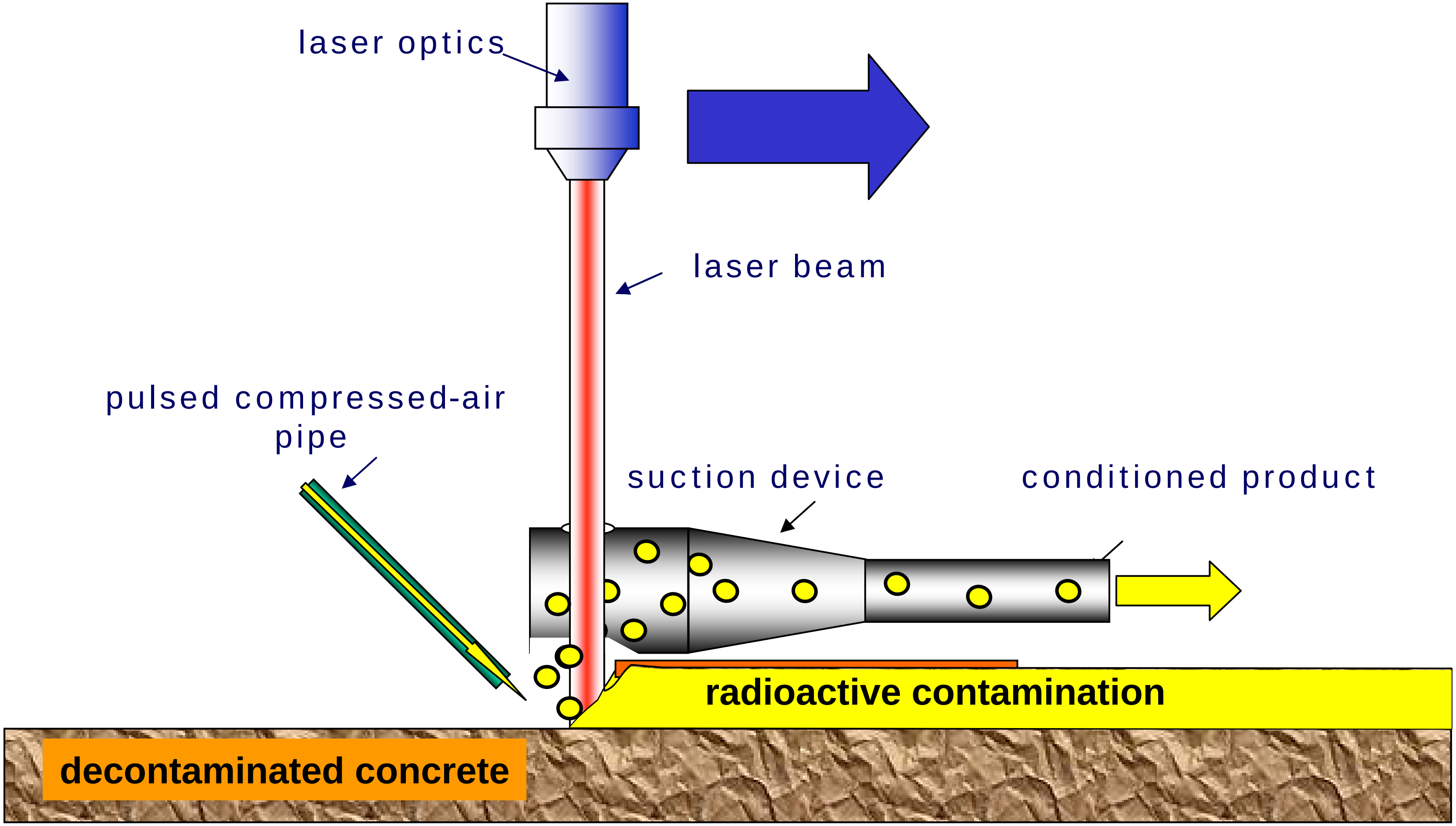
„LASABA“

W. Lippmann, J. Knorr, M. Herrmann, R. Wolf, A.-M. Reinecke, A. Zeuner

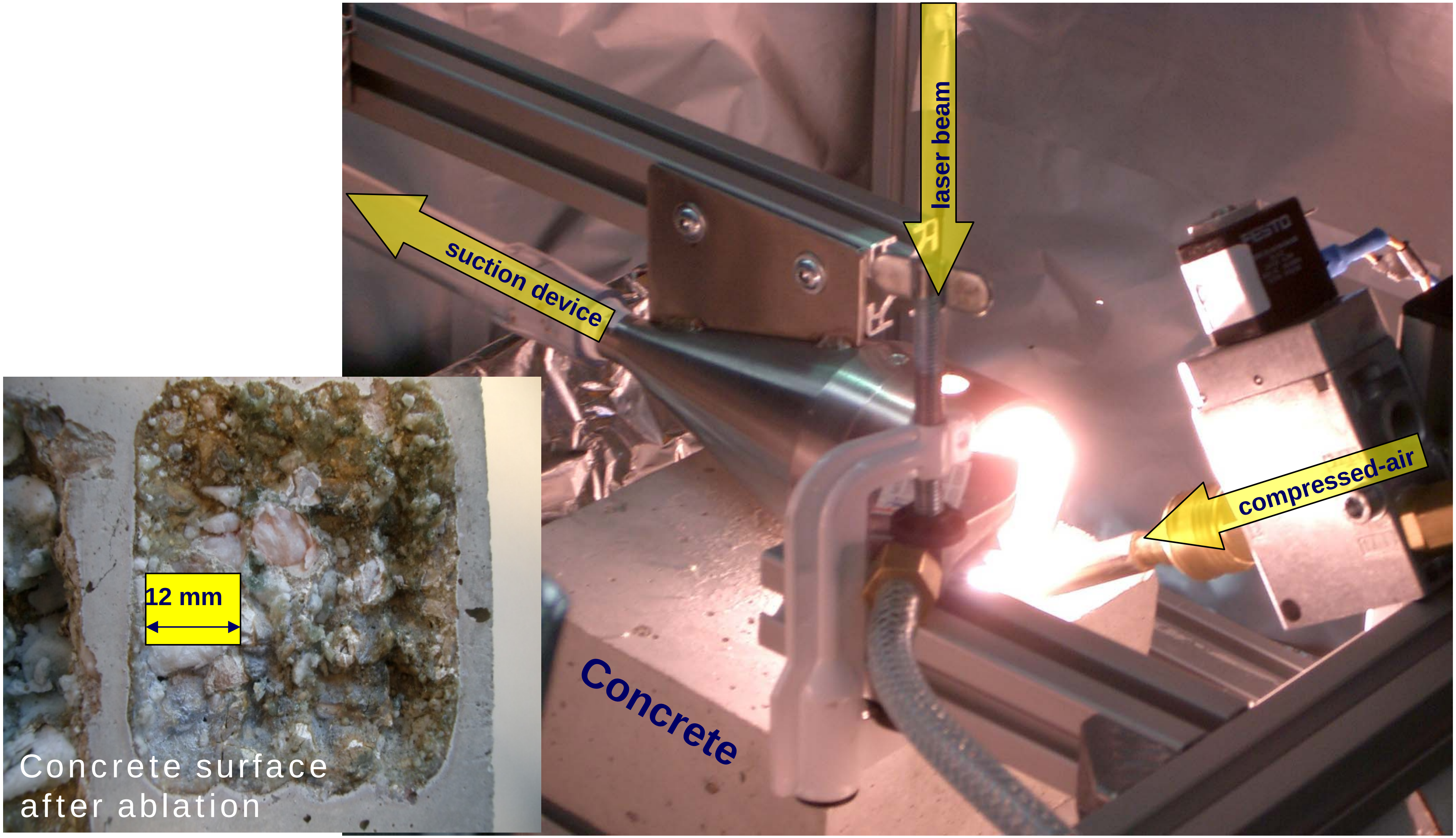
Projektträger: Forschungszentrum Karlsruhe
Wassertechnologie und Entsorgung
(PTKA-WTE)

Projektkoordinator: TU Dresden
Partner: Laserinstitut Mittelsachsen e.V. (LIM)
VKTA Rossendorf e.V.

Principle of the Ablation and Conditioning Process



Laser Ablation

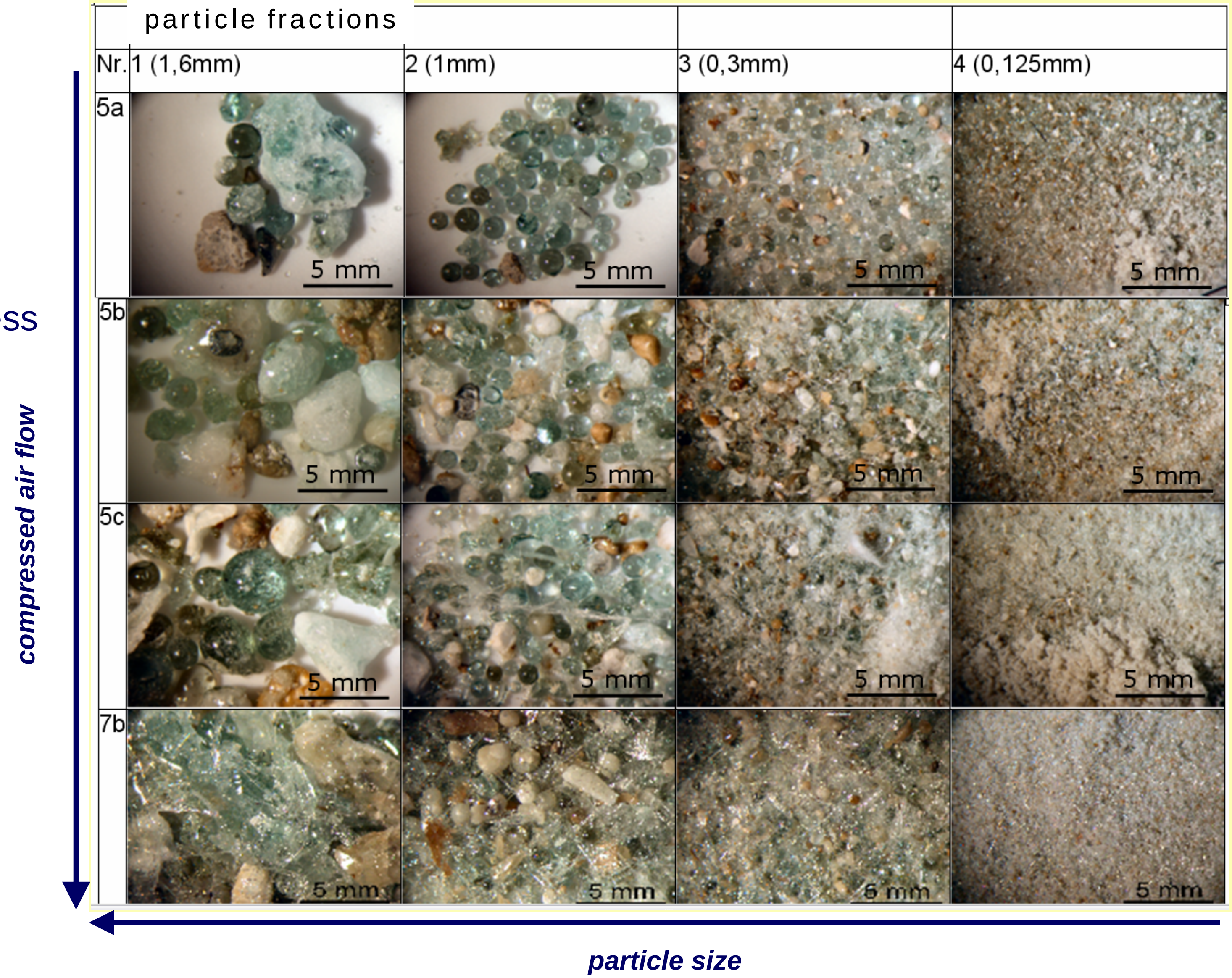


Conditioned Product

Classification of the product:

Yield of different particle fractions depending on process parameters

More than 90 % of the initial radioactivity is fixed in the product !



Bundesministerium
für Bildung
und Forschung

2. Cutting Technologies

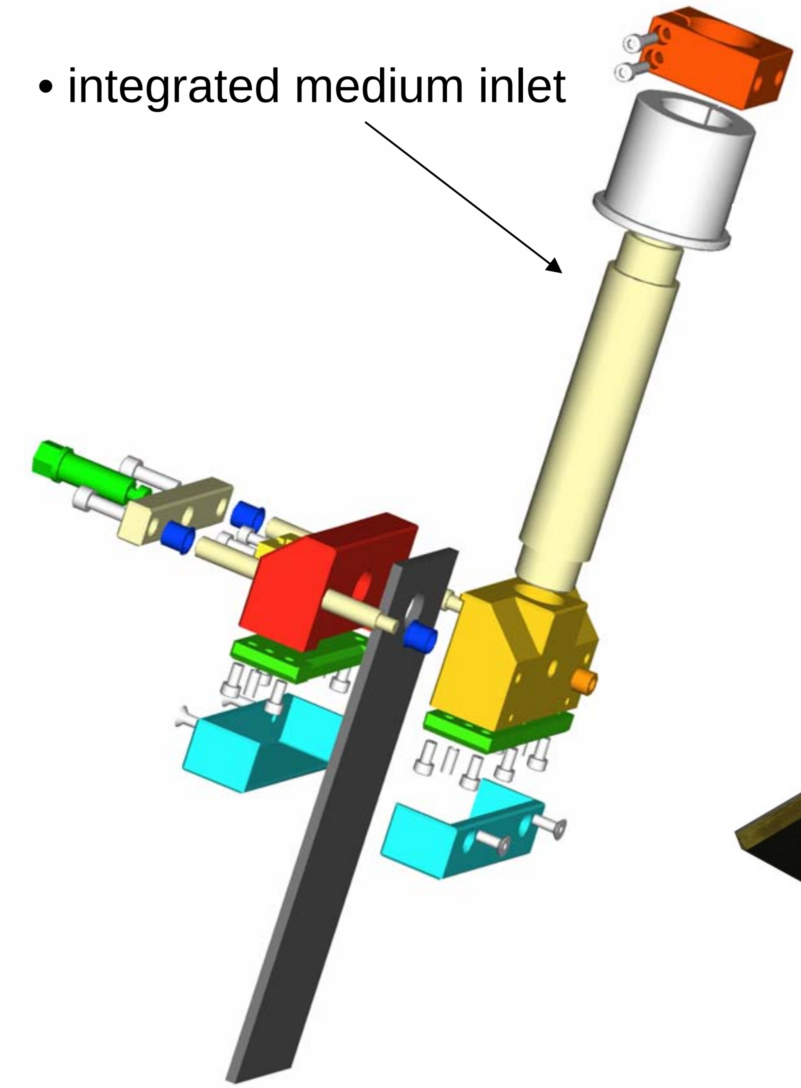
Ideen zünden!

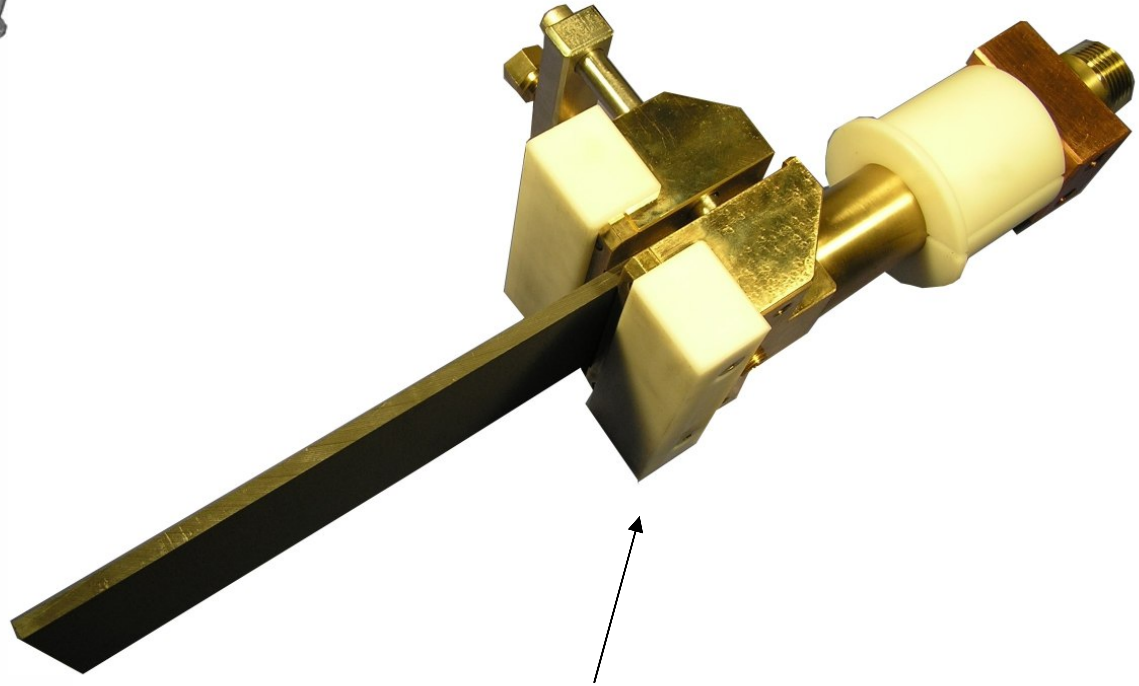
CAMC

Contact-Arc-Metal-Cutting (CAMC)

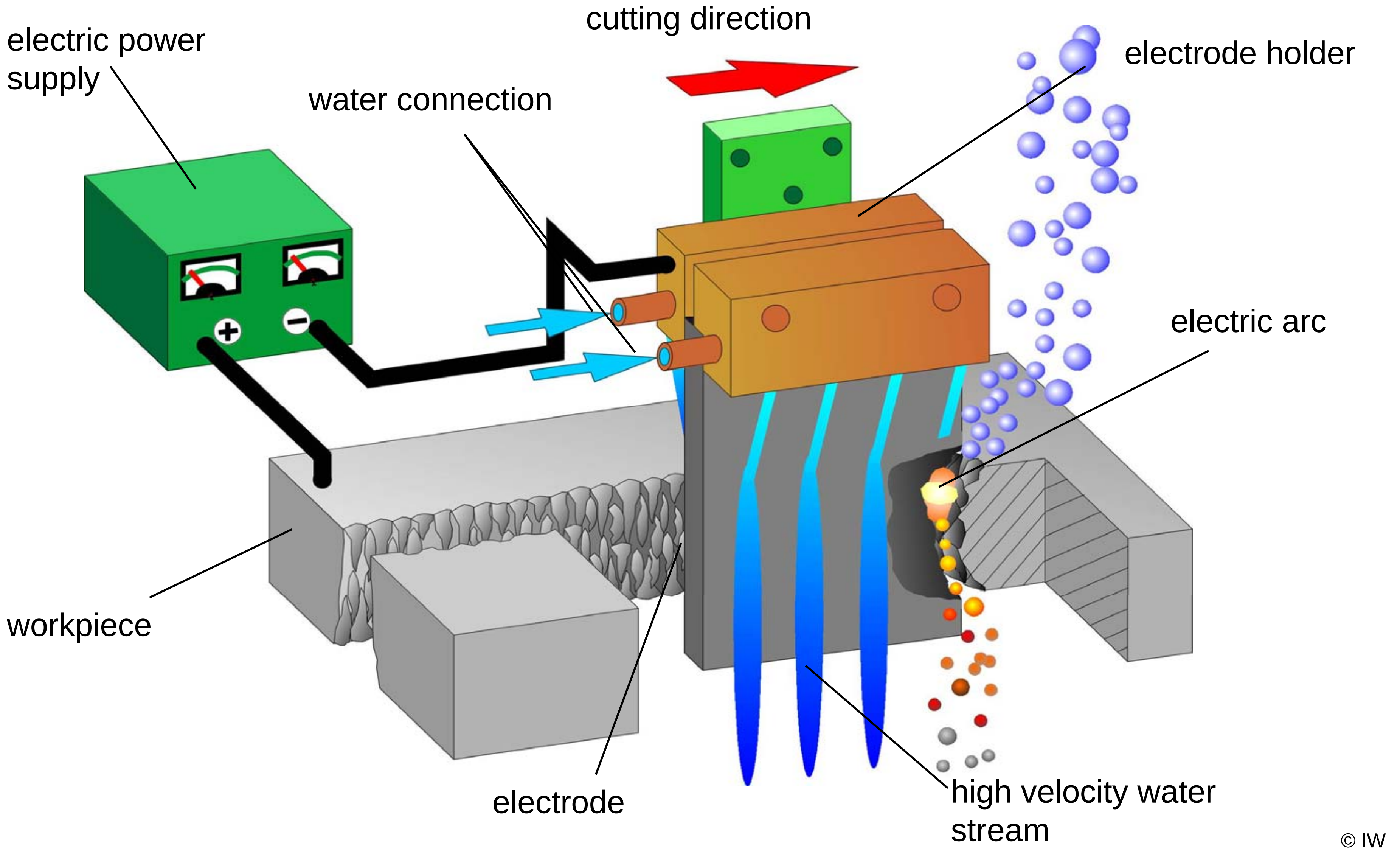
Guido Kremer, Friedrich-Wilhelm Bach

CAMC-Tool – Electrode holder with Electrode



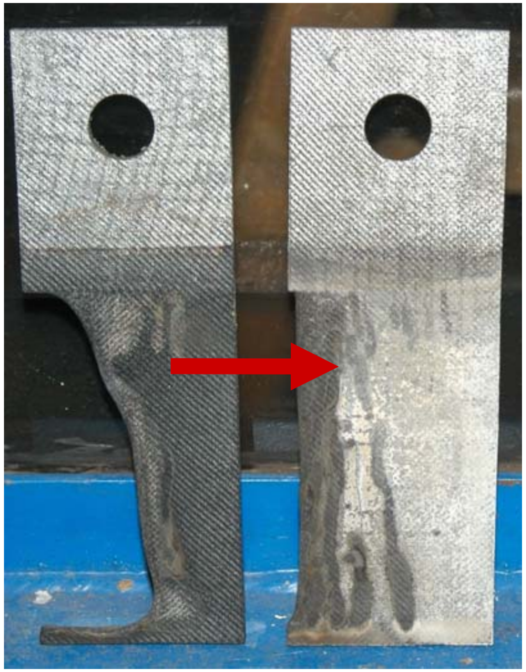


Contact-Arc-Metal-Cutting (CAMC) – principle



CAMC-Cuts into 130 mm solid material

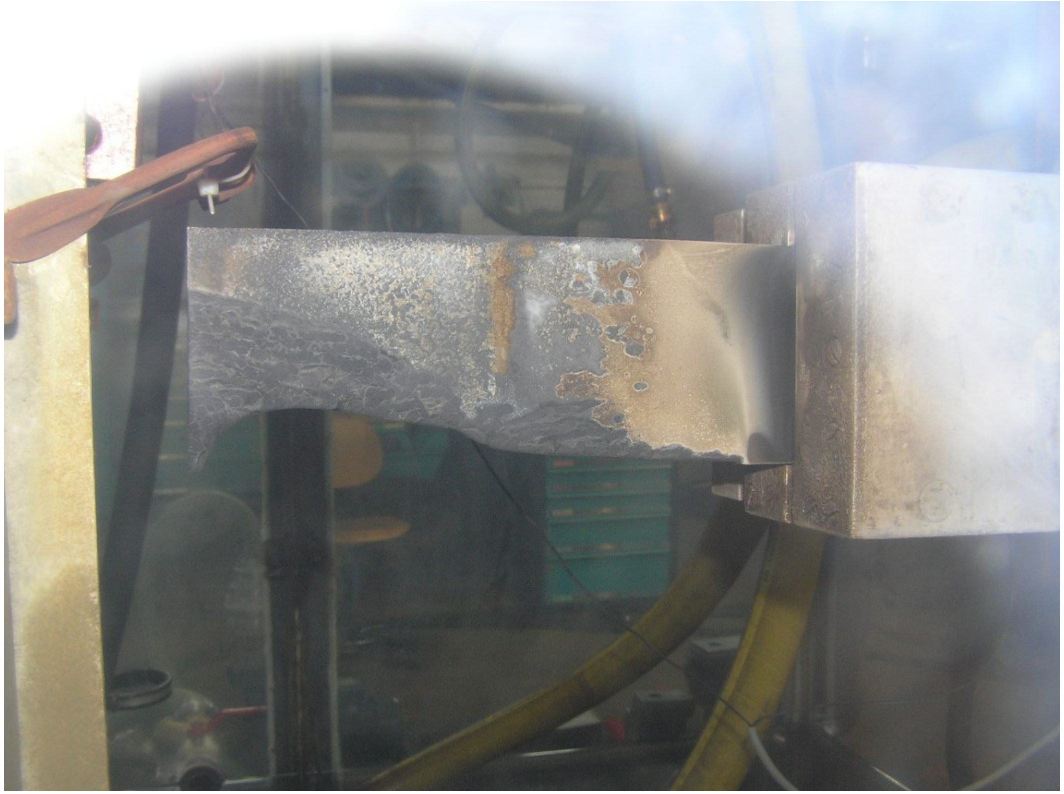
Parameter	**initial**	**optimized**
cutting voltage:	42 Volt	58 Volt
cutting current:	2000-3500 A	max. 700A (much smaller supply!)
water pressure:	5 bar	11 bar
quantity of water flow:	5-6 m^3/h	17m^3/h
electrode material:	fiber-reinforced graphite	pure graphite



abrasion was reduced to 10 %

CAMC-CUT through a Mock-Up – pure graphite electrode

CAMC-CUT: 70-130 mm



abrasion at the graphite electrode after complete cut through the mock-up

Bundesministerium
für Bildung
und Forschung

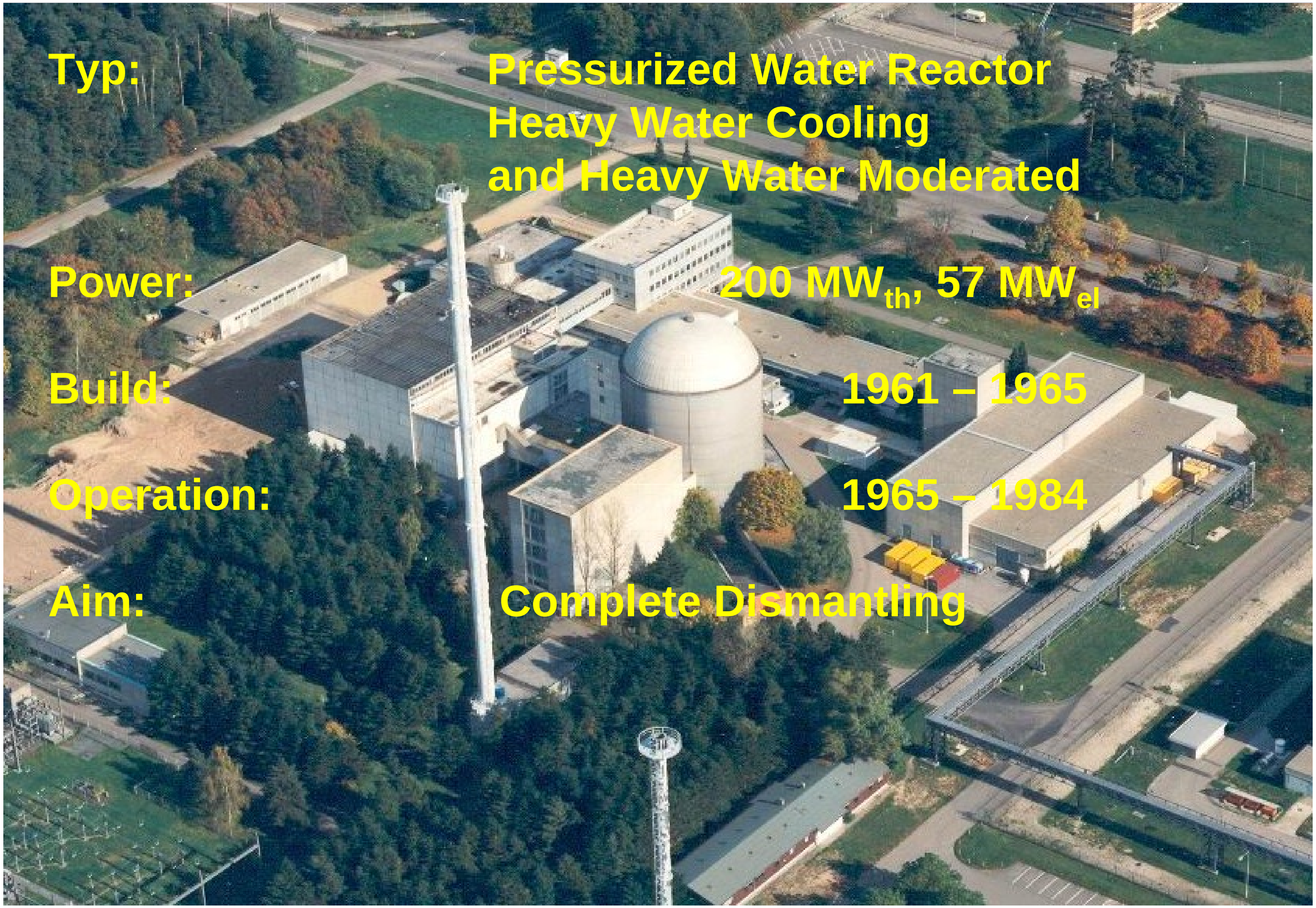
Decommissioning of MZFR: An example for the application of new technologies

Ideen zünden!

Decommissioning and Dismantling of the MZFR

E. Prechtl, B. Eisenmann
Hauptabteilung Projekte, Rückbauprojekt MZFR
Forschungszentrum Karlsruhe GmbH
W. Süßdorf, Fa. Studsvik
A. Loeb, Fa. Nukem

Decommissioning and Dismantling of the MZFR



Typ: Pressurized Water Reactor
Heavy Water Cooling
and Heavy Water Moderated

Power: 200 MW_{th}, 57 MW_{el}

Build: 1961 – 1965

Operation: 1965 – 1984

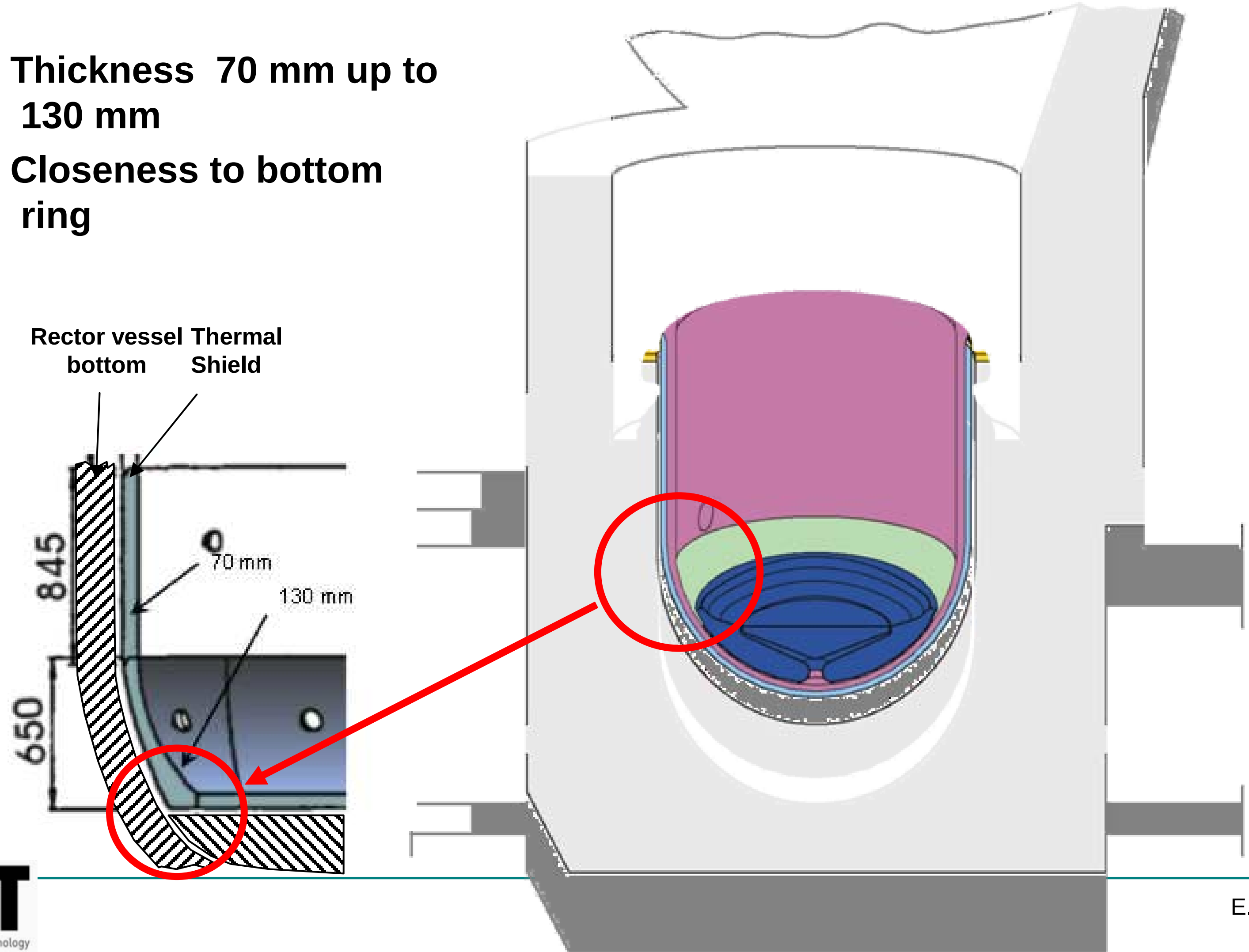
Aim: Complete Dismantling

Reactor vessel of the MZFR

Fabrication in 1964

Remote-controlled Cutting of the Thermal Shield: Cutting of part 5, Special task due to very special geometry

1. **Thickness 70 mm up to 130 mm**
2. **Closeness to bottom ring**

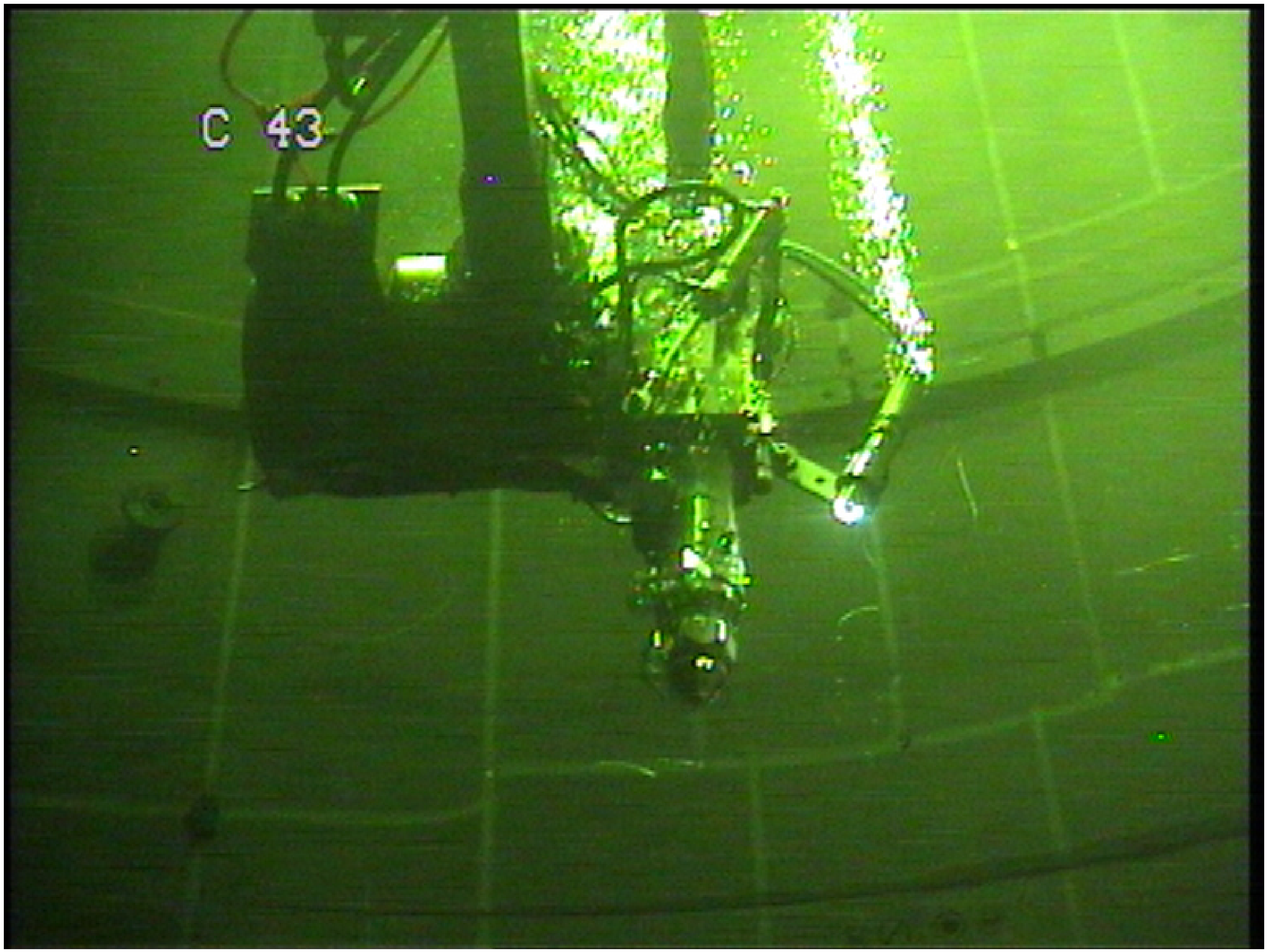


Test on a Dummy of Part 5 of the Thermal Shield

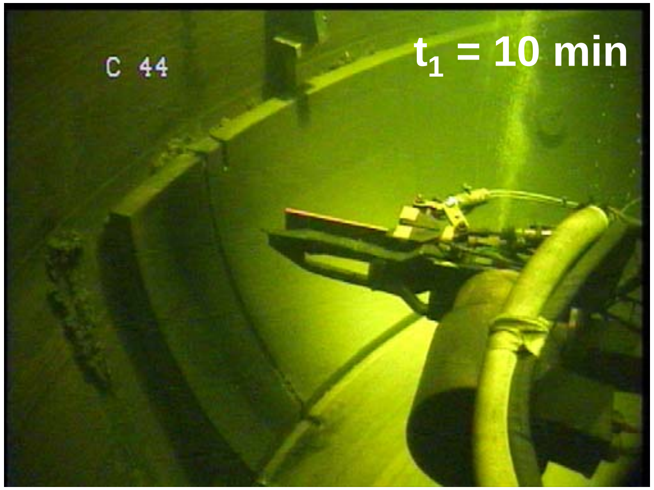
Underwater lab at Universität Hannover

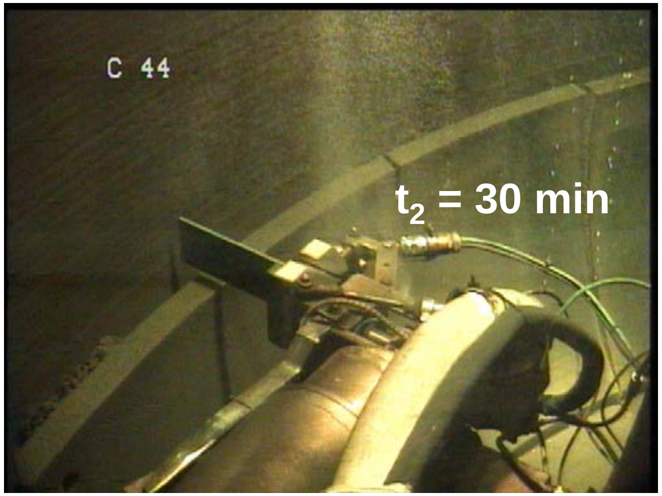
CAMC Cut: Thickness 70 – 130 mm)

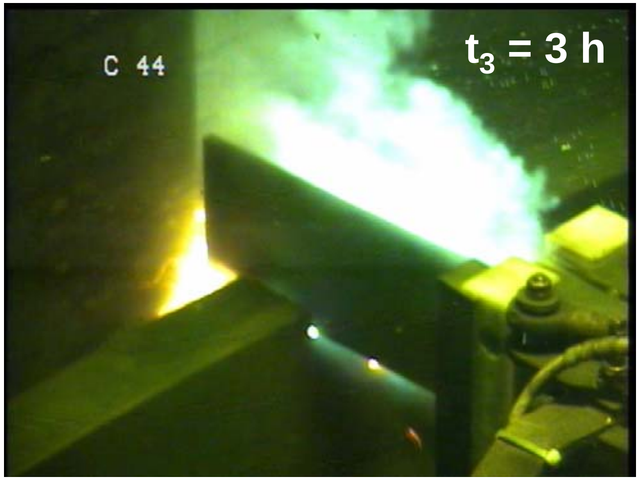
Remote-controlled Tool Carrier

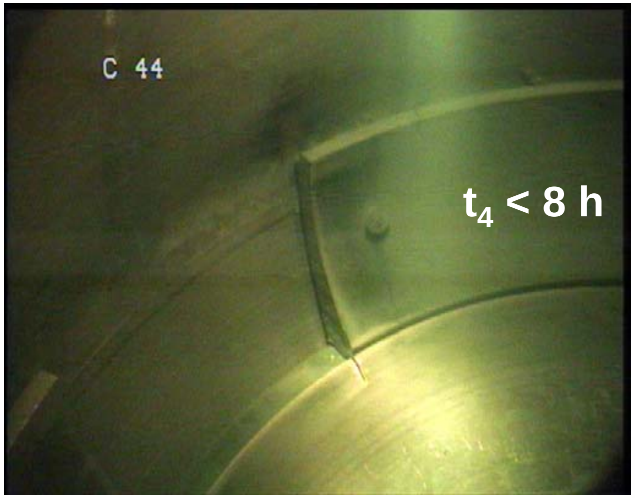


Remote-controlled CAMC Cutting of the Thermal Shield, Part 5







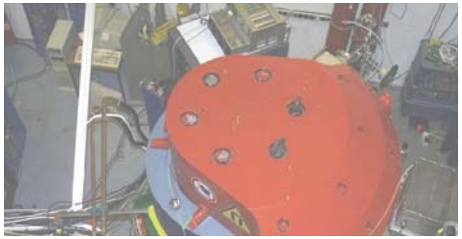



C 43
02-11-05 3H
12:39:59

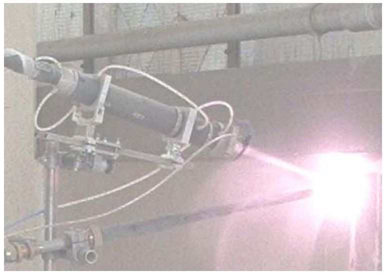
Outlook

- Techniques for decommissioning and dismantling of nuclear facilities are already available
- Improvement of common techniques and use of innovative techniques for special problems could reduce costs and improve safety of both the workers and the public
- Management of radioactive waste from decommissioning is a key consideration, therefore the availability of a final waste disposal is an increasing demand
- In future design of nuclear facilities considerations about decommissioning and dismantling have to be implemented.

Bundesministerium
für Bildung
und Forschung



Thank You for Your Attention !



Ideen zünden!

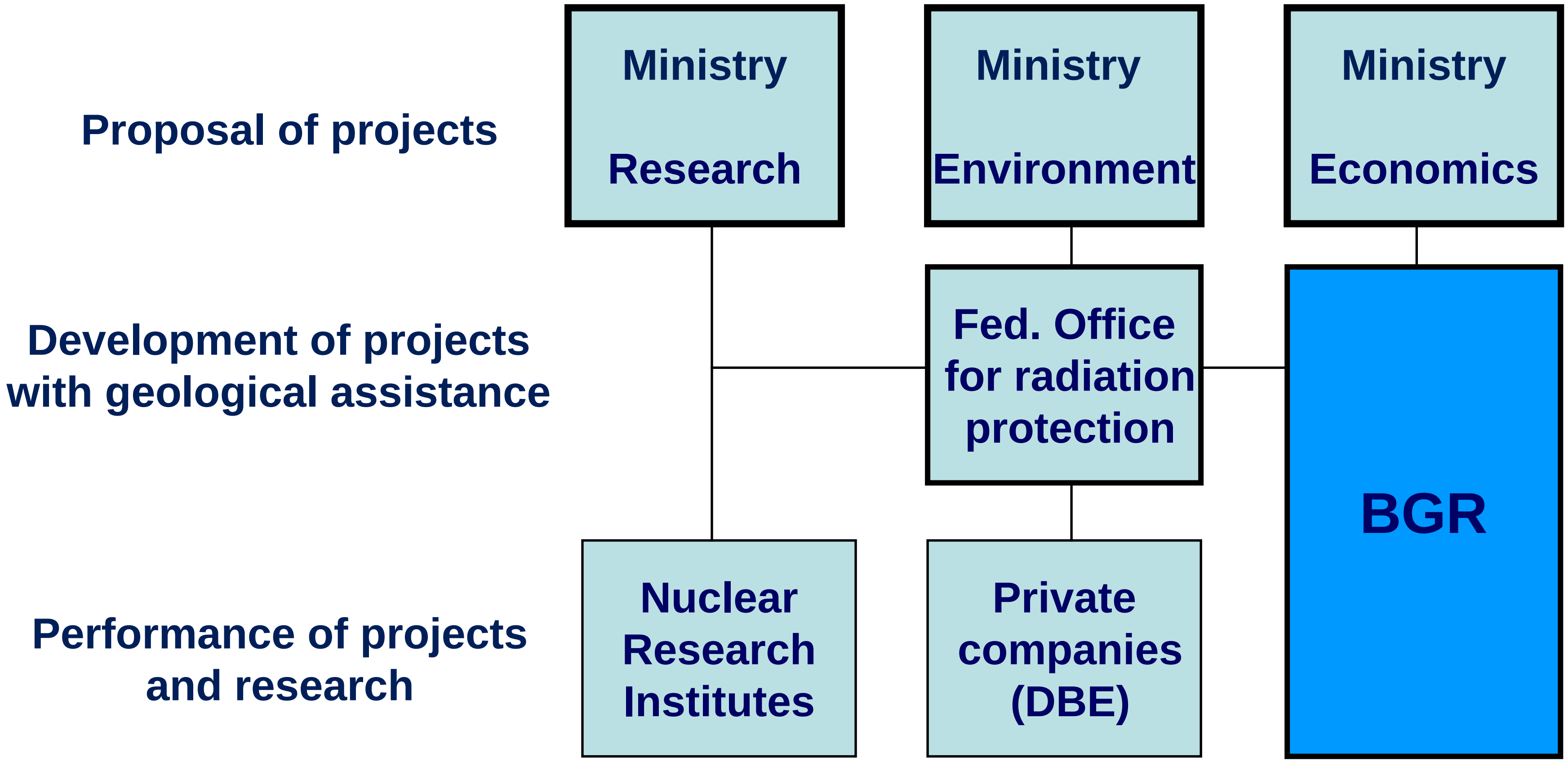
Clay formations – a possible alternative as host rocks for radioactive waste disposal in Germany ?

Volkmar Bräuer

Peer Hoth
Holger Wirth
Klaus Reinhold
Paul Krull
Hagen Feldrappe

BGR- „Clay report"
by order of the German Federal Ministry of Economics and Technology

Nuclear waste disposal in Germany
- Responsibilities -



Repository/Exploration Sites in Germany

Gorleben

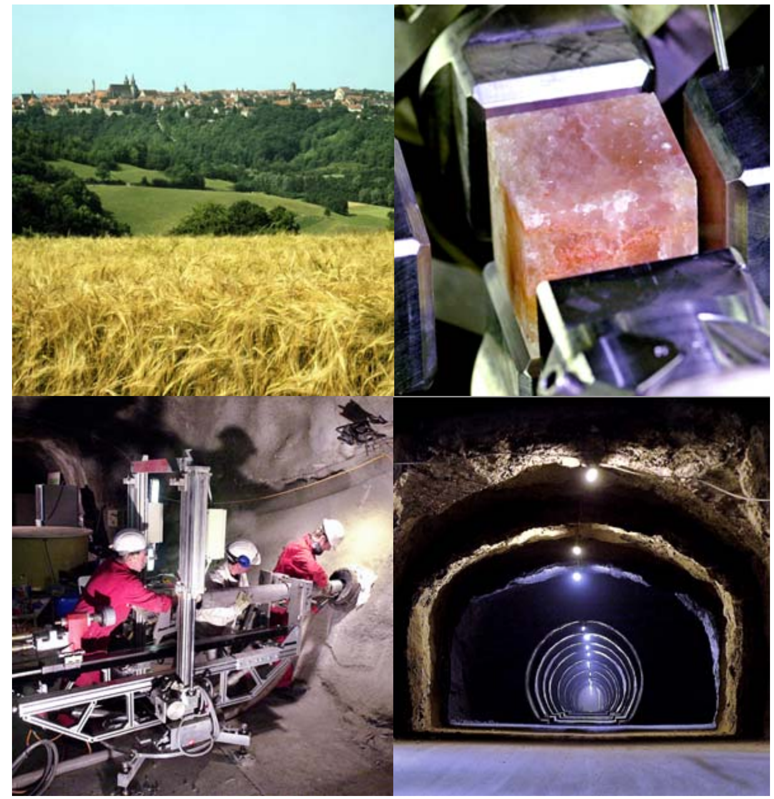
Konrad

Morsleben

BGR activities on radioactive waste disposal

- Research since more than 30 years
- Site specific investigations
  Morsleben, Gorleben, Konrad
- Research and development
  Host rocks, geotechnical barriers, scenario analyses
- International co-operation
  International URLs, bilateral agreements

Site Selection **Research**



Site Exploration **Long-Term Safety**

Properties	*Rock Salt*	*Clay/Clay Stone*	*Crystalline Rock (granite)*
thermal conductivity	high	low	medium
permeability	almost impermeable	very low to low	very low (not fractured) to permeable (fractured)
stability	medium	low to medium	high
deformation behaviour	viscous (creep)	plastic to brittle	brittle
excavation stability	inherent stability	support required	high (unfractured) low (fractured)
in situ stress	lithostatic isotropic	anisotropic	anisotropic
solution behaviour	high	very low	very low
sorption capacity	very low	very high	medium to high
temperature resistivity	high	low	high

Properties of potential host rocks

- favorable (green)
- unfavorable (red)
- medium (cream)

Components	*Rock Salt*	*Clay/Clay Stone*	*Crystalline Rock*
emplacement level	approx.. 900 m	approx.. 500 m	500 - 1200 m
disposal technique*	drifts and deep boreholes	drifts respectively . short boreholes	boreholes or drifts
design temperature	max. 200° C	max. 100° C	max. 100° C (bentonite backfill)
backfill material*	crushed salt	bentonite	bentonite
duration of interim storage (fuel element container and high active waste container)	min. 15 years	min. 30 - 40 years	min. 30 - 40 years
support	not necessary	necessary, under certain conditions very complex	necessary in fractured areas
waste container concept	existing	to be developed in Germany	to be developed in Germany
mining experience	wide experience (salt mining)	less experience	at lot of experience (ore mining)

Disposal concepts in different host rocks

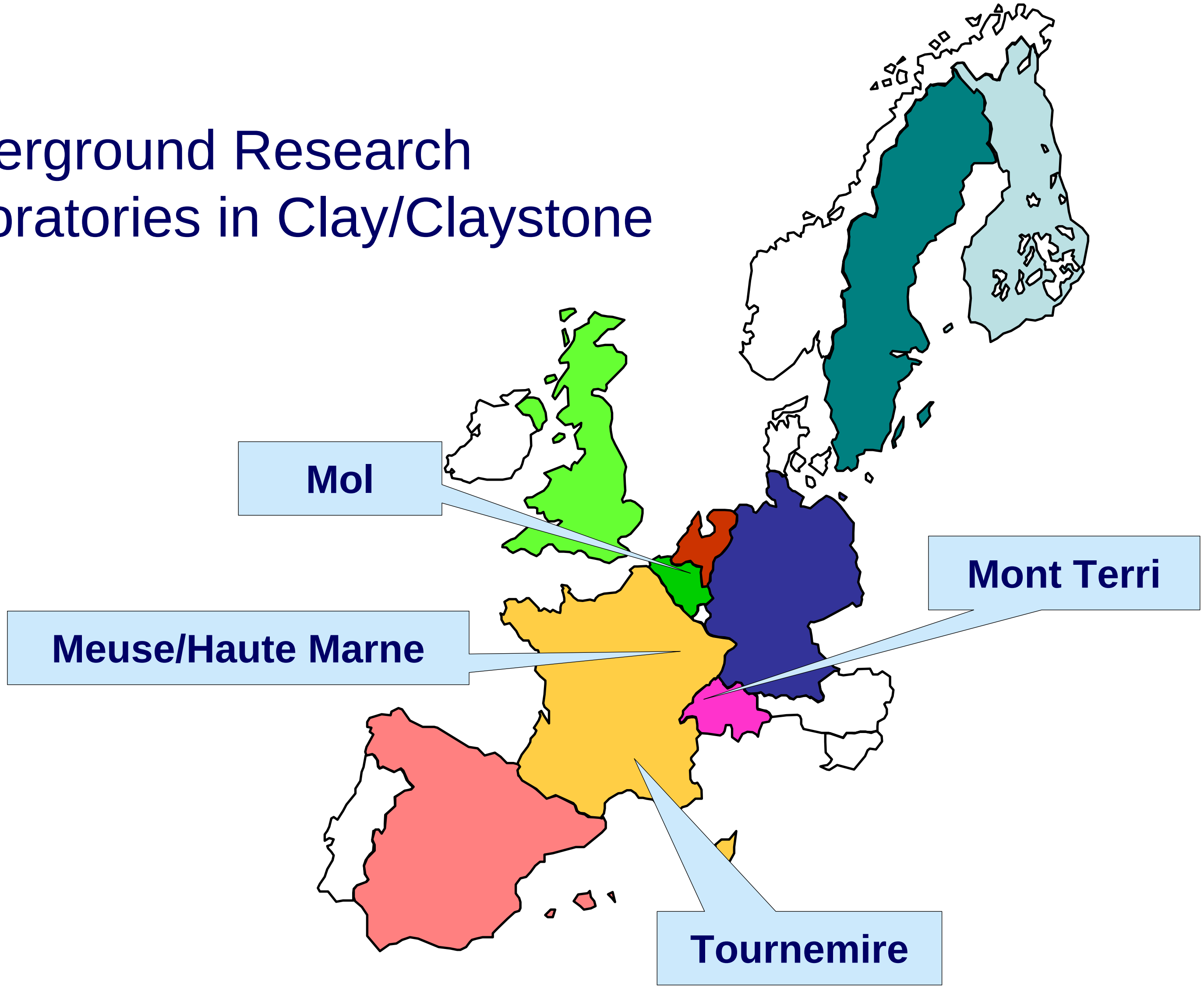
favorable

unfavorable

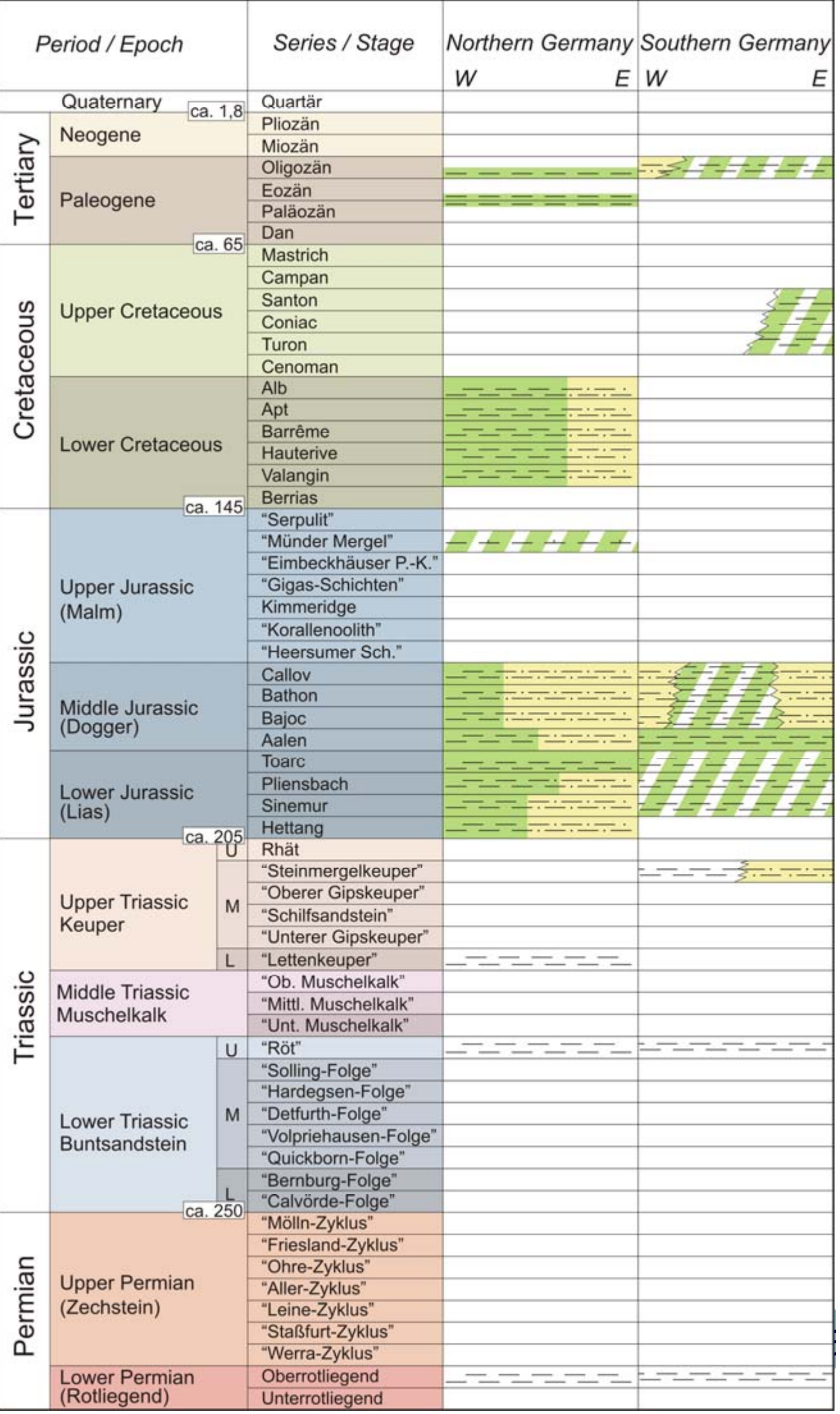
* has to be adopted to the host rock

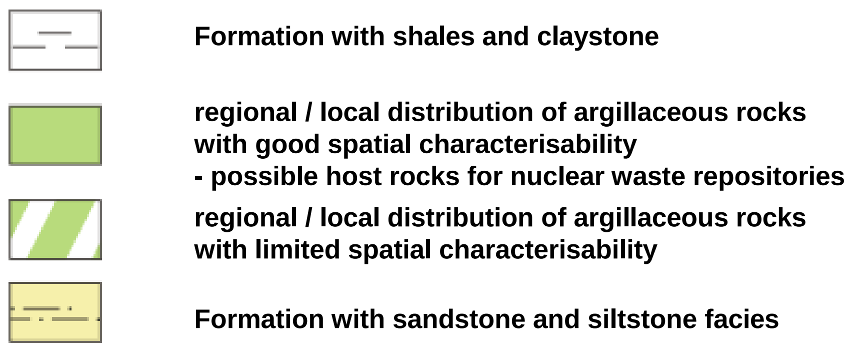
International Co-operation

Underground Research Laboratories in Clay/Claystone



Stratigraphic position of clay/claystone formations in Germany

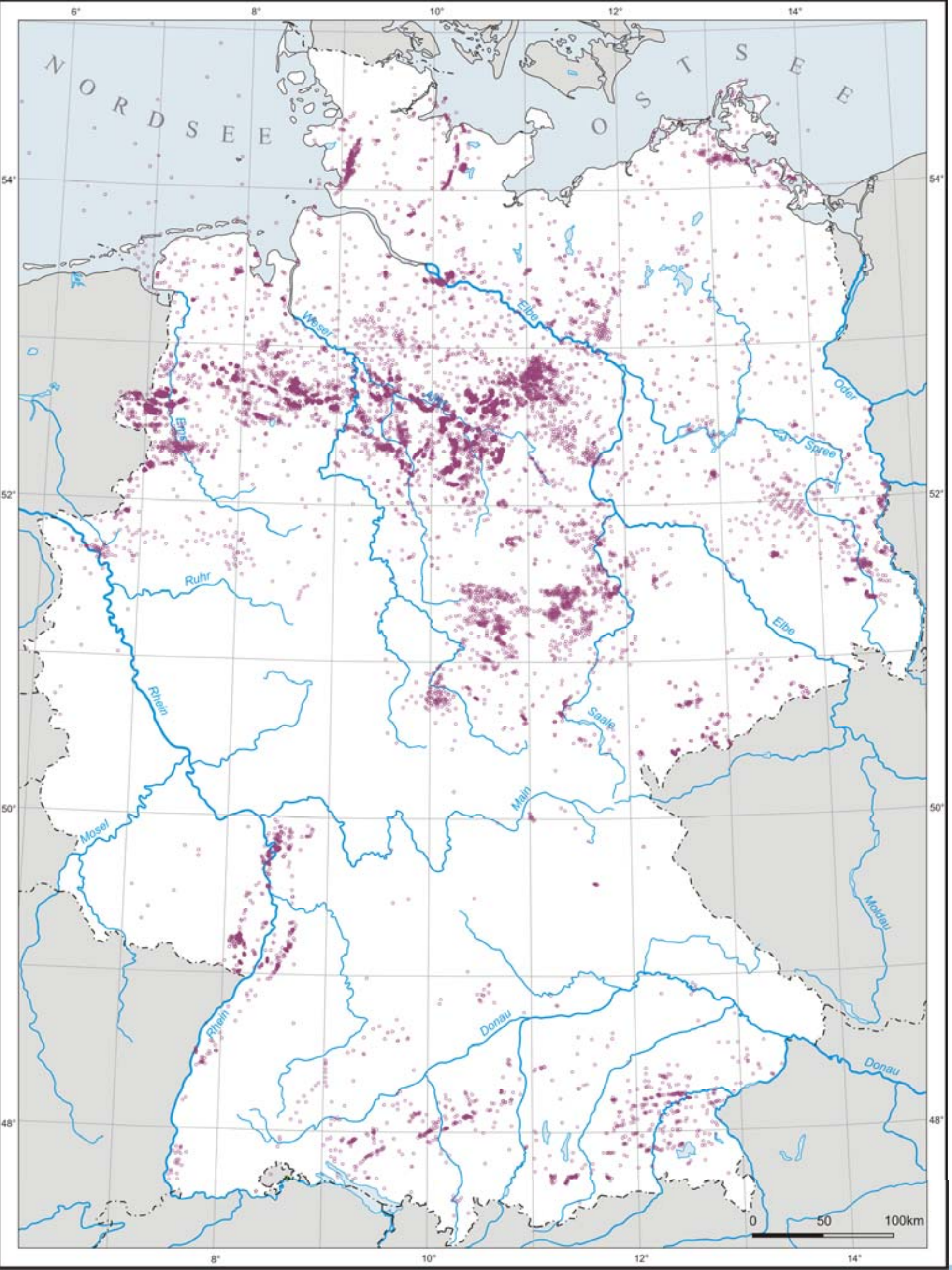




BGR Bundesanstalt für Geowissenschaften und Rohstoffe
GEOZENTRUM HANNOVER

Data base for the „BGR-clay report“

- Literature
- Drilling records
- Borehole logs
- Seismic-Data
- Borehole-correlations
- No in-situ tests



Boreholes in Germany

(approx. 25.000)

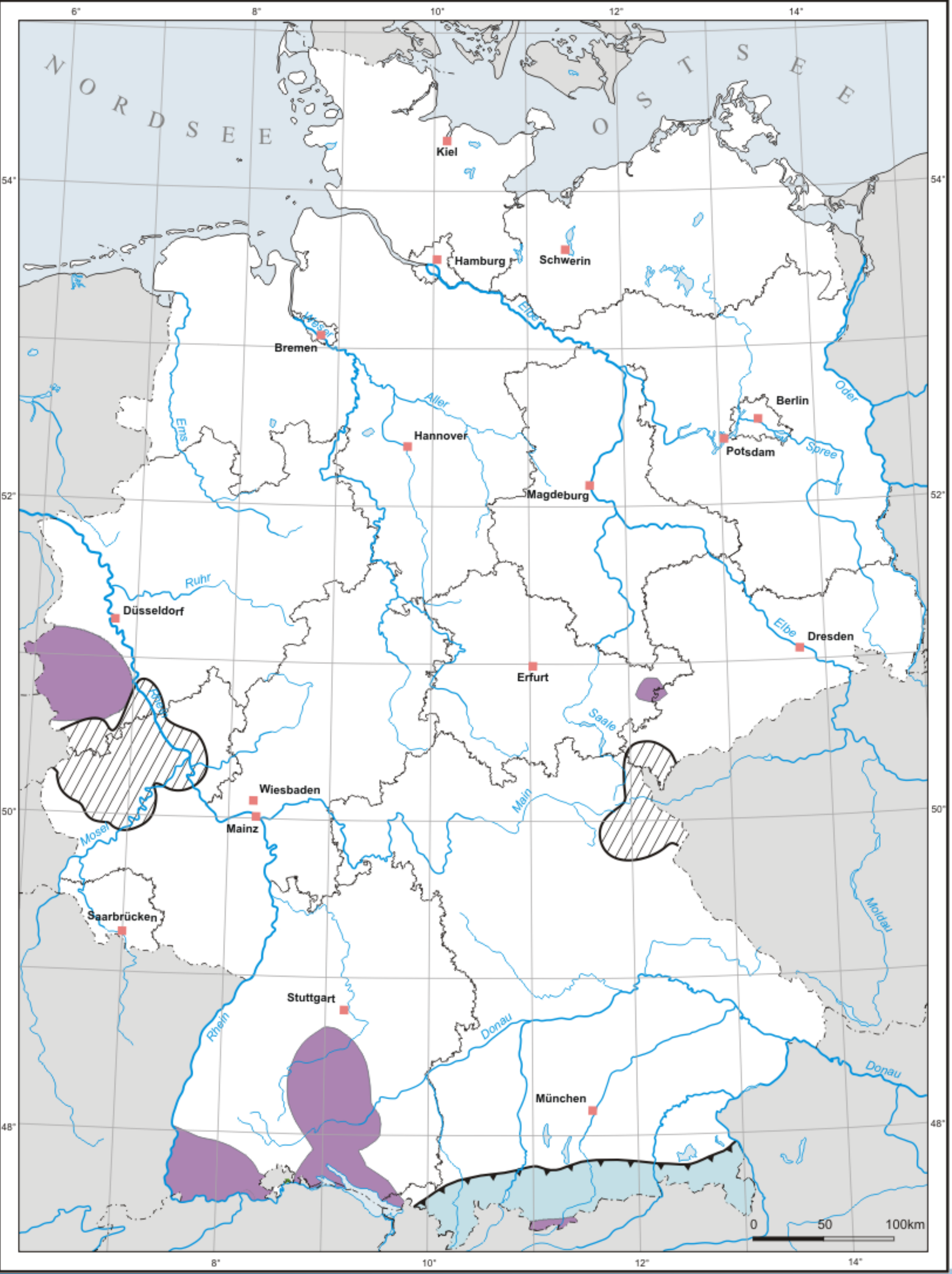
Deep boreholes (depth > 300m)

Fundamental requirements on the geological environment of a deep repository (IAEA, Nagra (CH), Andra (F))

- Long-term geological stability
- Favorable host rock properties
- Sufficient extent of host rock body
- Avoidance of, and insensitivity to, detrimental phenomena and perturbations
- Explorability
- Predictability

Basic exclusion criteria

- Large-area vertical movements
- Active fault zones
- Seismic activity
- Volcanic activity



Areas with seismic and volcanic risks in Germany

Seismic zone > 1 (DIN 4149)

Areas with increased risk of volcanism

Minimum requirements for disposal sites (1)

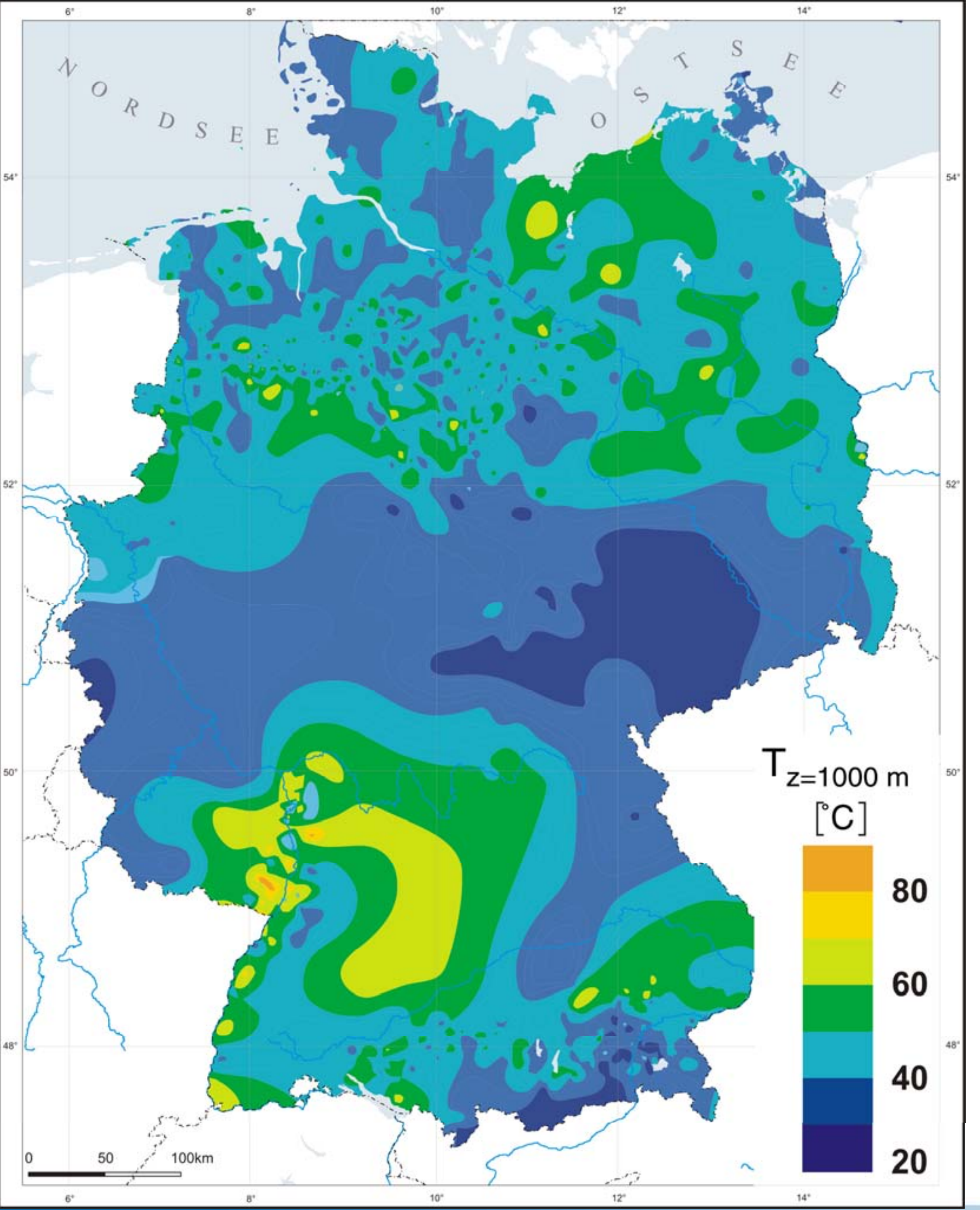
- The isolating rock zone must consist of rock types to which a field hydraulic conductivity of less than 10^{-10} m/s can be assigned
- The thickness of the isolating rock zone must be at least 300 m
- The repository mine must lie no deeper than 1,500m
- The isolating rock zone must have an areal extension that permits the realization of a repository (e. g. approximately 3 km^2 in salt or 10 km^2 in clay or granite)

Minimum requirements for disposal sites (2)

- Neither the isolating rock zone nor the host rock must be at risk from rock burst
- There must be no findings or data which give rise to doubts whether the geoscientific minimum requirements regarding field hydraulic conductivity, thickness and extent of the isolating rock zone can be fulfilled over a period of time in the order of magnitude of one million years

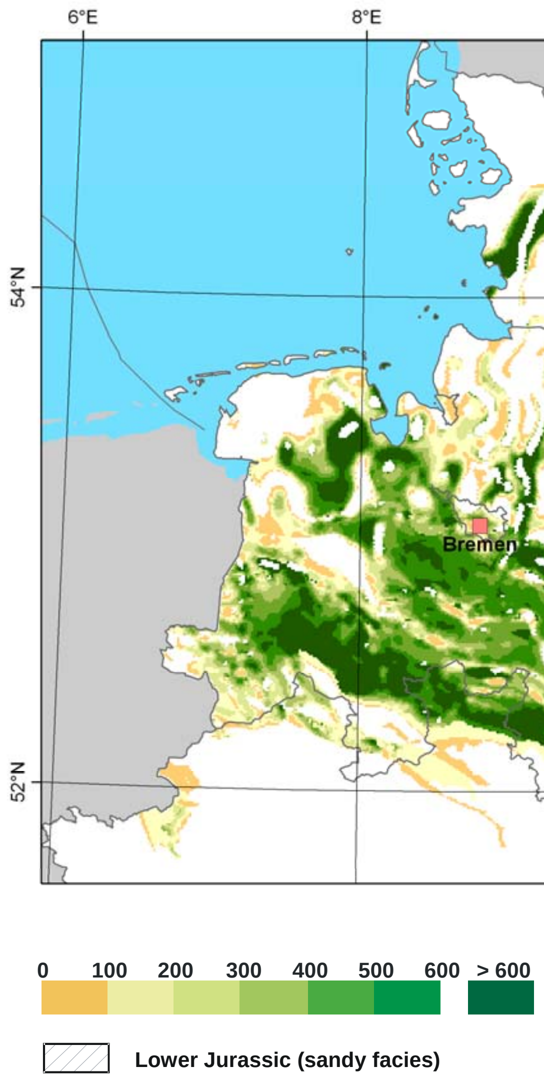
Additional specific exclusion criteria in Germany

- Repository must lie no deeper than 1000 m
- Clay with plastic behavior was excluded
- Additional regional restrictions

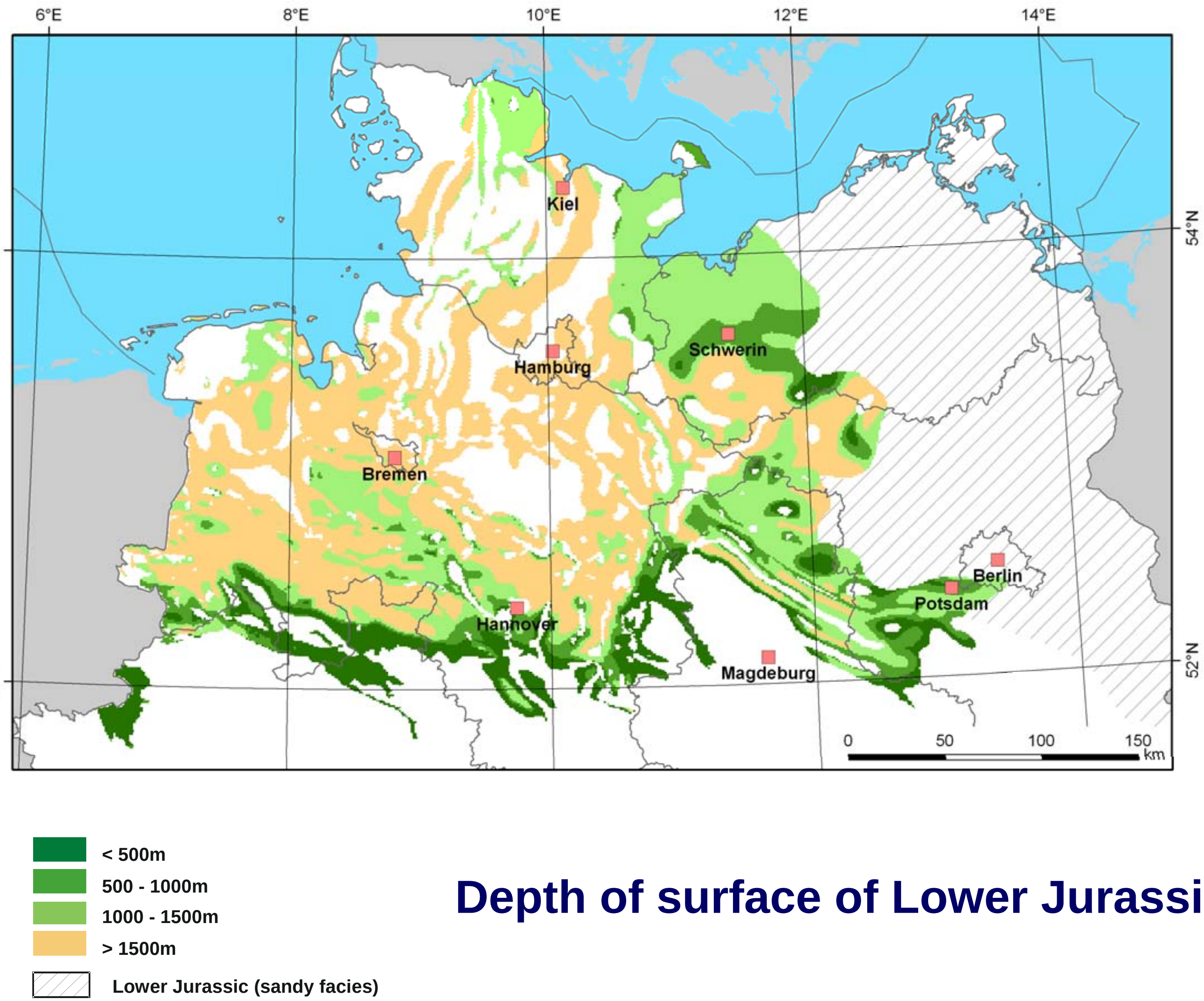


Temperature distribution in Germany

Temperature distribution (depth = 1000m)

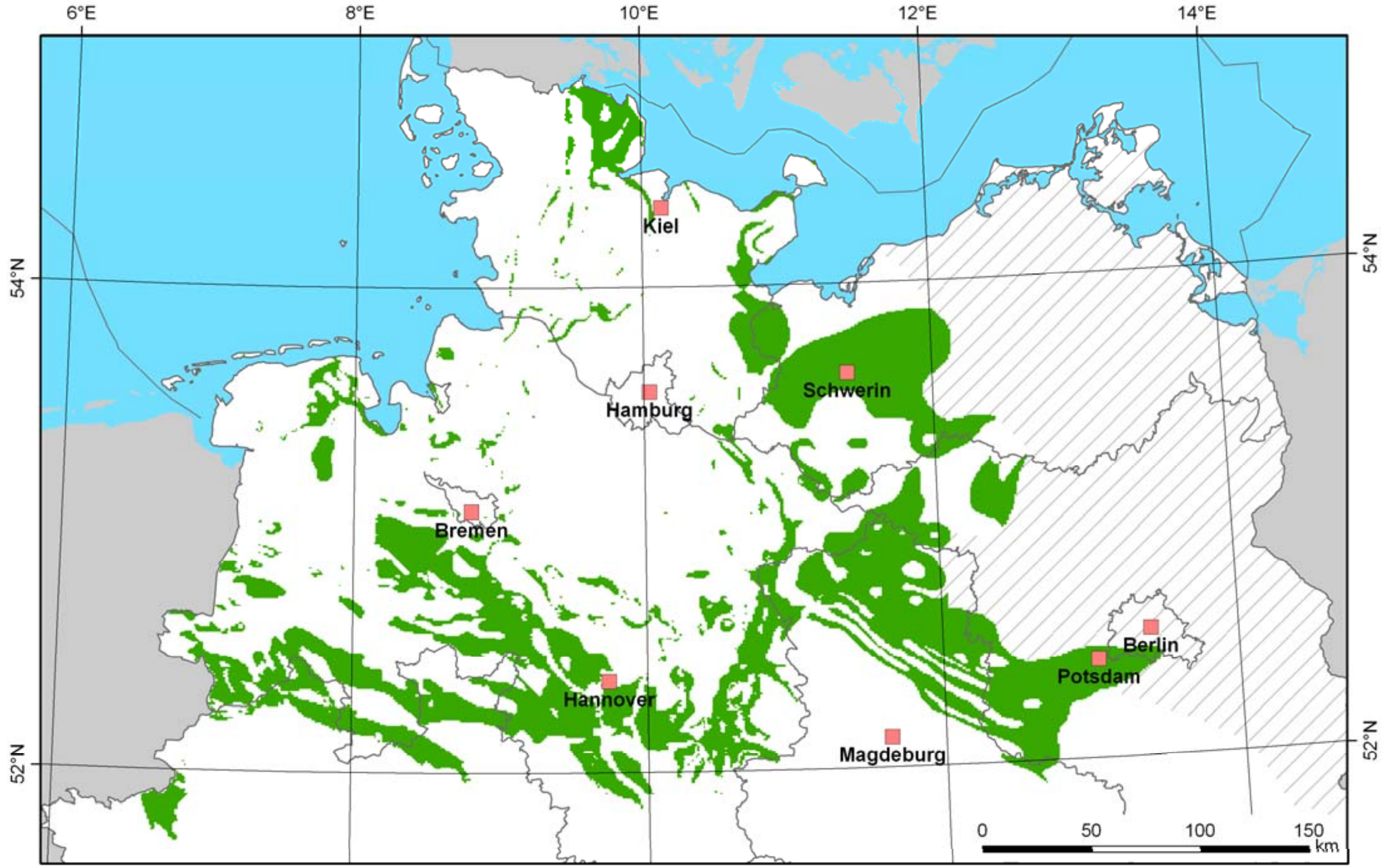


Thickness [meter] of Lower Jurassic



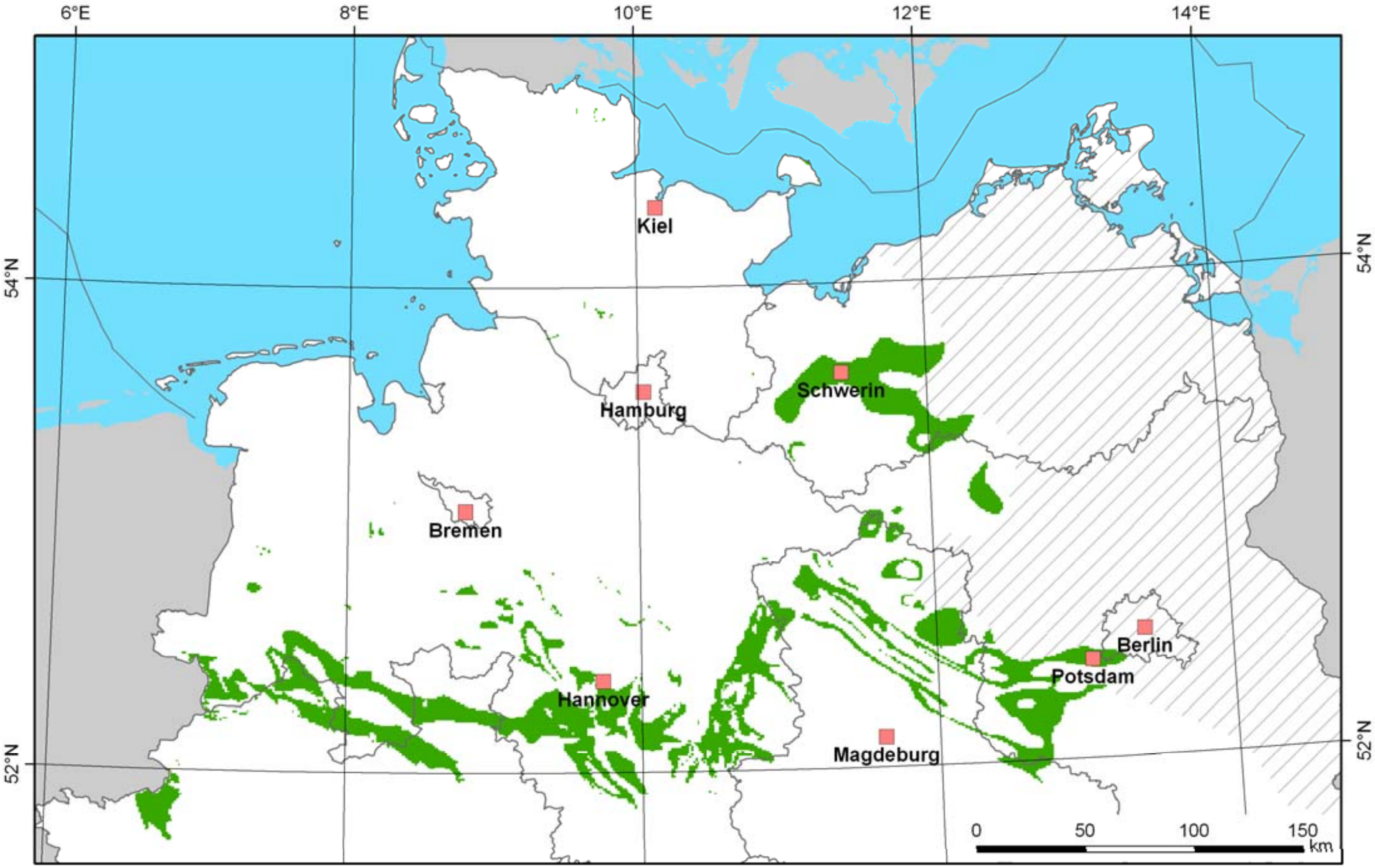
Depth of surface of Lower Jurassic [below Sea level]

Minimum requirements / Lower Jurassic



Thickness > 100m
Depth < 1500m (below ground surface)

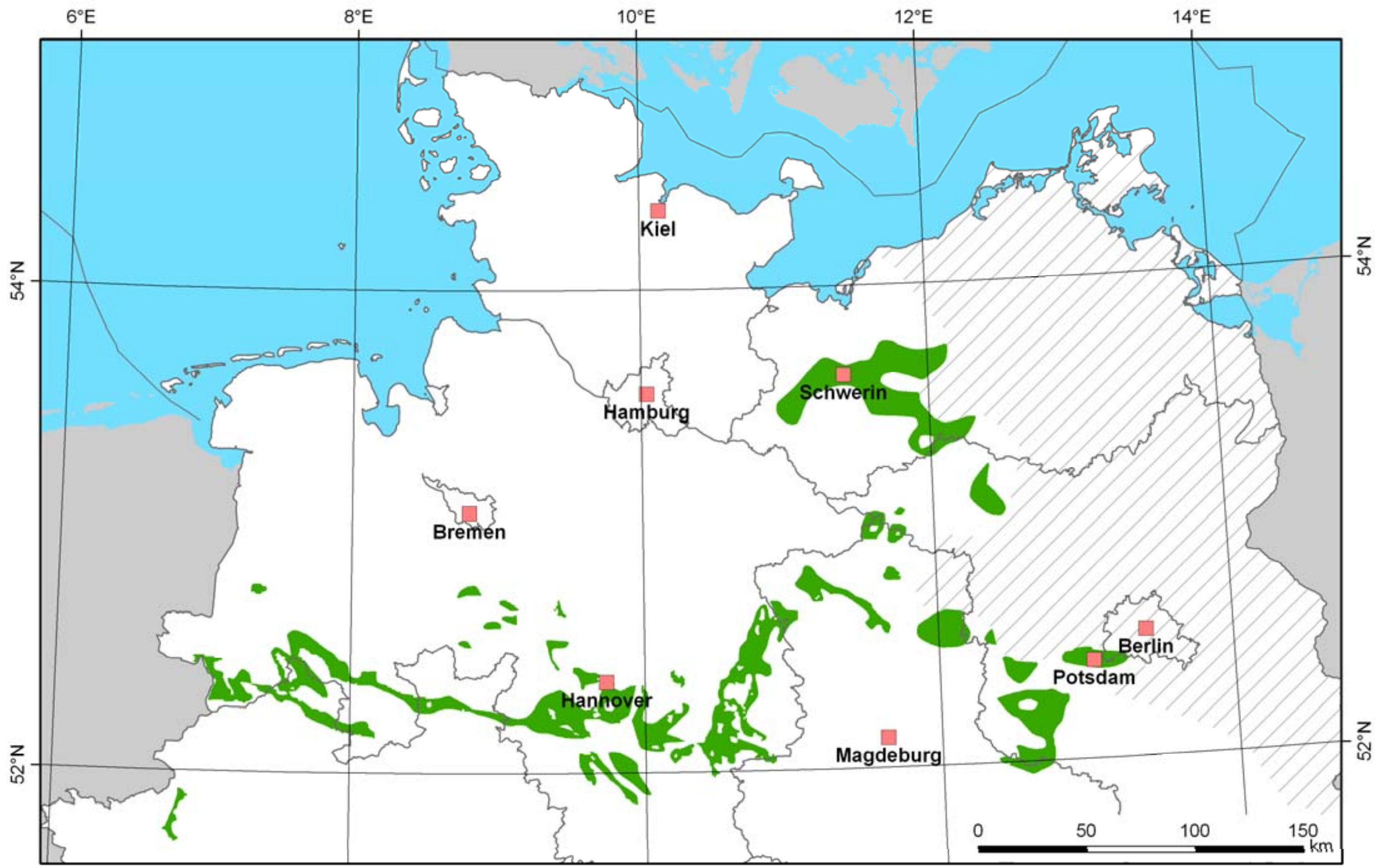
Lower Jurassic (sandy facies)



Thickness > 100m
Depth < 1000m
(below groundsurface)

Lower Jurassic (sandy facies)

Claystone specific criteria / Lower Jurassic



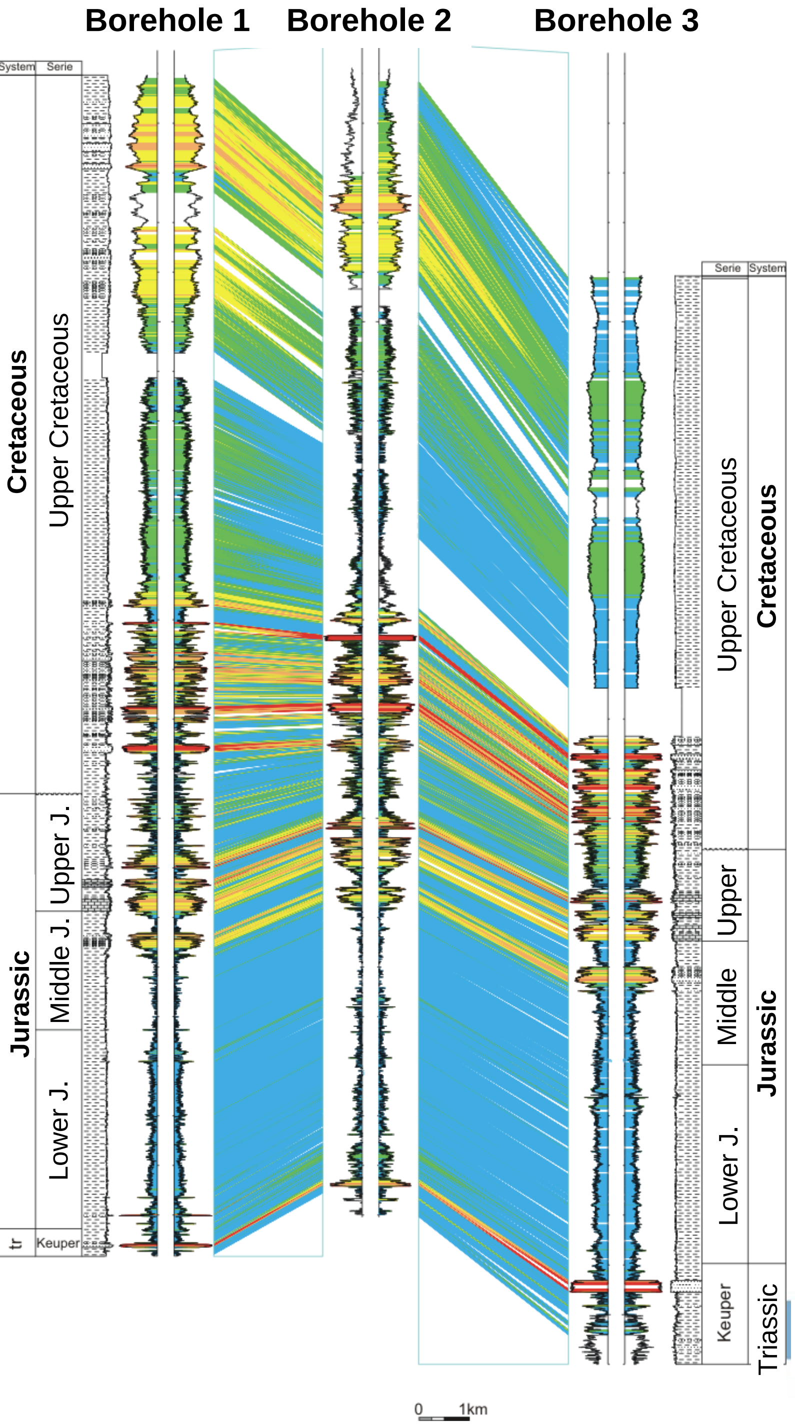
Thickness > 100m

Depth > 300m and < 1000m (below groundsurface)

area >10km²
(in good special characterisation)

Lower Jurassic (sandy facies)

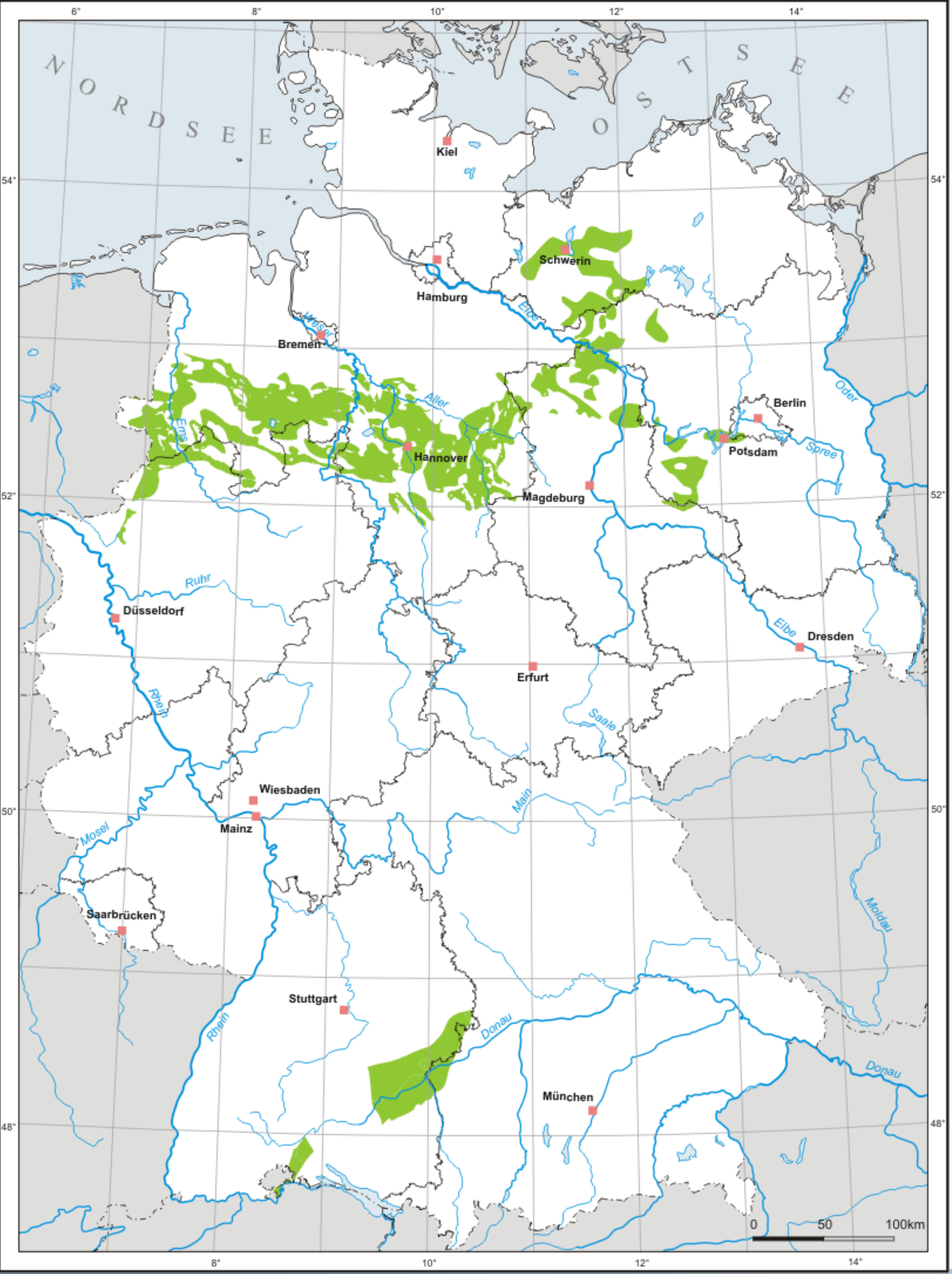
Application of all claystone specific criteria / Lower Jurassic



Claystone formations

Example of borehole correlation

(Code CORRELATOR)



Claystone formations

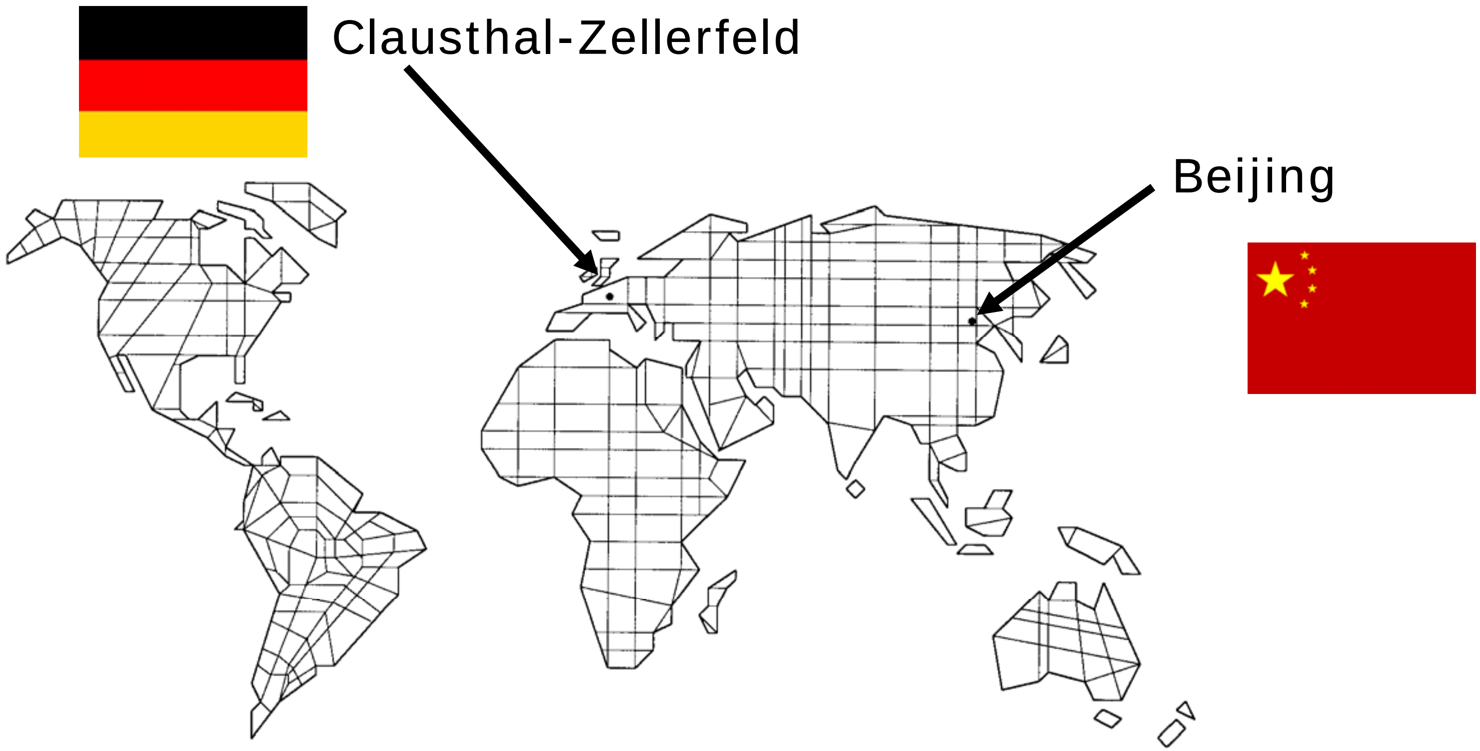
potentially suitable for further investigations in Germany

Future Research Activities

R+D	Salt	Claystone	Granite
Charakterisation of potential host rocks	x	**X**	(X)
Geotechnical barriers, Excav. Disturbed Zone	X	X	X
Siting of potential host rocks in Germany	(x)	X	(x)
Safety assessment	**X**	X	--

TU Clausthal

Chinese-German Workshop on Radioactive Waste Disposal



Sino-German Science Center, Beijing May 28-31, 2007

K.-H. Lux

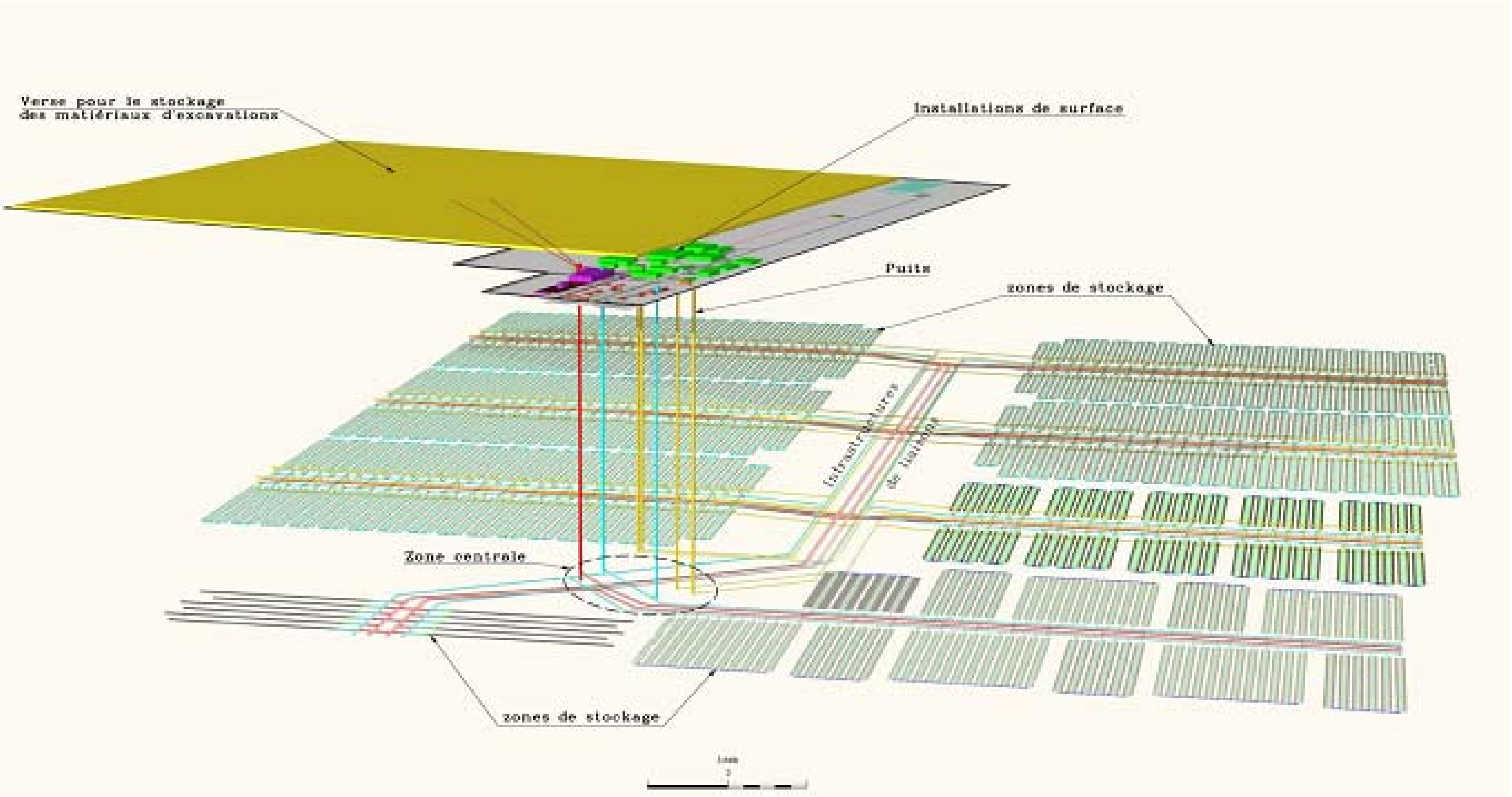
Radioactive Waste Disposal in Various Host Rock Formations – *Some Geomechanical Aspects (Fundamentals)*

Short Version with selected aspects…

Contents

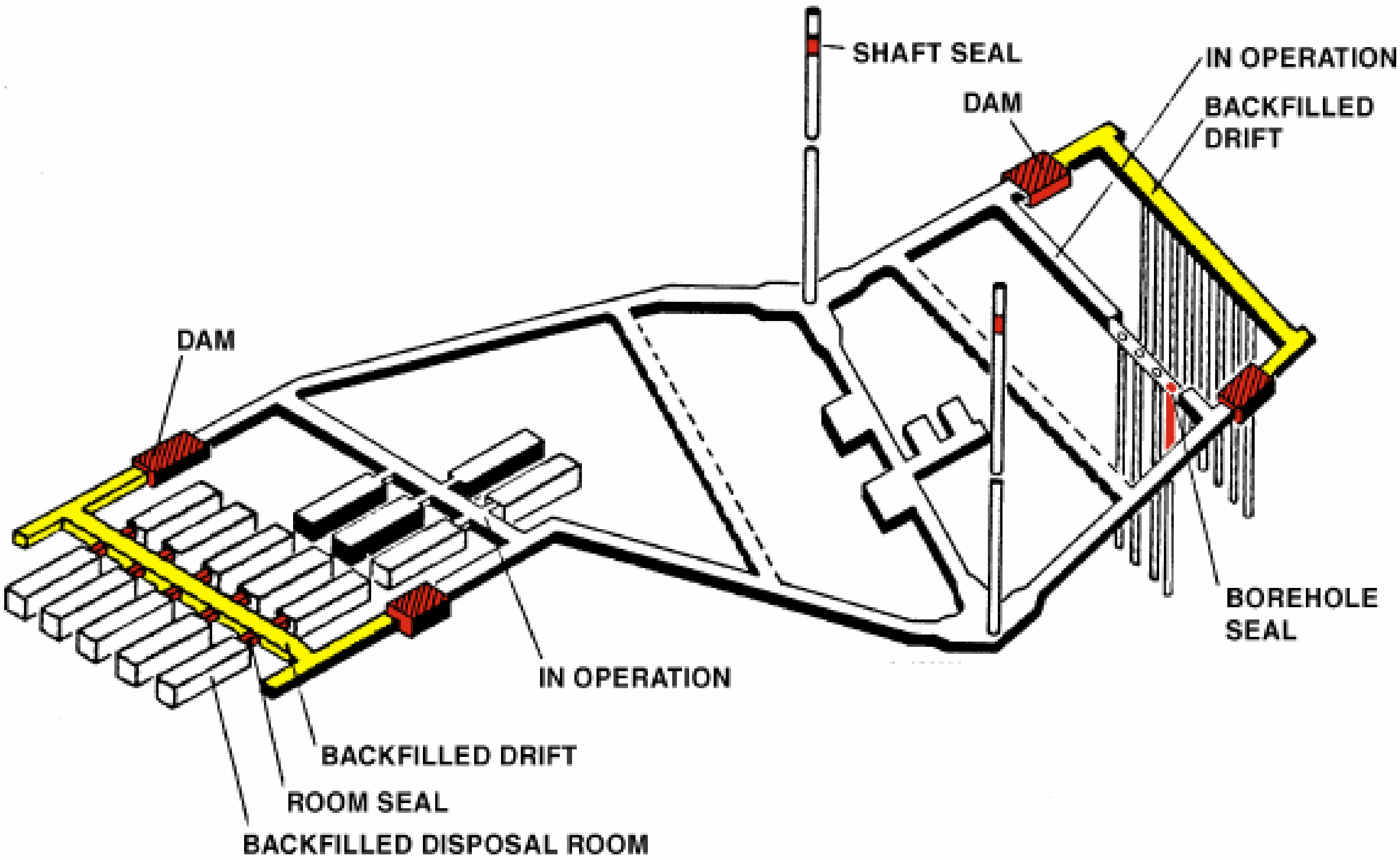
- Demonstration of Safety / General Aspects
- Waste Quantities and Properties
- Site Selection
- Physico-chemical Modelling / Coupled Processes
- Thermo-Mechanical – Hydraulic Aspects
- Geomechanical Aspects
- The Best Repository ?
- Conclusions

Reality and Prognosis: Disposal system (example)



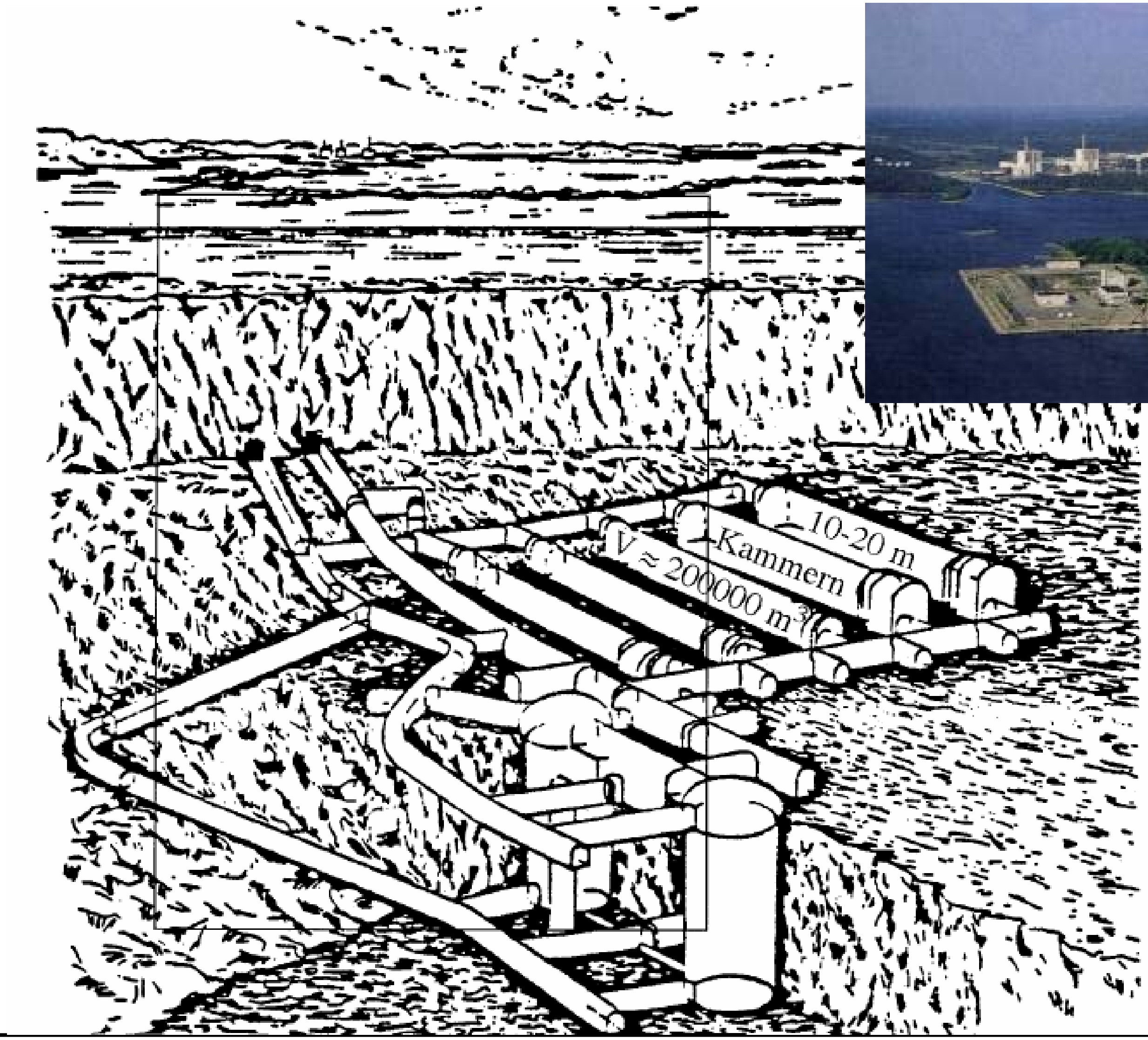
⇒Waste Repository = Complex geologic, geometric and physico-chemical system in space and time

Schematic design of HA-Waste repository / rock salt



GRS (2005)

Schematic design of RN-Waste repository / granite



Final Repository Concepts for guarantee of long-term Safety

General demand:

Long-term safe and maintenance-free isolation of hazardous substances from the biosphere (cc-principle)

Basic concept:

- disposal of hazardous waste in (deep) underground formations
- identification of natural barriers against contaminant release
- design and construction of geotechnical and technical barriers
- development of site-specific multi-barrier system (Redundancy and Diversity)

⇒ Appropriate Geosystems ?

General Concepts:

Geological Barrier(s)

Geotechnical Barrier(s)

(borehole-/ drift-/ shaft-sealing)

Technical Barrier(s)

Concept 1 (Geological Barrier(s) and Geotechnical Barrier(s))

Concept 2 (Geotechnical Barrier(s) and Technical Barrier(s))

Final Repository Concepts for guarantee of long-term Safety

Granit, Claystone / Clay, Rock Salt

Geological Barrier(s) Geotechnical Barrier(s) (borehole-/ drift-/ shaft-sealing)	Concept 1	**Requirement**: *Rock mass* with sufficient low permeability
Technical Barrier(s)	Concept 2	**Requirement** : *Containers* with sufficient functionality in the relevant ambience (M,H,T,C)

? Long-term Behaviour / Long-term Safety ?

⇒ favourable Geosystems ?

⇒ site selection procedure?

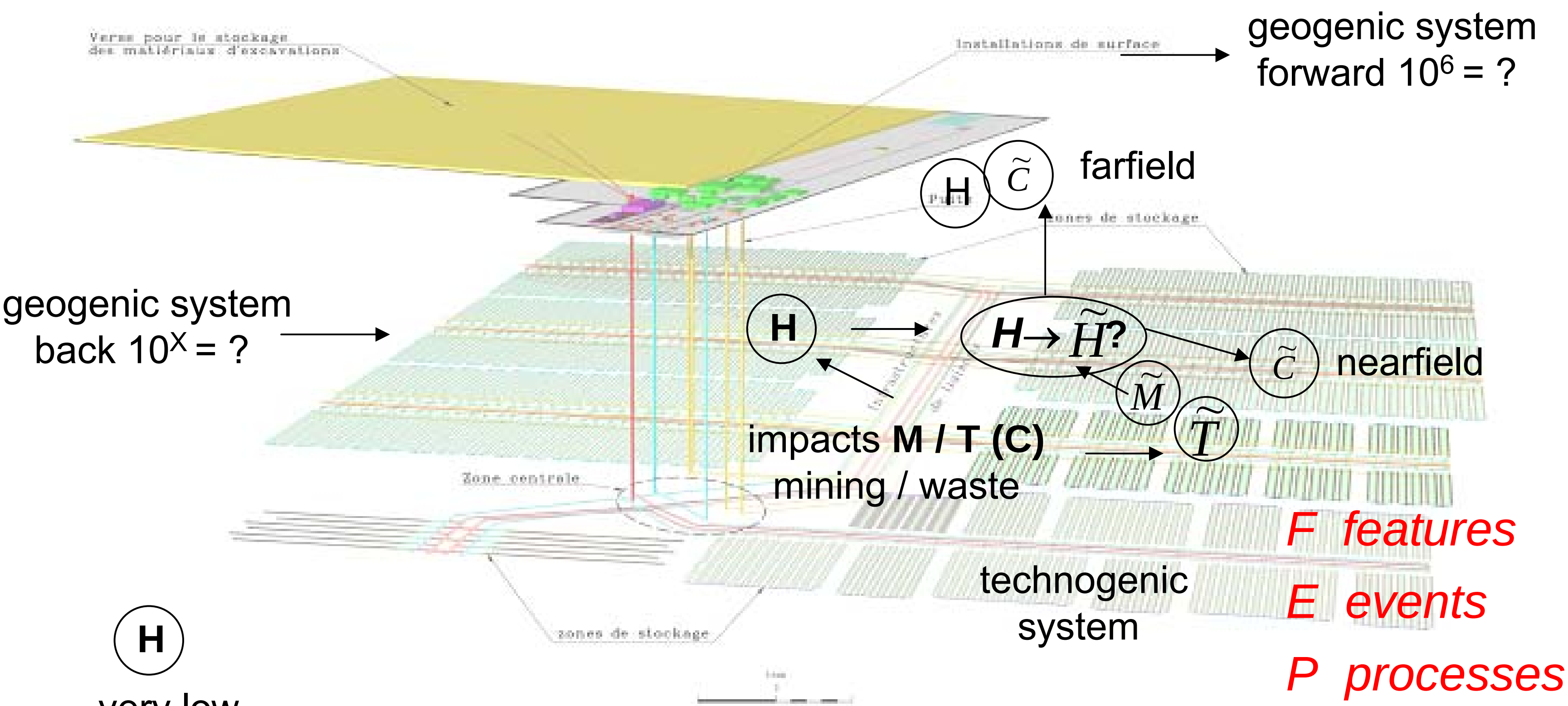
Basic experiences of Geoscience / Geotechnics

- Geosystems are exposed to natural/technical impacts
- Geosystems are changing with time at different rates depending on impacts and related physicochemical processes
- Processes active in geosystems are of different kind and intensity influencing each other:

⇩

thermal, hydraulic, mechanical, chemical as well as biological processes are possible, acting in space and time and depending on the individual geosystem and the technical activity.

Physico-chemical Modelling / Coupled processes
Repository-system and Effects / Processes



very low permeability

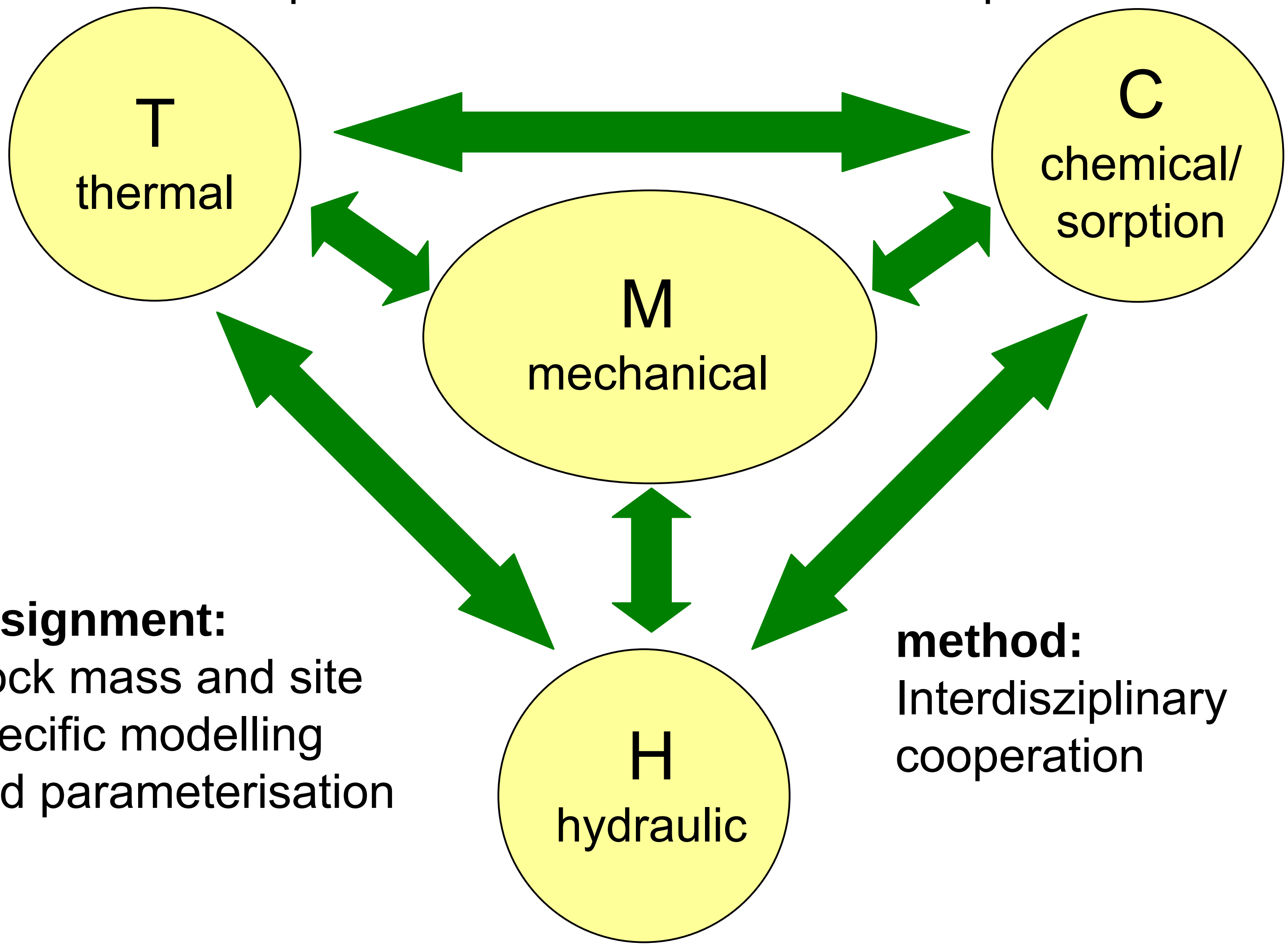
probability of occurrence of FEP's (impacts on geosystem)

high → ordinary development ⇒ complete isolation

low → case scenario ⇒ admissible release

Coupling of processes –
general/present state and further development

from present state ⇒ to further development



assignment:
Rock mass and site specific modelling and parameterisation

method:
Interdisziplinary cooperation

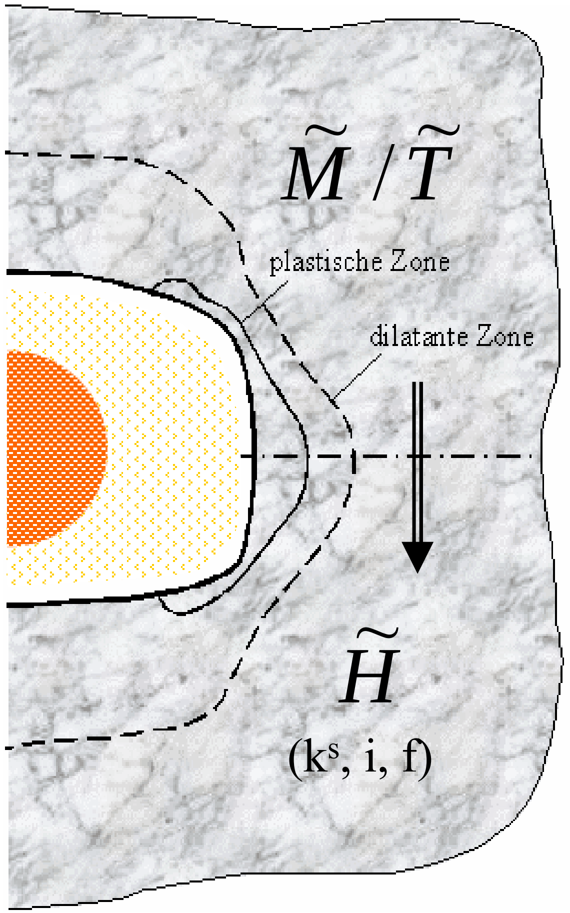
- Some Aspects with respect to change of mechanical / hydraulic properties
  - *Nearfield processes/EDZ*
  - *Damage process – rock salt*
  - *Damage process – claystone*
  - *Recreation of damage/Rehealing – rock salt*
  - *Pressure-forced infiltration of fluids (liquids, gas) in primarily impermeable or nearly impermeable rock formations*
  - *Damage process - granite*

- Some Aspects with respect to change of mechanical / hydraulic properties
  - *Nearfield processes/EDZ - basics*
  - *Damage process – rock salt*
  - *Damage process – claystone*
  - *Recreation of damage/Rehealing – rock salt*
  - *Pressure-forced infiltration of fluids (liquids, gas) in primarily impermeable or nearly impermeable rock formations*
  - *Damage process - granite*

THM-Processes
in the nearfield of a drift with disposed waste (EDZ)

rock salt - clay stone/clay - granite

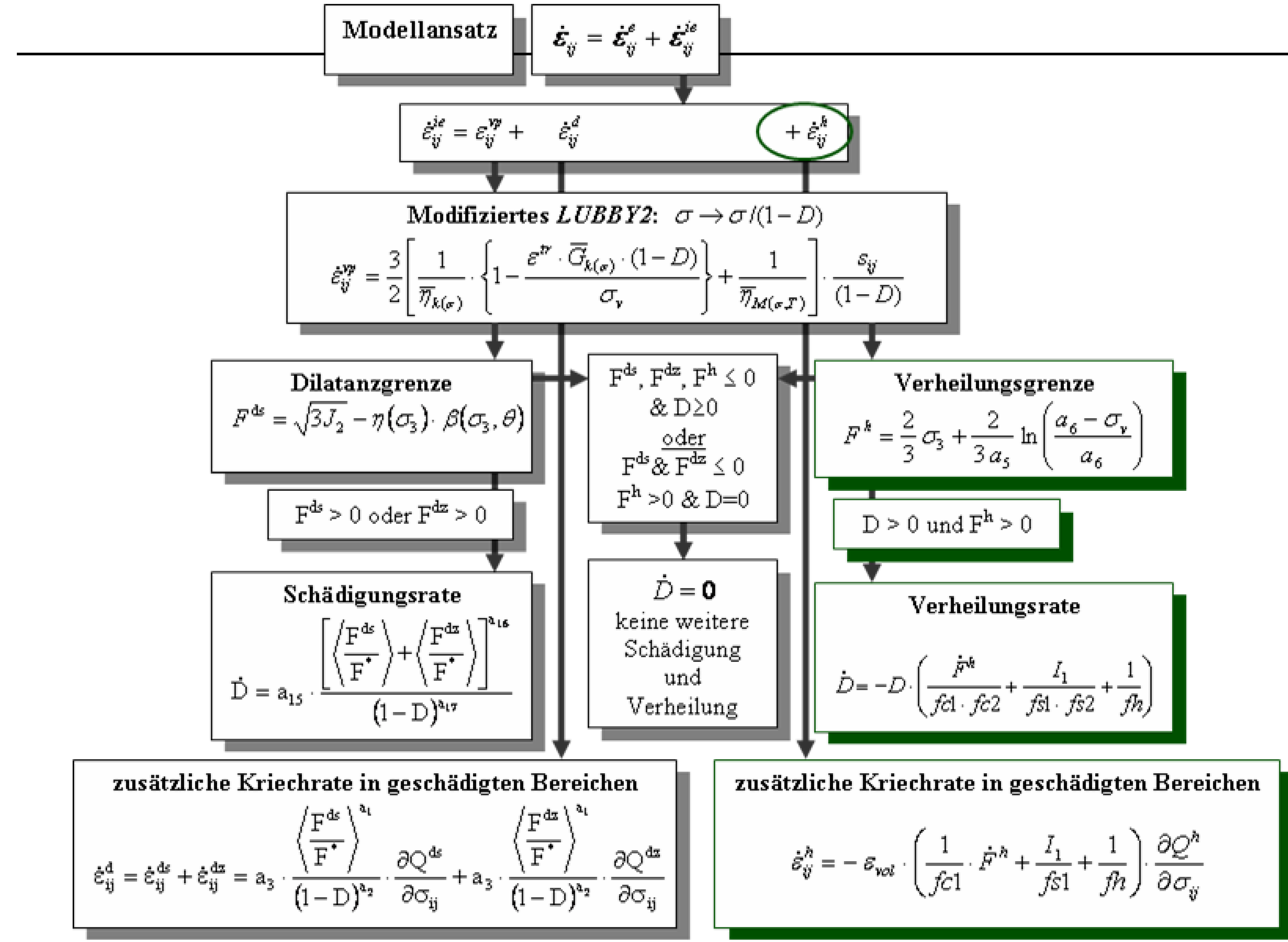
Nearfield processes - Excavation Damage Zone (EDZ)



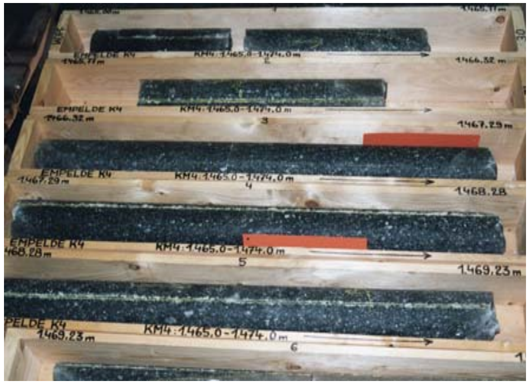
process	$\Rightarrow$	**influenced properties**
mechanical	M	stress rearrangement
		deformation
		rock mass loosening
		rock mass destability
		contour fracture
thermal	T	additional stress
		additional deformation
		strength
		strain
hydraulical	H	fluid viscosity (water, brine, gas)
		fluid pressure
secondary pathways?		porosity
		permeability

$\Rightarrow$ dilatancy limit / rupture limit ?

Constitutive Model including creep, damage and re-healing of damage



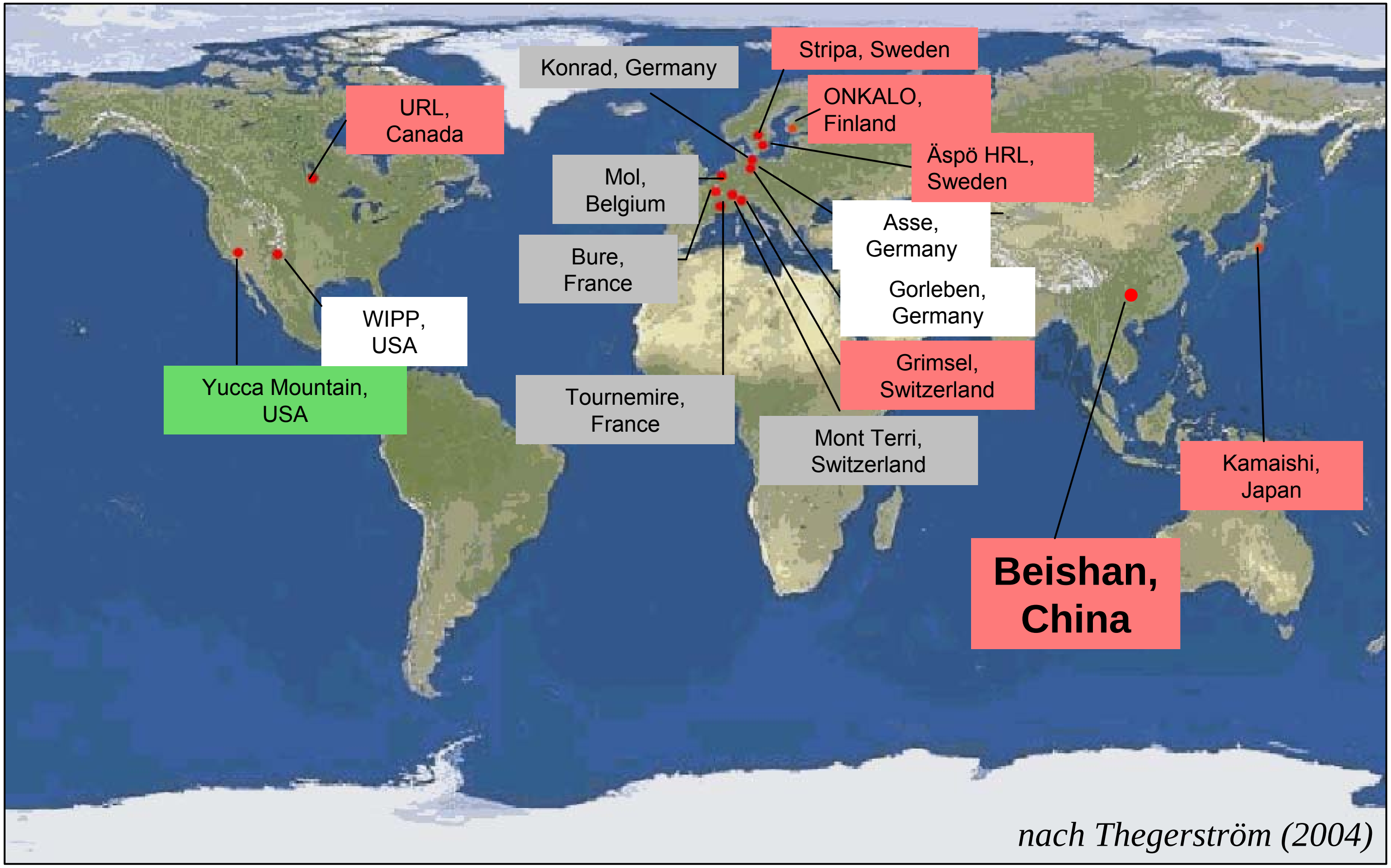
Rock salt samples and laboratory investigation



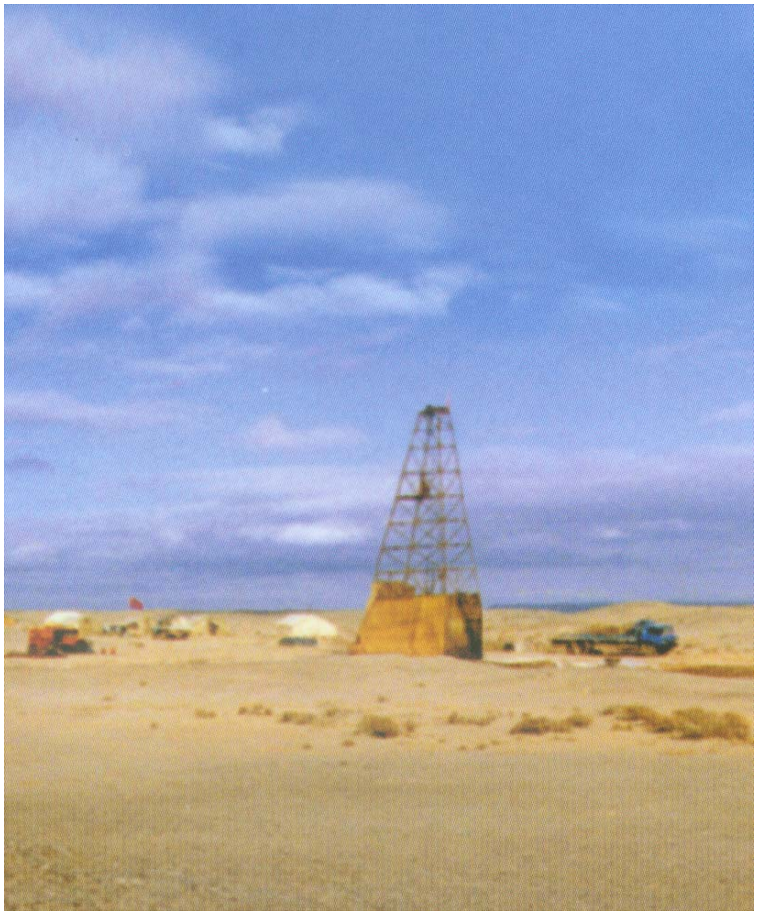
- Some Aspects with respect to change of mechanical / hydraulic properties
  - *Nearfield processes/EDZ - basics*
  - *Damage process – rock salt*
  - *Damage process – claystone*
  - *Recreation of damage/Rehealing – rock salt*
  - *Pressure-forced infiltration of fluids (liquids, gas) in primarily impermeable or nearly impermeable rock formations*
  - *Damage process – granite*
    - Lab Investigations:
      - Some preliminary calculations with respect to static stability/ EDZ evolution - granite

Repository sites and URL– Geographic Positions

HLW-Repository site in China



HLW-Repository in China – Some Impressions of Site



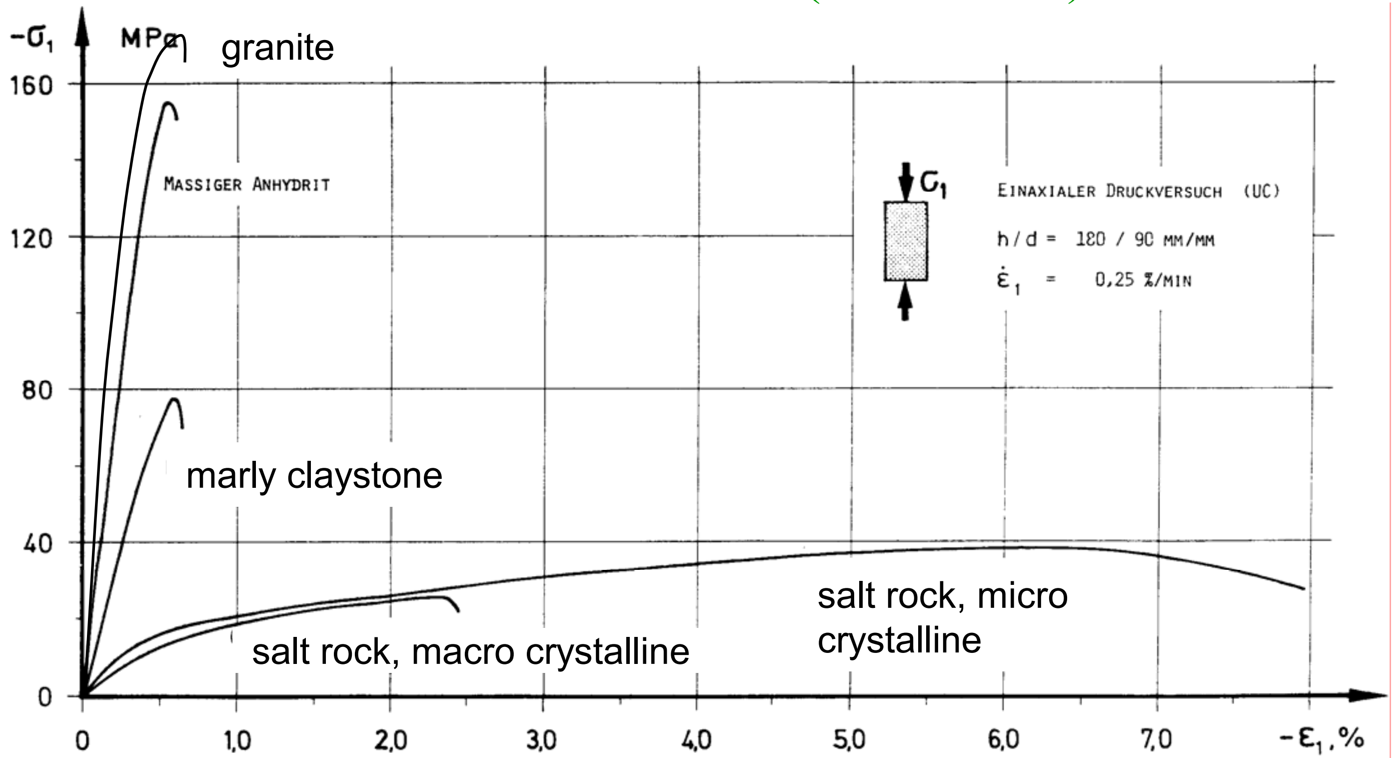
HLW-Repository in China – Investigation 2004

Rock Material / Granite

Test sample before and after failure with single macro-fracture (different scale)

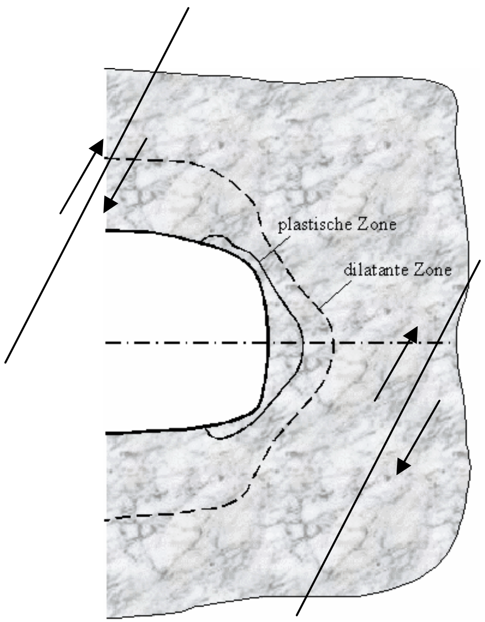
Thermo mechanical – hydraulical Aspects
Exemplary drift – granite / operation mode (1/2)

No viscous deformation rates (rock matrix)



Deformation rates of different rocks of uniaxial compression load at room temperature, *Lux (1984)*

Thermo mechanical – hydraulical Aspects
Exemplary drift – granite / operation mode (2/2)



fissure opening/
-enlargement?

β = f(rock, discontinuities)

β_D = f(rock)

Modelling of geomechanical Processes (M)

$$\dot{\varepsilon} = \dot{\varepsilon}^{el} (+\dot{\varepsilon}^{vp})$$

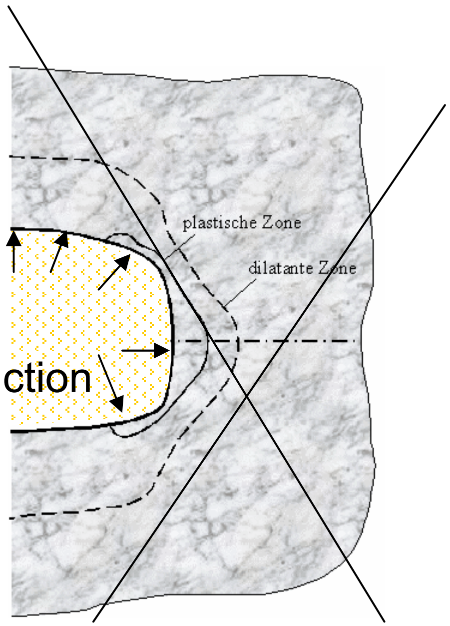
$$\dot{\varepsilon} = f\left(\sigma, T, E, \nu, \beta, \beta_S, \beta_D\right)$$

Modelling of geomechanical / geohydraulic Processes (M→H)

$K^P = K^P_{Matrix} + K^P_{Fis}$ (?)

K^S caused by the type of excavation (blasting, TBM)?
K^S because of excavation?
K^S because of temperature change?
PoroPerm-Model: ...

Thermo mechanical – hydraulical Aspects
Exemplary drift – granit / post operation mode (2/2)



Fissure degeneration caused by P_A?

β = f(rock, discontinuities)

β_D = f(rock)

Modelling of geomechanical Processes (M)

$$\dot{\varepsilon} = \dot{\varepsilon}^{el} \left(+\dot{\varepsilon}^{vp}\right)$$

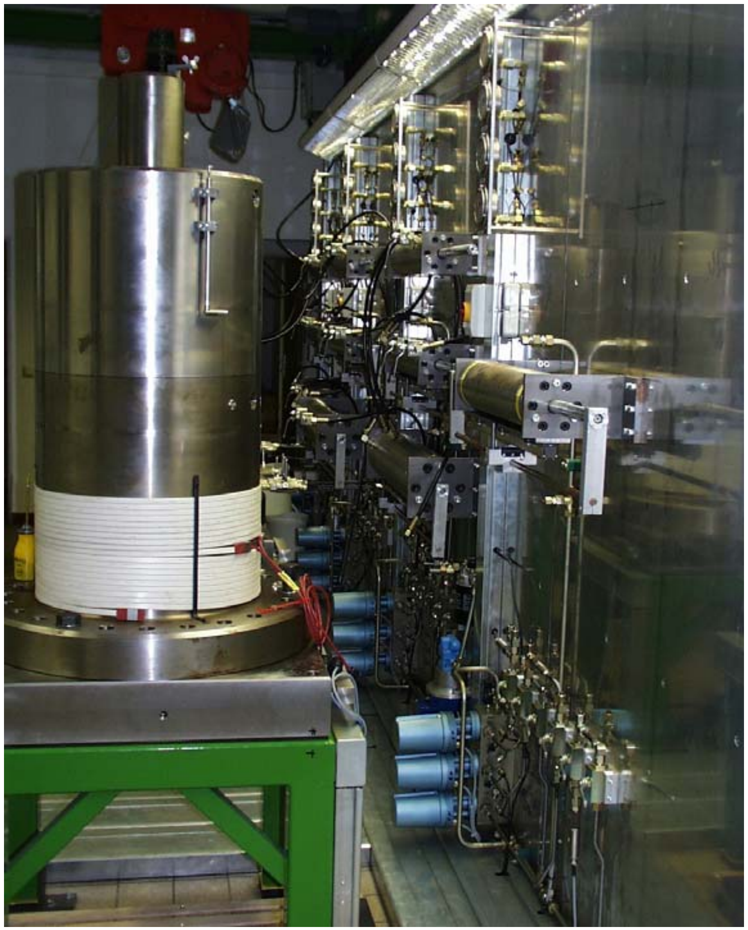
$$\dot{\varepsilon} = f\left(\sigma, T; E, \nu; \beta, \beta_S, \beta_D\right)$$

Modelling of geomechanical / geohydraulic Processes (M→H)

$K^S_{Matrix} << K^S_{Fis}$ bzw. K^P_{Fis}

$\Rightarrow$ fissure permeability dependent (in situ-tests)

Thermo mechanical – hydraulical Aspects
Exemplary drift – granit / post operation mode (1/2)

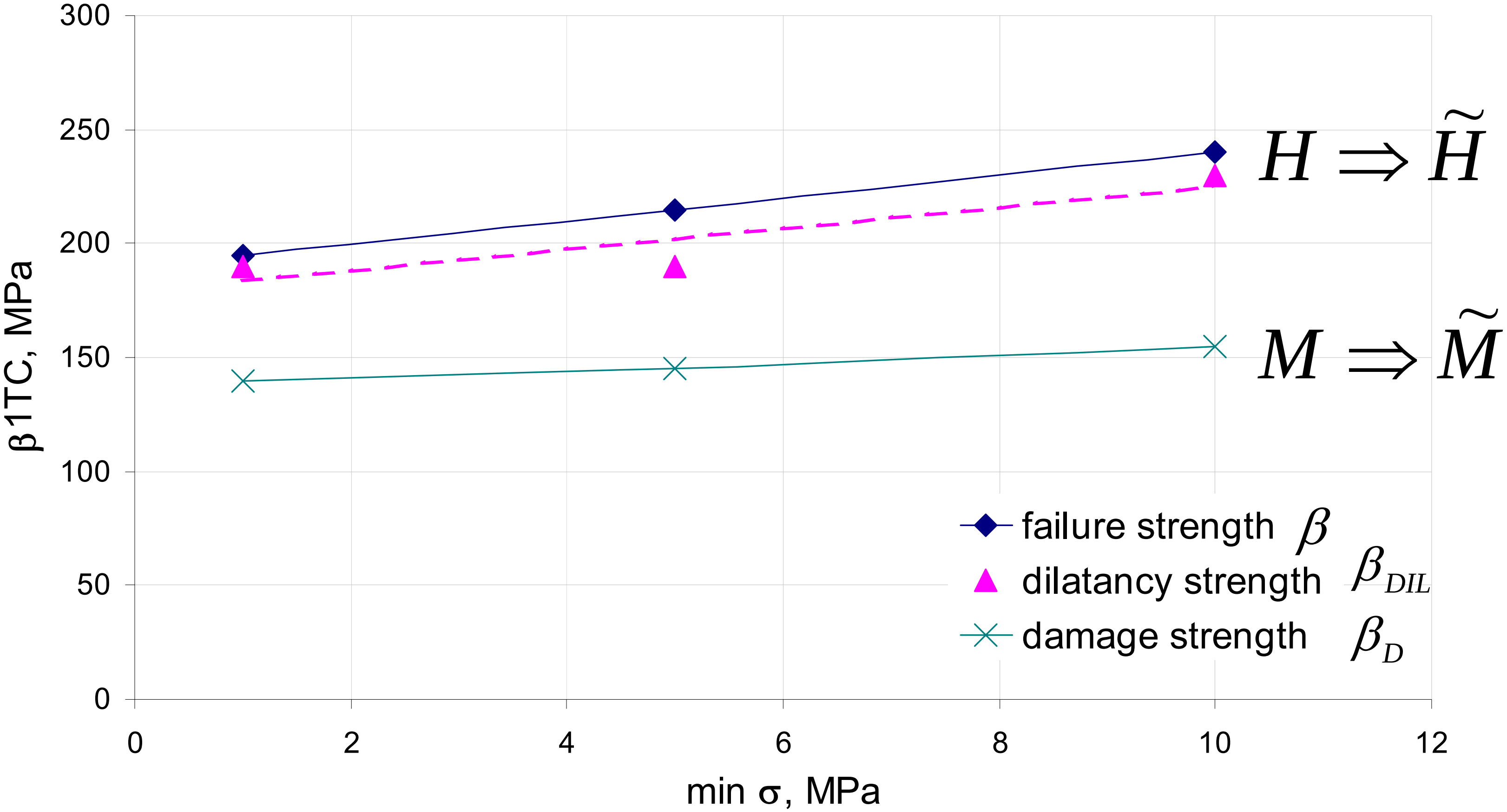


Current assessment:

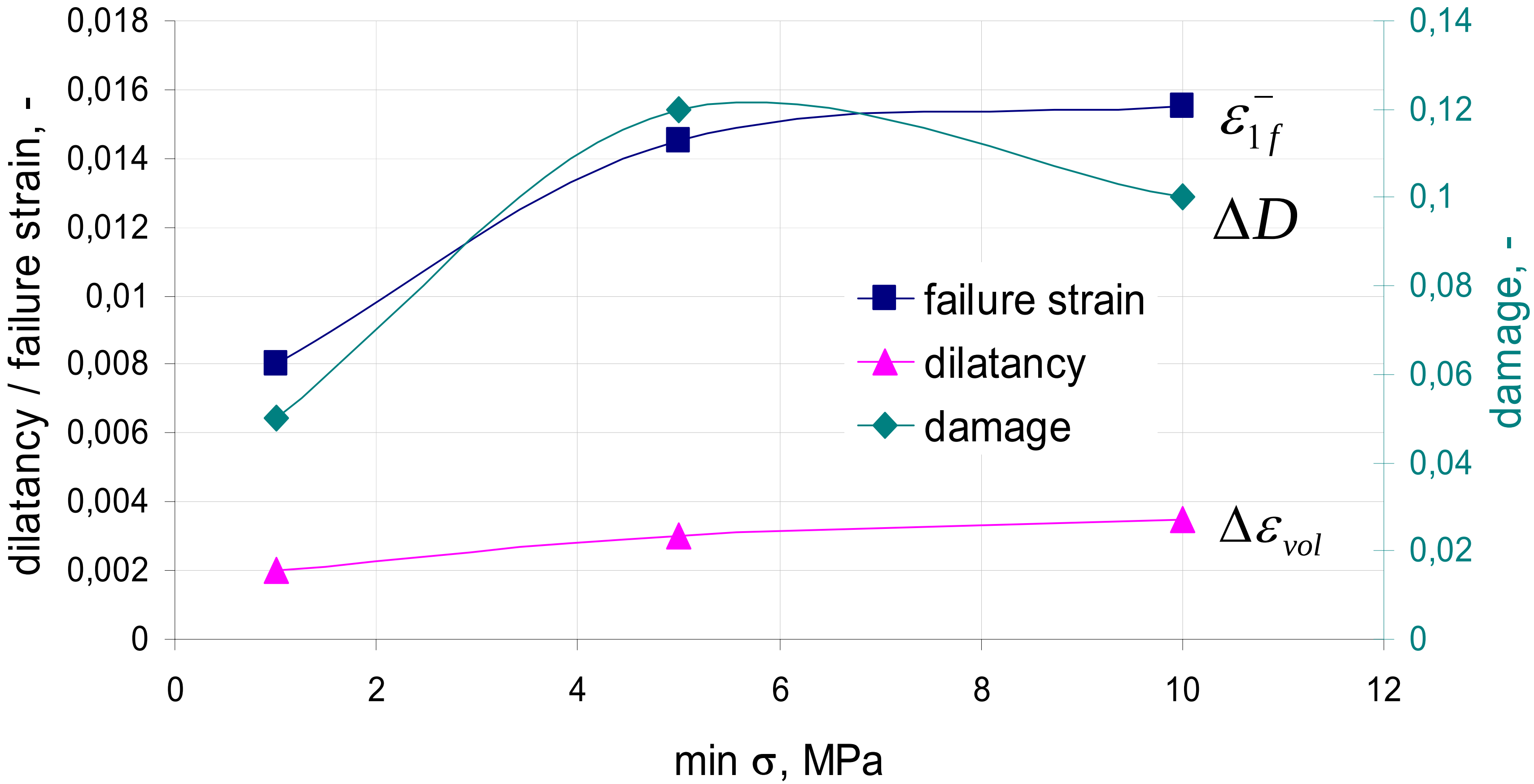
Only marginal fissure regeneration

- elastic recompaction
- no fissure healing without secondary mineralisation caused by precipitation

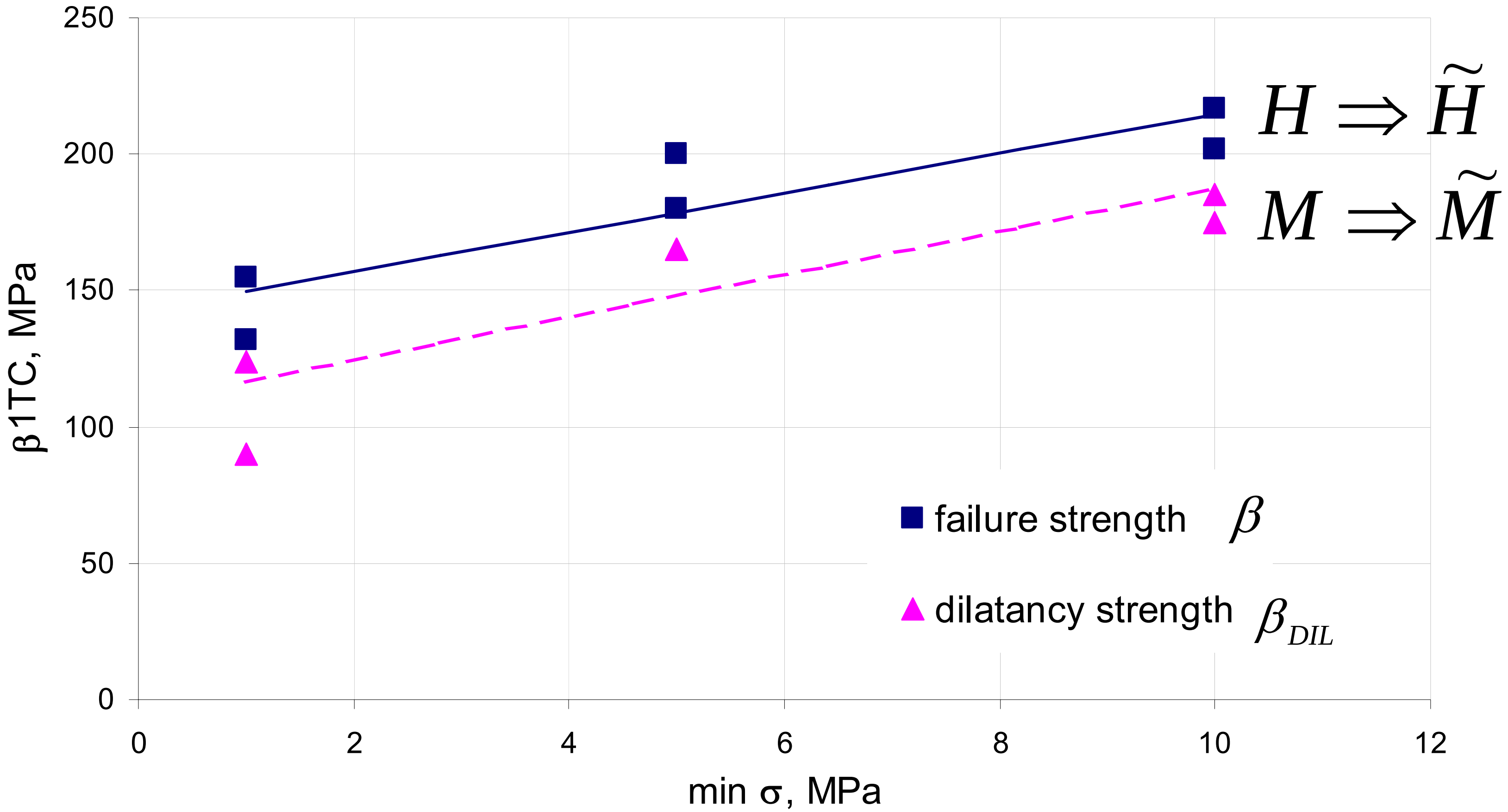
Mechanical data for granite type 1 with respect to minimal stress: failure strength, dilatancy strength, damage strength



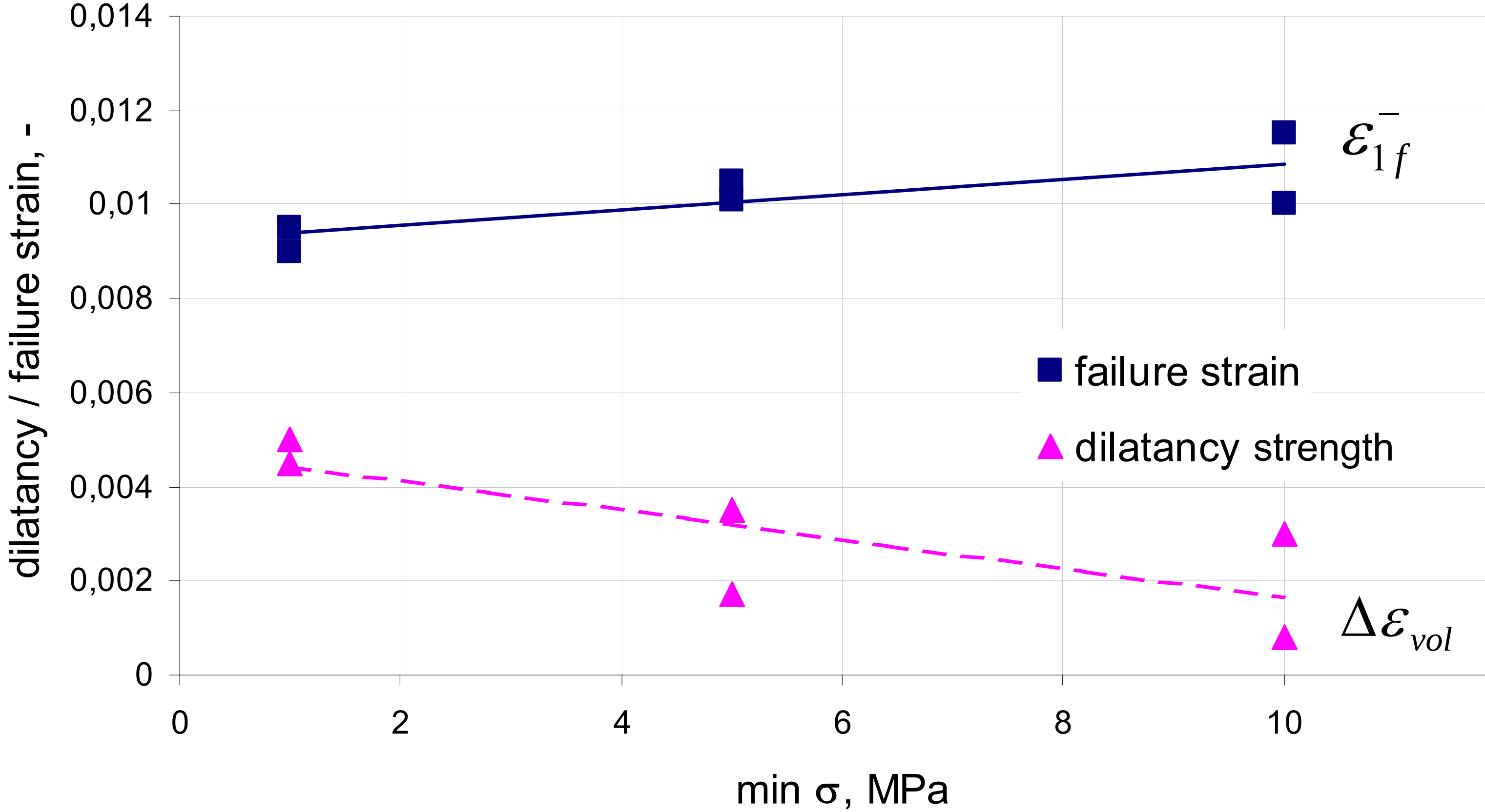
Mechanical data for granite type 1 with respect to minimal stress: failure strain, dilatancy, damage



Mechanical data for granite type 2 with respect to minimal stress: failure strength, dilatancy strength, damage strength



Mechanical data for granite type 2 with respect to minimal stress: failure strain, dilatancy, damage

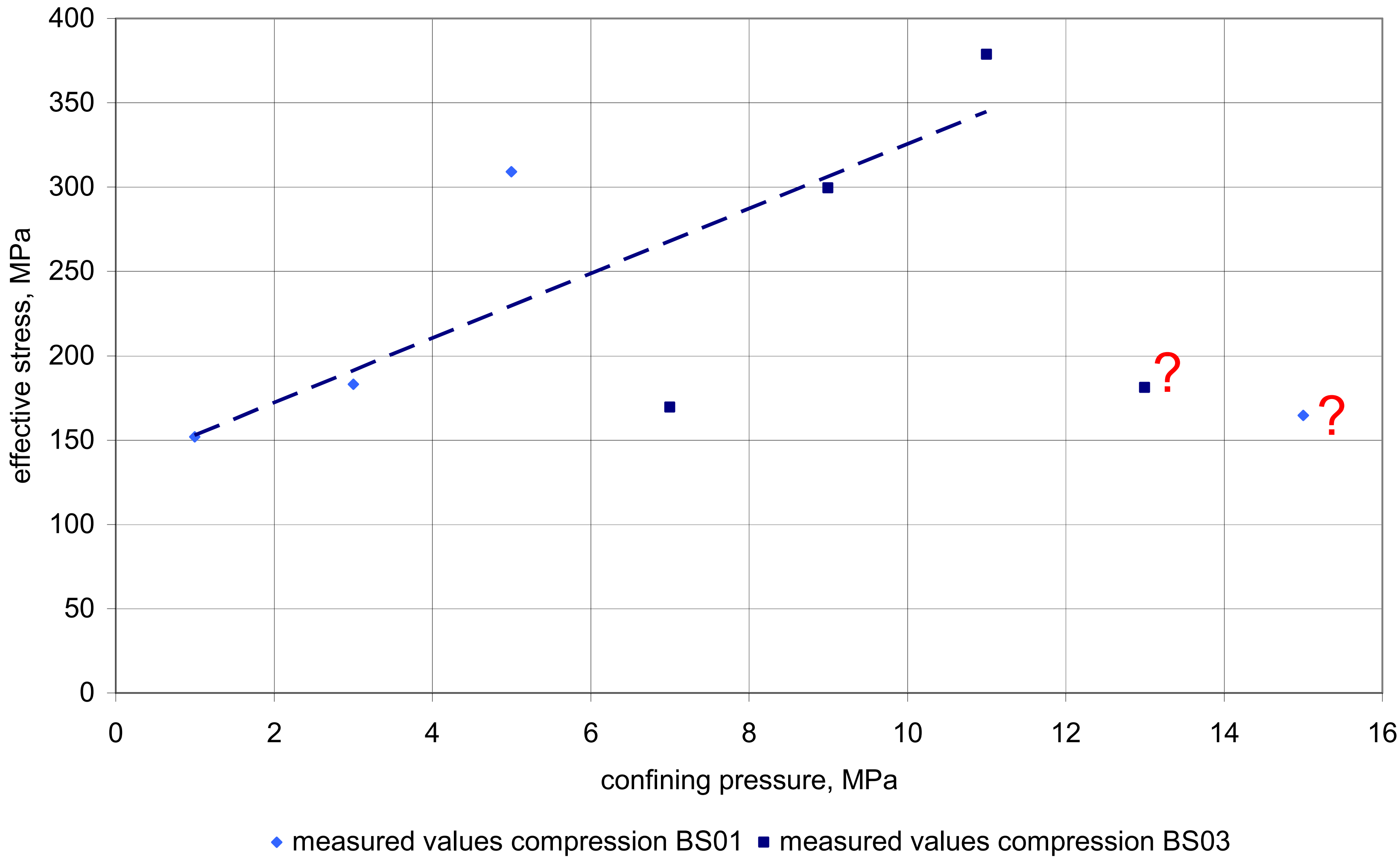


Investigation 2007…

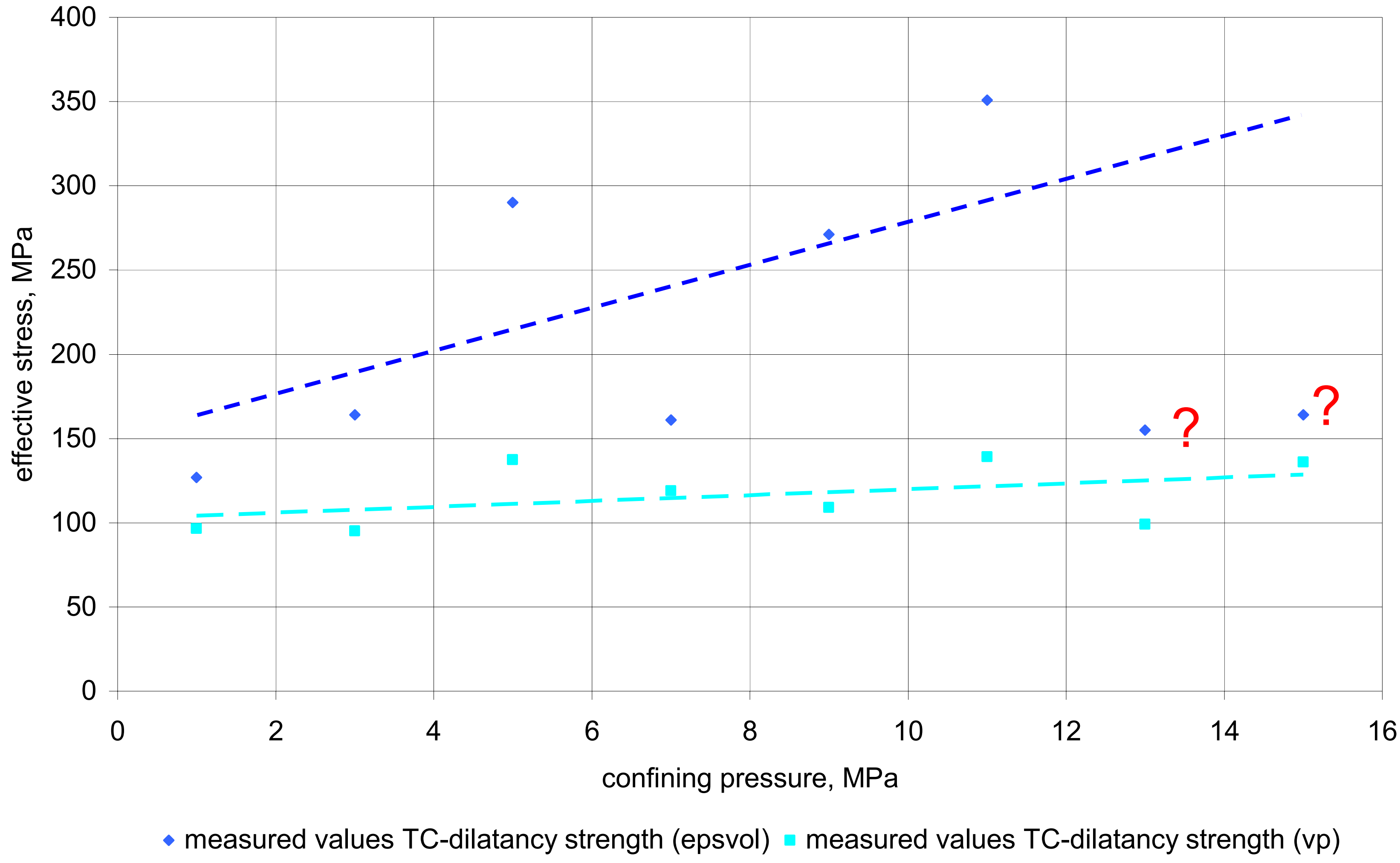
Granite samples from Beishan locations BS01 and BS03

…within the context of an agreement between CNNC and TUC on research in the field of radioactive waste disposal in granite formations

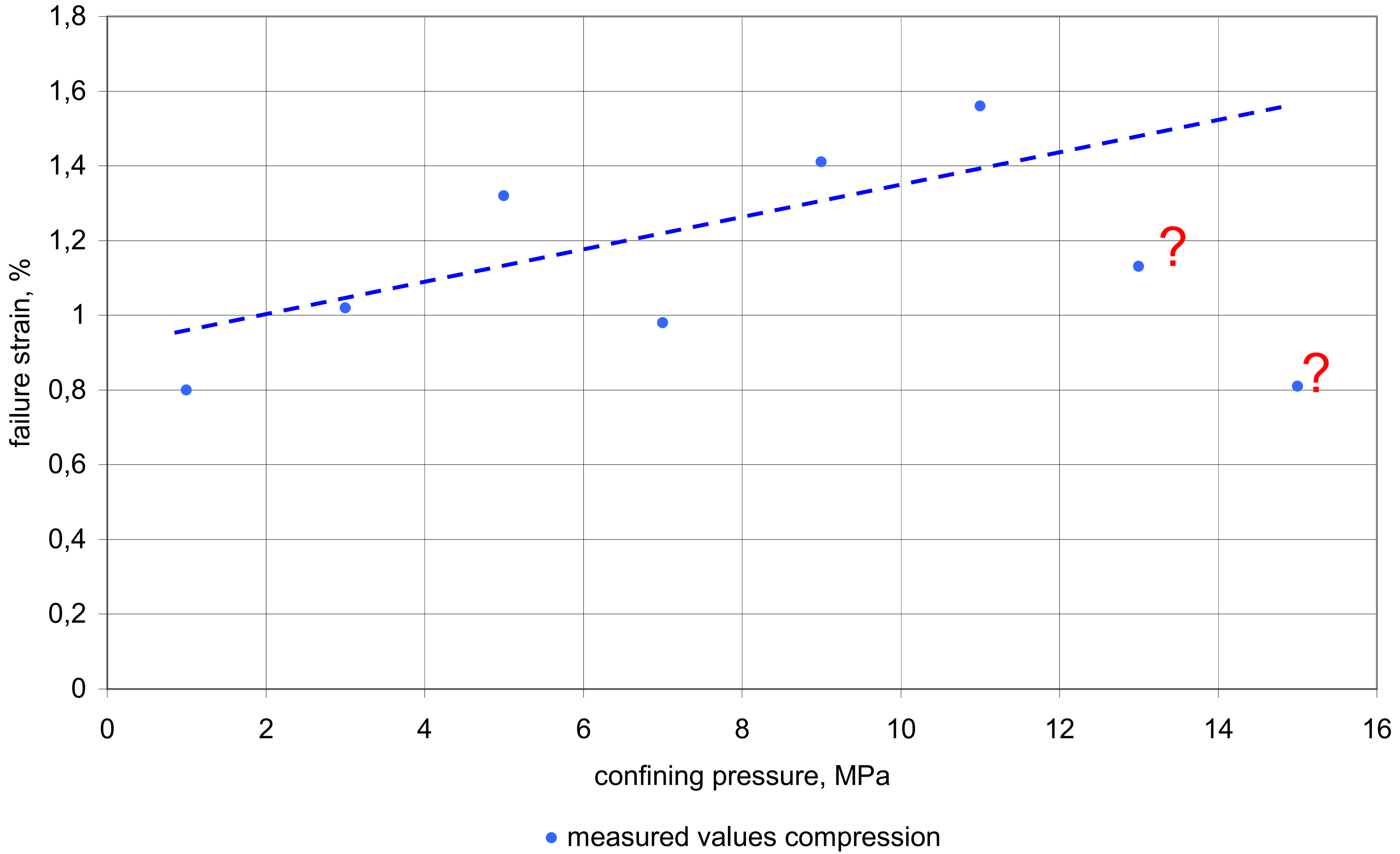
Failure strength of granite from Beishan locations BS01 and BS03



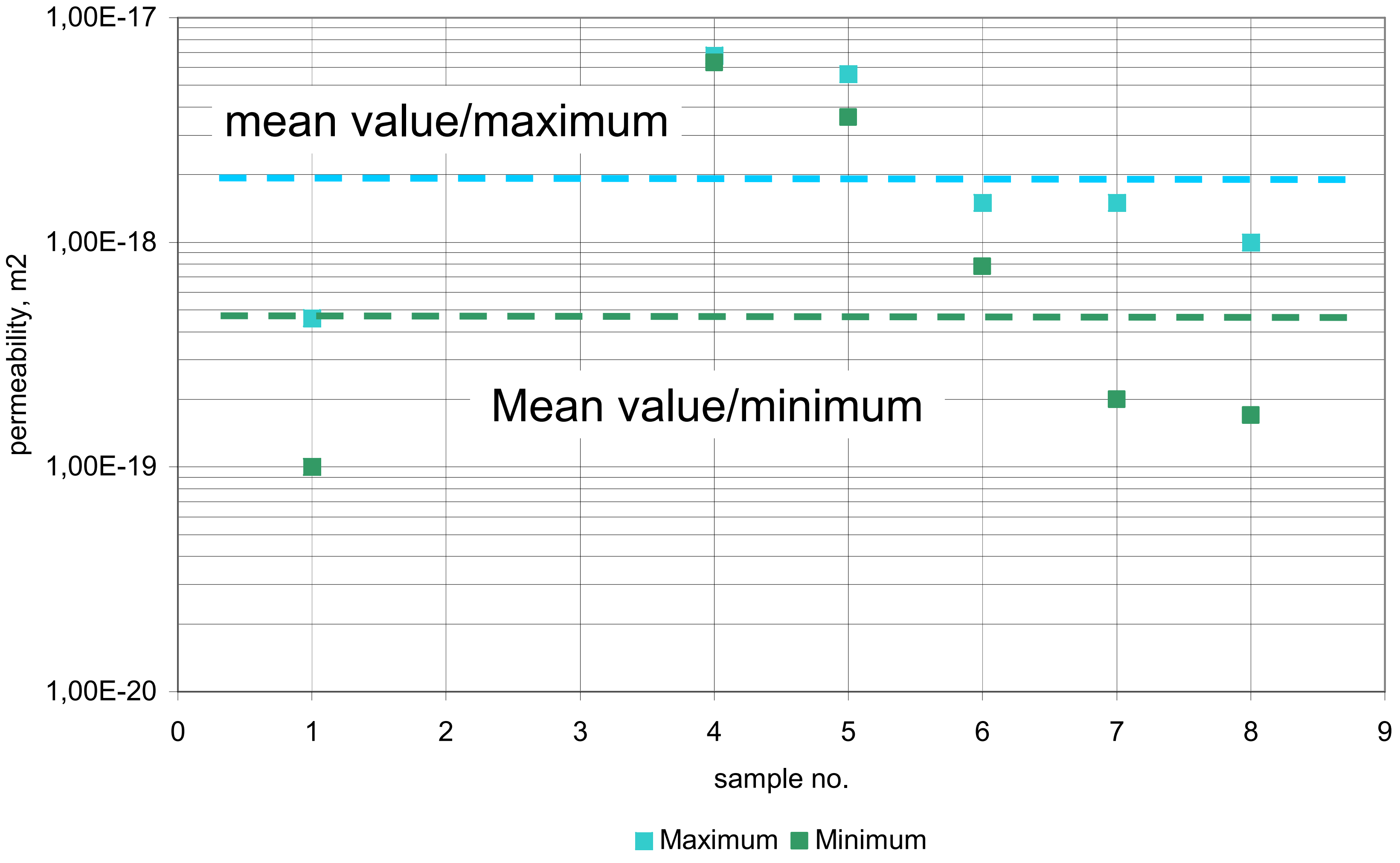
Dilation strength of granite from Beishan locations BS01 and BS03



Failure strain (TC) of granite from Beishan location BS01 and BS03



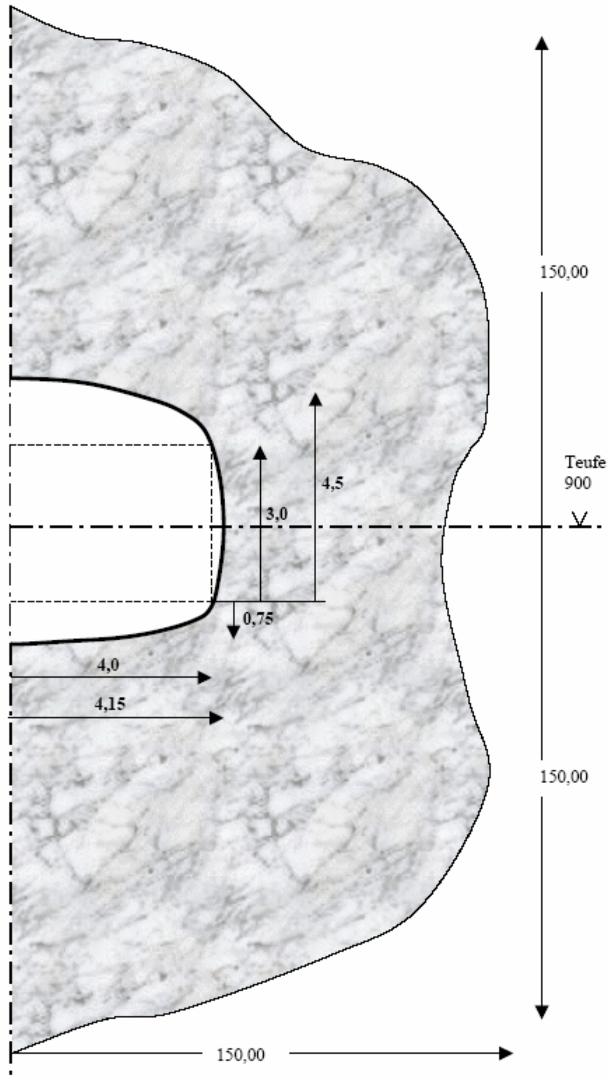
Permeability of granite from Beishan locations BS01 and BS03



Contents

- Demonstration of Safety / General Aspects
- Waste Quantities and Properties
- Site Selection
- Physico-chemical Modelling / Coupled Processes
- Thermo-mechanical – Hydraulic Aspects
- Some Aspects with Respect to change of mechanical / hydraulic properties
  - Nearfield processes/EDZ
  - Damage process – rock salt
  - Damage process – claystone
  - Recreation of damage/Rehealing – rock salt
  - Damage process – granite
    lab investigations
  - Some preliminary calculations with respect to static stability / EDZ evolution - granite
- The Best Repository ?
- Conclusions

Drift in granitic rock mass - example



Basic assumptions:

- Homogeneous isotropic rock mass
- linear - elastic ideal plastic material behavior
- Material properties

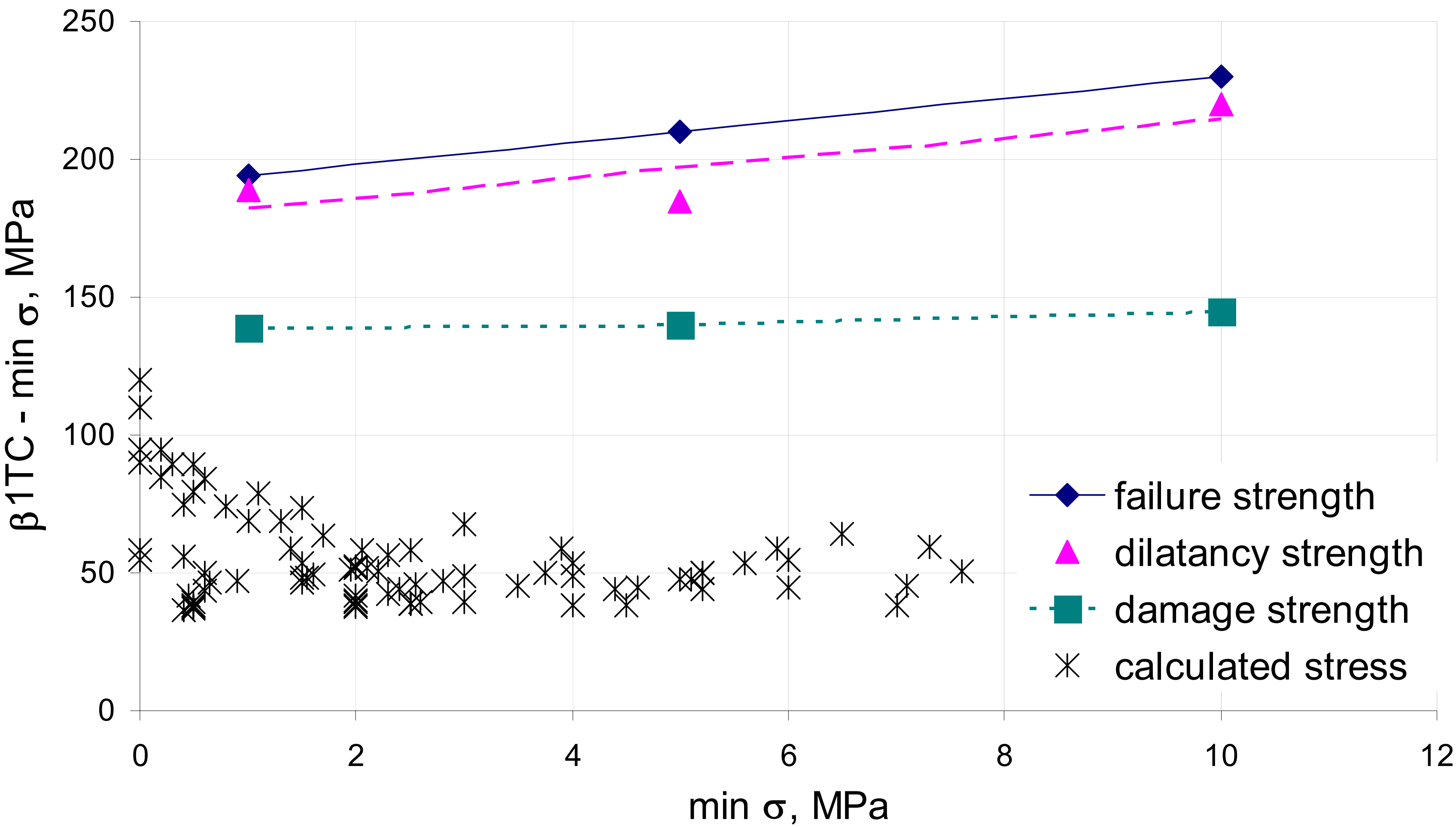
Granite type 1: E = 40.000 MPa

φ = 48,8° c = 31,3 MPa

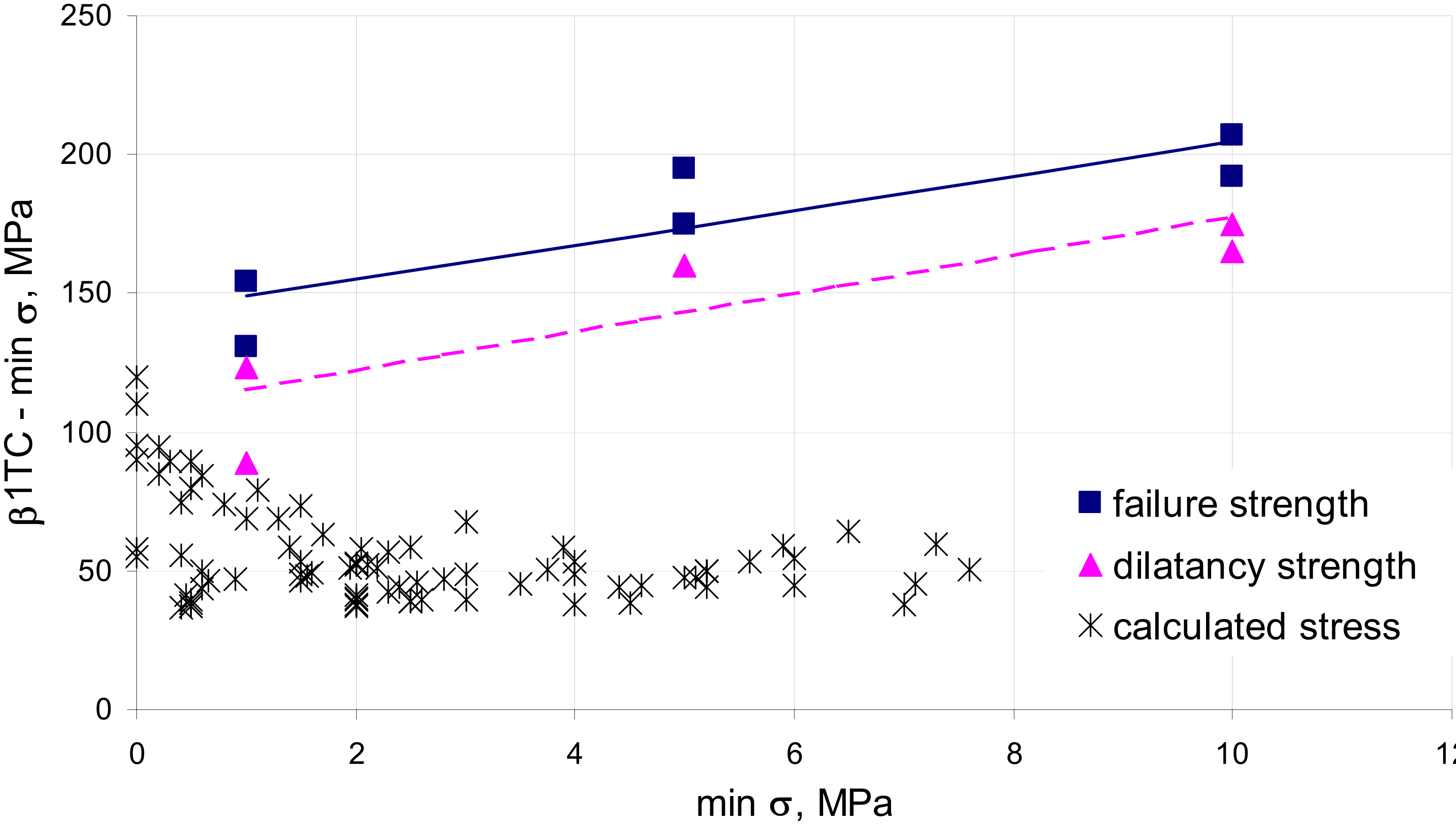
Granite type 2: E = 30.000 MPa

φ = 45,6° c = 15,1 MPa

Comparison of rock mass strength (= rock strength granite type 1) and rock stress caused by mining and waste disposal (z = 900m)



Comparison of rock mass strength (=rock strength granite type 2) and rock stress caused by mining and waste disposal (z=900m)



Conclusions

Germany's situation today / Waste disposal sites

Licensed now / in operation in some years

LAW/MAW – repository Konrad (lime stone/claystone)

pastly explorated/exploration stopped

HAW-repository Gorleben (rock salt)

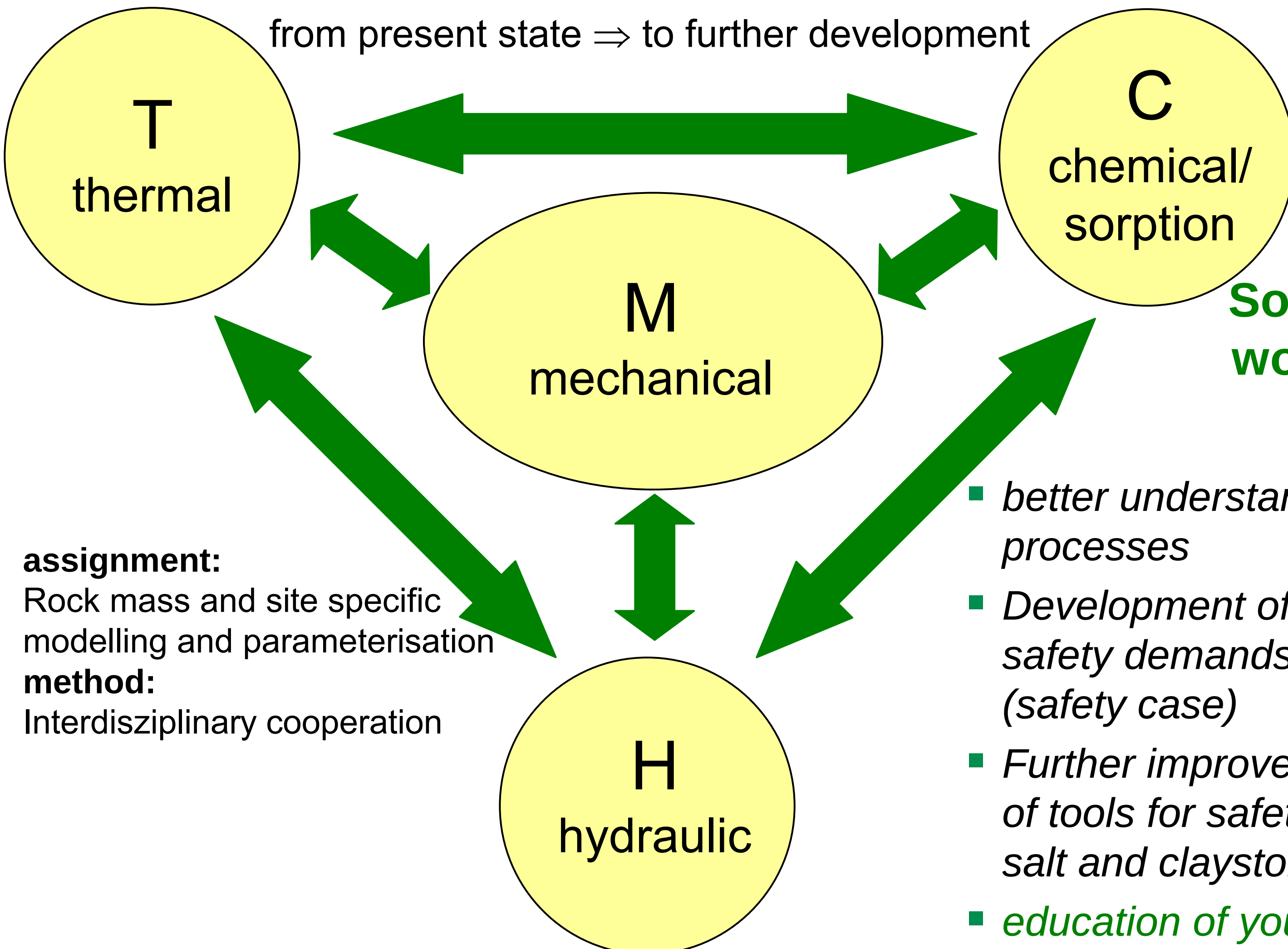
New site selection procedure

?

Rock salt

claystone

Scientific work – selected aspects



assignment:
Rock mass and site specific modelling and parameterisation
method:
Interdisziplinary cooperation

Some tasks of work in future

- *better understanding of coupled processes*
- *Development of legal regulations for safety demands and proof of safety (safety case)*
- *Further improvement and validation of tools for safety analysis in rock salt and claystone*
- *education of young engineers/ scientists and transfer of knowledge*

Curriculum

Radioactive and Hazardous Waste Management

120 ECTS

Master of Science in Radioactive and Hazardous Waste Management

Competence in Engineering and Geoscience

→

for all Processes and Phases of Radioactive and Hazardous Waste Management

Waste and Conditioning → Site investigation of Unterground Repositories → Geotechnical and Geoscientific Analysis → Long-Time Safety Assessment and Permission → Construction, Operation and Closure

General construction of the curriculum

- **11 compulsory modules — 96 ECTS**
  - **10 Lectures / courses / seminars — 66 ECTS**
  - **Master thesis — 30 ECTS**

- **7 compulsory optional modules — 36 ECTS**
  - **3 or 4 out of 7 lectures / courses with 6 ECTS each**

- **4 complementary modules — 18 ECTS**

Compulsory modules (1)

■	**Module 1: Site Characterization**	**9 ECTS**
	- Methods of site characterization	6,0 ECTS
	- Fluid flow in porous media II	3,0 ECTS
■	**Module 2: Geomechanics**	**6 ECTS**
	- Static of tunnels and mechanics of salt	3,0 ECTS
	- Geological and geotechnical barriers - Safety assessment	3,0 ECTS
■	**Module 3: Numerical Simulation**	**6 ECTS**
	- Geological and geotechnical barriers - numerical modelling	3,0 ECTS
	- THMC – processes and numerical simulation	3,0 ECTS
■	**Module 4: Waste Inventory**	**6 ECTS**
	- Radioactive Waste and legal regulations	2,0 ECTS
	- Origin, quantity and conditioning of radioactive waste	2,0 ECTS
	- Radiation physics and radiation protection	2,0 ECTS
■	**Module 5: Permission and Legal Regulations**	**5 ECTS**
	- Permission process	2,0 ECTS
	- Energy politics	1,0 ECTS
	- Special waste and waste industry	2,0 ECTS
■	**Module 6: Petrology and Geochemistry**	**6 ECTS**
	- Petrology and geochemistry of repository relevant host rocks	3,0 ECTS
	- Petrophysics	3,0 ECTS

Compulsory modules (2)

Module 7: Repository Concepts	**7 ECTS**
- Repository concepts	2,0 ECTS
- Planing of final repositories	2,0 ECTS
- International strategies in long term safety assessment	3,0 ECTS
Module 8: Long-Term Safety	**8 ECTS**
- Principles of long term safety assessment and monitoring	5,0 ECTS
- Numerical simulation in long term safety assessment	3,0 ECTS
Module 9: Repository Technics	**5 ECTS**
- Underground disposal	3,0 ECTS
- Transport and intermediate storage	3,0 ECTS
Module 11: Main Seminar and Field Trips	**8 ECTS**
- Main seminar	6,0 ECTS
- Field trips	2,0 ECTS
Module 12: Master Thesis	**30 ECTS**

Compulsory optional modules

Module 1: Handling of Hazardous Waste	**6 ECTS**
- Processing of hazardous waste	3,0 ECTS
- Combustion technics	3,0 ECTS
Module 2: Course Geochemistry	**6 ECTS**
- Course geochemistry I	3,0 ECTS
- Course geochemistry II	3,0 ECTS
Module 3: Course Petrology	**6 ECTS**
- Course petrology I	3,0 ECTS
- Course petrology II	3,0 ECTS
Module 4: Isotope Geochemistry	**6 ECTS**
- Introduction to isotope geochemistry	3,0 ECTS
- Applied isotope geochemistry	3,0 ECTS
Module 5: Applied Hydrogeochemical Flux Modelling	**6 ECTS**
Module 6: Environmental Monitoring	**6 ECTS**
- Environmental monitoring	2,5 ECTS
- Mine surveying in underground repositories	1,0 ECTS
- Cartography and map of mine	2,5 ECTS
Module 7: Risk Management and Communication	**6 ECTS**
- Risk management	3,0 ECTS
- Project management and project planning	3,0 ECTS

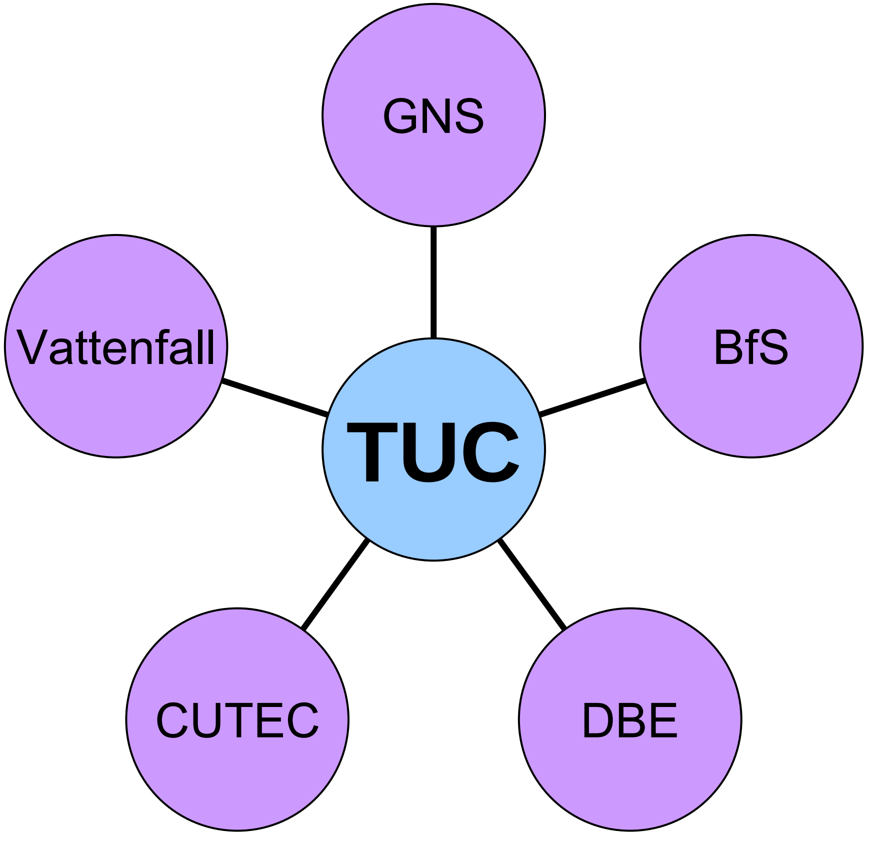
Complementary modules

Module 1: Characterization and Groundwater flux	**6 ECTS**
- Fluid flow in porous media	3,0 ECTS
- Cycles of matter in the environment	3,0 ECTS
Module 2: Course Hydrogeology	**6 ECTS**
- Flux calculation of water and matter in the hydrogeosphere - hydrogeochemistry	3,0 ECTS
- Flux calculation of water and matter in the hydrogeosphere – geohydraulic systems	3,0 ECTS
Module 3: Principles of Hydrogeology and Geochemistry	**6 ECTS**
- Hydrogeology	3,0 ECTS
- Geochemistry I	3,0 ECTS
Module 4: Investigation of Geological Structures	**6 ECTS**
- Geophysical investigation	3,0 ECTS
- Geological and tectonical principles of site investigation	3,0 ECTS

25 % of lectures and seminars are given by experts of industrial companies (energy suppliers as well as research bureaus) and legal authorities.

