13th NAWG Workshop

(Nagoya Univ)

Session: Long-term repository site stability

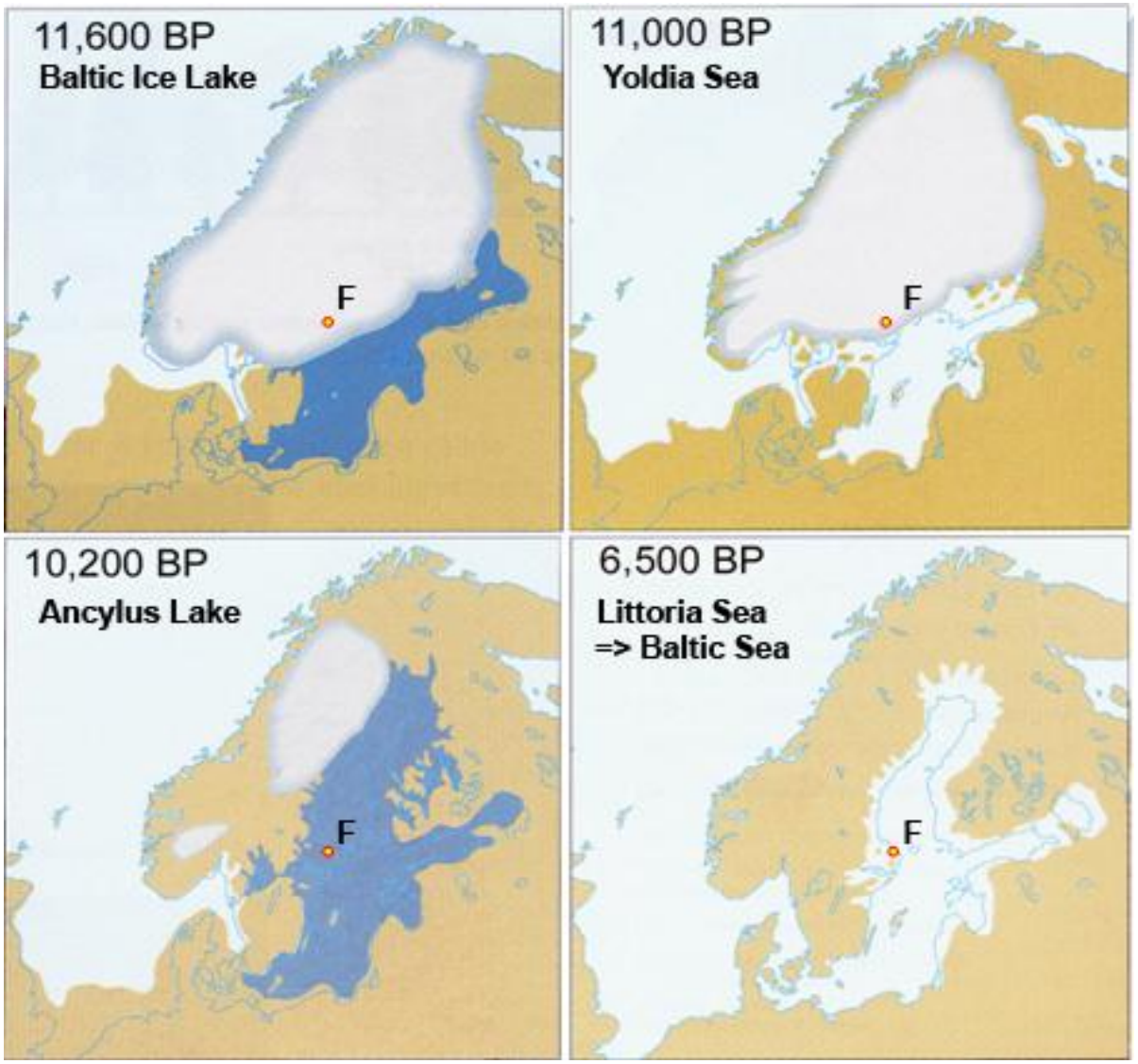
Palaeohydrogeology in coastal systems: Sea of Japan project: a case study

Kenji Amano (JAEA, Japan)

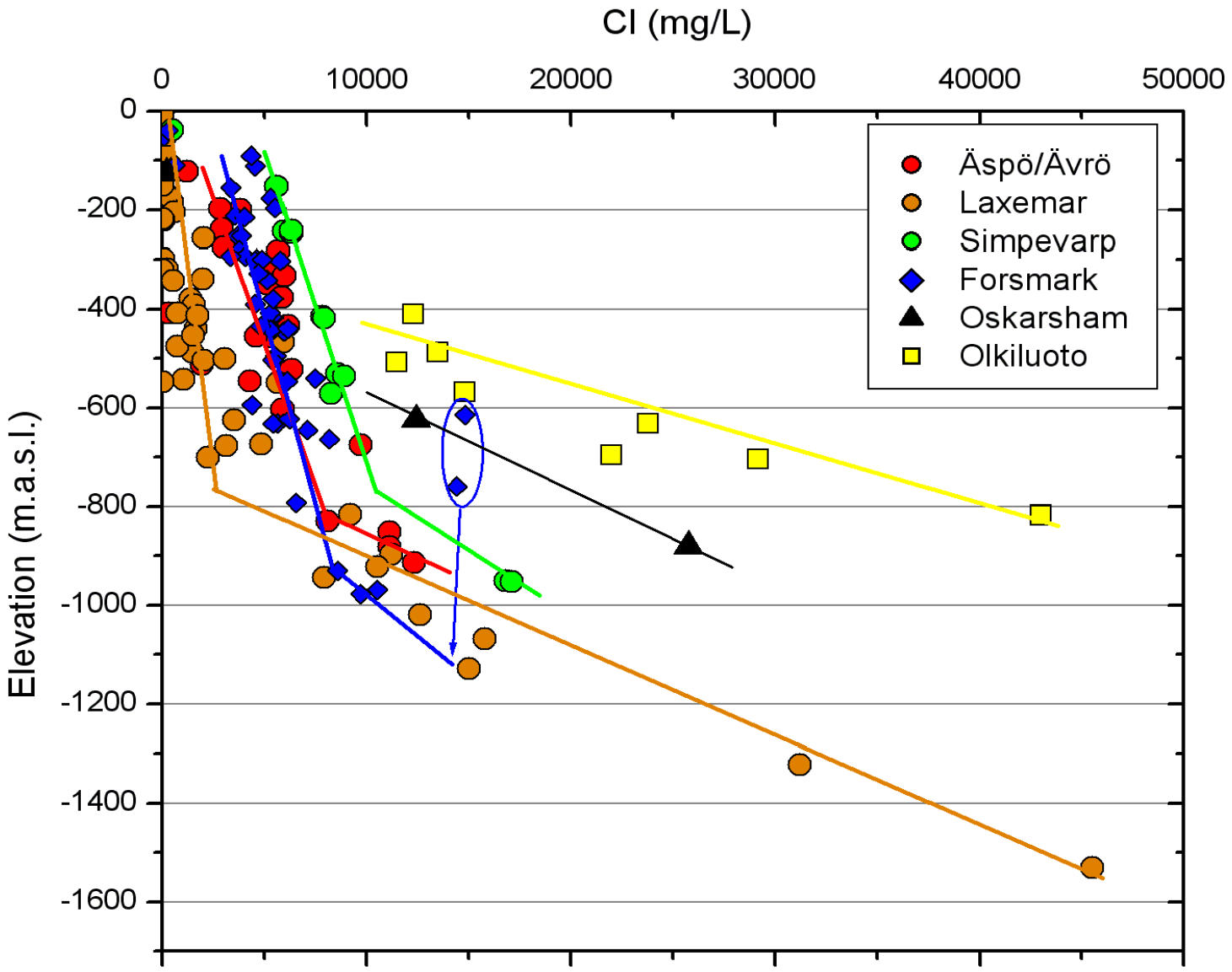
Bill Lanyon (Nagra, Switzerland - Fracture Systems, UK)

W.Russell Alexander (Bedrock Geosciences, Switzerland)

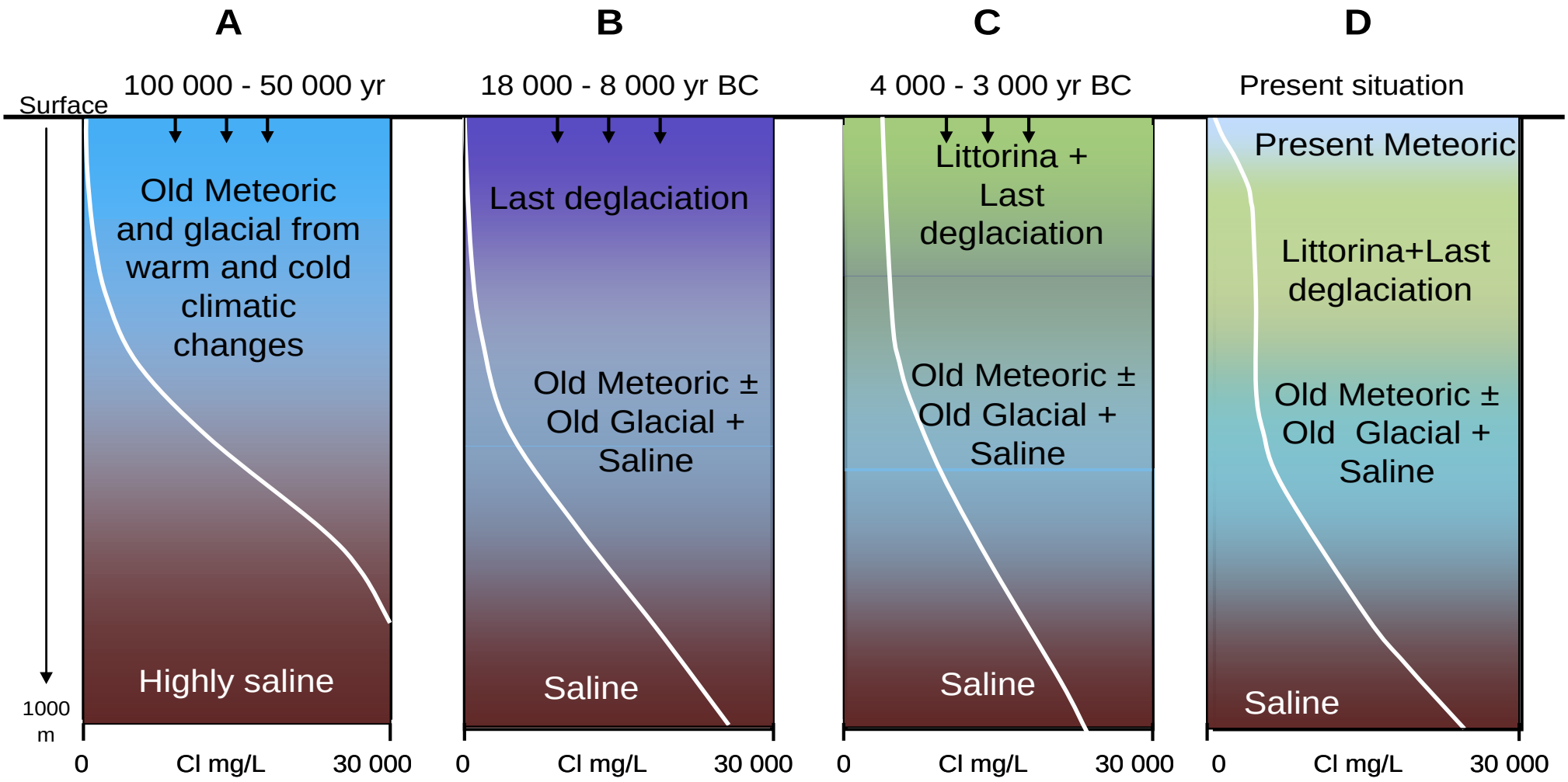
Fennoscandian Shield



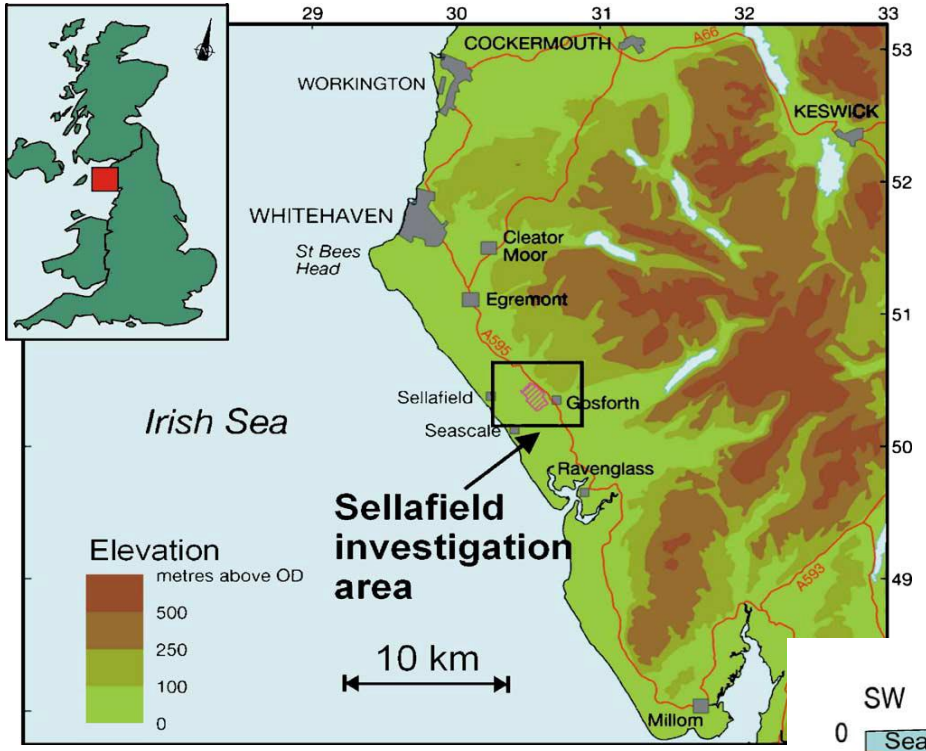
Fennoscandian Shield



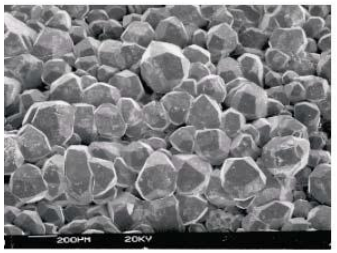
Fennoscandian Shield - evolution



Sellafield

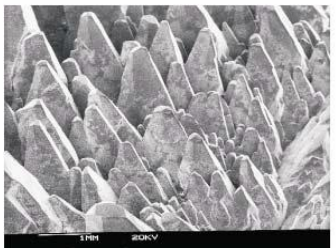


Shallow freshwater zone

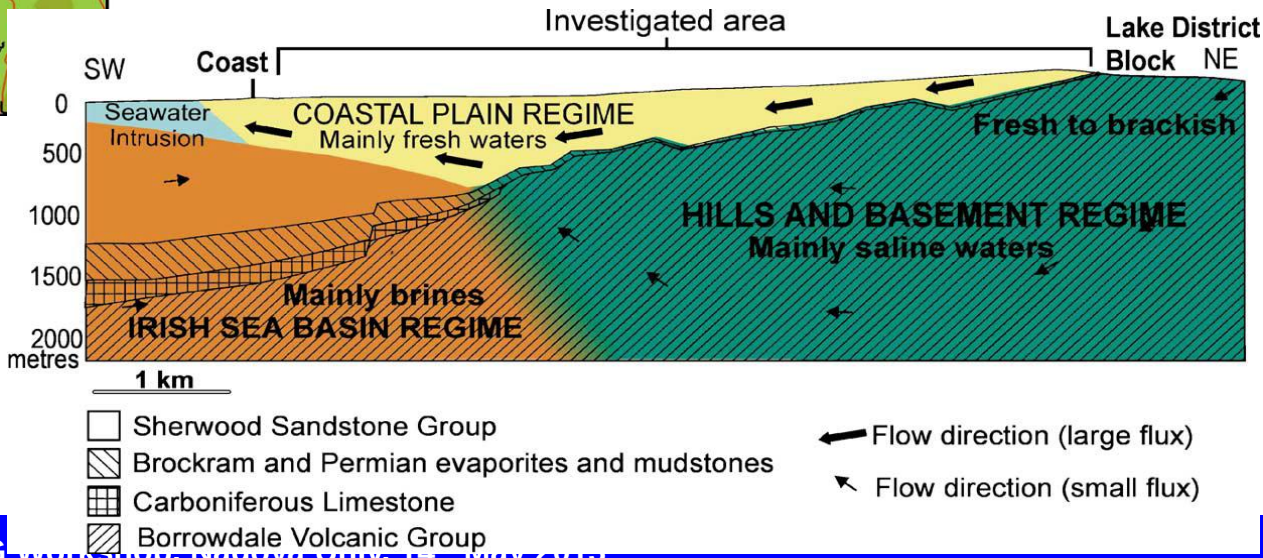


Base of freshwater zone

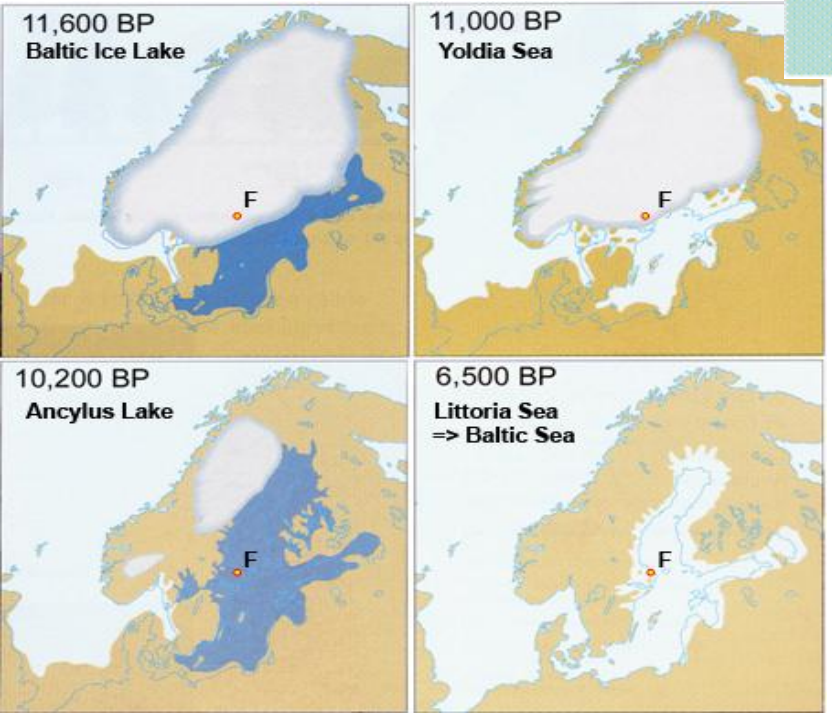
Morphological Transition Zone (MTZ)