The main part of teaching in accomplished by the TUC departments

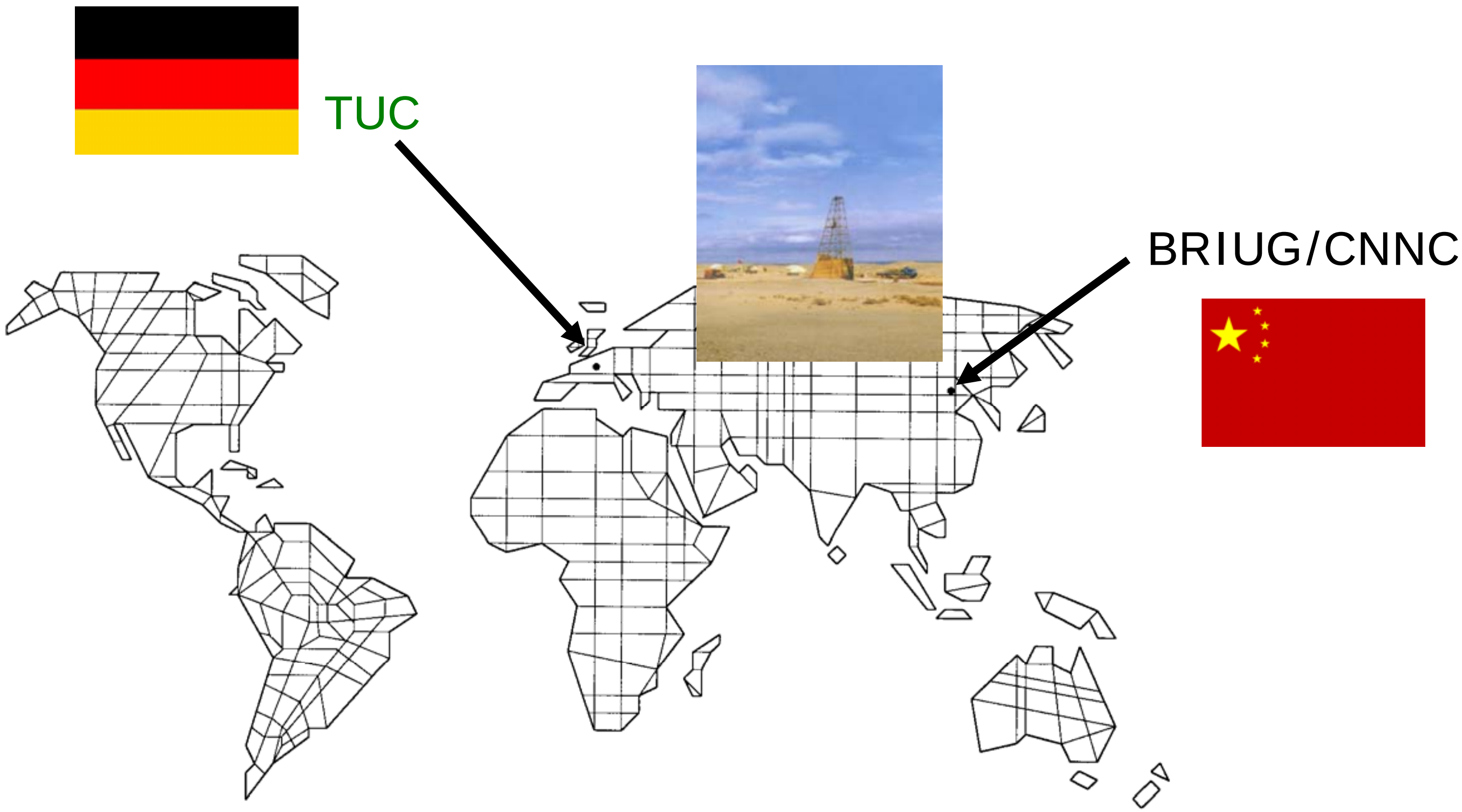
- **Petrology and Geochemistry**
- **Geomechanics**
- **Hydrogeochemistry**
- **Mining Engineering**
- **Geophysics**



Internal (TUC) and external (waste industry and authorities) lecturers

		1. Semester	2. Semester	3. Semester	4. Semester
COMPULSORY MODULES	1	Methods of site charakterization	Origin, quantity and conditioning of radioactive waste	THMC-processes and numerical simulation	Master thesis
	2				
	3		Fluid flow in porous media II	Numerical simulation in long term safety assessement	
	4				
	5	Underground disposal	Geological and geotechnical barriers - numerical modelling	Planing of final repositories	
	6				
	7	Petrophysics I	Radioactive waste and legal regulations	International strategies in long-term safety assessment	
	8				
	9	Static of tunnels and mechanics of salt	Repository concepts	Energy politics	
	10			Radiation physics and radiation protection	
	11	Geological and geotechnical barriers - safety assessment	Priciples of long-term safety assessment and monitoring		
	12			Permission process	
	13				
	14			Main seminar and field trips	
	15		Special waste and waste industry		
	16				
	17		Petrology and geochemistry of repository relevant host rocks		
	18				
	19		Transport and intermediate storage		
	20				

Thanks for attention as well as …



... Good luck for further fruitful and interesting cooperation

Site selection and characterization for China’s HLW repository in Beishan,Gansu

Rock mass mechanical properties and Seepage Characteristics

Yang Chunhe

Institute of Rock and Soil Mechanics,
Chinese Academy of Sciences

2007.5

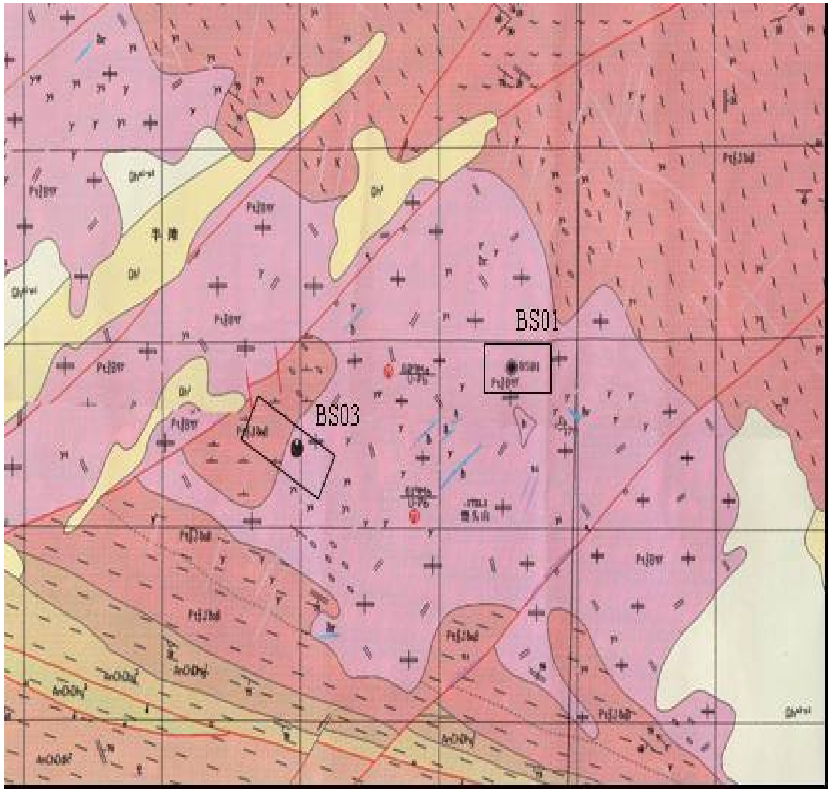
Outline

- Introduction
- Field survey and tests
- Joint characteristics
- Mechanical properties
- Geostress and seepage characteristics
- Conclusions

Introduction

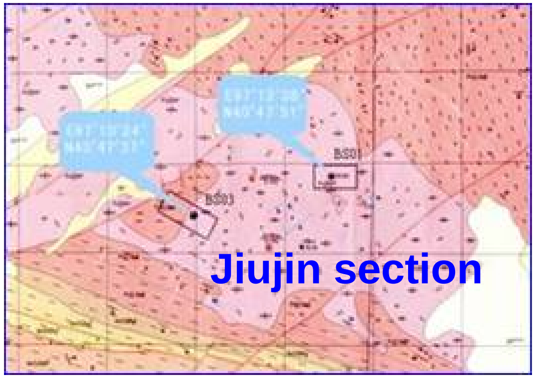
- **Jiujin section, Jijicao quarry and Xinchang are candidates in Beishan-the preselected area for China′s HLW repository**

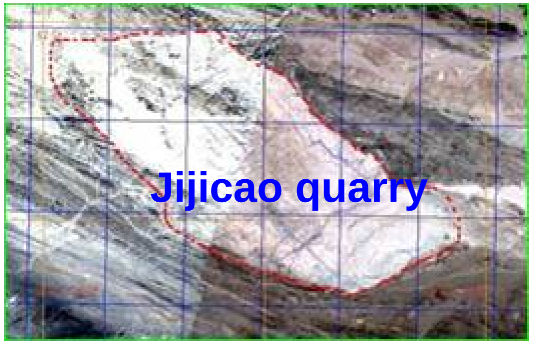
- **During 2001-2006, series of investigation were done by Wuhan Institute of Rock and Soil mechanics, CAS**

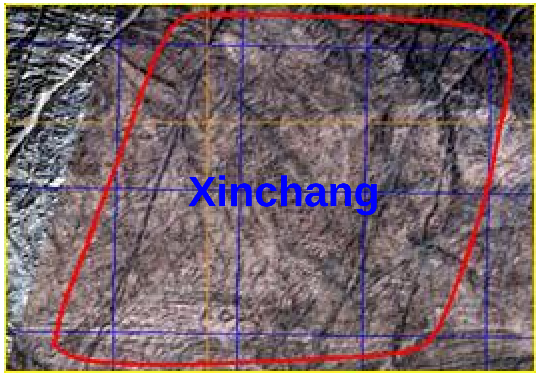


中国科学院武汉岩土力学研究所
INSTITUTE OF ROCK AND SOIL MECHANICS
CHINESE ACADEMY OF SCIENCES

Rock mass mechanical properties and Seepage Characteristics

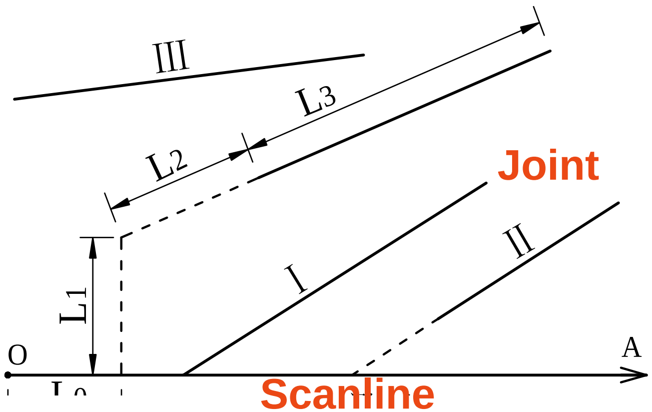






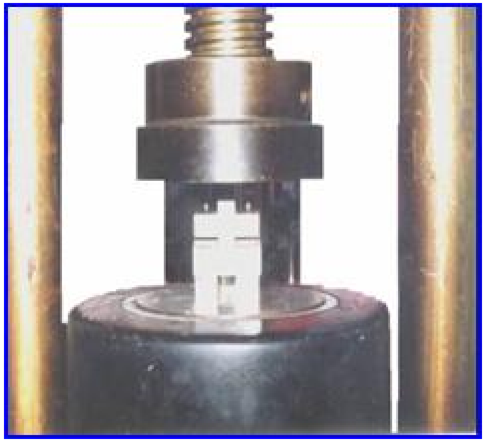
- Introduction
- **Field survey and tests**
- Joint characteristics
- Mechanical properties
- Geostress seepage characteristics
- Conclusions

Field Joint Survey

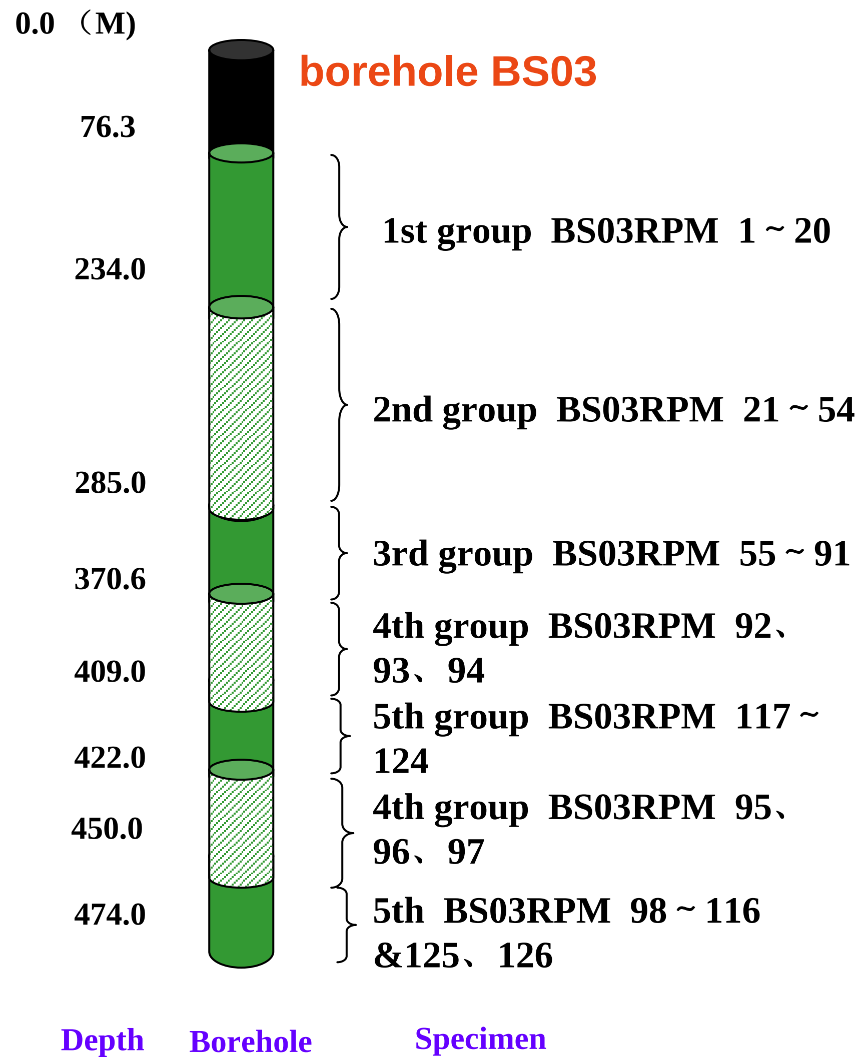


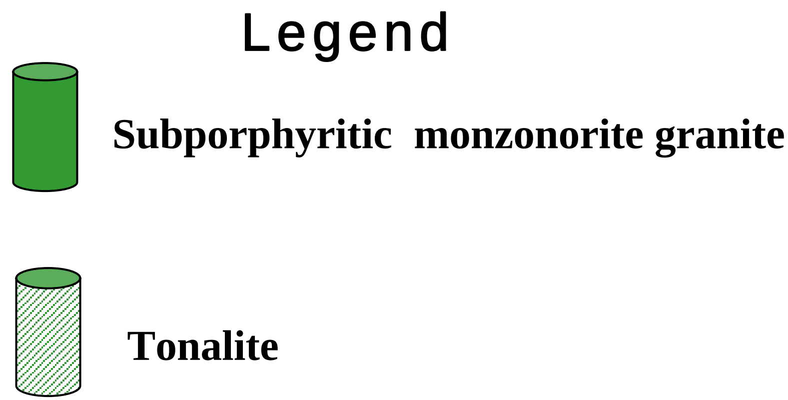
Schematic Joint survey method

Rock Sampling and Laboratory Tests



Rock mass mechanical properties and Seepage Characteristics

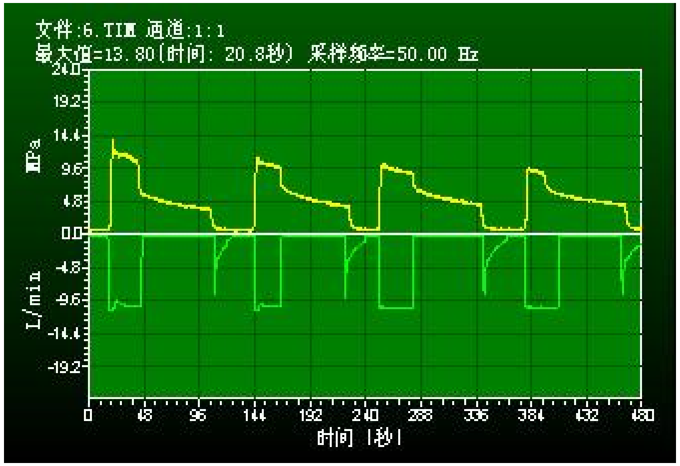




The lithology is mainly monzonorite granite and partially tonalite .

Five groups of rock samples were chosen from different depths

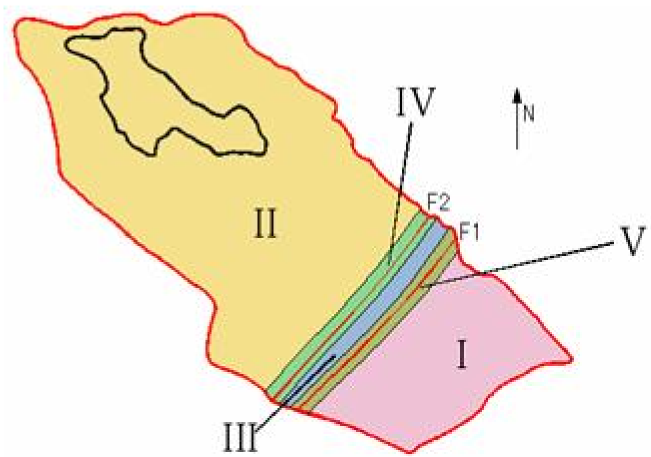
Hydraulic Fracture and High-pressure Injection were done in borehole BS03

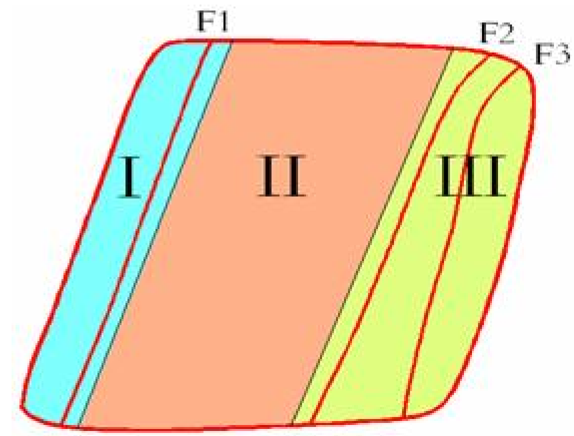


- Introduction
- Field survey and tests
- **Joint characteristics**
- Mechanical properties
- Geostress and seepage characteristics
- Conclusions

Rock mass mechanical properties and Seepage Characteristics

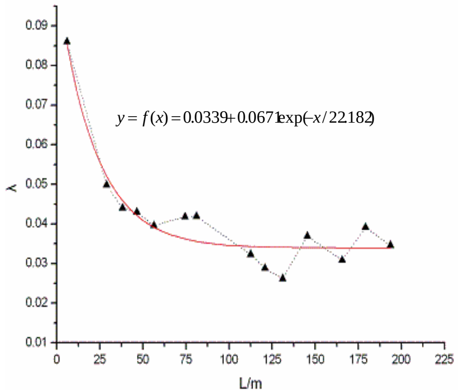
- ✓**Joints are principally steep shear joints.**
- ✓**Joints of dip angle greater than 60^{o} are about 90.89%.**
- ✓**X shear joints can be observed in some outcrops.**
- ✓**One set joints is visible for most joints.**
- ✓**Joint is flat, smooth with stable strike and long extension.**

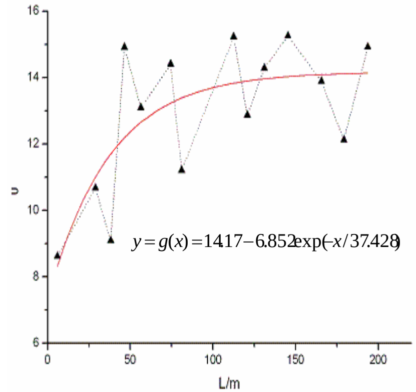




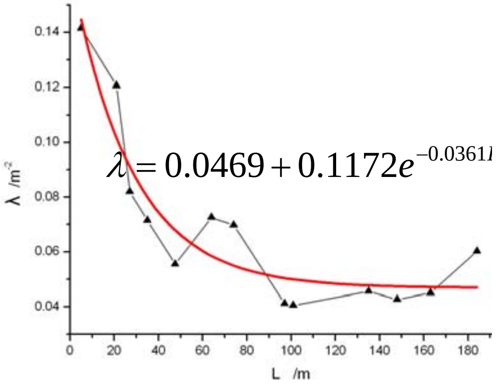
According to the faults, Jijicao quarry and Xinchang are roughly divided into statistical homogeneities and the region which is influenced by the faults.

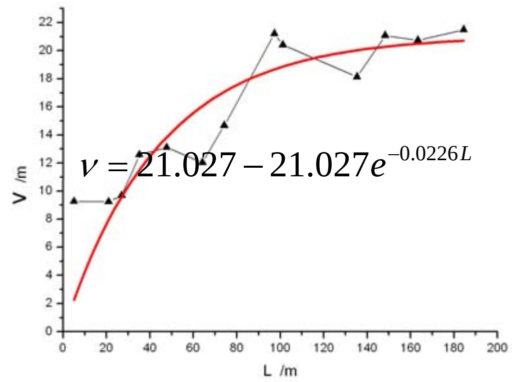
Rock mass mechanical properties and Seepage Characteristics





Mean trace length and trace midpoint density-L in Jiji quarry

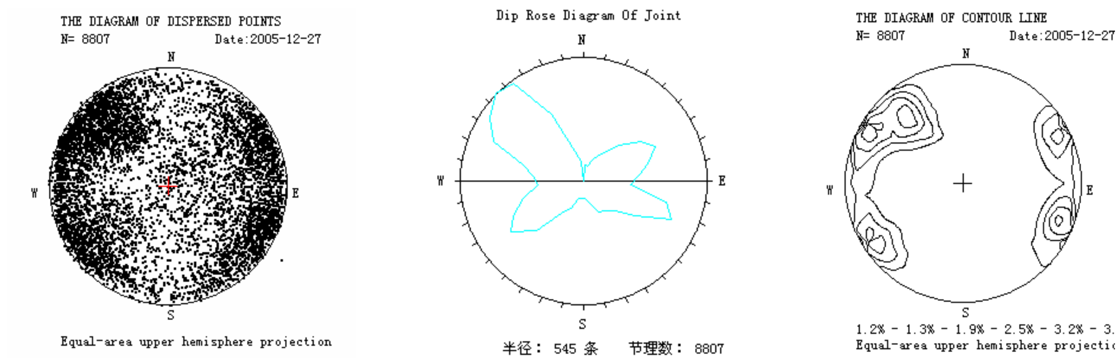




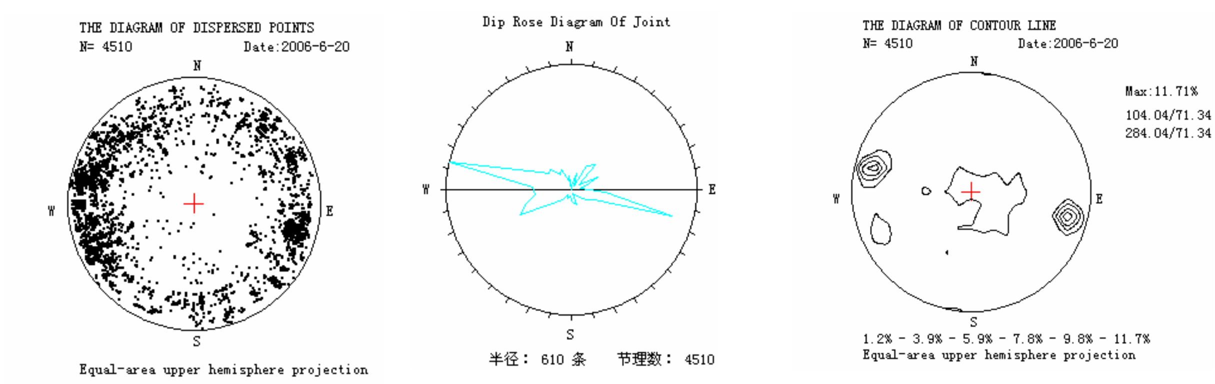
Mean trace length and trace midpoint density-L in Xingchang

- **The boundary of the statistical homogeneous domains is determined**

Statistic of joint orientation

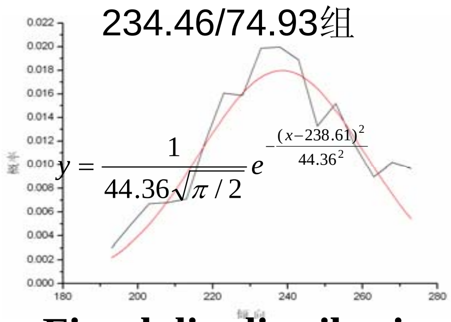


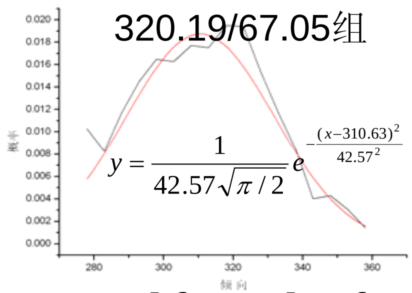
Joint polar points and Dip rose diagram of II statistical homogeneity of Jiji quarry



Joint polar points and Dip rose diagram of II statistical homogeneity of Xingchang

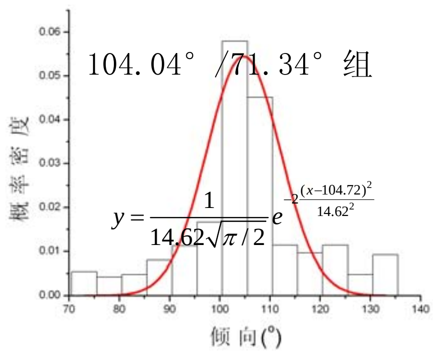
Probability analysis of joint orientation

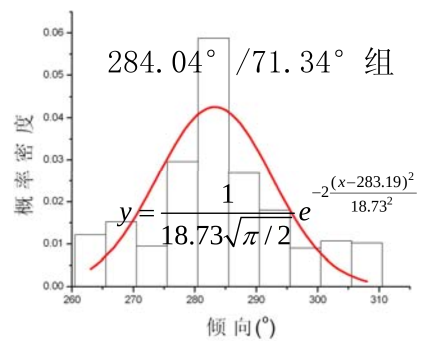




Fitted dip distribution curve and formula of

II statistical homogeneity of Jiji quarry

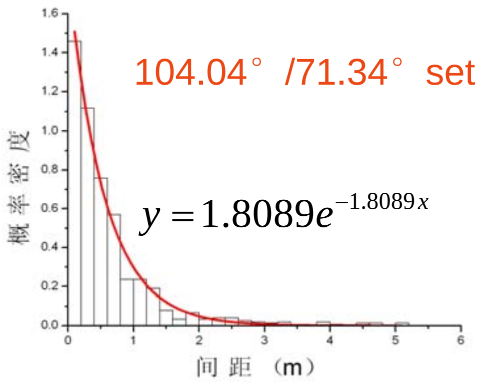


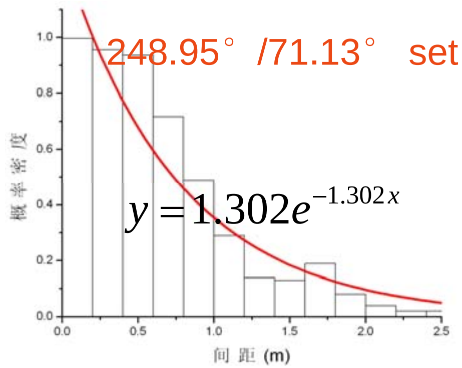


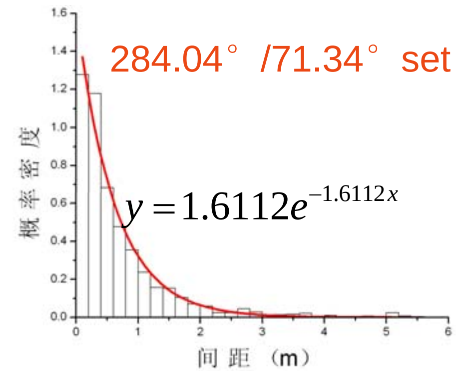
Fitted dip distribution curve and formula of

II statistical homogeneity of Xingchang

Statistic of joint space







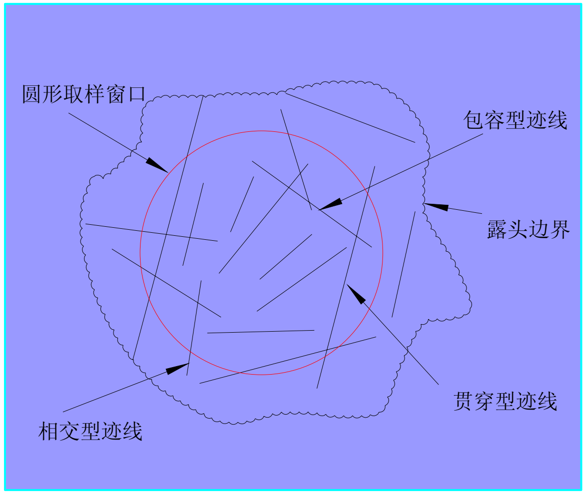
Fitted joint space distribution and formula of II statistical homogeneity of xingchang

Joint spacing of Xingchang

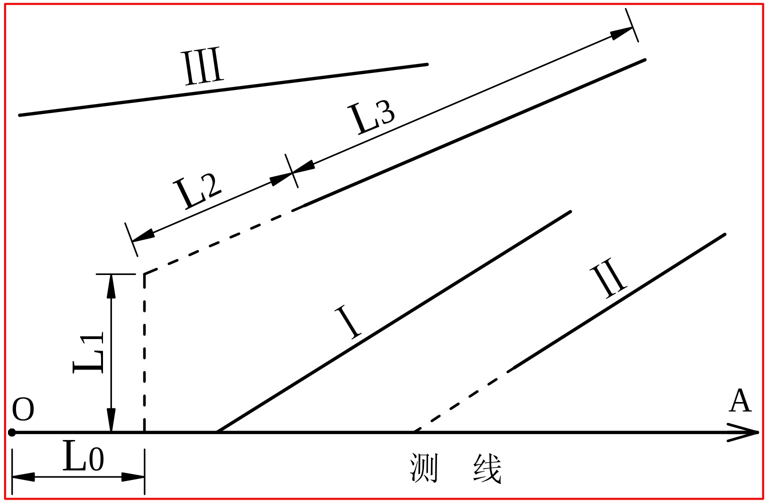
	SET	ORIENTATION	SPACING (m)
II	1	104.04°/71.34°	0.55
	2	248.95°/71.13°	0.77
	3	284.04°/71.34°	0.62

According to ISRM (1978) joint space of the 104.04 /71.34 set of Xinchang is moderate spacing and the others are wide spacing.

Estimation of mean trace length and midpoint density



Schematic circular sample window



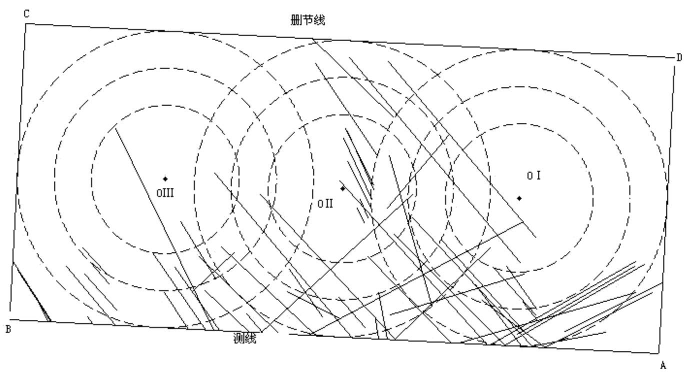
Types of endpoints of joint traces

Mean trace length $\upsilon = \dfrac{\pi(N + N_2 - N_0)}{2(N - N_2 + N_0)} c$

Midpoint density $\lambda = \dfrac{N - N_2 - N_0}{2\pi c^2}$

Estimation of mean trace length and midpoint density (continued)

Concentric circles method

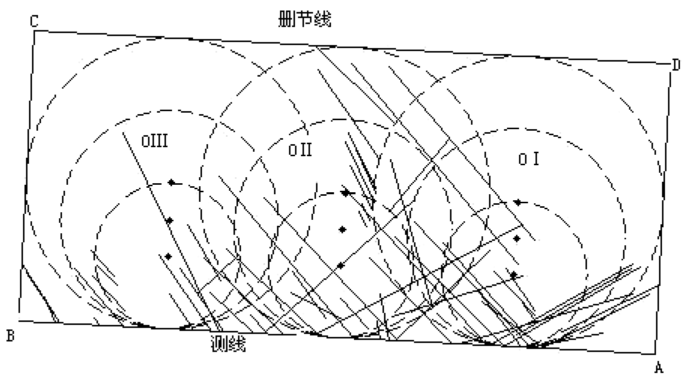


Resultes of Concentric circles

同心圆法所得露头F90平均迹长和迹线中点的面密度

窗口半径/m	窗口编号	各类迹线条数 N_0	N_1	N_2	迹线中点面密度λ	平均迹长估计值υ/m
13.5287	OⅠ	7	16	4	0.0261	17.001
	OⅡ	12	16	3	0.0348	11.688
	OⅢ	5	10	0	0.0174	10.625
10.1465	OⅠ	0	14	0	0.0216	15.938
	OⅡ	6	13	2	0.0386	10.838
	OⅢ	1	9	0	0.0170	13.040
6.7644	OⅠ	0	5	0	0.0174	10.625
	OⅡ	6	7	1	0.0661	5.033
	OⅢ	0	3	0	0.0104	10.625

Tangent circles method



Resultes of tangent circles

相切圆法所得露头F90平均迹长和迹线中点的面密度

窗口半径/m	窗口编号	各类迹线条数 N_0	N_1	N_2	迹线中点面密度λ	平均迹长估计值υ/m
13.5287	OⅠ	7	16	4	0.0261	17.001
	OⅡ	12	16	3	0.0348	11.688
	OⅢ	5	10	0	0.0174	10.625
10.1465	OⅠ	4	11	5	0.0294	17.6158
	OⅡ	9	14	3	0.0495	9.9613
	OⅢ	5	10	0	0.0309	7.9691
6.7644	OⅠ	3	9	6	0.0522	14.8756
	OⅡ	5	8	6	0.0626	11.8060
	OⅢ	3	8	1	0.0487	7.5896

➢Stable and reasonable results can be obtained from Tangent circles method

Estimation of mean trace length and midpoint density (continued)

Trace length and midpoint density for each statistical homogeneous domains of Jiji quarry

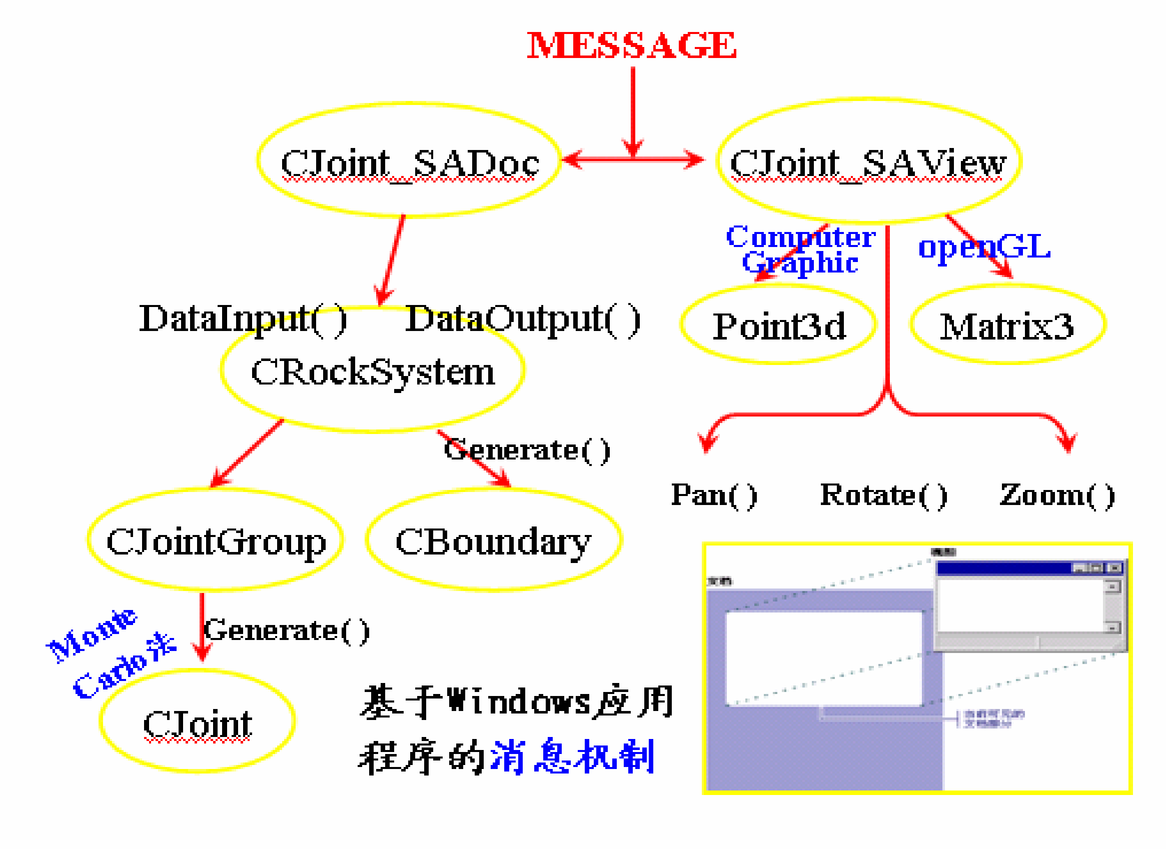
NO.	I	II	III	IV	V
/m	14. 834	14. 398	15. 167	15. 667	12. 184
/m^{-2}	0. 034	0. 0387	0. 034	0. 0408	0. 0414

Trace length and midpoint density for each statistical homogene0us domains of Xingchang

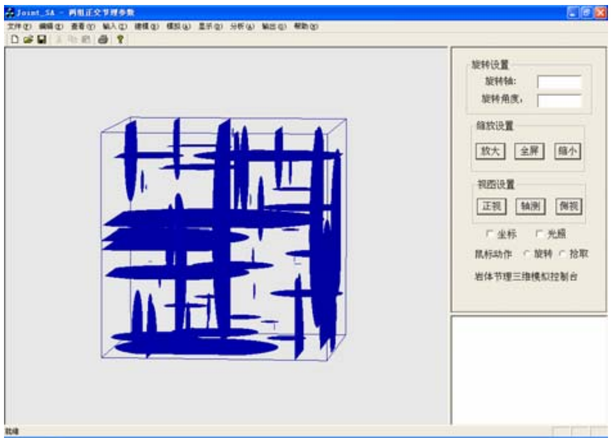
NO.	I	II	III
/m	14. 129	18. 671	14. 173
/m^{-2}	0. 1058	0. 0586	0. 0827

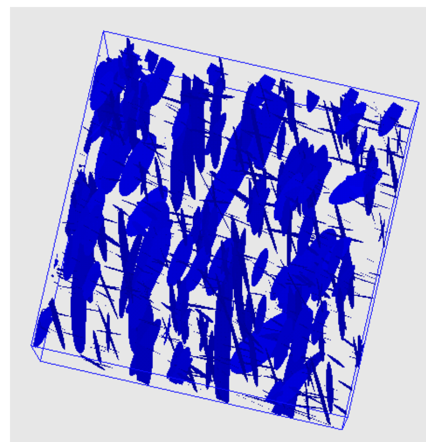
➢**Mean trace length is smaller and midpoint density is greater in the region that influenced by faults than that in statistical homogeneity**

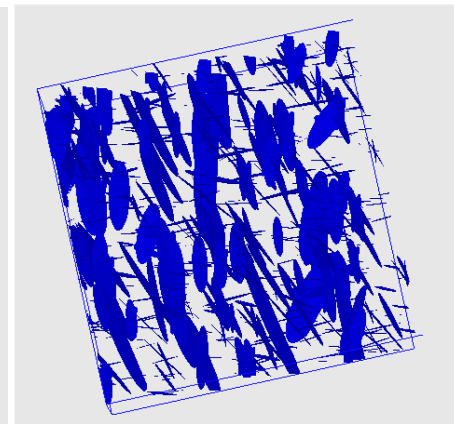
Development of 3-D joint simulation system

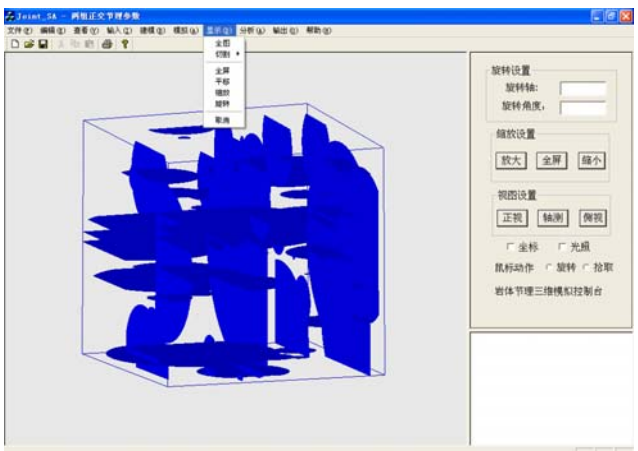


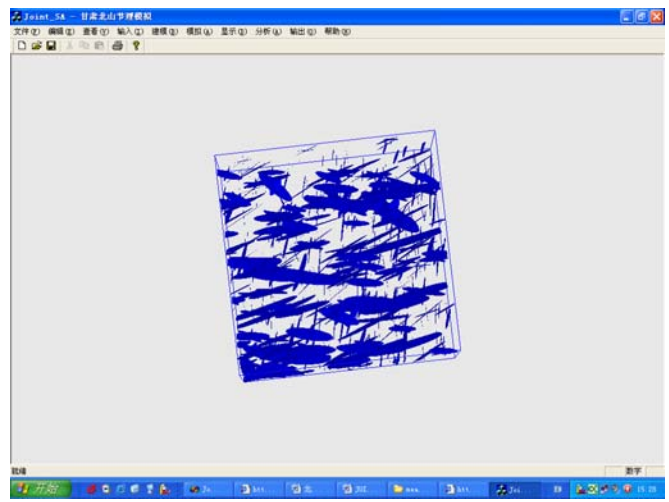
Development of 3-D joint simulation system (continued)





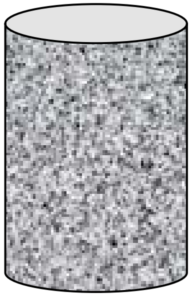
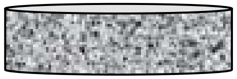
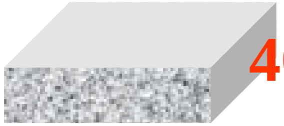






- Introduction
- Field survey and tests
- Joint characteristics
- **Mechanical properties**
- Geostress and seepage characteristics
- Conclusions

mechanical properties of intact rock

Specimen size		Test items
	ϕ50×100	Water-content coefficient ;Hygroscopic coefficient; Dry density ; Acoustic wave measurement ; Uniaxial compression strength and deformation; Triaxial strength and deformation
	ϕ60×30	Water-content coefficient ;Hygroscopic coefficient; Dry density ; Brazil test
	40×40×20	Shear strength
Broken blocks		Specific gravity ; specific heat

Specimen after tests

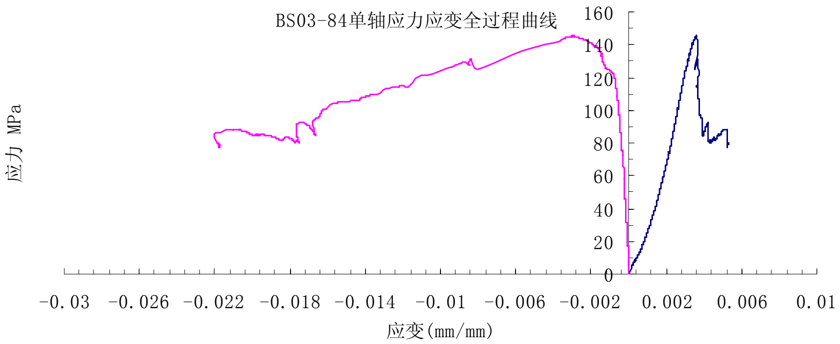
Uniaxial compression

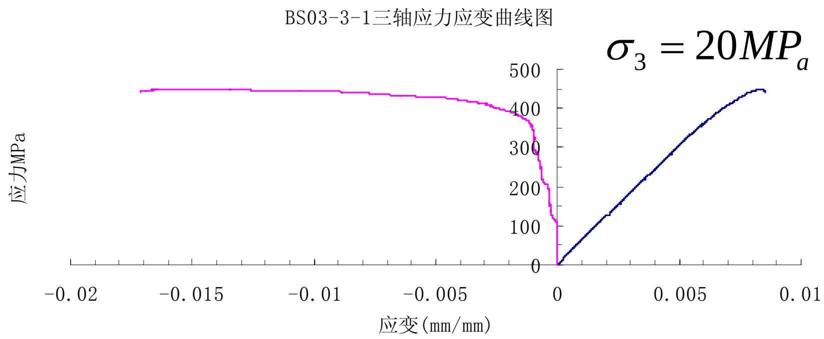
Triaxial compression

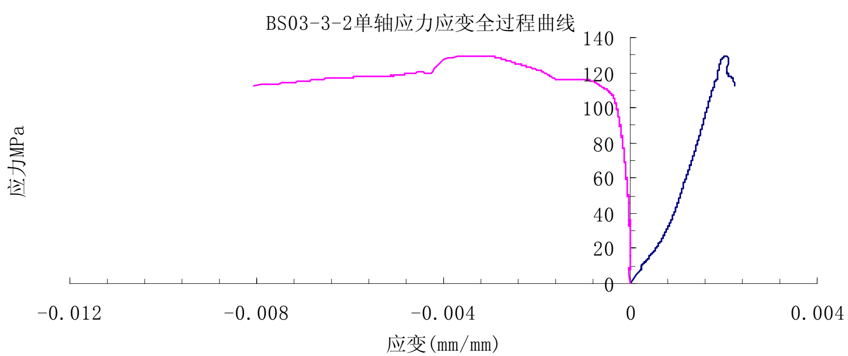
Direct shear

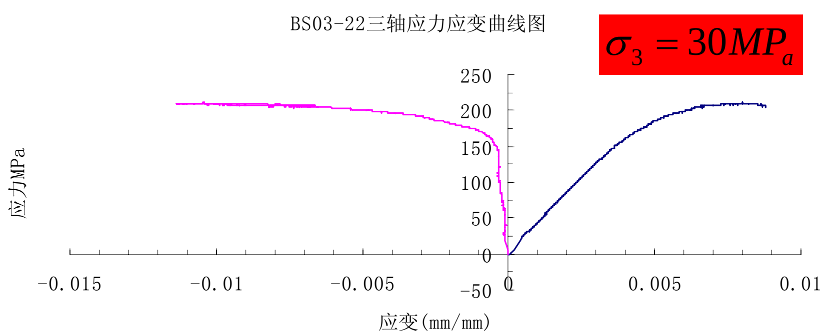
BRAZIL split

Curve of uniaxial and triaxial compression test









Uniaxial compression test

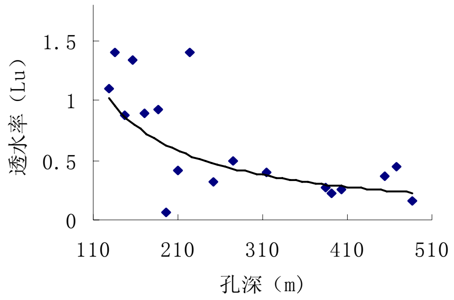
Triaxial compression test

Conclusions of rock mechanics characteristics

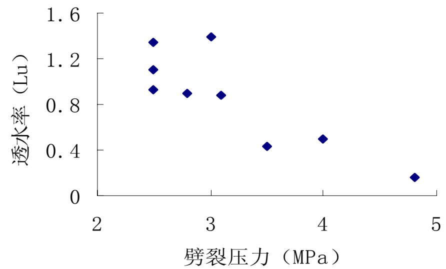
- **Both have high mechanical strength, small deformation, high brittleness.**
- **Subporphyritic monzonorite granite is more homogeneous and has high mechanical strength.**
- **Tonalite is inhomogeneous and its mechanical strength is enhanced with depth.**
- **Homogeneity of shallow rock is inferior. Homogeneity of rock under 300m is superior and mechanical strength is high.**

- Introduction
- Field survey and tests
- Joint characteristics
- Mechanical properties
- **Geostress and seepage characteristic**
- Conclusions

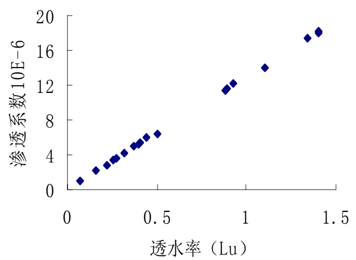
Seepage characteristic



Permeability rate-depth curve



Splitting water pressure- Permeability rate curve



Permeability coefficient -permeability rate curve

Permeability coefficient of individual sections can be measured with high pressure injection water tests.

object

Average permeability character definite units was obtained.

The mean value of permeability coefficient for individual sections can be used to describe permeability coefficient of definite geological units.

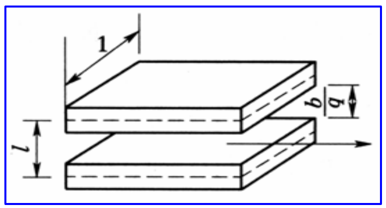
$$\bar{K} = \sqrt[n]{K_1 K_2 \cdots K_n}$$

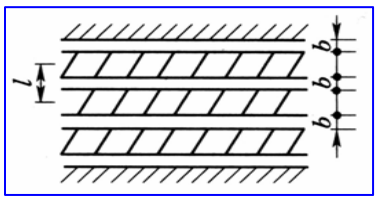
➢ **The geometric mean permeability coefficient of borehole BS03 is 4.4×10^{-6} cm/s .**

Seepage characteristic (continued)

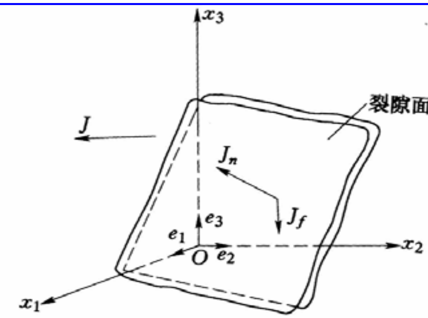
Flow in single fracture is the basis to determination of hydraulic conductivity tensor for fractured medium.

Generally , in permeability domain, hydraulic gradient is unparallel with fracture plane. But water flow velocity in fractures is related to hydraulic gradient which is parallel with fracture plane.





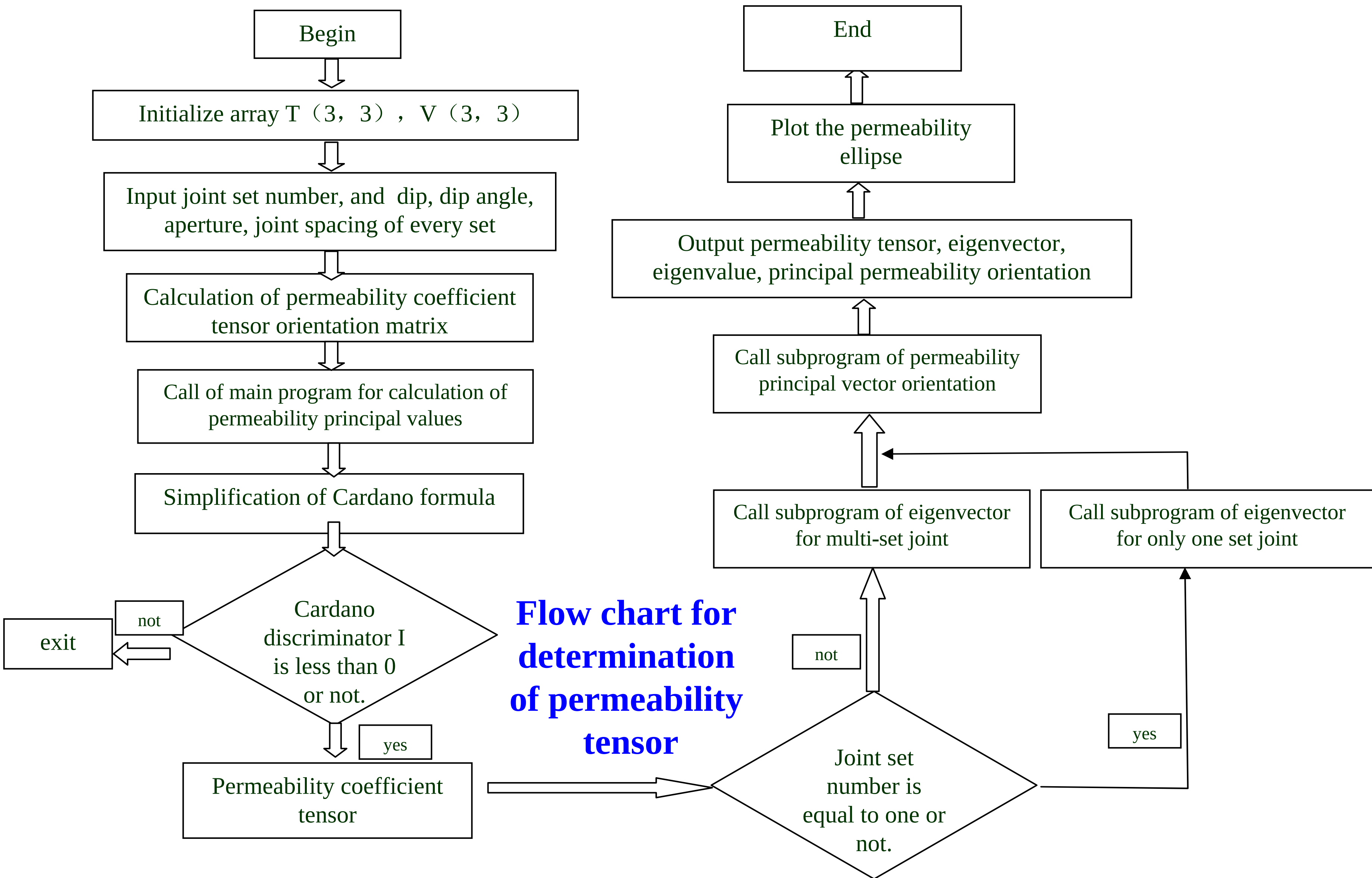
Permeability figure of hydraulic gradient parallel with fracture plane



Permeability figure of hydraulic gradient unparallel with fracture plane

$$K=\sum_{i=1}^{n}K_{ei}\begin{bmatrix}1-\cos^2\beta_i\sin^2\gamma_i & -\sin\beta_i\cos\beta_i\sin^2\gamma_i & -\cos\beta_i\sin\gamma_i\cos\gamma_i\\ -\sin\beta_i\cos\beta_i\sin^2{}_i & 1-\sin^2\beta_i\sin^2\gamma_i & -\sin\beta_i\sin\gamma_i\cos\gamma_i\\ -\cos\beta_i\sin\gamma_i\cos\gamma_i & -\sin\beta_i\sin\gamma_i\cos\gamma_i & 1-\cos^2\gamma_i\end{bmatrix}$$

Rock mass mechanical properties and Seepage Characteristics



Flow chart for determination of permeability tensor

中国科学院武汉岩土力学研究所
INSTITUTE OF ROCK AND SOIL MECHANICS
CHINESE ACADEMY OF SCIENCES

Seepage characteristic (continued)

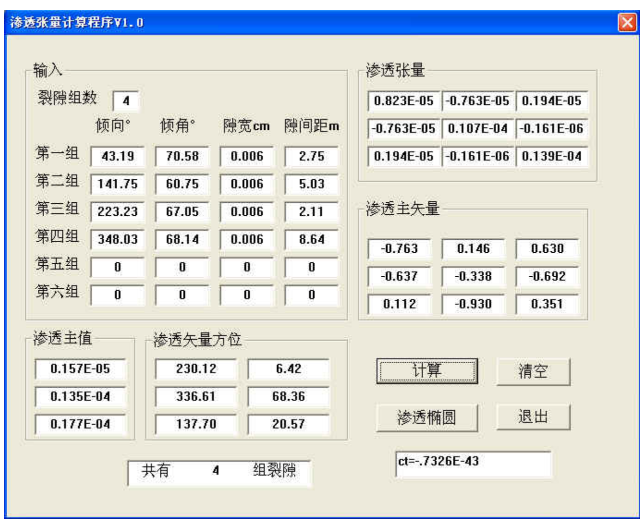
Hydraulic parameters of 4 set joint：

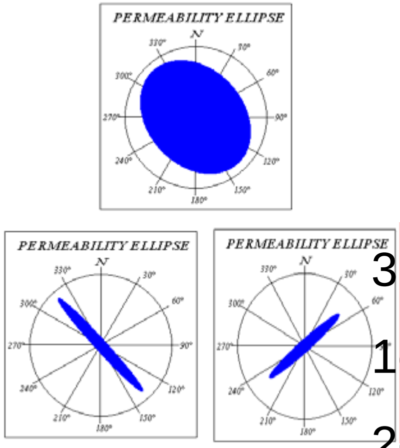
1st：dip 43.19°， dip angle 70.58°，spacing 2.75m

2nd：dip 141.75°，dip angle 60.75°，spacing 5.03m

3rd：dip 223.23°，dip angle 67.05°，spacing 2.11m

4th：dip 348.03°，dip angle 68.14°，spacing 8.64m





Permeability ellipse

Hydraulic conductivity tensor

$$K=\begin{bmatrix}0.823\times10^{-5} & -0.763\times10^{-5} & 0.194\times10^{-5}\\ -0.763\times10^{-5} & 1.070\times10^{-5} & -0.016\times10^{-5}\\ 0.194\times10^{-5} & -0.016\times10^{-5} & 1.390\times10^{-5}\end{bmatrix}$$

Permeability principal value

0.157×10^{-5} 0.135×10^{-4} 0.177×10^{-4}

Permeability principal vector

$$\alpha_1(-0.763,\quad -0.637,\quad 0.112)$$

$$\alpha_2(0.146,\quad -0.338,\quad -0.930)$$

$$\alpha_3(0.630,\quad -0.692,\quad 0.351)$$

3 permeability principal orientation：

1dip 230.12°， dip angle 6.42°

2dip 336.61°， dip angle 68.36°

3dip 137.70°， dip angle 20.57°

Geostress characteristic

Geostress measured by hydraulic fracture method

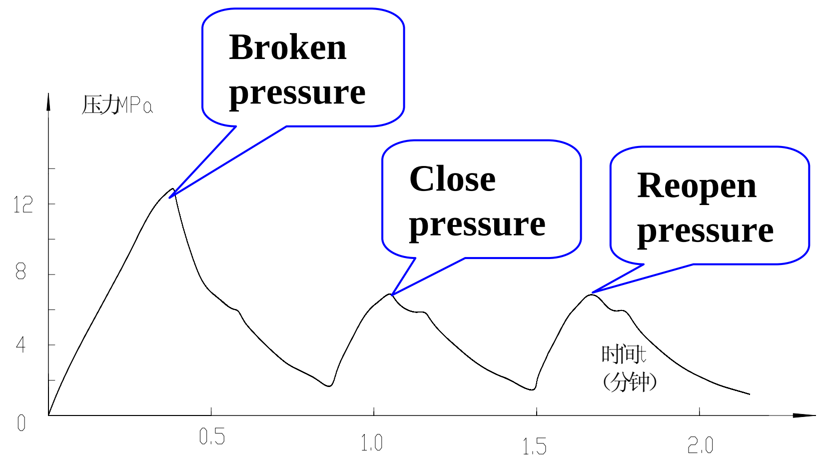
Hypothesis:

1.Host rock is the linear, homogeneous, isotropic elastic medium.

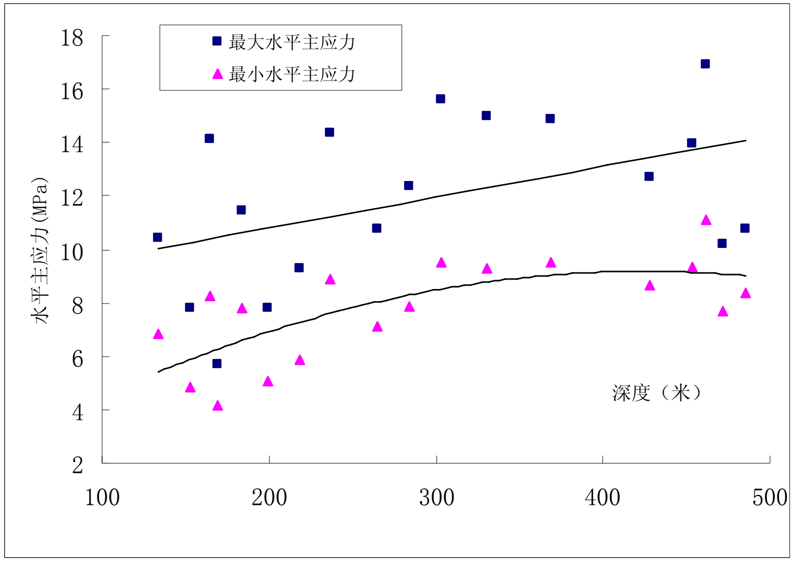
2.Injection water flow obey the Darcy’s law in rock pore .

3. Perpendicular stress σ V is one of principal stress

Results of measurement of geostress



Pressure-time curve of 283.51-284.51m



➢The geostress of Beishan a is moderate and the magnitude of geostress increases with the depth.

Conclusions

- **The quantitative parameters of joint characteristic are obtained**
- **Rock in the research area is high density, low Water-content, low Hygroscopic coefficient, low porosity, low permeability**
- **Rock in the research area is high mechanical strength, small deformation, high brittleness.**
- **The geostress of Beishan a is moderate and the magnitude of geostress increases with the depth.**

Thank you!

BGR Research Activities in Crystalline Rock

- Grimsel Test Site (CH), Hard Rock Laboratory Äspö (SE) -

Dr. SHAO, Hua

Federal Institute for Geosciences and Natural Resources (BGR)
Hanover, Germany

Objects of investigation programs

- Additional research work to salt rock
- Test and examination of the methods for characterising rock mass,
- Collection of the geological, hydraulic and geomechanical data for developing a structural model and validation of developed model,
- Determination of the effective parameter values for the numerical modelling,
- Exchange of experiences with international partners

Focuses of the BGR's investigation programs

- German - Swiss co-operation: Grimsel Test Site, 1984 –

  ! ***Development of methodology***

  Geology, Rock mechanics, Hydraulics/mass transport and THMC

  Projects: BK, GS, ZPK, CTN, EFP, GMT, FEBEX

- German - Swedish co-operation: Hard Rock Laboratory Äspö, 1996 –

  ! ***Application of methods and models***

  Hydraulics/mass transport and THMC coupling

  Projects: TURE, TASK 5, TPF, PR, EBS, LASGIT

BGR's investigation programs in granite (Grimsel Test Site)

In situ activities

- Geological characterisation of fractured rock
- Rock stress measurements to determine the stress distribution around the tunnel
- Fracture flow test to determine potential flow paths in fractures/fracture network
- **Near-field characterisation**
- **Tracer tests in different scales (1 /10 / 70 / > 100 m)**

Participation & co-operation

- *Engineered barrier system and interface between geological and engineered barrier systems*

Theory and modelling

- Development and validation of conceptual models
- **Development of computer code for numerical simulations (flow and transport, two-phase flow, and coupled THMC)**

BGR's investigation programs in granite (HRL Äspö)

In situ activity

- Two-phase flow and gas tracer transport experiment in water saturated fractured rock (laboratory test, in situ experiment, and numerical modelling)
- Large-Scale Gas Injection Test (LASGIT)

Theory and modelling

- *Modelling Task Force 4 (TRUE – Tracer Retention Understanding Experiments): Modelling of groundwater flow and solute transport*
- *Modelling Task 5: Hydrological and hydro-chemical modelling*
- *Prototype Repository (THM modelling)*
- *Modelling Task Force on Engineered Barrier System (EBS)*

Properties of granitic rock types

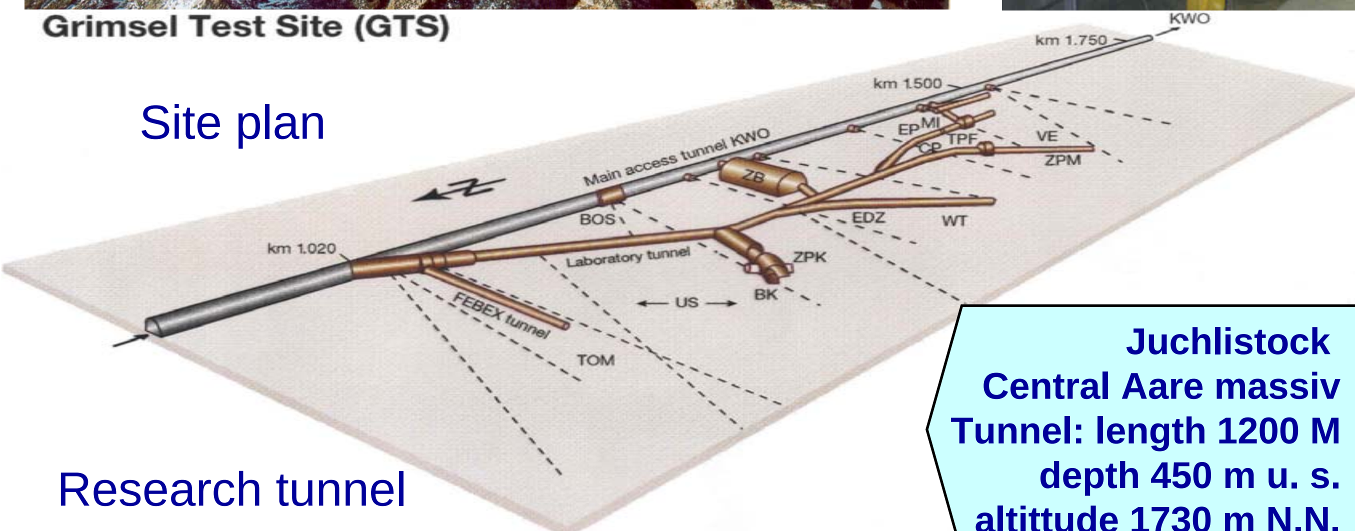
- Mechanical and constructional stability of rock mass
- Heterogeneity (discontinuity and fracture network) for potential flow
- High permeability
- High sorption and matrix diffusion property
- Small extension of EDZ

==> **Engineered Barrier System**

Grimsel Test Site (Switzerland)

Grimsel Test Site (GTS)

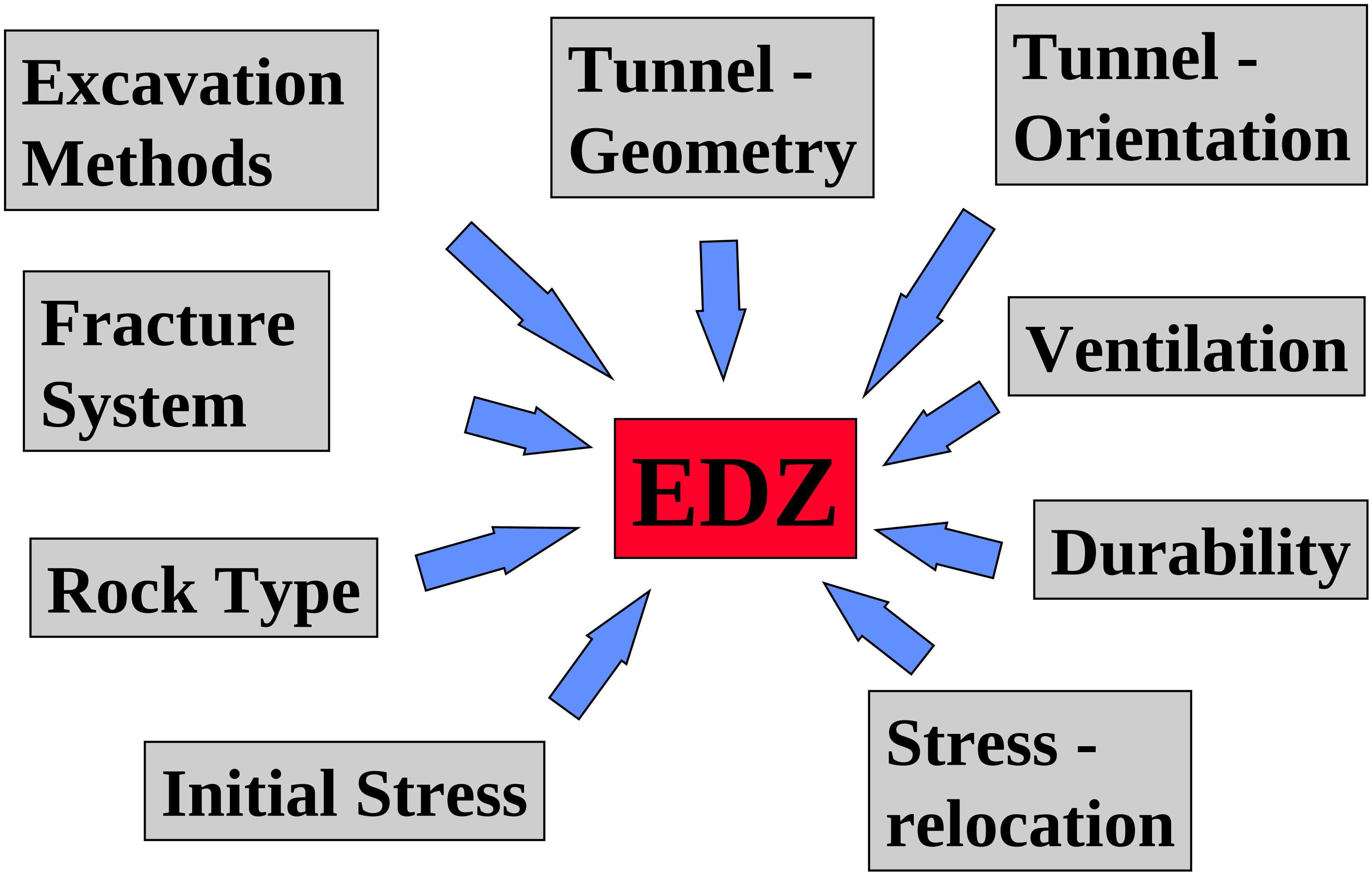
Site plan



Research tunnel

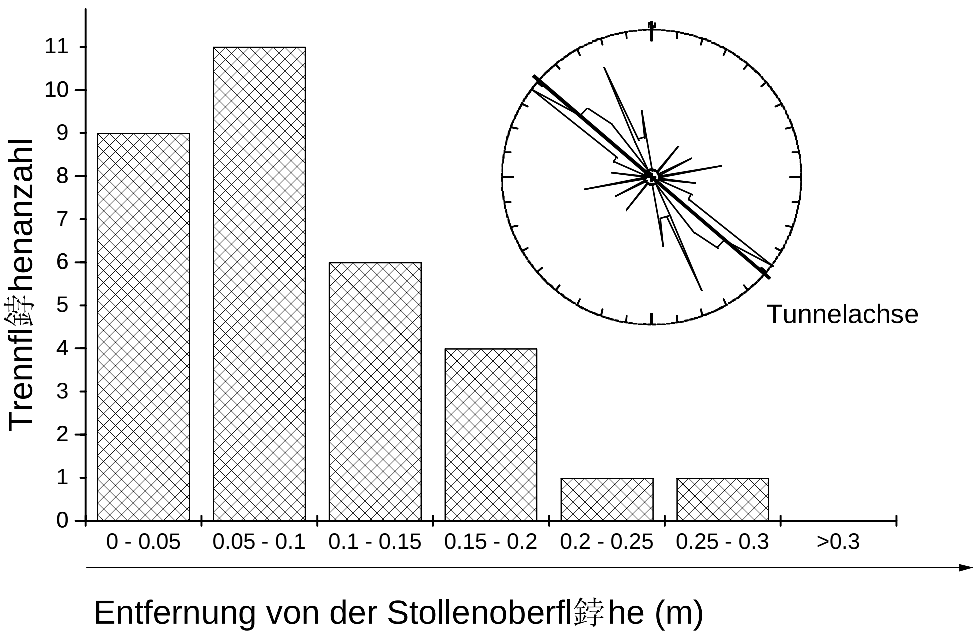
Juchlistock
Central Aare massiv
Tunnel: length 1200 M
depth 450 m u. s.
altititude 1730 m N.N.

Near-field characterisation - Parameters affect EDZ



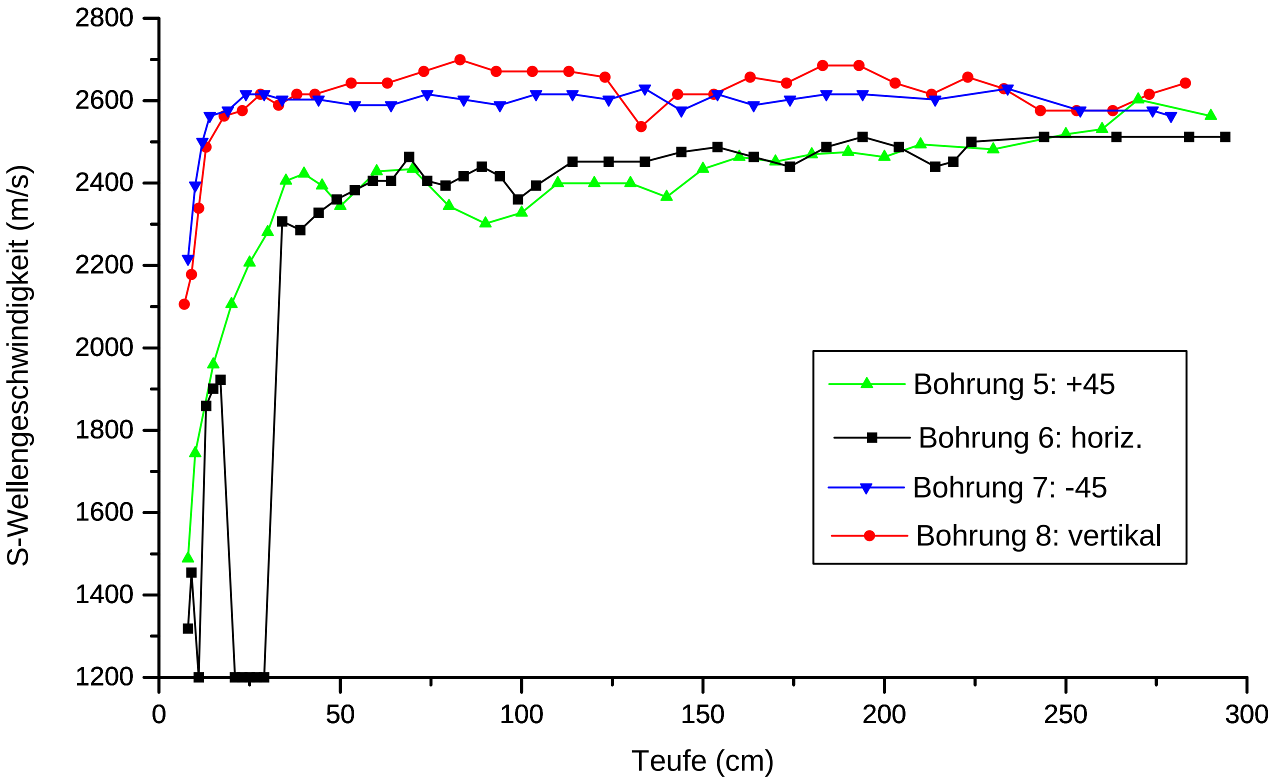
Near-field geology

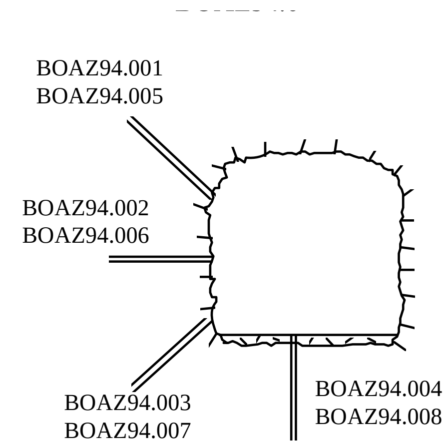
Fracture frequency



Thin section photo: micro fissure network marked with the fluoresced resin (picture 1.2 mm)

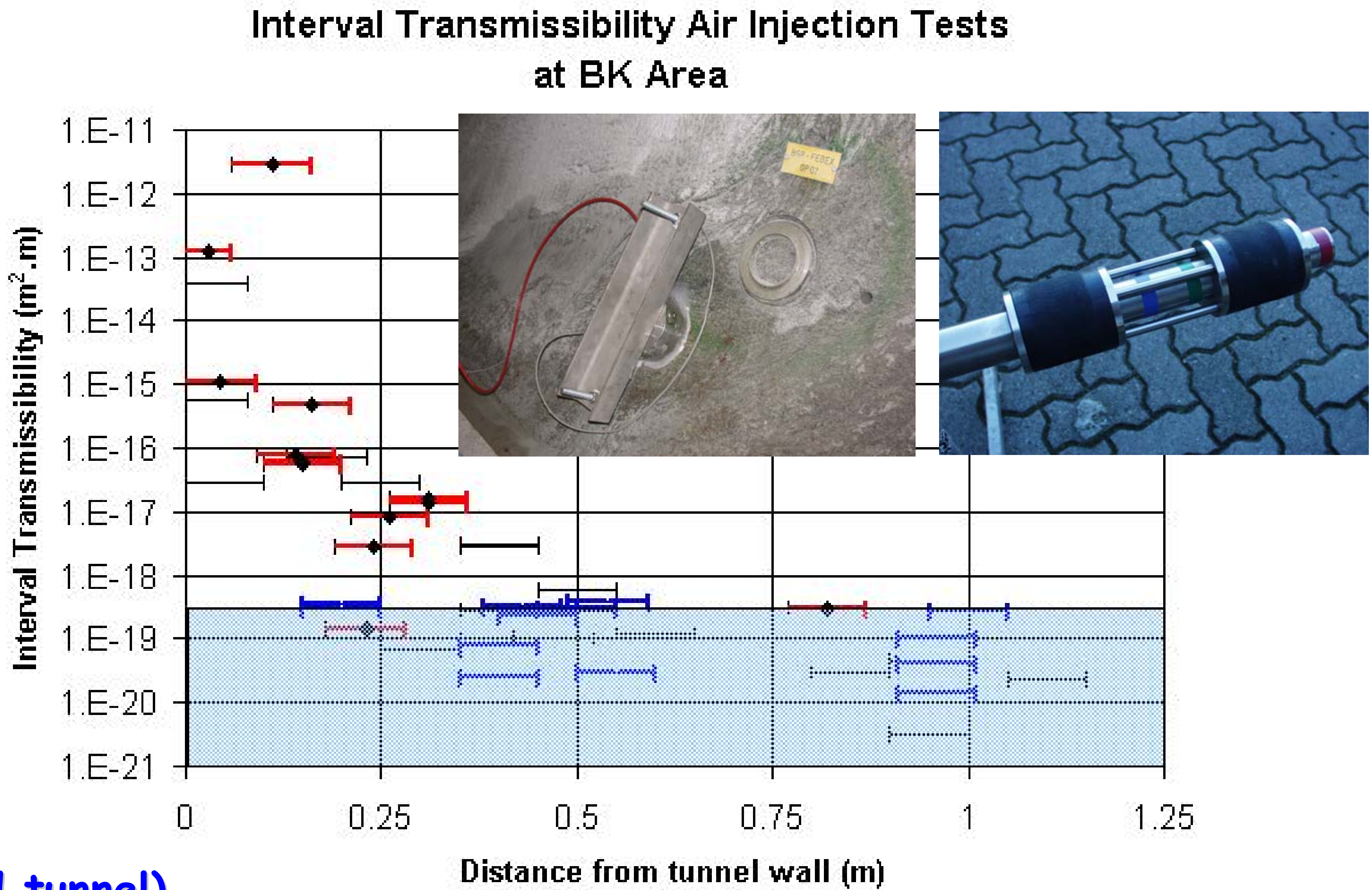
Borehole seismic measurements





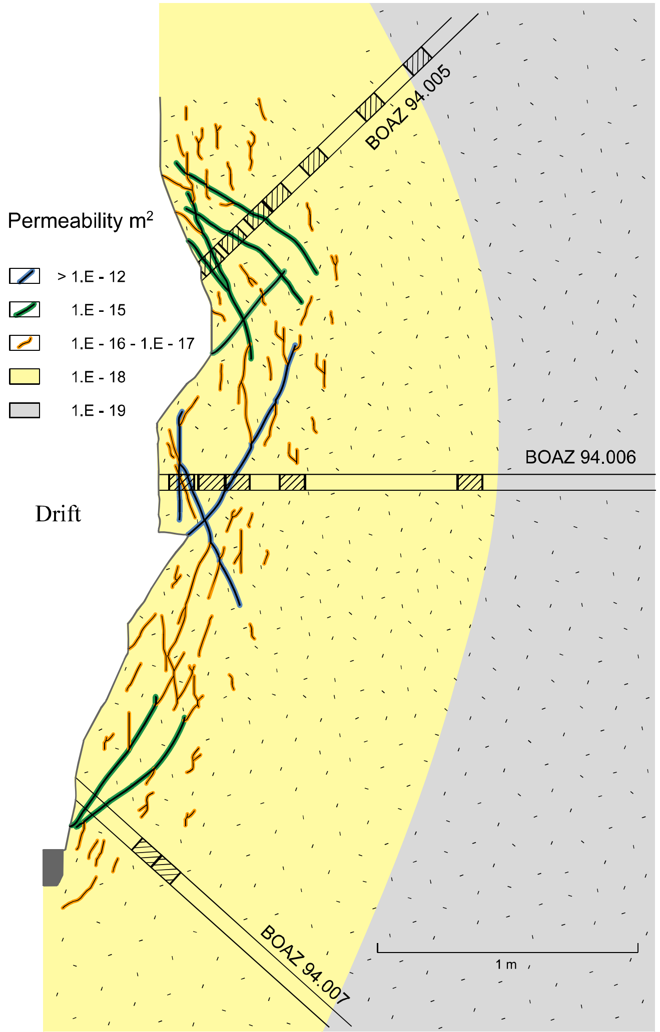
Querschnitt und
Lage der Bohrungen

Distribution of near-field hydraulic permeability



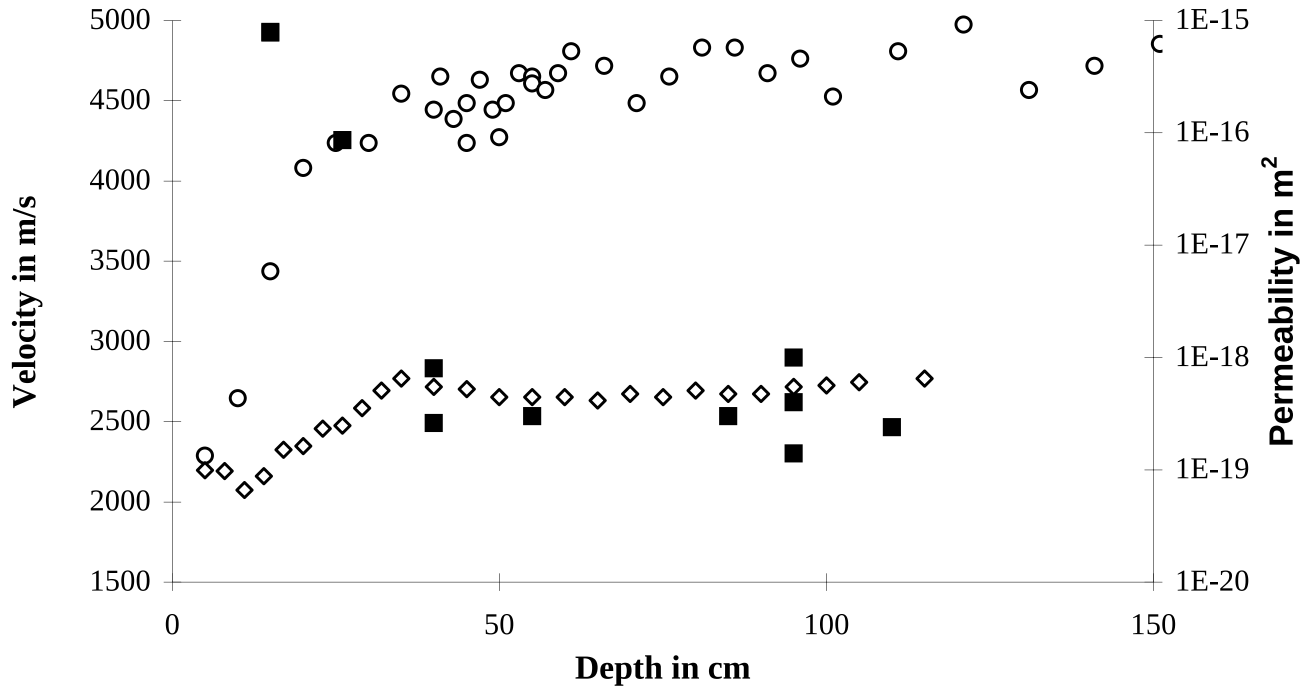
(blasted tunnel)

Near-field fracture model



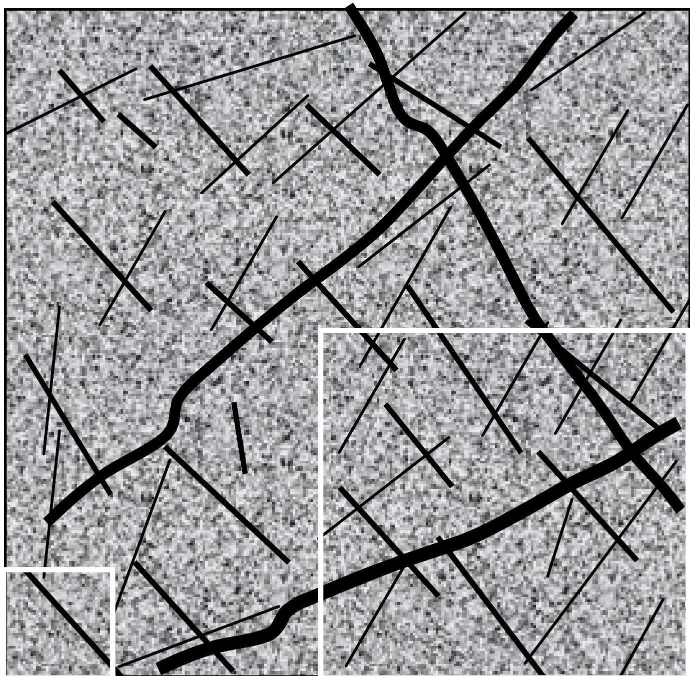
Seismic and hydraulic measurements

Compressional (circles) and shear wave (diamonds) velocities and permeabilities (squares) vs. depth for borehole 94001 (Alheid et al. 1999).



(blasted tunnel)

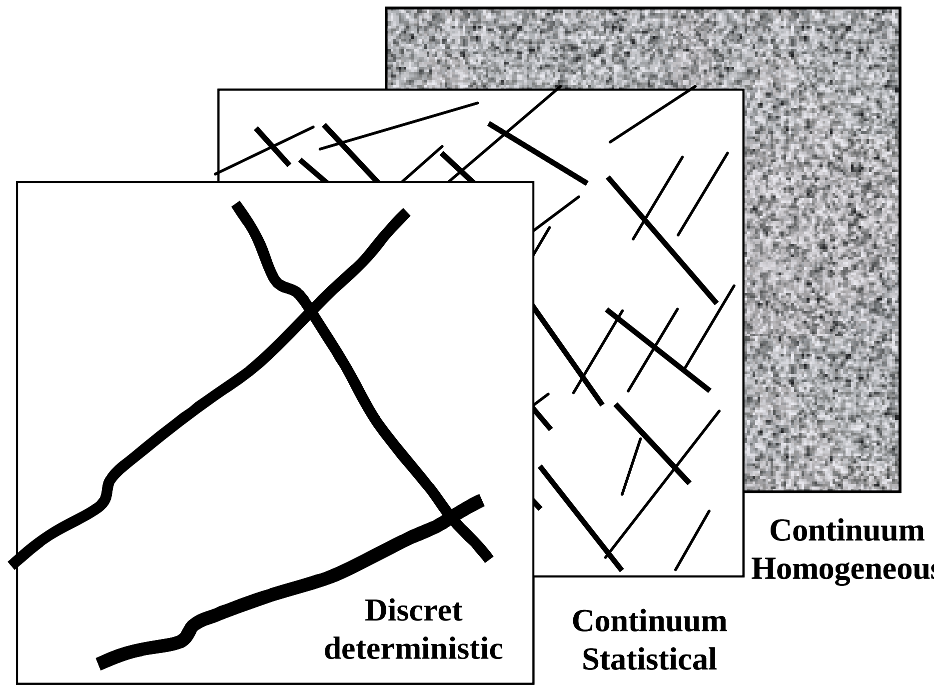
Principle of flow and transport mechanism in fractured rock



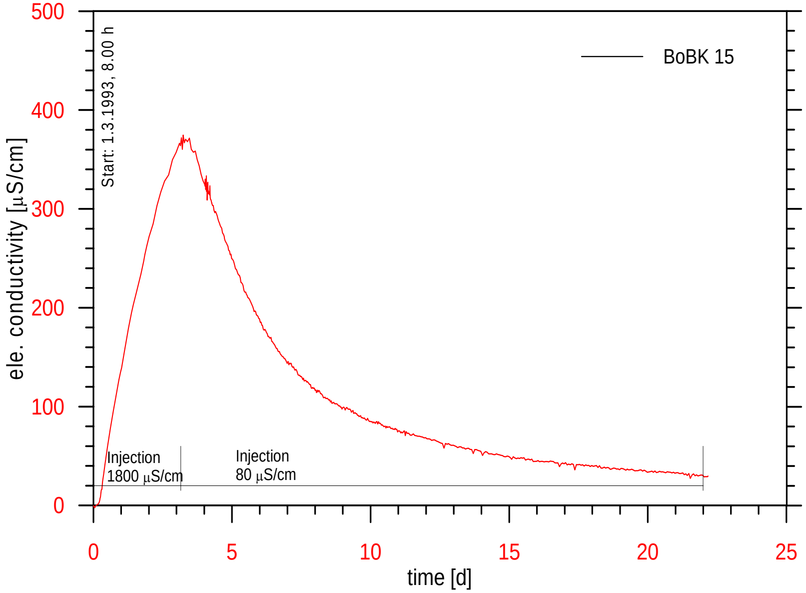
Large Scale
(> 100 m)
Coupled Fracture and Matrix model
Flow and Advection in Fracture System
Diffusion and Sorption in Matrix

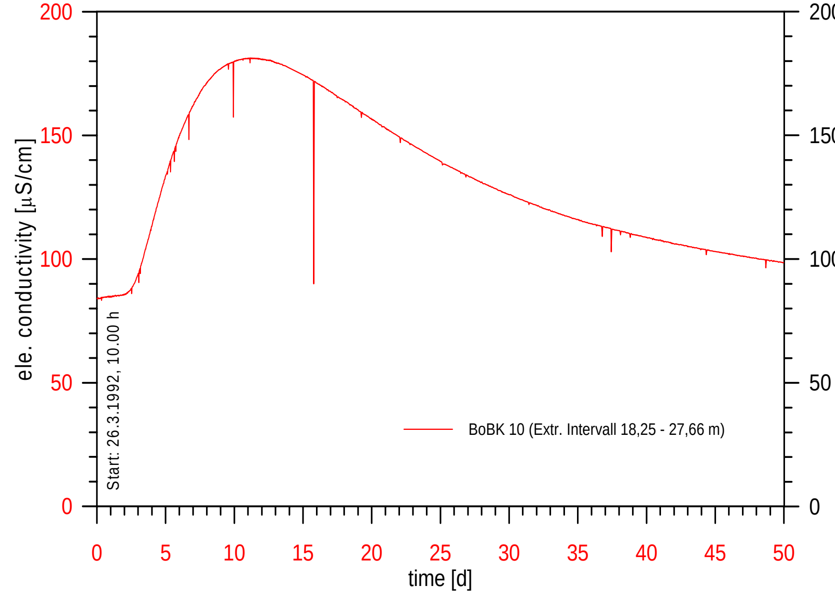
Small Scale
(< 10 m)
Single Feature Model
Flow and Advection
in Fracture

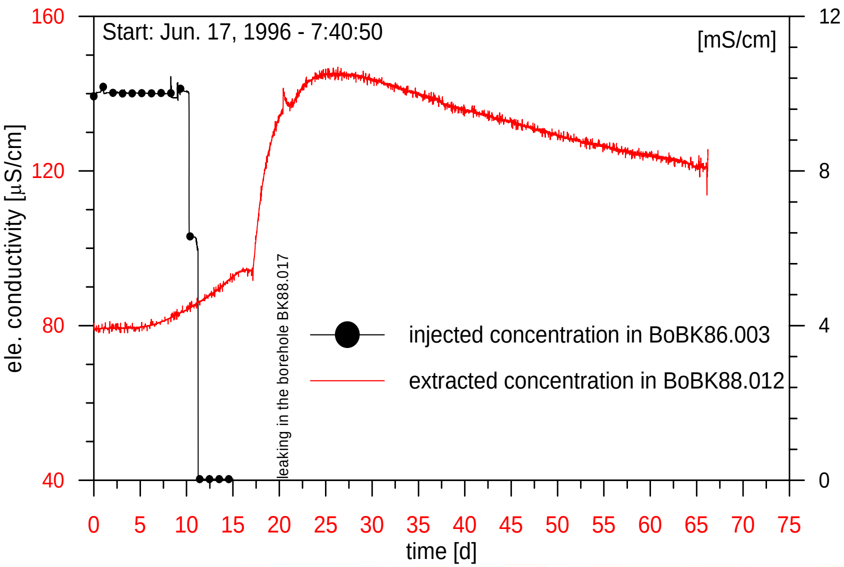
Intermediate Scale
(< 50 m)
Fracture Network Model
Flow and Advection
in Fracture System



Scale dependence of solute transport in fractured rock



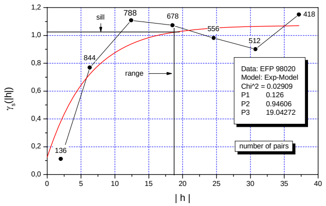


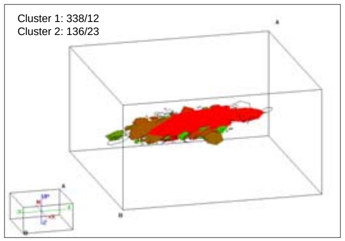


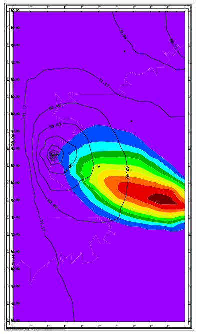
	C_{max}/C_0(-)	t_{max} (d)	$t_{5\%}$(d)	$t_{50\%}$(d)	$t_{95\%}$(d)
Small scale (< 10 m) (VE520)	0.25	3.5	1.4	5.1	18.4
Intermediate scale (<70 m) (VE493)	0.018	11	5.8	19.4	49.6
Large scale (> 100 m) (VE800)	0.015	26.7	19.9	38.6	63

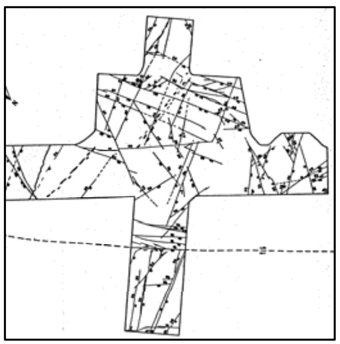
EFP - Effective Field Parameter

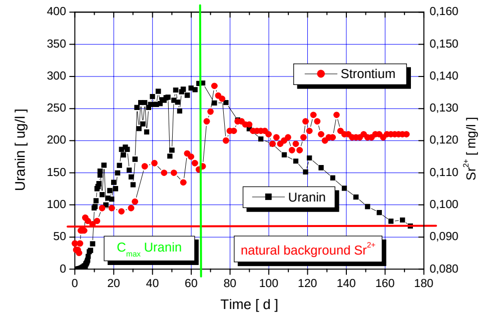
a **combined modelling strategy** considering deterministic **and** stochastic distribution of effective parameters

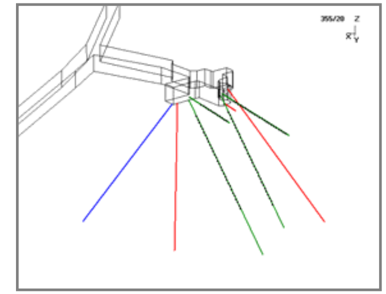


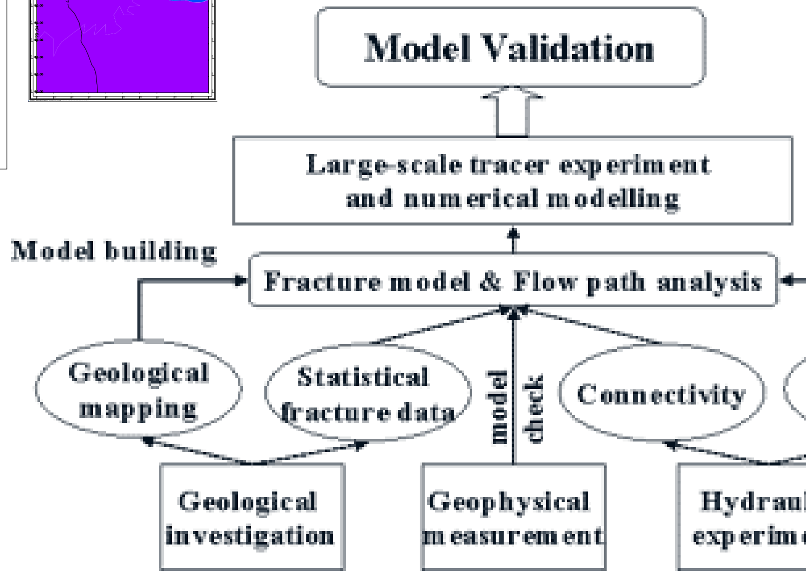


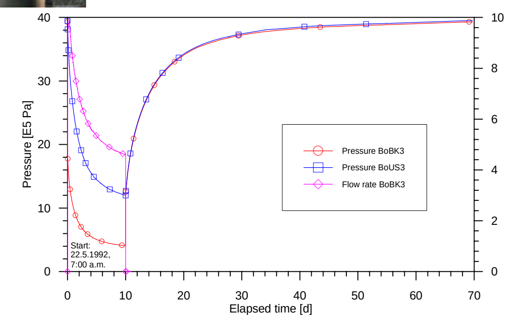


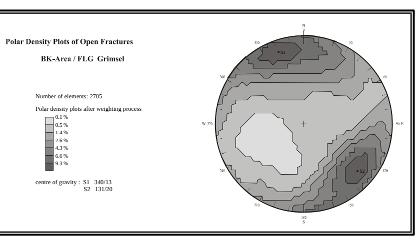


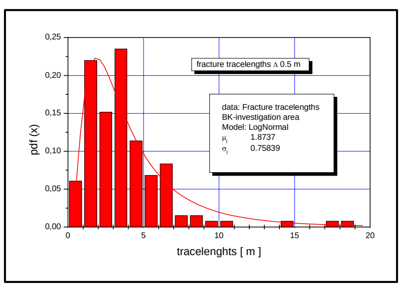


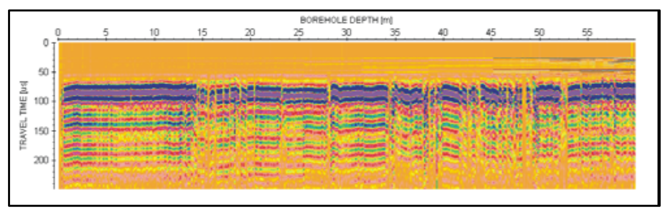


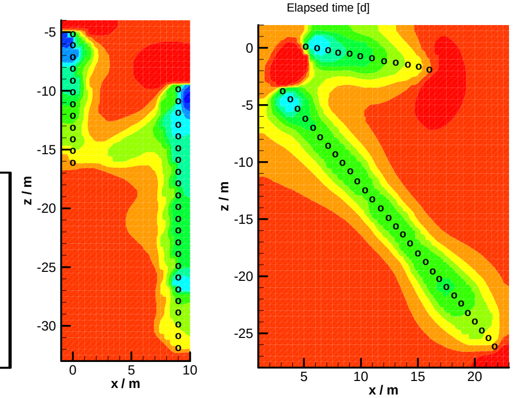




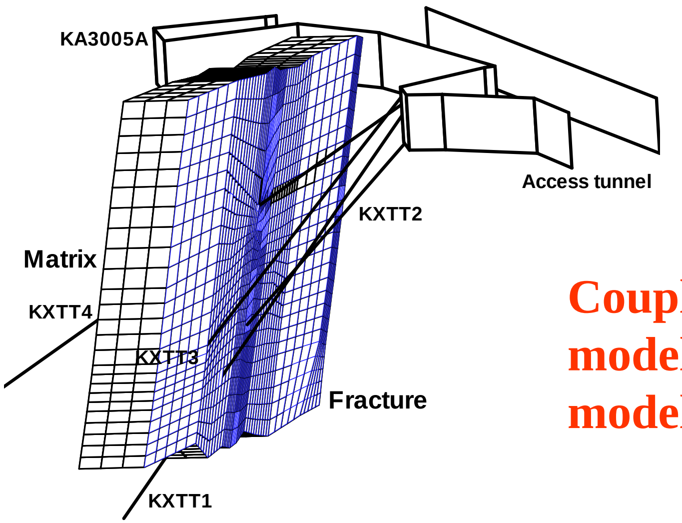




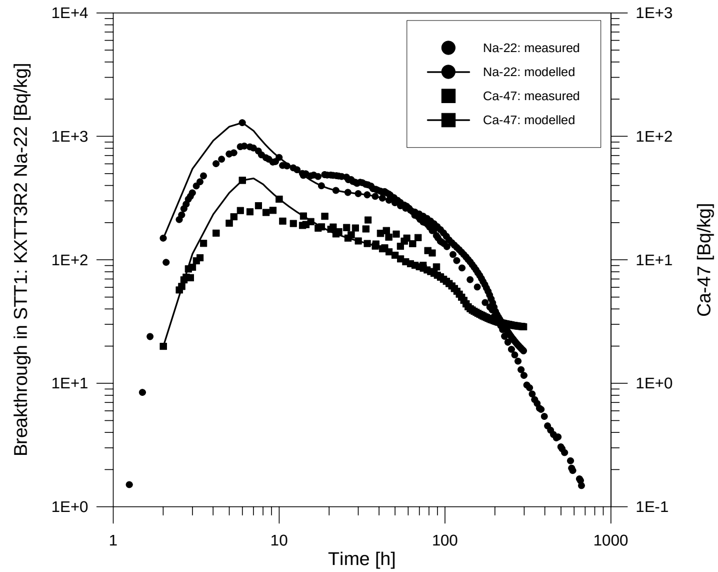




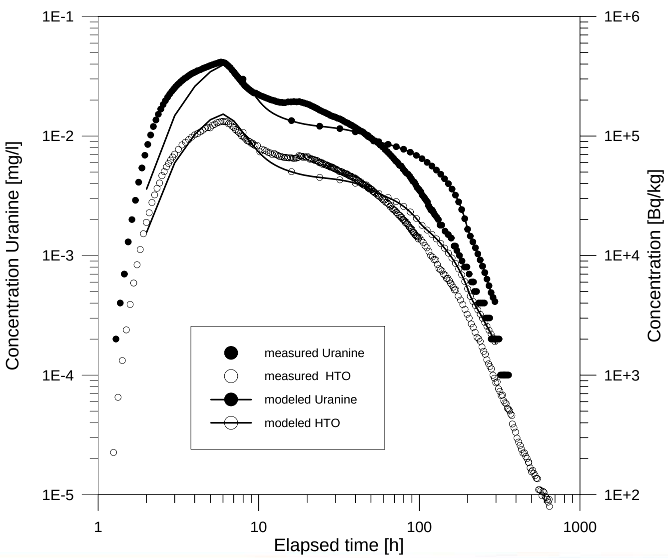
Numerical modelling of tracer transport in STT-1 Experiment
TURE-1 / HRL Äspö (Sweden)



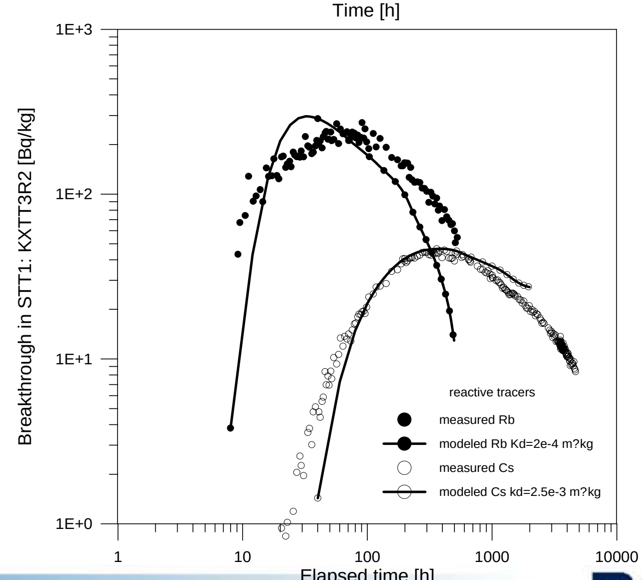
Coupled 3D model for numerical modelling



Weak sorbing tracers: Na^{22}, Ca^{147}



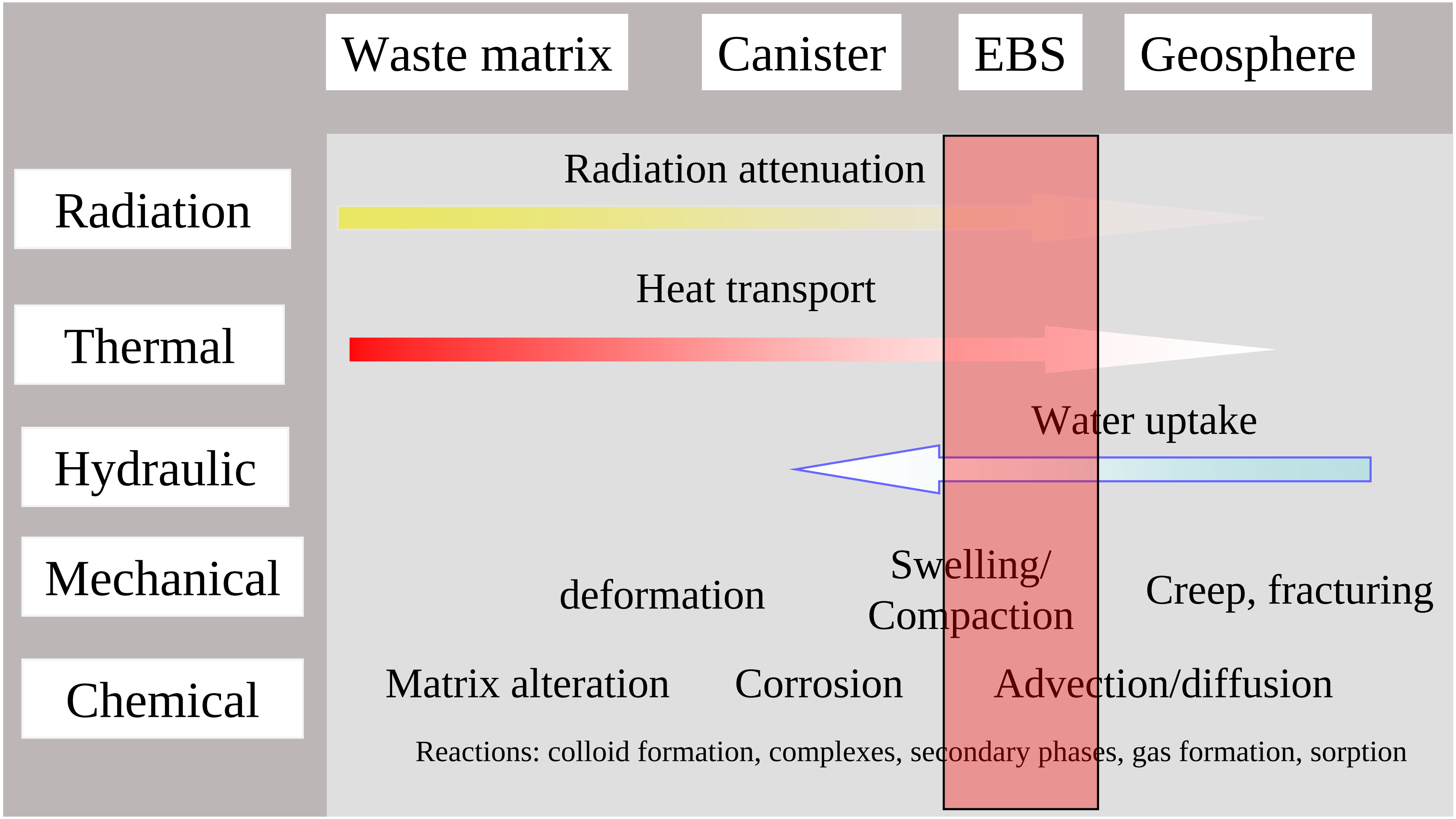
Conservative tracers: Ur, HTO



Sorbing tracers: Rb^{86}, Cs^{137}

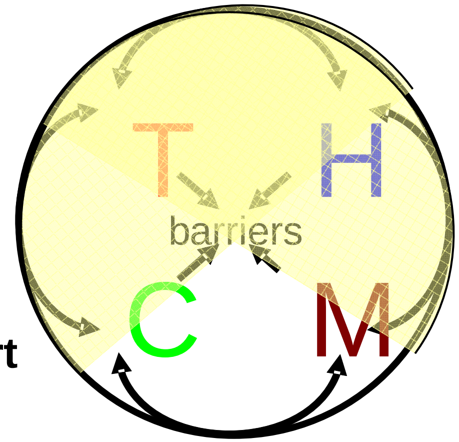
BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Interacting near-field components and predominant processes



Simulation of coupled THMC processes

Heat transport
(conduction,
Advection)



Groundwater flow
Gas flow
Multiphase flow
Unsaturated flow

Solute transport
Dispersion,
Diffusion,
Sorption,
decay und
chem. Chain reaction
(Equilibrium & Non-equilibrium reactions)
Ext. Chemical Simulators (PHREEQC, ChemApp…)

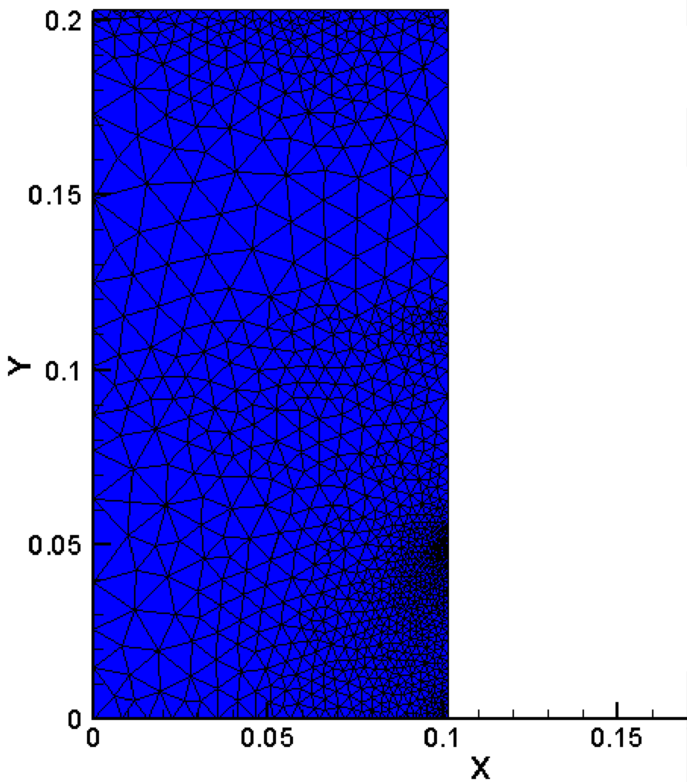
Deformation process
(elastic, plastic, creep)

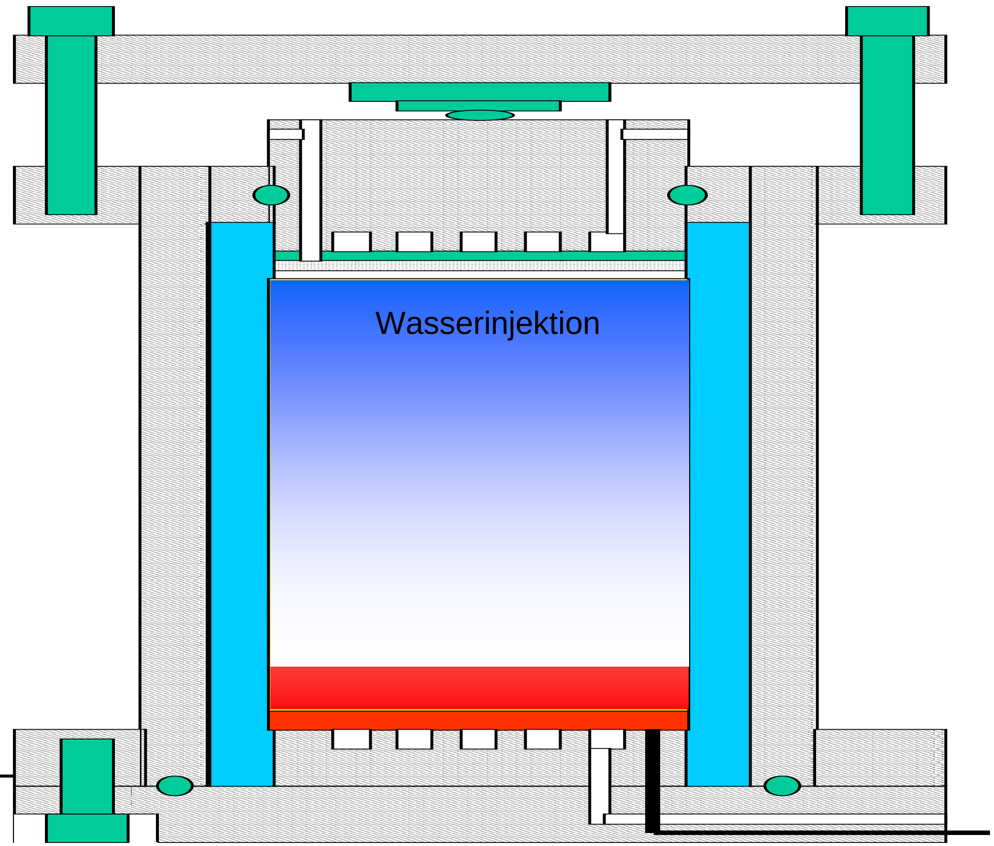
Code GeoSys/RockFlow:

- *Object-Oriented implementation*
- *Partitioned method*
- *Different time stepping for different processes*
- *Sub-Domain deactivation techniques*
- *Parallelization*

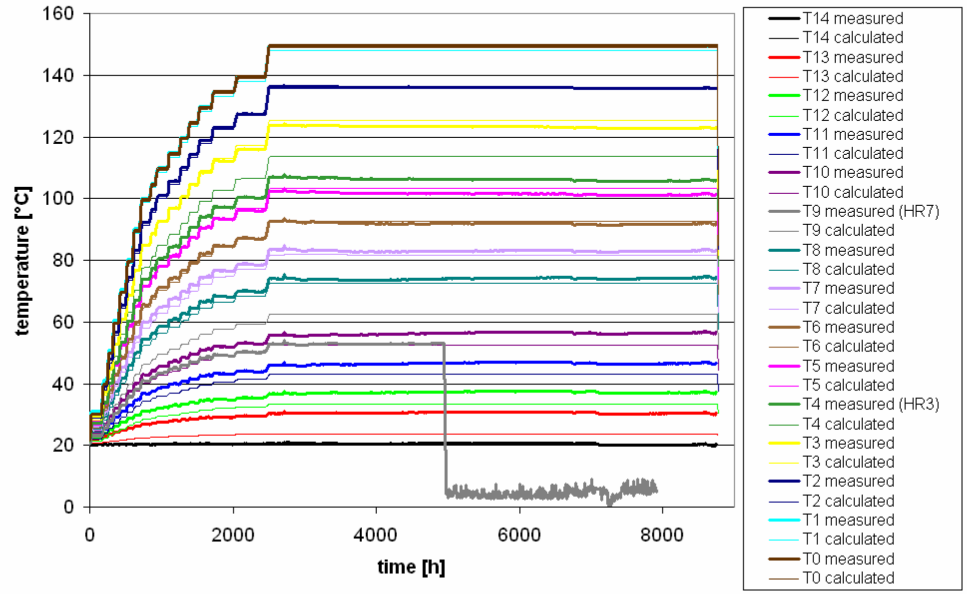
Benchmarking THM

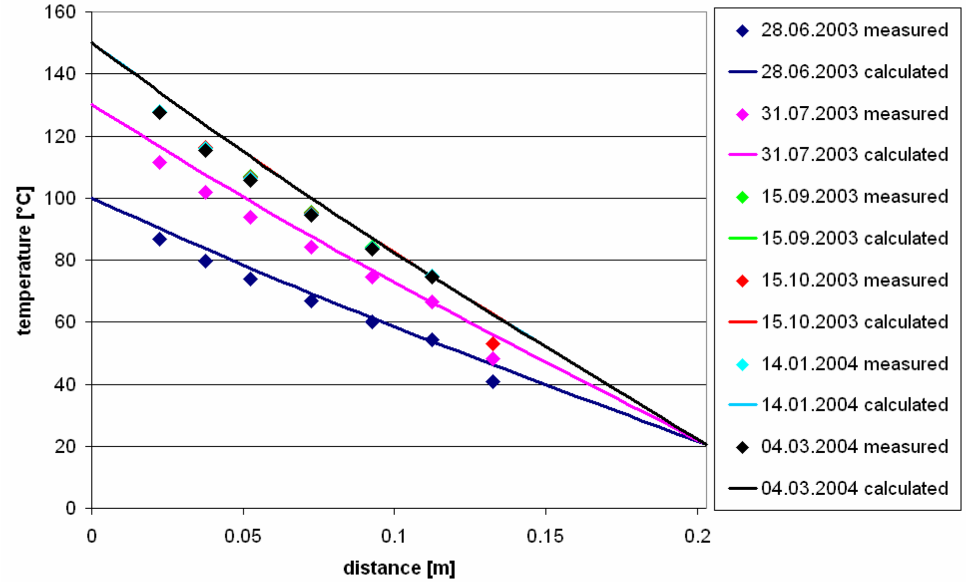
Laboratory experiments on bentonite-buffer



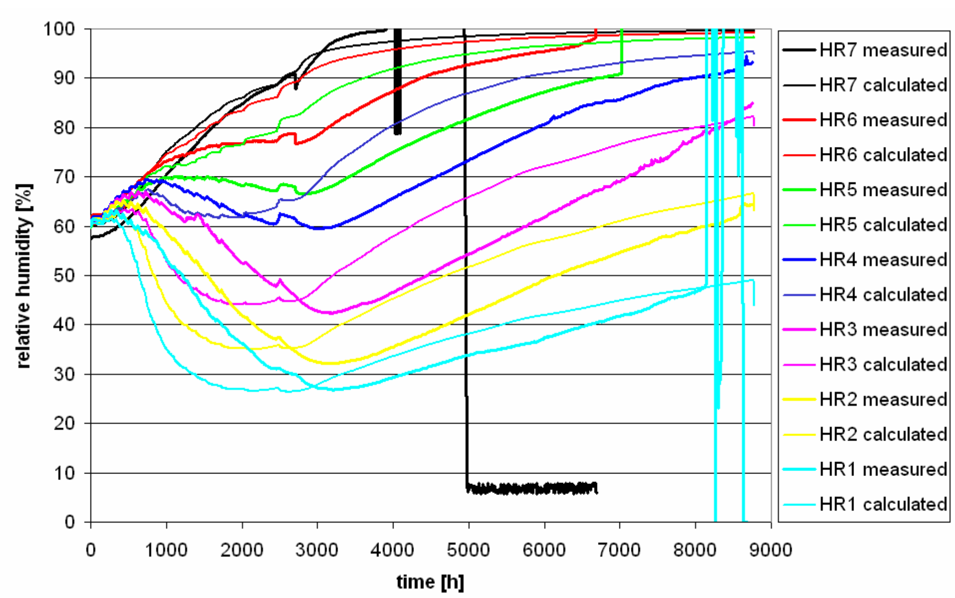


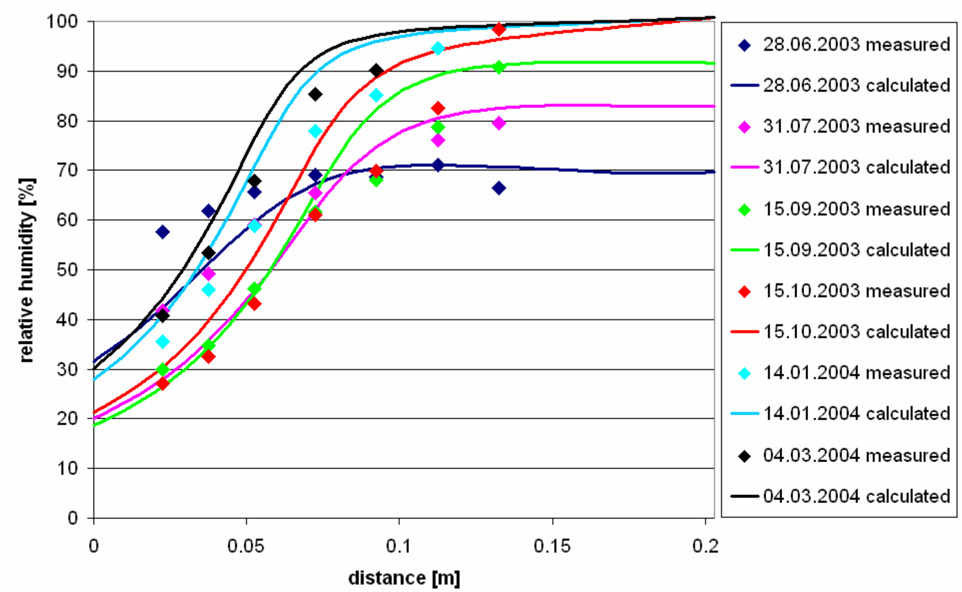
Results T: Temperature



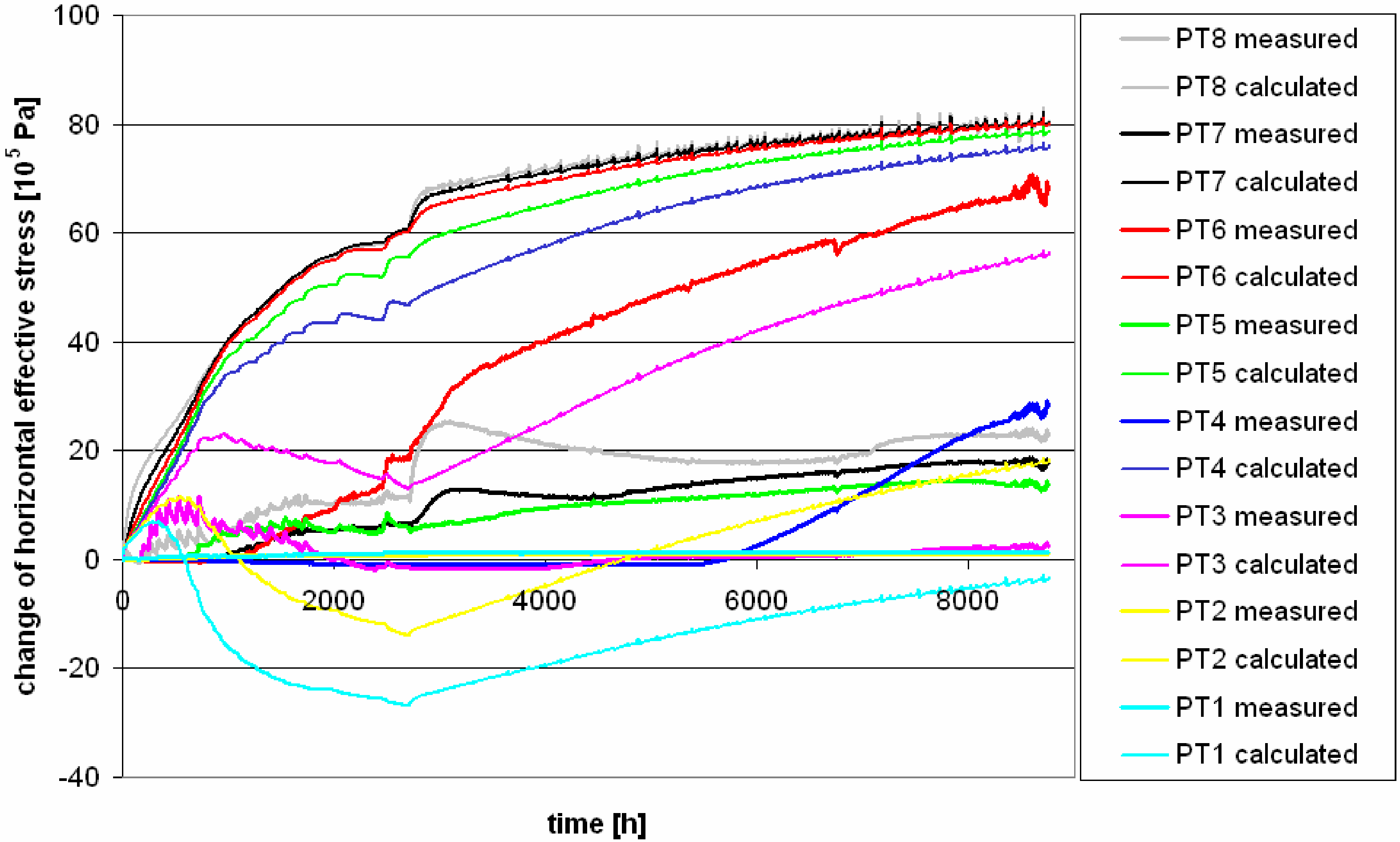


Results H: Relative humidity





Results M: Change of horizontal effective stress - evolutions



Conclusions

- Successful interdisciplinary team work
- Test of investigation concept for large-scale flow and transport processes in fractured rock
- Near-field characterisation of possible potential flow path for transport process
- Heterogeneity of the fractured rock plays an important role, which may be simulated by fracture network model using stochastic generation of parameters based on the statistical evaluation of geological fracture data
- Long-term monitoring and modelling of the coupled THM(C) processes under natural conditions
- Validation of numerical code against laboratory and in situ experiments for ‘confidence building’
- Investigation of interaction between geological and geotechnical barrier systems

in situ Hydro-Mechanical Characterisation of Clay Formation and Coupled HM Modelling

Dr. SHAO, Hua
Federal Institute for Geosciences and Natural Resources (BGR)
Hanover, Germany

Bundesanstalt für Geowissenschaften und Rohstoffe

BGR Research Programs in Clay Formations

In situ measurements

- **Permeability**
- ***In situ* stress**
- **Seismic**

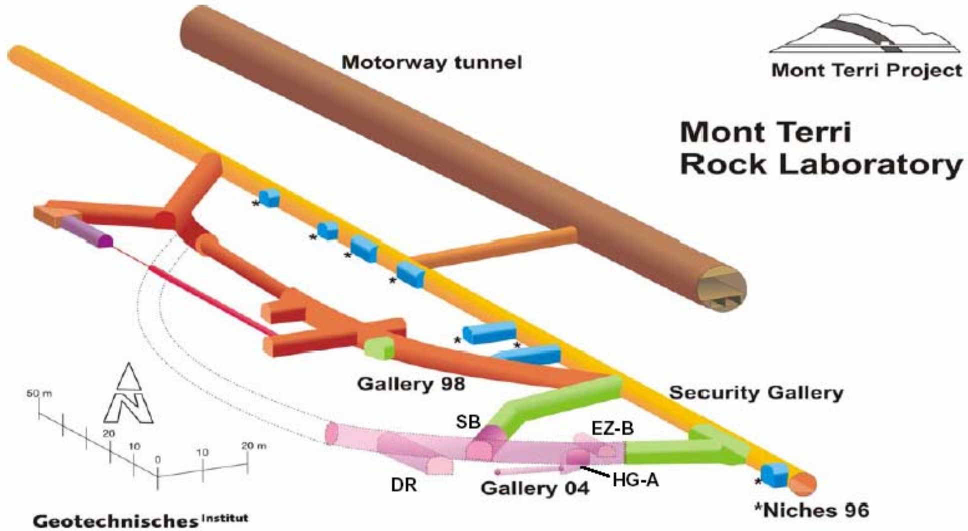
Laboratory tests & Modelling

- *Rock properties*
- **Coupled HM processes**

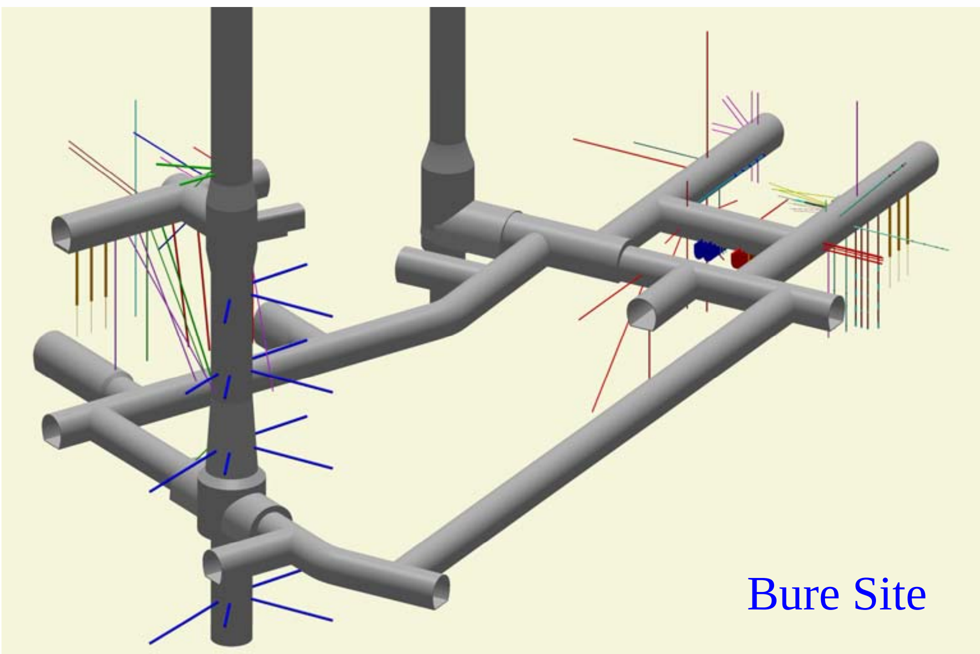
(Schuster (BGR), 2005)

Test Sites

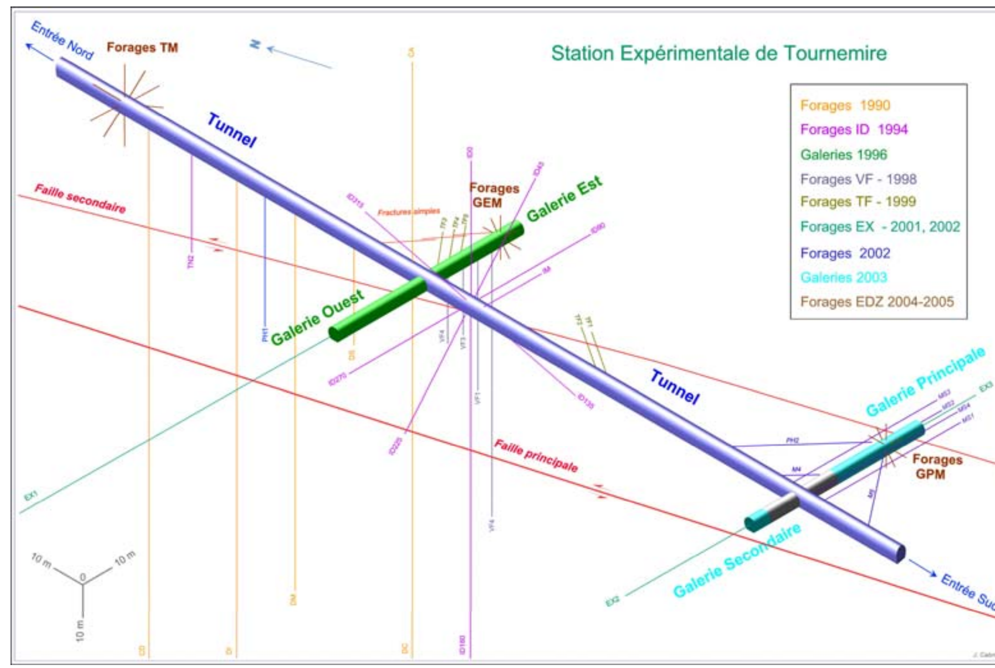
- Mont Terri (CH)
- Bure (F)
- Tournemire (F)



(GI, 2006)

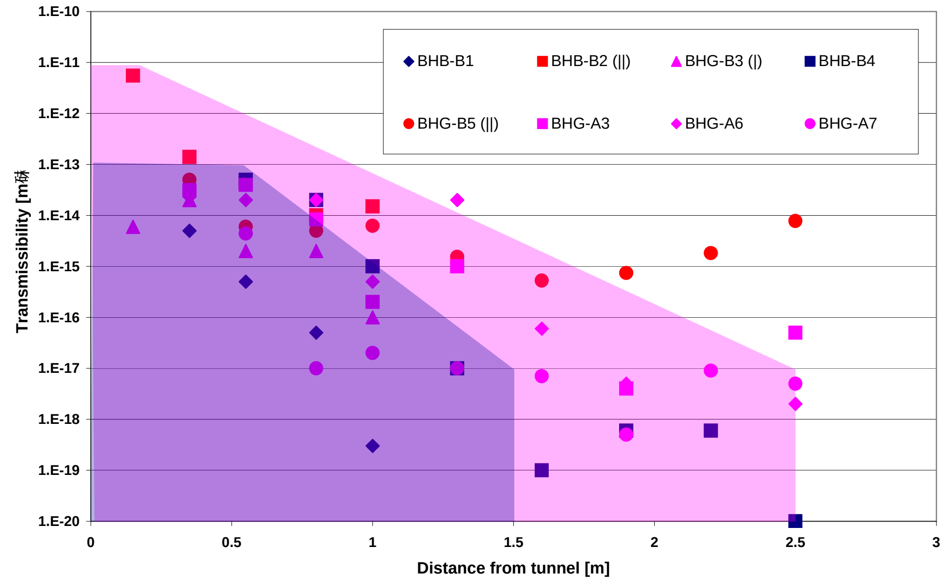


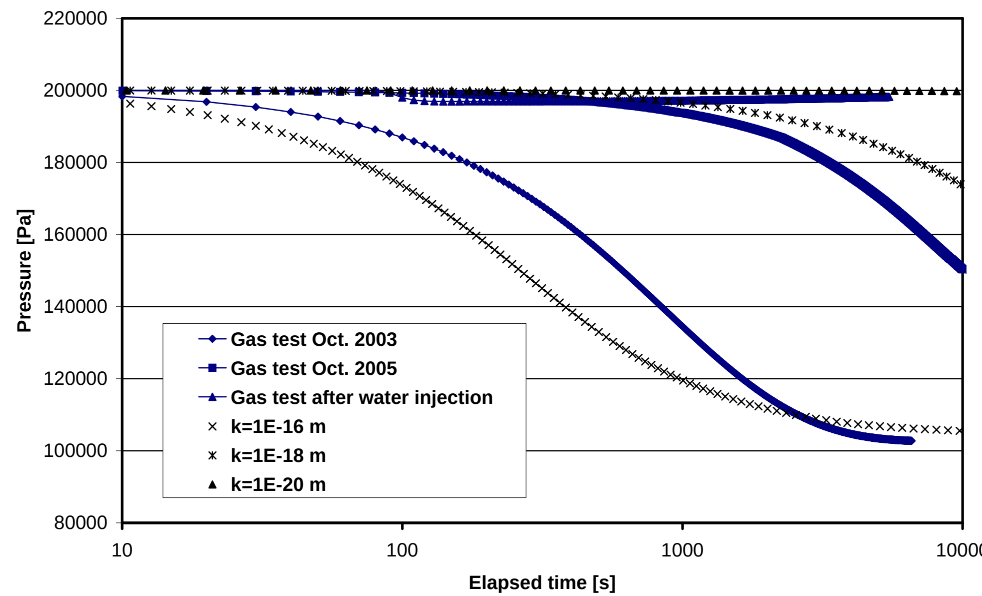
(ANDRA, 2006)



(IRSN, 2006)

EDZ Permeability / Permeability Development

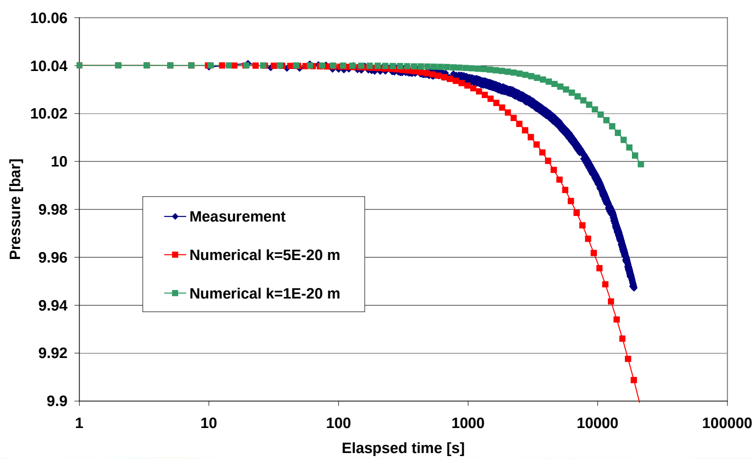


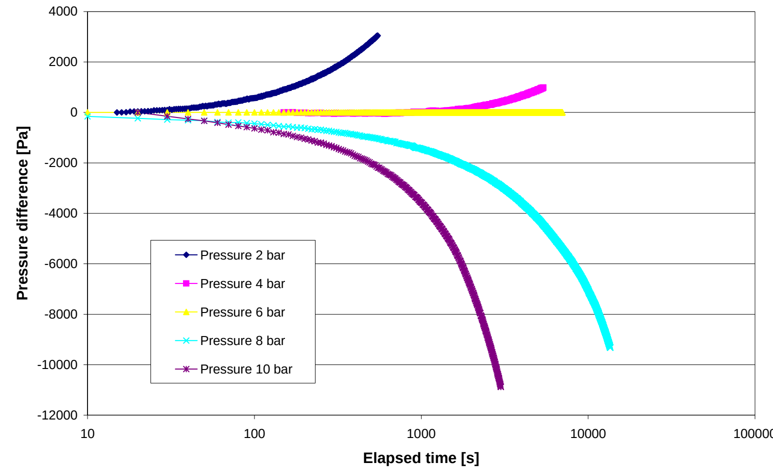


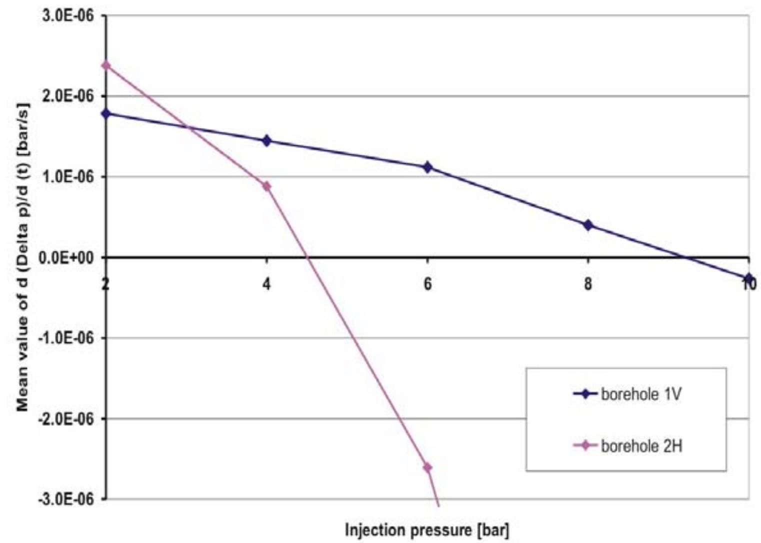
- Testing immediately after the drilling
- Mechanical double packer with 10 cm interval for testing (max. 2.5 m)
- High k > 1.E-16 m²: 1.5 m (⊥) and 2.5 m (||)
- Instable borehole parallel to bedding
- Permeability decrease up to one order of magnitude after two years (temporary)
- Permeability decrease up to two orders of magnitude due to humidity (swelling)

Far-Field Gas Permeability / Gas Entry Pressure

- ➢ Testing using a single packer (max. 20 m)
- ➢ Stepwise Increase of Gas Injection Pressure → Gas entry pressure (0.4 – 1.0 MPa)
- ➢ Evaluation of experiment using numerical two-phase-flow model taking capillary and pore water pressure into consideration
- ➢ Gas permeability k < 5.E-20 m² (10 bar)

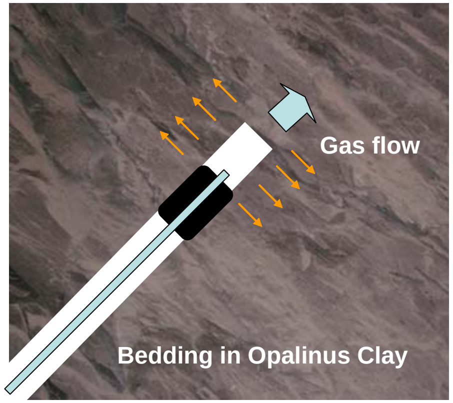


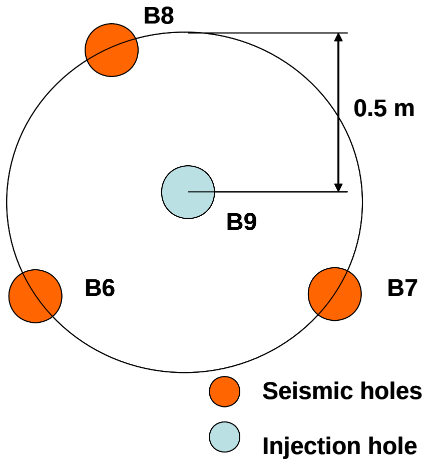


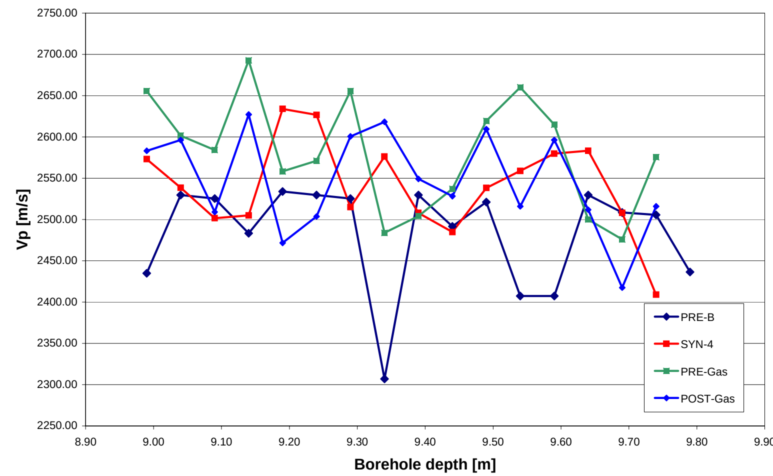


Dilatancy controlled gas flow and self-sealing capability

Concept

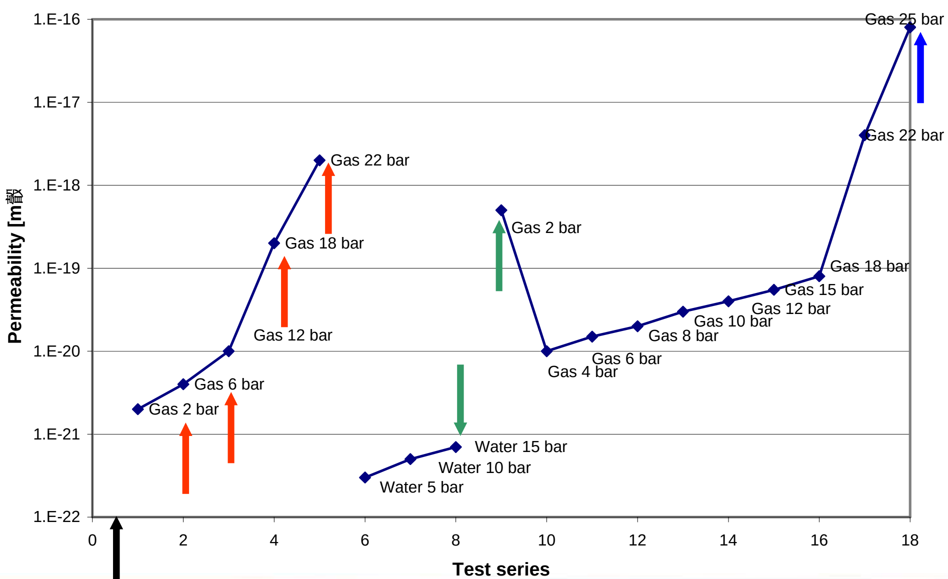


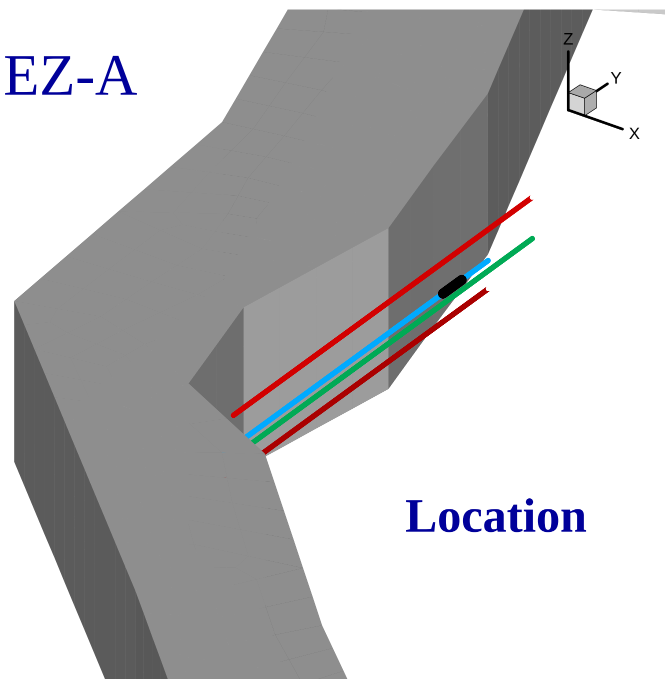




Seismic result

Test series

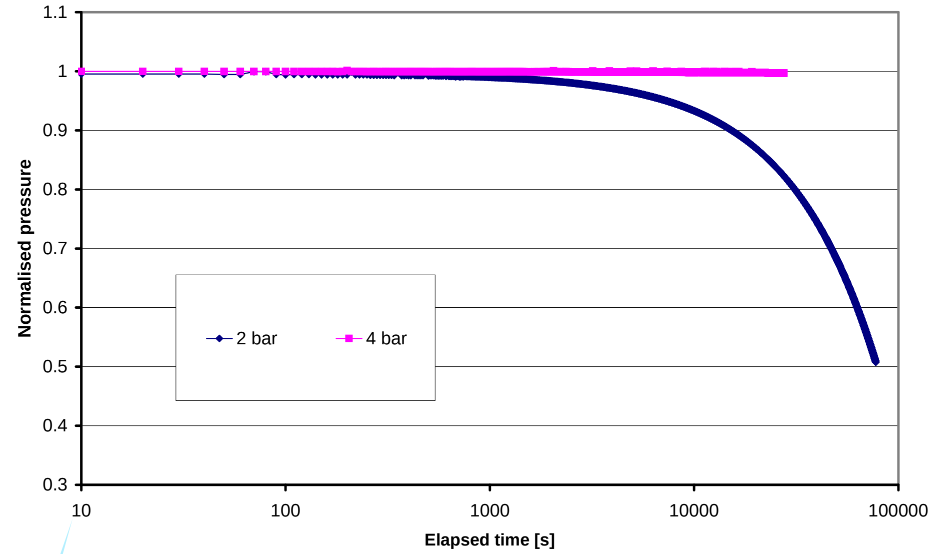


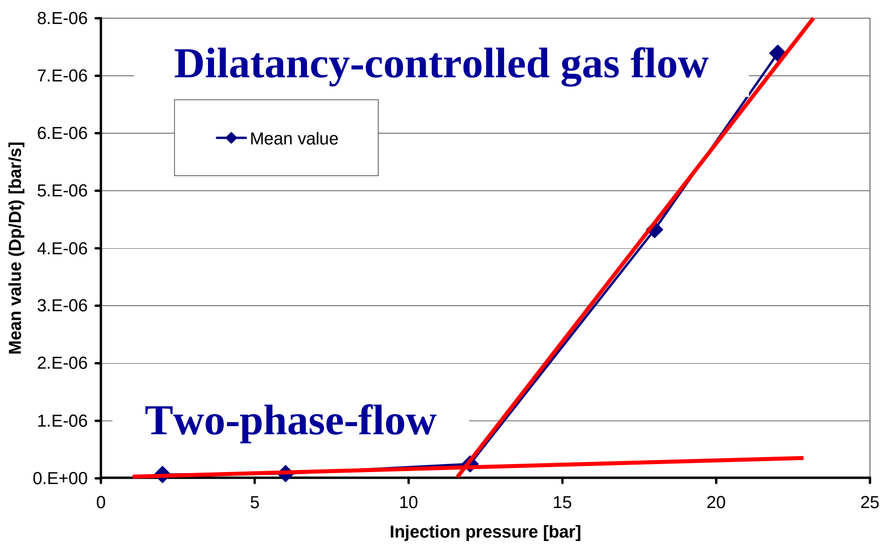


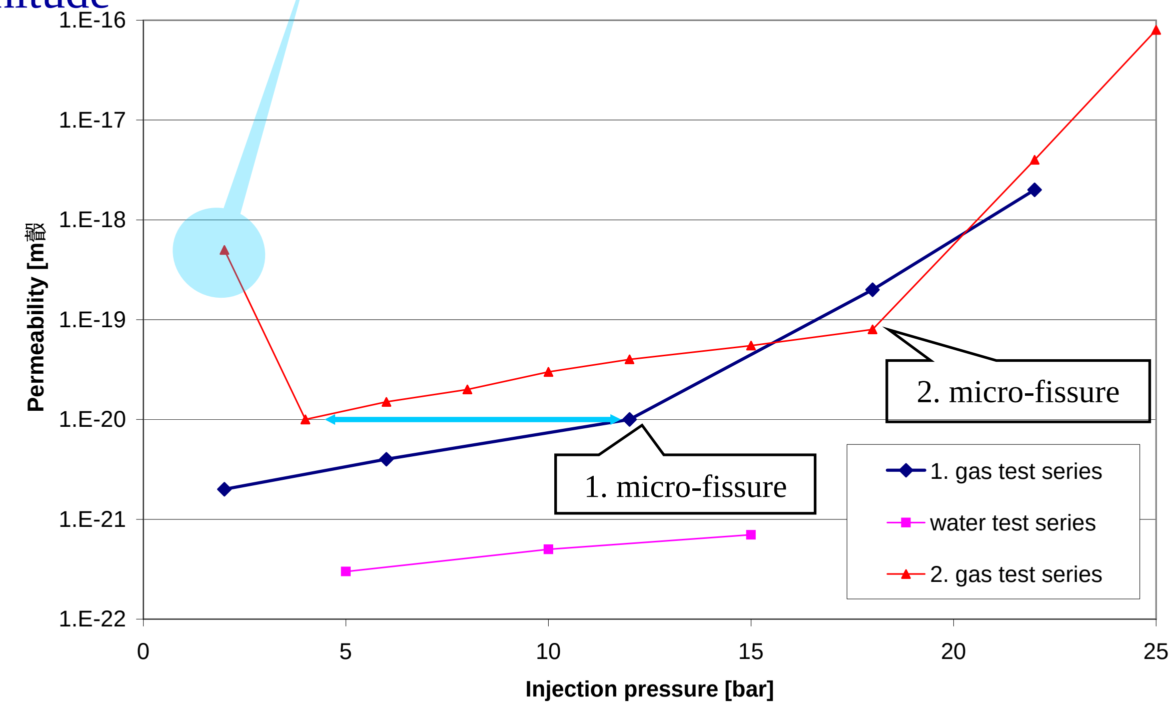
Location

Semi-Permeable Membrane Function

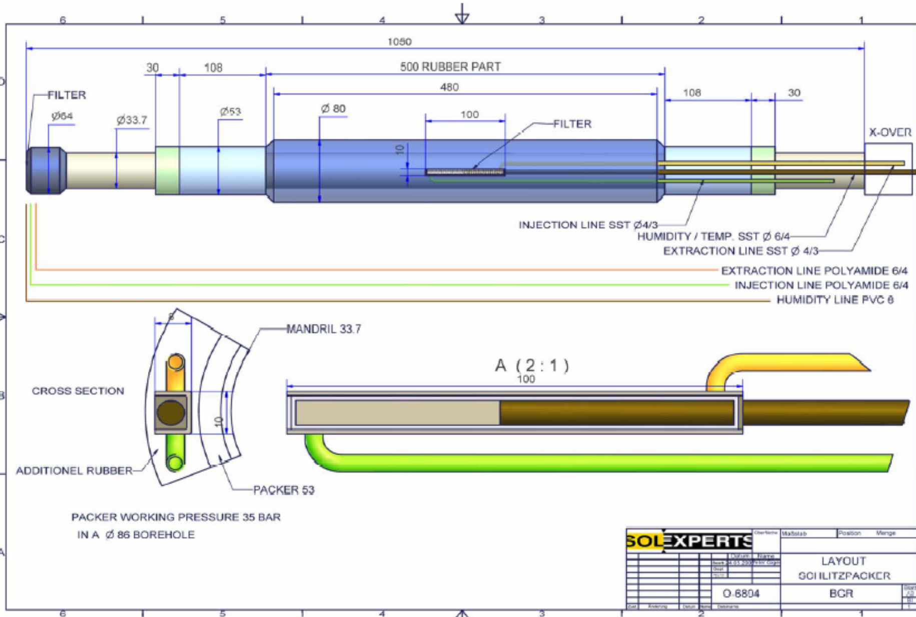
- Determination of two gas-flow-regimes (1.2 MPa)
- Linear relationship between permeability and injection pressure
- (Gas/Water) Pressure dependent permeability
- Sealing through swelling reduce the permeability (2 orders of magnitude)
- Permeability to water is 2 orders of magnitude lower than permeability to gas



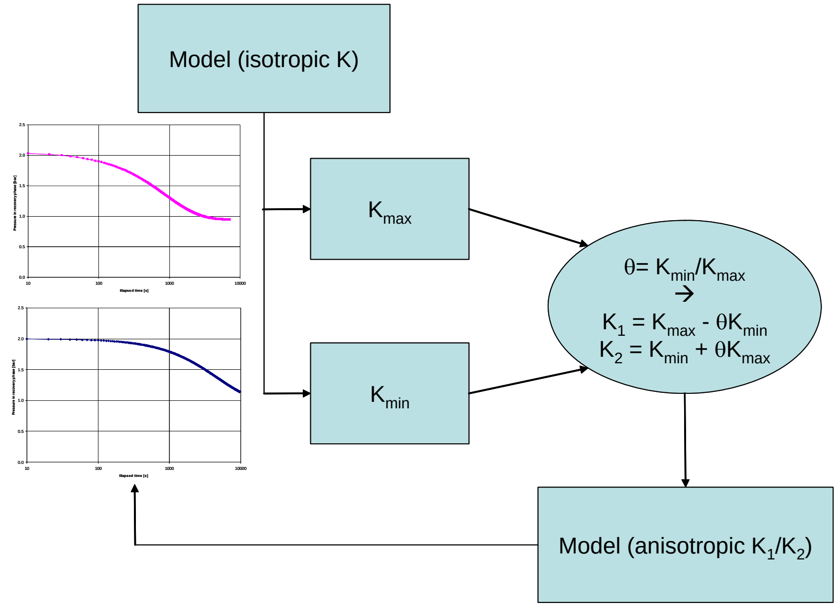




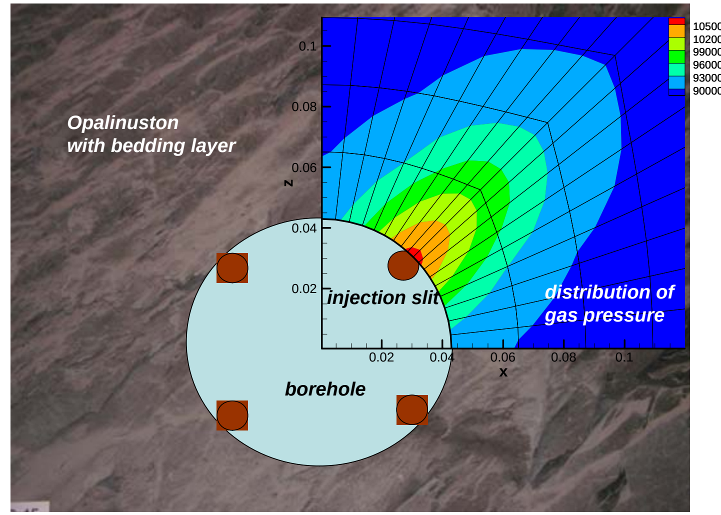
Determination of Hydraulic Anisotropy

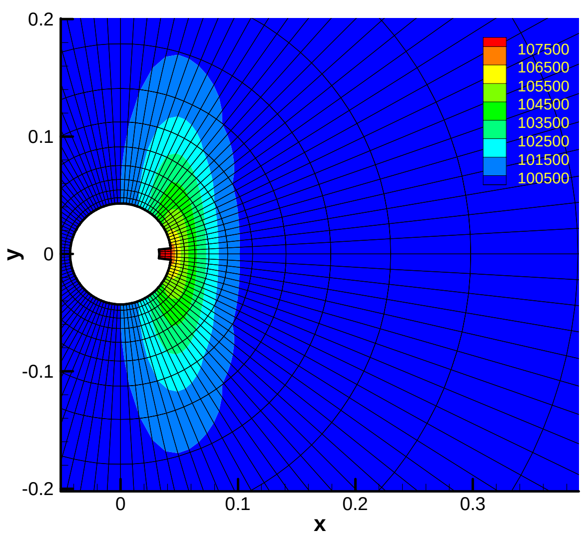


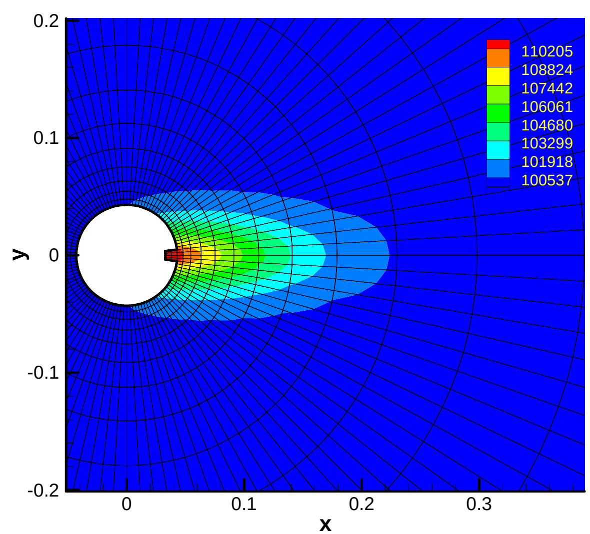
Numerical Evaluation

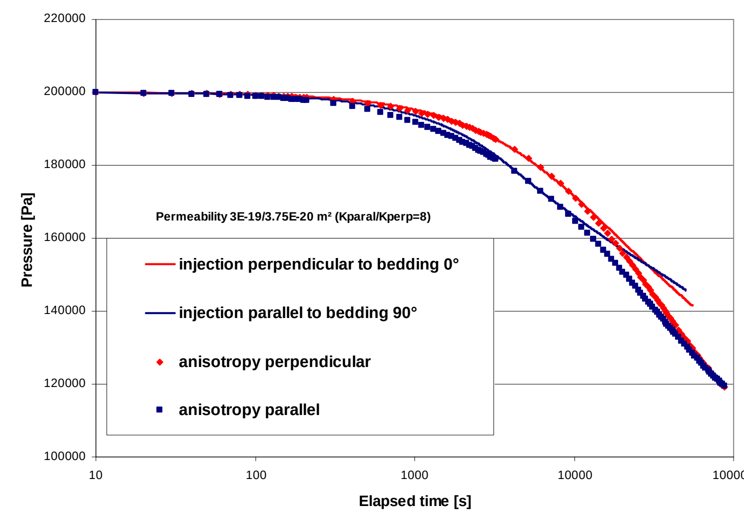


$K_{\parallel}/K_{\perp}=8$

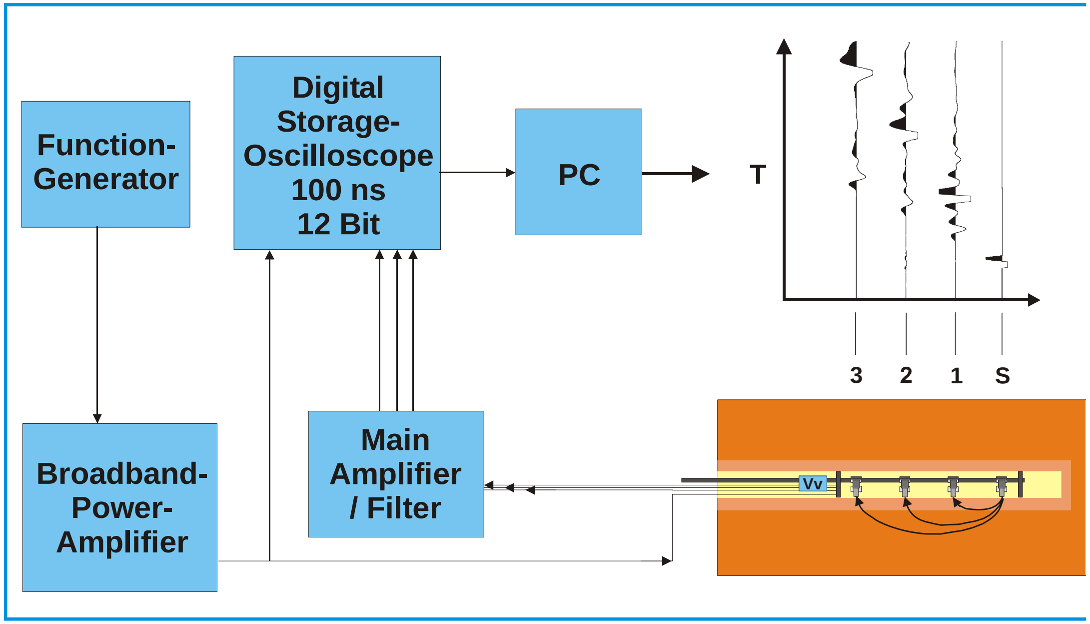


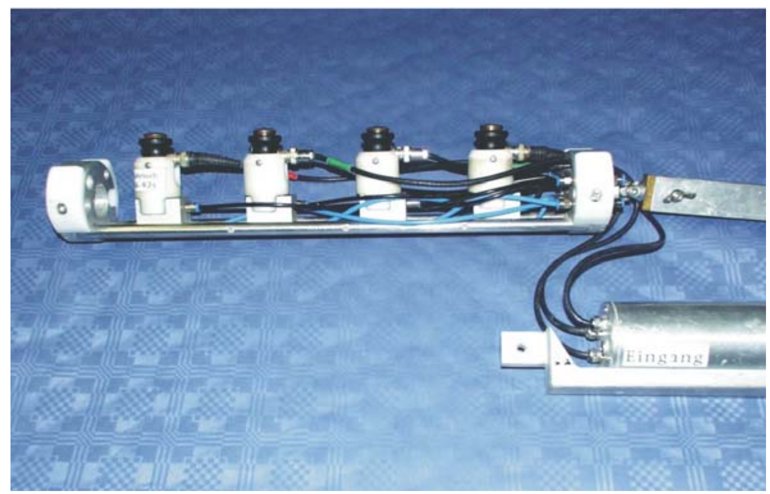






Mini-Sonic-Probe

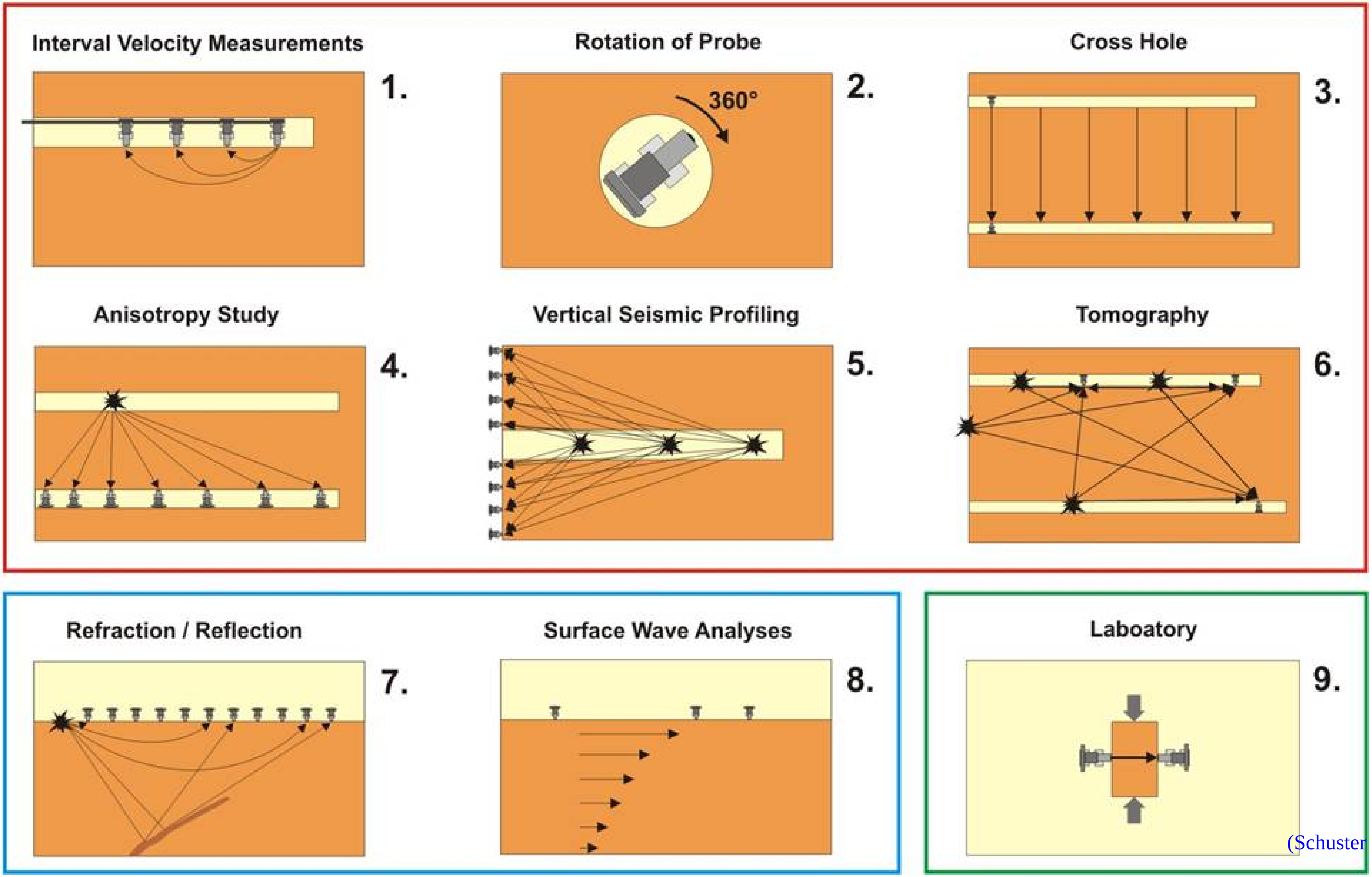




- ➢ Crystalline rock: Grimsel, Äspö
- ➢ Salt rock: Morsleben, Gorleben
- ➢ Clay stone: Mont Terri, Bure

(Schuster (BGR), 2005)

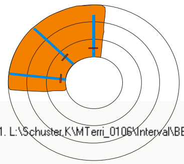
Applied seismic in situ methods



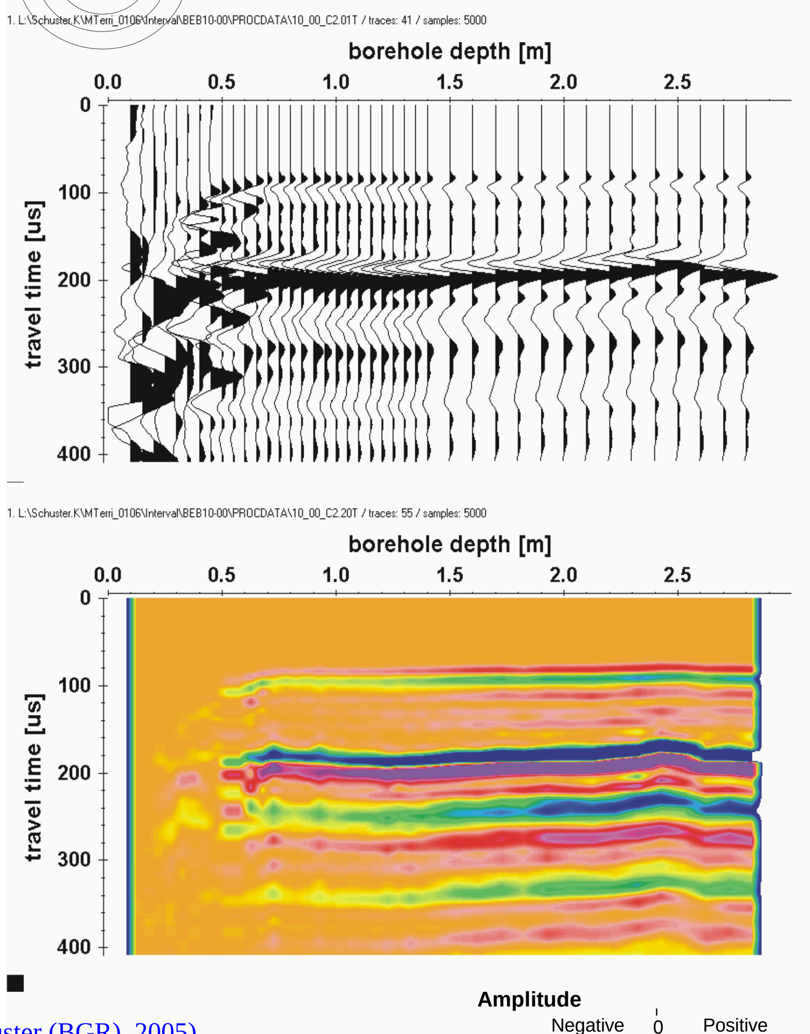
(Schuster (BGR), 2007)

EDZ Characterisation

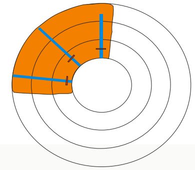
B 10



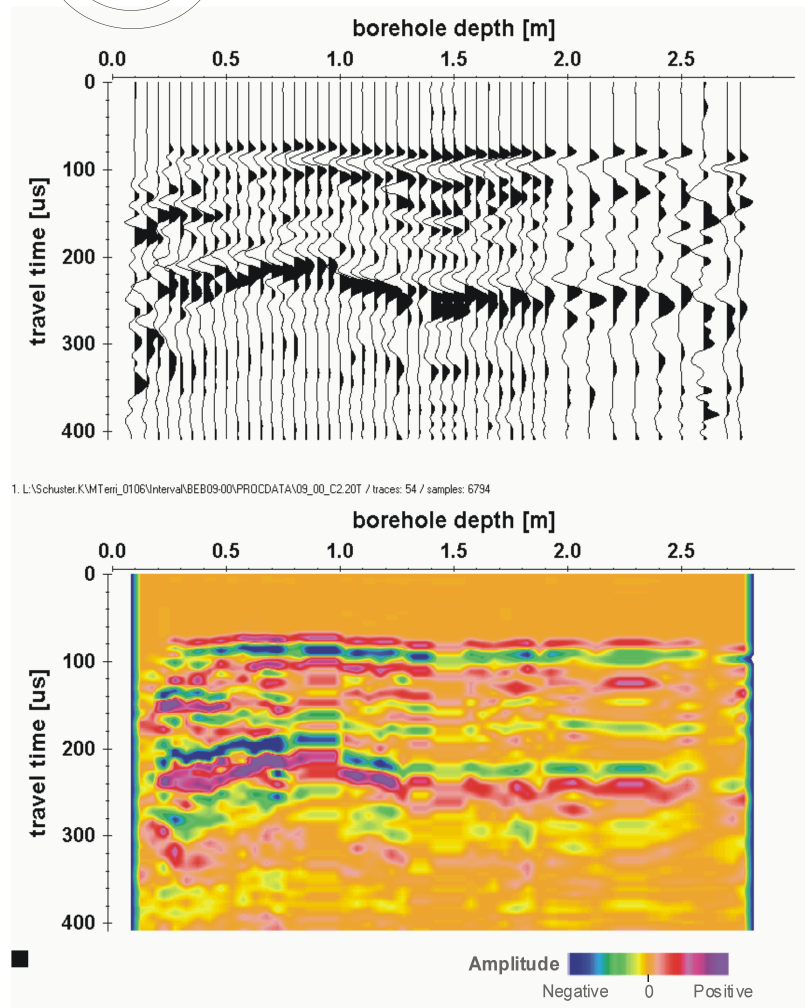
Borehole B10, 45° inclined



B 9



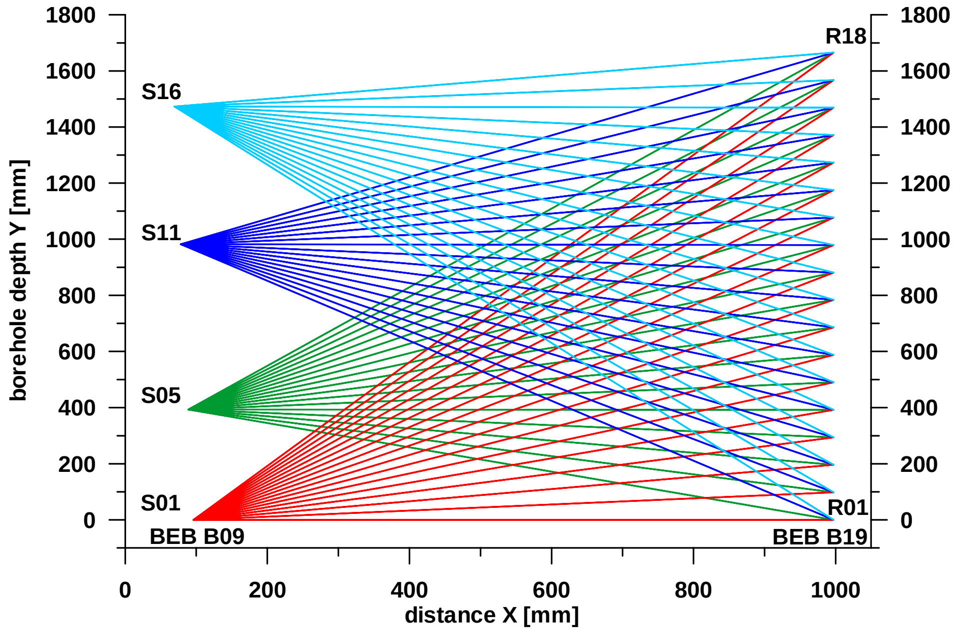
Borehole B9, 10° inclined



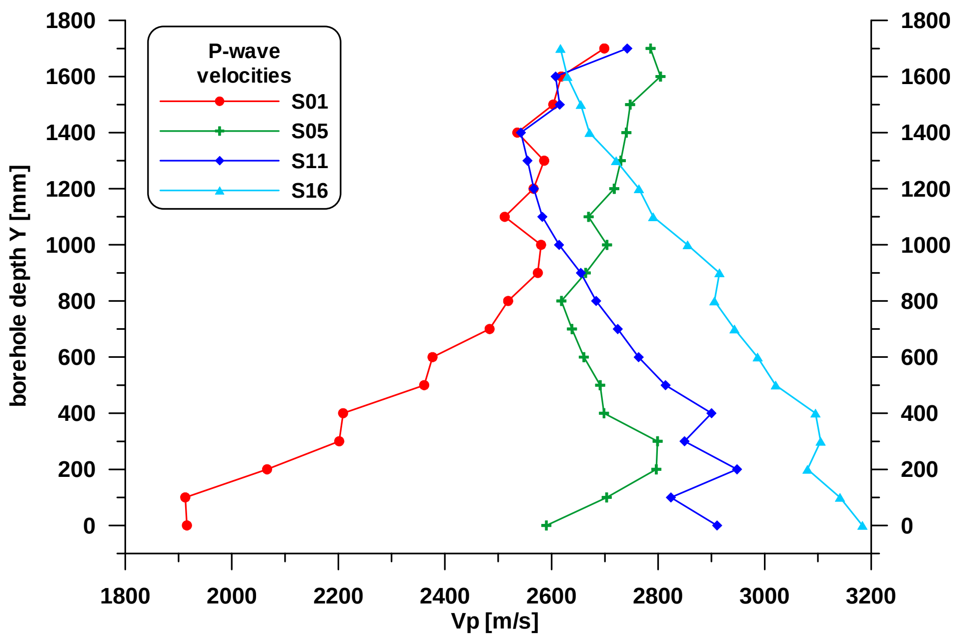
(Schuster (BGR), 2005)

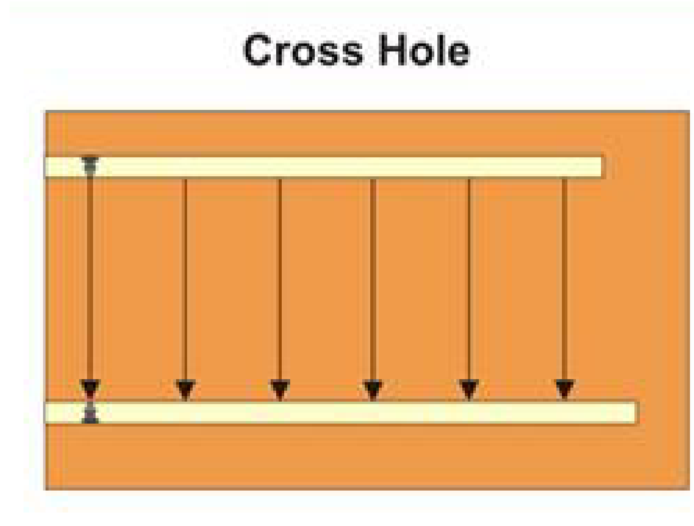
High resolution

cross hole measurements

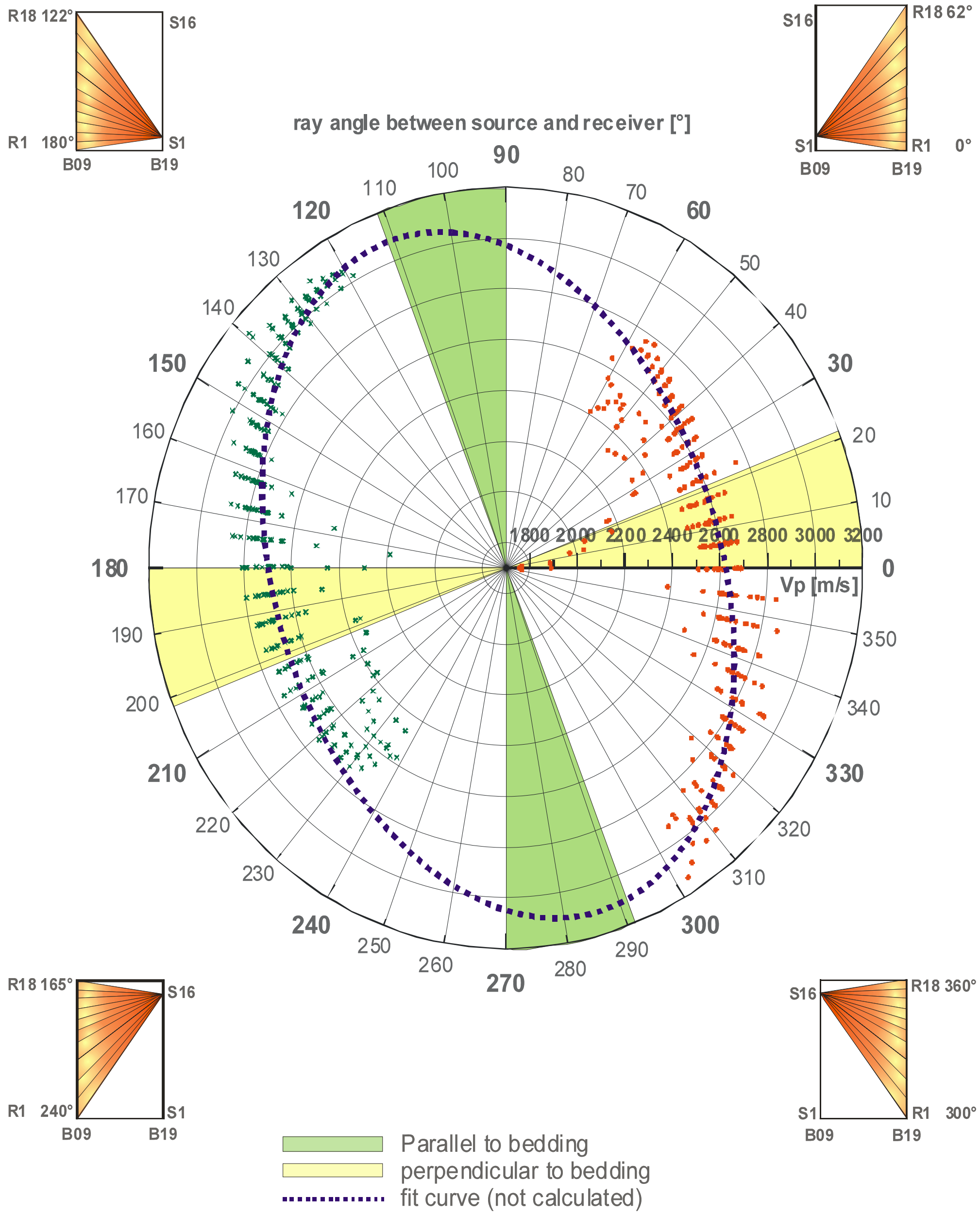


between subhorizontal boreholes
distance: 1 m





(Schuster (BGR), 2007)



Seismic Anisotropy

Result of cross hole measurements

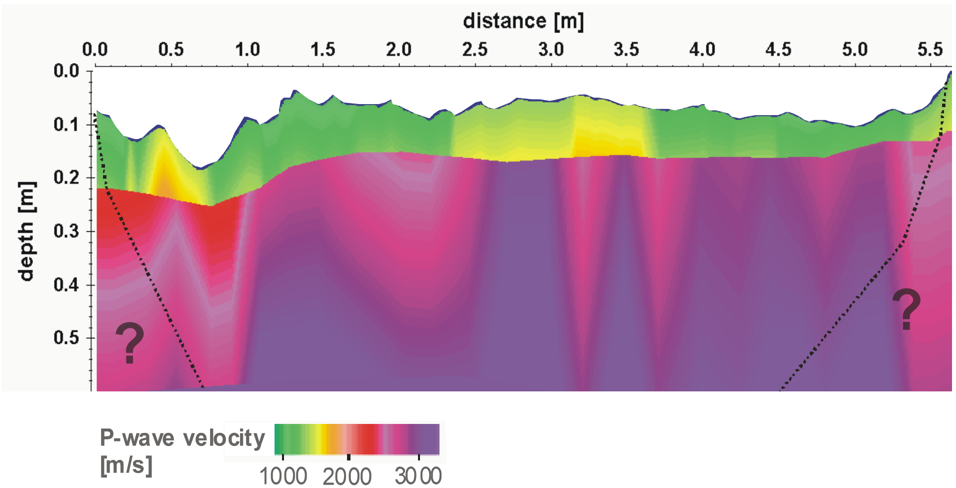
EB-Niche

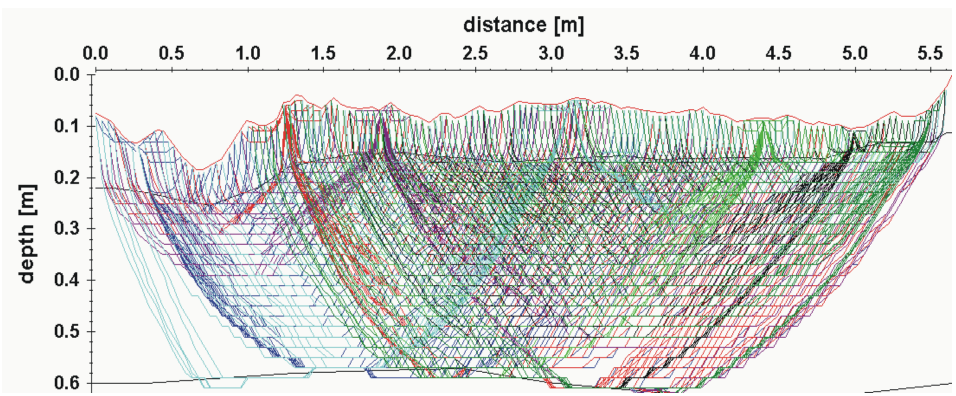
Total no. of rays: 576

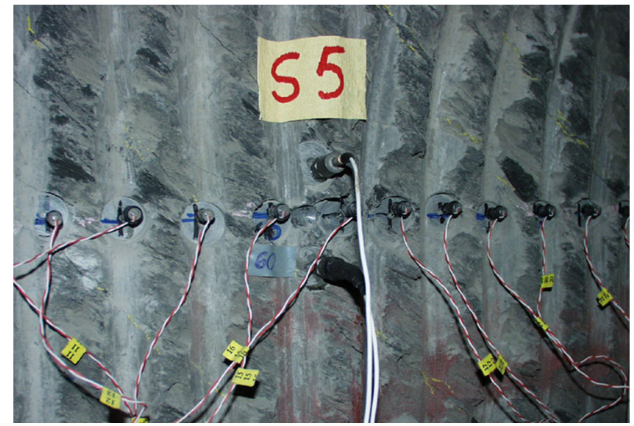
(Schuster (BGR), 2007)

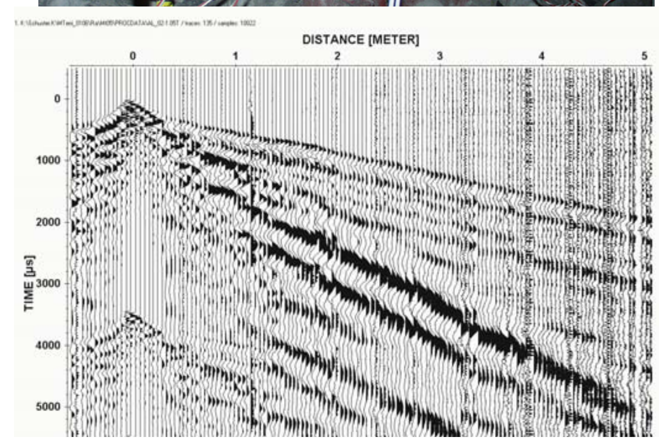
Seismic refraction measurements

traveltime inversion and iterative FD foreward modelling







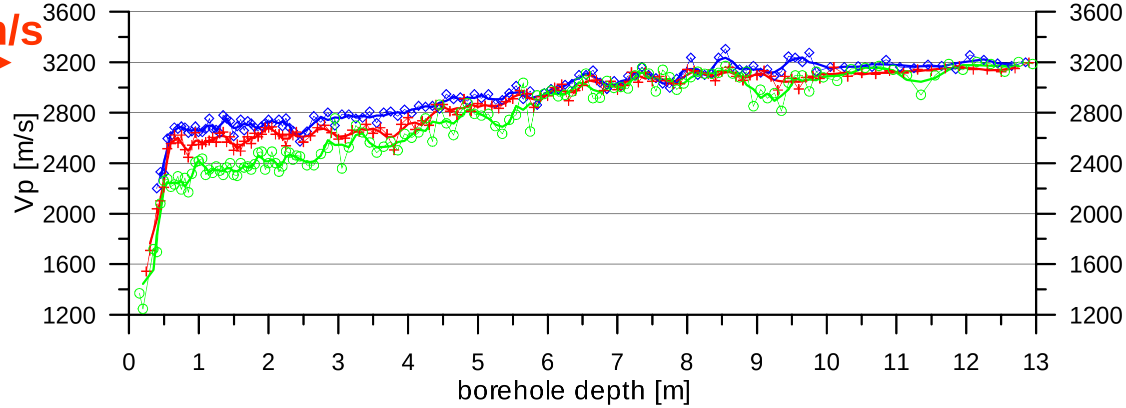


(Schuster (BGR), 2007)

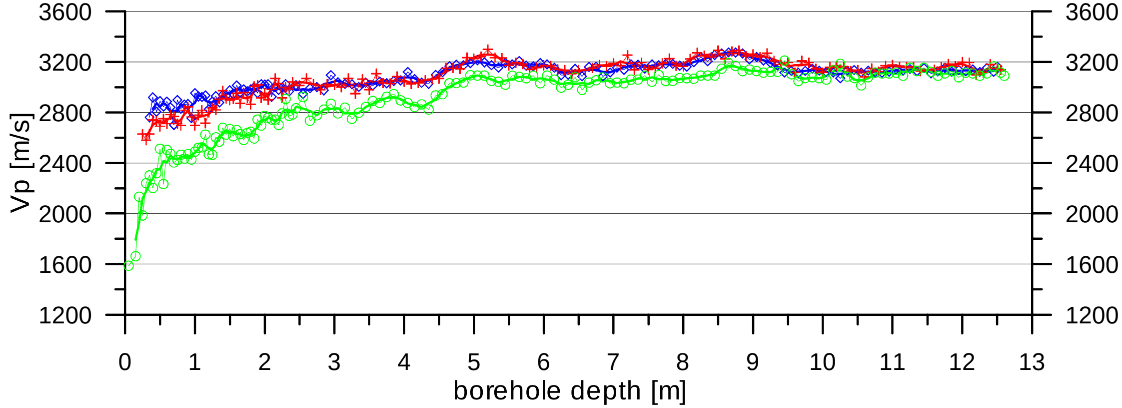
(Schuster (BGR), 2007)

Results from shaft measurements

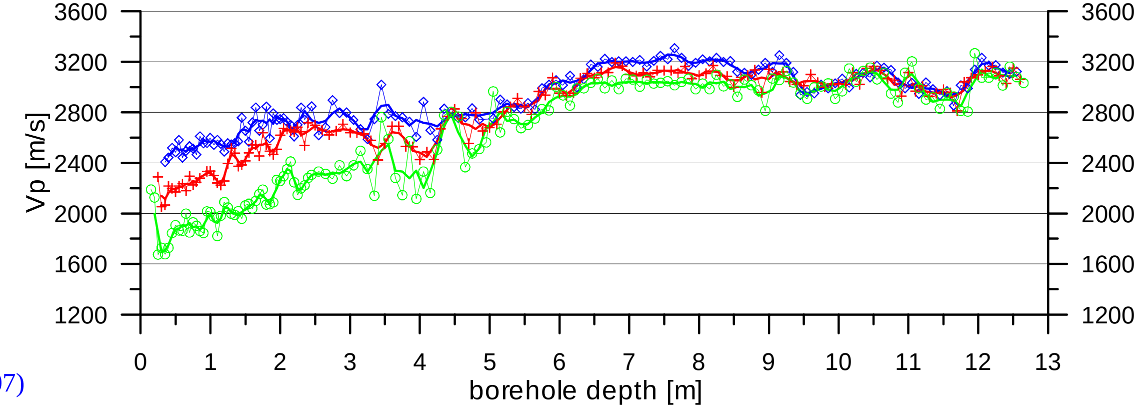
SUG1103
(GalPX, -490,8m level, NNW)



PPA0035
(shaft PA, -480.3m level, F1, N320°E)



PPA0039
(shaft PA, -504m level, F1, N320° E)

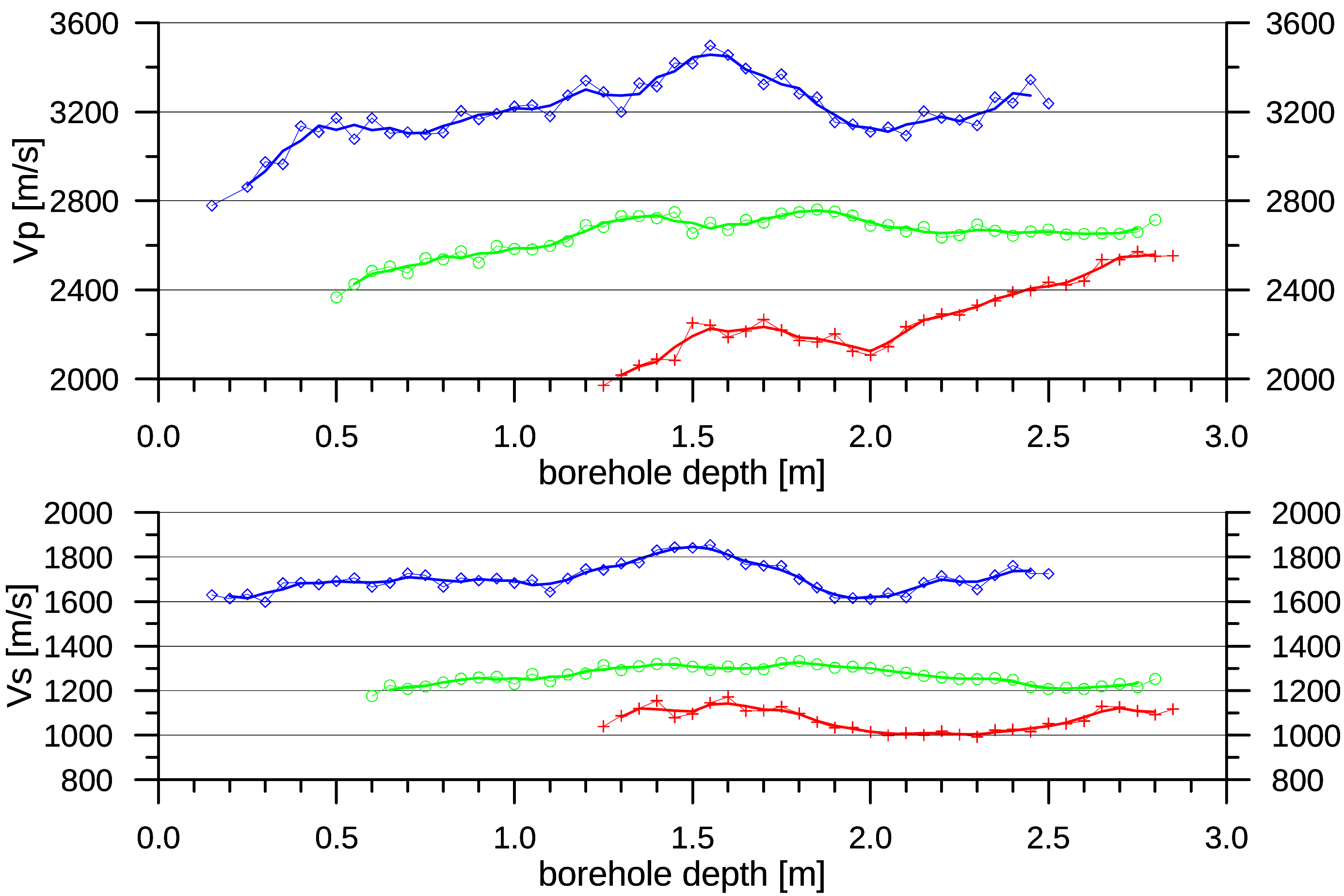


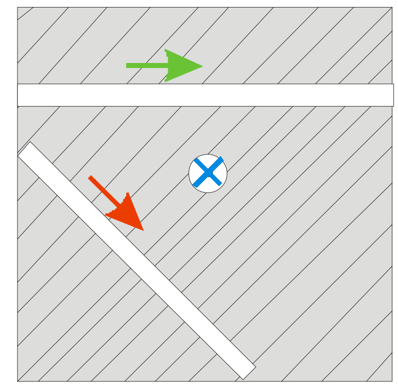
Horizontal distance „SUG – PPA“ : > 100 m
all boreholes sub-horizontal

circles: chan 1 **crosses: chan 2** **diamonds: chan 3**
dz = 10 cm **dz = 20 cm** **dz = 30 cm**

(Schuster (BGR), 2007)

Derived parameters from seismic interval velocity measurements

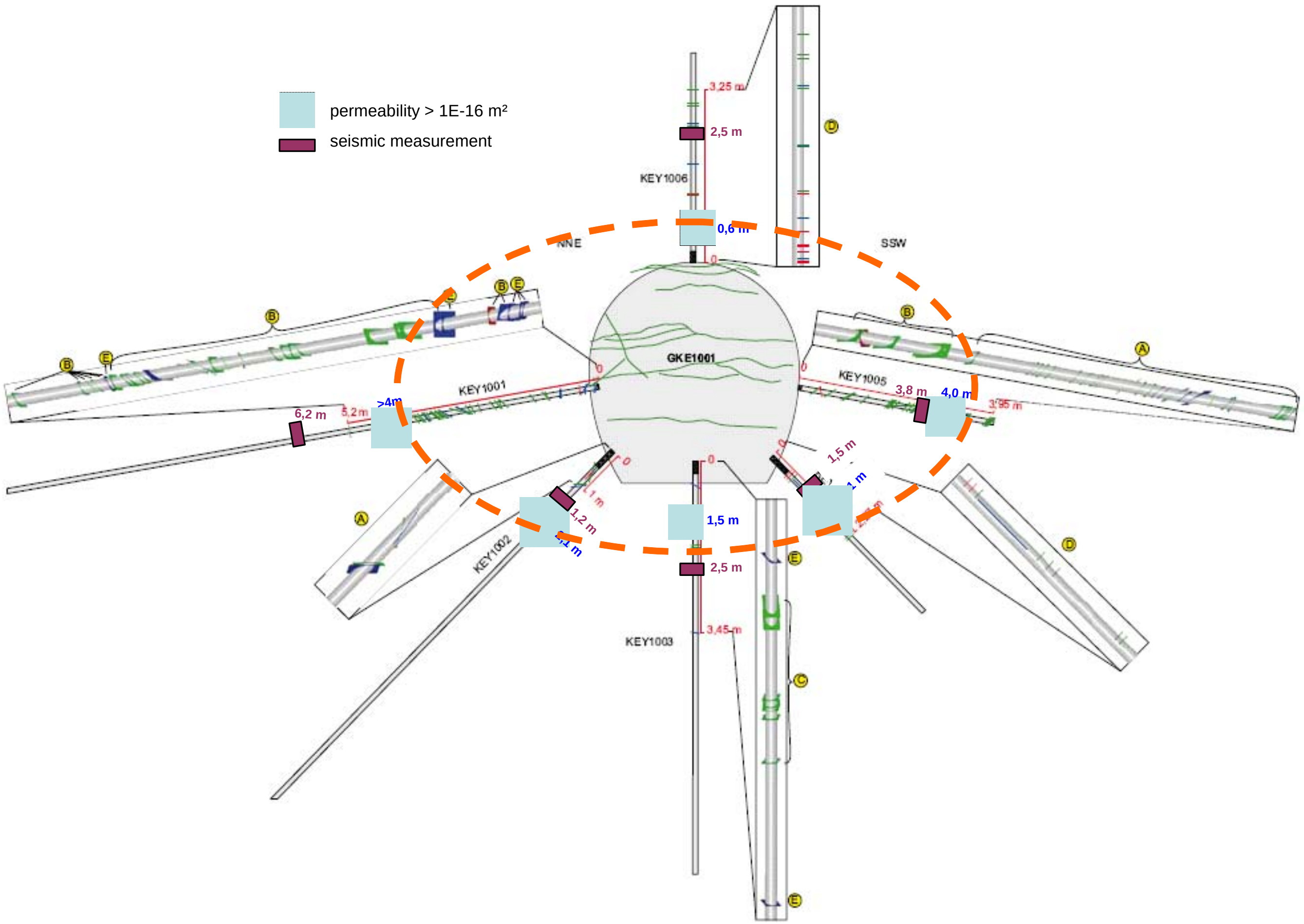




Orientation to bedding:
circles: B03 45°
crosses: B13 perpendic.
diamonds: B14 parallel

(Schuster (BGR), 2007)

Permeability Distribution - Comparison with Seismic Results and Geology



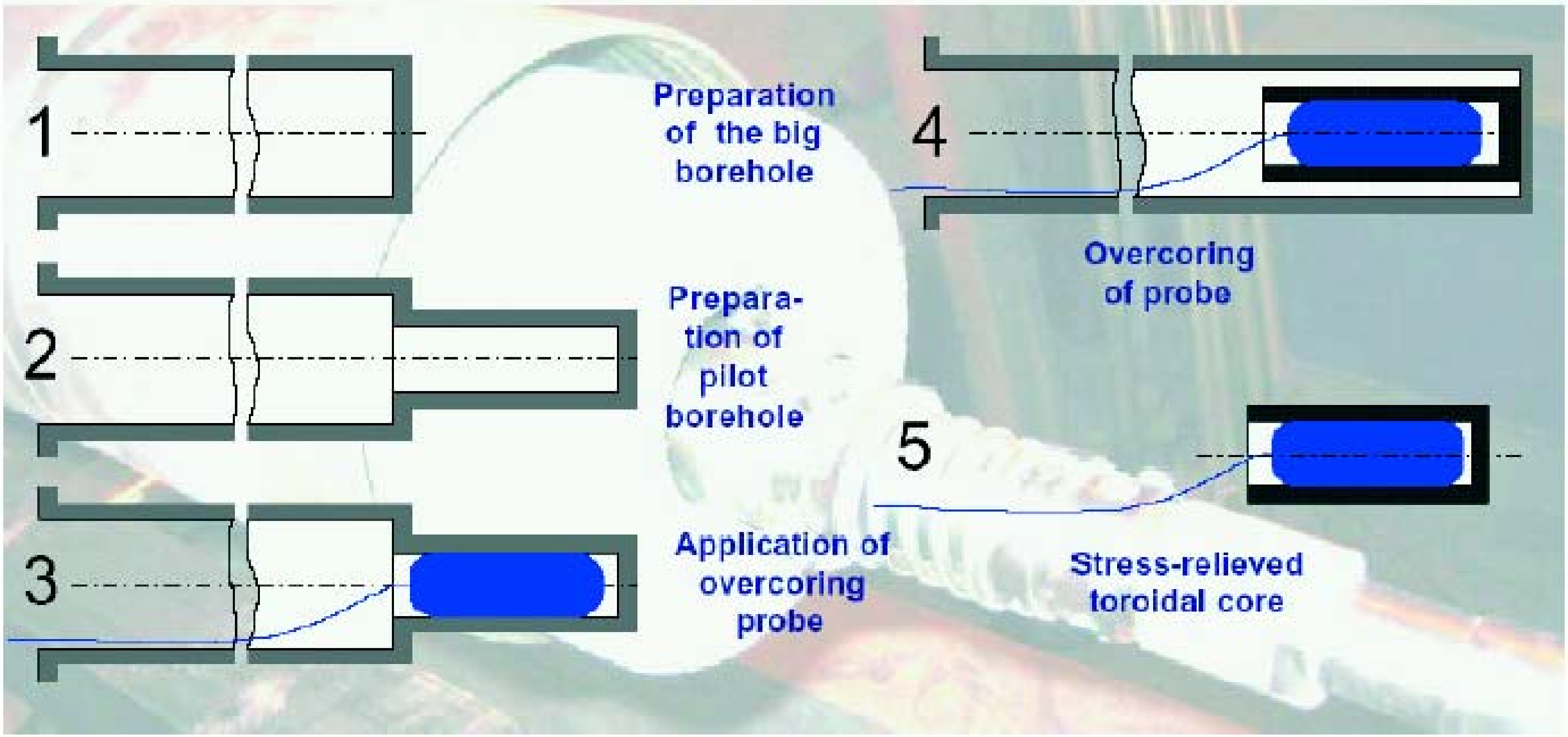
(BGR, 2005)

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Initial Rock Stress Measurement

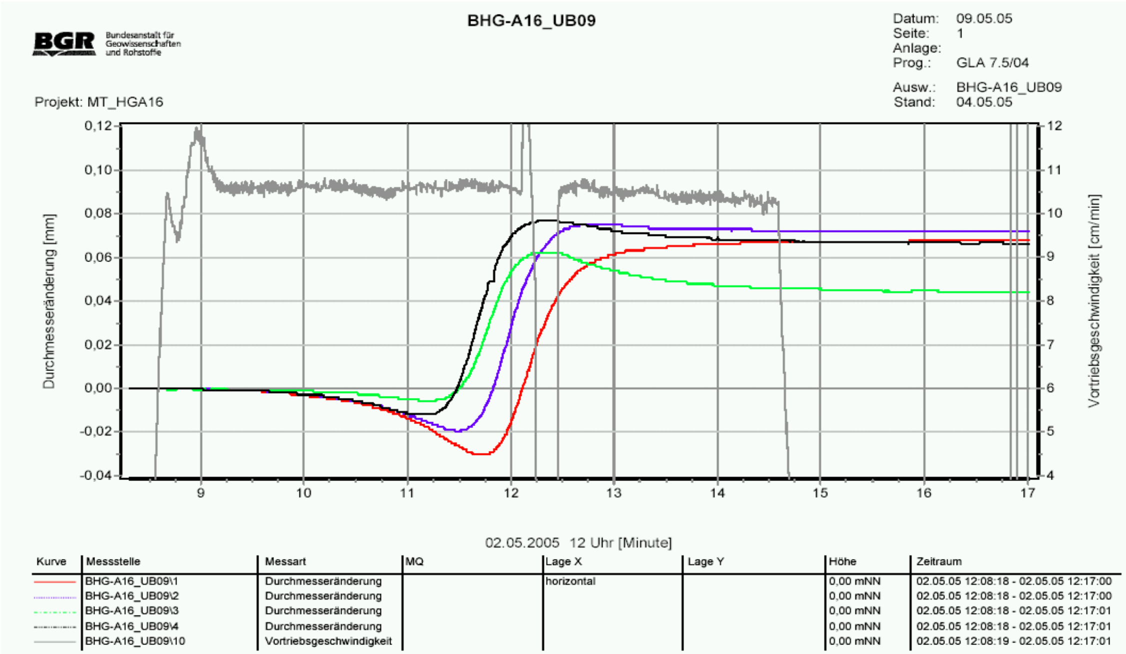
Installation of the overcoring drilling rod

BGR Overcoring Experiment



Principle of stress measurement with overcoring probe

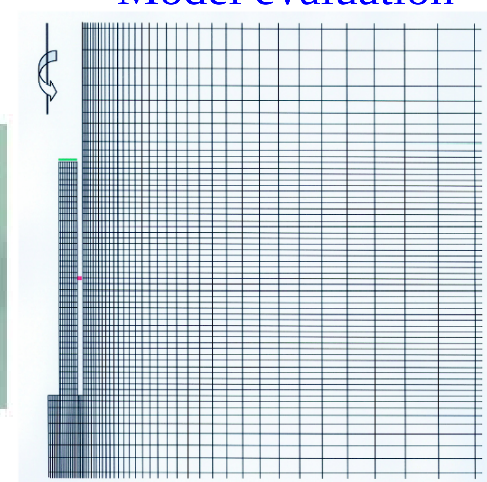
in situ Stress Measurement (BGR Overcoring Experiment)



Measurements

In situ test preparation

Model evaluation



BGR 2D overcoring probe

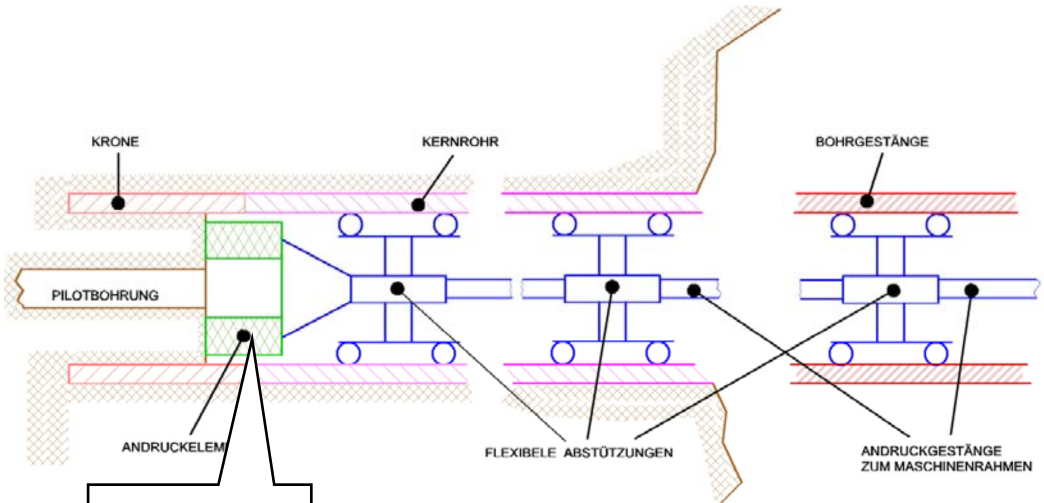
Core-disking & Failure

Breaking & failure (bedding, operation etc.)