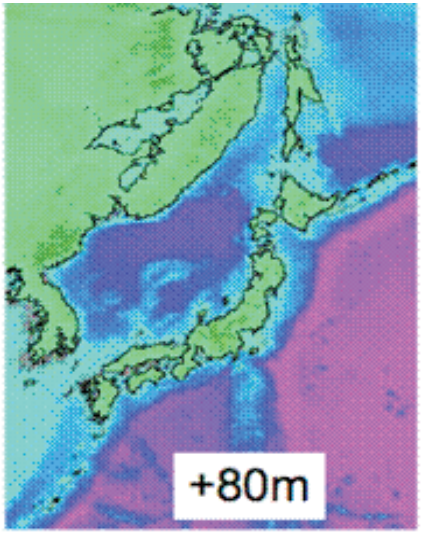


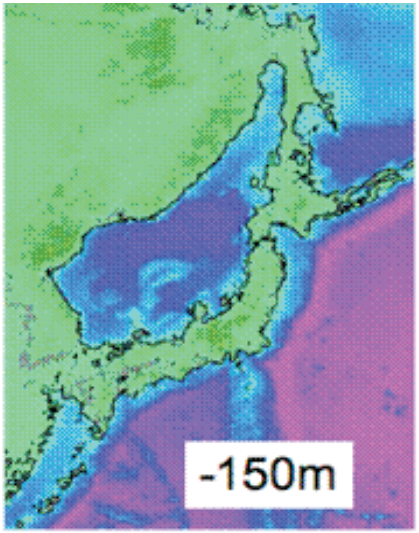
Deep saline groundwater zone



Fennoscandian Shield vs Sea of Japan





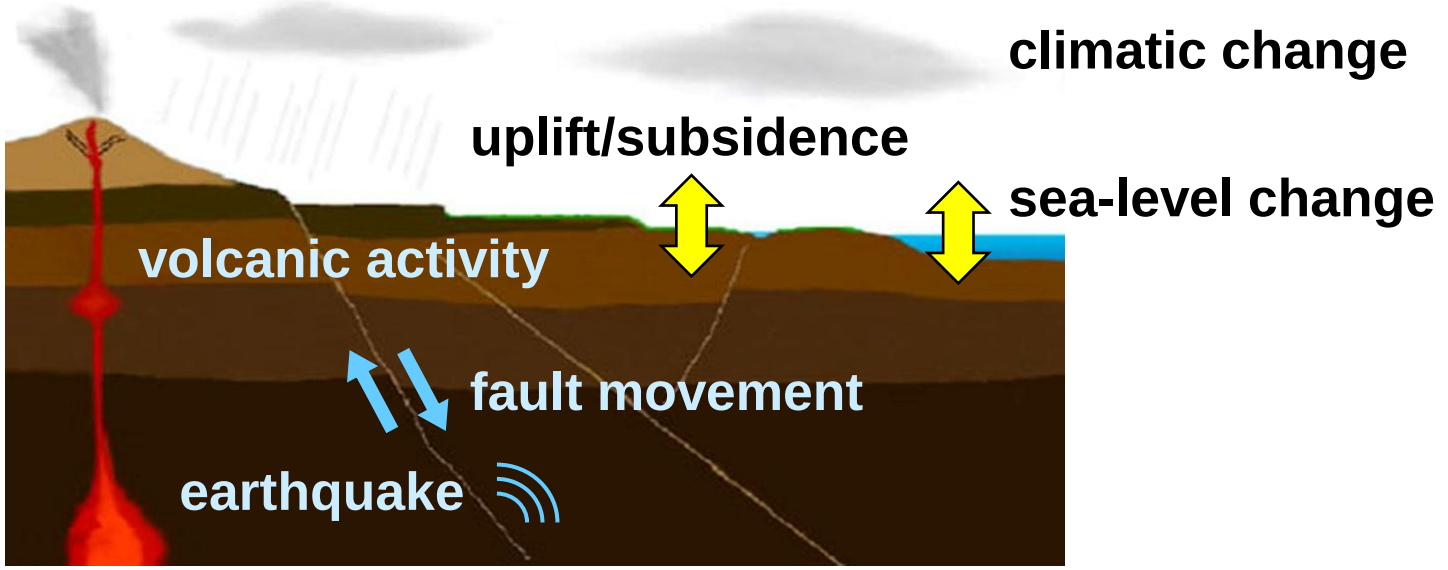


Of great importance…

- **Assurance of the long-term stability of geological environment**
  - **In the siting process…**

significant impacts to be precluded

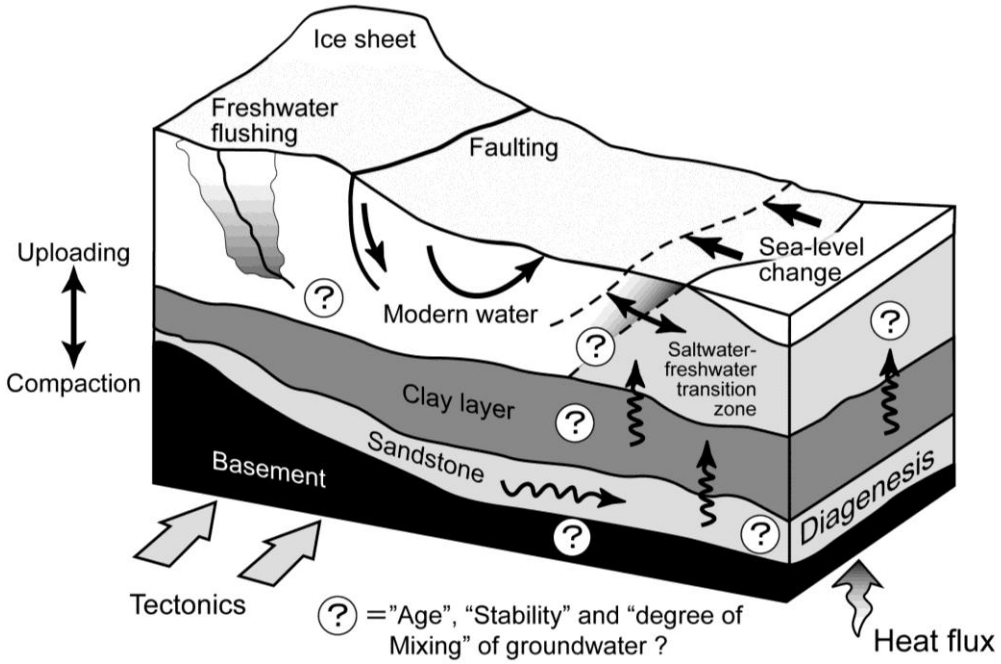
very slow but constant accumulation of potential impacts NOT to be precluded



➔ **Development of a set of analyses / arguments to demonstrate if key safety functions are adequate not only at present but also into the future – understanding of site evolution**

Palaeohydrogeological evolution

- An understanding of the site evolution is gained by studying the palaeohydrogeological evolution of the area, defining temporal and spatial changes of various characteristics, events, and processes over geological time, up to the present.
- An understanding of the palaeohydrogeological evolution of the site provides the firm foundation to describe the likely future evolution of the site.

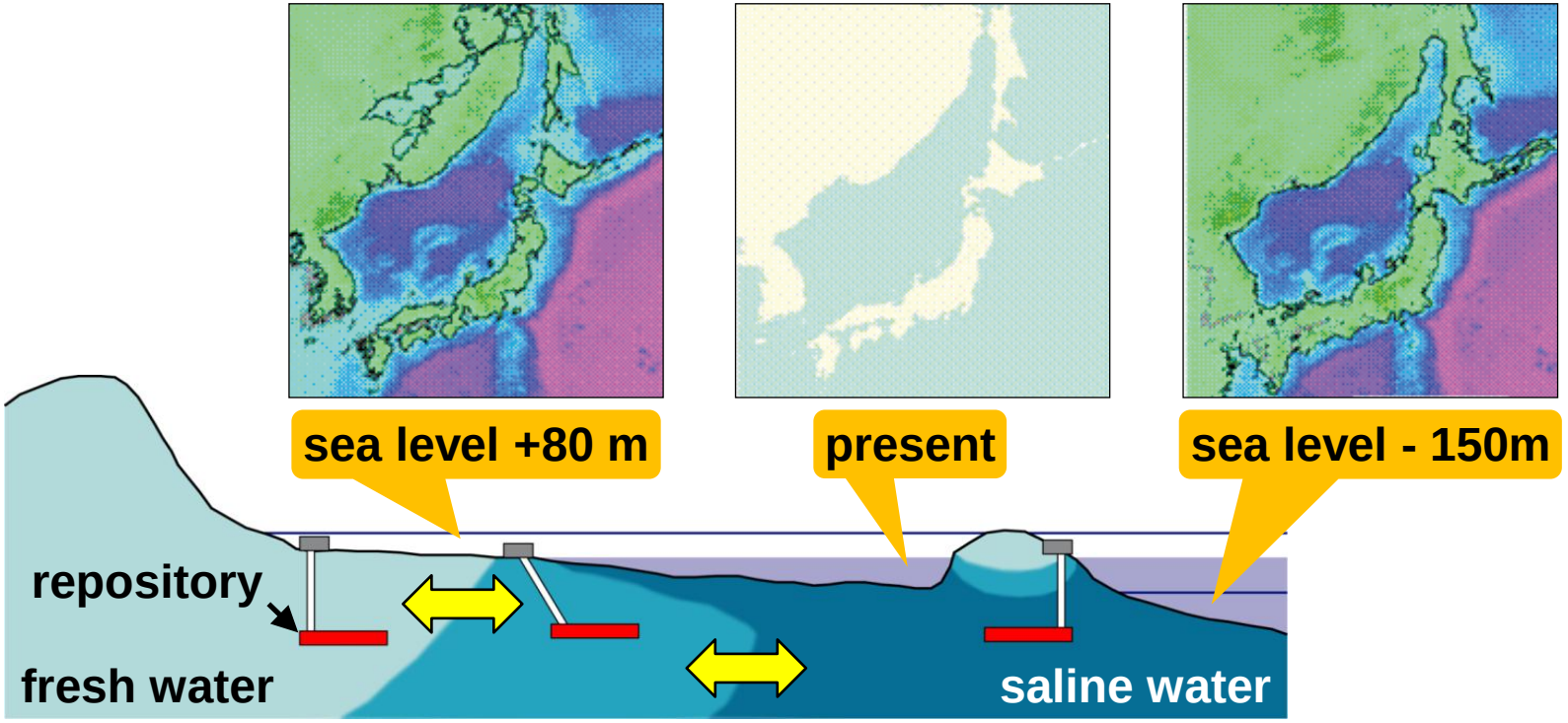


After Chapman & McEwen (1993)

The geosynthesis methodology can provide the framework for the studying of the palaeohydrogeological evolution of a site

Of particular concern…

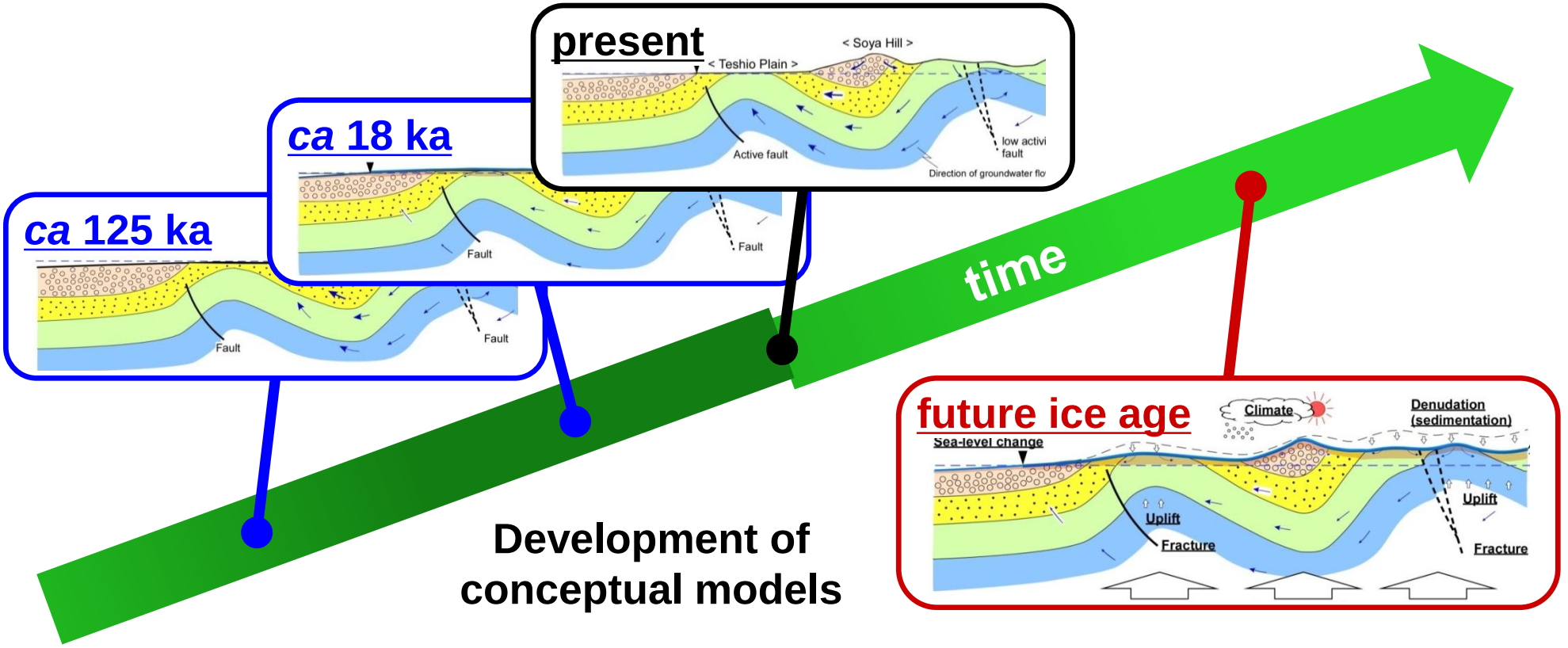
- Global sea-level changes
  - Drop up to 150 m during the last ice age
  - Rise currently but drop in the future by return to ice-age conditions?



➔ Extremely dramatic changes to hydraulic / hydrochemical conditions at coastal sites

Palaeohydrogeology as powerful tool

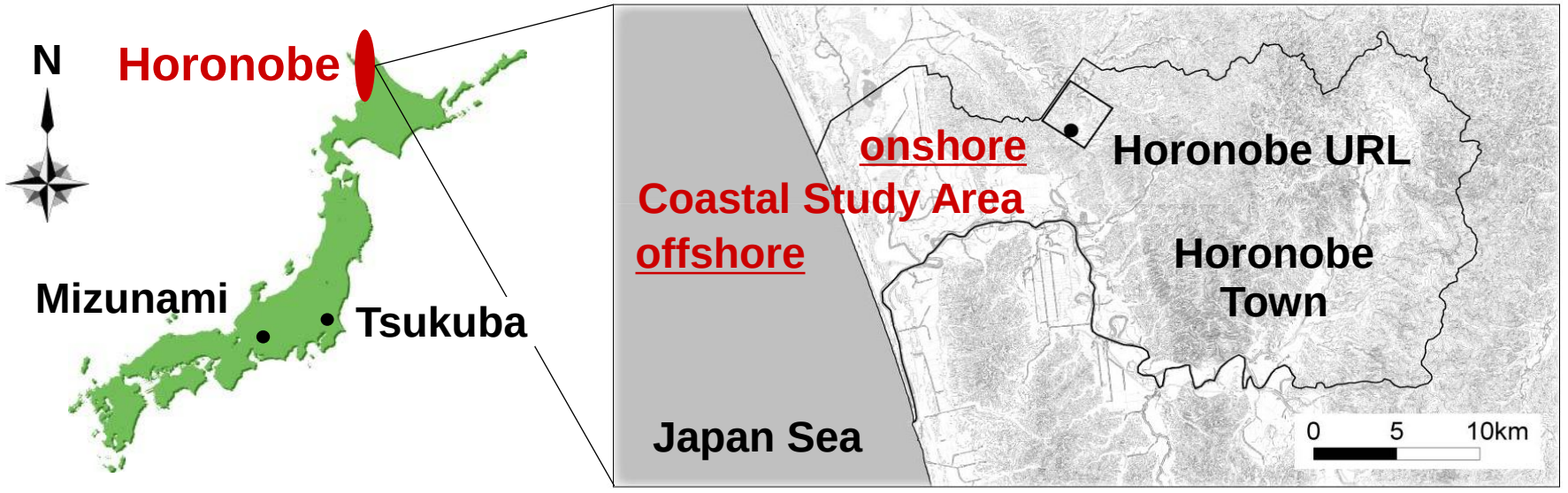
- **Characterisation of 4D evolution of various properties / processes – overall site evolution over geological time up to the present**



➔ **Understanding of likely site evolution and persistence of key safety functions into the future**

Programme involves…

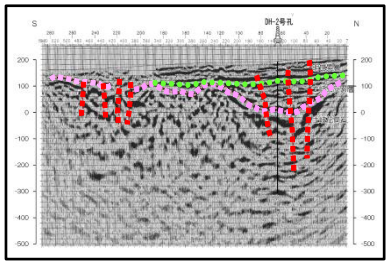
- Surface-based investigations in Horonobe coastal study area
  - Case study as '**dry run**' – not actual site characterisation
  - **Palaeohydrogeological site evolution** as focal point
- Establishment of **basic strategy** for stepwise site characterisation
  - Formulation of **Geosynthesis Data Flow Diagram** (GDFD)
- Conceptualisation of coastal geological environment
- Development of site evolution model

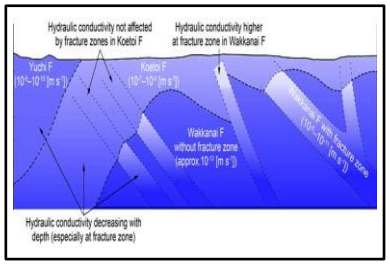


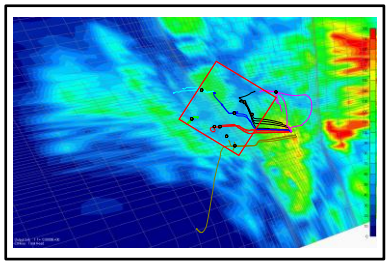
Site characterisation requires…

- Surface-based investigations in a variety of disciplines
- Comprehensive / consistent site overview, as required for repository design and safety assessment

investigation data acquisition → data interpretation → conceptual modelling → numerical modelling → site understanding





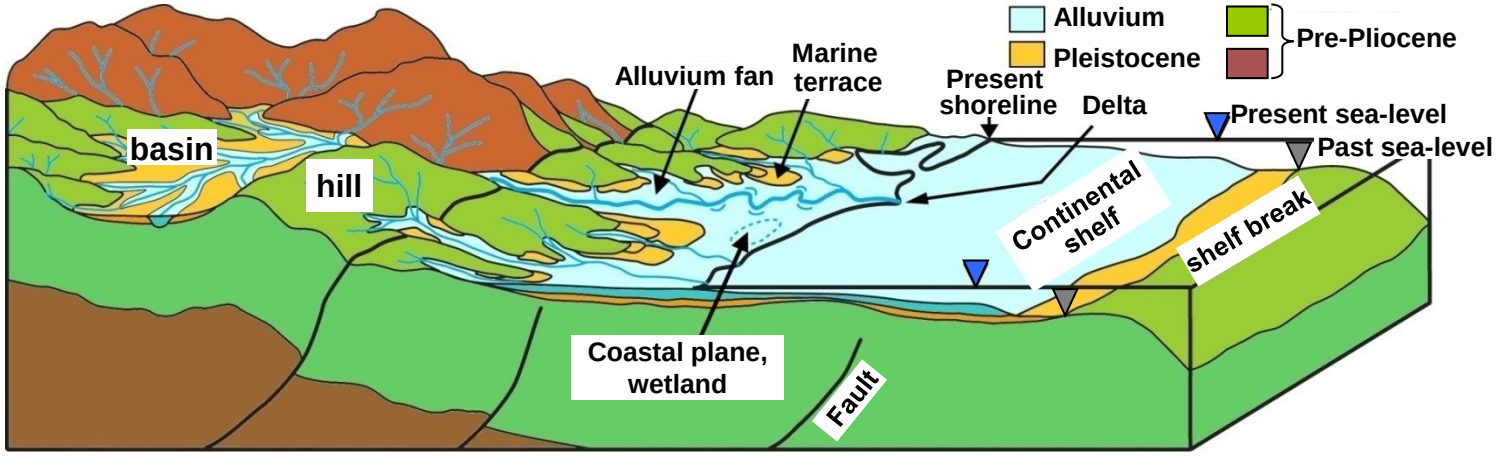


➔ Global integration methodology **"Geosynthesis"**

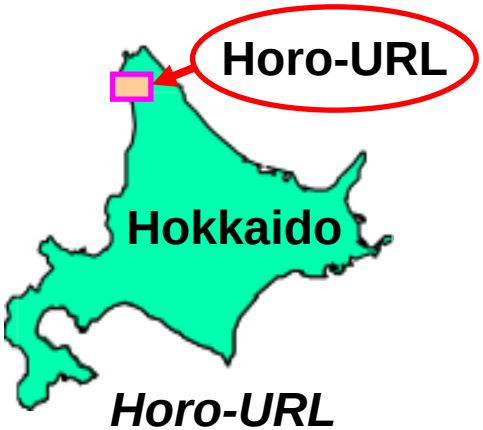
- clearly define goals of individual investigations
- interpret / synthesise information into a consistent site model
- enhance interactions among different disciplines
- ensure the transparency / traceability of outcome needed by end users

Aims

- **Establish comprehensive techniques for overall geosphere evolution in the coastal system taking into account the potential impacts of natural events and processes through the case study in the Horonobe, Hokkaido, northern Japan**



Schematic diagram on a coastal field with gently-dipping submarine topography



Horo-URL =Horonobe URL

Formulation of coastal GDFD

- **Illustration of basic road map of geosynthesis methodology**
  - ➢ **identify key properties / processes and 4D evolution based on siting criteria / factors and FEPs ➔**
  - ➢ **visualise a sequence of activities as data flow**

investigations
↓
data acquisition
↓
interpretation / dataset
↓
conceptualisation modelling / simulation
↓
clarification of key properties / processes – site understanding

Geology and geological structure
- Spatial distribution and geometry of transport pathways
- Size and extent of host rock
- Heterogeneity within host rock
- 4D geomorphological changes; 4D evolution of geological structure

Groundwater flow characteristics
- Groundwater flow field and process
- Spatial variability of groundwater fluxes
- 4D evolution of groundwater flow field and process
- 4D evolution of groundwater flux distribution

Geochemical characteristics of groundwater
- Spatial distribution of saline/fresh groundwater (interface); degree of groundwater mineralisation
- Groundwater pH-Eh conditions
- 4D evolution of groundwater chemistry

Transport/retardation of nuclides
- Geometry of transport pathways; depth of diffusion-accessible matrix
- Sorption capacity and diffusivity of rock matrix and of transport pathways
- Effect of colloid/organics/microbes on nuclide transport/retardation

Dilution of nuclides
- Spatial distribution of higher-permeability rocks, aquifers and surface waters; extent of marine environments
- Sorption capacity and diffusivity of rock matrix and of transport pathways

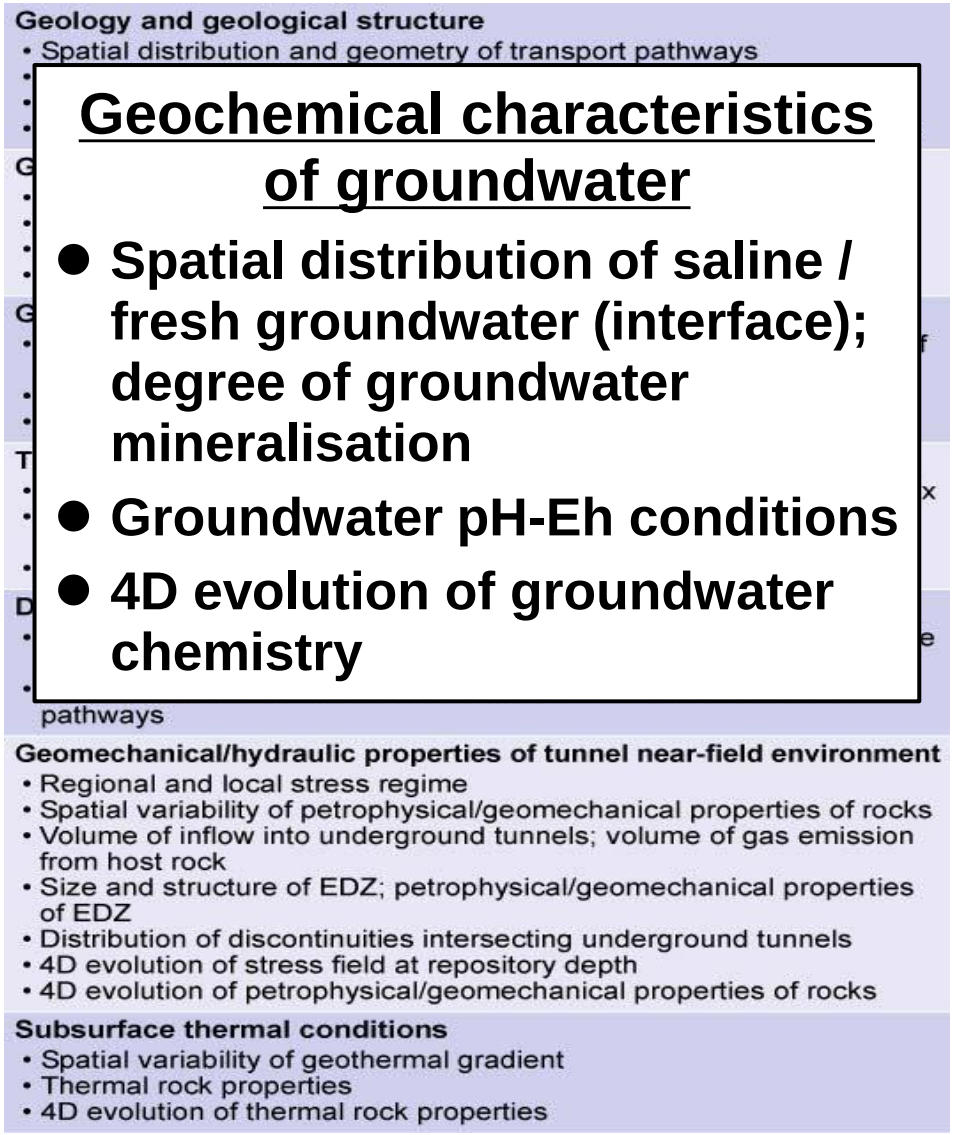
Geomechanical/hydraulic properties of tunnel near-field environment
- Regional and local stress regime
- Spatial variability of petrophysical/geomechanical properties of rocks
- Volume of inflow into underground tunnels; volume of gas emission from host rock
- Size and structure of EDZ; petrophysical/geomechanical properties of EDZ
- Distribution of discontinuities intersecting underground tunnels
- 4D evolution of stress field at repository depth
- 4D evolution of petrophysical/geomechanical properties of rocks

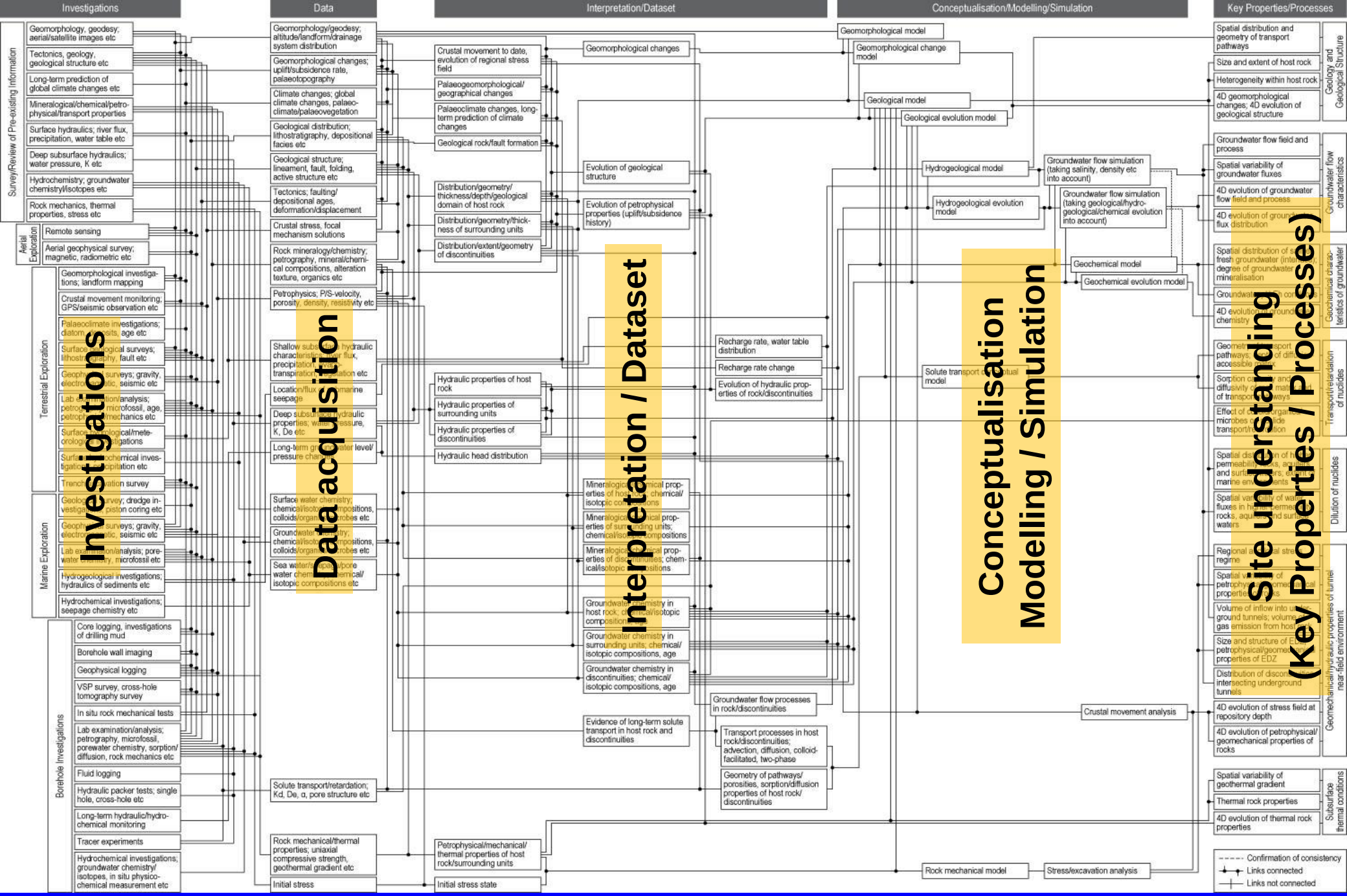
Subsurface thermal conditions
- Spatial variability of geothermal gradient
- Thermal rock properties
- 4D evolution of thermal rock properties