Disking

- Overcoring tests in both boreholes were distinctly influenced by core-disking, failure and corelosses (obviously caused by geological situation)
- Only 1 successful overcoring test (BIS-D3 – OC 03)

Techniques Improvement



Pressure element

Test	Interval		Remarks	Results
	from	to		
OC 01	5,22 m	5,72 m	core failure	not successful
OC 02	7,23 m	8,22 m	-/-	successful
OC 03	8,24 m	9,22 m	-/-	successful
OC 04	9,24 m	10,22 m	-/-	evaluation not possible
OC 05	10,34 m	11,22 m	-/-	limited evaluation possible
OC 06	11,54 m	12,42 m	-/-	successful
OC 07	12,42 m	13,40 m	-/-	successful
OC 08	13,74 m	14,45 m	-/-	successful
OC 09	14,47 m	15,07 m	-/-	successful

(Hoppe (BGR), 2005)

Comparison of Elasticity and in situ Stress

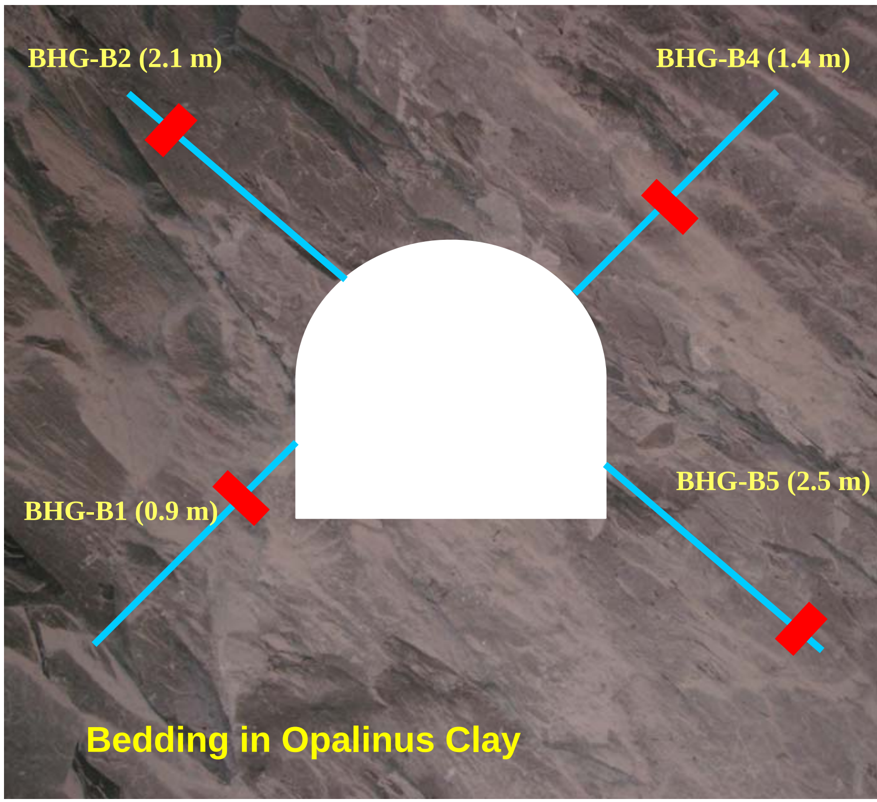
		E 1 [MPa]	E 2 [MPa]
IS-A	Undercoring	12.300	4.100
IS-B	Borehole-slotter	6.400 - 7.000	2.200 - 3.600
IS-C	Hydraulic fracturing	-/-	-/-
IS-D	Overcoring	4.600 - 10.800	1.000 - 2.200

		σ 1 [MPa]	σ 2 [MPa]	ω [°]
IS-A	Undercoring	6,5 - 8,0	0,6 - 1,1	90
IS-B	Borehole-slotter	2,0 - 5,7	0,1 - 0,4	45
IS-C	Hydraulic fracturing	7	3	90
IS-D	Overcoring	5,5 (2,5 … 8,4)	2,6 (1,5 … 4,4)	56 (44 … 86)

(Heusermann (BGR))

Measurement and Observation (Mt Terri Site)

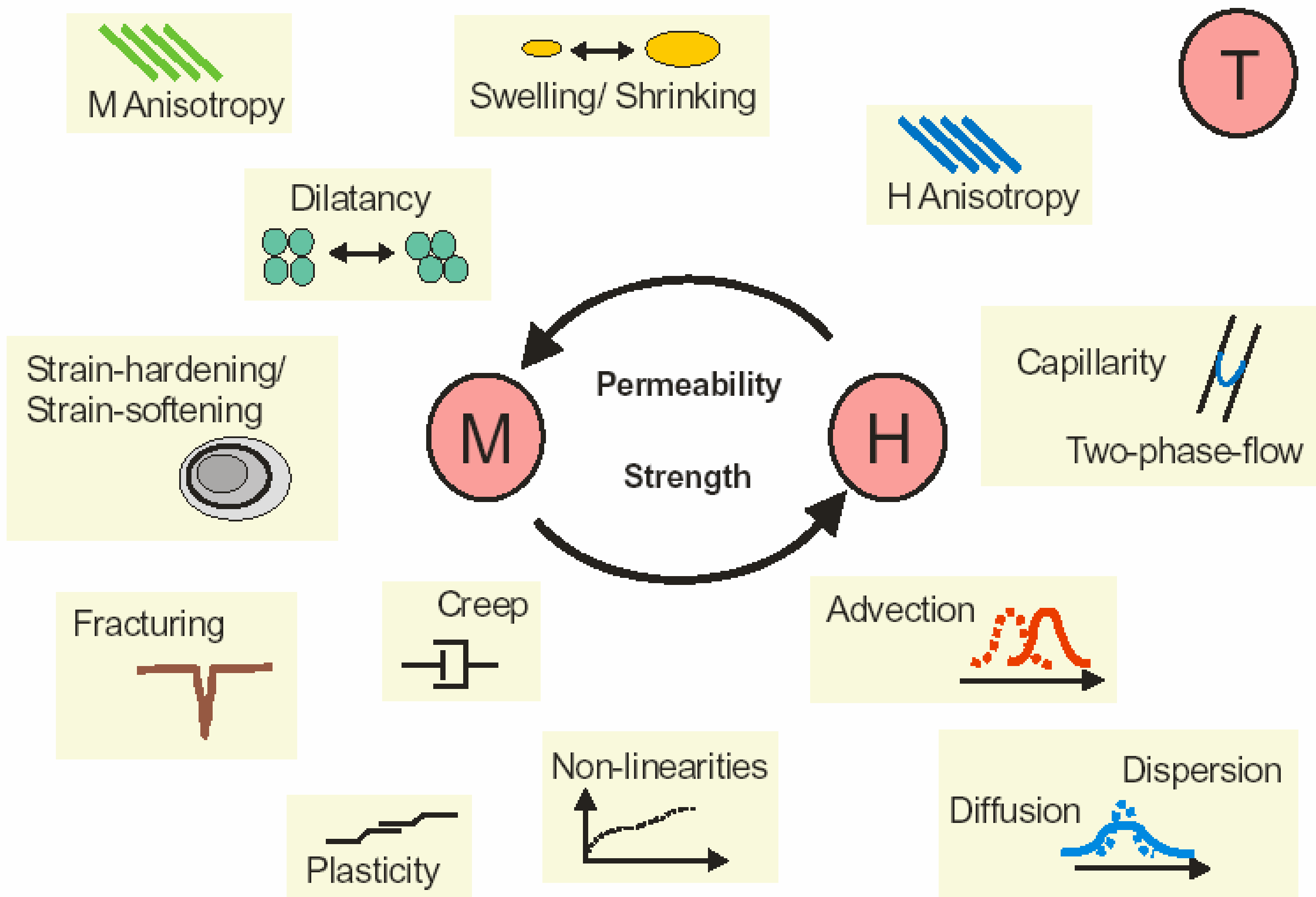
Low strength



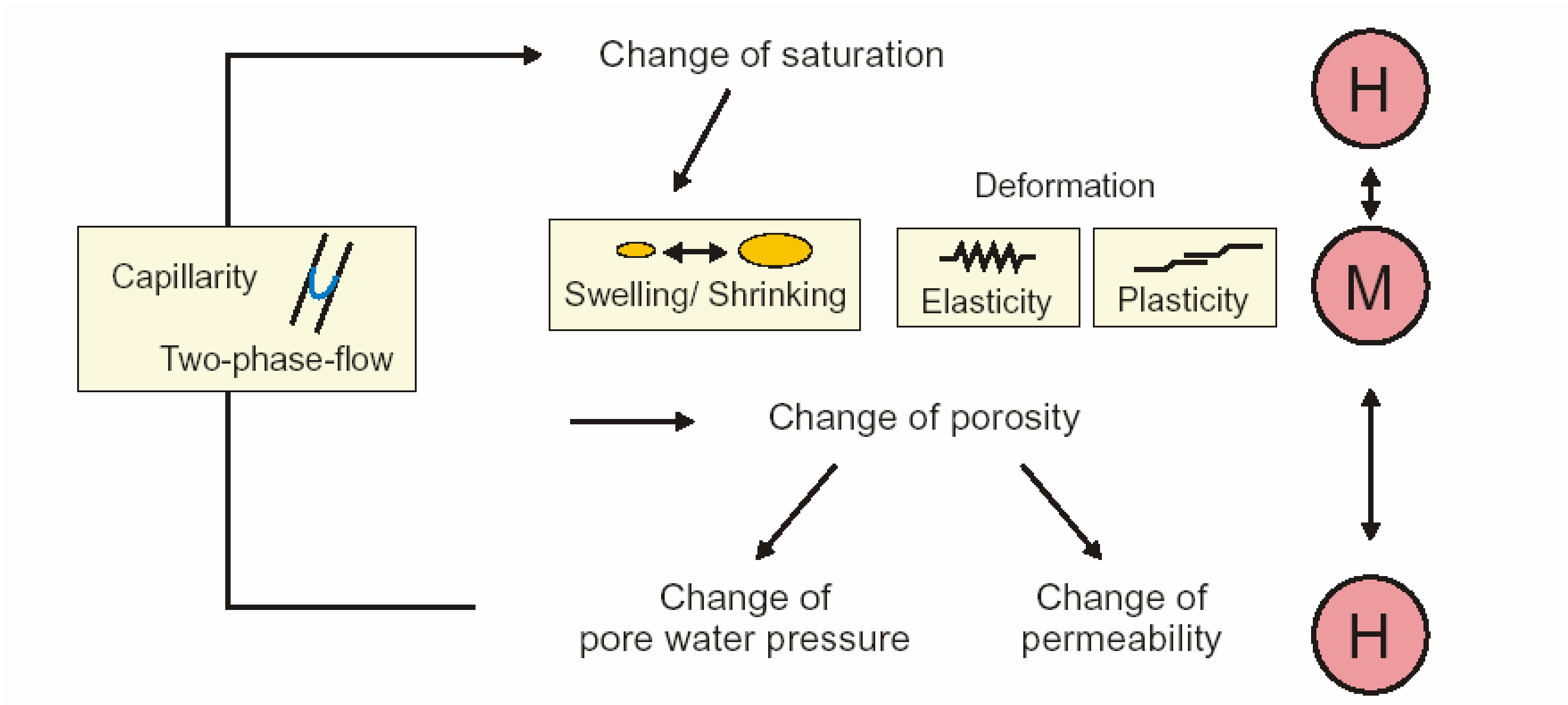
High permeability - ellipse -

Permeability > 1E-16 m²

Processes to be considered



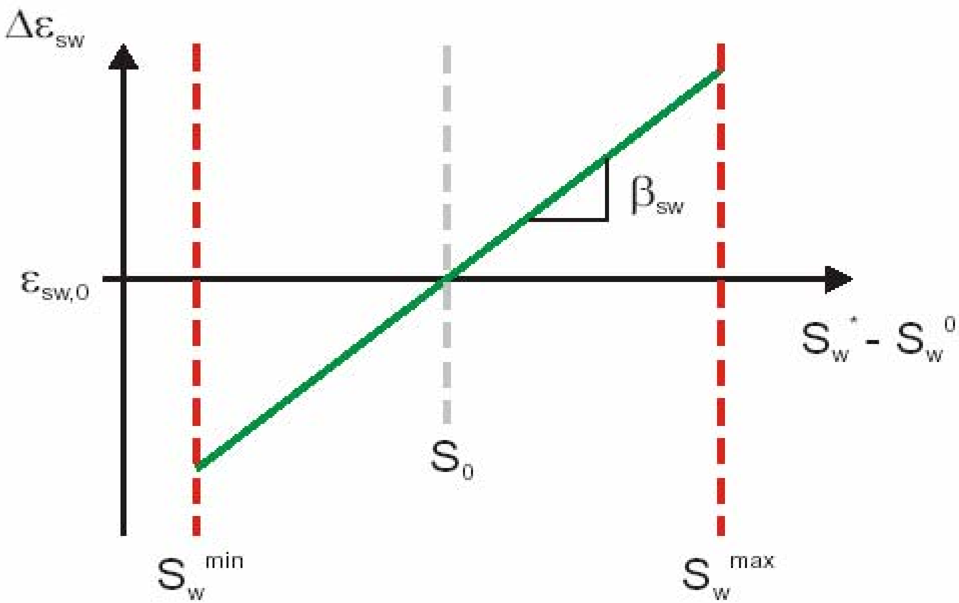
Coupled Hydro-Mechanical Processes



Linear Swelling Model

$$\sigma^{s}_{\text{eff}} = \mathbf{C} : \left(\varepsilon - \frac{1}{3}\varepsilon_{vol,sw}\mathbf{1}\right)$$

$$= \mathbf{C} : (\varepsilon - \mathbf{1}\beta_{sw}\Delta S_w)$$



With:

$$\Delta S_w = S_w^* - S_w^0$$

Biot coefficient:

$$\alpha = 1.0$$

Volumetric swelling coefficient:

$$\beta_{sw}$$

Input parameters:

- Swelling coefficient β_{sw}
- Reference data $S_0,\ \varepsilon_{sw,0}$
- Swelling area $S_{max},\ S_{min}$

Change of porosity

A change of porosity can result from swelling/shrinking or stress induced deformation.

- Deformation without swelling/shrinking

Volumetric strains influence the porosity:

$$n = n_0 + \varepsilon_{vol}$$

- Deformation with swelling/shrinking

Volumetric strains influence the clay particles:

$$n = n_0 + \varepsilon_{vol} - \varepsilon_{vol,sw}$$

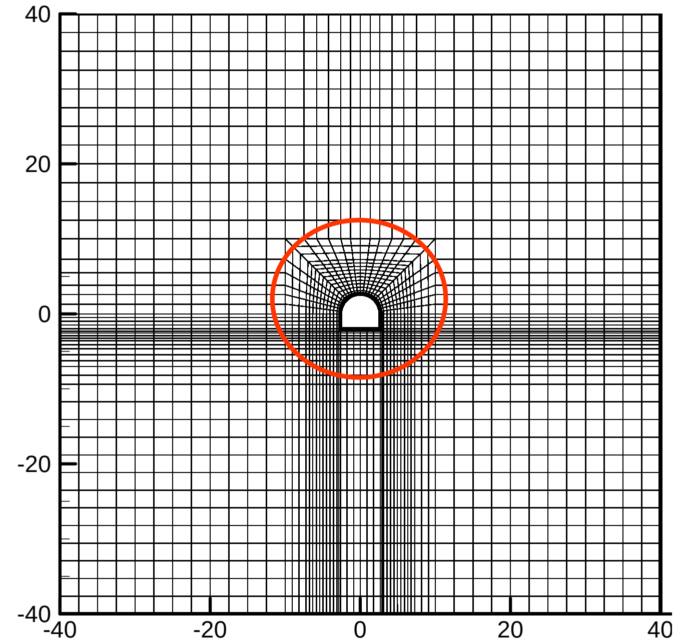
Model Mont Terri Near-field

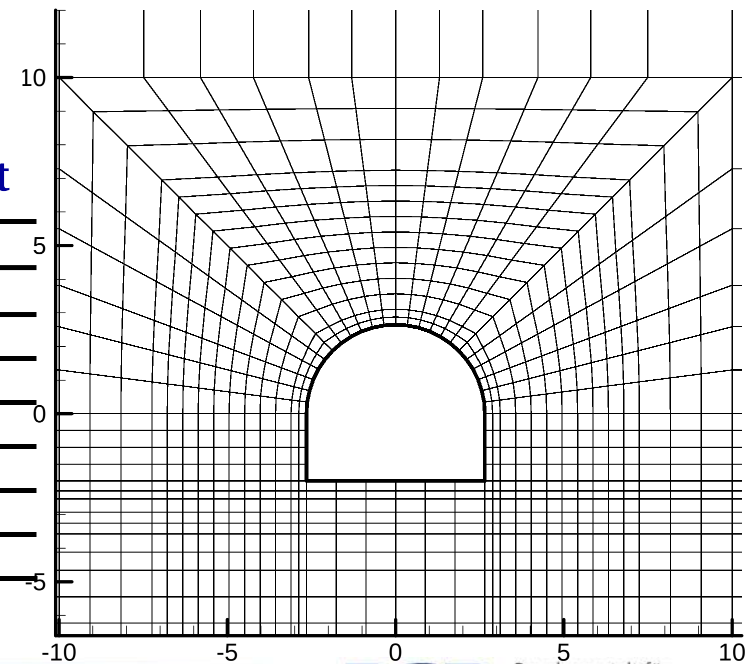
- Anisotropic Darcy flow
- Transverse isotropic elasticity
- Richard‘s approximation (two-phase flow p_g)
- Linear swelling function (saturation)

$$\varepsilon_{sw} = \beta_{sw}(S_w - S_w^0)$$

total_volumetric_strain (elastic + swelling)

- Change of porosity
- Change of permeability (Kozeny-Carman)





Basic parameter set

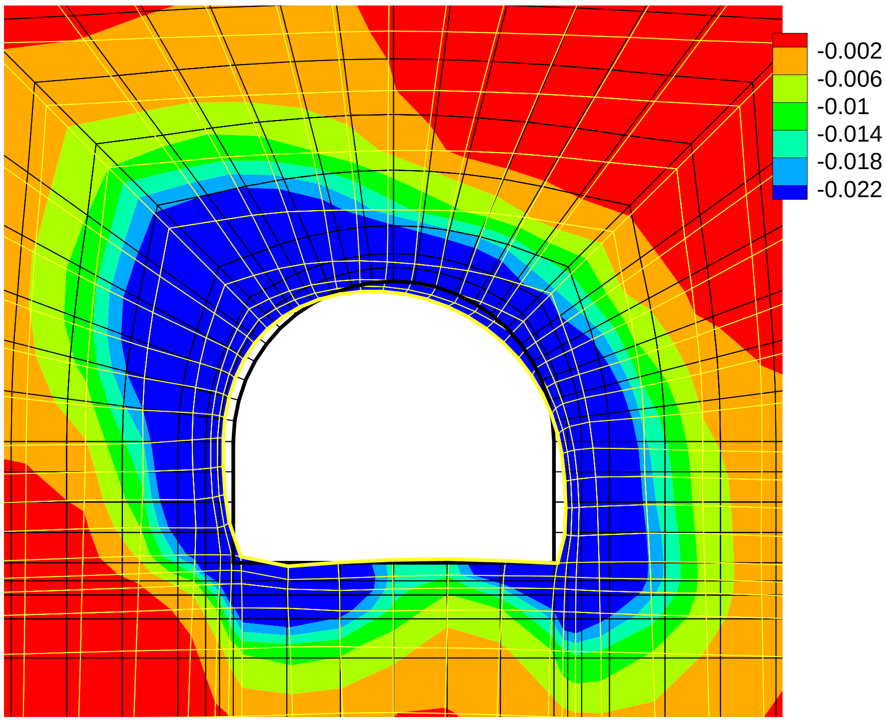
Parameter	Werte ⊥	Werte ‖	Einheit
Permeabilität	2×10^{-19}	10^{-18}	m²
Porosität	0.16	0.16	-
E-Modulus	8	15	GPa
Poisson’s Zahl	0.27	0.27	-
Quellkoeffizient	0.3	0.3	-
Feuchtigkeit im Tunnel	100 → 40	Abb. 7	%
Temperatur im Tunnel	15 → 7	Abb. 8	°C

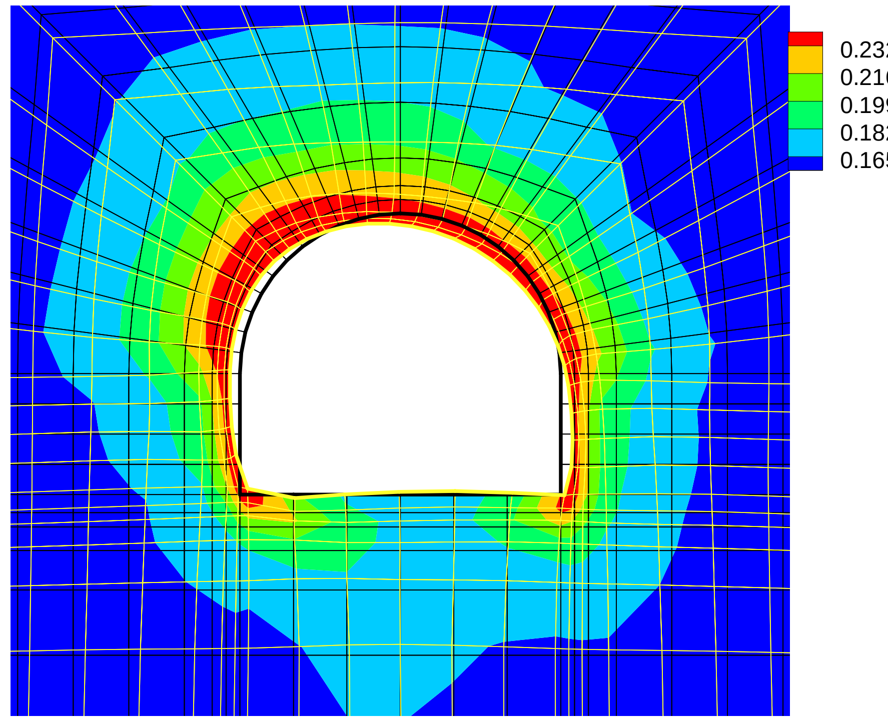
Coupled Hydro-Mechanical Modelling with Swelling Model

Swelling strain = 90% total_volumetric_strain

Strain + deformation

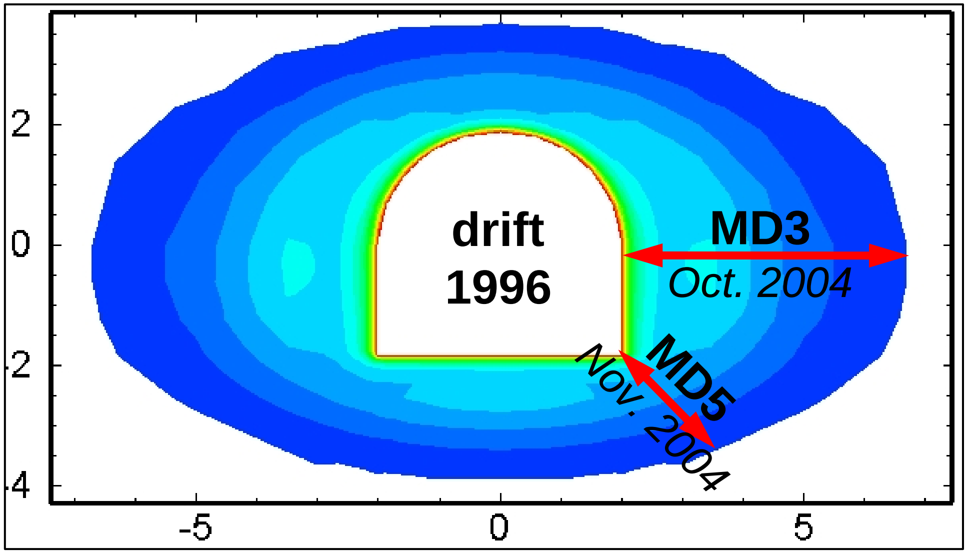
porosity





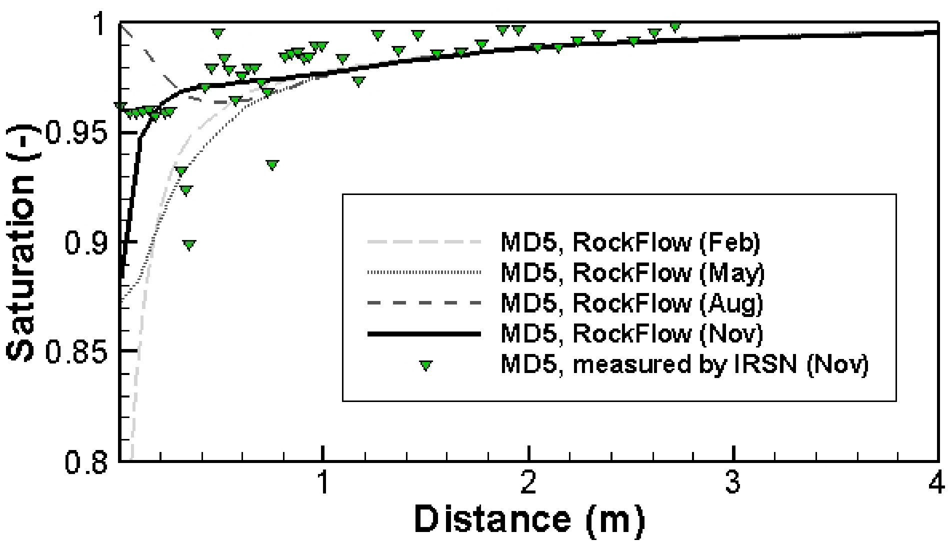
➔ Current development: Strain induced anisotropic permeability

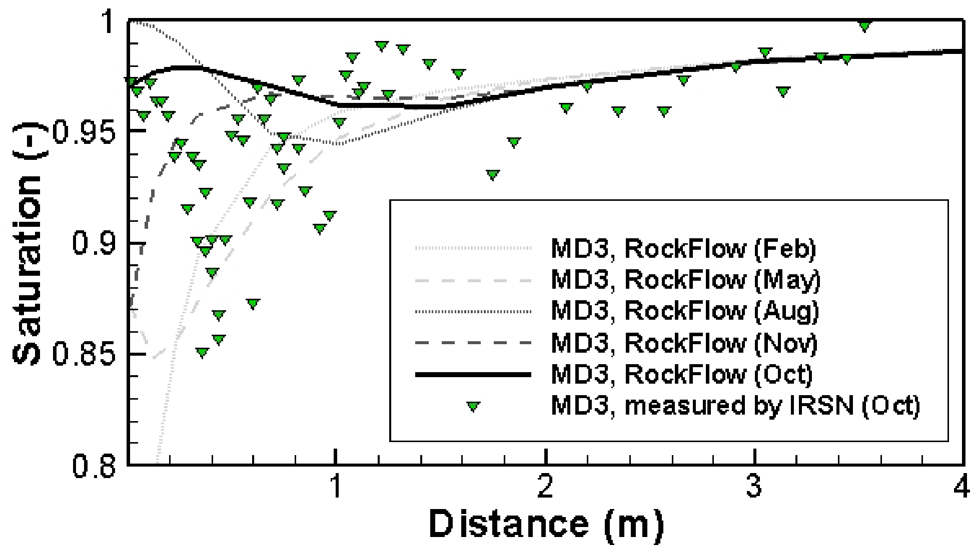
Desaturated Zone (Tournemire Site)



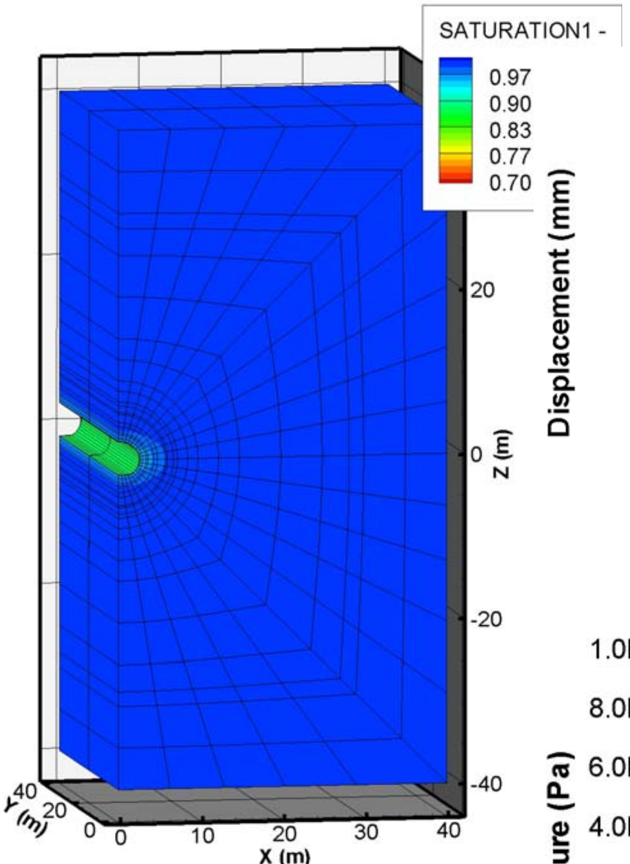
- Order of magnitude of the calculated results agrees with the measured data
- Anisotropic behavior can be simulated well

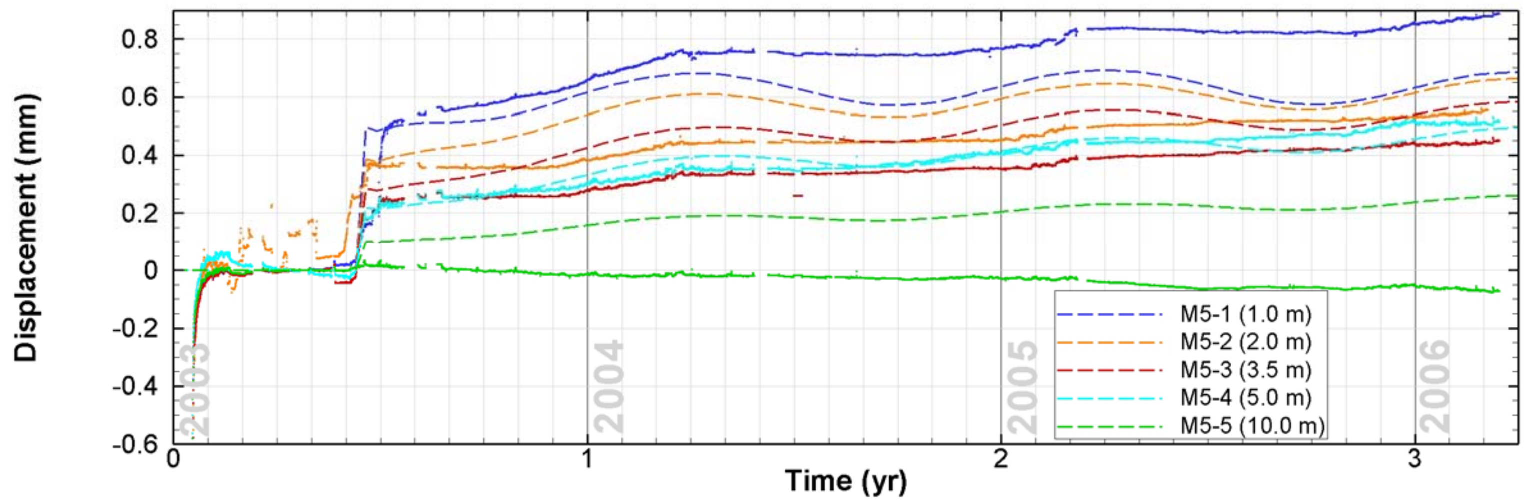
(IRSN/ISEB/BGR, 2006)

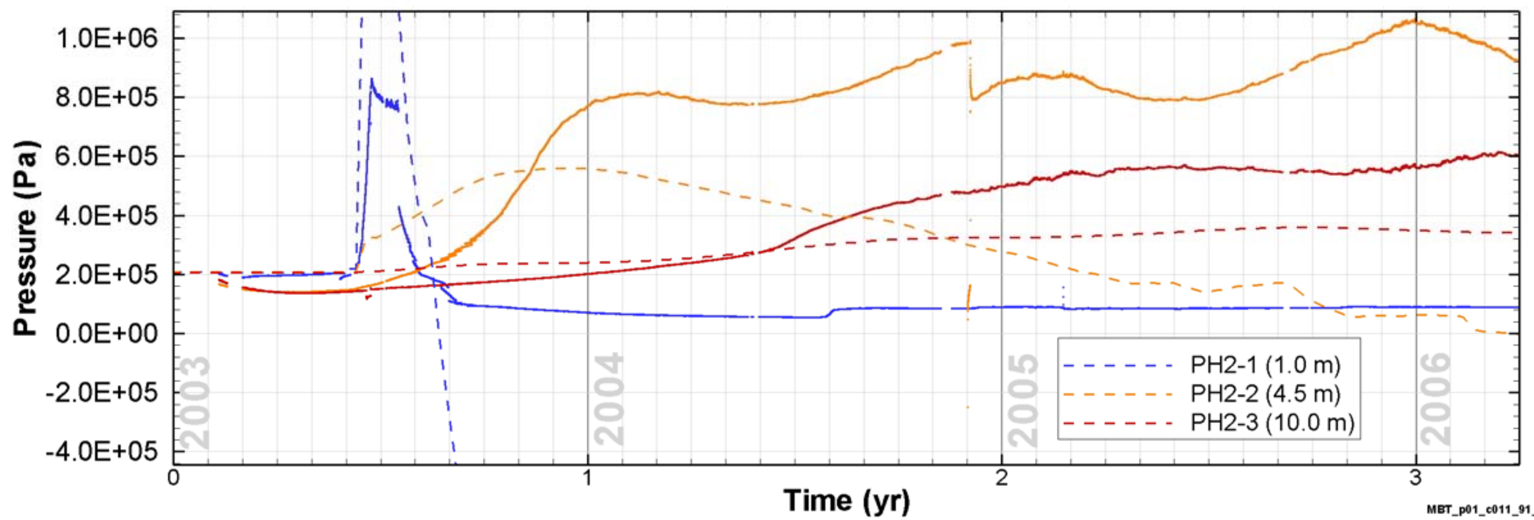




Mine-by experiment (Tournemire site)







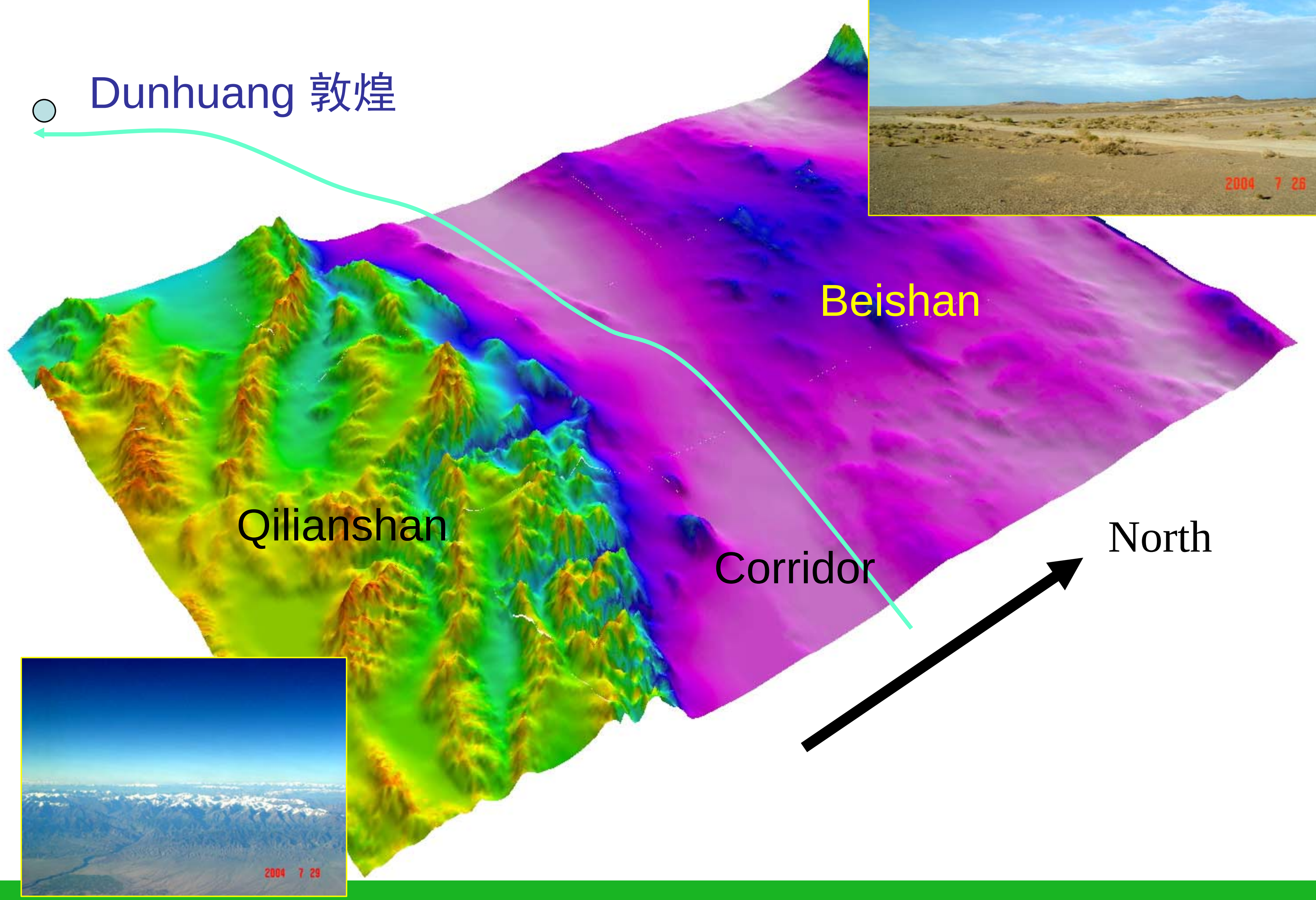
(IRSN/ISEB/BGR, 2006)

Geology of Beishan,

A Pre-selected Region for Disposal of High Level Radioactive Waste in China

CHEN Weiming (陈伟明)

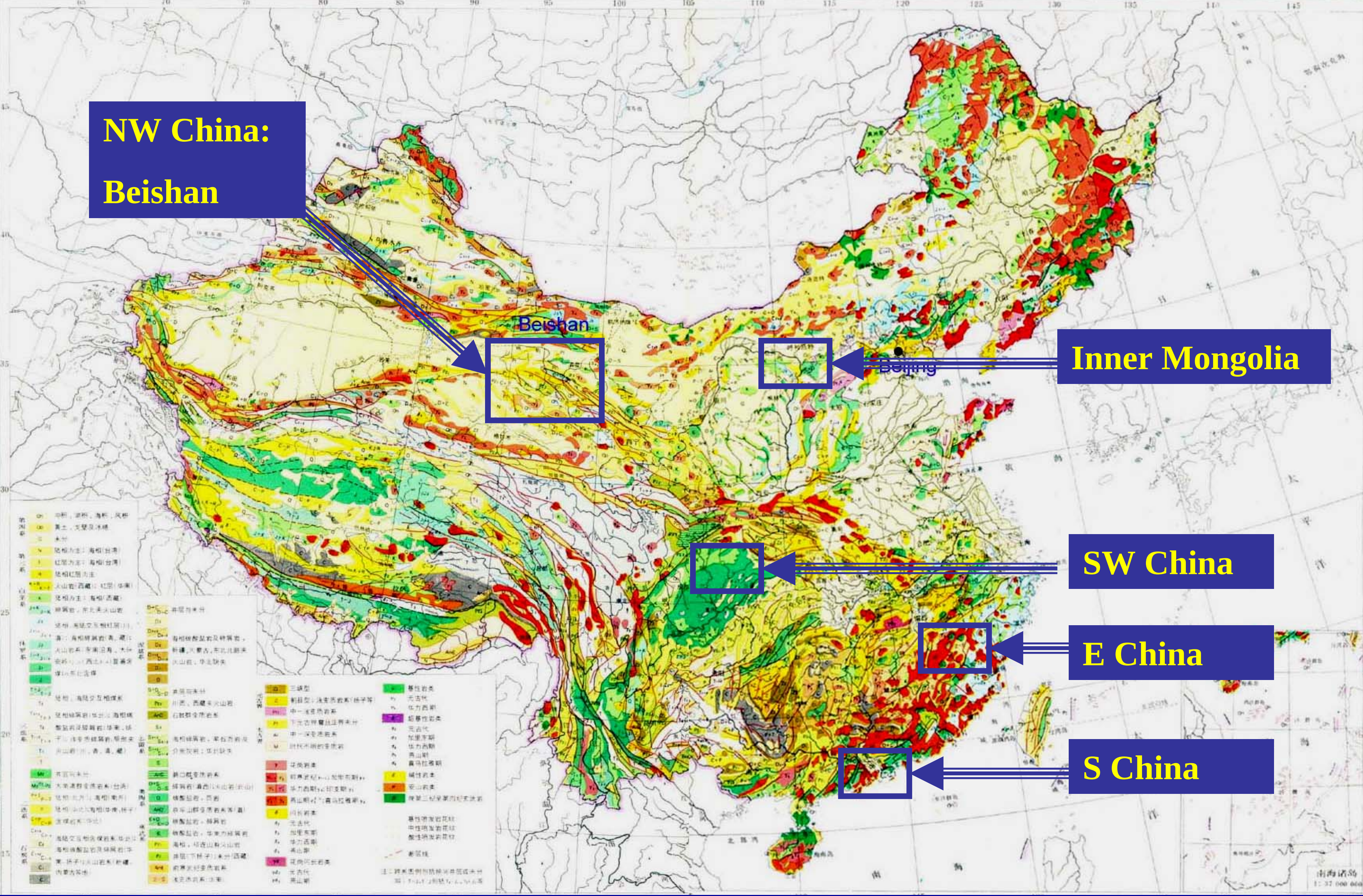
Beijing Research Institute of Uranium Geology



3-D DEM of Beishan and Qilianshan

Outline

- Overview of Beishan (North Mt.)
- Major Activities 2000-2004
- Major Activities 2005-2006
- Summary and Coming Activities



5 Pre-selected regions for China's HLW repository 1986-1989

Efforts concentrated in Beishan area since 1990

Beishan Region

Beishan Region (1990-1999)

- in Gansu （甘肃）province, NW China
- the most potential area for China's repository
- gobi desert area
- low population density
- low precipitation : 60--80 mm/a
- high evaporation: 2900-3200 mm/a
- no economical prospect
- no important mineral resources
- convenient transportation
- stable crust, no earthquakes
- favouable hydrogeological conditions
- host rock: granite and diorite

Potential Areas in Beishan Region

1.Jiujing Area (granodiorite) 旧井

2. Xiangyangshan Area (diorite)向阳山

3. Yemaquan Area (diorite)野马泉

4.Xinchang Area(granite)新场

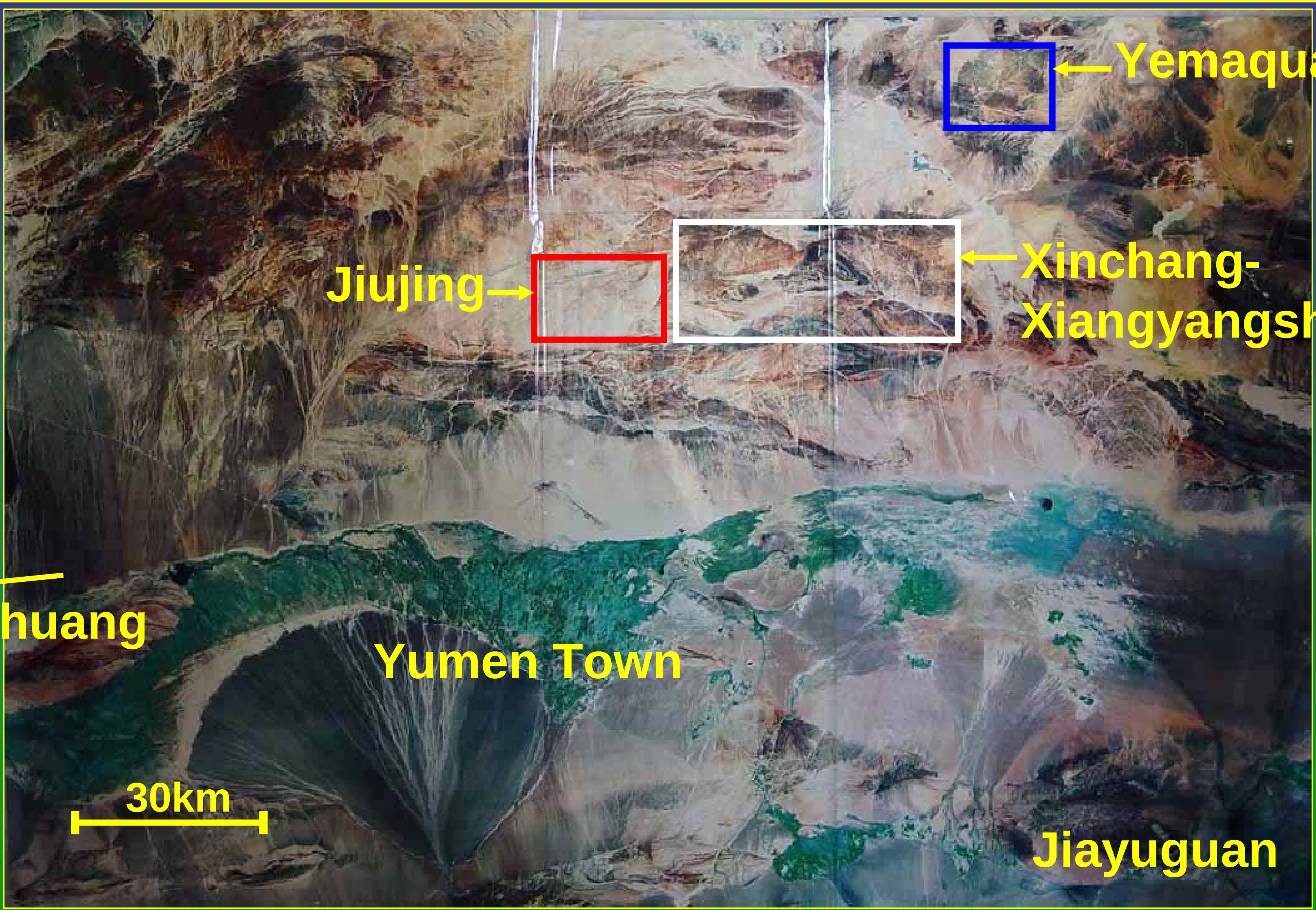
5. Qianhongquan Area(granite)前红泉

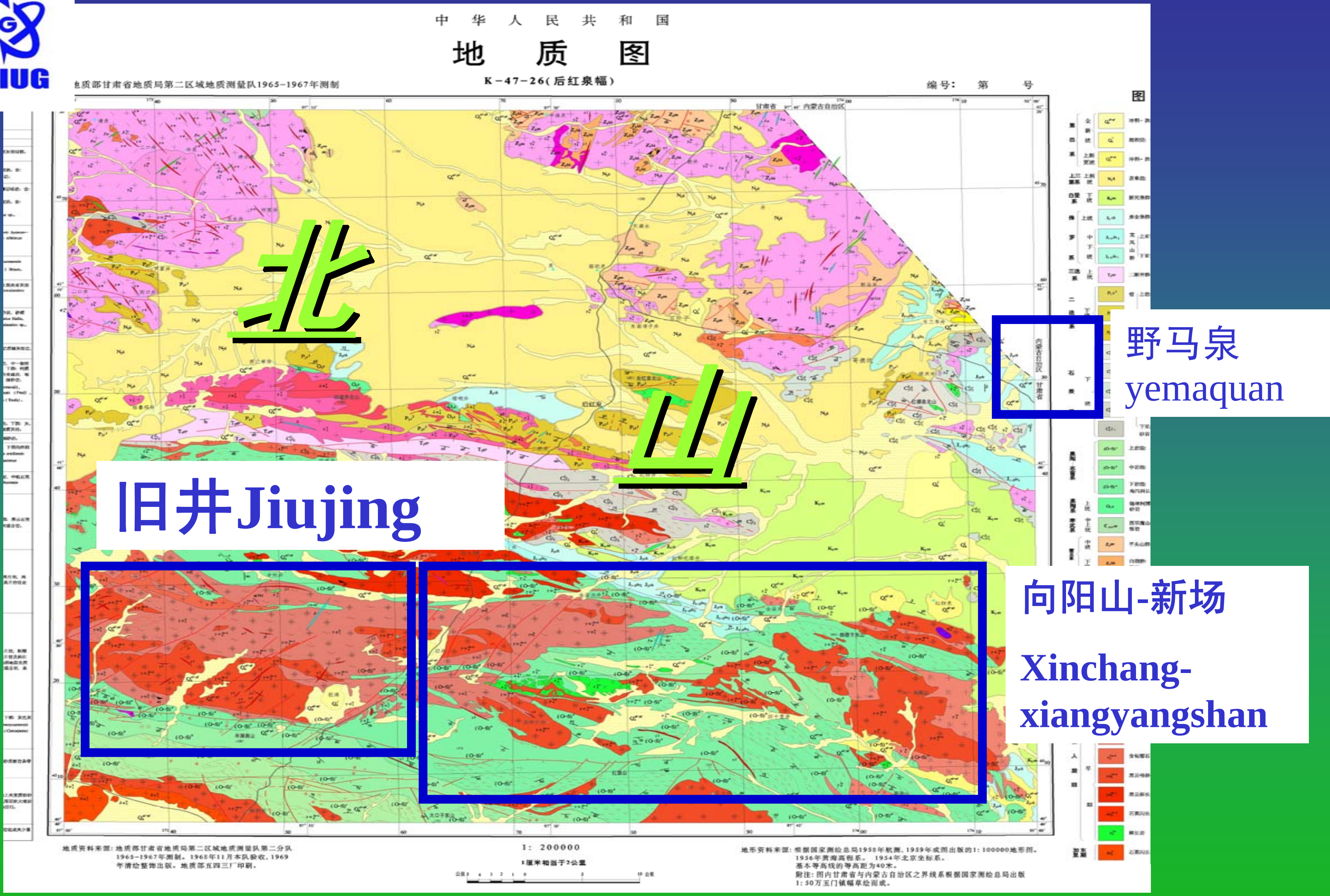
6.Yinmachang-beishan Area(granite)饮马场北山

7. Xianshuijing Area (diorite)咸水井

8.Baiyuantoushan-Heishantou Area (granite) 白圆头山-黑山头

Beishan Region



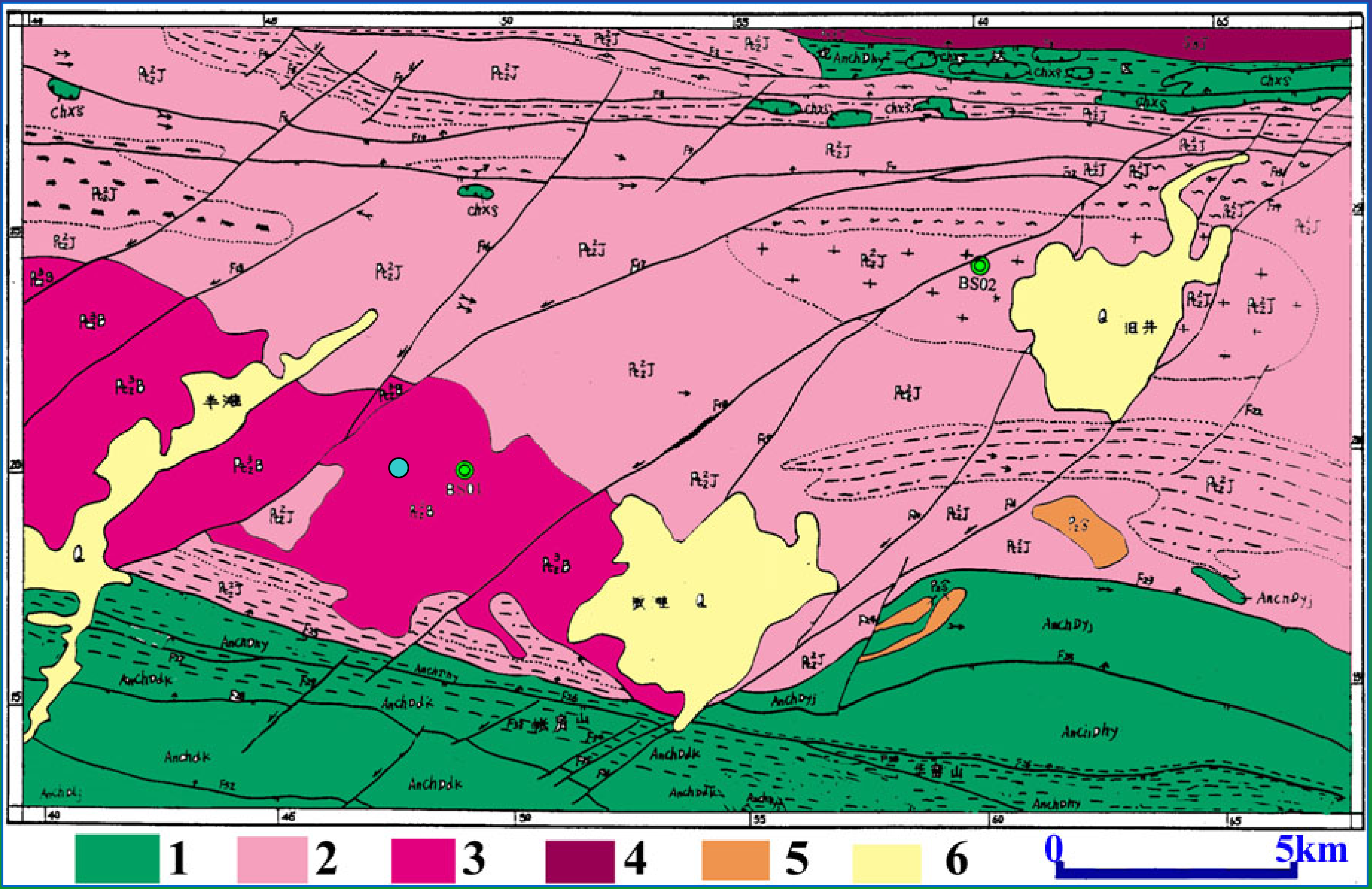


甘肃北山预选区3个重点预选地段对比

Major Activities 2000--2004

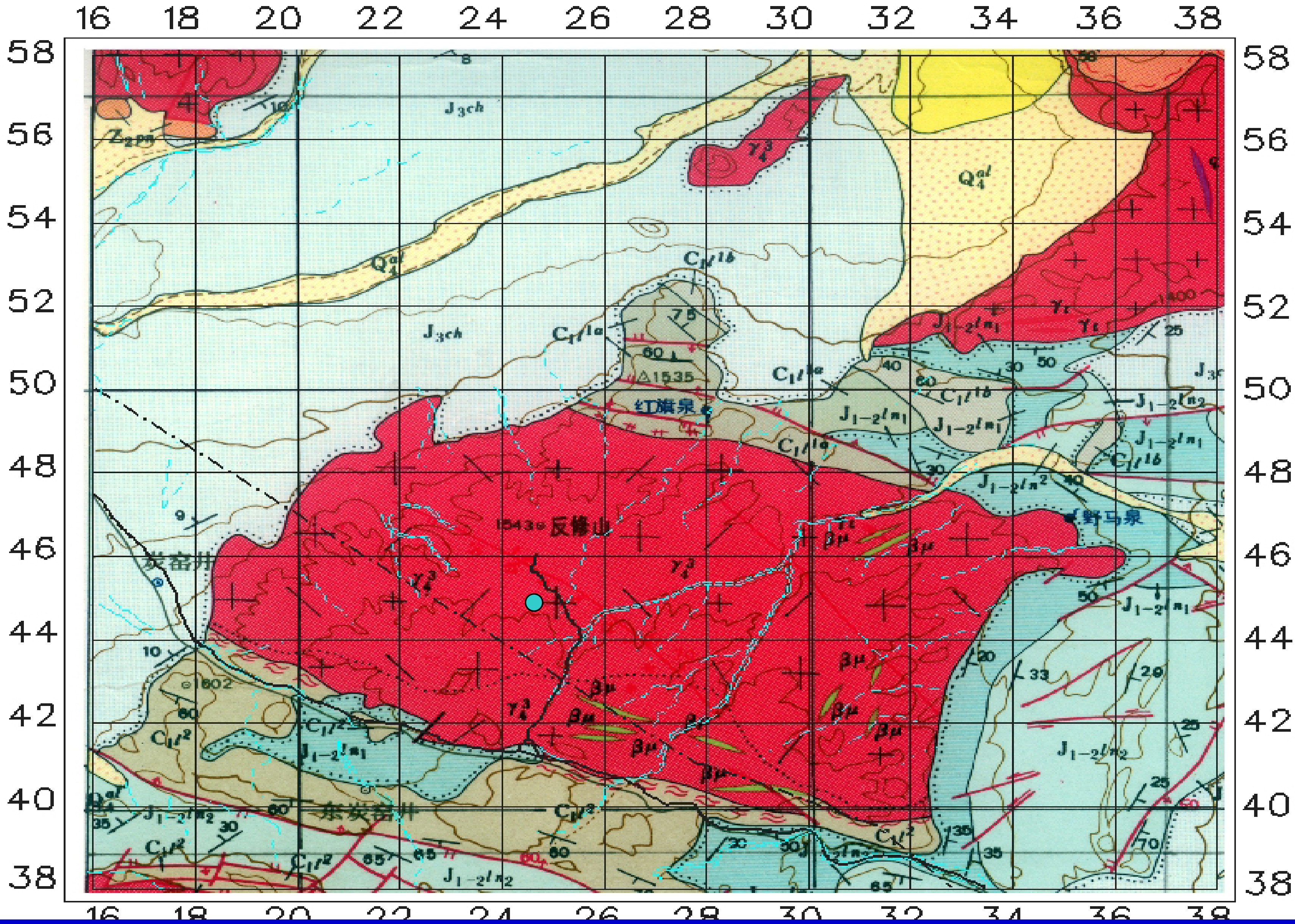
- surface geological, hydrogeological and geophysical survey at Jiujing Area and Yemaquan Area (1:50,000 scale)
- bore hole drilling for BS01, 02, 03, 04
- in situ tests in bore holes
- evaluation of deep geological environment and site suitability

Geological Map of Jiujing Area



1-Metamorphic rock, 2～5-Various granite unites, 6-Quarternary system

比例尺 1: 50000



Geological map of Yemaquan Area



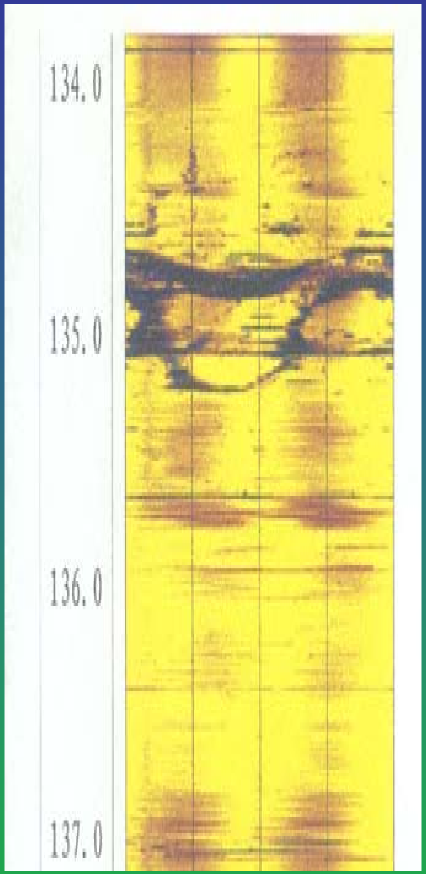

drilling sites at BS01, BS02, BS03, BS04 boreholes

Major borehole survey

- Borehole optical camera
- Borehole acoustic televiewer
- Borehole hydrogeochemical logging
- Borehole radar survey
- Borehole geostress measurement
- Vertical seismic profile

BRIUG

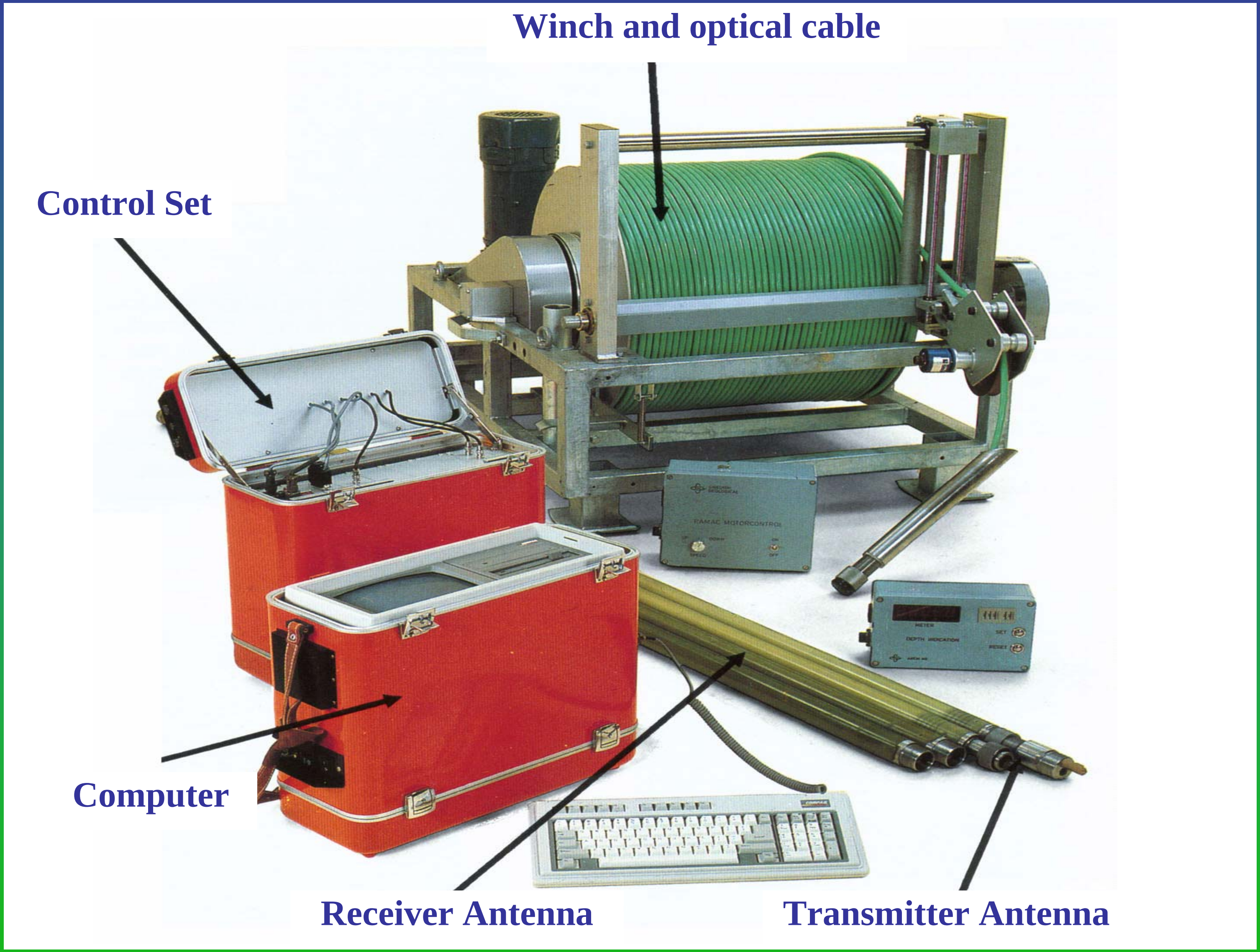
Vertical Joint



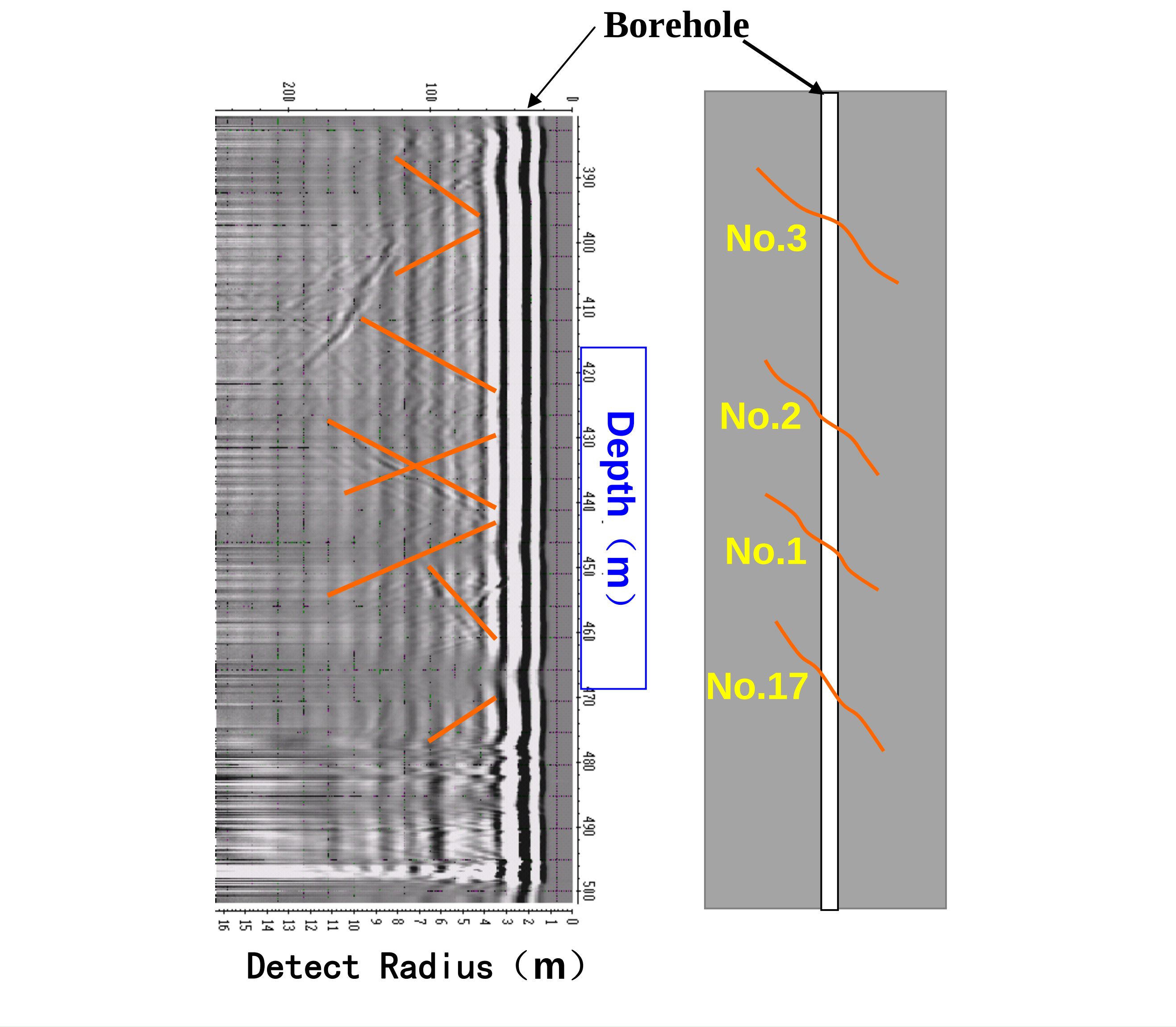
borehole televiewer survey

钻孔电视测量

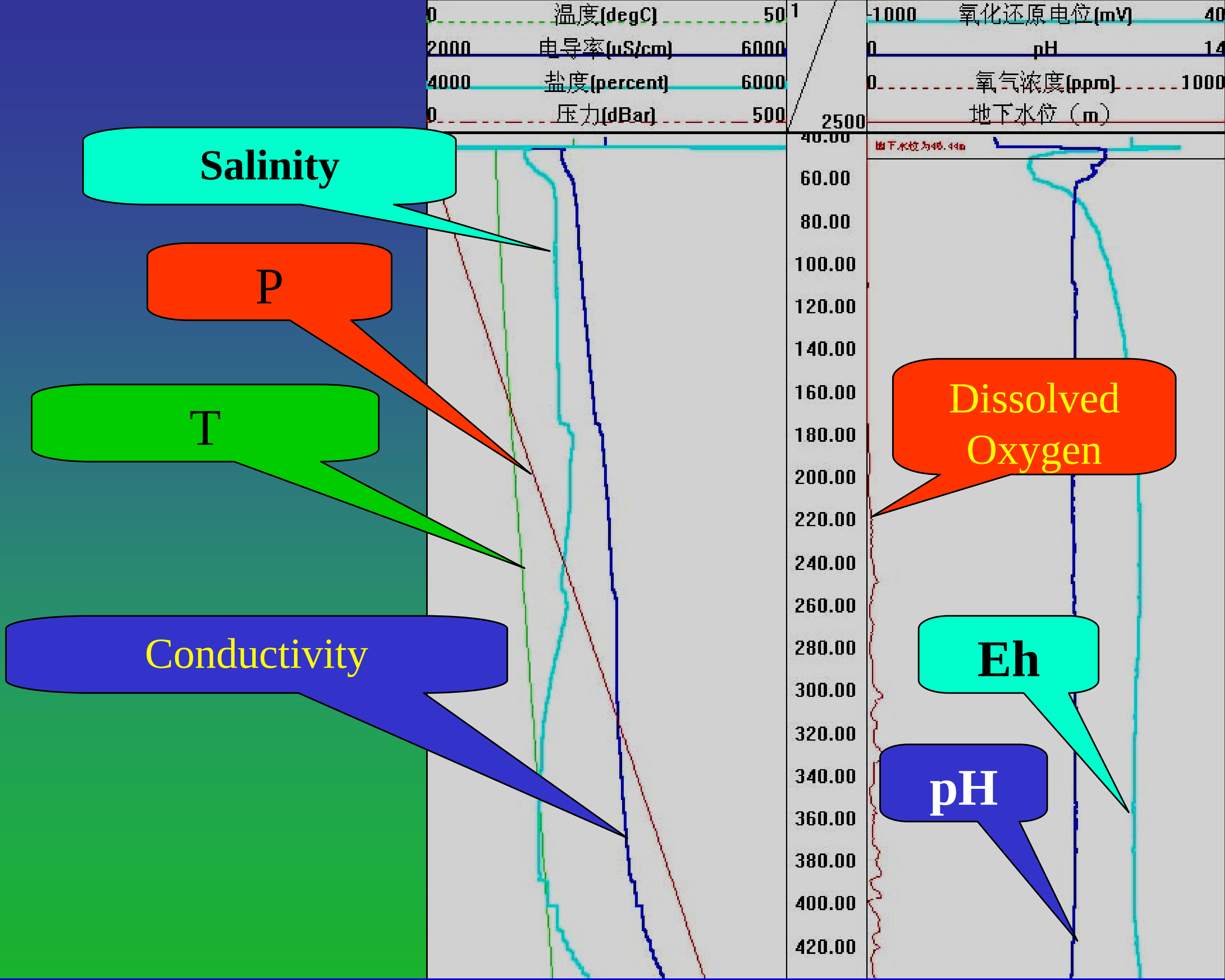
Borehole Radar



Radar Image (BS01:380～500m)



BS01孔综合水质测量曲线图



Borehole water quality logging in BS01

Double packer system

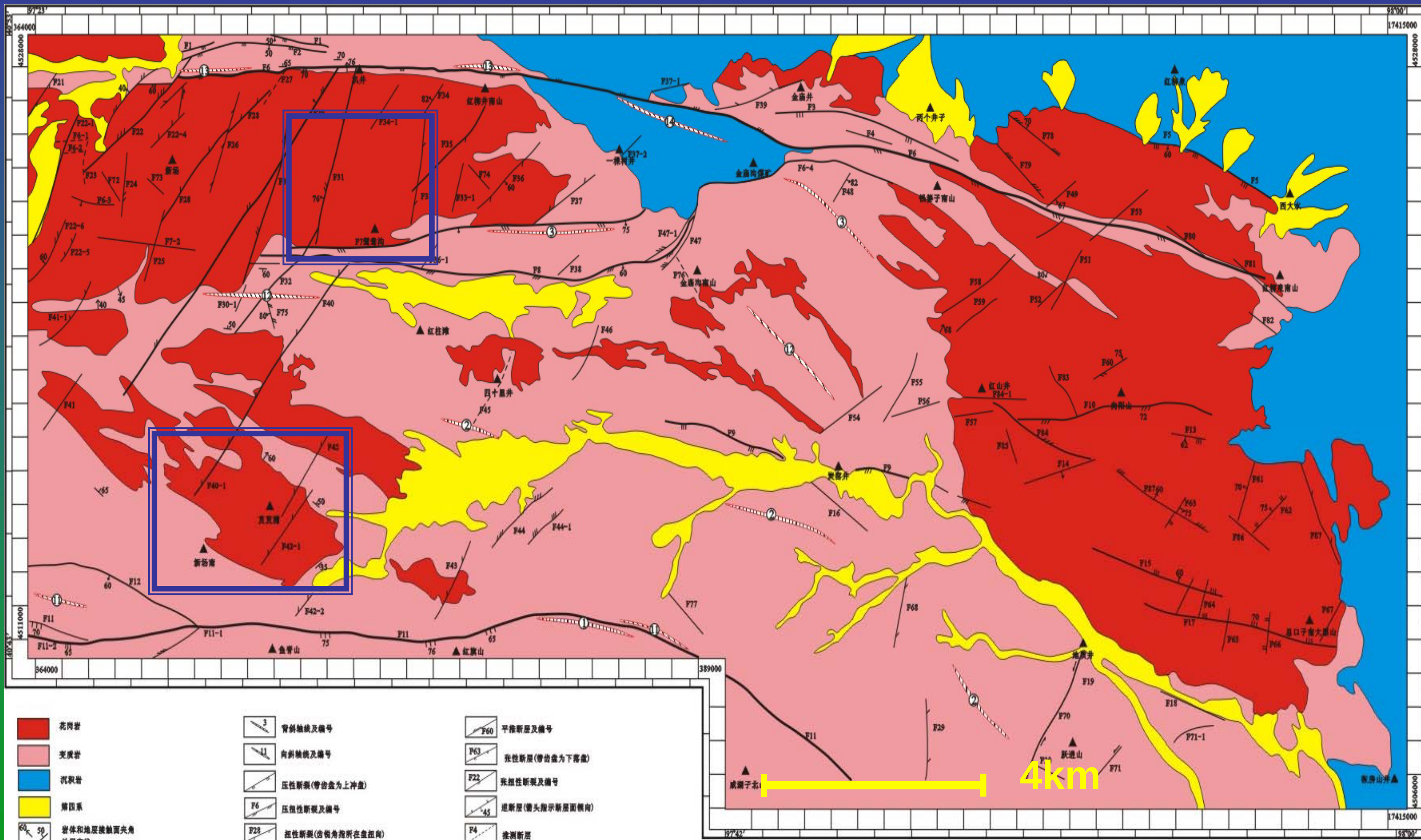
Stator of Moyno Pump

Rotor of Moyno Pump

Major Activities 2005-2006

- Surface geological, hydrogeological and geophysical survey at Xinchang-xiangyangshan Area (1:50,000 scale)
- Detailed surface geological survey at two potential sites (1:2000 scale)

Geological map of Xinchang-Xiangyangshan Area



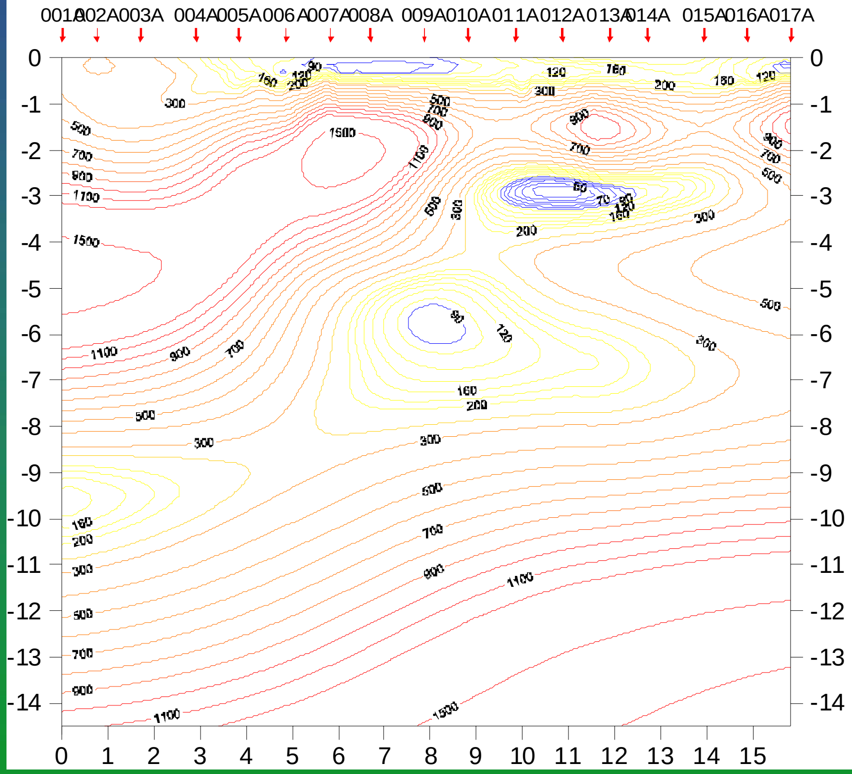
Major geophysical activities

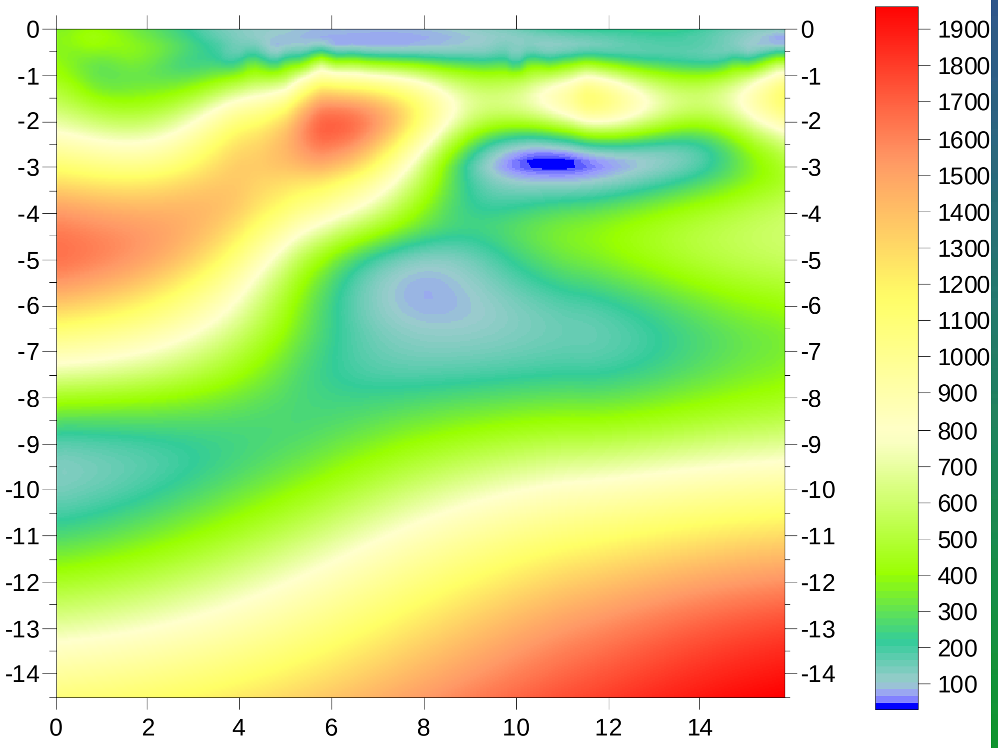
1 Electromagnetic measurement : EH4

2 High-resolution magnetic survey

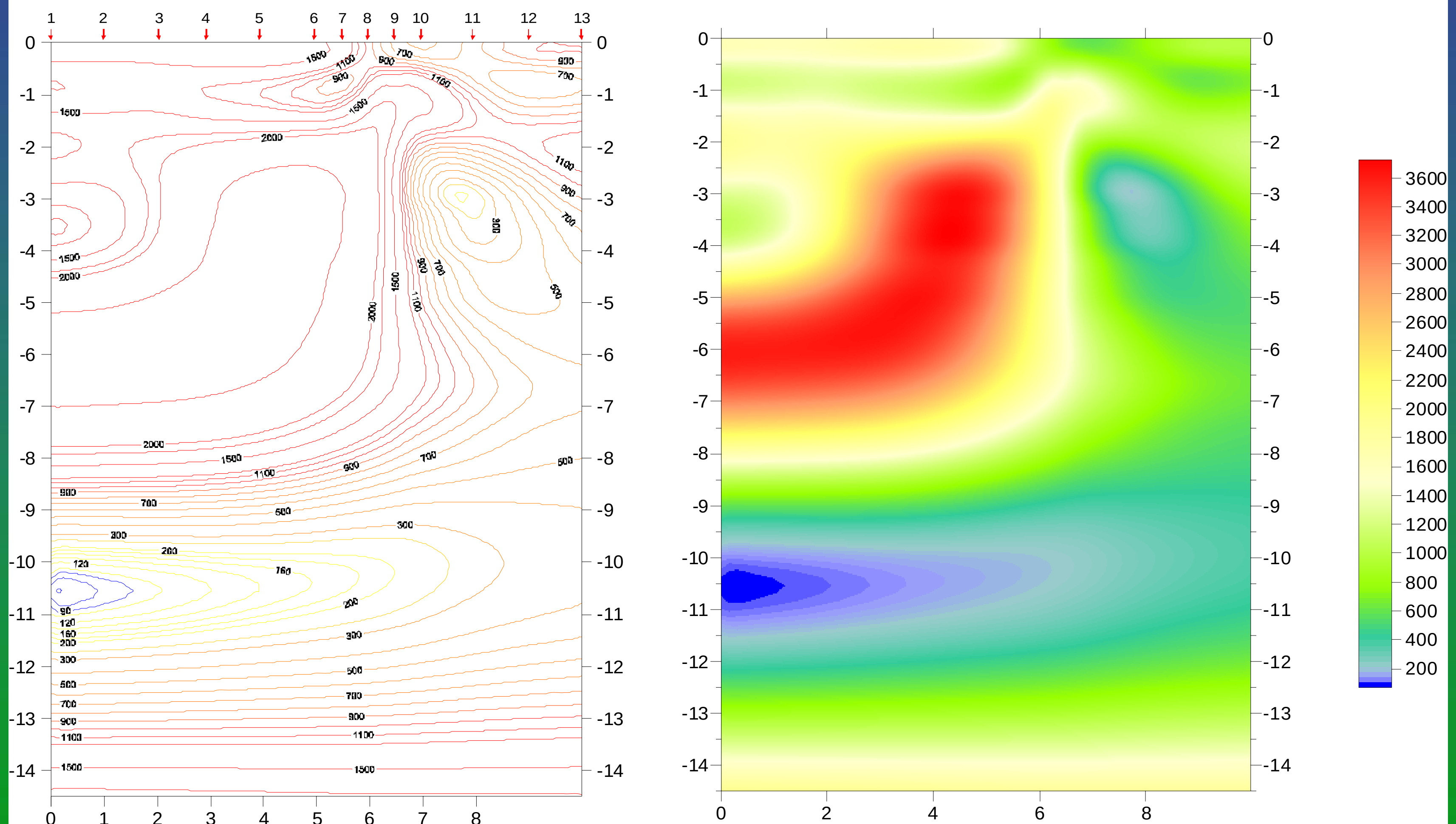
3 Magnetotelluric Survey: MT-1

MT survey in Xiangshan Area

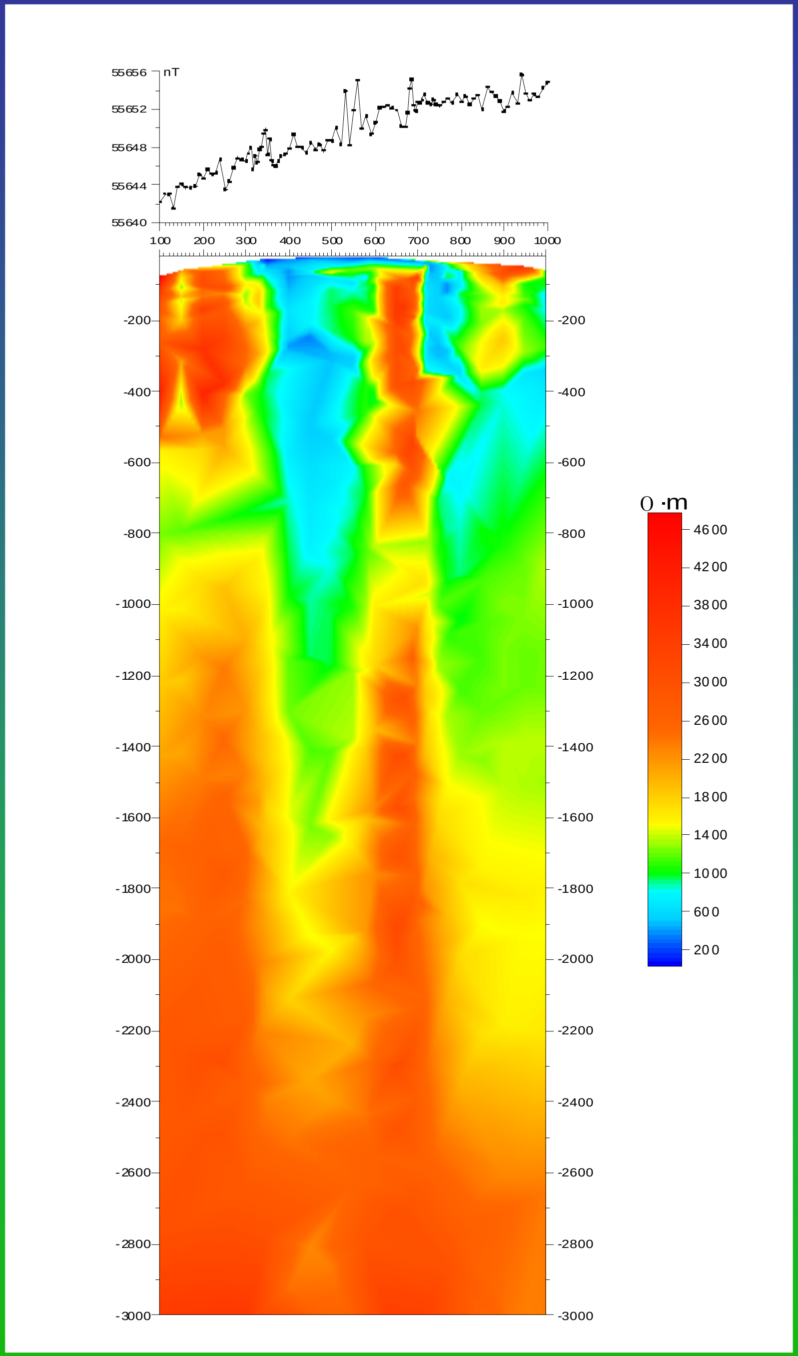




MT survey in Jijicao potential site



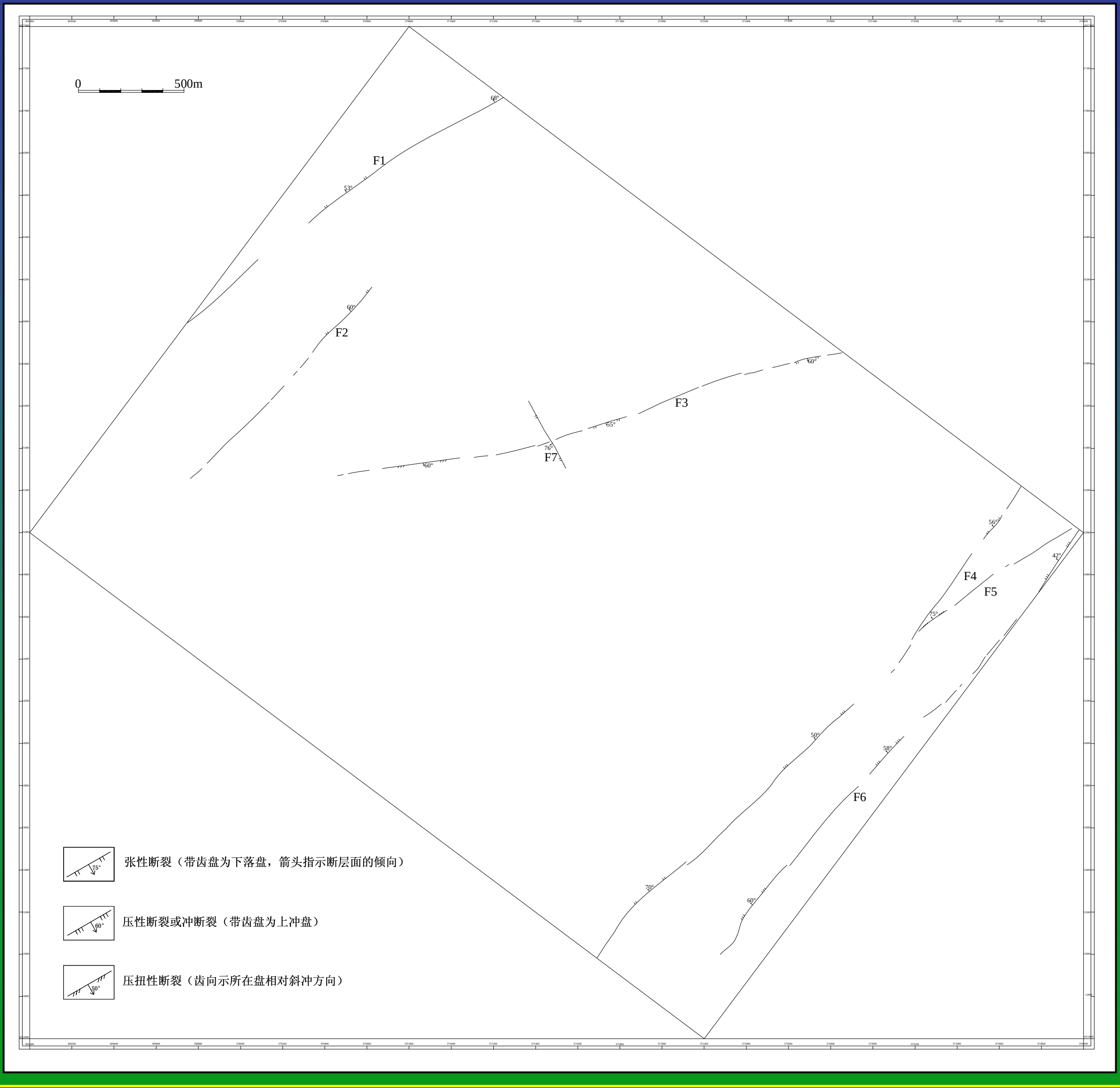
Magnetic and electromagnet section of fault



Antenna of EH4

Geological map of Jijican potential site

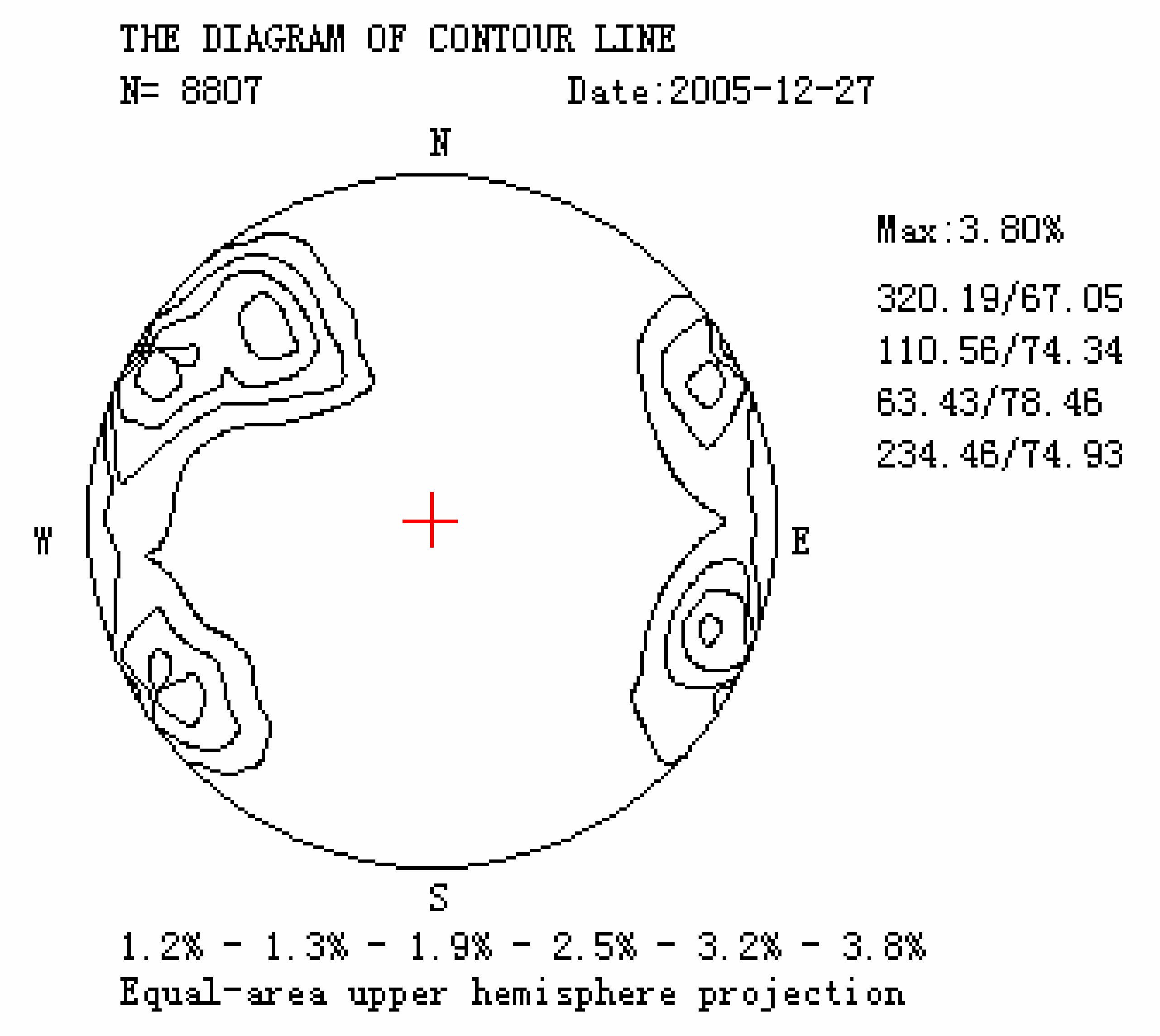
Fault map of Jijicao potential site



Fault

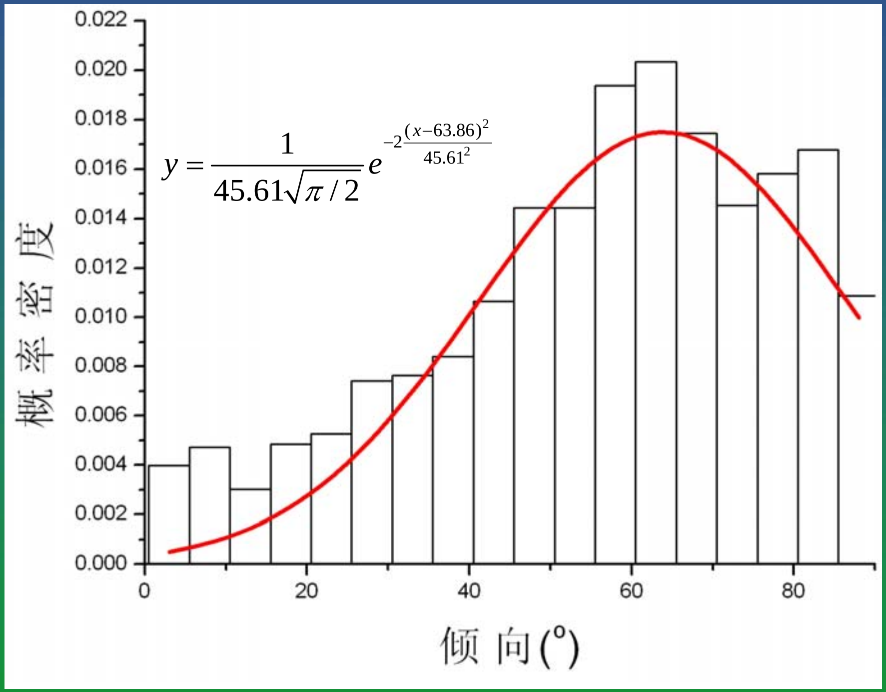
Outcrops of granite

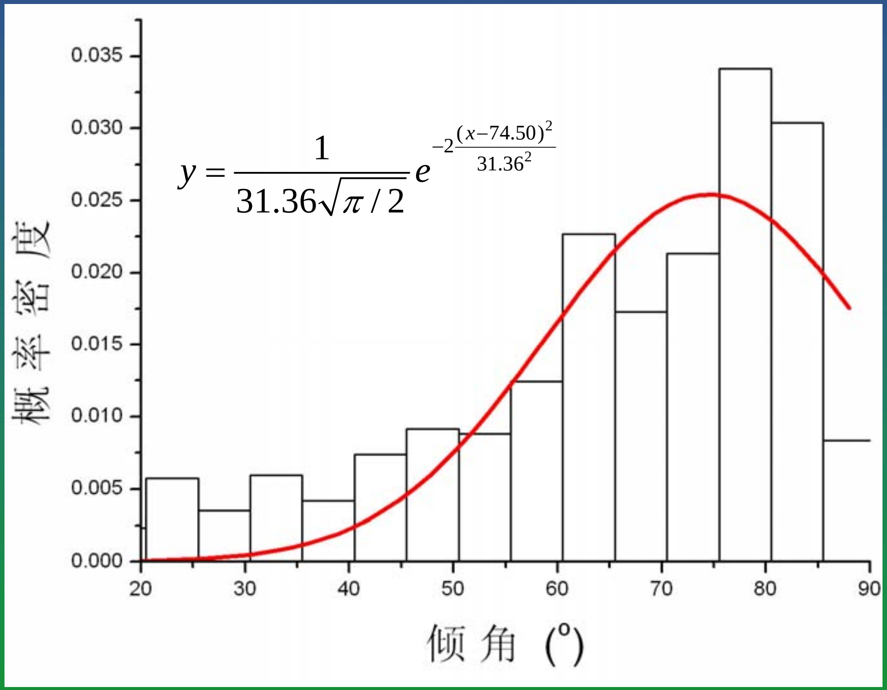
Joint pole diagram – 4 groups



Joint attitude – logarithmic normal

Probability Density

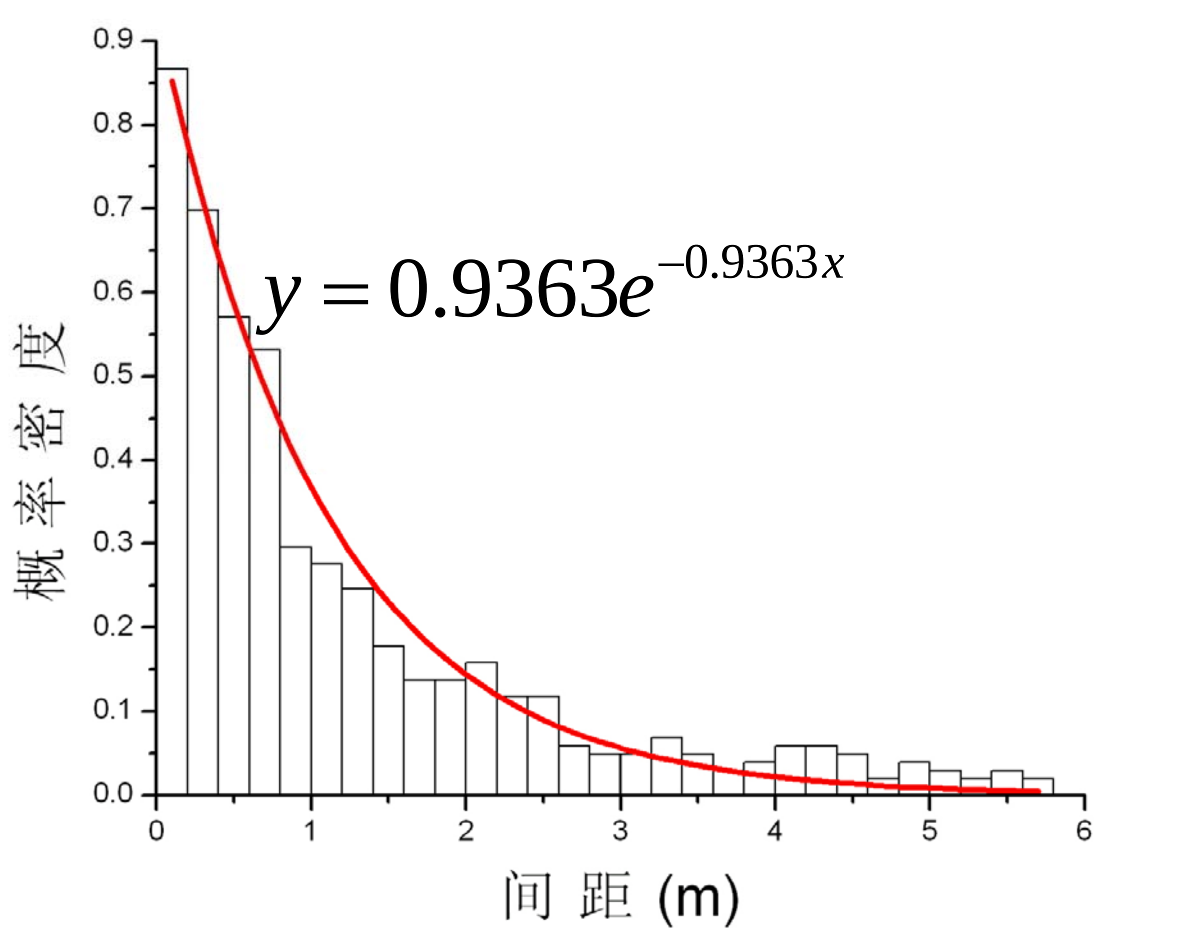




Dip direction **Dip Angle**

Joint Spacing – Negative exponent

Probability Density



Spacing

Summary

Region →	**Area →**	**Potential site**
1:200,000	**1:50,000**	**1:2,000 & borehole**
Beishan	**3 areas**	**2 potential sites**

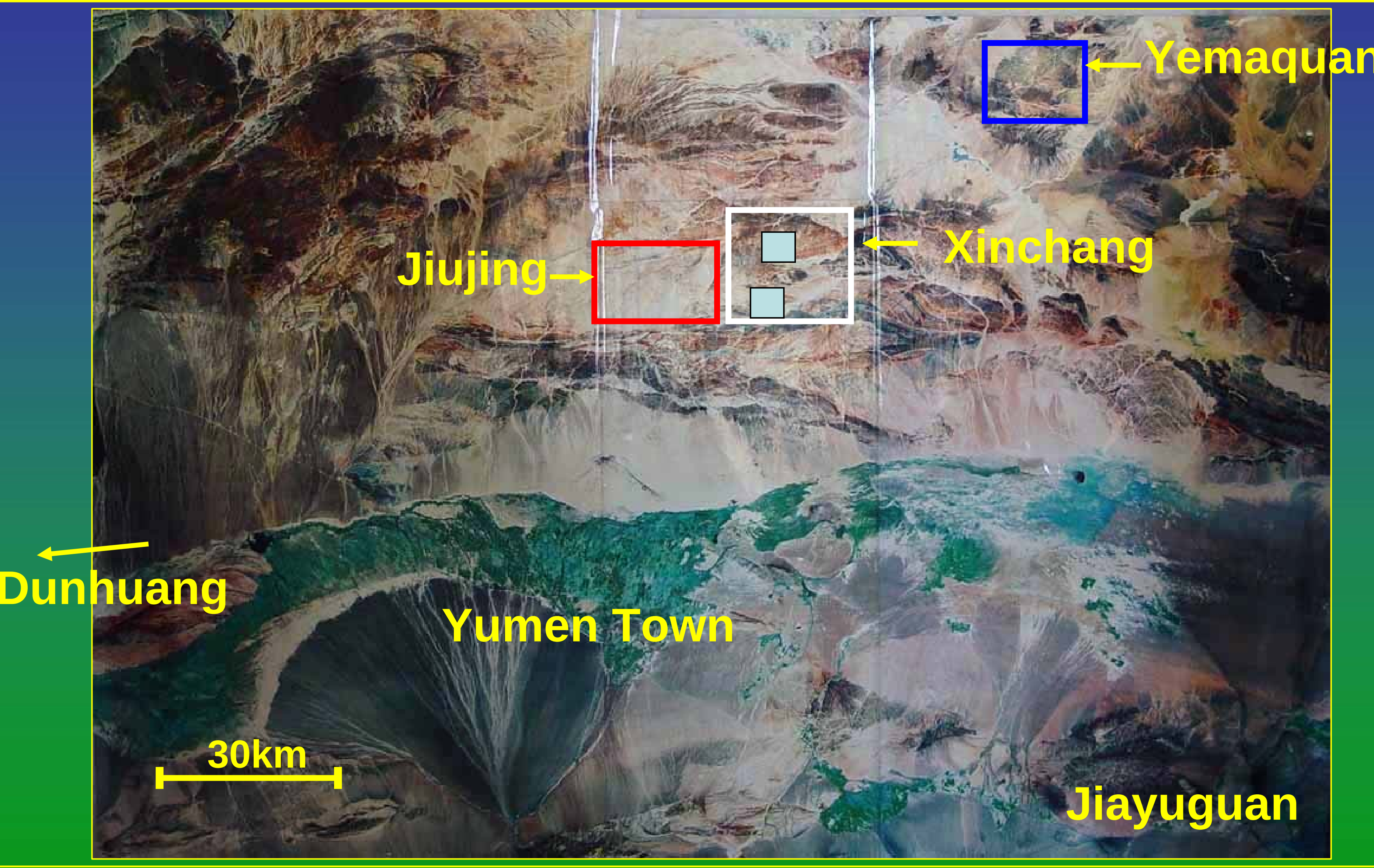
Next Objects

To compare these 3 areas

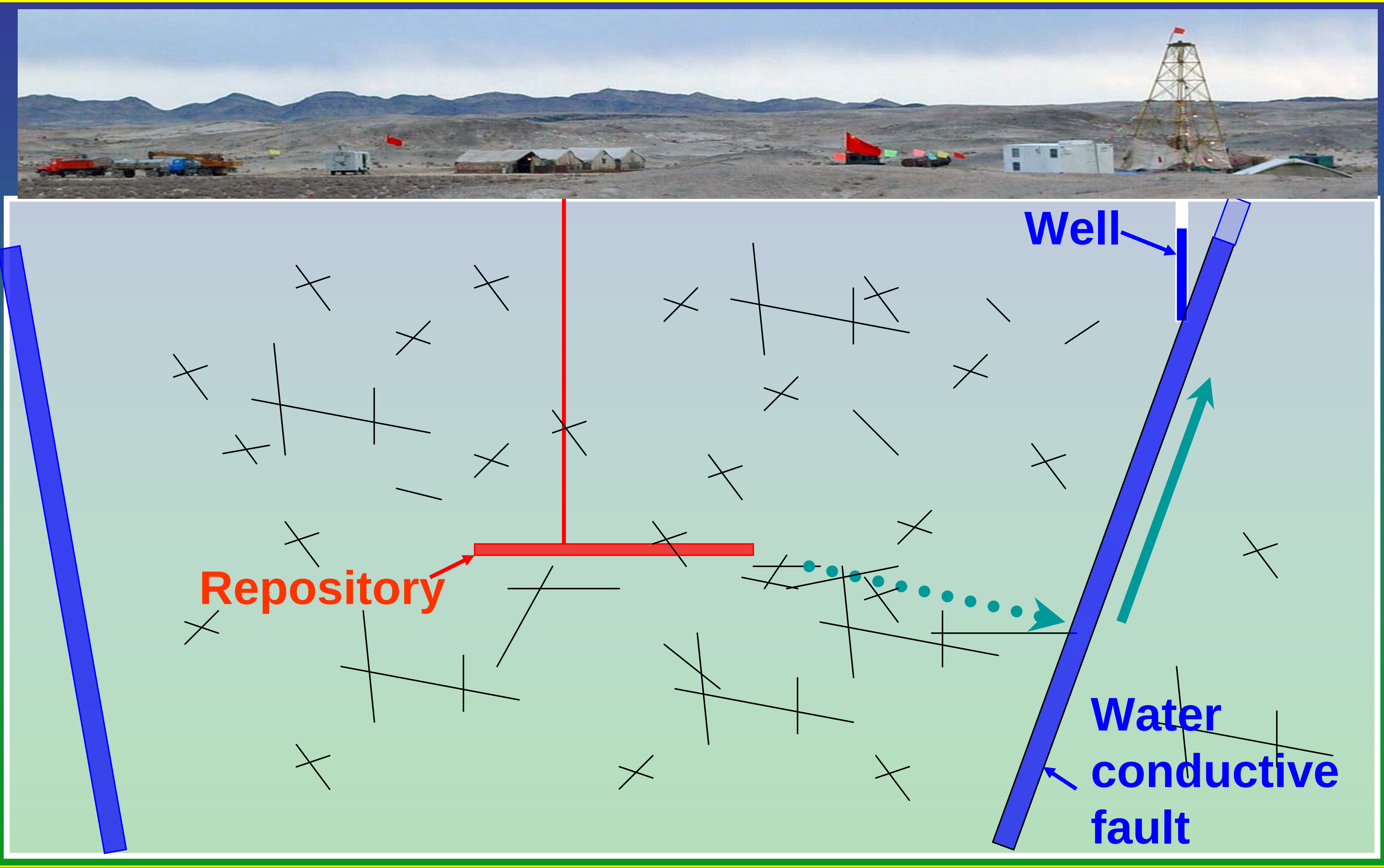
To select more potential sites

To build 3-D map of potential site

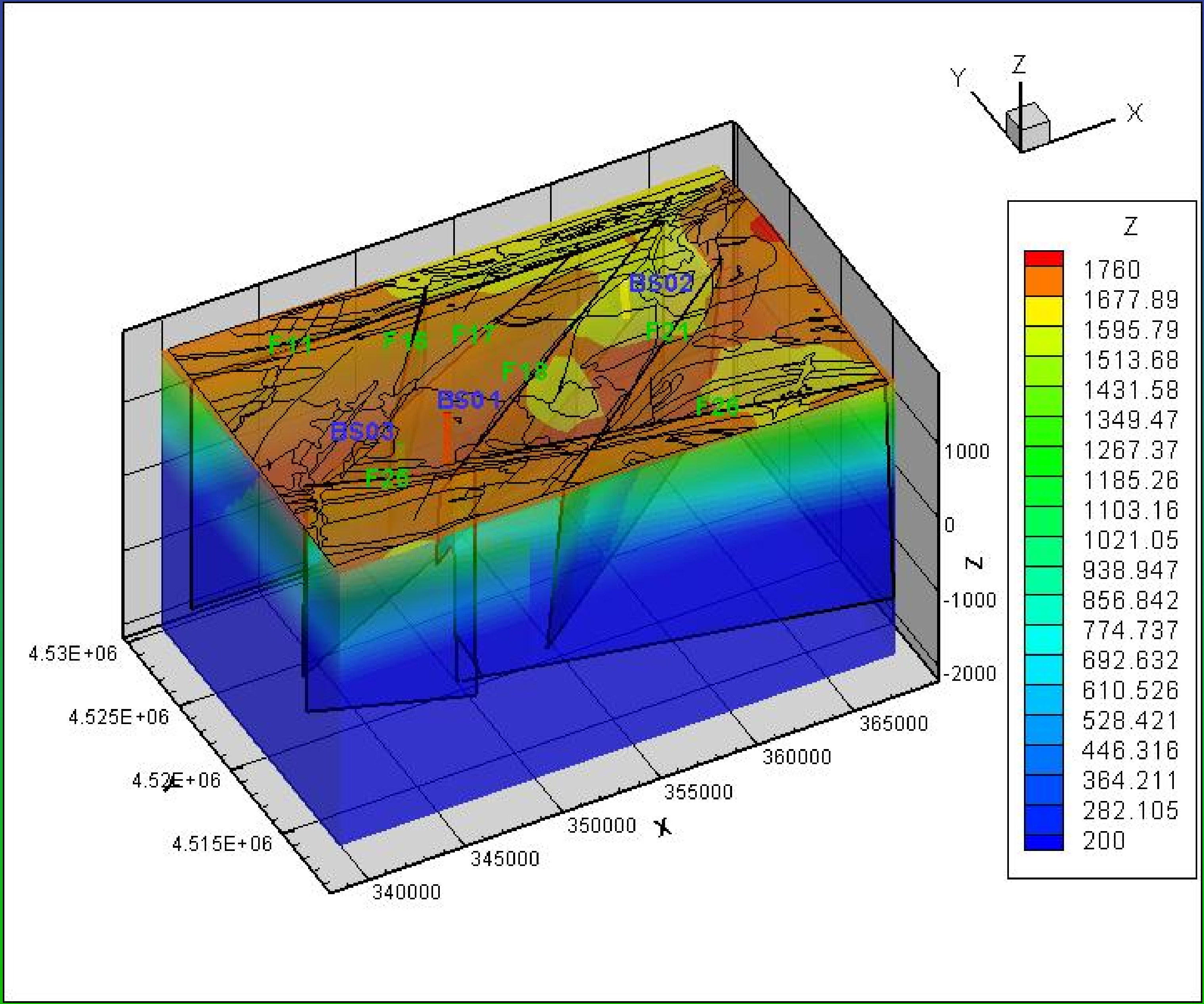
Beishan Region



Conceptual Model of Site



3D Geological Map



Major Activities 2007-2009

- 2 deep boreholes
- 8 shallow boreholes
- Which area is the best one?
- More surface survey, other area?

Geological Survey

Geological Group

Picnic

Experts from France, Switzerland dispatched by IAEA, Sep. 2003

So far, more than 60 foreign experts working or visiting at Beishan

Beishan Home

Beishan Holiday

Beishan Seasons




Welcome to Beishan

Weiming.chen@263.net

Hydrogeological Investigation of Beishan Area, Gansu province, China

GUO Yonghai

Beijing Research Institute of Uranium Geology

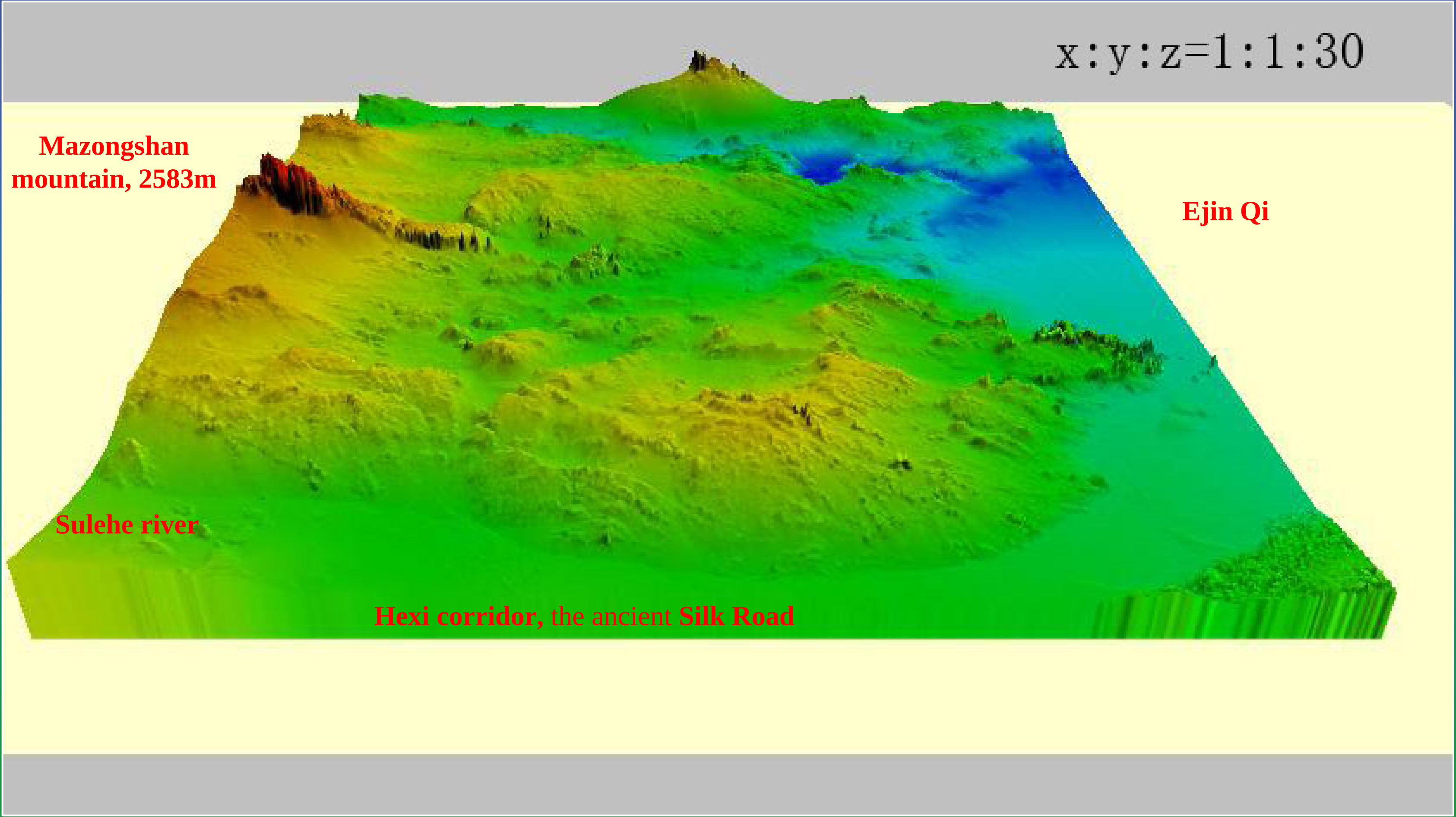
2007-05-28

OUTLINE OF PRESENTATION

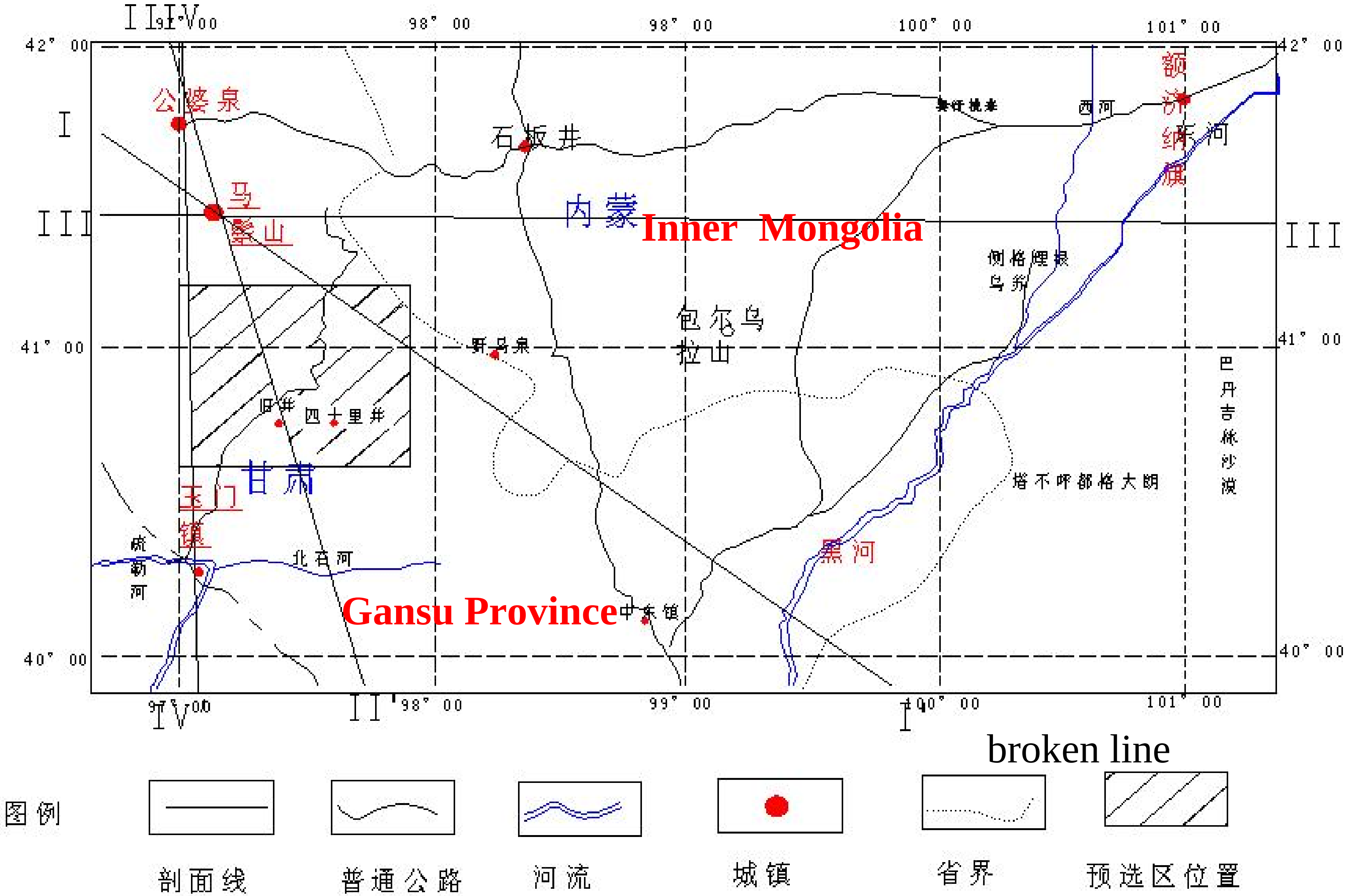
- General Introduction
- Regional Hydrogeological Conditions
- Groundwater Chemistry
- Groundwater Isotopes
- Regional Groundwater Modeling
- Summary and Conclusions

General Introduction

3 dimension view of the investigation area



北山地区地理位置示意图



•belong to the rocky Gobi Desert region;

• geographic features are rocky uplands, Gobi, and sandy dunes;

• with dry climate , little precipitation (40-120mm annually), high evaporation (>3000mm annually);

- few or no inhabitants;
- no industry and agriculture;
- no prospects of economic development;
- the granite is widely distributed.

General Introduction

The hydrogeological investigation was started in 1995. The total investigated area is more than 80000km^2.

- **Stage 1: 1995-2000, field investigation in Jiujing section;**
- **Stage 2: 2000-2002, field and borehole investigation in Jiujing section**

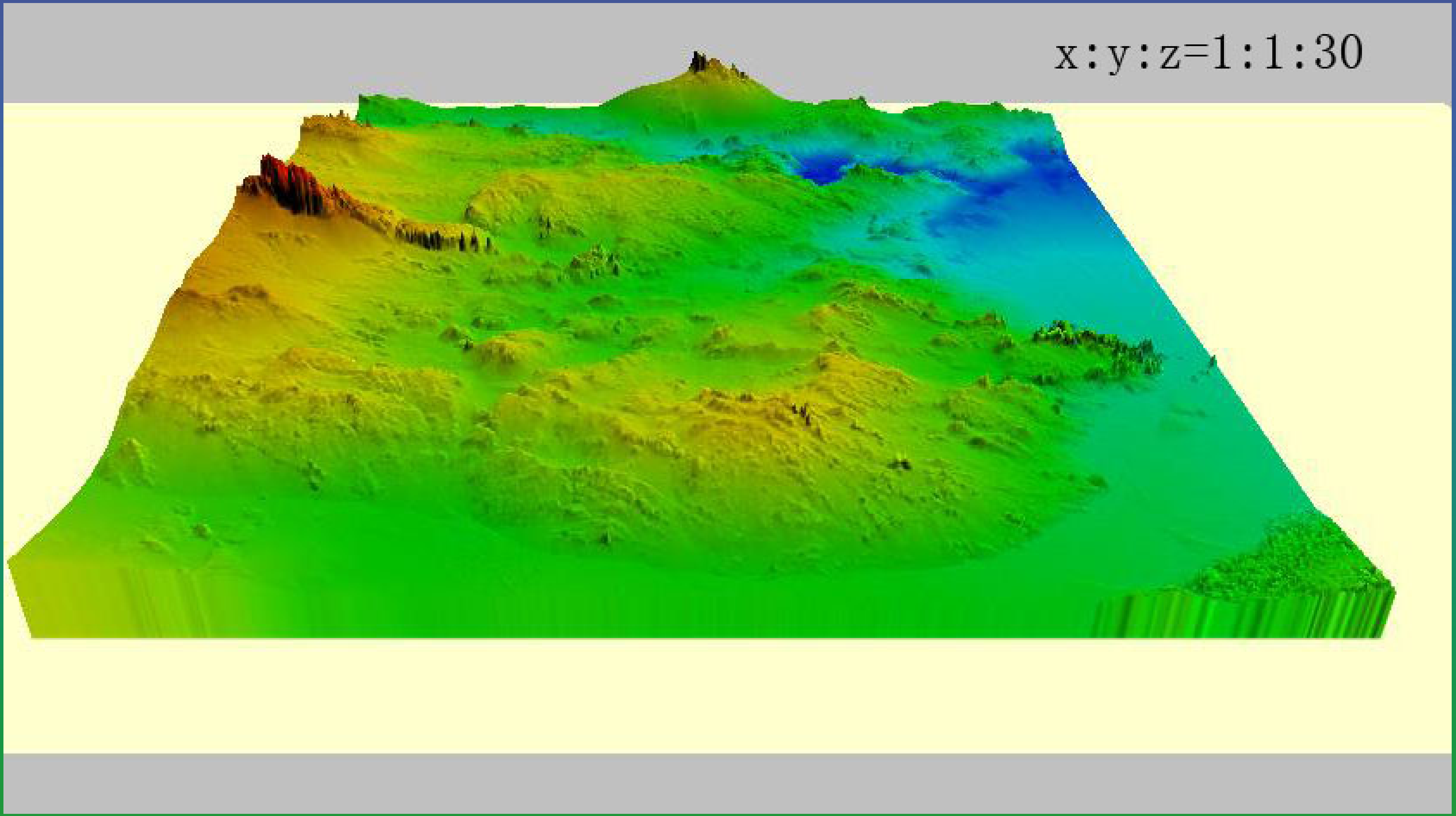
General Introduction

The hydrogeological investigation was started in 1995. The total investigated area is about 80000km^2.

- Stage 3: 2002-2004, field and borehole investigation in Yemaquan section
- Stage 4: 2004-2007, field investigation in Xinchang and Xiangyangshan section and regional investigation and modeling.

Field hydrogeological investigation and results

研究区三维视图



Field hydrogeological investigation and results

Groundwater outcrops

Field hydrogeological investigation and results

Field hydrogeological investigation and results

Groundwater sampling

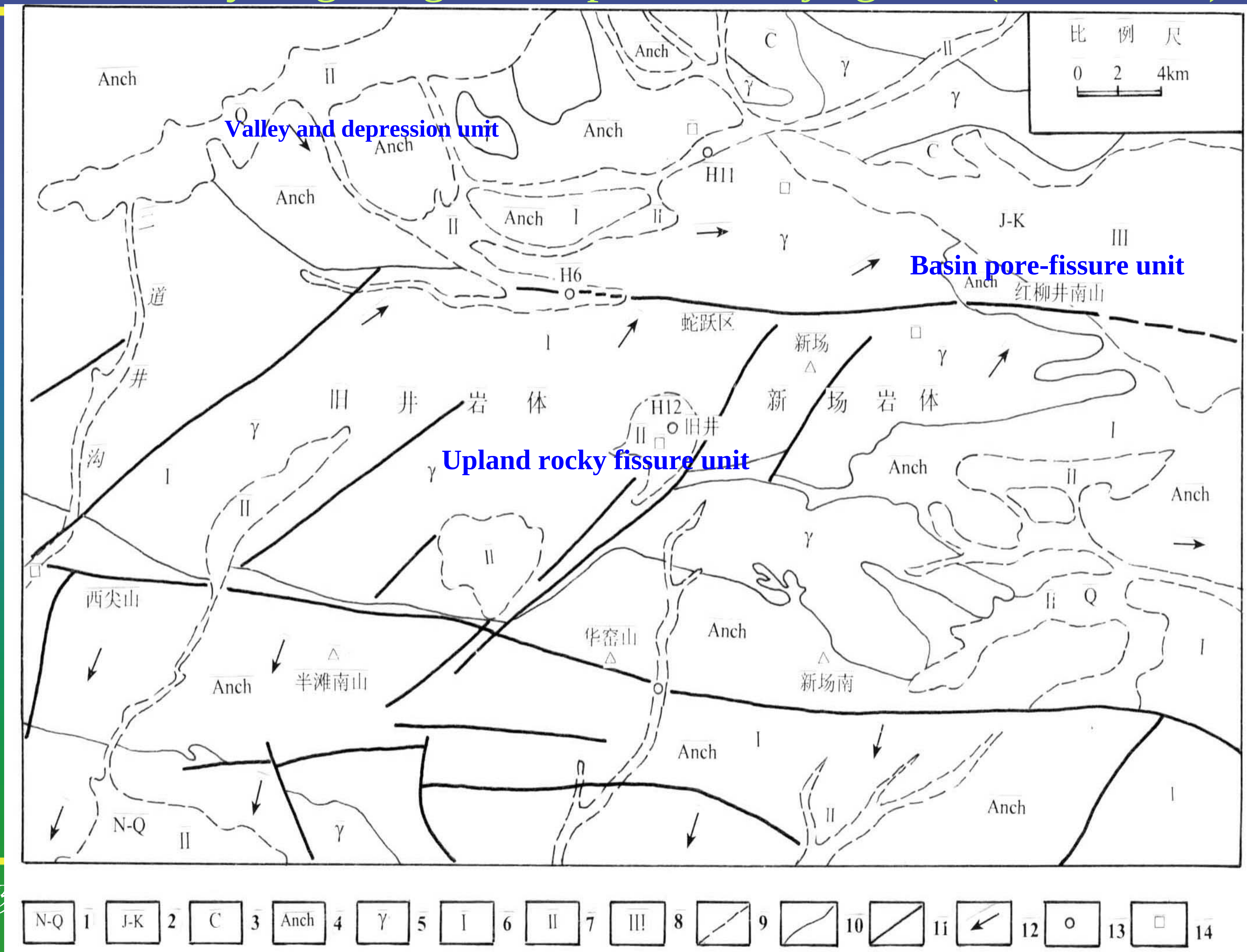

Measurement of groundwater level
2005 7 4

Regional hydrogeological conditions

Based on the topography, lithology, and geological structure, we grouped the Beishan groundwater system into three categories:

1. **the upland rocky fissure unit,**
2. **the valley and depression pore-fissure unit and**
3. **the basin pore-fissure unit.**

Figure 1　The hydrogeological map of the Jiujing area (1995-2002)



Hydrogeological map of Yemaquan area (2002-2004)

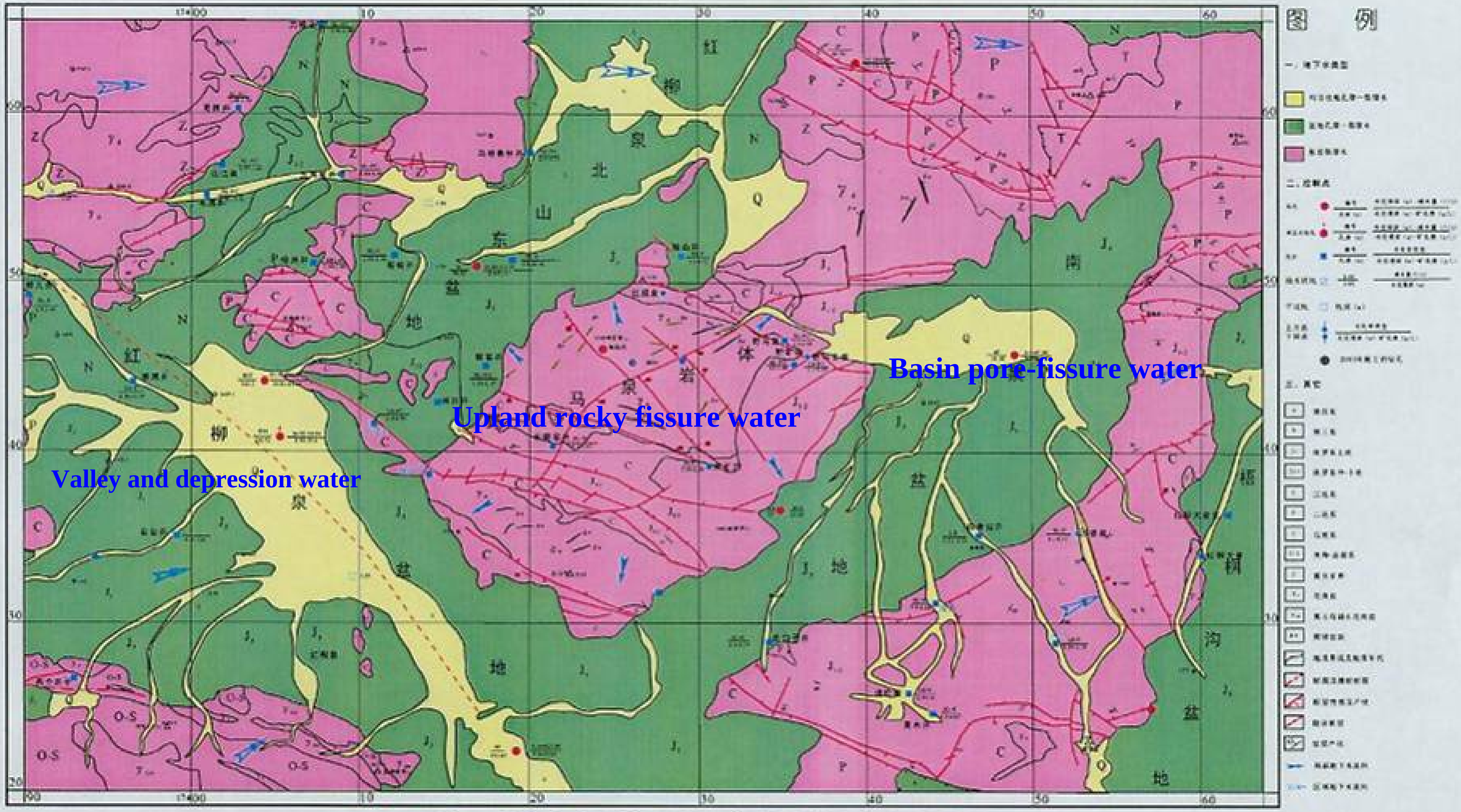
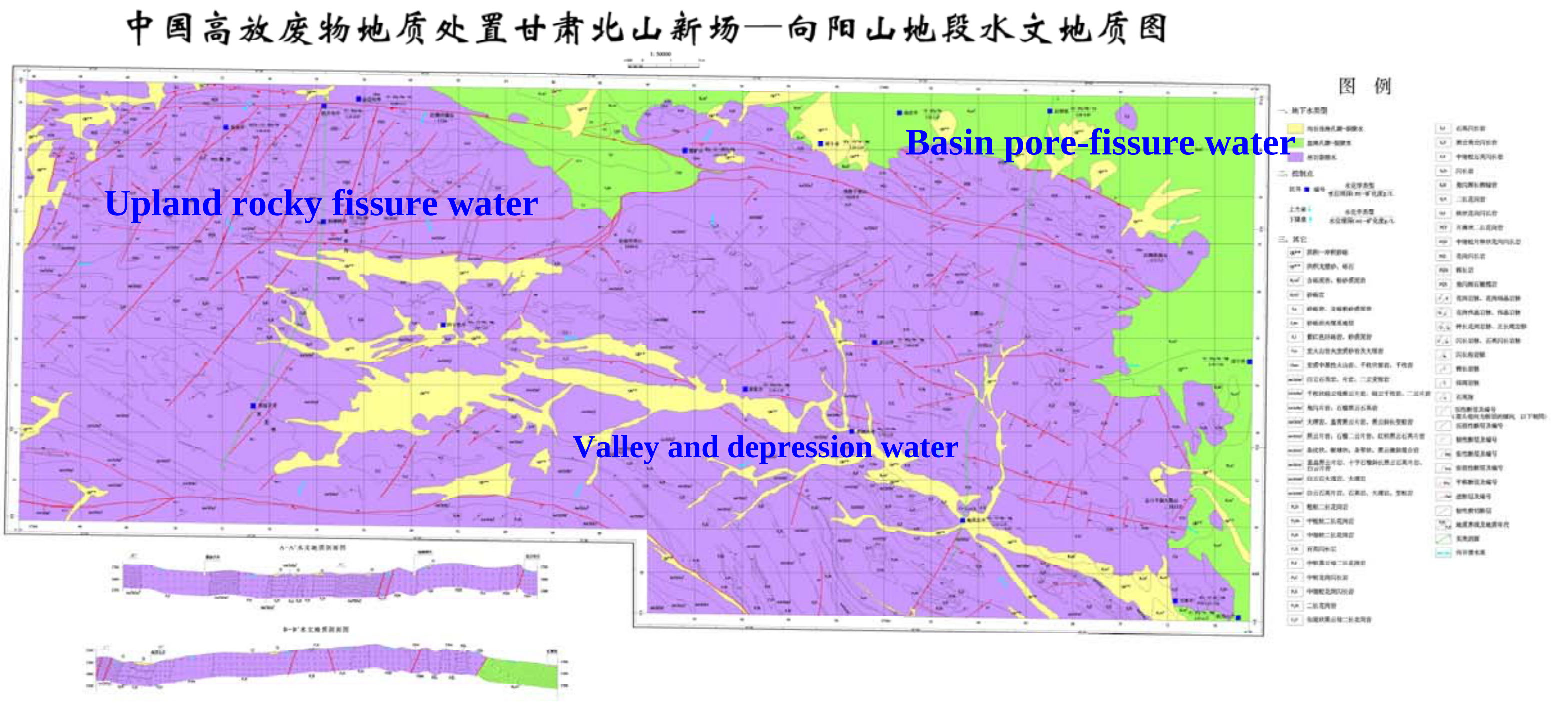
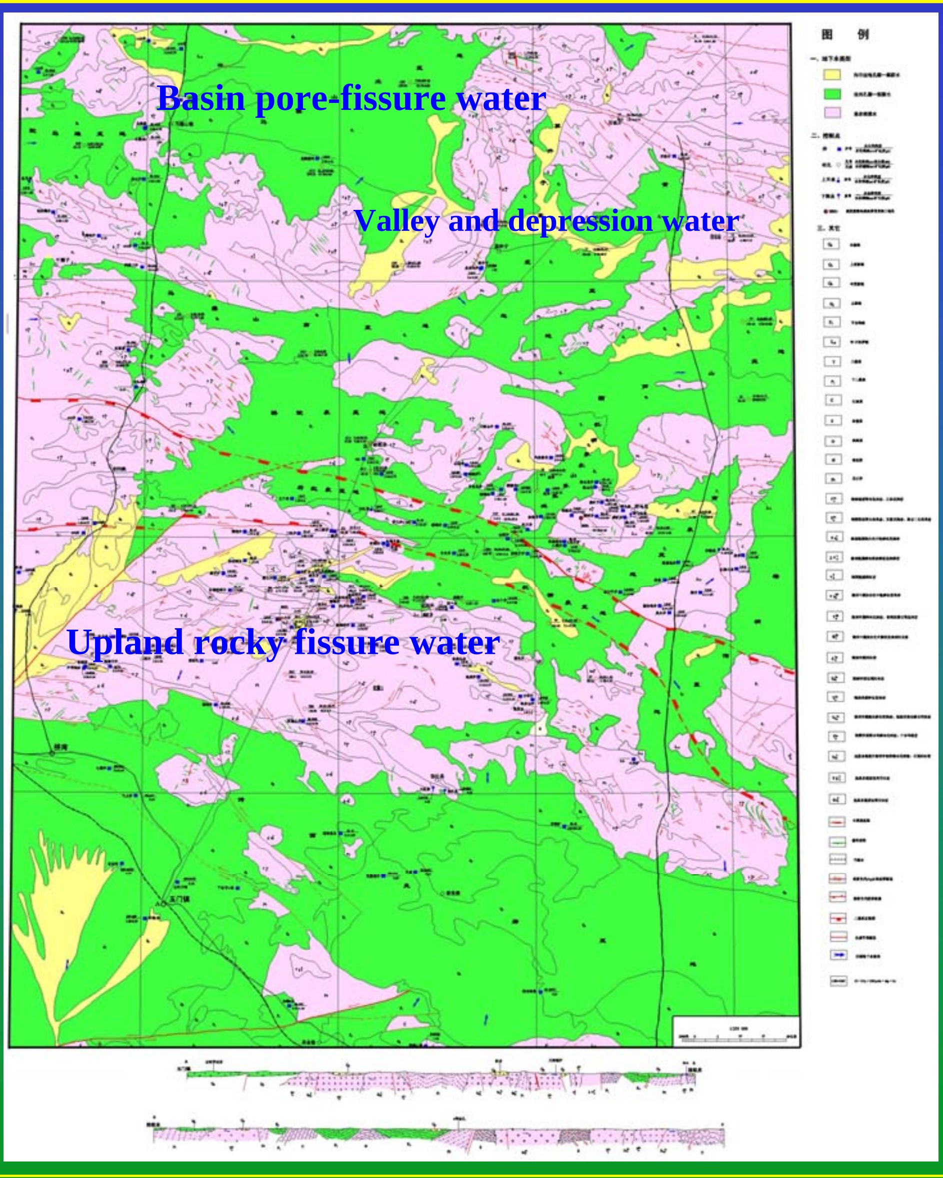


图1 甘肃北山预选区野马泉地段综合水文地质图

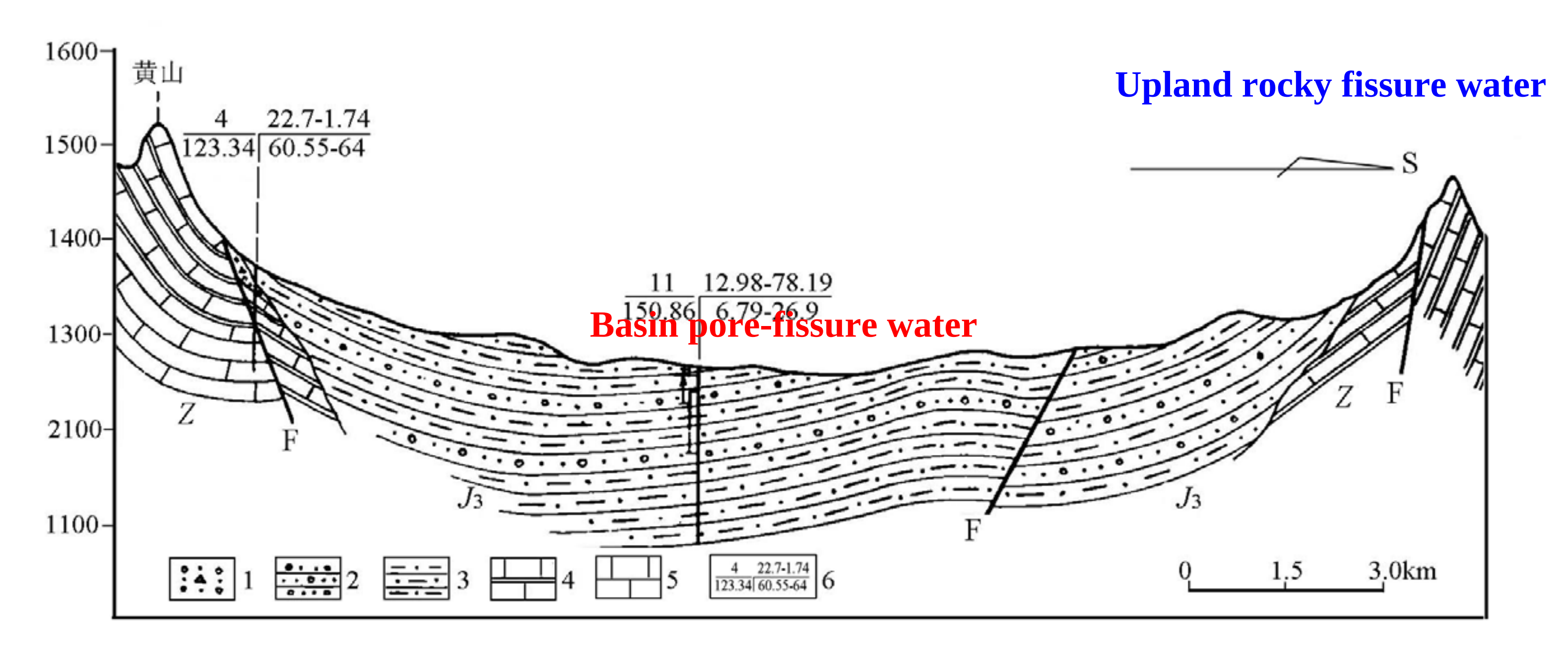
Hydrogeological map of Xinchang-Xiangyangshan area (2004-2007)



Regional hydrogeological map of Beishan area (2004-2007)



水文地质特征



Basin hydrogeological sectional drawing 盆地水文地质剖面图

Groundwater depth

Upland rocky fissure water: > 40 m;
Valley and depression water: 1 to 6m;
Basin pore-fissure water: <10m

Variation of groundwater table in the past

The dead red- willows showing the drought of climate and drop of groundwater level in the past

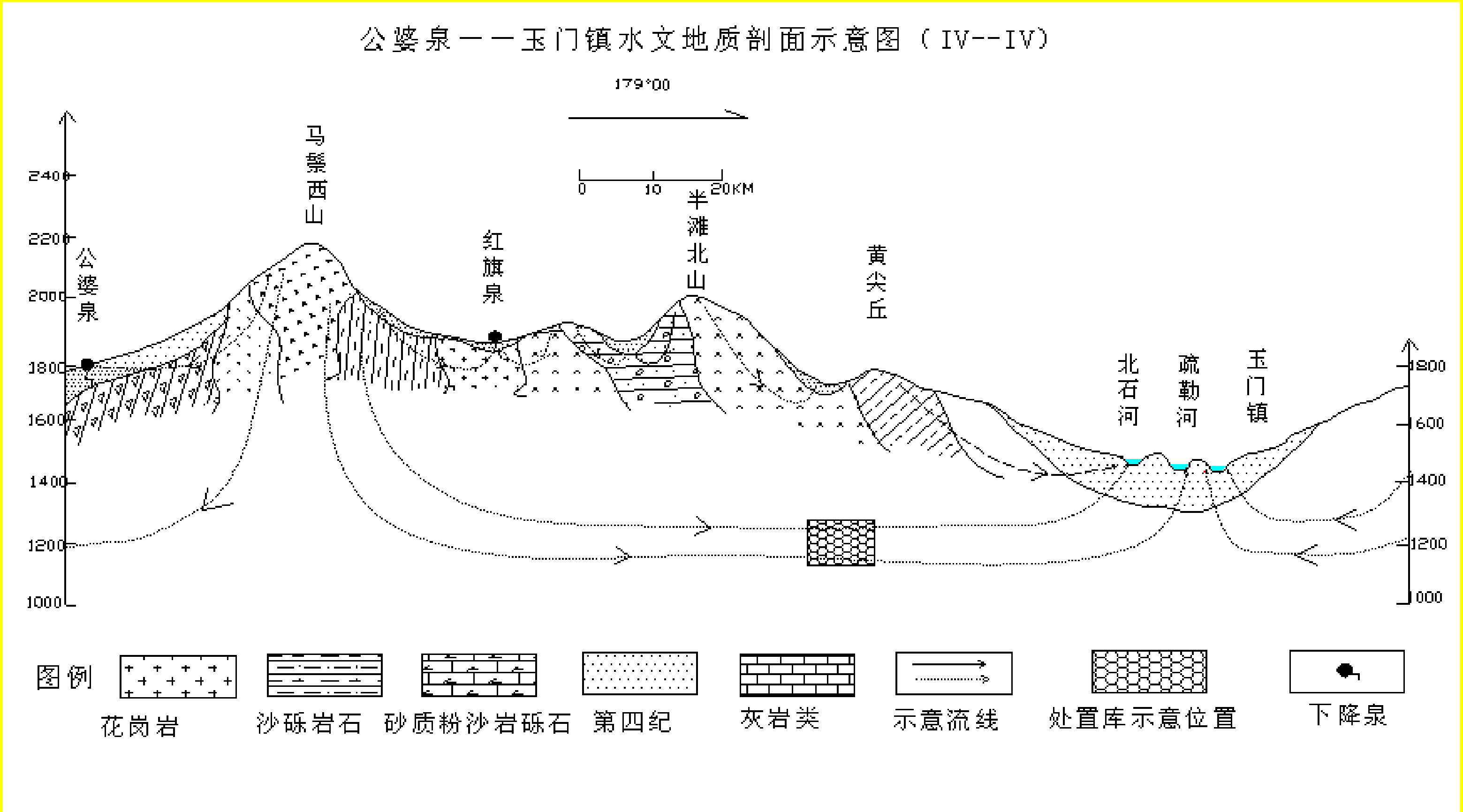
Water-bearing features of different mediums

- In general, granite is the better water-bearing medium in the area;
- Metamorphic rocks are the worse water-bearing medium;

Water-bearing features of different medium

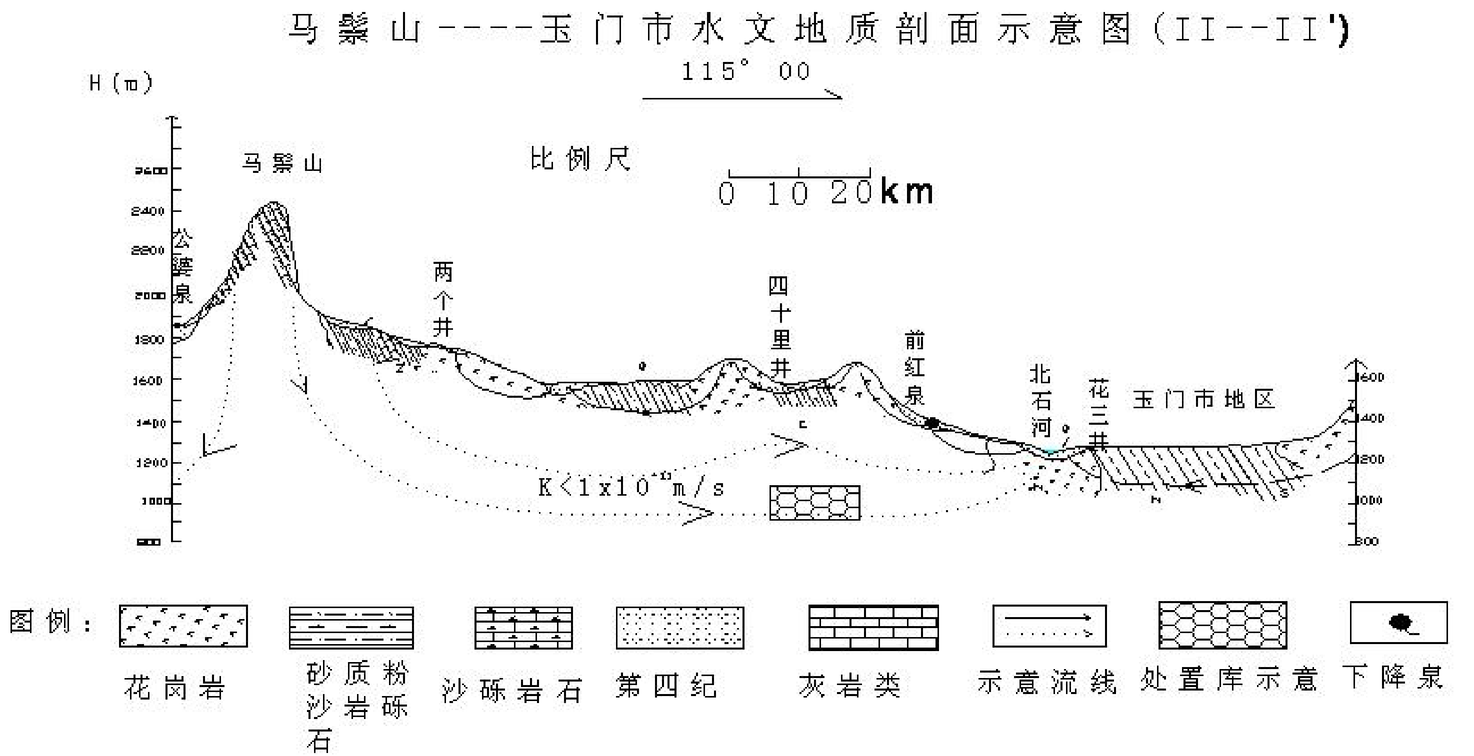
- **Sedimentary rocks and the fault zone without fillings of gouge are the best water-bearing medium.**

Regional groundwater flow sketch sectional drawing



Profile from Mazongshan to Sulehe river

Regional Groundwater Flow Sketch Sectional Ddrawing



Profile from Mazongshan to Yumen city

Borehole hydrogeological investigation

4 boreholes have been drilled in Jiujing and Yemaquan sections (2000-2004)

- **Water sampling for isotope and chemical component analysis.**
- **Pumping and injection tests for getting hydrogeological parameters.**
- **Long term monitoring for getting groundwater dynamic features.**

Groundwater Chemistry

Table 6 The content distribution of major ions in Beishan groundwater(mg/L)

Ions	Mean content	Range of content
Na (main cation)	631.00	37.2～4010.4
K	58.66	7.0～465.6
Ca	154.88	29.9～561.1
Mg	42.45	3.9～173.8
HCO_3	201.64	68.9～637.0
Cl (main anion)	645.39	38.6～3694.2
SO_4(main anion)	750.98	67.7～4025.0

Groundwater chemistry

Water chemical type: Cl-Na, Cl . SO4 –Na, SO4 . Cl-Na;

TDS: mostly >2g/L to 5g/L, the highest one can reach 80g/L;

pH value: mostly >7.5 to 9

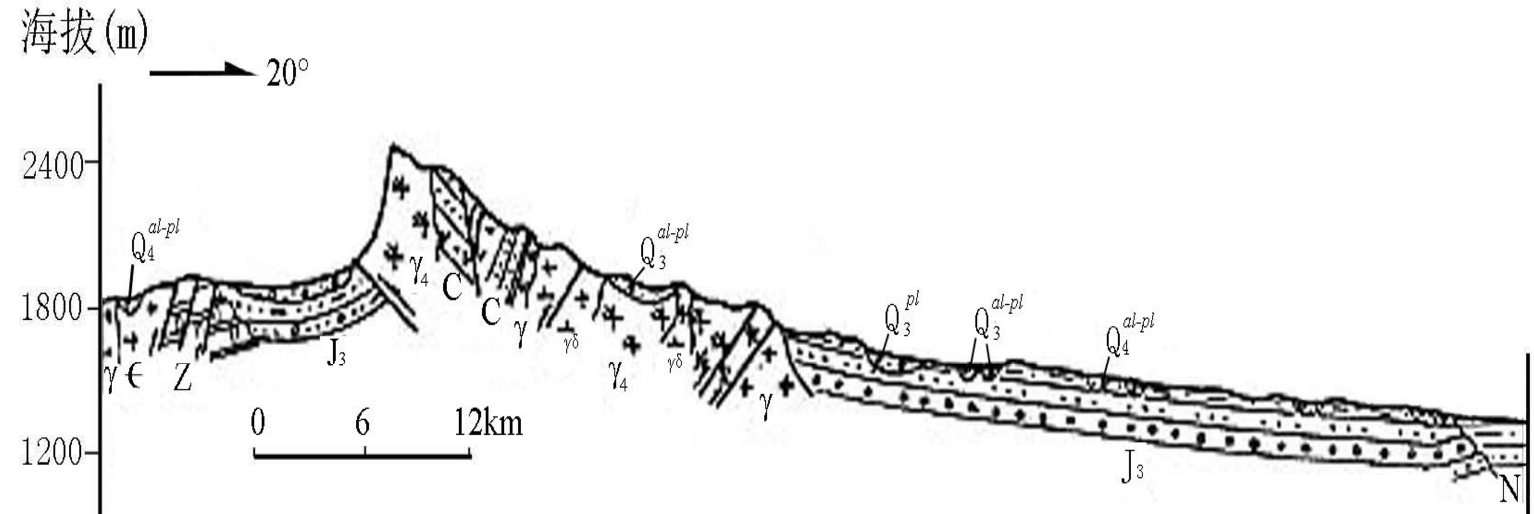
Groundwater chemical data in study area (mg/L)

Sample No.	取样位置	水温℃	pH	TDS	化学类型
W01-00-07	金庙沟	13.0	7.8	1238.0	Cl SO_4-Na
S02-00-07	后红泉	11.6	7.8	5129.3	Cl SO_4-Na
W03-00-07	咸水井	11.6	6.8	5013.2	Cl SO_4-Na
S03--00-09	二道井泉	12.0	7.7	1157.2	Cl -NaCa
W05-00-07	梧桐井	12.6	7.6	773.4	Cl SO_4-Na
W08-00-07	旧井（南）	7.5	8.0	4012.6	Cl SO_4-Na
W11--00-07	十月井（北）	13.1	8.0	4265.2	Cl SO_4-Na
W12-00-07	月亮湾	10.0	7.2	2620.2	Cl SO_4-NaCa
S04-00-07	骆驼泉	10.0	7.3	1851.0	SO_4Cl -NaCa
W16--00-09	花三井	14	7.8	722.3	SO_4-NaCa
W17-00-09	花二井	14	7.9	1195.0	SO_4-MgNa
W20-00-09	地质井（2）	17.4	8.3	911.7	Cl -NaCa
W19--00-09	地质井（1）	15.3	7.9	1166.5	Cl -NaCa
W21-00-09	羊角井（1）	15.8	7.7	835.6	Cl -CaNa
W22--00-09	羊角井（2）	14.1	7.8	1051.9	Cl SO_4-NaCa
W 24-00-09	草爬子	17.2	6.7	1887.8	Cl -NaCa
W28-00-09	英格尔雄井	12	7.6	5365.5	Cl -NaCa
W29-00-09	旧井（北）	7.6	8.1	3919.3	Cl SO_4-Na
S05-00-09	小泉	12.5	7.0	742.1	SO_4 HCO_3-MgNa

Groundwater chemical data in study area (mg/L)

Sample No.	取样位置	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO^-_3	SO^{2-}_4	SiO_2
W01-00-07	金庙沟		339.0	78.0	20.4	369.0	221.4	302.9	8.7
S02-00-07	后红泉	9.3	1677.0	117.5	60.0	1873.6	197.8	1269.9	2.9
W03-00-07	咸水井	29.5	1313.0	363.0	70.7	1764.1	209.9	1357.6	3.3
S03--00-09	二道井泉	36.5	187.2	157.6	37.8	465.8	145.7	215.2	--
W05-00-07	梧桐井	20.7	150.6	85.8	20.5	196.0	139.6	230.8	14.4
W08-00-07	旧井（南）	5.48	1075.5	322.4	40.4	1470.1	250.9	948.1	12.3
W11--00-07	十月井（北）	18.4	1185.8	253.8	46.1	1420.0	279.7	1185.1	13.7
W12-00-07	月亮湾	20.9	602.4	217.4	44.8	522.9	233.0	1097.8	7.9
S04-00-07	骆驼泉	10.5	430.3	157.0	25.3	415.1	274.3	652.4	21.8
W16--00-09	花三井	12.0	128.0	56.2	29.0	85.0	79.3	366.8	14.5
W17-00-09	花二井	3.07	150.2	89.9	96.3	247.9	93.3	541.4	15.1
W20-00-09	地质井（2）	7.47	180.6	95.3	26.7	390.4	83.2	158.1	--
W19--00-09	地质井（1）	20.0	223.9	130.1	36.7	515.7	145.6	162.5	--
W21-00-09	羊角井（1）	24.8	114.9	126.4	35.6	381.9	99.9	114.2	--
W22--00-09	羊角井（2）	12.7	216.1	93.5	36.7	462.2	87.4	175.7	--
W 24-00-09	草爬子	24.0	366.1	230.9	44.4	964.5	105.0	188.8	--
W28-00-09	英格尔雄井	40.6	1286.5	505.8	164.4	3278.6	58.3	87.8	--
W26-00-09	炭窑井	13.0	208.6	58.6	33.3	332.1	149.8	188.8	--
W29-00-09	旧井（北）	23.2	531.2	643.8	55.84	734.1	192.6	1802.6	18.0
S05-00-09	小泉	37.5	112.4	36.8	64.7	108.2	270.7	259.5	15.1

Groundwater chemistry



水化学类型	SO_4^{2-}-Cl^--Na^+		Cl^--SO_4^{2-}-HCO_3^--Na^+	SO_4^{2-}-Cl^--Na^+			Cl^--SO_4^{2-}-Na^+	
矿化度	1-2g/l		<1g/l	1-2g/l			2-5g/l	>5g/l
地貌单元	丘陵	山前倾斜平原	低中山	山间平原	低山	山前倾斜平原	波状平原	

The main influence factors of groundwater chemistry

- **Landform**
- **Precipitation**
- **Water level**
- **Evaporation (fundamental factor)**

Summary of groundwater chemistry

- **High TDS**

  from 0.4 to 12.0 g/L, and the highest TDS can reach 80 g/L

- **Slightly alkaline**

The pH values are mainly from 7.2 to 8.8

- **Low solubility**

  Most of waters are oversaturated with calcite, dolomite and clay minerals

- **Water chemical types**
  - **Sodium chloride sulphate**
  - **Sodium sulphate chloride**
- **The main influence factors of groundwater chemistry**
  - **Landform**
  - **Precipitation**
  - **Water level**
  - **Evaperation (fundamental factor)**

Groundwater isotopes

^{18}O: -7.0‰ to-11‰;

^{2}H :-53‰ to -66.5‰;

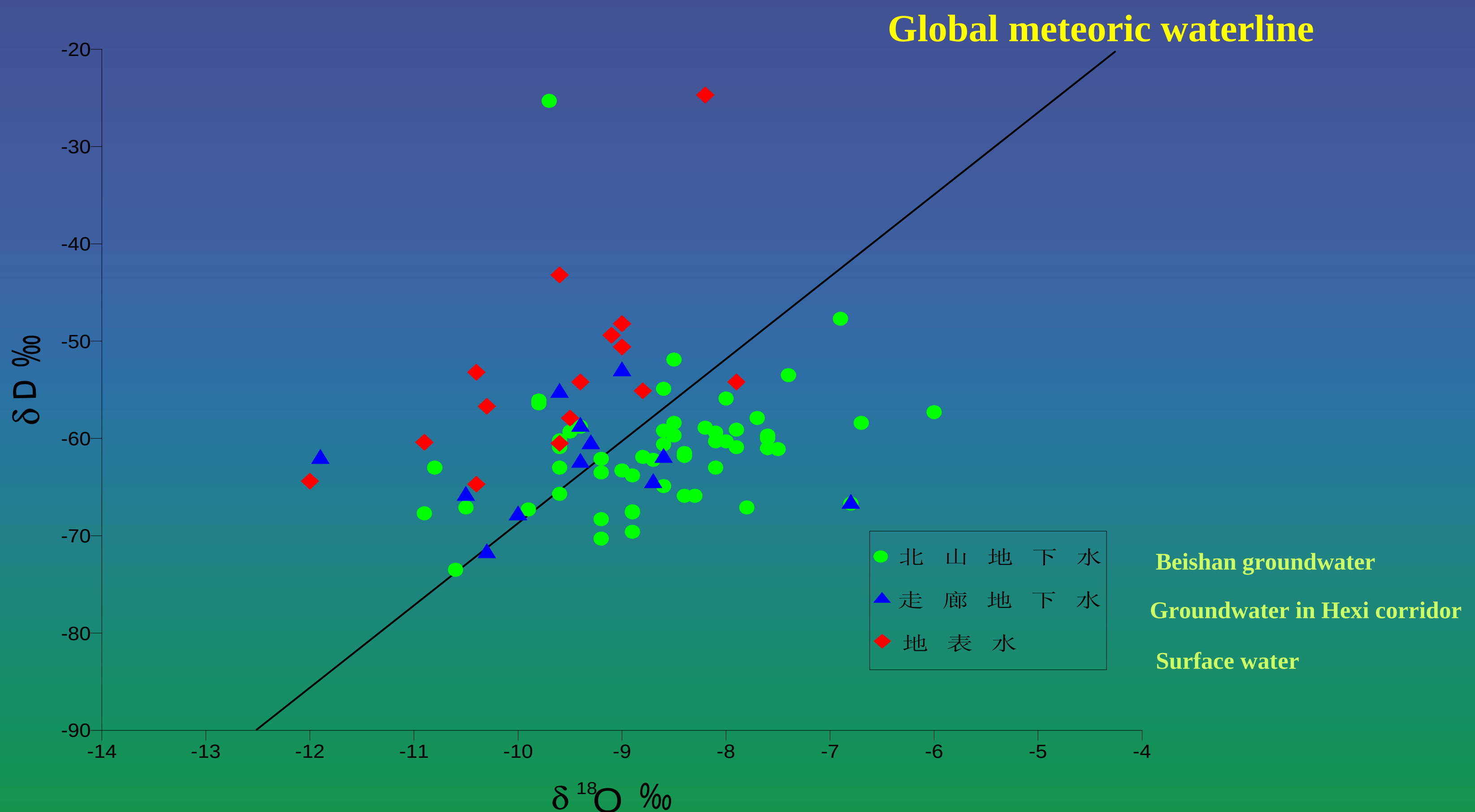
^{3}H : 5.08 TU to 38.5 TU.

Groundwater Isotopes

Groundwater hydrogen and oxygen isotope

Sample No.	Location	δ ^{18}O (‰)	δD (‰)	tritium(TU)
W05-00-07	梧桐井	-9.3	-59	59.54
W05-00-07	旧井（南）	-8.7	-56	34.1
W29-00-09	旧井（北）	-10.4	-67	33.24
W30-00-09	十月井（南）	-7.6	-56	37.27
W11-00-07	十月井（北）	-7.7	-54	31.10
W12-00-07	月亮湾	-9.2	-62	6.77
S02-00-07	后红泉	-9.1	-66	0.94
S04-00-07	骆驼泉	-9.6	-63	40.26
W03-00-07	咸水井	-8.2	-54	14.48
W01-00-07	金庙沟	-9.0	-58	12.34
W24-00-09	草爬子	-7.4	-63	24.44
W19-00-09	地质井（1）	-8.9	-65	41.61
W20-00-09	地质井（2）	-8.6	-70	35.78
W16-00-09	花三井	-10.7	-73	10.34
W17-00-09	花二井	-10.2	-74	36.53
W21-00-09	羊角井（1）	-8.0	-69	61.55
W22-00-09	羊角井（2）	-8.2	-70	69.80
W28-00-09	英格尔雄井	-6.9	-70	17.68
S03-00-09	二道井泉	-8.8	-61	48.20
W26-00-09	炭窑井	-8.4	-59	45.62
S05-00-09	小泉	-10.0	-66	36.61
R01-00-07	雨水	-8.3	-66	64.38

Groundwater Isotopes



Plot of ^{18}O vs. ^{2}H in groundwater in Beishan Area

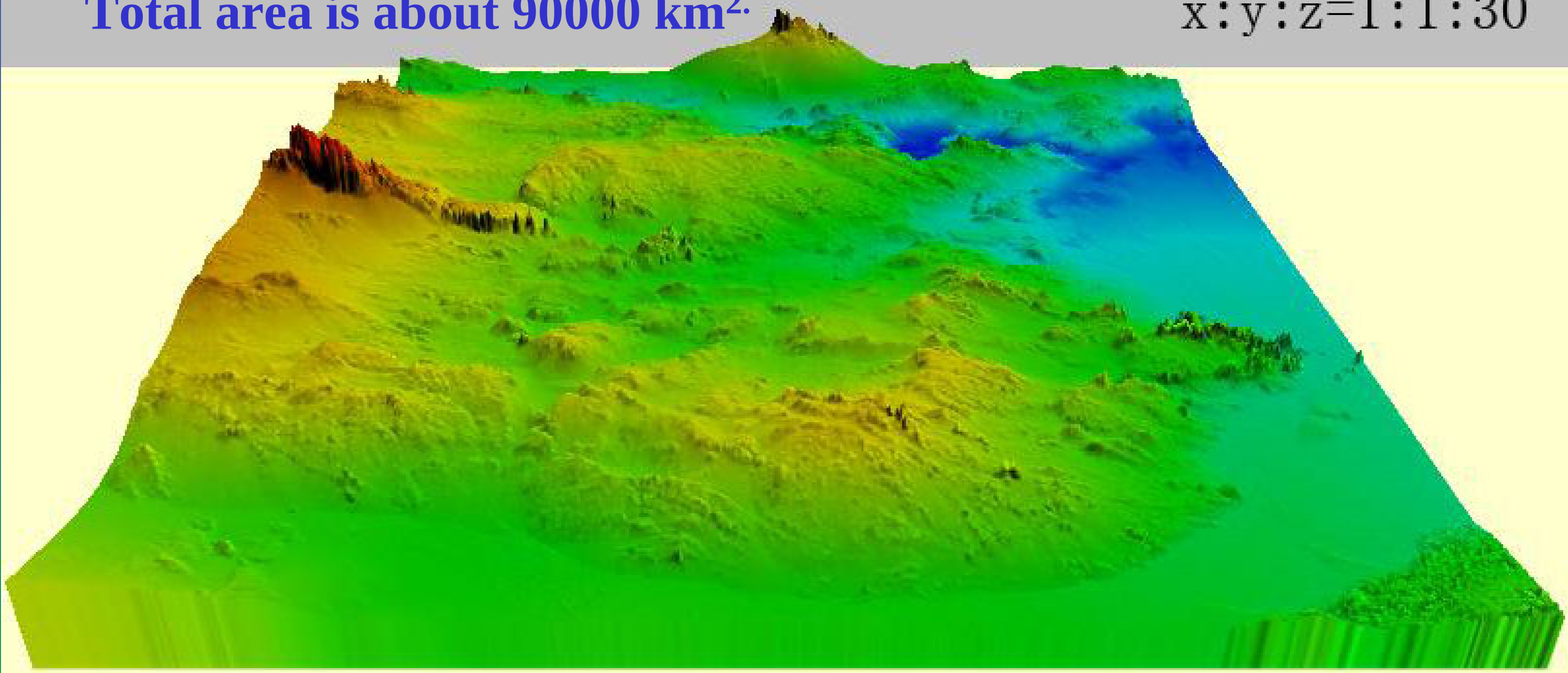
Groundwater flow modeling

From 2005 to this year, a cooperated project of groundwater flow modeling was carried out by our group and Institute of Geology and Geophysics, Academy of Sciences . The project was completed mainly by Dr. Guomin Li.

Groundwater flow modeling

Total area is about 90000 km^2.

x:y:z=1:1:30



3 dimension view of the study area

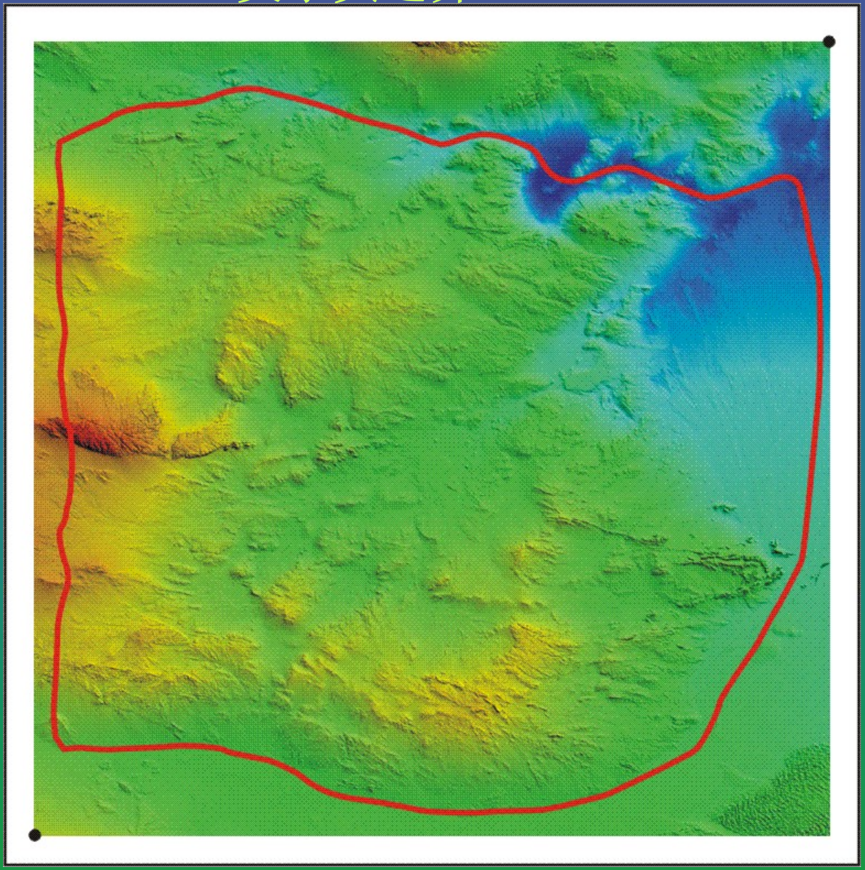
Regional Groundwater Flow Modelling

Define the boundary conditions

Water level boundary

一类水头边界

North



water divide，zero flux boundary

零通量边界

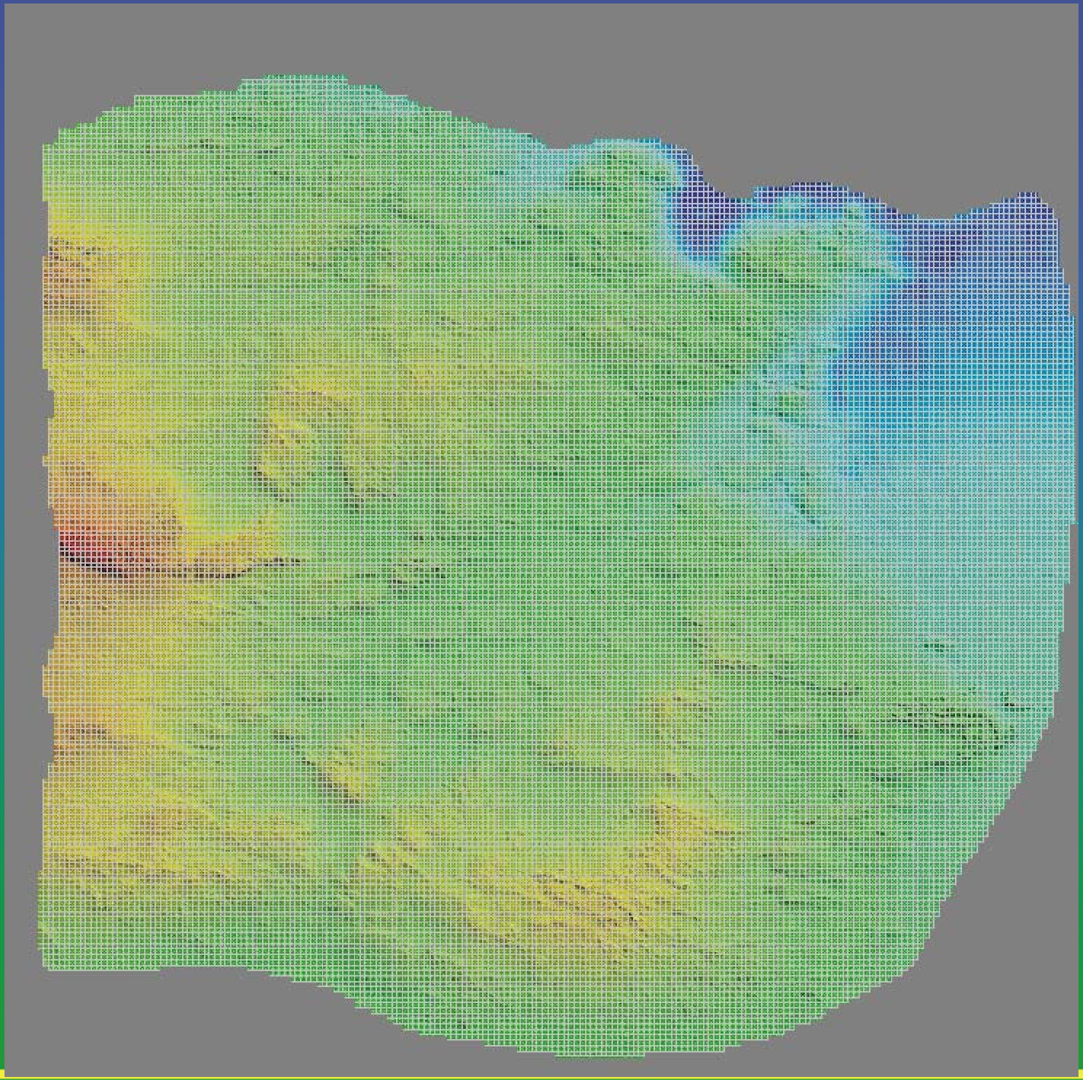
Heihe River, water level boundary

一类水头边界

Hexi corridor,and Sulehe river

Water level boundary一类水头边界

Defining the grid

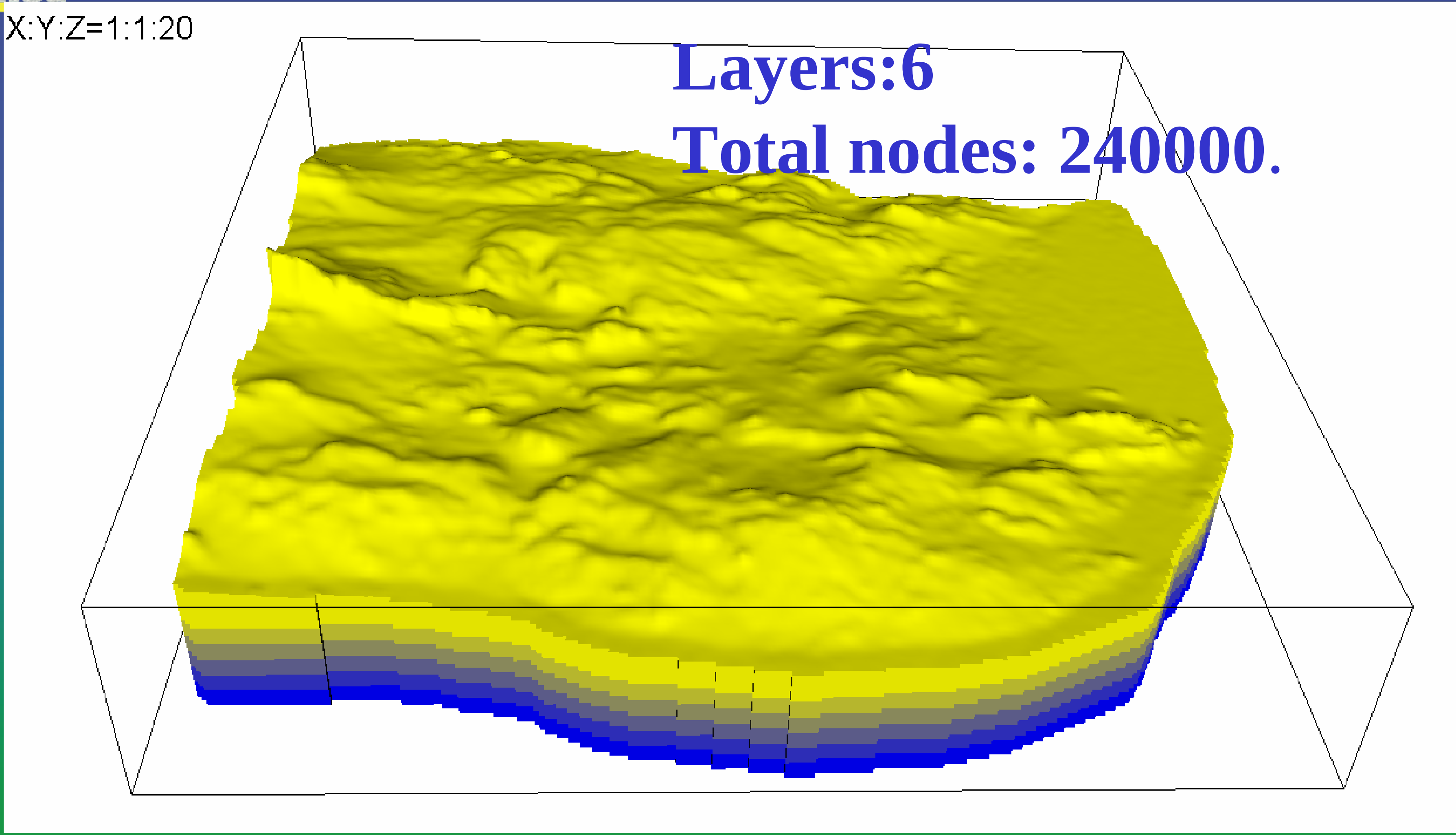


Rows: 200

Columns: 200

Finite difference method

Regional Groundwater flow modelling



Input Hydrogeological Parameters

- **Rainfall:**
- **West part :80mm/y;**
- **Middle part : 65mm/y;**
- **East part:50mm/y.**

- **Evaporation:**
- **West part : 2800mm/y**
- **Middle part : 3100mm/y。**
- **East part: 3500mm/y,**

Input Hydrogeological Parameters

- **Permeability coefficient:** (almost have no real data). Design different schemes:

  scheme 1: 10^{-6}m/s

  scheme 2: 10^{-7}m/s

  scheme 3: 10^{-8}m/s

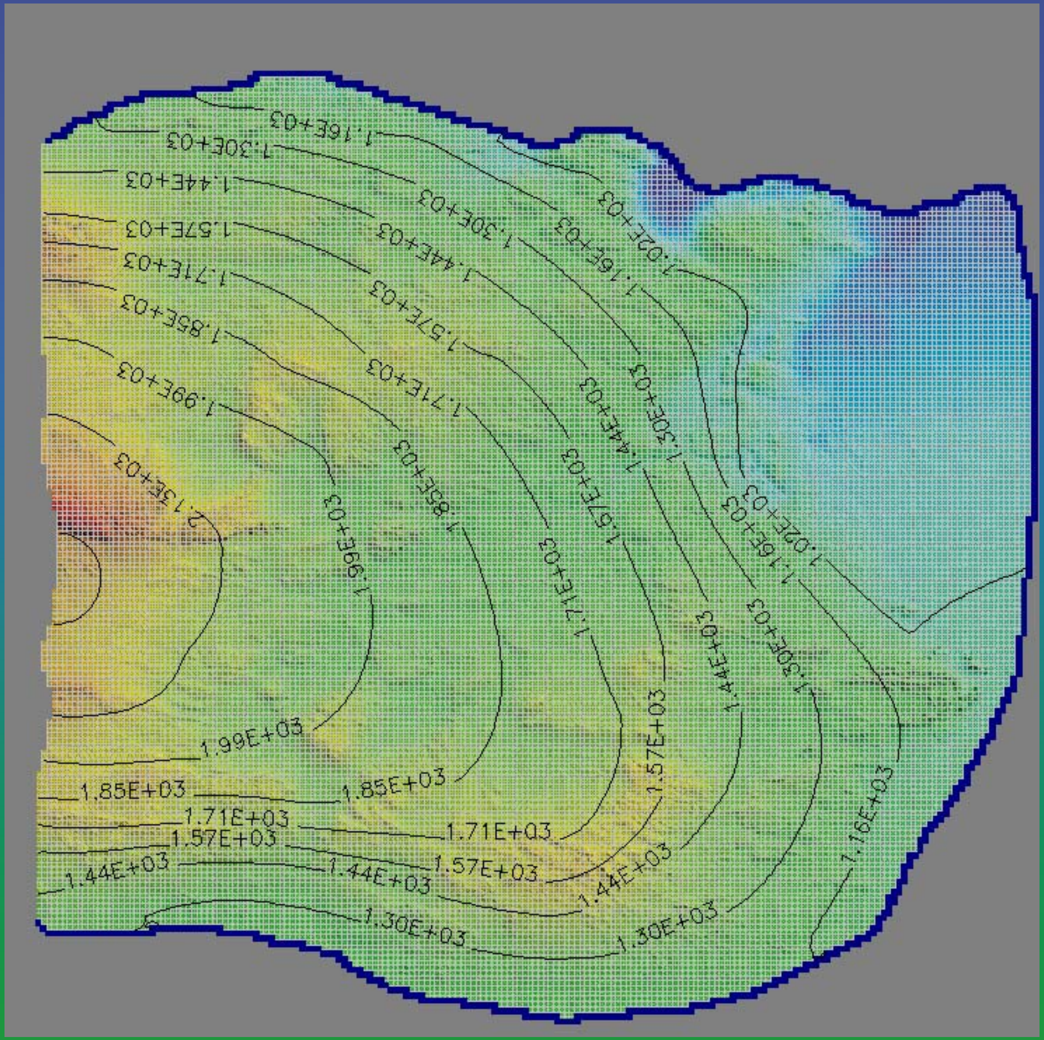
  scheme 4: 10^{-9}m/s

Regional Groundwater Flow Modelling

Groundwater flow field modeling result:

Scheme 4:

Permeability coefficient: 10^{-9}m/s



Regional Groundwater Flow Modelling

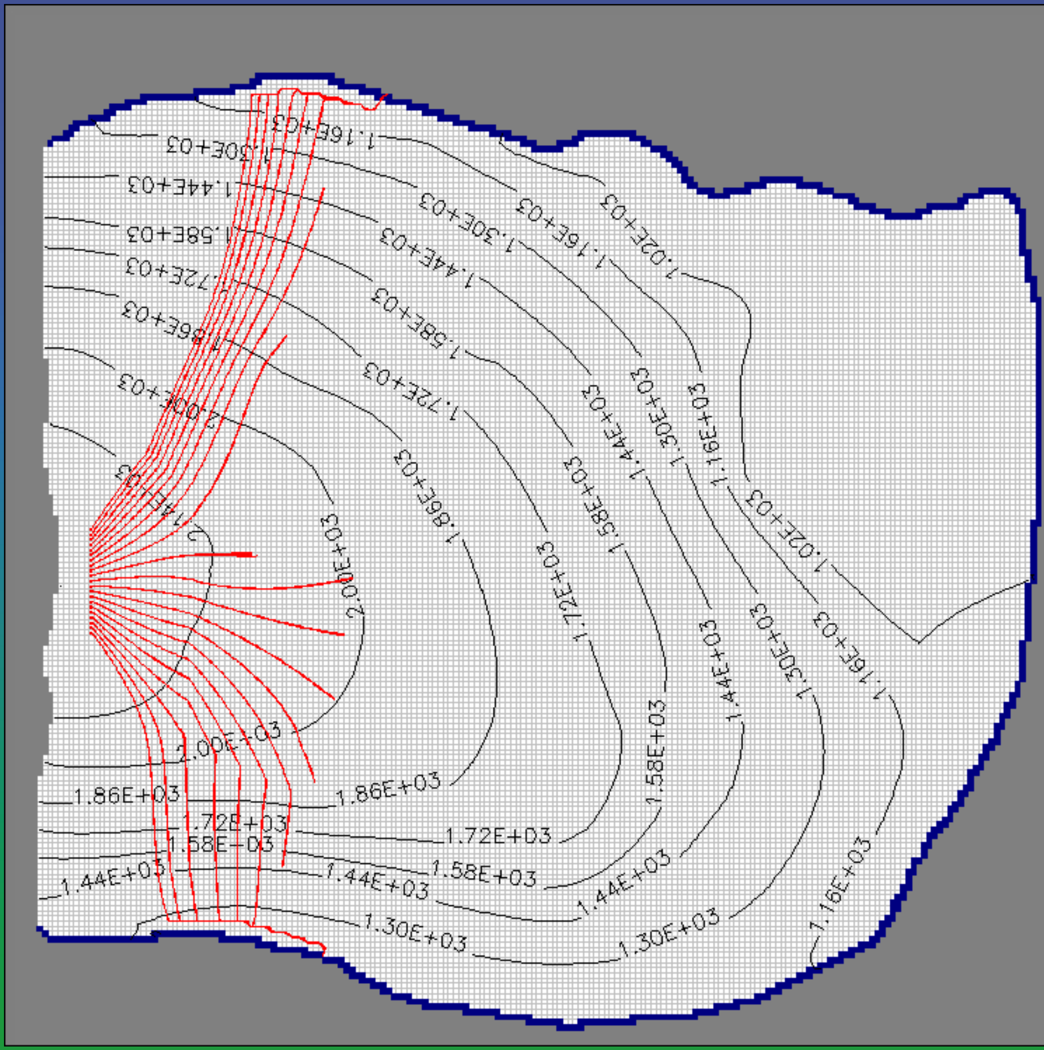
Groundwater pathline modeling result:

Scheme 4

Permeability coefficient:

10^{-9}m/s

Red line shows the particl travel track in 1 million years.



Summary of the presentation

- Groundwater system in Beishan area can be classified into three units:(1) upland rocky fracture unit; (2) valley and depression pore-fracture unit; and (3) basin pore-fracture unite, in which the upland rocky unit is the principal hydrogeological unit in the area.

Summary of the presentation

- **Water content is mainly depend on lithology, topography, fracture and fault. In general, water content of magmatic rocks is much more than that of metamorphic rocks.**

Summary of the presentation

- **Chemically, groundwater in Beishan area is characterized by high TDS.**

Summary of the presentation

- **Isotope study shown both shallow groundwater and deep groundwater are of meteoric origin.**

Summary of the presentation

- Groundwater modeling was done initially and the result could provide valuable reference for site selection and evaluation.

Future Prospect

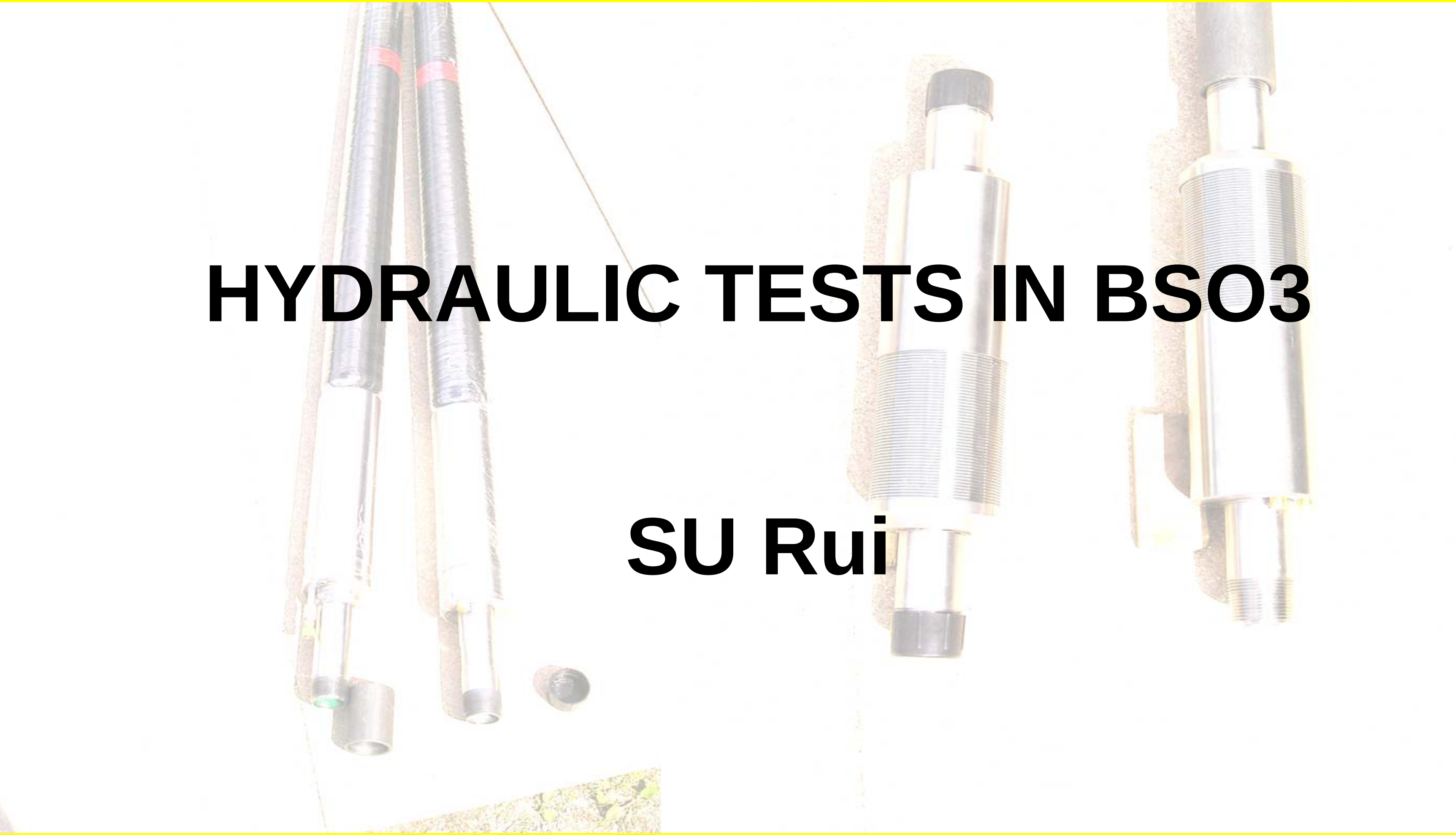
- Regional hydrogeological investigation
  - regional circulation;
- More shallow borehole drilling
  - site groundwater flow field;
- More deep borehole drilling
  - site deep hydrogeological environment;
- Hydrogeological test
  - hydrogeological parameters.
- Groundwater modeling continually
  - provide support for site evaluation

radioactive waste is a major problem facing many countries worldwide.

It is our dream to make a wonderful future in this field.

Let us cooperate and work together on it to protect our beautiful global village.