Coastal Geosynthesis Data Flow Diagram formulated by…

- Review / update and integration of inland GDFDs – all in one
- Identification of key properties / processes for 4D site evolution ➔ based on siting criteria / factors, coastal FEPs *etc*
- Involvement of potential exploration onshore / offshore

- ✓ seabed geological survey (piston coring, dredging *etc*)
- ✓ geophysical (seismic, side-scan sonar *etc*) survey
- ✓ hydrochemical investigations (seepage, porewater chemistry *etc*)
- ✓ hydrogeological investigations (hydraulics of sediments *etc*)



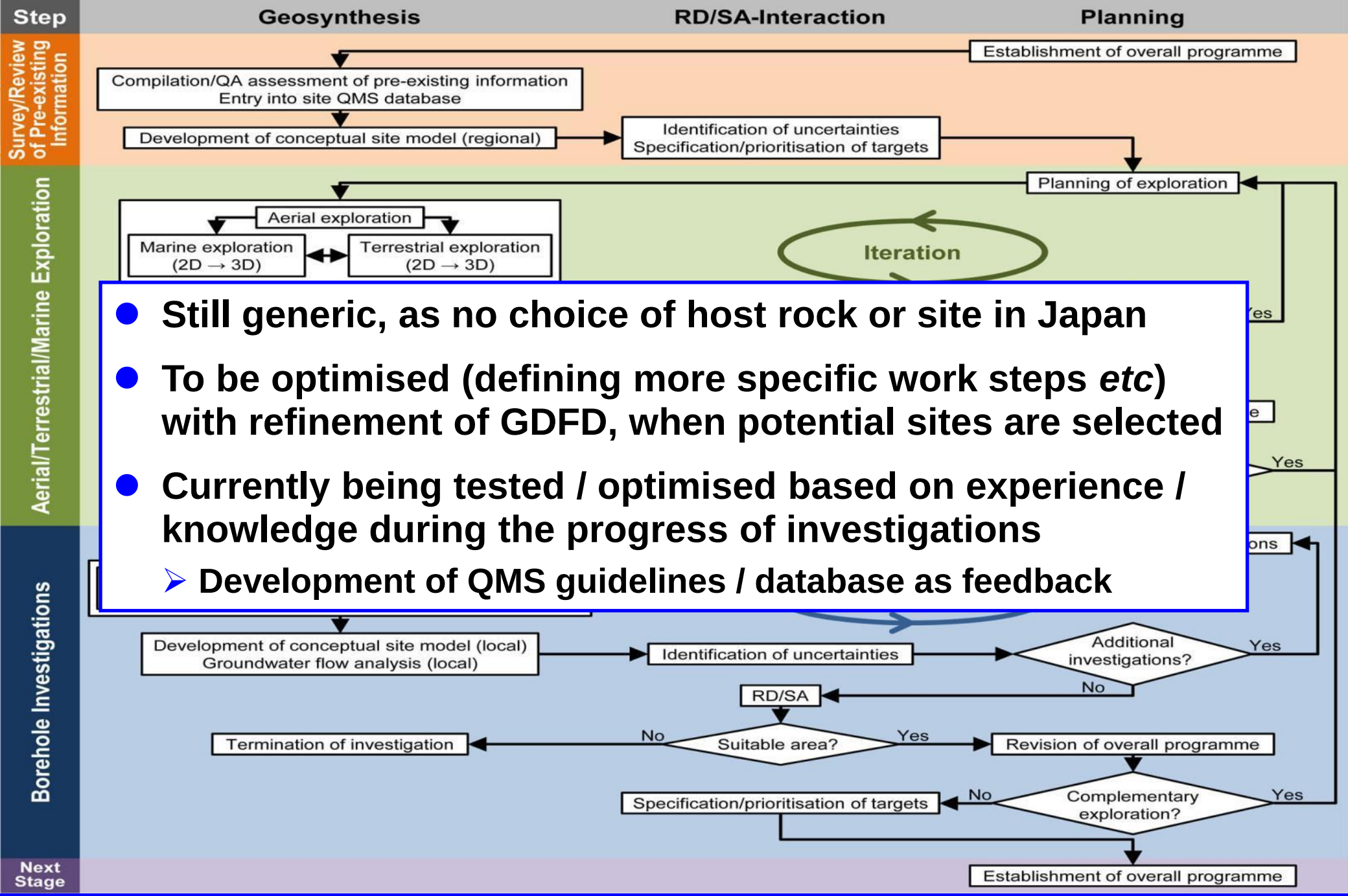

Investigations
Data acquisition
Interpretation / Dataset
Conceptualisation
Modelling / Simulation
Site understanding
(Key Properties / Processes)
Investigations
Data
Interpretation/Dataset
Conceptualisation/Modelling/Simulation
Key Properties/Processes
Survey/Review of Pre-existing Information
Aerial Exploration
Terrestrial Exploration
Marine Exploration
Borehole Investigations
Geomorphology, geodesy; aerial/satellite images etc
Tectonics, geology, geological structure etc
Long-term prediction of global climate changes etc
Mineralogical/chemical/petrophysical/transport properties
Surface hydraulics; river flux, precipitation, water table etc
Deep subsurface hydraulics; water pressure, K etc
Hydrochemistry; groundwater chemistry/isotopes etc
Rock mechanics, thermal properties, stress etc
Remote sensing
Aerial geophysical survey; magnetic, radiometric etc
Geomorphological investigations; landform mapping
Crustal movement monitoring; GPS/seismic observation etc
Palaeoclimate investigations; diatom, pollen, loess, peat deposits, age etc
Surface geological surveys; lithostratigraphy, fault etc
Geophysical surveys; gravity, electromagnetic, seismic etc
Lab examination/analysis; petrography, microfossil, age, petrophysical, mechanics etc
Surface geochemical/meteorological investigations
Surface hydrochemical investigations; precipitation etc
Trench excavation survey
Geological survey; dredge investigations; piston coring etc
Geophysical surveys; gravity, electromagnetic, seismic etc
Lab examination/analysis; porewater chemistry, microfossil etc
Hydrogeological investigations; hydraulics of sediments etc
Hydrochemical investigations; seepage chemistry etc
Core logging, investigations of drilling mud
Borehole wall imaging
Geophysical logging
VSP survey, cross-hole tomography survey
In situ rock mechanical tests
Lab examination/analysis; petrography, microfossil, porewater chemistry, sorption/diffusion, rock mechanics etc
Fluid logging
Hydraulic packer tests; single hole, cross-hole etc
Long-term hydraulic/hydrochemical monitoring
Tracer experiments
Hydrochemical investigations; groundwater chemistry/isotopes, in situ physico-chemical measurement etc
Geomorphology/geodesy; altitude/landform/drainage system distribution
Geomorphological changes; uplift/subsidence rate, palaeotopography
Climate changes; global climate changes, palaeoclimate/palaeovegetation
Geological distribution; lithostratigraphy, depositional facies etc
Geological structure; lineament, fault, folding, active structure etc
Tectonics; faulting/depositional ages, deformation/displacement
Crustal stress, focal mechanism solutions
Rock mineralogy/chemistry; petrography, mineral/chemical compositions, alteration texture, organics etc
Petrophysics; P/S-velocity, porosity, density, resistivity etc
Shallow subsurface hydraulic characteristics; water flux, precipitation, transpiration, evaporation etc
Location/flux of submarine seepage
Deep subsurface hydraulic properties; water pressure, K, De etc
Long-term groundwater level/pressure changes
Surface water chemistry; chemical/isotopic compositions, colloids/organics/microbes etc
Groundwater chemistry; chemical/isotopic compositions, colloids/organics/microbes etc
Sea water/porewater chemistry; chemical/isotopic compositions etc
Solute transport/retardation; Kd, De, α, pore structure etc
Rock mechanical/thermal properties; uniaxial compressive strength, geothermal gradient etc
Initial stress
Crustal movement to date, evolution of regional stress field
Palaeogeomorphological/geographical changes
Palaeoclimate changes, long-term prediction of climate changes
Geological rock/fault formation
Distribution/geometry/thickness/depth/geological domain of host rock
Distribution/geometry/thickness of surrounding units
Distribution/extent/geometry of discontinuities
Hydraulic properties of host rock
Hydraulic properties of surrounding units
Hydraulic properties of discontinuities
Hydraulic head distribution
Petrophysical/mechanical/thermal properties of host rock/surrounding units
Initial stress state
Geomorphological changes
Evolution of geological structure
Evolution of petrophysical properties (uplift/subsidence history)
Recharge rate, water table distribution
Recharge rate change
Evolution of hydraulic properties of rock/discontinuities
Mineralogical/chemical properties of host rock; chemical/isotopic compositions
Mineralogical/chemical properties of surrounding units; chemical/isotopic compositions
Mineralogical/chemical properties of discontinuities; chemical/isotopic compositions
Groundwater chemistry in host rock; chemical/isotopic composition
Groundwater chemistry in surrounding units; chemical/isotopic compositions, age
Groundwater chemistry in discontinuities; chemical/isotopic compositions, age
Groundwater flow processes in rock/discontinuities
Evidence of long-term solute transport in host rock and discontinuities
Transport processes in host rock/discontinuities; advection, diffusion, colloid-facilitated, two-phase
Geometry of pathways/porosities, sorption/diffusion properties of host rock/discontinuities
Geomorphological model
Geomorphological change model
Geological model
Geological evolution model
Hydrogeological model
Hydrogeological evolution model
Groundwater flow simulation (taking salinity, density etc into account)
Groundwater flow simulation (taking geological/hydrogeological/chemical evolution into account)
Geochemical model
Geochemical evolution model
Solute transport/retardation model
Crustal movement analysis
Rock mechanical model
Stress/excavation analysis
Spatial distribution and geometry of transport pathways
Size and extent of host rock
Heterogeneity within host rock
4D geomorphological changes; 4D evolution of geological structure
Geology and Geological Structure
Groundwater flow field and process
Spatial variability of groundwater fluxes
4D evolution of groundwater flow field and process
4D evolution of groundwater flux distribution
Groundwater flow characteristics
Spatial distribution of saline/fresh groundwater (interface); degree of groundwater mineralisation
Groundwater chemistry conditions
4D evolution of groundwater chemistry
Geochemical characteristics of groundwater
Geometry of transport pathways; extent of diffusion accessible
Sorption characteristics and diffusivity of materials; mechanisms of transport/retardation
Effect of colloids/organics/microbes on radionuclide transport/retardation
Transport/retardation of nuclides
Spatial distribution of hydraulic permeability of rocks, aquifers and surface waters; distribution of marine environments
Spatial variability of water fluxes in hydraulic/thermal rocks, aquifers and surface waters
Dilution of nuclides
Regional and local stress regime
Spatial variability of petrophysical/geomechanical properties
Volume of inflow into underground tunnels; volume of gas emission from host rock
Size and structure of EDZ; petrophysical/geomechanical properties of EDZ
Distribution of discontinuities intersecting underground tunnels
4D evolution of stress field at repository depth
4D evolution of petrophysical/geomechanical properties of rocks
Geomechanical/hydraulic properties of tunnel near field environment
Spatial variability of geothermal gradient
Thermal rock properties
4D evolution of thermal rock properties
Subsurface thermal conditions
Confirmation of consistency
Links connected
Links not connected

Site characterisation proceeds…

- **Stepwise, incorporating geosynthesis in an effective manner**
  - **address key issues remained or newly identified in the previous steps**
  - **ensure improvement of site understanding**
  - **identify the degree of uncertainties in output**
  - **specify / prioritise investigation targets in the subsequent steps**

Consequently…

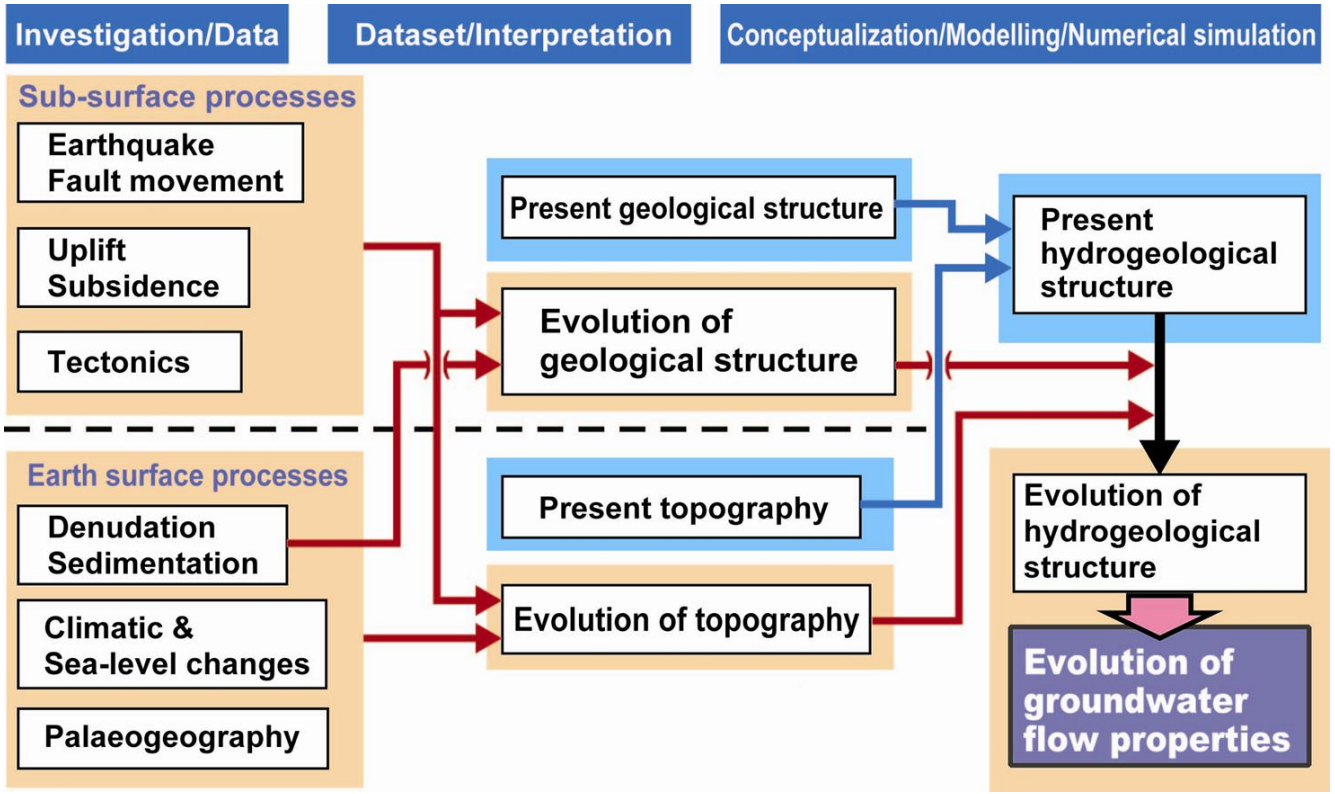
- **Providing flexibility to practically respond to the surprises that inevitably occur**
- **Enhancing the opportunity to adopt the investigations to the site specific conditions**
- **Assessment of impact of limitations in knowledge and data uncertainties by end users to provide feedback for optimisation**


Step
Geosynthesis
RD/SA-Interaction
Planning
Survey/Review of Pre-existing Information
Aerial/Terrestrial/Marine Exploration
Borehole Investigations
Next Stage
Establishment of overall programme
Compilation/QA assessment of pre-existing information
Entry into site QMS database
Development of conceptual site model (regional)
Identification of uncertainties
Specification/prioritisation of targets
Planning of exploration
Aerial exploration
Marine exploration (2D → 3D)
Terrestrial exploration (2D → 3D)
Iteration
Development of conceptual site model (local)
Groundwater flow analysis (local)
Identification of uncertainties
Additional investigations?
Yes
No
RD/SA
Termination of investigation
No
Suitable area?
Yes
Revision of overall programme
Specification/prioritisation of targets
No
Complementary exploration?
Yes
Establishment of overall programme
Still generic, as no choice of host rock or site in Japan
To be optimised (defining more specific work steps etc) with refinement of GDFD, when potential sites are selected
Currently being tested / optimised based on experience / knowledge during the progress of investigations
Development of QMS guidelines / database as feedback

Application of the Geosynthesis methodology

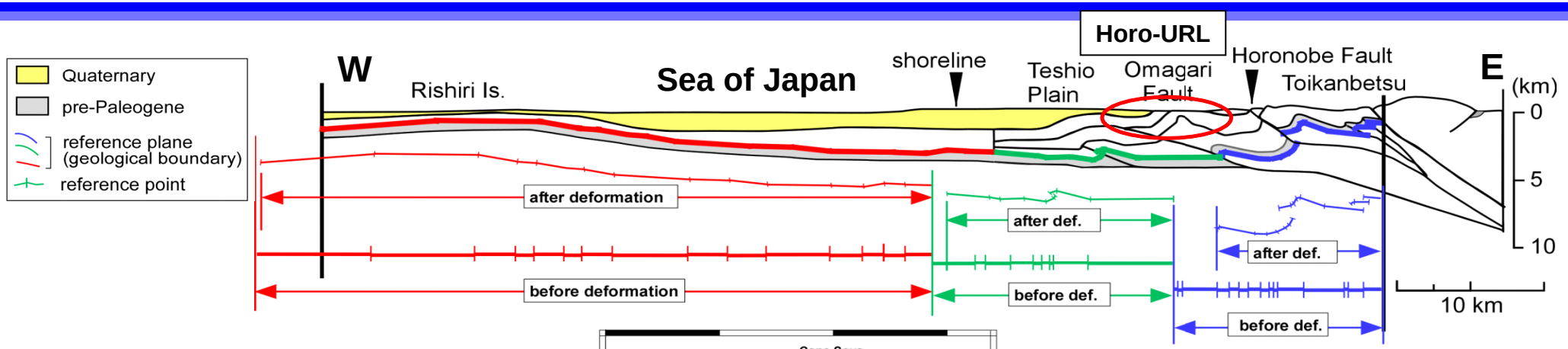
- The temporal and spatial changes of various characteristics of a site are studied to build up a conceptual model for the overall site evolution over geological time, up to the present.