Thank you



HYDRAULIC TESTS IN BSO3

SU Rui

OUTLINE

- INTRODUCTION
- HYDRAULIC TEST TECHNIQUE WITH DOUBLE PACKERS
- DATA INTERPRETATION OF TESTS
- Summaries

INTRODUCTION

OBJECTIVES

- To establish the approaches and techniques
- To take groundwater samples
- To obtain the hydraulic parameters

INTRODUCTION

Basic information of BS03

- Geometry: 500m, 95mm, vertical
- Host rock: Porphyritic monzonitic granite
- Aquifer features: heterogeneity, anisotropy, fractured-rock aquifer
- Water level below the ground: ~60m
- Drilling was finished in 2003

HYDRAULIC TEST TECHNOLOGY WITH DOUBLE PACKERS

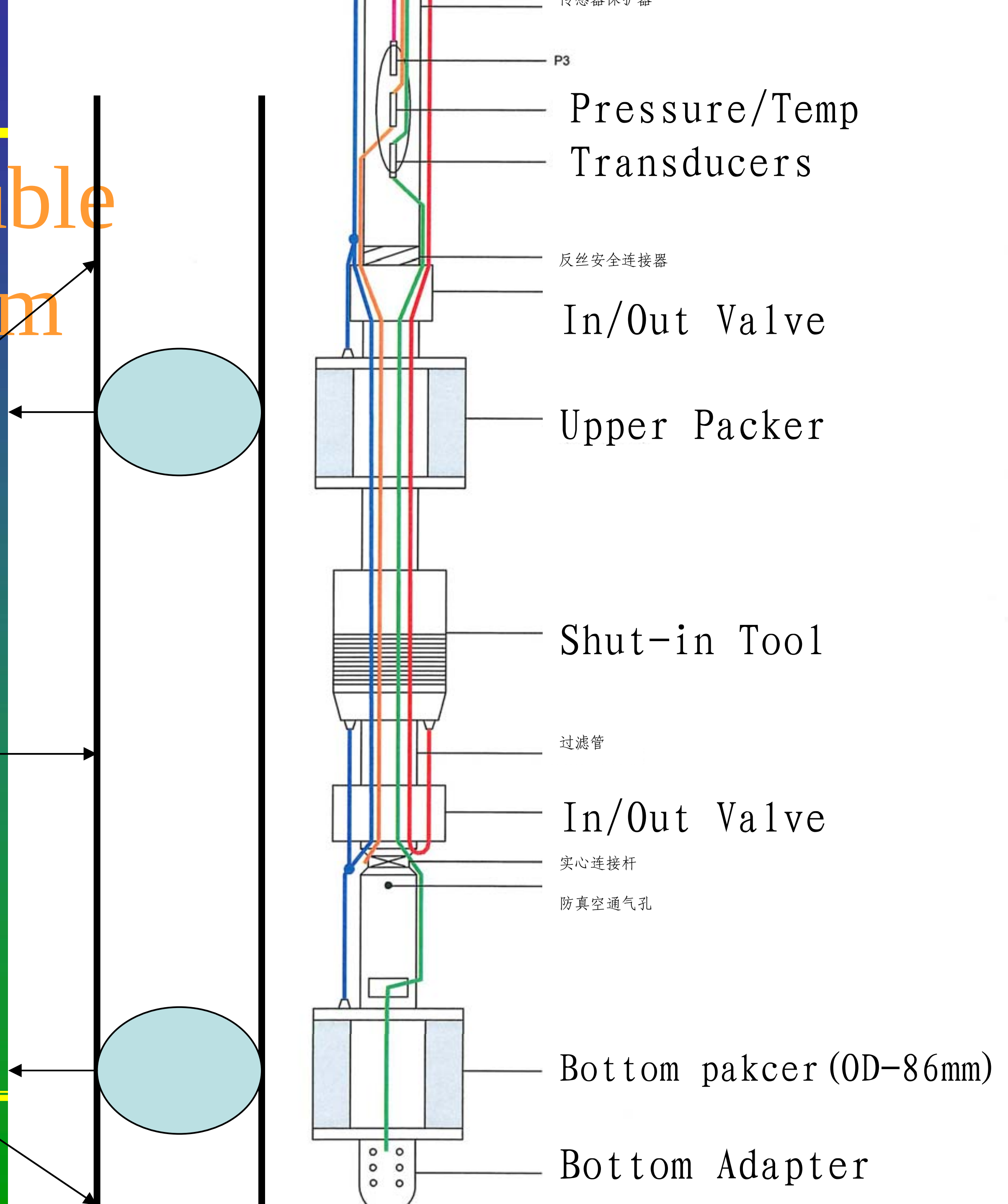
- Equipments
- Test design
- Preparation for test
- Implementation of test in situ
- Data interpretation

Layout of double packer system

Upper Interval

Test interval

Bottom Interval



Double Packer

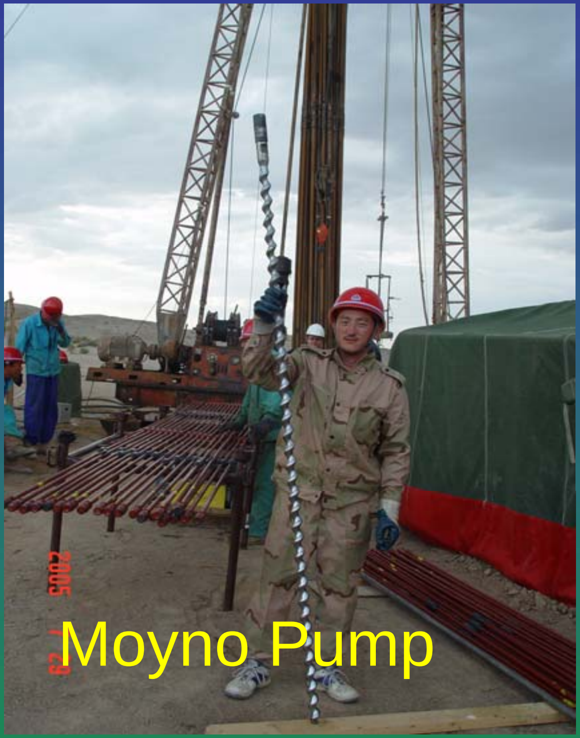
Shut-in Tool

主要设备

Pressure Transducer

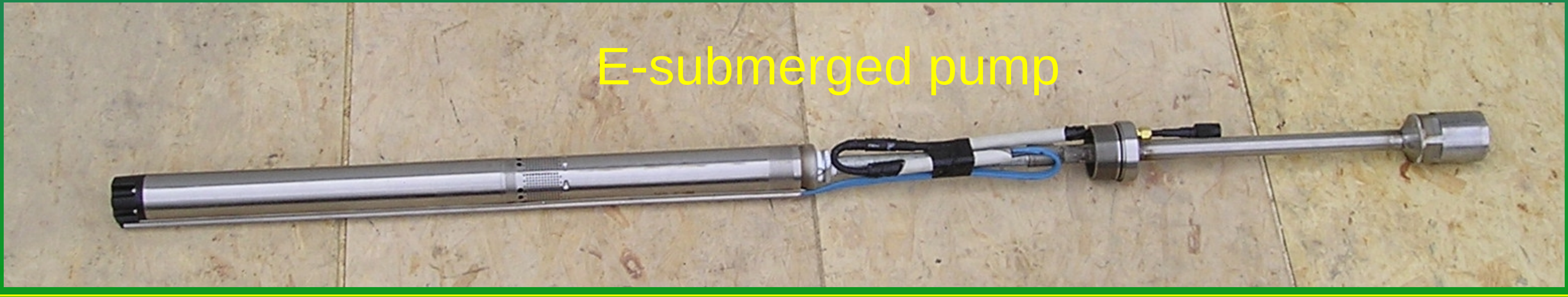
Calibration tool

主要设备


Moyno Pump


Swabbing tool


Head of air-lift tool


E-submerged pump

主要设备

Magnetic Flow meter

Data acquisitions system

Test Design

表 2-2 BS03 钻孔水文地质试验设计

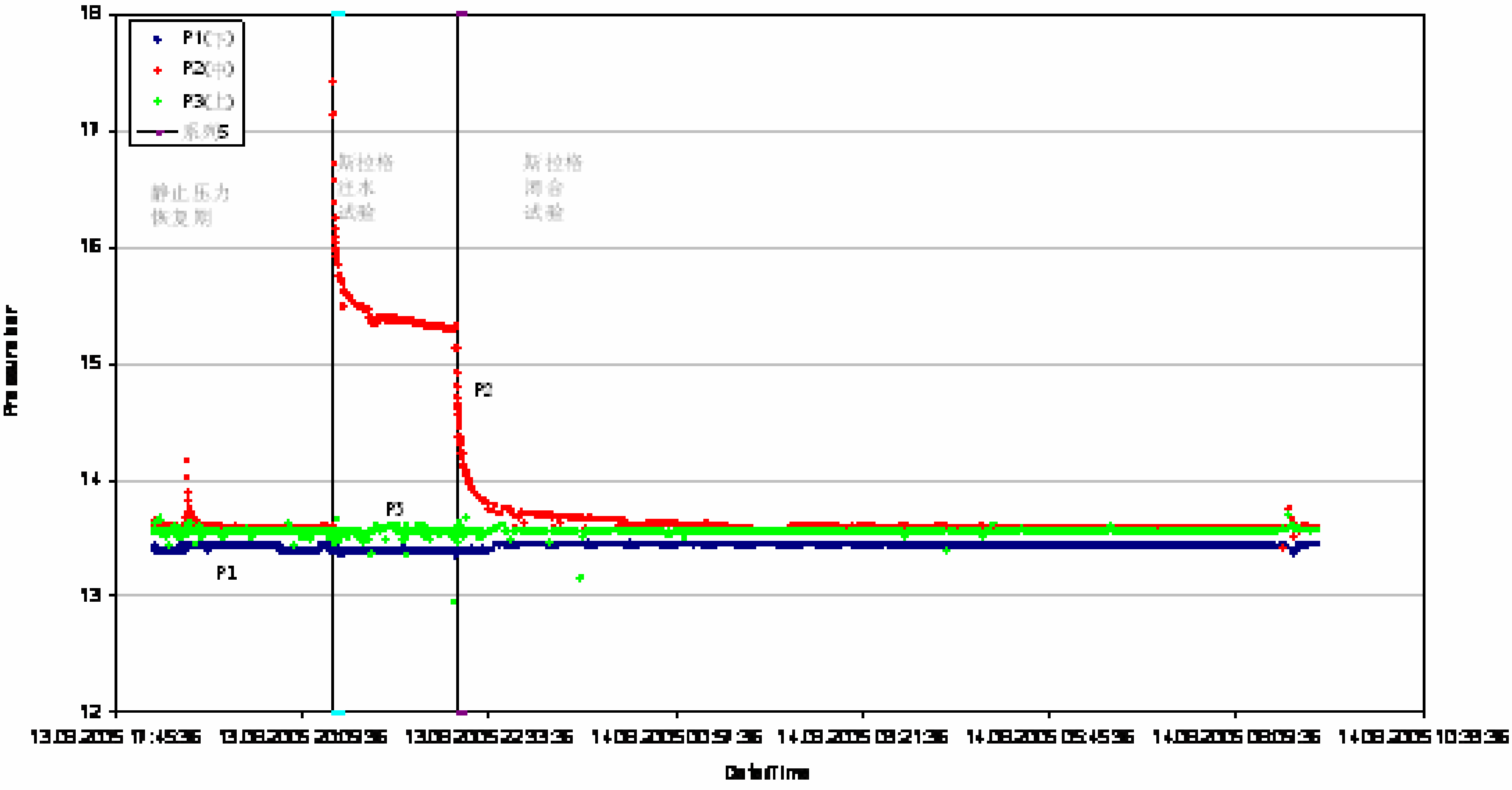
试验编号	上栓塞下封隔点(m)	下栓塞上封隔点(m)	试验段长度(m)	试验目的	试验方法	备注
1	144.23	157	12.77	W、T/K、H、G	S、C、R	
2	126.25	139.02	12.77	T/K、H	S、P、I	
3	95.26	108.03	12.77	T/K、H	S、P、I	
4	108.26	121.03	12.77	T/K、H	S、P、I	
5	160	172.77	12.77	T/K、H	S、P、I	
6	172.77	185.54	12.77	T/K、H	S、P、SS	
7	182.26	195.03	12.77	T/K、H	S、P、I	
8	196	208.77	12.77	T/K、H	S、P、I	
9	208.51	238.51	30.00	W、T/K、H、G	S、C、R	
10	238.26	253.47	15.21	T/K、H	S、P、I	
11	253.26	268.47	15.21	T/K、H	S、P、I	
12	268.26	283.47	15.21	T/K、H	S、P、I	
13	283.26	298.47	15.21	T/K、H	S、P、I	
14	298.53	313.735	15.21	T/K、H	S、P、I	
15	313.26	328.26	15.21	T/K、H	S、P、I	
16	328.26	343.465	15.21	T/K、H	S、P、I	
17	430.51	445.72	15.21	W、T/K、H、G	S、C、R	
18	473.51	488.72	15.21	W、T/K、H、G	S、C、R	
19	343.51	358.72	15.21	T/K、H	S、P、I	
20	358.51	373.72	15.21	T/K、H	S、P、I	
21	373.51	388.72	15.21	T/K、H	S、P、I	
22	391.51	406.72	15.21	T/K、H	S、P、I	
23	406.51	421.72	15.21	T/K、H	S、P、I	
24	416.79	432	15.21	T/K、H	S、P、I	
25	448.01	463.22	15.21	T/K、H	S、P、I	
26	458.26	473.47	15.21	T/K、H	S、P、I	

BRIUG

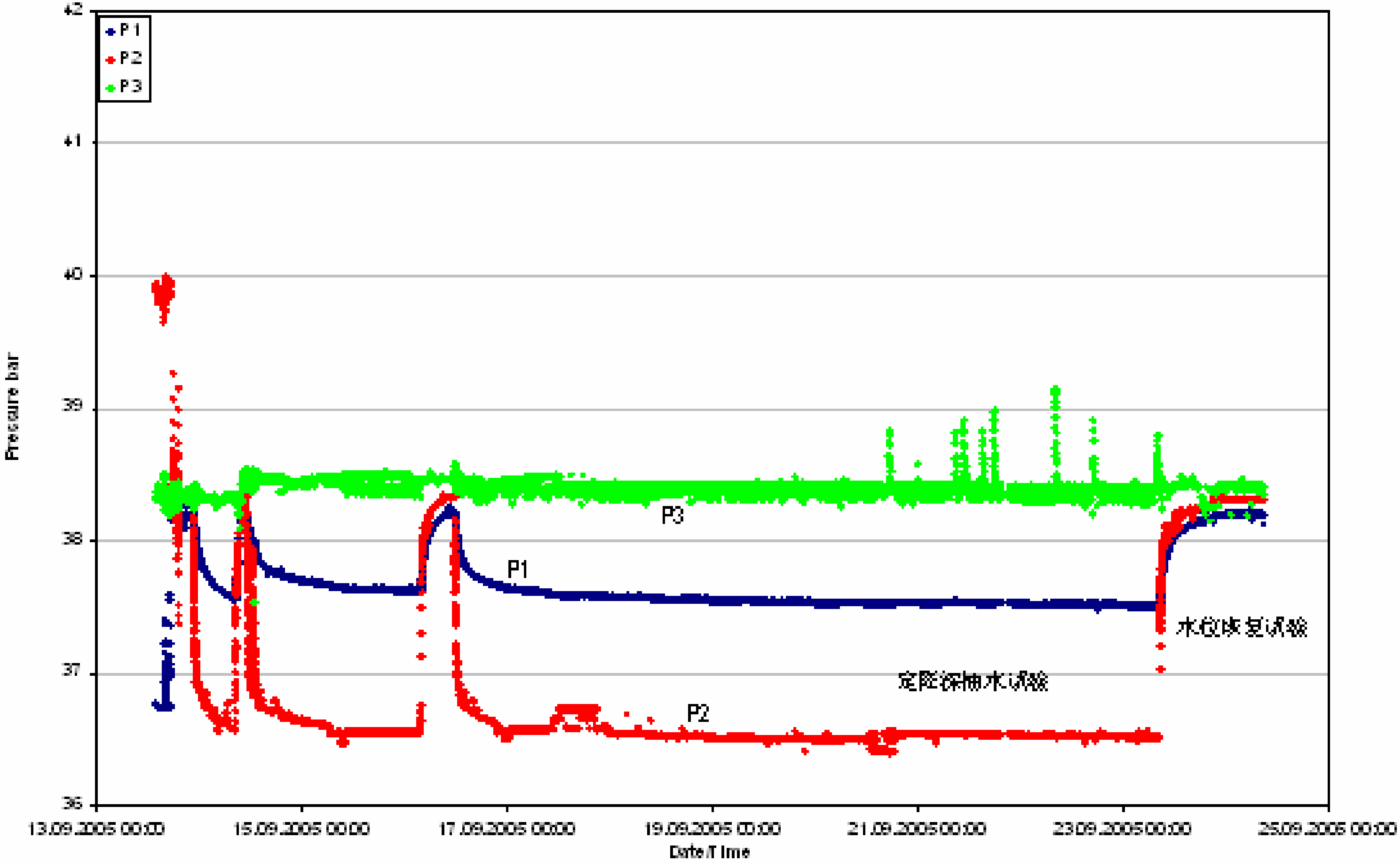
Installation

Installation

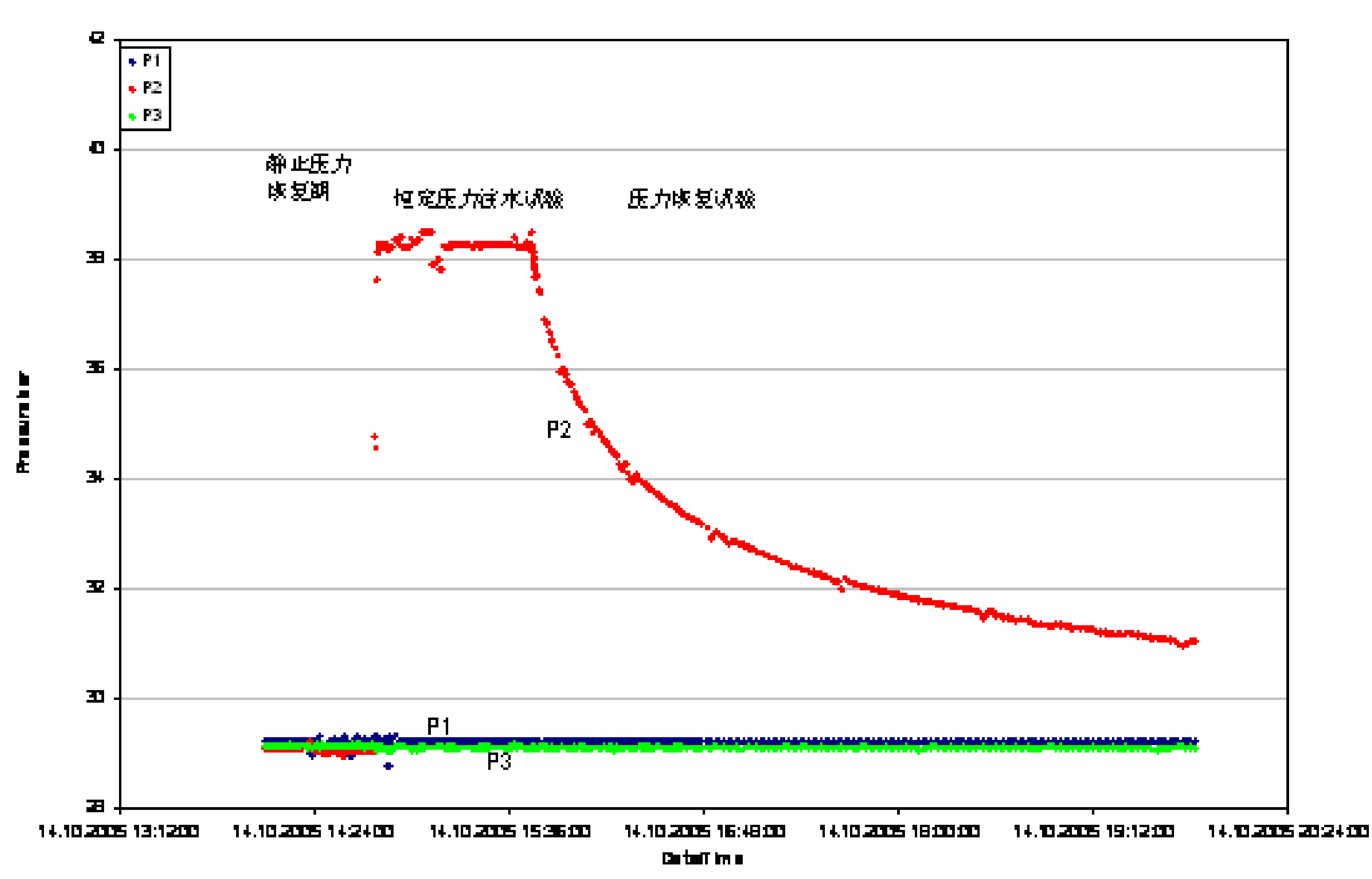
Data Response Curve—Shut-in Slug T.



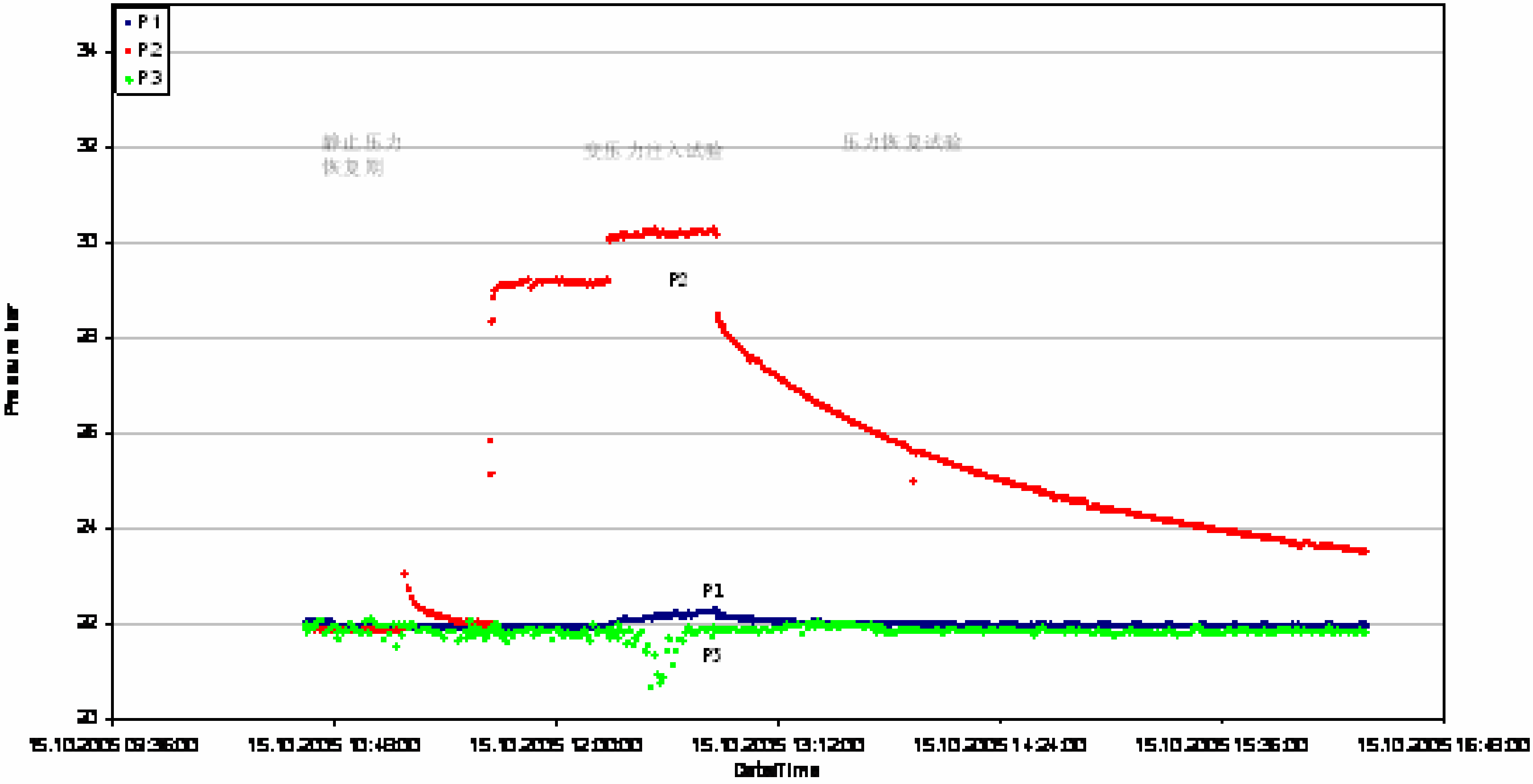
Data Response Curve—Pumping T.



Data Res. Curve—Water Injection T.

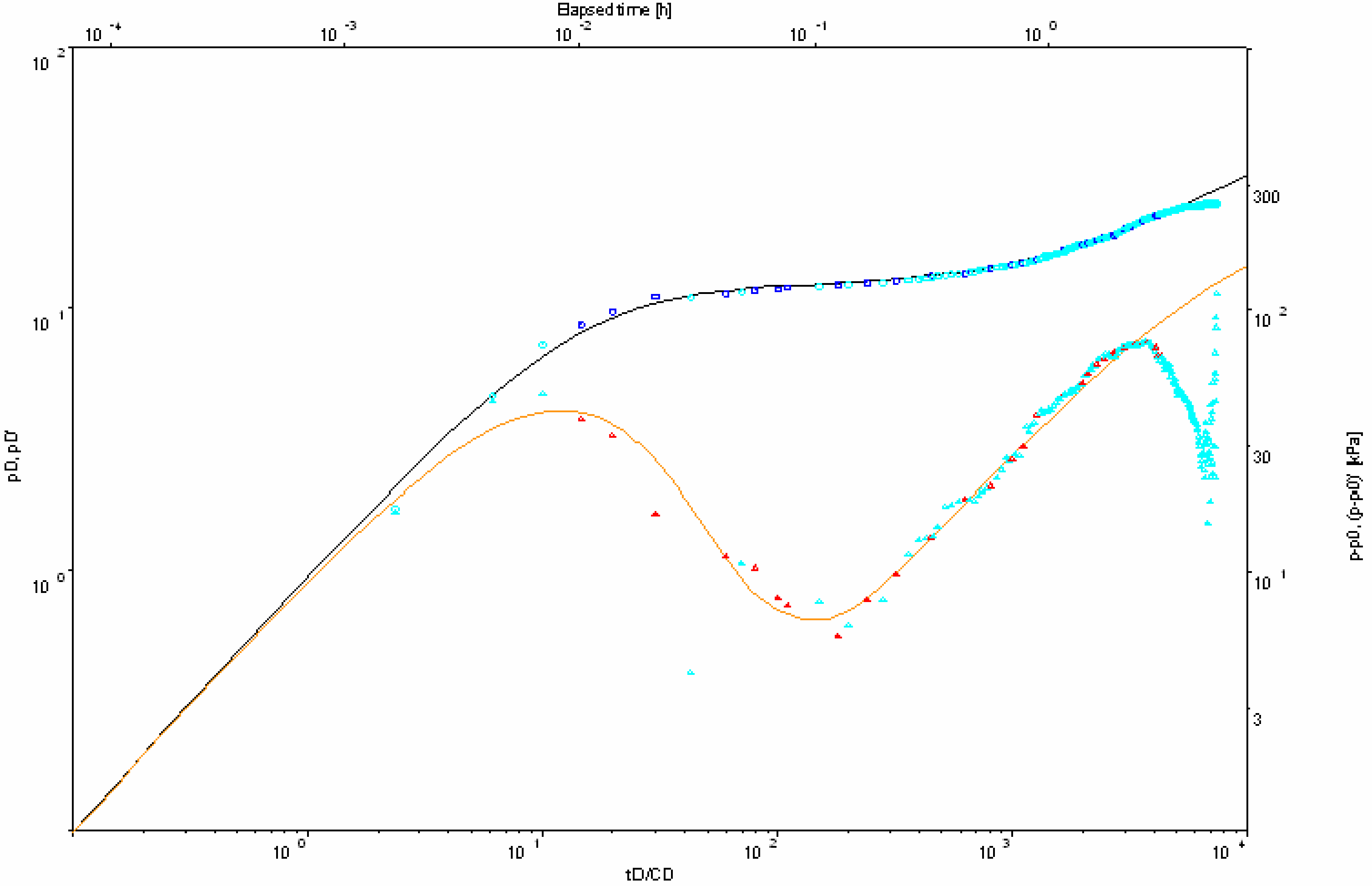


Data Response Curve—Variable Head T.



Beishan
T1 / SI

Flow Dim Version 2.14b
(c) Golder Associates

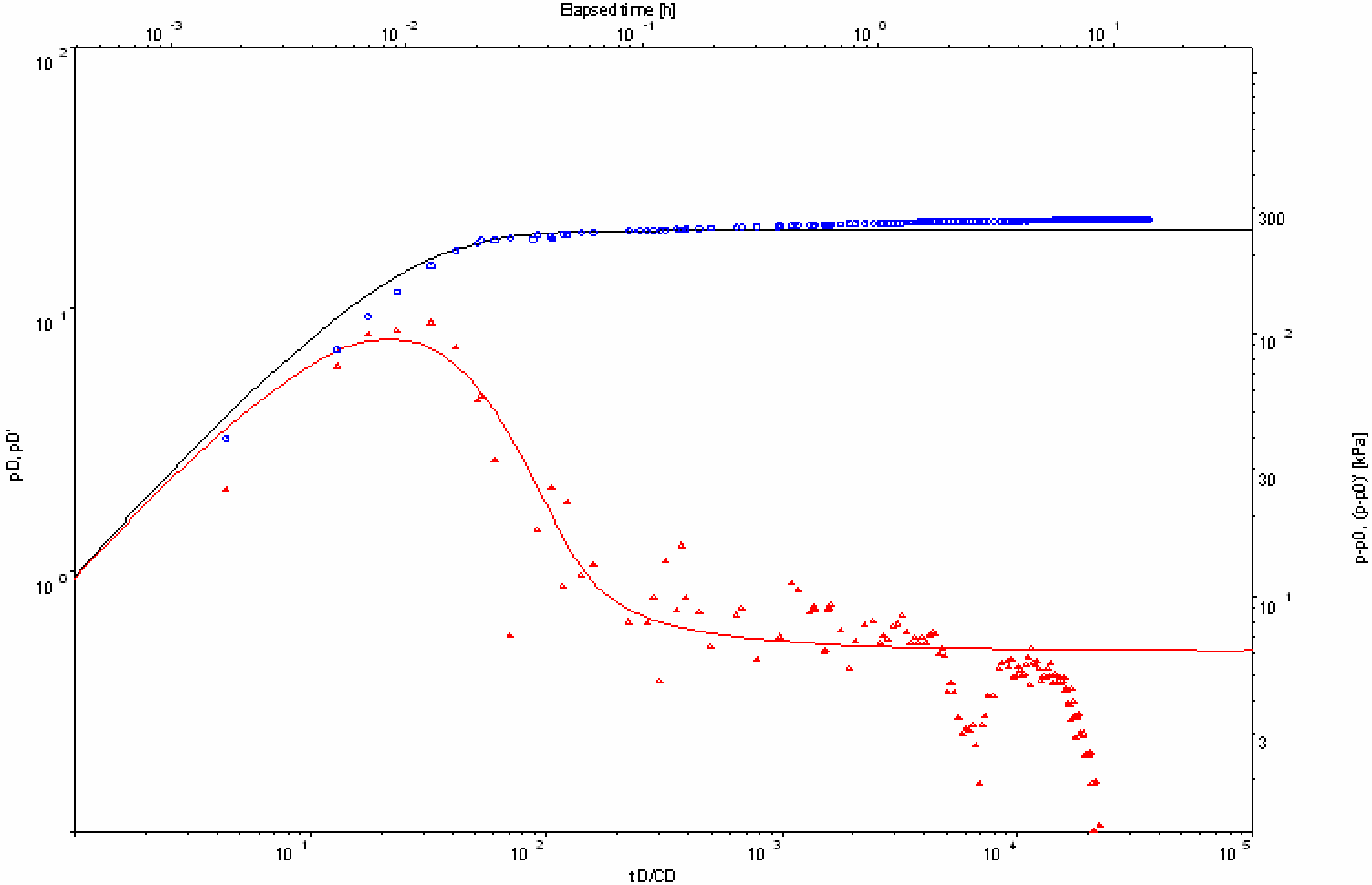


T	3.46E-05	m2/s
S	1.88E-10	-
C	5.54E-08	m3/Pa
n1	2.00E+00	-
n2	2.00E+00	-
rD1	3.53E+05	-
brw	2.25E+01	-

FLOW MODEL : Two shell composite
BOUNDARY CONDITIONS: Constant rate
WELL TYPE : Source
SUPERPOSITION TYPE : No superposition
PLOT TYPE : Log-log

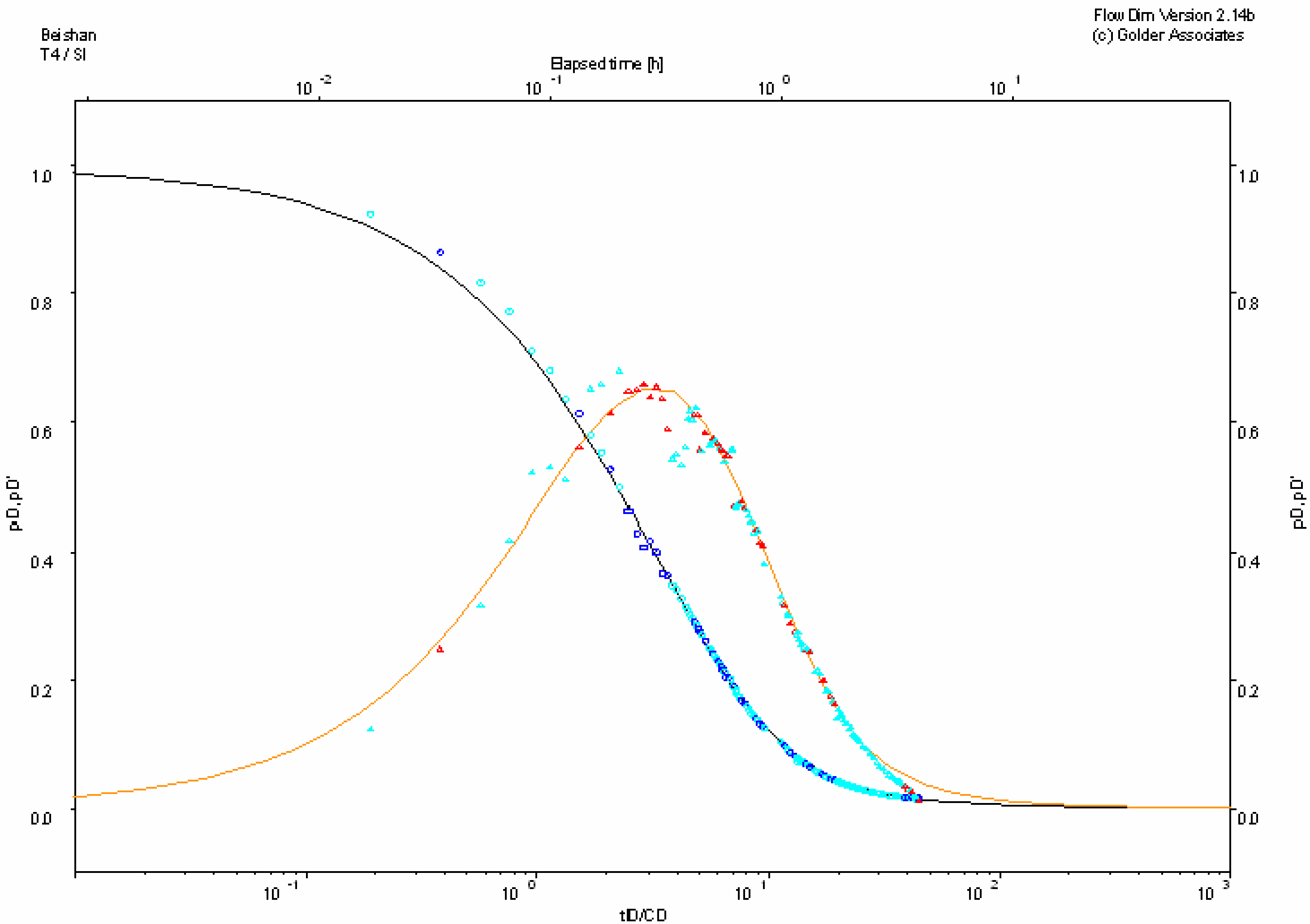
Beishan
T1 / RWS

Flow Dim Version 2.14b
(c) Golder Associates



FLOW MODEL : Homogeneous
BOUNDARY CONDITIONS: Constant rate
WELL TYPE : Source
SUPERPOSITION TYPE : Build-up TC
PLOT TYPE : Log-log

C=	2.55E-08	m3/Pa
T=	2.83E-05	m2/s
S=	1.73E-17	-
s=	0.00E+00	-
n=	2.00E+00	-



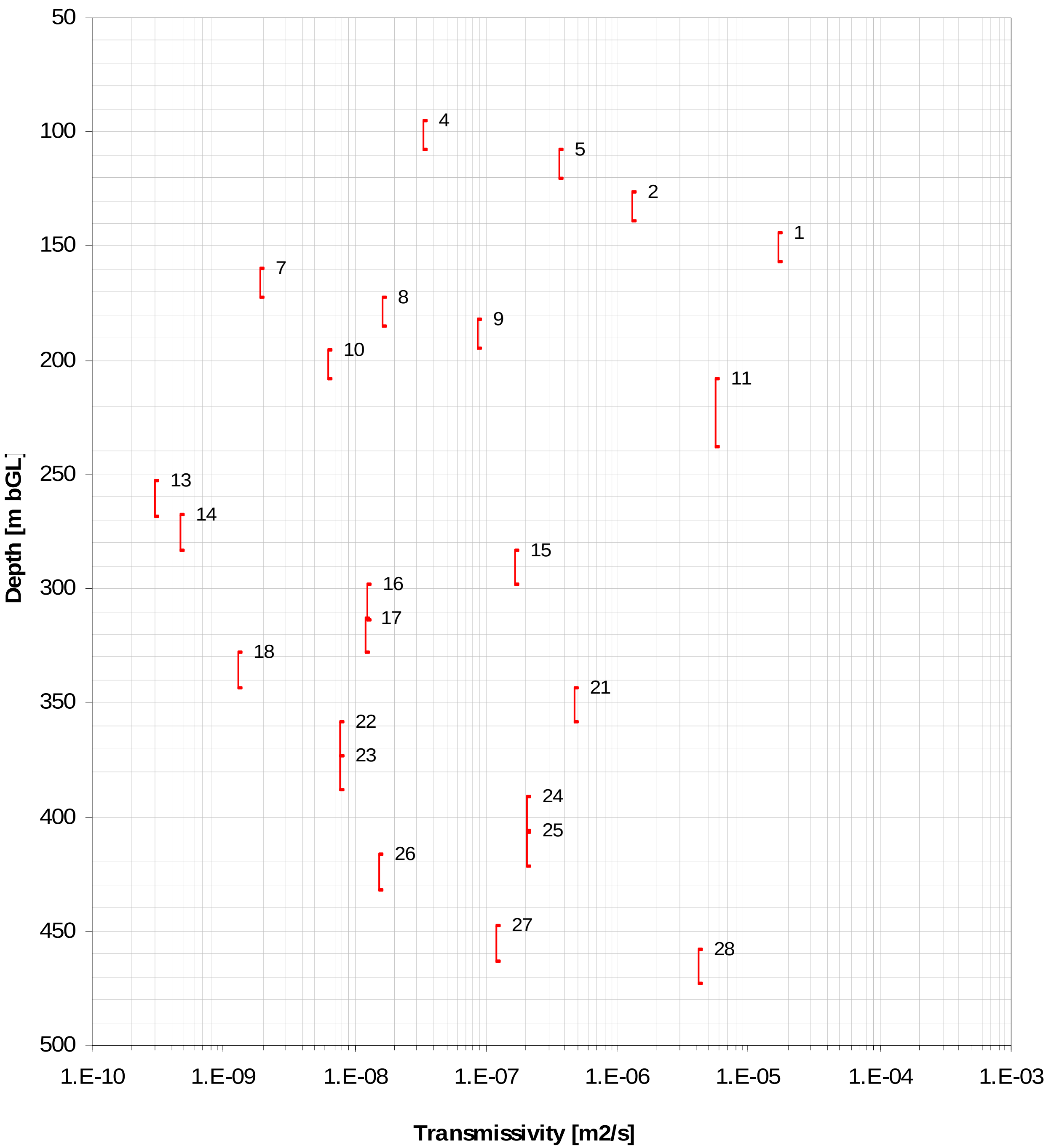
FLOW MODEL : Two shell composite
BOUNDARY CONDITIONS : Slug/pulse
WELL TYPE : Source
SUPERPOSITION TYPE : No superposition
PLOT TYPE : Ramey A

T	9.93E-07	m2/s
S	1.30E-02	-
C	2.00E-07	m3/Pa
n1	2.00E+00	-
n2	2.00E+00	-
rD1	2.50E+03	-
brw	1.50E-01	-

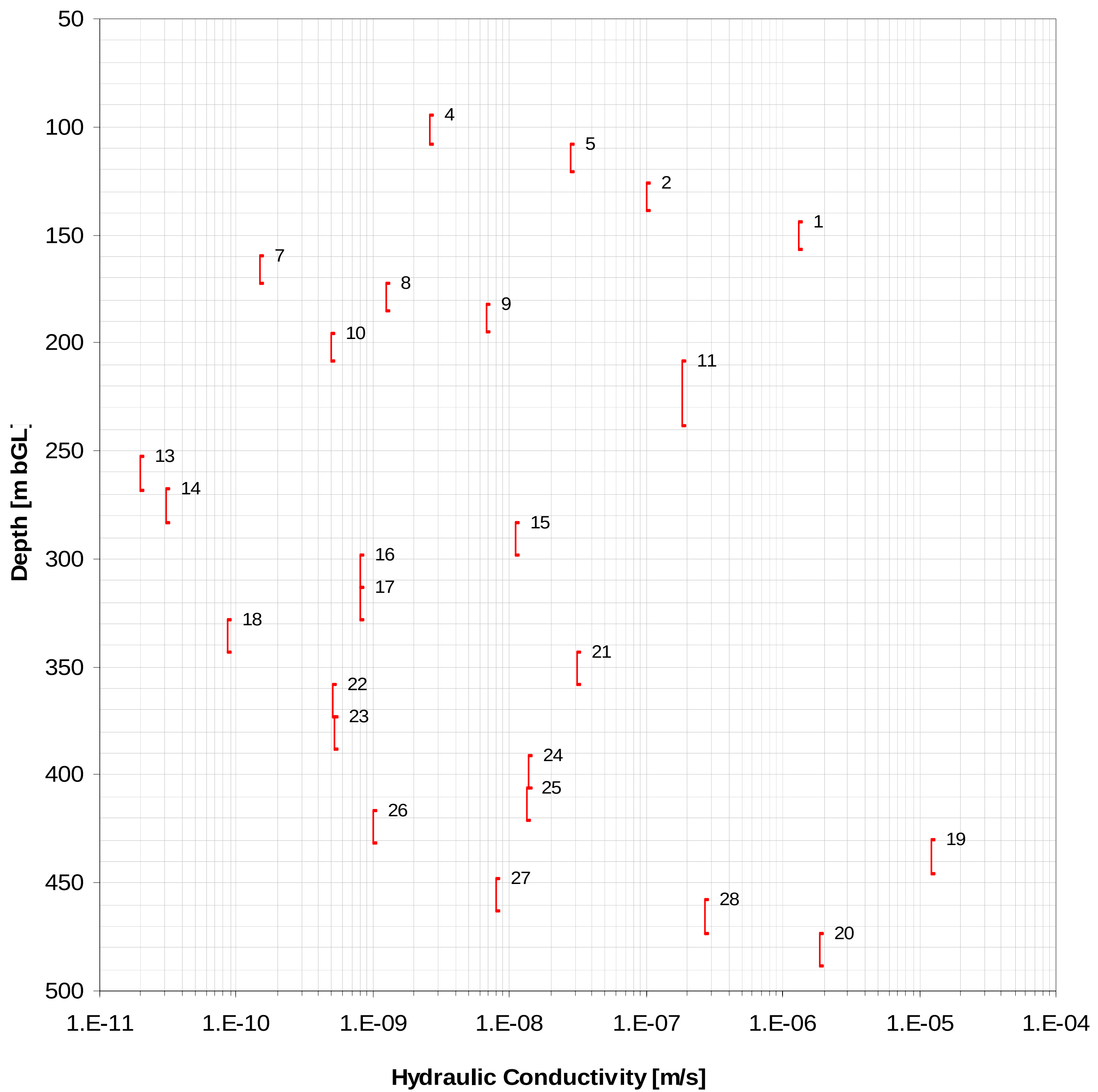
Summary of hydraulic tests in BS03

- Drilling campaign: 2003-9
- Test campaign: 2005-7-26~10-16
- Range of depth: 95m-489m
- Test intervals: 12.77m，15.21m，30m
- Test approaches: Slug test; Shut-in slug test; Pulse test; Constant discharge/Withdrawal test; Water injection test and recovery test.
- Water sampling: 144m-156.77m、208m-238m、430.51m-445.72m

95m-489m, Transmissivity Profile in BS03



95m-489m, Hydraulic Conductivity Profile in BS03



THANK YOU FOR YOUR ATTENTION

TU Clausthal

Chinese-German Workshop on Radioactive Waste Disposal

Radioactive Waste Disposal in Various Host Rock Formations – Geomechanical Aspects (Selected Applications)

O. Czaikowski

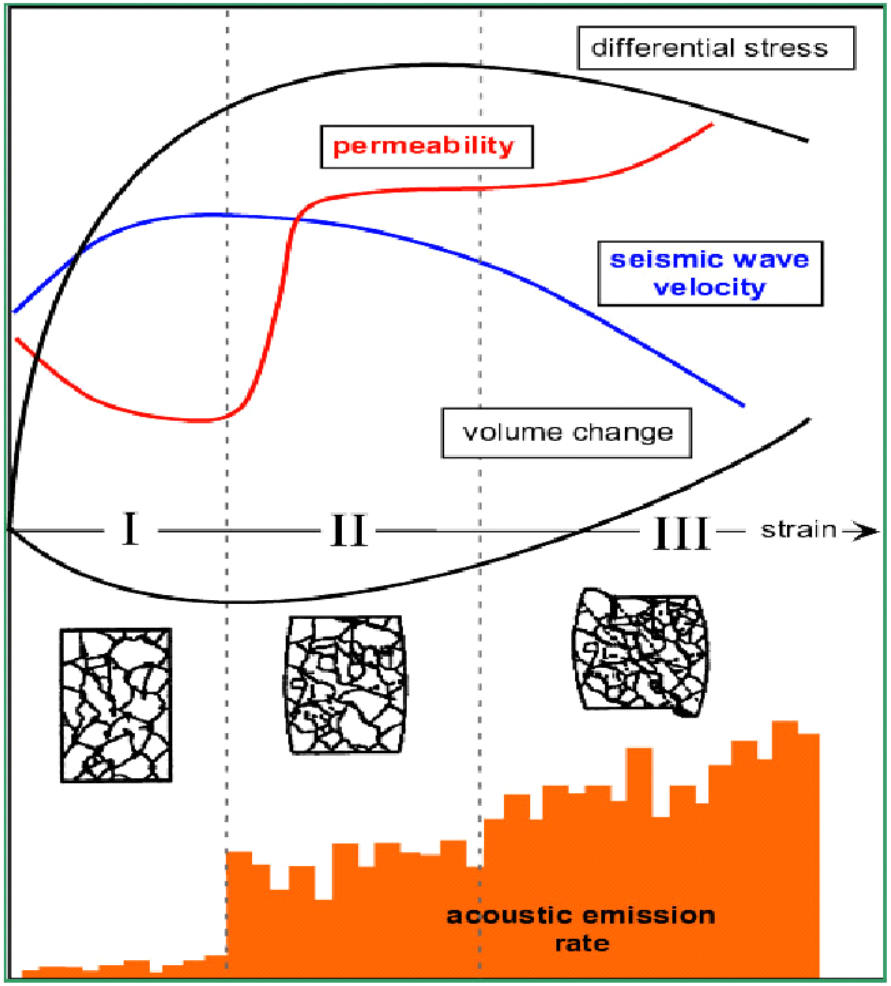
Sino-German Science Center, Beijing
May 28-31, 2007

Contents

- Demonstration of Safety / General Aspects
- Waste Properties
- Site Selection
- Physico-chemical Modelling / Coupled Processes
- Thermo-Mechanical – Hydraulic Aspects
- Some Aspects with respect to change of mechanical / hydraulic properties
  - Nearfield processes/EDZ
  - Damage process – rock salt
  - Damage process – claystone
  - Recreation of damage/Rehealing – rock salt
  - Damage process – granite
    lab investigations
  - Some preliminary calculations with respect to static stability / EDZ evolution - granite
- The Best Repository
- Conclusions

- Some Aspects with respect to change of mechanical / hydraulic properties
  - *Nearfield processes/EDZ*
  - *Damage process – rock salt*
  - *Damage process – claystone* → presentation *O. Czaikowski*
  - *Recreation of damage/Rehealing – rock salt*
  - *Pressure-forced infiltration of fluids (liquids, gas) in primarily impermeable or nearly impermeable rock formations*
  - *Damage process - granite*

Change of Material properties with respect to fabric damage



Change of properties is used for monitoring and determination of dilatancy / damage

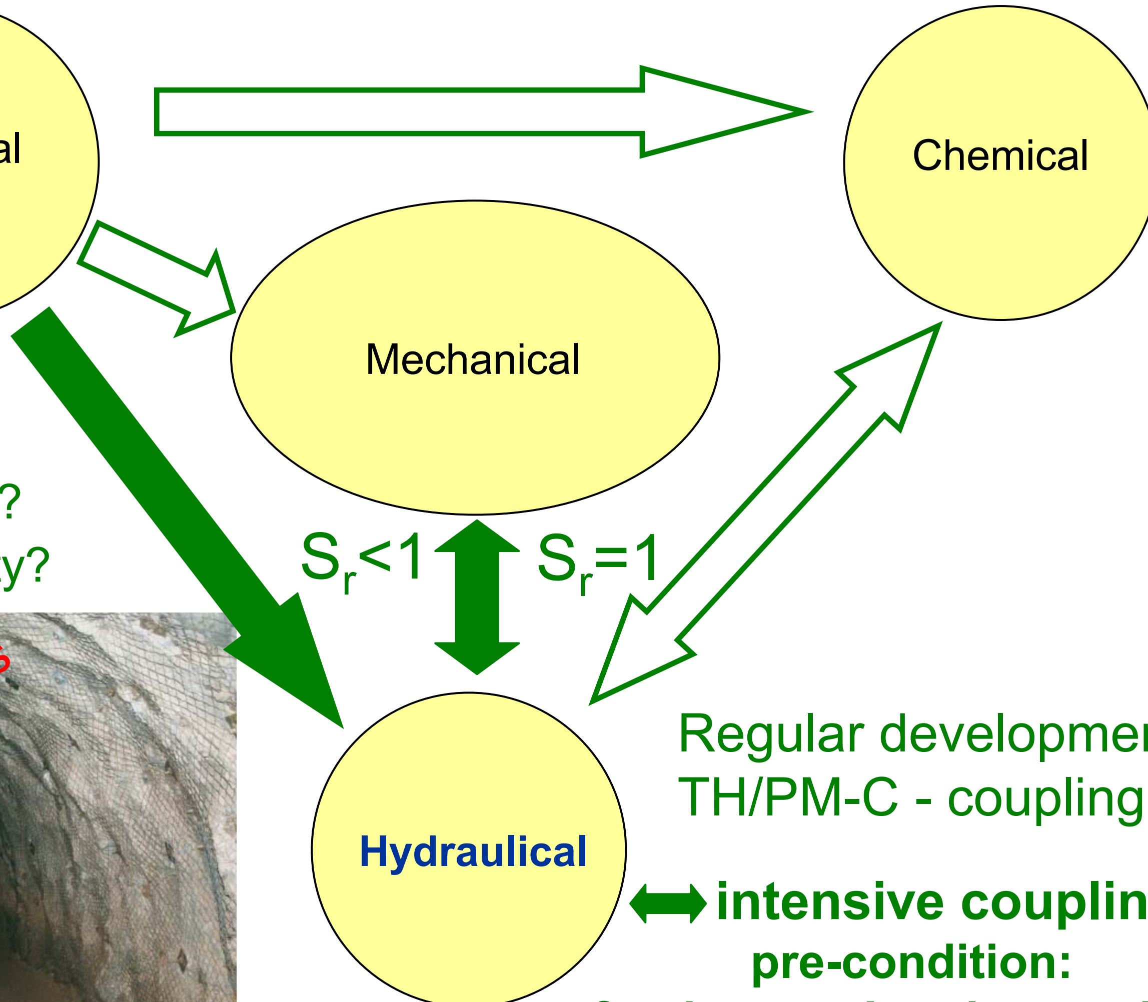
I - compaction

II - damage (micro)

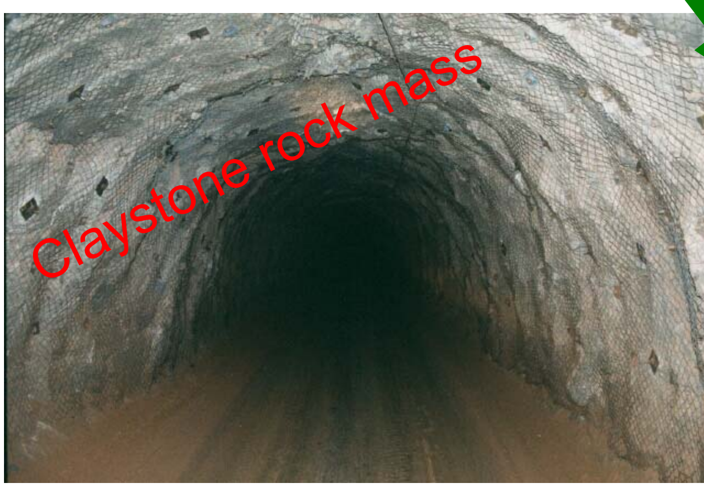
III - rupture (macro)

BGR (2001)

Change of Material properties with respect to saturation degree /pore water pressure



Rock mass behaviour?
Geotechnical feasibility?



Regular development:
TH/PM-C - coupling

⟷ **intensive coupling**
pre-condition:
fundamental understanding of individual processes

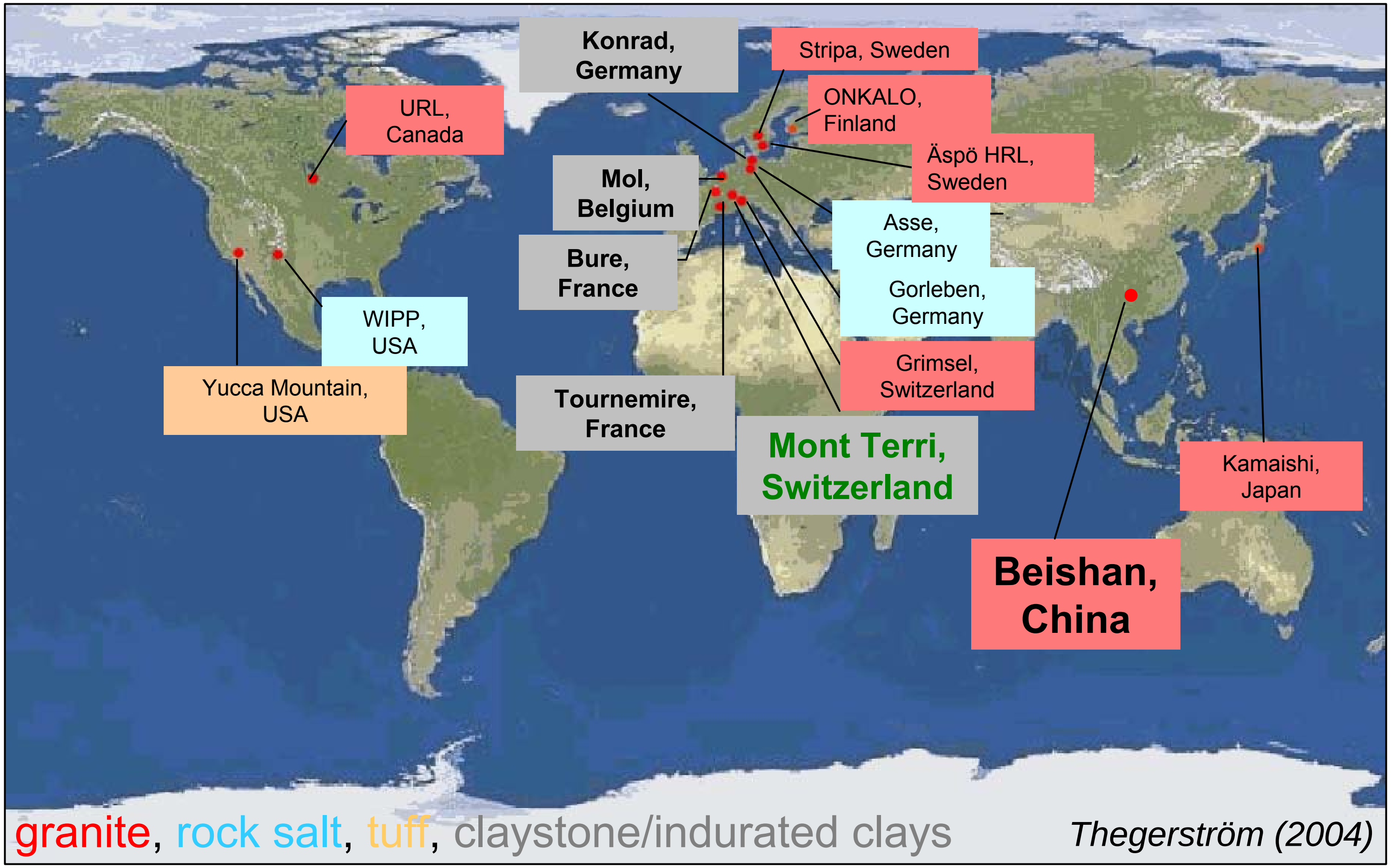
laboratory investigation on international claystone samples



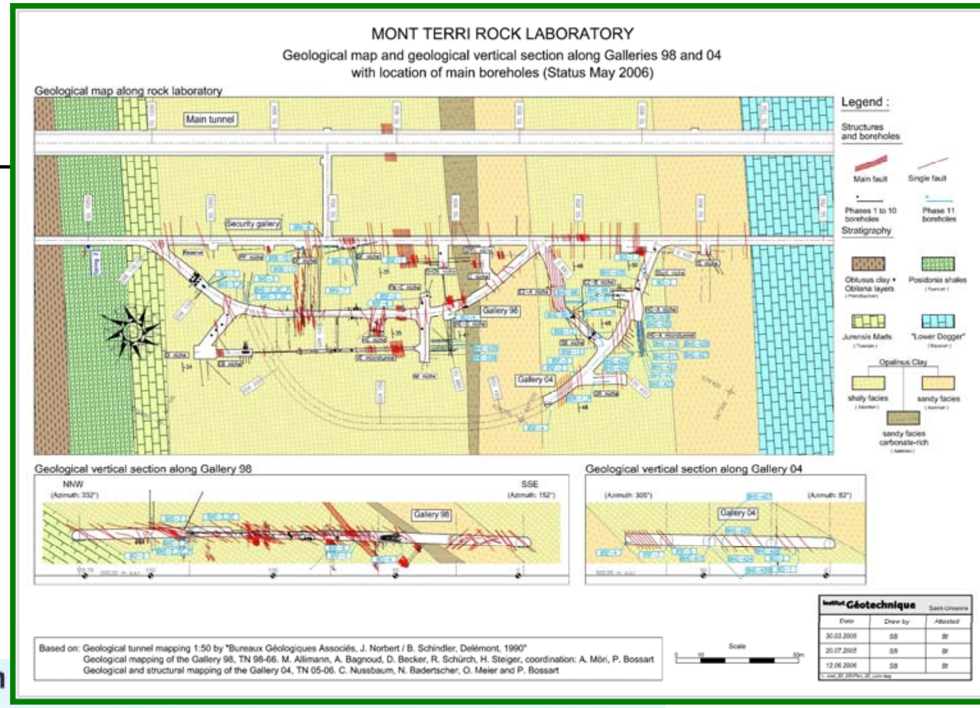


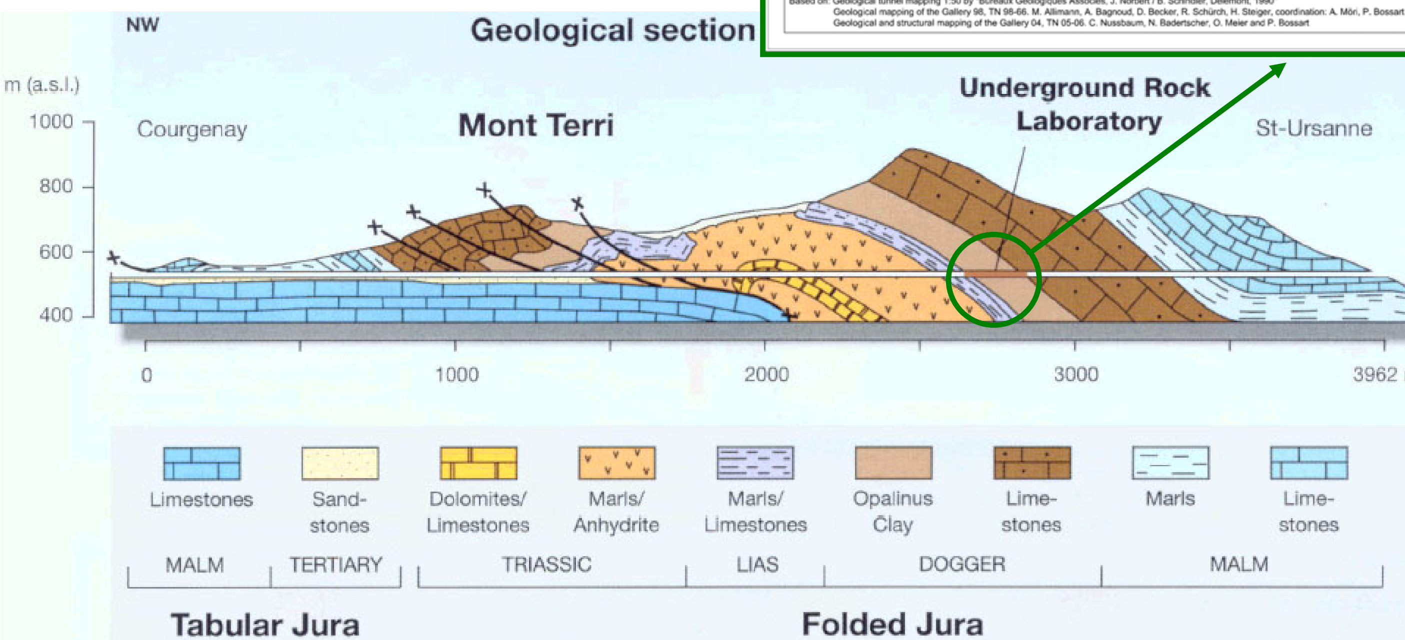



International scientific state of the art in claystone / indurated clays

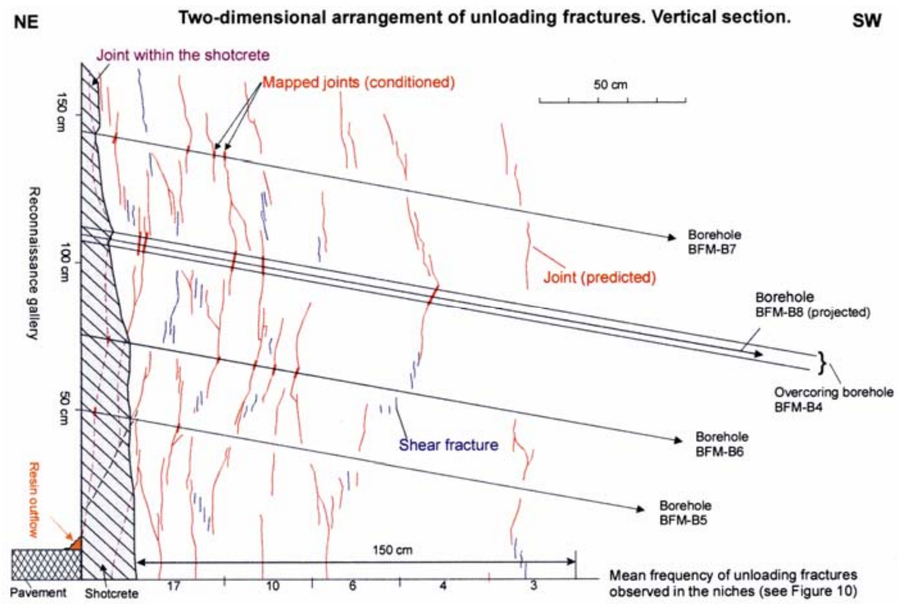


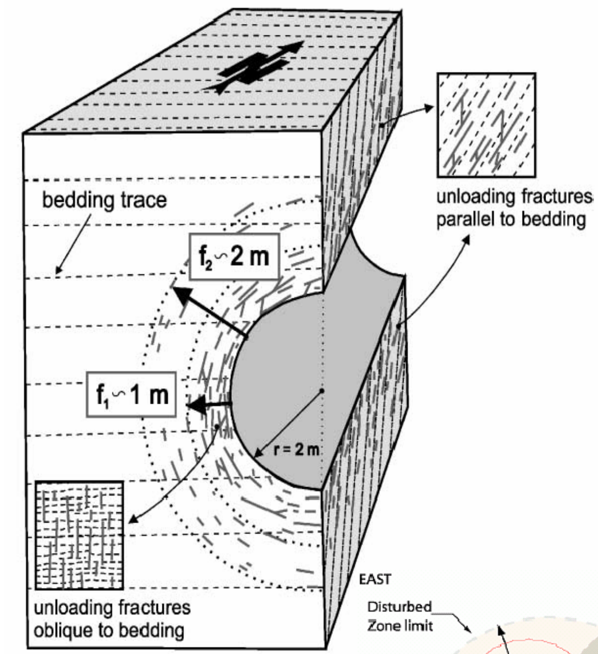
Mont Terri Site





EDZ and coupled processes

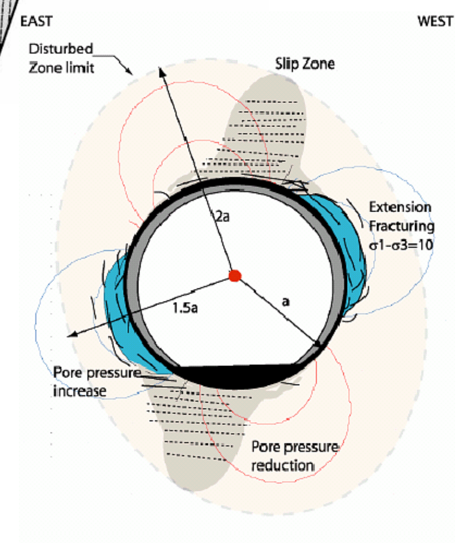




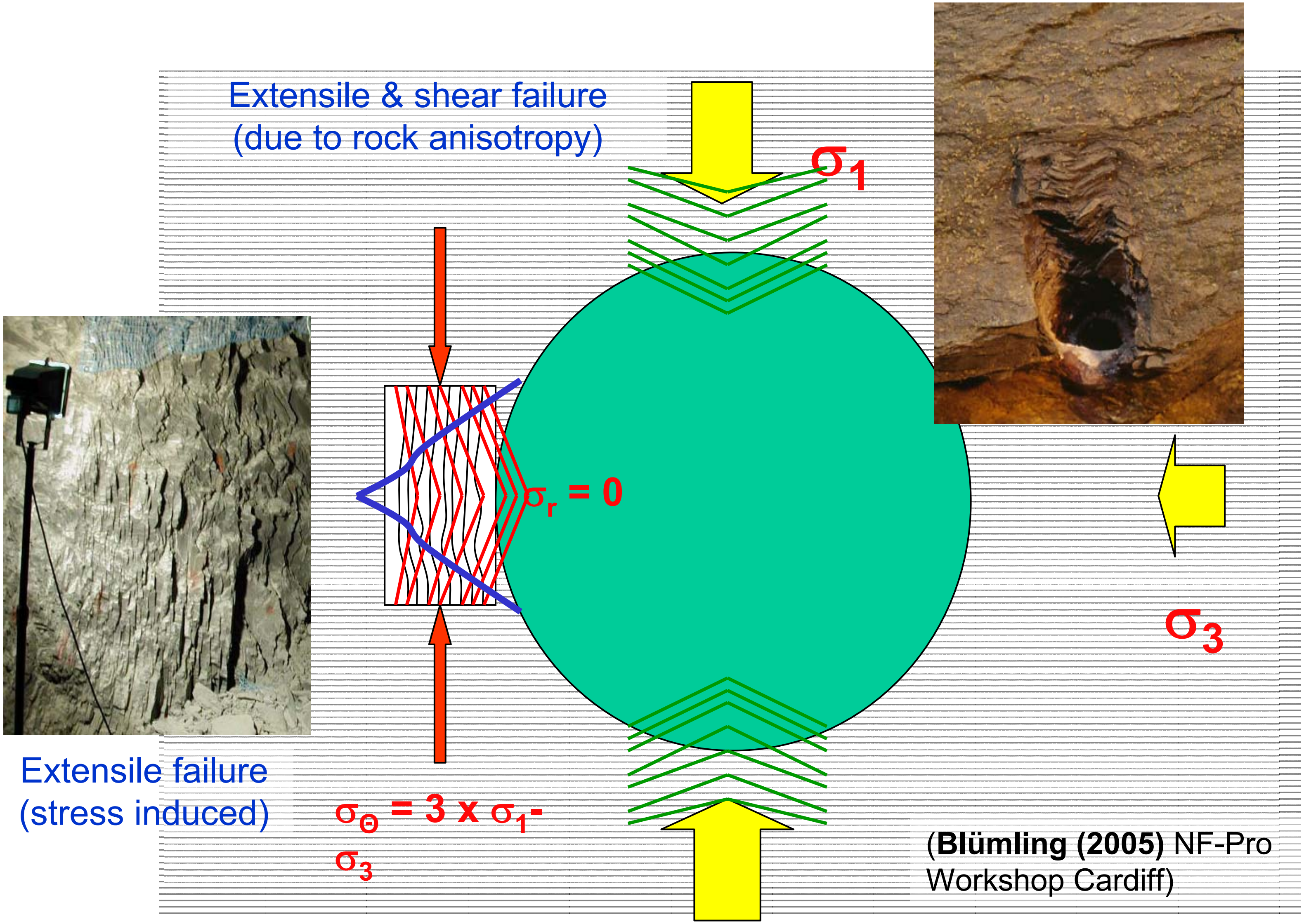
Arrangement of investigated and interpolated macro fractures,
Thury & Bossart (1999)

Contour destrengthening behind shotcrete liner

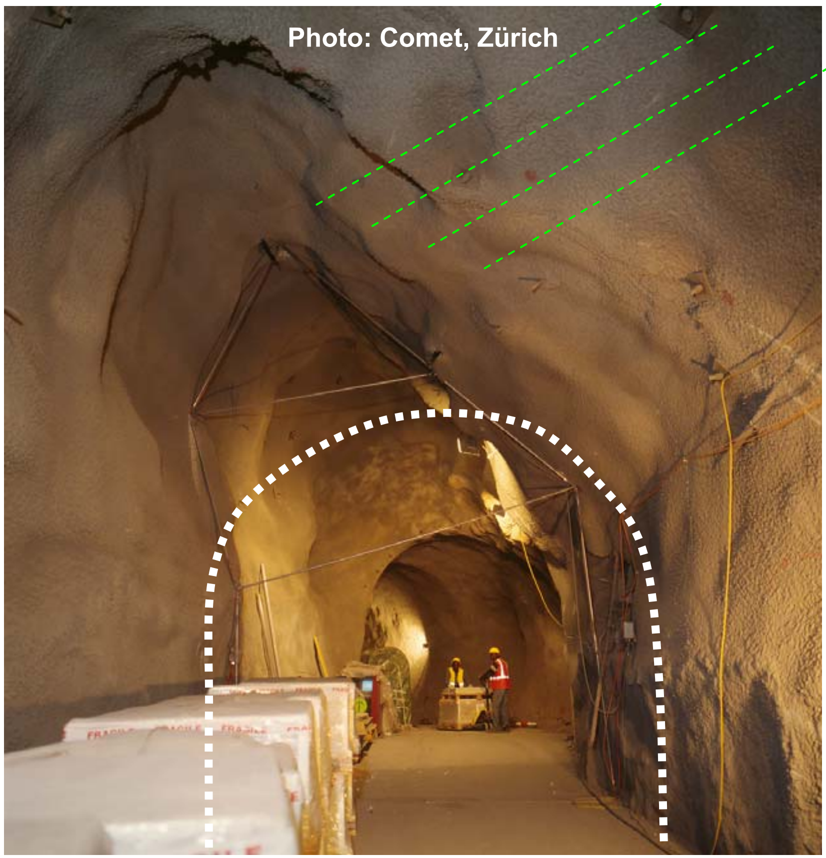
Conceptual model of the EDZ, *NAGRA NTB 02-02 und NTB 02-03 (2002)*



Failure process mainly dominated by bedding plane orientation



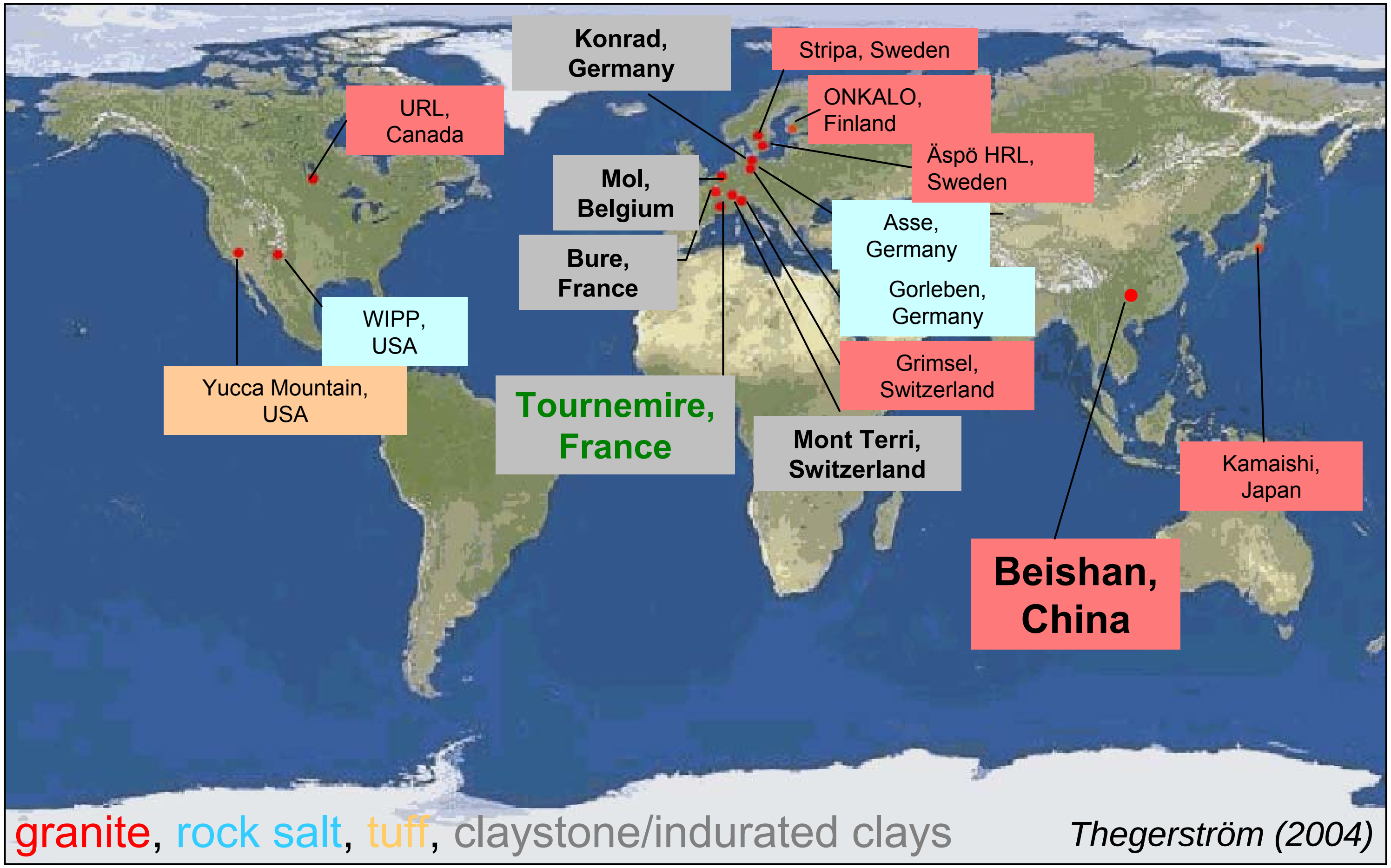
In Situ



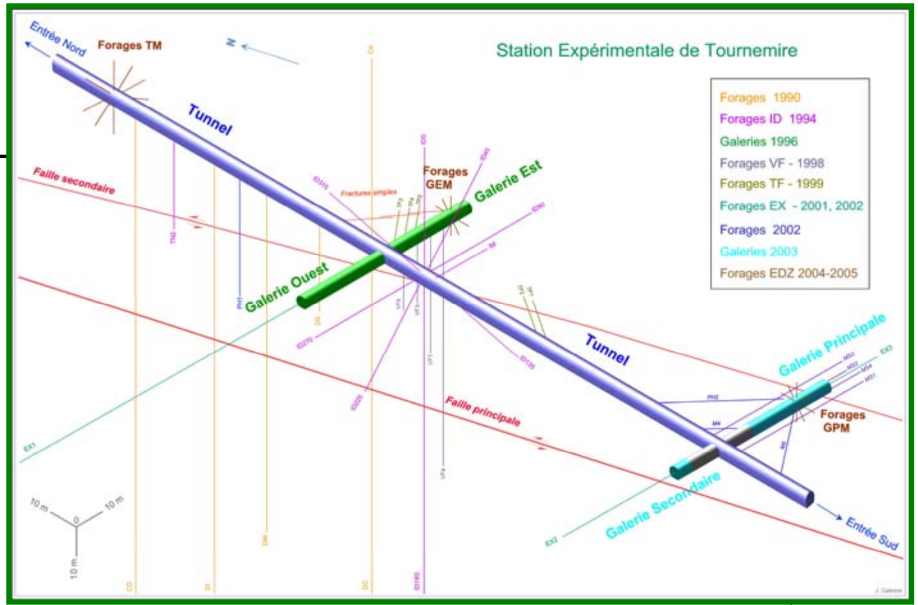
Bedding plane failure

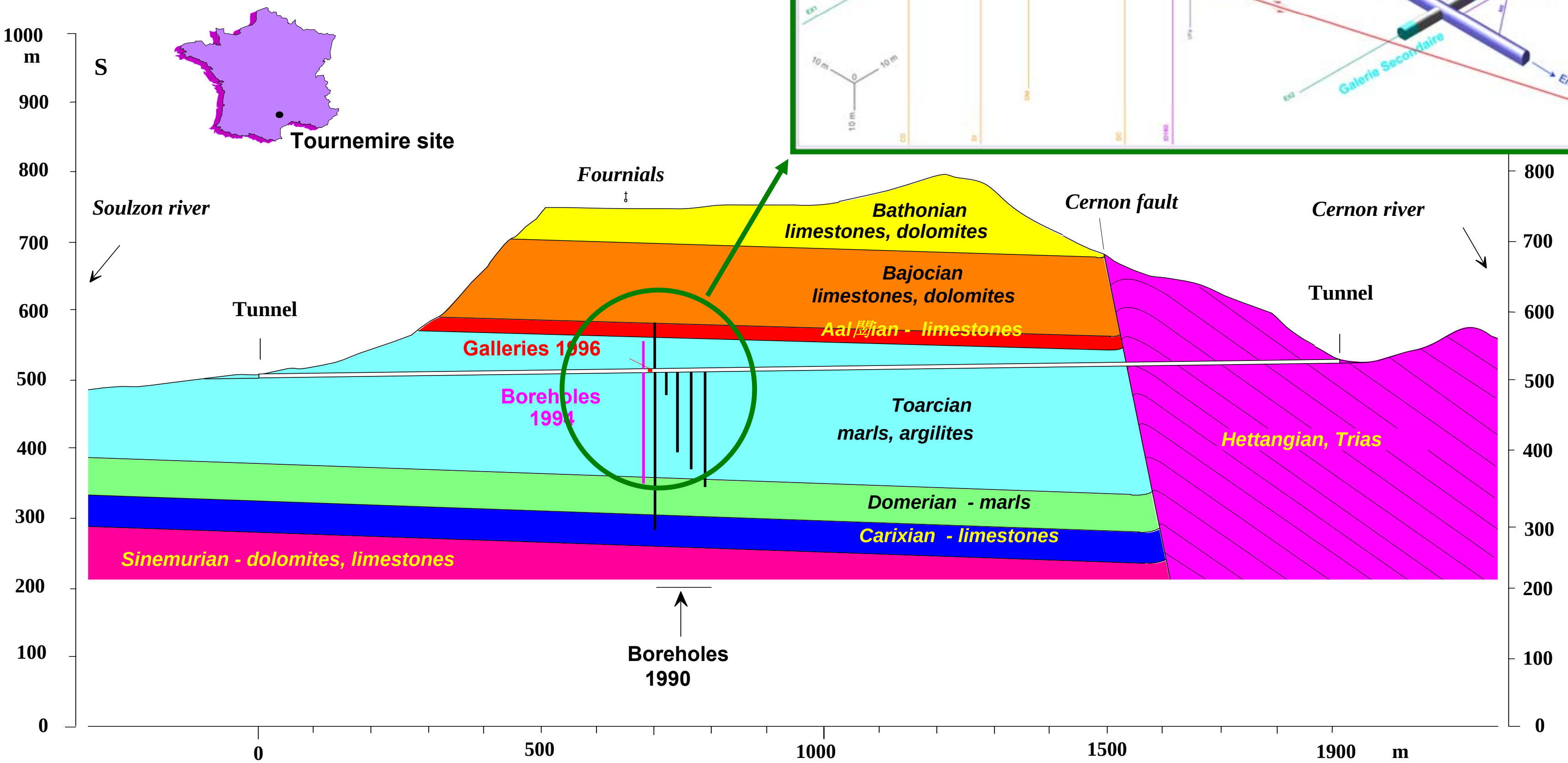
Matrix induced contour failure

Tournemire site

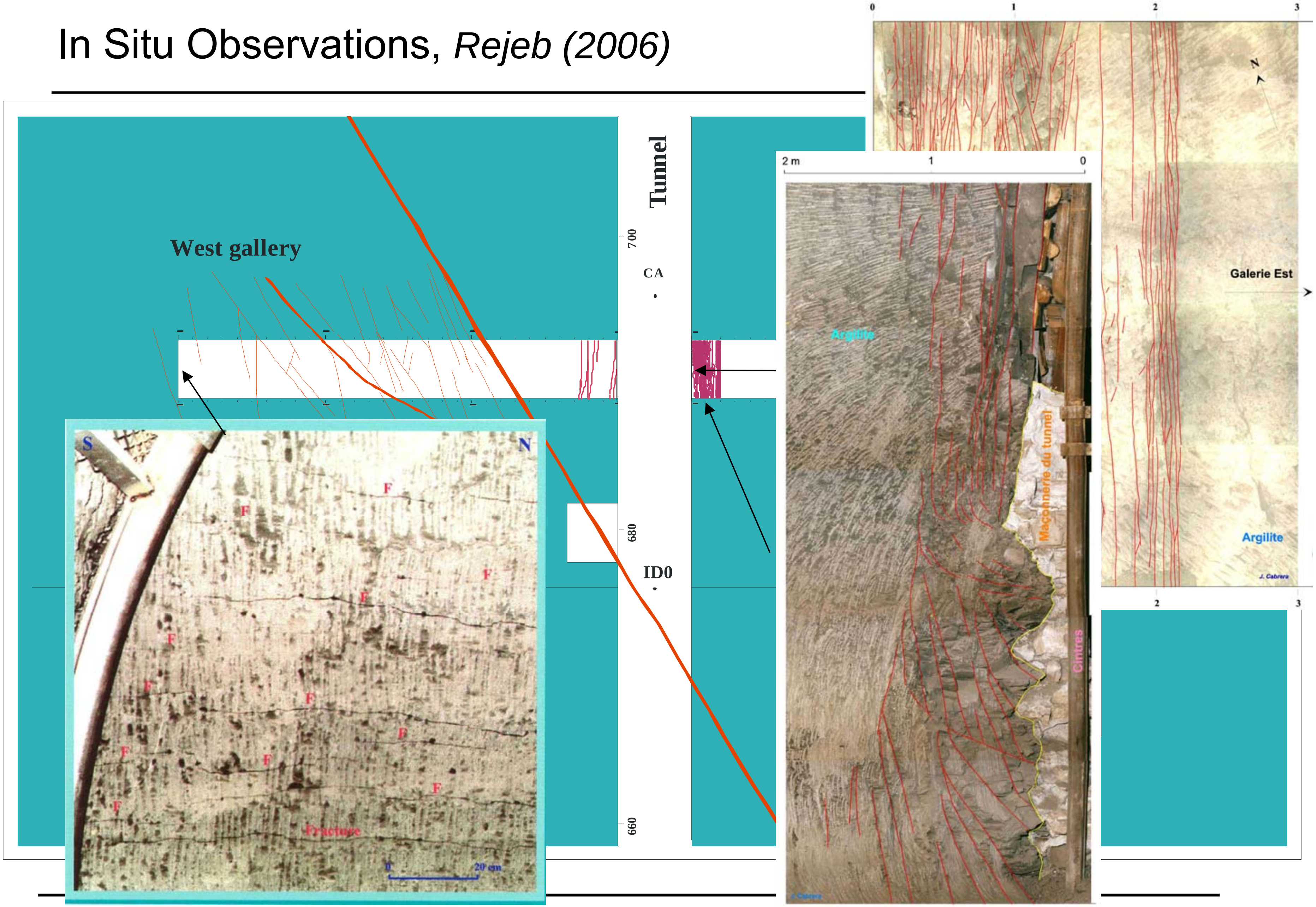


Tournemire site

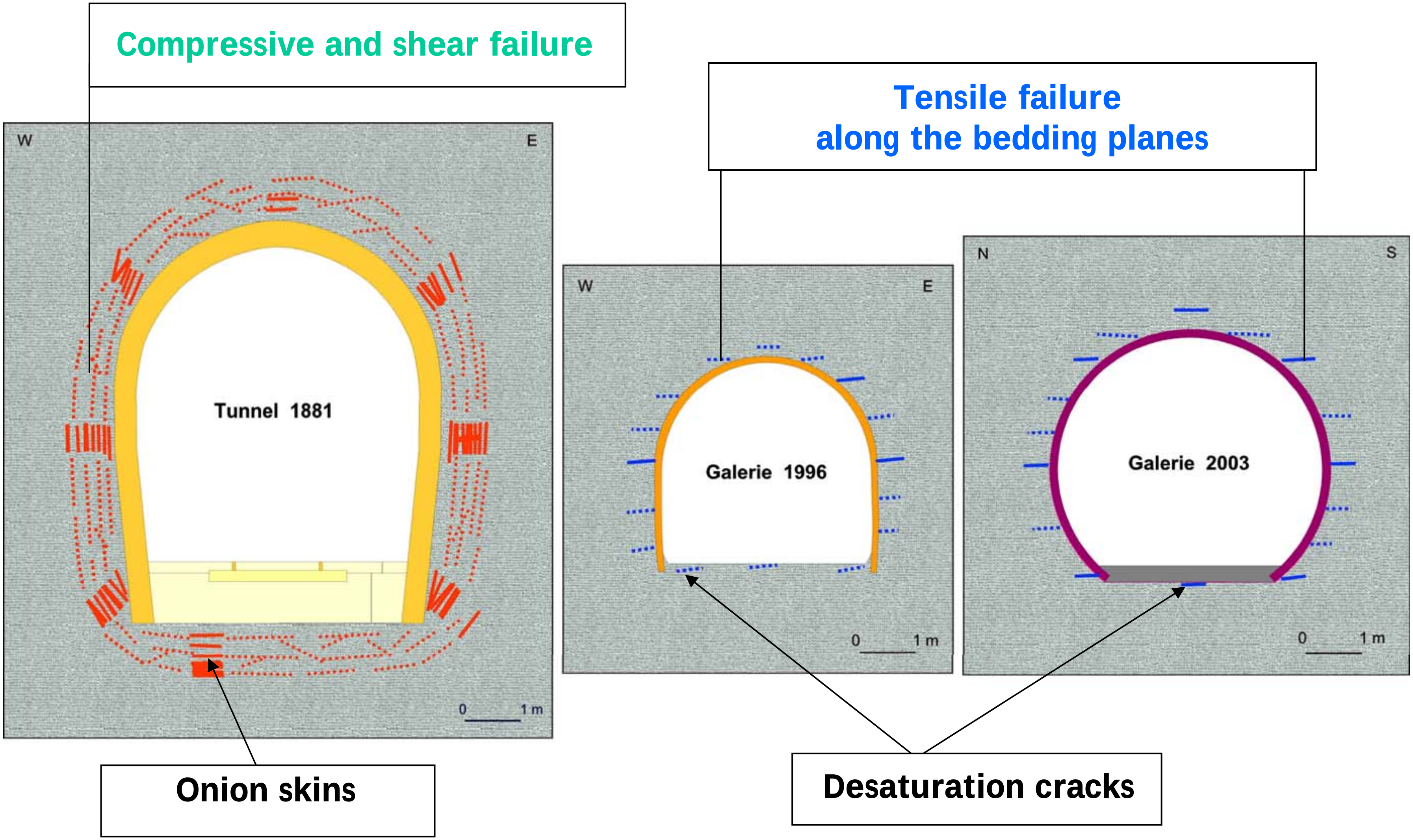




In Situ Observations, *Rejeb (2006)*



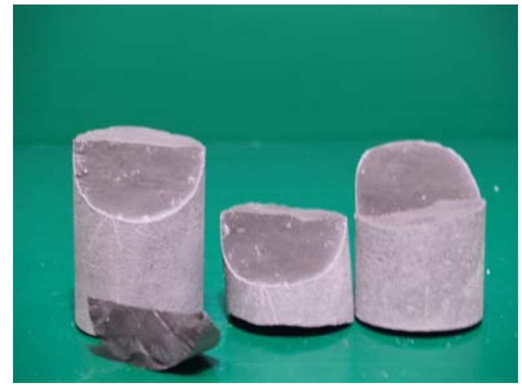
EDZ - Deferred failure around the three openings, *Rejeb (2006)*



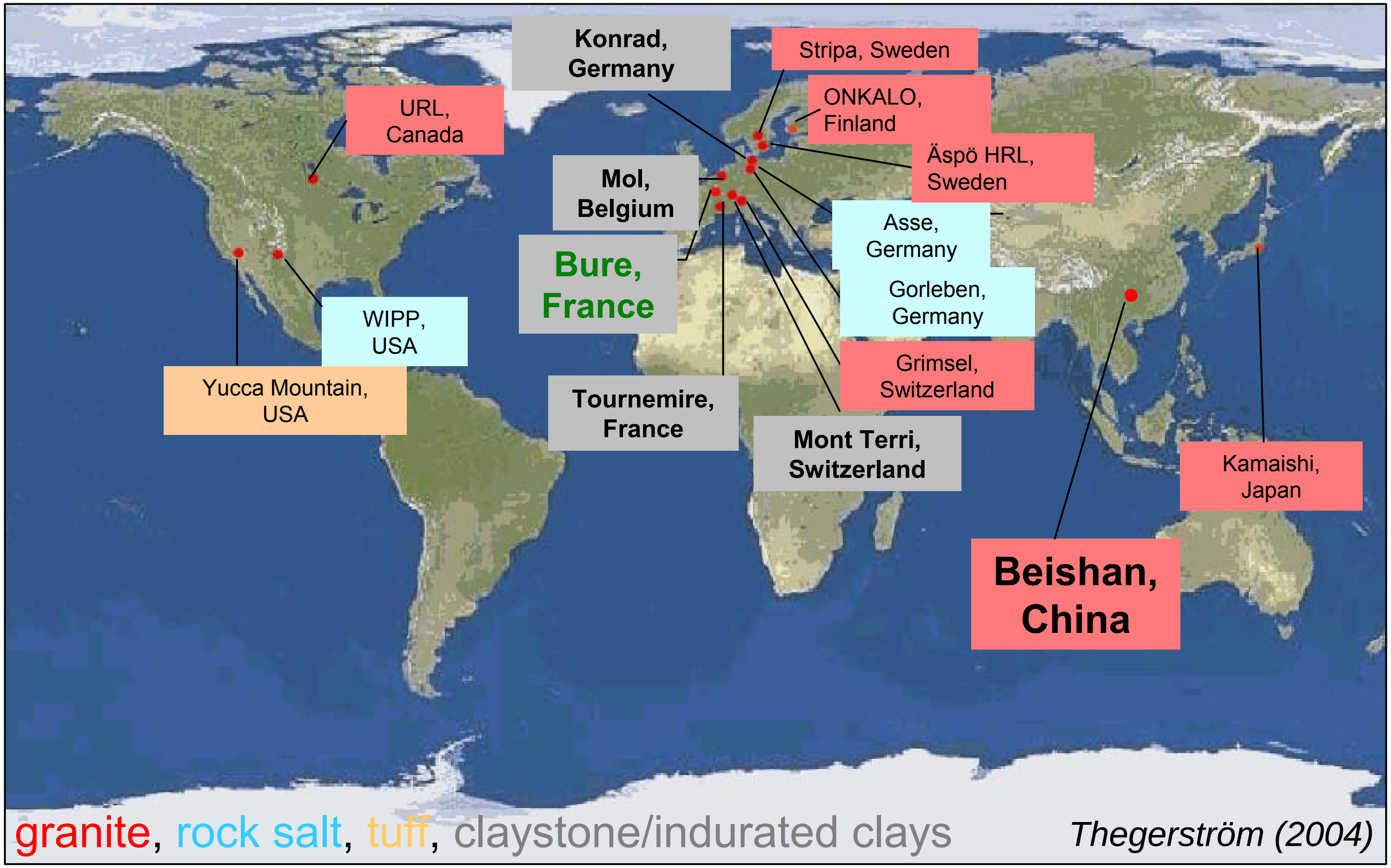
test program

- Unfortunately most of the delivered samples were broken according to bedding plane orientation(PH4-MGM-16931 / PH4-MGM-19050).

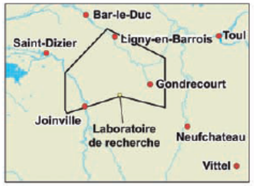


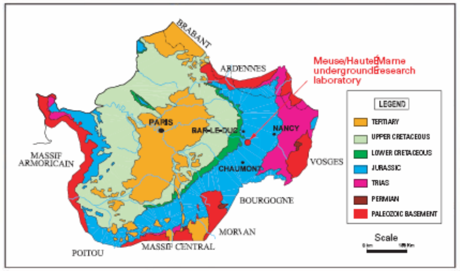


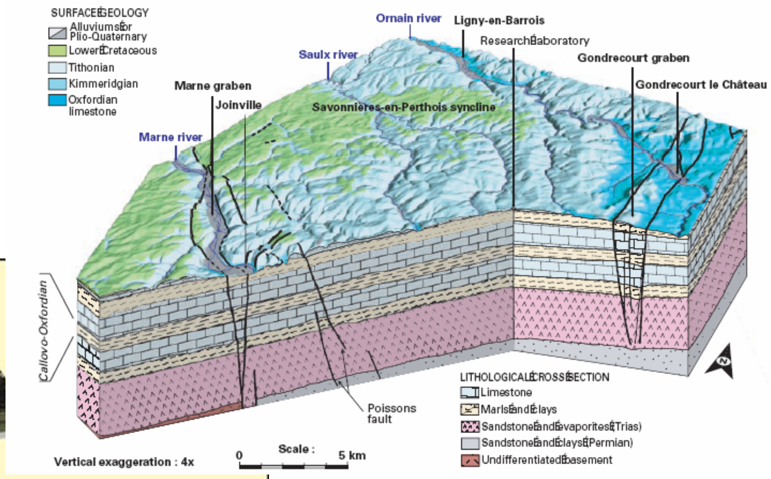

Bure site


Konrad,
Germany
Stripa, Sweden
ONKALO,
Finland
URL,
Canada
Äspö HRL,
Sweden
Mol,
Belgium
Bure,
France
Asse,
Germany
Gorleben,
Germany
WIPP,
USA
Yucca Mountain,
USA
Grimsel,
Switzerland
Tournemire,
France
Mont Terri,
Switzerland
Kamaishi,
Japan
Beishan,
China
granite, rock salt, tuff, claystone/indurated clays
Thegerström (2004)

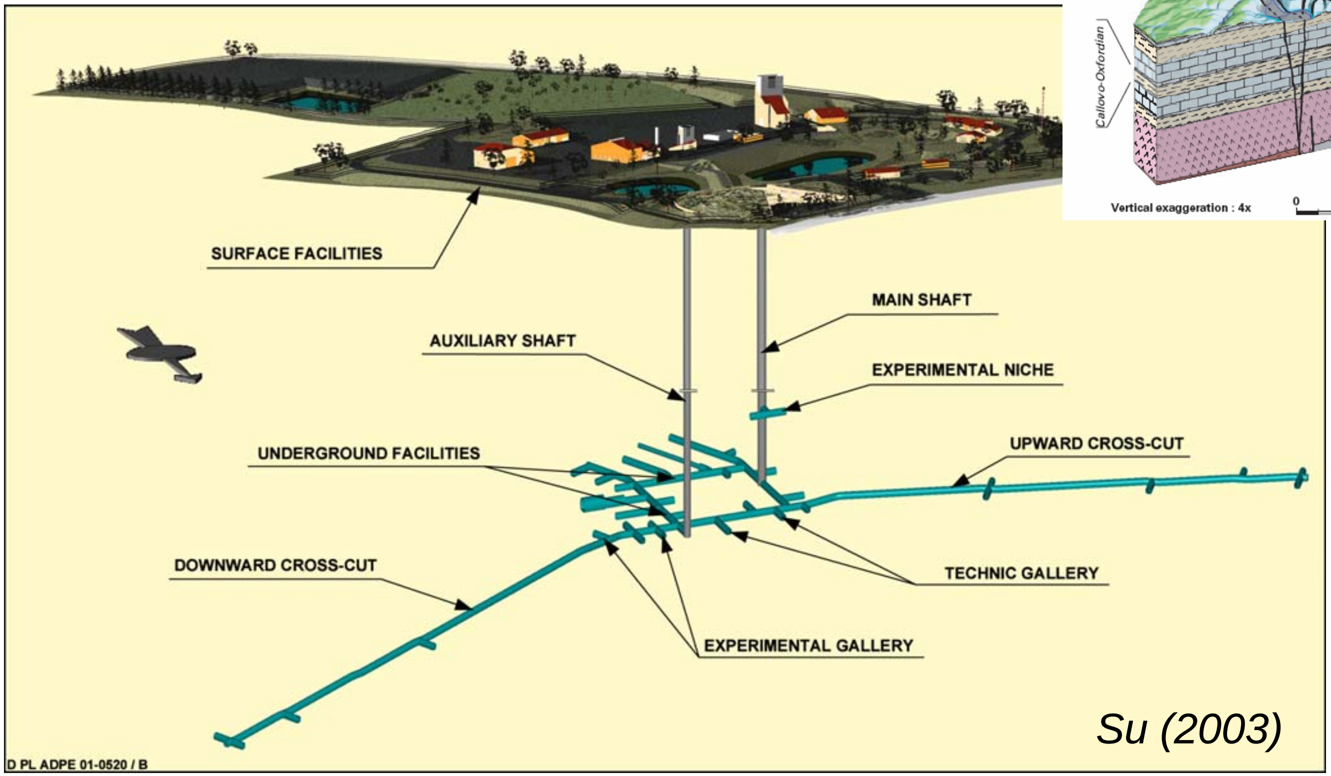
Bure site





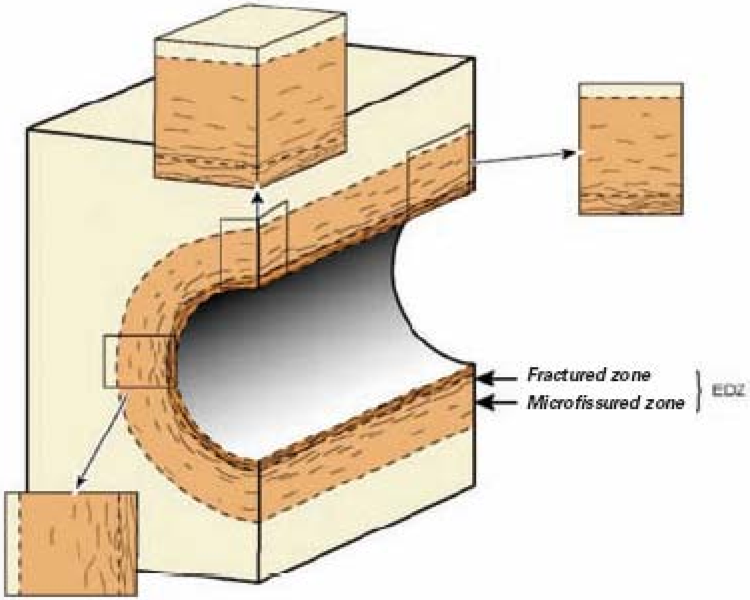


Dossier 2005



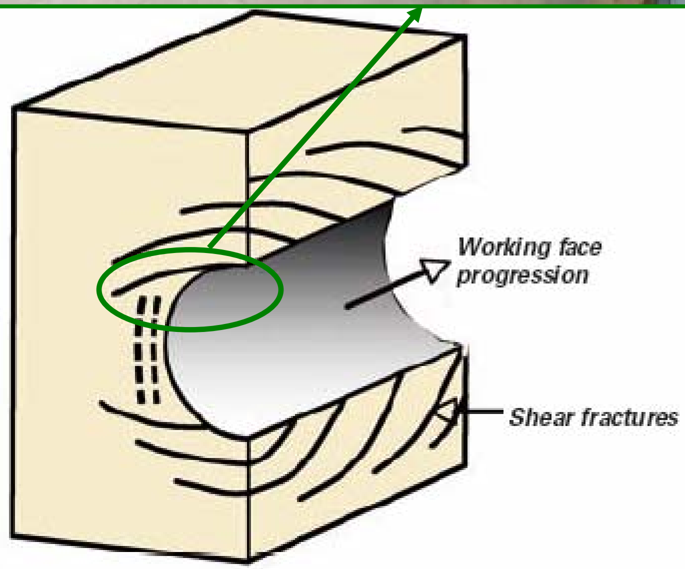
Su (2003)

In Situ



Current conceptual model of EDZ (associated to wall deconfinement)

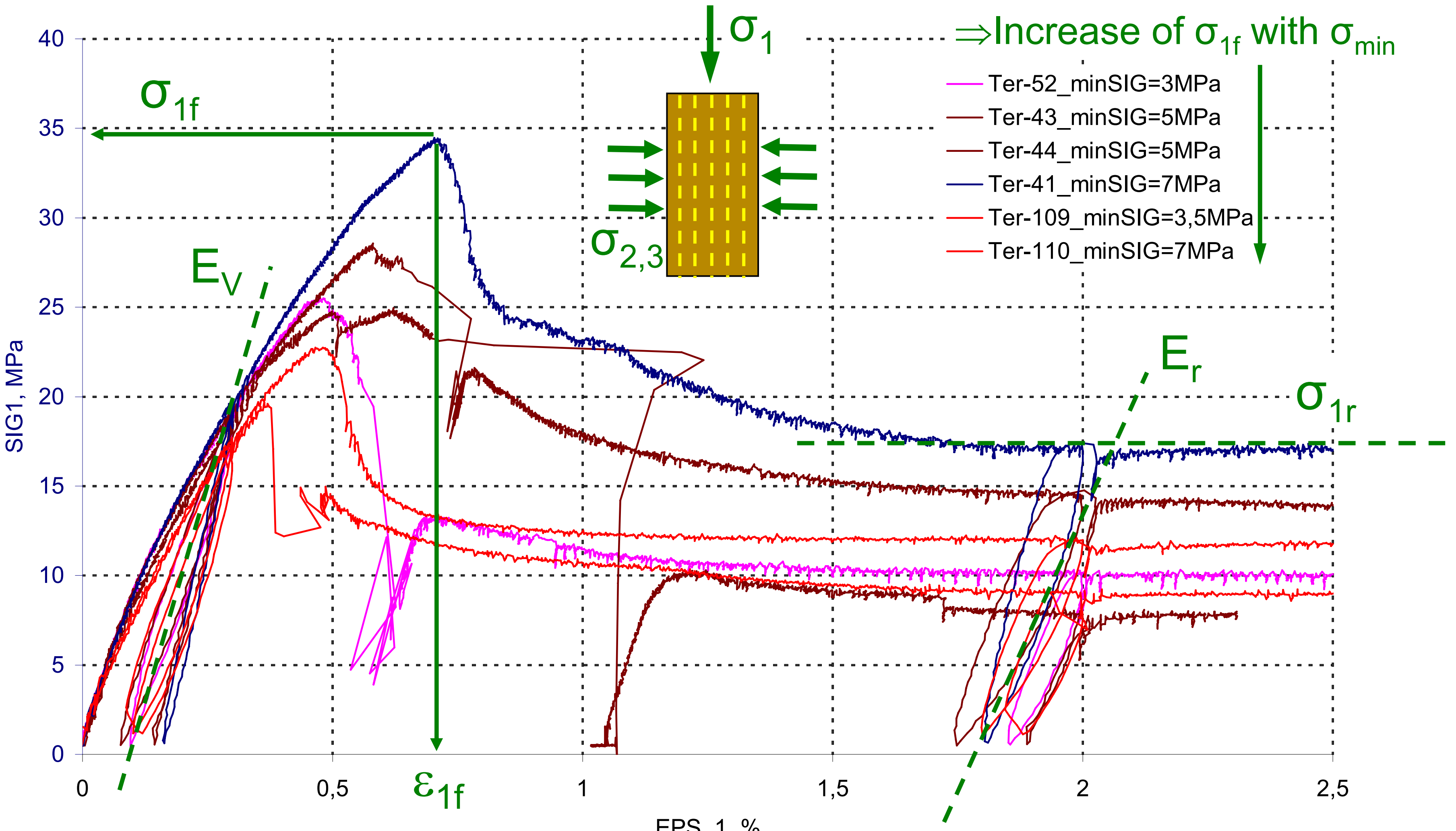
+



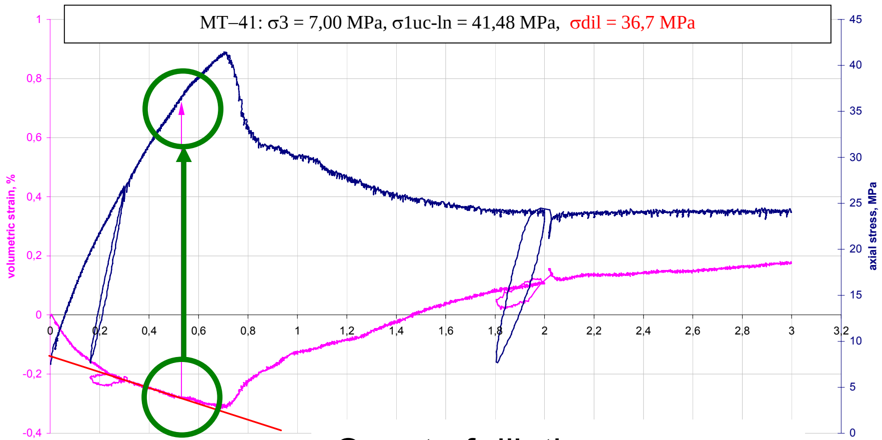
Conceptual model of shear fractures as observed in the Meuse/Haute-Marne Laboratory

Selected laboratory investigation on international claystone samples

Determination of deformation and failure material behaviour

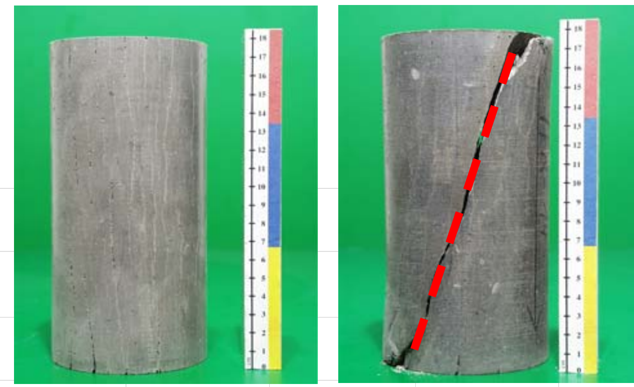


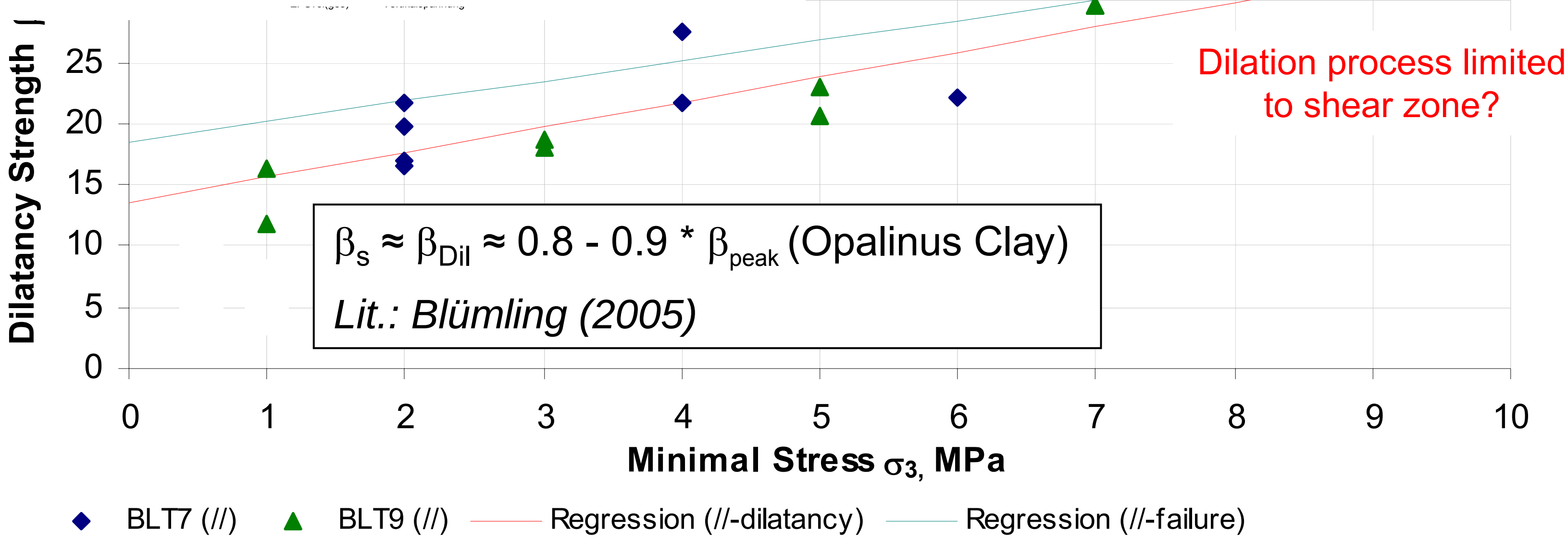
Determination of damage induced deformation behaviour



Onset of dilation processes

P-Sample Mont Terri (pre- and post-testing)



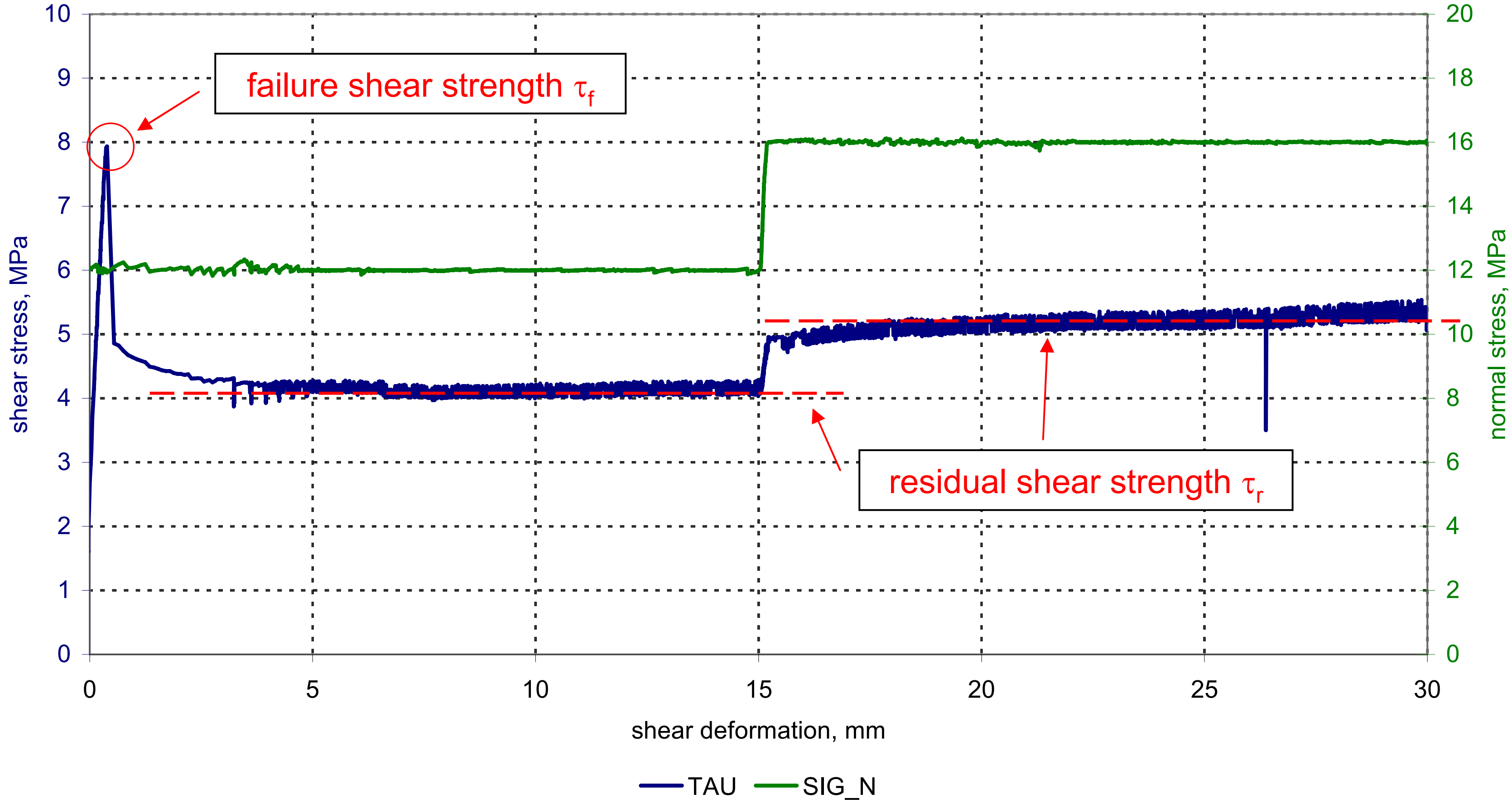


Dilation process limited to shear zone?

DST-tests (Direct-Shear-Test)

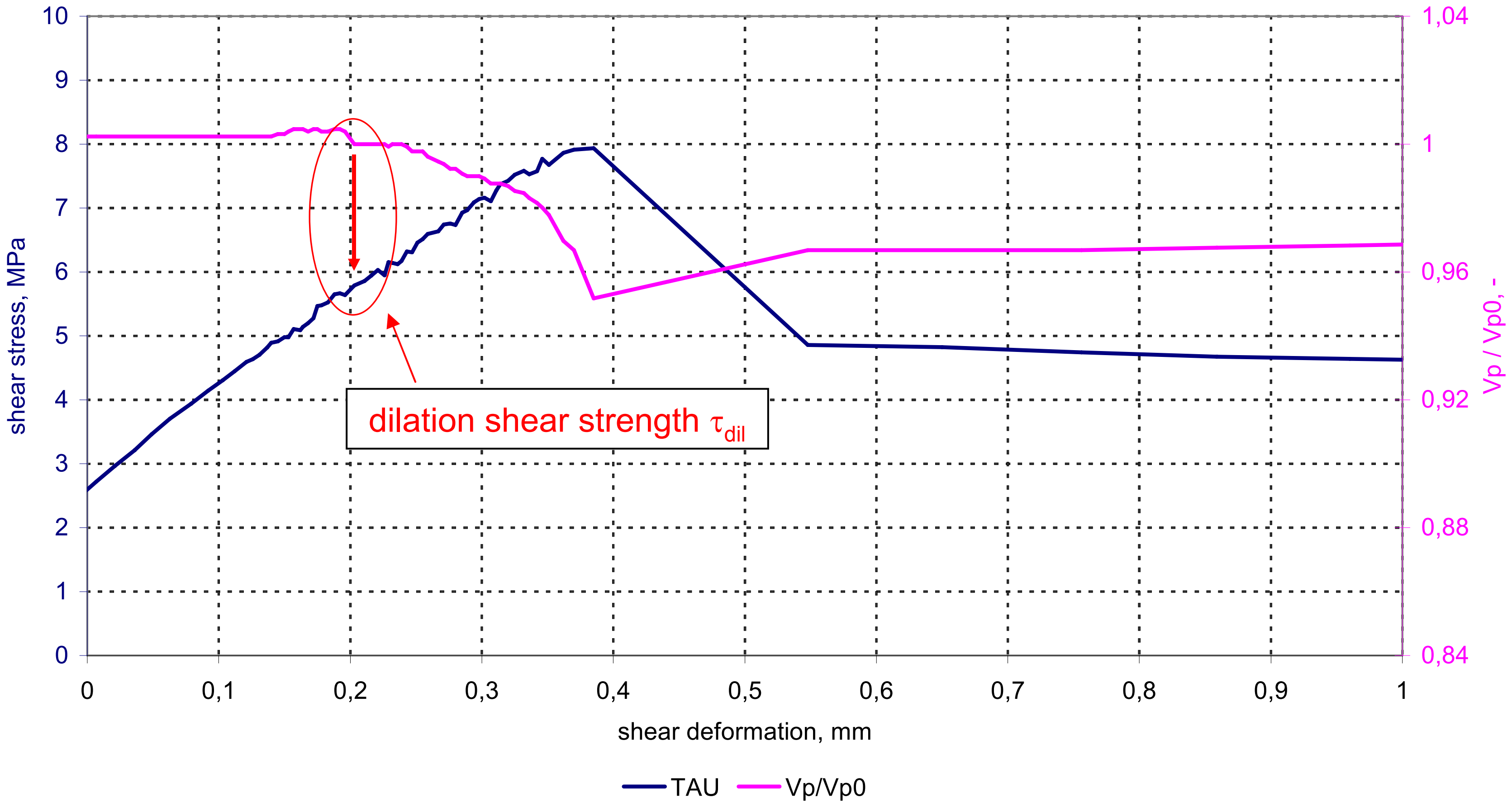
test results

- Definition of failure shear strength and residual shear strength for sample Tou-4.12



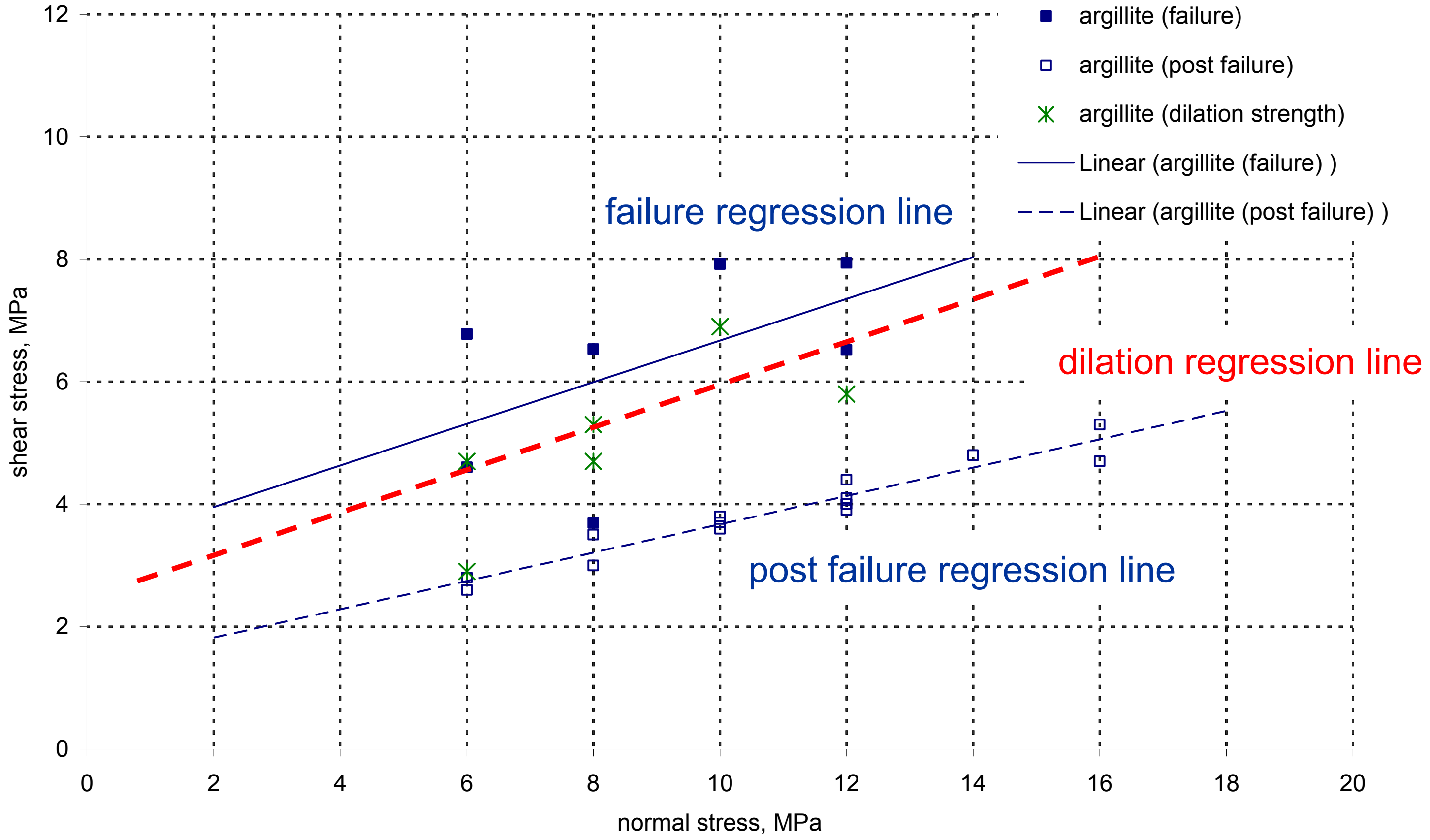
test results

- Determination of dilation strength on the basis of ultrasonic travel times

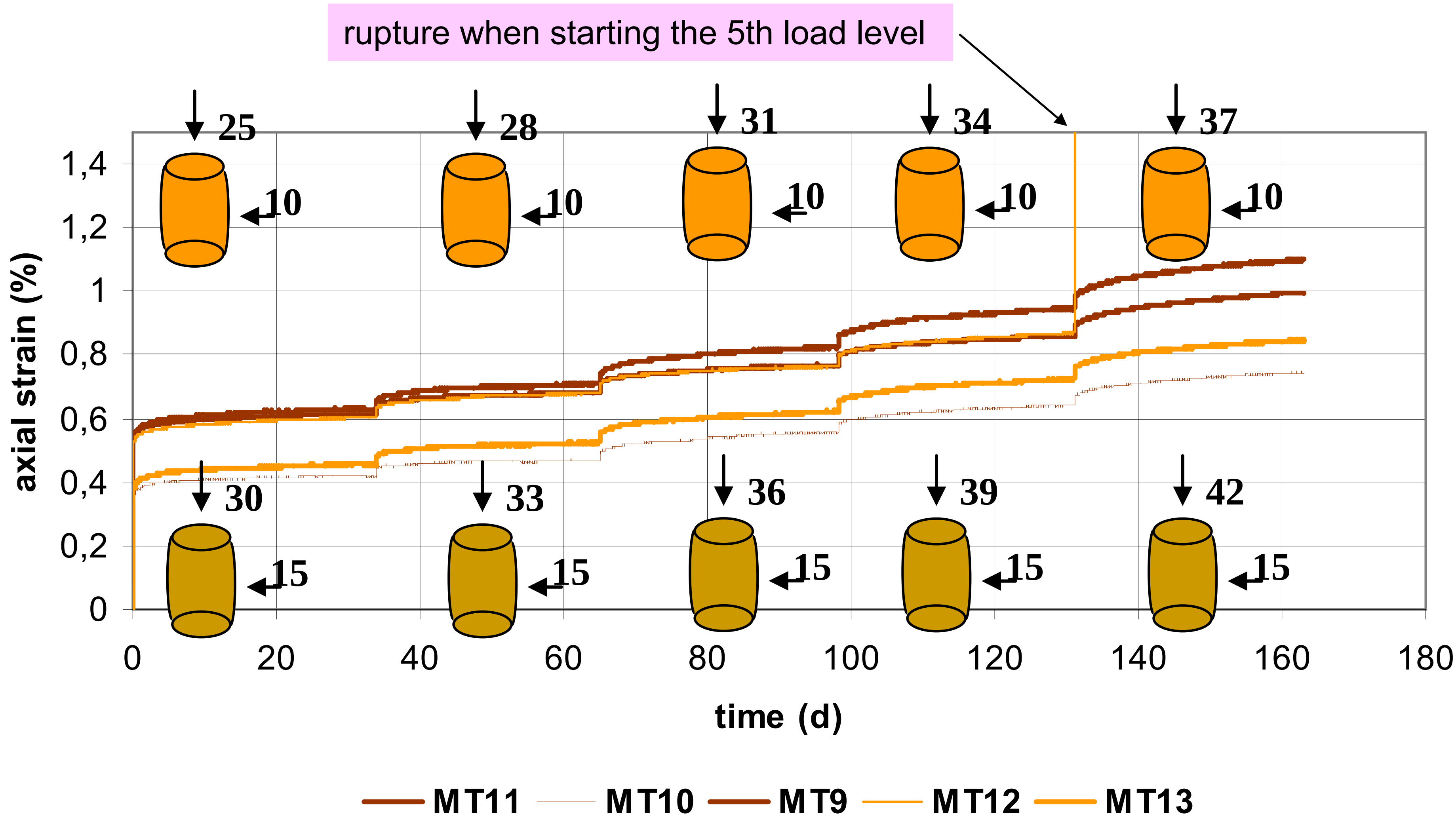


Determination of material model parameters

- Shear strength, residual strength, dilation strength for Tournemire PH4 argillite
  Shear strength: c = 3,27 MPa; φ = 18,8°
  Residual shear strength: c = 1,36 MPa; φ = 13,0°

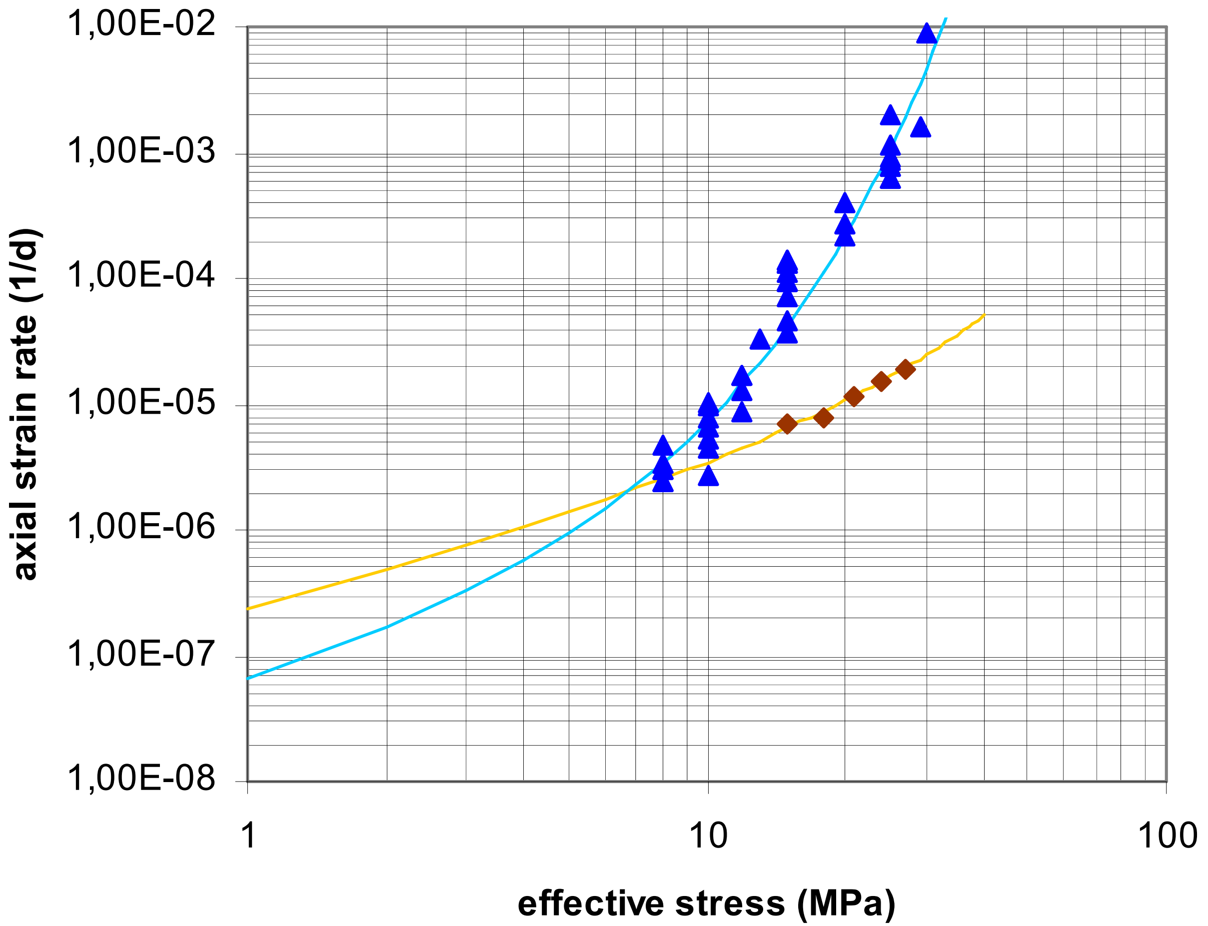


Triaxial creep tests (5 load levels)



NF-Pro Deliverable 4.4.5

Determination of time-depending material parameters



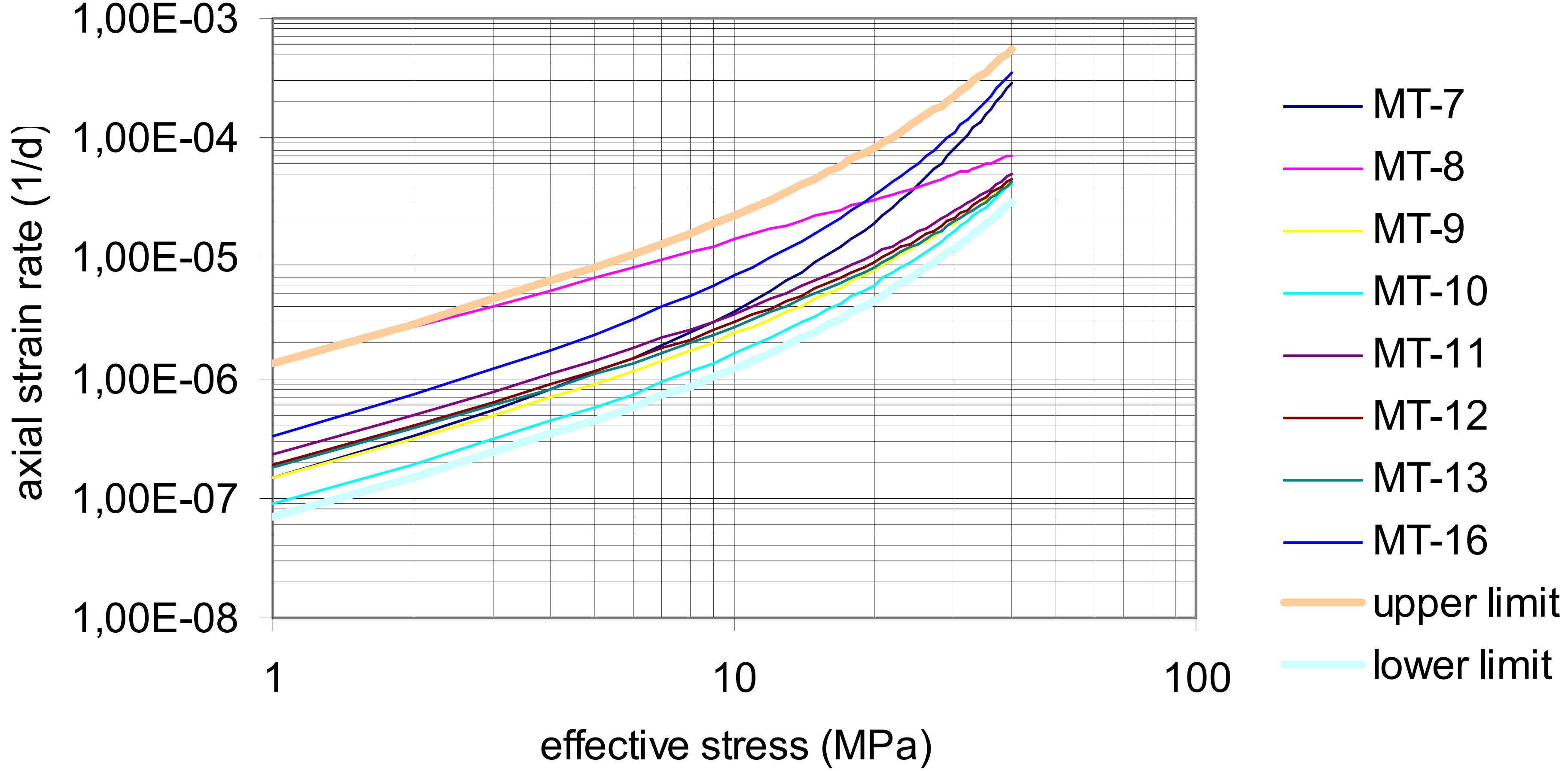
Parameter determination only feasible for one sample

⇓

limited scatter band

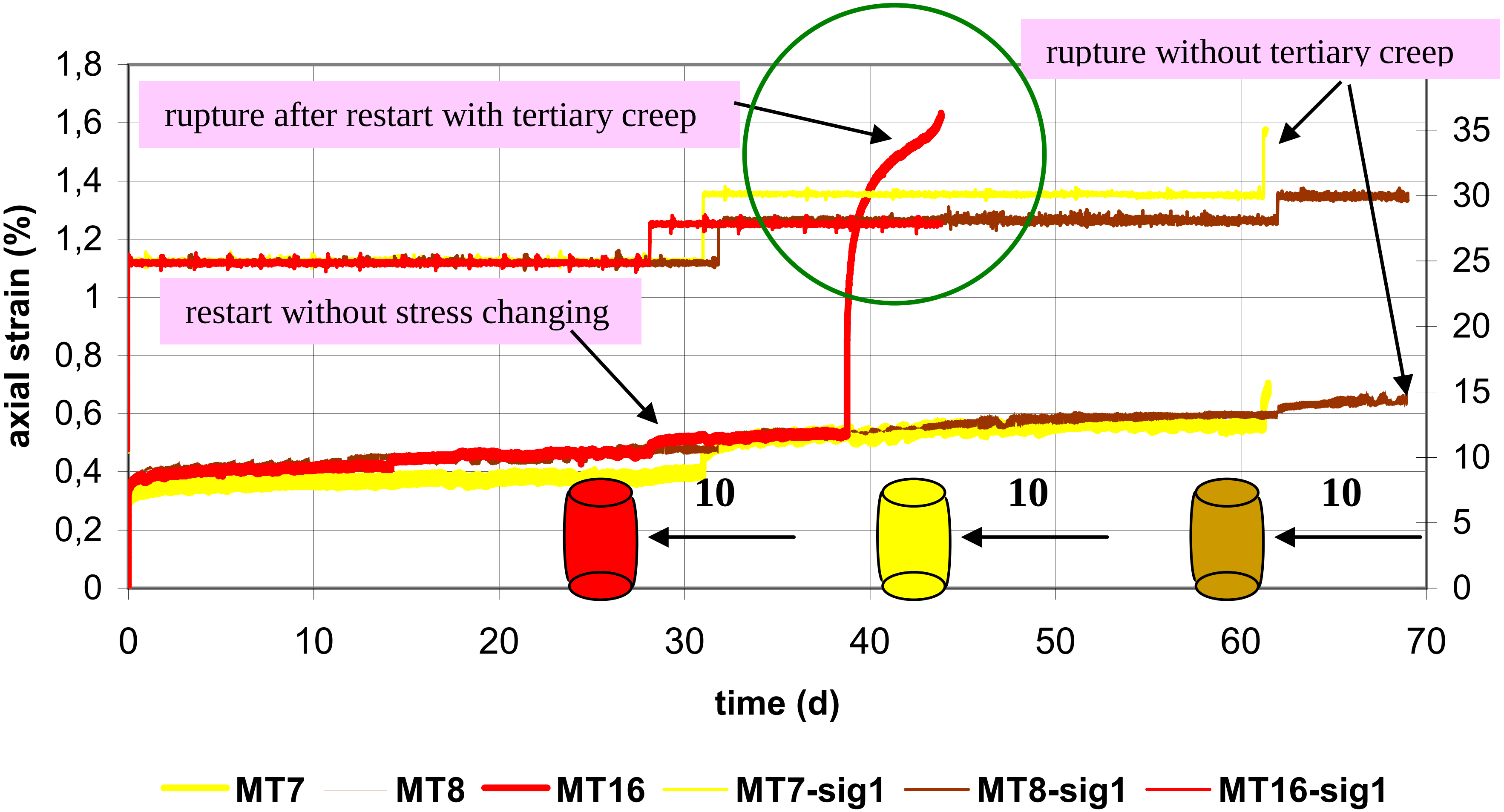
NF-Pro Deliverable 4.4.5

Stationary creep behaviour (limited scatter band)



NF-Pro Deliverable 4.4.5

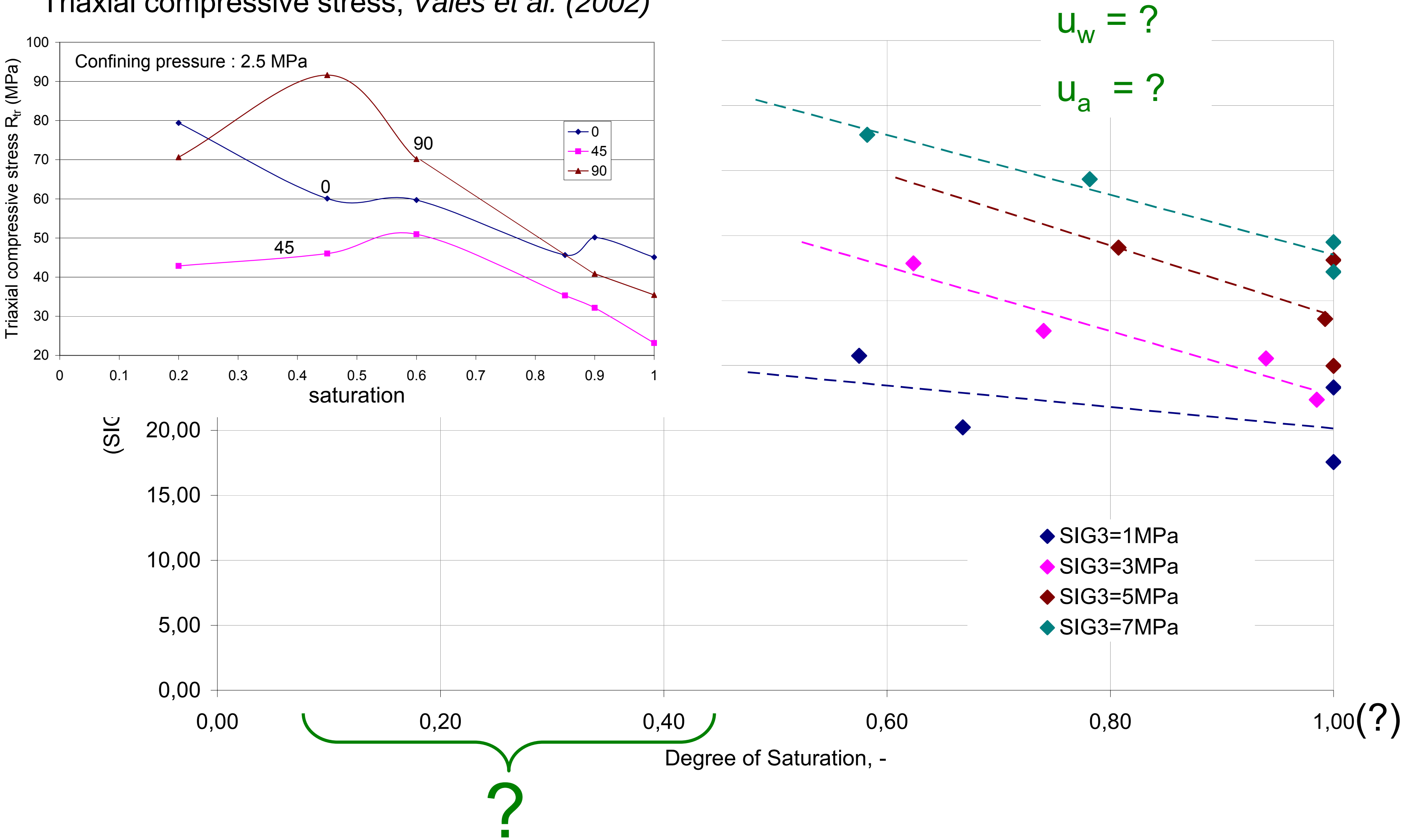
Damage induced creep behaviour



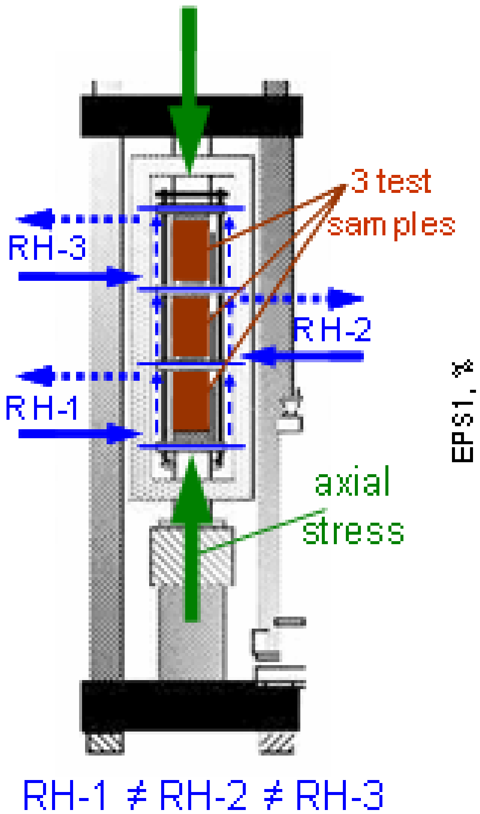
NF-Pro Deliverable 4.4.5

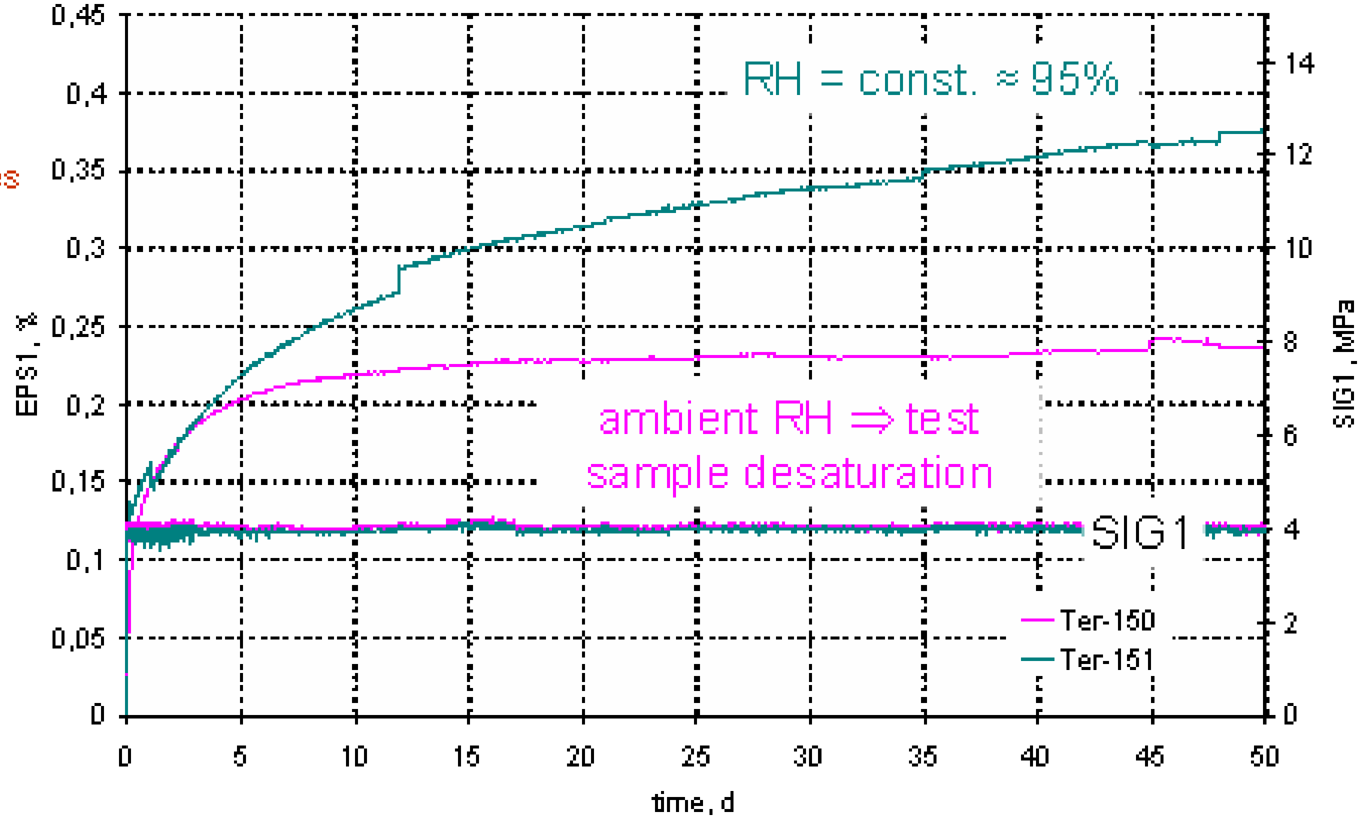
Short-term investigation for $S_r < 1{,}0$

Triaxial compressive stress, *Vales et al. (2002)*



Long-term investigation for $S_r < 1,0$





- Uniaxial creep test with different relative humidity (RH) to determine the long-term deformation behaviour depending on desaturation effects for Mont Terri samples

General Outcome

- Minor deformation capacity ($\bar{\varepsilon}_1 < 1\%$)
- Marginal stress depending stationary creep rate
- No significant transient creep phase detectable after increasing deviatoric stress
- A change in the parameter determination procedure is recommended as follows:

  (a) performing tests with more than one load level (multi load level tests)

  (b) determination of creep parameters separately for each sample

  (c) determination of (average) mean material parameters from sample-related separately determined parameters.

  (d) The sample size should be enlarged, h:d ratio should be 2.5:1 or 3:1

  (e) High accuracy displacement transducers with optimised measurement range are recommended

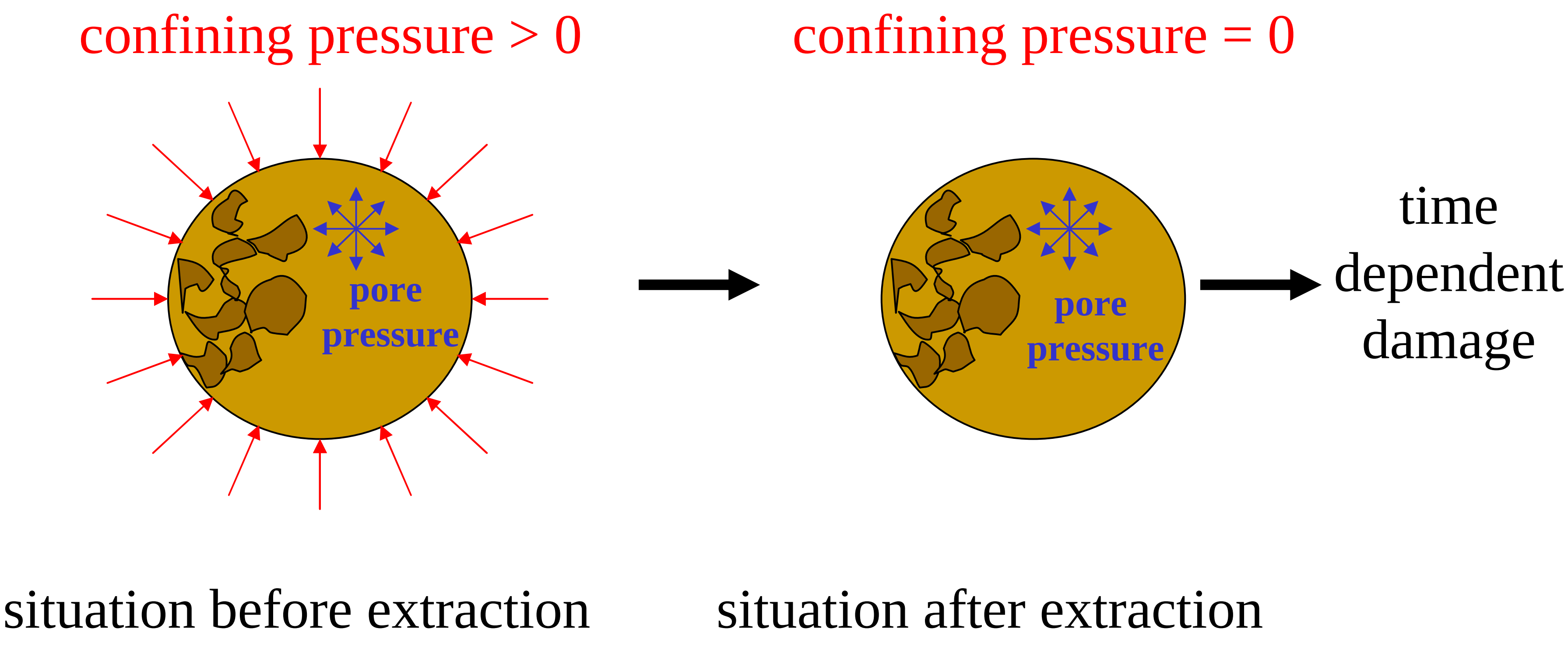
Material behaviour depending on storage conditions

Plastic bag sealed
and stored claystone sample
(6 weeks storage time)

Ageing cracks in plastic bag
sealed and stored claystone
sample (6 months storage time)

Schematic overview on effects in rock mass

Pore pressure induced tensile stress after core extraction



Phenomenological identifications dependent on the storage time

- increase in shear strength of the rock (increase of the effective stress because of the reduced pore water pressure or desaturation (build-up of a water potential, suction),
- increasing damage to (or destruction of) the rock structure resulting from the pressure difference now active, i.e. the difference between the pore water pressure and the ambient pressure that has now been reduced to the atmospheric pressure, as well as
- increasing damage to the rock structure by further desaturation which leads to the formation of contraction cracks (shrinkage, enlarged suction).

Photographic view of the storage containers

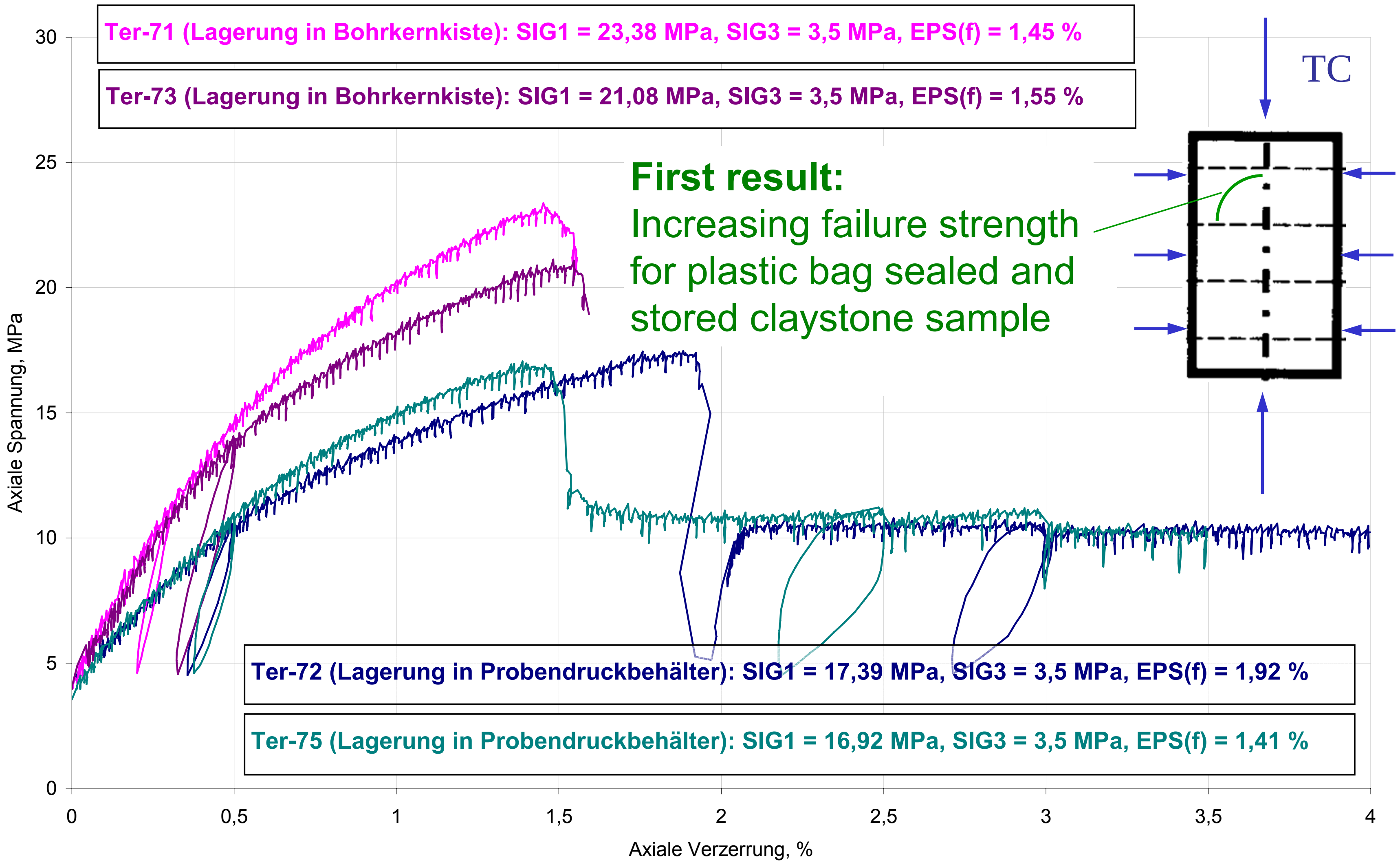
plastic bag sealed and stored claystone sample

claystone sample stored in **TUC container**

TUC storage container

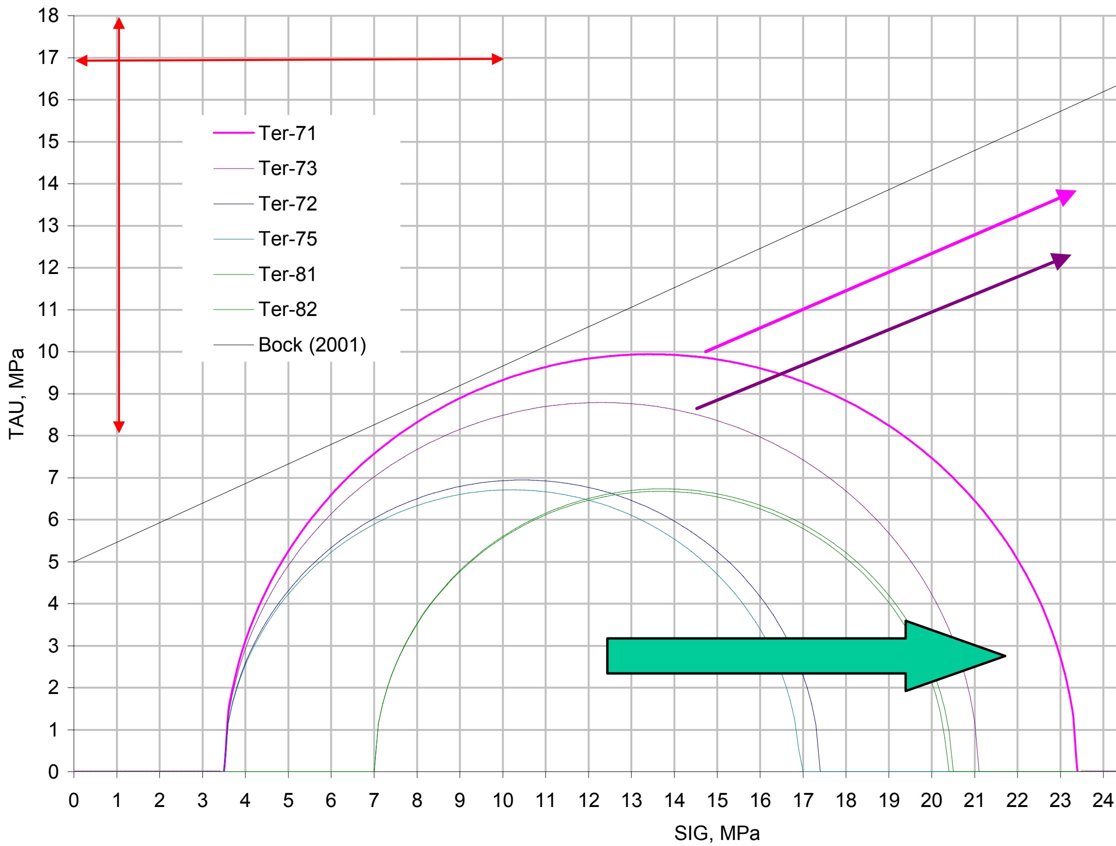
Impression of the installation sequence

Results of short-term TC tests depending on storage conditions



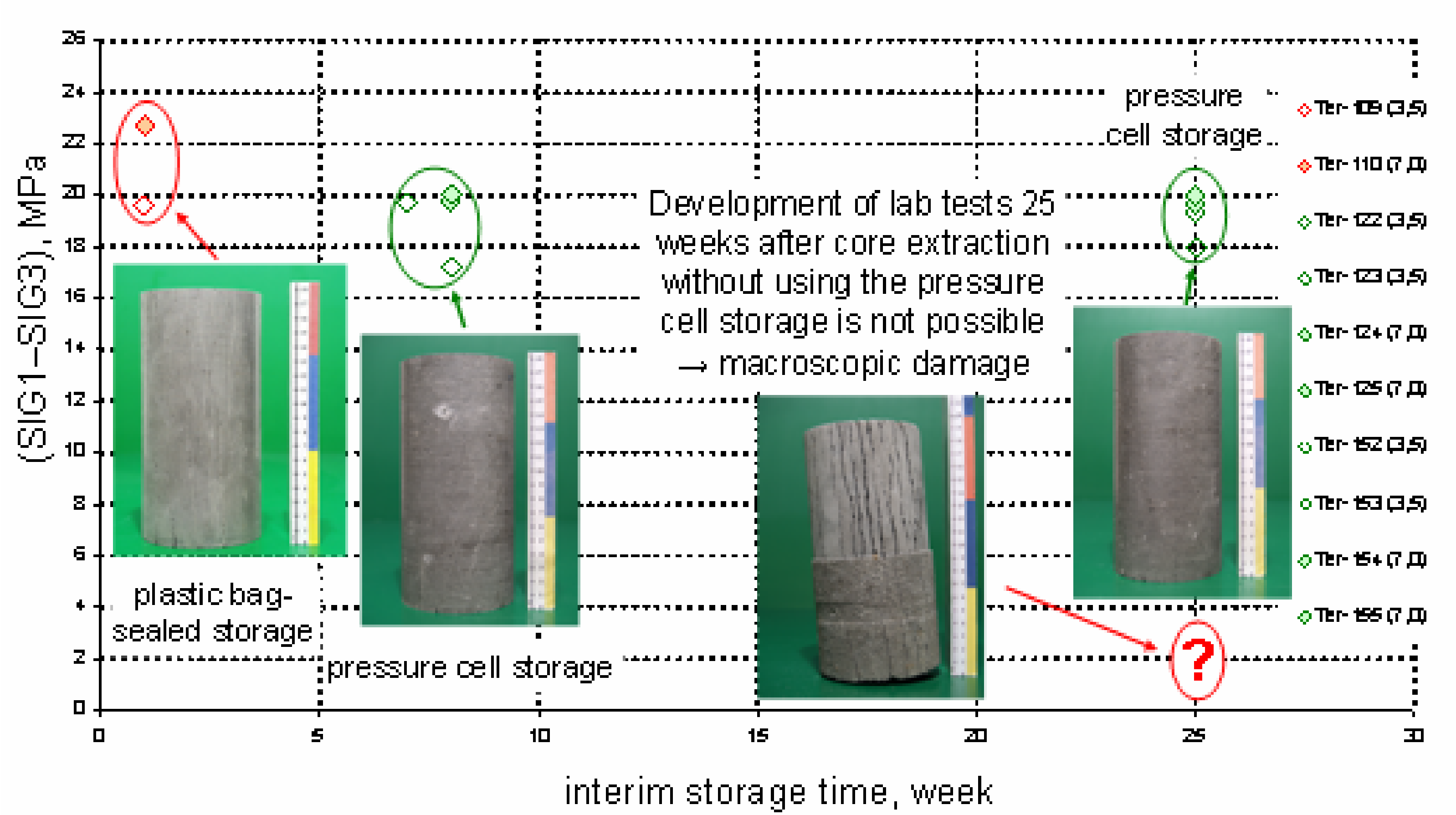
Results of short-term TC tests depending on storage conditions

- A comparison of the results of triaxial compression experiments on claystone from the same extraction location and after the same storage time in dependence on the type of storage



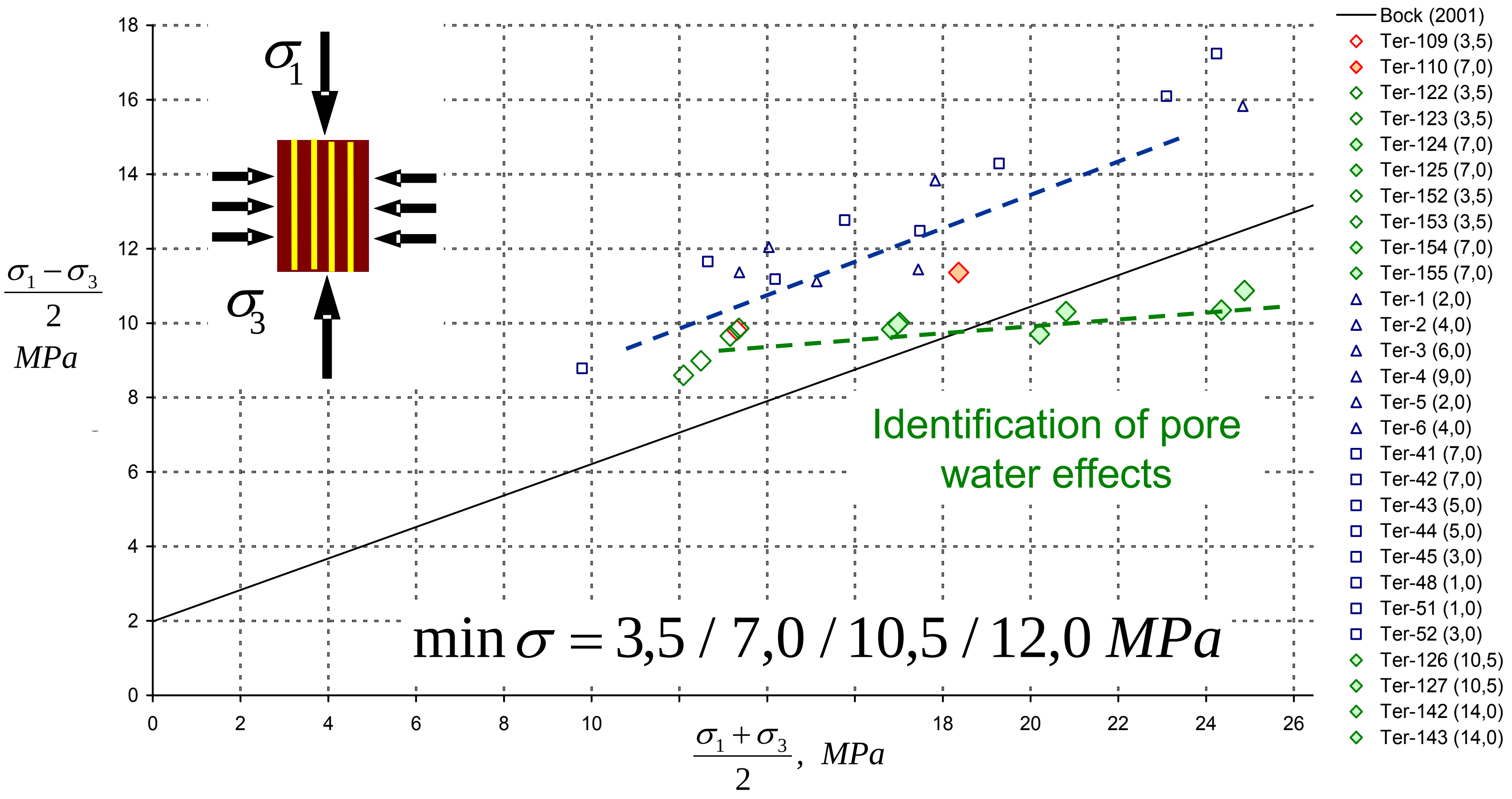
Results of short-term TC tests depending on storage conditions

- Current results of triaxial compression tests P-samples from Mont Terri (same drilling location) in dependence on interim storage time and type of storage (red – plastig bag sealed interim storage / green – interim container storage)



Results of short-term TC tests depending on storage conditions

- Current results of triaxial compression tests P-samples from Mont Terri in dependence on the type of storage (red/blue – plastig bag sealed interim storage / green – interim container storage)

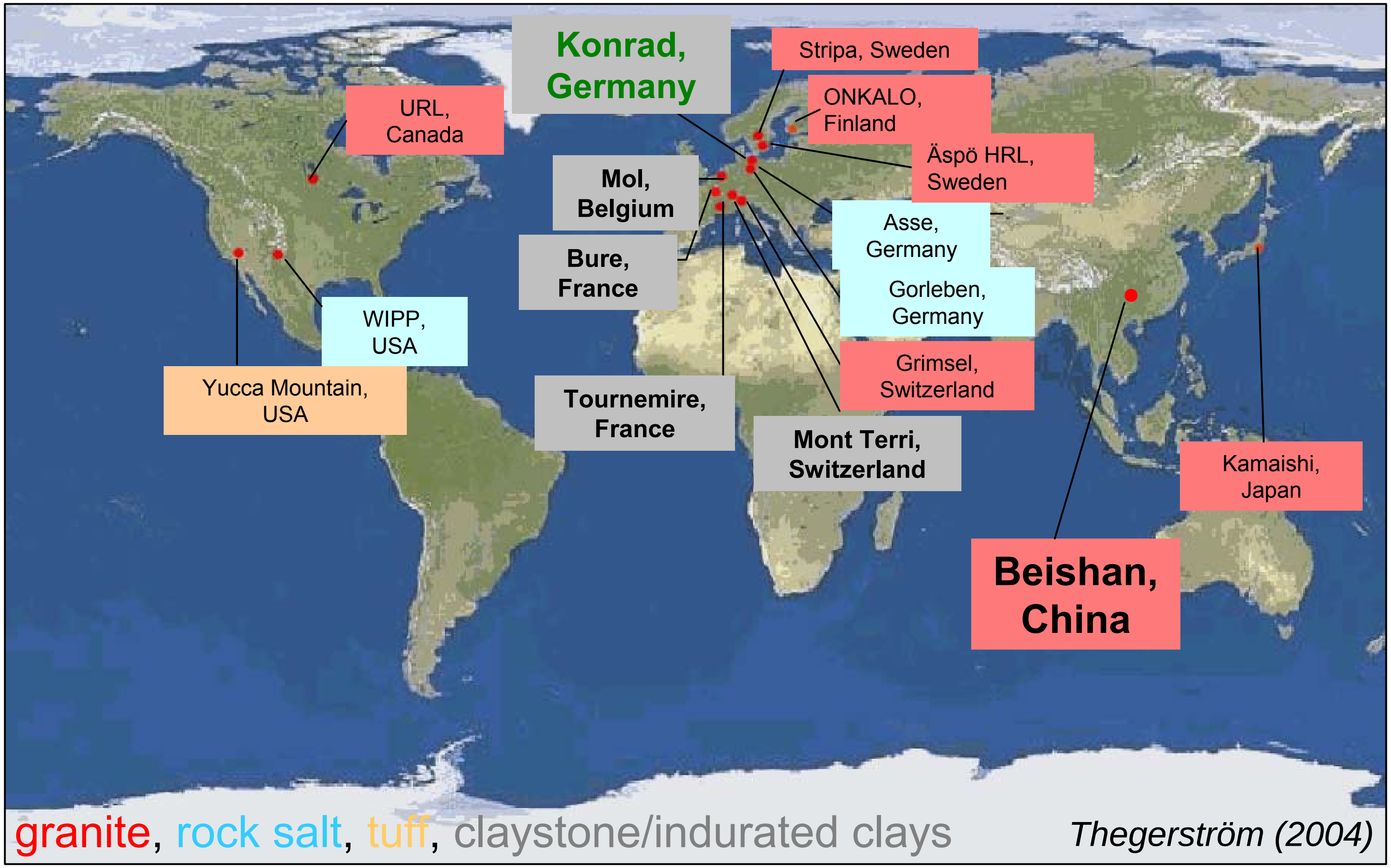


Conclusion *on lab testing results*

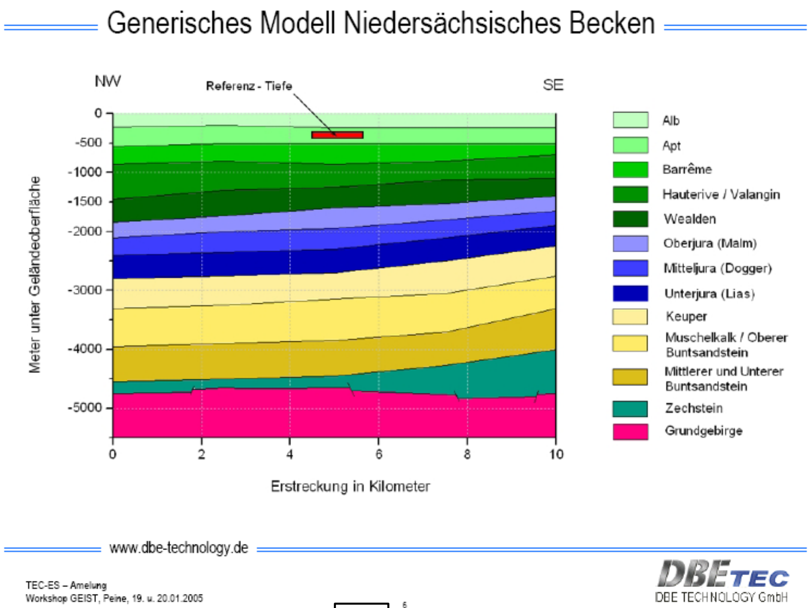
- As, in pressure cell storage, desaturation processes to the extent of those given in wooden box storage are prevented,
- lab test results are reproducible,
- the pore water pressure described in the introduction is assumed to be the major cause of storage-dependent effects.

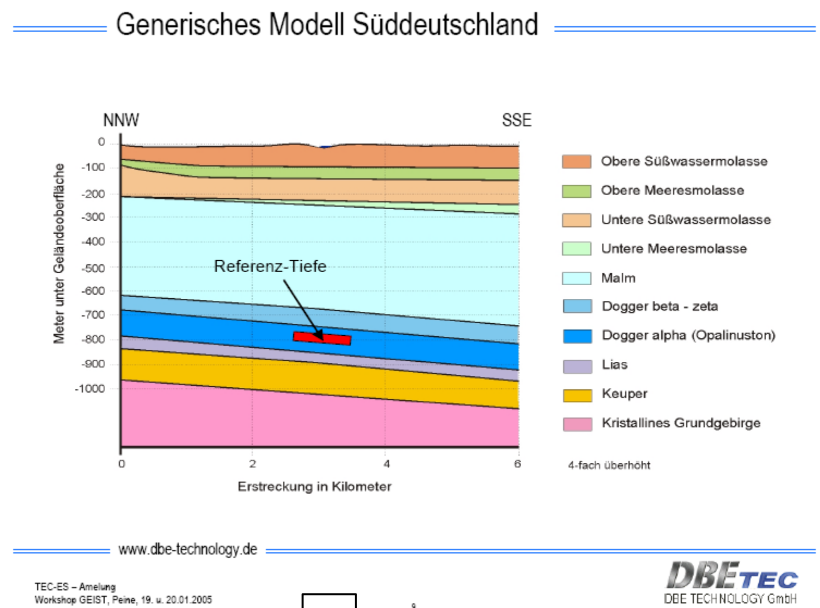
⇒ In order to make this thesis more precise, work is in progress to integrate a pore water pressure measurement in the experimental set-up for future laboratory experiments.

Germany


Konrad, Germany
URL, Canada
Stripa, Sweden
ONKALO, Finland
Äspö HRL, Sweden
Mol, Belgium
Bure, France
Asse, Germany
Gorleben, Germany
WIPP, USA
Yucca Mountain, USA
Tournemire, France
Grimsel, Switzerland
Mont Terri, Switzerland
Kamaishi, Japan
Beishan, China
granite, rock salt, tuff, claystone/indurated clays
Thegerström (2004)

Generic Investigations in Germany



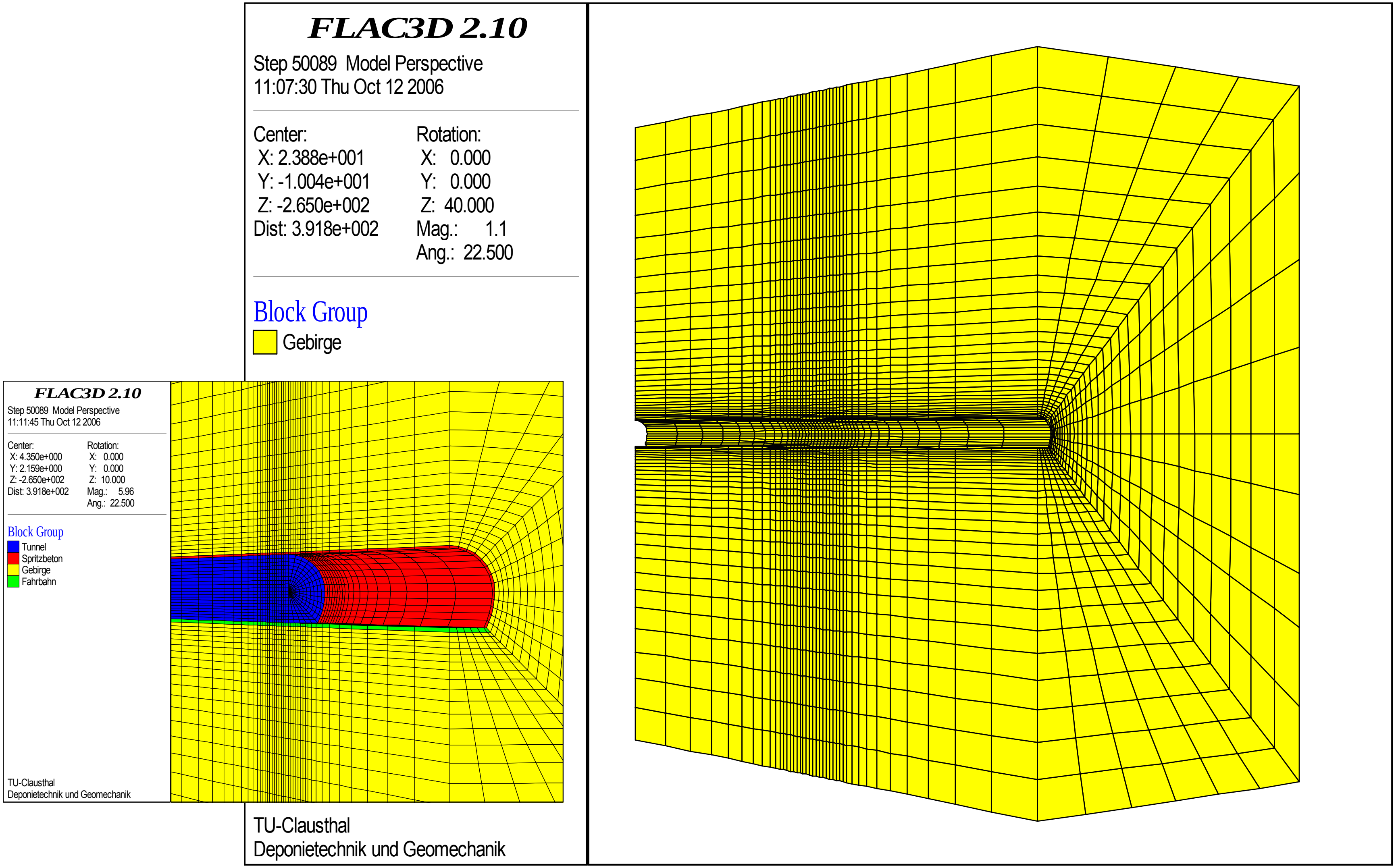


Indurated Clay – Marlstone mixture

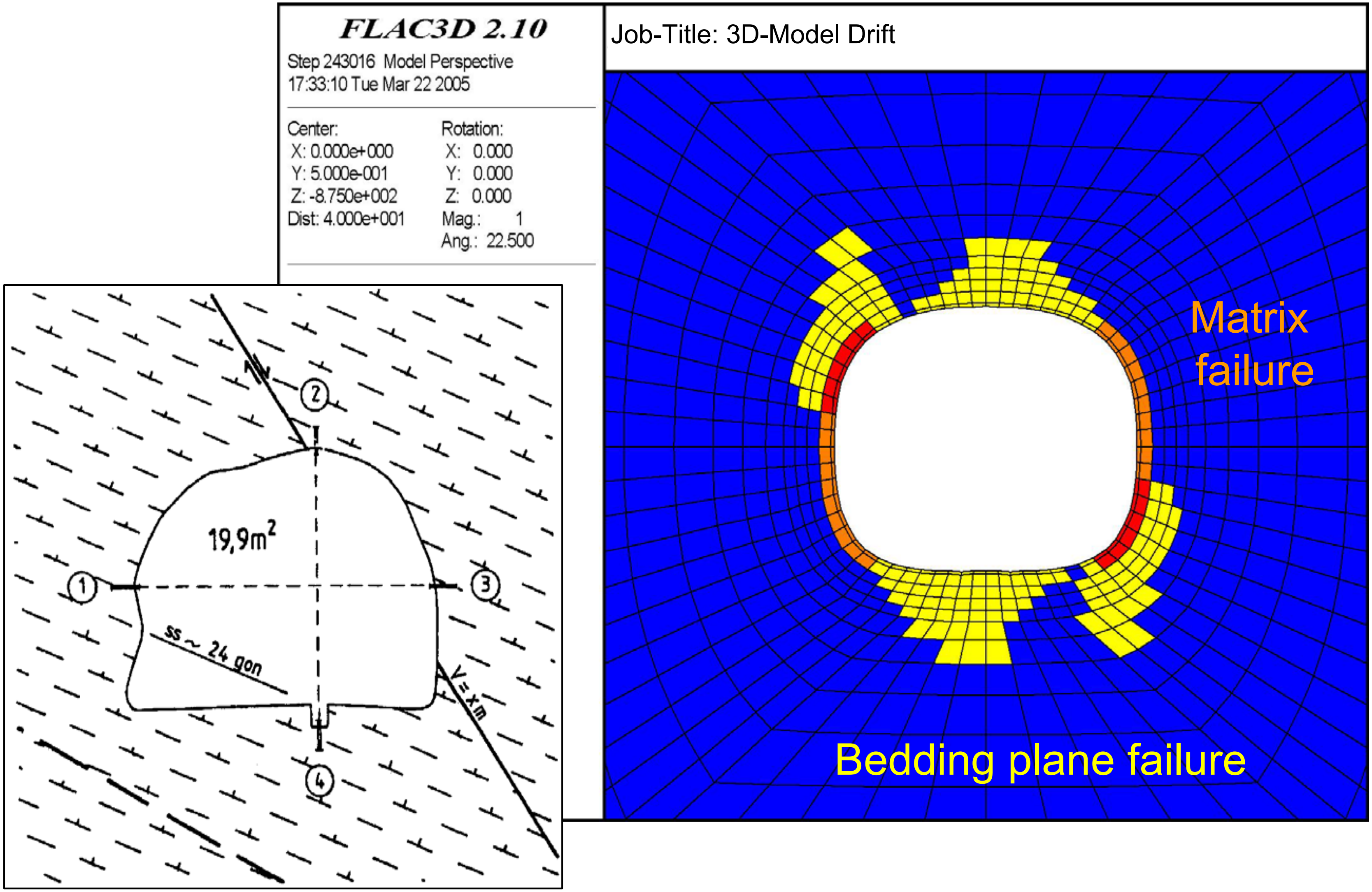
Claystone / Opalinusclay (similar to Switzerland)

In situ

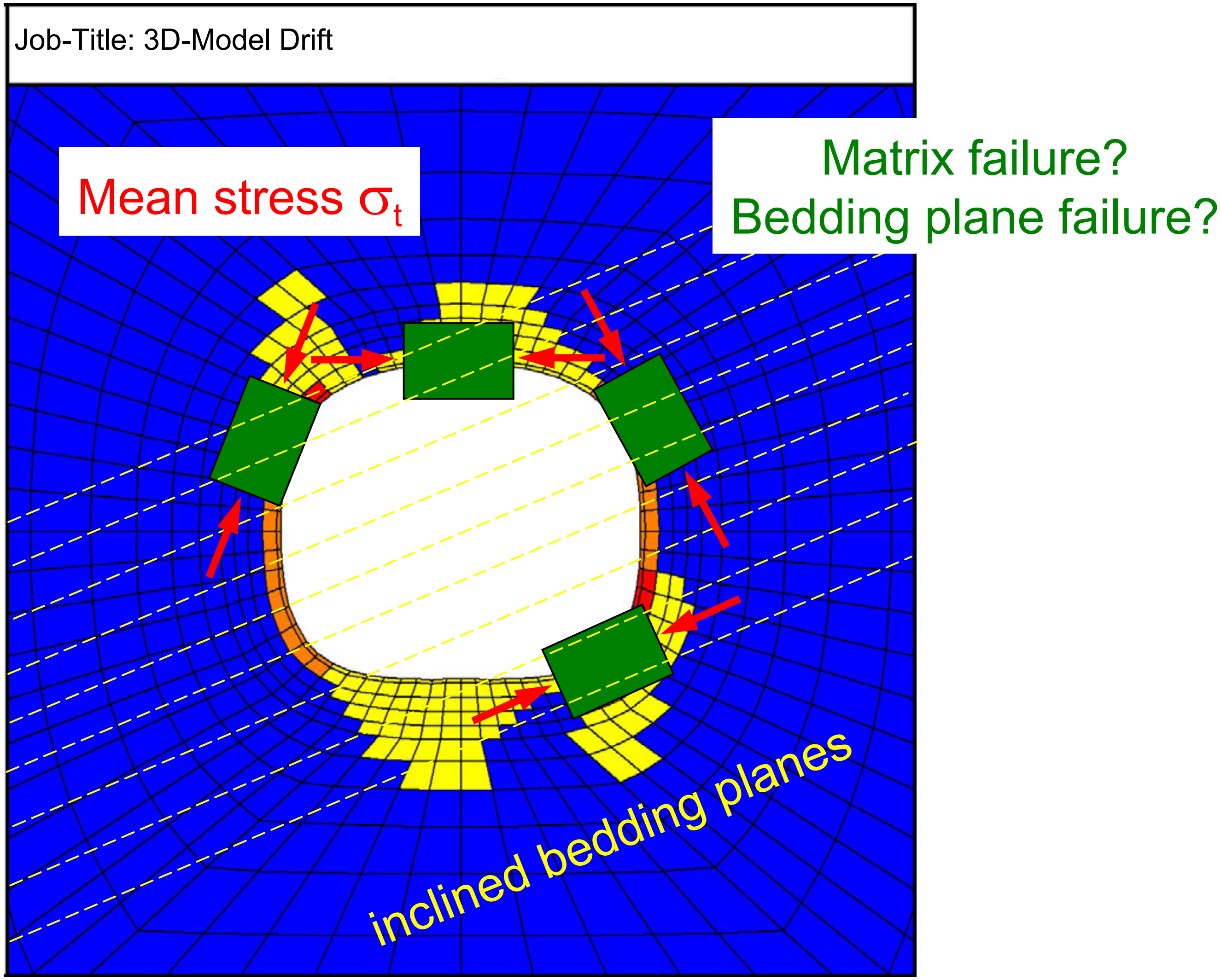
Physical Modelling and numerical Simulation (3D)



What is possible? – Identification of (potential) failure processes (zones)

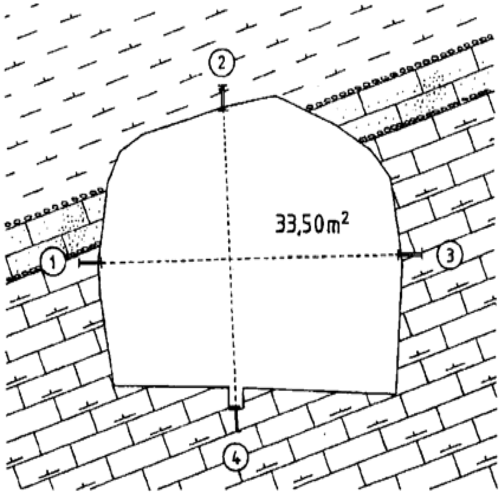


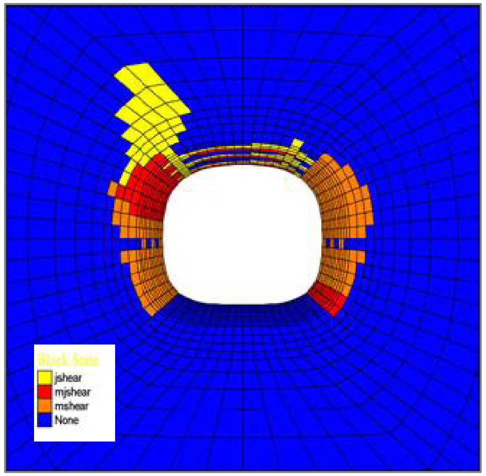
Determination of anisotropic effects on rock mass failure

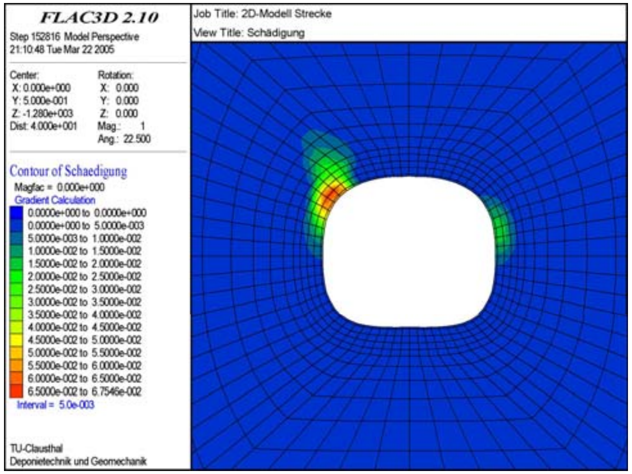


$k_0 = 0{,}7$

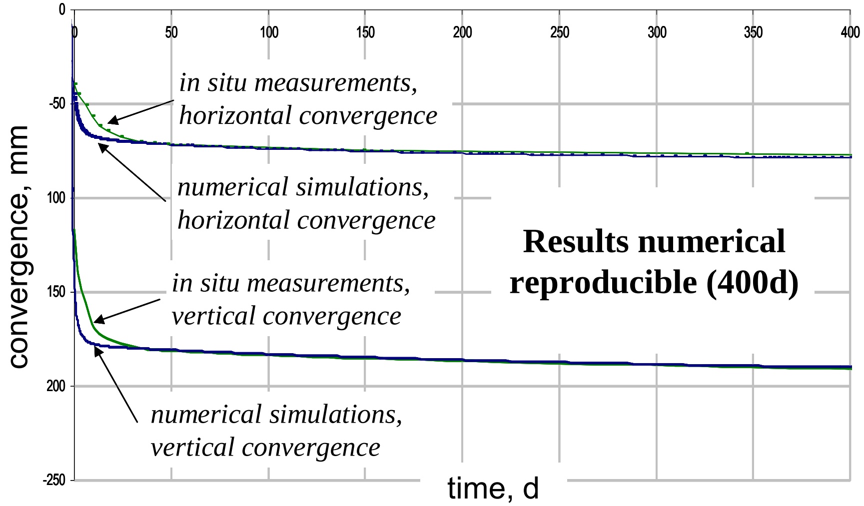
Selected drift in argillaceous rock mass with simulation results



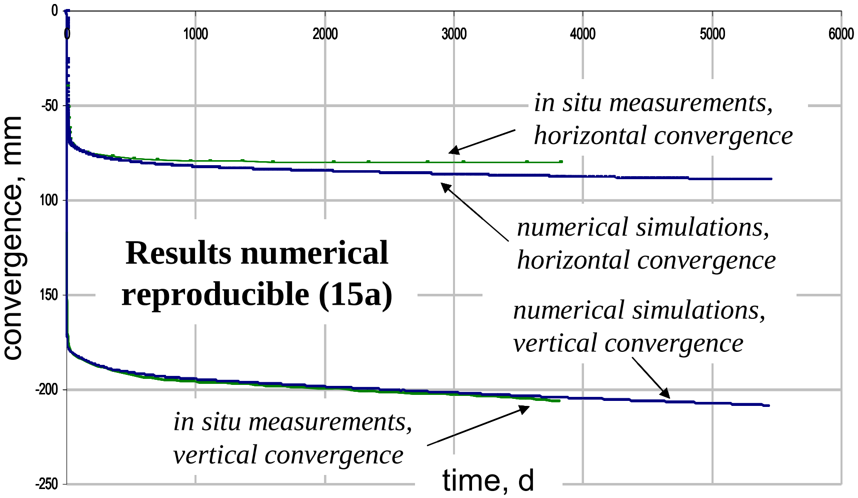




a) drift cross section area , b) damaged zones, c) intensity of damage



Deformation process during the first year

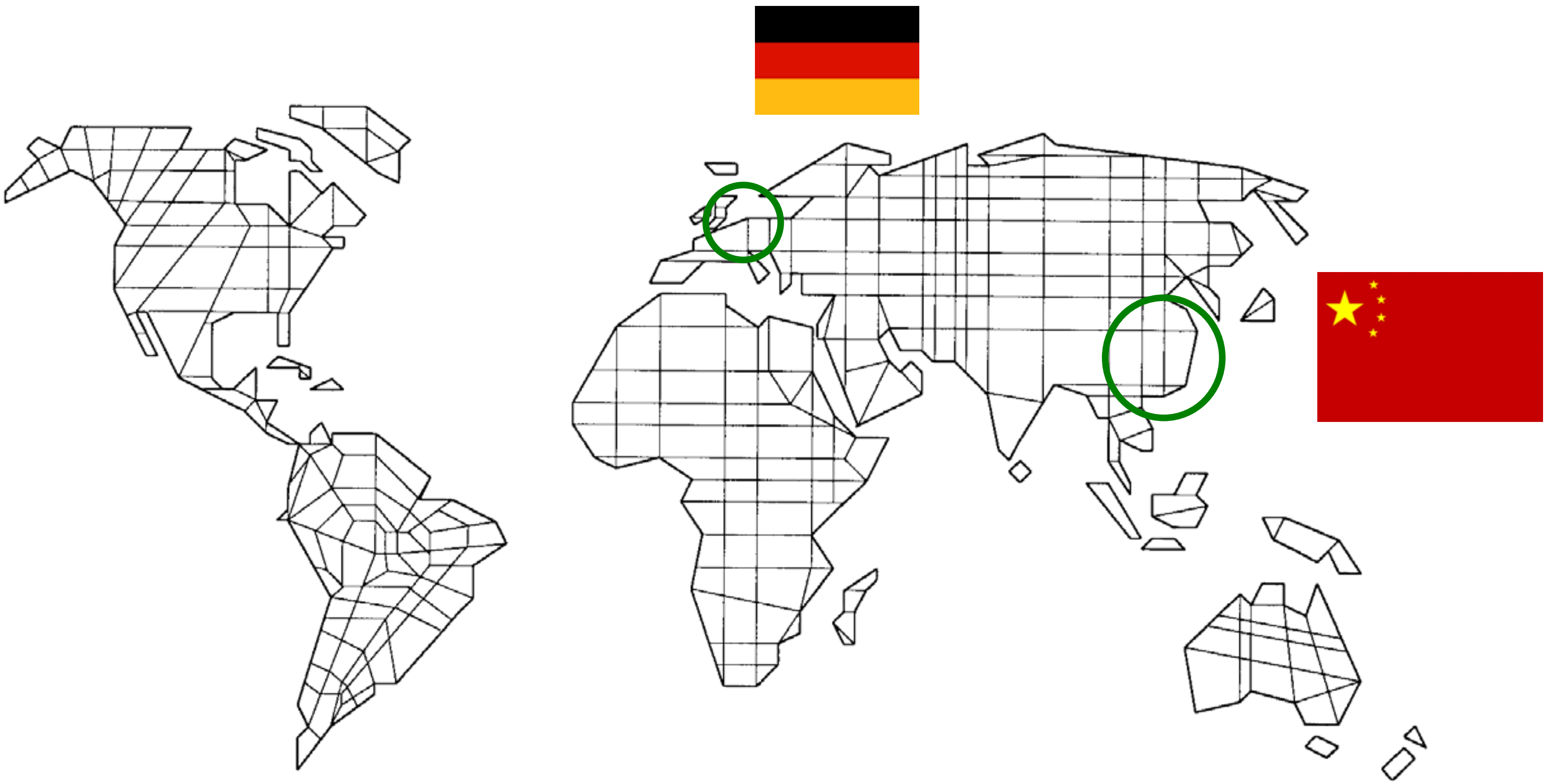


Observation period of 15 years

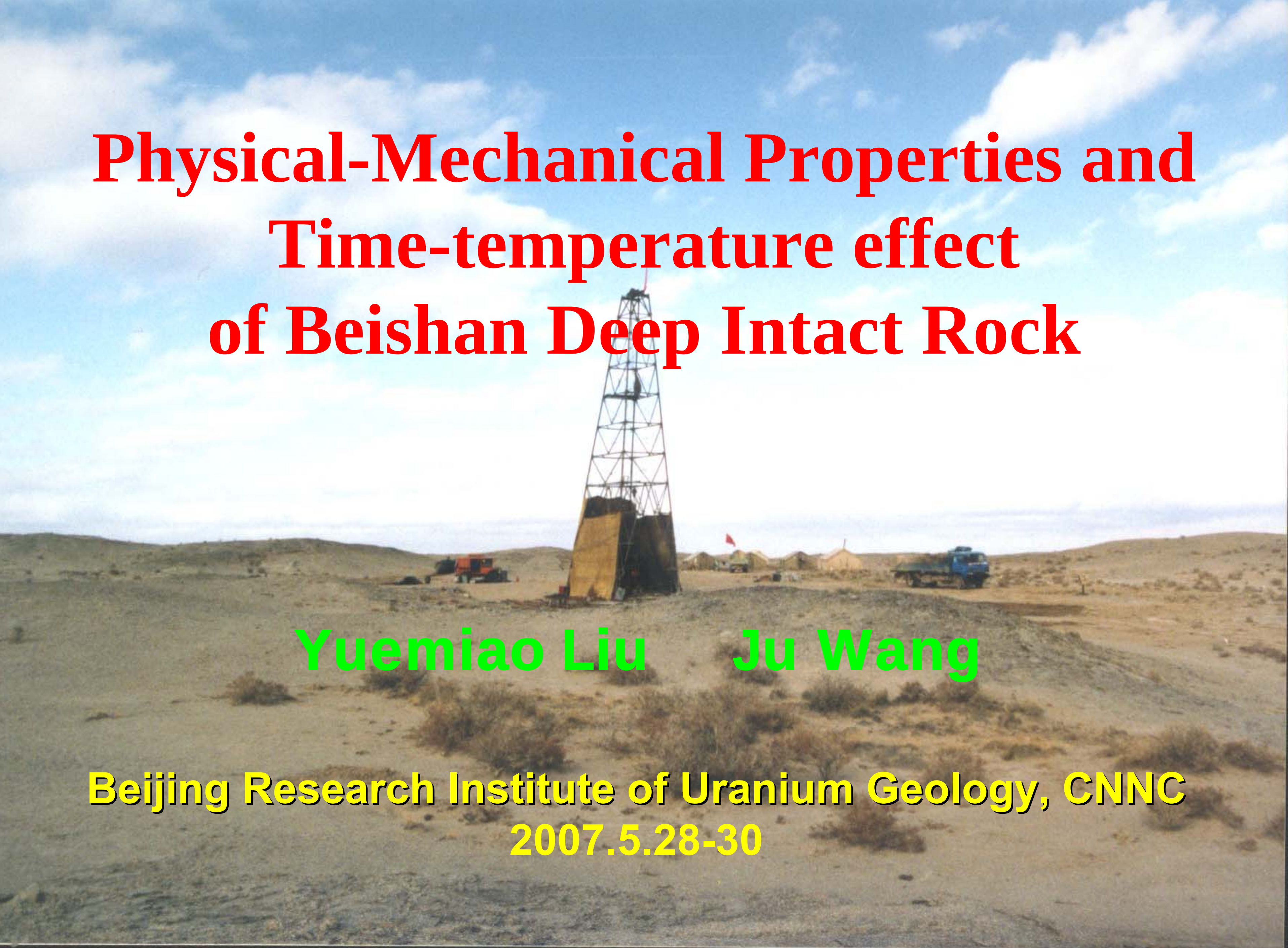
Final Slide

Thanks for your interest!

Hope for beneficial scientific cooperation!