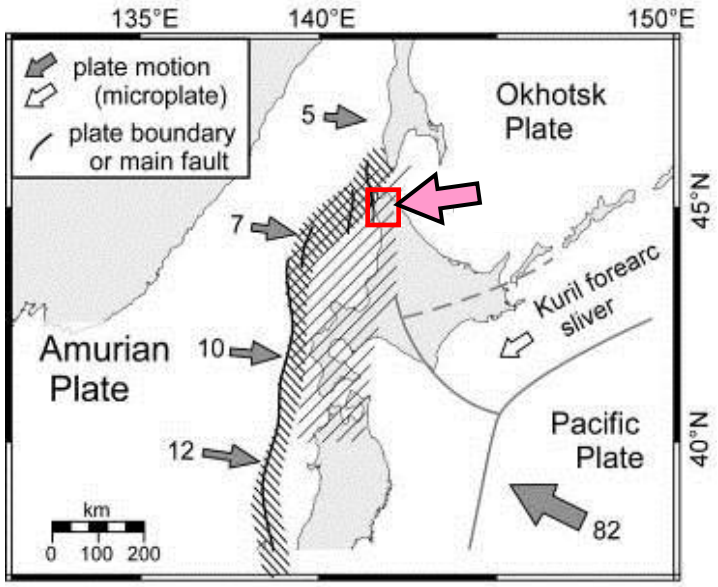
- The data produced are synthesised into a conceptual model of the site evolution over geological time. This is used to define the likely future evolution of the site and to assess if the main safety features will continue to function adequately.



Simplified Geosynthesis Data Flow Diagram for palaeohydrogeological evolution

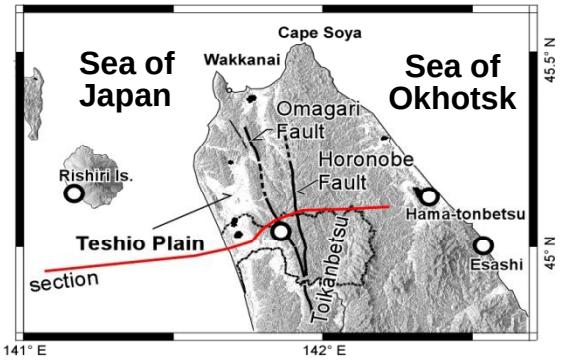
Regional tectonics and geological structure

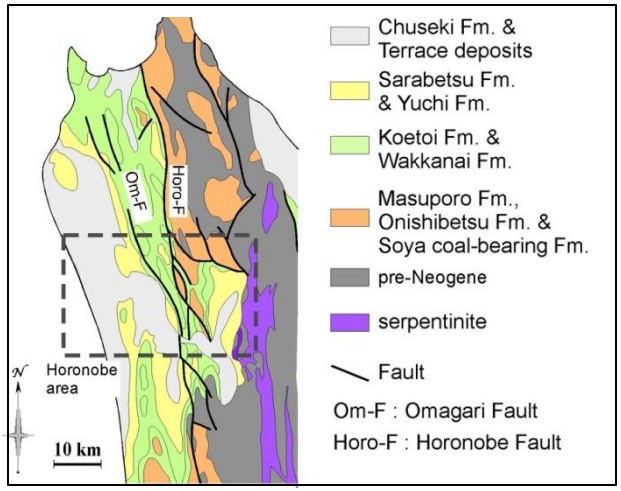




Tectonic zones I and VI, after Oka (1997)

the tectonic belt of eastern margin of Japan Sea, after Taira (2002)

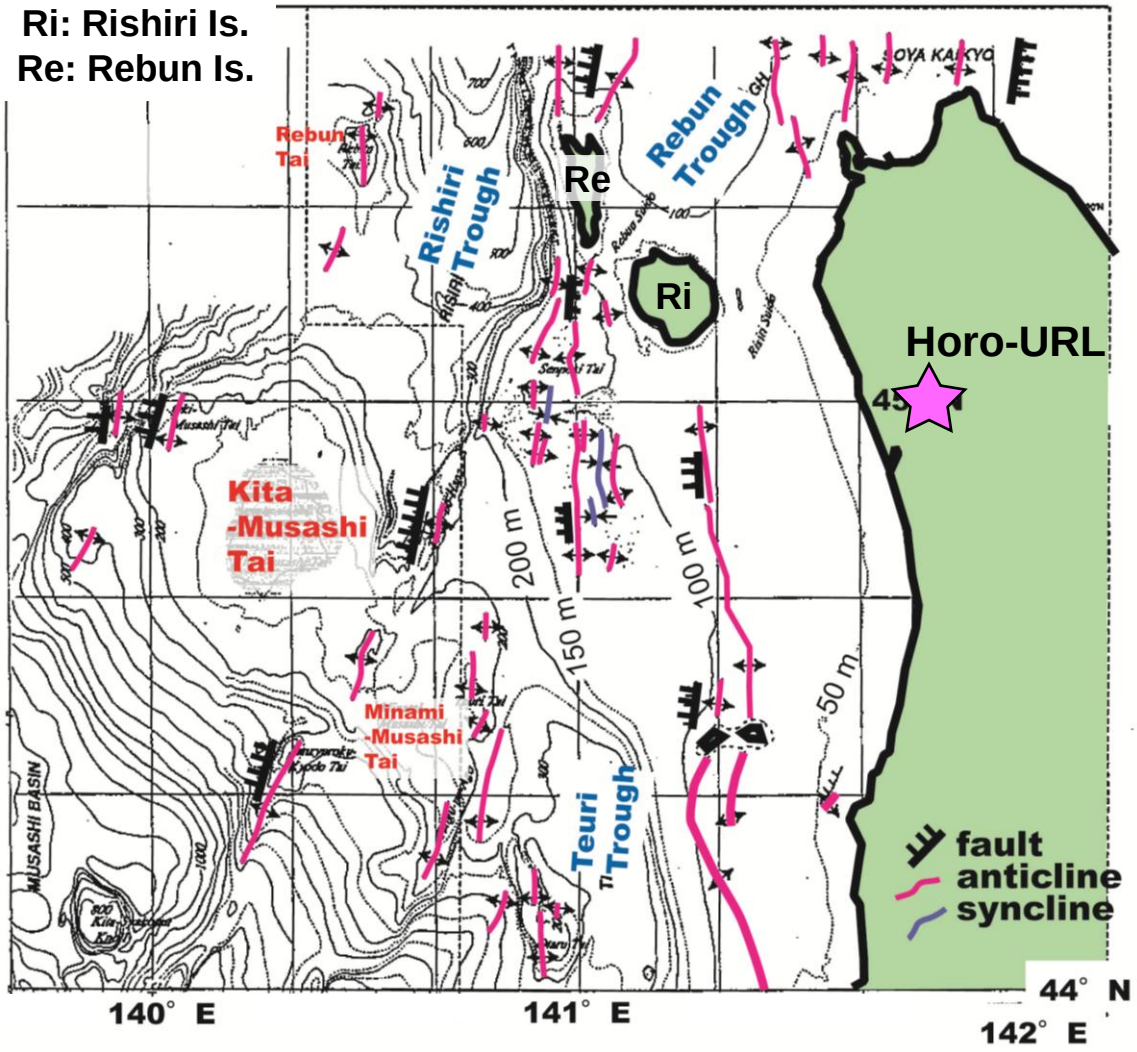




- ✓Tectonic setting
- ✓Time-space distribution of geological structures
- ✓Strain in each province
- ✓Focal mechanism
- ✓Present active province

- East-West compressive stress field since late Pliocene in the northern most part of Hokkaido

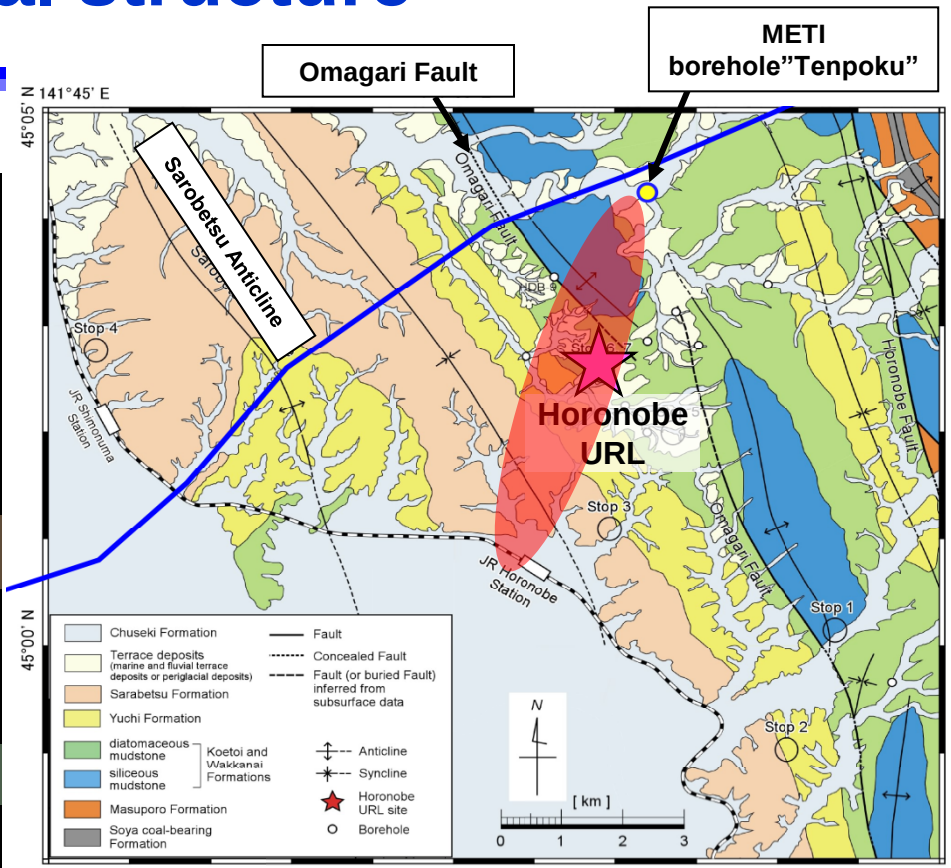
Submarine topography & geological structure

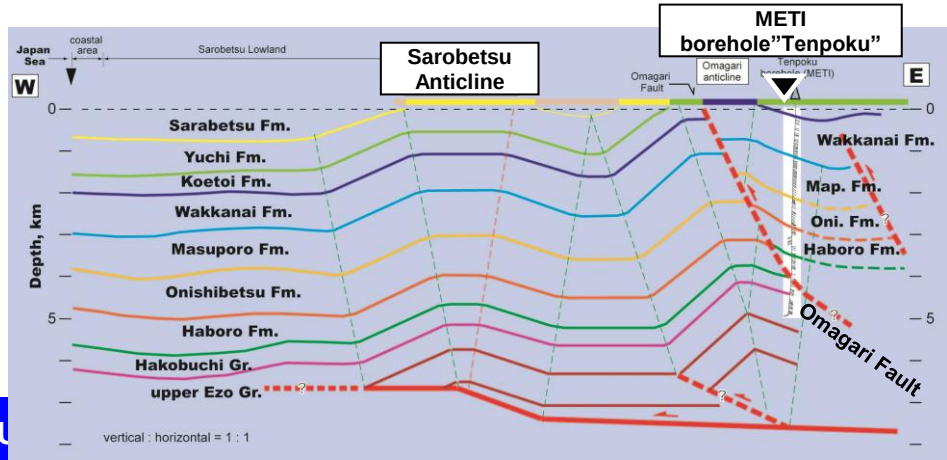


- Continental shelf with **60km in width**
- North-South trending **uplift zone** with fold from Rishiri Is. to SW Hokkaido
- **Fold zone** along the edge of continental shelf from the south of Rebun Is.
- Thickness of sedimentary formations increase to the east (Tenpoku Basin)

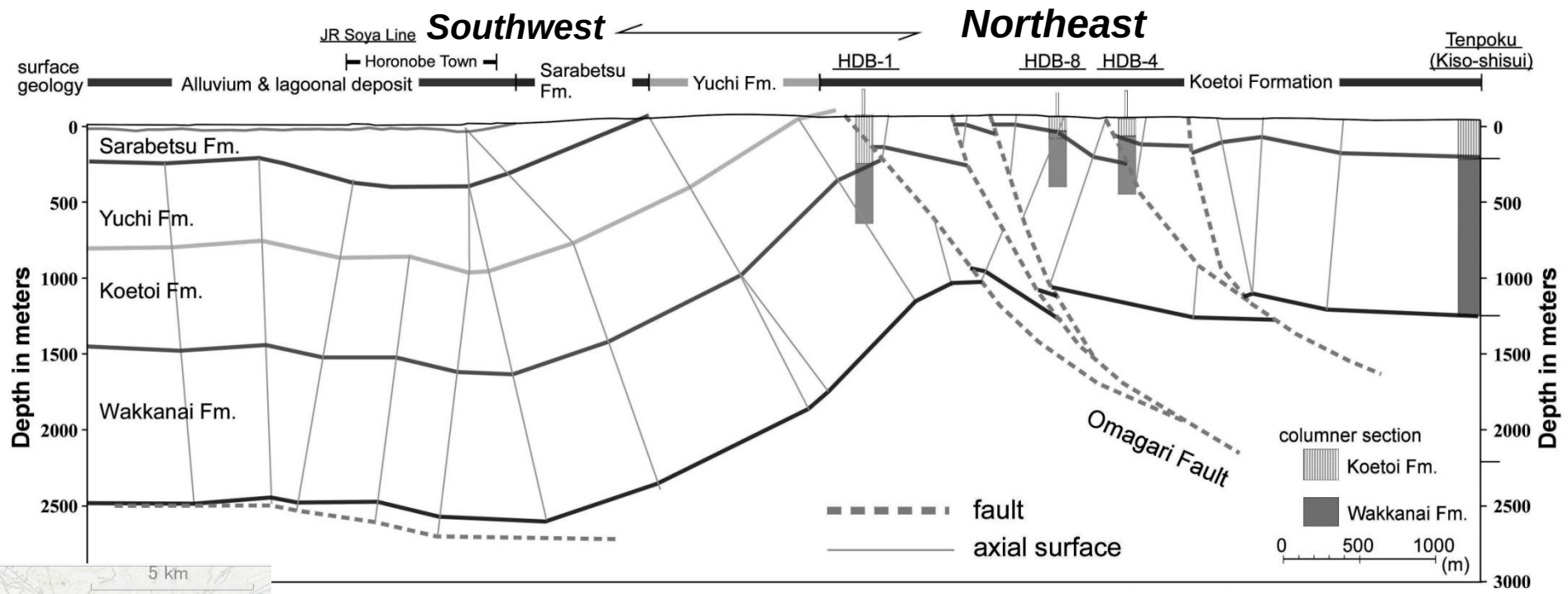
Stratigraphy and geological structure

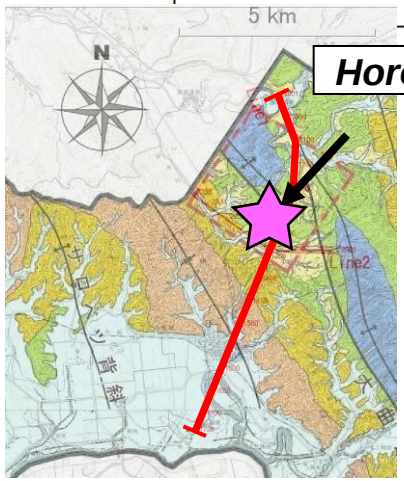
Period	Epoch		Litho-stratigraphic units (West (Horonobe))	Litho-stratigraphic units (East (Toikanbetsu))	Lithology (West (Horonobe))	Lithology (East (Toikanbetsu))
Quaternary	Holocene		Chuseki Fm. (Alluvium)		Alternating beds of gravel, sand, mud, and peat	
	Pleistocene	L	Terrace deposits (marine and fluvial terrace deposits, and periglacial deposit)		Alternating beds of gravel, sand, mud, and peat	
		M	Sarabetsu Fm.		Alternating beds of conglomerate, sandstone, and mudstone, intercalated with coal seams	
		E	Yuchi Fm.		Fine to medium grained sandstone	
Neogene	Pliocene	L	Koetoi Fm. ~ Wakkanai ? Fm.	Yuchi Fm.	Diatomaceous mudstone & siliceous mudstone	Fine to medium grained sandstone
		E		Koetoi Fm.		Diatomaceous pebbly mudstone
	Miocene	L		Wakkanai Fm.	(Siliceous shale & Diatomaceous shale?)	Siliceous shale & Diatomaceous shale
		M	Masuporo Fm.		Alternating beds of conglomerate, sandstone, and mudstone, intercalated with slumping beds	
			Onishibetsu Fm.		Sandstone intercalated with conglomerate and mudstone	
		E	Soya coal-bearing Fm.		Alternating beds of conglomerate, sandstone, and mudstone, intercalated with coal seams	