Physical-Mechanical Properties and Time-temperature effect of Beishan Deep Intact Rock



Yuemiao Liu Ju Wang

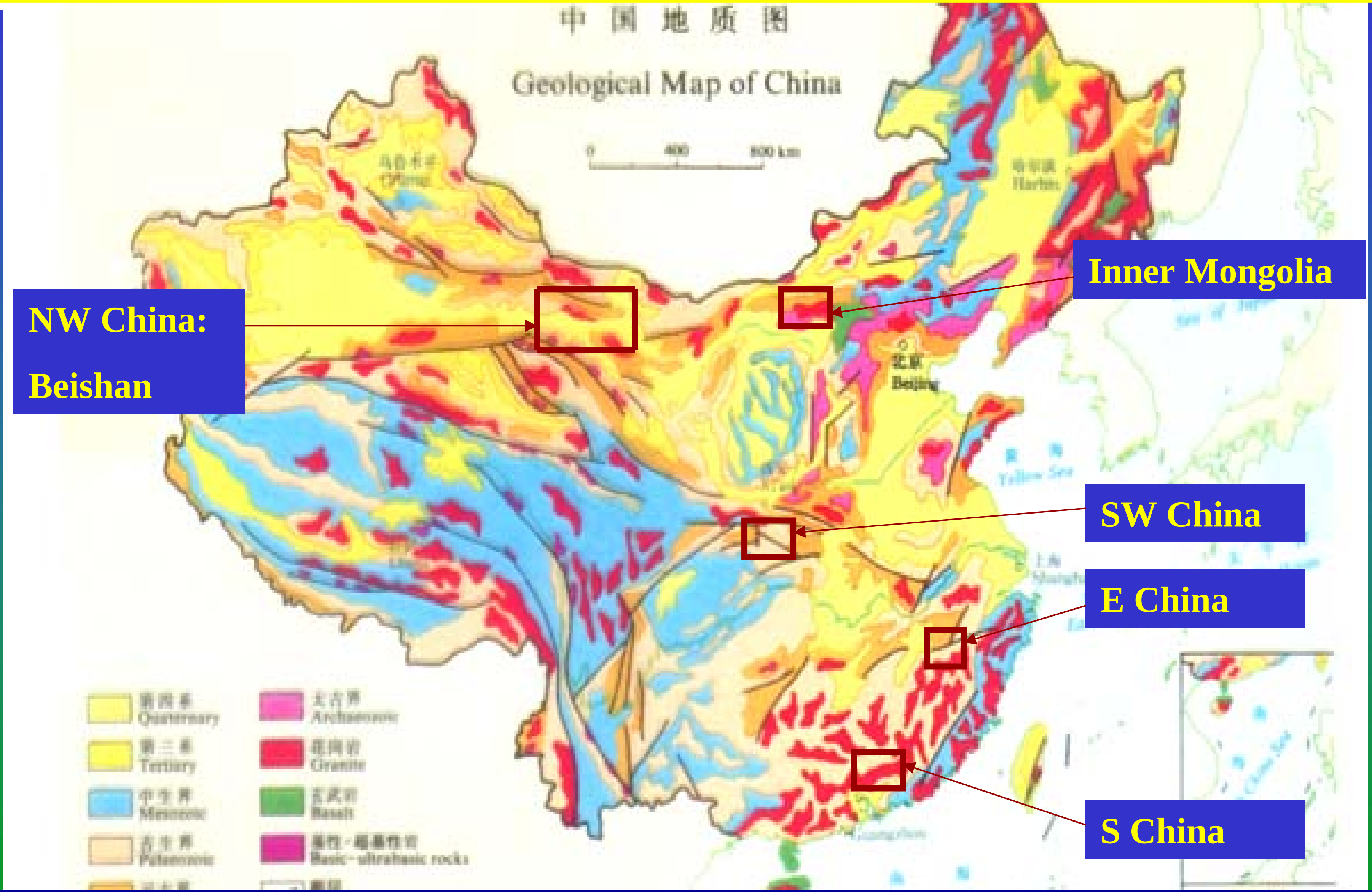
Beijing Research Institute of Uranium Geology, CNNC

2007.5.28-30

Contents

- Introduction
- Physical Property
- Mechanical Property
- Long-Term Behaviour at High Temperature
- Conclusion

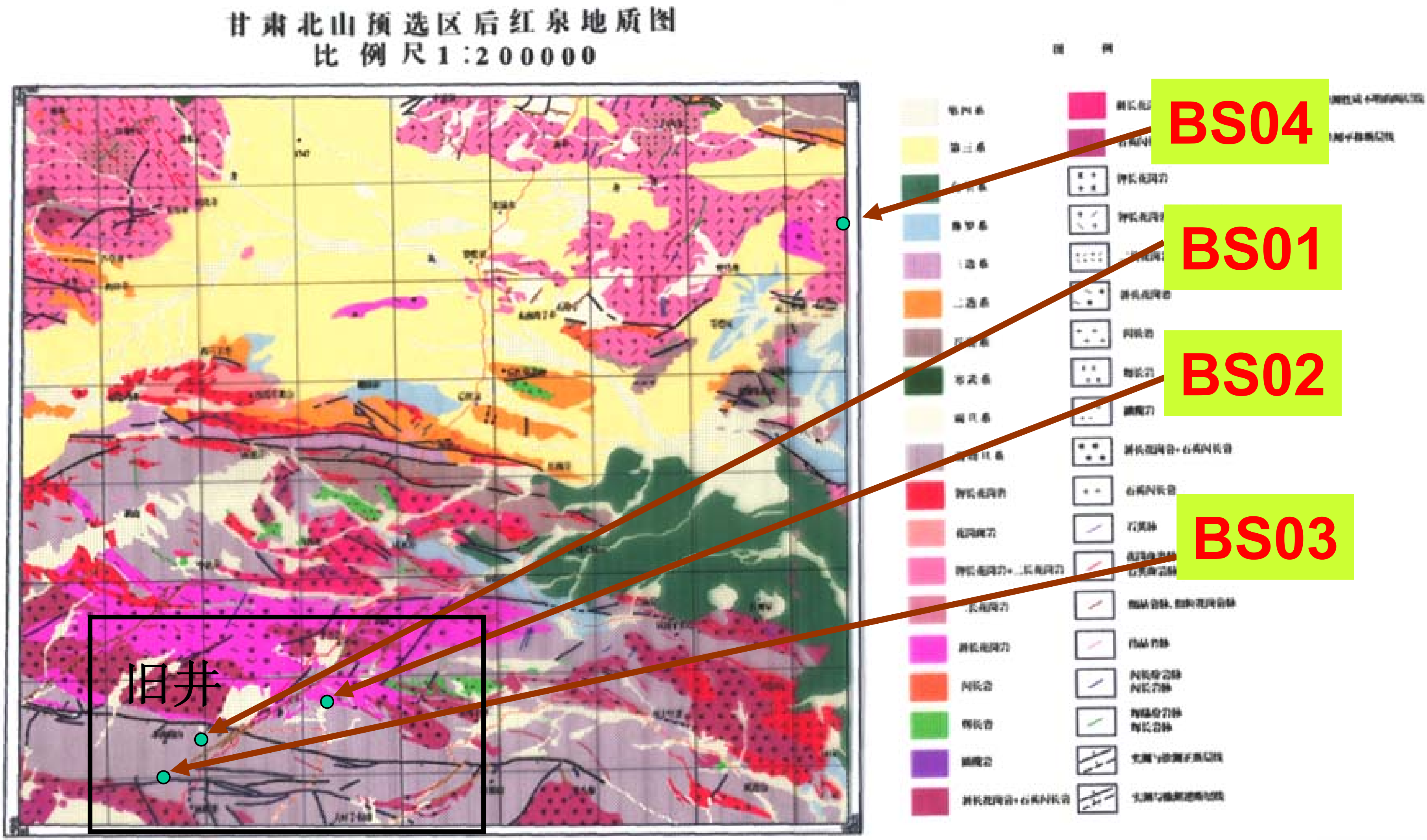
Major Activities: Site selection and site characterization



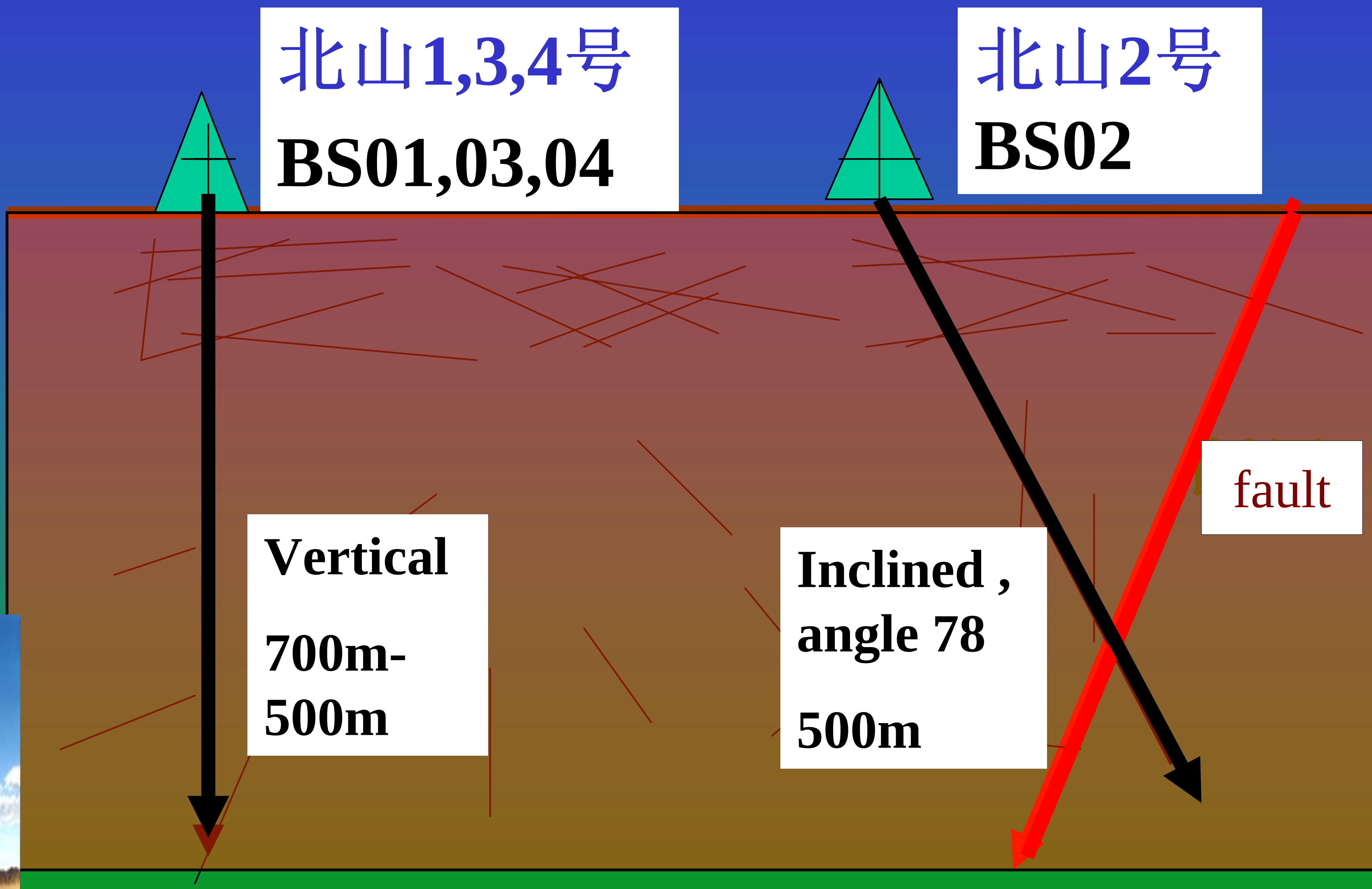
Preselected regions for HLW repository in China

BRIUG

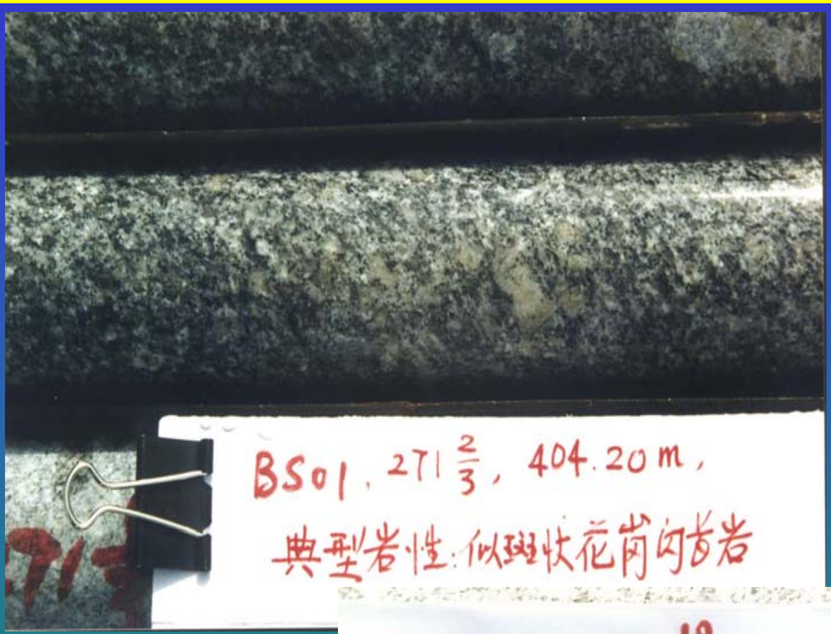
Borehole Location in Beishan Area



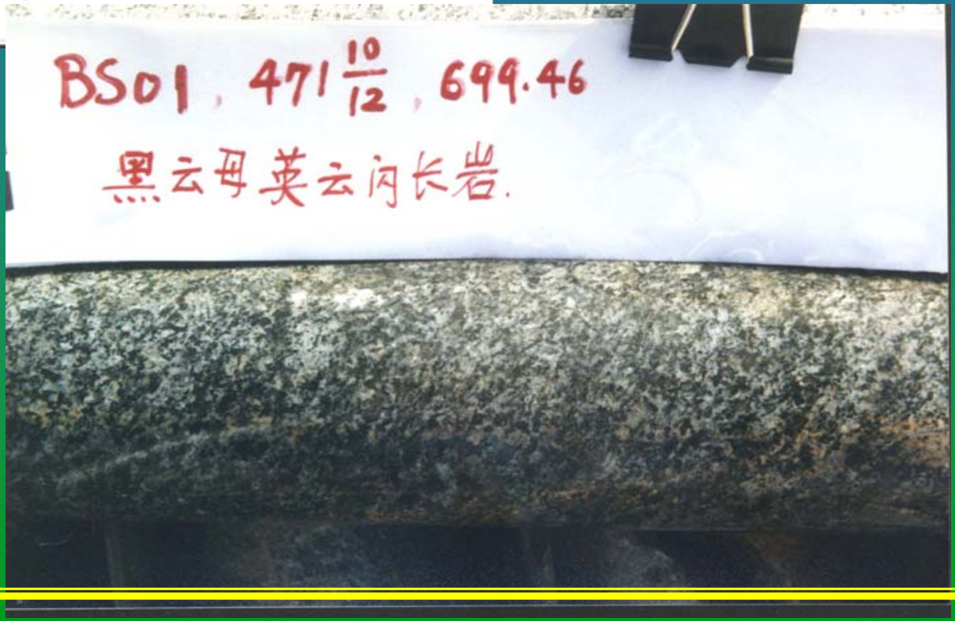
Bore holes BS01, 02, 03, 04



Main rock



porphyritic monzonitie granite

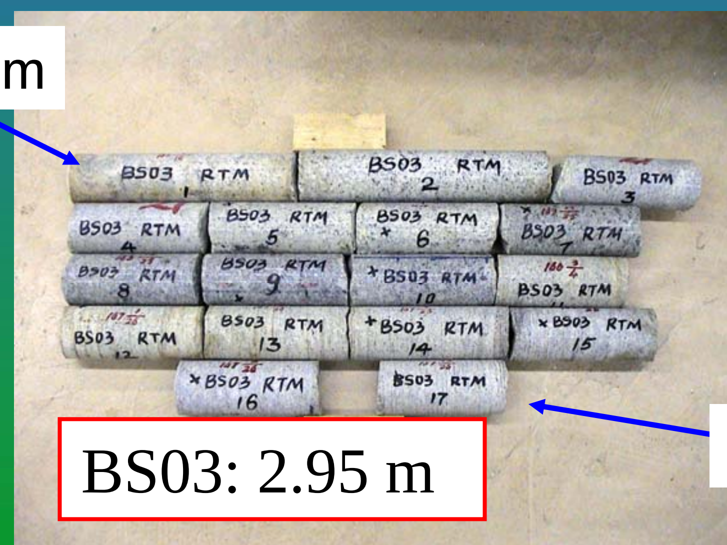


tonalite

core sample from BS01: the integrity

core sample with fracture

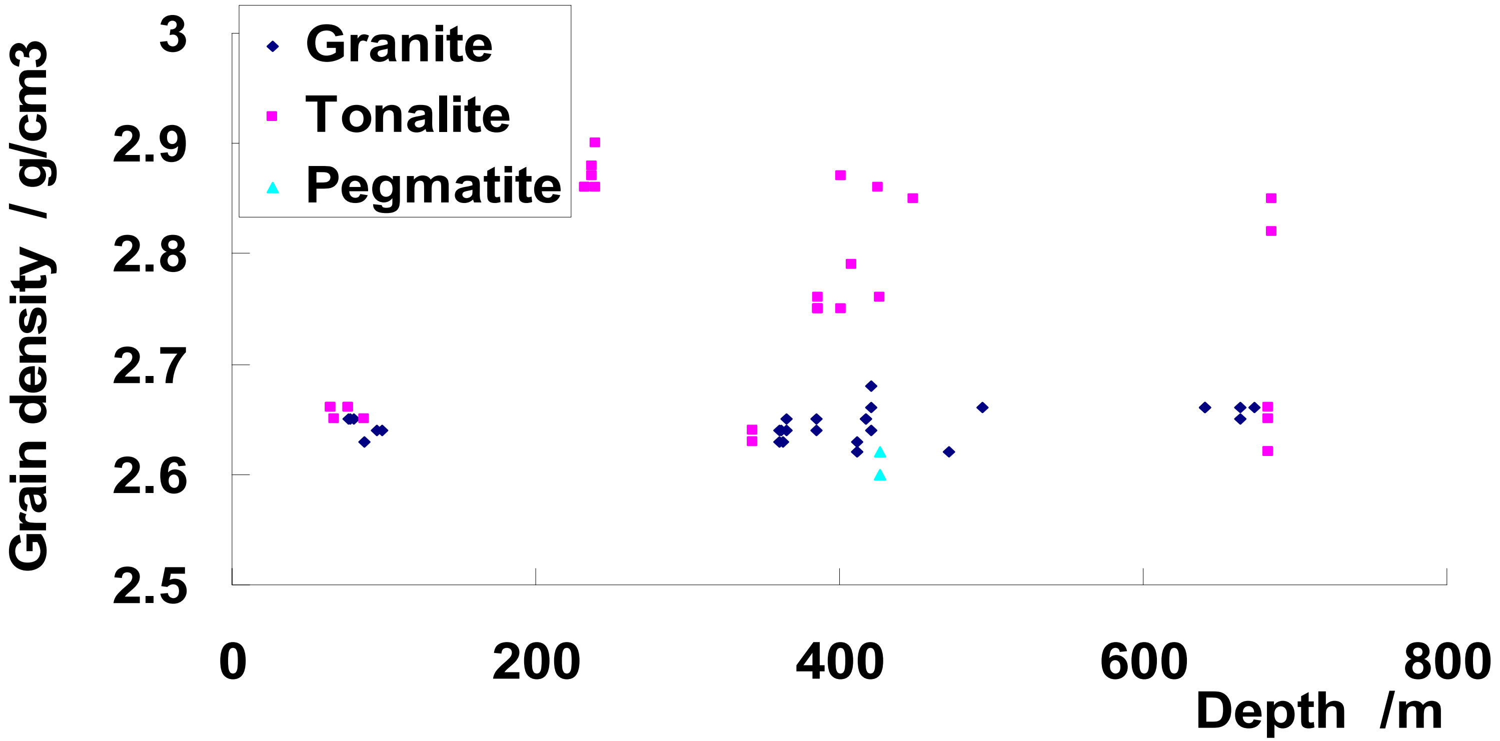
Intact Sample for Rock Mechanics



Physical property

- Density
- Water content
- Percent sorption
- Porosity factor
- Sound wave property

Density

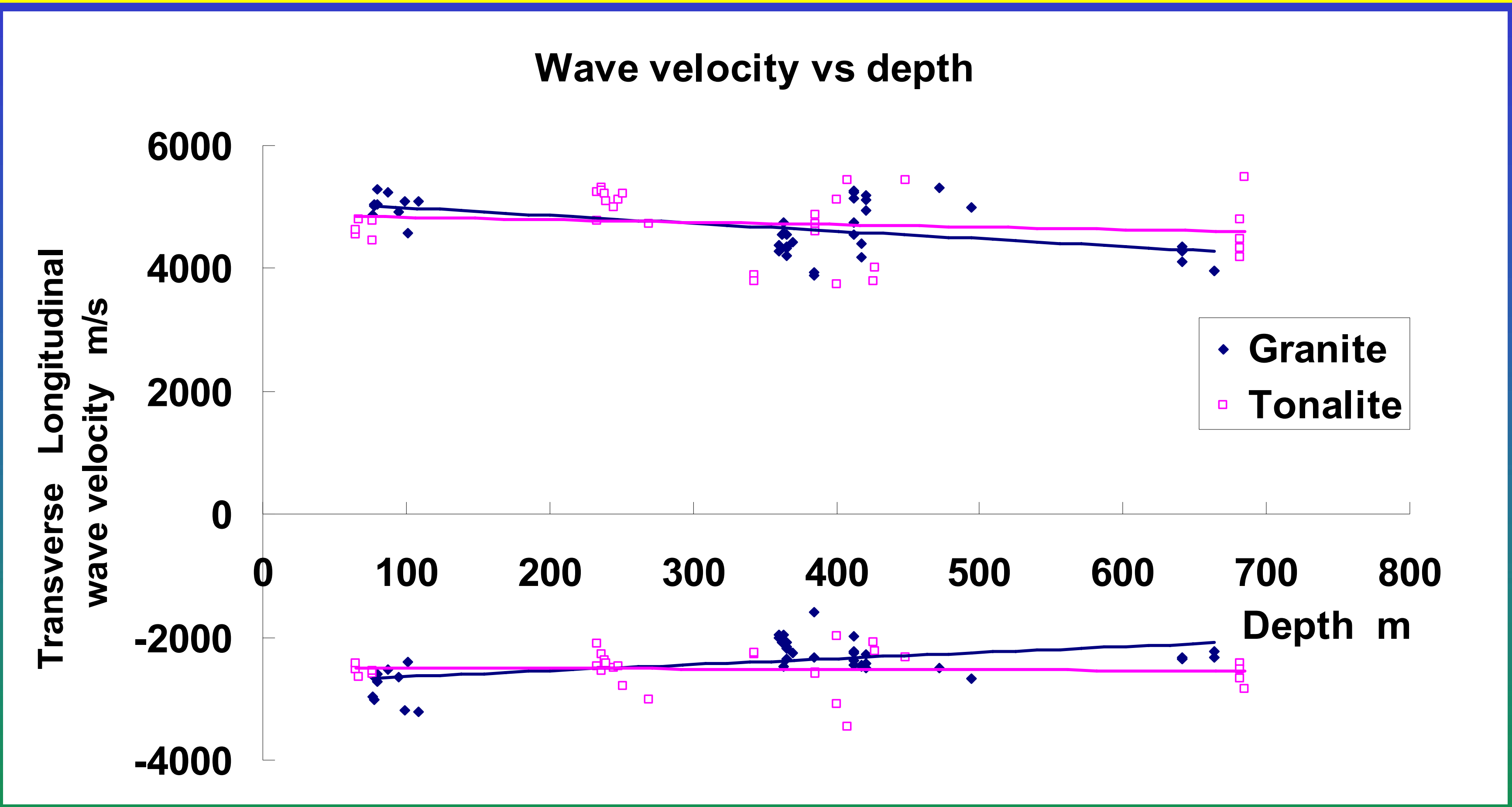


- The density of tonalite is bigger than granite’s.
- The density of granite is homogenized.

Percent sorption and porosity factor

- Percent sorption 0.10~0.23%
- Saturation percent sorption 0.15~0.28%
- open porosity factor 0.34~0.65%
- close porosity factor 0.04~0.11%
- total porosity factor 0.44~0.77%

Sound Wave Analyses



- The wave velocity of granite is less discrete than tonalite.
- Homogenization of granite is higher than tonalite.

Summary--Physical Property

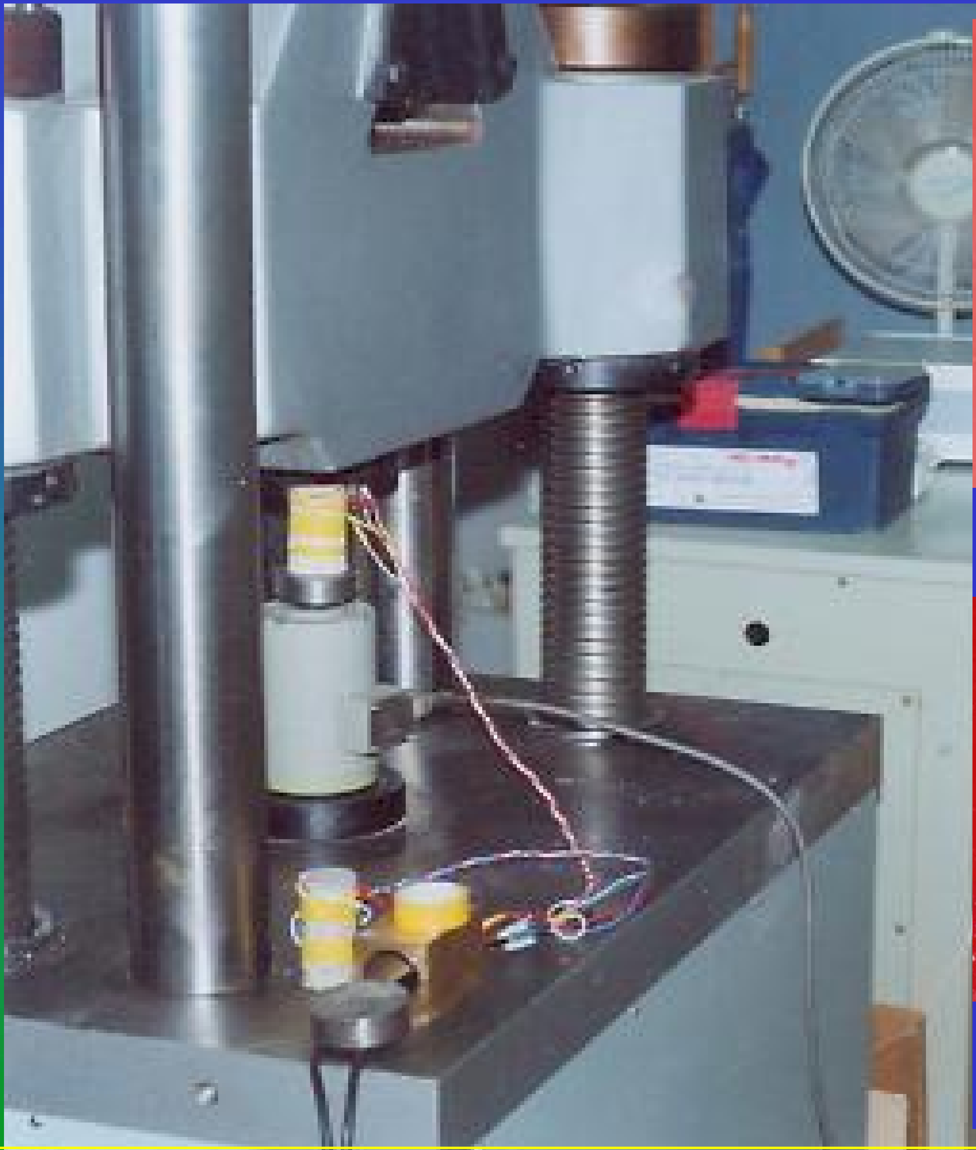
- High Density
- High Homogenization

  ---- porphyritic monzonitic granite
- Low water content
- Low porosity

Mechanical property

- Uniaxial compressive strength,
  Elastic modulus, poisson's ratio
- Brazilian tensile strength
- Shear strength
- Triaxial strength, internal friction angle, cohesion

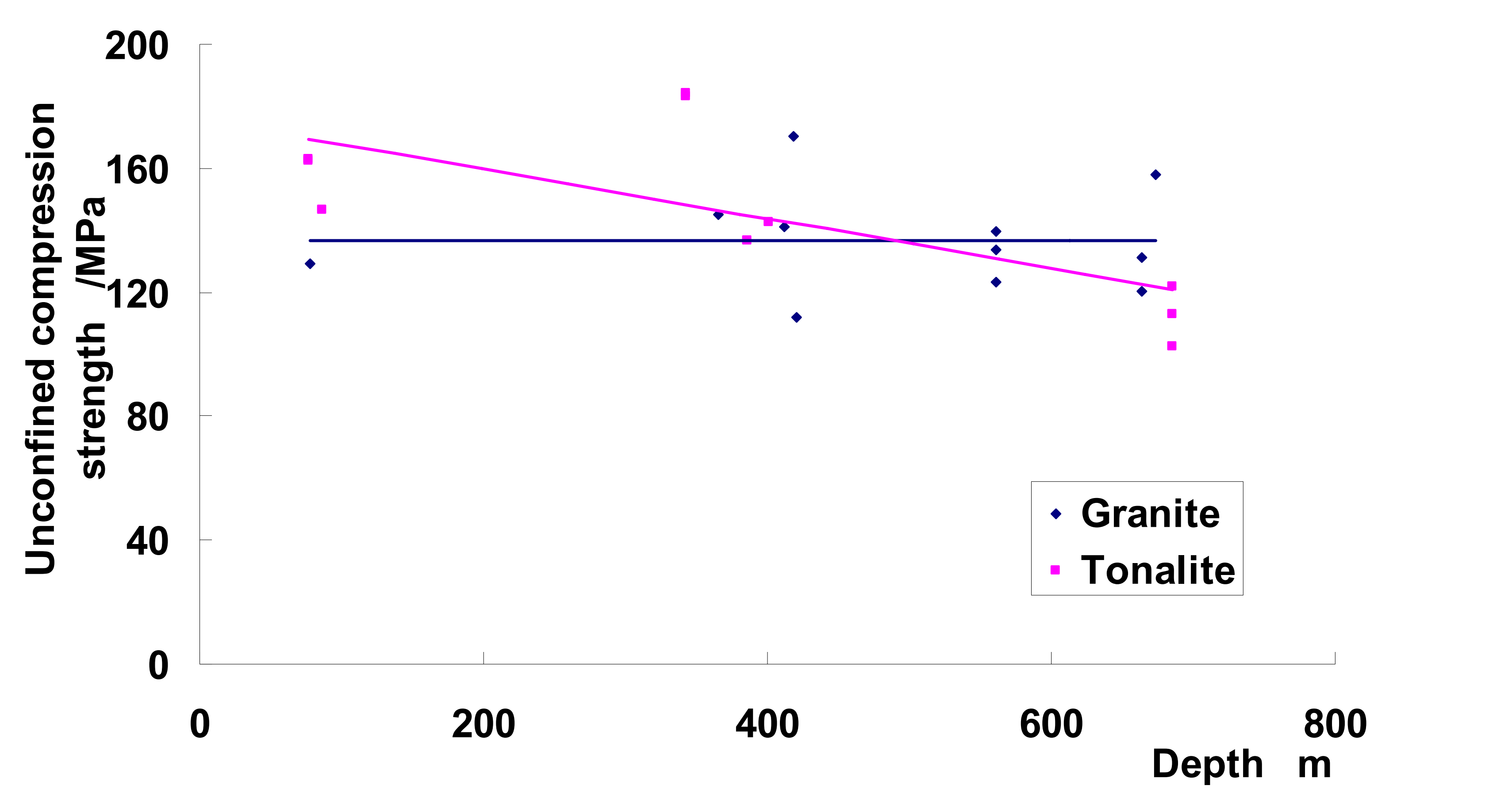
Test of Uniaxial compressive strength



Sample of before compression

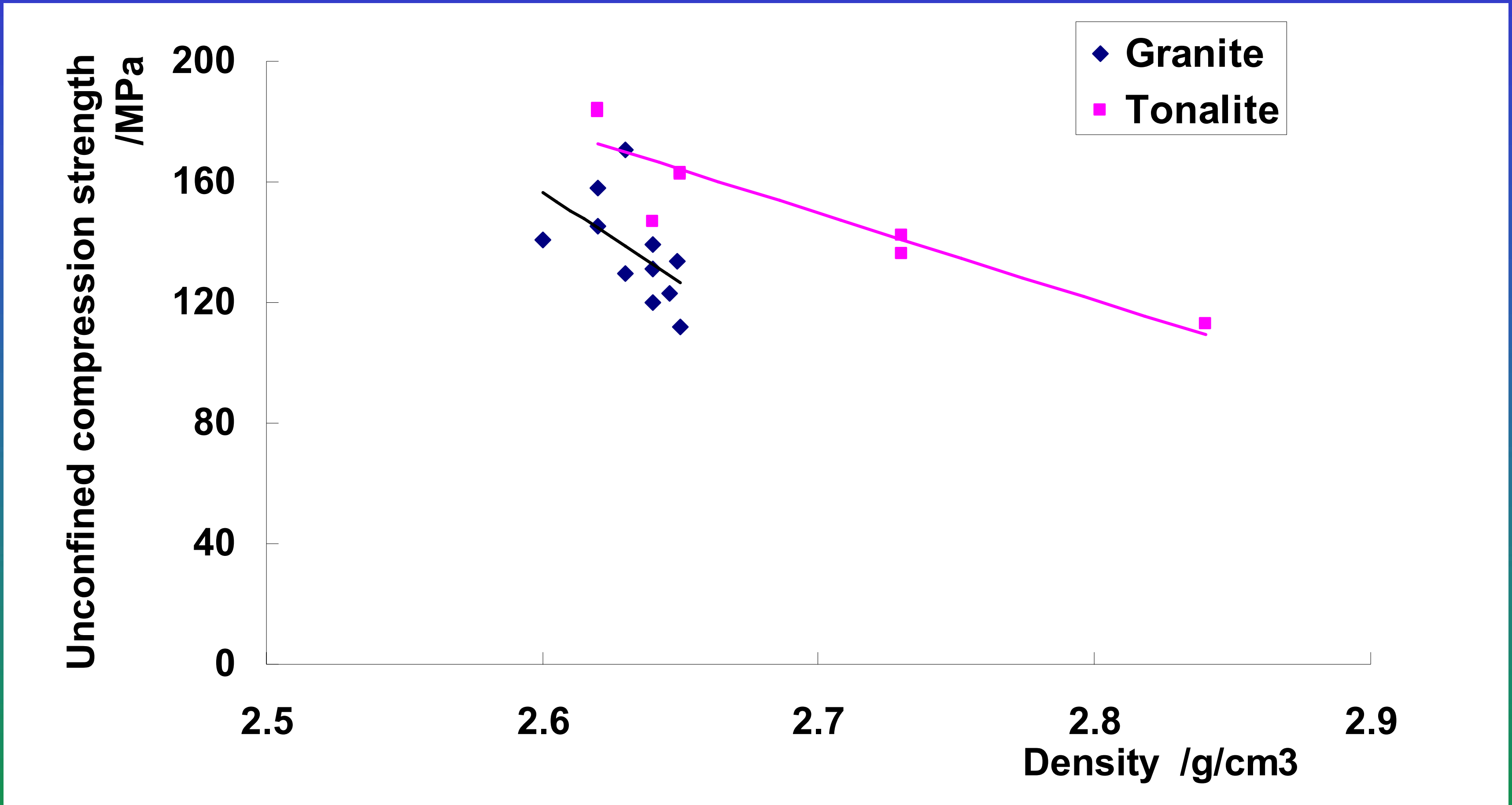
Sample of after compression

Uniaxial compressive strength Analyses



- tonalite 102~184MPa
- porphyritic monzonitie granite 111~171MPa

Uniaxial compressive strength Analyses



The unconfined compression strength of the rock decrease with the density of the rock increase.

Uniaxial compressive strength Analyses

	porphyritic monzonitie granite	Tonalite
• Uniaxial compressive strength	111~171	102~184Mpa
• Elastic modulus	57~67	41~67Gpa
• Poisson's ratio	0.23~0.31	0.15~0.31

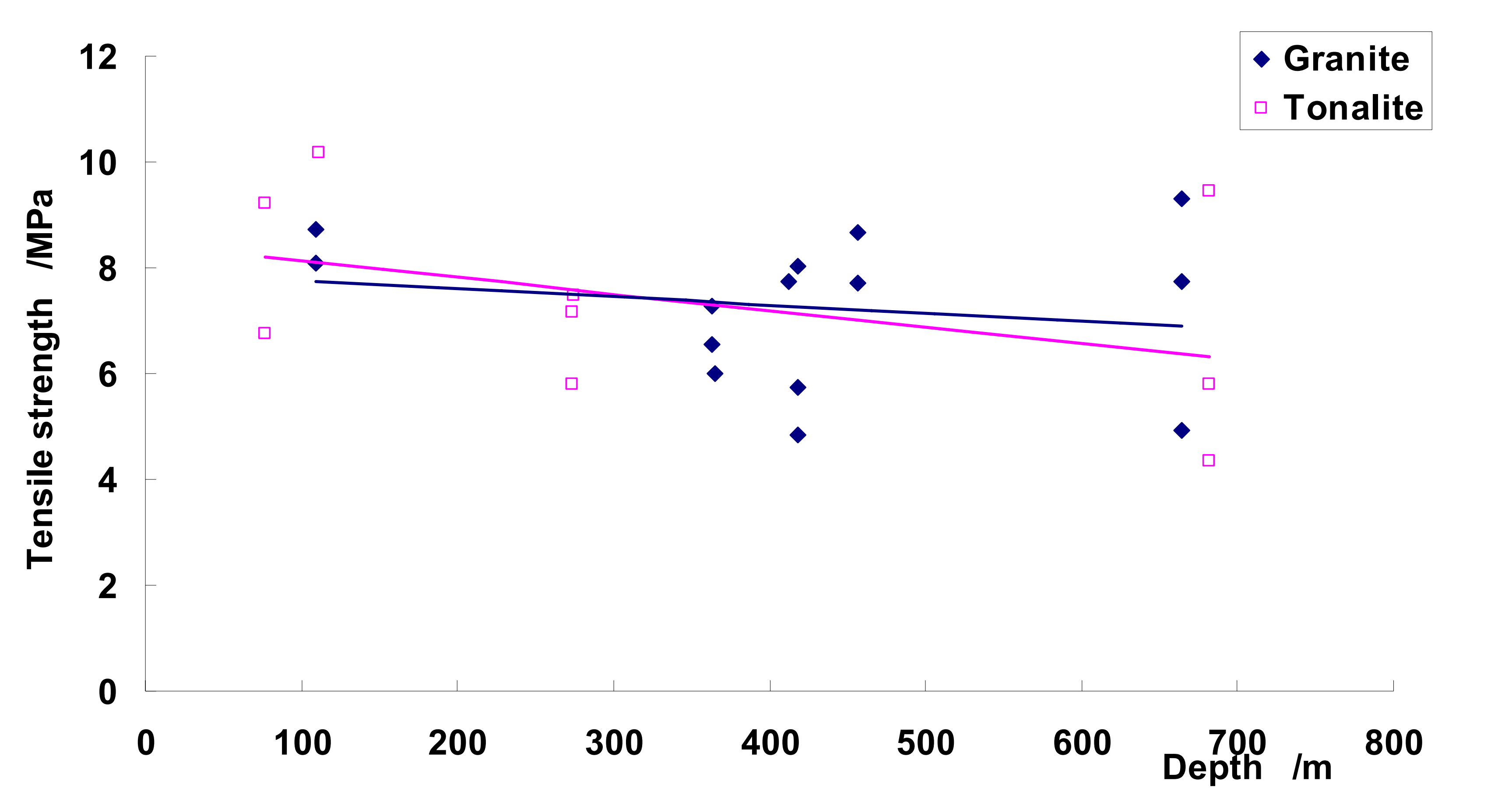
Brazilian Tensile Test

Brazilian Tensile Test

Sample of after tension

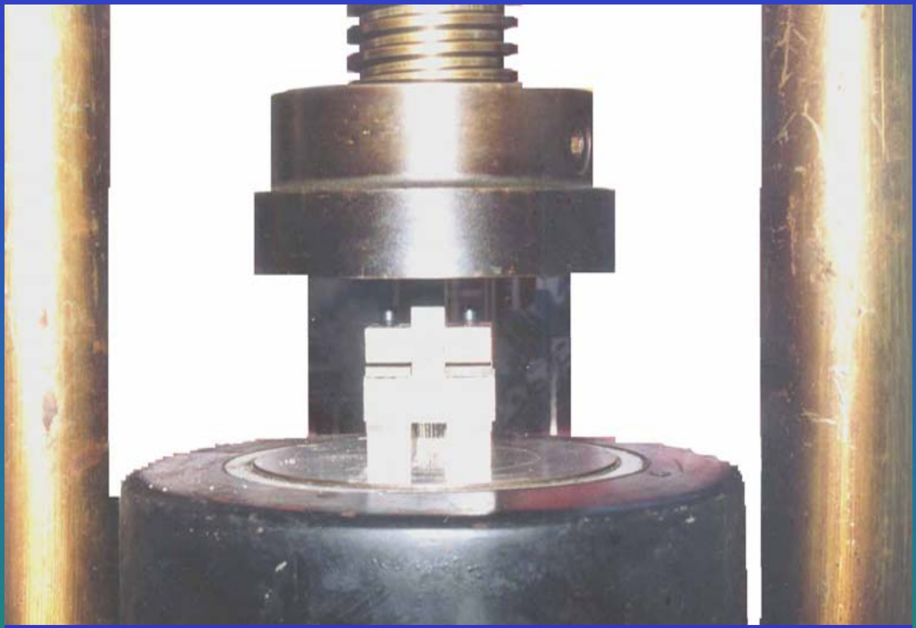
	Tensile strength
tonalite	4.36-10.17Mpa
porphyritic monzonitie granite	4.83-9.31Mpa

Brazilian Tensile



Tensile strength decreased appreciably with depth.

Shear Strength Test

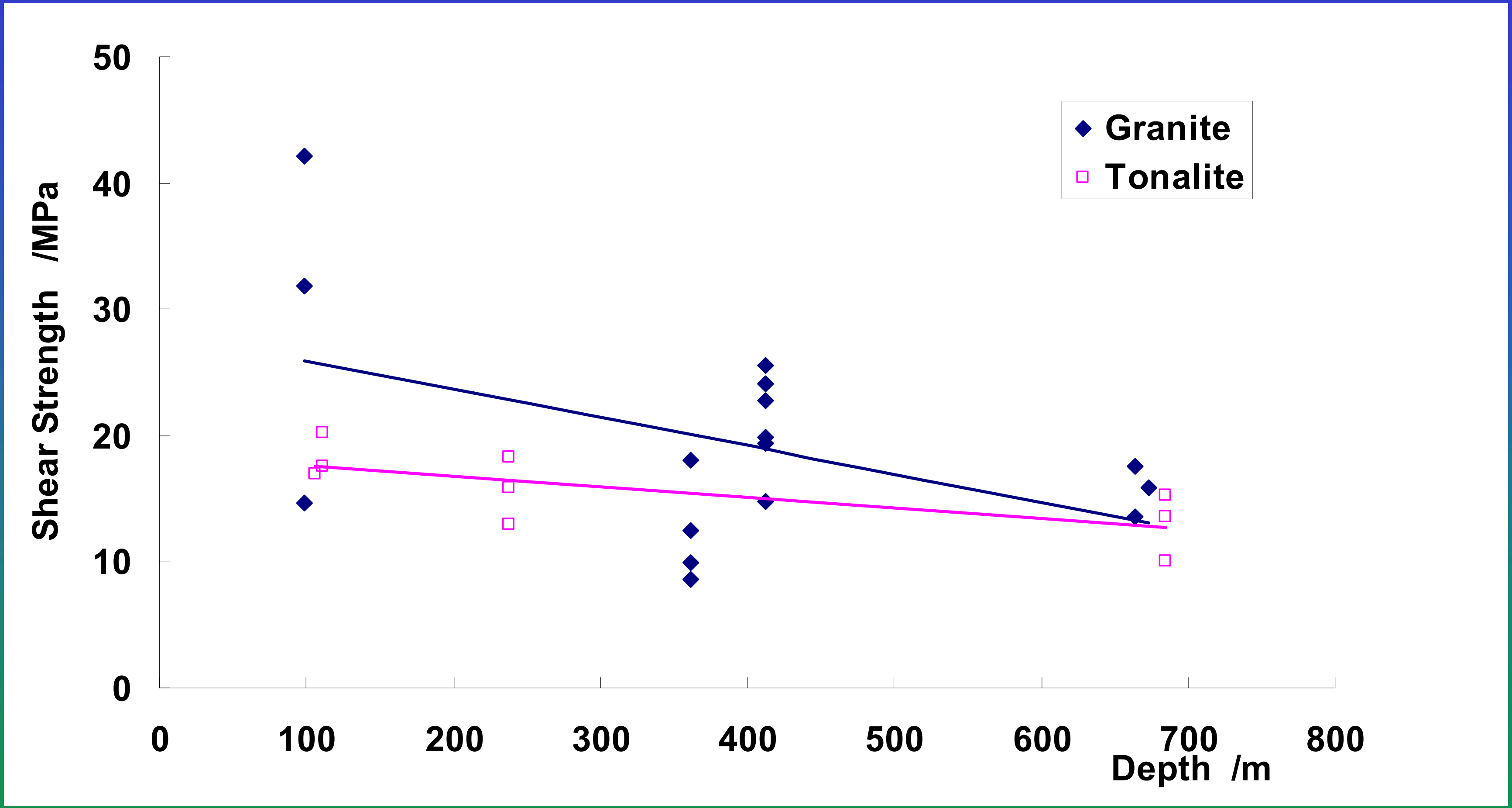


Shear Strength Test

Sample of after shear

	Shear strength
tonalite	10.1~20.2Mpa
porphyritic monzonitie granite	13.6~22.7Mpa

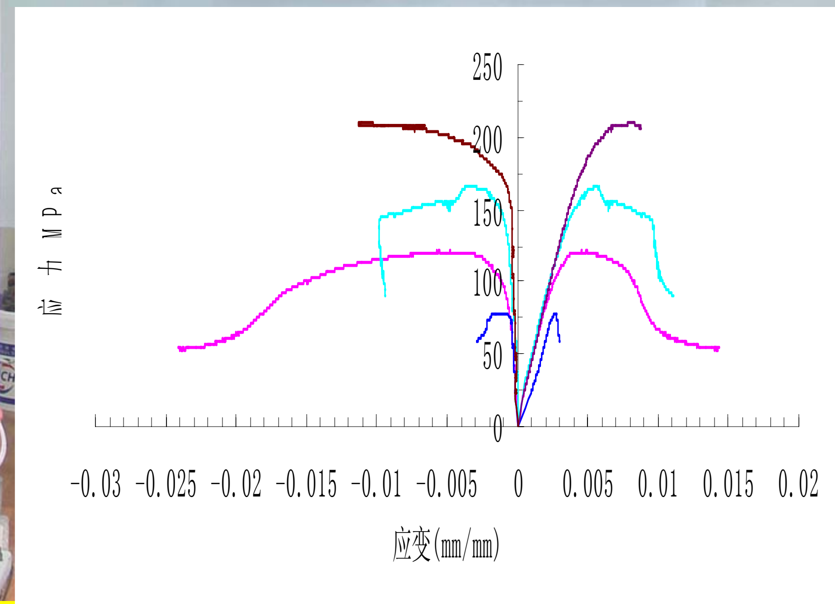
Shear Strength



Shear strength decreased appreciably with depth.

Experiment of Triaxial Compression

Triaxial strength



Triaxial Compress results analysis

	Internal friction angle	Cohesion
tonalite	45.8~56.2°	29.4~49.9Mpa
porphyritic monzonitie granite	47.7~52.3°	31.1~54.9Mpa

Summary --Mechanical property

- High Uniaxial compressive strength
- High shear strength
- High tensile strength
- Low strain and high brittle

Long-Term Behaviour of Granite under Constant Loading and High Temperature Condition

花岗岩在恒定荷载与高温条件下的长期性状

Beijing Research Institute of Uranium Geology, CNNC
Department of Civil Engineering, The University of Hong Kong

Test plan

Confining pressure (MPa)	Stress ratio	Temperature （℃）		
		RT(23)	50	90
0	1.10	√	√	√
	1.15	√	√	√
	1.20	√	√	√
	1.25	√	√	√
10	1.20	√	√	√
	1.25	√	√	√
	1.30	√	√	√
	1.35	√	√	√
30	1.25	√	√	√
	1.30	√	√	√
	1.40	√	√	√
	1.55	√	√	√

BRIUG

Test facilities

MISTRAS 2001
(Acoustic emission rate)

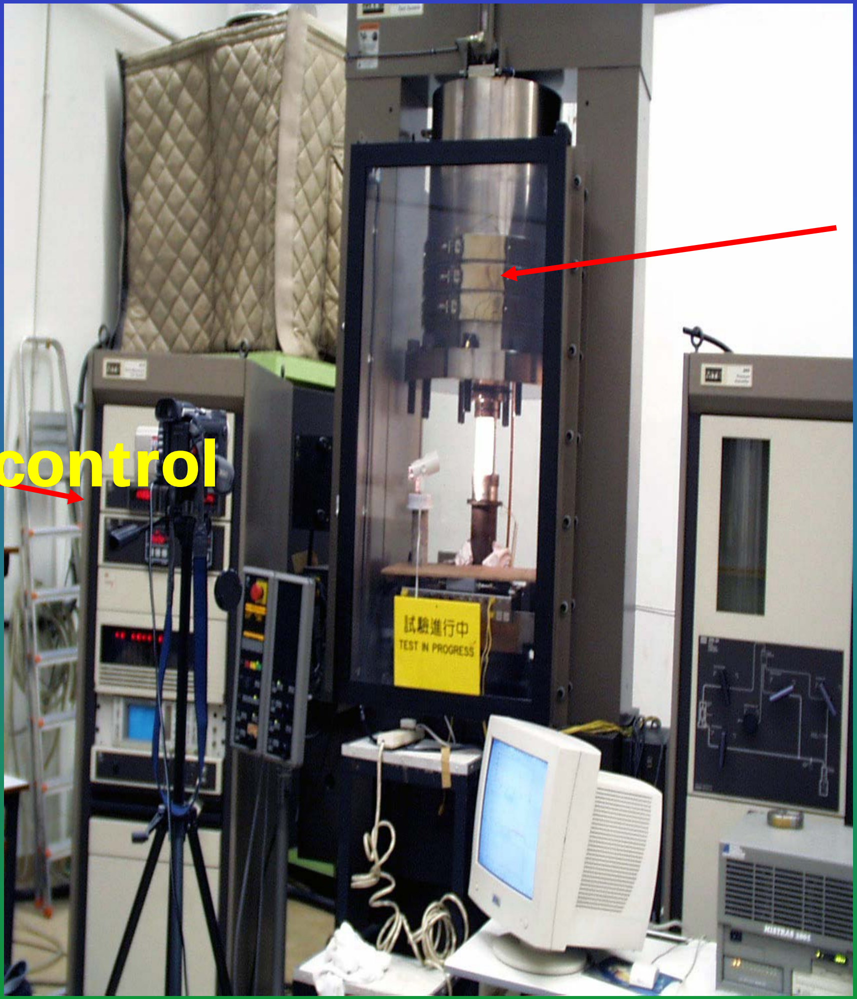
前置

数据
采集
计算
机

声发

High temperature tests

Temperature control



Heat band

BRIUG

Sample

Φ50x125mm (ASTM D4543)

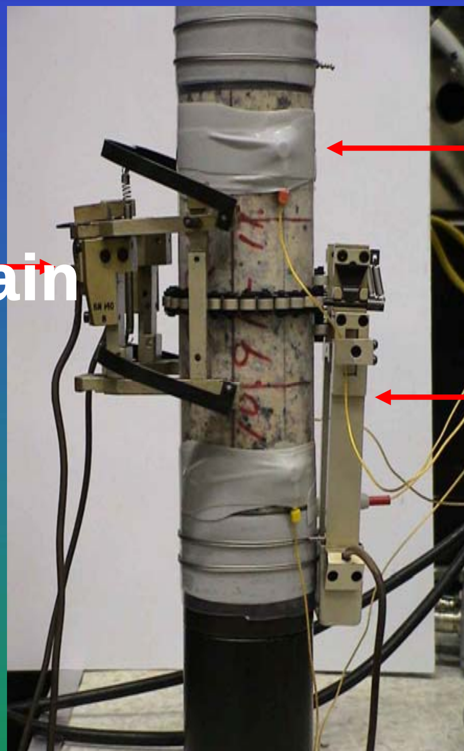
Before test:

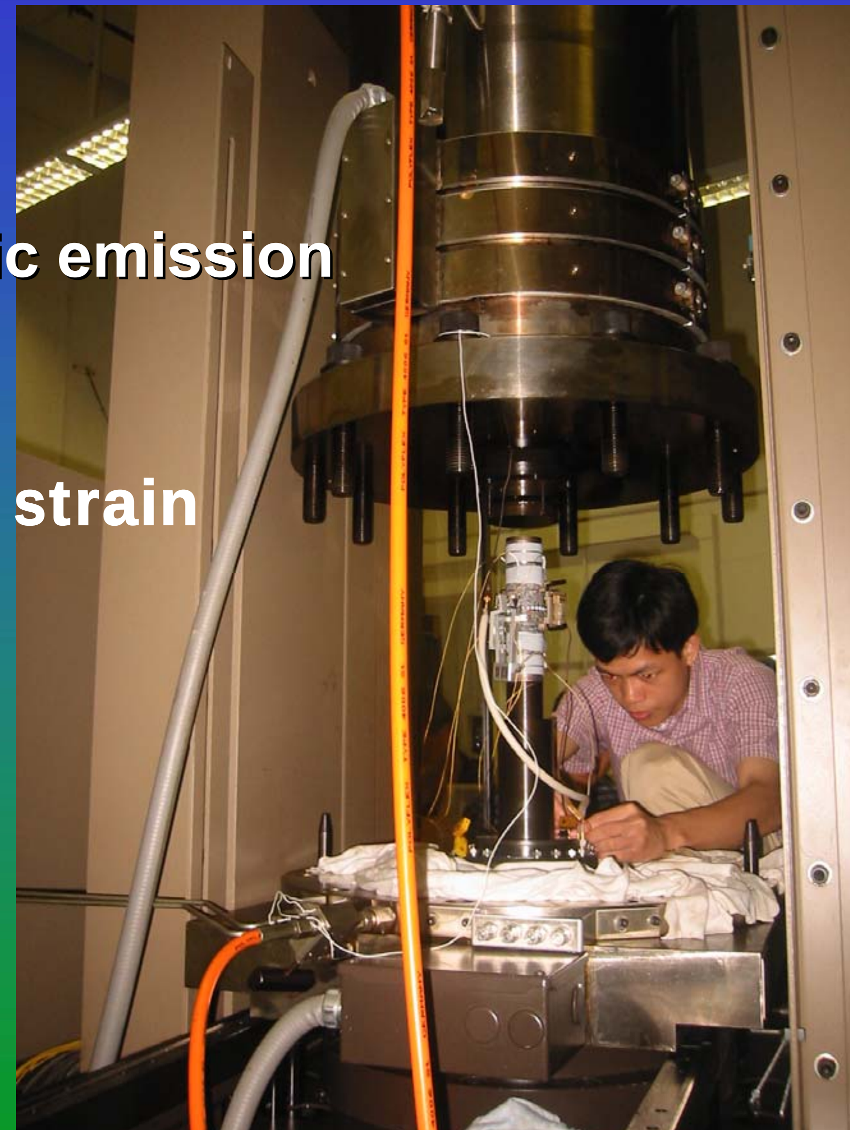
Put in water more than 30days

Measure P wave velocity

BRIUG

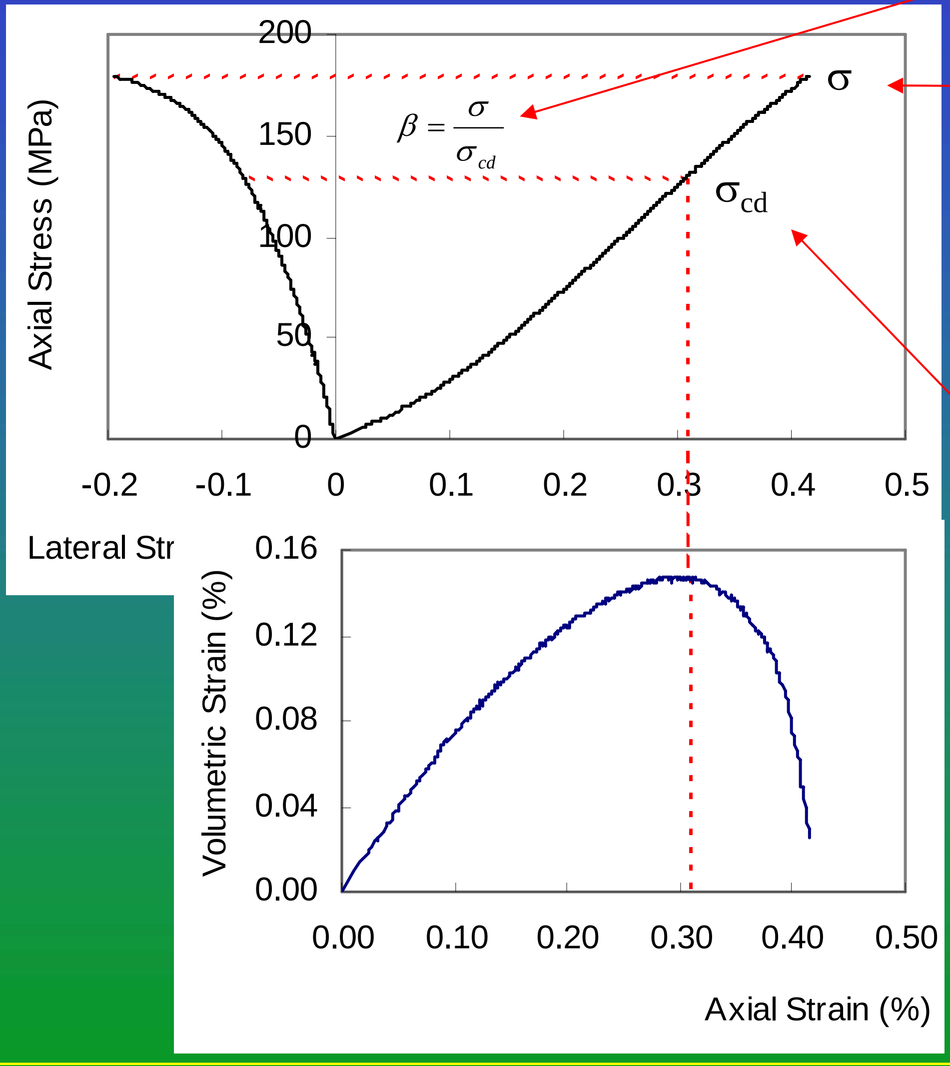
Assemble smaple





Test procedure

Stress ratio

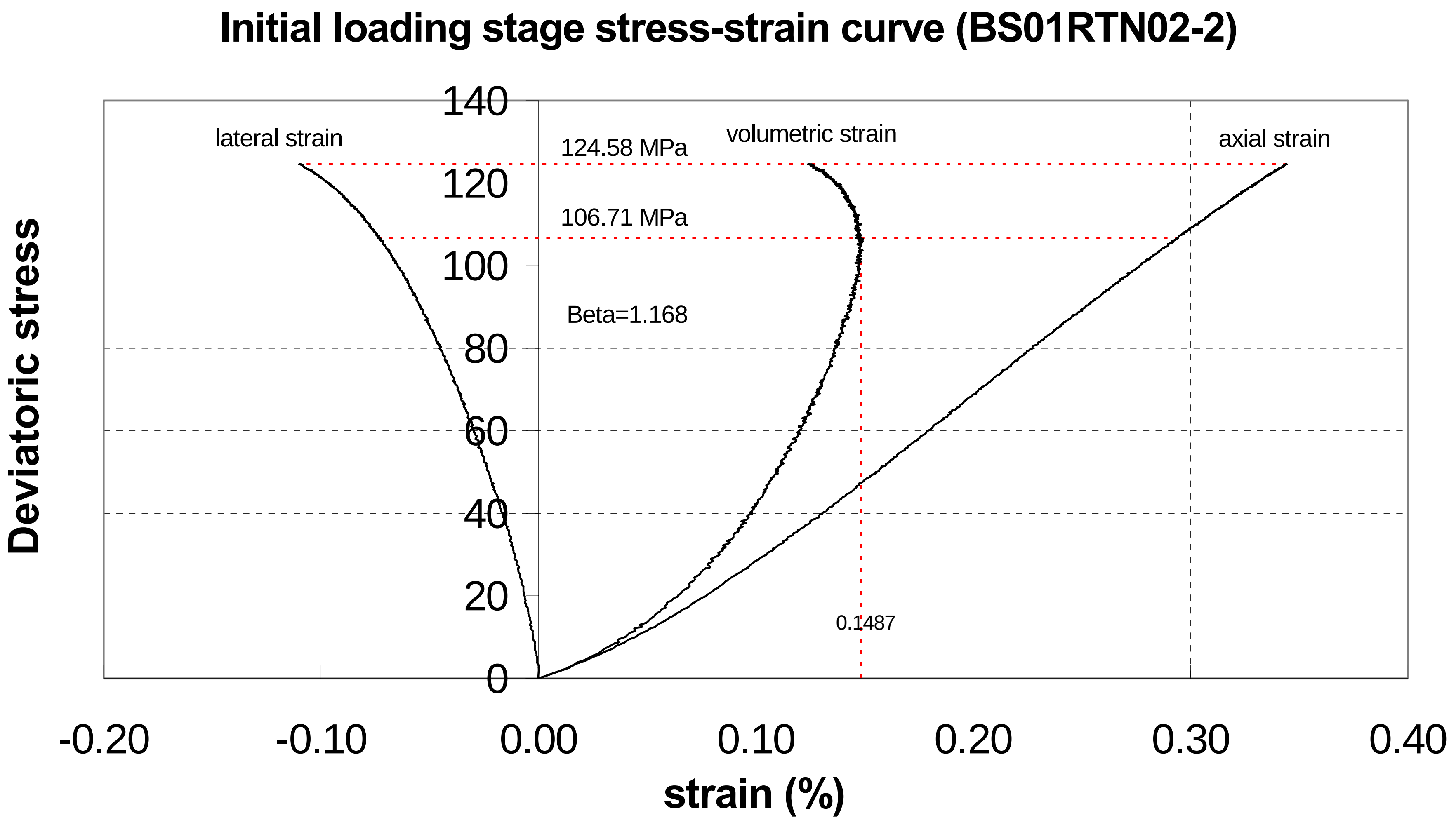


2. Hold constant loading

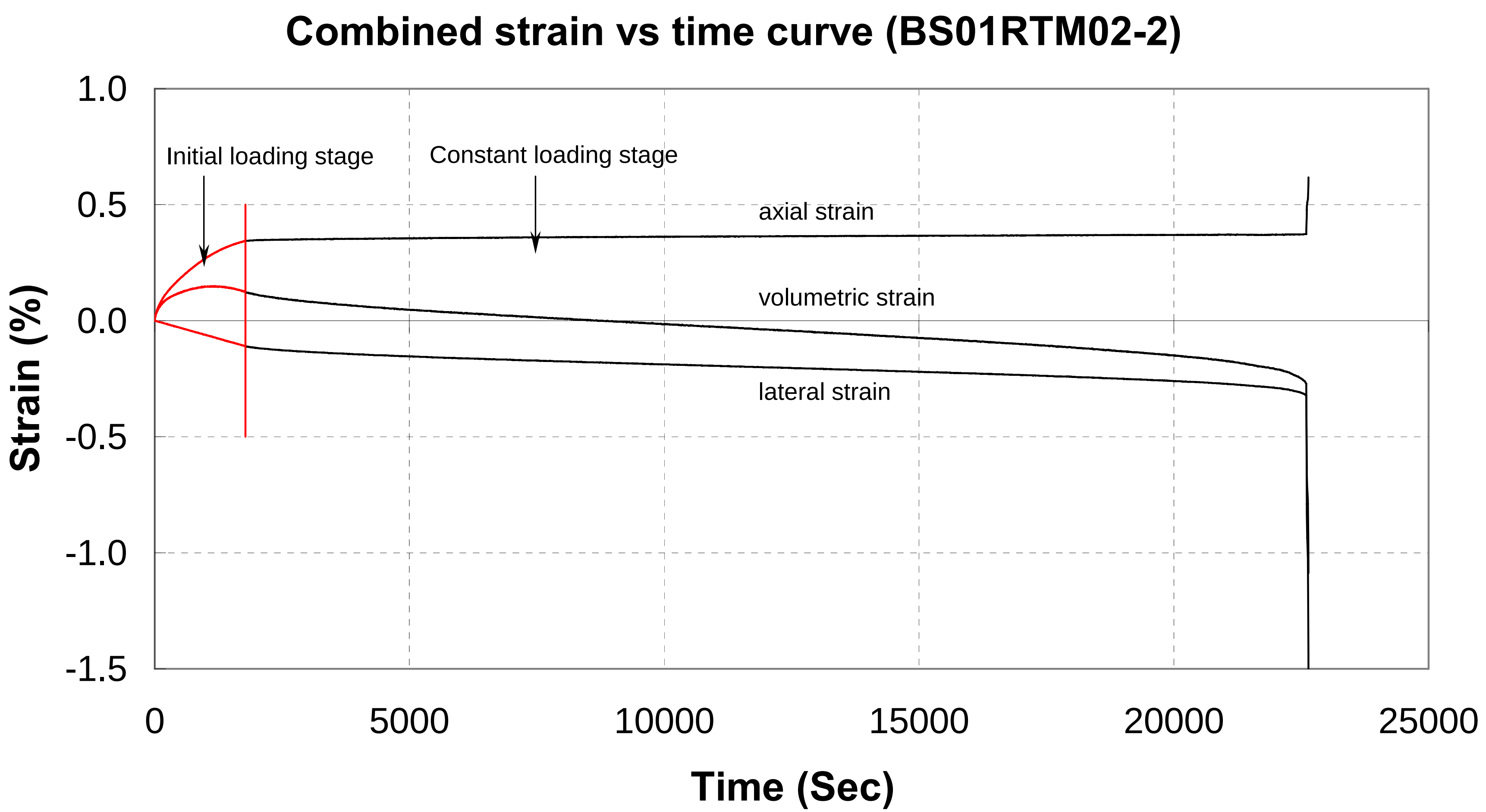
1. determine σ_{cd}

- Vol. strain reversal
- Unstable crack growth
- Related to long-term strength

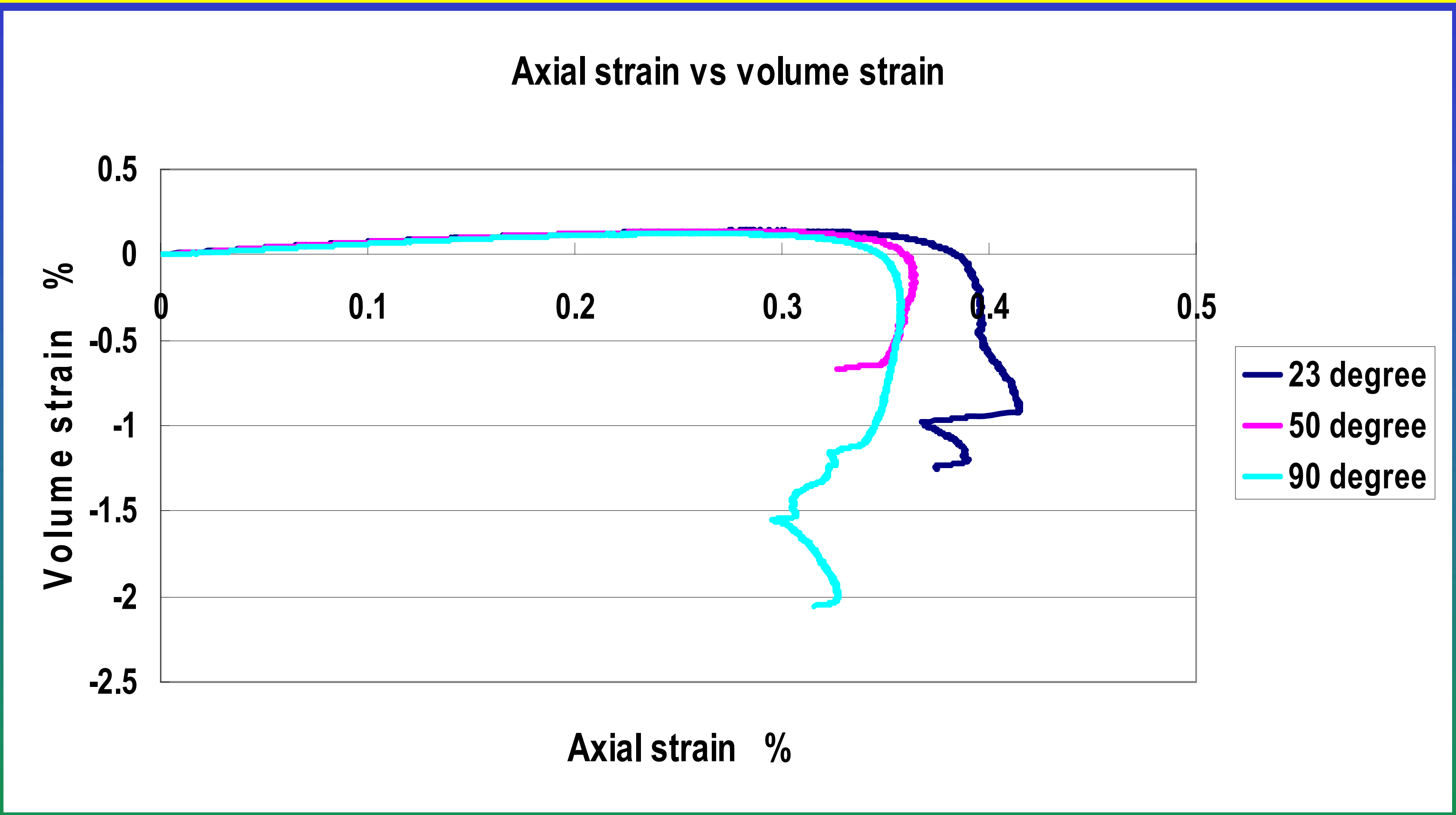
Stress-strain curve



Strain-time curves



Vol. strain vs Axial strain



Axial strain and volume strain decrease as temperature increase.

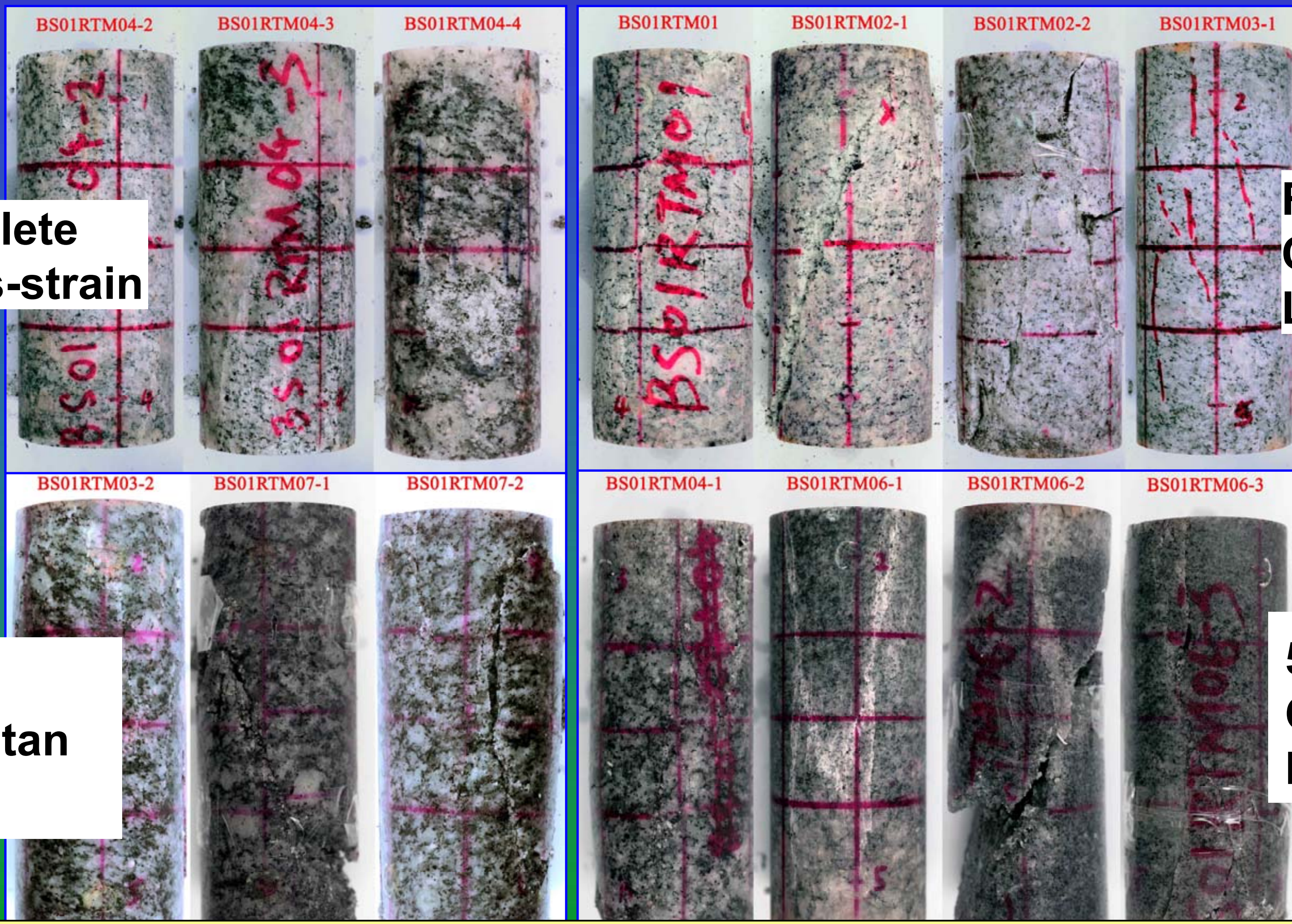
Sample failed

Φ50Ⅹ125 mm，90℃， 恒载223KN,

破坏时响声很大,岩样分为两大块

2004.07.2—07.20

Samples after tests



Complete stress-strain

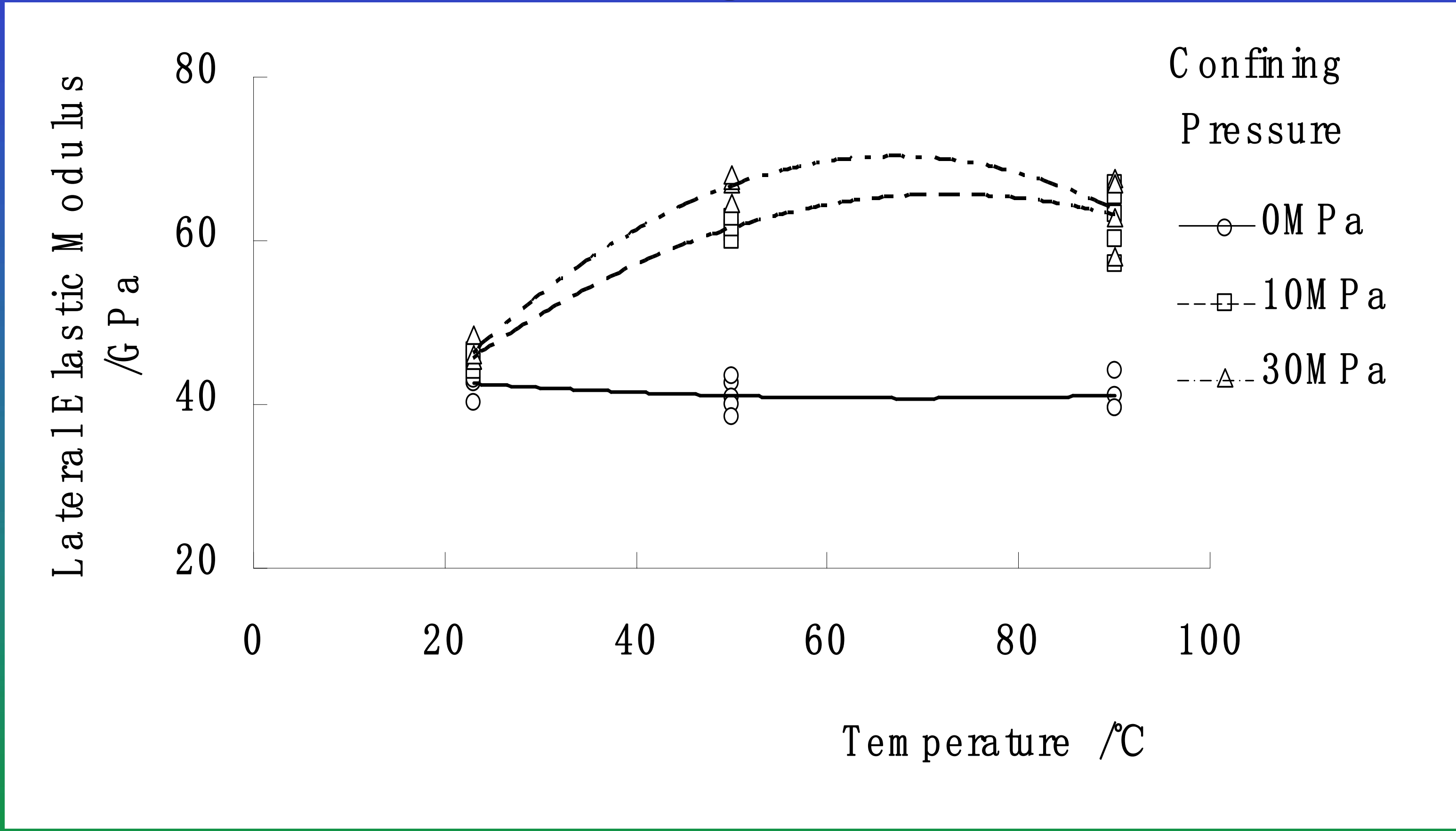
RT Constant Load

90 ℃ Constan Load

50℃ Constant Load

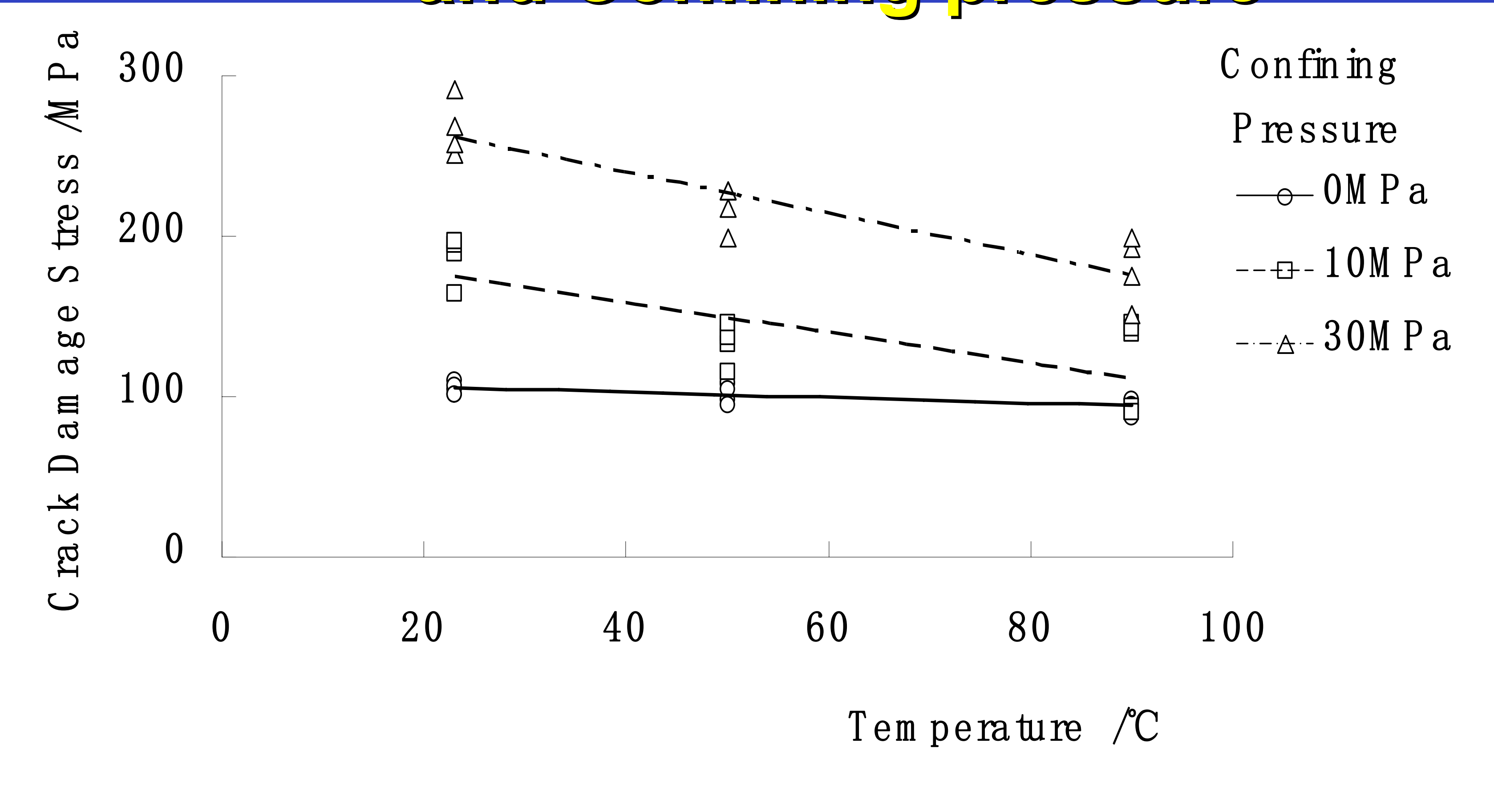
The tests are done under uniaxial and different temperatures.

Elastic modulus with Temperature and Confining pressure



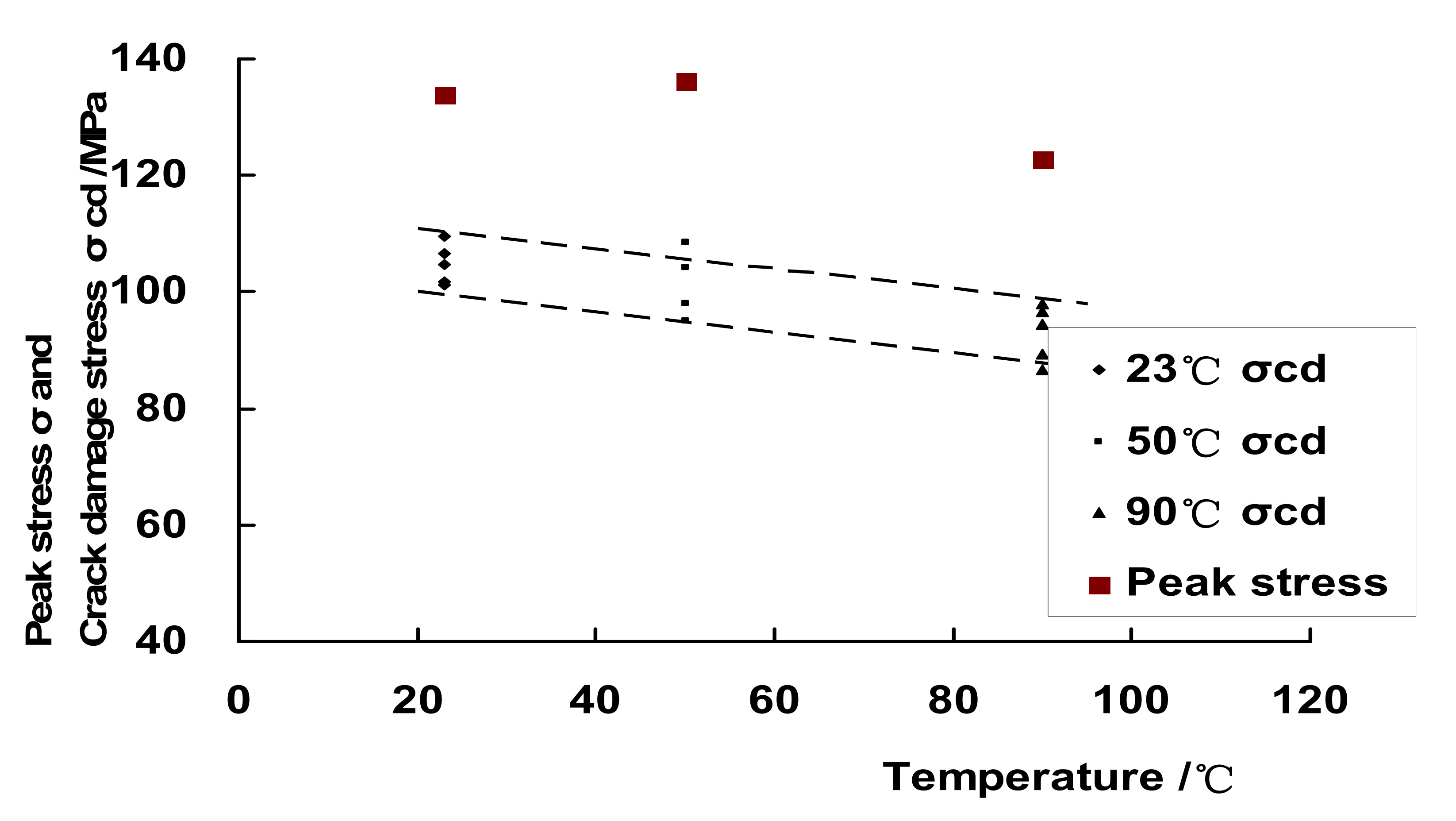
Elastic modulus increase when confining pressure increase, increase then decrease when temperature increase.

Crack damage stress with Temperature and Confining pressure



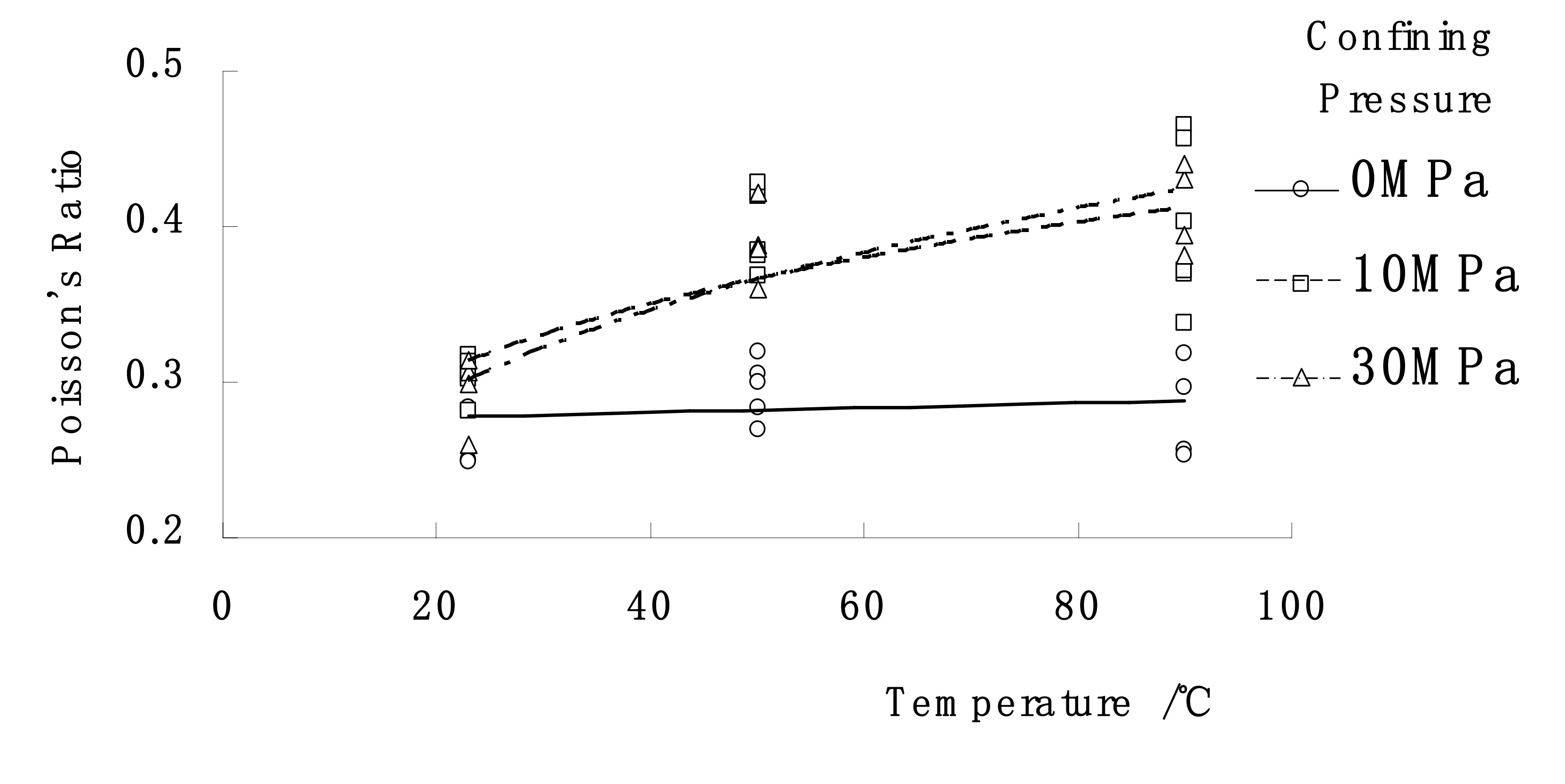
Crack damage stress increase when confining pressure increase and decrease when temperature increase

Peak and Crack damage stress with T



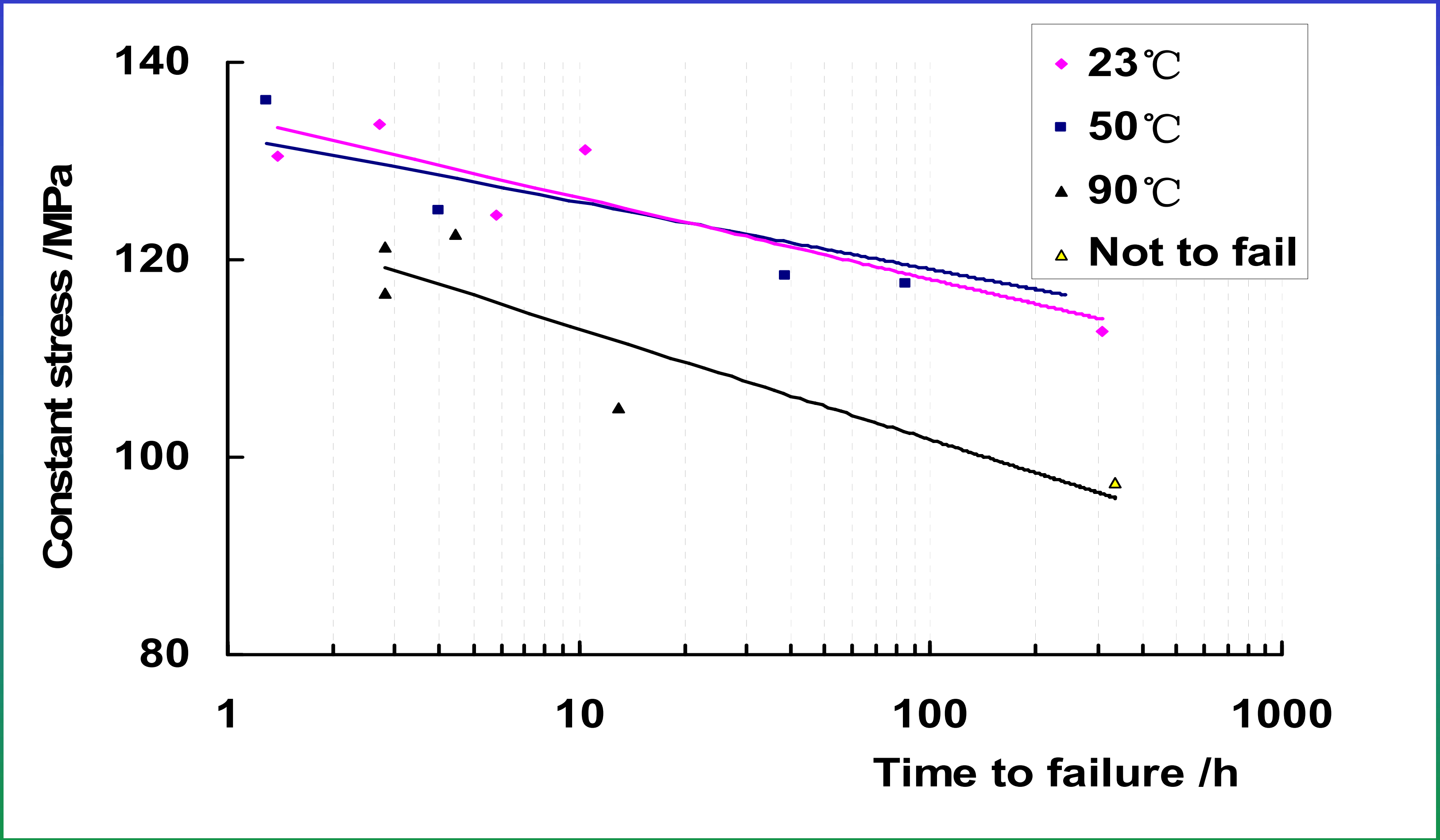
Peak stress and Crack damage stress decrease when temperature increase

Poisson's ratio with Temperature and Confining pressure



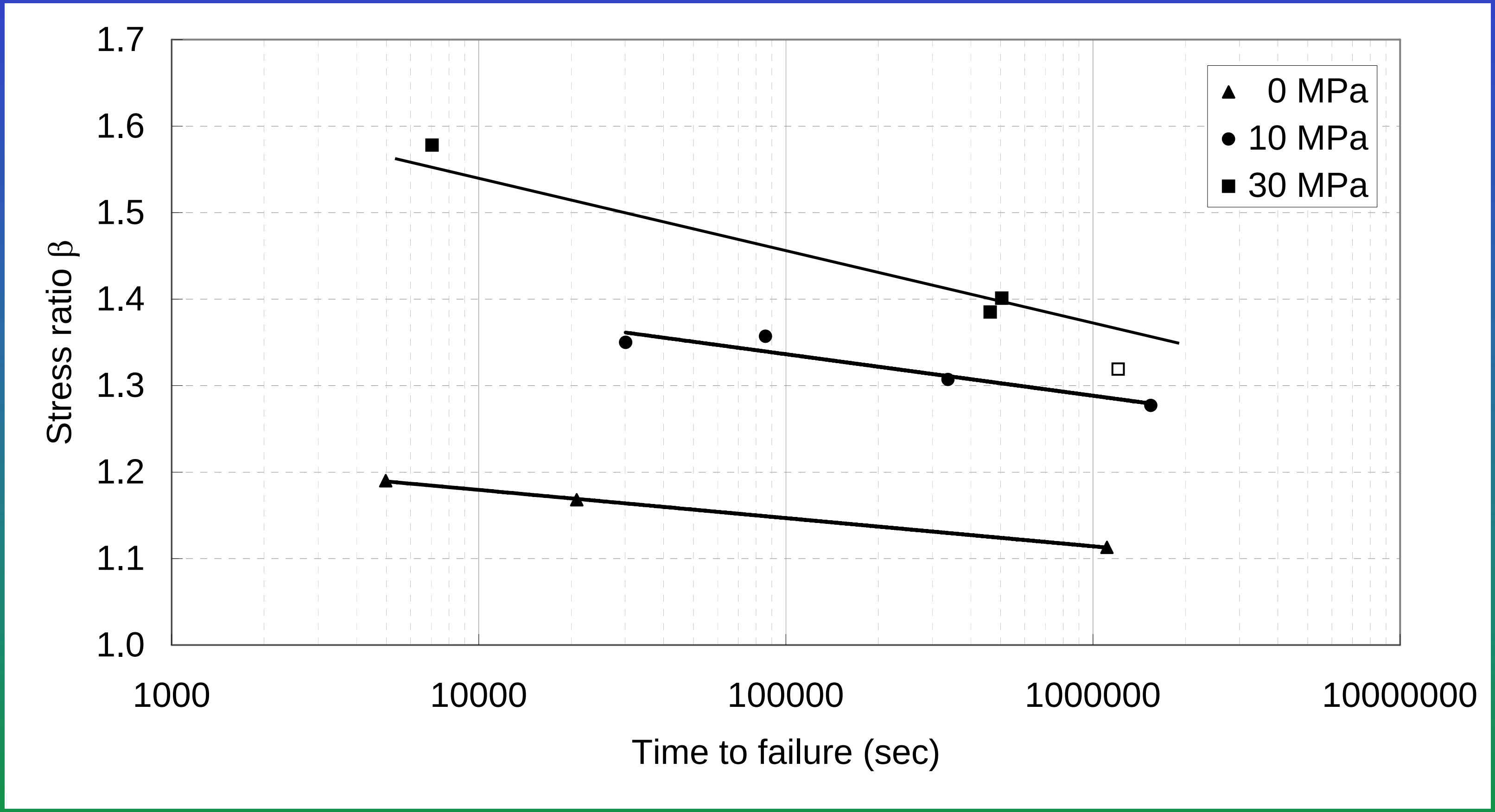
Poisson's ratio increase when confining pressure and temperature increase

Constant stress with time



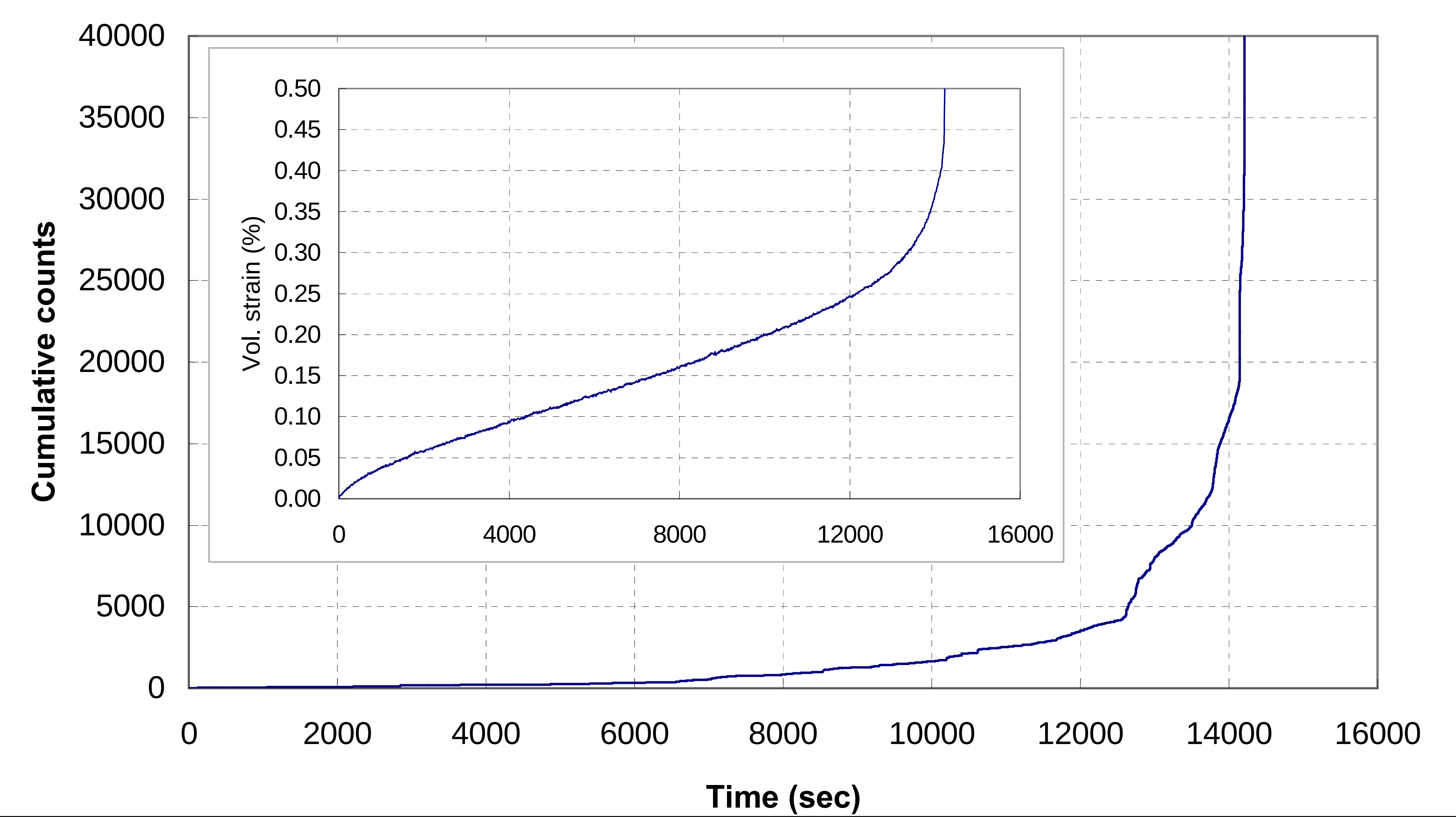
The time to failure increases rapidly when the constant load decreases. Time to failure decrease when temperature increase.

Constant stress with confining pressure



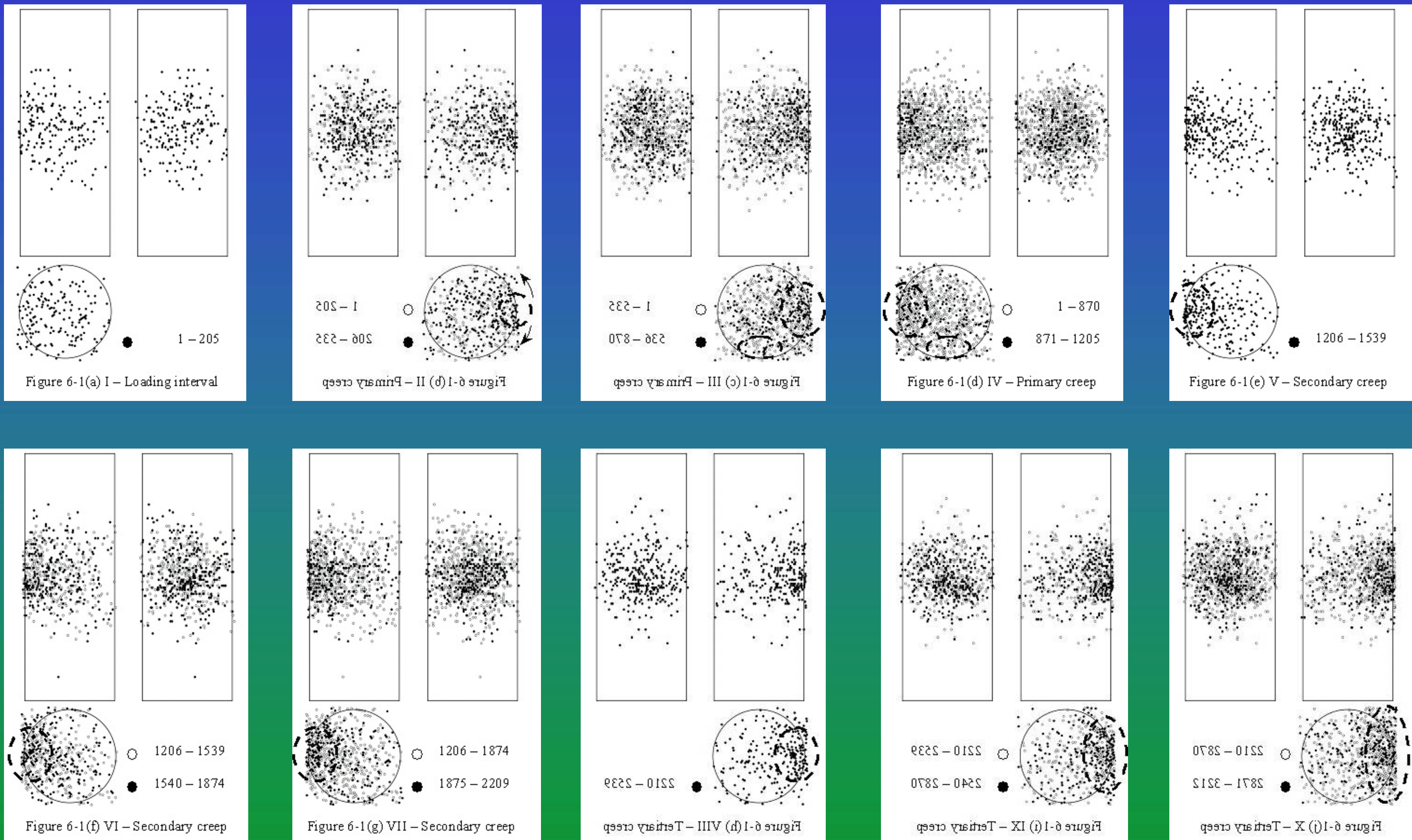
The time to failure increases rapidly when the stress ratio decreases and confining pressure increase

AE rate and Vol. strain vs time



The trend is quite similar, but AE is more sensitive and well represent the start of accelerating creep stage.

Acoustic emissions record



Acoustic emissions record

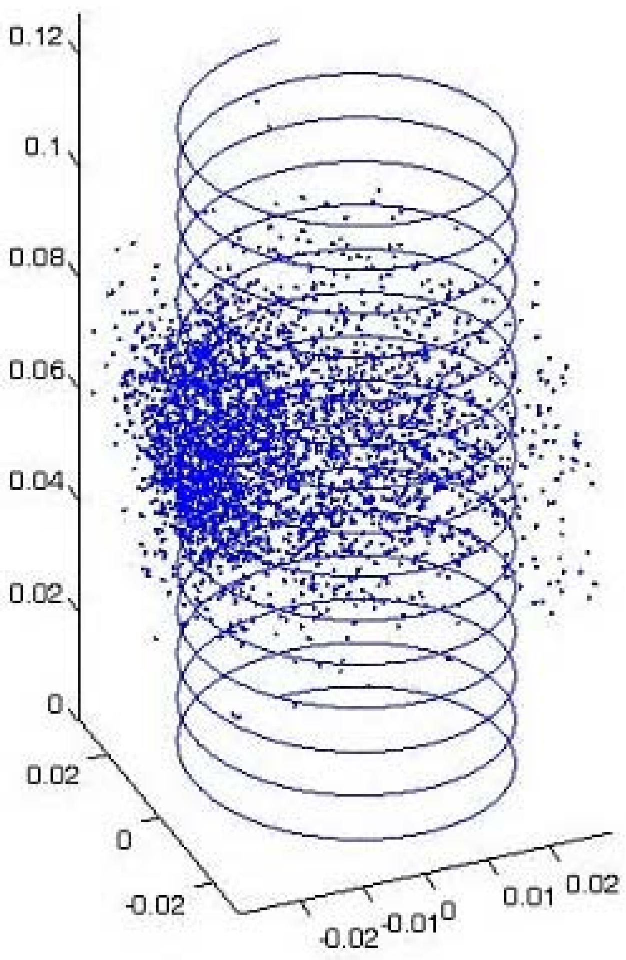


Figure 6-2 Stereoscopic projection of acoustic emission hypocentres

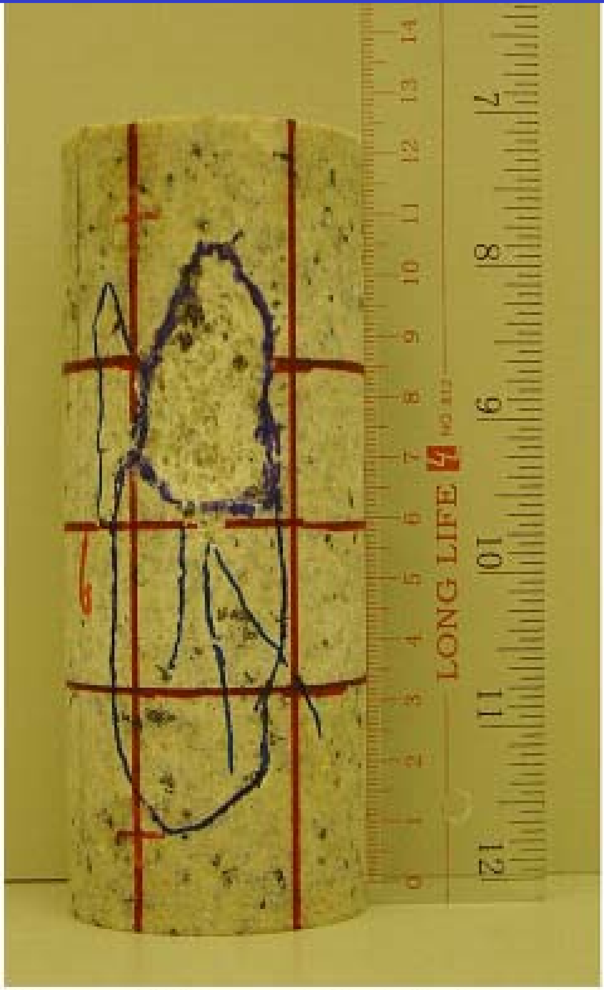


Figure 6-3 Photo of the failed sample showing the actual faulting

Conclusion-1

- High Density and high homogenization (porphyritic monzonitic granite)
- Low porosity, Low water content
- High Uniaxial compressive strength, shear strength and tensile strength
- Low strain and high brittle

Conclusion-2

- Temperature has significant influence on the property of granite when confining pressure increase.
- Elastic modulus, Crack damage stress, Poisson's ratio and peak stress increase when confining pressure increase.
- when temperature increase, Elastic modulus increase then decrease, Crack damage stress decrease and Poisson's ratio increase

Conclusion-3

- Time to failure decrease when temperature increase.
- The time to failure increases rapidly when the constant load or the stress ratio decreases and confining pressure increase
- AE is more sensitive and well represent the start of accelerating creep stage.


谢谢！
Thank you!
BRIUG

Handling of Nuclear waste in Germany in the Light of Final Disposal

Dipl.-Ing. Michael Sailer

中德放射性废物处置研讨会
CHINESE-GERMAN WORKSHOP ON RADIOACTIVE WASTE DISPOSAL
May 28 – 31, 2007
Sino-German Science Centre, Beijing, CHINA

Content

- General overview
- Clearance
- Non heat generating waste
- Heat generating waste
- Conclusions

General overview (1)

- Germany is using nuclear materials and nuclear power since more than 50 years
- Nuclear waste mainly stems from
  - Operation of nuclear power plants
  - Research facilities and research reactors
  - Decommissioning of nuclear installations
  - Industrial and medical application

General Overview (2)

- Basic policy is to dispose German radioactive waste in Germany
- Waste from nuclear activities:

  - Heat generating waste, i.e. high active waste

  - Non heat generating waste, i.e. low and medium active waste

  - waste discarded according to clearance procedures

Clearance (1)

- Clearance is based on the 10 µSv concept
- annual collective dose from entire clearance operations in Germany checked against 1 person-Sv criterion
- Clearance levels
  - available for various clearance options
  - derived from radiological analyses taking account of all relevant characteristics of particular clearance option

Clearance (2)

- Clearance is widely used at decommissioning, more than 95% of the masses of nuclear installations can be handled in that way
- Clearance is also used for waste from operation
- After clearance the material do not remain under governance of the atomic act
- Clearance seriously reduces the amount of low active waste

Final Disposal for Non heat generating waste

- No separation of waste with long living and short living isotopes in Germany
- Deep underground disposal is necessary to provide protection of biosphere
- Disposal facility will be Schacht Konrad
- After court decisions in 2006 and 2007 the way is open to start with construction work
- Start of operation is foreseen for the year 2013

Konrad repository

History	Abandoned iron ore mine
Location	Salzgitter, Northern Germany
Host rock	Coral Oolite

Emplacement depth	800 m to 1,300 m
Type of waste	Non heat generating waste

Volume of waste packages	303,000 m³
Total alpha emitter activity	$1.5 \cdot 10^{17}$ Bq
Total beta/gamma emitter activity	$5.0 \cdot 10^{18}$ Bq

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Actual Inventory of Non heat generating waste

Type of waste December, 31th, 2004	With negligible heat generation [m^3]	Heat-generating (without spent fuel) [m^3]
Untreated waste (raw waste with residues yet to be recycled)	29,773	56
Interim products	7,902 (2001: 4,675)	
Conditioned waste	82,645	1,743
Disposed waste in Morsleben repository and research mine Asse	83,753	

Handling of Non heat generating waste (1)

- Raw waste has to be conditioned according the Schacht Konrad acceptance criteria
- Conditioning methods used:
  - incineration
  - high pressure compactation
  - evaporation (liquids)
  - fixation by concrete

Handling of Non heat generating waste (2)

- Conditioning provided by
  - external facilities
  - on-site with mobile facilities
  - on-site with fixed installations
- Conditioned packages have to be approved by BfS

Handling of Non heat generating waste (3)

- Conditioned waste has to be stored in interim storage facilities
  - on-site facilities (e.g. NPPs, research centers)
  - external facilities (e.g. Mitterteich, Gorleben interim storage facilities)

Handling of Non heat generating waste (4)

- Package forms according Schacht Konrad acceptance criteria
  - Different kinds of specified drums
  - Container with drums inside

Handling of Non heat generating waste (5)

- Special collection system for small producers

→ Each state provides

  - collection system
  - advises regarding conditioning and characterization
  - state operated interim storage facility, so-called "Landessammelstelle"

- Accepted waste is formally owned by state

Special questions regarding Non heat generating waste

- Characterisation of very old waste (partially lack of information about content)
- Waste with high content of alpha emitting isotopes or other special isotopes e.g. C-14 (exceeds acceptance criteria of Schacht Konrad → other solution for disposal is necessary)

Disposal site for Heat generating waste

- Disposal in deep underground in a special facility for heat generating waste
- Decision on site is pending. Moratorium exists since 2000. Two proposals within federal government:
  - To continue with the research in Gorleben salt dome
  - To compare several other possible sites with Gorleben to check whether a remarkable better site than Gorleben exists

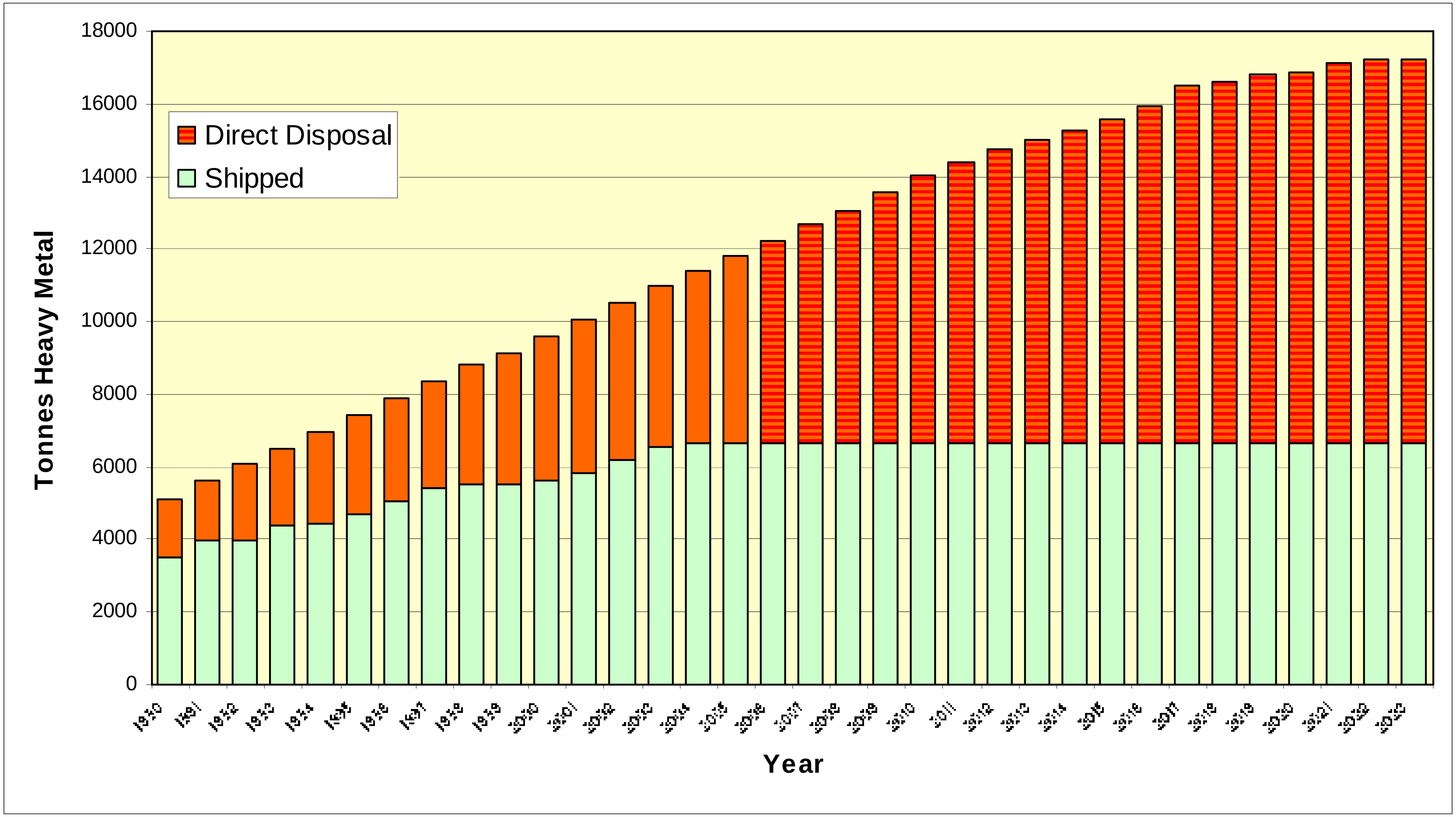
Types of waste for a Repository for Heat generating waste

- From reprocessing
  - Vitrified High level waste (from vitrification plants in La Hague/F, Sellafield/GB, Karlsruhe/D)
  - Compacted fuel structures
- Spent fuel from light water reactors
- Spent fuel from other reactors (high temperature reactors, research reactors)
- core installations with heat generation
- Other waste, which cannot disposed in Schacht Konrad

Spent fuel from light water reactors

- Annual unloading per reactor: 15 to 30 tHM/a
- Total annual production in Germany: ~ 400 tHM/a
- Produced by end 2005: 11,810 tHM
- Storage (December 2005): 5,140 tHM
- Expected quantity produced by 2025: ~ 17,200 tHM

- Decision to stop further reprocessing of German spent fuel
  → elder spent fuel results in reprocessing products
  → newer spent fuel will be disposed directly


Direct Disposal
Shipped
Tonnes Heavy Metal
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Year

Heat generating waste from reprocessing

- Coquilles with vitrified glass stored in massive casks
- Regular transports to Gorleben interim storage facility

Interim storage of spent fuel

- Storage in massive casks
- Interim storage facility at each NPP site

Packages for Final disposal (1)

- Up to now no formal decision on packages for high level waste
- Possible packages:
  - massive casks especially for final disposal (e.g. Pollux)
  - final disposal coquilles for spent fuel analogue to coquilles of vitrified high level waste
  - Use of the interim storage casks also as final disposal casks

Packages for Final disposal (2)

- The type of package influences
  - the techniques of handling at the final disposal site
  - the details of disposing (galleries or boreholes)
- Special Question to be clarified:
  - Packages for spent fuel other than LWR
  - Packages for waste other than vitrified glasses and spent fuel

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Conclusions

- The widespread use of regulated clearance reduces the amount of waste for final disposal seriously
- The way to the disposal of Non heat generating waste is now clear regarding technical questions as also other necessary decisions
- Regarding Heat generating waste: The site decision is pending. Technical decisions have to be made afterwards regarding the type of packages and related issues.

Thank you very much for your attention

Experiences with Performance of High-Level Radioactive Waste Forms in Various Host Rock Media

Chinese-German Workshop on
„Radioactive Waste Disposal“
May 28-31, 2007, Beijing, China

Bernhard Kienzler
Forschungszentrum Karlsruhe
Institute for Nuclear Waste Disposal (INE)

Content

- Overview on research organizations
  KIT, HGF, FZK, INE
- Frame, scenarios and outline of INE‘s R&D
- Waste Form Investigations
  - HLW glass / Spent LWR Fuel
  - Experiments
  - Modelling
- Conclusions
- Cooperation

„Karlsruhe Institute of Technology - KIT”

The University Karlsruhe (Technical University) and the Forschungszentrum Karlsruhe have founded the **„Karlsruhe Institute of Technology - KIT”.**

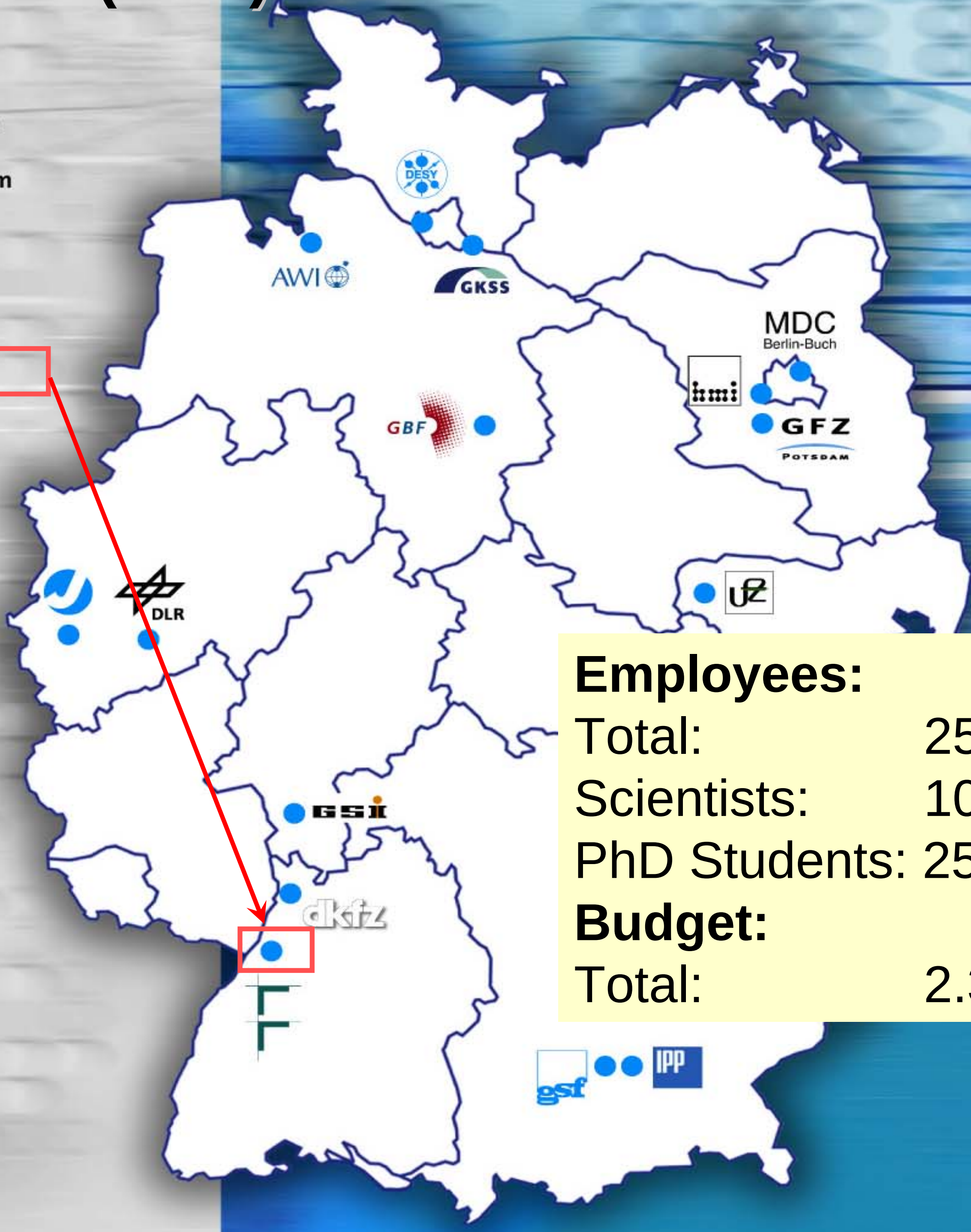
KIT combines the strengths of both partners, in

- micro- and nanotechnologies,
- scientific computing with the focus on grid computing,
- materials research for the energy sector.

KIT is a unique in Germany for the strategic bundling of common issues and resources.

„Helmholtz Association“ (HGF)

AWI	Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung
DESY	Stiftung Deutsches Elektronen-Synchrotron
DKFZ	Stiftung Deutsches Krebsforschungszentrum
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
FZJ	Forschungszentrum Jülich GmbH
FZK	Forschungszentrum Karlsruhe GmbH
GBF	Gesellschaft für Biotechnologische Forschung mbH
GFZ	Stiftung GeoForschungsZentrum Potsdam
GKSS	GKSS-Forschungszentrum Geesthacht GmbH
GSF	GSF-Forschungszentrum für Umwelt und Gesundheit GmbH
GSI	Gesellschaft für Schwerionenforschung mbH
HMI	Hahn-Meitner-Institut Berlin GmbH
IPP	Max-Planck-Institut für Plasmaphysik
MDC	Stiftung Max-Delbrück-Centrum für Molekulare Medizin
UFZ	UFZ-Umweltforschungszentrum Leipzig-Halle GmbH



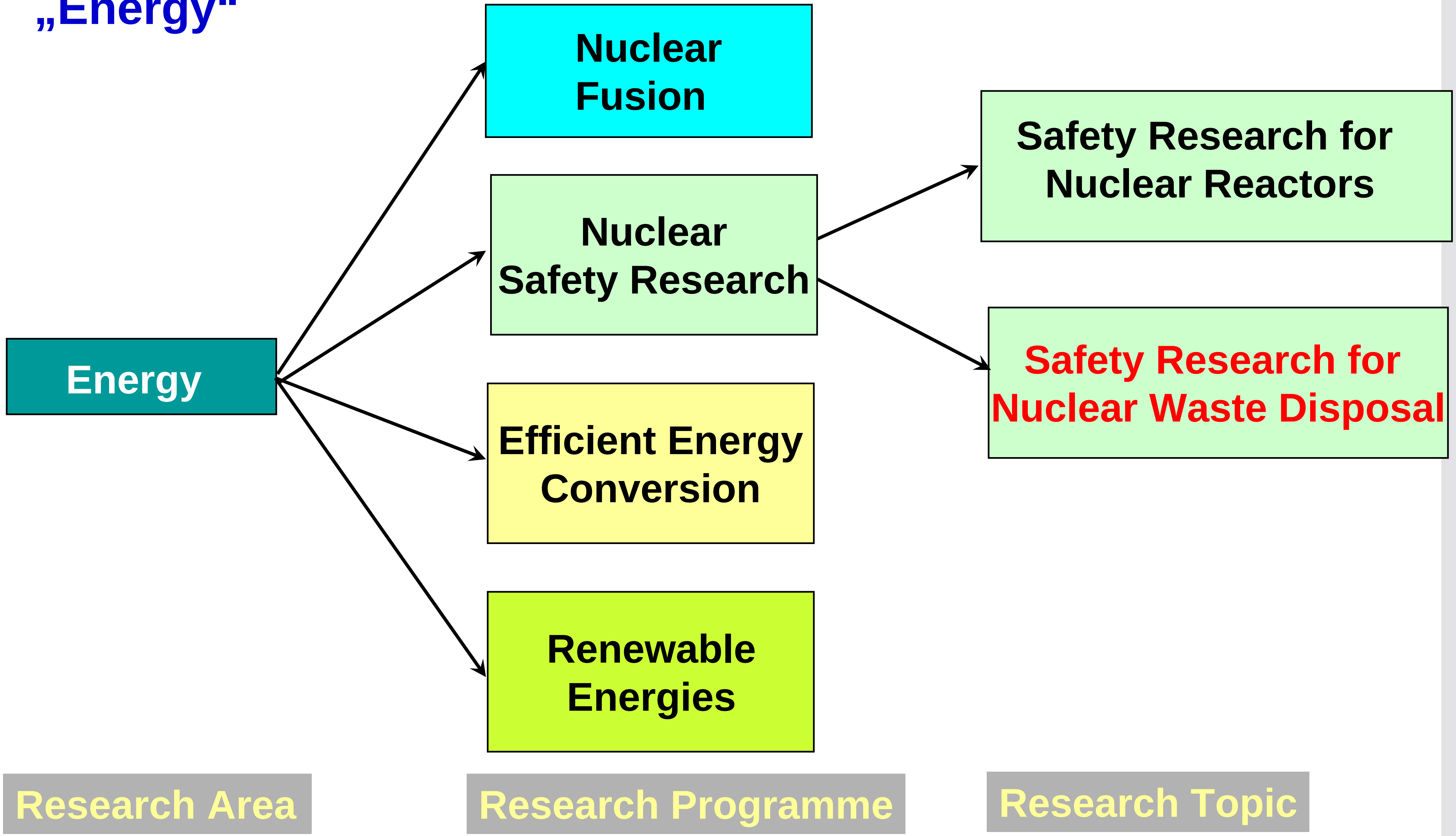
Employees:
Total: 25,700
Scientists: 10,000
PhD Students: 2500
Budget:
Total: 2.3 billion €/yr.

Research Areas of the „Helmholtz Association“ and FZK

Structure of Matter	Health
Earth and Environment	Energy
Transport and Space	Key Technologies

FZK contribution

FZK involvement in HGF Research Area „Energy“



Forschungszentrum Karlsruhe

- 2005 -

- **3800 employees** **(1420 scientists, incl. 190 foreign guests, 185 post docs, 300 trainees)**

- **Annual Budget:**
  316 Million € for Research (23 % by contracts)
  88 Million € for Decommissioning (25 % by contracts)

- **22 Scientific Institutes**
- **11 Programs in 5 Research Areas**
- **Project Agencies of Federal and State Government**
- **2000 publications p.a.**
- **1100 cooperative ventures with 250 R&D centers, 140 universities, 150 industrial companies, and 40 authorities, etc. in 47 states**

www.fzk.de

Safety Research for Nuclear Waste Disposal

Institut für Nukleare Entsorgung (INE)
Institute for Nuclear Waste Disposal

R+D Topics:

- Vitrification of High Level Liquid Waste
- Reduction of Radiotoxicity (Separation of Actinides)
- Long Term Safety of Nuclear Waste Disposal

Vitrification of High Level Liquid Waste

WAK

- **70 m³ HLLW**
- **8.9×10^{17} Bq**
- **50 t Glass**
- **130 Canisters**

INE:
Melter and
Process Technology

Active Operation
VEK-Plant (2007-2008)

Safety Research for Nuclear Waste Disposal

R+D Topics of INE

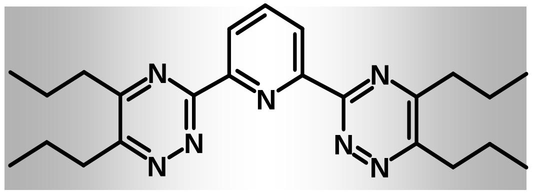
- Vitrification of High Level Liquid Waste
- **Reduction of Radiotoxicity (Separation of Actinides)**
- Long Term Safety of Nuclear Waste Disposal

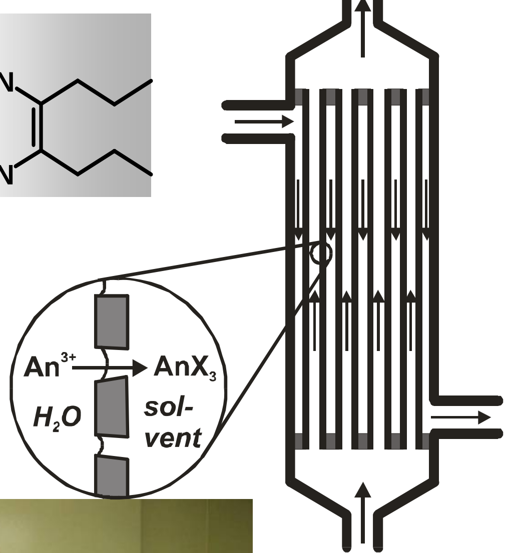
Reduction of Radiotoxicity
- MA Partitioning -

Basic studies

- New stable (hydrolysis, radiolysis) selective extractants (C,H,N,O)
- Study the molecular mechanism (TRLFS, EXAFS, Quantum Chemistry)
- Mass-transfer kinetics (experiments and modelling)

N-donor extracting agent:
alkylated 2,6-ditriazinylpyridines (BTP)





Process design

- Hollow fibres modules as extractors
- Process optimization (Flow Sheet calculations)

(EC FP: 5th PARTNEW, 6th EUROPART)

Safety Research for Nuclear Waste Disposal

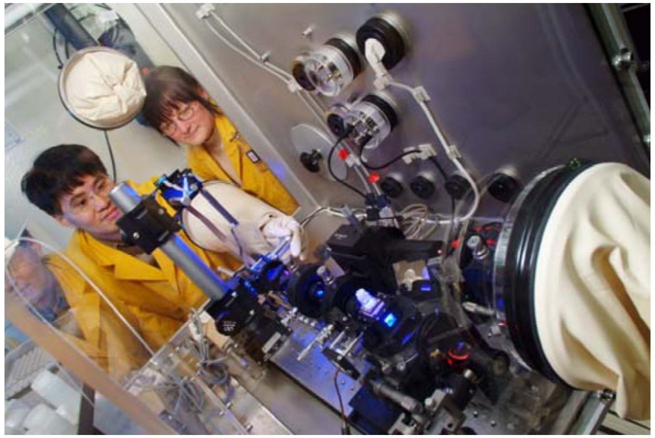
R+D Topics of INE

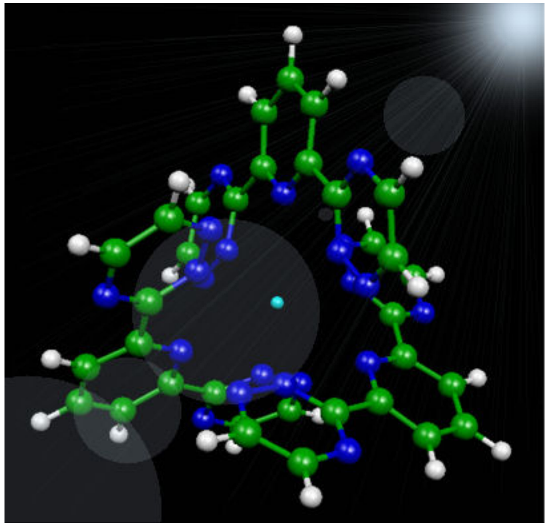
- Vitrification of High Level Liquid Waste
- Reduction of Radiotoxicity (Separation of Actinides)
- **Long Term Safety of Nuclear Waste Disposal**

R+D-Work on Long-Term Safety

- Geochemically Based Long-Term Safety Assessment -

Basic Investigations	Development of Speciation Methods	Applied Investigations
Molecular Process Understanding	**Molecular Structure of Trace Actinides**	**Radionuclide-Retention in the Multibarrier System**



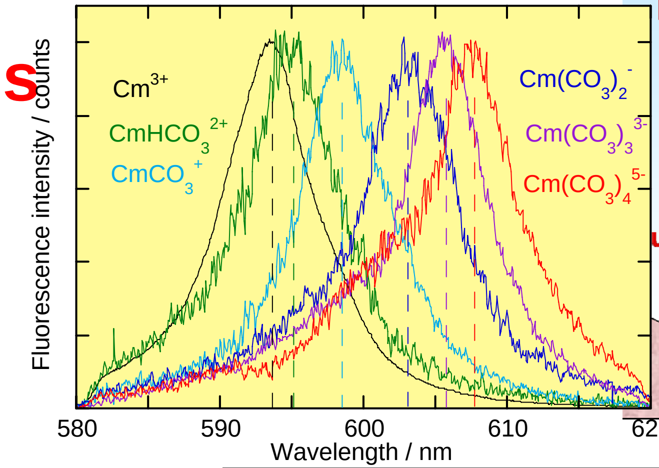


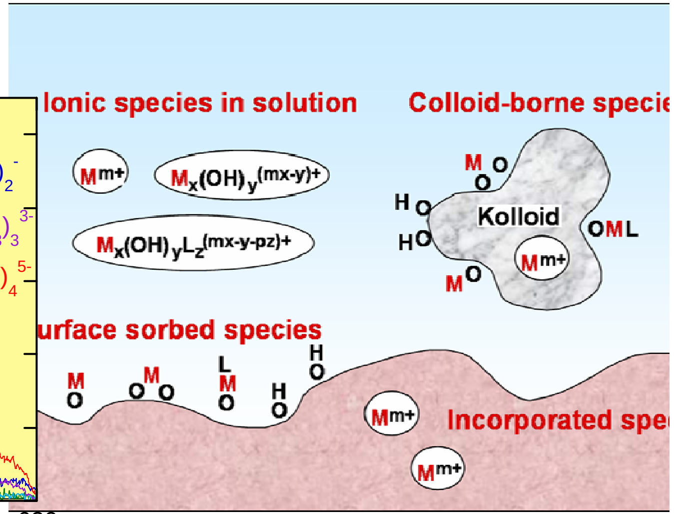
R+D-Work on Long-Term Safety
- Geochemically Based Long-Term Safety Assessment-

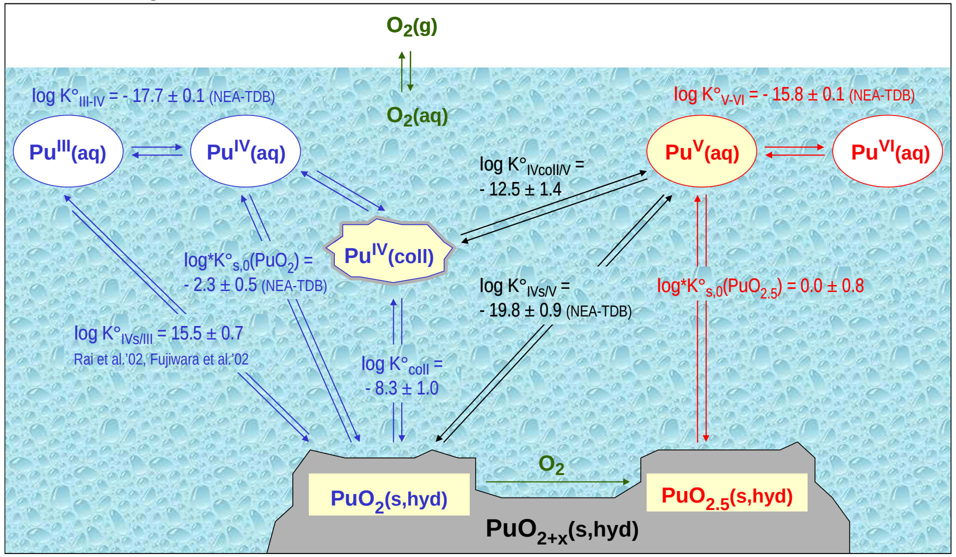
Fundamental Investigations

Molecular process understanding

- Aquatic chemistry / thermodynamics of actinides
- Interaction of actinides with mineral surfaces
- Secondary phase formation
- Stability of colloids/ interaction with actinides
- Quantum molecular calculations



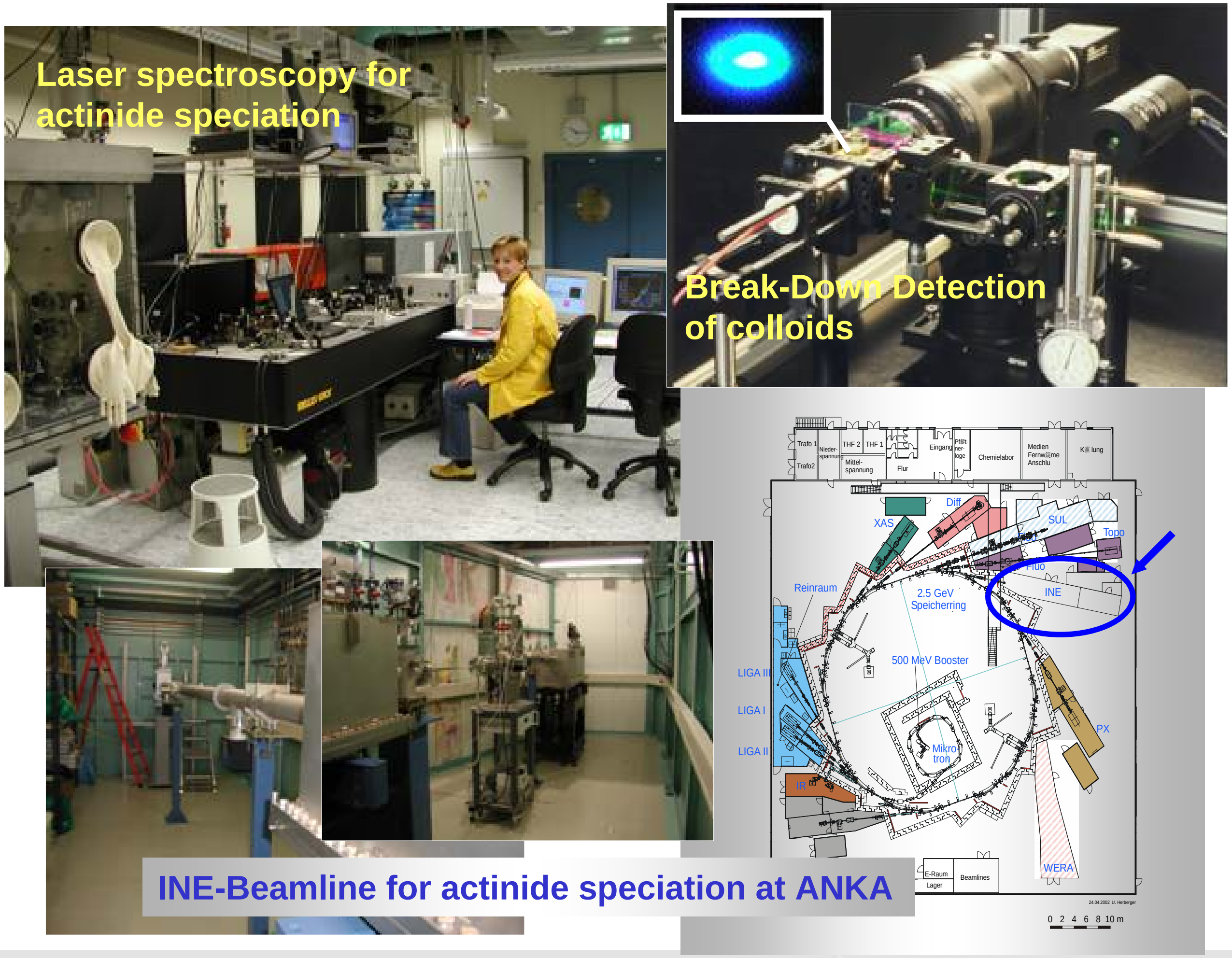




R+D-Work on Long-Term Safety
- Geochemcal Based Long-Term Safety Assessment-
Development of Speciation Methods

Molecular structure of trace actinides

- Laser spectroscopy TRLFS, LPAS
- Laser induced break-down detection / spectroscopy
- Sum-frequency-IR-spectros- copy
- X-Ray spectroscopy (Synchrotron Radiation) EXAFS, XANES, GIXAFS µ-XAFS, µ-XRD

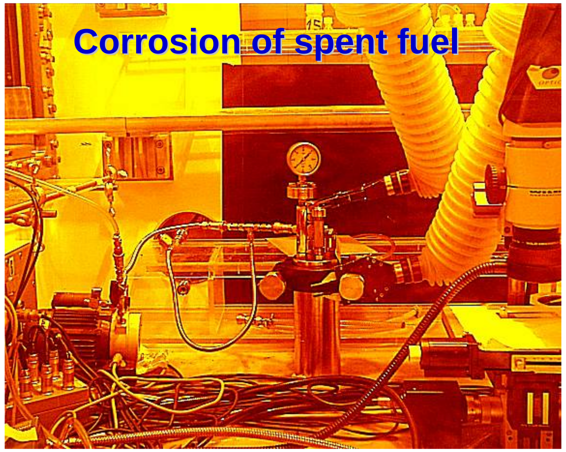


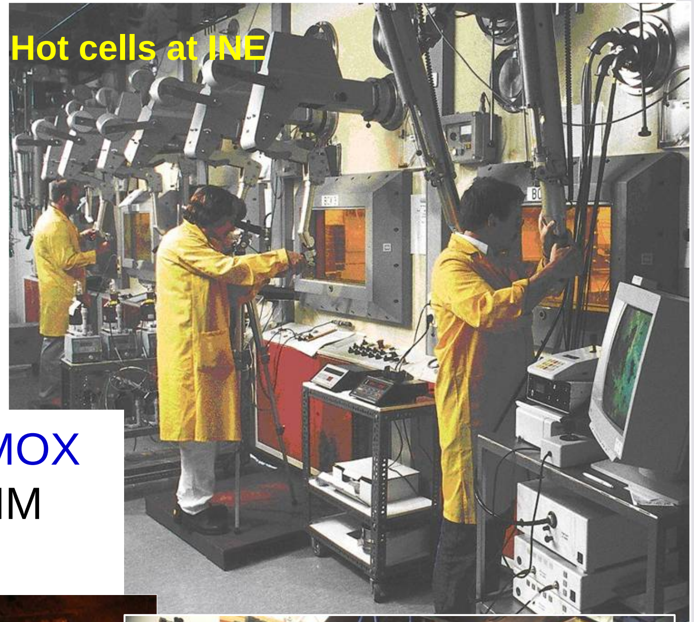
R+D-Work on Long-Term Safety
- Geochemically Based Long-Term Safety Assessment-

Applied Investigations

Radionuclide retention in the multibarrier system

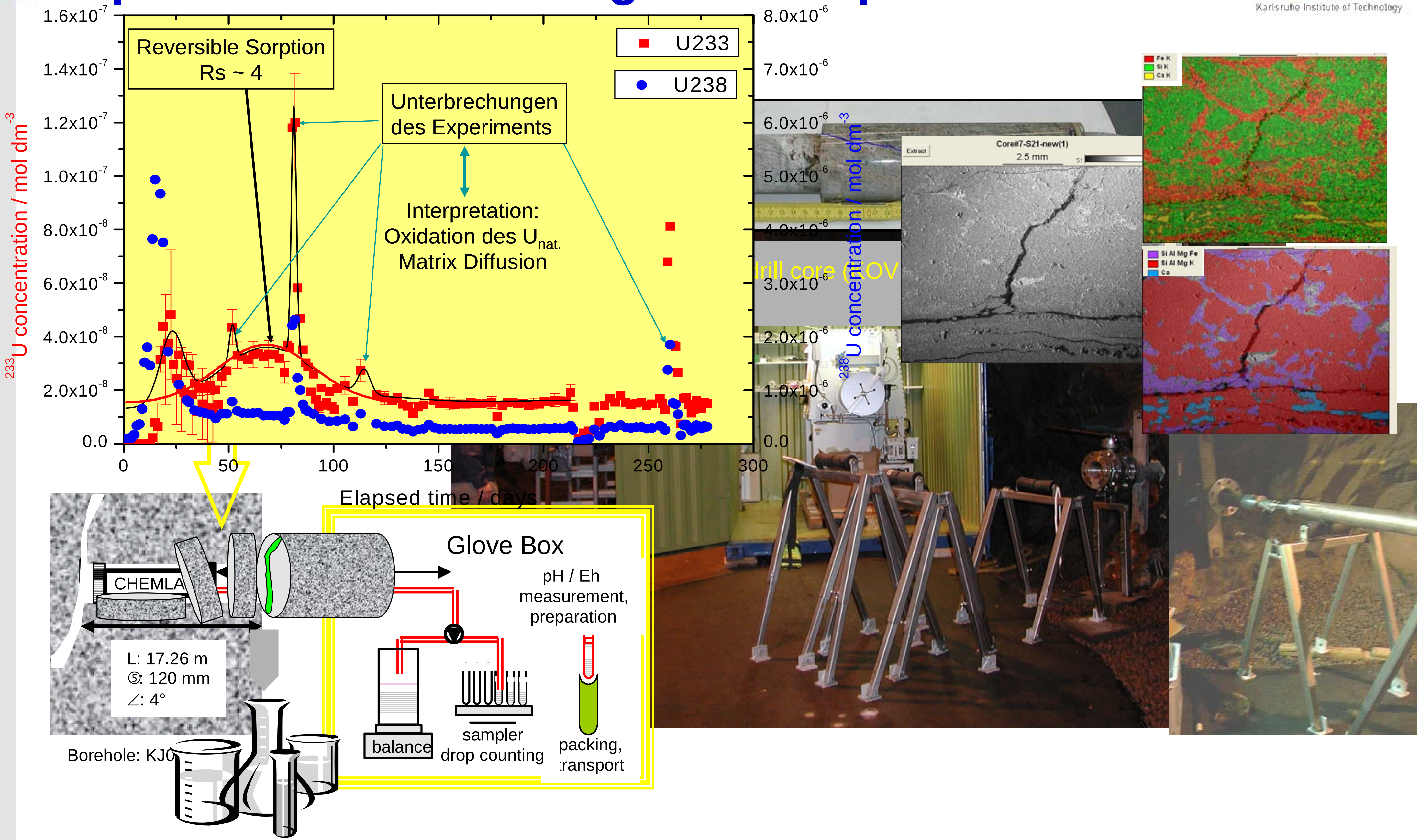
- Waste Forms (spent fuel, HLW glass)
- Radiation chemical effects
- Canister / backfill materials
- Hostrock / far-field
- Large scale experiments (Underground laboratories)
- Reactive transport modelling



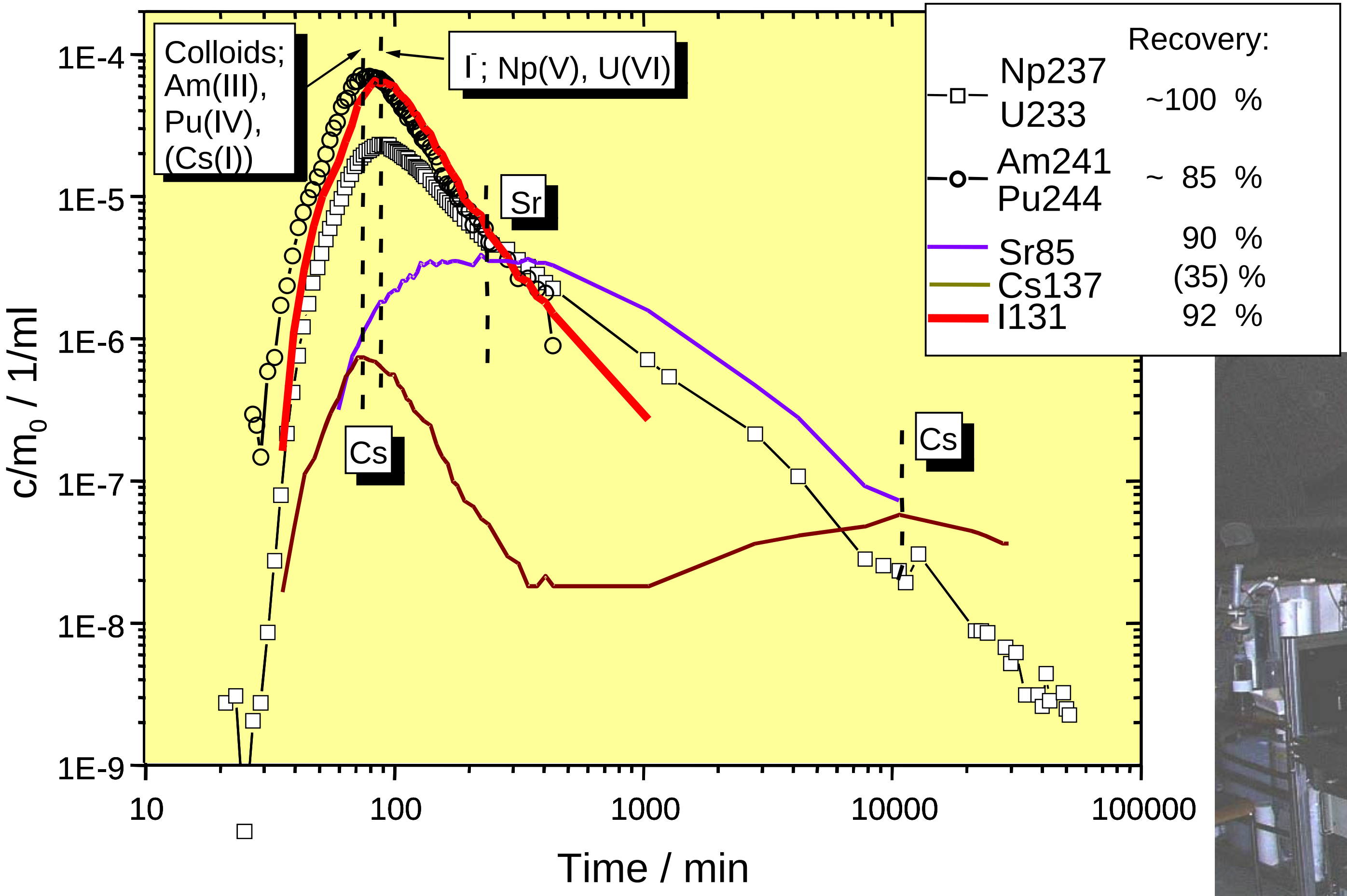


Spent LWR fuel, UOX and MOX
burn-up: 36 – 52 MWd/kg HM
activity: > 10^{10} Bq/g

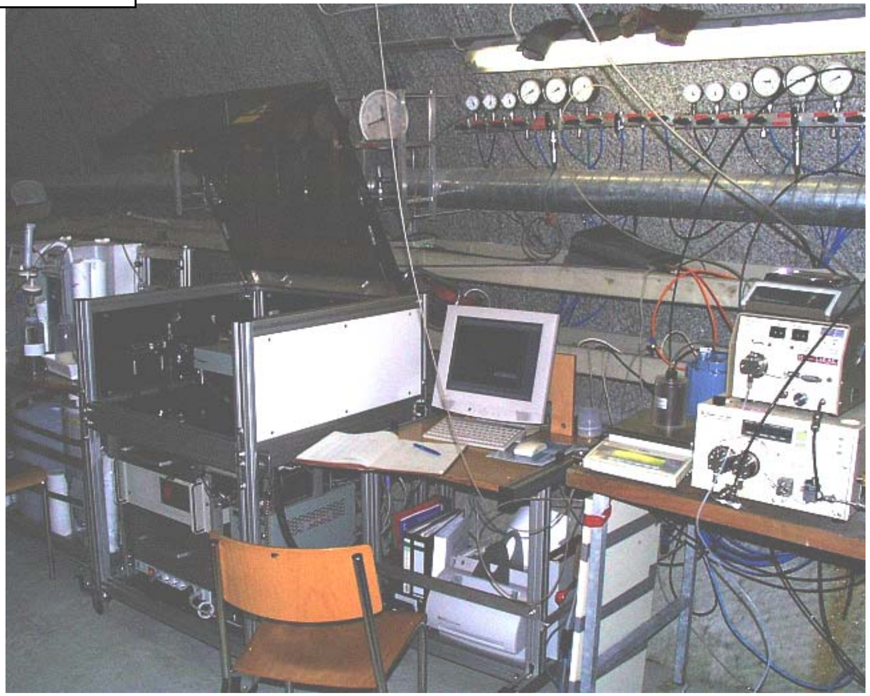
Äspö HRL: Actinide migration experiments



Colloid-mediated migration of tri- and tetravalent actinides and a part of Cs

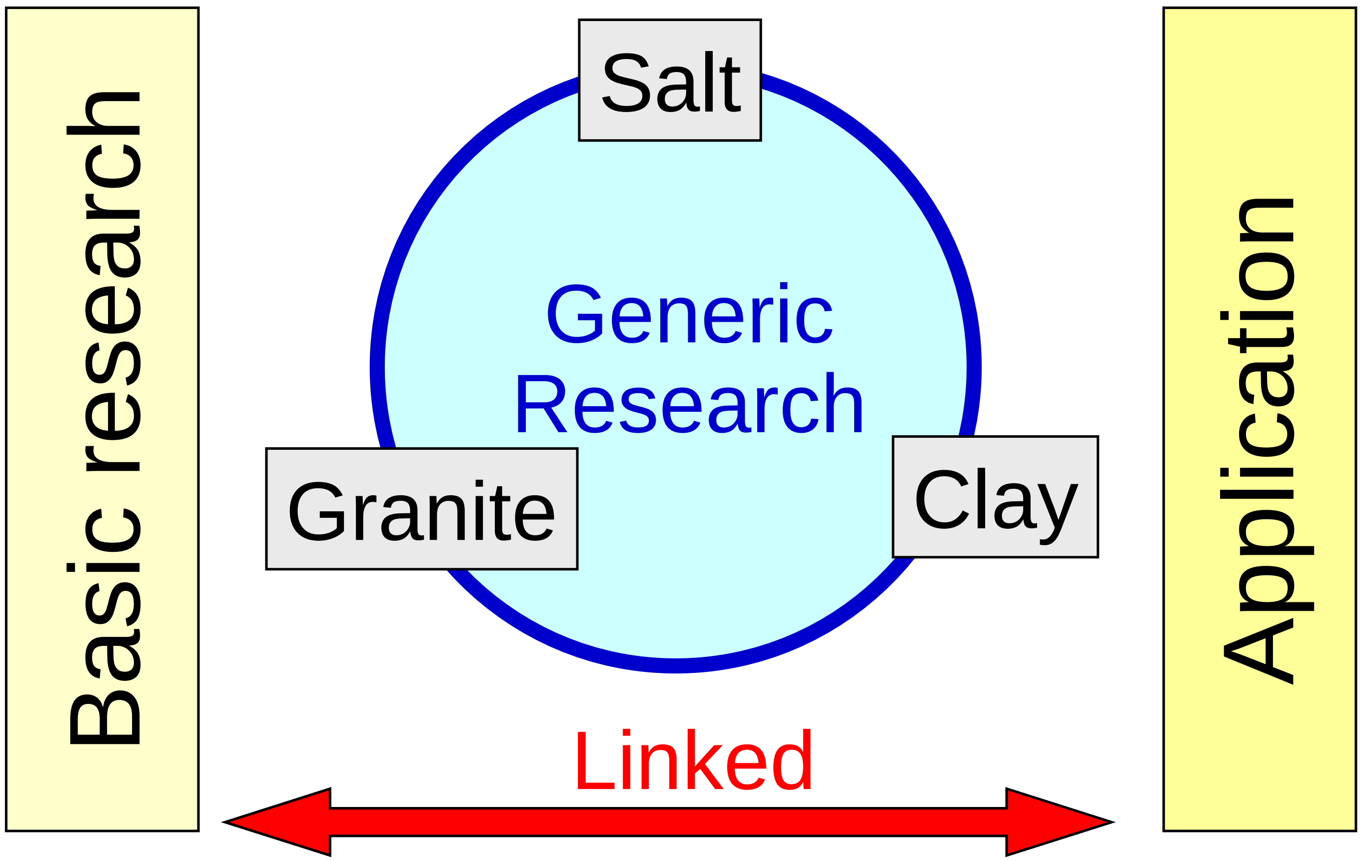


Mobile laser-induced breakdown detection (LIBD) for the in-situ colloid characterisation



Safety Research for Disposal of Nuclear Wastes

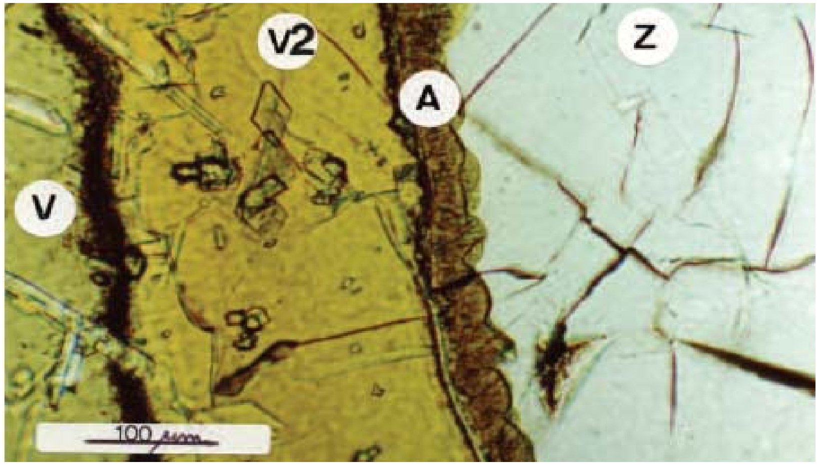
Geochemically based Long-term Safety Assessment



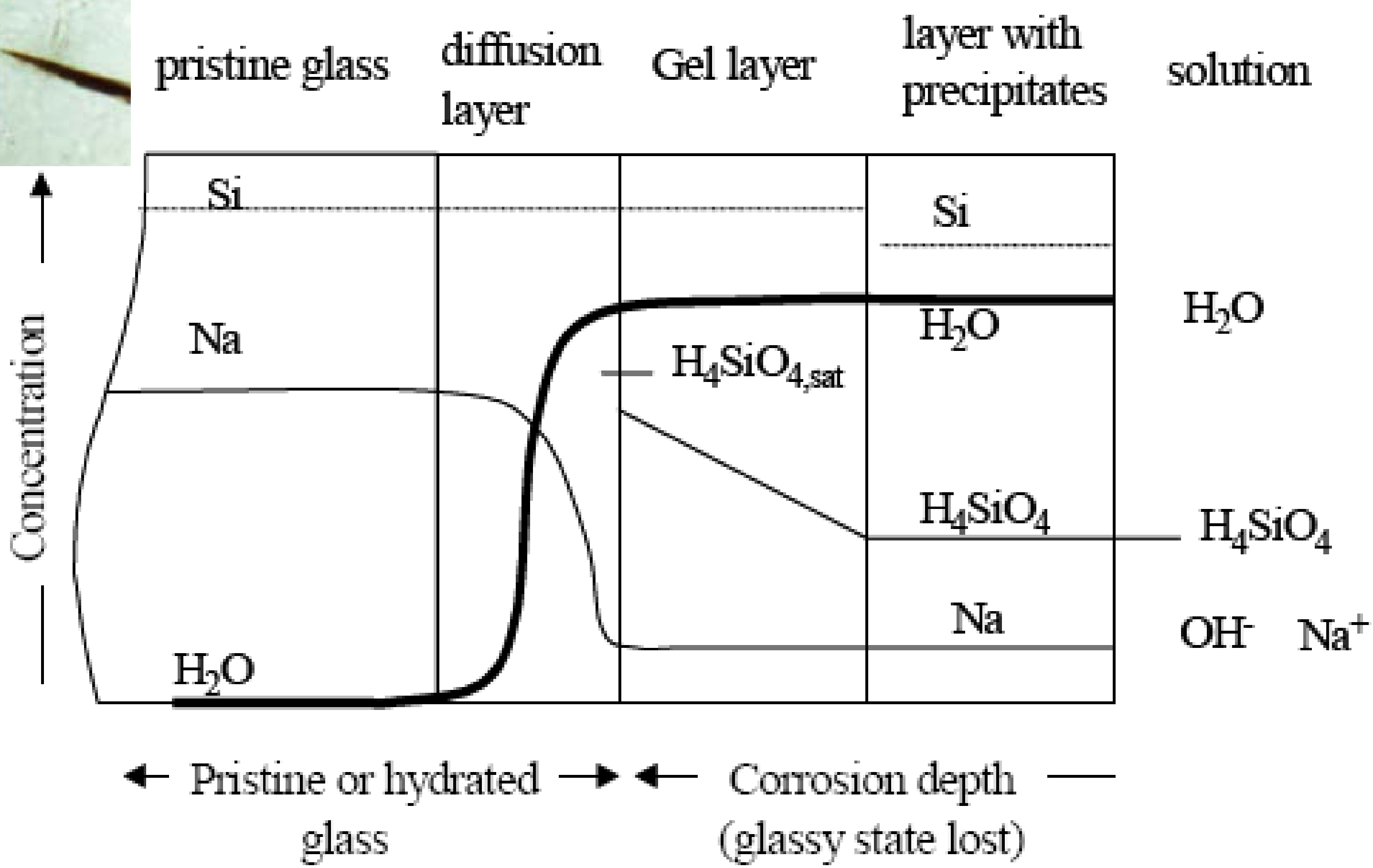
Waste Forms Investigations

- Boundary Conditions:
  - Rock Salt
  - Clay
  - Granite
- Experimental Set-up
  - Presence of canister / backfill material
  - Specific conditions
- Experimental Results
  - Leachate concentrations
  - Solids
  - Gases
- Modelling

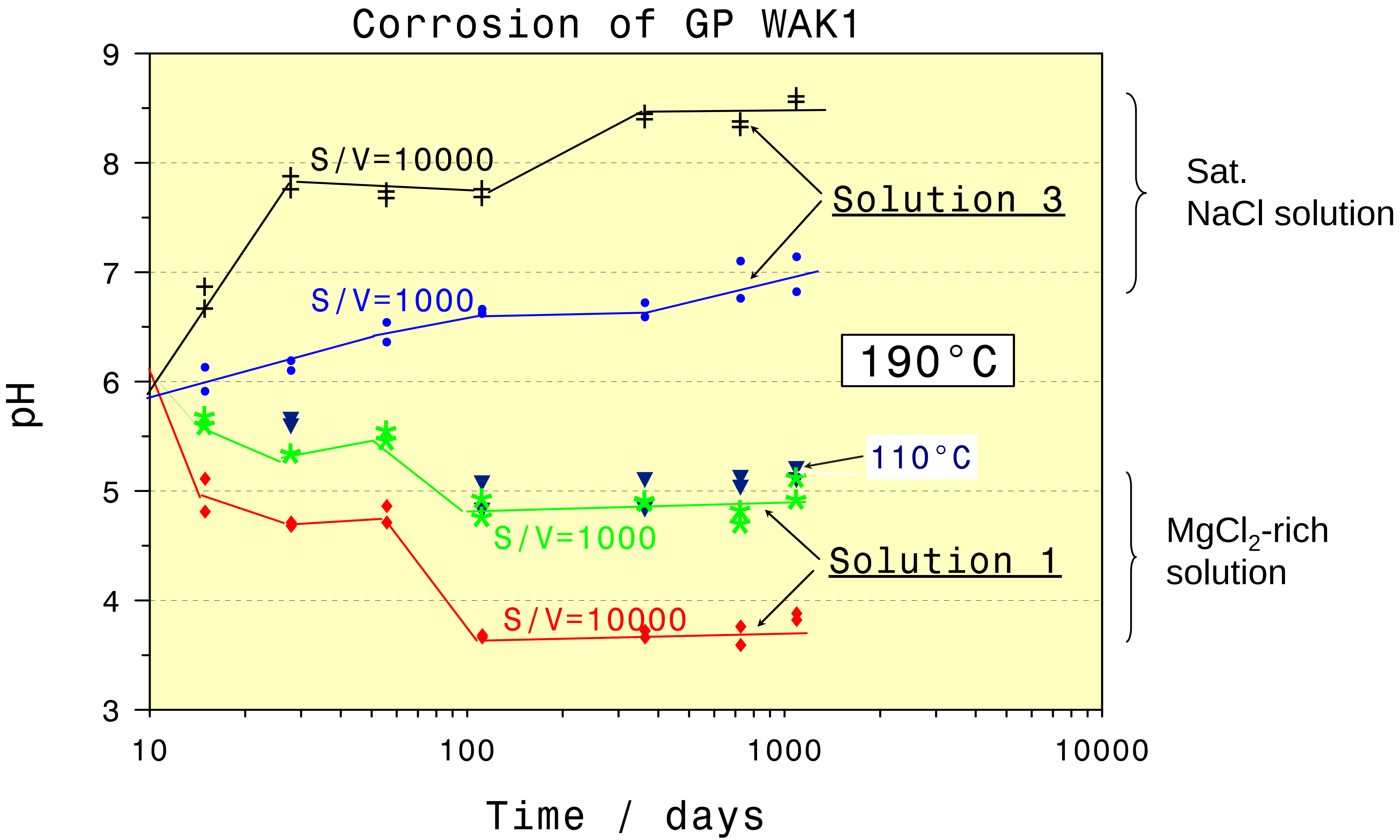
Simplified Scheme of Corroding Glass



V: original glass;
V2: hydrated glass;
A: clay;
Z: zeolite

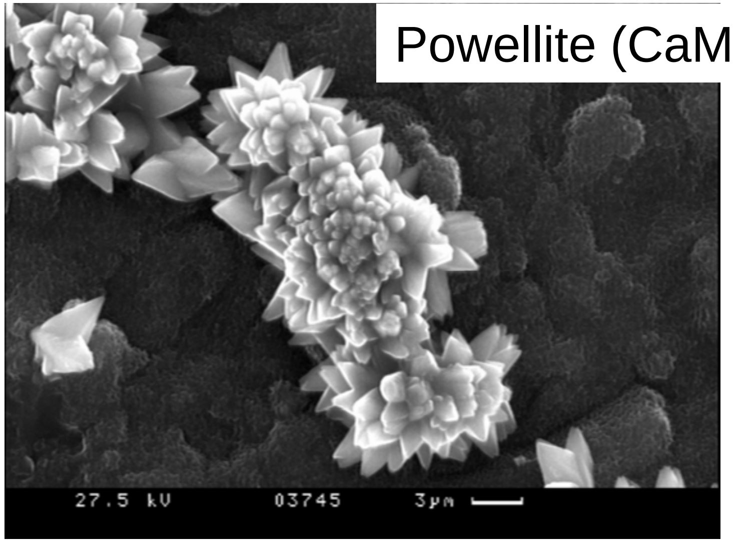


Corrosion of simulated HLW Glass GP WAK1 (pH effect)

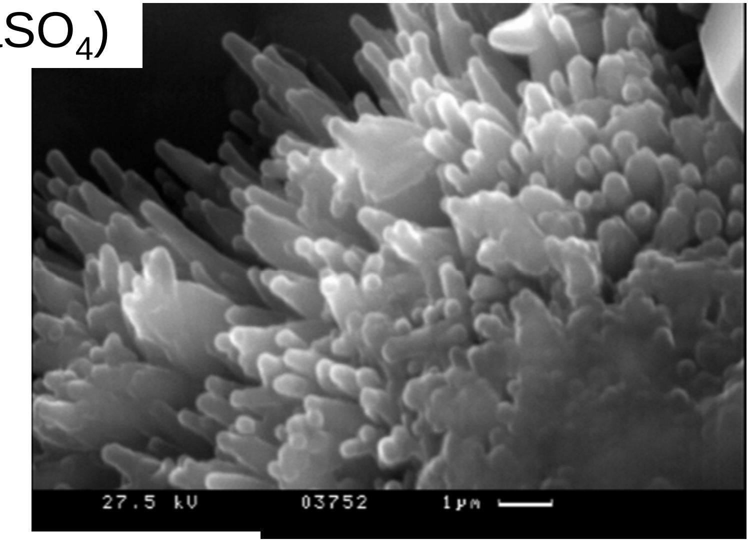


Secondary Phases in Glass Corrosion

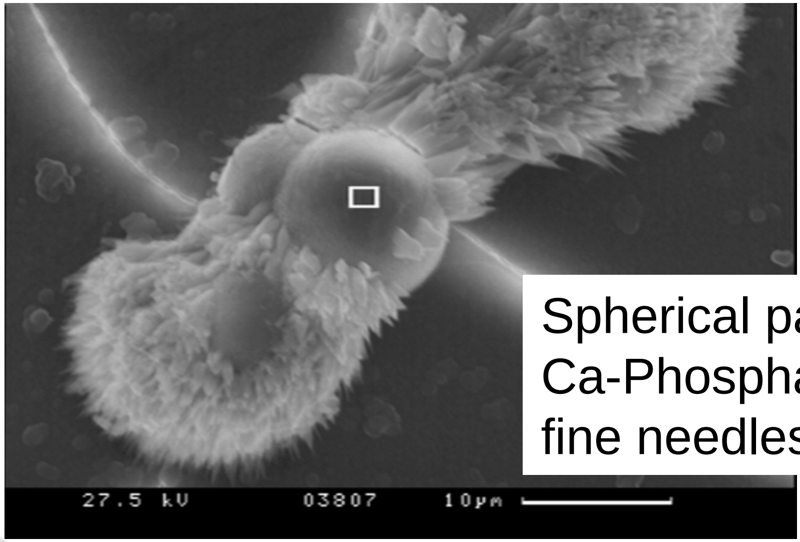
Powellite ($CaMoO_4$)



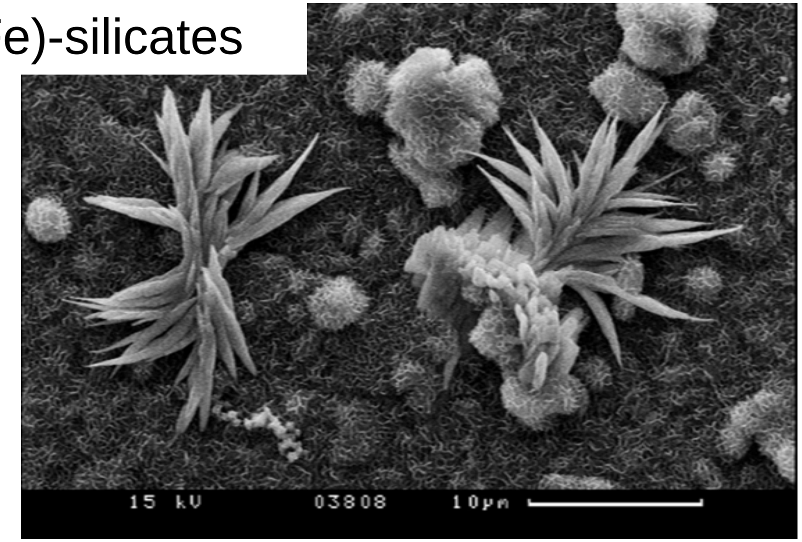
Barite ($BaSO_4$)



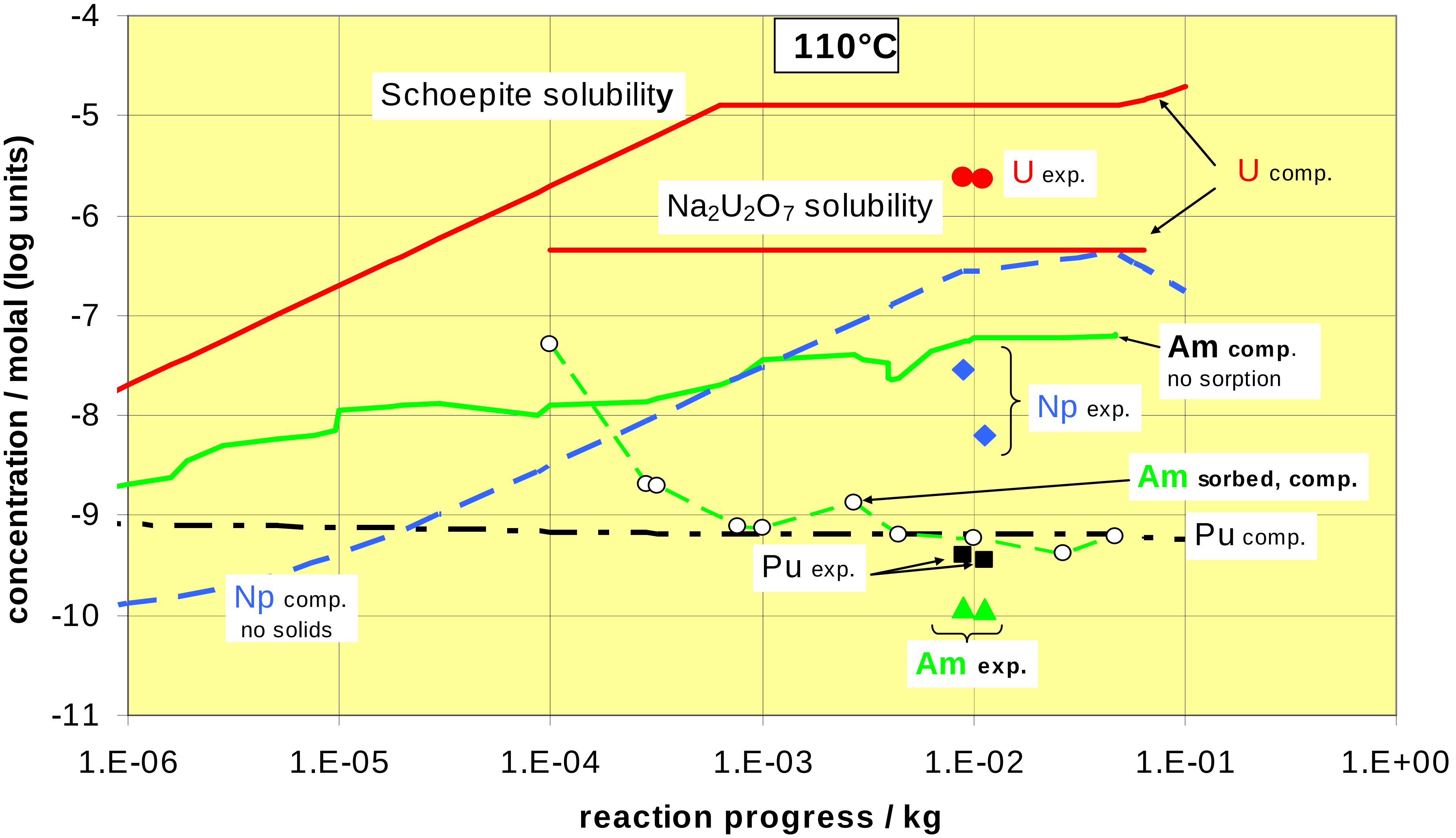
glass surface
covered with small
clay-like Mg(Ca,Fe)-silicates



Spherical particles:
Ca-Phosphate,
fine needles: Barite



Concentrations of actinides released from the Glass R7T7 in NaCl brine



Studies on Spent Fuel Behavior

„Hot Cells“ at INE

Radiolysis effects,
radiation chemical effects:

Materials: UO_2, ^{238}Pu-doped UO_2
Solutions: NaCl-brine, Pu doped NaCl sol.
External γ -source

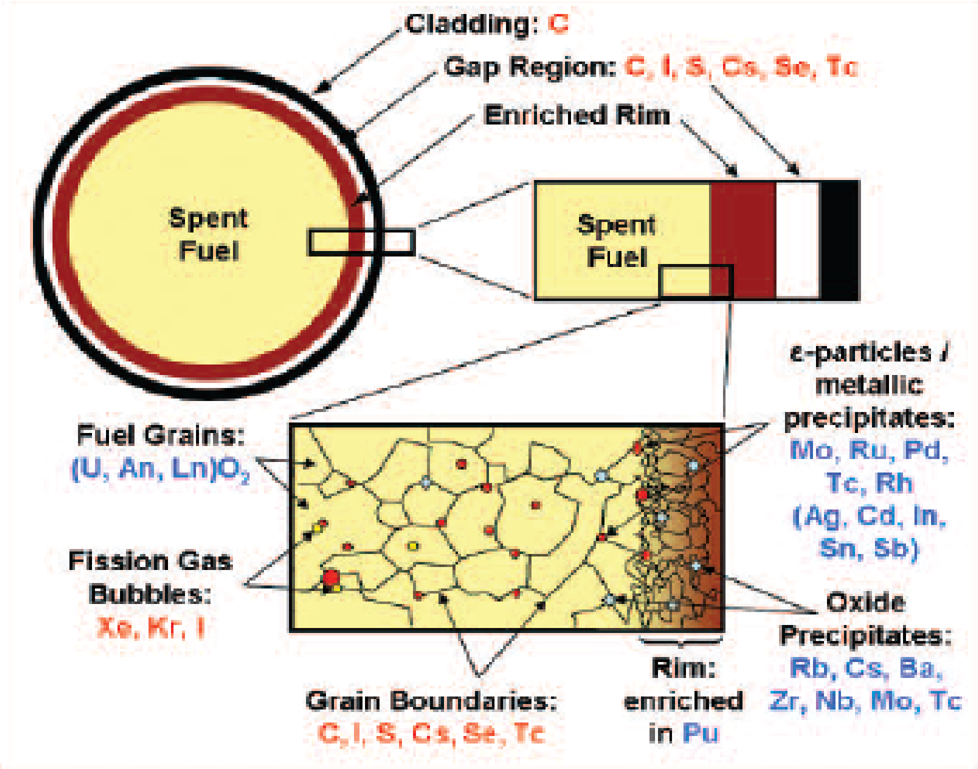
Corrosion Behavior of Spent Fuel

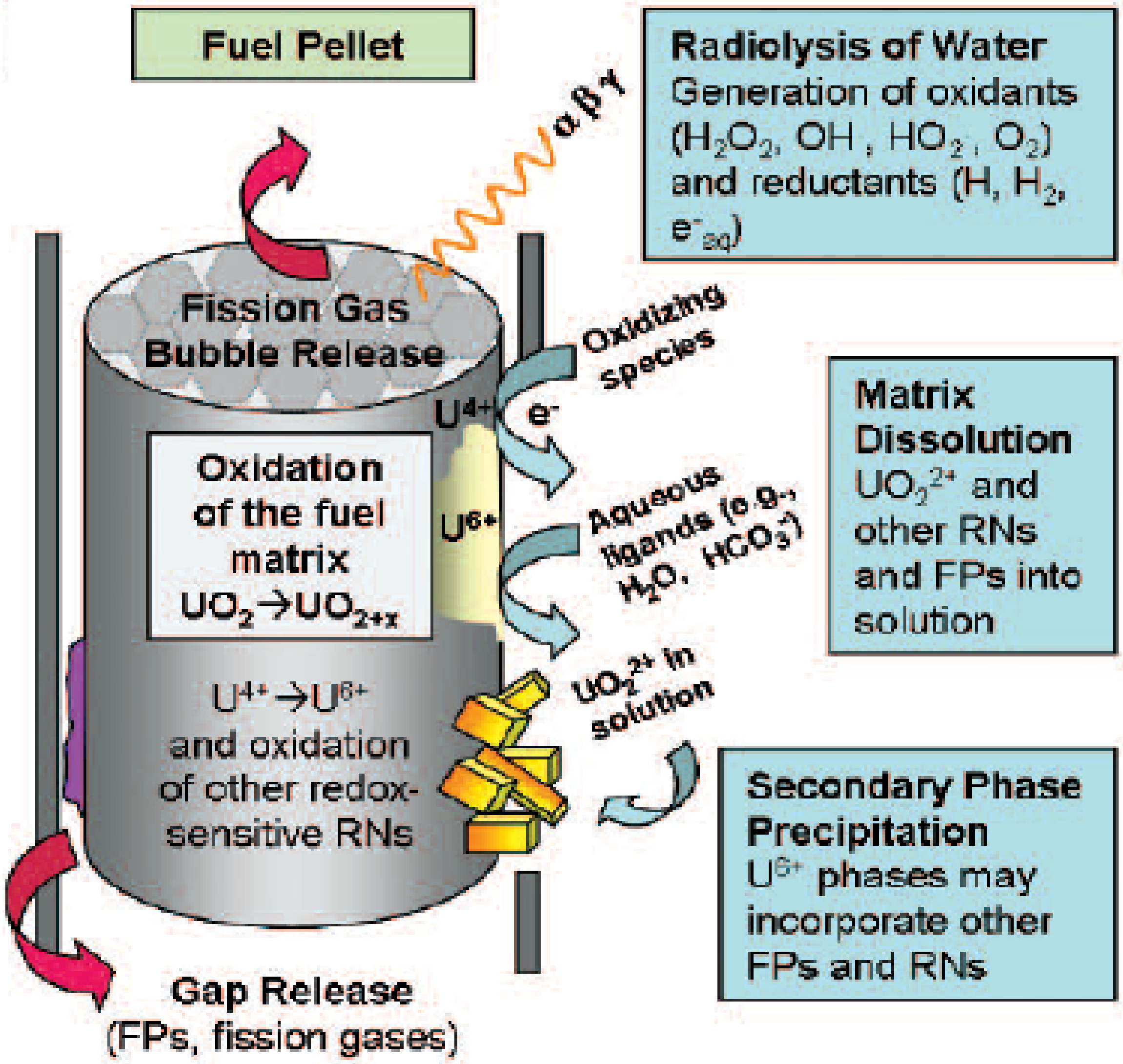
Material: High burnup spent fuel
(50.4 MWd/kgU, 30 kW/m, T> 1700° C)
Solutions: NaCl-Solution, Q-brine, DIW,
Granite Waters

Studies on the effect of

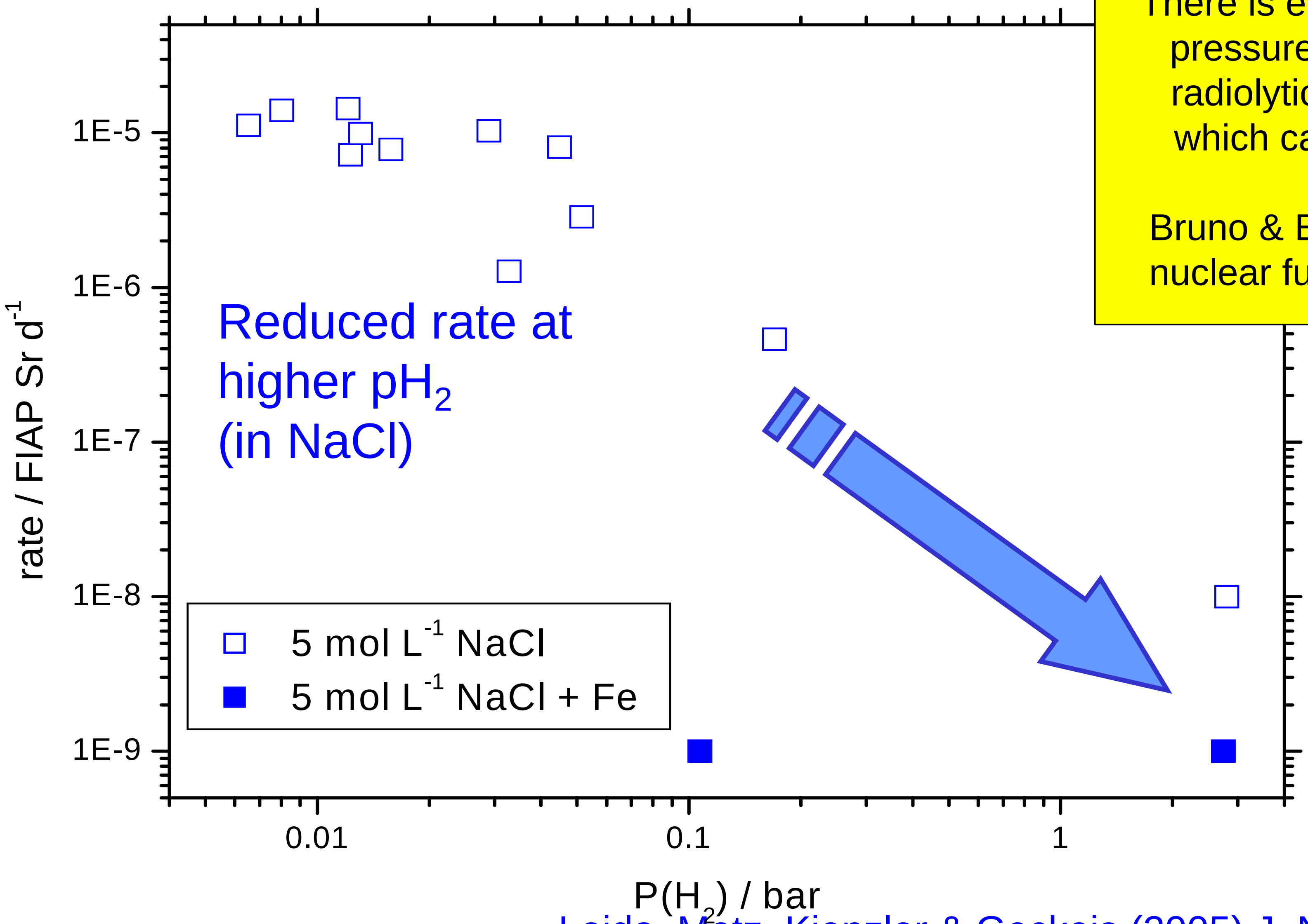
- sample geometry (S/V),
- brine/groundwater composition
- pre-oxidation of the matrix
- container material (Fe powder),
- backfill materials (Magnetite, Apatite)
- impact of hydrogen overpressure
- direct contact between spent fuel and bentonite immersed in granite water

Reactions of spent nuclear fuel





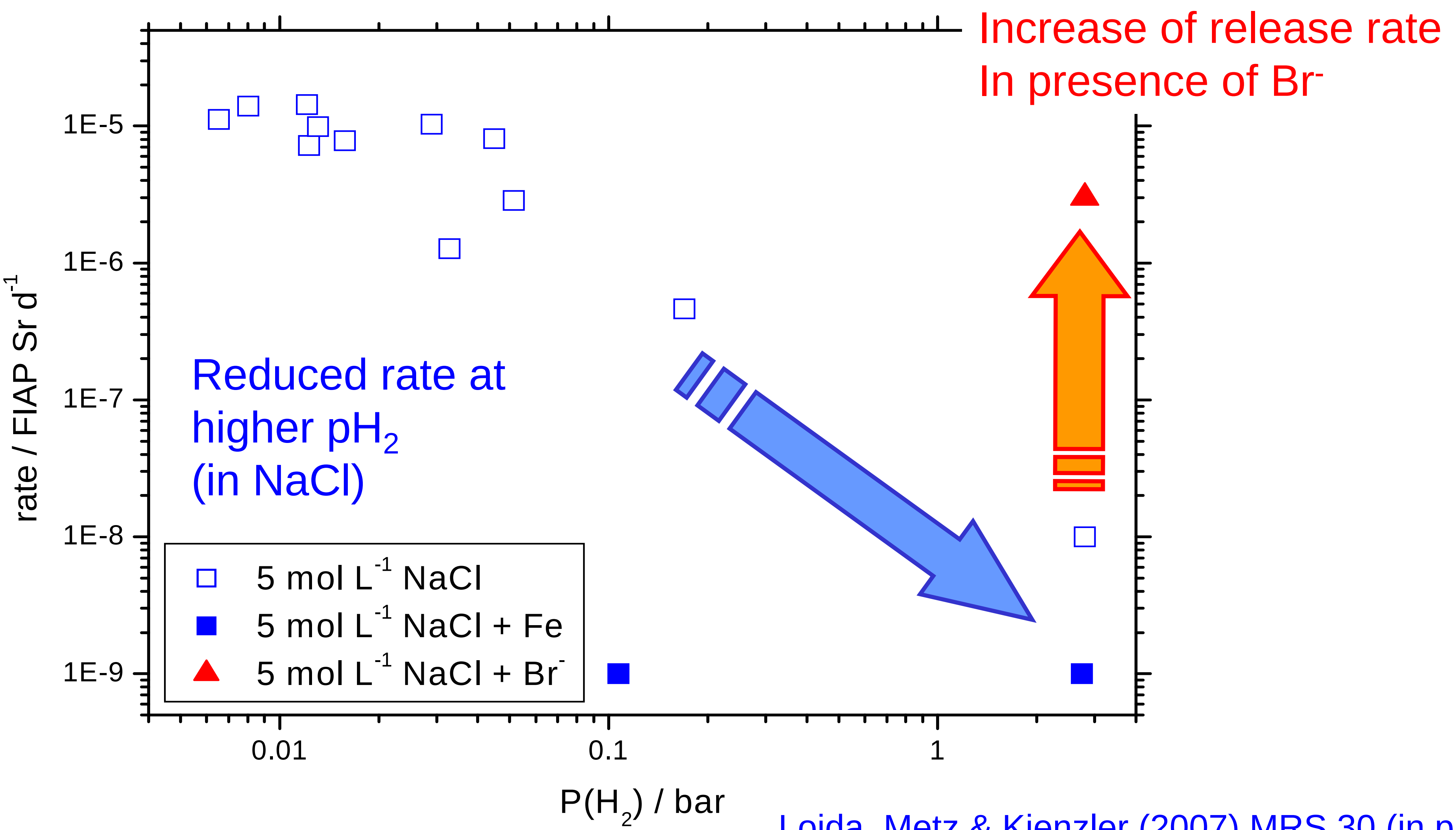
Effect of pH_2 on Spent Fuel Leaching: Sr release rate / UO_2 release rate



"There is evidence that H_2 over-pressures switches off the radiolytic processes (…) in which case no dissolution occurs."
Bruno & Ewing (2006): Spent nuclear fuel. *Elements* 2, 343

Loida, Metz, Kienzler & Geckeis (2005) J. Nucl. Mat. 346, 24-31

Effect of pH_2 on Spent Fuel Leaching: Sr release rate / UO_2 release rate



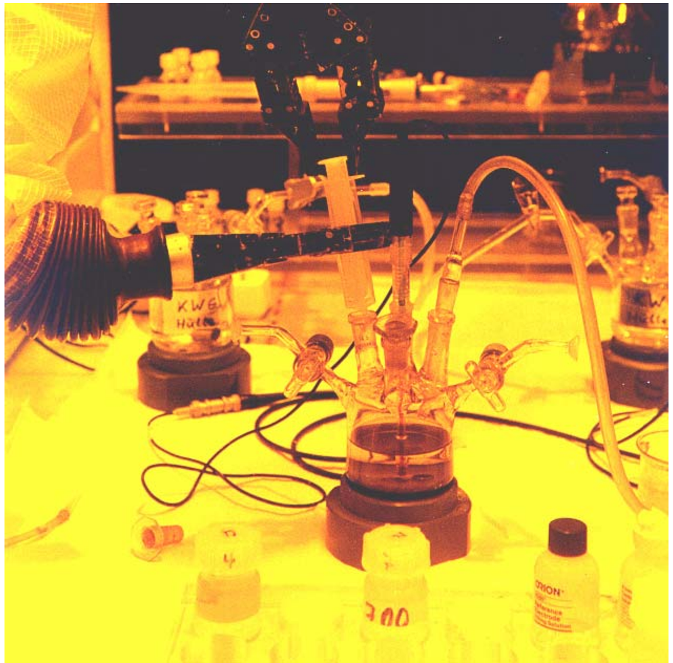
Loida, Metz & Kienzler (2007) MRS 30 (in press)

Experimental arrangement

Anoxic conditions (Ar atm), no carbonate,
Spent fuel sample, near field materials, 200 ml NaCl - solution (5m)

Ti/Pd lined autoclave (ca. 500 ml)

Quartz glass vessel (ca. 280 ml)

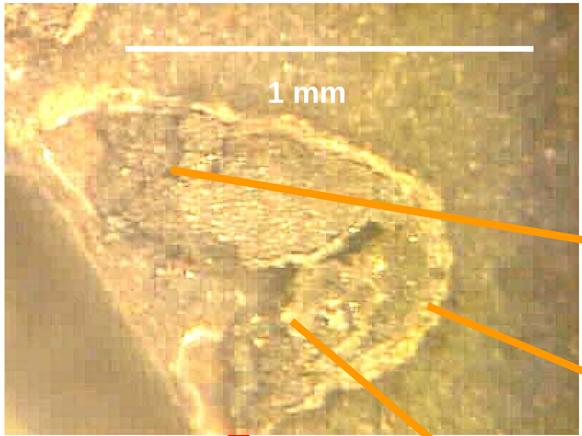


Determination of the reaction progress

Periodically analyzing of
•solution (0.45µm- 1.8 nm filtration)
•gases (Xe, Kr, H_2, O_2)

End of test:
SEM/XRD-investigation of
all solid phases

Spent fuel corrosion: Solid phases in presence of Fe corrosion products



Fuel, (non) oxidized Fe-particles

Secondary electron image

3 µm

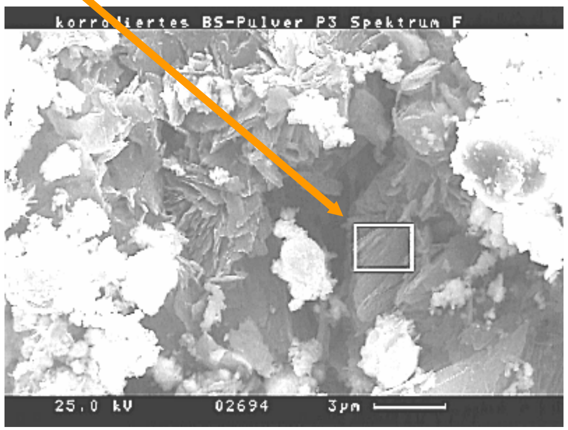
Backscattered electron image

Fuel-, Fe-powder, Reaction product agglomerations

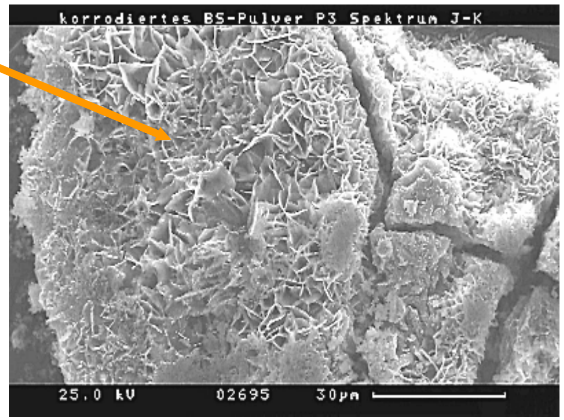
Secondary reaction products

Mg, Fe,O

(EDX-Analysis)



3 µm



30 µm

Secondary reaction products Fe, Si, O, Cl

(EDS-Analysis)

Conclusions

- R+D of INE is independent on site selection process and political implications
- R+D covers
  - Basic investigations
  - Speciation methods / development
  - Applied investigations
- R+D oriented towards „geochemically based long-term safety assessment“
- Quasi closed system approach successfully applied to
  - Cemented waste forms (JNST 44(3), 420-456, 2007)
  - HLW glass (Waste Manag. 21(8), 741-752, 2001)
  - Spent Fuel (MRS Conf., EU projects)
- Modeling verfied by experiments
- Strong links to INE's „Basic Investigations“ e.g. thermo-dynamics of actinides and „development of speciation meth.“

INE's actual cooperation with Chinese partners

- Joint Venture „HLLW Vitrification Project"

  Germany: Consortium STEAG encotec and EWN (WAK) (Sub-contractor INE)

  China BINE (Beijing Institute of Nuclear Engineering

  CNNC (China National Nuclear Cooperation)

  CNEIC (China Nuclear Engineering Industry Cooperation)

  SEPEC (Sichuan Environmental and Protection Engineering Cooperation)

- Research Partnership with CIAE (China Institute of Atomic Energy) in the area of "Safety of Nuclear Waste Disposal)
  e.g. laser spectroscopy
- MIGRATION 2011 Conference
  Beijing University (Beijing National Laboratory for Molecular Sciences, Department of Applied Chemistry)

Thank you for your attention

Methods available at INE (1)

Chemical and radioactive laboratories

Glove boxes, shielded remote handled boxes

- Radiometrical Methods
- Element and Isotop Analyses
- Solid phase- / surface methods
- Anion / Gas Analysis Methods
- Laser spectroscopy
- Colloid characterization methods:

Methods available at FZK-INE (2)

- Chemical and radioactive laboratories
- glove boxes
- shielded remote handled boxes

- Radiometrical Methods:
  - γ-Spectrometry,
  - Low-Level Anti-Compton-Spectrometry
  - HPGe- Detectory
  - α-Spectrometry
  - LSC / Low-Level-LSC

- Element and Isotop Analyses:
  - ICP-AES (Glove-Box)
  - ICP-AES Atom Emission Spectrometry
  - FIAS,
  - ICP-MS (glove Box) with FIAS

- Solid phase- / surface methods:
  - XRF
  - X-Ray Diffraction Analysis (XRD)
  - Raman spectroscopy
  - ESCA / Auger Spectroscopy.
  - Electron Microscopy
  - Electron-Probe Microanalysis (SEM-EDX)
  - Laser-Ablation

- Anion / Gas Analysis Methods
  - Ion-Chromatography
  - Gas-Chromatography
  - Carbon Determination
  - Gas- Mass Spectrometry
  - DTA, TG
  - UV-Spectrometry

- Laser spectroscopy:
  - Time Resolved Laser Fluorescence Spectroscopy (TRLFS)
  - LPAS Laser Photo Acoustic Spectroscopy
  - Laser Induced Breakdown Spectroscopy (LIBS)

- Colloid characterization methods:
  - Laser Induced Breakdown Detection (LIBD)
  - Photon Correlation Spectroscopy (dynamic light scattering: PCS)
  - Multi-Angle Laser Light Scattering (MALLS)
  - Flow Field Flow Fractionation (FFFF) coupled with UV-vis, MALLS, ICP-MS, LIBD

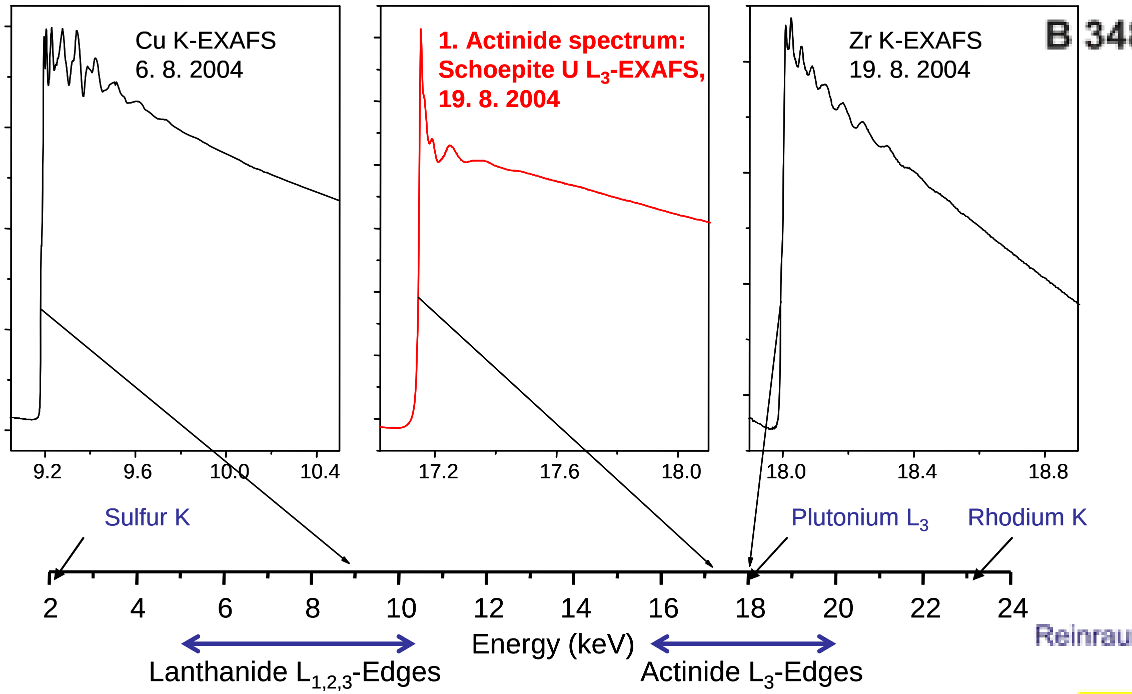
INE Beamline for actinide research and for in-situ speciation

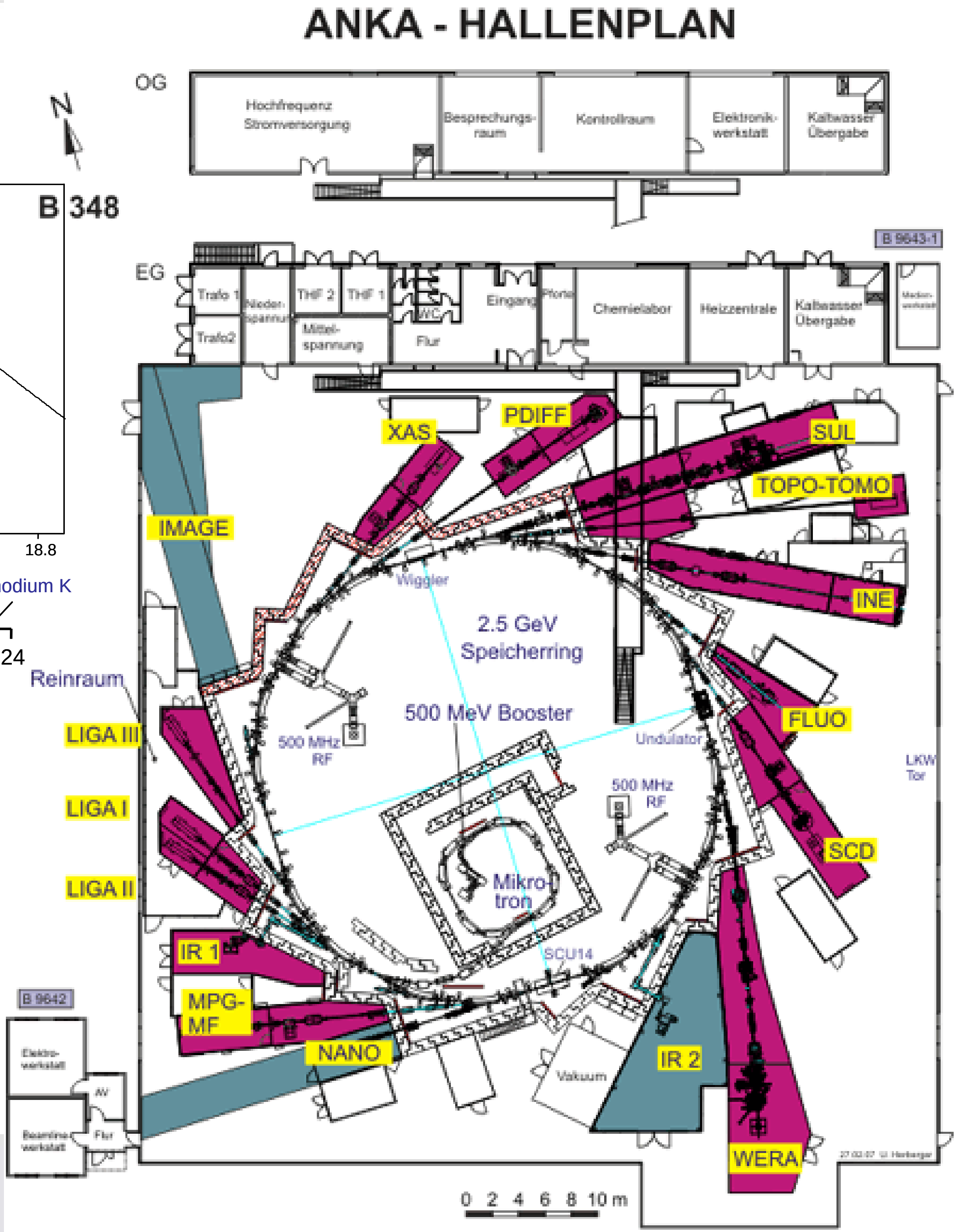
- **ANKA facility on site**
- **INE Beamline**
  - ✓ **Research program in synchrotron-based actinide speciation.**
  - ✓ **On-site, *in situ* actinide research backed by know-how and infrastructure.**
  - ✓ **Activities up to 10^6 times the exemption level. Allows studies not possible at other synchrotron laboratories.**
  - ✓ **Multi-purpose beamline → a number of dynamic methods (surface sensitive and spatial resolved techniques)**
  - ✓ **Safe and flexible containment concept**

Fields of possible cooperation with BRIUG

- To be defined during this workshop

ANKA





http://ankaweb.fzk.de/

Experimental Techniques for the Researches on the Migration of Radionuclides and the Alteration of High Level Waste

Laboratory for the Research on the Treatment and Disposal of Radioactive Waste

CONTENT

- **1. Introduction of our lab**

  2. The Disposal of High Level Waste and The Task of Our Lab

- **3. The Experimental Techniques for the Study of Migration of Radionuclides**

- 4. **The Experimental Techniques for the study of the Alteration**

- **5. Summary**

1. Introduction of our lab

- CIAE
  - Dept.Nuclear Physics
  - Dept. Radiochemistry
    - Reprocessing
    - Nuclear and Radiochemistry
    - Radioactive Waste Treatment and Disposal
    - Chemical Analysis
    - Radioactive Analysis
  - Dept. Reactor Engineering
  - Dept. Radioisotopes
  - Dept. Nuclear technique Application
  - Dept. Radiation Safety
  - Dept. Radiodosage Measurement

中国原子能科学研究院
China Institute of Atomic Energy

Research Areas of Our Lab

- **1. Migration of Radionuclides**
  2. Vitrification and SYNROC
- **3. Low and Intermediate Level Waste Treatment**
- 4. **Decontamination**

Research Areas of Our Lab

- **1. Migration of Radionuclides**

_Solubility of Longlived Radinuclides(LLR) in Aqueous Media

_Distribution and Diffusion coefficents of LLR in the Backfiling/Engineering Materials

Research Areas of Our Lab

- **2. Vitrification and SYNROC**
- **-Formulation of HLW Glass**
- **-Immobilization of Minor Actinides by SYNROC**
- **-Glass Ceramique**
- **-Cold Crucible**
- **-Alteration of Waste Matrice in Aqueous Media**

Research Areas of Our Lab

- **3. Low and Intermediate Level Waste Treatment**
- **-TBP/OK Pyrolysis**
- **-Cementation**
- **-Bituminization**
- **-Polymerization**

- 4. **Decontamination**
- **-Decontamination of Plutonium equipment**
- **-Decontamination of Big tanks**

2. The Disposal of High Level Waste and The Task of Our Lab

- **The Research Areas on the Disposal of High Level Waste of China:**
- **_Strategy Study**
- **_Disposal Engineering Study**
- **_Disposal Geology Study**
- **_Disposal Chemistry Study**
- **_Disposal Assesment Study**

Disposal Chemistry Study

- -The longterm Stability Study of Glass And the Package
- The Alteration of Glass and the Metal Copper
- _Aqueous Chemistry of Radionuclides
- The Interation of Humic Acids with the Np and Tc
- _Migration of Radionuclides in the Near Field of the Repository
- The Disposal Behavior of Key Radionuclides
- -DataBase and Model of Disposal Chemistry

- **3. The Experimental Techniques for the Study of Migration of Radionuclides**

_The Characteristics of Minor Actinides

_The anoxic glove-box

_ low level liquid scintillation spectrometer

_The Diffusion device

_Granite Core Diffusion Device

- **The Characteristics of Actinides**

  _Polyvalent

  _Sensentive to Eh-Ph Value

  _Too dilute or even ultra dilute concentration

The anoxic glove-box

The concentration ofO2 <5ppm

_Solubility of the Actinides

_Distribution and Diffusion Coefficent

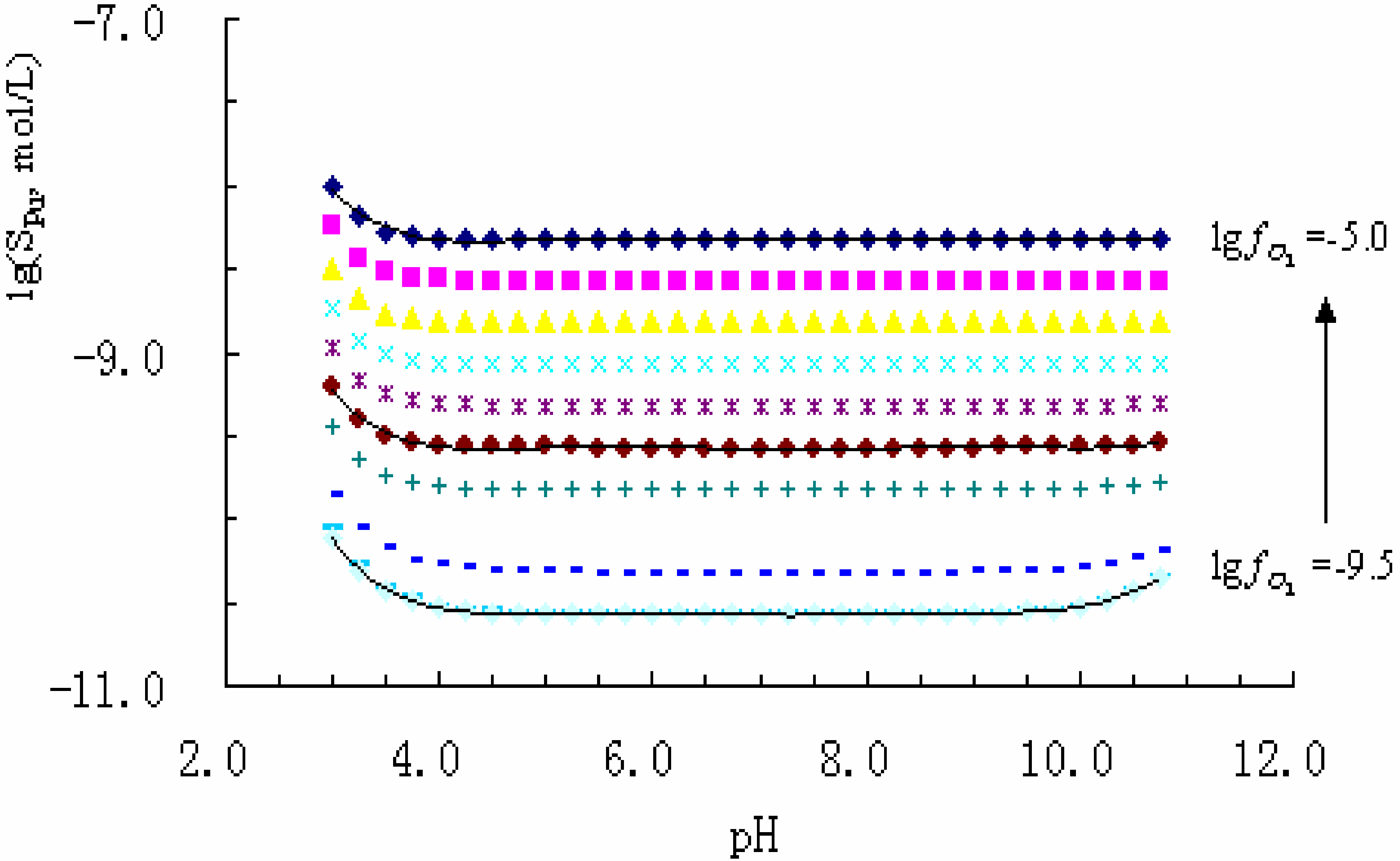
The anoxic glove-box

low level liquid scintillation spectrometer

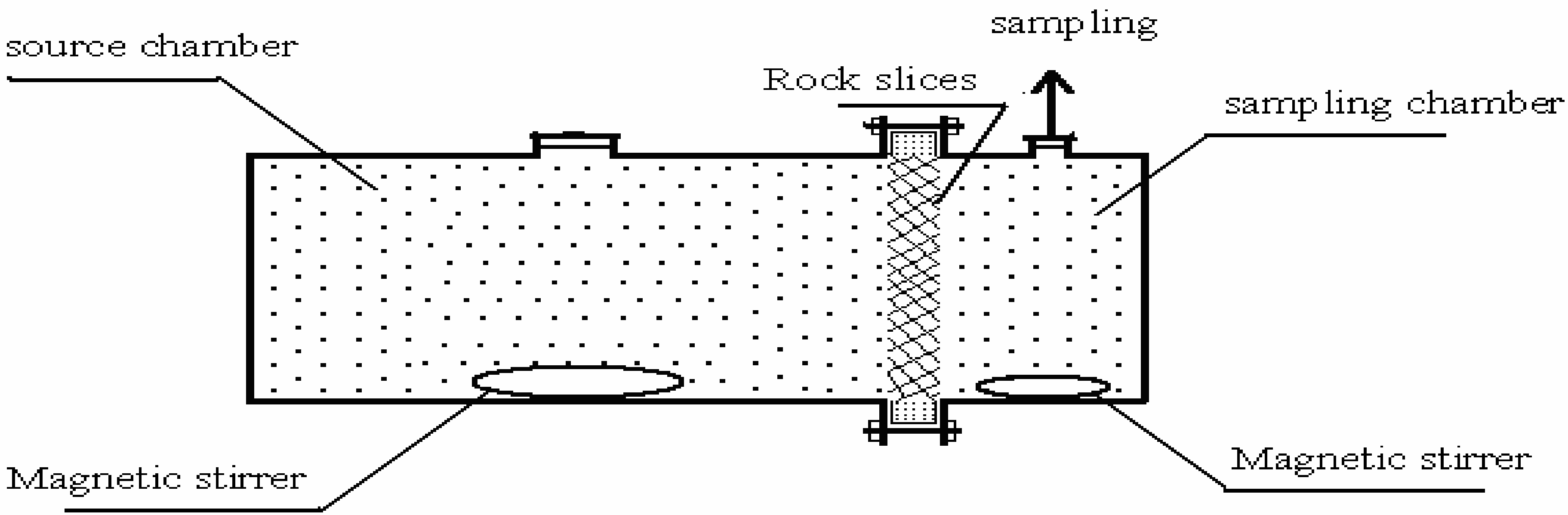
Alpha:0.22cpm

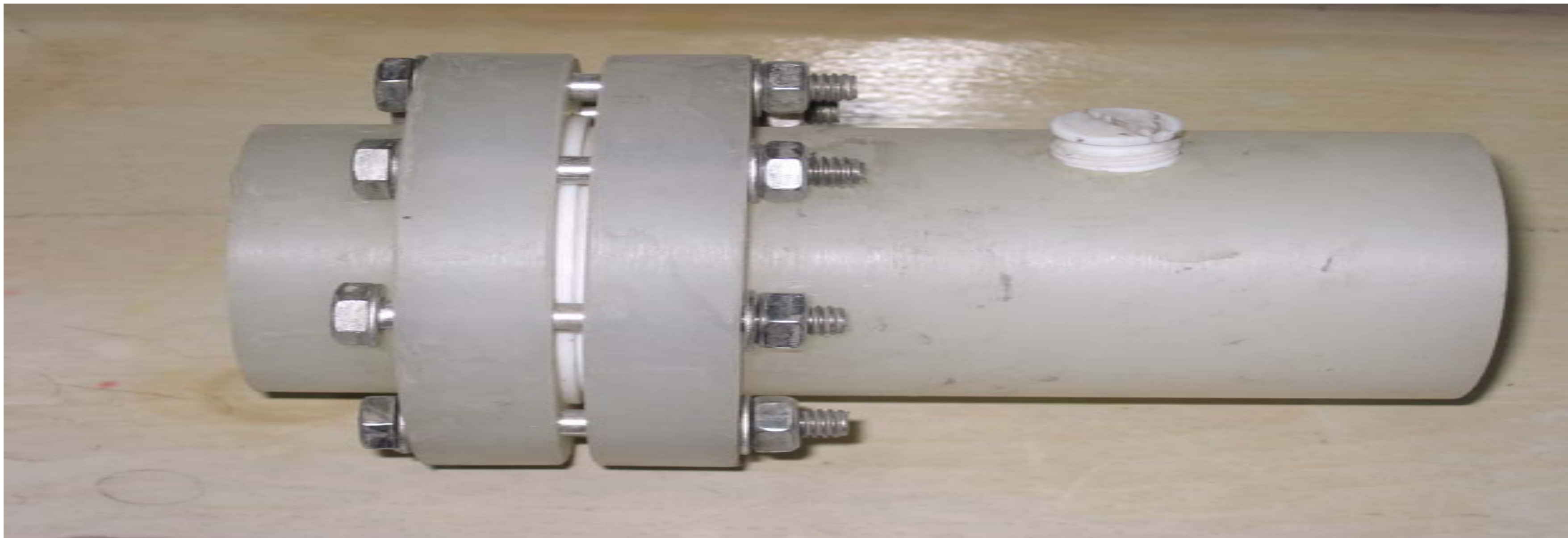
Beta: 1.55cpm

The solubility of Plutonium in Beishan Underground water



The Diffusion device





Granite Core Diffusion Device

P : 100MPa
T:180℃.