Geological structure around the Horonobe URL





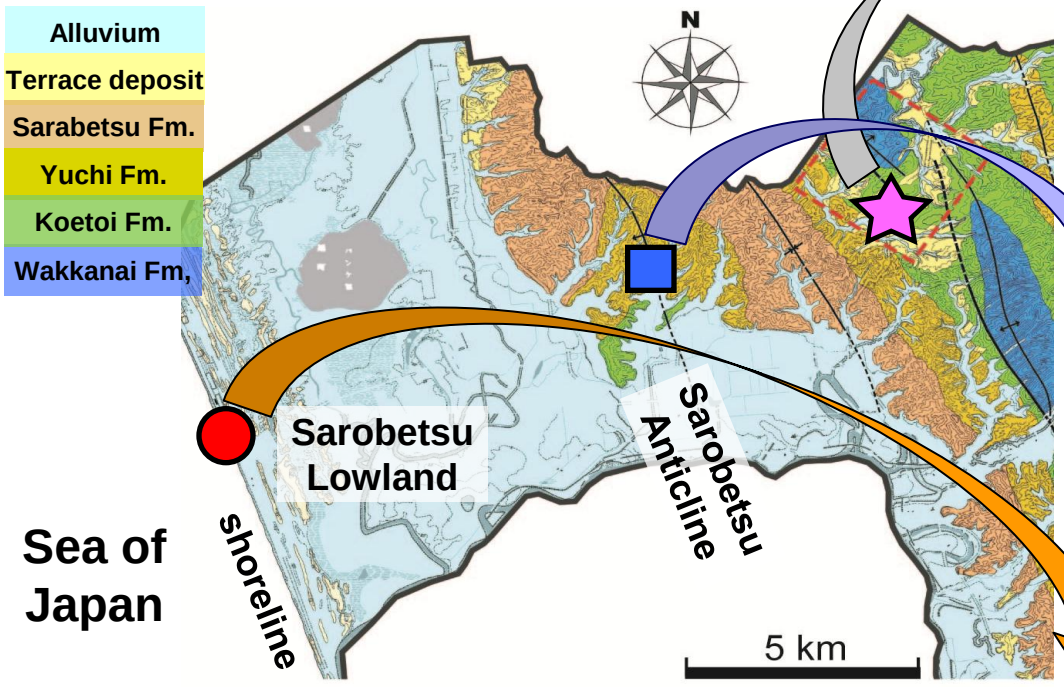
Horo-URL

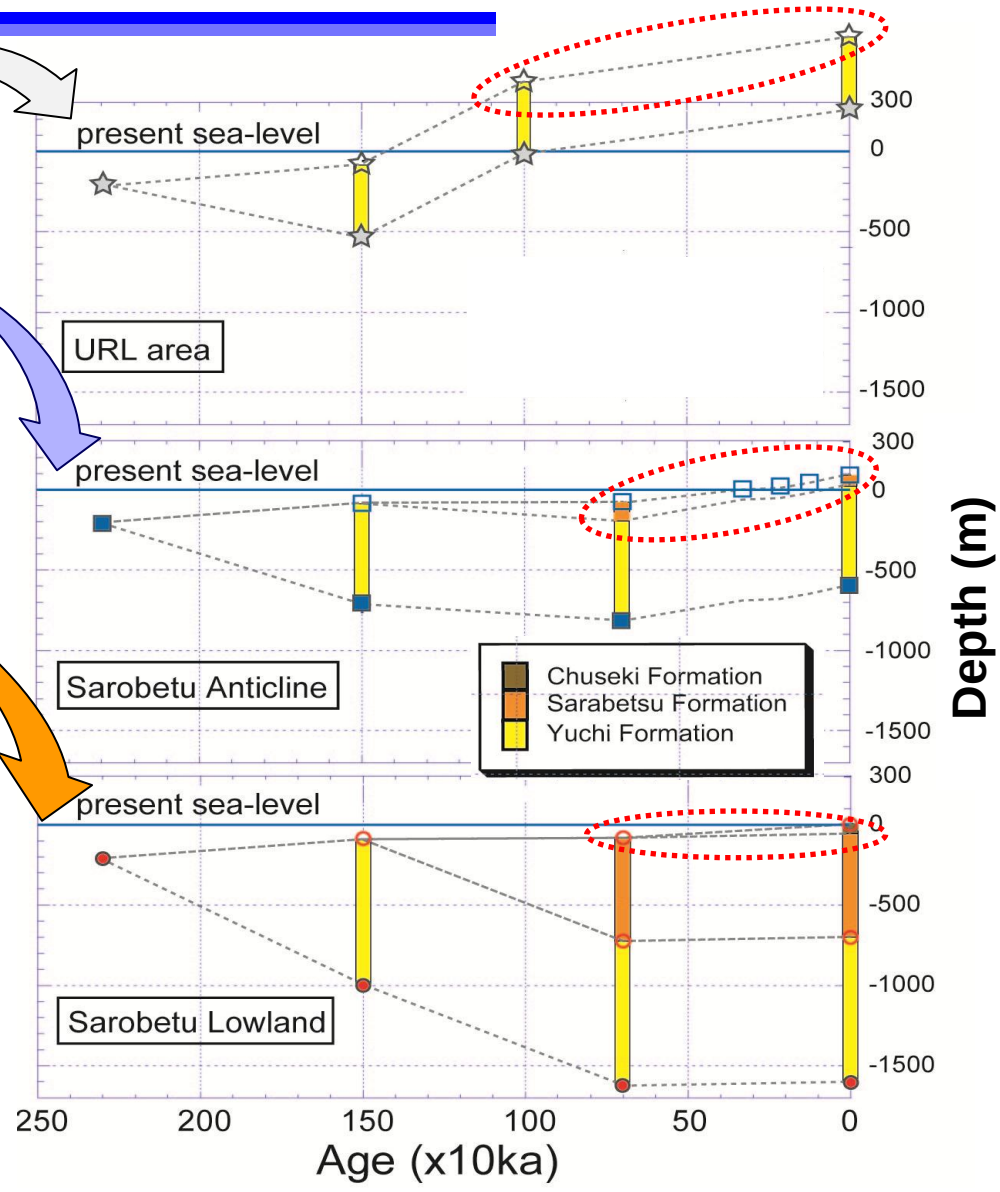
- ✓ **Surface geology**
- ✓ **Seismic profile**
- ✓ **Borehole investigation**

- ✓ **Extraction of seismic event-surface on the velocity profile**
- ✓ **Interpretation of geological structure by dip-domain method**
- ✓ **Taking into consideration of area-balancing (Balanced cross section)**

- ● **Listric reverse faults**
- ● **Westward vergence**
- ● **Eastern part (hanging wall) of the area is topographically higher than that of western part (footwall)**

Uplift/Subsidence



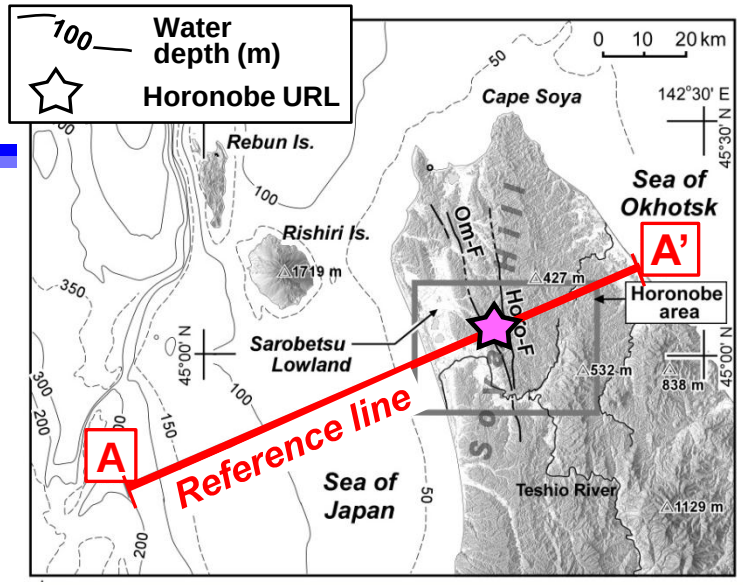


Geo-history (subsidence) analysis

- ✓ Marine terrace, geology, stratigraphy
- ✓ Global sea-level change, sedimentary environment, palaeo-bathymetry
- ✓ Distribution of fault and fold

- ● Whole of the Horonobe area is under E-W compressive stress field since 2.5 Ma but uplift/subsidence history differ from one location to another

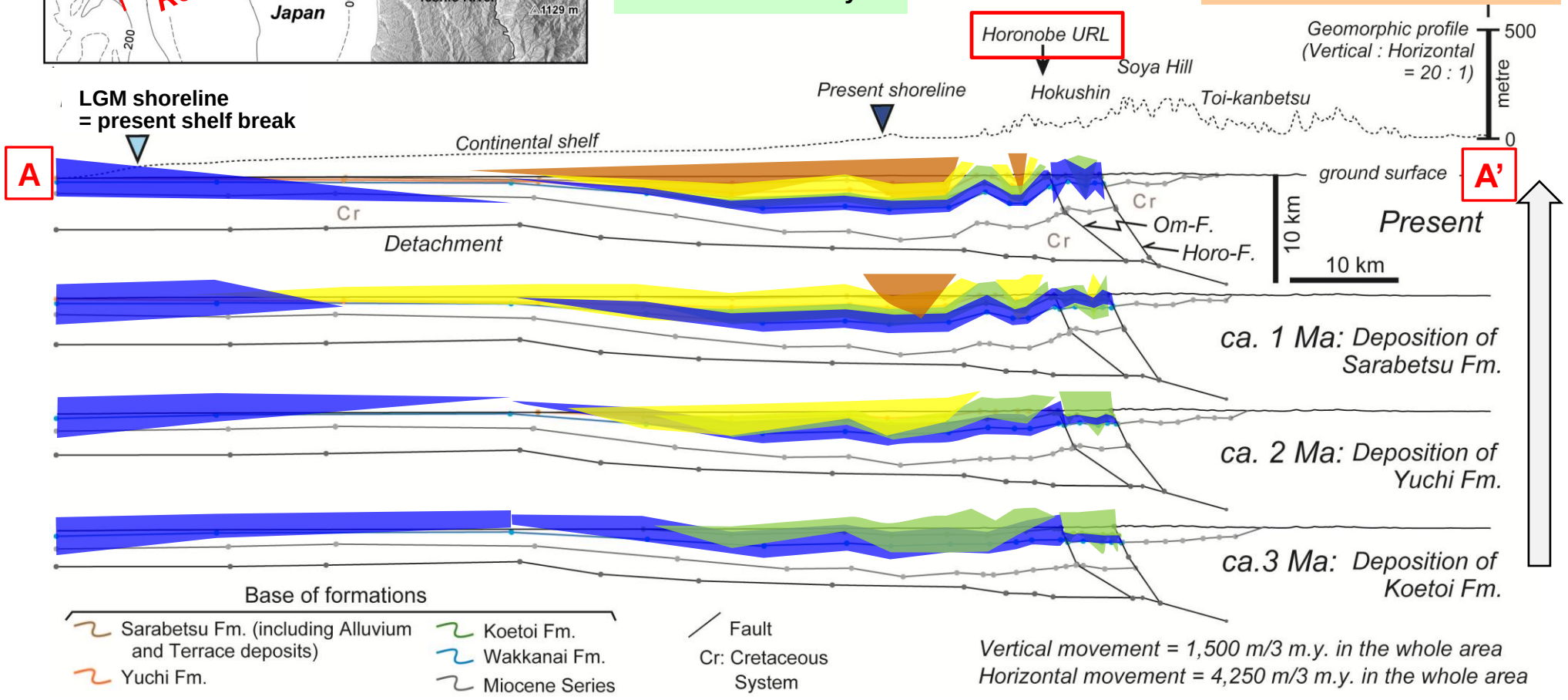
Evolution of the geological structure



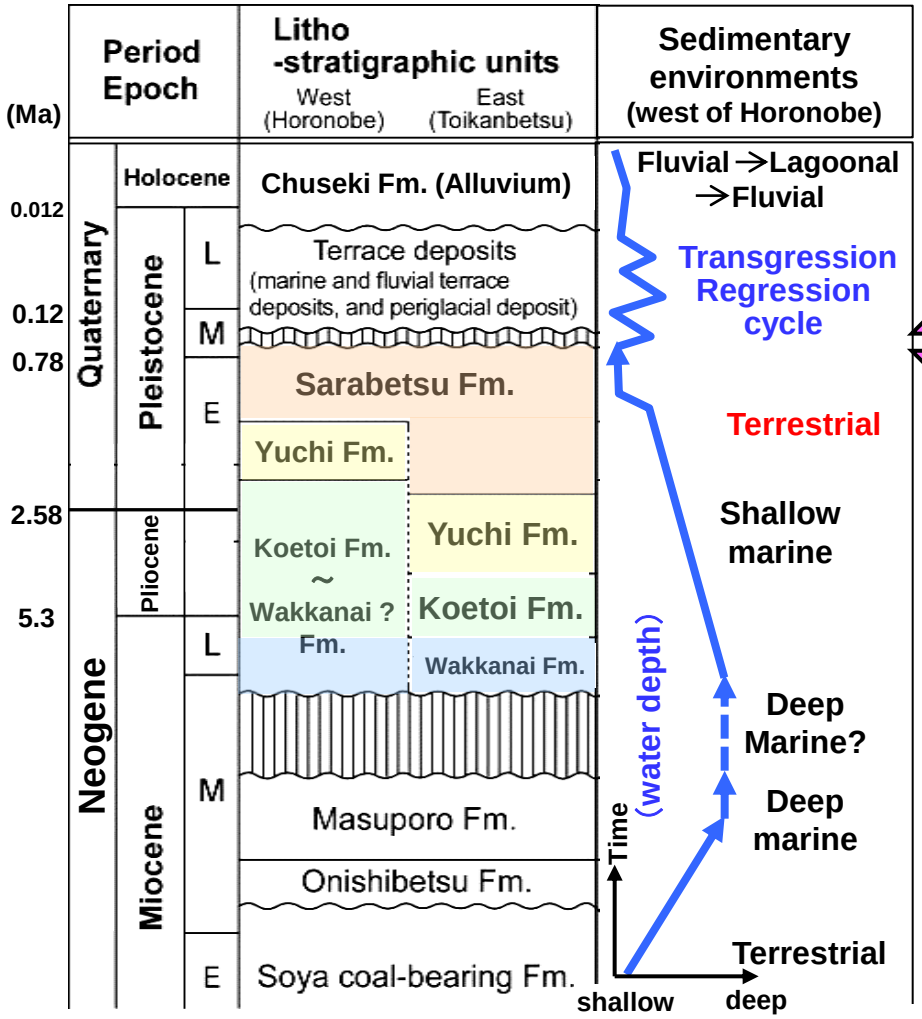
- ✓ Geology, geological structure on land and submarine, mainly pre-existing information related to the oil exploration
- ✓ Results of subsidence analysis