- **4. The Experemental Techniques for the study of the Alteration of HLW Matrix**

- **_The release of radionuclides into the environment is only realized though the alteration of the matrix glass**

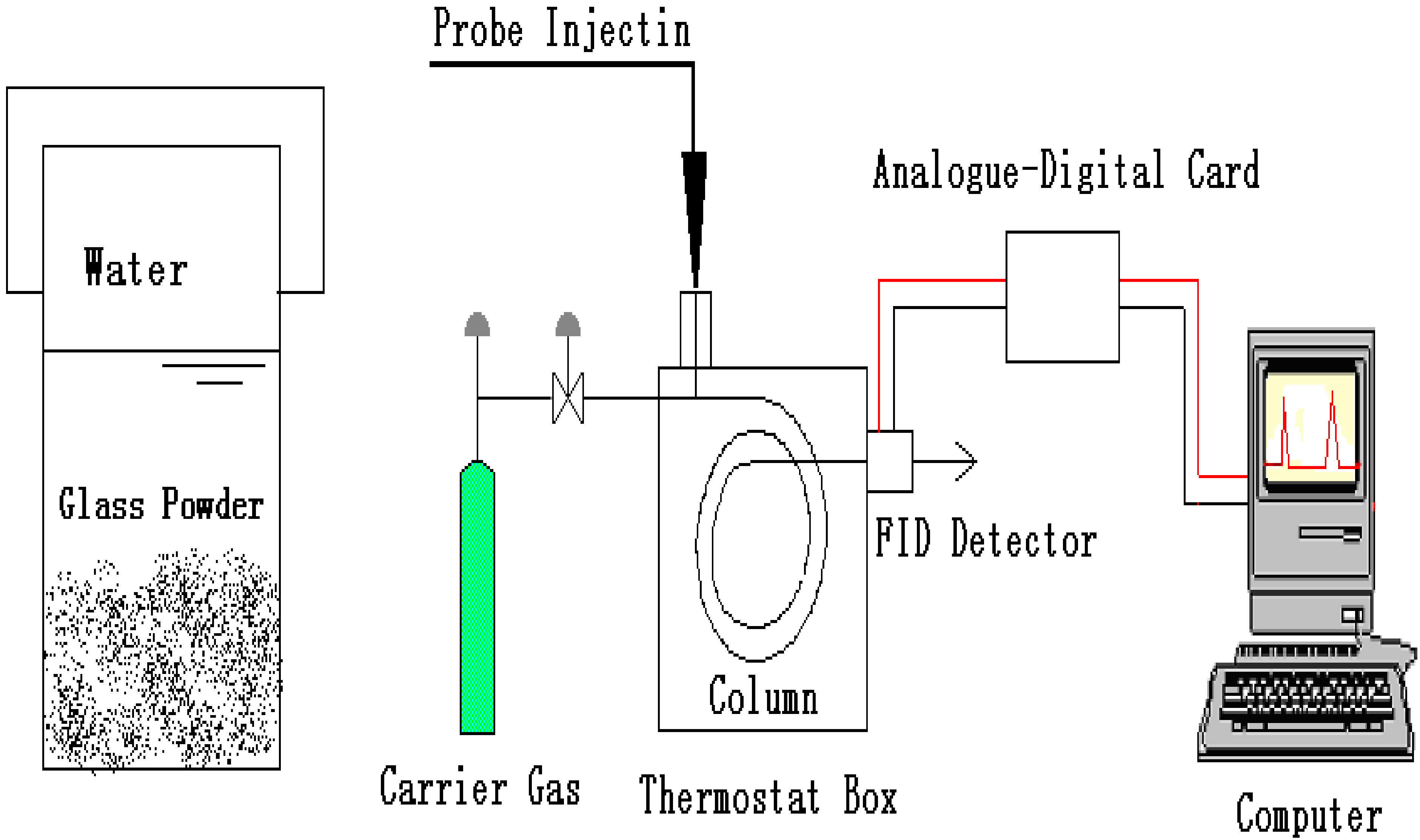
- **_The Underground water will contact the waste by seeping into the canister through the corrosion holes.**

- **_The waste block has many fissures and the alteration will start on the fissure surfaces**

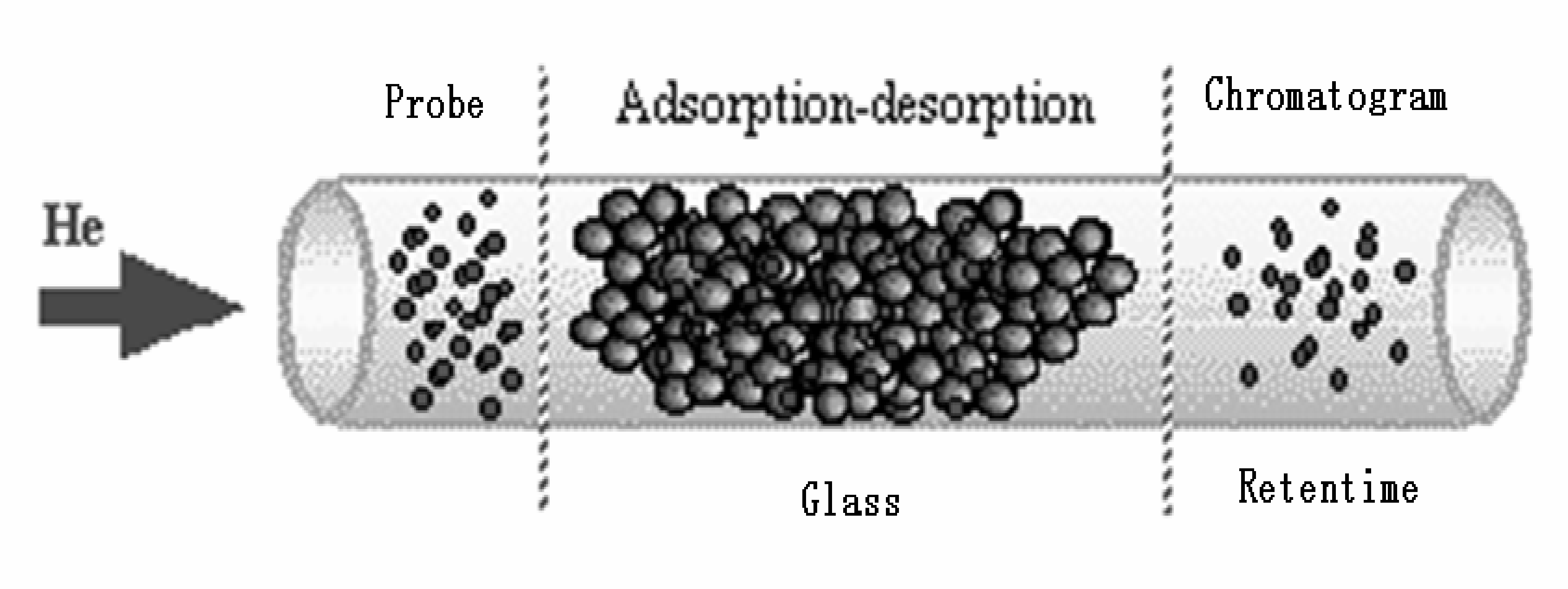
- **_We will use the inverse gas chromatography(IGC) to study the evolution of the altered surface**

中国原子能科学研究院
China Institute of Atomic Energy

The Study of Glass Surface Alteration by Inverse Gas Chromatography



The Study of Glass Surface Alteration by Inverse Gas Chromatography

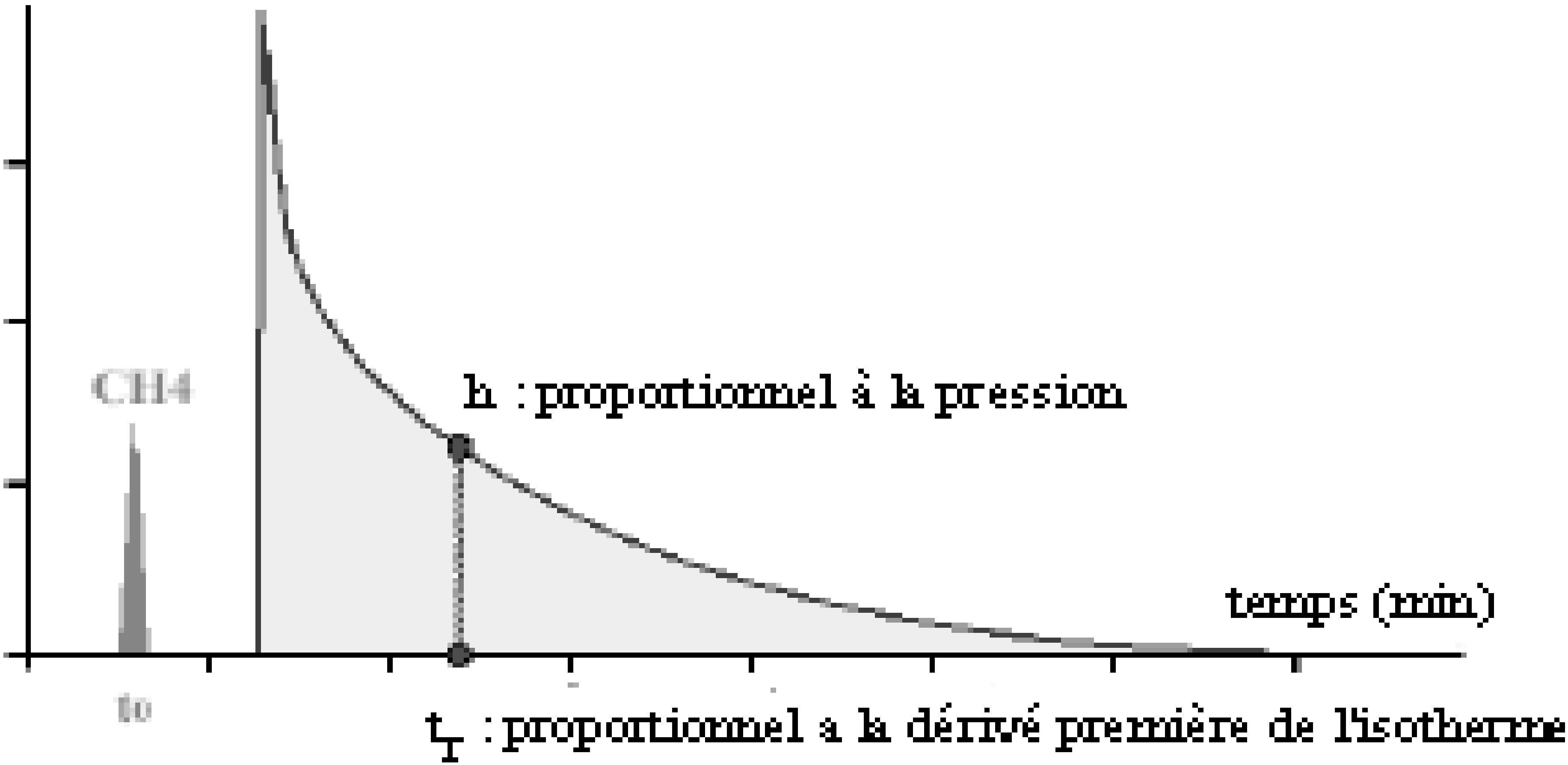


IGC can measure the following surface parameters:

_The Specific Surface Area S(m2/g)

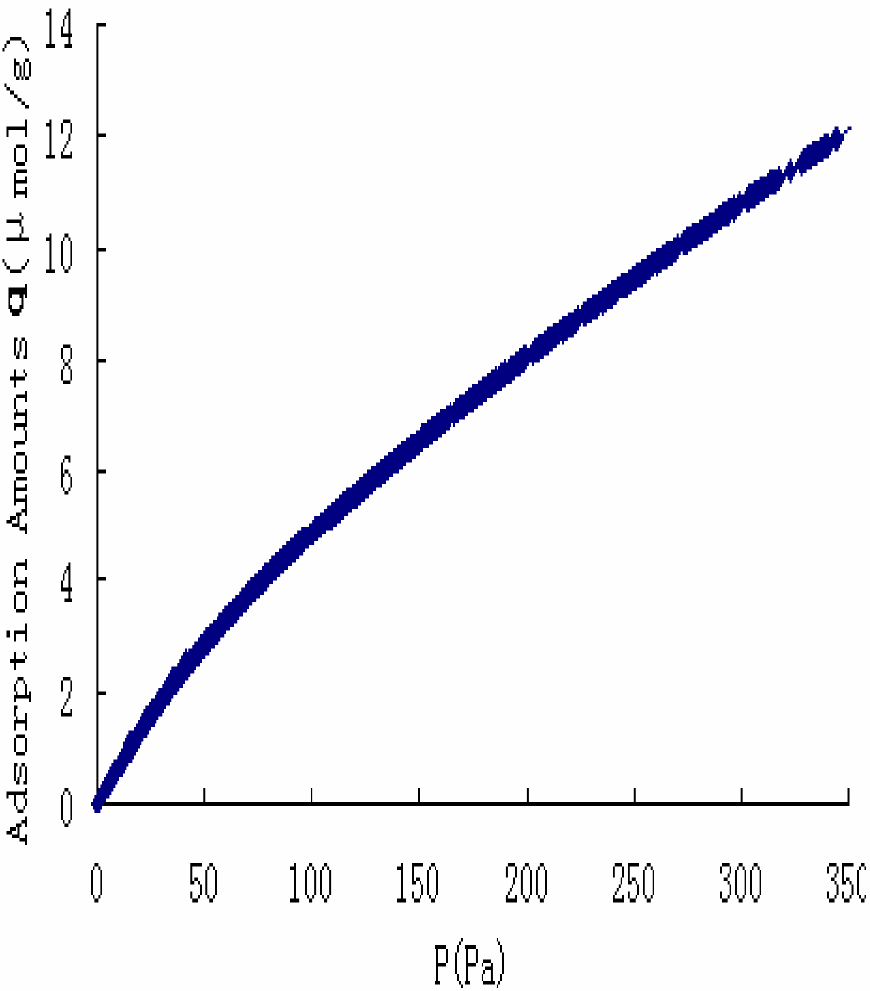
_The Surface Morphology Index IM

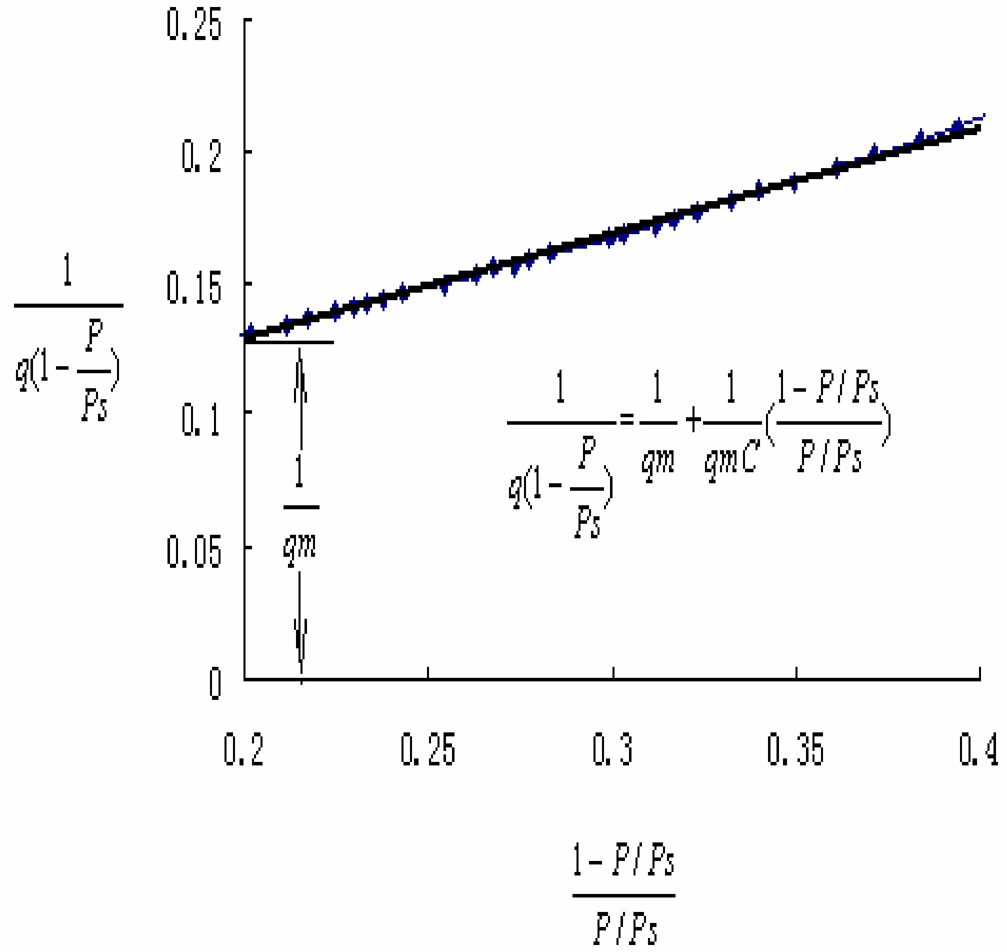
From Chromatogram to the Specific Surface Area



$$\left(\frac{\partial N}{\partial P}\right)_{L,\ t_R} = \frac{1}{RT}\,\frac{D_c}{m}\,(t_R - t_0)$$

The Specific Surface Area

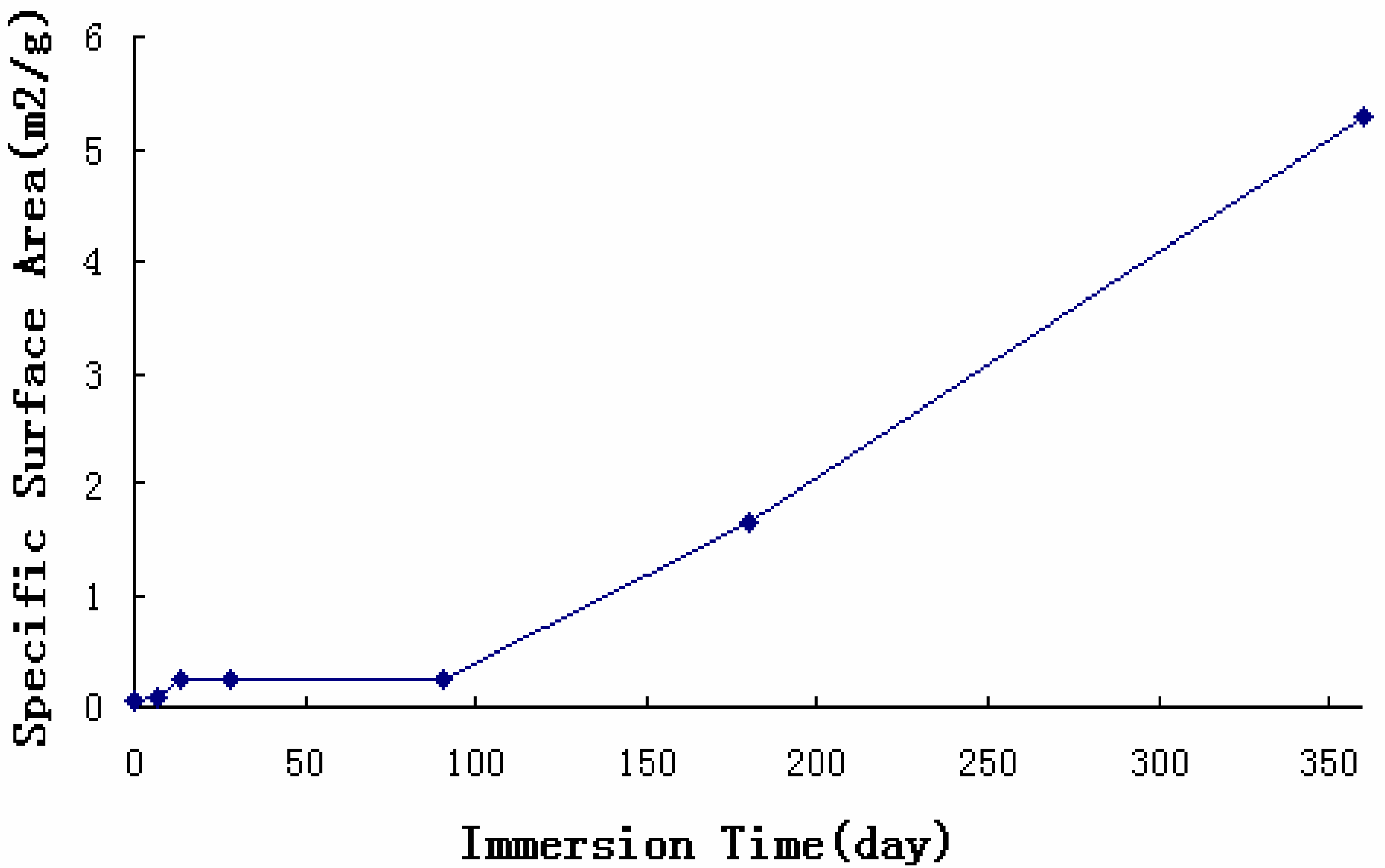




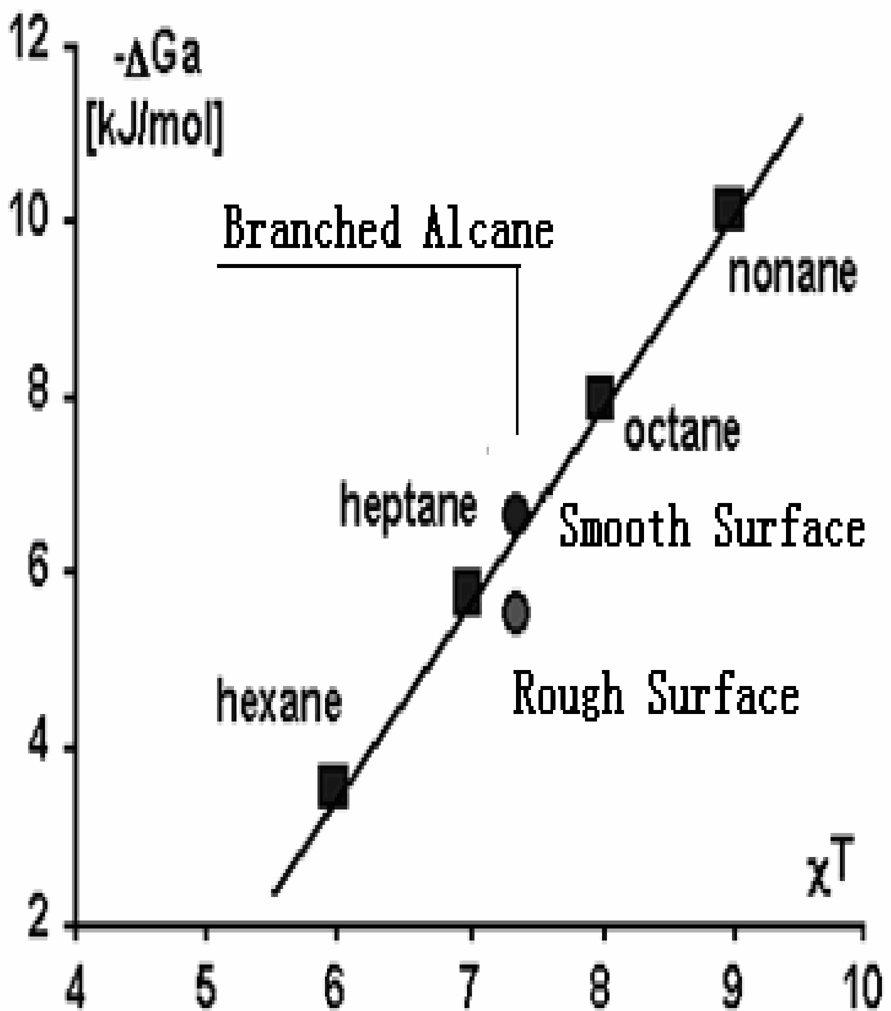
By linearization of the adsorption isotherm, the monlayer capacity can be calculated ;

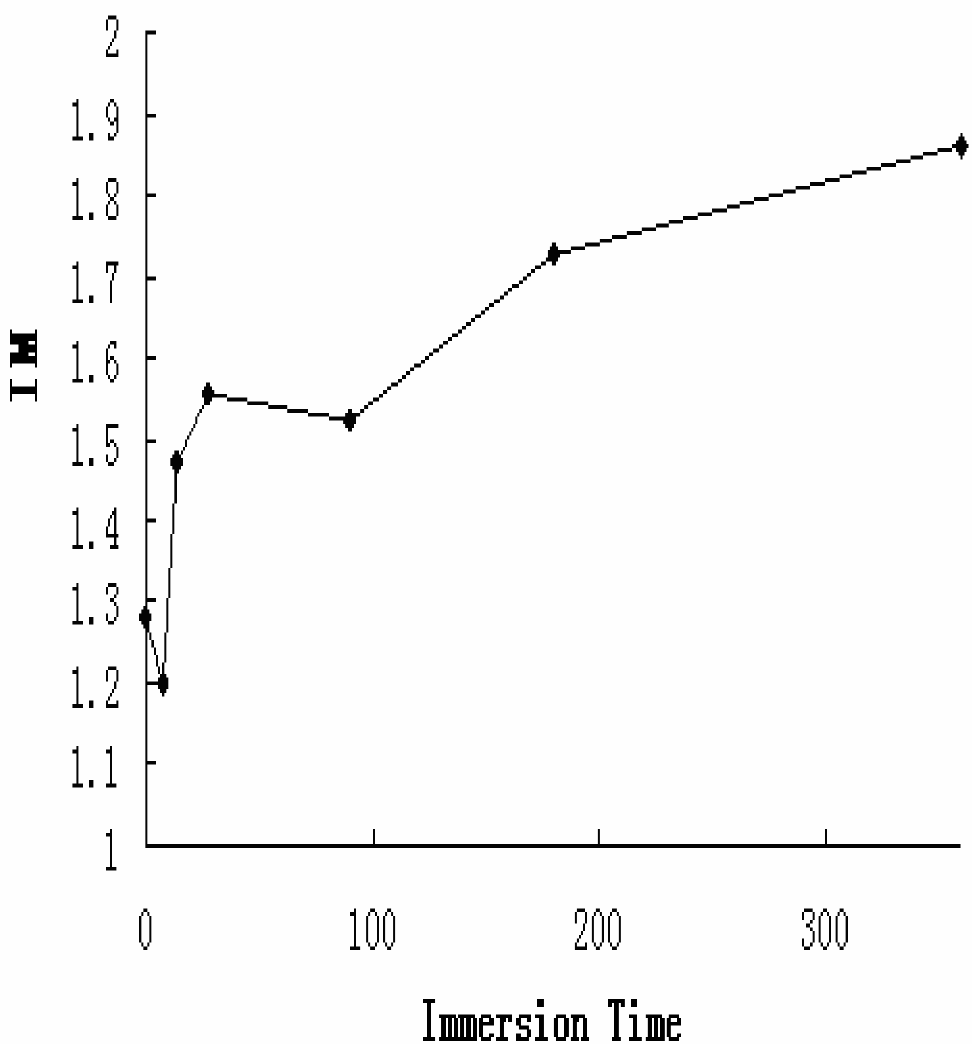
Using the monolayer capacity, the specific surface area can be calculated

Specific Surface Area S vs Immersion Time



The Surface Morphology Index





IM(Branched Alcane) = exp[DGa(M)/DGa(C)]

- **The three-stage could be explained by the three-stage model of glass corrosion**

- **The first stage is dominated by interdiffusion**

- **The second stage is dominated by matrix dissolution.**

- **The third stage is due to the formation of surface layers by the precipitation and adsorption of the insoluable compounds**

5. Summary

- _We have established some small scale experimental techniques for the Study of Migration and Alteration in the laboratory
- _We will develop More large scale techniques to simulate some scenaios.
- _We will establish our databases for the Migration and Glass alteration
- _We wish to cooperate with German scientists in Waste treatment and Disposal

Technical Aspects
of Direct Disposal of Spent Fuel and HLW

Wilhelm Bollingerfehr

DBE TECHNOLOGY GmbH

Chinese-German Workshop on Radioactive Waste Disposal

May 28 – 31, 2007

Beijing

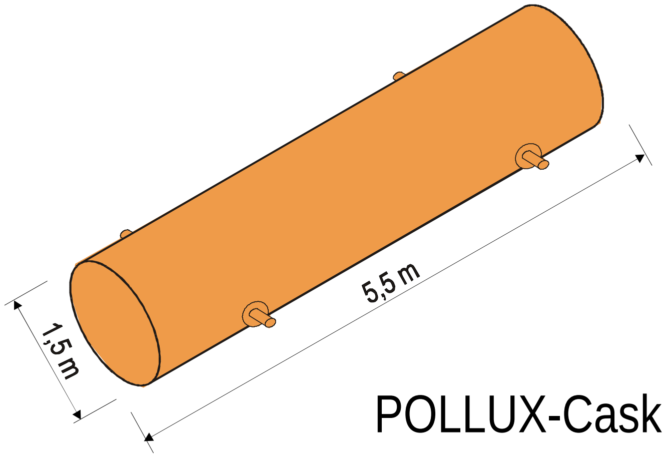
Outline

1. Introductory remarks to spent fuel direct disposal
2. German R & D program on direct disposal
3. Full-scale demonstration program
4. Recent developments
5. Summary and Conclusions

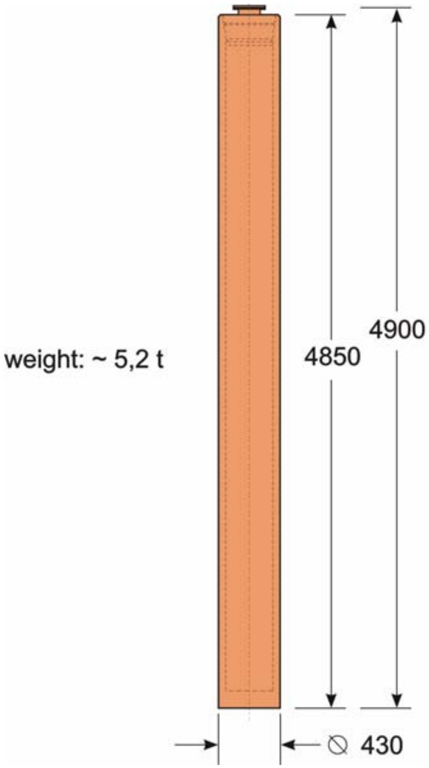
German Waste Accumulation and Forecast

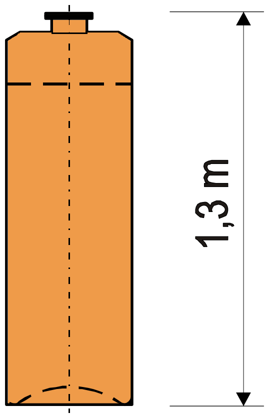
	Until 2000	2001-10	2011-20	2021-30	2031-40	Total	Total [m³]
• Heat generating waste							24,000.00
HAW-canisters	84.00	4,852.00	112.00	0.00	0.00	4,778.00	908.00
HAW-packages	0.00	840.00	7,576.00	2,400.00	0.00	10,816.00	2,814.00
AVR+THTR SNF elements	908,705.00	0.00	0.00	0.00	0.00	908,705.00	1,890.00
LWR SNF (Mg)	3,142.00	3,962.00	1,819.00	24.00	0.00	8,947.00	18,258.00
Research reactor SNF (Mg)							≈ 130.00
• IL/LLW non-heat generating (m³)	76,000.00	58,000.00	54,000.00	76,000.00	33,000.00	297,000.00	297,000.00
NNP	23,000.00	23,000.00	46,000.00	73,000.00	22,000.00	195,000.00	
Government facilities	53,000.00	27,000.00	8,000.00	3,000.00	11,000.00	102,000.00	

Disposal Canisters



POLLUX-Cask
(spent fuel)
weight: 65 t

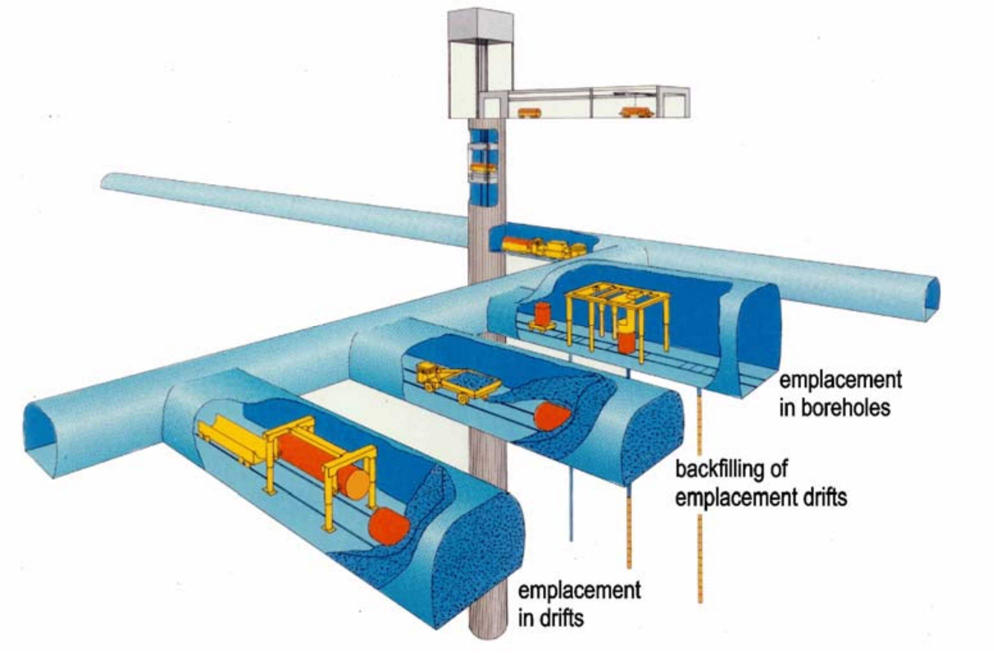




HLW-Canister
(vitrified waste)
weight: ~ 500 kg

BSK 3-Canister
(spent fuel)
weight: ~ 5.2 t

Disposal Concept



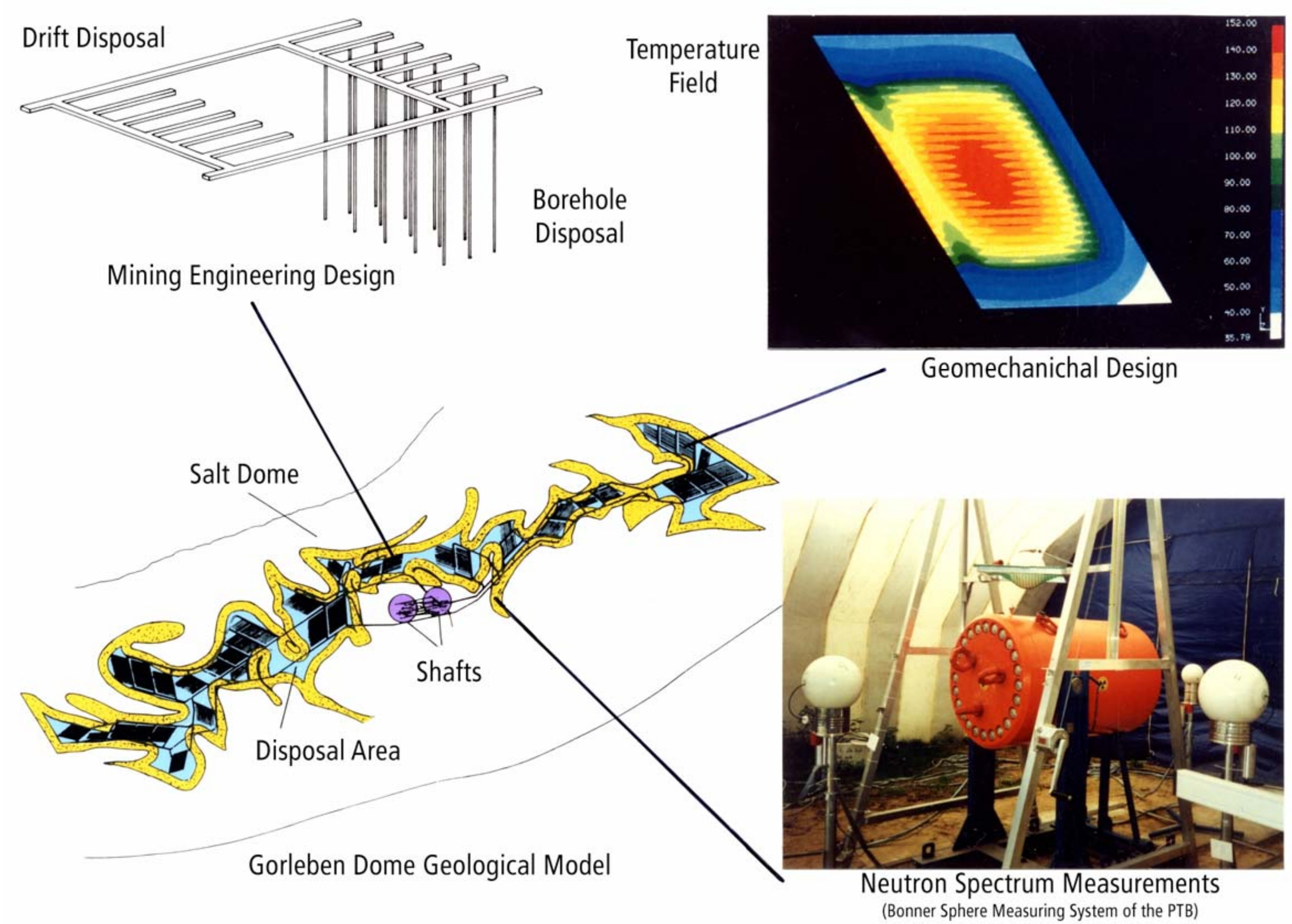
German Reference Concept
for HLW and Spent Fuel:
Direct Disposal in Rock Salt

- Deep geological disposal (depth: 840 m)
- Emplacement of HLW in boreholes and spent fuel casks in drifts
- Backfill material: crushed salt

Objectives of R & D Program

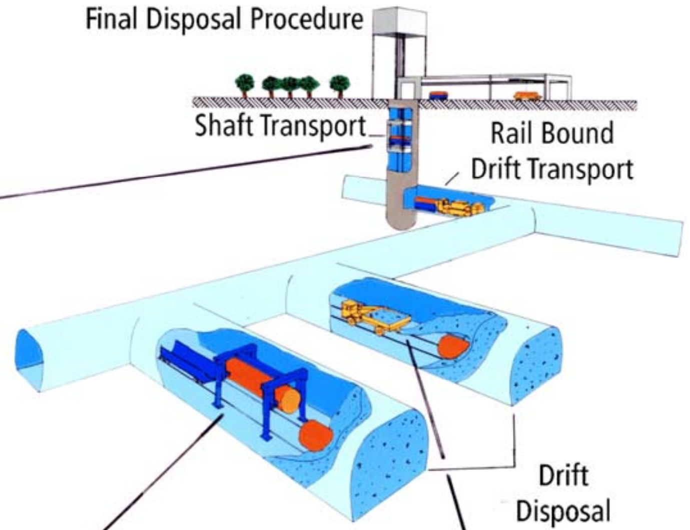
- Demonstrate safe and reliable transport of waste canisters
- Demonstrate technical feasibility of safe spent fuel emplacement in rock salt
- Increase the data base on important phenomena and processes in and around a backfilled repository
- Strengthen the scientific basis required for repository design and performance assessment

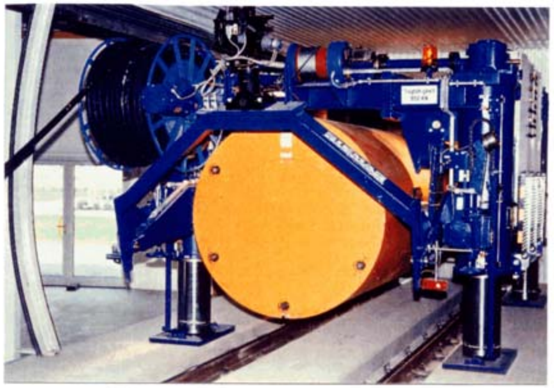
Repository Layout



Scope of Full-Scale Demonstration Program

Hoisting Cage for 85t Payload





Waste Emplacement Machine

Backfilling Slinger Truck in a Disposal Drift

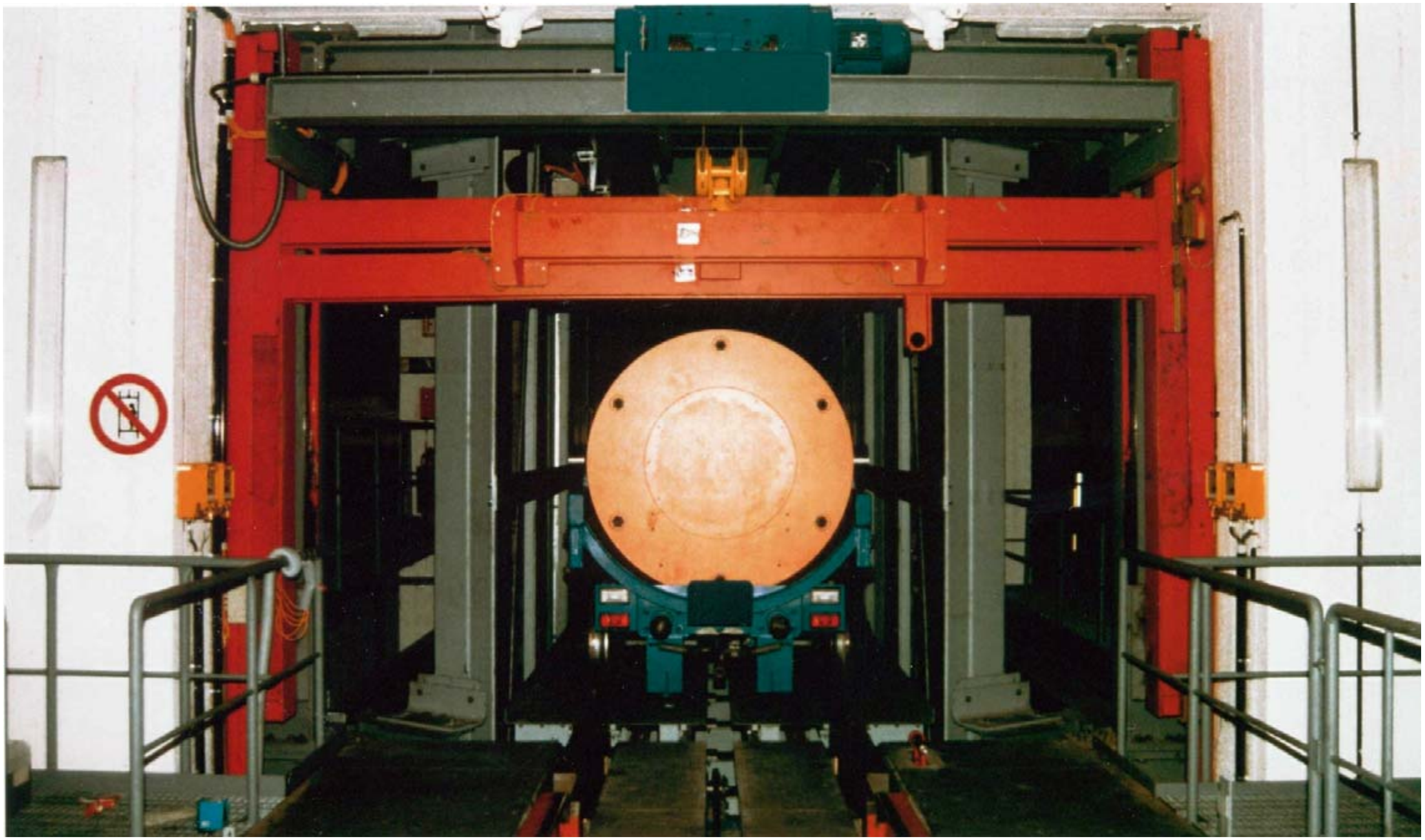
Design of a Shaft Hoisting System

Technical data:

Depth of shaft:	1,000 m
Max. payload:	85 t
Max. speed:	12 m/s at 30 t
	5 m/s at 85 t
Motor power:	2 x 2,800 kW

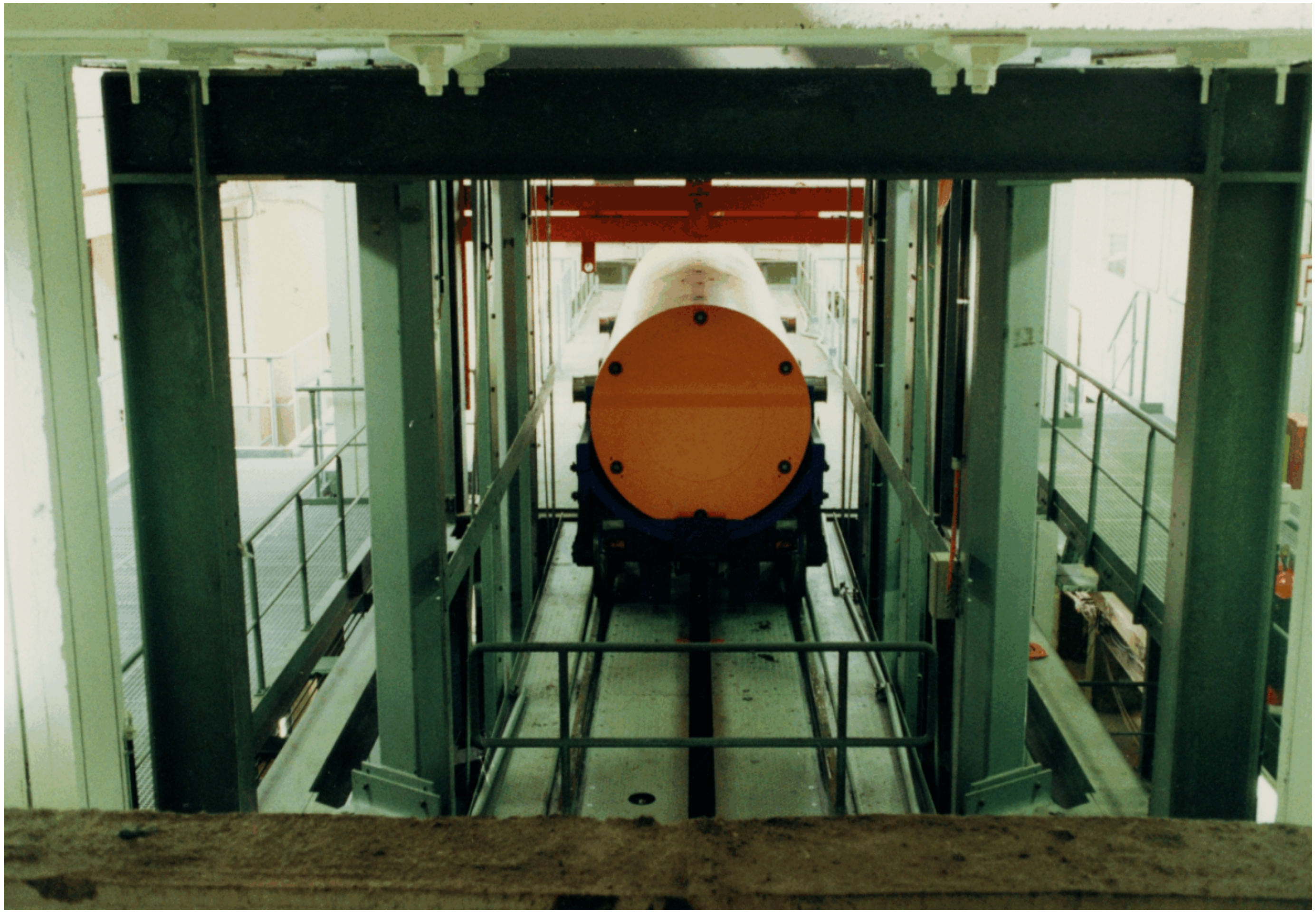
Longitudinal section through the shaft hoisting system

Shaft Hoisting System



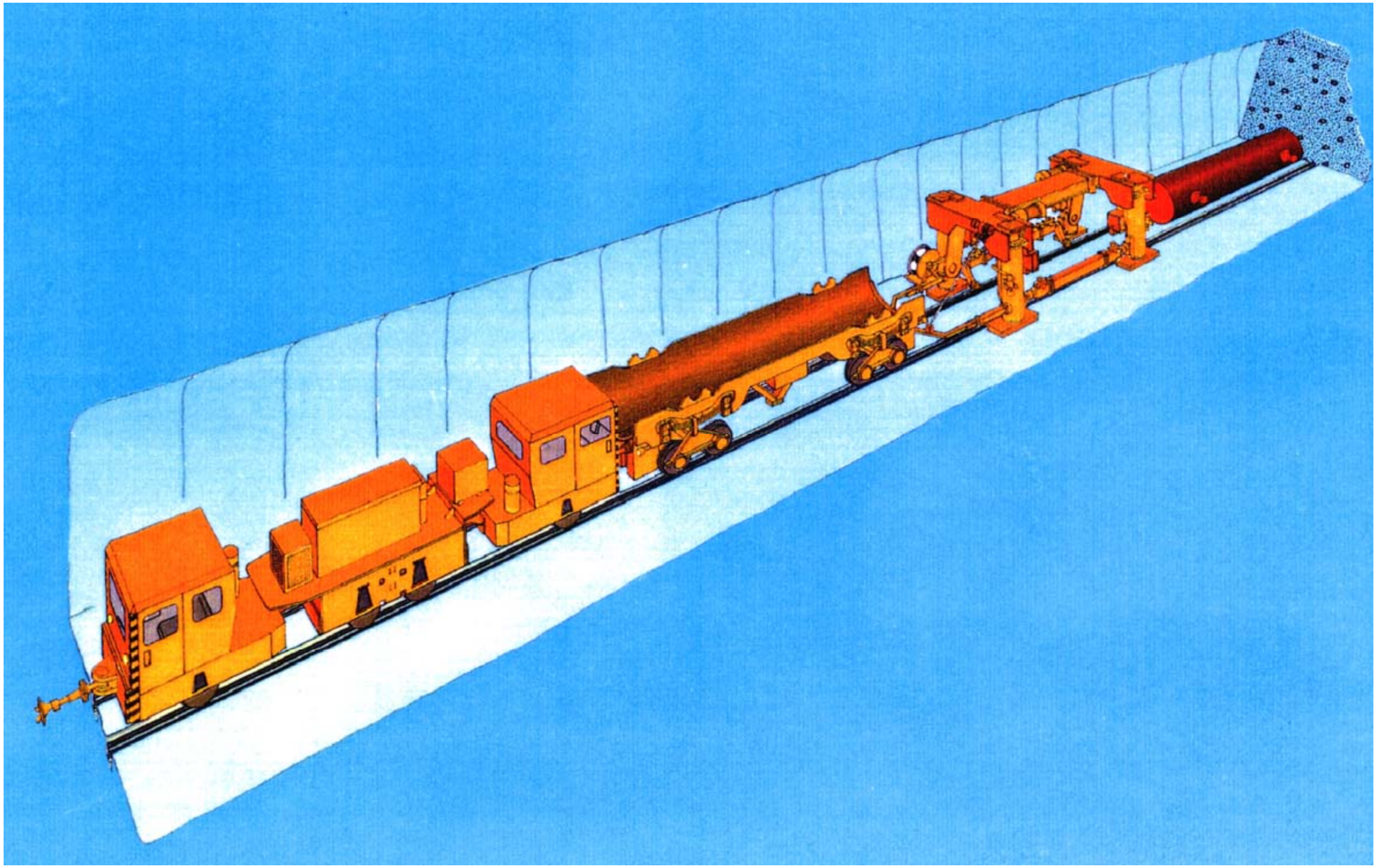
Full-scale demonstration of the shaft hoisting system at the test site

Shaft Hoisting System



Full-scale demonstration of the shaft hoisting system at the test site

Emplacement Technology

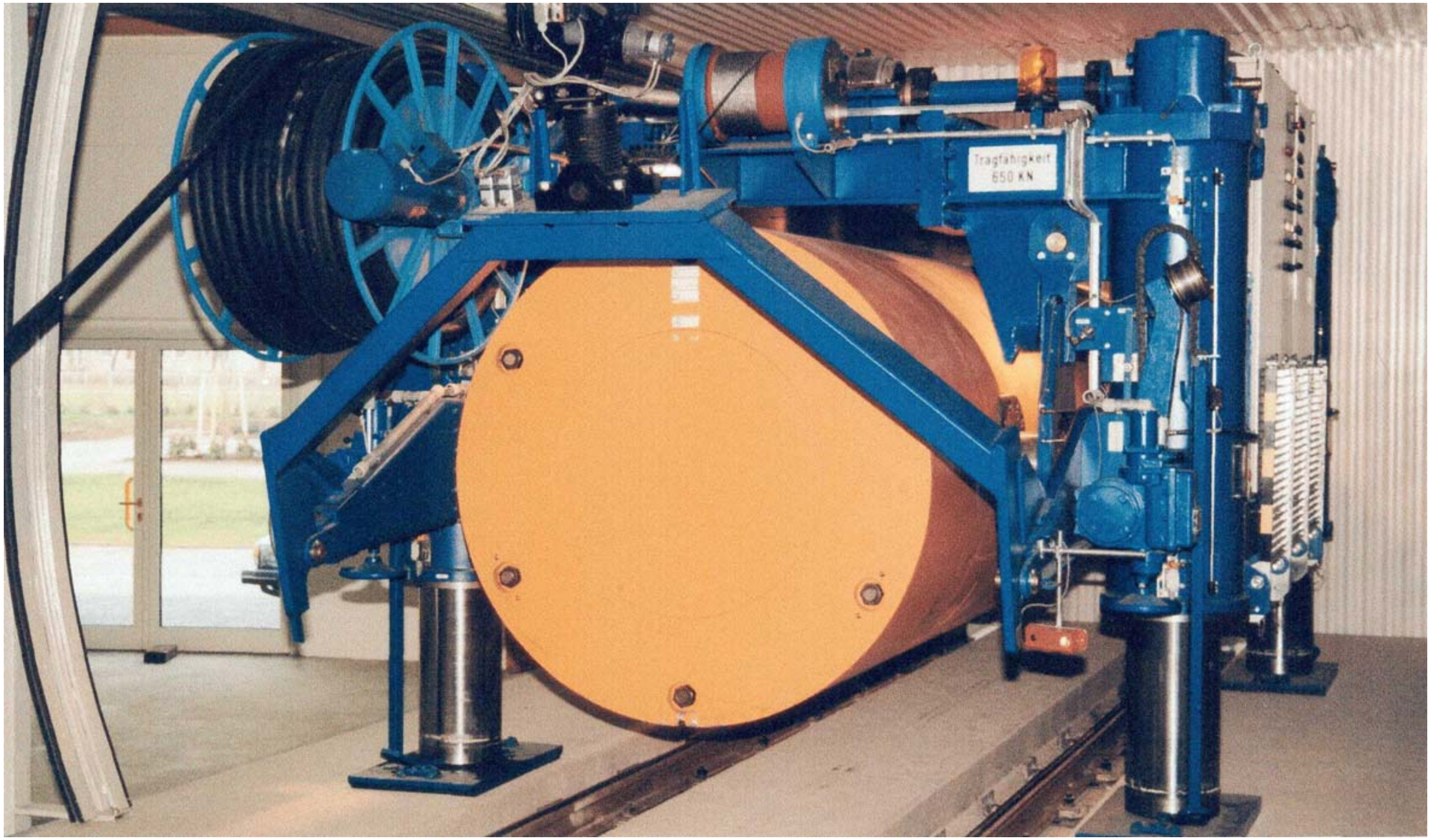


Concept of the emplacement system for POLLUX casks

Emplacement Technology

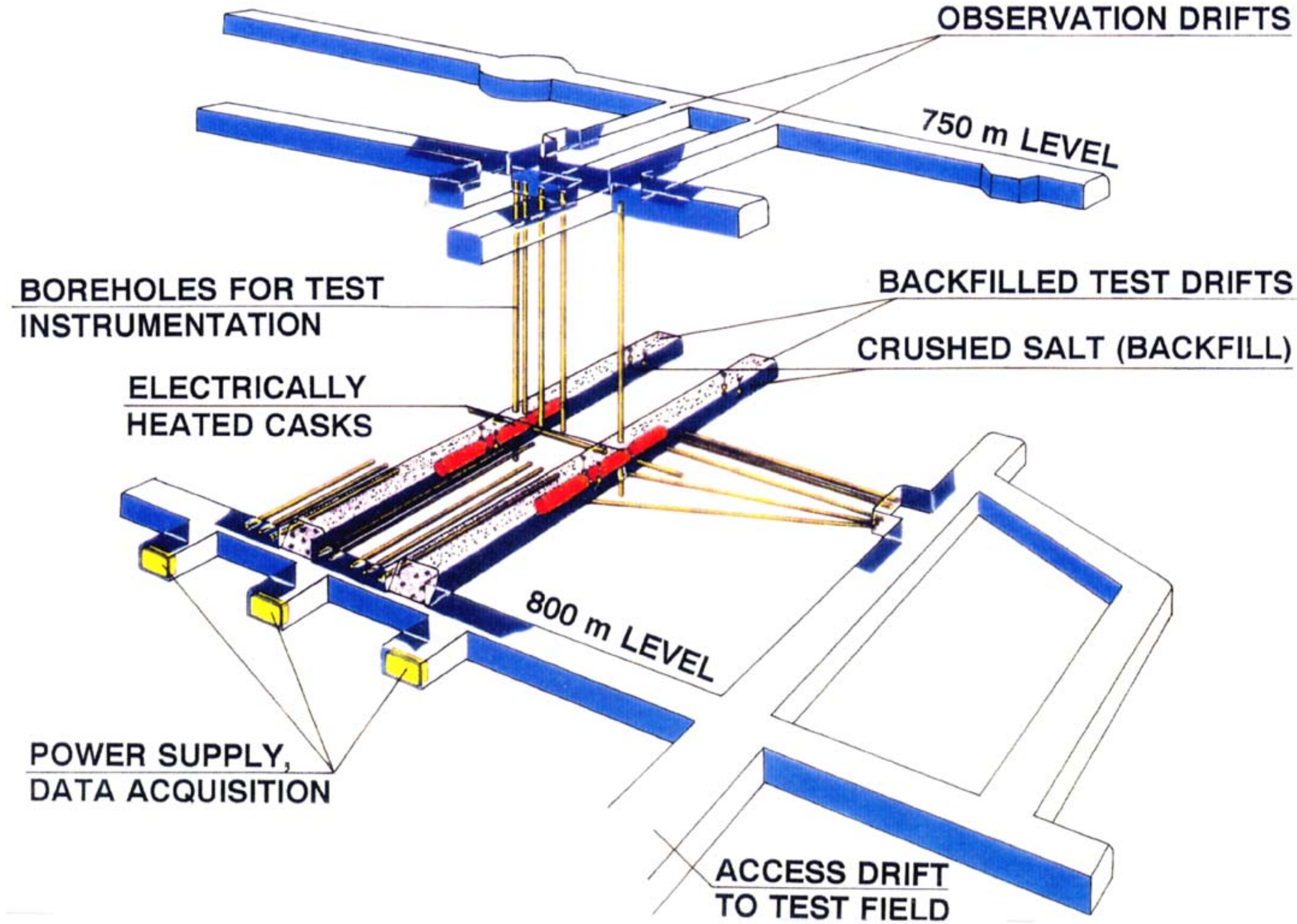
Full-scale demonstration of the POLLUX emplacement system
at the test site in Peine

Emplacement Technology

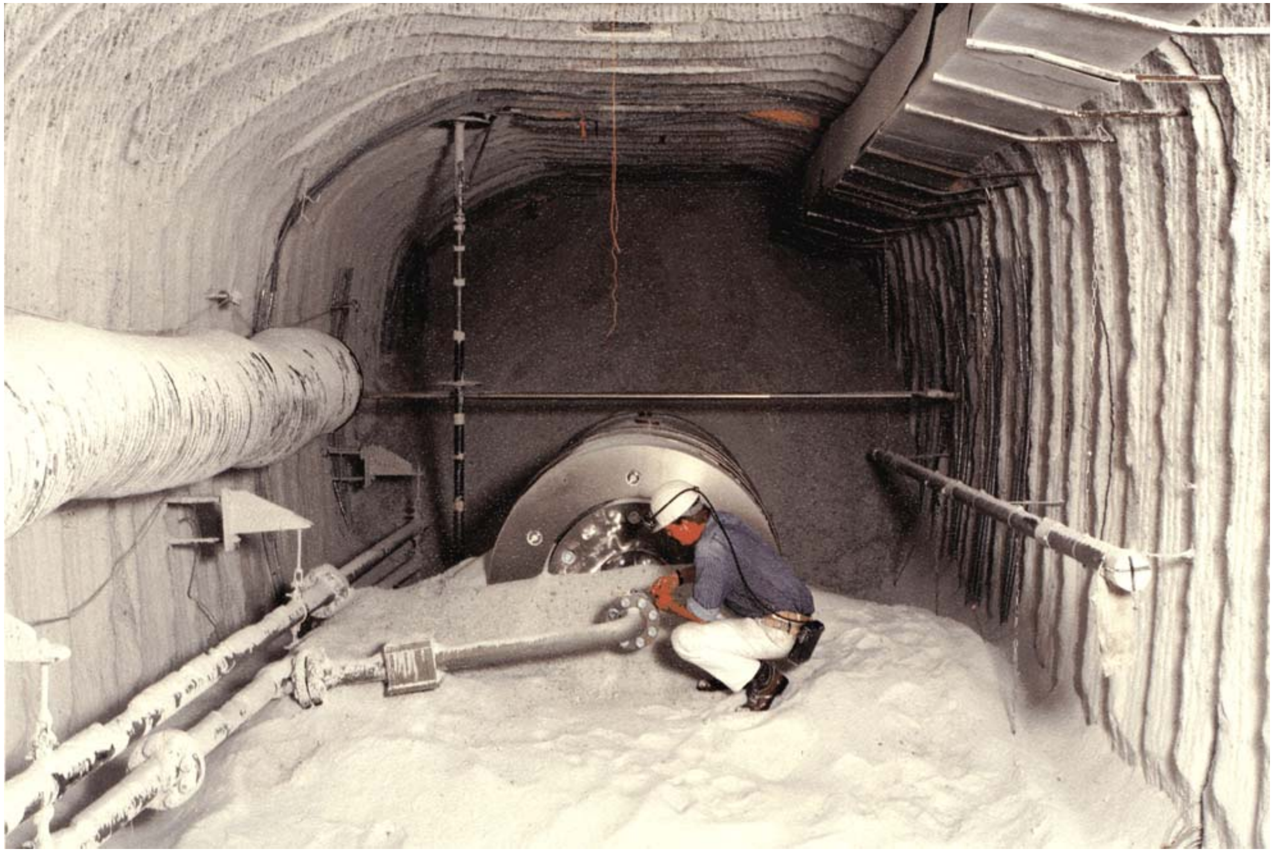


Full-Scale Emplacement machine

In situ-Test in the Asse Mine

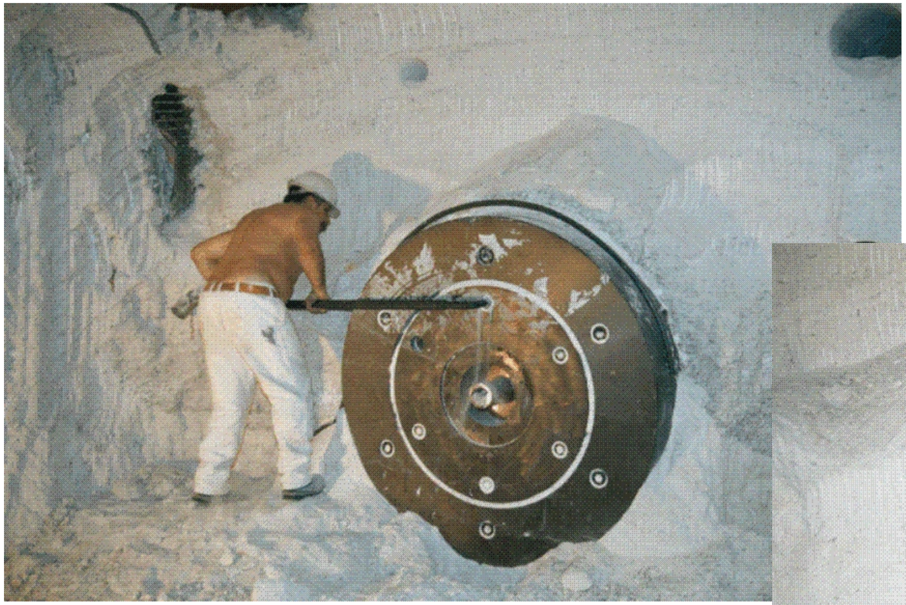


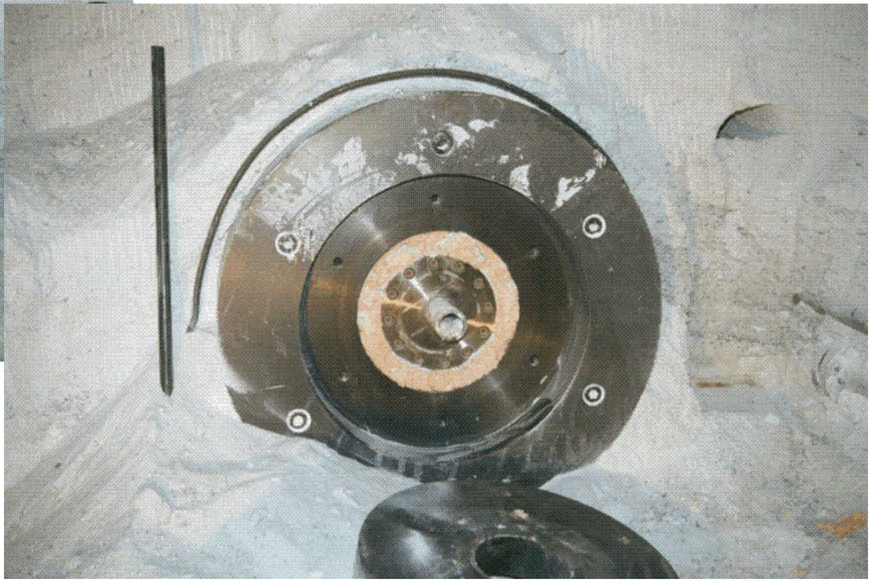
In-situ test in the Asse mine



Fulls-scale test set up for investigating heat impact on host rock and backfill

In situ test in the Asse mine

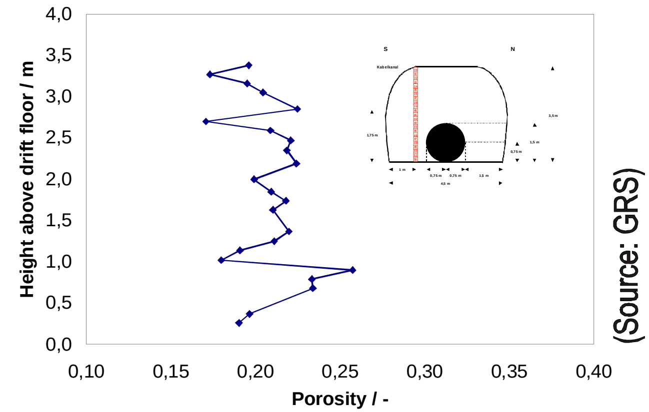




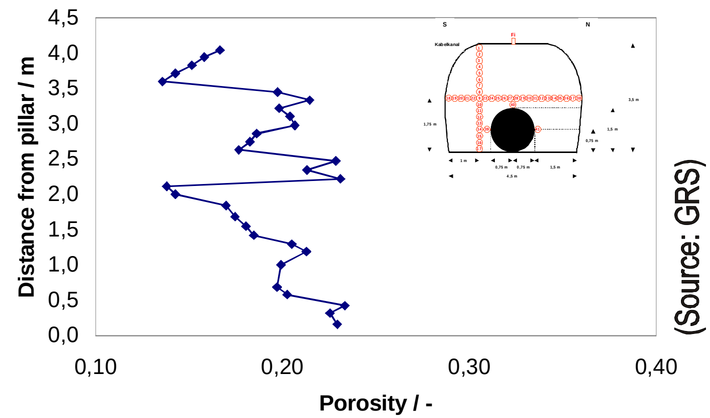
Dismantling of heater casks after approx. 10 years of in-situ operating

Results of Backfill in-situ Tests

Backfill sampling around the central heater after dismantling

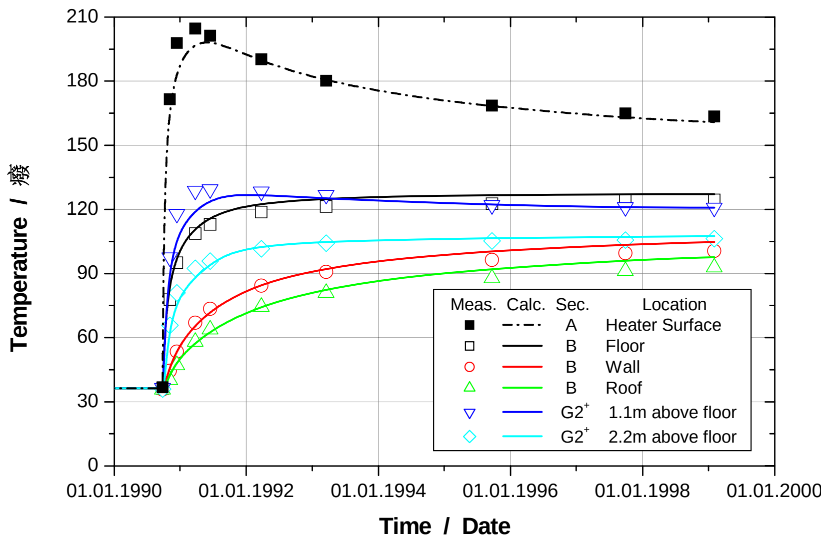


Vertical distribution of backfill porosity at the central heater

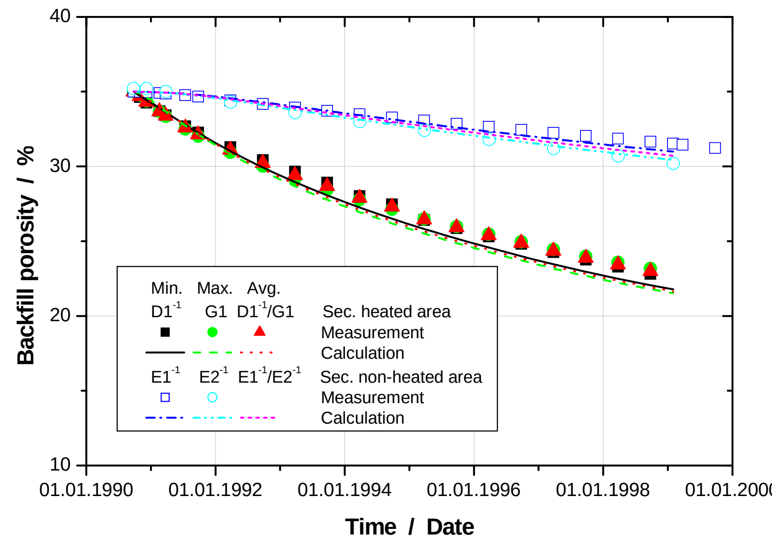


Horizontal distribution of backfill porosity at the central heater

Validation of Predicted Results



Measured and predicted temperature evolution in the TSDE experiment



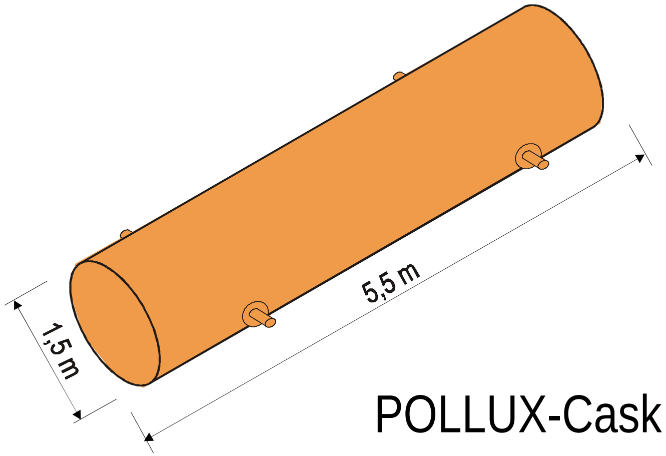
Measured and predicted porosities in the backfill in the TSDE experiment

Recent development

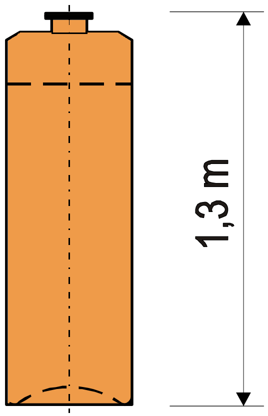
In the context of the 6th framework programme of EC

- Integrated project ESDRED was launched
  (Engineering Studies and Demonstration of Repository Designs)
- Objective: Development and demonstration of safe and reliable emplacement technology for deep vertical boreholes (Mature of nuclear and mining licencing)
- 13 partners from 9 countries cooperating in developing and demonstrating repository relevant transport and emplacement technologies as well as sealings/plugs
- Five years program (from 01/2004 to 01/2009)
- Funded by: EC; PTKA and German Nuclear Industry

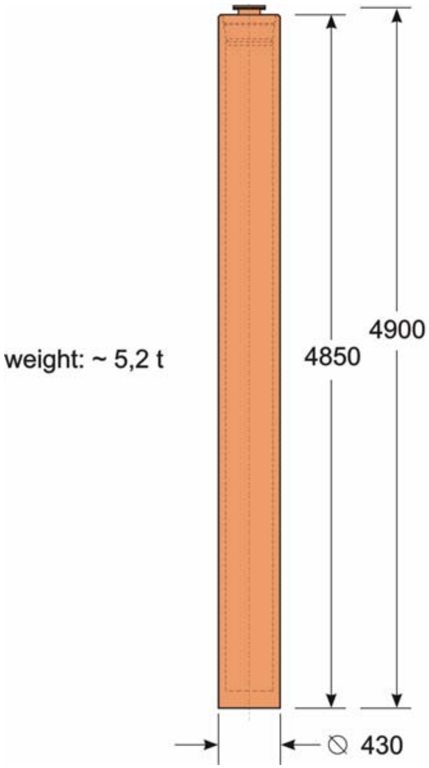
Disposal Canisters



POLLUX-Cask
(spent fuel)
weight: 65 t



HLW-Canister
(vitrified waste)
weight: ~ 500 kg



BSK 3-Canister
(spent fuel)
weight: ~ 5.2 t

Design criteria BSK 3-canister

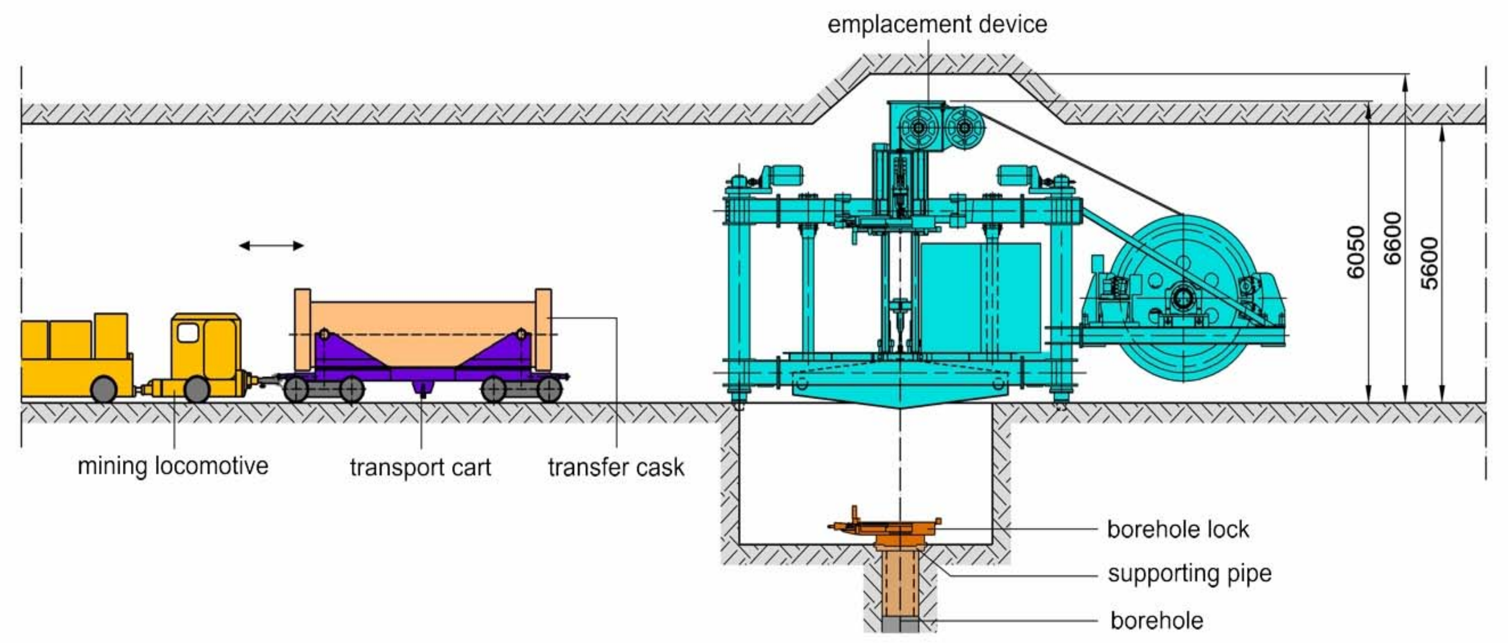
Design criteria	**Explanation**	
Inventory of heavy metals	Loading with fuel rods from disassembled fuel assemblies from pressurized and boiling water reactors	Up to 1.63 tHM
Heat	Max. heat output capacity of the canister contents	6 kW
	Max. cladding strain for the storage time by limitation of the cladding temperature	< 1 %
	Max. tangential tension	< 100 MPa
Criticality	Neutron multiplication factor during transport and inspection conditions	k_{eff} + 2 ó < 0.95
Tightness	Allowable He-Standard-Leakage rate Sealing of the primary lid	$1 \cdot 10^{-3}$ hPa *l/s
	Allowable He-Standard-Leakage rate after welding of the secondary lid	<< $1 \cdot 10^{-7}$ hPa *l/s
Strength	Design for maximum isostatic rock pressure in the repository	30 MPa

Disposal Canister Characteristics

		HLW Canister	CSD-C Canister	BSK 3 Canister
Number of canisters		4,778	8,764	app. 5,525
Number of boreholes needed		30	55	95
Length	mm	1,338	≤ 1,345	4,980
Diameter	mm	430	≤ 440	≤ 440
Total mass	kg	app. 492	≤ 850	5,226
Mass HM	tHM	-	-	1.6
Heat generation	kW			
• at loading			0.02	21,220
• after 10 years		1.12*)		3,030
• after 30 years		0.67**)		1,930

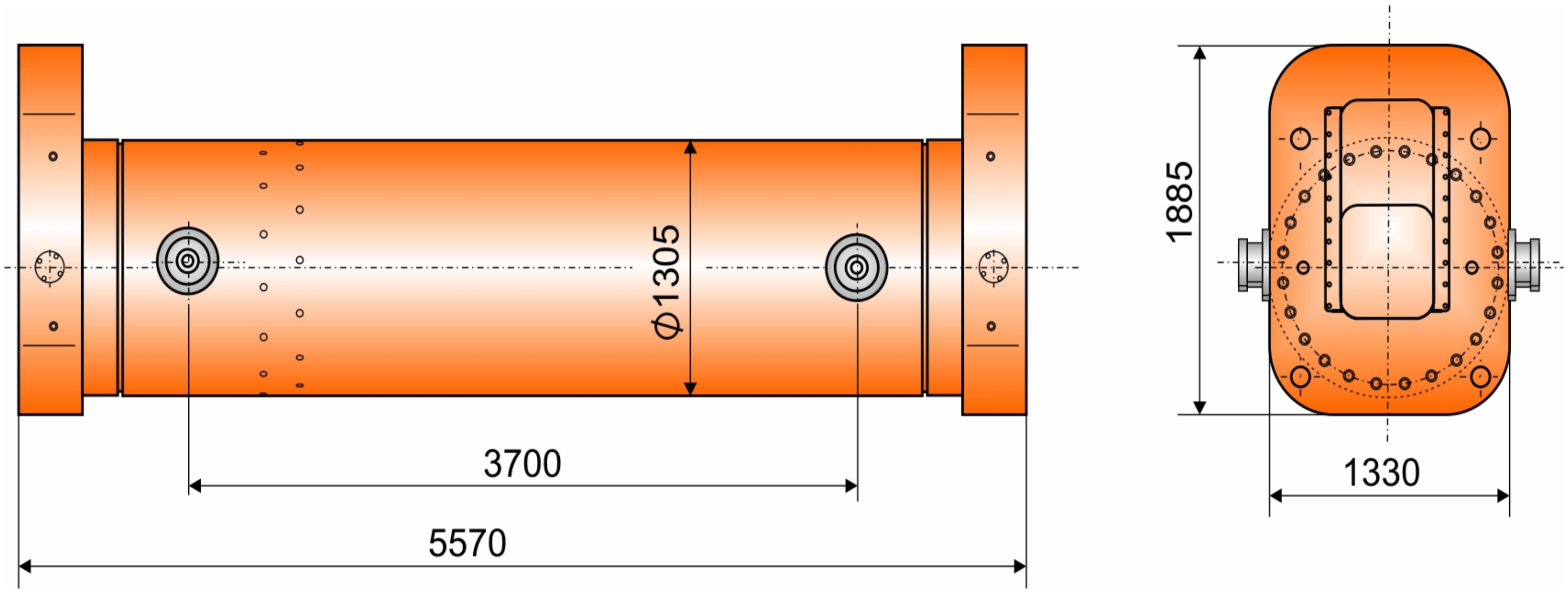
***) after 9 years**
****) after 29 years**

Another Full-scale demonstration



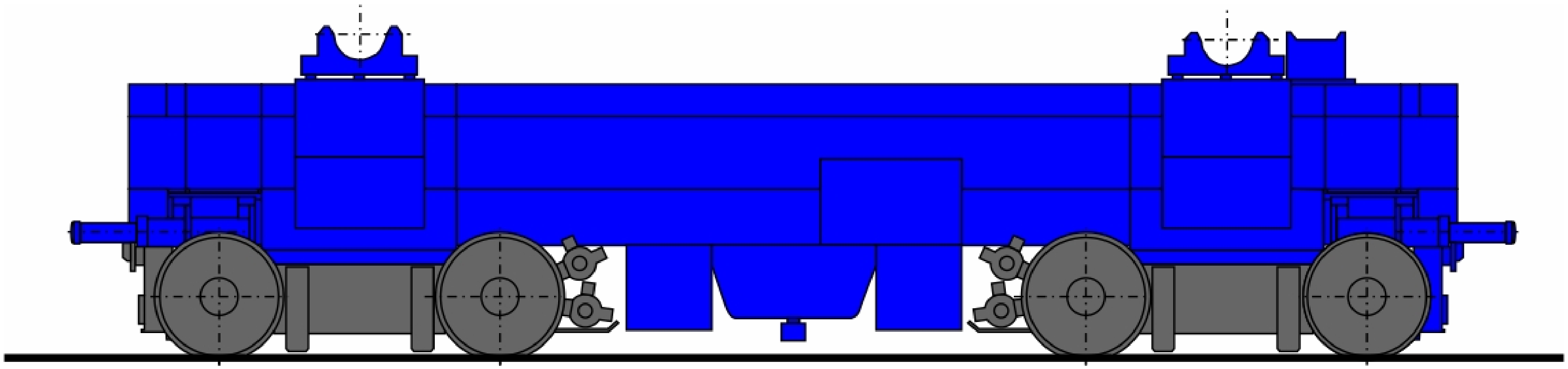
Concept of the emplacement system for BSK 3 canister

Transfer Cask

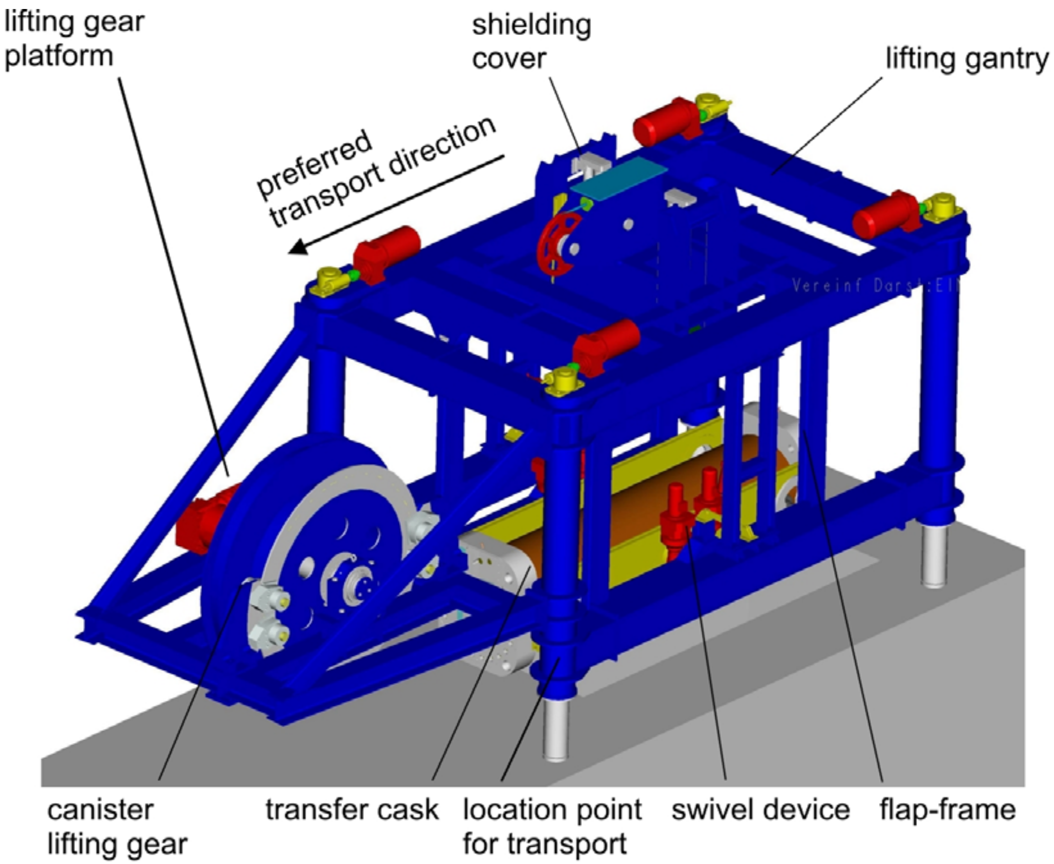


Total weight: 45 t

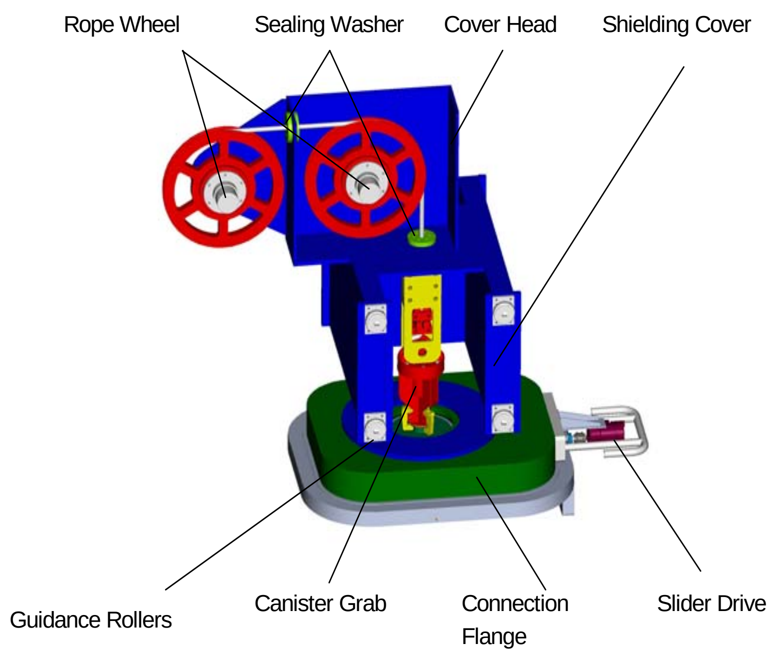
New Transport Cart



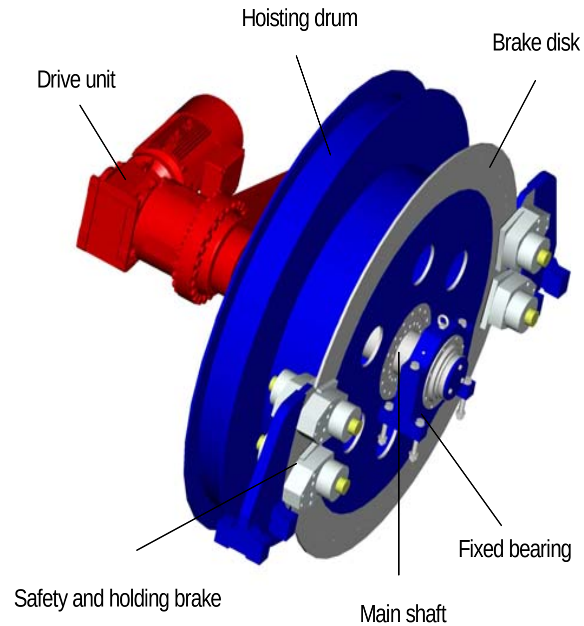
Emplacement Device



Details of Emplacement Device

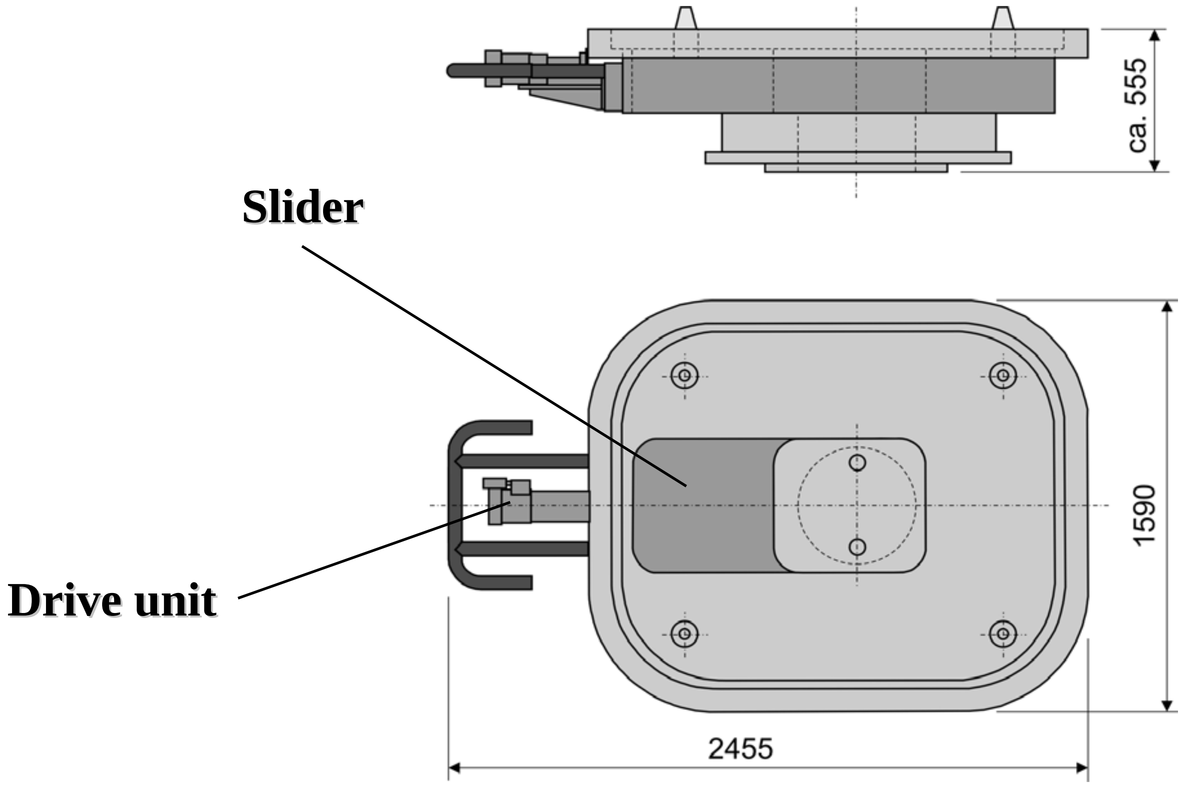


Shielding cover



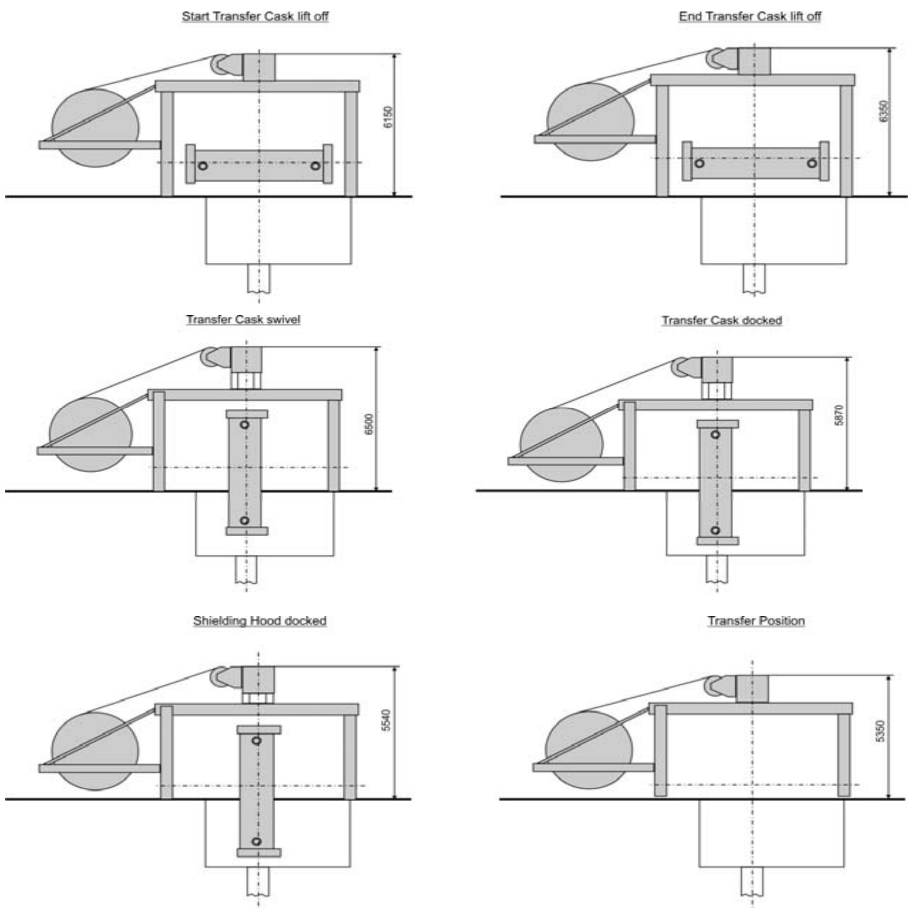
Canister lifting gear

Borehole Lock



Total weight: 5.2 t

Optimization of Emplacement Drift Height

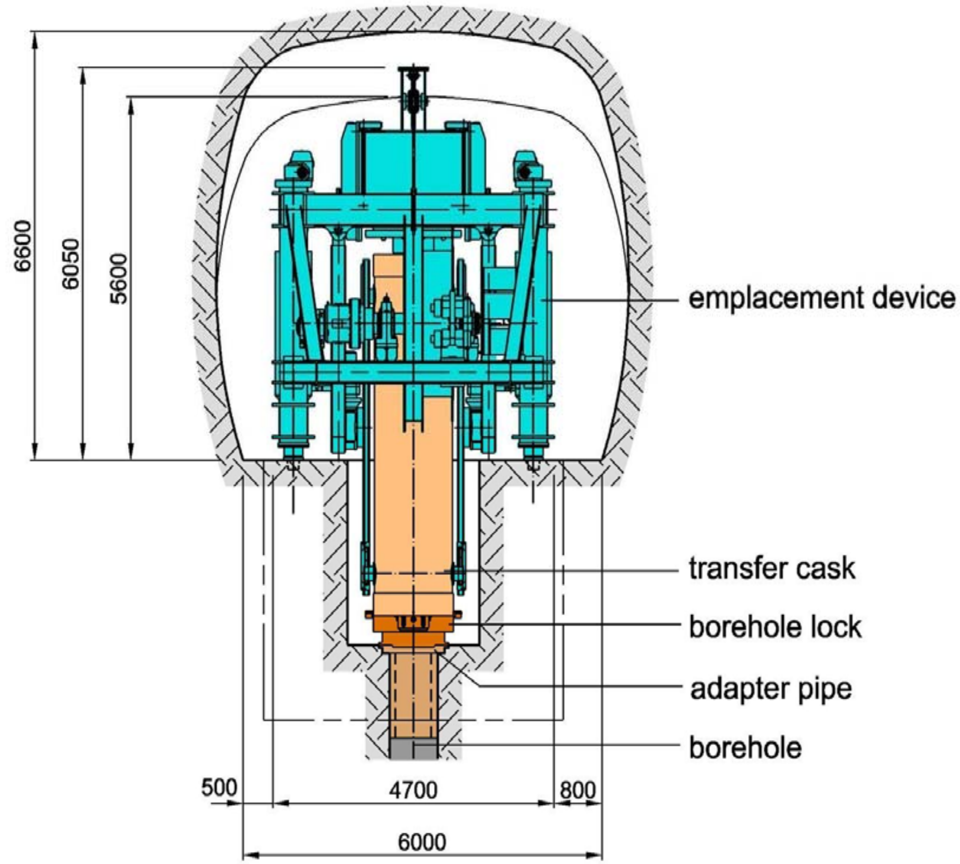


Emplacement device heights during operation I

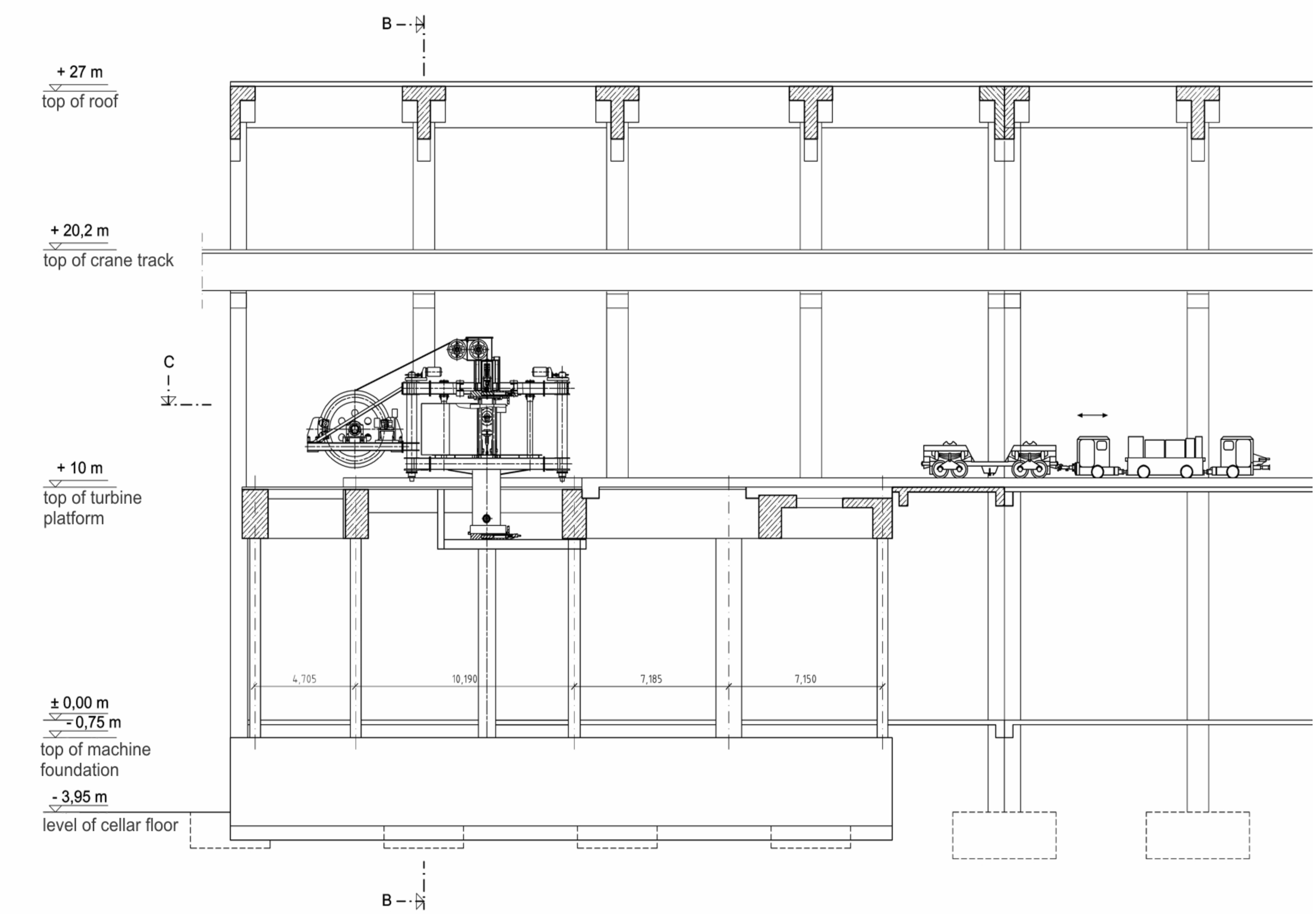
Emplacement device heights during operation II

Emplacement device heights during operation III

Emplacement Drift Cross Section



BSK 3 Test Stand in E-ON Power Plant



Next steps

- Manufacturing of components and construction
- Preparation of the test stand (2007)
- Performance of demonstration tests (all 2008):
  - Test site acceptance tests
  - Demonstration of proper emplacement process (reliability and maintenance requirements)
  - Simulation tests (prove design)
  - Tests to solve potential operational malfunctions
- Evaluation of test results and final report (end 2008)

Summary

- Direct disposal of spent fuel elements in horizontal drifts of a repository in salt successfully demonstrated in the 90ies by means of full-scale demonstration tests:
  - Shaft hoisting system
  - Emplacement technology for POLLUX casks
  - Impact of heat on host rock and backfill
- Direct disposal of spent fuel elements in vertical boreholes of a repository in salt is progressing:
  - Emplacement system designed
  - Components to be manufactured 2007
  - Demonstration program in 2008

Conclusions

Benefit of full-scale demonstration:

- Fulfilment of legal requirements (e.g. full-scale testing prior to repository implementation)
- Validation of the functionality and reliability of developed technical repository components (e.g. emplacement machine)
- Validation of predicted thermo mechanical backfill and host rock behaviour by comparison with in-situ measurement results
- Increase public acceptance by means of demonstration of safe and reliable waste transport and emplacement prior to implementation

Thank you for your attention!

Chinese-German Workshop on Radioactive Waste disposal
May 28-31 ,2007, Beijing

Characteristics of GMZ Bentonite as potential buffer/backfill material for China's HLW repository

Zhijian WEN

Beijing Research Institute of Uranium Geology
China National Nuclear Corporation

BRIUG

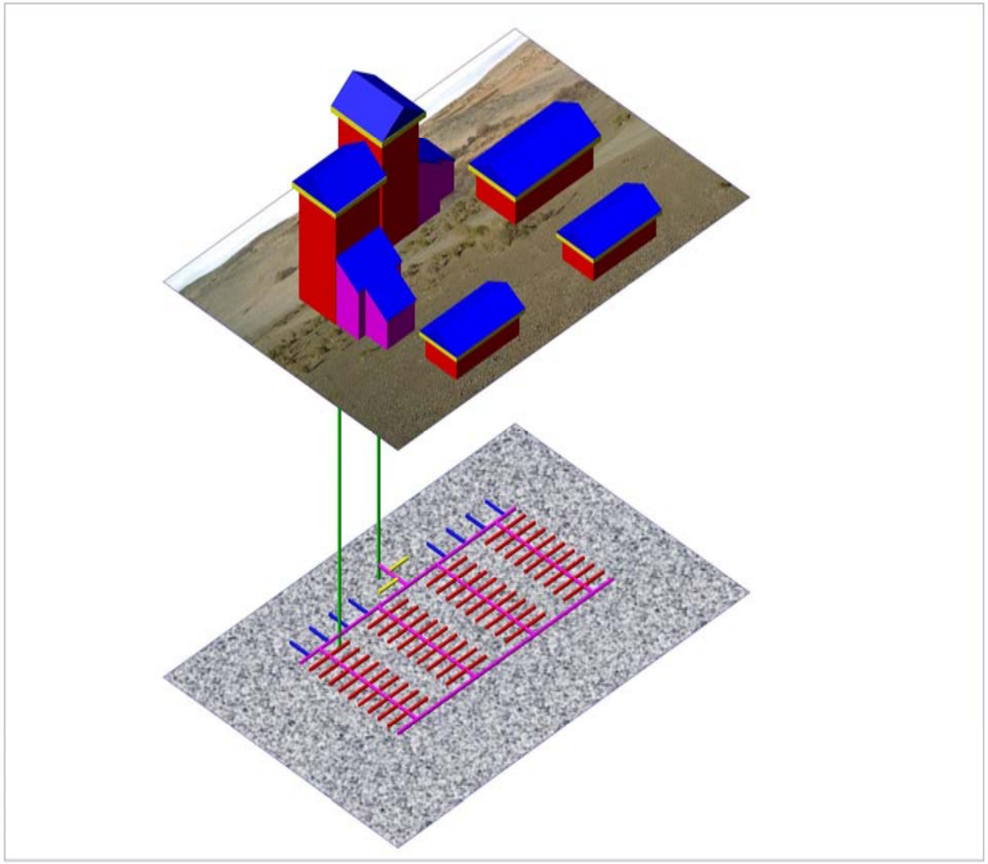
Outline

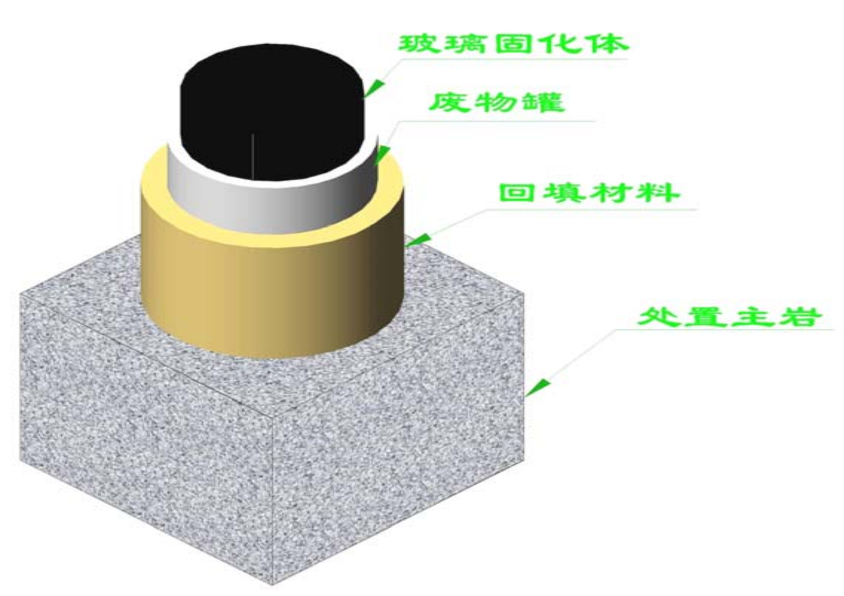
1. Introduction
2. Geological features
3. GMZ Basic property
4. Remarks

1、Introduction

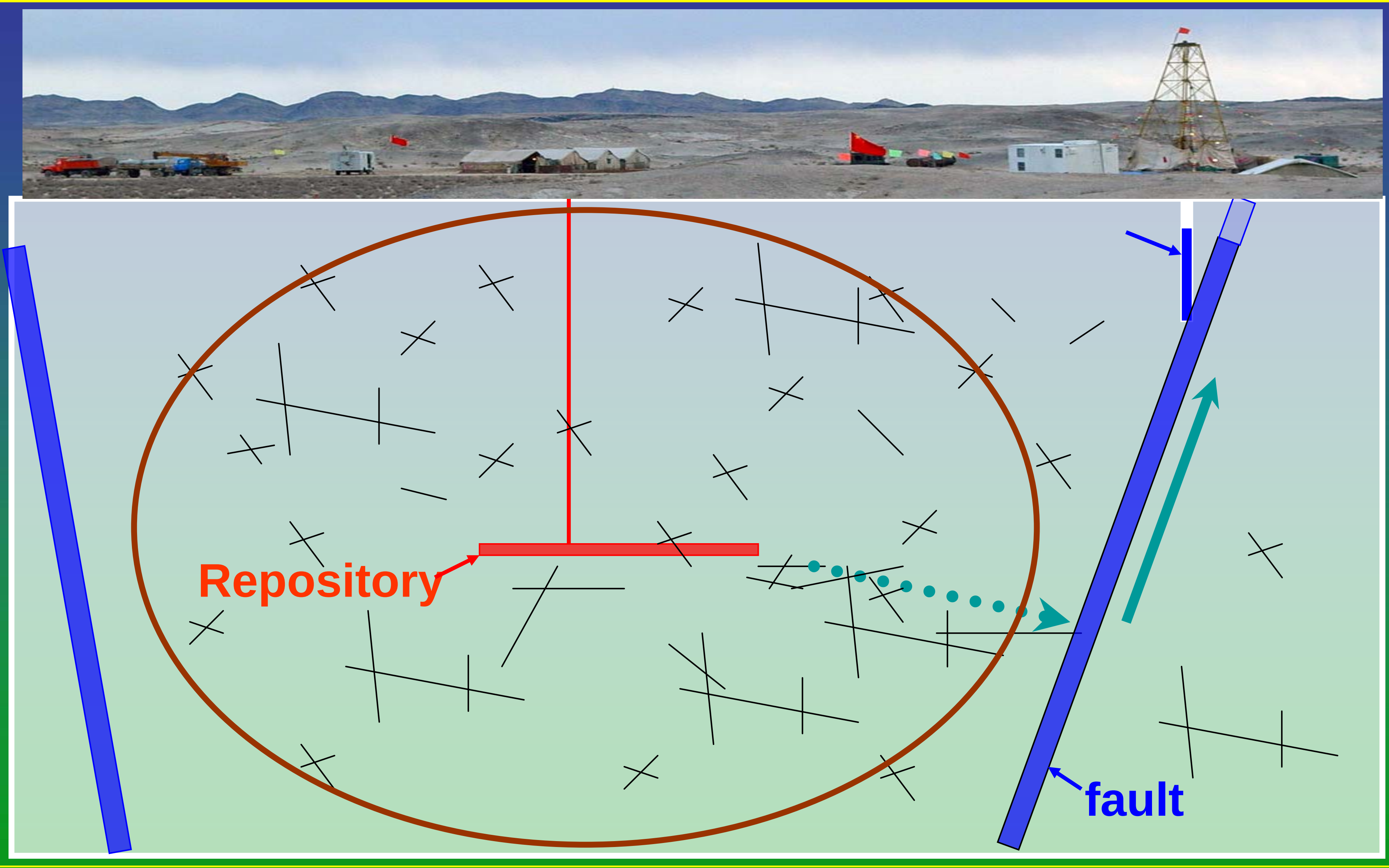
- The deep geological disposal is regarded as the most reasonable and effective way to safely dispose high-level radioactive wastes (HLW) in the world.
- The repository is based on a multi-barrier system that combines an isolating geological environment with an engineered barrier system (Inc. vitrified HLW, canister, overpack and buffer/backfill material).

Preliminary Conceptual model





Preliminary Concept model



1、Introduction

- Due to the very low permeability and excellent retardation of nuclides from migration etc.， the bentonite is selected as base material of the buffer/backfill material in HLW repository.
- GMZ deposit is selected as the candidate supplier for buffer material of HLW repository in China.
- Since 2000， systemic study was conducted on GMZ-1 that is Na-bentonite produced from GMZ deposit and selected as reference material for Chinese buffer material study.

History of buffer material study

- 1986-1990 start of R&D program
  literature investigation and IAEA CRP “inorganic adsorbent as buffer material for HLW repository”
- 1990-1994 Preliminary study of bentonite
- 1994-1996 bentonite deposit screening in China
  GMZ deposit as candidate supplier
- 1996-2000 Study on GMZ Ca-bentonite
  Basic property, hydraulic, swelling, mechanical, chemical, compaction, nuclide
- 2001- Systemic study on GMZ Na-bentonite

Bentonite deposits in China

86 bentonite deposits (L12/M31/S43) 60%

- **large-scale (proved reserves > 50 million tons)**
- **middle-scale (5 million tons ~ 50 million tons)**
- **small scale deposits (proved reserves < 5 million tons)**

Main bentonite deposits in China (Xu et al, 1996)

Deposit screening

- Scale
- Quality
- Economic limitation
- Location

The candidate bentonite deposit should be large-scale deposit in order to meet the demand for the installation of HLW repository 30 or 40 years later.

2、Geological features

The GMZ deposit is located in the northern Chinese Inner Mongolia autonomous region, 300 km northwest of Beijing .

The GMZ bentonite deposit is a large-scale deposit. In China, the proved reserves of GMZ deposit ranks the third of its kind and the reserves of sodium bentonite ranks the second.


GMZ deposit
The reserves in GMZ is about 160 million tons with 120 million tons Na-bentonite reserves.

Outcrop of GMZ bentonite

Generic characteristics

The GMZ bentonite deposit is formed in upper Jurassic period. Bentonite is bedded, with a soapy texture and waxy appearance. It ranges in colour from white to yellow to olive green to brown to pink. The mineralization is a process of firstly continental volcanic sendiment and then suffering from interaction with ground water and weathering.

Ore bodies

The deposit is composed of 5 ore bed, numbered by 0, I, II, III, IV.. The third ore bed is the most important part that is the main industrial ore bed. All the ores are occurred bedded appearance. The third ore bed extends about 8,150m with thickness from 8.78m~20.47m.

Borehole drilling

Minerals

- <u>Ore mineralogy</u>:

  Montmorillonite, sometimes coexist with illite.

- <u>Gangue mineralogy:</u>

  feldspar, quartz, calcite, zeolites, cristobalite, unaltered volcanic glass.

At present, the bentonite is mined on a small scale only. Mining is done on a seasonal basis and by primitive manual methods. .

Chinese Buffer study

- Composition & Structure
  - Mineral
  - Chemical
  - Granular composition
- Physical property
  - Swelling
  - Thermal
  - Mechanical
- Chemical Property
  - Sorption of dissolved nuclides
  - Diffusuion of nuclides
- Bentonite /ballast mixtures
  - Ballast materials (Selection)
- Engineering Property
  - T-H-M-C coupling

3 Basic property

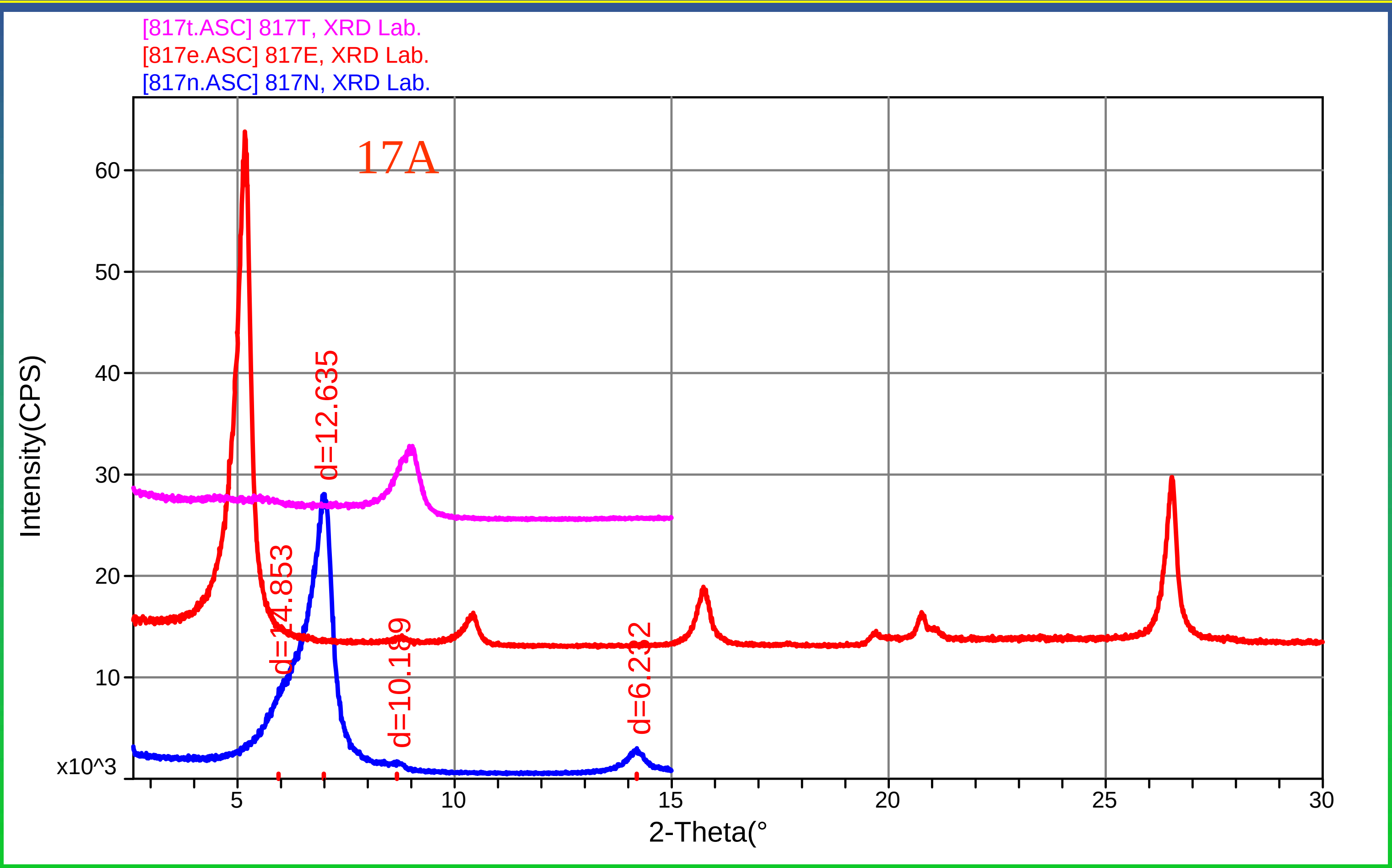
- Mineral composition
- Physical property
- Chemical property

Research work completed on GMZ Ca-bentonite

- Composition, Chemical component
- Physical property (swelling, hydraulic,mechanic & thermal property)
- Additive selection
- Nuclides migration

Na-bentonite

X-ray Diffration pattern



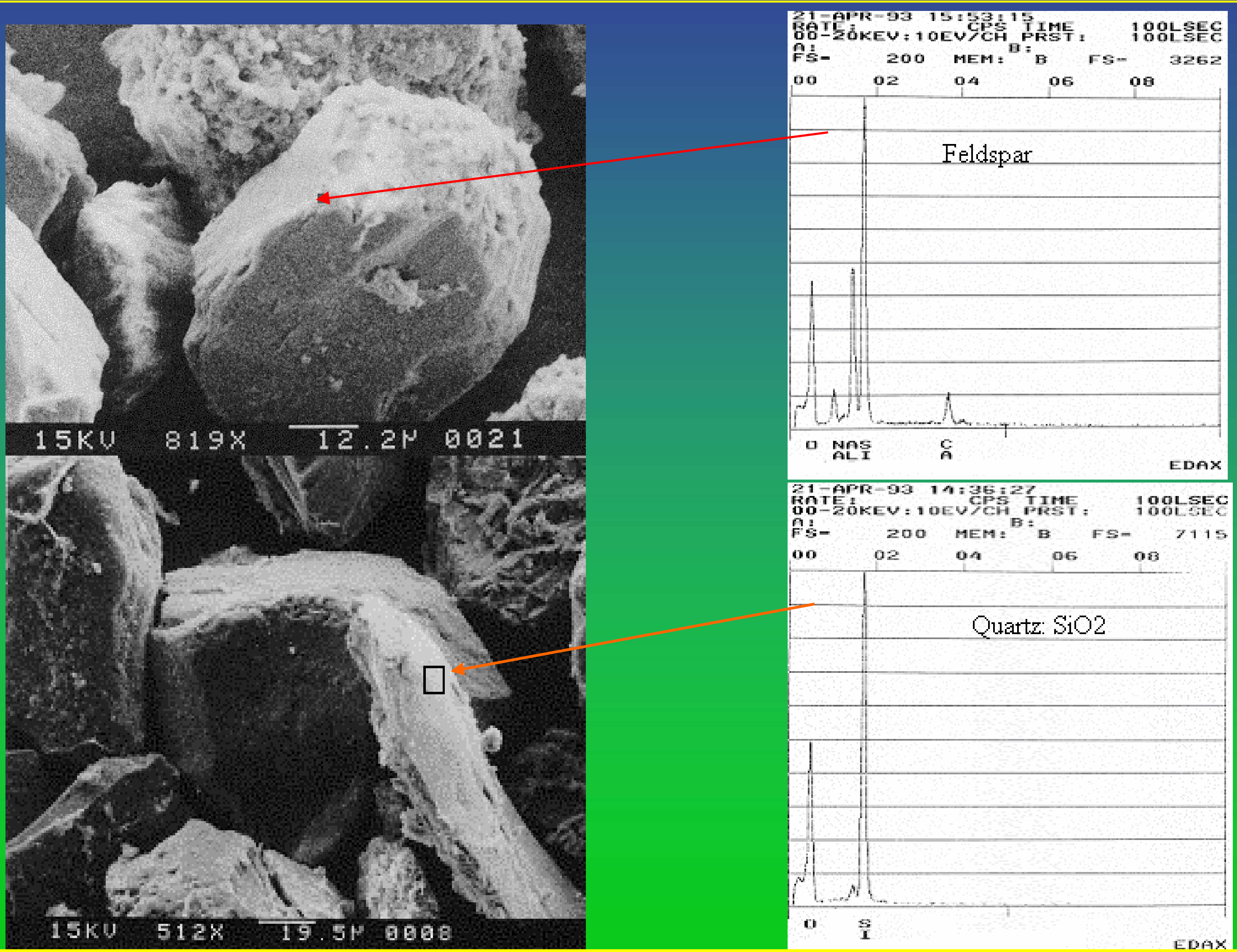
Beijing Research Institute of Uranium Geology, Beijing, China

3.1 Mineral composition

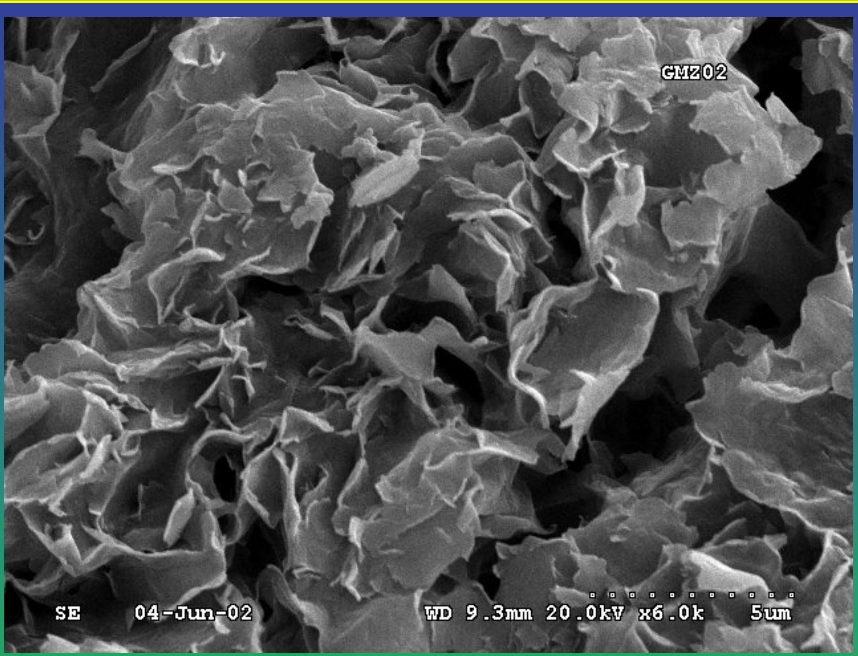
Quartz	Feldspar	Cristobalite	Montmorillonite	Illite	Kaolinite	Carbonate
11.7	4.3	7.3	75.4	/	0.8	0.5（Calcite）

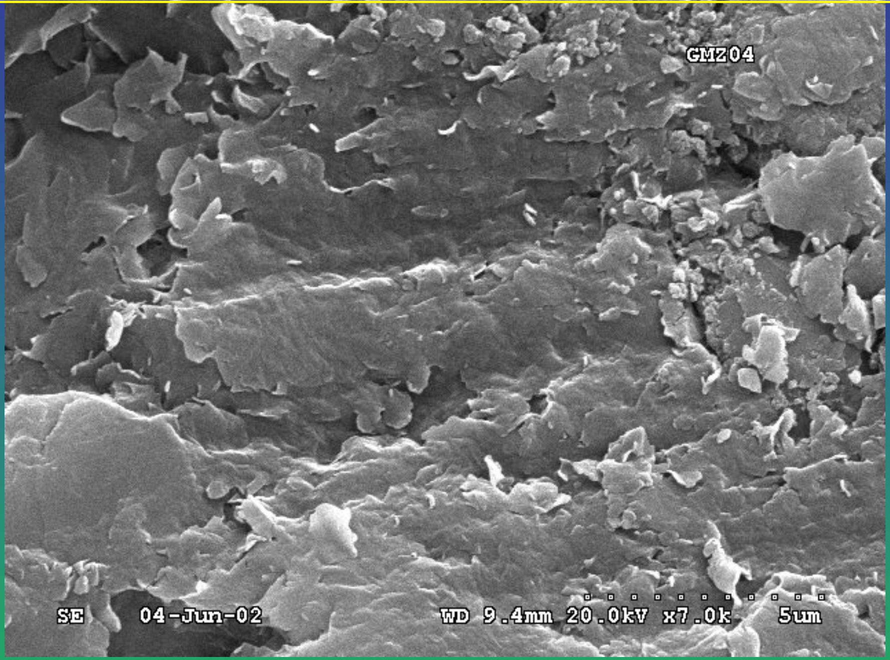
Content of (%)*	Methylene Blue exchange Capacity (MBC)	Cation Exchange Capacity CEC	Real density	Alkali Index
75.4	102 mmol/100g	77.06 mmol/100g	2.66g/cm^3	1.14
Type	Exchangeable cation (mmol/100g)			
Sodium bentonite				
pH	E(k^+)	E(Na^+)	E($1/2Ca^{2+}$)	E ($1/2Mg^{2+}$)
8.68-9.86	0.55	37.52	23.18	10.17

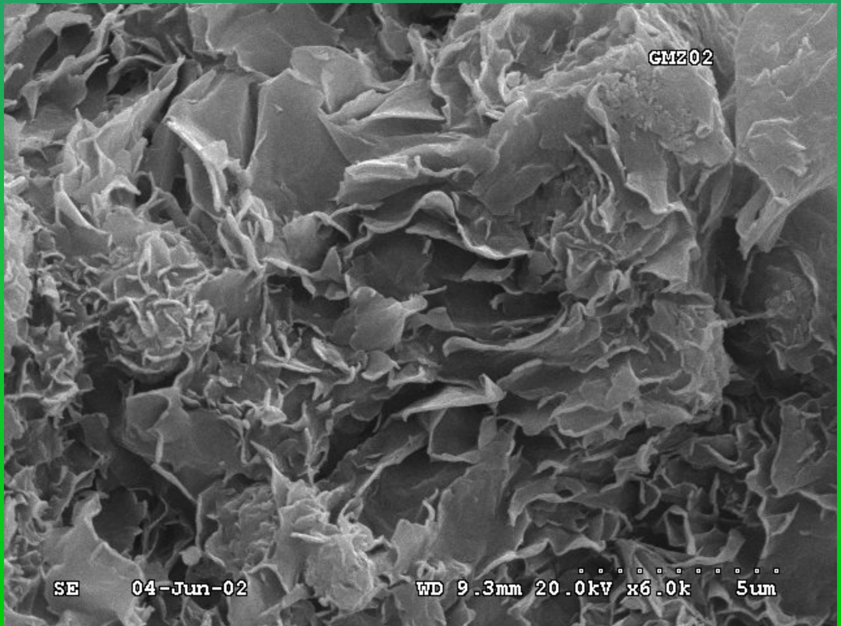
SEM-XPS measurement

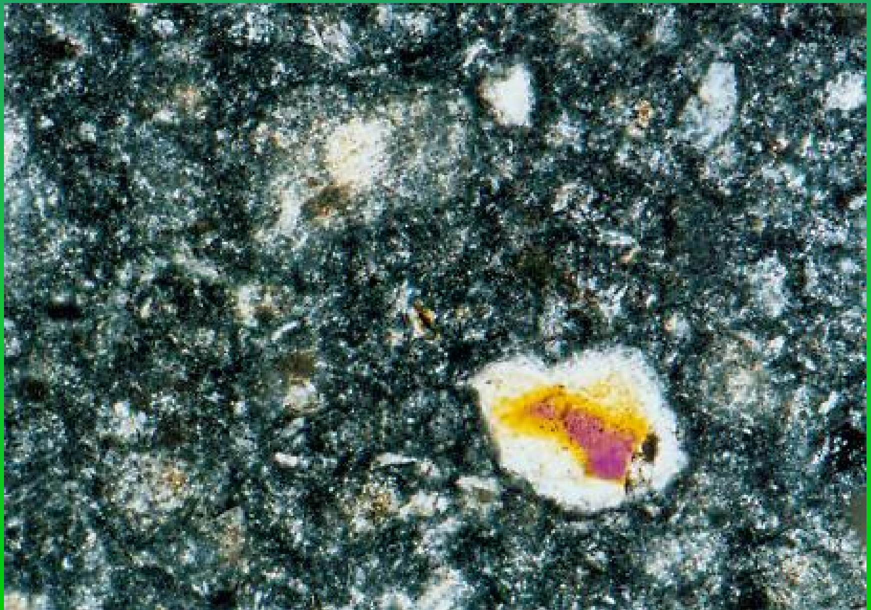


SEM Image


GMZ02
SE 04-Jun-02 WD 9.3mm 20.0kV x6.0k 5um


GMZ04
SE 04-Jun-02 WD 9.4mm 20.0kV x7.0k 5um


GMZ02
SE 04-Jun-02 WD 9.3mm 20.0kV x6.0k 5um



3.2 Physical property

- Thermal ϕ50mm$\times$h10mm

  Thermal conductivity as function of dry density (1.4, 1.6, 1.8Mg/m^3) and water content (9%, 14%, 18%, 24%, 36%) was measured

- Hydraulic ϕ50mm$\times$h10mm

  Density (1.4, 1.6, 1.8kg/m^3)

  temperature: 25° C$\rightarrow$ 60° C$\rightarrow$ 90° C

  Compressed air of 0.3 MPa(1.4kg/m^3) /0.6MPa(1.6, 1.8kg/m^3)

- Mechanical ϕ30mm$\times$h60mm

  Mechanical conductivity as function of dry density (1.4, 1.6, 1.8kg/m^3) and water content (9%, 14%, 18%, 24%) was measured

- Swelling ϕ20mm$\times$h20mm

  Swelling stress as function of dry density (1.2, 1.4, 1.6, 1.8kg/m^3)

  Swelling amount

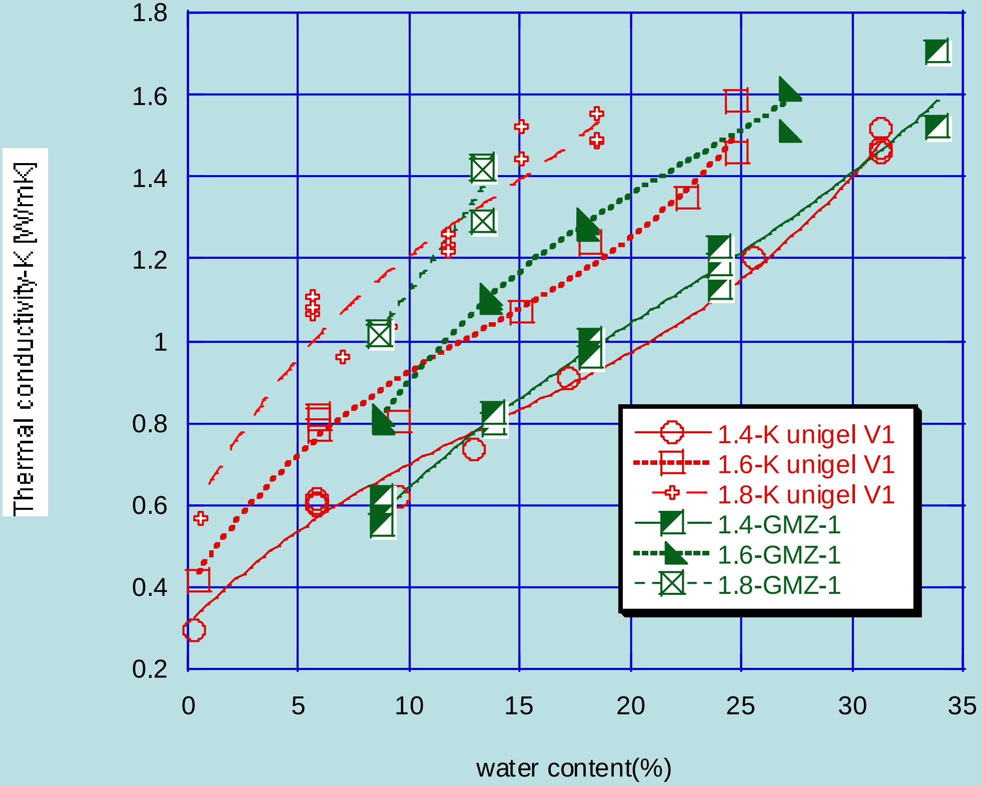
Thermal property

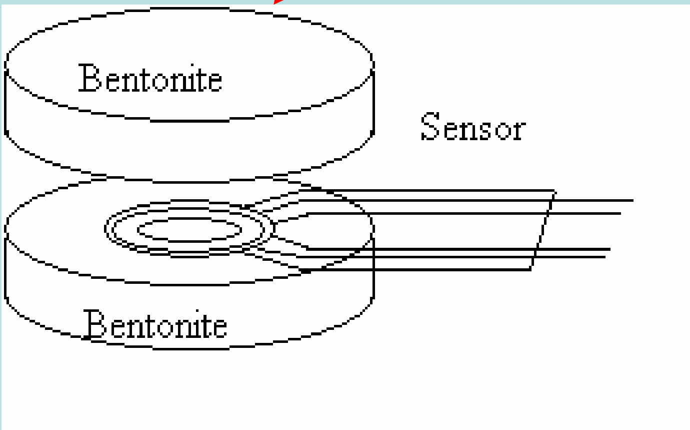
Instrument: Thermophysical Properties Analyzer (TPA 501): surface heat source method

Size: ϕ50mm×h10mm

Dry density : 1.4, 1.6, 1.8Mg/m^3

water content : 9%, 14%, 18%, 24%, 36%



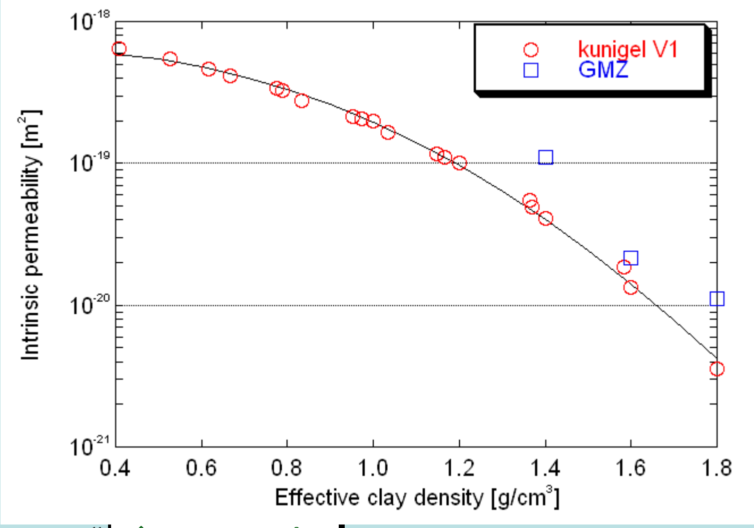


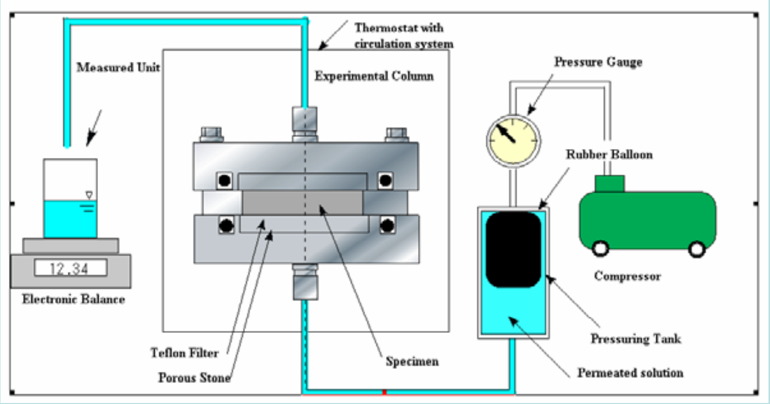
Thermal conductivity: increases with water content & dry density

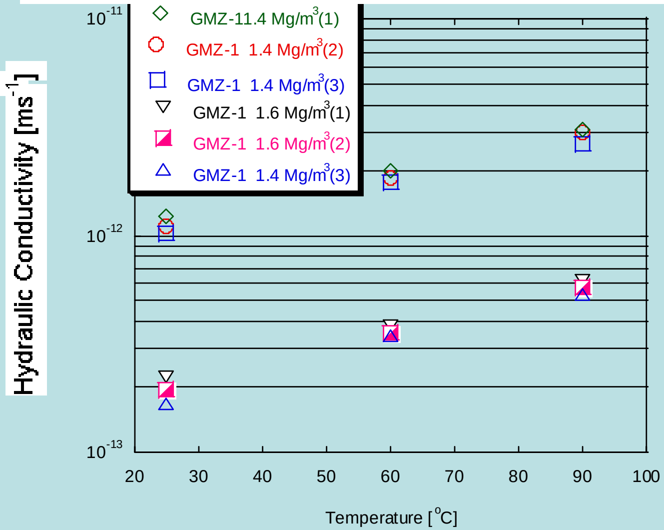
Hydraulic property

ϕ50mm×h10mm 1.4, 1.6, 1.8Mg/m^3 25° C→ 60° C→ 90° C

Compressed air: 0.3 MPa(1.4Mg/m^3) /0.6MPa(1.6, 1.8Mg/m^3)



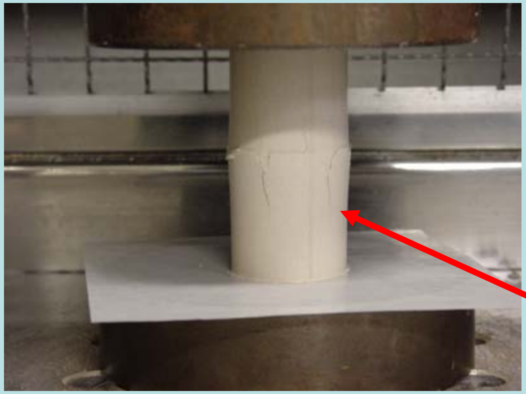


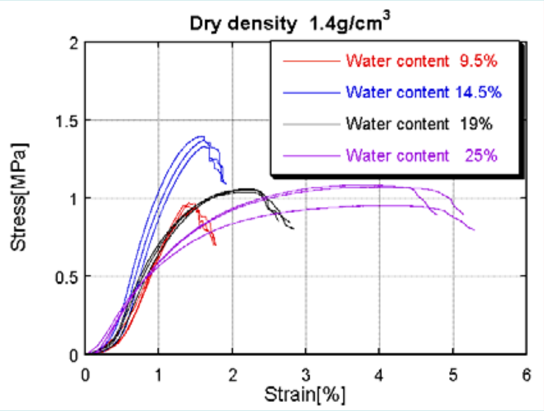


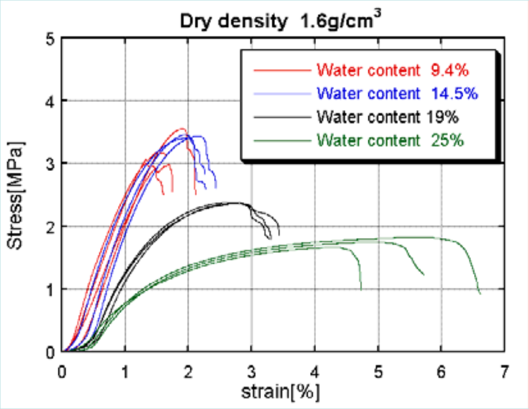
Saturated hydraulic conductivity increases as temperature increases and decrease as the effective density increases

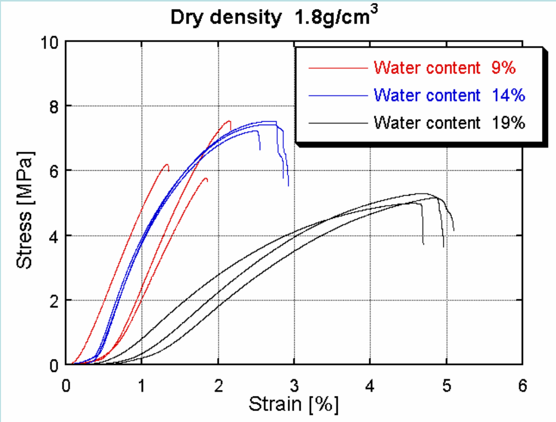
Mechanical characteristics

ϕ30mm×h60mm
1.4,1.6,1.8Mg/m³
9%, 14%, 18%, 24%
Strain rate: 1% min⁻¹
JGS T511





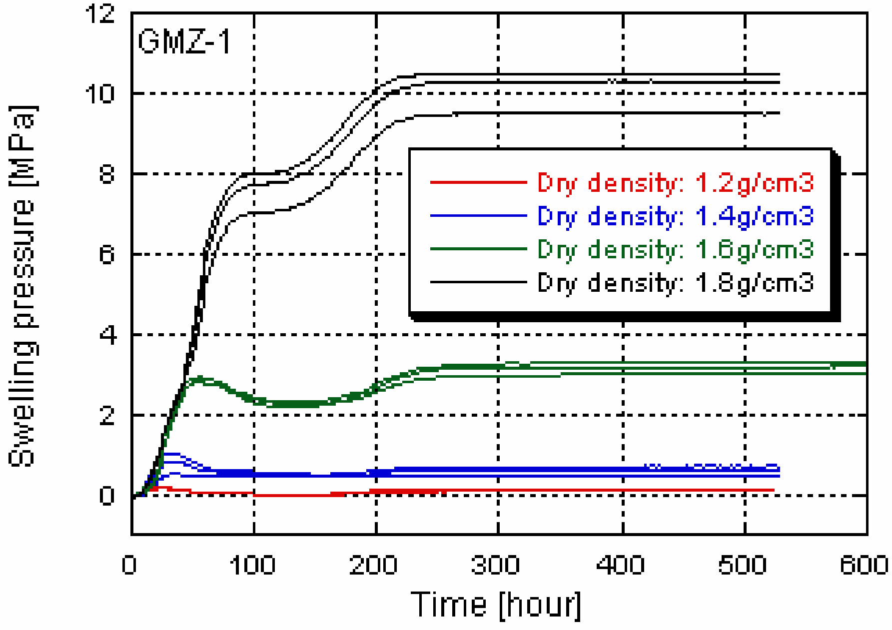


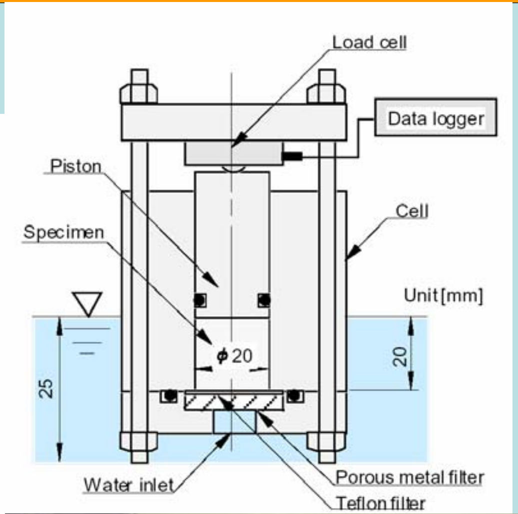


In general, with the same water content, a larger initial dry density leads to a larger unconfined compressive strength, and with the same dry density, a larger water content leads to a less unconfined compressive strength.

Swelling property

ϕ20mm×h20mm
1.2, 1.4, 1.6, 1.8 Mg/m^3

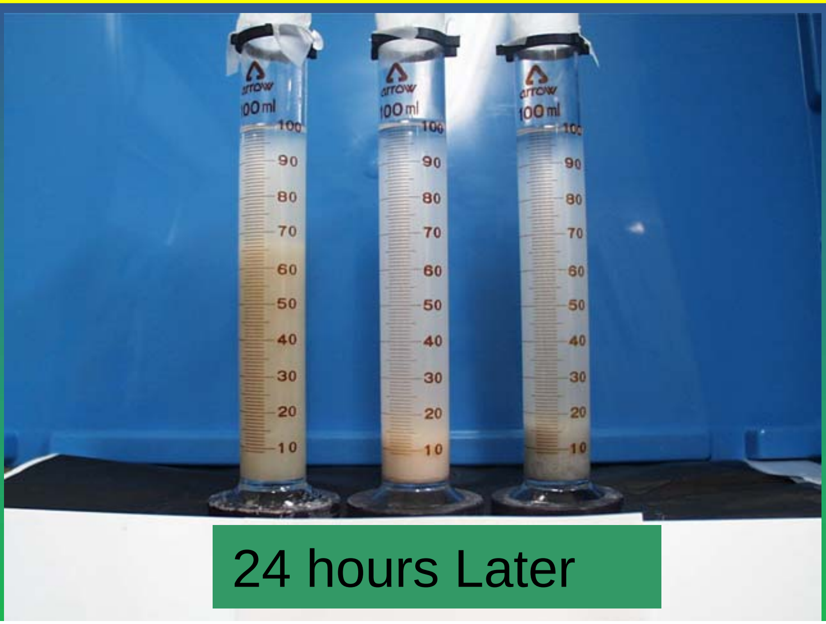




A key property of the buffer material is its ability to swell by water uptake, thereby filling voids in the engineered barriers and fractures in the surrounding host rock.

Swelling stress increases as dry density increases.

Bentonite (powder) swelling amount



Sample	Kunipia F	GMZ-1	Kunigel V1
Time [hr]	24		
Water	Distilled water		
Swelling amount	68.0	18.0	18.0

3.3 Chemical property

- Batch test

  Sample: 100% Chinese GMZ-1

  S/L: 10, 100, 200[g/L]   Atmosphere

  room temperature

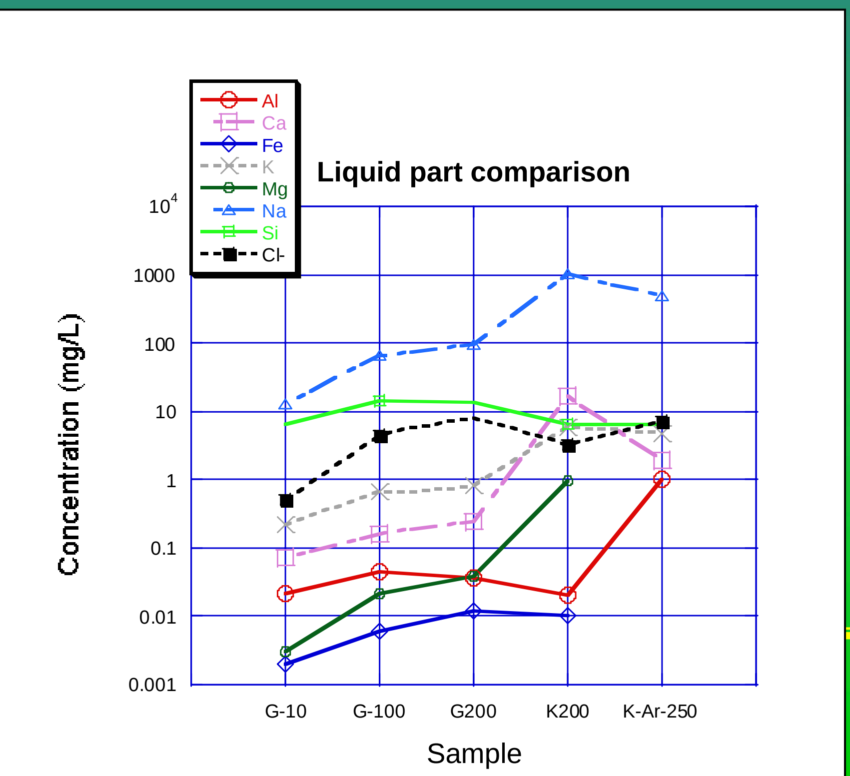
  Solution: Distilled water

  Time: 14 days

  Parallel experiment: 3

- Modeling of bentonite-water interaction

Chemical property



4. Remarks

GMZ–1 bentonite is characterized by high content of montmorillonite (about 75%) and less impurities. GMZ–1 is a pure natural material, it comes to be one of the best buffer material with high quality in the world.

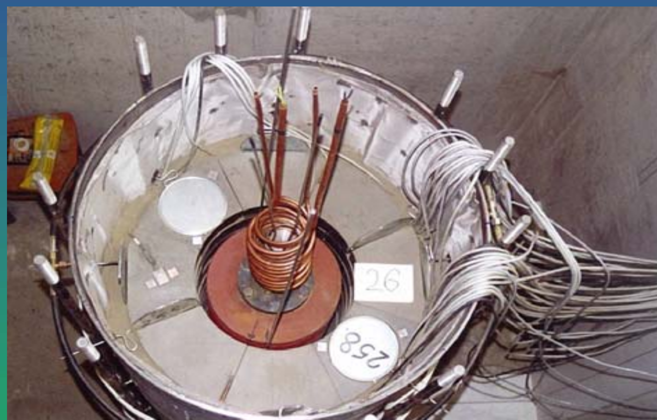
Comparison of Chinese bentonite and other bentonite

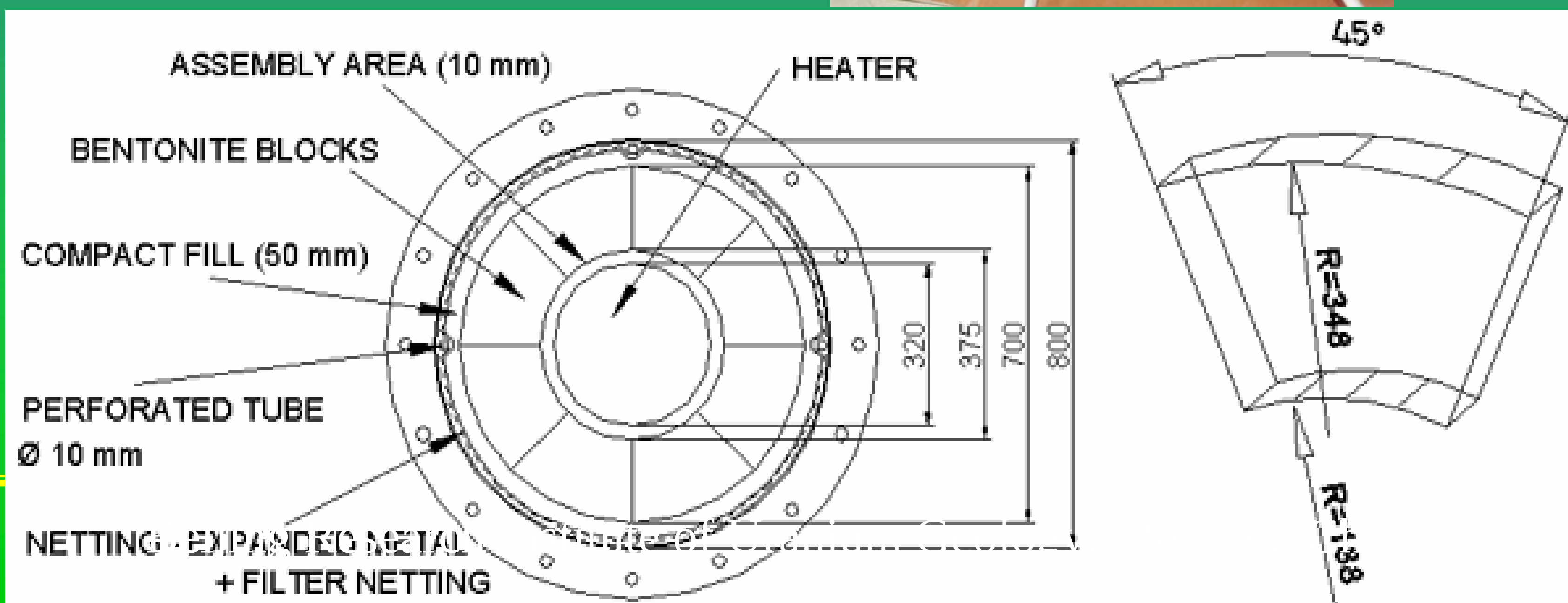
Component	MX80 瑞典	S-2 西班牙	Montigel 瑞士	Avonseal 加拿大	Kunigel V1 日本	GMZ 中国
Montmorillonite	75%	84	66	79	46-55	72.5
quartz	15.2	3.6	8.3	5	29-38	19.0
feldspar	5-8	6.1	2-4	3	2.7-5.5	4.3
remark	Na-	Ca-	Ca-	Na-	Na-	Na-

The key point for the further study

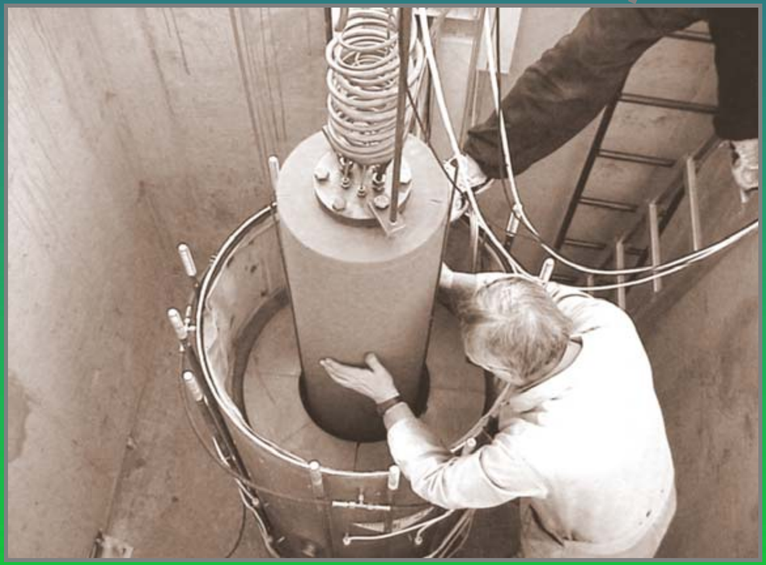
- Mock-up
- Porewater Chemistry
- Instrumentation
- T-H-M coupling study
- Open for international cooperation

Mock-Up


26
258


ASSEMBLY AREA (10 mm)
HEATER
BENTONITE BLOCKS
COMPACT FILL (50 mm)
PERFORATED TUBE
Ø 10 mm
NETTING - EXPANDED METAL
+ FILTER NETTING
320
375
700
800
45°
R=348
R=138

T-H-M-C coupling study



Beijing Research Institute of Uranium Geology, Beijing, China

THANKS!

Some Basic Properties of Densely Compacted GMZ Bentonite

Prof W. M. YE

Grand Ceremony of the Centennial Ceremony

1907-2007

百年同济

TONGJI UNIVERSITY


百年同济
TONGJI UNIVERSITY
热烈欢迎德国联邦总统霍斯特·克勒访问同济大学
Wir heißen Bundespräsident Horst Köhler
zum hundertjährigen Jubiläum der Tongji
iversität herzlich willkommen.

时代的城市发展
TION AND URBAN DEVELOPMENT
指
联合国
UN-HABIT
中华
Ministry
Republi
上海市
Shanghai
TONGJI UNIVERSITY
1907

Contents

1 Introduction

2 Basic features of GMZ bentonite

3 Soil Water Characteristics

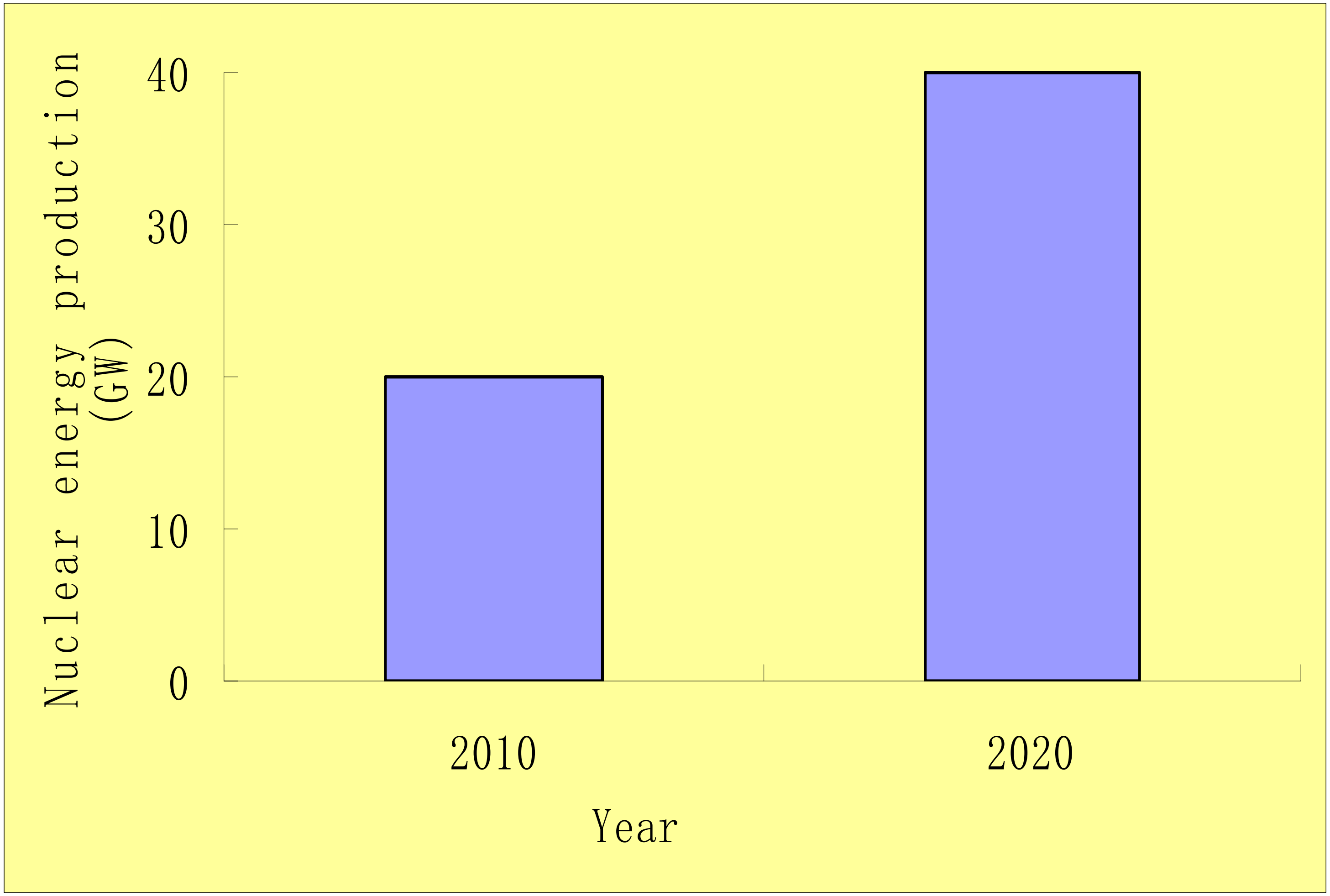
4 Microstructure investigation

5 Swelling pressure

6 Conclusions

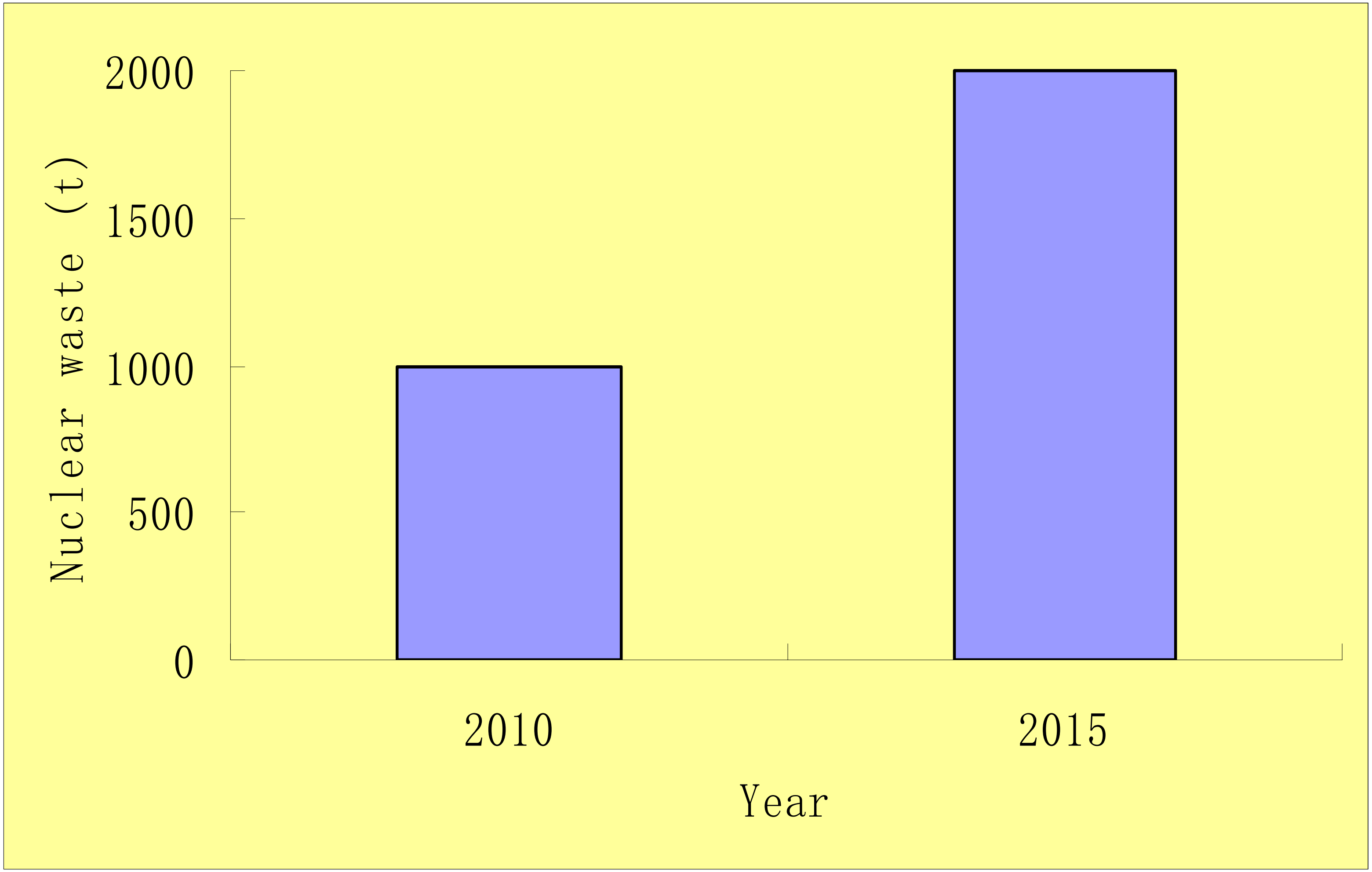
1 Introduction

Nuclear energy production in China



1 Introduction

Nuclear waste in China



2 Basic features of GMZ

GMZ bentonite locates in Xinghe county, the Inner Mongolia Autonomous Region.

2 Basic features of GMZ

Mineralogical composition of GMZ

Mineral	Content(%)
Quartz	11.7
Cristobalite	7.3
Feldspar	4.3
Calcite	0.5
Kaolinite	0.8
Montmorillonite	75.4

2 Basic features of GMZ

CEC and exchangeable cation of GMZ

Sample	CEC (mmol/100g)	Exchangeable cation (mmol/100g)				Alkali Index
		$E(k^+)$	$E(Na^+)$	$E(Ca^{2+})$	$E(Mg^{2+})$	
GMZ01	77.06	0.55	37.52	23.18	10.17	1.14

Sample	G_s	w_L(%)	w_P(%)	I_p	S(m^2/g)
GMZ01	2.71	276	37	237	570

3 Soil Water Characteristics

Preparation of specimen

Here, GMZ01 bentonite is compacted to a cylinder, height 6mm, diameter 20mm, and the dry density is 1.7g/cm^3, the initial water content is 12.13%.

3 Soil Water Characteristics

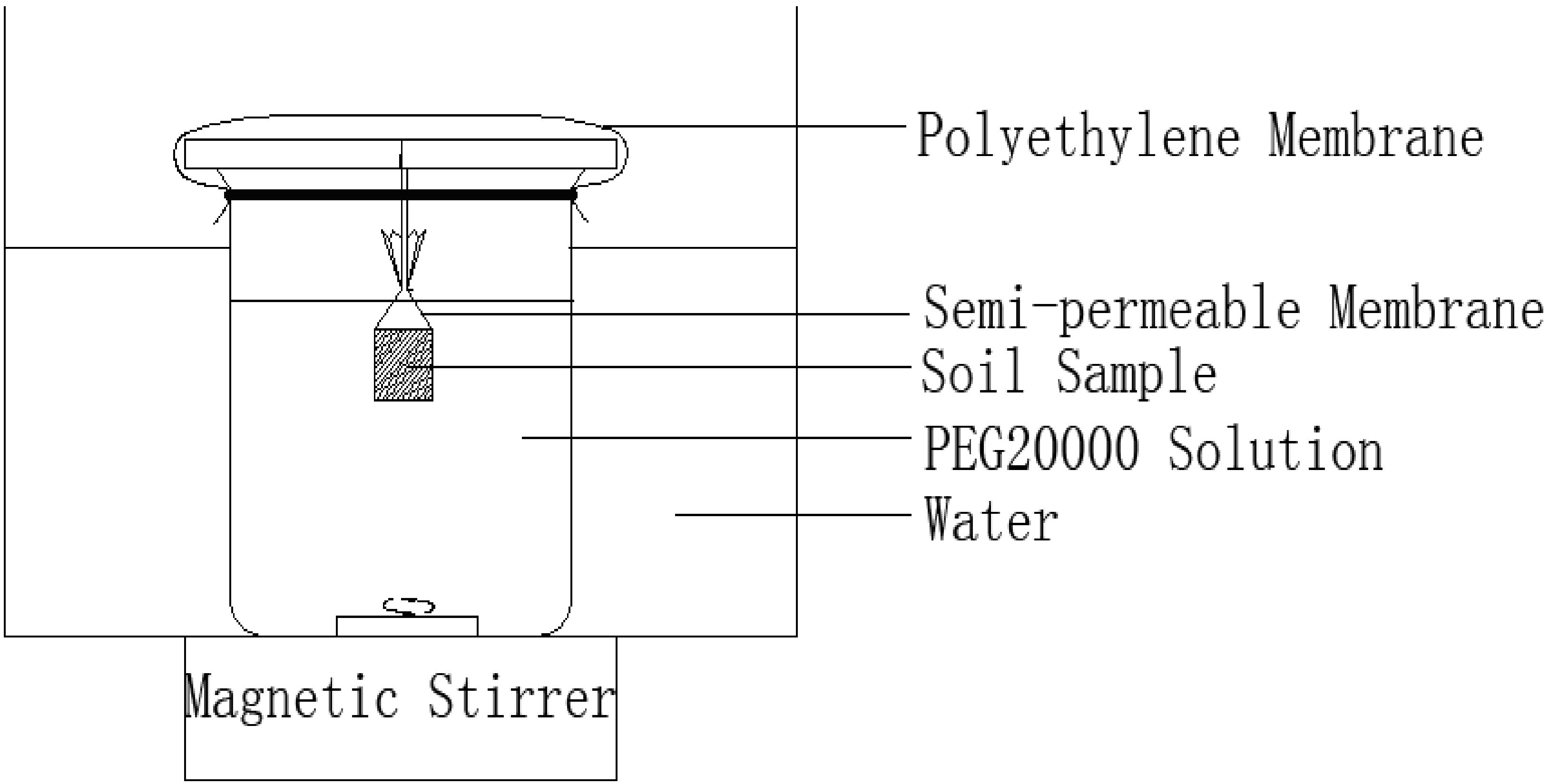
A special metal mold for the test under confined conditions

3 Soil Water Characteristics

The osmotic technique and vapour phase technique are employed for controlling suction.

3 Soil Water Characteristics

Osmotic Technique



Osmotic Technique

During the test, the soil specimen is placed in a cellulotic, semi-permeable membrane, which is permeable to water, and a solution of polyethylene glycol (PEG) is circulated outside the membrane. The large sized PEG molecules cannot penetrate the membrane.

Osmotic Technique

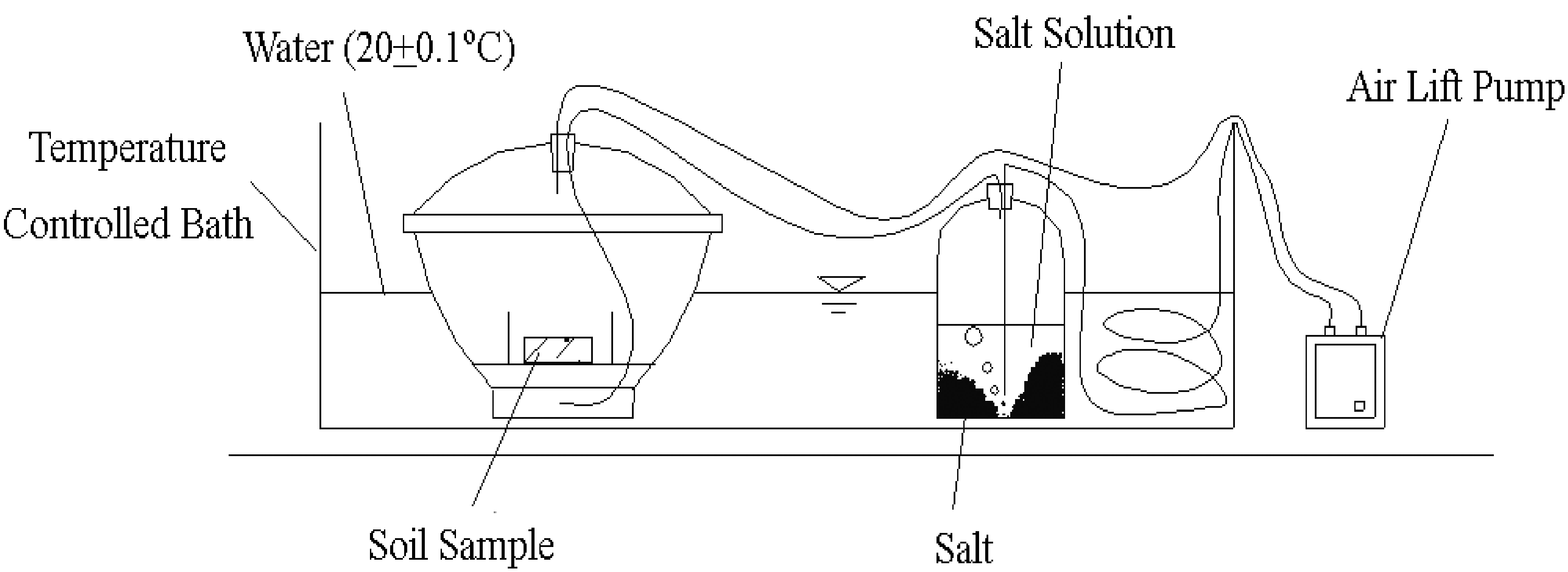
Drainage of the specimen is caused by the process of osmosis.

An osmotic suction applied to the specimen through the membrane.

The suction value depends on the concentration of the solution; the higher the concentration, the higher the suction.

3 Soil Water Characteristics

Vapor Phase Technique



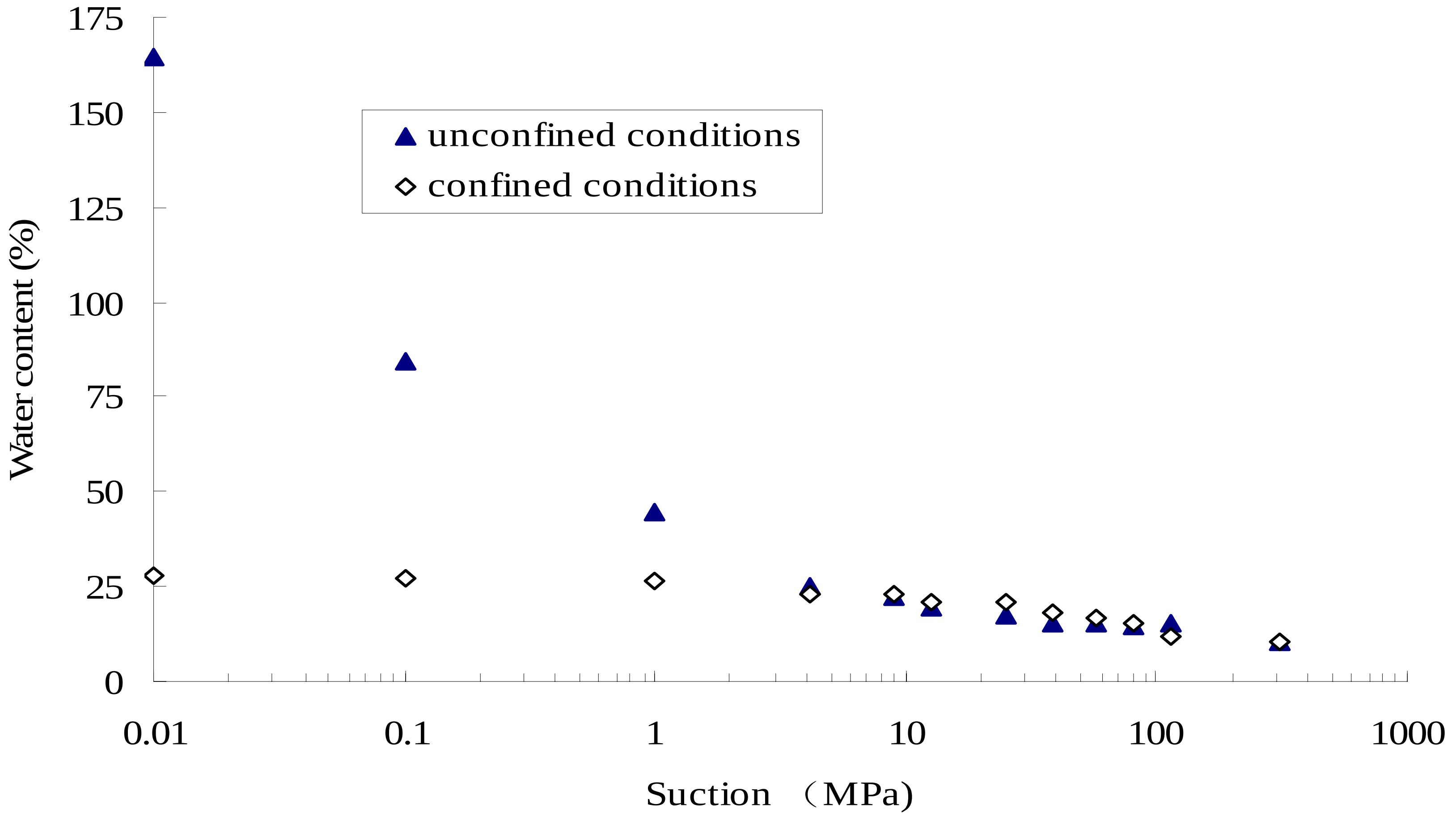
3 Soil Water Characteristics

Salts used and corresponding suctions

Salt	K_2SO_4	KNO_3	$ZnSO_4$	$(NH_4)_2SO_4$
Suctinon (MPa)	4.2	9	12.6	24.9
Salt	NaCl	$NaNO_2$	$MgNO_3$	K_2CO_3
Suctinon (MPa)	38	57	82	113

3 Soil Water Characteristics

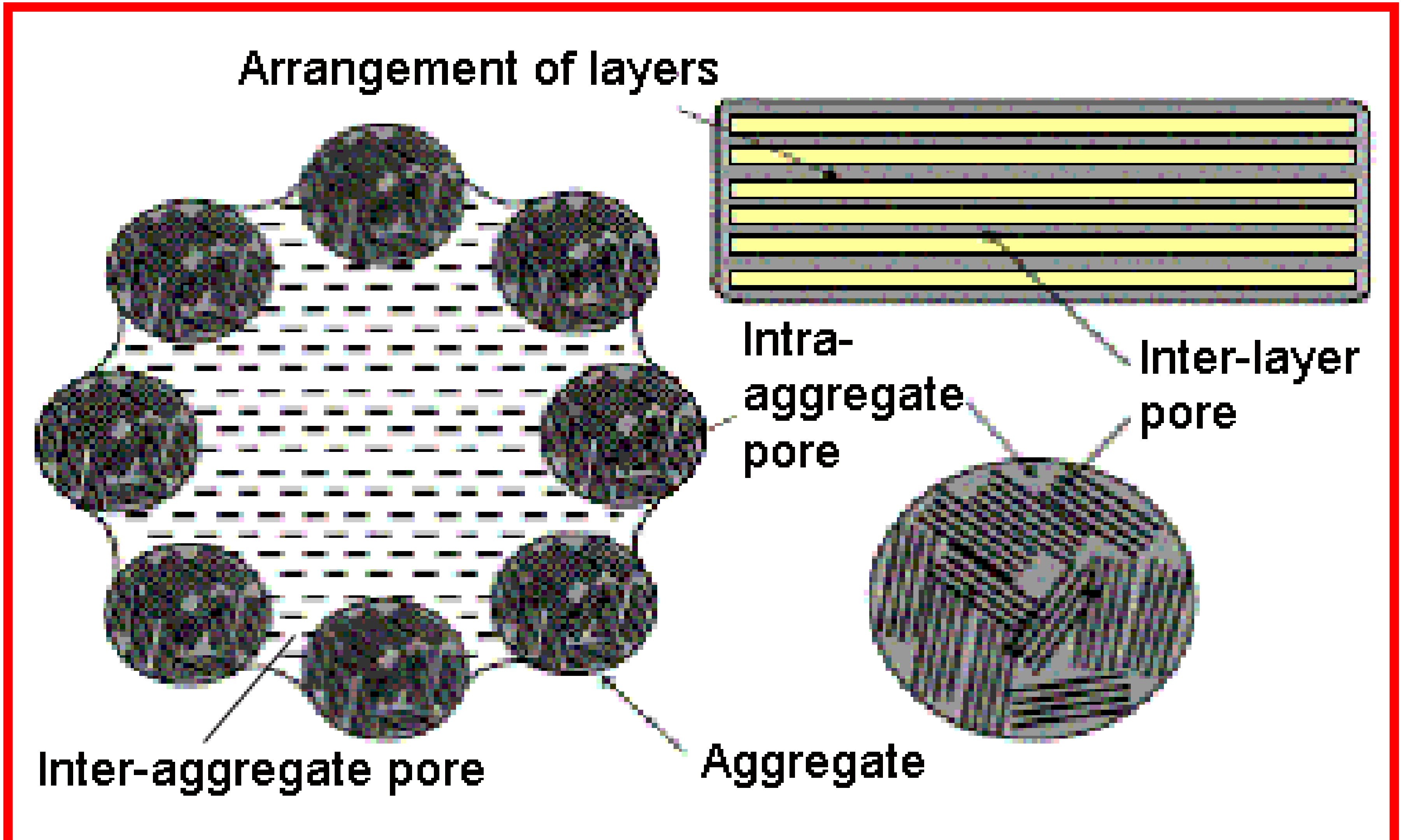
Water Retention Curves



3 Soil Water Characteristics

The fig shows that, starting from the initial suction of 4.2 MPa, the difference between different confining conditions becomes less significant as the suction increases.