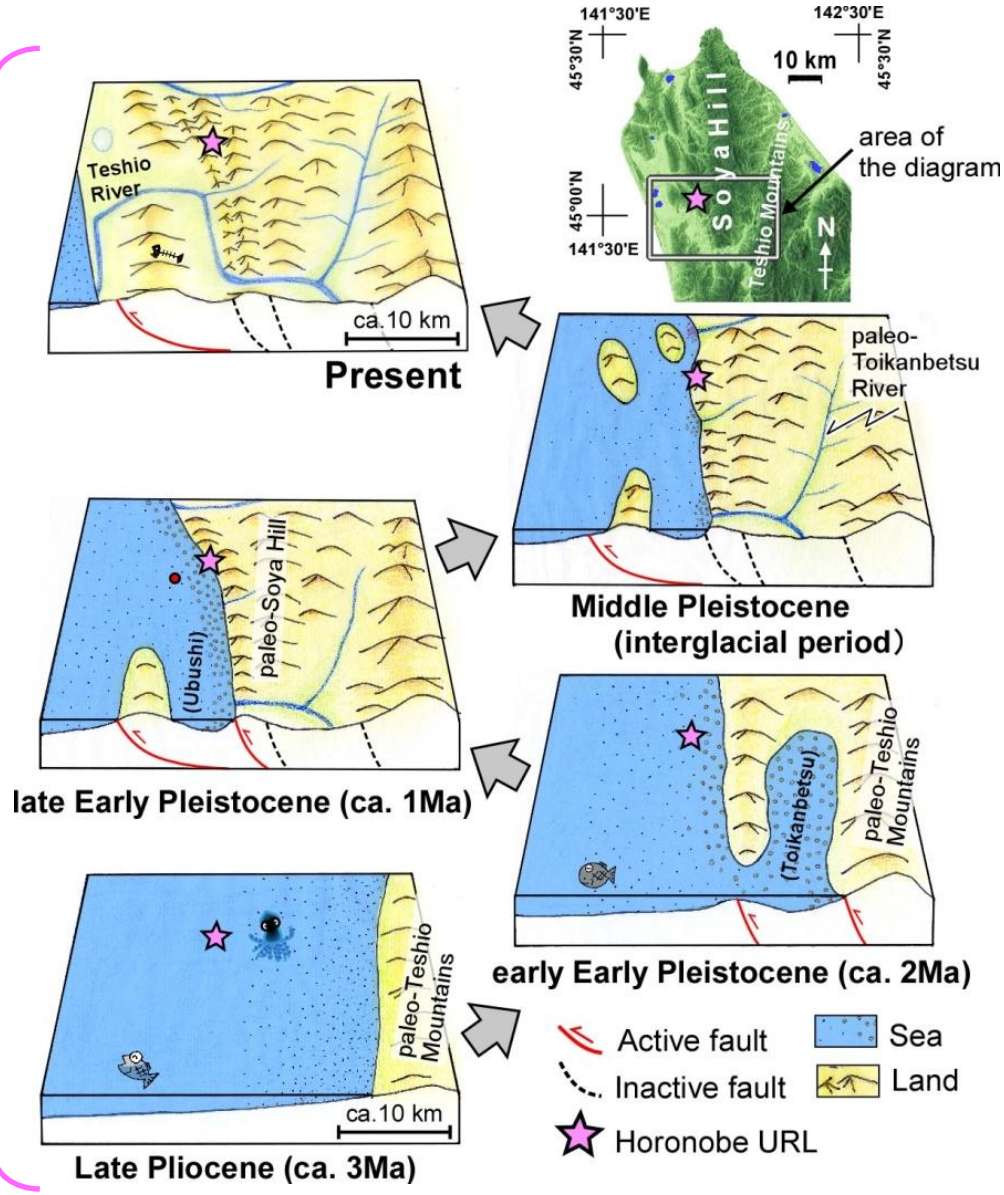
- ✓ Consideration of bed-length balancing
- ✓ No consideration of a compaction of stratum

- Development of geological structures of fold-and-thrust belt in the order of one million years
- Development of sedimentary basin (Tenpoku Basin) in the west of Horonobe



Palaeogeography (2/3)

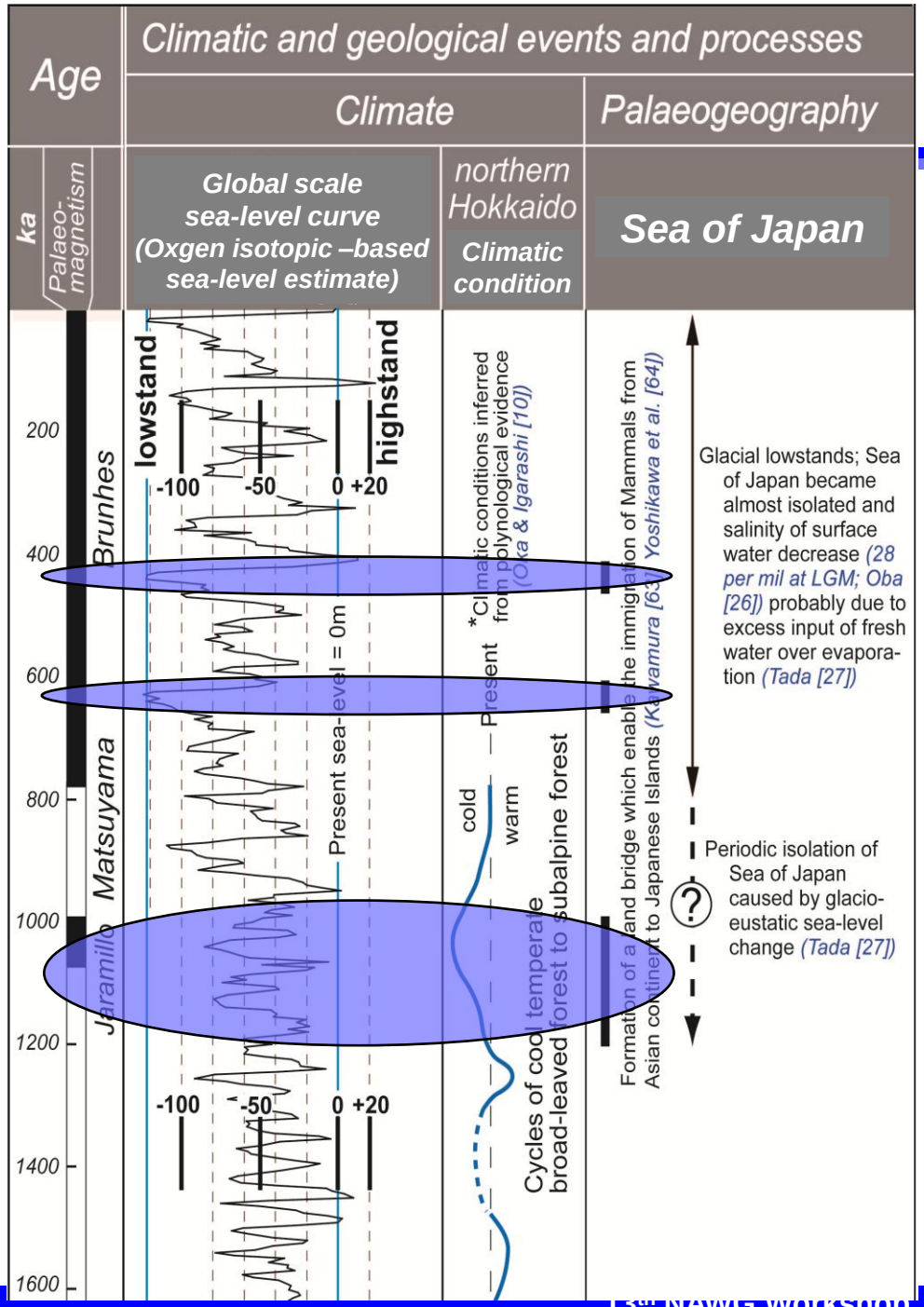


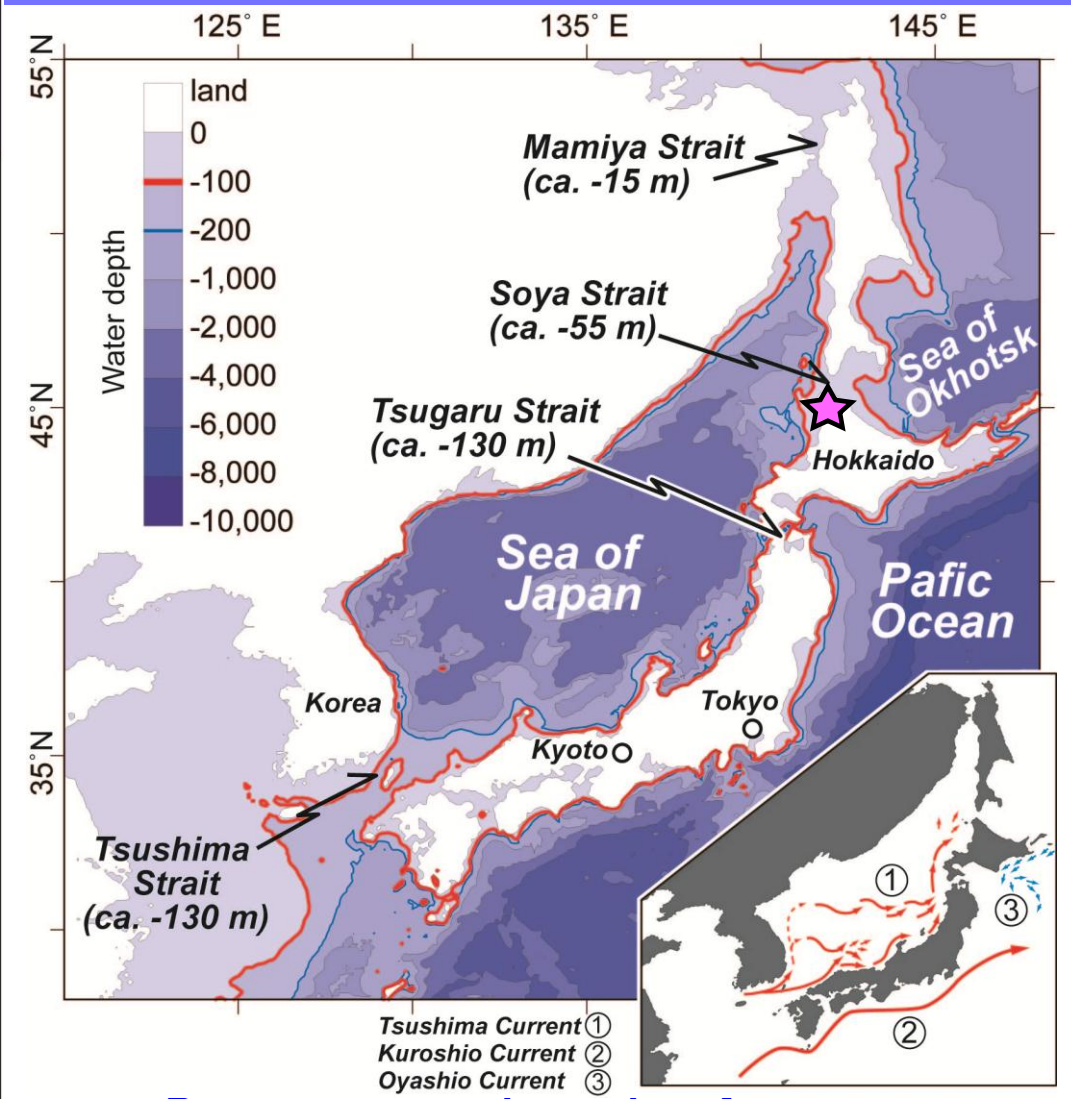


- ✓ Provenance analysis (gravel composition, palaeo-current)
- ✓ Distribution of geological structures
- ✓ Marine terrace (distribution, age)
- ✓ Submarine topography
- ✓ Global-scale sea-level change

- ● Westward expansion of the land since early Late Pliocene
- ● Transgression-regression cycle