4 Microstructure Investigation



4 Microstructure Investigation

Techniques:

Mercury Intrusion Porosimetry (MIP)

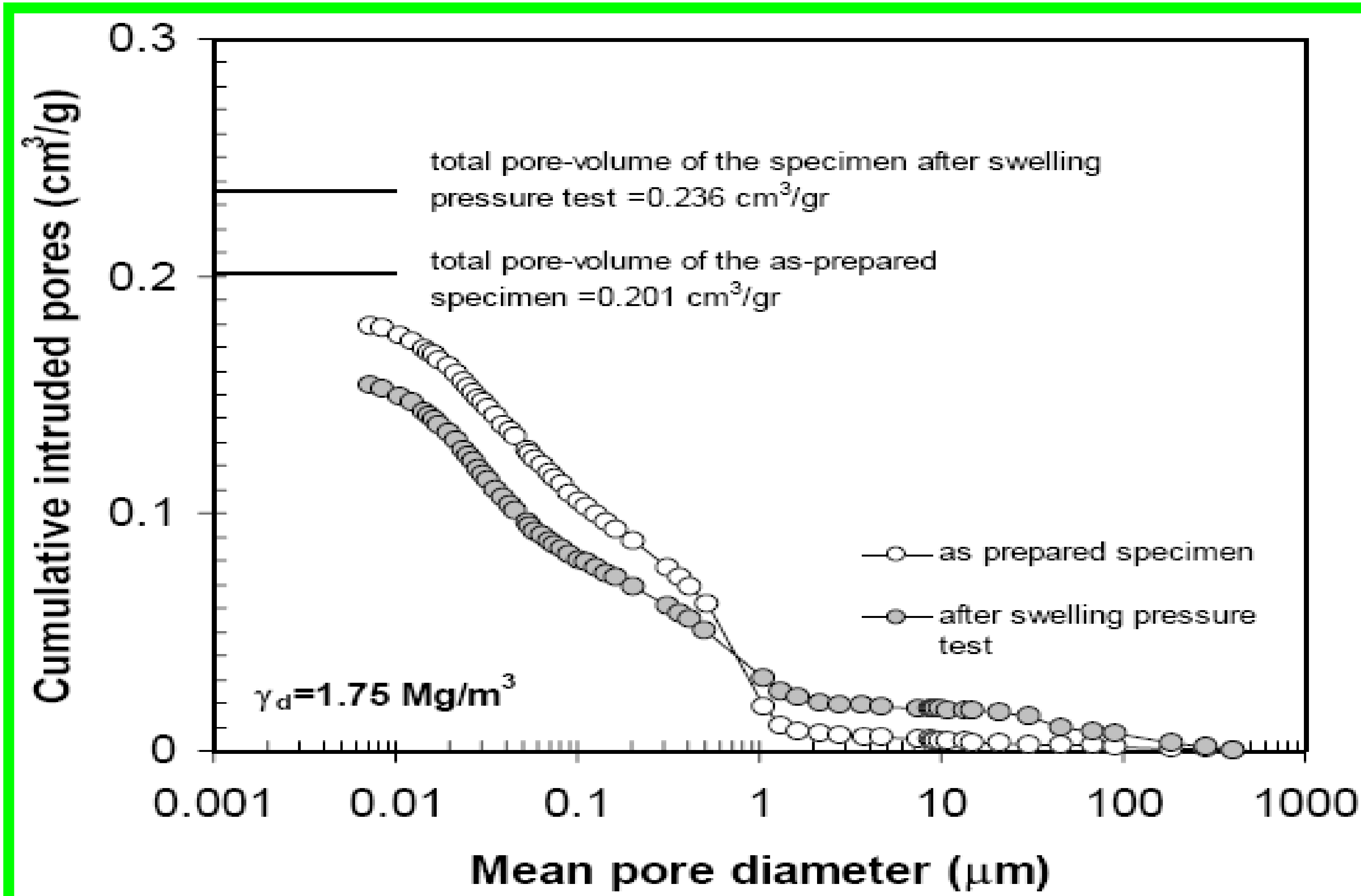
Environmental Scanning Electron Microscopy (ESEM)

MIP Test

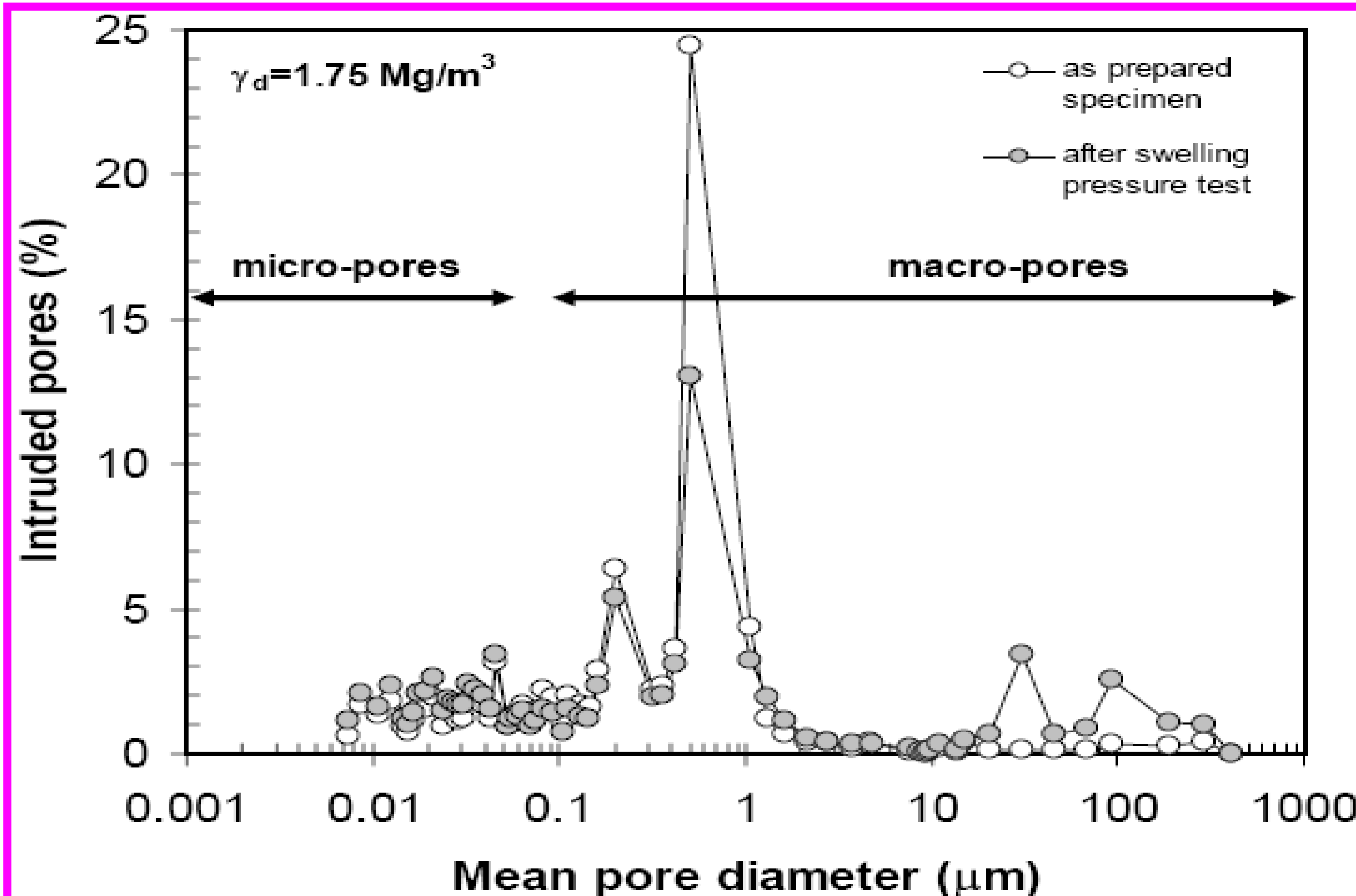
Initial conditions of specimens (dry density 1.75g/cm^3)

Specimen	Water content (%)	Void Ratio
As-prepared	11.14	0.55
Swollen	24.41	0.64

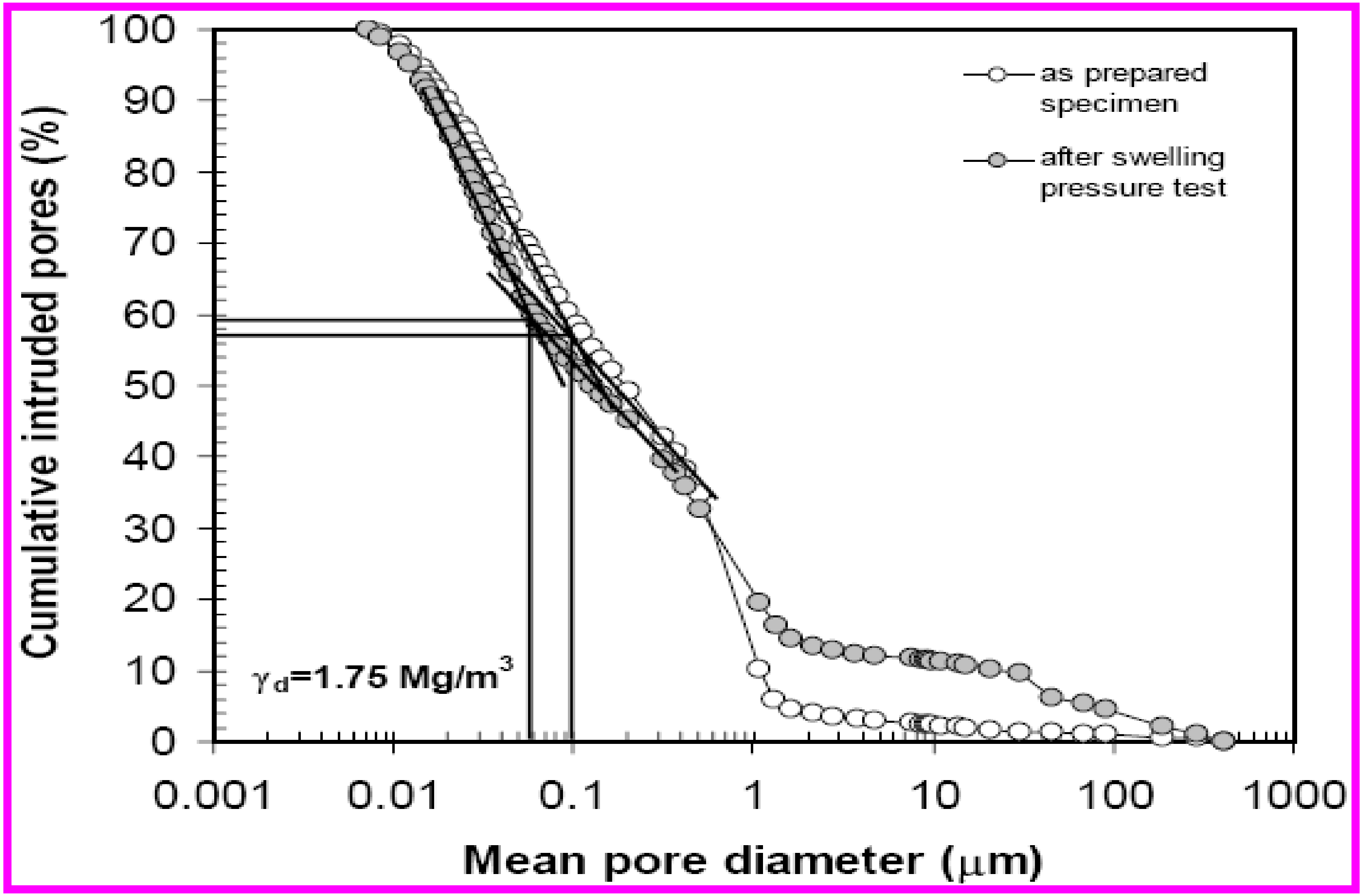
Pore-size distribution of compacted GMZ bentonite at two different states



Intruded pore volume vs. mean pore diameter at two different states



Determination of micro- and macropores from the pore size distribution data of the compacted GMZ bentonite



Summary of MIP test

MIP data	As-prepared	Swollen
Total pore volume(cm^3/g)	0.201	0.236
Total intr. pore volume(cm^3/g)	0.179	0.154
Percent of total pore volume(%)	89.1	65.3
Average diameter(μ m)	20.5	20.5
Micro-pore: diameter(μ m)	<0.1	<0.06
Average diameter(μ m)	0.037	0.025
volume(cm^3/g)	0.096	0.141
Percent of total pore volume(%)	48	60
Macro-pore: diameter(μ m)	0.1-409.22	0.06-409.38
Average diameter(μ m)	37.9	31.3
volume(cm3/g)	0.105	0.095
Percent of total pore volume(%)	52	40

Summary of MIP test

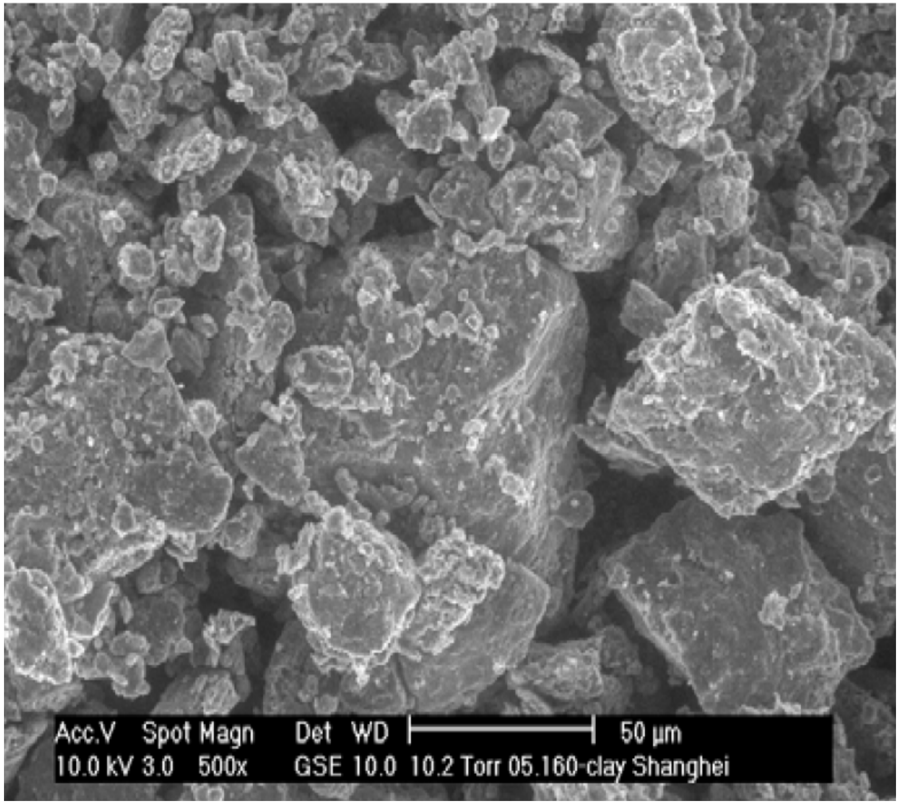
An internal rearrangement of clay clusters may occur when the specimen is wetted under constant volume conditions.

ESEM Test

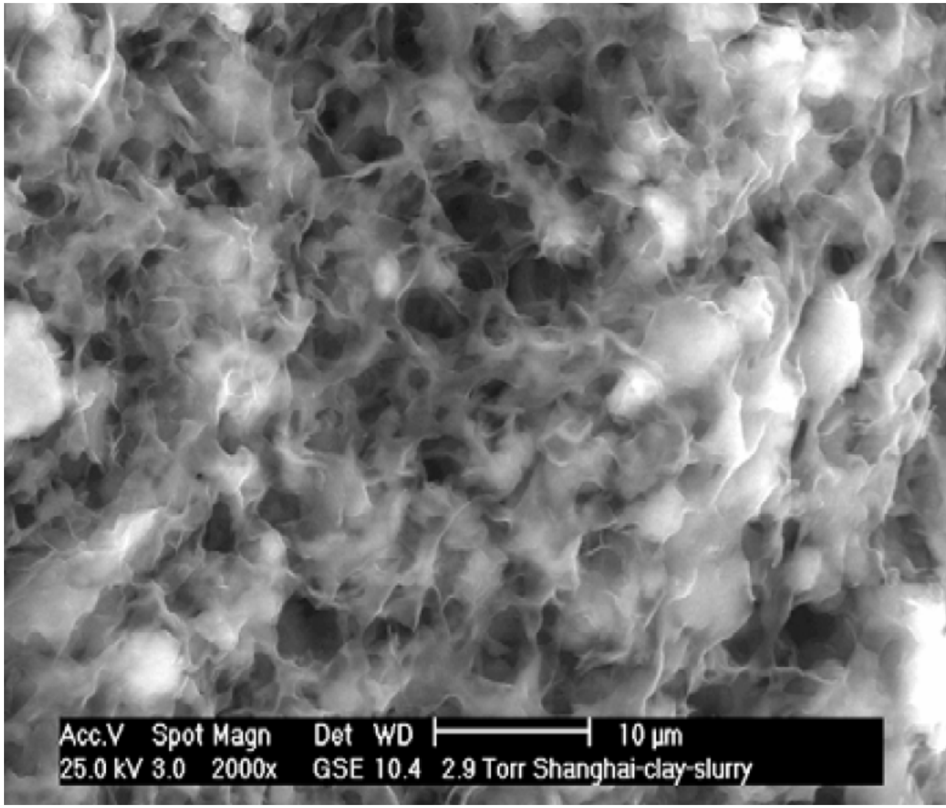
Initial conditions of the specimens tested

Specimen	Water content (%)	Dry density (g/cm^3)	Remarks
1	11.14		Powder
2	>270		Slurry
3	11.14	1.35	As-prepared
4	11.14	1.75	As-prepared
5???	24.41	1.65	Swollen

Effect of water content on microstructure of GMZ bentonite

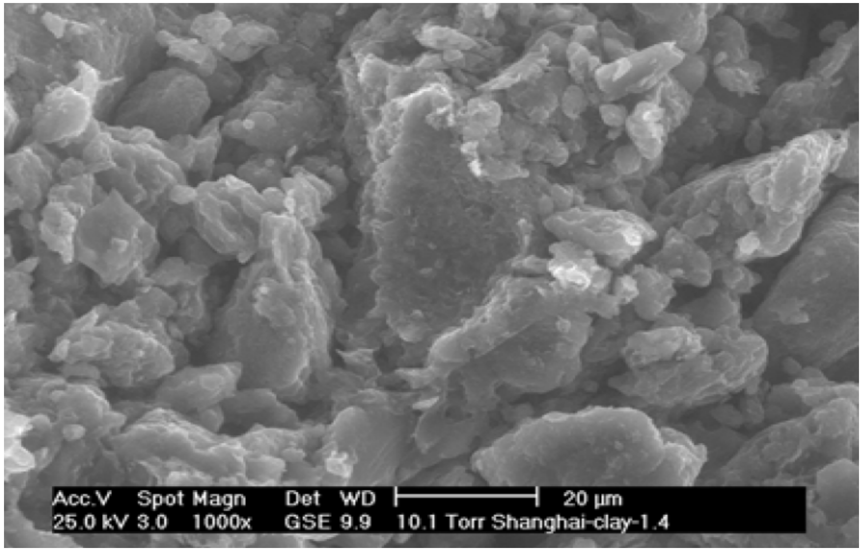


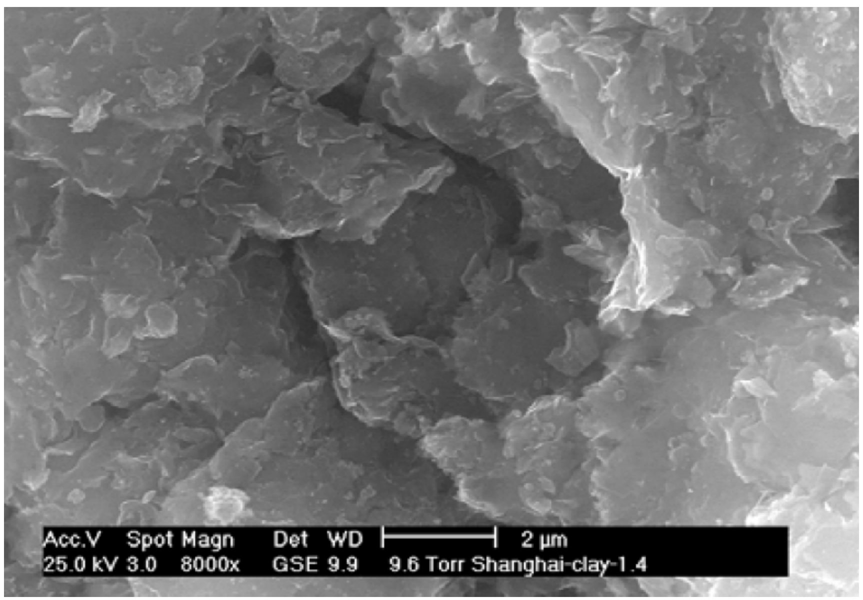
ESEM photo of GMZ bentonite (powder form, 500×)



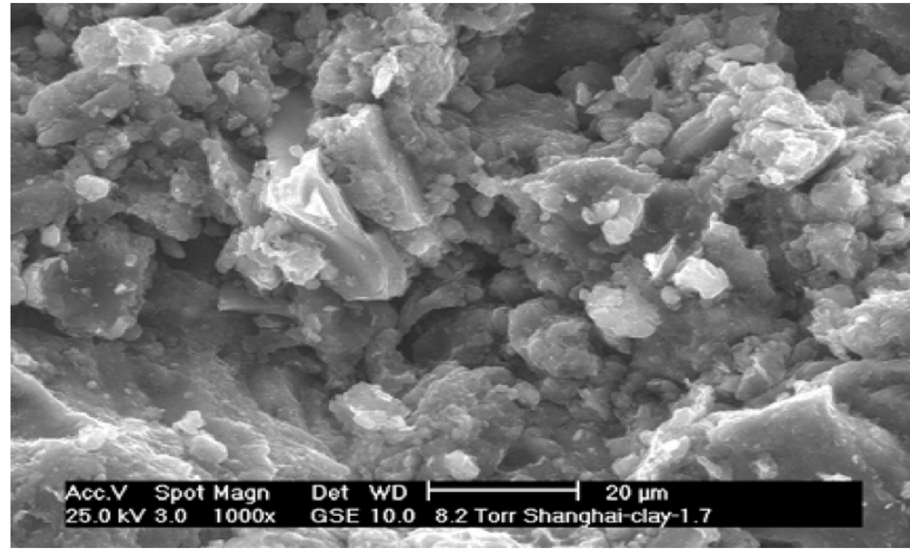
ESEM photo of GMZ bentonite (slurry form, 2000×)

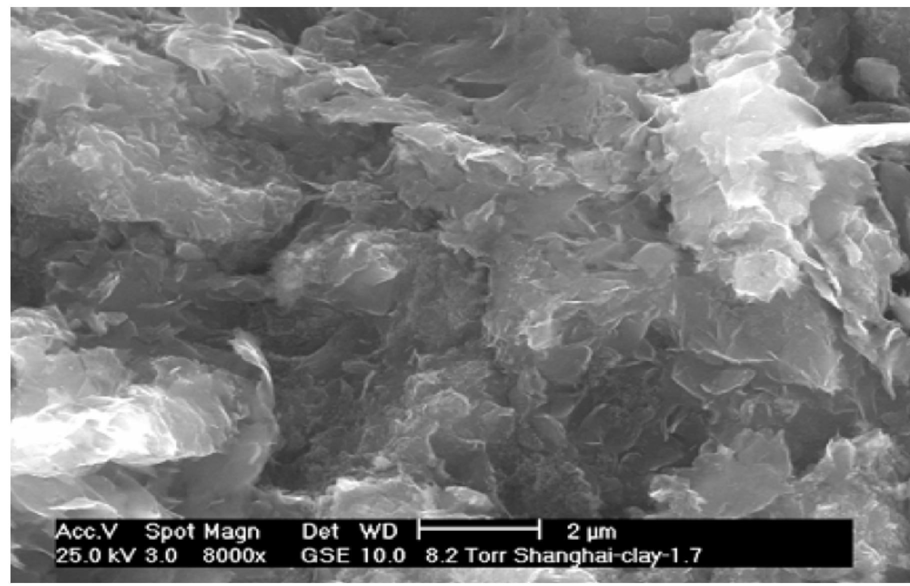
Effect of density on microstructure of GMZ bentonite





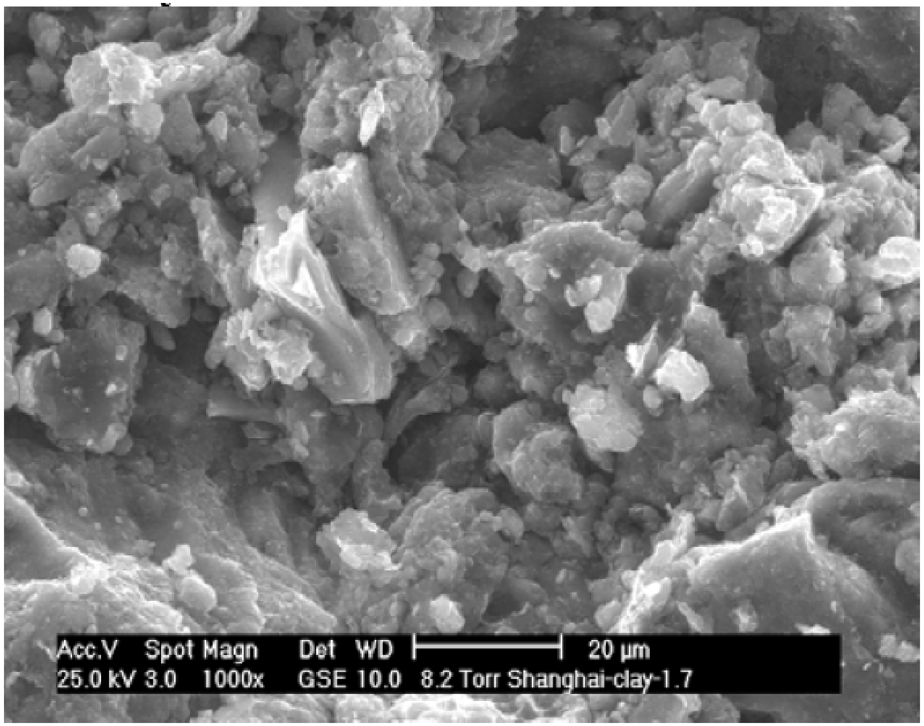
ESEM photo of GMZ bentonite (dry density1.35g/cm3)

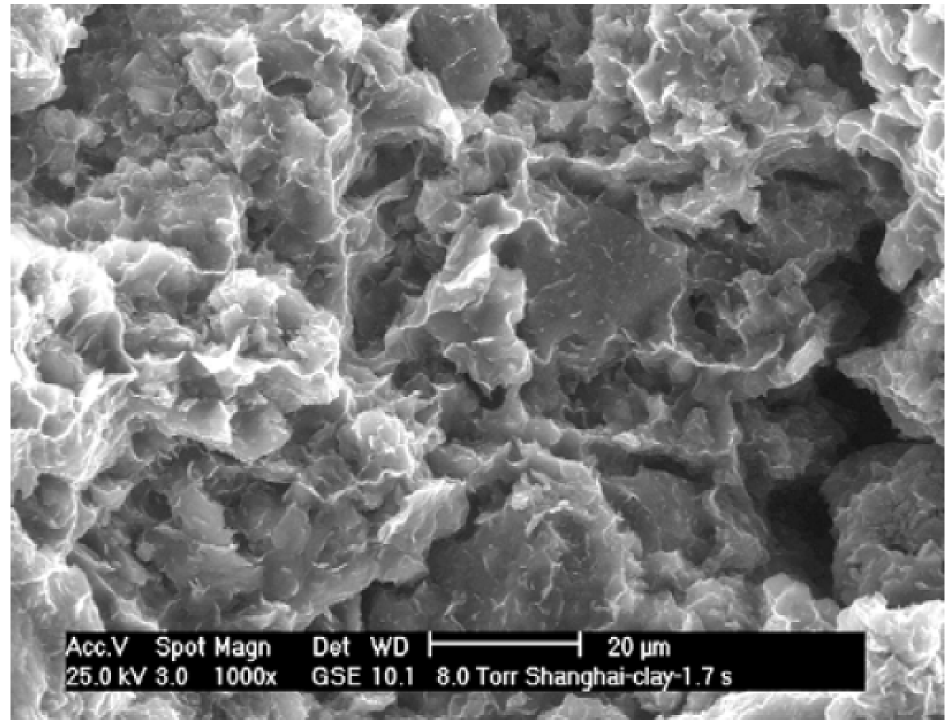




ESEM photo of GMZ bentonite (dry density1.75g/cm3)

Effect of swelling on microstructure of GMZ bentonite





as-prepared

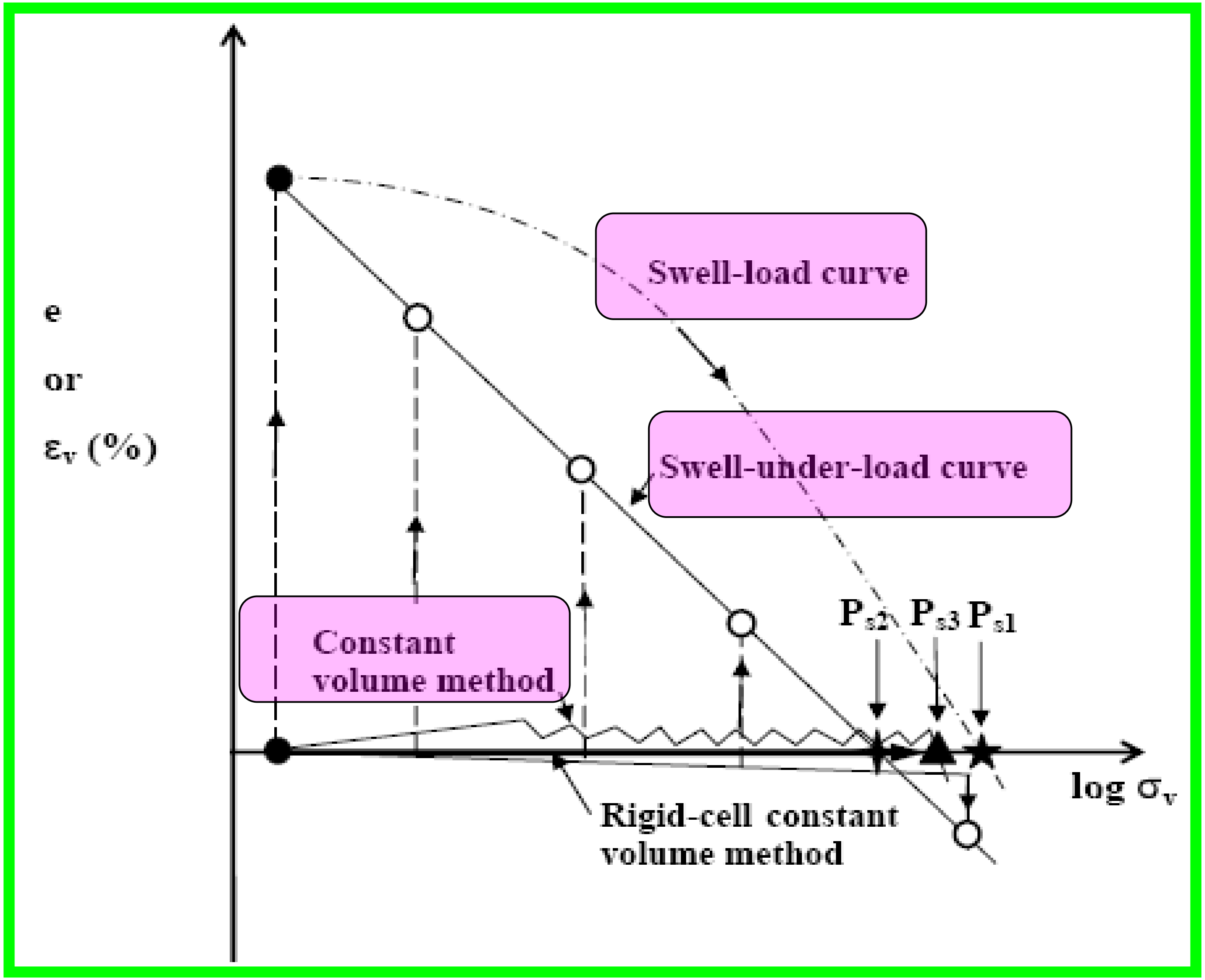
swollen

5 Swelling Pressure

Swelling pressure is defined as the pressure needed to maintain constant volume conditions when water is added to an expansive soil.

5 Swelling Pressure

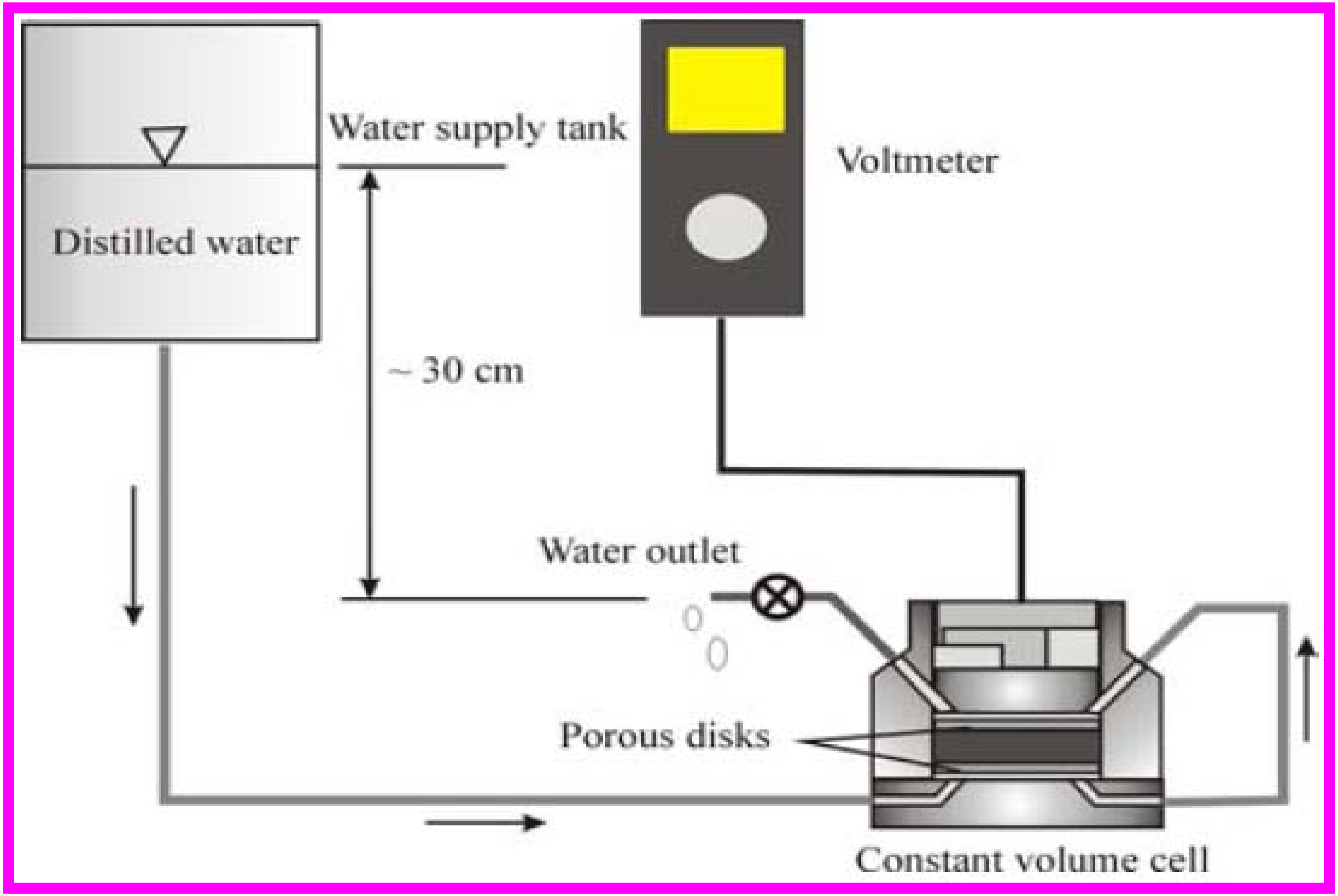
Methods



Experimental Techniques

Constant Volume

UPC Barcelona constant volume cell



The scheme of constant volume test (Weimar 2005)

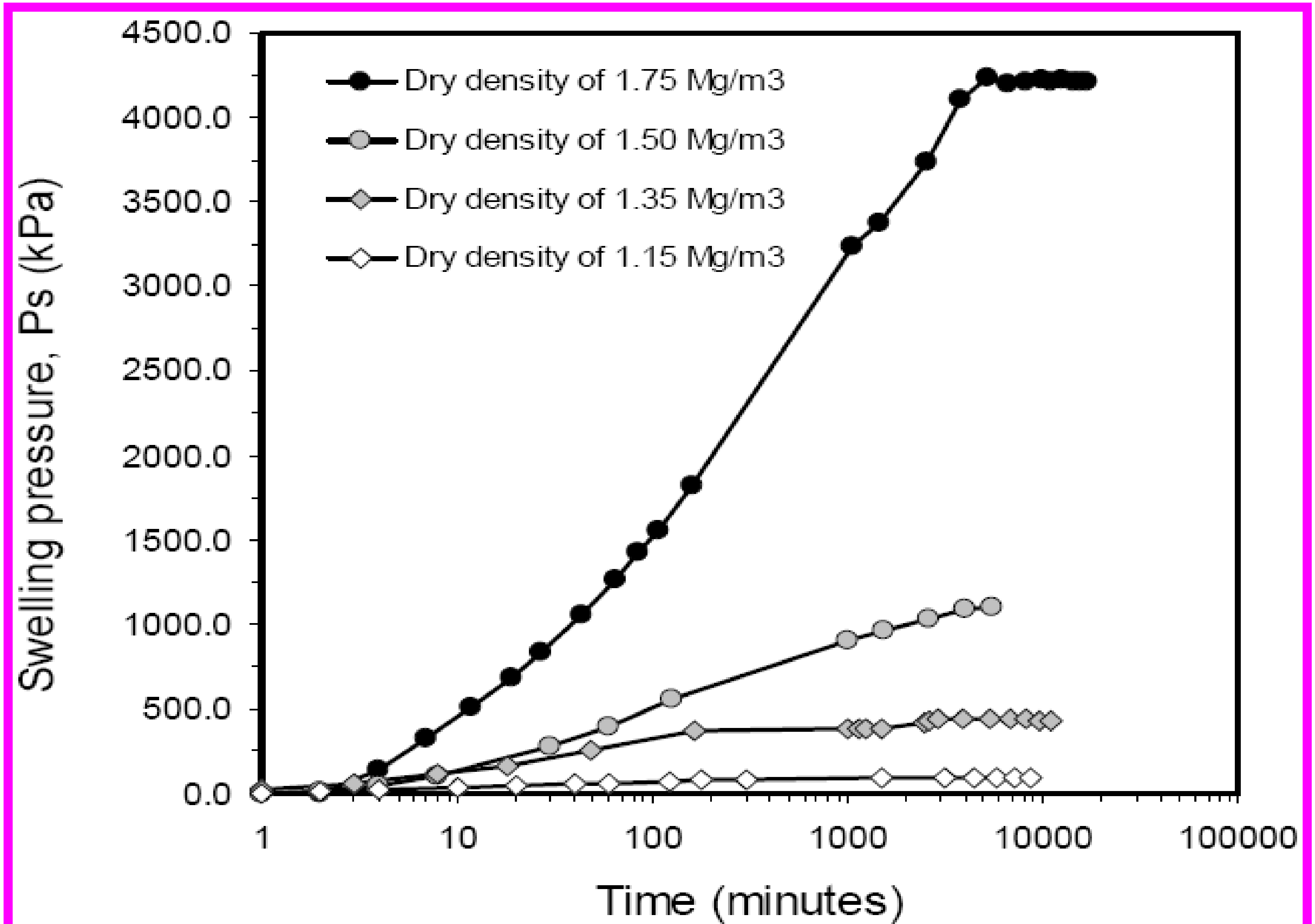
5 Swelling pressure

Initial conditions of the specimens in swelling pressure test

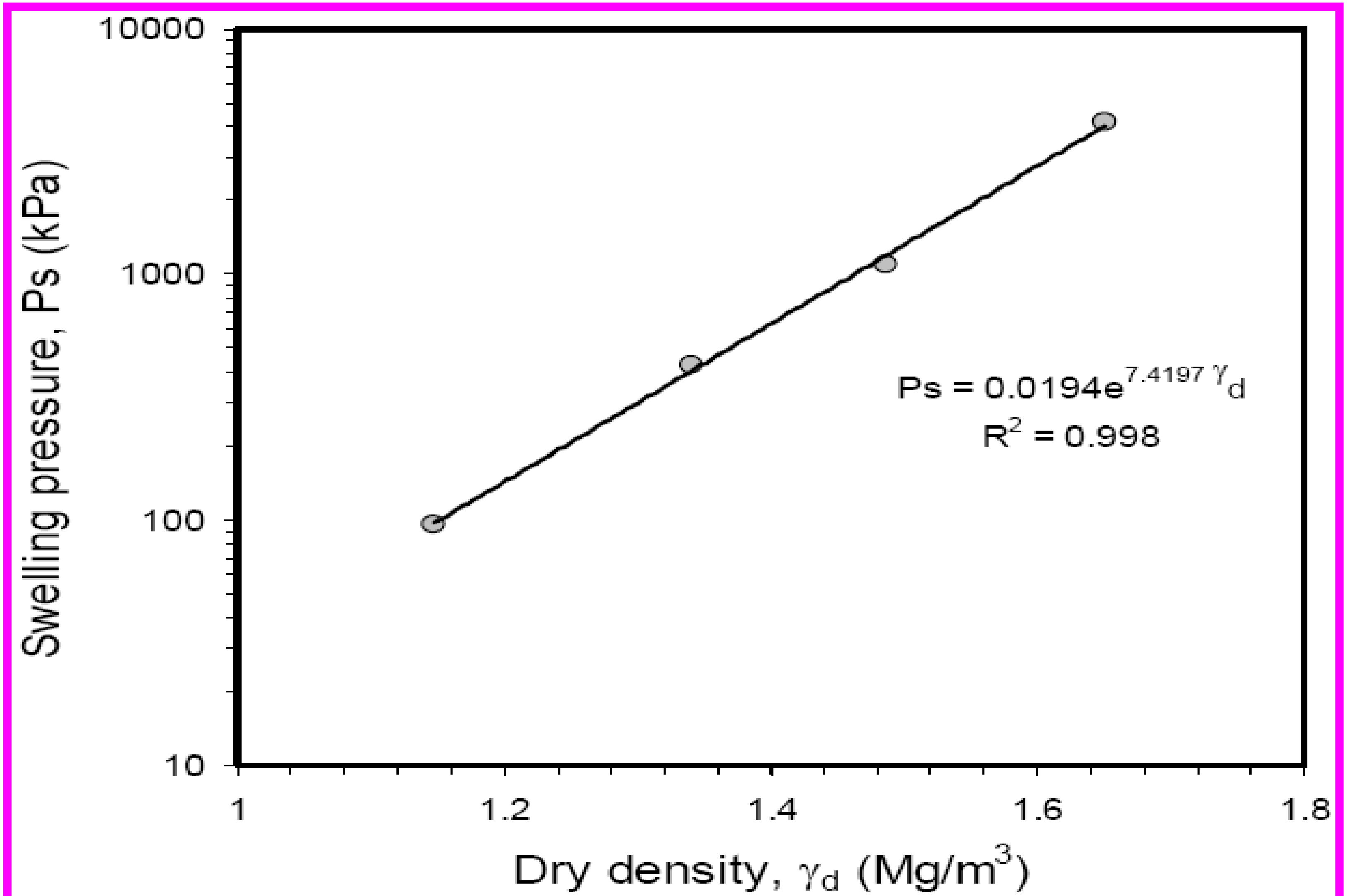
Specimen	Water content (%)	Dry density (g/cm^3)
1	11.14	1.15
2	11.14	1.35
3	11.14	1.50
4	11.14	1.75

Swelling pressure development with time

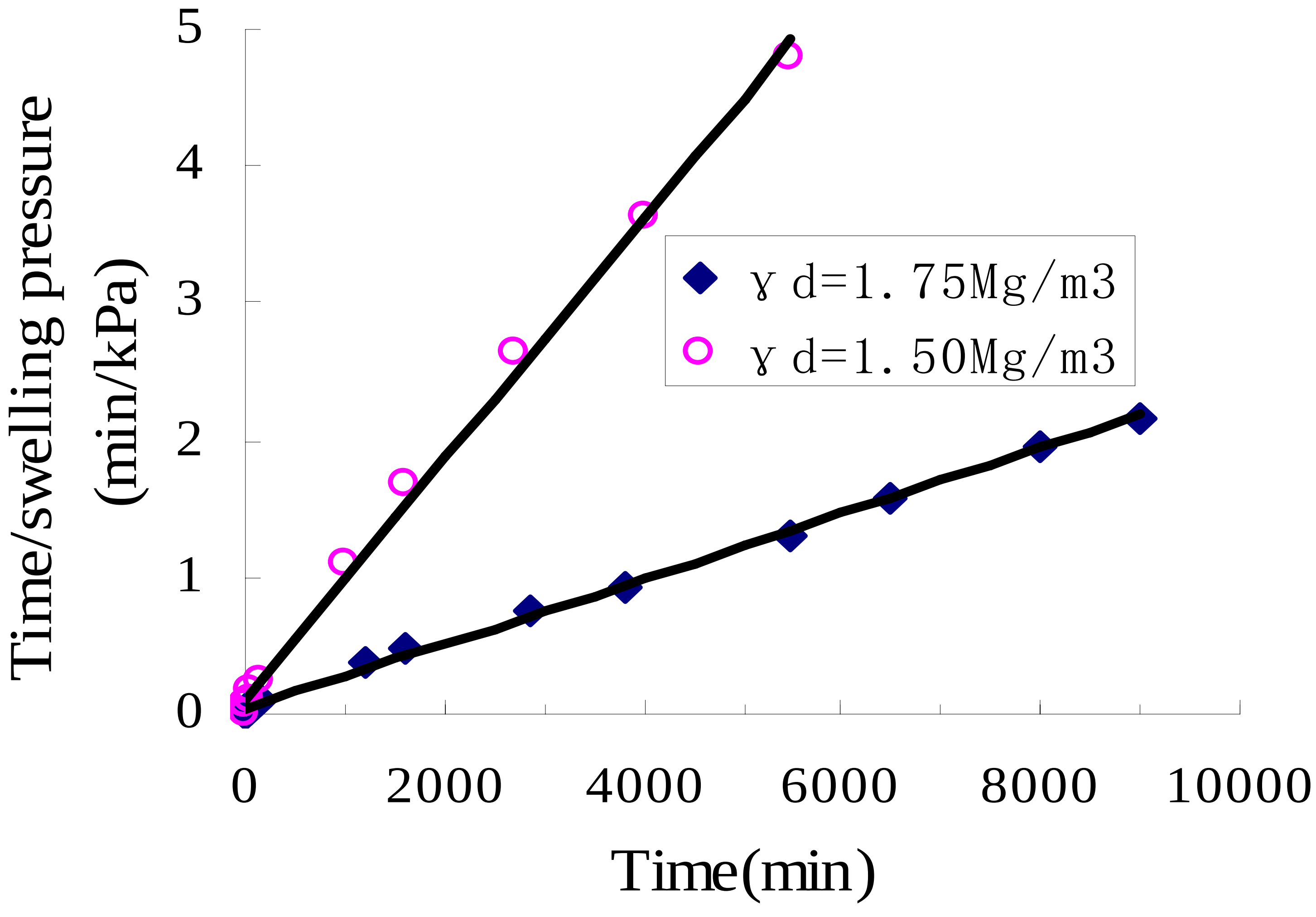
(Weimar 2005)



Swelling pressure vs. bentonite dry density (Weimar, 2005)



Time vs. (time/swelling pressure) relationship



$$\frac{t}{P_s} = a + bt$$

t —— time

P_s —— swelling pressure

a —— intercept

b —— slope of the straight line

1/*b*: ultimate swelling pressure

6 Conclusions

Compare to moderately plastic unsaturated soils, compacted bentonites are characterized by a high plasticity index and a high density that confer them a particular behavior.

6 Conclusions

Starting from the initial suction of 4.2 MPa, the difference between different confining conditions becomes less significant as the suction increases.

6 Conclusions

The as-prepared compacted specimen exhibits a bimodal pore-size distribution curve indicating the presence of a double porosity structure.

An internal rearrangement of clay clusters may occur when the specimen is wetted under constant volume conditions.

6 Conclusions

The swelling pressure increases with increase in dry density. The time over swelling pressure vs. time bears a good linear relationship.

Acknowledgement

- National Natural Science Foundation of China
- DAAD, Bauhaus University Weimar and Prof T. Schanz
- Commission of Science Technology and Industry for National Defense

Thank you!

Development of a new Closure Concept for the Richard Repository, Czech Republic

An Example for Successful International Cooperation

Disposal of Radioactive Waste -

An Area of International Cooperation with Long Tradition

Since the early times of nuclear power production the importance of not only safe operation of the NPPs but also for safe management and disposal of radioactive waste has been recognized.

It also had been recognized that potential dangers are not limited to the borders of the individual nations.

Therefore the first organisations for international cooperation in the field of the peaceful use of nuclear energy were established very early and they also promote international cooperation in finding solutions for the safe disposal of radioactive waste.

Main International Organisations

- IAEA (International Atomic Energy Agency)
  Technology Section and Waste Safety Section
- OECD (Organisation for Economic Cooperation and Development
  NEA (Nuclear Energy Agency) – RWMC (Radioactive Waste Management Committee)
- EDRAM (Environmental Safe Disposal of Radioactive Material)
- EURATOM (European Atomic Energy Community)
- European Commission (Research and Transport & Energy)
- Club of Agencies (most Western Waste Management Agencies)
- Large number of multi- and bilateral cooperations

DBE/DBE TECHNOLOGY mbH has

cooperation agreements with a broad range of waste management organisations and institutions working in the same field:

- including most of the radioactive waste management organisation in Western and East Europe, DOE of the USA and engineering companies working in the US in this area, with institutions in Russia, IHI and RWMC of Japan, Organisations in South Africa, Argentina, and BRIUG of the People's Republic of China

is a member of EDRAM, Club of Agencies, ITC (International Training Center for Geological Disposal)

has carried out a wide range of R&D projects in the framework of EC financed projects

European Projects

Phare Project

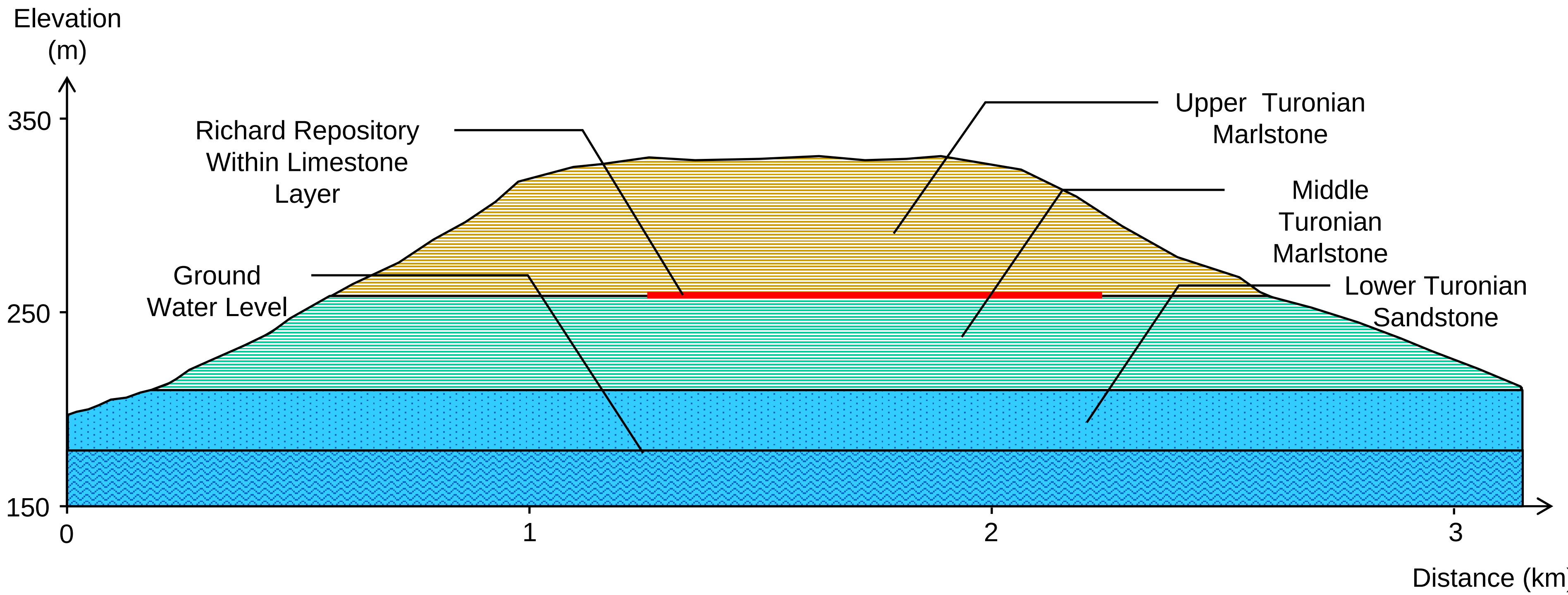
Solution for the Closure of a Chamber in the Richard Repository

EUROPEAID/113986/D/SV/CZ

A project funded by the European Union and the Czech Republic

Location of Richard Repository

Simplified Geological Cross Section



- 1930´s Limestone mine
- 1940´s Military production
- 1960´s Repository
- Inventory ca. 10^{15} Bq
- Approx. 25,000 waste packages disposed of
- 2000 RAWRA takes over RICHARD

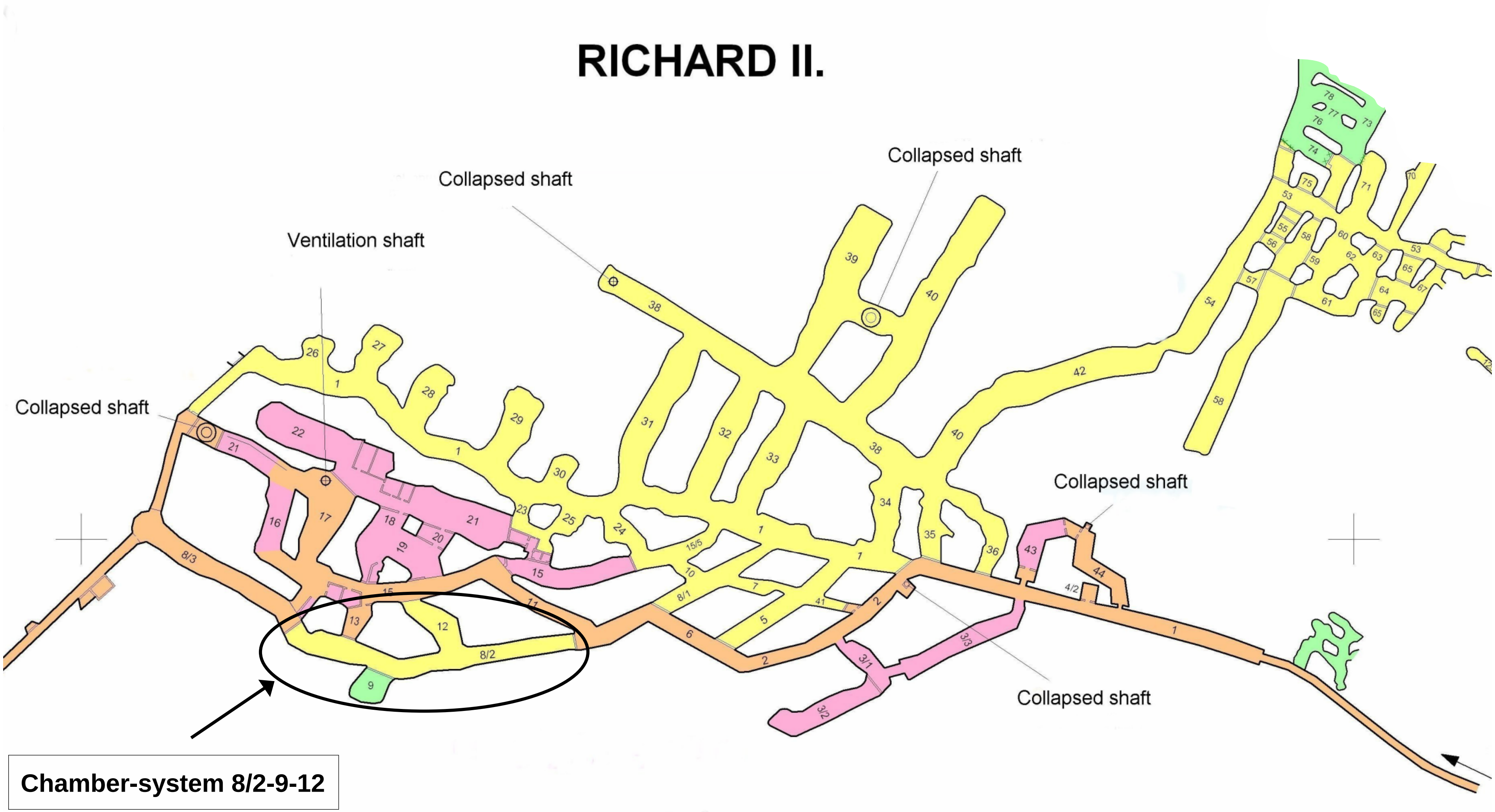
Main Tasks of Phare Project on Richard Repository

- Review of existing closure plan and safety assessment
- Revision of closure plan (if necessary)
- Update of the safety assessment
- Detailed technical planning for specific chamber-system
  - Preparation of the non operated chamber-system
  - Handling and treatment of waste (incl. historical waste)
  - Backfilling of chamber-system
- Preparation of documents for realization of closure concept
  - licensing
  - tender process

Main Topics of Presentation

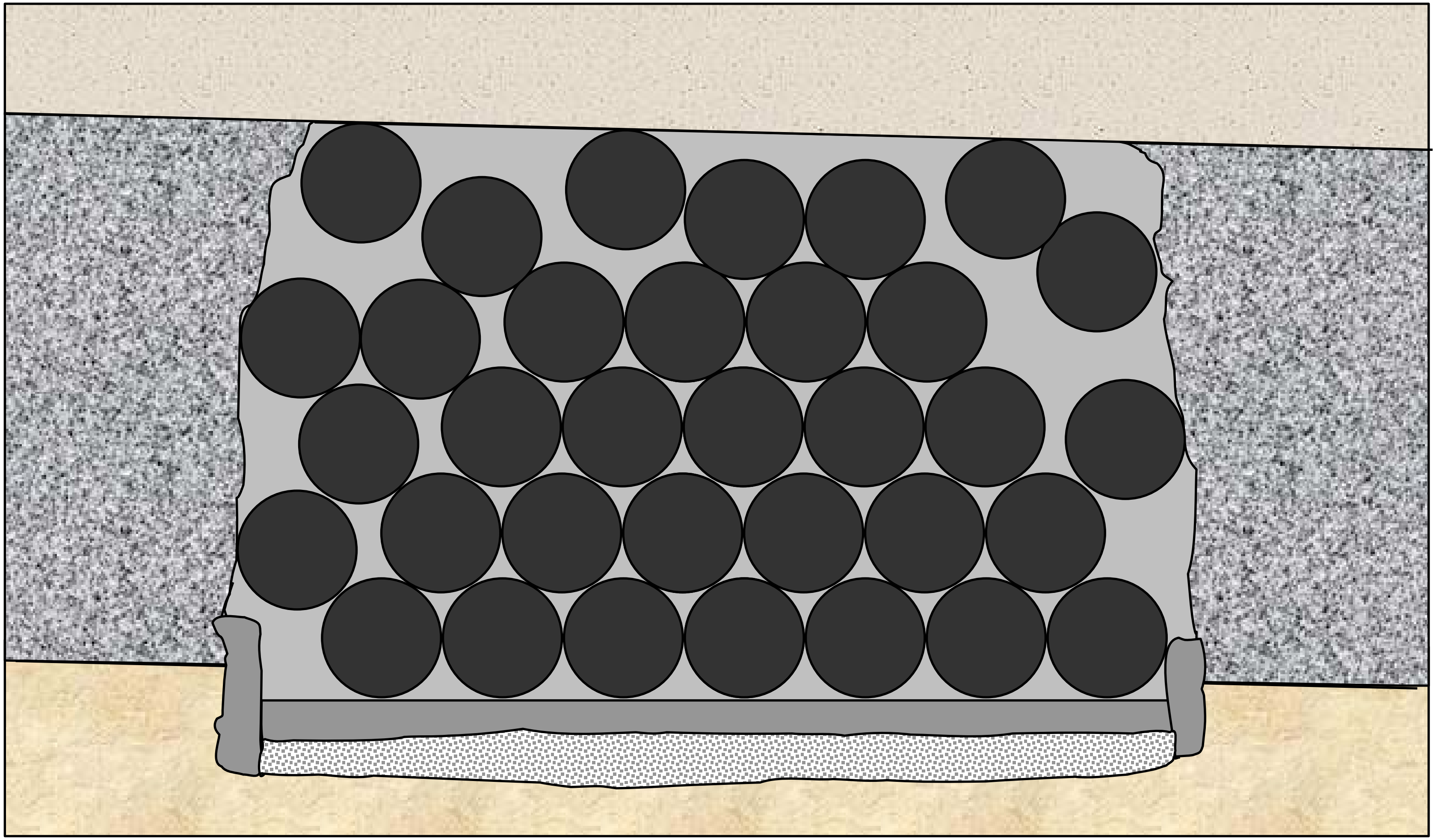
- Brief description on the reasons for changing the former closure concept
- Principal description of new closure concept and its impact on the long-term safety
- Description of planned technical implementation and its realisation

Map of Richard Repository



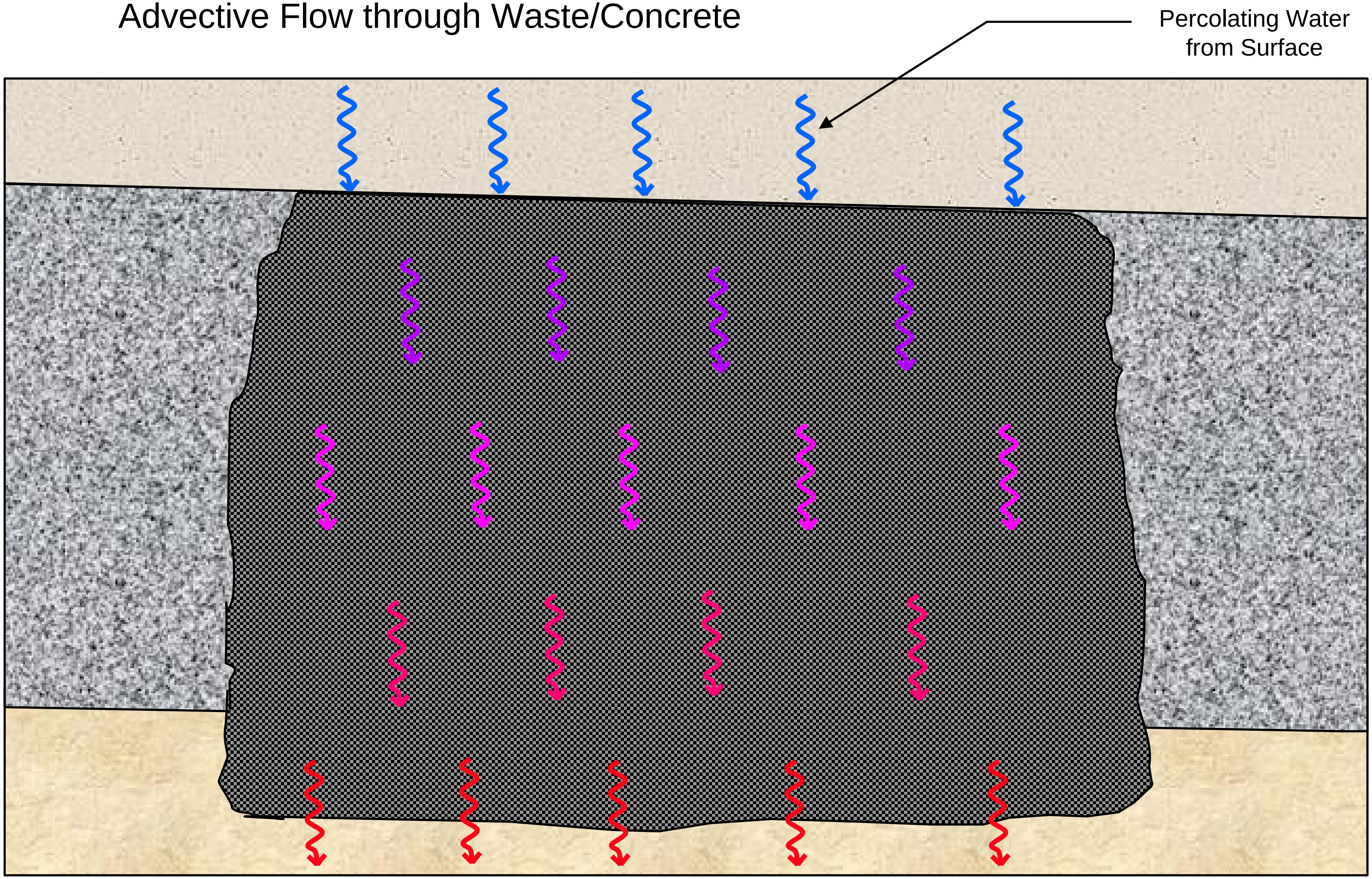
Waste Chamber

Previous Closure Concept
Simplified Chamber Model



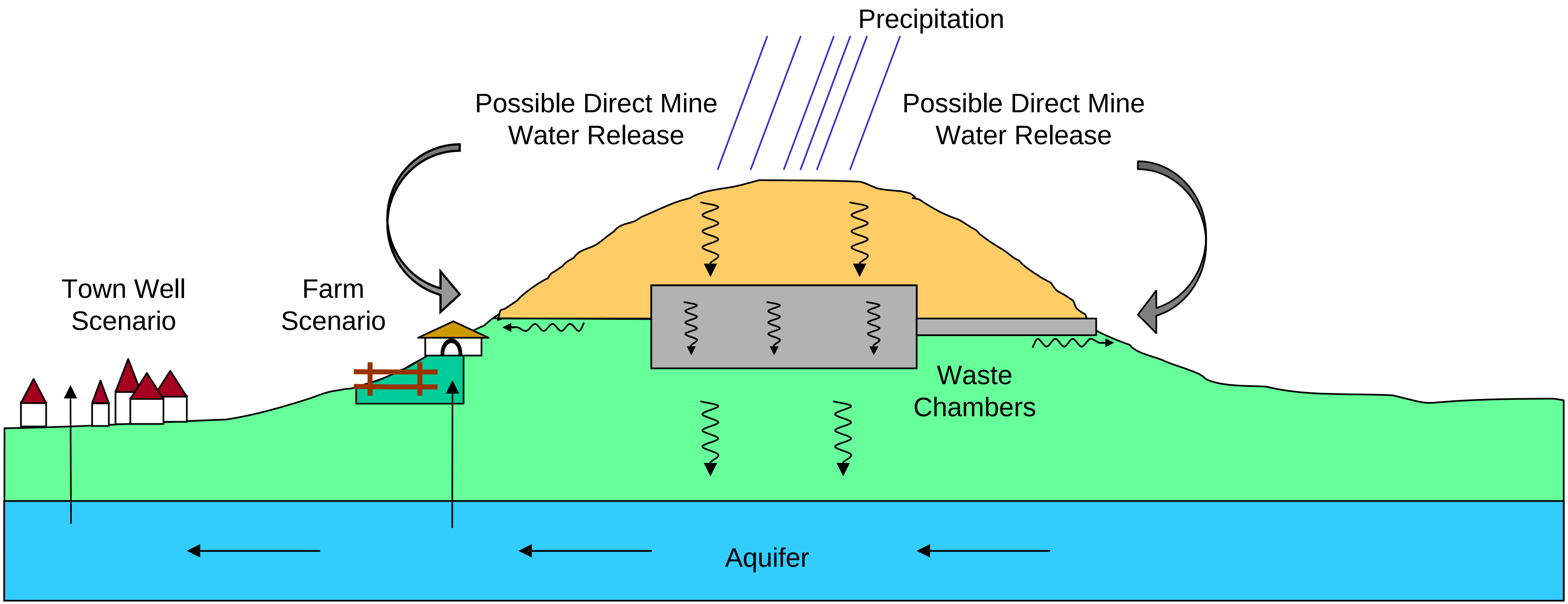
Previous Closure Concept

Advective Flow through Waste/Concrete



Previous Closure Concept

Simplified Model for Scenarios



Main Problems of Previous Closure Concept

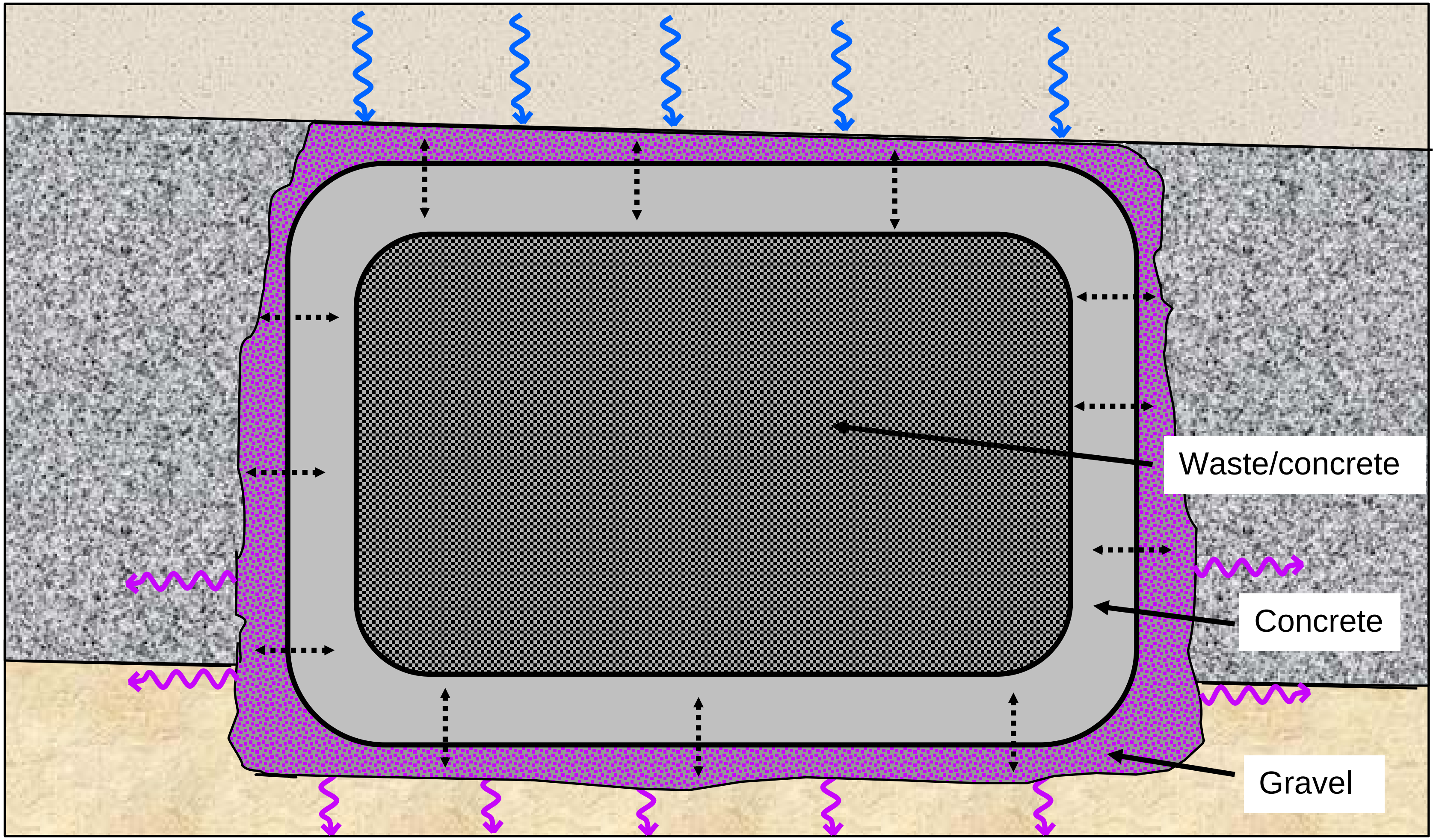
- Direct contact between water and waste packages not prevented
- Advective transport without delay
- Due to special stratigraphy, scenarios related to direct release of mine water difficult to exclude

Hydraulic Cage Concept

Elimination of radionuclide transport mechanism
by transport gradient elimination
through implementation of an HYDRAULIC CAGE

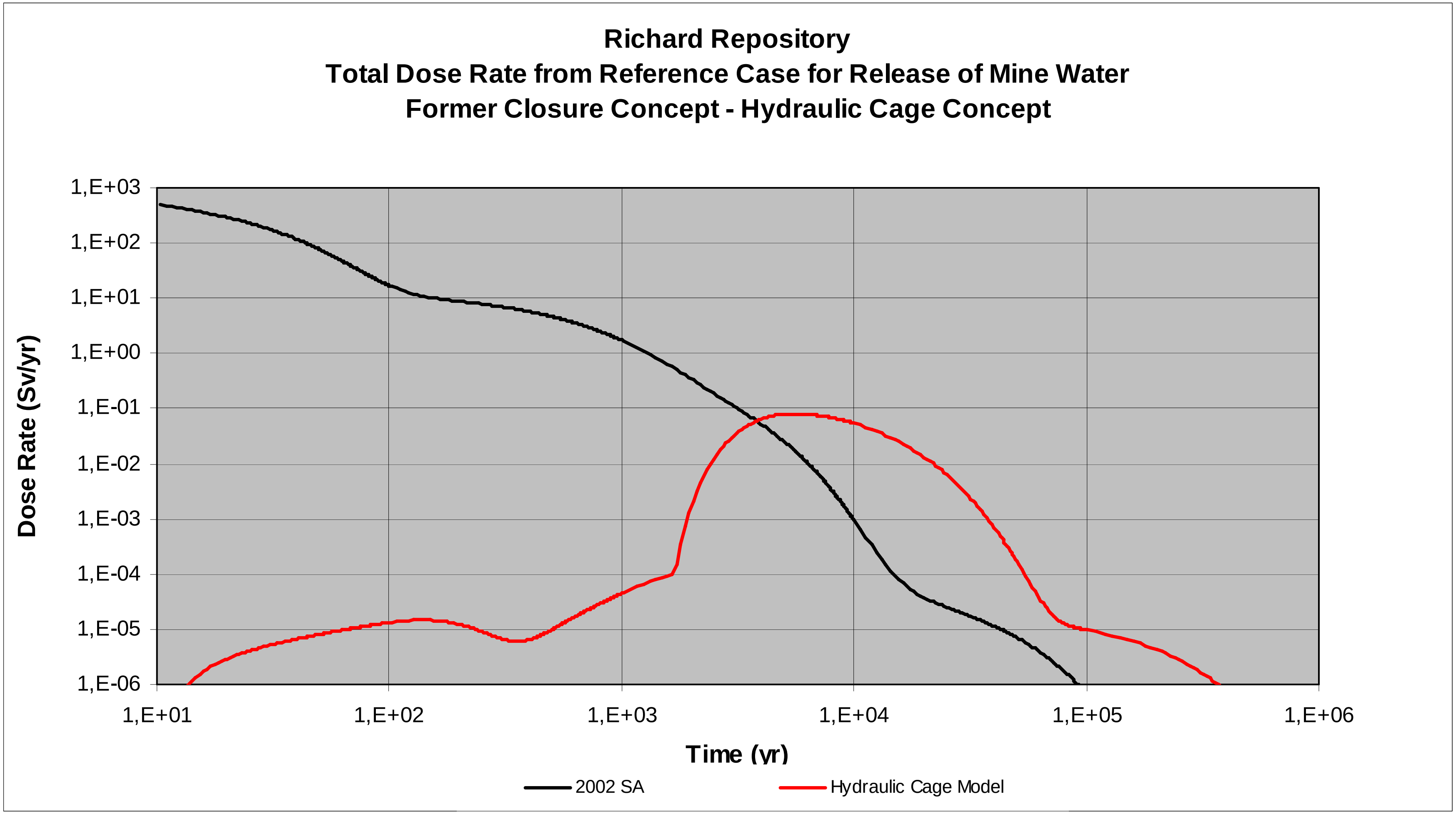
Hydraulic Cage Concept

Simplified Radionuclide Transport



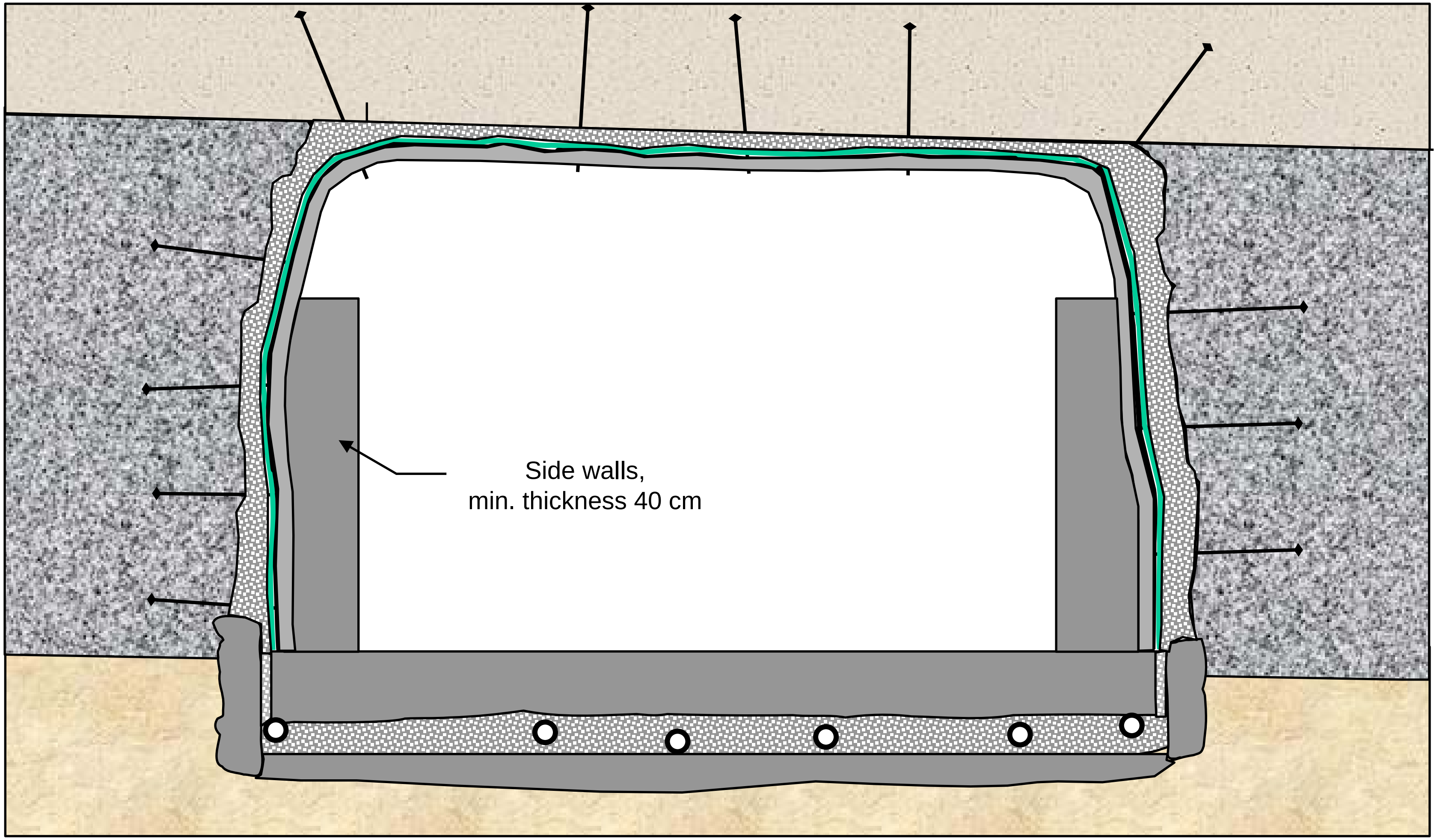
Safety Assessment Richard Repository

Total Dose Rates from Mine Water Release Scenario



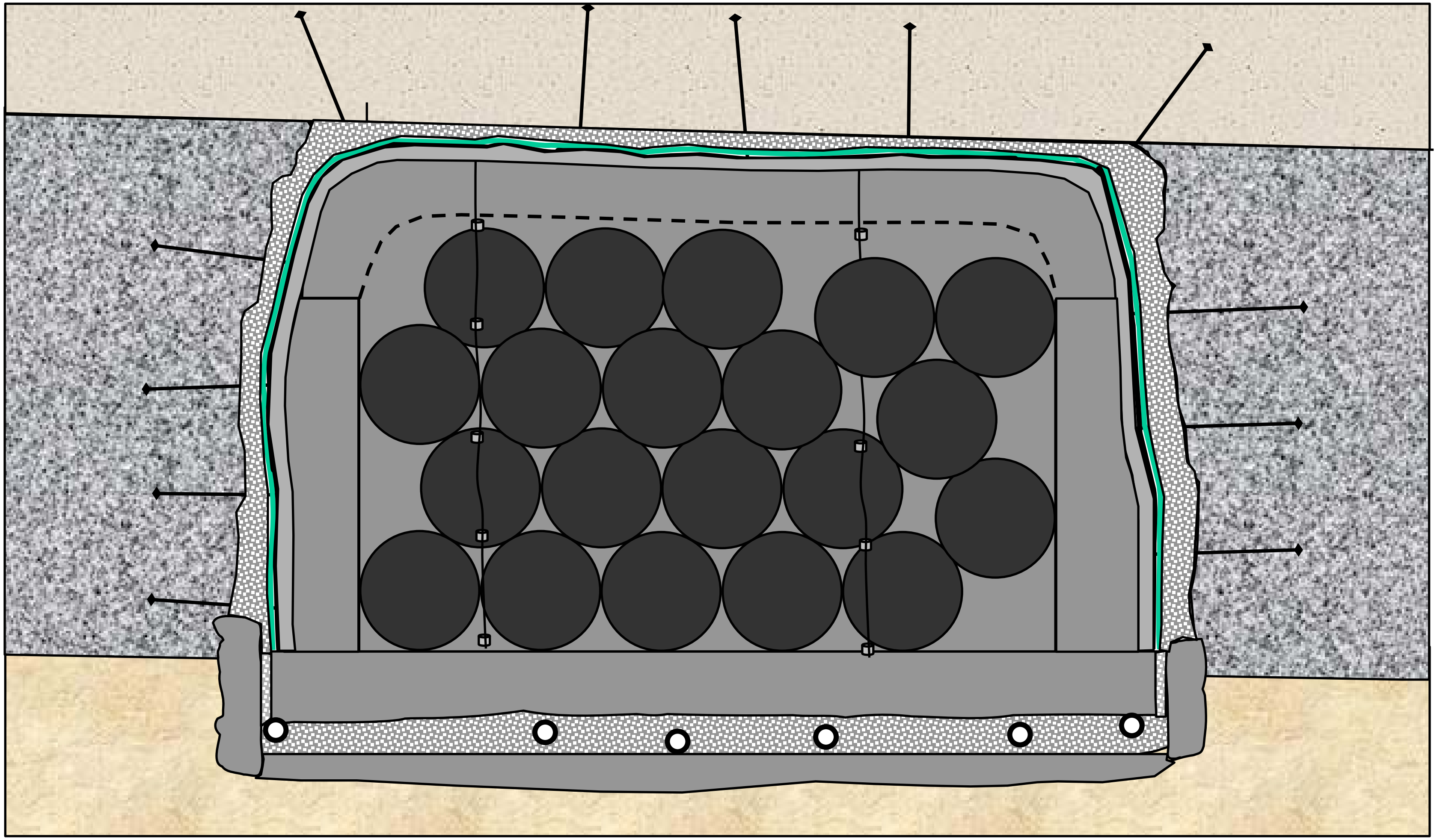
Chamber Preparation

Preparation of Concrete Side Walls



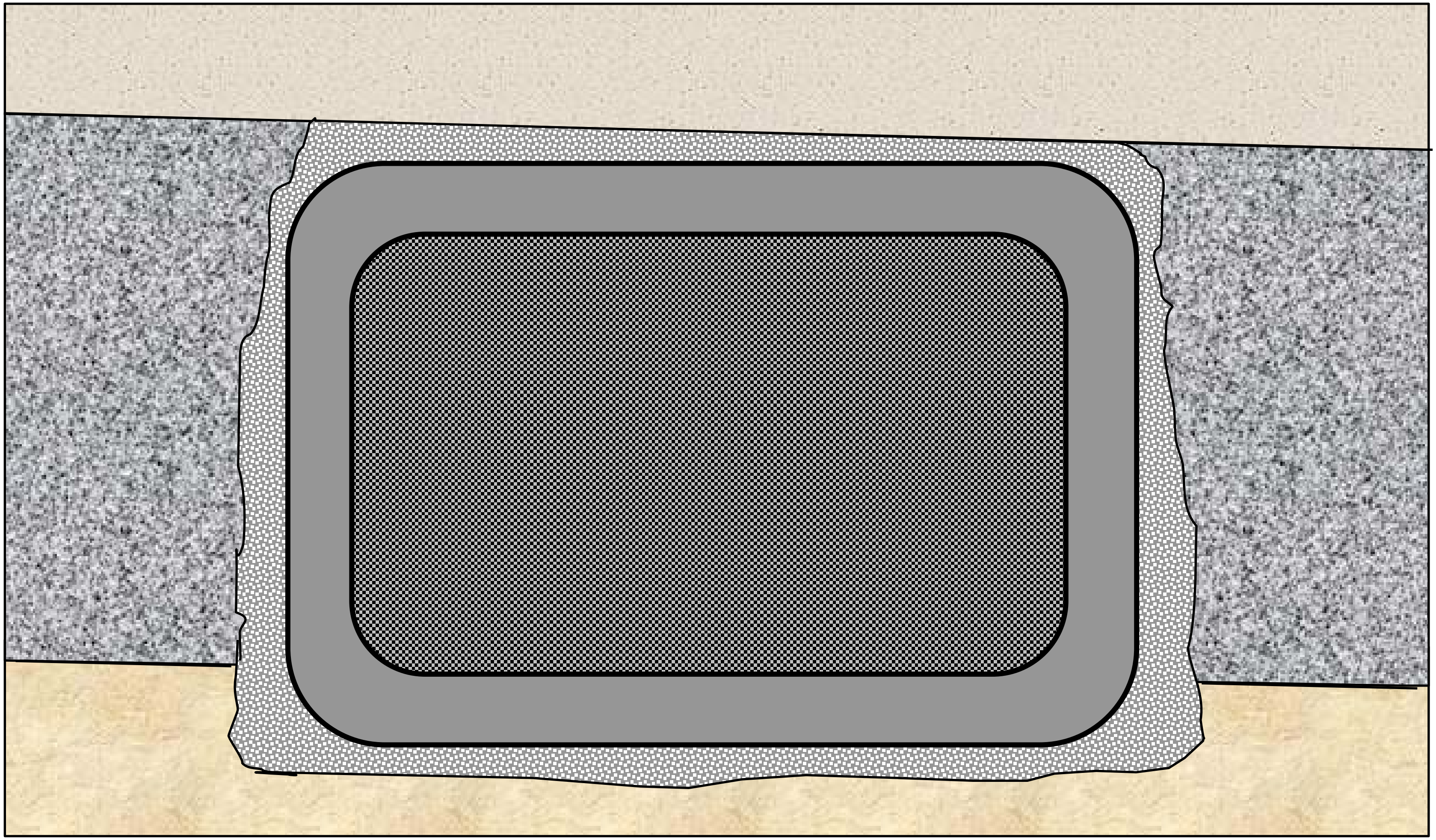
Closure of Chamber

Situation after Backfilling



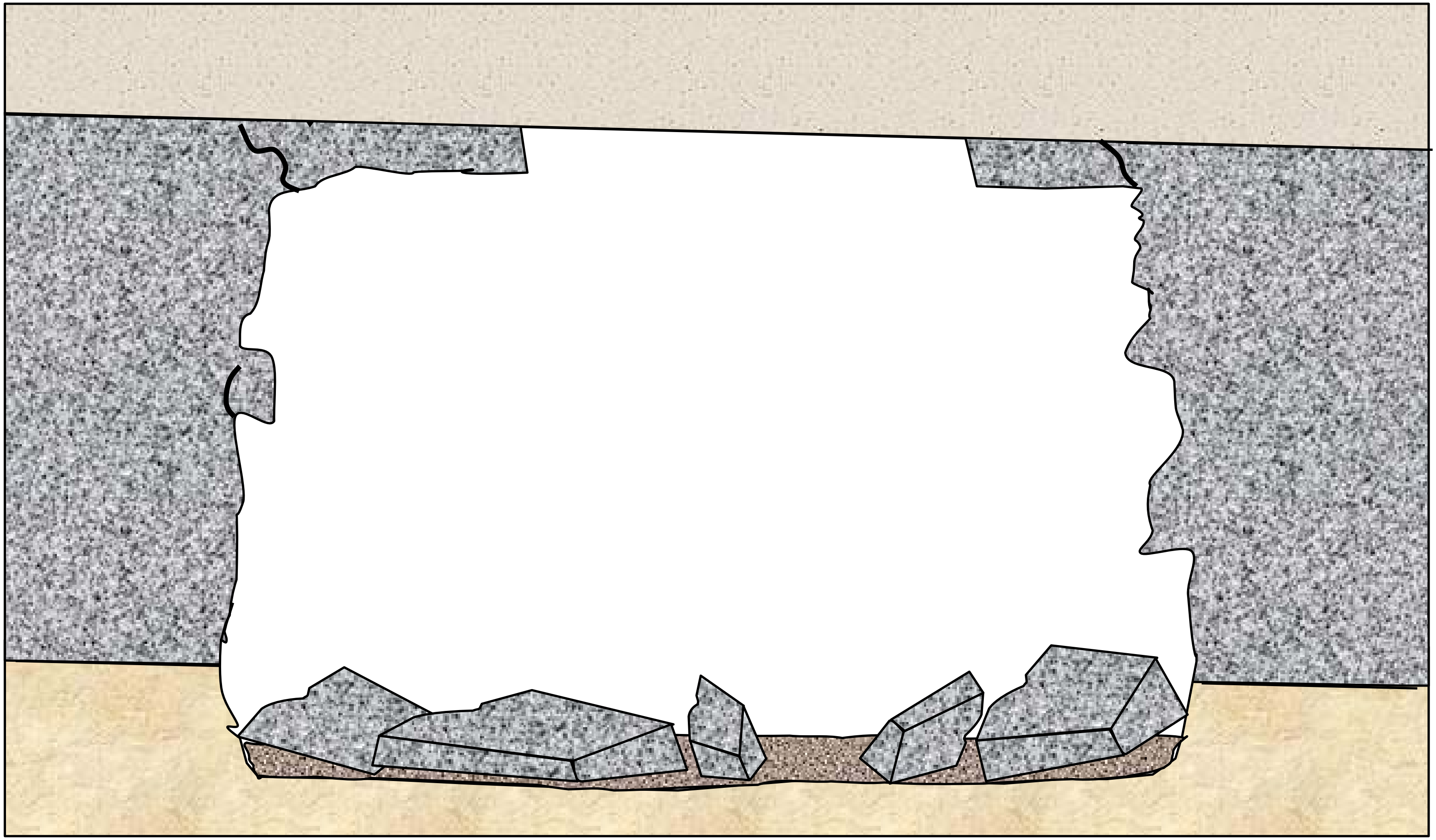
Closure of Chamber

Further Simplified Model of Situation after Backfilling



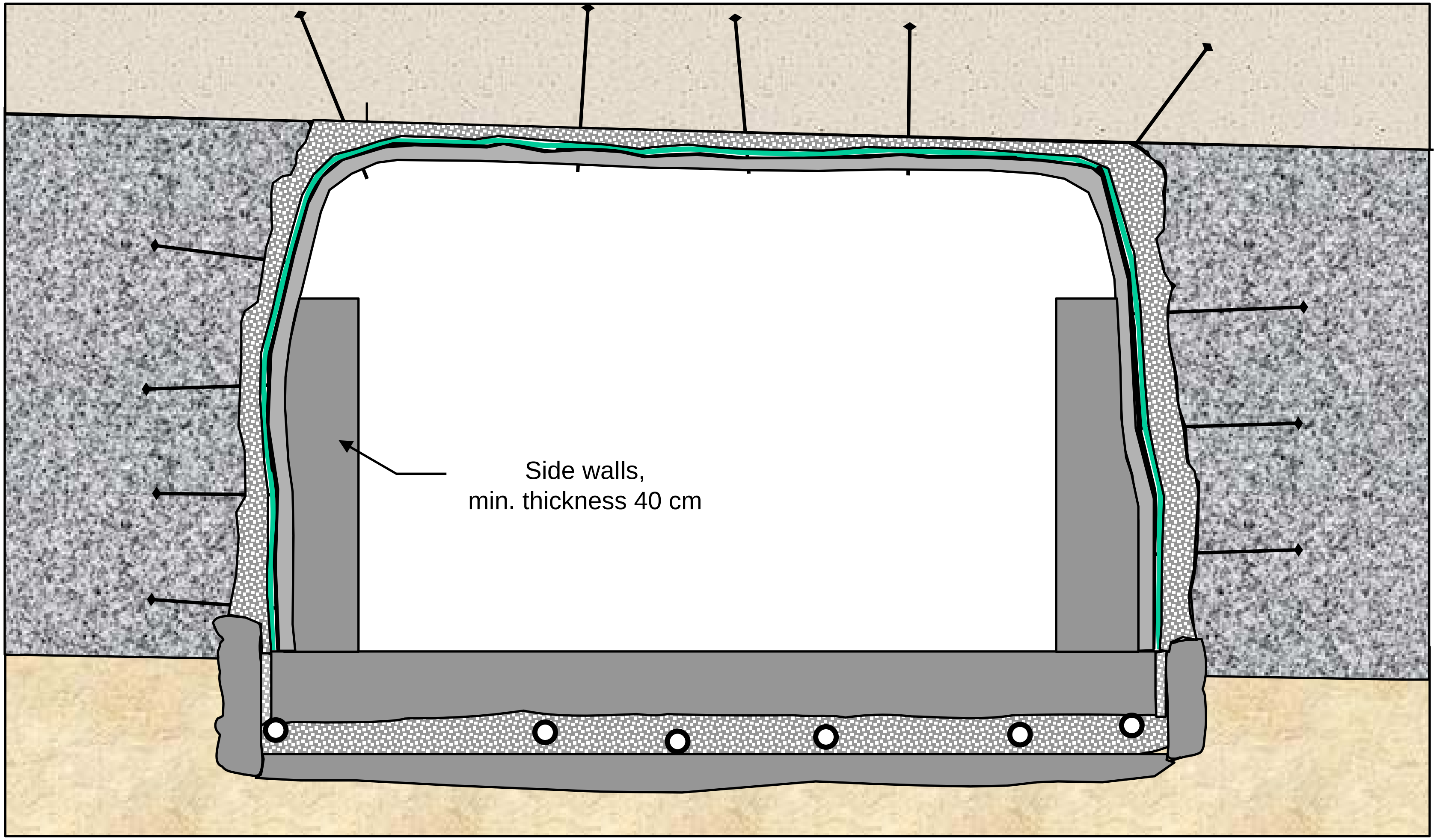
Chamber Preparation

Present Situation



Chamber Preparation

Preparation of Concrete Side Walls



Chamber Preparation

Initial Situation

Presentation TopSeal 2006, Olkiluoto

UVVVR
229-90
U
312
139-90
88-90
9-90
67-90

Thank you very much for your attention

Technical Implementation of

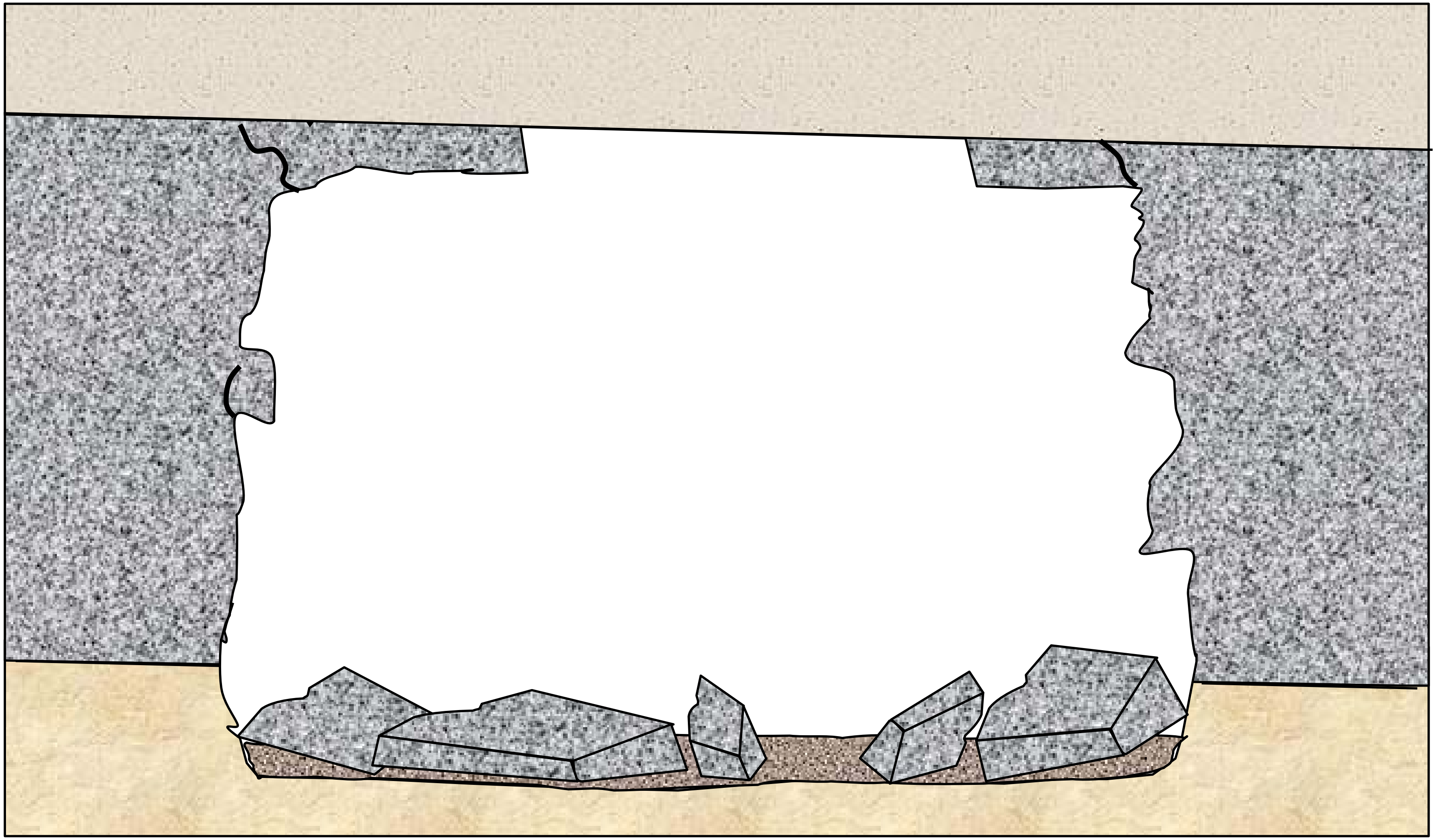
Hydraulic Cage Concept

Main Steps during Technical Implementation of Hydraulic Cage

- Clearing of Chamber
- Construction of Roadway and Hydraulic Cage
- Preparation for Waste Disposal
- Disposal and Backfilling

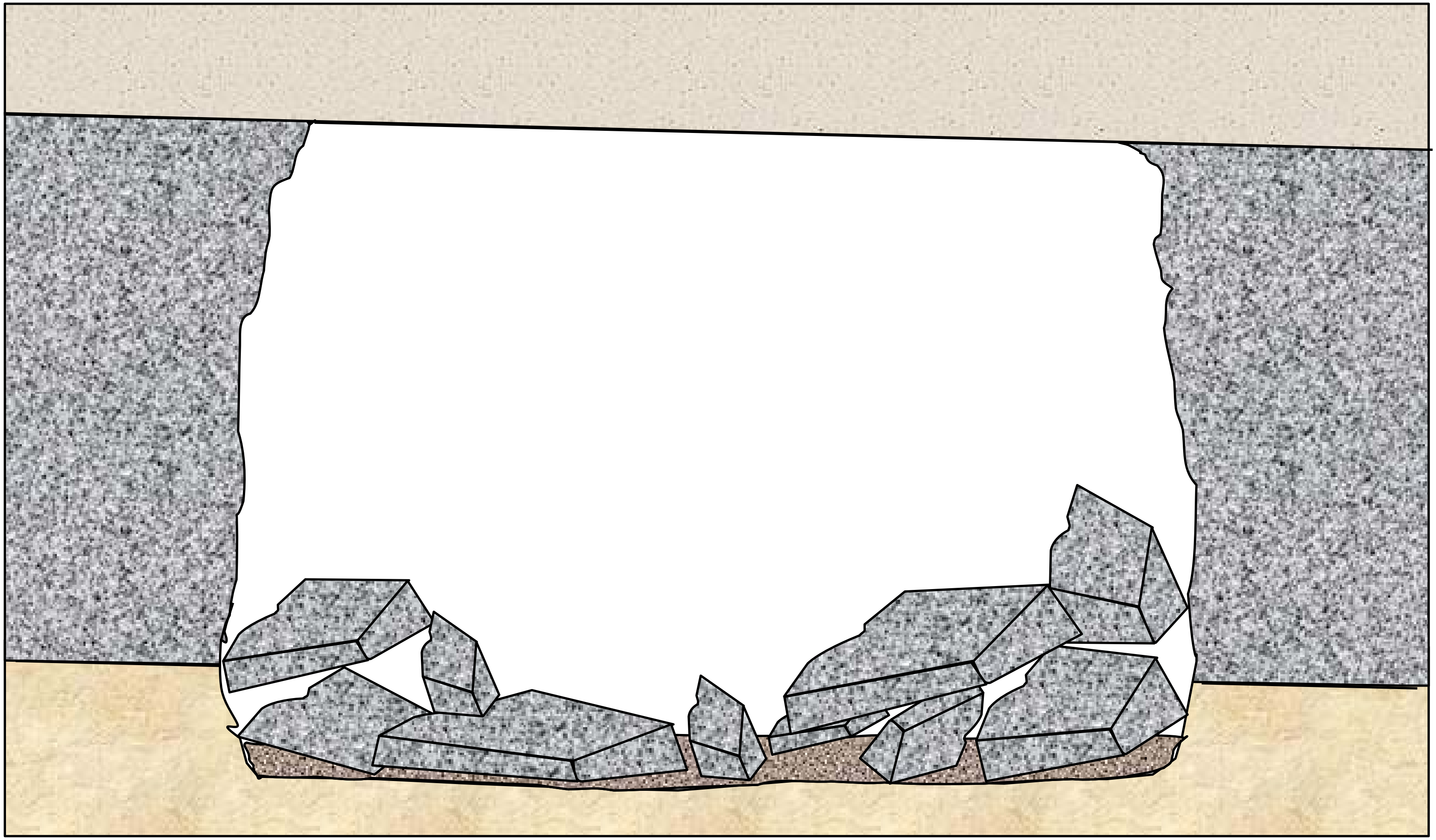
Chamber Preparation

Present Situation



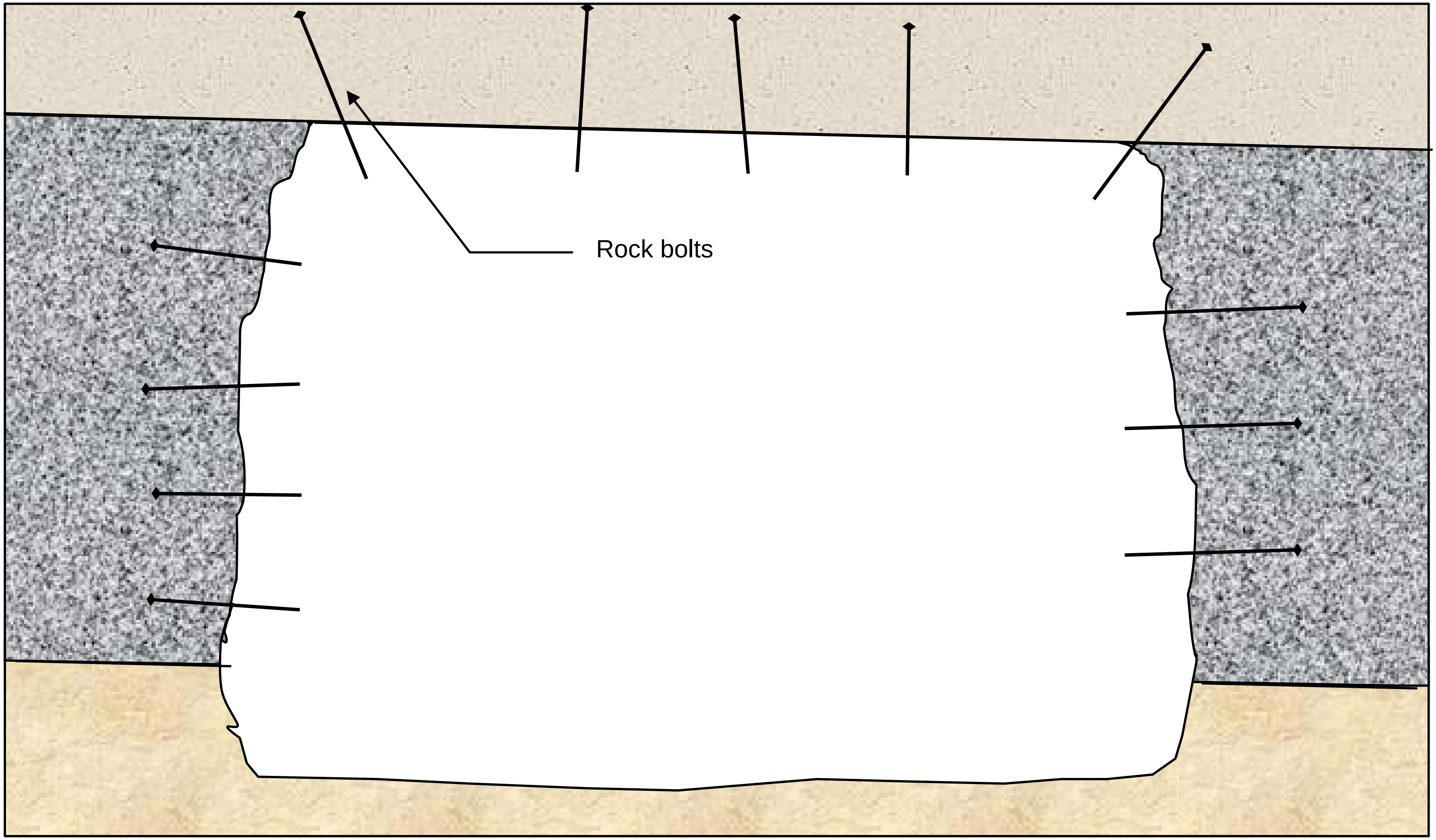
Chamber Preparation

Situation After Clearing of Loosened Rocks



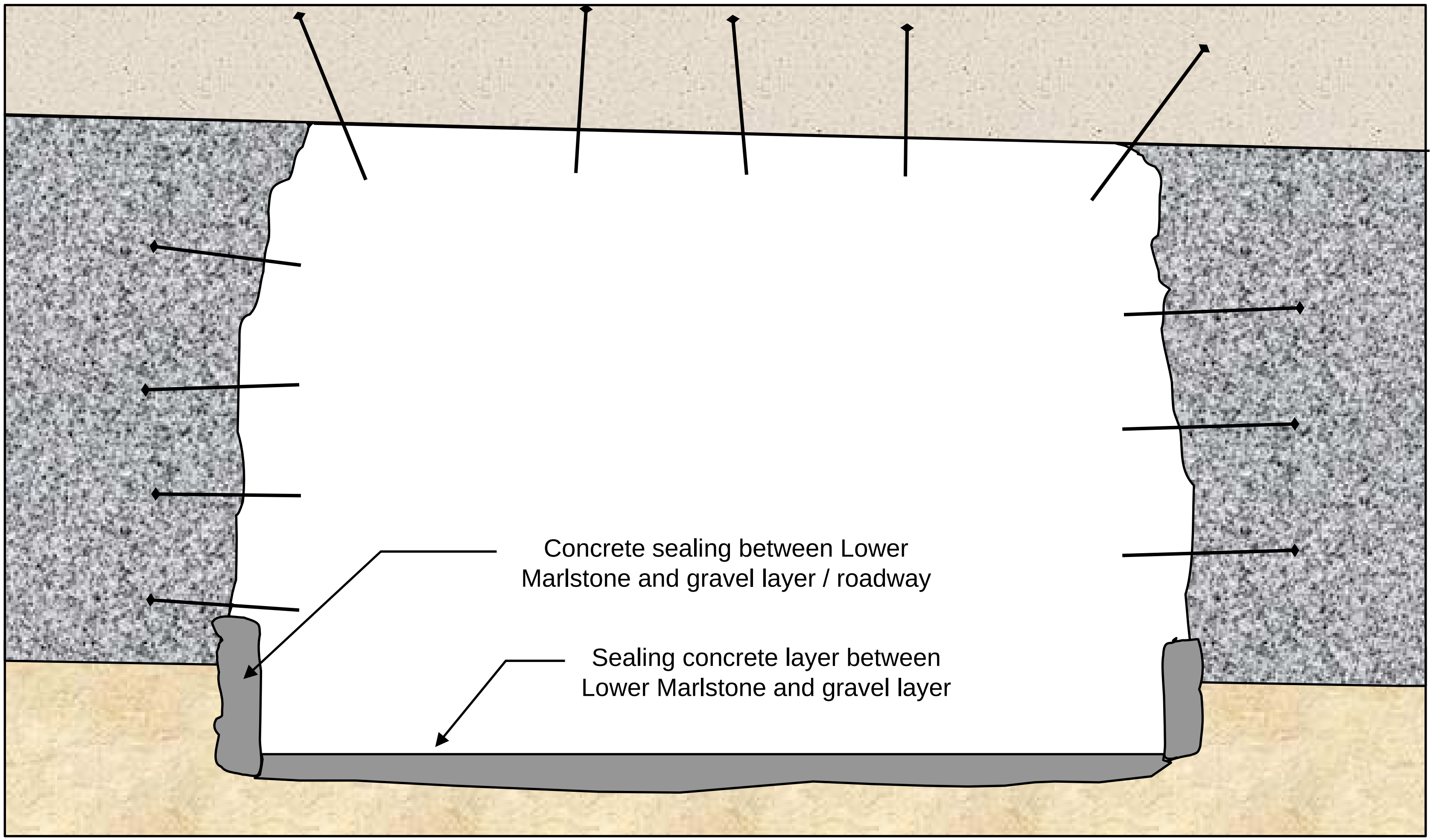
Chamber Preparation

Installation of Rock Bolts



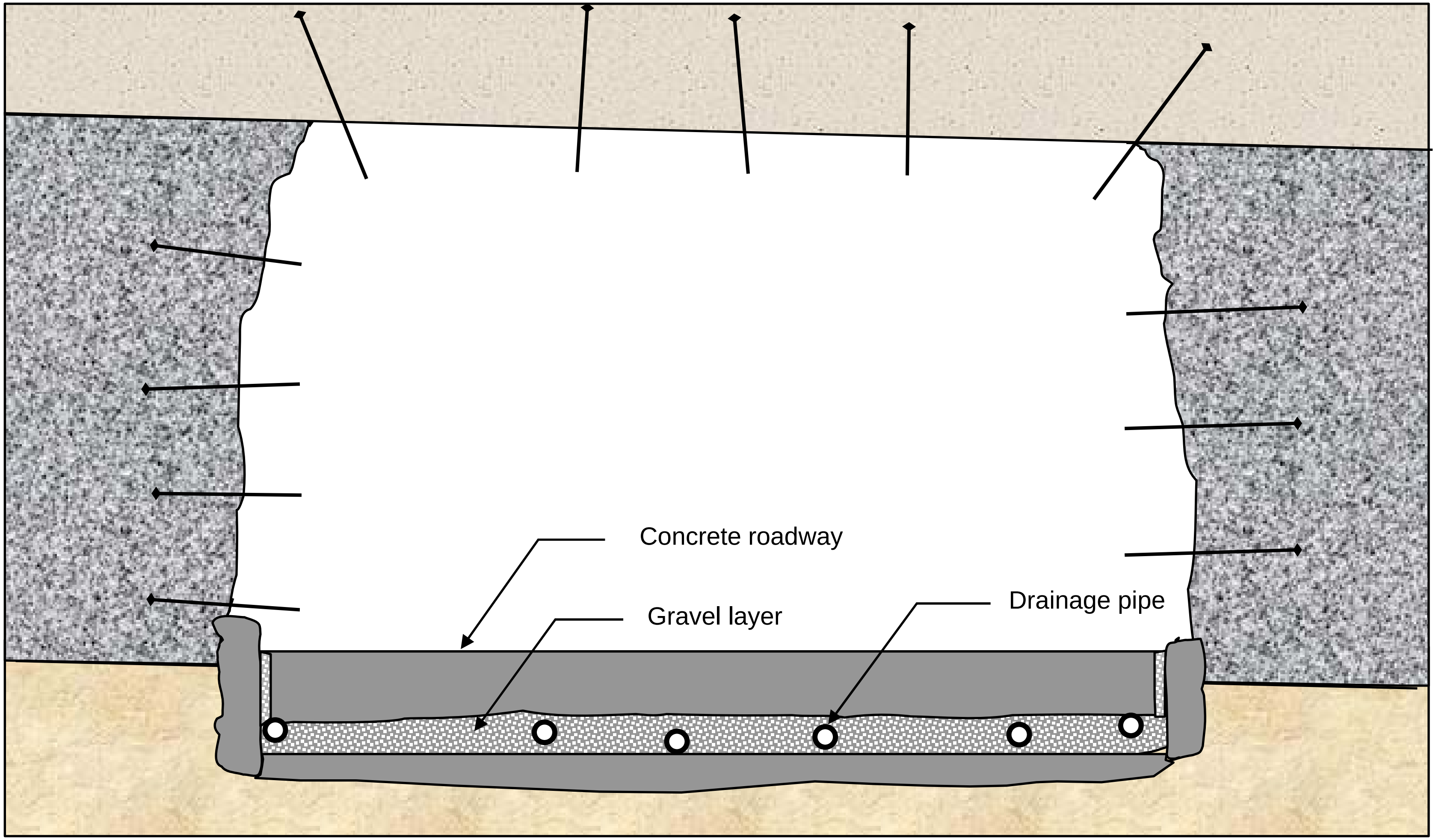
Chamber Preparation

Installation of Separating Layer



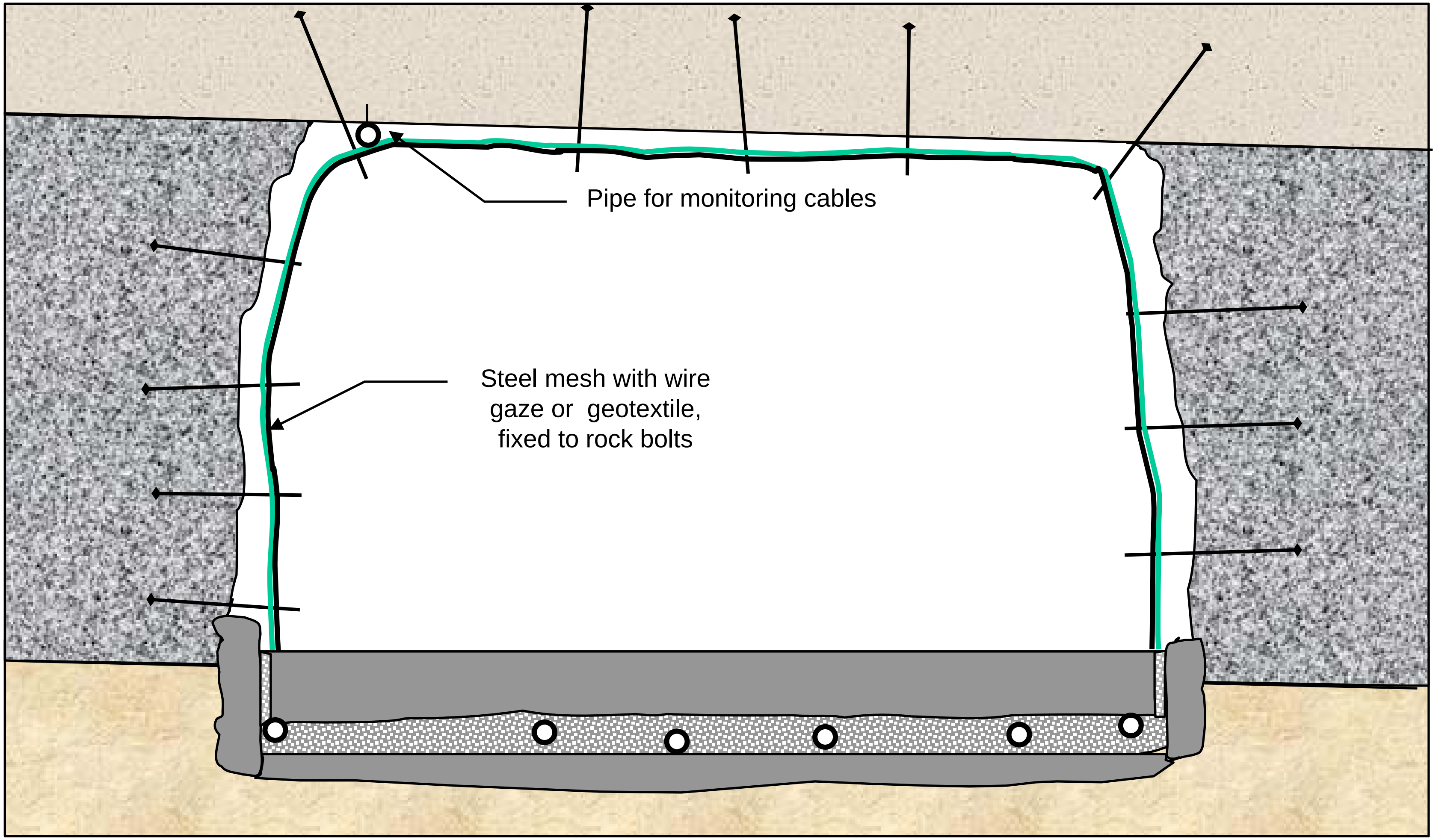
Chamber Preparation

Installation of Concrete Roadway



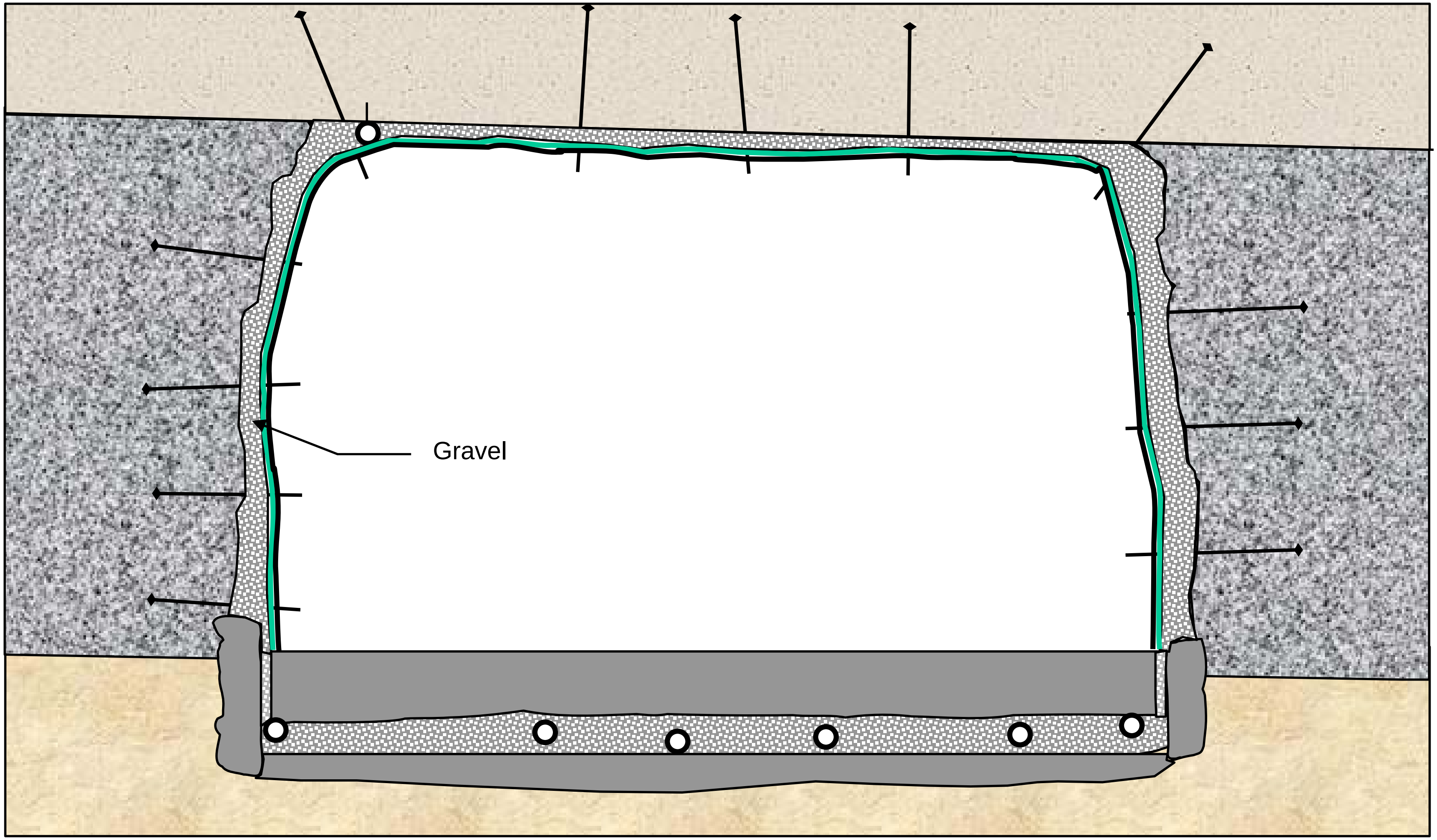
Chamber Preparation

Installation of Hydraulic Cage



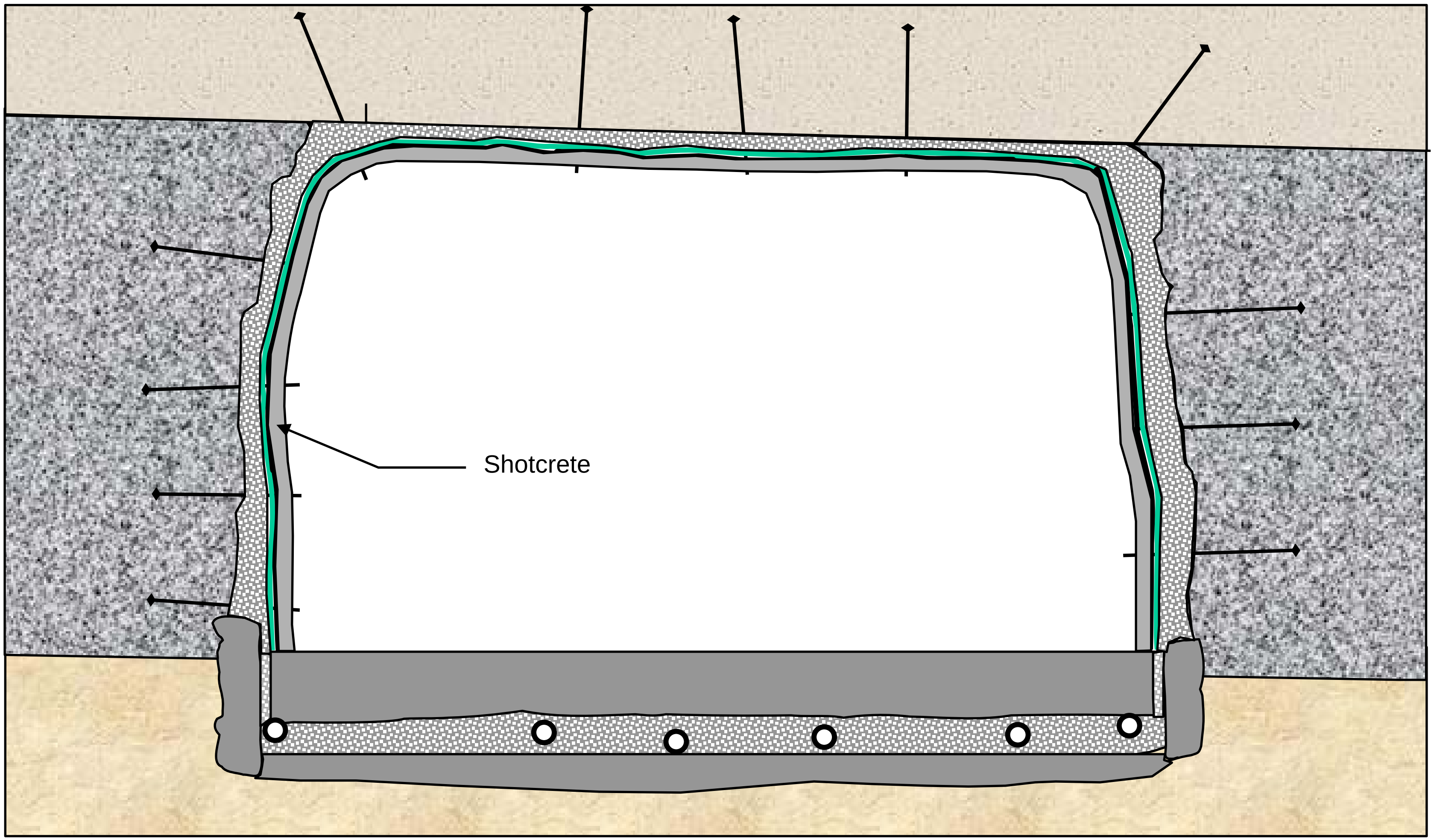
Chamber Preparation

Installation of Gravel Layer



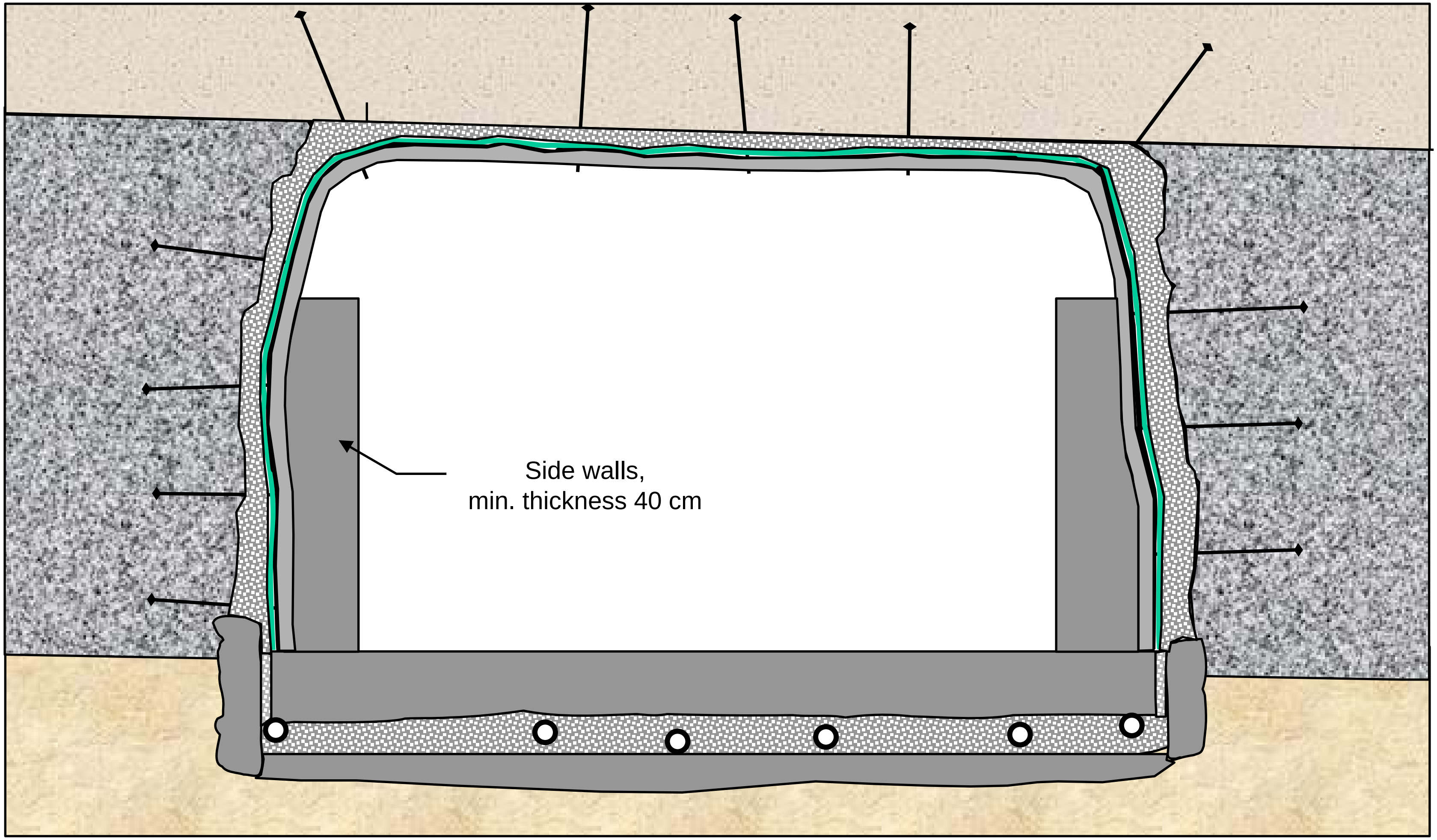
Chamber Preparation

Application of Shotcrete Layer



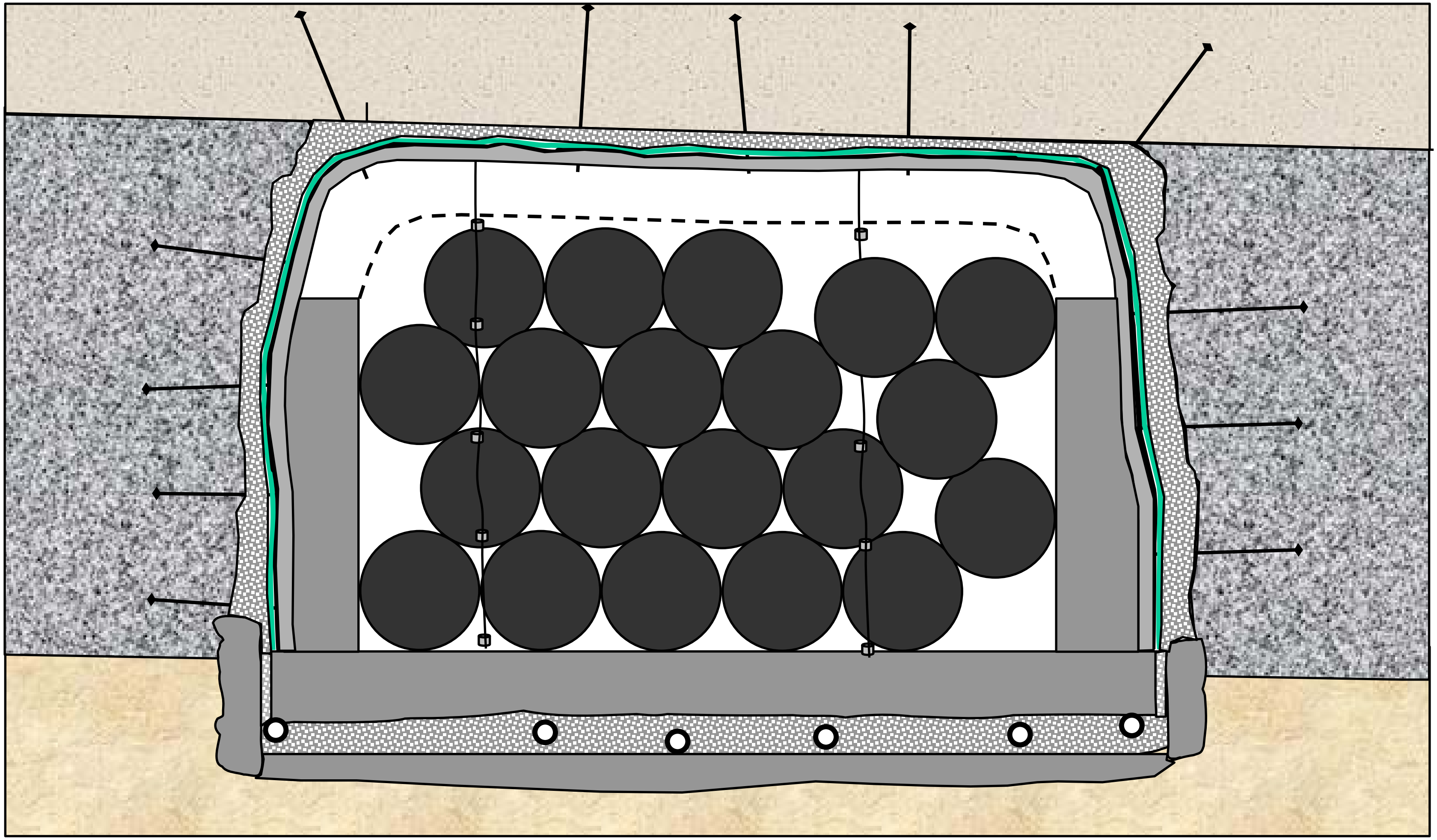
Chamber Preparation

Preparation of Concrete Side Walls



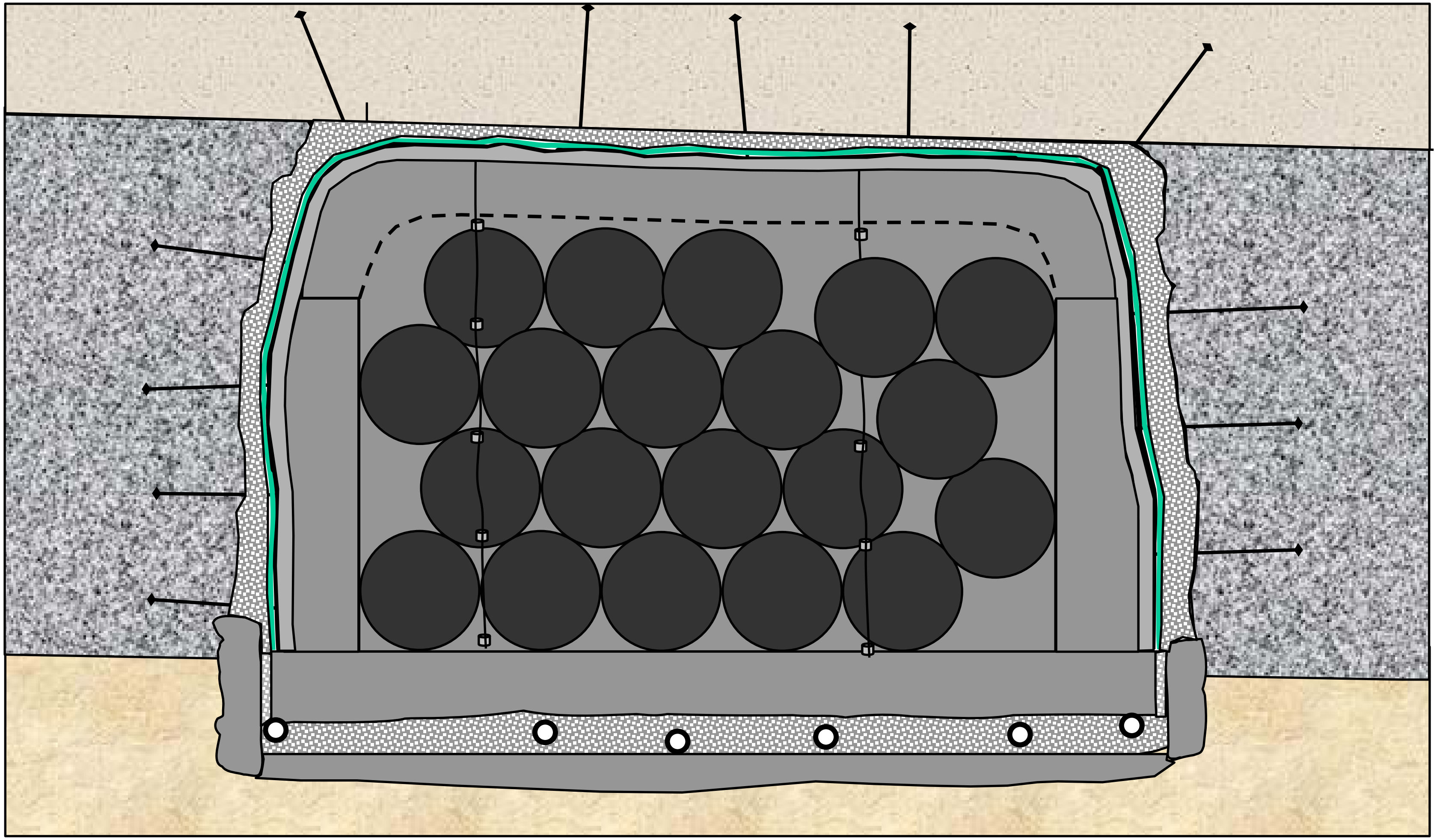
Disposal of Waste

Disposal of Waste Drums



Closure of Chamber

Situation after Backfilling

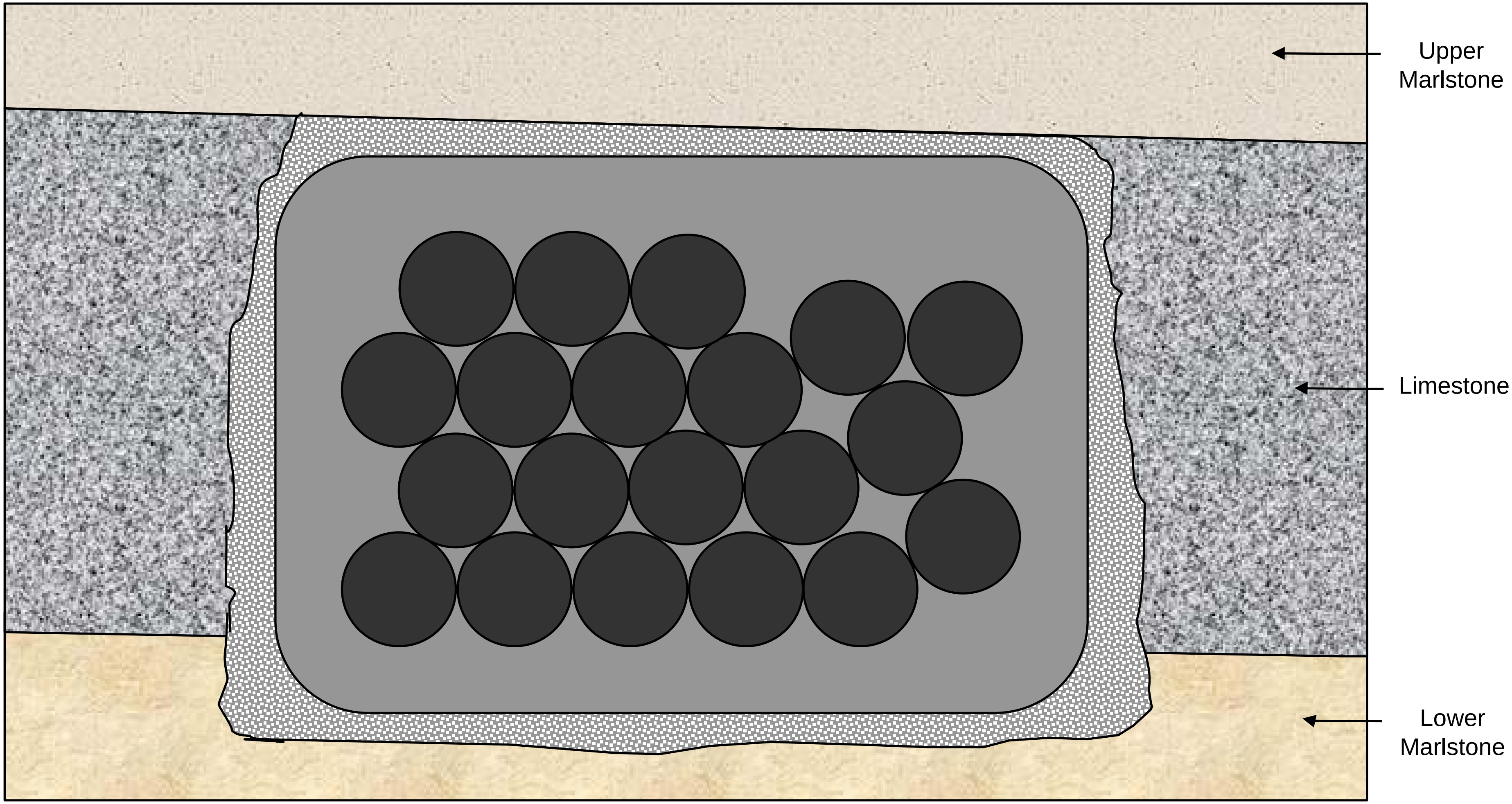


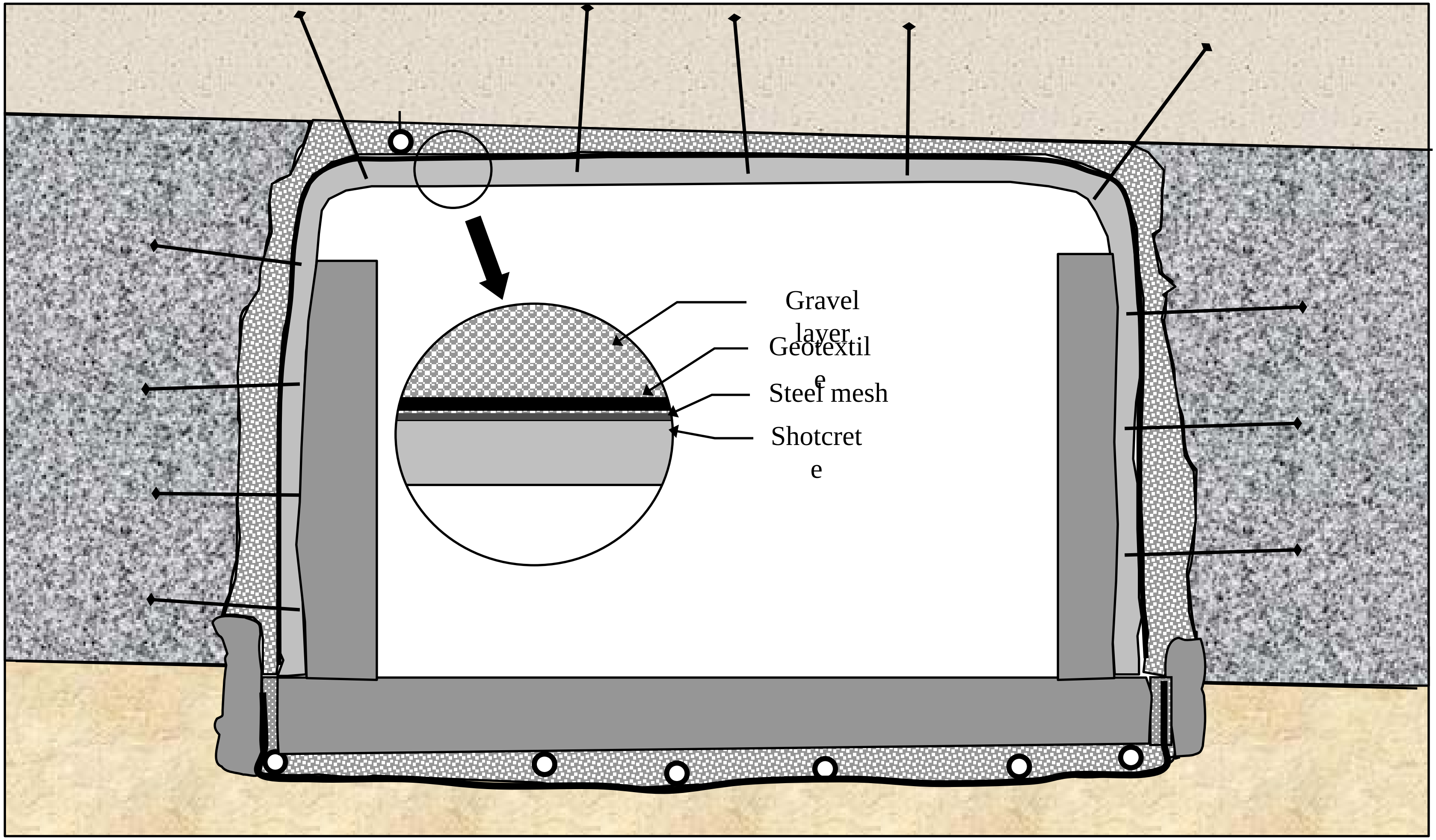
DBE TEC
May 2007

DBE TEC
DBE TECHNOLOGY GmbH

Closure of Chamber

Simplified Model of Situation after Backfilling





Gravel layer
Geotextile
Steel mesh
Shotcrete

Presentation TopSeal 2006, Olkiluoto

Presentation TopSeal 2006, Olkiluoto

Monitoring and Modelling of Groundwater Parameters as a Basis for Radionuclide Transport Modelling

Wernt Brewitz
GRS – Final Repository Research Division
Technical University of Braunschweig

Sino-German Workshop
Beijing, May 28 – June 1, 2007

The importance of groundwater in radwaste disposal

- Water / groundwater is a source of life
- Water has to be protected in order to ensure an adequate living standard for present and future generations
- Groundwater reacts with the waste and can mobilize radionuclides in the repository
- Groundwater is <u>the</u> medium for transporting contaminants from the deep repository to the biosphere
- Groundwater can disperse contaminants in the entire system
- Groundwater quality has a direct impact on the quality of food and stocks and on the health of mankind

The feasibility of a disposal site depends predominantly on the hydrogeology

- Any disposal site has to be characterised in detail for its hydro-geological system and properties before construction
- Flow velocity and groundwater age of each aquifer are important for the classification of the groundwater regime
- By numerical modelling it has to be demonstrated that all governing parameters and their interactions are well understood
- On the basis of hydrogeological models the radionuclide transport by groundwater has to be simulated for extended periods of time
- The hydraulic regime has to be monitored during construction and operation in order to check the model parameters

Hydrological modelling and understanding of the geological processes are important for the safety case

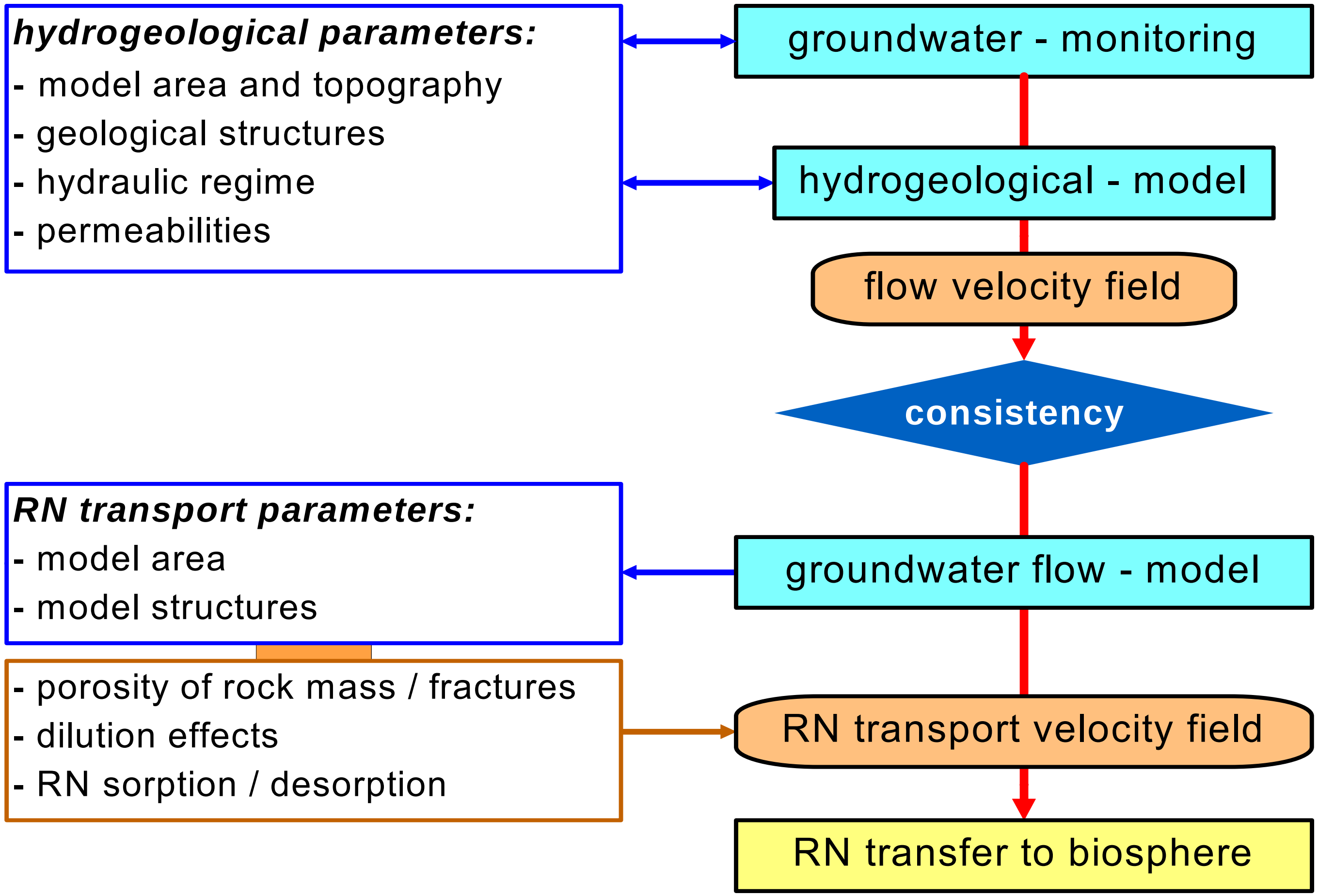
- For any High Level radioactive waste repository the **normal evolultion** has to be assessed for about 10^4 to 10^6 years. **Load cases** as well as **scenarios** have to be taken into account.

- For **tight and dry** rock formations **(rock salt)** the durability of the geological barrier is of utmost importance. Barrier failure and possible consequences are essential for any performance assessment.

- In **tight** and **slightly moist** rock formations **(clay, indurated claystone)** diffusion is the most relevant transport process. Fracturing might occur, fracture flow is often suppressed by swelling of clay minerals.

- In **hard rock** formations **(granite, basalt, tuff)** fracturing is very common. Advective flow in fracture networks is very site specific and has to be investigated and modelled in detail. Mineral fillings in fractures might contribute substantially to the retardation of radionuclides.

Stylized approach in RN transport modelling



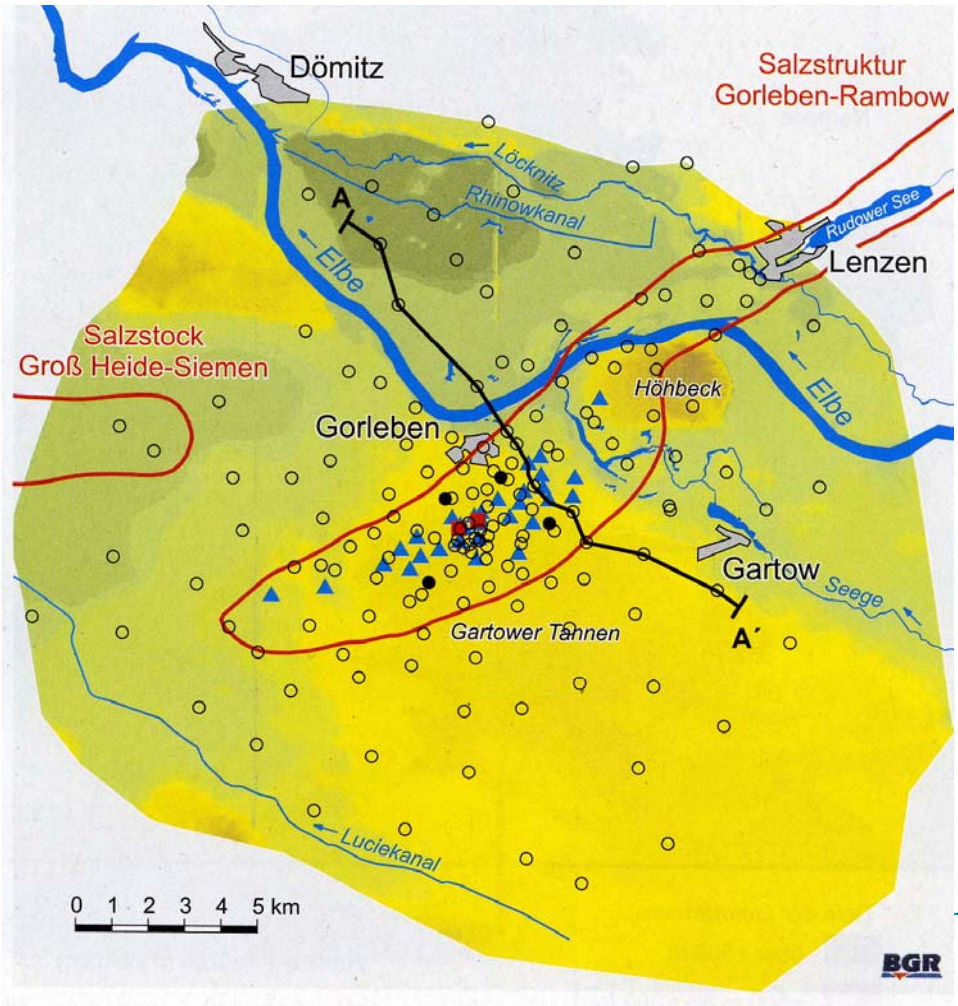
Groundwater monitoring

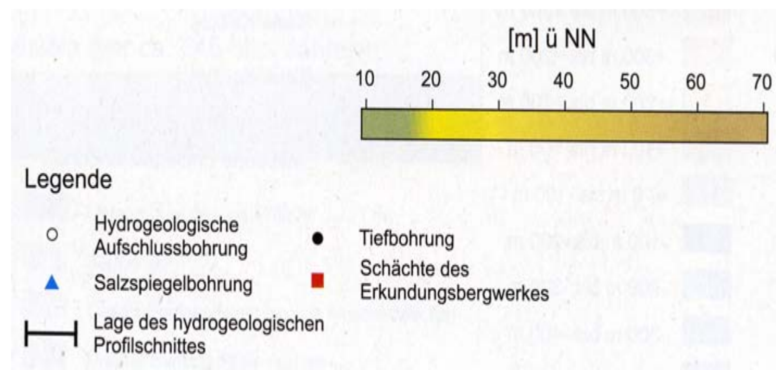
Groundwater regime in Tertiary and Quaternary Sediments

Measurements at the Gorleben site performed by BGR

Modelling and interpretation of flow and age by BGR

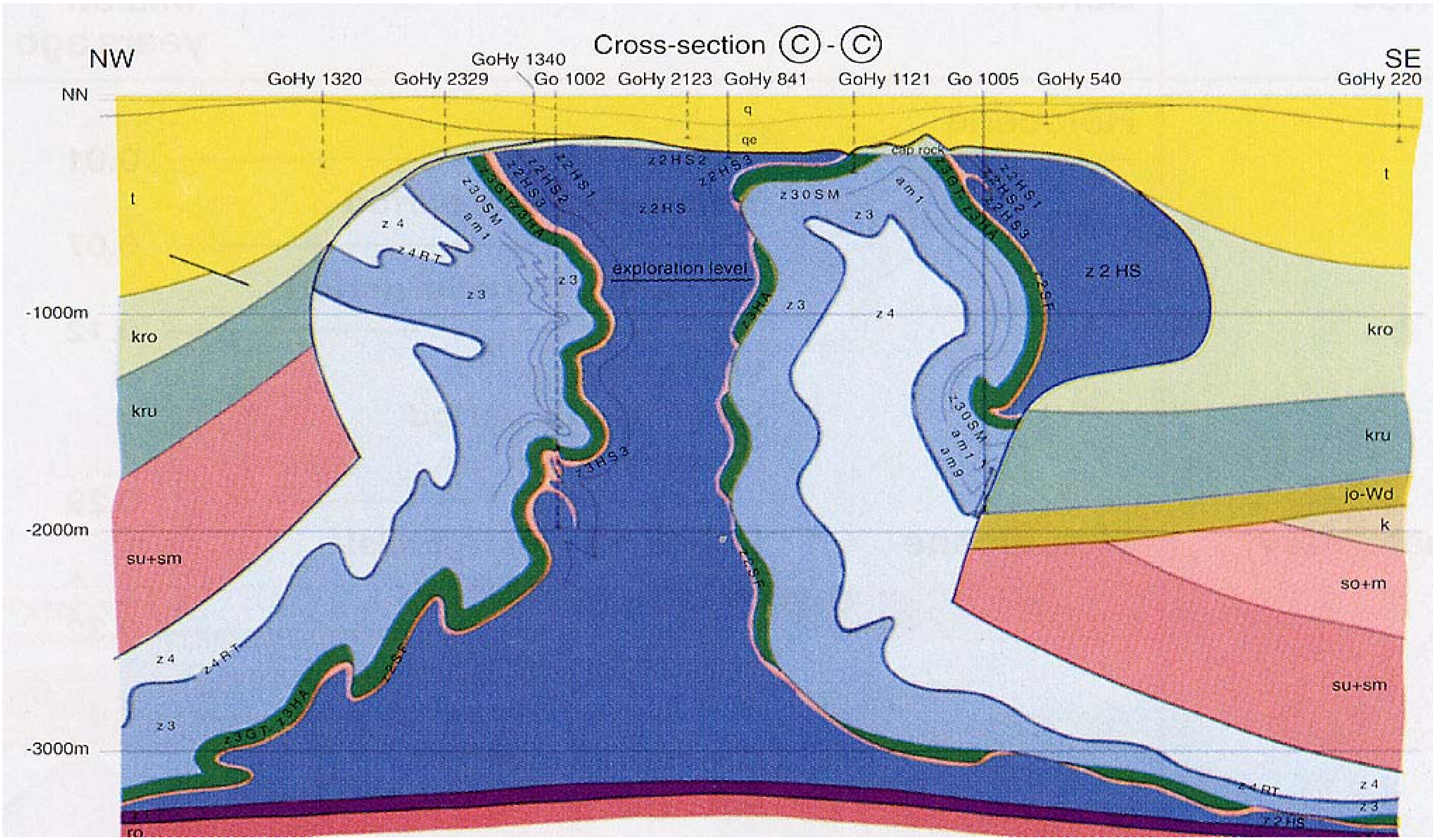
Hydrogeological Characterisation of the Gorleben Site (Groundwater Monitoring)





BGR

Salt dome Gorleben with overlying Quaternary and Tertiary Sediments

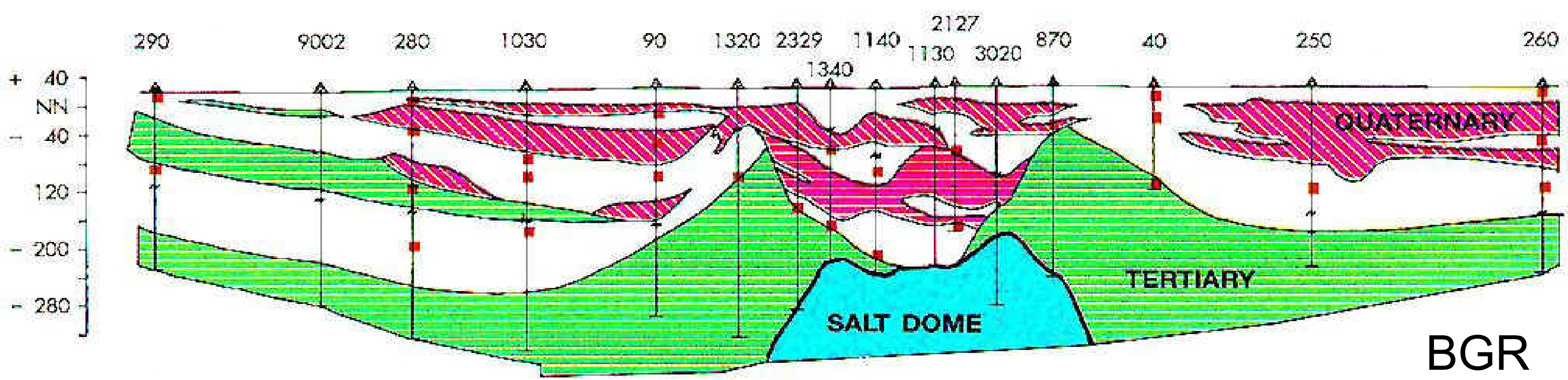


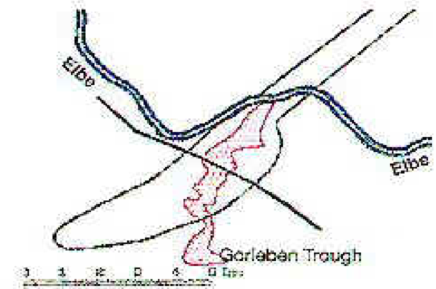
BGR

W. Brewitz

Beijing, May 28 to June 1, 2007

Aquifers and aquicludes in the covering rock formations





BGR

Groundwater salinity rises with depth

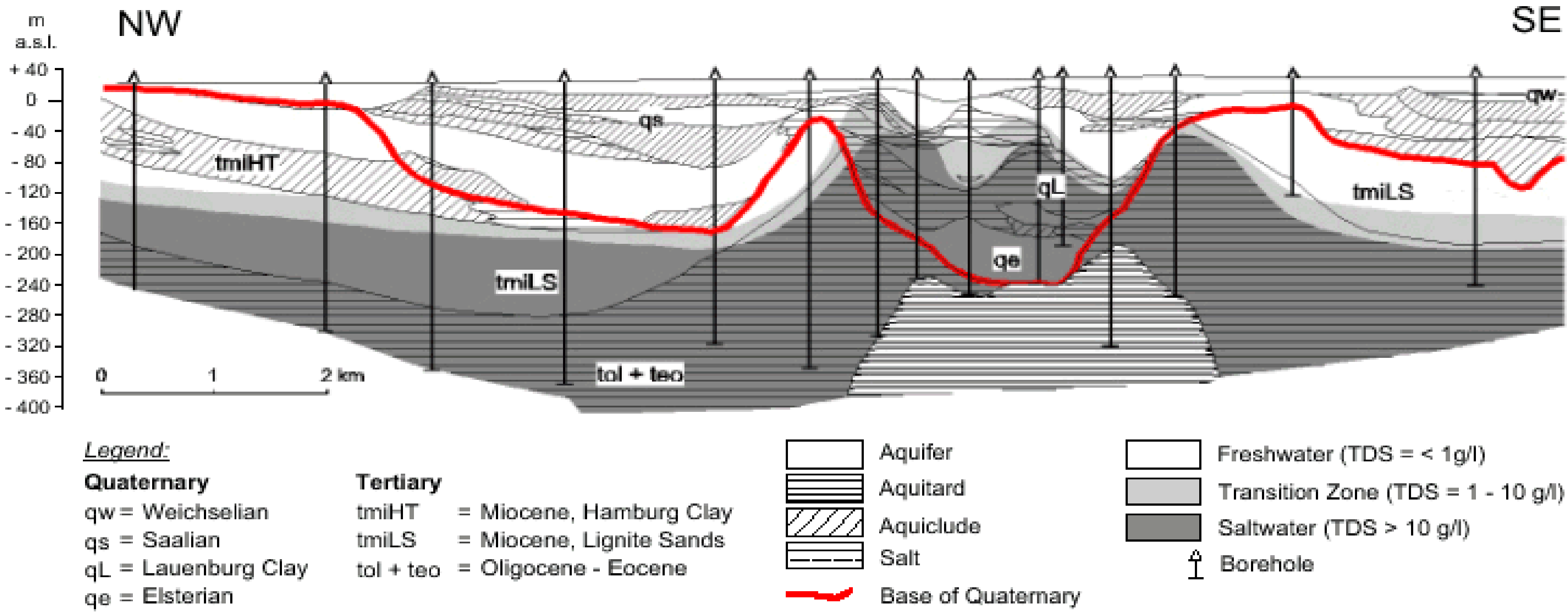
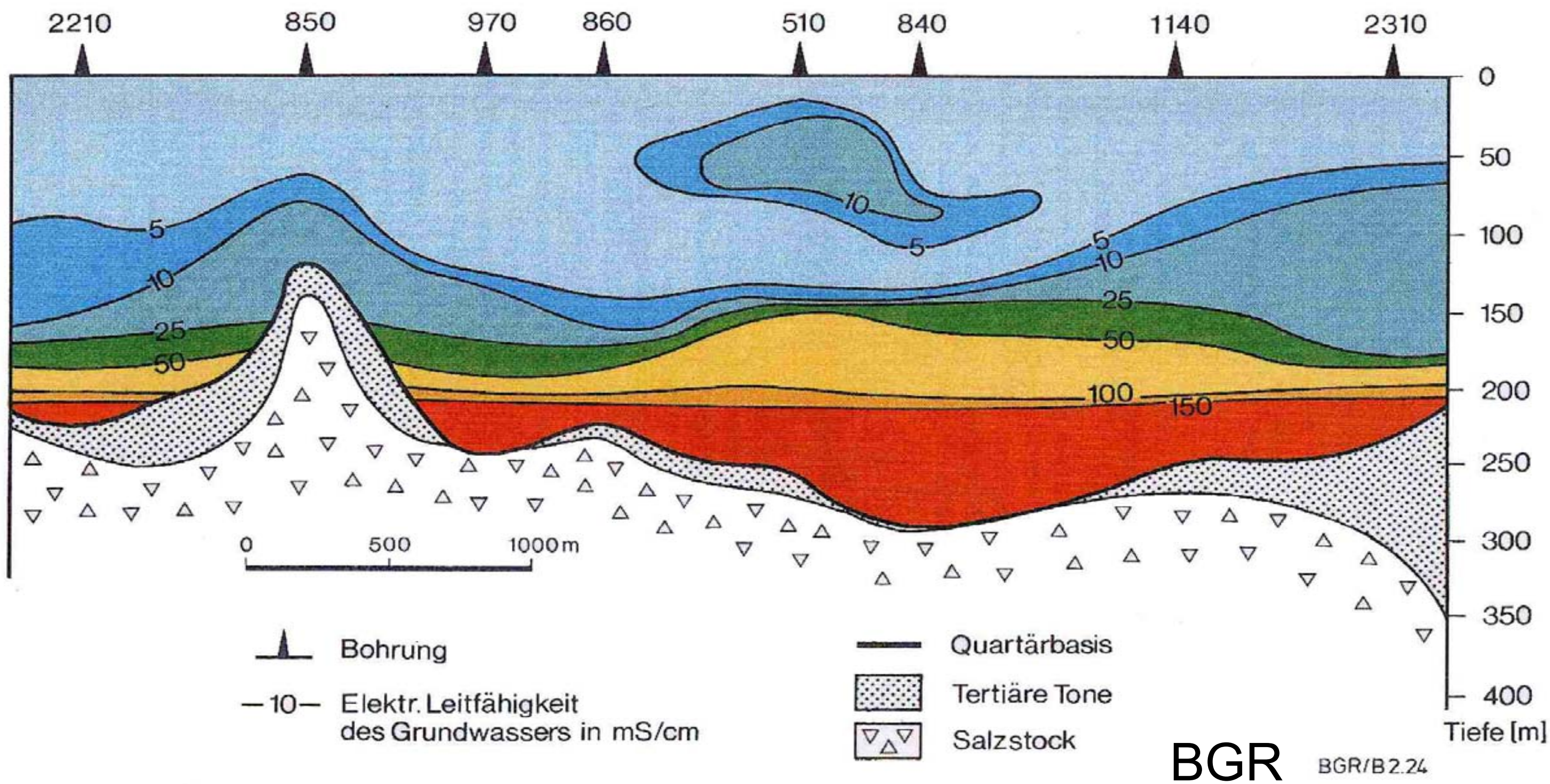


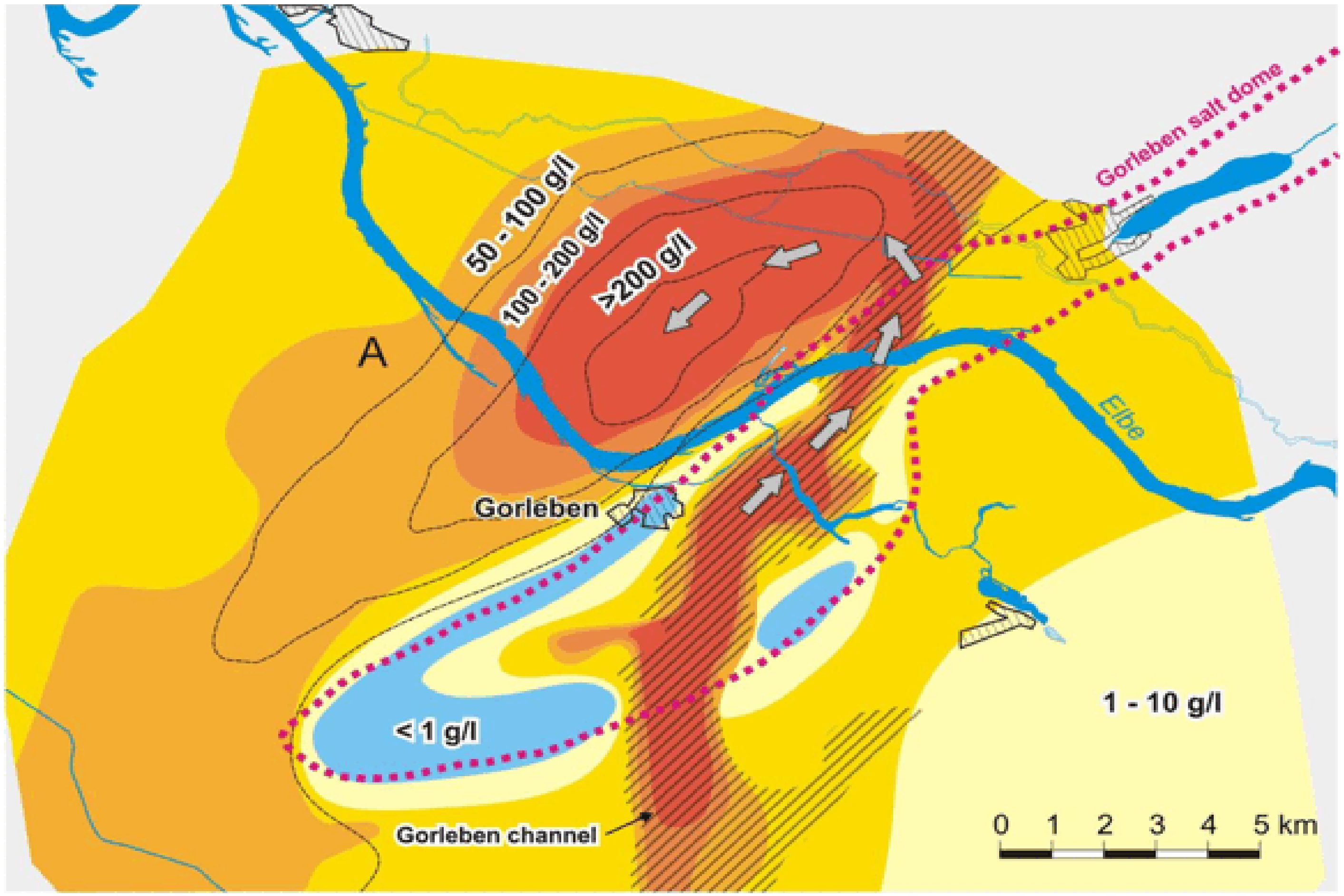
Figure 6: Hydrogeological and hydrochemical cross section along the buried channel at Gorleben (TDS = Total dissolved solids)

BGR

Residual groundwater disturbance - imprints of the last ice age



Groundwater regime in the Quaternary channel



BGR

Development of computer programs for 3D simulation of density driven flow and radionuclide transport in complex hydrogeological systems

Basics of program development

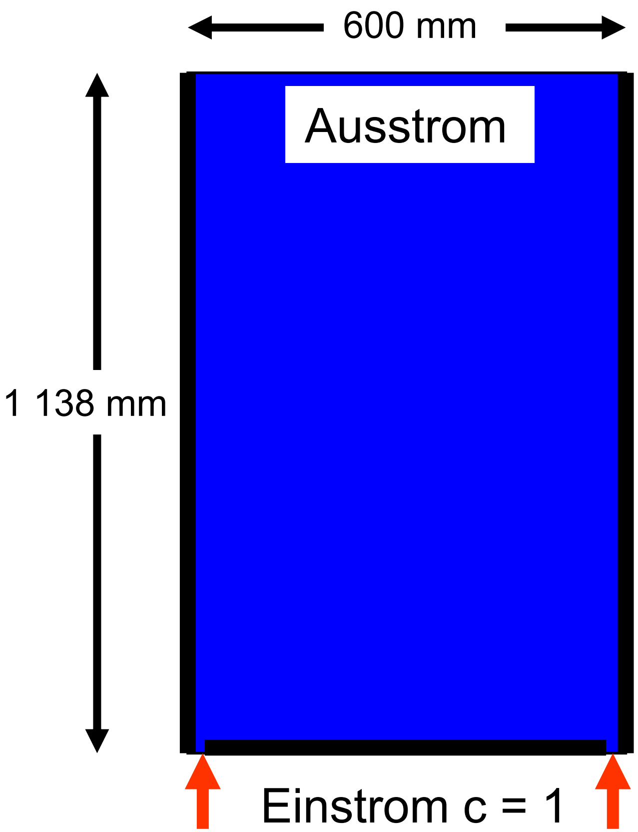
Test cases

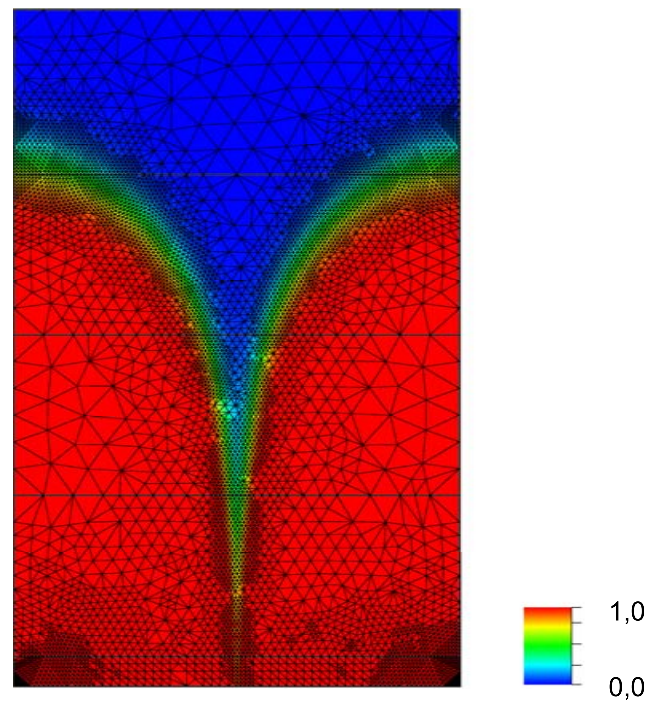
Simulations

W. Brewitz

Beijing, May 28 to June 1, 2007

Lab experiment: Fresh water / salt water displacement (RIVM)





15,5 h

PA Codes developed and applied in Germany

- **EMOS group of codes** *(GRS)*:
  Near-, Far-Field, Biosphere-Model

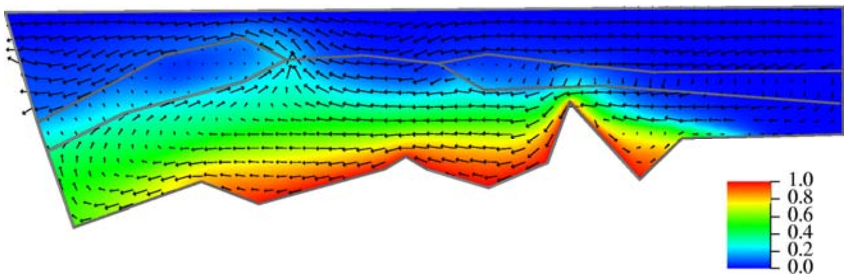
  output => breakthrough curves of radionuclides

  programs in testing stage
  for porous media:

- **d^{3}f**: groundwater flow model
- **r^{3}t**: contaminant transport model

- radionuclide decay
- element dependent sorption
- kinetically controlled sorption
- diffusion in immobile porewater
- precipitation
- complexation
- formation of colloids

Distributed Density-Driven Flow: d^3f

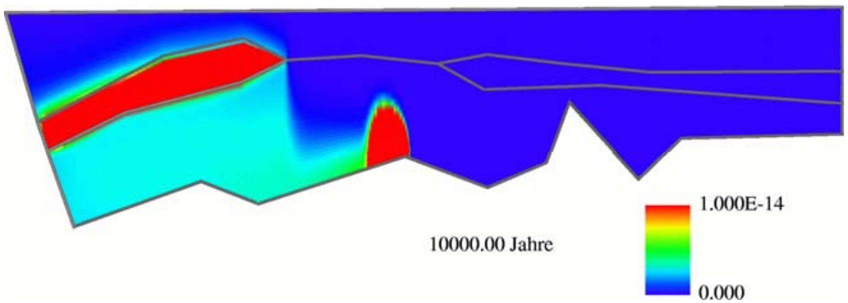


- finite volume discretisation
- spatial and temporal adaptivity controlled by a-posteriori error estimator
- multigrid solver
- completely parallelised

- flow through porous, fluid-saturated, heterogeneous, anisotrope media
- confined aquifersystems
- transient transport of salt (or heat)
- constitutive equation for density and viscosity dependent on concentration (or temperature)
- stochastic modelling

Radionuclide, Reaction, Retardation, and Transport: r³t

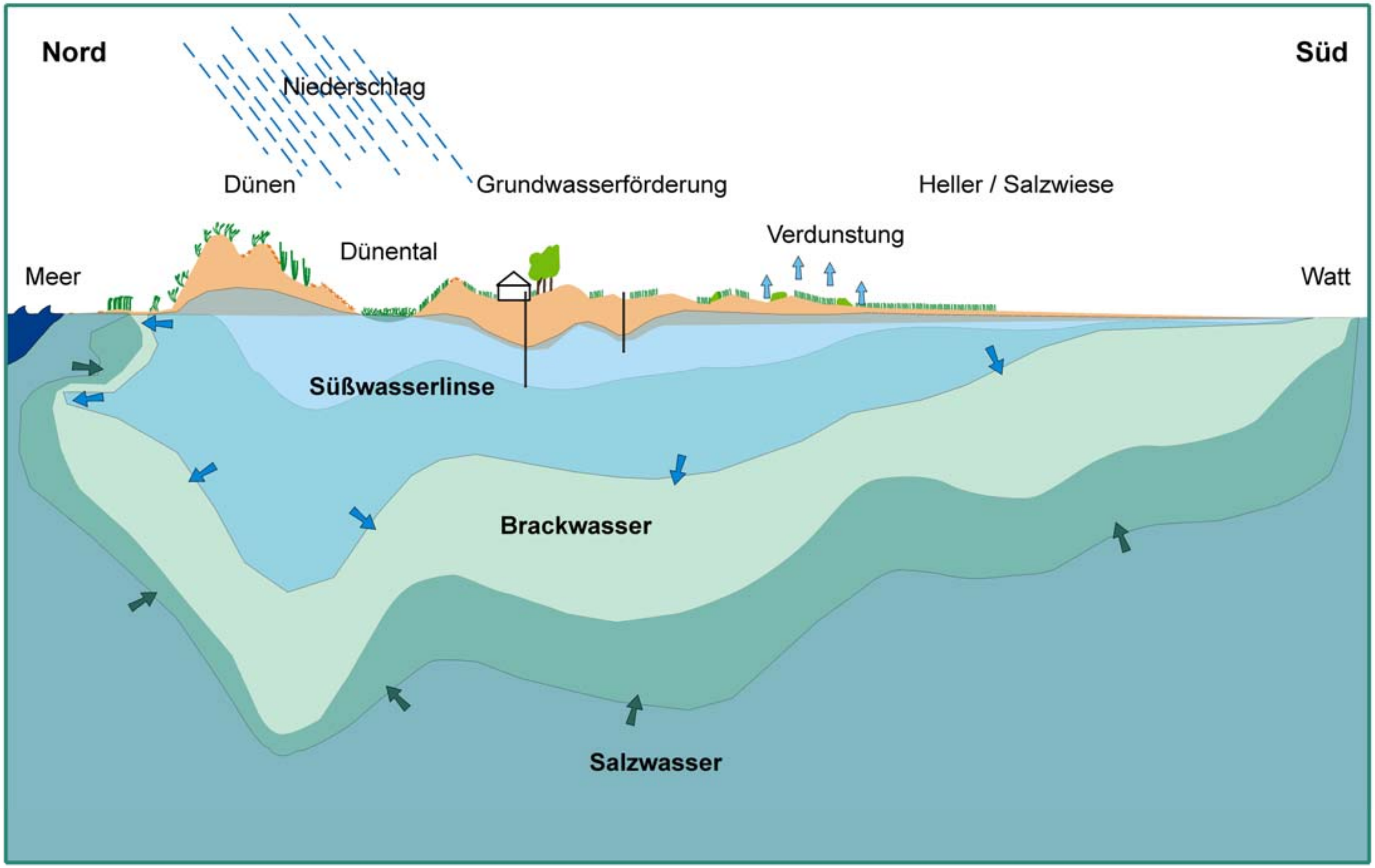
Th-230



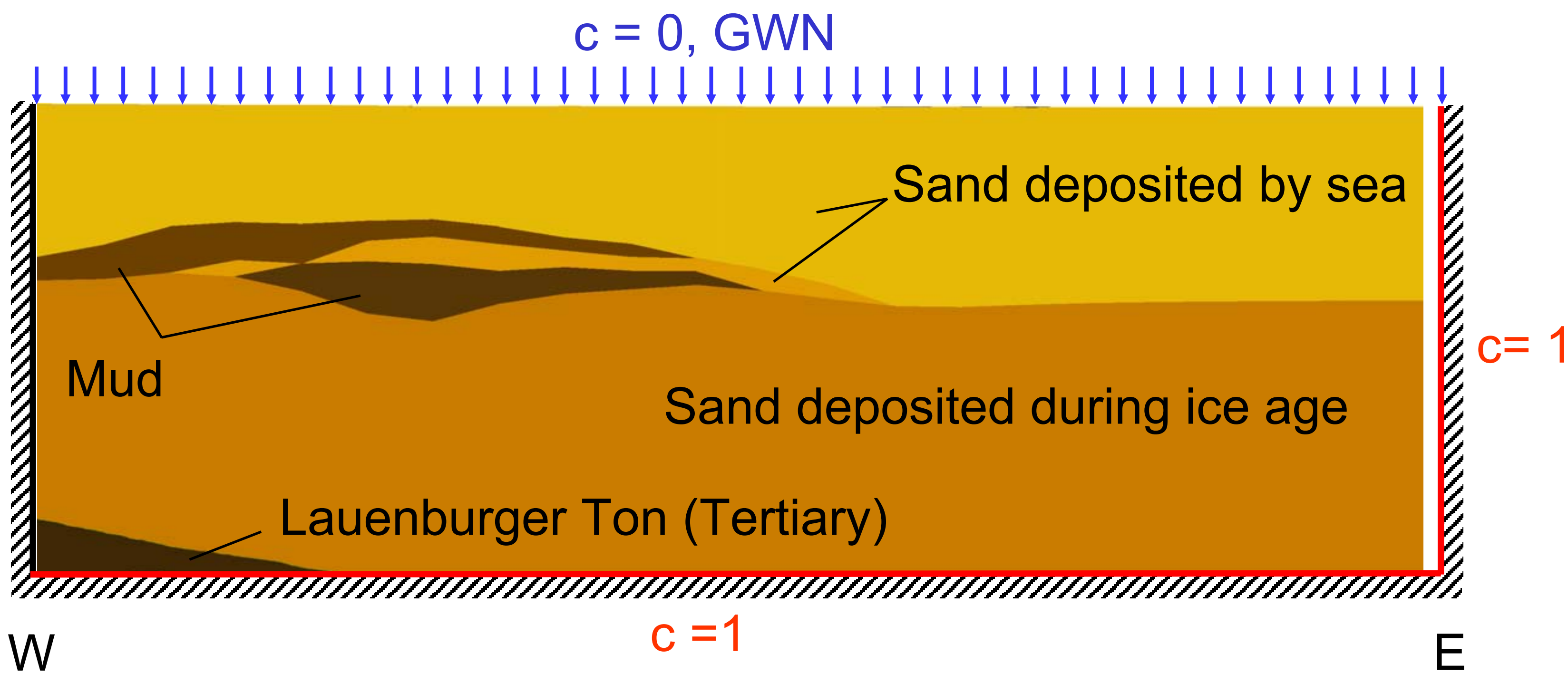
- finite volume discretisation
- spatial and temporal adaptivity controlled by a-posteriori error estimator
- multigrid solver
- completely parallelised

- transport through porous media
- radioactive decay (chains)
- linear and nonlinear sorption (equilibrium, kinetically controlled)
- precipitation / dissolution
- complexation
- diffusion into immobile porewater
- no speciation

Sea water intrusion model into a fresh water aquifer

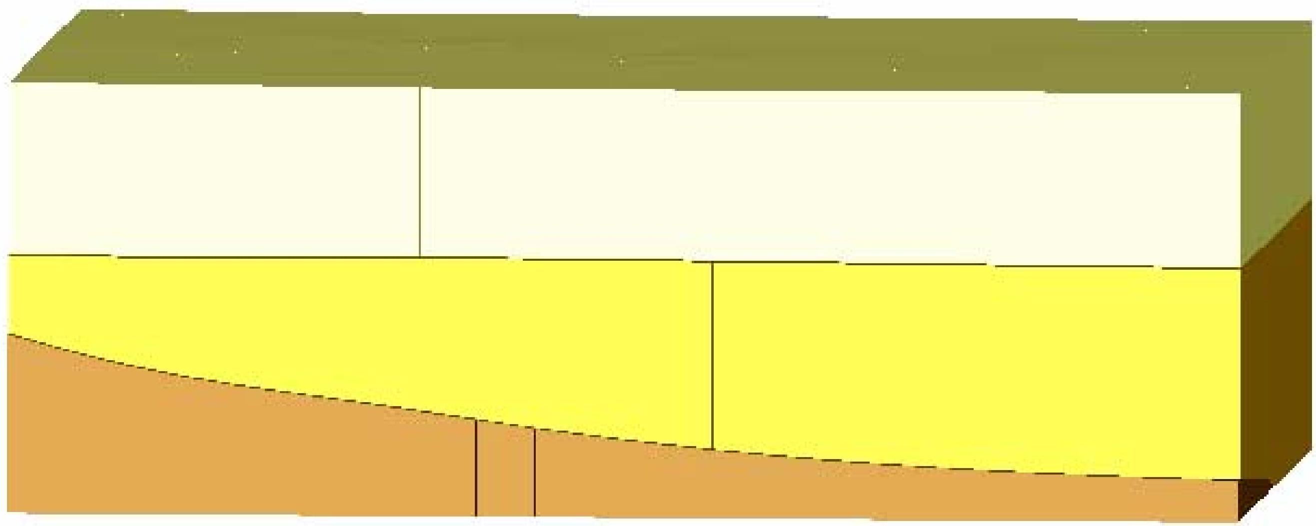


Conceptual hydrogeological model

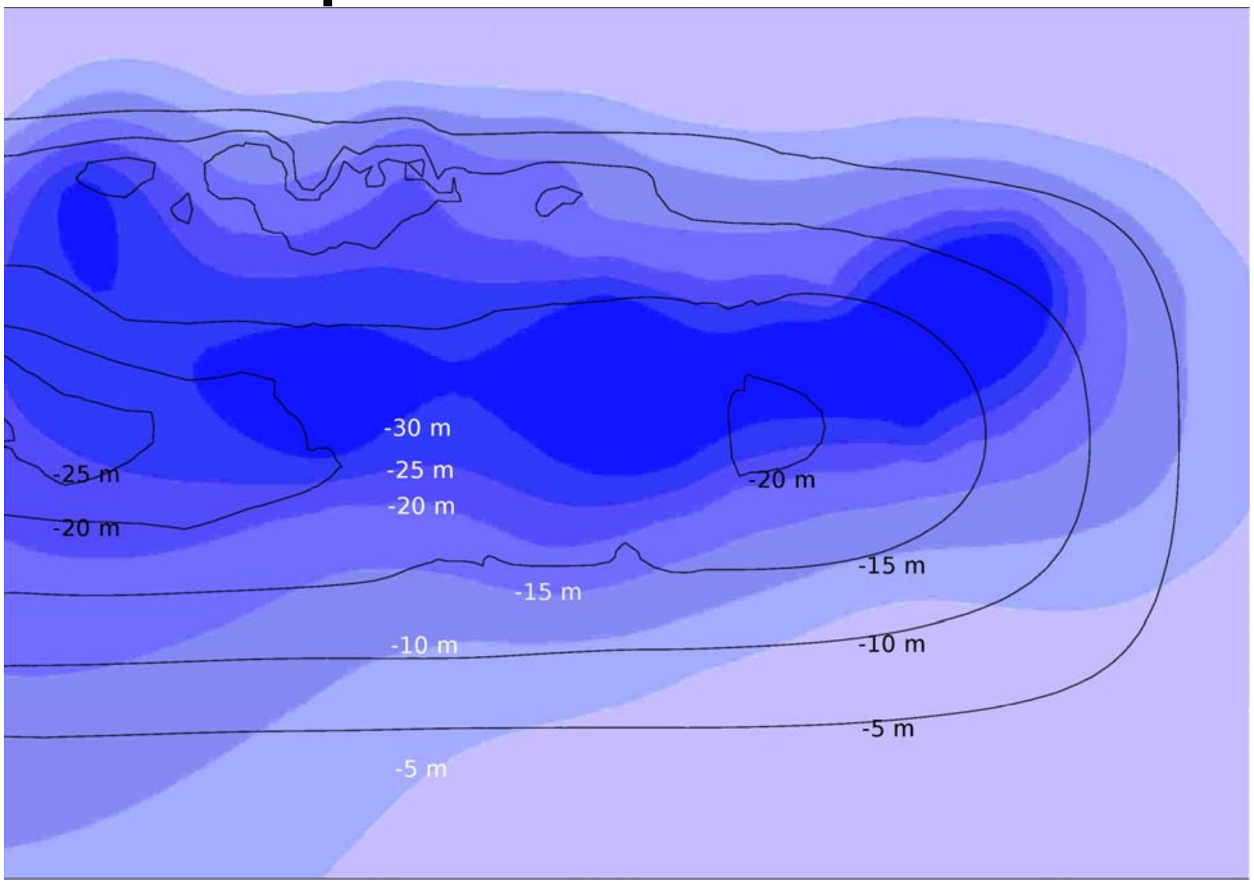


north- und south boundary: c = 1 (Seawater), hydrostatic pressure

Drinking water boundary (calculated) C_{TW} = 1,0 g TDS / l



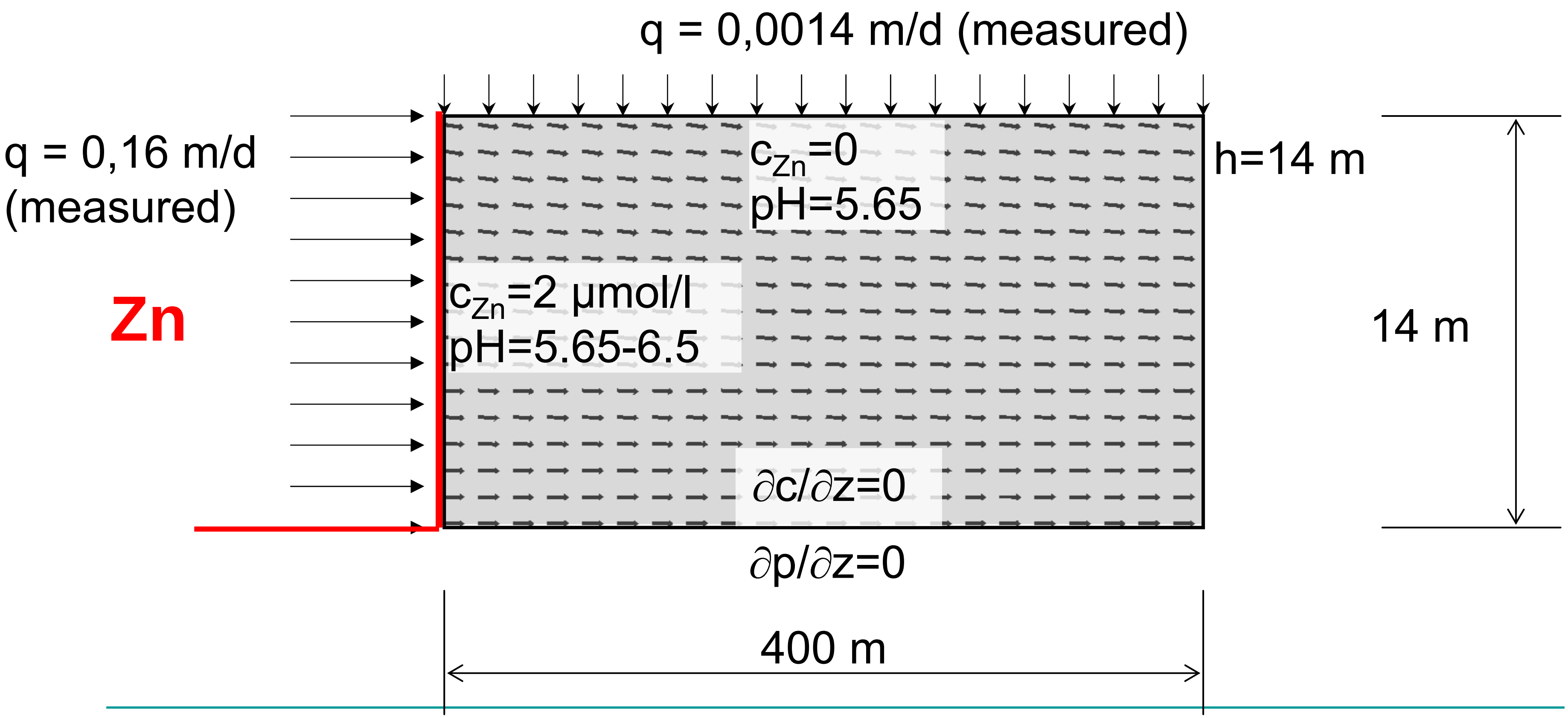
Drinking water boundary development: comparison measurement vs d^3f-simulation



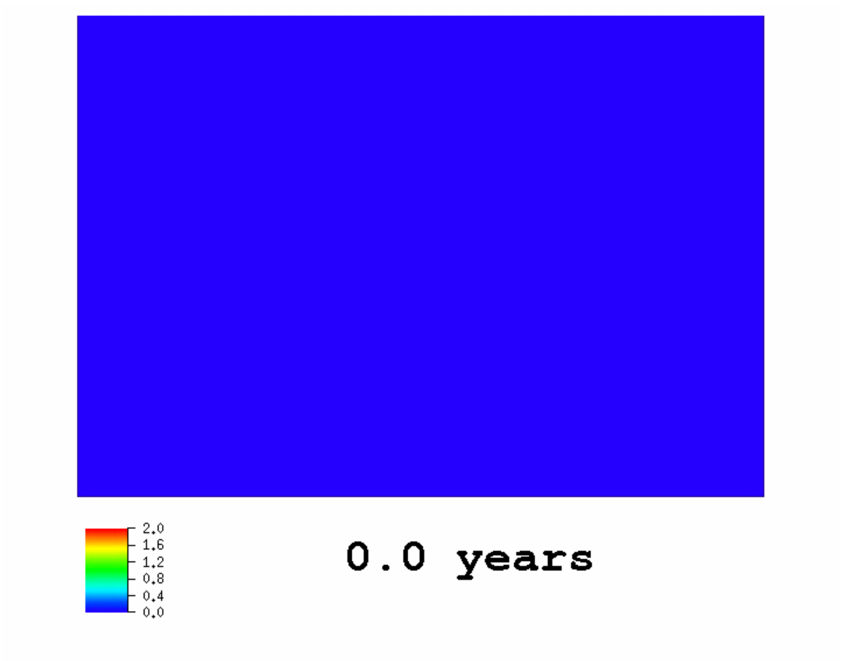
Geoelectric survey (blue)

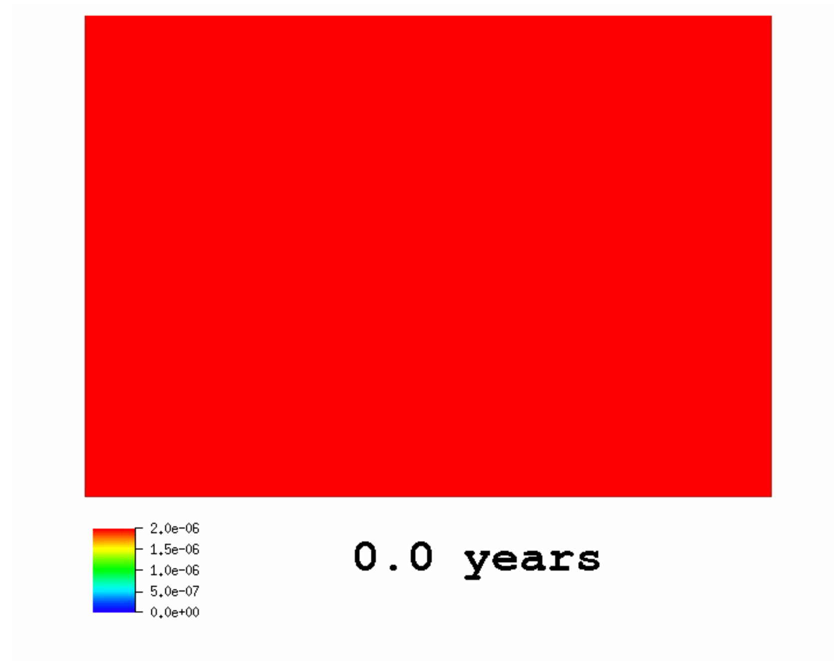
d^3f (black)

Flow / Transport model Cape Cod (USA)



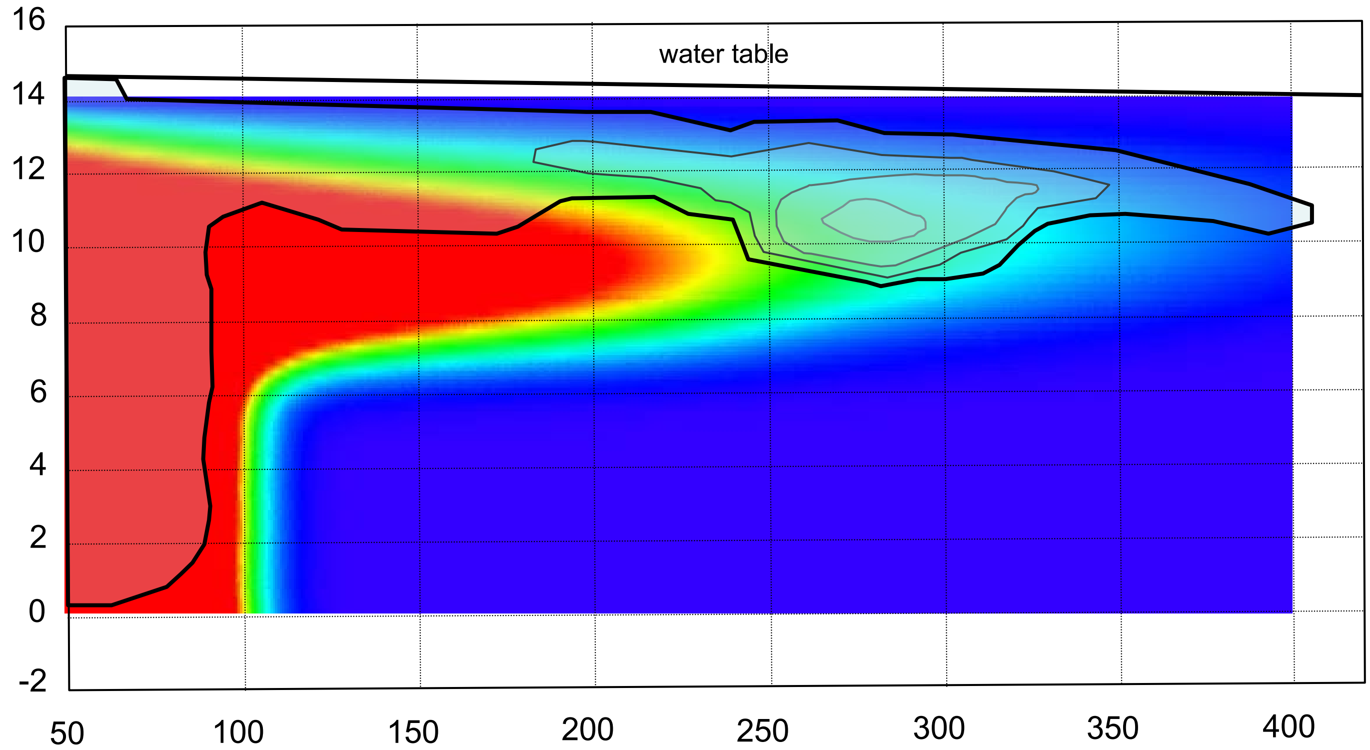
Changing Zn concentration and pH value with time





Start Animation

Comparison of results: r^3t - simulation / field data



Zn concentration in aquifer after 61 years

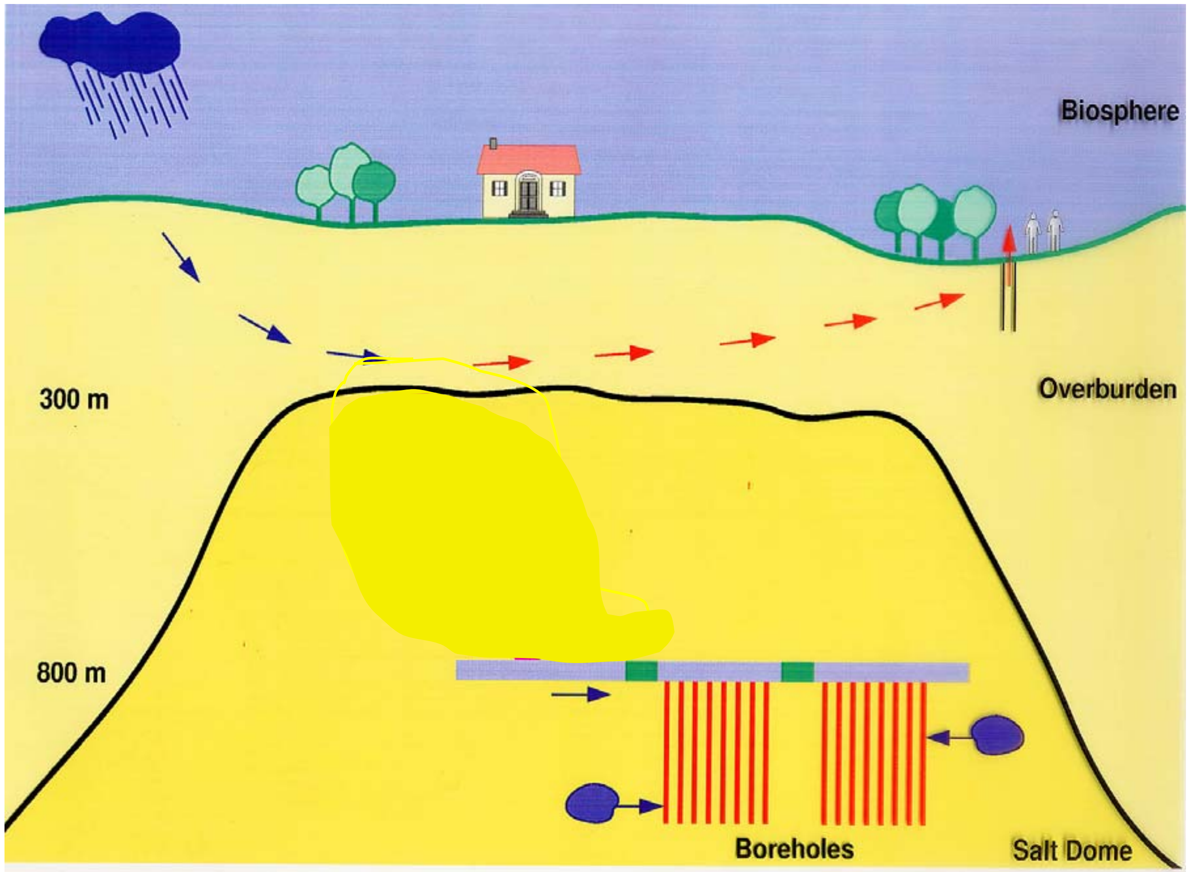
Radionuclide transport
in Tertiary and Quaternary sediments

The Gorleben case

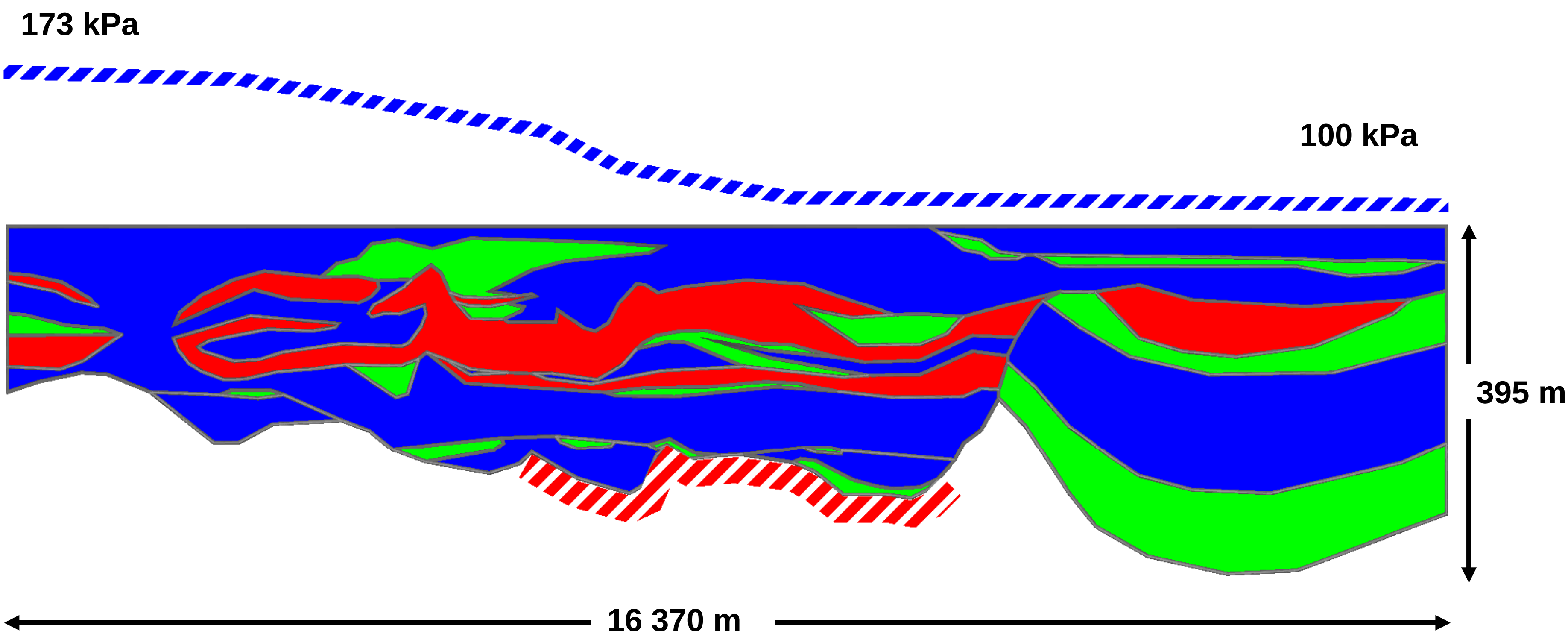
W. Brewitz

Beijing, May 28 to June 1, 2007

Worst case scenario of brine intrusion into the repository



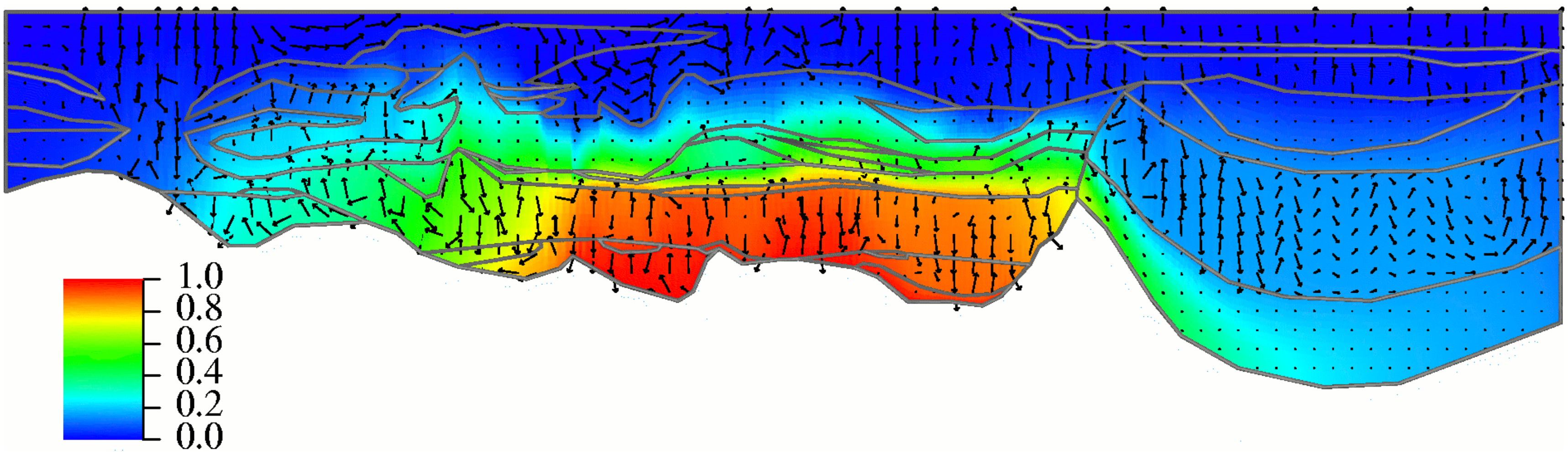
Hydrogeological model Gorleben



$k=1{,}0\cdot10^{-12}\ m^2$ $k=1{,}0\cdot10^{-14}\ m^2$ $k=1{,}0\cdot10^{-16}\ m^2$

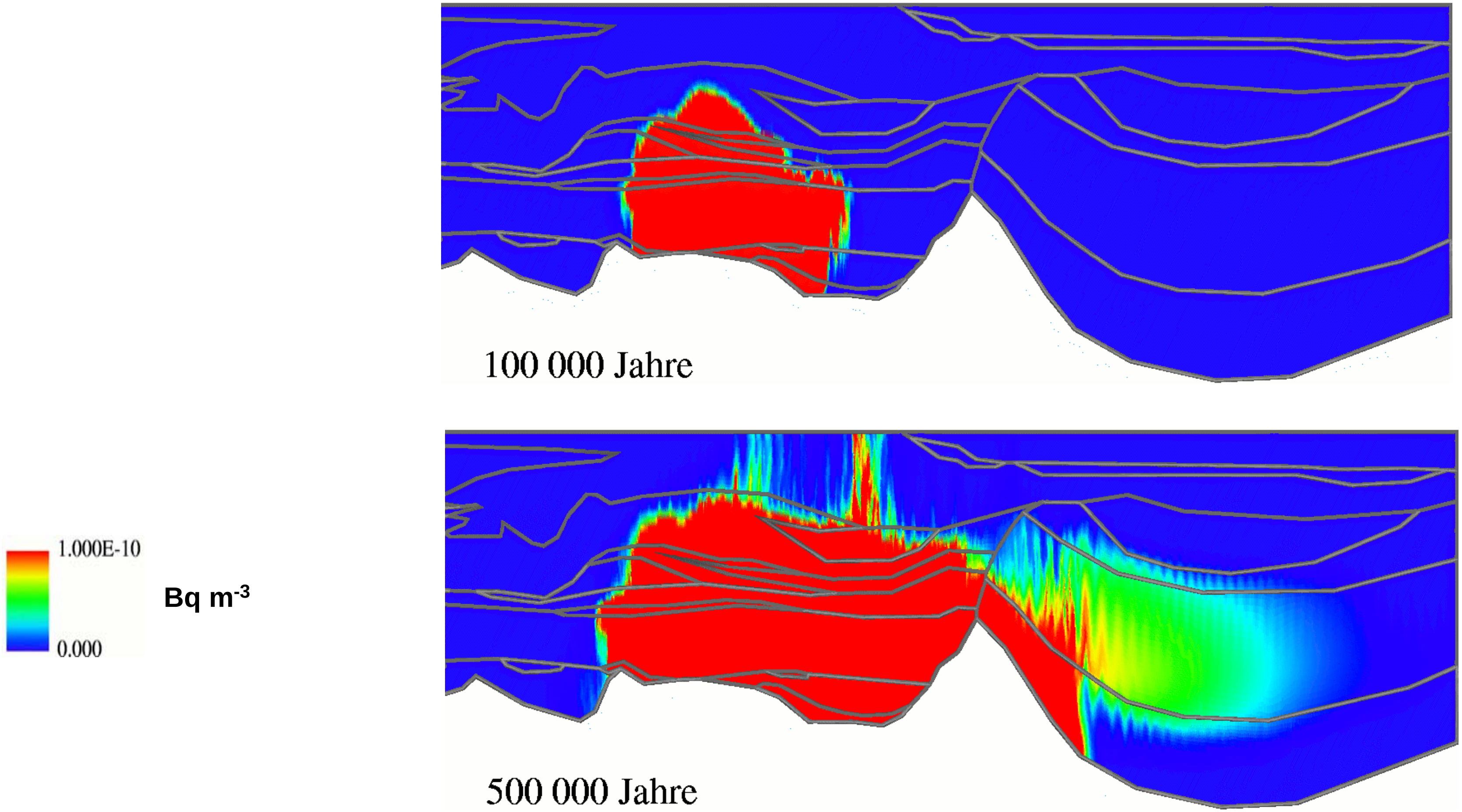
(Schelkes 1994)

Advective flow and change of density by dissolved salt in the covering formations of the Gorleben saltdome

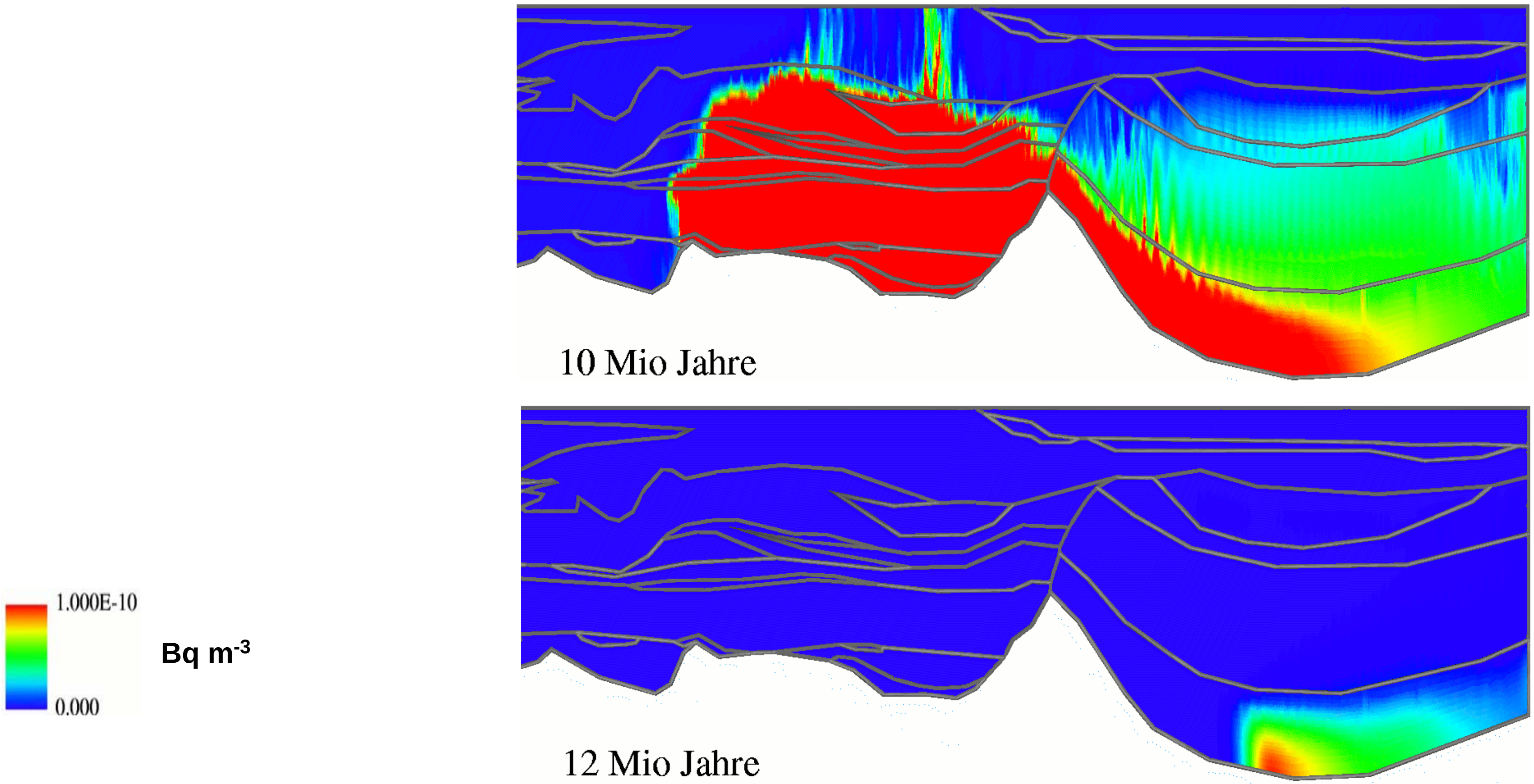


250 000 years

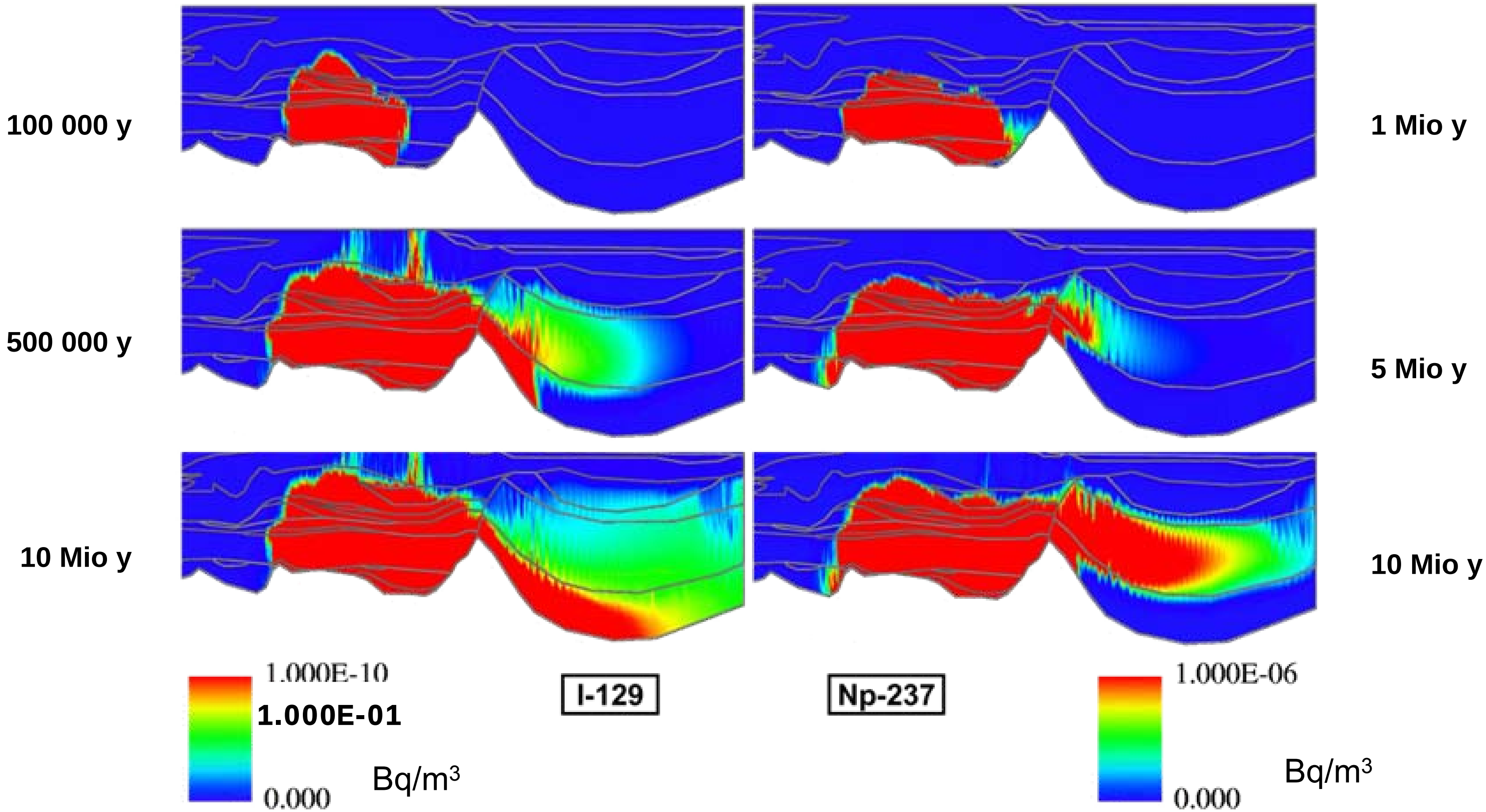
Hypothetical release of I-129 into the covering sediments (I)



Hypothetical release of I-129 into the covering sediments (II)



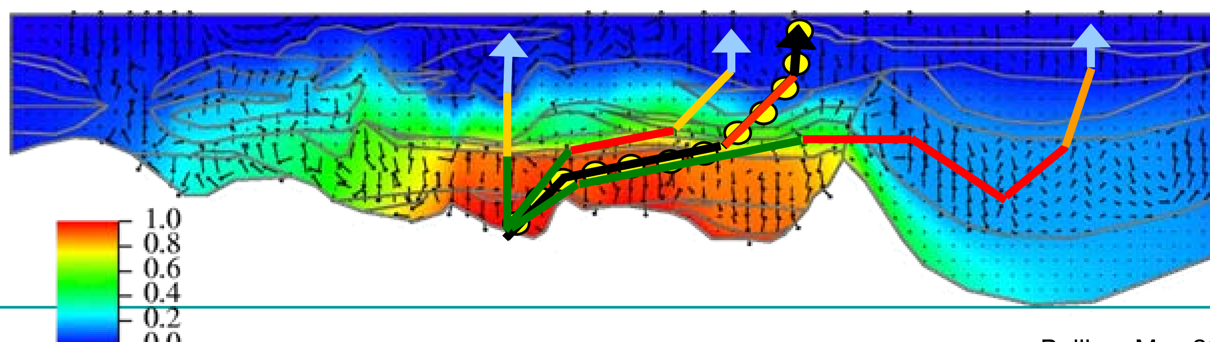
Simulation with d³f/r³t



W. Brewitz

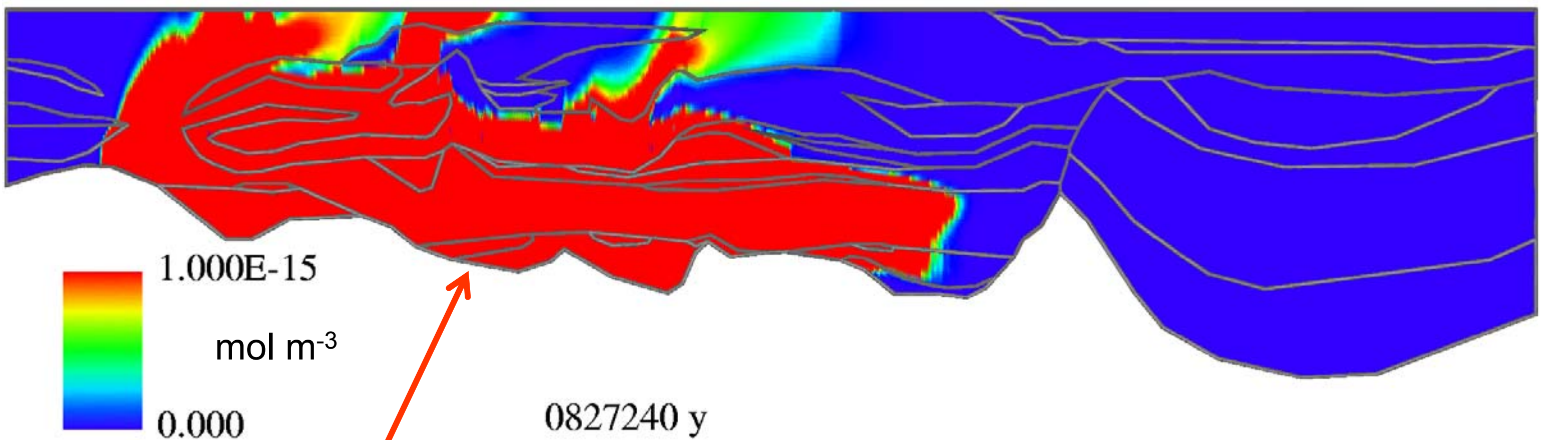
Abstraction to Performance Assessment

- Current approach: particle tracking
  1D, few hydrological units
  - Particle tracking
  - 1D model
  - Few hydrological units
- Alternative approach
  - Multi 1D model
  - Heterogeneous model



Distribution of U^{238} after 827 240 years

transport calculation with r^3t code
= radionuclide, reaction, retardation, and transport



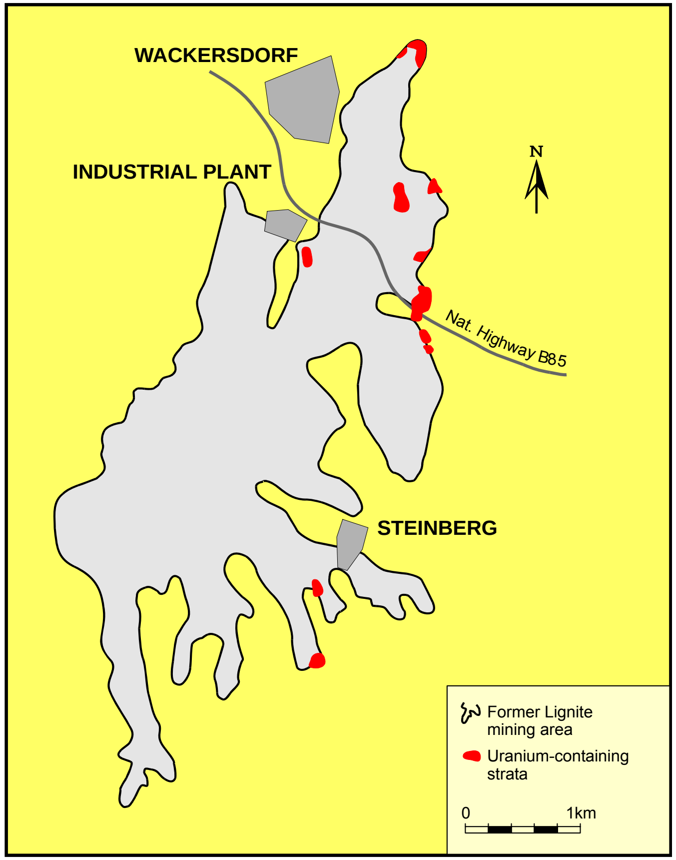
entry point for pollutants

Uranium transport in Tertiary sediments

The Heselbach study area

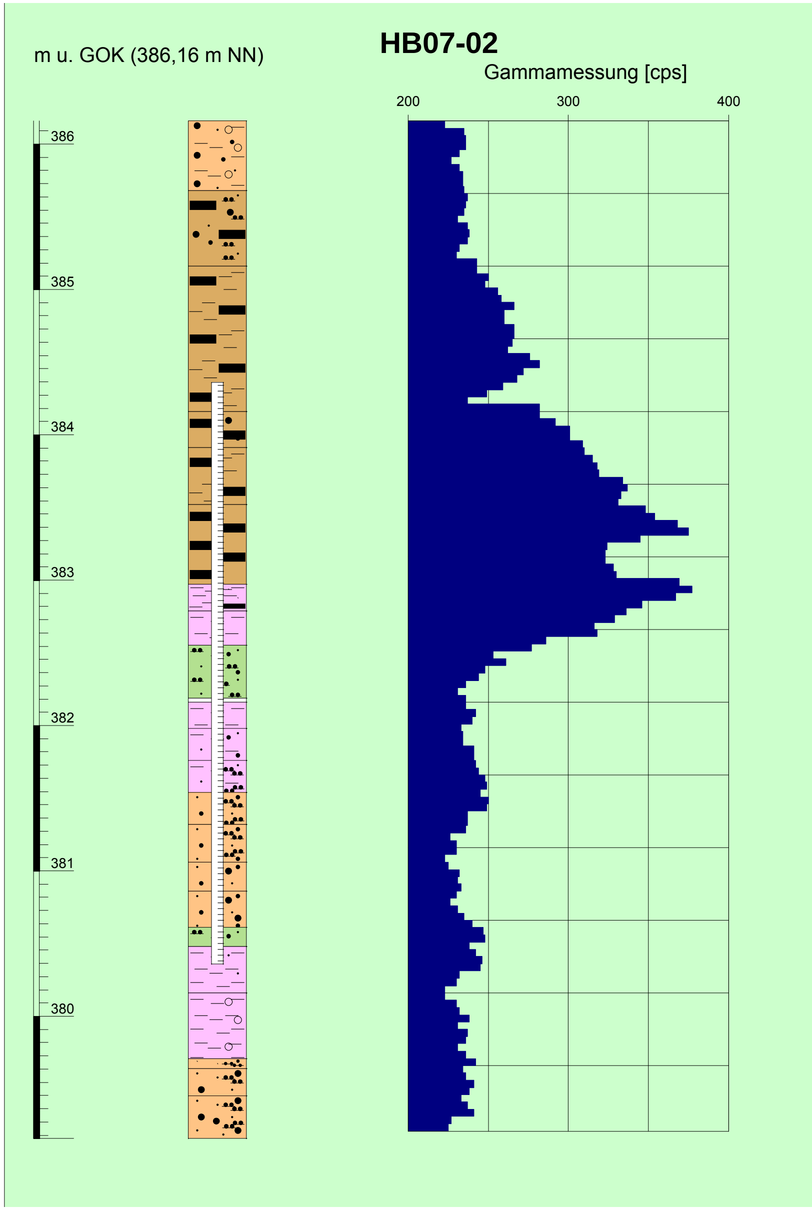
Uranium bearing sediments at Heselbach site

- Uranium rich strata at the outer rim of a lignite mining area
- Investigation as natural analogue for uranium mobilisation and transport in sedimentary rocks under Middle European climatic conditions

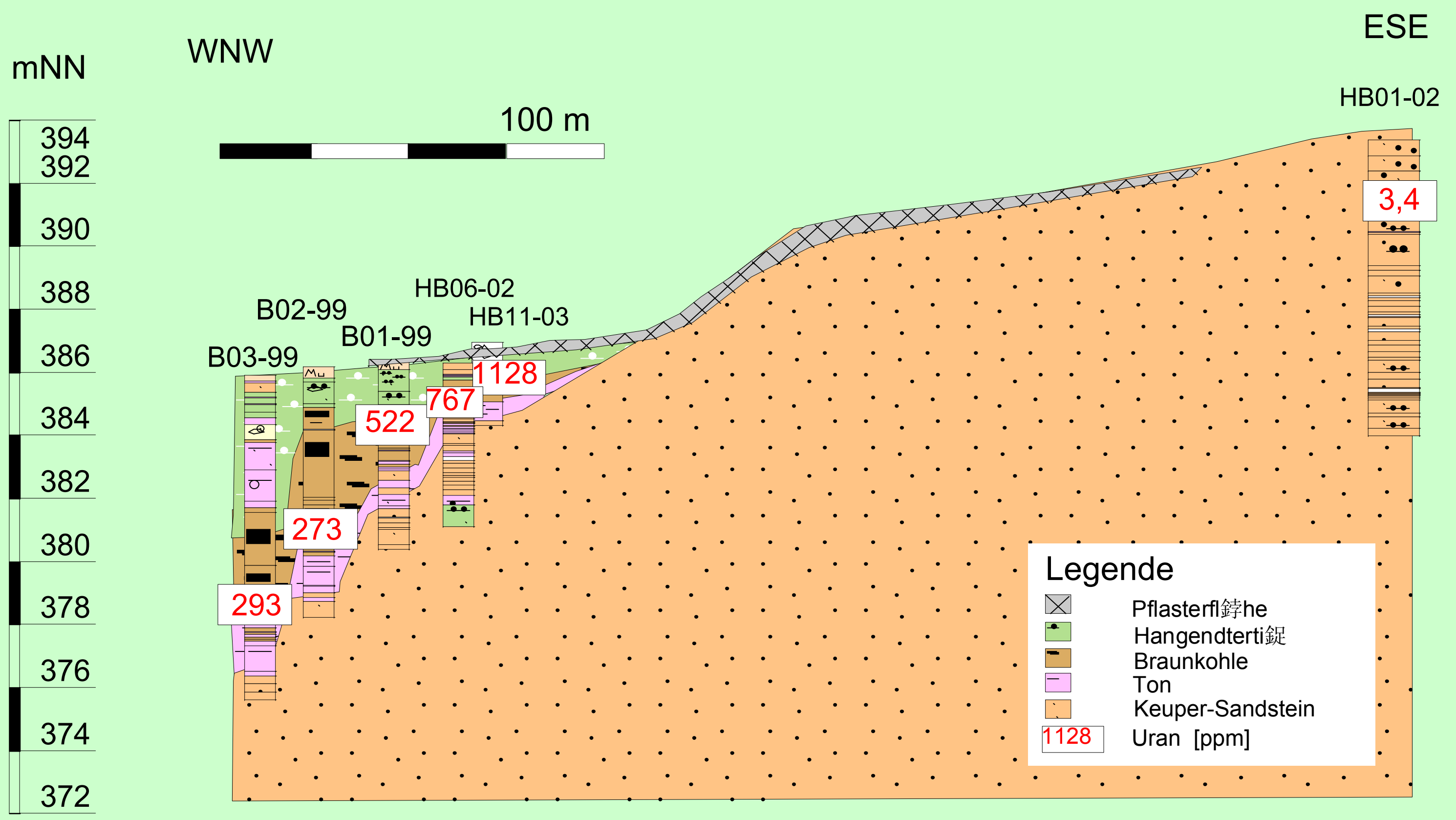


Schönwiese, TU BS

Geological profile with uranium peaks in lignite rich layers

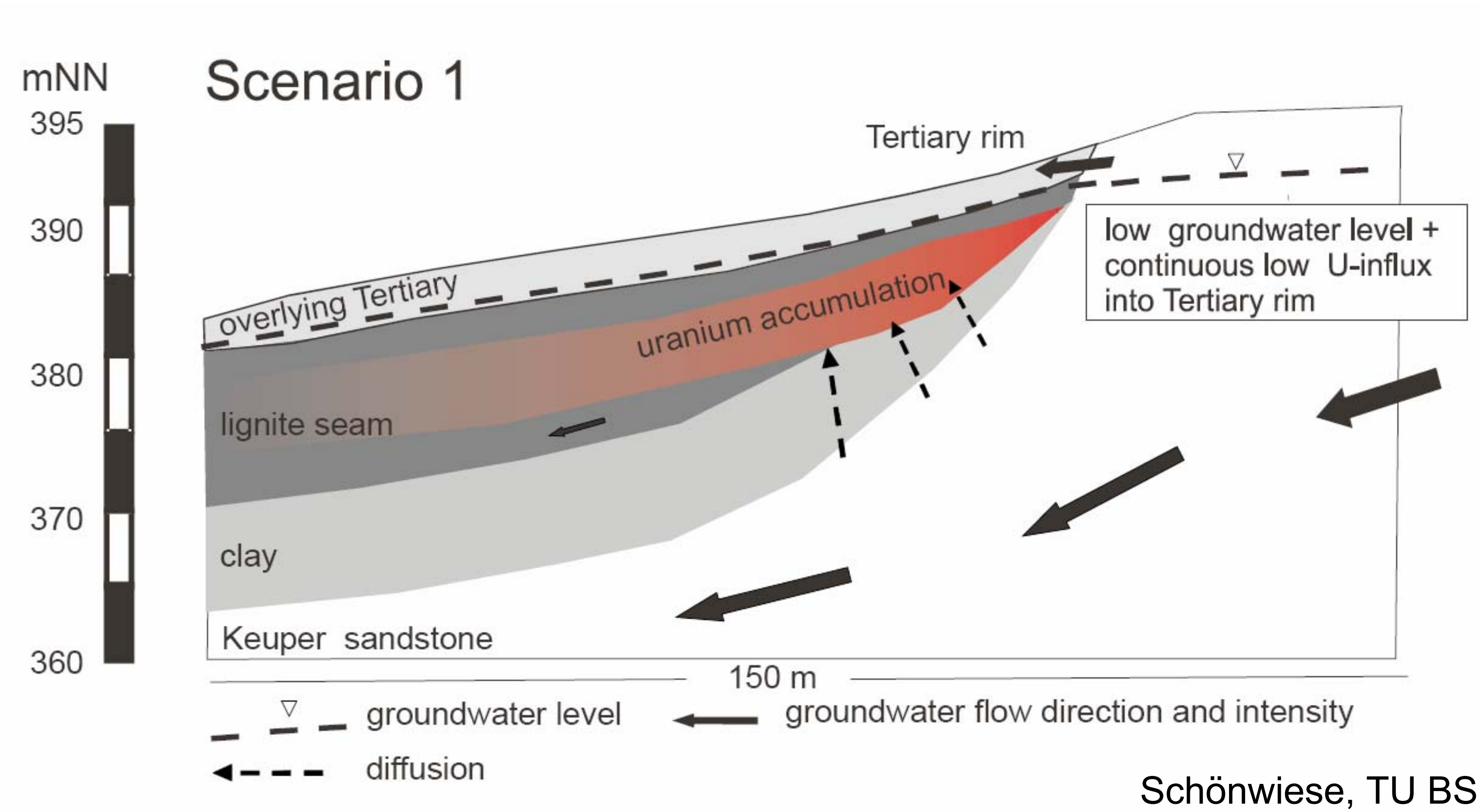


Geological cross section showing uranium contents

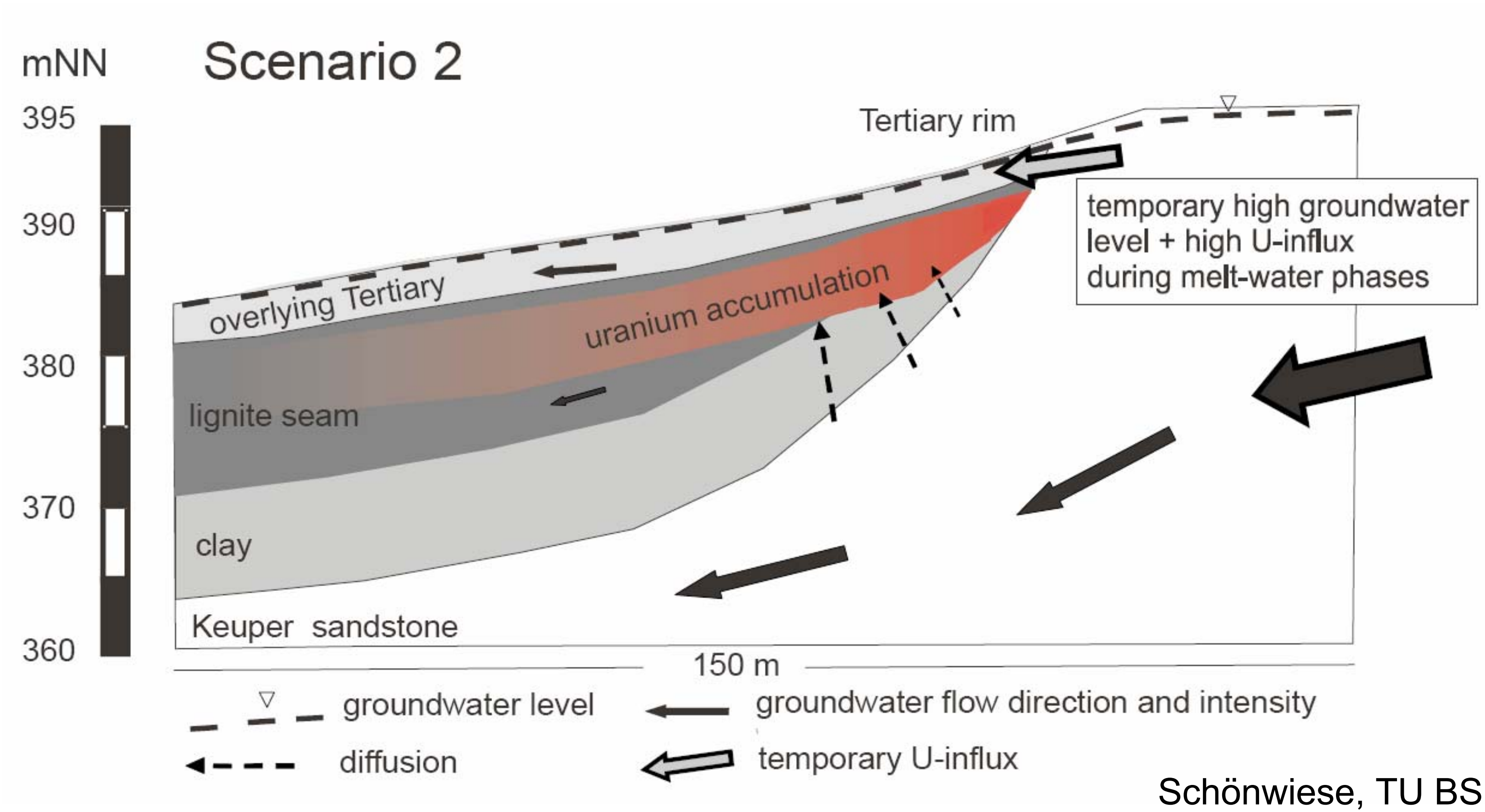


Schönwiese, TU BS

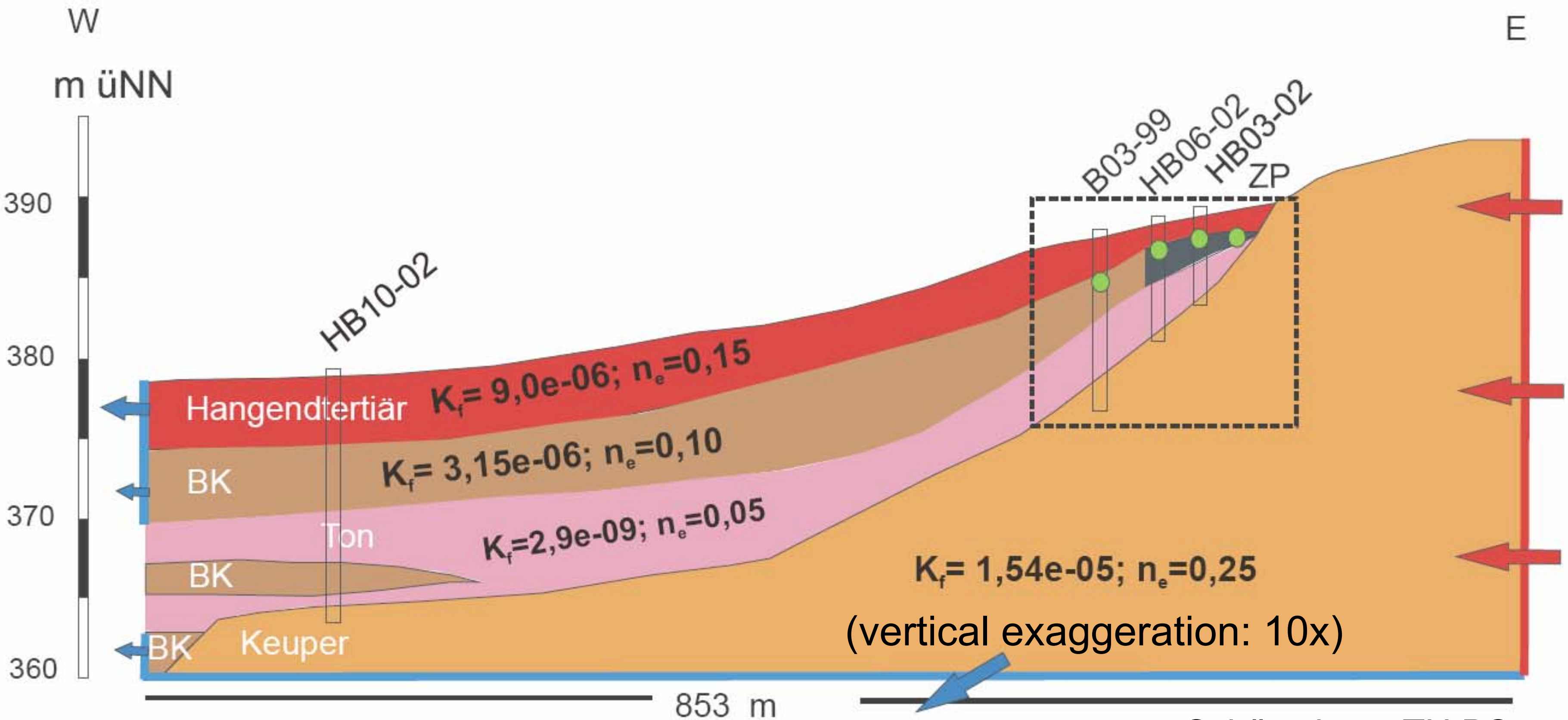
Scenario 1 for uranium enrichment at Heselbach site



Scenario 2 for uranium enrichment at Heselbach site

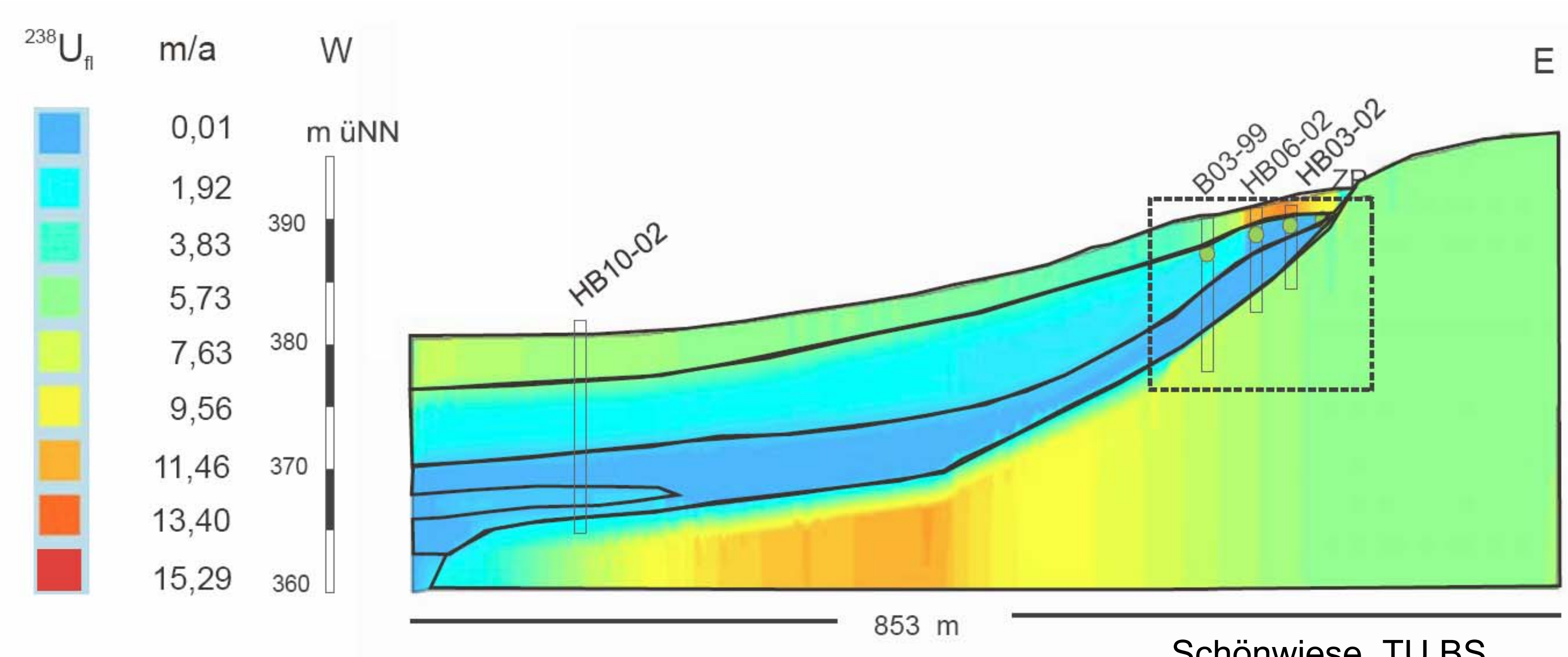


Schematic 2D-Vertical Model of Heselbach site for flow and transport calculations with computer program Feflow

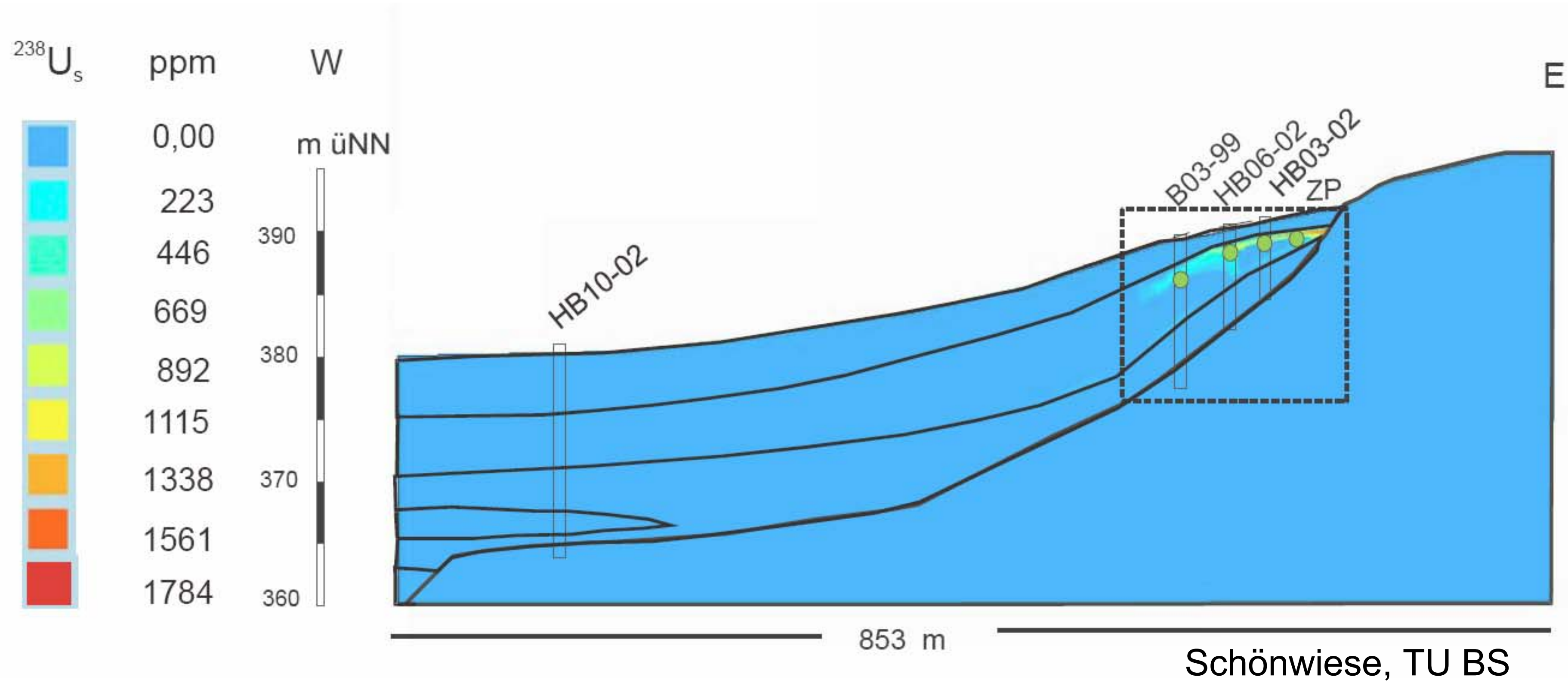


Schönwiese, TU BS

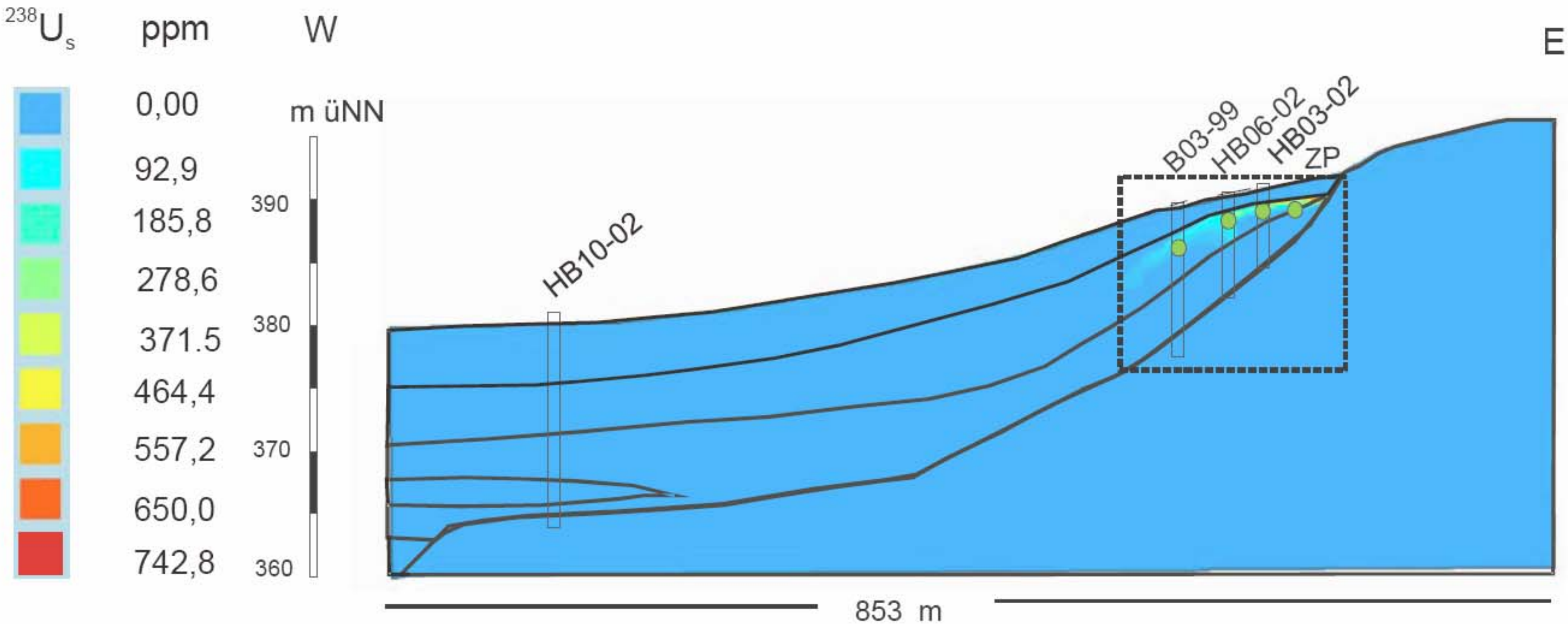
Calculated groundwater velocity under present conditions



Model results (Scenario 1) : Uranium content in the lignite-rich layer after continuous input during 800 000 years



Model results (Scenario 2) : Uranium content in the lignite-rich layer after input during one melt water phase in interglacial of 20 000 years



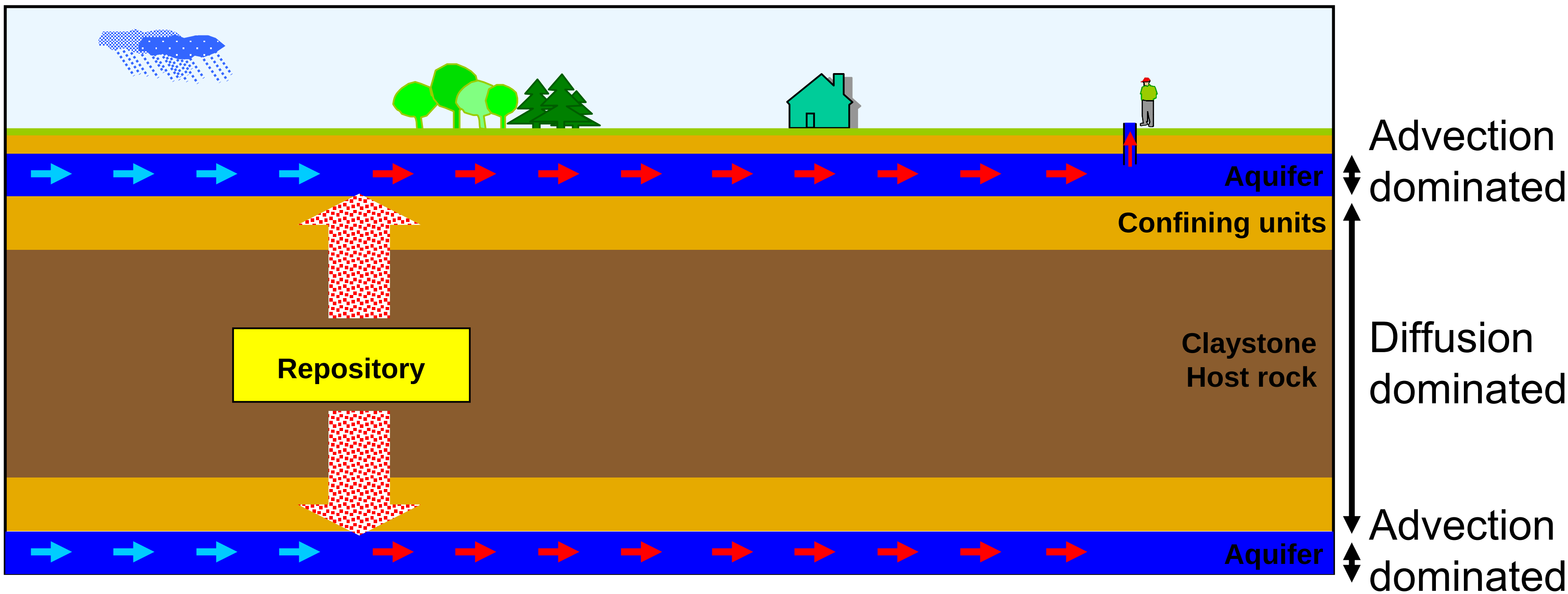
Schönwiese, TU BS

Radionuclide transport in clay formations

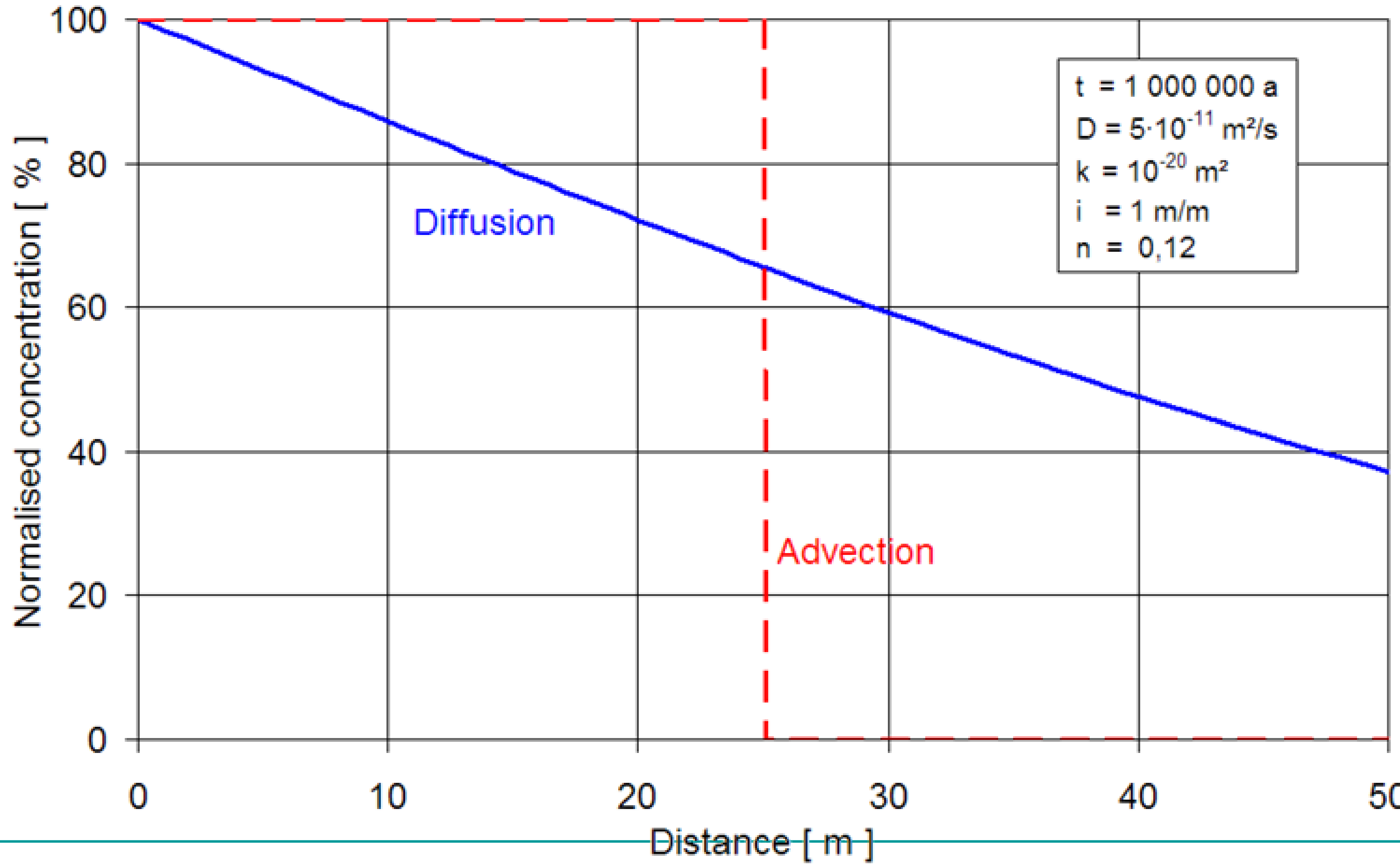
Generic concept in accordance
with site studies in Switzerland

W. Brewitz

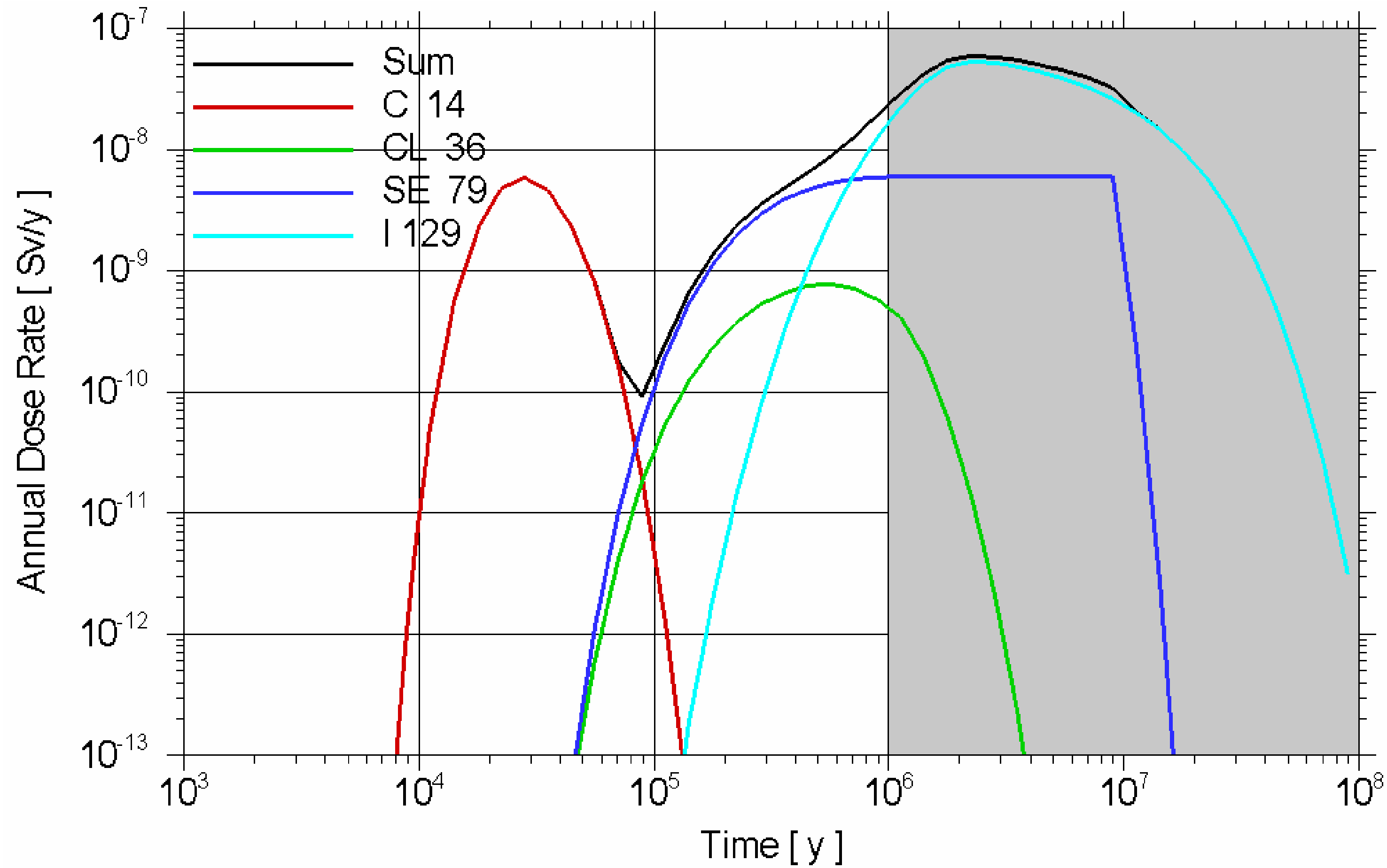
Claystone formations: Transport processes



Claystone formations: Transport processes



Claystone formations: Annual dose rates



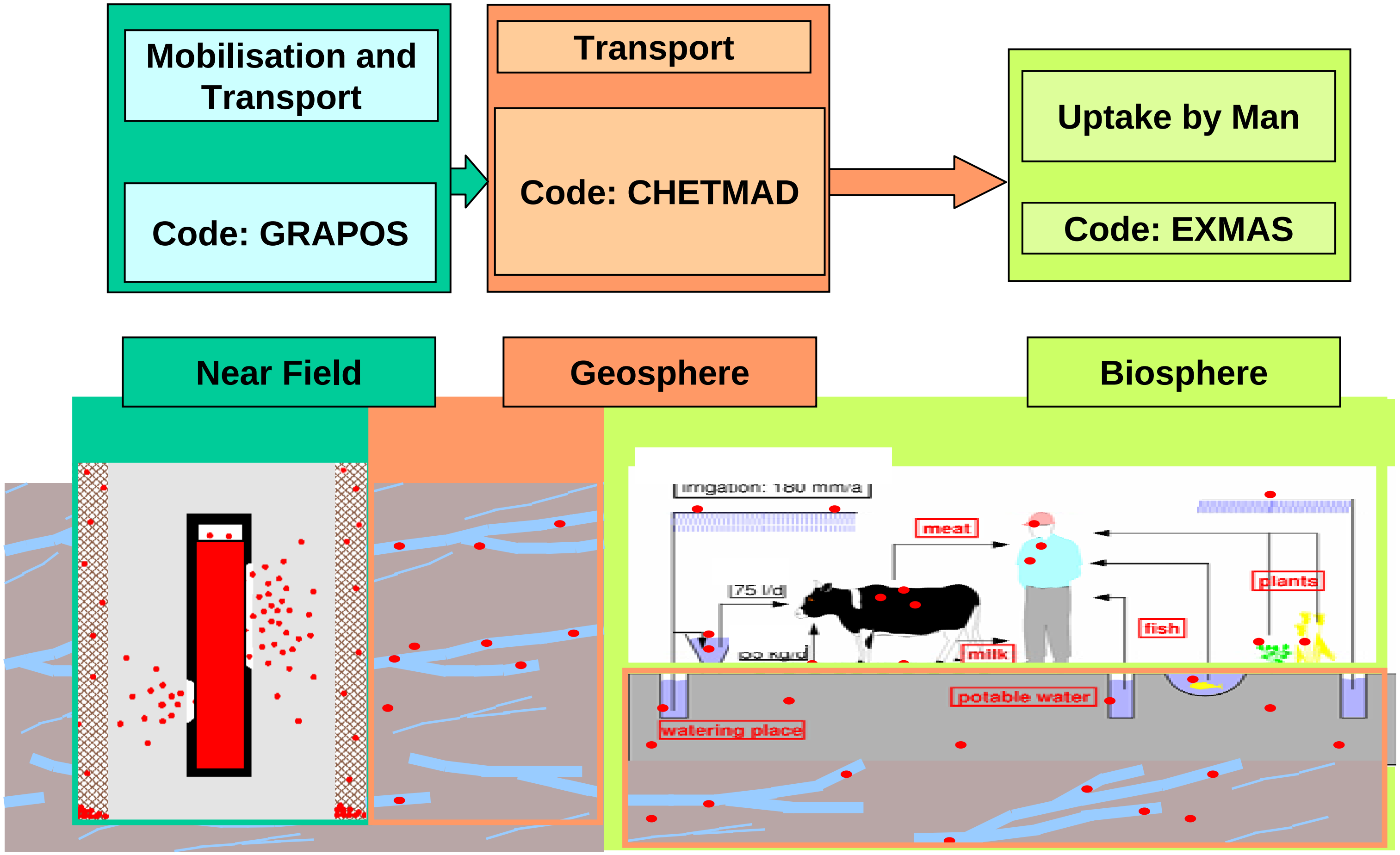
Granite

Hydrogeological modelling studies in order to check the feasibility of a disposal concept in the Siberian Shield

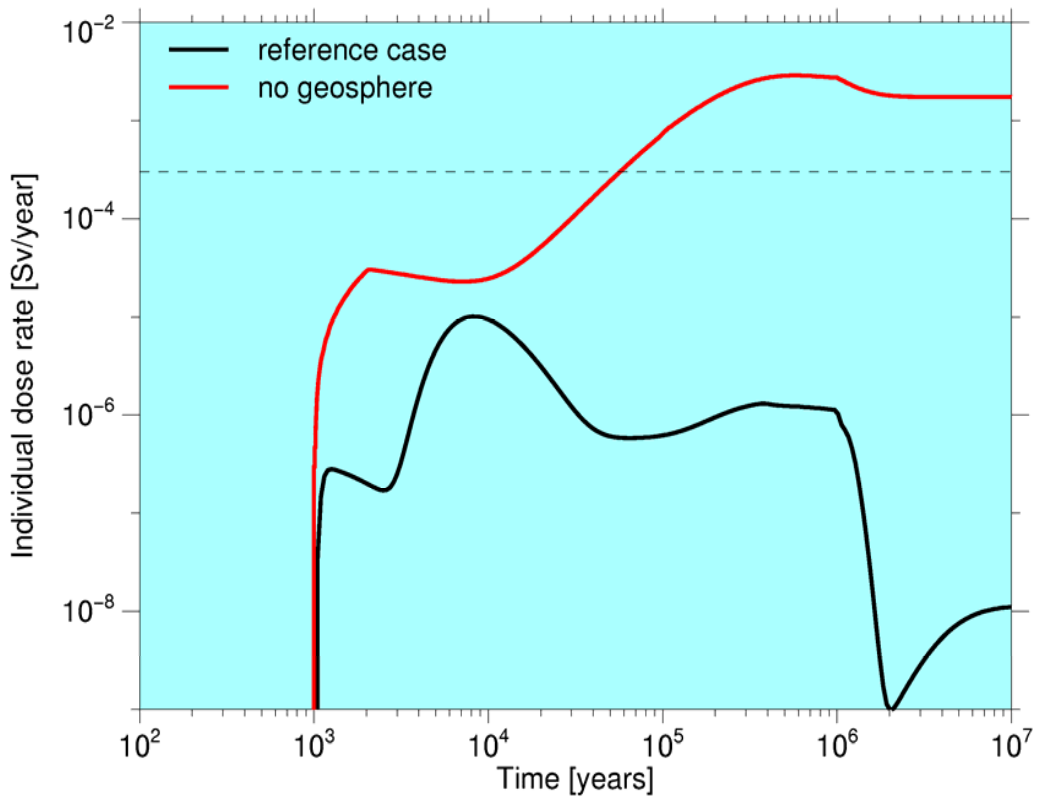
Evaluation of Disposal Concept and Sites by Performance Assessment (PA)

- Development of computer models for the different subsystems of the Russian disposal concept
  (waste - container - geobarrier system - biosphere)
- Identification of the safety-relevant parameters and processes of a granite environment
  (Inventory - RN mobilisation - transport - exposure of man)
- Stepwise improvement of the system understanding and optimization of the disposal concept ***(safety requirements)***
- Integrated performance assessment ISPA for concrete disposal sites and check with ***safety criteria and regulations***

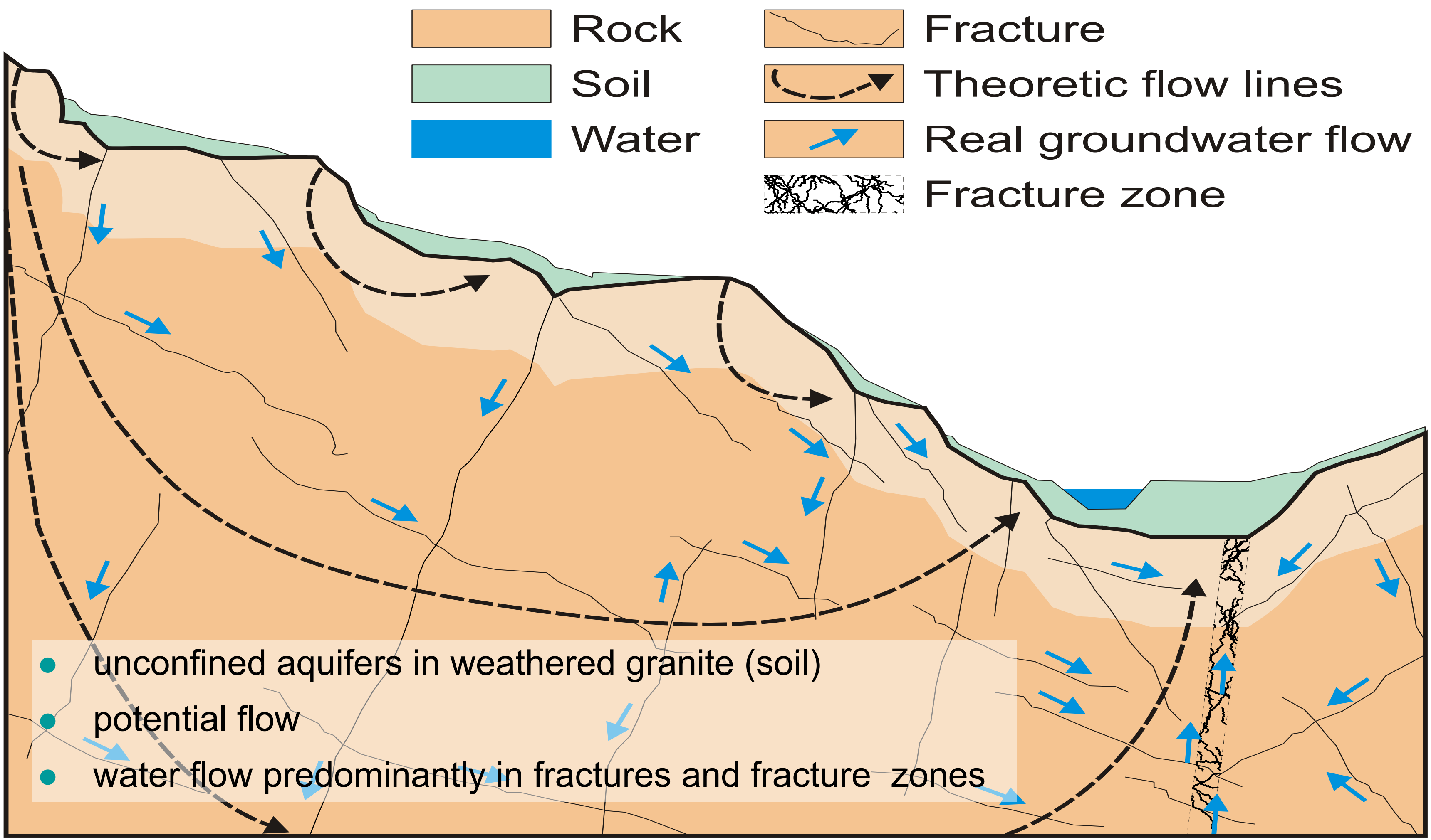
EMOS code for RN Transport & Dose Calculations



Generic studies on the contribution of granitic bedrock to long-term isolation of SF / radioactive waste

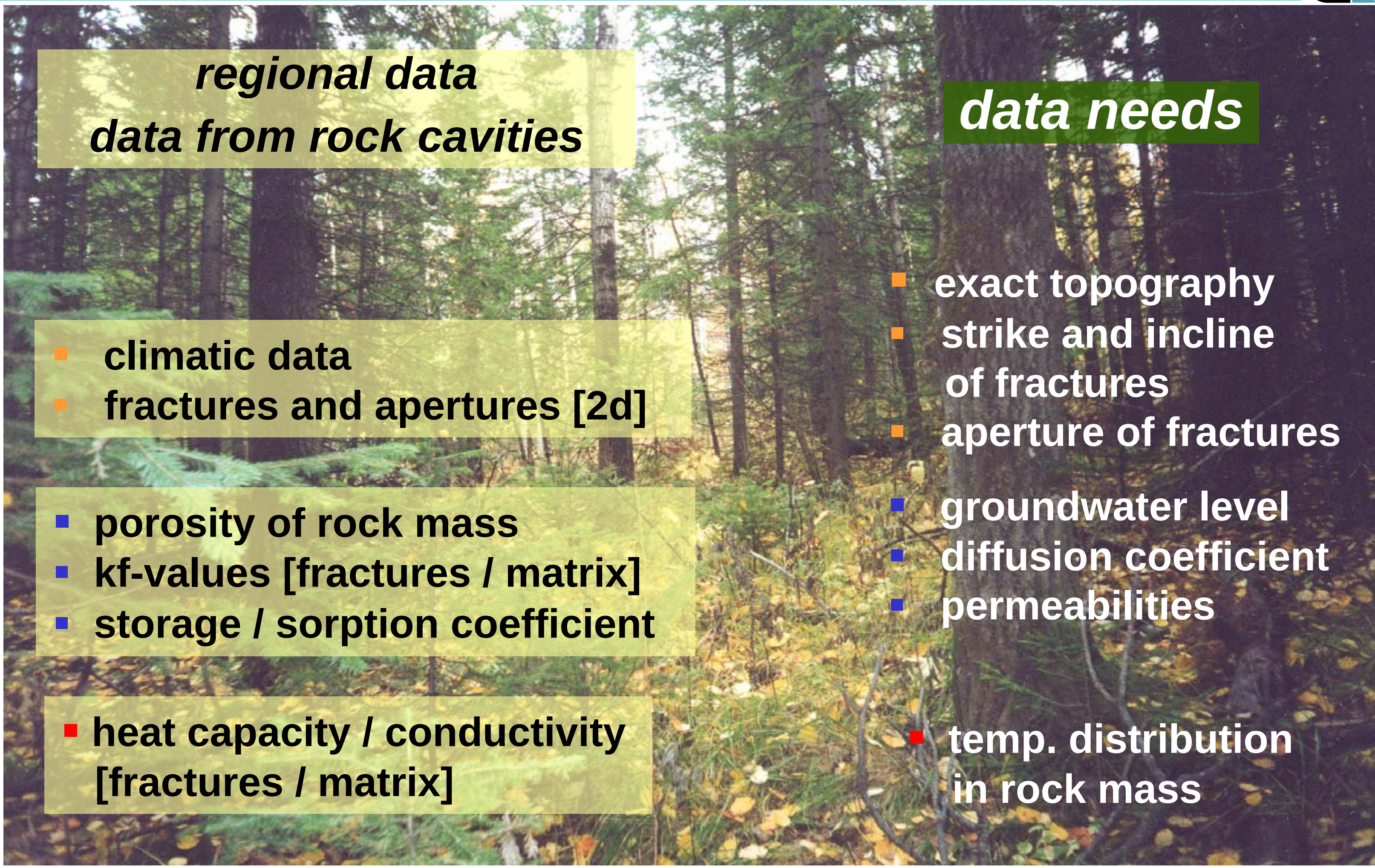


Groundwater flow in granitic bedrocks



- unconfined aquifers in weathered granite (soil)
- potential flow
- water flow predominantly in fractures and fracture zones

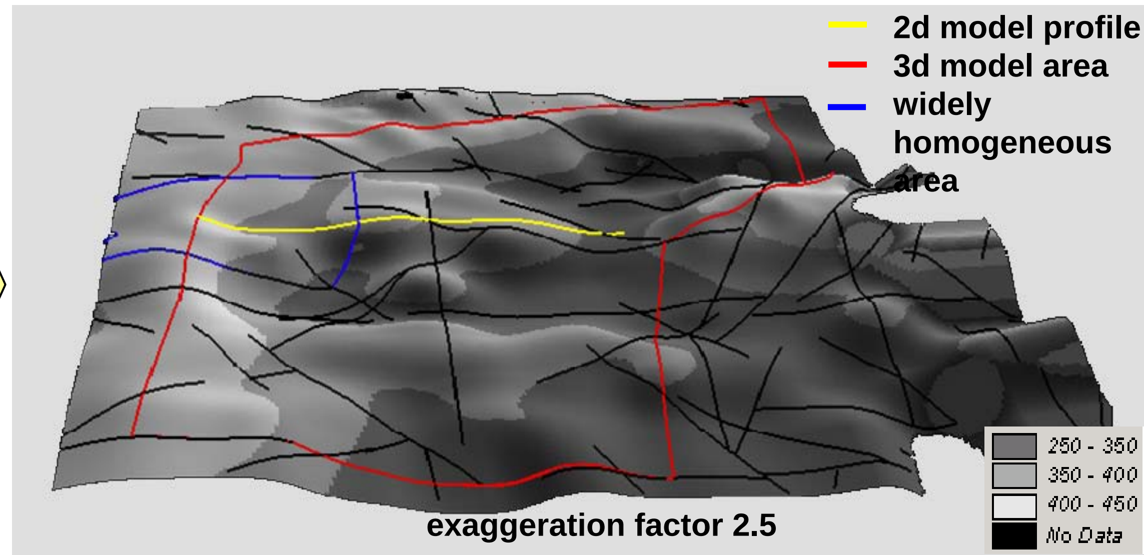
Russian Taiga: The Problem of Data Aquisition



Contour mapping by use of GIS

Map of slopes [Lopatin et al.]

Elevation Model

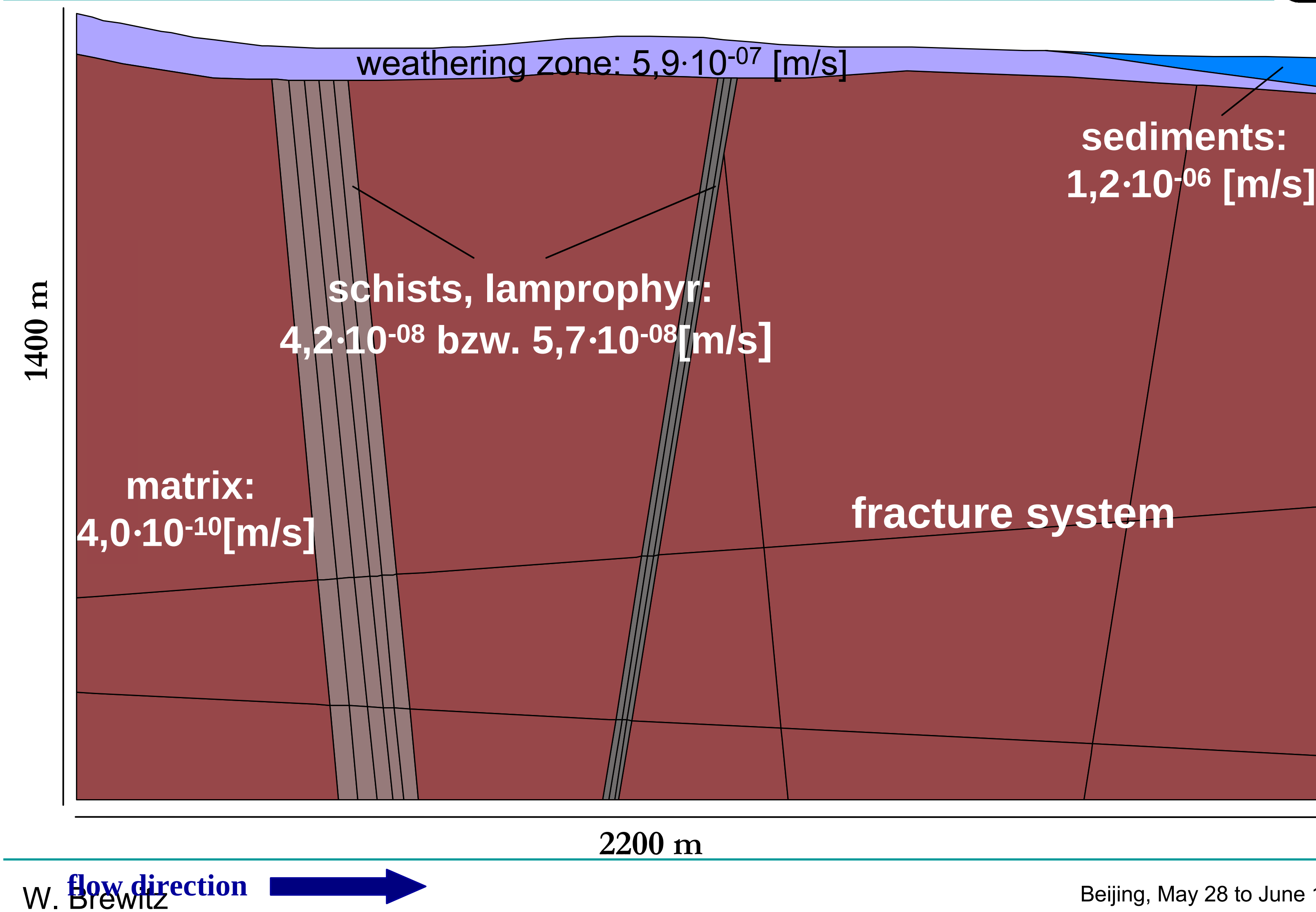


Groundwater flow in granitic bedrock

section	depth [km]	permeability [m/s]			
		matrix		**Fractures of III. and IV. order**	
		min/max	average	min/max	average
section 1 weathered zone	0 - 0,1	$5{,}7\cdot10^{-8}/5{,}8\cdot10^{-6}$	$1{,}2\cdot10^{-7}$	$1{,}2\cdot10^{-7}/1{,}2\cdot10^{-5}$	$5{,}8\cdot10^{-6}$
section 2 stress relaxation	0,1 - 2,5	$1\cdot10^{-10}/1\cdot10^{-7}$	$\mathbf{5\cdot10^{-8}}$	$1\cdot10^{-9}/\mathbf{1{,}2\cdot10^{-6}}$	$3{,}4\cdot10^{-8}$
section 3 increased regional stress	1 - 5	$1{,}2\cdot10^{-14}/3{,}5\cdot10^{-12}$	$3{,}5\cdot10^{-13}$	$1{,}2\cdot10^{-12}/1{,}2\cdot10^{-10}$	$1{,}2\cdot10^{-11}$
section 4 decreased stress	5 - 7	$1{,}2\cdot10^{-13}/1{,}2\cdot10^{-10}$	$\mathbf{5\cdot10^{-11}}$	$1{,}2\cdot10^{-14}/\mathbf{5{,}8\cdot10^{-7}}$	$1\cdot10^{-9}$
section 5 high regional stress	>7	$1{,}2\cdot10^{-15}/1{,}2\cdot10^{-13}$	$3{,}5\cdot10^{-14}$	$1{,}2\cdot10^{-13}/1{,}2\cdot10^{-11}$	$1{,}2\cdot10^{-12}$

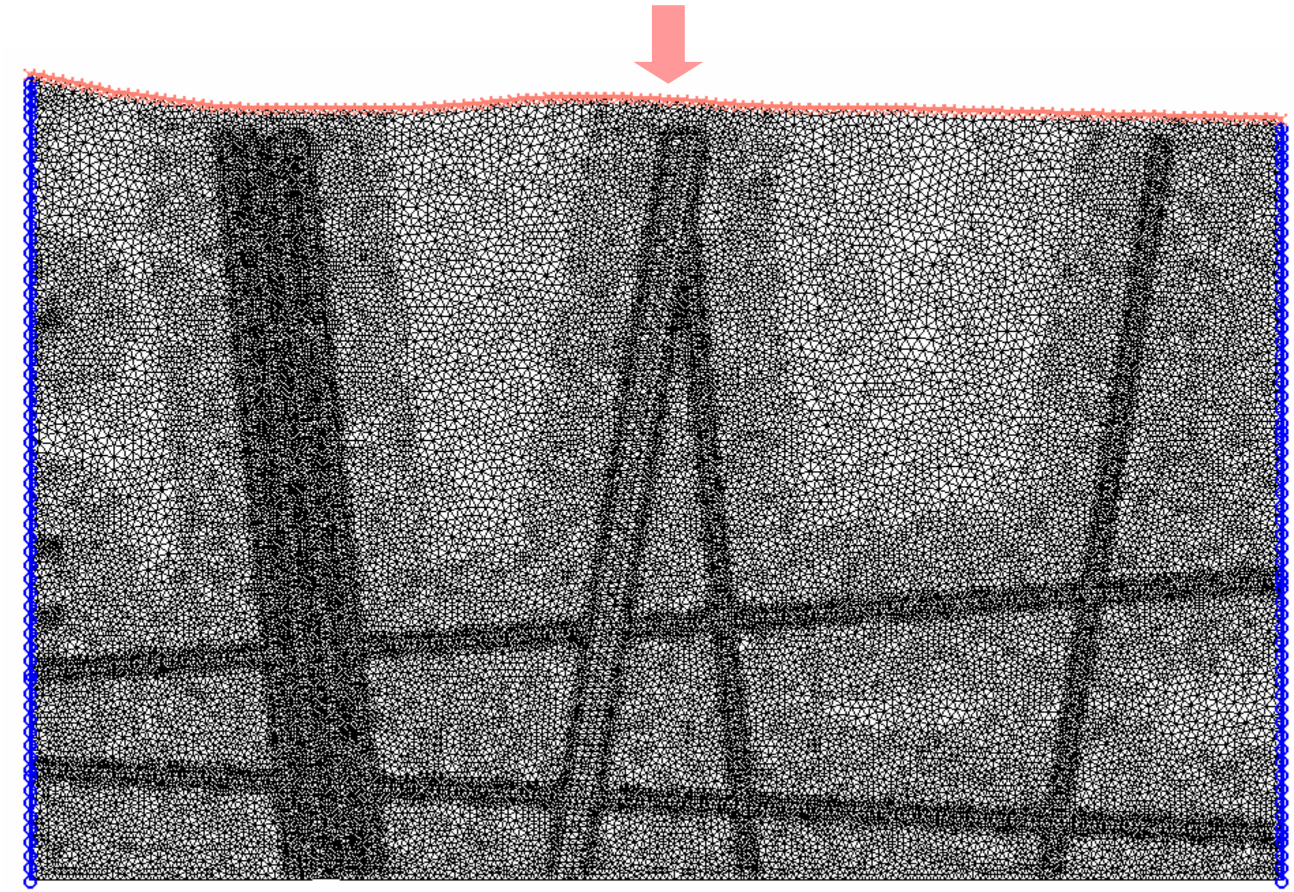
Parameterisation of soil & fracture permeability with respect to sections of different rock pressure (Anderson et al. 1998)

Geological Structure Model



Hydraulic Boundary Conditions

Groundwater Recharge:
$1{,}64 \cdot 10^{-04}$ [m/d]



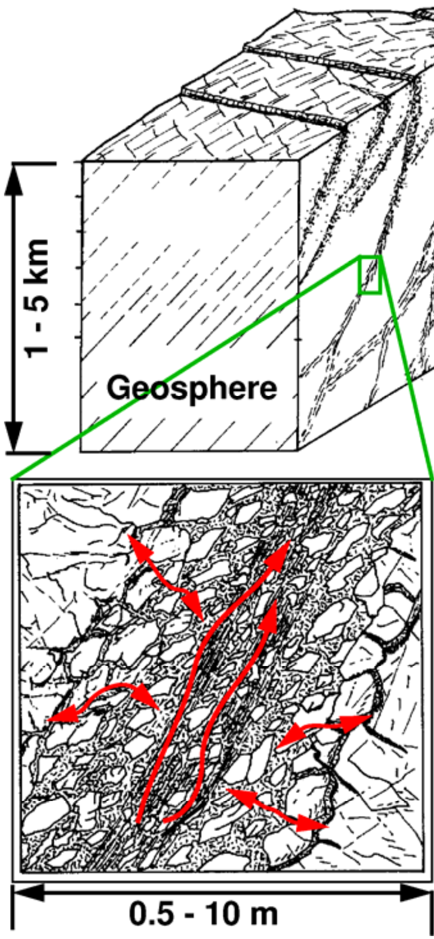
Hydraulic Gradient:
$3 \cdot 10^{-02}$

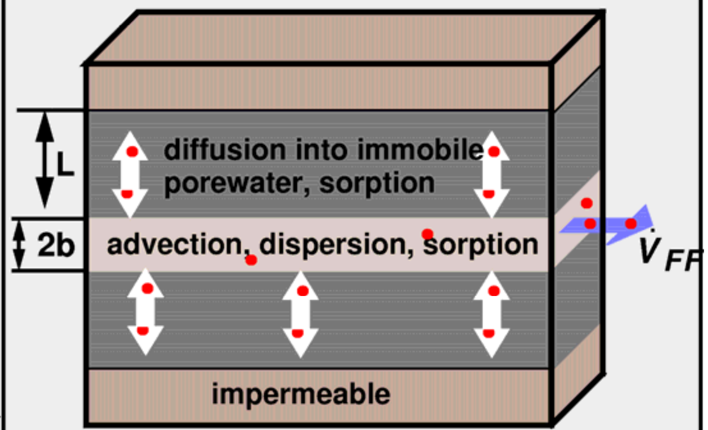
Elements: 61.322

Knotes: 30.936

Far field granite – RN transport in Kakirite zone

CHETMAD code

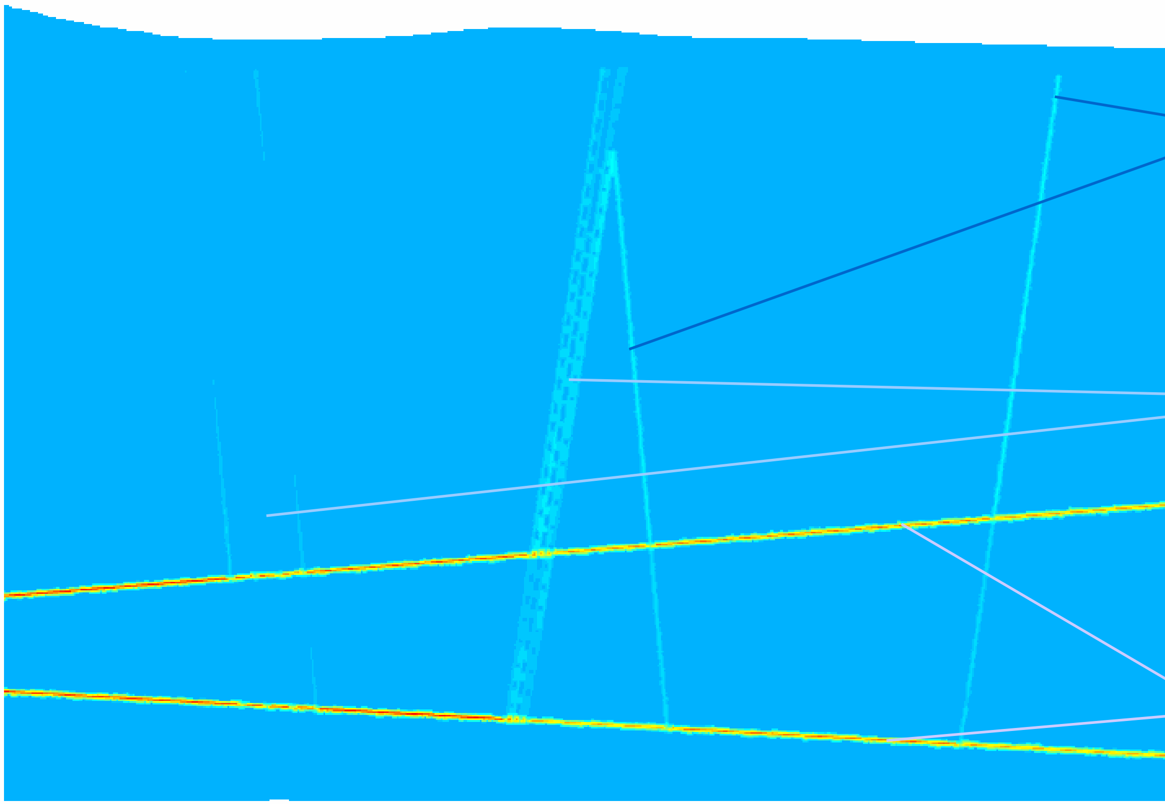




example: SPA Project

Kakirite thickness:	2b = 0.3 m
Penetration depth:	y_m = 0.05 m
Darcy velocity:	q = $3.5 \cdot 10^{-5}$ m/y
Pathway length:	L = 200 m
Advective velocity:	u = 0.05 m/y

Groundwater Flow Velocity

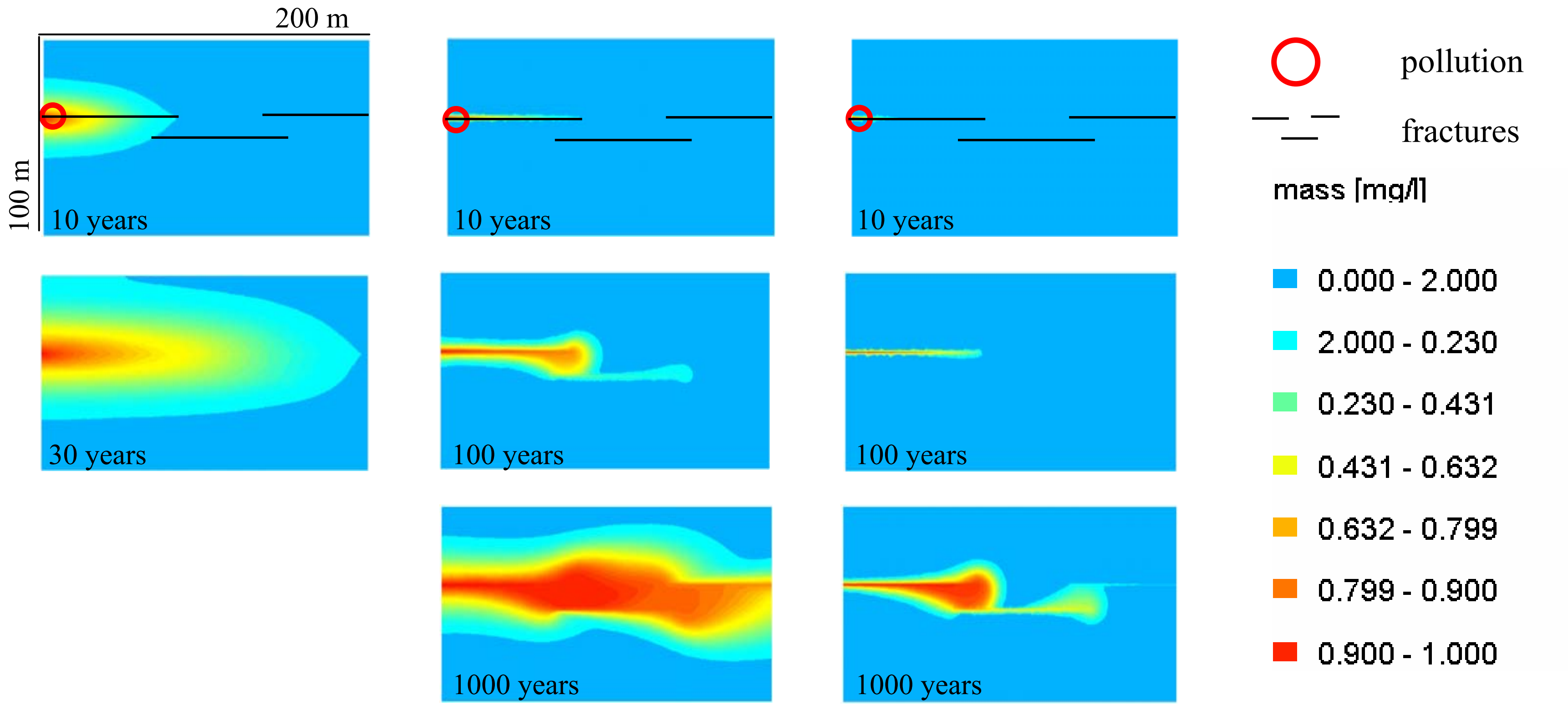


Fractures perpendicular to groundwater flow
=> lower groundwater flow velocity as in the horizontal fractures.
=> taking the radionuclides to the surface

Sections with high fracture density
=> decreasing groundwater flow velocity, increasing diffusion und dispersion.
=> „stand-alone“ fractures are the most effective pathways

Fractures in direction of groundwater flow
=> fast and far radionuclide transport

Schematic 2d Transport Model with FEFLOW



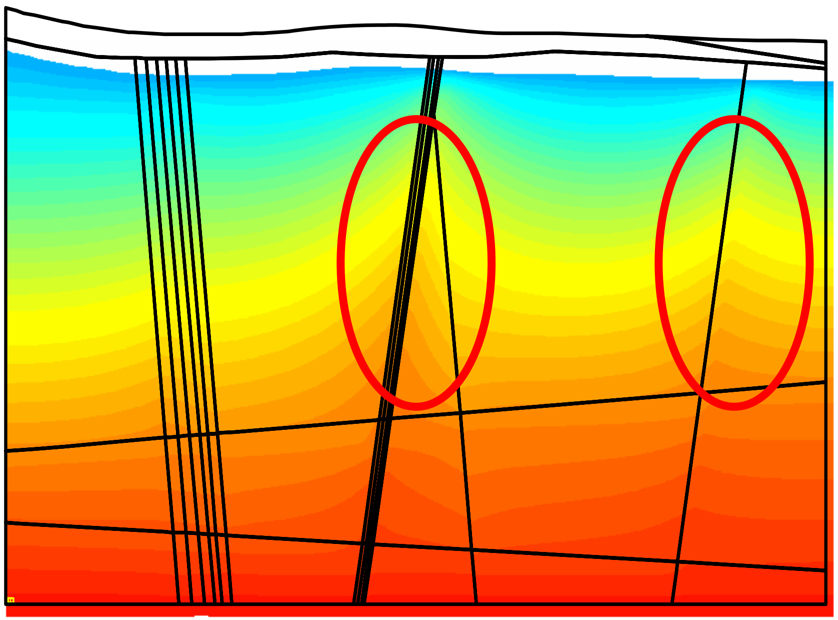
matrix k_f: $5{,}8\cdot10^{-08}$ m/s
fracture k_f: $1{,}2\cdot10^{-6}$ m/s

matrix k_f: $1\cdot10^{-09}$ m/s
fracture k_f: $1{,}2\cdot10^{-6}$ m/s

matrix k_f: $5\cdot10^{-11}$ m/s
fracture k_f: $1{,}2\cdot10^{-6}$ m/s

2d Transportmodel with Temperature Gradient

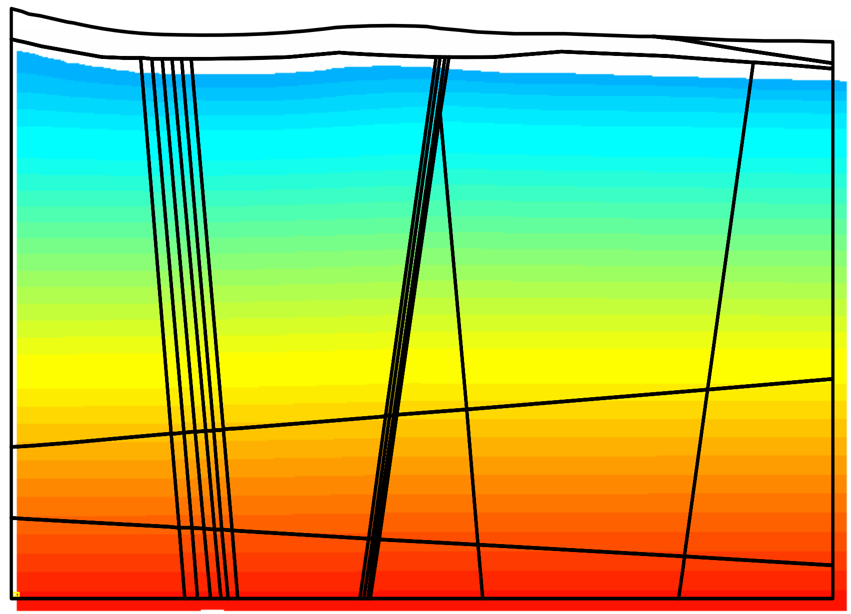
matrix kf: $4 \cdot 10^{-10}$ [m/s]
fracture aperture: 50 [cm]



fractures with a fast groundwater flow

fracture kf: $7 \cdot 10^{-05}$ [m/s]

=> inhomogenic natural heat field
=> alteration of the groundwater flow direction

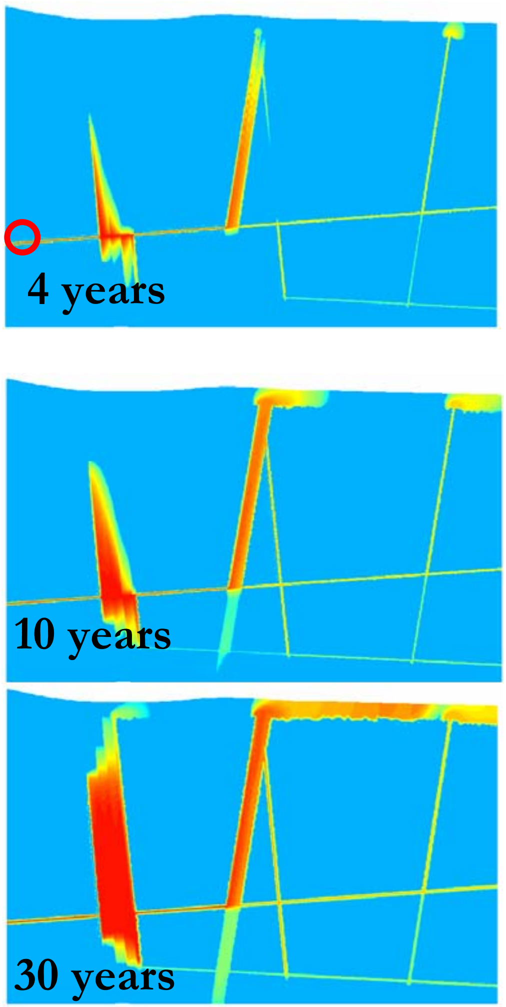


fractures with a low groundwater flow

fracture kf: $6 \cdot 10^{-07}$ [m/s]

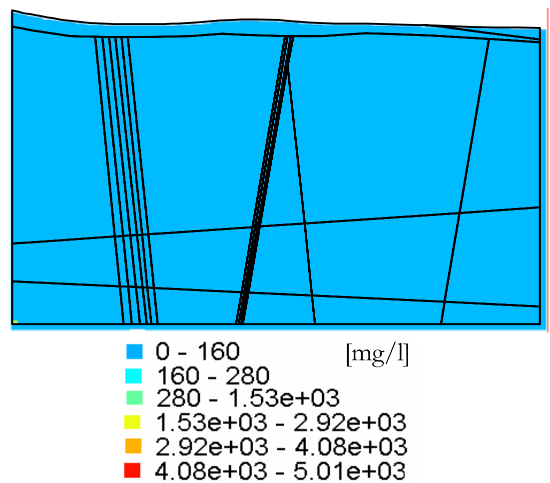
=> homogeneous heat field
=> groundwater flow direction to the surface

2d Transportmodel with Temp. Gradient and Tracer



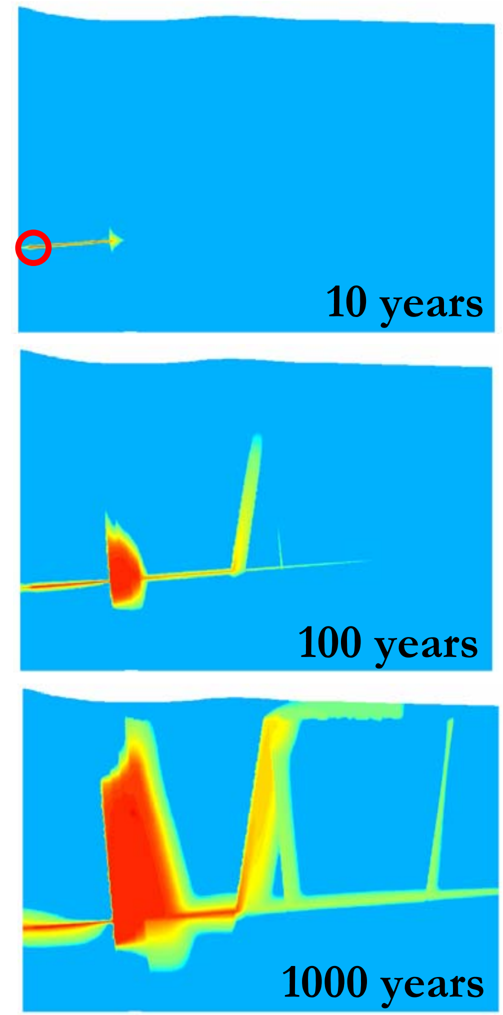
Model 2

K_f matrix [m/s]: $4{\cdot}10^{-10}$
K_f fracture [m/s]: $5.8{\cdot}10^{-07}$
Fracture aperture: 1m



Model 1

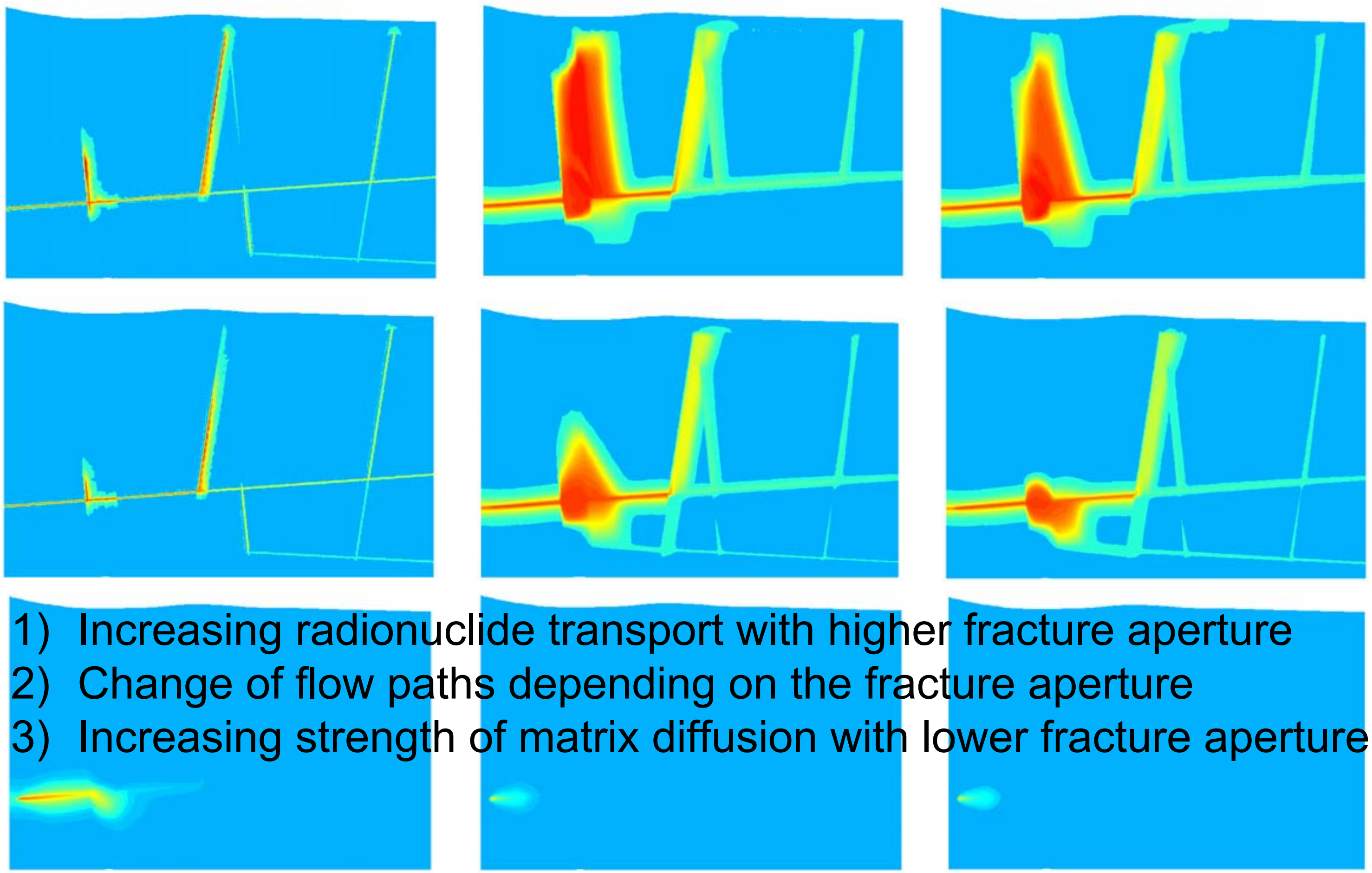
K_f matrix [m/s]: $4e^{-10}$
K_f fracture [m/s]: $6.9e^{-05}$
Fracture aperture: 1m



2d Model with Temperature Gradient after 10.000 Years

GRS

matrix k_f [m/s]: $4e^{-10}$	matrix k_f [m/s]: $4e^{-10}$	matrix k_f [m/s]: $4e^{-10}$
fracture k_f [m/s]: $6,9e^{-05}$	fracture k_f [m/s]: 1,2e-06	fracture k_f [m/s]: 5,8e-07



fracture aperture [m]: 1

fracture aperture [m]: 0,5

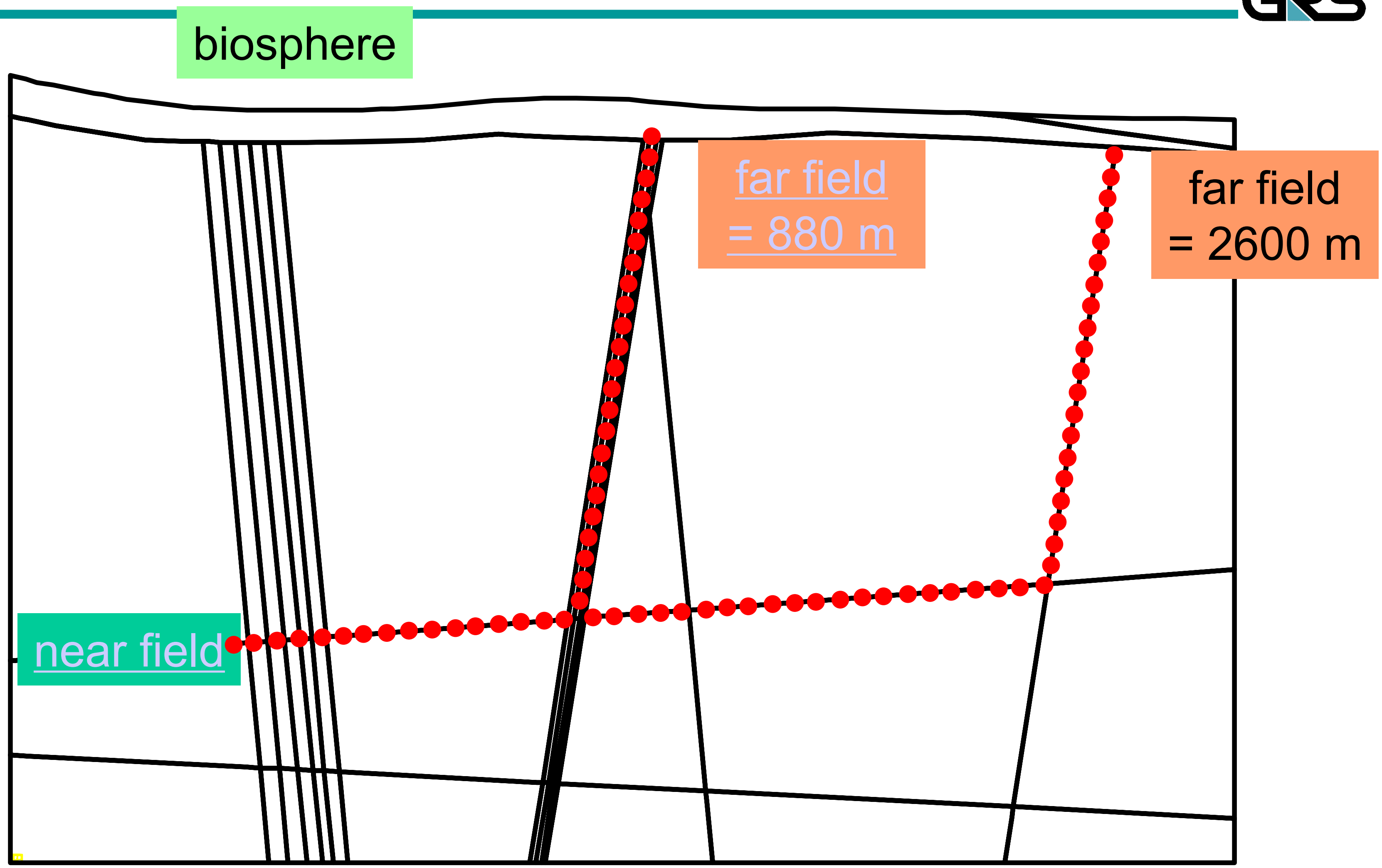
fracture aperture [m]: 0,01

1) Increasing radionuclide transport with higher fracture aperture
2) Change of flow paths depending on the fracture aperture
3) Increasing strength of matrix diffusion with lower fracture aperture

mass [mg/l] ·e

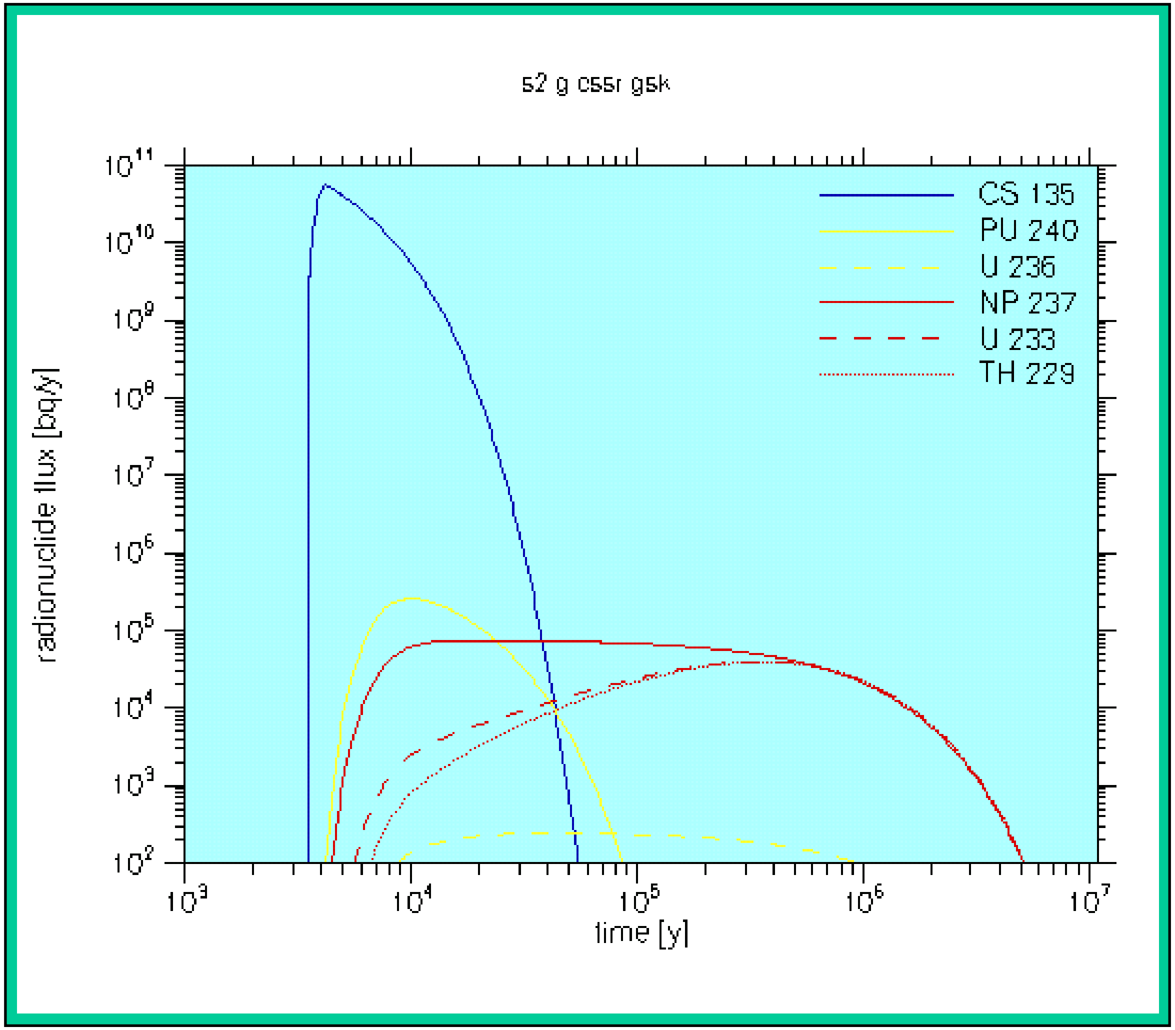
- 0.00e+00 - 2e+03
- 2.0e+03 - 2.78e+04
- 2.78e+04 - 5.1e+04
- 5.10e+04 - 6.69e+04
- 6.69e+04 - 8.36e+04
- 8.36e+04 - 1.00e+05
- 1.00e+05 - 1.17e+05
- 1.17e+05 - 1.28e+05
- 1.28e+05 - 1.45e+05

Results of Emos Calculation and Realistic 2d Modelling



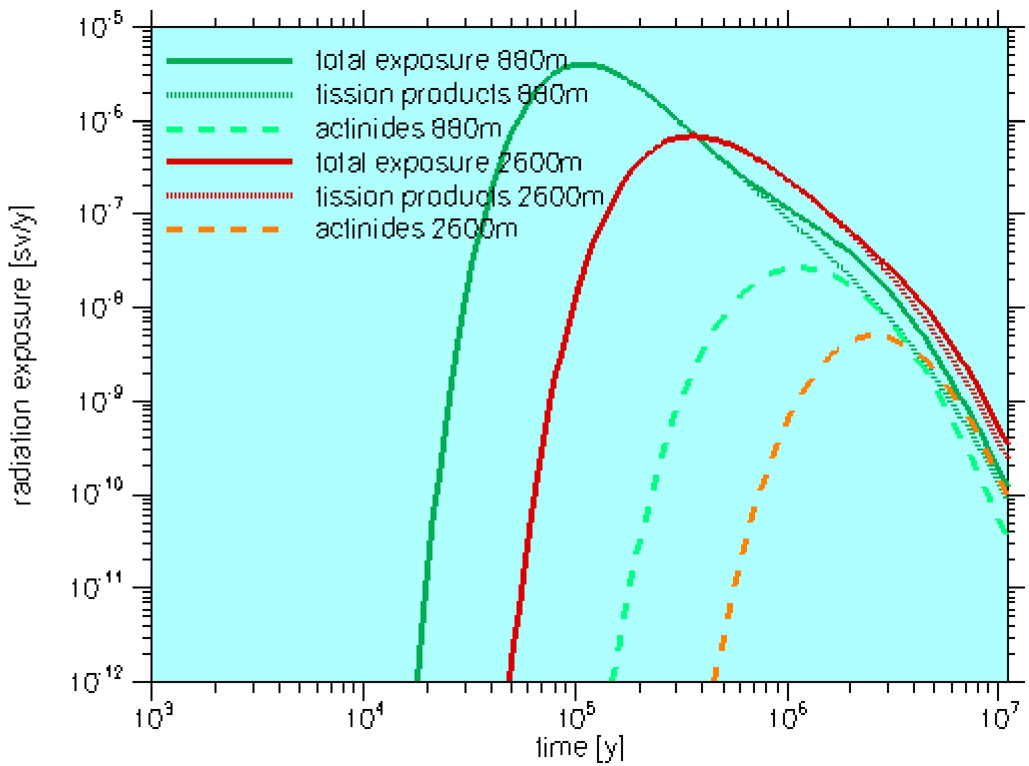
Transport Calculation for the Near Field

Case S2 CsSr



Transport Calculation for the Far Field and Biosphere

Case S2 CsSr



Models Used for Preselection of Potential Areas

Task - 2d and 3d simulation of groundwater regime and contaminant transport in fractured rock

- Geostructural model – *ArcView, FEFLOW*
- Density-driven groundwater flow, induced by heat or / and salt – *d^3f , FEFLOW*
- Mobilisation of radionuclides, time-dependent release rate - *EMOS*
- Transport and retention of radionuclides - *EMOS, r^3t*

Future Works

- **Improvement of data base**

  - geometrical 3 d model of fractures

  - intersection of fractures

  - mineralisation and filling of fractures

  - retardation parameters in rock mass (far field)

- **Further development of computer models**

  - incorporation of radionuclide decay chains in FEFLOW code

  - application of GRAPOS code to non fractured rock

- **Investigation of the effects the heat generating waste has on the near field of the repository and the ground water flow**

Braunschweig Die Löwenstadt

„Europas heißeste Forschungs- und Entwicklungsregion ist... Braunschweig!"

Quelle: Deutsche Bank Research

www.braunschweig.de/wissenschaft

Stadt der Wissenschaft 2007

Ideenküche Braunschweig
Ausgezeichnet durch den Stifterverband
www.braunschweig.de/stadt-der-wissenschaft

BS|ENERGY VEOLIA ENVIRONNEMENT

NEW YORKER Dress for the moment.

NORD/LB ÖFFENTLICHE

Braunschweig Stadtmarketing

Medienpartner:
BRAUNSCHWEIGER ZEITUNG SALZGITTER ZEITUNG WOLFSBURGER NACHRICHTEN

Mit freundlicher Unterstützung von:
STRÖER deutsche städte medien


Thank you very much
for your hospitality

ROCK MECHANICS FOR YUCCA MOUNTAIN

An overview of rock mechanics investigations in support of a proposed high level nuclear waste repository at Yucca Mountain, NV, USA

Jaak J.K. Daemen
University of Nevada, Reno

Lumin Ma
Vector Engineering, Inc
Grass Valley, CA

5/24/2007

Summary/overview

- Initial Site Selection
- Narrowing down sites considered
- Characterization studies for three sites
- Yucca Mountain
- Initial Yucca Mtn site investigations
- Yucca Mtn site characterization
- Rock Mechanics at Yucca Mountain

A Little Bit of History

- 1957: NAS (National Academy of Sciences) recommends deep geologic disposal, with emphasis on disposal in salt.

  Early salt mechanics investigations (Lyons, Kansas)
- 1982: NWPA (Nuclear Waste Policy Act)

  → Nine sites identified as potential candidate sites: 7 in salt, 1 in basalt, 1 in volcanic ash flow (tuff)
- 1984: 3 sites selected for detailed studies (site characterization) (Tuff, basalt, bedded salt)
- 1987: Yucca Mountain designated as only site to be characterized

Initial investigations to select a potential nuclear waste repository site.

- Nationwide review of geological formations that might be acceptable for high level nuclear waste disposal.
- Preliminary selection of 17 (?) sites that might be acceptable.
- Narrowed down to three sites for detailed geological characterization.

Site selection criteria

- Waste isolation
- Geology
- Hydrology
- Geochemistry
- Rock mechanics

Initial Site Screening for the First Repository (starting in 1976) (DOE, 1984, p. 3-A-9)

Twofold approach:

- systematic survey of areas underlain by salt
- evaluate lands owned by the Department of energy, and dedicated to nuclear activities (Hanford, Washington; Nevada Test Site (Yucca Mountain), Nevada)

GEIS (Generic Environmental Impact Statement) (1978)

Rock Properties, Repository Preconceptual Design Studies, Feasibility and Cost Studies, Thermal and Thermo-mechanical analysis for Salt, Granite, Shale, and Basalt. (Science Applications, Inc., 1978) (23 volumes)

U.S. Nuclear Regulatory Commission (NRC) Site Characterization Information Needs (1985)

(From NRC, 1985)

- Rock types: granite, shale, basalt, tuff, bedded salt, dome salt.
  - Summarizes properties in the literature.
  - Identifies properties/characteristics that need to be identified/defined.

NRC (1985) Information Needs Geomechanics

Precharacterization

- Temperature
- Stress field
- Thermal conductivity and specific heat
- Deformation moduli
- Geometry of discontinuities and inhomogeneities

NRC (1985) Information Needs Geomechanics

Site Characterization

- Detailed survey of discontinuities and inhomogeneities
- Mechanical behavior of host rock at elevated temperatures
- Radiation effects
- Structural stability of the repository

Rock types identified for site selection (1986) (DOE, August 1986, p. 19)

Mined Geological Disposal System

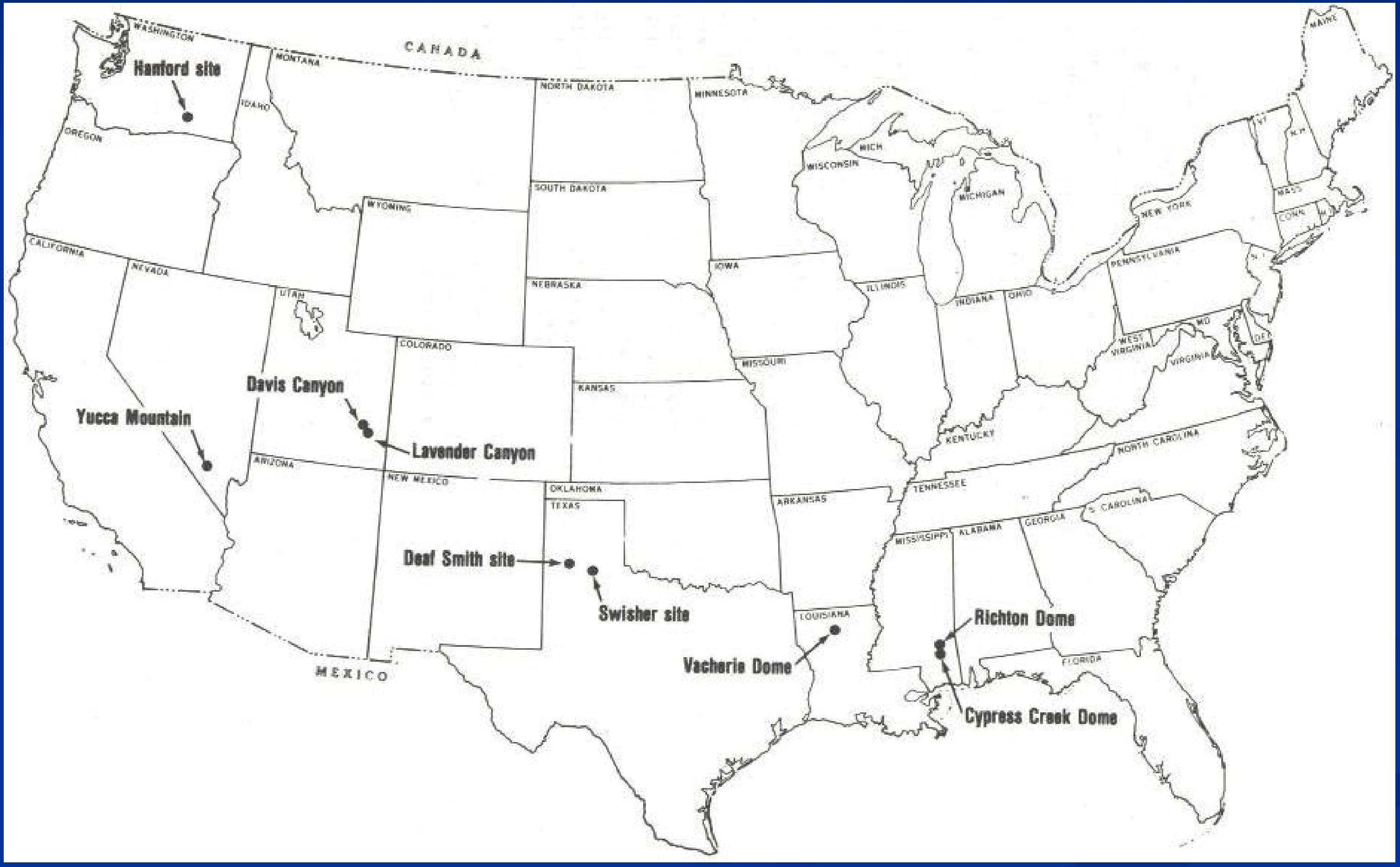
Program Components:

- Basalt
- Tuff
- Salt
- Crystalline

Civilian Radioactive Waste Management Program (1986)

Mined Geological Disposal System (MGDS) will investigate: Basalt, Tuff, Salt, and Crystalline rock. (DOE, 1986, August)

Nine sites selected for early site selection Basalt, tuff, bedded salt (4), salt domes(3)



From DOE, 1984, May, b, p. 2

Selection of three sites for final site characterization

DOE, 1986: preferred sites for site characterization, in order:

1. Yucca Mountain, NV
2. Deaf Smith County, Texas (bedded salt)
3. Hanford, Washington (basalt flows)

(DOE, 1986, May, b)

Five sites investigated to select these three included two (rejected) salt sites: a dome (Richton), and a bedded site (Davis Canyon).

Sites selected for detailed characterization

- Yucca Mountain: ashflow tuffs/volcanic
  - Unsaturated: above the water table
- BWIP: basalt flows (Hanford, Washington)
- Deaf Smith County (Texas): bedded salt

HLW Salt Mechanics Research Examples

- Dome-Salt Thermomechanical Experiments at Avery Island, Louisiana (Van Sambeek, 1981)
- Influence of Specimen Size on the Creep of Rock Salt (Senseny, 1982)

Yucca Mountain designated by U.S. Congress

Decision by congress (December 1987)

→

Strong opposition by the State of Nevada

Location

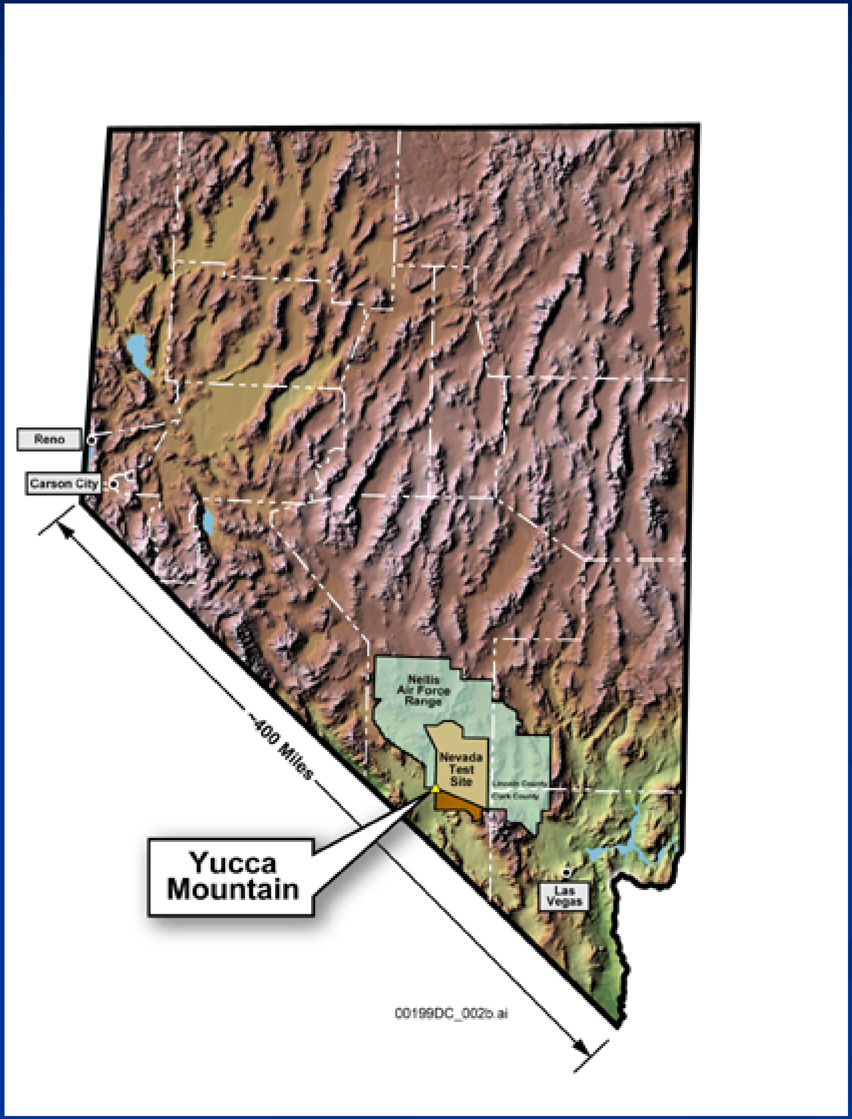
Yucca Mountain location

From OCRWM web page

Yucca Mountain: western edge of (Nevada) Test Site

From OCRWM web page

Location: 100 km SW of Las Vegas



From OCRWM web page


Yucca Mountain

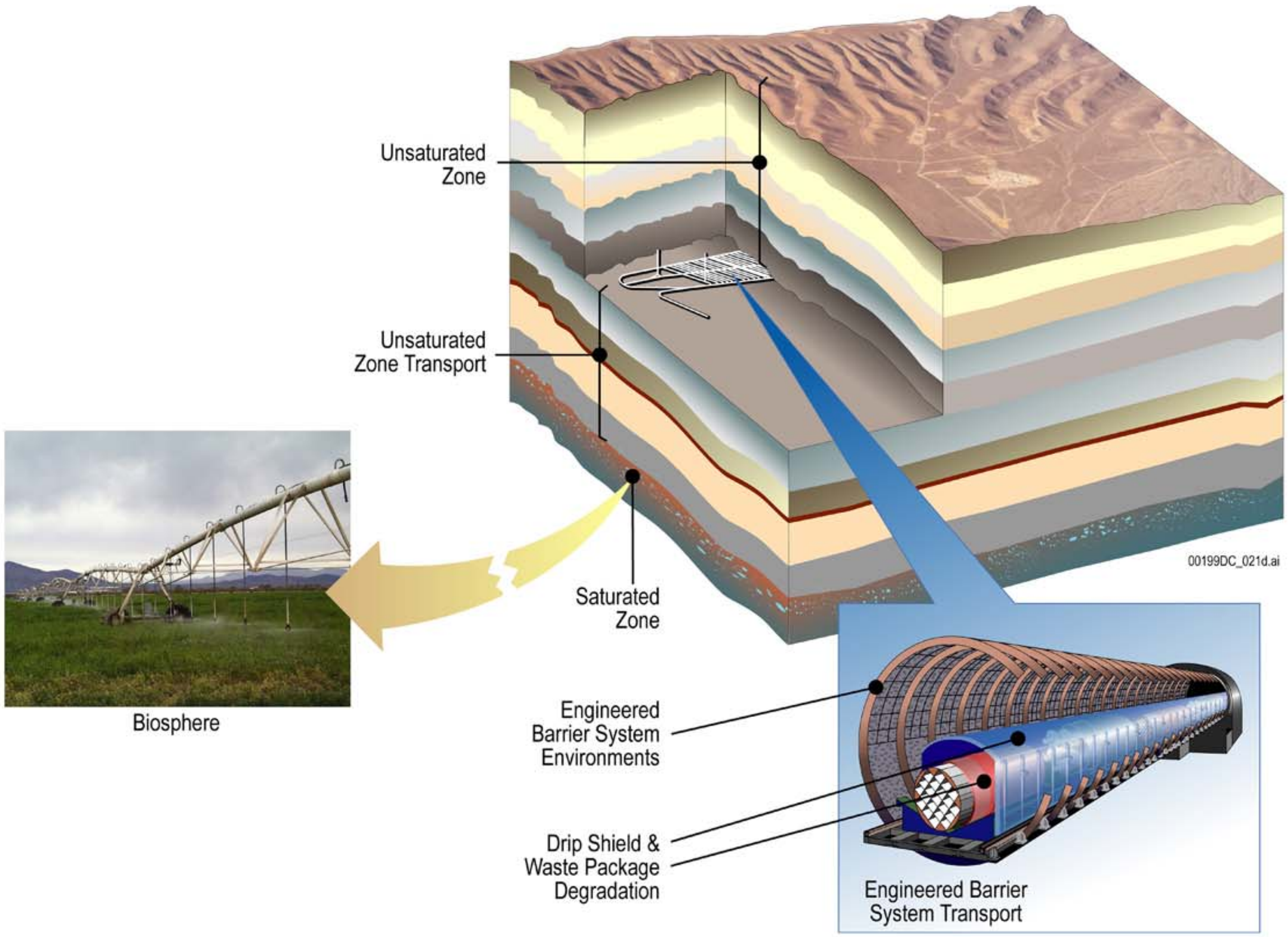
Aerial view of north end of the Yucca Mountain crest

From OCRWM web page

Regulatory/legal context

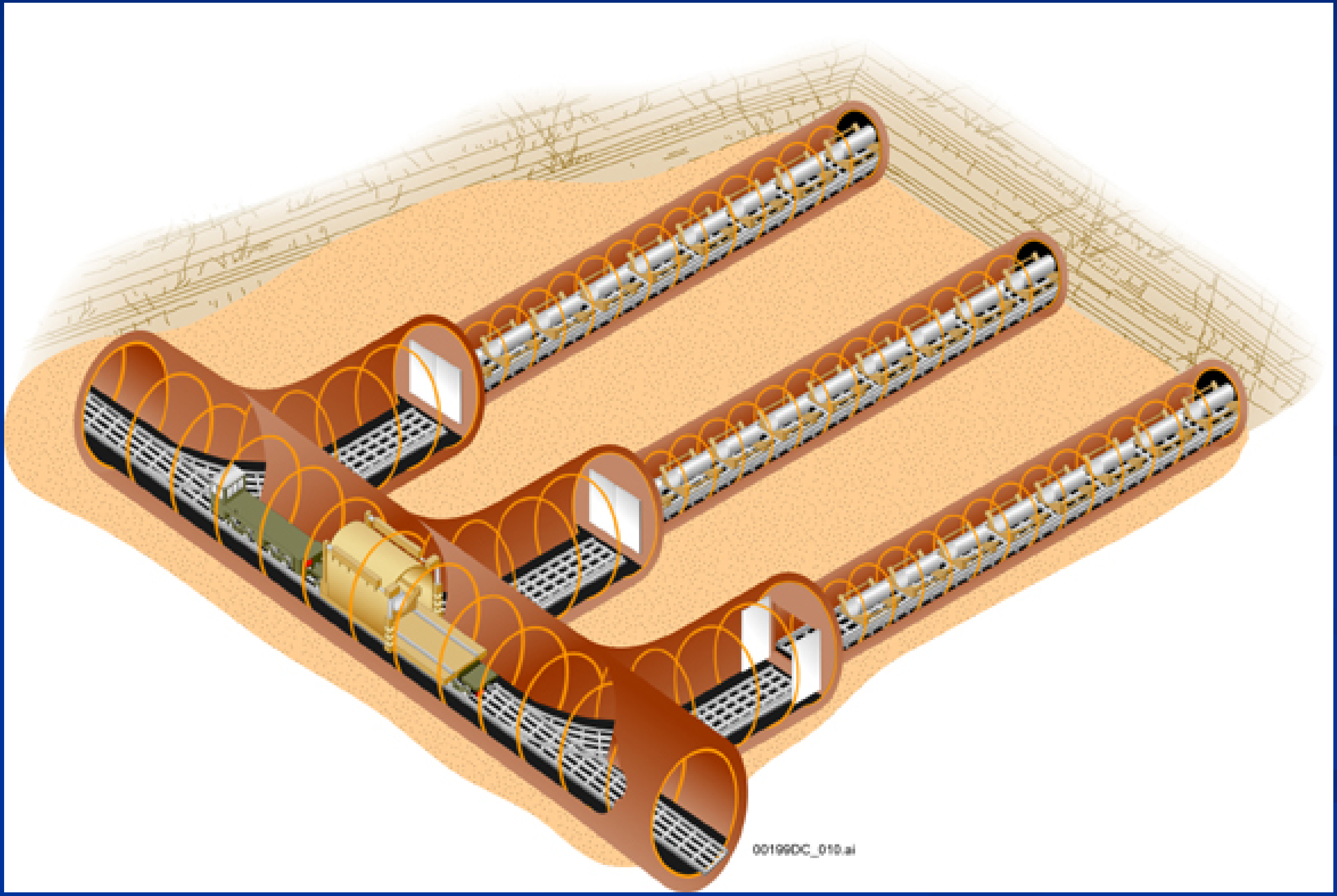
- Operator, designer, builder, owner: DOE (U.S. Department of Energy)

  OCRWM (Office of Civilian Radioactive Waste Management)
- Environmental standards set by: EPA (U.S. Environmental Protection Agency)
- Licensed by: NRC (U.S. Nuclear Regulatory Commission)
- Reviewed by NWTRB (Nuclear Waste Technical Review Board)
- Interactions with numerous stakeholders,e.g. state(s), Indian tribes, utilities, environmental groups, etc..



Unsaturated Zone
Unsaturated Zone Transport
Saturated Zone
00199DC_021d.ai
Biosphere
Engineered Barrier System Environments
Drip Shield & Waste Package Degradation
Engineered Barrier System Transport

The repository would be a series of emplacement drifts where waste packages would be emplaced and monitored.



From OCRWM web page

Waste emplacement configuration

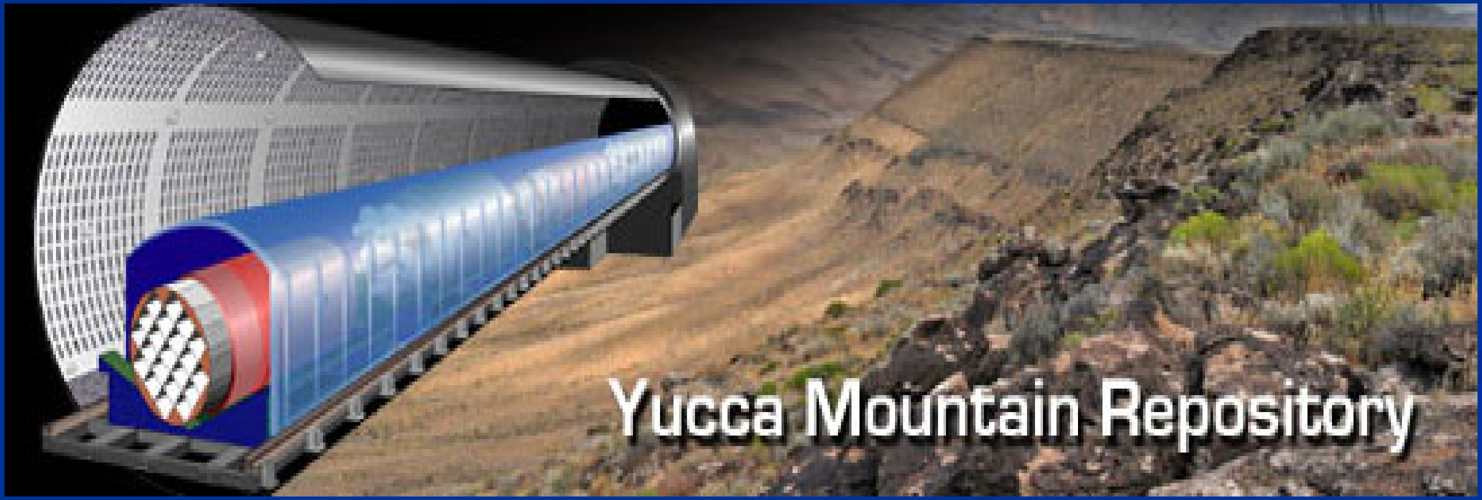
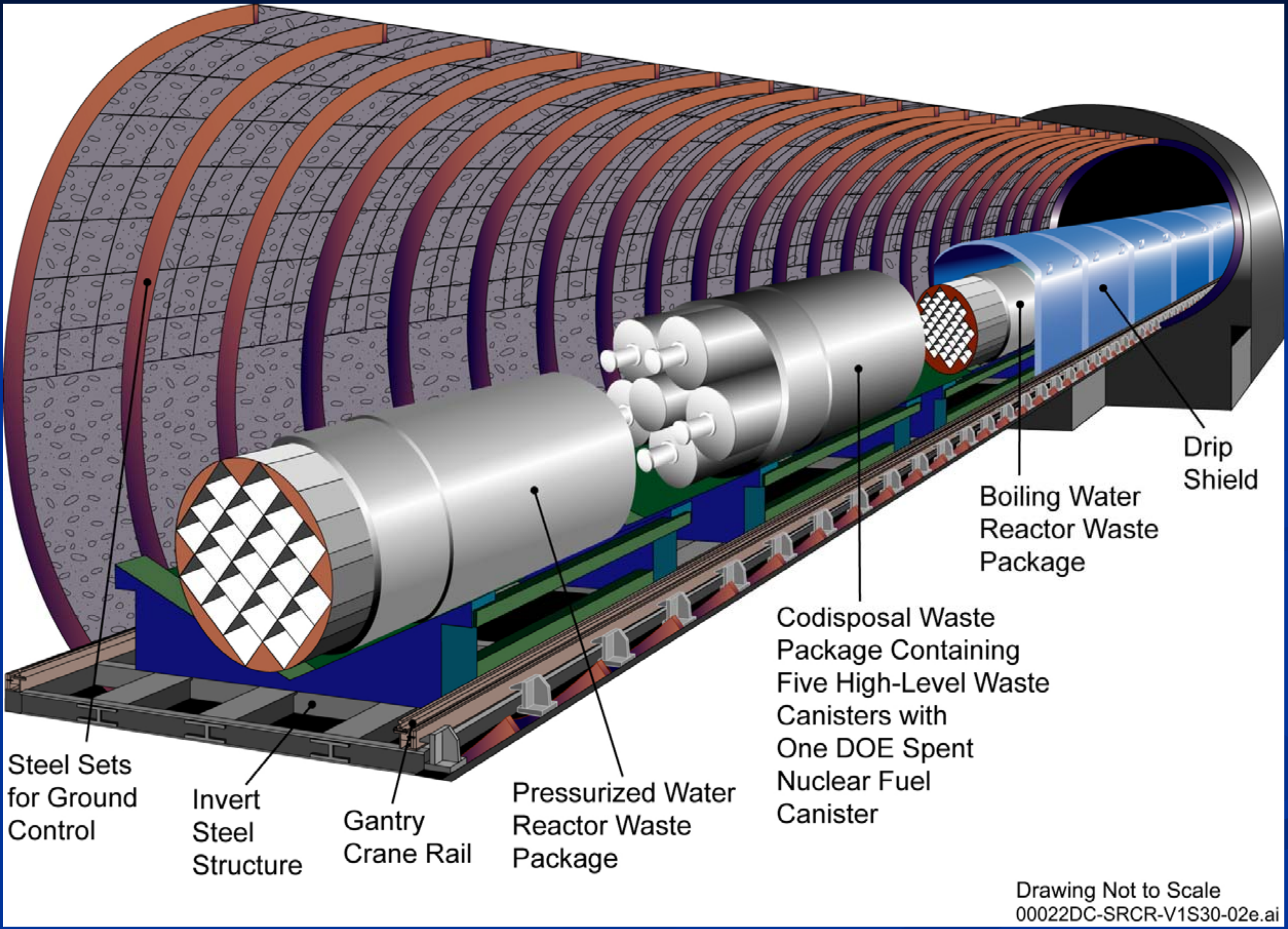
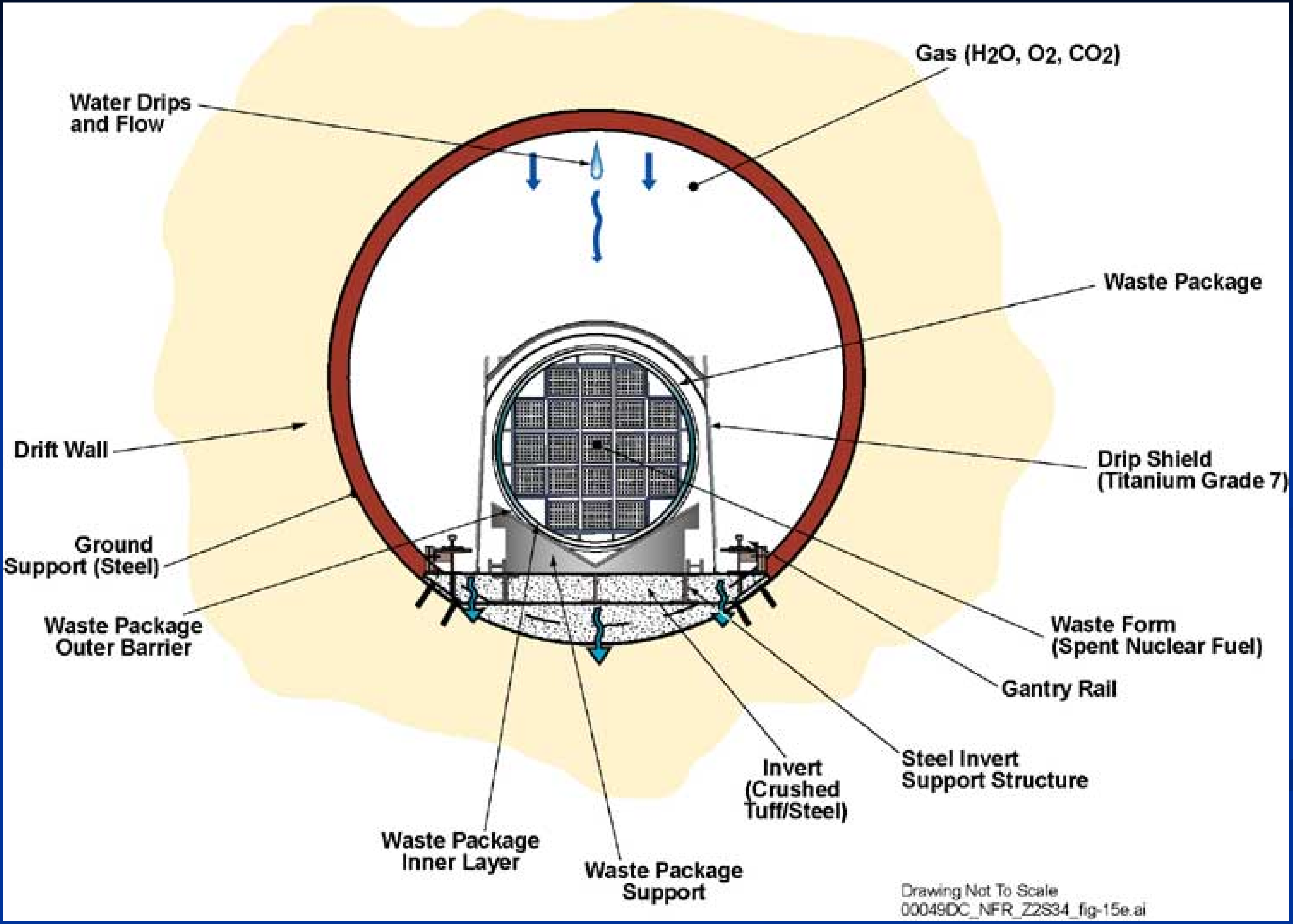


Photo from OCRWM web page


Steel Sets for Ground Control
Invert Steel Structure
Gantry Crane Rail
Pressurized Water Reactor Waste Package
Codisposal Waste Package Containing Five High-Level Waste Canisters with One DOE Spent Nuclear Fuel Canister
Boiling Water Reactor Waste Package
Drip Shield
Drawing Not to Scale
00022DC-SRCR-V1S30-02e.ai


Gas (H_2O, O_2, CO_2)
Water Drips and Flow
Waste Package
Drift Wall
Drip Shield (Titanium Grade 7)
Ground Support (Steel)
Waste Package Outer Barrier
Waste Form (Spent Nuclear Fuel)
Gantry Rail
Invert (Crushed Tuff/Steel)
Steel Invert Support Structure
Waste Package Inner Layer
Waste Package Support
Drawing Not To Scale
00049DC_NFR_Z2S34_fig-15e.ai

Example of "early" (1980's) rock mechanics investigations

Summary of Geomechanical Measurements Taken in and Around the G-Tunnel Underground Facility, NTS (Zimmerman and Finley, 1987)

G-Tunnel Tuffs: description:

- Description of Tuff
- Bulk Physical Properties
- Joint Characterization
- Rock Mass Classification
- Stress measurements: overcoring, hydrofracturing
- Strength: uniaxial compression, shear, tensile
- Deformational properties: Young's modulus and Poisson's ratio

  Laboratory

  Field: borehole jacks; slot tests; block tests (with flatjacks)

  cross hole geophysics

Further examples of early (1980's) rock mechanics studies

An analysis of the G-Tunnel Heated Block Experiment Using a Compliant-Joint Rock-Mass Model (Costin and Chen, 1988)

Continuum 2-D finite element model

Near Field Mechanical Calculations Using a Continuum Jointed Rock Model in the JAC Code (Thomas, 1987)

A Three-Dimensional Model of Reference Thermal/Mechanical and Hydrological Stratigraphy at Yucca Mountain, Southern Nevada (Ortiz et al., 1985)

"The reference stratigraphy defines units with distinct thermal, physical, mechanical, and hydrological properties."

Example of early "rock mechanics" (Mining engineering?) study

- Repository Drilled Hole Methods Study (The Robbins Company, 1984)

  Analysis of technical feasibility and of cost of drilling vertical and horizontal waste canister emplacement holes.

- Feasibility Studies and Conceptual Design for Placing Steel Liner in Long, Horizontal Boreholes for a Prospective Nuclear Waste Repository in Tuff (The Robbins Company, 1985)

Regulatory Review – an example

U.S. Nuclear Regulatory Commission Rock Mechanics Concerns (After NRC, 1989)

- Will site investigations adequately cover the full range of rock characteristics?
- Is there sufficient integration of all site characterization activities (e.g. mapping, drilling, geophysics)?
- Are expected operational conditions addressed in sufficient detail?

Initial site characterization

- Boreholes
- Geological mapping
- Hydrological/geochemical testing
- Rock mechanics: core sample testing
  - Uniaxial compression
  - Density/porosity/water content

Prototype dry-hole drilling operations at Mercury Gold Mine near Salt Lake City, Utah, in May 1989.

Photo from OCRWM web page

Rock mechanics issues

Drift stability

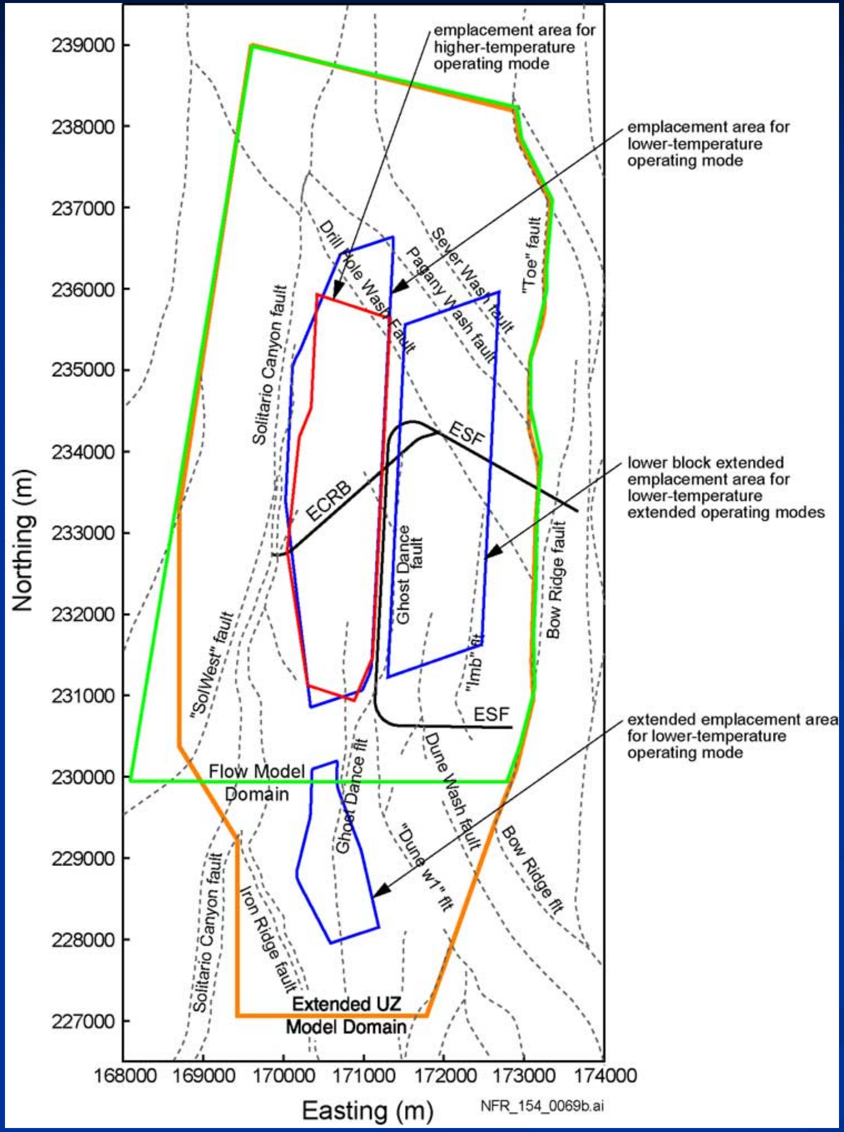
- Retrievability: access needs to be maintained
  - Long term rock strength?
- Waste (drift shield) package loading

Dynamic (earthquake) effects on drift stability

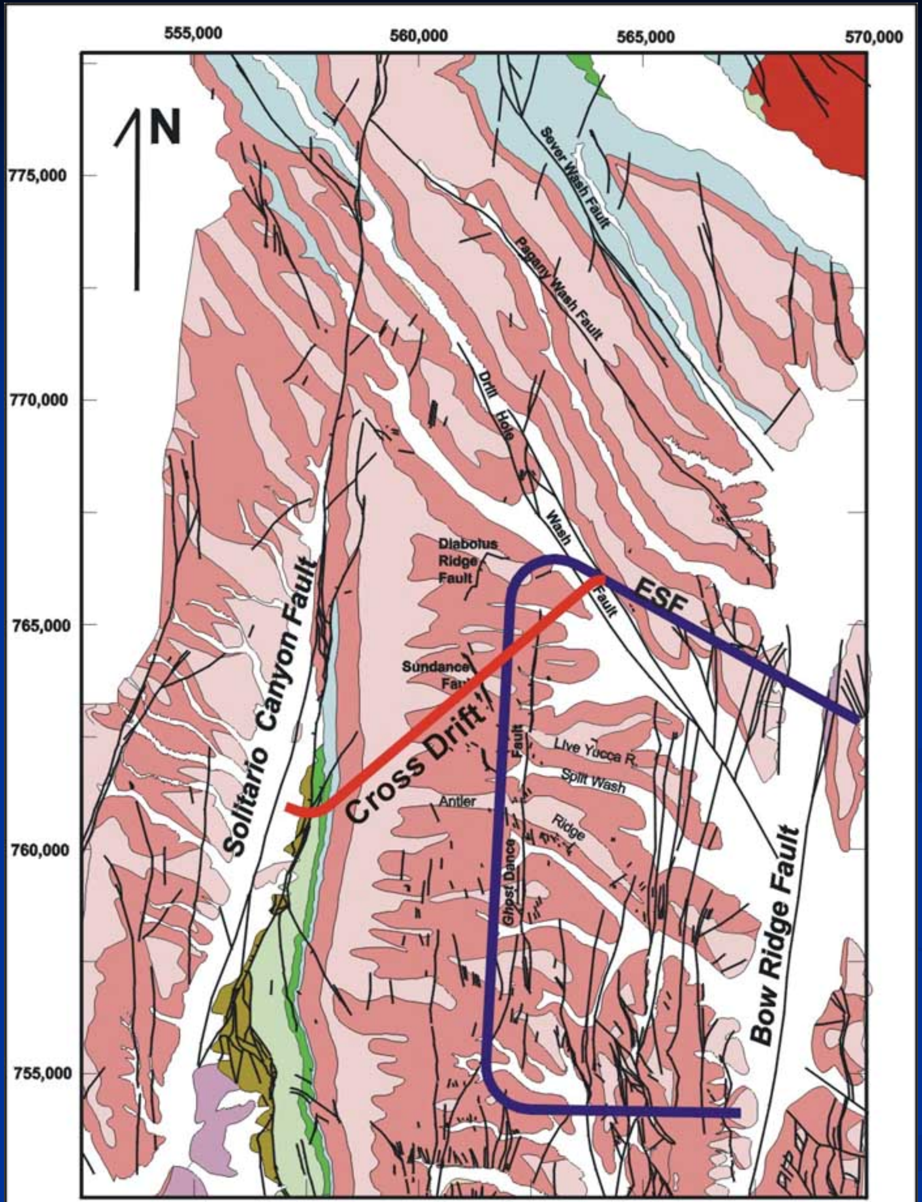
e.g. fault shear?

Technical rock mechanics questions

- Rock strength
  - Effects of heat, moisture content, long term sustained loading
  - Extrapolation from laboratory scale to field scale
- Discontinuity geometry, strength
  - Wedge formation?



emplacement area for higher-temperature operating mode
emplacement area for lower-temperature operating mode
lower block extended emplacement area for lower-temperature extended operating modes
extended emplacement area for lower-temperature operating mode
Northing (m)
Easting (m)
239000
238000
237000
236000
235000
234000
233000
232000
231000
230000
229000
228000
227000
168000
169000
170000
171000
172000
173000
174000
Drill Hole Wash Fault
Sever Wash fault
Pagany Wash fault
"Toe" fault
Solitario Canyon fault
ESF
ECRB
Ghost Dance fault
Bow Ridge fault
"SolWest" fault
"Imb" flt
ESF
Flow Model Domain
Ghost Dance flt
Dune Wash fault
"Dune w1" flt
Bow Ridge flt
Solitario Canyon fault
Iron Ridge fault
Extended UZ Model Domain
NFR_154_0069b.ai



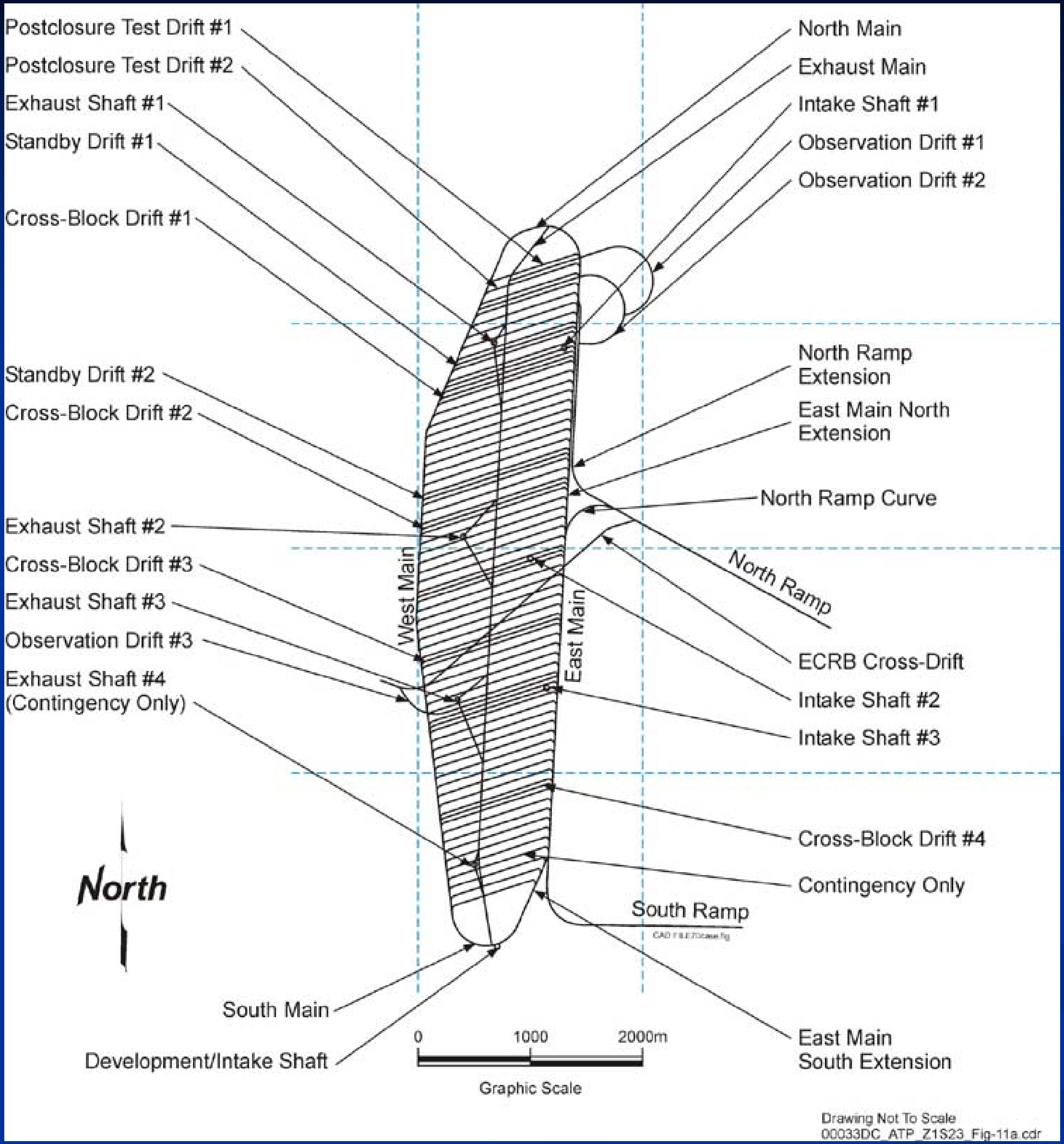
Bedrock Geologic Map of the Central Block
Yucca Mountain, Nevada (Day and others, 1998)

Figure 2. Simplified geologic map of the Yucca Mountain region with plan view of the ESF and the Cross Drift.

From:

GEOLOGY OF THE ECRB CROSS DRIFT - EXPLORATORY STUDIES FACILITY, YUCCA MOUNTAIN PROJECT, YUCCA MOUNTAIN, NEVADA

G.S. Mongano, W.L. Singleton, T.C. Moyer, S.C. Beason, G.L.W. Eatman, A.L. Albin, and R.C. Lung


Postclosure Test Drift #1
Postclosure Test Drift #2
Exhaust Shaft #1
Standby Drift #1
Cross-Block Drift #1
Standby Drift #2
Cross-Block Drift #2
Exhaust Shaft #2
Cross-Block Drift #3
Exhaust Shaft #3
Observation Drift #3
Exhaust Shaft #4
(Contingency Only)
North
South Main
Development/Intake Shaft
North Main
Exhaust Main
Intake Shaft #1
Observation Drift #1
Observation Drift #2
North Ramp
Extension
East Main North
Extension
North Ramp Curve
North Ramp
ECRB Cross-Drift
Intake Shaft #2
Intake Shaft #3
Cross-Block Drift #4
Contingency Only
South Ramp
East Main
South Extension
West Main
East Main
0
1000
2000m
Graphic Scale
Drawing Not To Scale
00033DC_ATP_Z1S23_Fig-11a.cdr

Tunnel boring machine cutter head at the South Portal in April 1997.

Photo from OCRWM web page

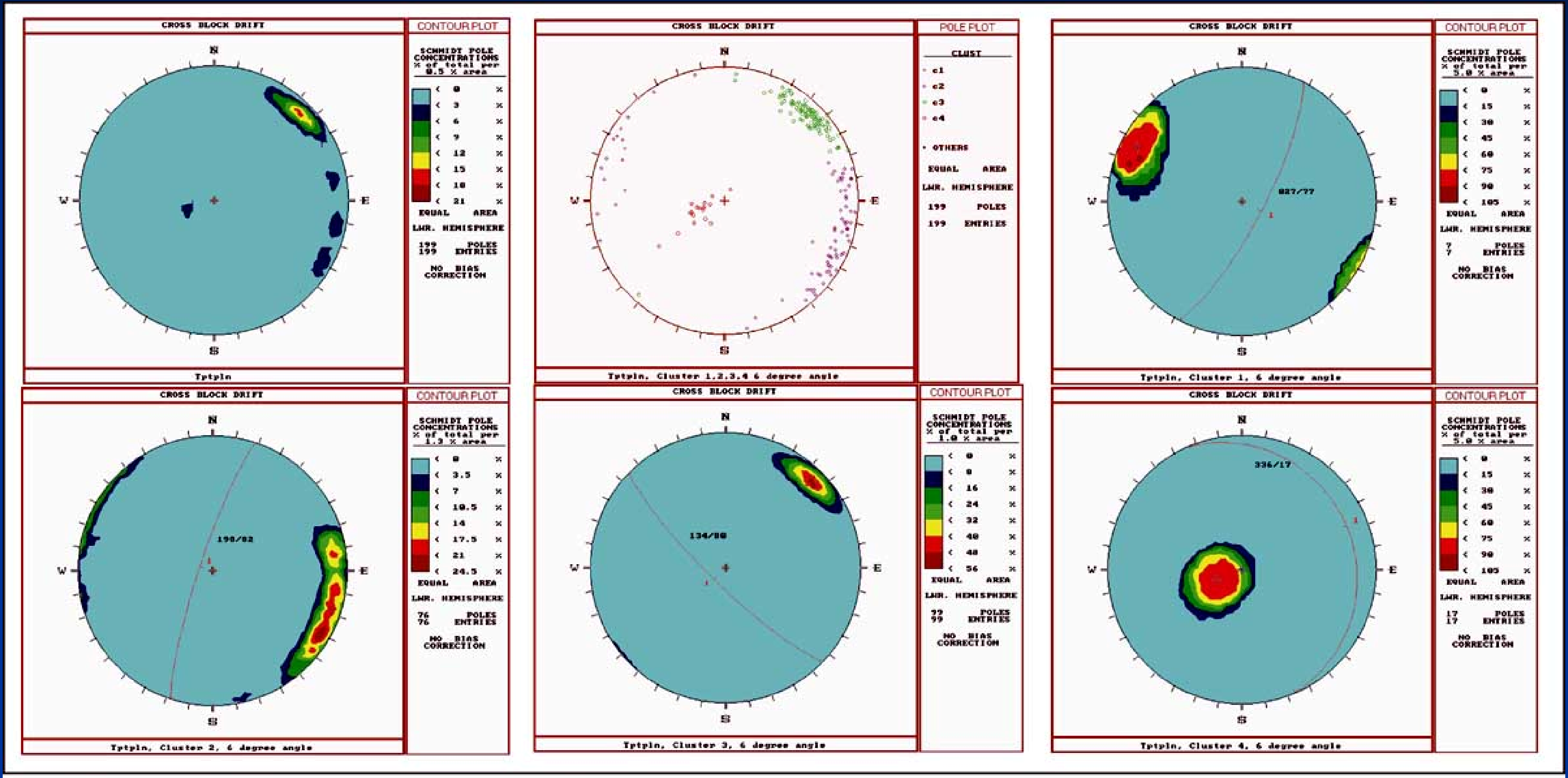


Figure 12. Tptpln contour plot of all fractures compared with pole plot (each cluster with a unique symbol), and contour plots for each cluster.

From:

GEOLOGY OF THE ECRB CROSS DRIFT - EXPLORATORY STUDIES FACILITY, YUCCA MOUNTAIN PROJECT, YUCCA MOUNTAIN, NEVADA
G.S. Mongano, W.L. Singleton, T.C. Moyer, S.C. Beason, G.L.W. Eatman, A.L. Albin, and R.C. Lung

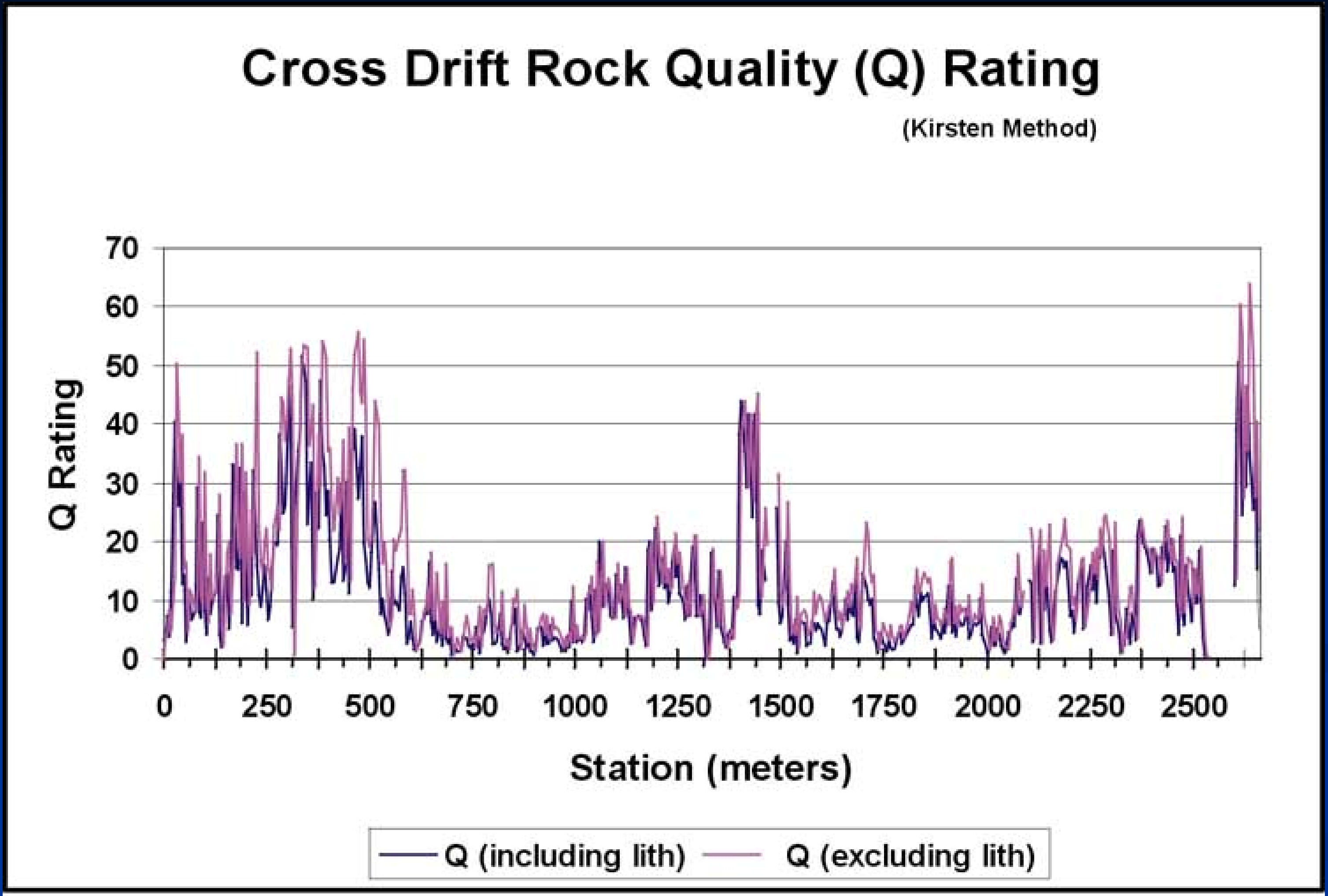


Figure 27. Q ratings, including and excluding, lithophysae for the Cross Drift against stationing.

From:

GEOLOGY OF THE ECRB CROSS DRIFT - EXPLORATORY STUDIES FACILITY, YUCCA MOUNTAIN PROJECT, YUCCA MOUNTAIN, NEVADA

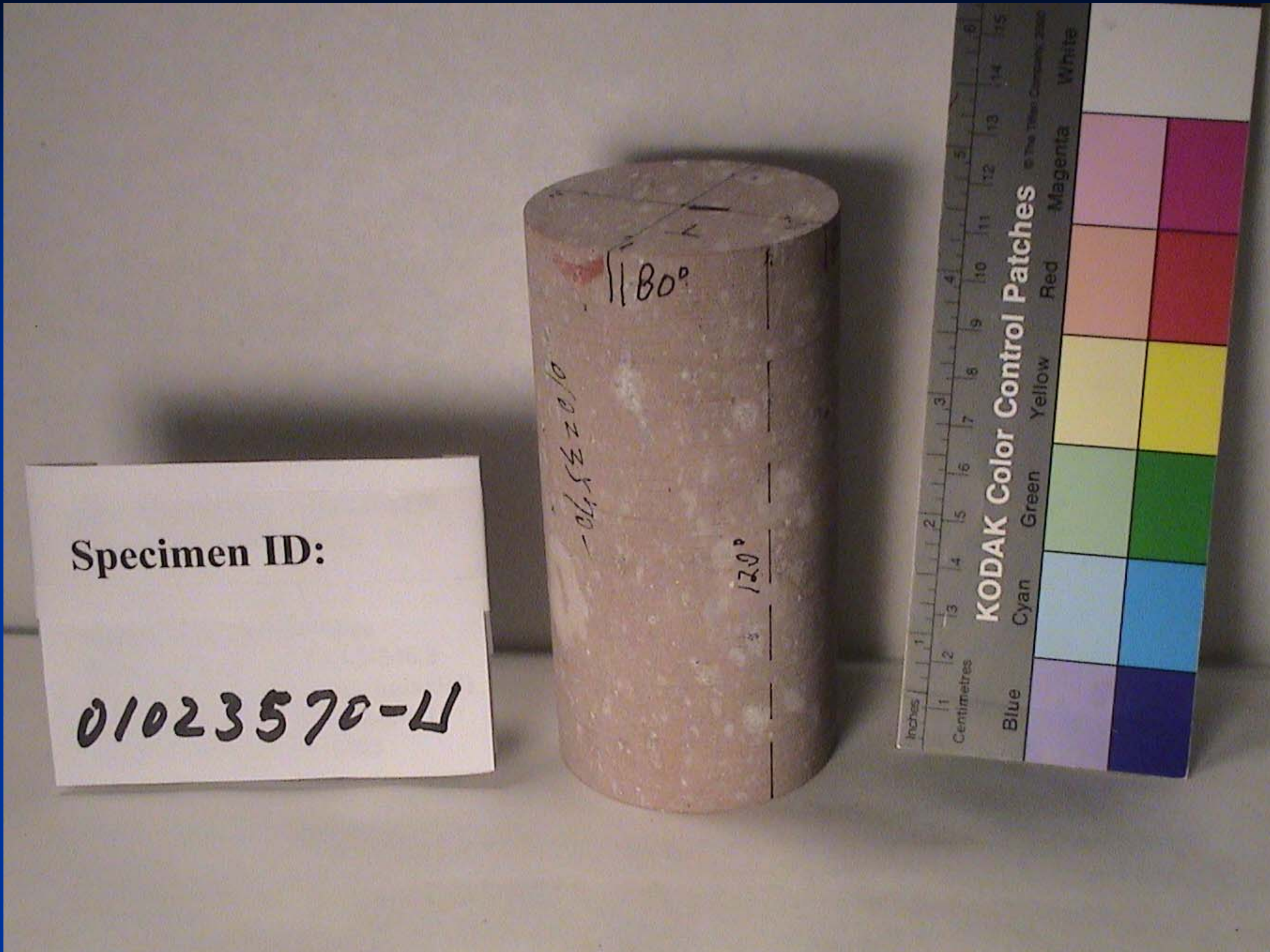
G.S. Mongano, W.L. Singleton, T.C. Moyer, S.C. Beason, G.L.W. Eatman, A.L. Albin, and R.C. Lung

Rock mechanics testing

- Laboratory
- Small scale (in borehole) field tests
- Large scale field tests
  - Block tests
  - Plate bearing tests
  - Heater tests
  - Large scale heated room tests

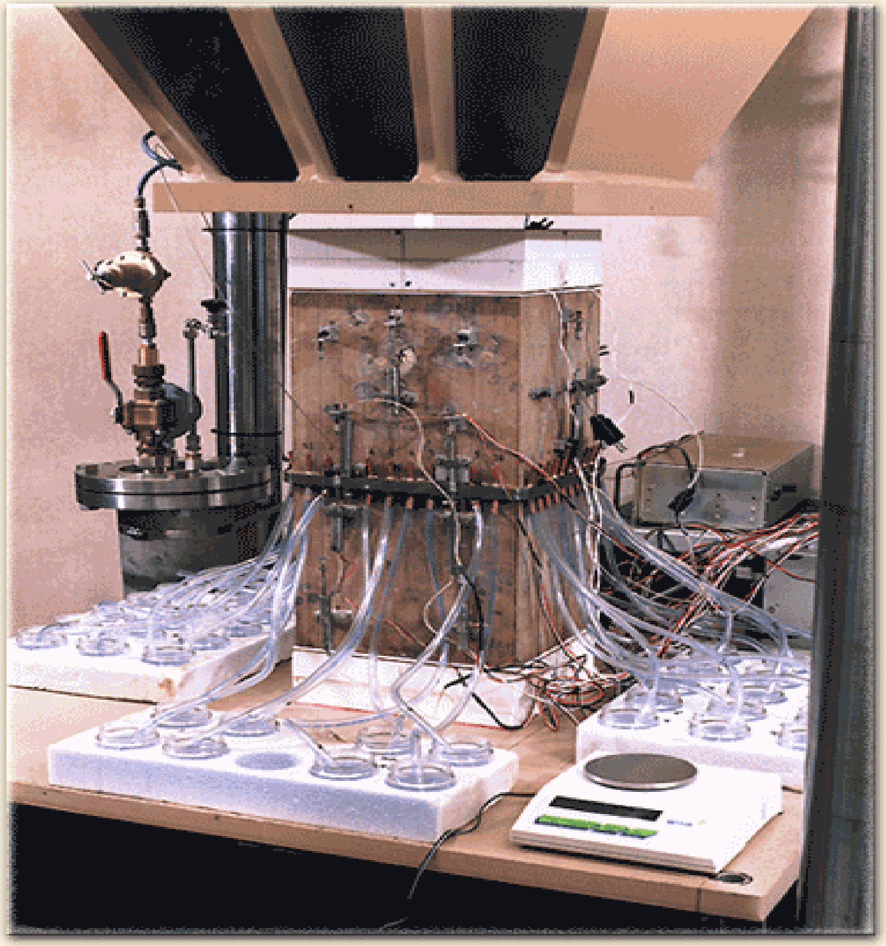

Specimen ID:
01014759-U
0
KODAK Color Control Patches
Kodak


Specimen ID:
01014979-4
270°
KODAK Color Control Patches


Specimen ID:
01023570-U
KODAK Color Control Patches
Blue
Cyan
Green
Yellow
Red
Magenta
White
Inches
Centimetres

Tuff samples
Left and right: nonlithophysal, welded
Center: lithophysal

Laboratory heated block test



Heating tests help scientists predict rock's behavior

Photo from OCRWM web page

Sawing operation at the large block experiment on Fran Ridge in January 1994

Photo from OCRWM web page; technical description of test: e.g. Lin et al, 1994

Installation of heat exchanger for large block test at Fran Ridge in January 1997.

Photo from OCRWM web page; for test description, e.g. see Lin et al, 1994.

Single heater assembly installation in the single heater test, July 1996.

Photo from OCRWM web page

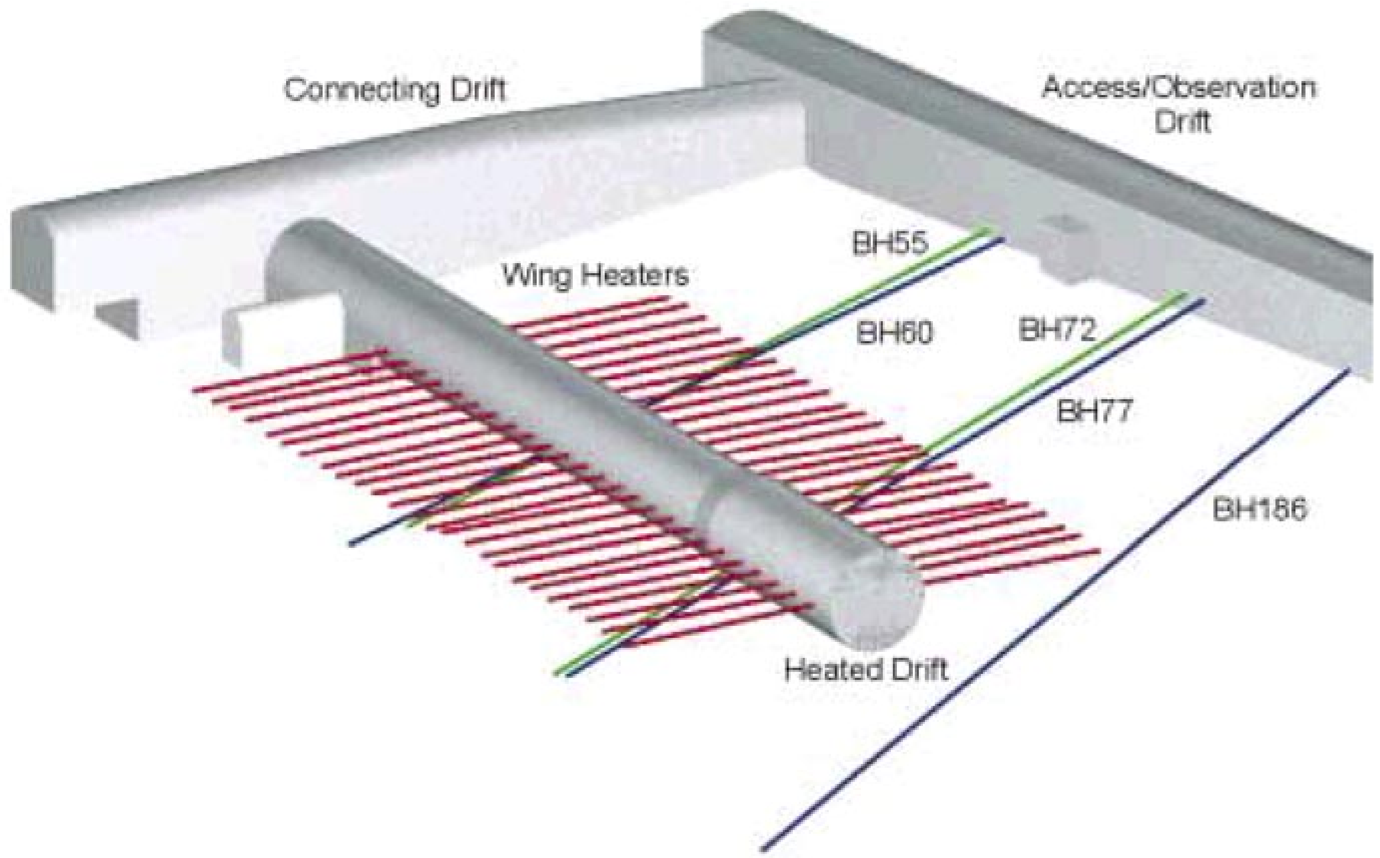


Figure 1. 3-Dimensional view of the Drift Scale Test showing the hydrology boreholes (blue) that contain Viton™ packers, wing heater boreholes (red), and SEAMIST™ holes (green).

Interior view of the drift scale test. This experiment is designed to determine how heat would affect the rock in a potential repository

From OCRWM web page

Ground support / rock reinforcement Longevity/durability/corrosion

Stainless steel rock bolts, steel sets, straps?

(e.g. Shaffer et al, 1994)

Research, e.g. Prof Dhanesh Chandra (University of Nevada, Reno)(Numerous publications in corrosion research journals, conferences, etc…)

Seismic Drift Stability

Yucca Mountain: earthquake prone

Seismically active

→ extensive seismic stability investigations

(e.g. Marine et al, 1982; Damjanac e al, 2007)

Yucca Mountain time frame

- License application: 2008
- License granted (or denied?): 2012
- Start receiving waste: 2017 (??)

Site selection Summary

1. Project "Salt Vault"
2. Broader rock type investigations:
   granite, basalt, shale, tuff
   bedded and domal salt
3. Nine sites
4. Five sites
5. One site: Yucca Mountain

Yucca Mountain Rock Mechanics Summary

- Site characterization: boreholes, geophysics, mapping
- Rock testing: laboratory tests on core
- Stress measurements
- Rock testing: laboratory: large core, blocks
- Field testing: blocks, boreholes, plate
- Drift monitoring
- Drift scale tests

Rock Mechanics for Yucca Mtn Reviews - Summary

- U.S. Nuclear Regulatory Commission (NRC)
  CNWRA (Center for Nuclear Waste Regulatory Analysis)
- NWTRB (Nuclear Waste Technical Review Board)
- State of Nevada
- EPRI (Electric Power Research Institute)

References

Costin, L.S. and E.P. Chen, 1988, An Analysis of the G-tunnel Heated Block Experiment using a Compliant-Joint Rock-Mass Model, Sandia Report, SAND87-1938C·UC-70, Sandia National Laboratories, Albuquerque, NM.*

Damjanac, B., M. Board, M. Lin, D. Kicker, J. Leem, 2007, Mechanical degradation of emplacement drifts a Yucca Mountain – A modeling case study Part II: Lithophysal rock, International Journal of Rock Mechanics and Mining Sciences, Vol. 44, pp. 368-399.

DOE, 1984, April, Mission Plan for the Civilian Radioactive Waste Management Program, DOE/RW-0005 DRAFT, Volume I of II, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, DC*.

DOE, 1986, May,a, Recommendation By The Secretary of Energy of Candidate Sites for Site Characterization For the First Radioactive-Waste Repository, DOE/S-0048, U.S. Department of Energy, Washington, D.C., office of Nuclear Waste Isolation. Available from National Technical Information Service, U.S. Department of Commerce.

DOE, 1986, May, b, Environmental Overview, Yucca Mountain Site, Nevada Research and Development Area, Nevada, DOE/RW-0079, Washington, D.C.

DOE, 1986, August, Systems Engineering Management Plan for the Salt Repository Project, DOE/CH-1, Office of Civilian Radioactive Waste Management, Salt Repository Project Office, Columbus, OH. Available from National Technical Information Service, U.S. Department of Commerce.

Lin, W., D.G. Wilder, J.A. Blink, S.C. Blair, T.A. Buscheck, D.A. Chesnut, W.E. Glassley, K. Lee, and J.J. Roberts, 1994, The Testing of Thermal-Mechanical-Hydrological-Chemical Processes Using a Large Block, pp. 1938-45, Vol. 4, High Level Radioactive Waste Management, Proceedings of the Fifth Annual International Conference, Las Vegas, NV, American Nuclear Society, Inc. La Grange Park, Il. And American Society opf Civil Engineers, New York, New York

Marine, I. Wendell, Howard R. Pratt, and Krishan Wahi, 1982, Seismic Effects on Underground Openings, pp. 179 – 206, The Technology of High-Level Nuclear Waste Disposal, Vol. 2, Peter L. Hofmann, Editor, U.S. Department of Energy, Technical Information Center.

*Many of these reports have been summarized in publications that are readily and widely available, e.g. in US rock mechanics symposia, journals, etc…

References (Contin.)

NRC, 1985, May, Information Needs for Characterization of High-Level Waste Repository Sites in Six Geological Media, U.S. Nuclear Regulatory Commission Report NUREG/CR-2663, Washington, D.C.

NRC Staff, 1989, Site Characterization Analysis of the Department of Energy's Site Characterization Plan, Yucca Mountain Site, Nevada, NUREG-1347, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Washington, D.C.

Ortiz, Terri S., Robert L. Williams, Francis B. Nimick, Bruce C. Whittet, Don L. South, 1985, A three-Dimensional Model of Reference "Thermal/mechanical and Hydrological Stratigraphy at Yucca Mountain, Southern Nevada, Report SAND84-1076, Sandia National Laboratories, Albuquerque, New Mexico.

The Robbins Company, 1985, Feasibility Studies and Conceptual Design for Placing Steel Liner in Long, Horizontal Boreholes for a Prospective Nuclear Waste Repository in Tuff, Contractor Report SAND84-7209, Sandia National Laboratories, Albuquerque, NM.

The Robbins Company, 1984, Repository Drilled Hole Methods Study, Contractor Report SAND84-7085, Sandia National Laboratories, Albuquerque, NM.

Science Applications, Inc., 1978, Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, Volume 1: Executive Summary, Y/OWI/TM-36/1, Oak Ridge, Tennessee. Available from National Technical Information Service, U.S. Department of Commerce.

Senseny, Paul E, 1982, Influence of Specimen Size on the Creep of Rock Salt, pp. 165-178, The Technology of High-Level Nuclear Waste Disposal, Vol. 2, Peter L. Hofmann, Editor, U.S. Department of Energy, Available from National Technical Information Service, U.S. Department of Commerce.

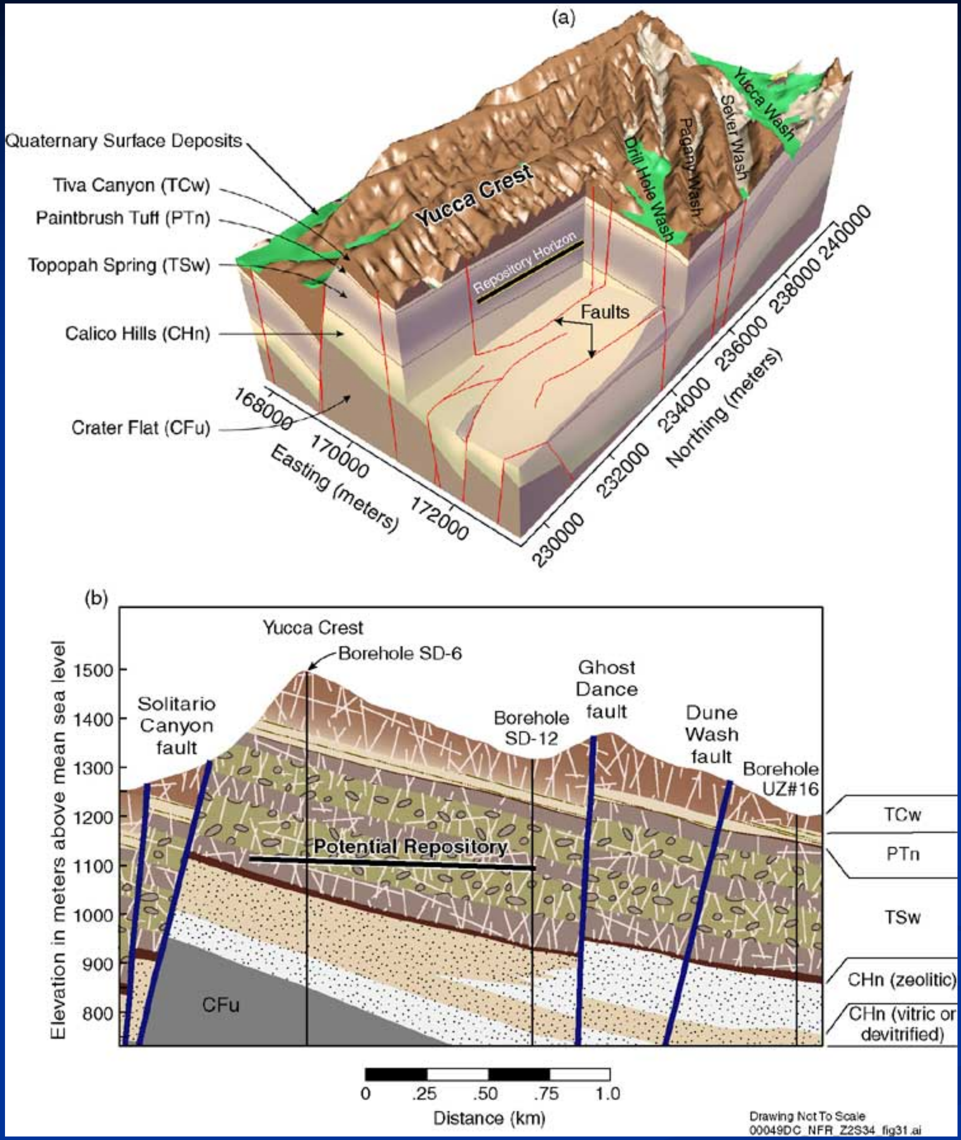
Shaffer, Thomas F., R. Winston Revic, and Anita Mandal, 1994, Long Term Ground Support with Stainless Steel and Nickel Alloy Rock Bolts, pp. 696 – 704,. Vol. 2, High Level Radioactive Waste Management, Proceedings of the Fifth Annual International Conference, Las Vegas, NV, American Nuclear Society, Inc. La Grange Park, Il. and American Society of Civil Engineers, New York, New York

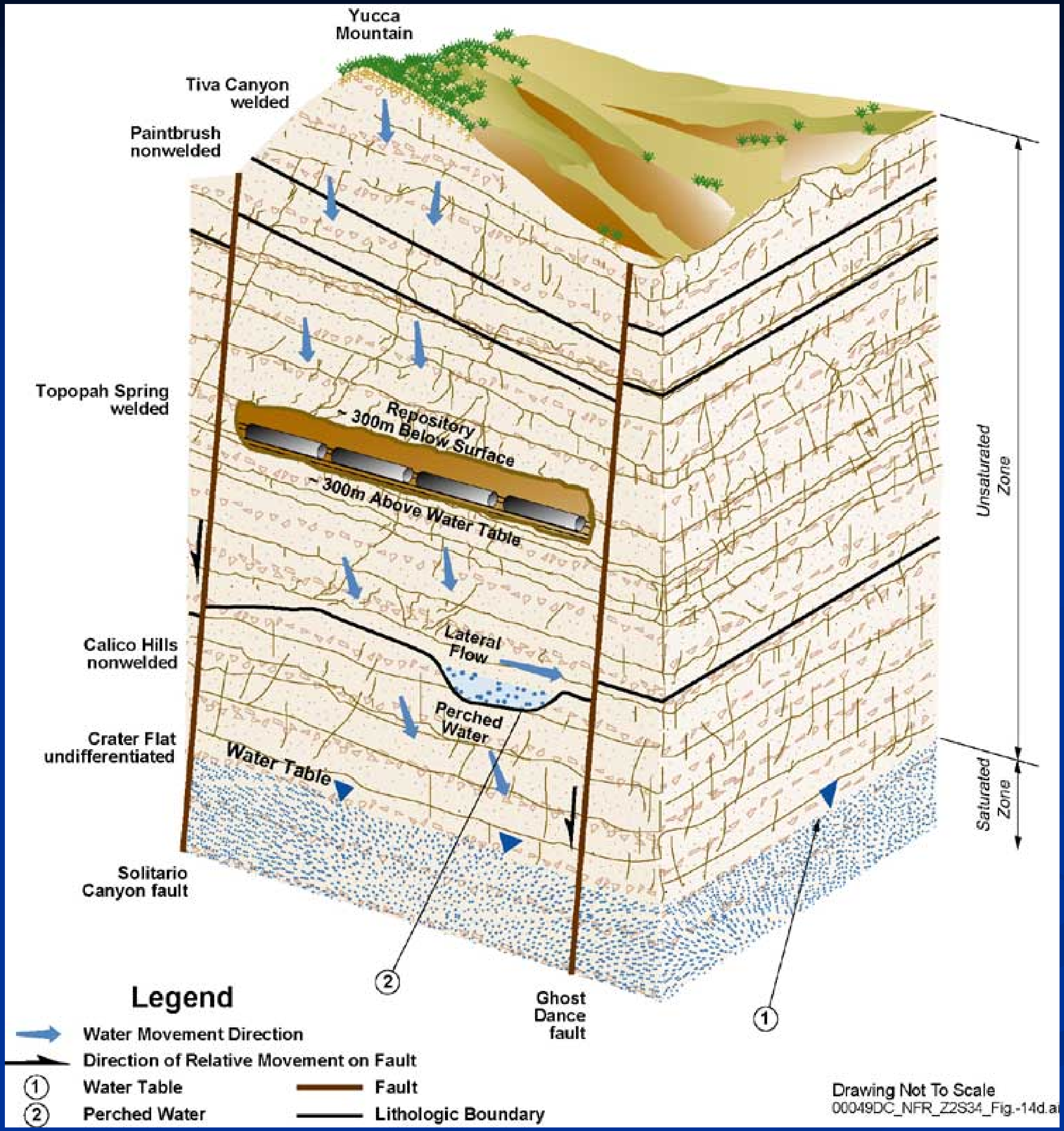
Thomas, Robert K., 1987, Near Field Mechanical Calculations Using a Continuum Jointed Rock Model in the JAC Code, Sandia Report SAND83-0070·UC-70, Sandia National Laboratories, Albuquerque, NM.

Zimmerman, Roger M. and Ray E. Finley, 1987, Summary of Geomechanical Measurements Taken in and Around G-Tunnel Underground Facility, NTS, Sandia Report SAND86-1015·UC-70, Sandia National Laboratories, Albuquerque, NM*.

Location


State of Nevada
NYE
NELLIS
AIR FORCE
RANGE
NV TEST SITE
YUCCA MOUNTAIN
Yucca Mountain lies within the Nevada Test Site. The Nevada Test Site is in Nye County, Nevada.


(a)
Quaternary Surface Deposits
Tiva Canyon (TCw)
Paintbrush Tuff (PTn)
Topopah Spring (TSw)
Calico Hills (CHn)
Crater Flat (CFu)
Yucca Crest
Repository Horizon
Faults
Drill Hole Wash
Pagany Wash
Sever Wash
Yucca Wash
168000
170000
172000
Easting (meters)
230000
232000
234000
236000
238000
240000
Northing (meters)
(b)
Yucca Crest
Borehole SD-6
Solitario Canyon fault
Borehole SD-12
Ghost Dance fault
Dune Wash fault
Borehole UZ#16
Potential Repository
CFu
Elevation in meters above mean sea level
1500
1400
1300
1200
1100
1000
900
800
TCw
PTn
TSw
CHn (zeolitic)
CHn (vitric or devitrified)
0 .25 .50 .75 1.0
Distance (km)
Drawing Not To Scale
00049DC_NFR_Z2S34_fig31.ai


Yucca Mountain
Tiva Canyon welded
Paintbrush nonwelded
Topopah Spring welded
Repository ~ 300m Below Surface
~ 300m Above Water Table
Calico Hills nonwelded
Lateral Flow
Perched Water
Crater Flat undifferentiated
Water Table
Solitario Canyon fault
Ghost Dance fault
Unsaturated Zone
Saturated Zone
Legend
Water Movement Direction
Direction of Relative Movement on Fault
1 Water Table
2 Perched Water
Fault
Lithologic Boundary
Drawing Not To Scale
00049DC_NFR_Z2S34_Fig.-14d.ai