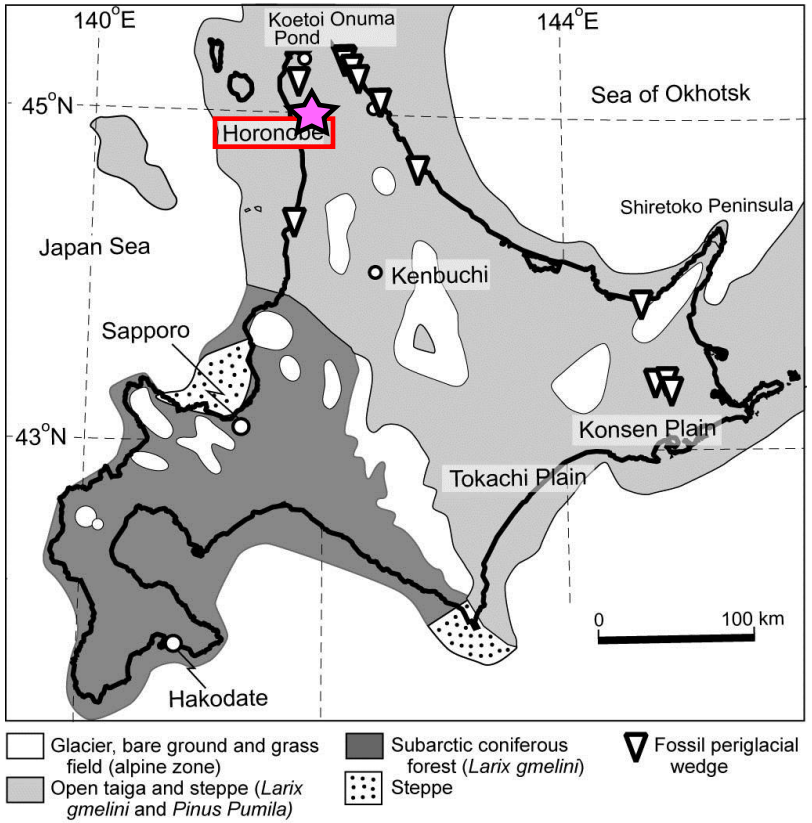
Present geography around Sea of Japan



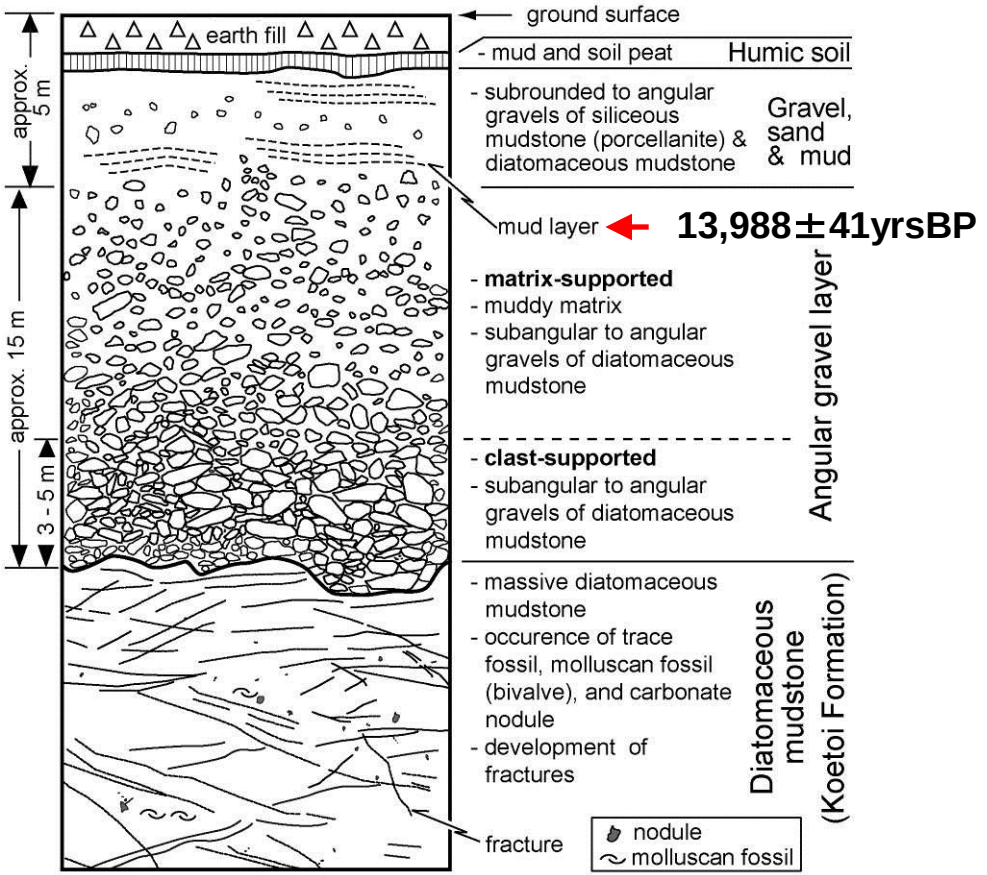


Present geography and surface ocean currents around Sea of Japan

Palaeo-vegetation and periglacial phenomena in the Last Glacial period



Palaeo-vegetation and fossil periglacial phenomena in the Last Glacial period



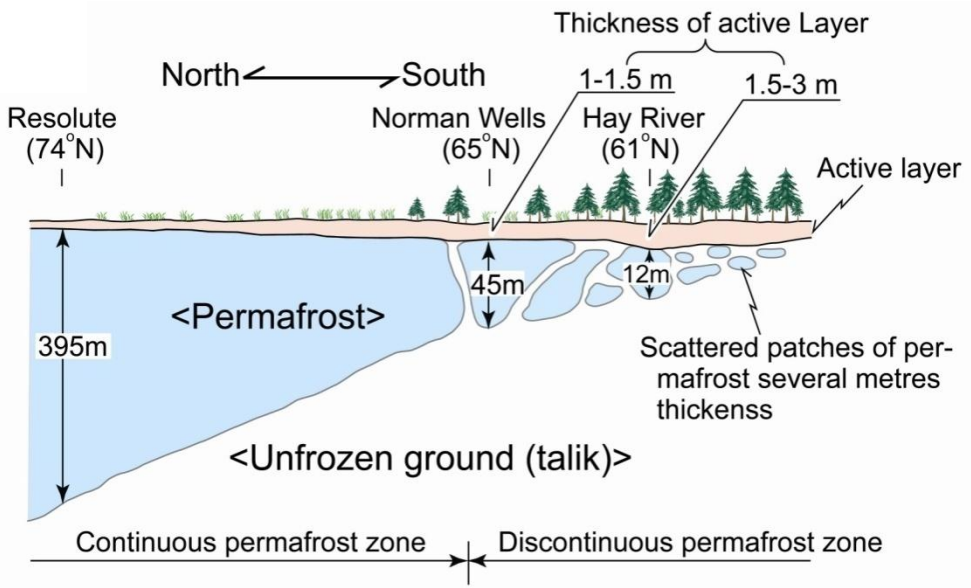
Angular gravel layer formed by periglacial phenomena

- ✓ **Palaeo-vegetation**
- ✓ **Fossil periglacial phenomena**
- ✓ **Depositional age**

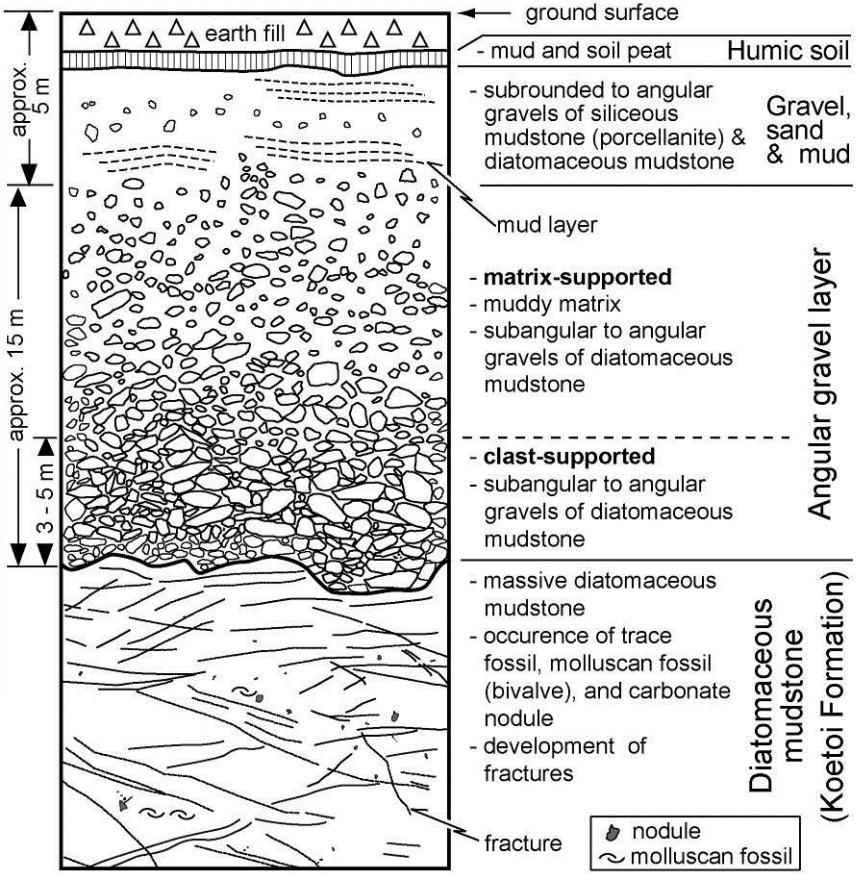
- ✓ **Northern Hokkaido was located at the northern margin of the discontinuous permafrost zone during the maximum cold stage of the Last Glacial period**

- ● **Physical weathering of surface rock material and decreasing of recharge rate will be expected in the future glacial period**

Permafrost in the Last Glacial period



North-South distribution of the permafrost in the present Canada



Angular gravel layer formed by periglacial phenomena

- ✓ **Palaeo-vegetation**
- ✓ **Fossil periglacial phenomena**
- ✓ **Depositional age**

→

- ✓ **Northern Hokkaido was located at the northern margin of the discontinuous permafrost zone during the maximum cold stage of the Last Glacial period**

→

- ● **Physical weathering of surface rock material and decreasing of recharge rate will be expected in the future glacial period**

Palaeoclimate in the late Last Glacial period

Palaeo-vegetation based on pollen analysis

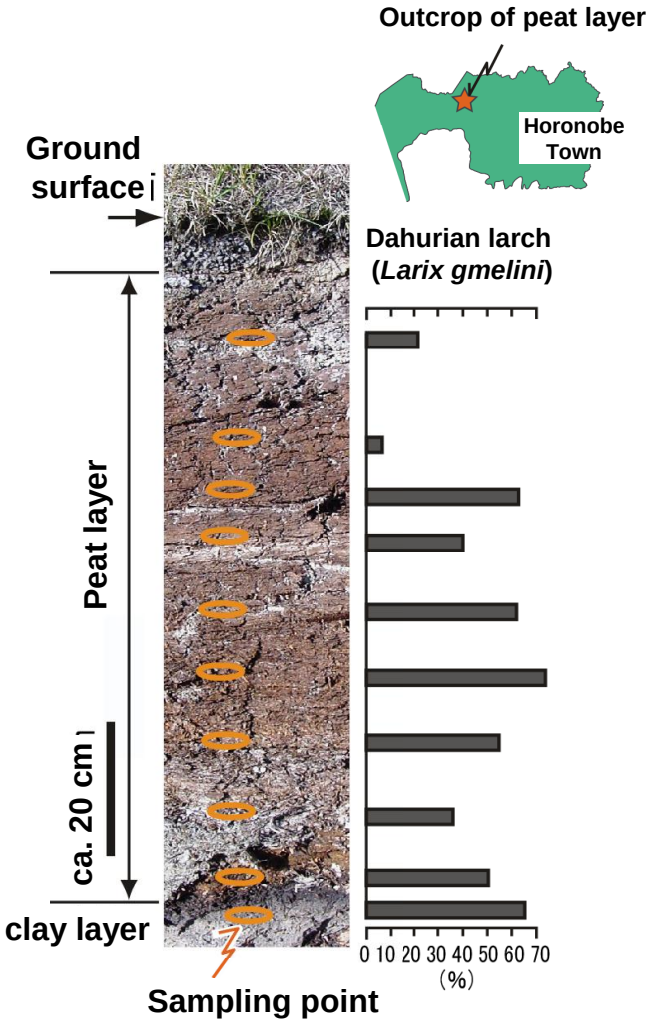
✓ Pure forest of *Larix gmellini (Dahurian larch) during the late Last Glacial period*

Estimation of palaeo-vegetation zone

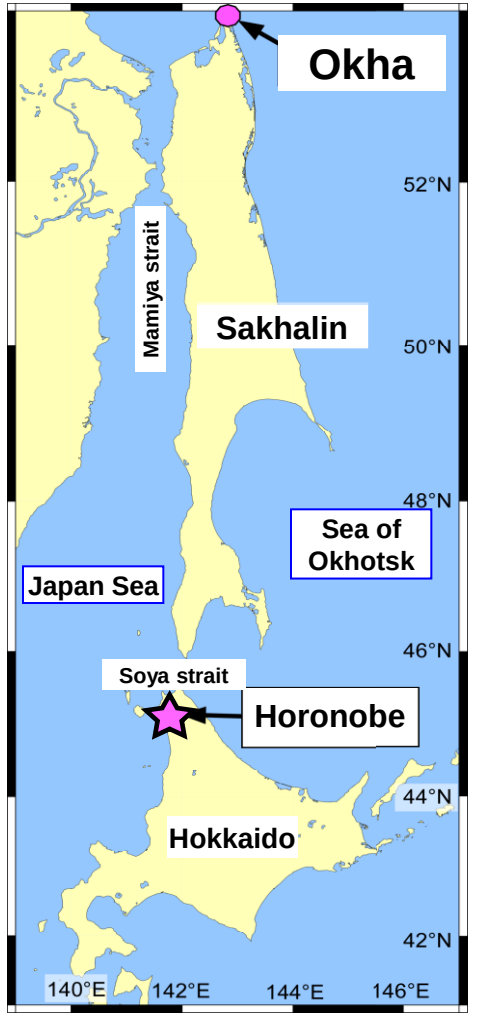
✓ Corresponding to sub-arctic coniferous forest distributed at Siberia in the present

Palaeo-climate condition during late Last Glacial period

- Annual average air temperature: dropping by more than 8℃ to the present
- Monthly average air temperature:
  - ✓ Winter: dropping by more than 12℃
  - ✓ Summer: dropping by more than 6℃
- Annual rainfall: dropping by more than ca.750～1,000mm

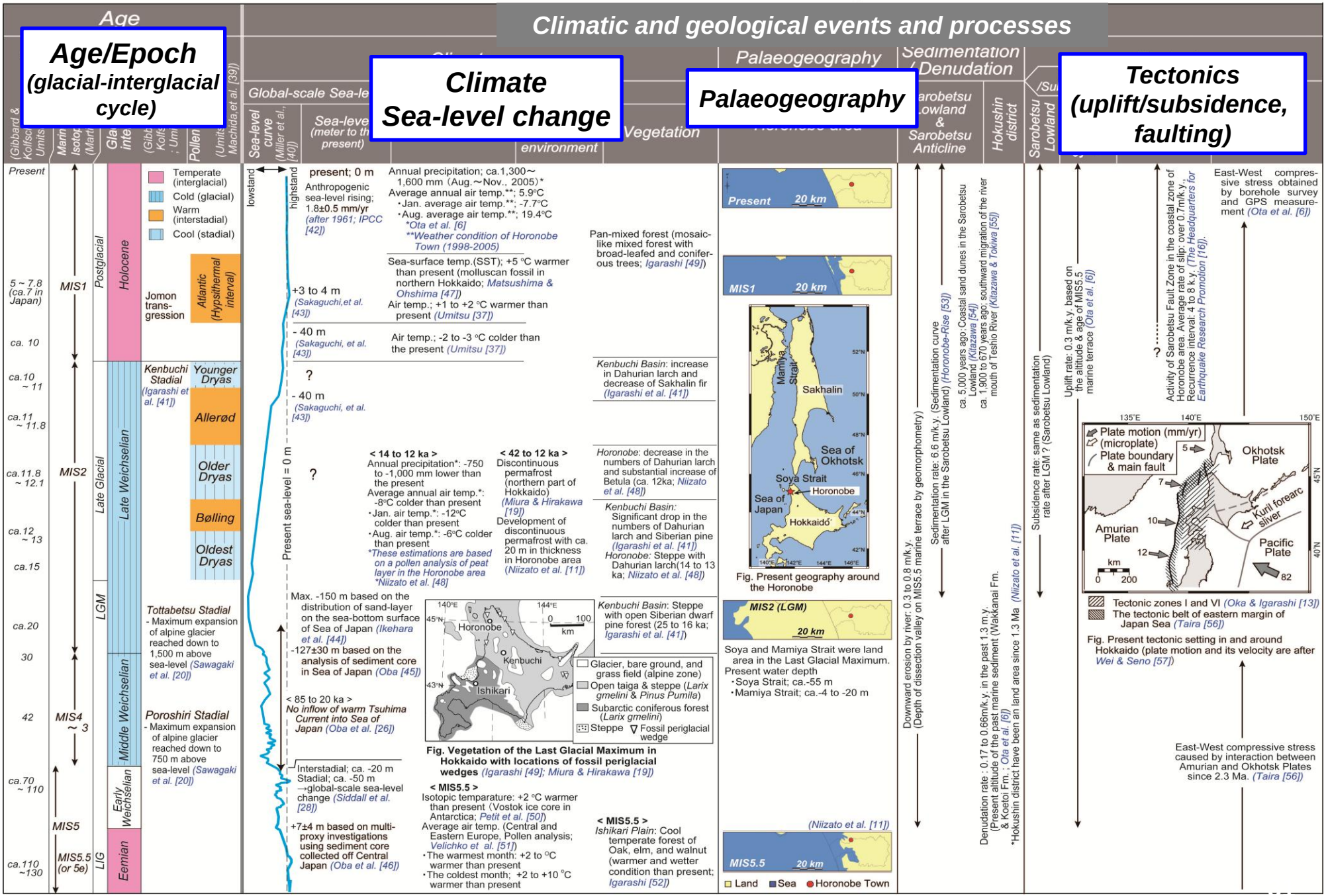


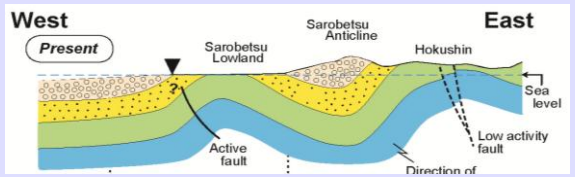
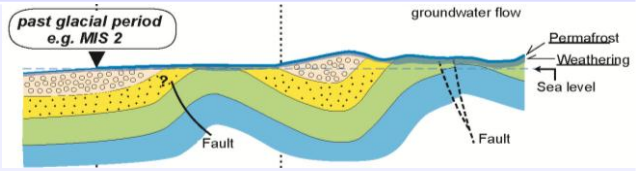
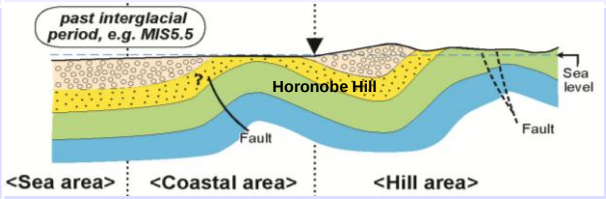
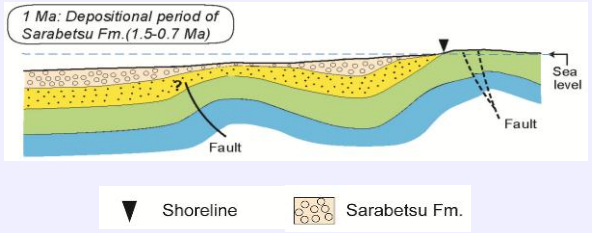
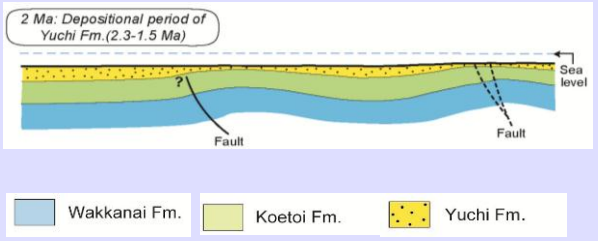
Pollen analysis of peat cropping out in the Horonobe area



Horonobe area and its surrounding sea

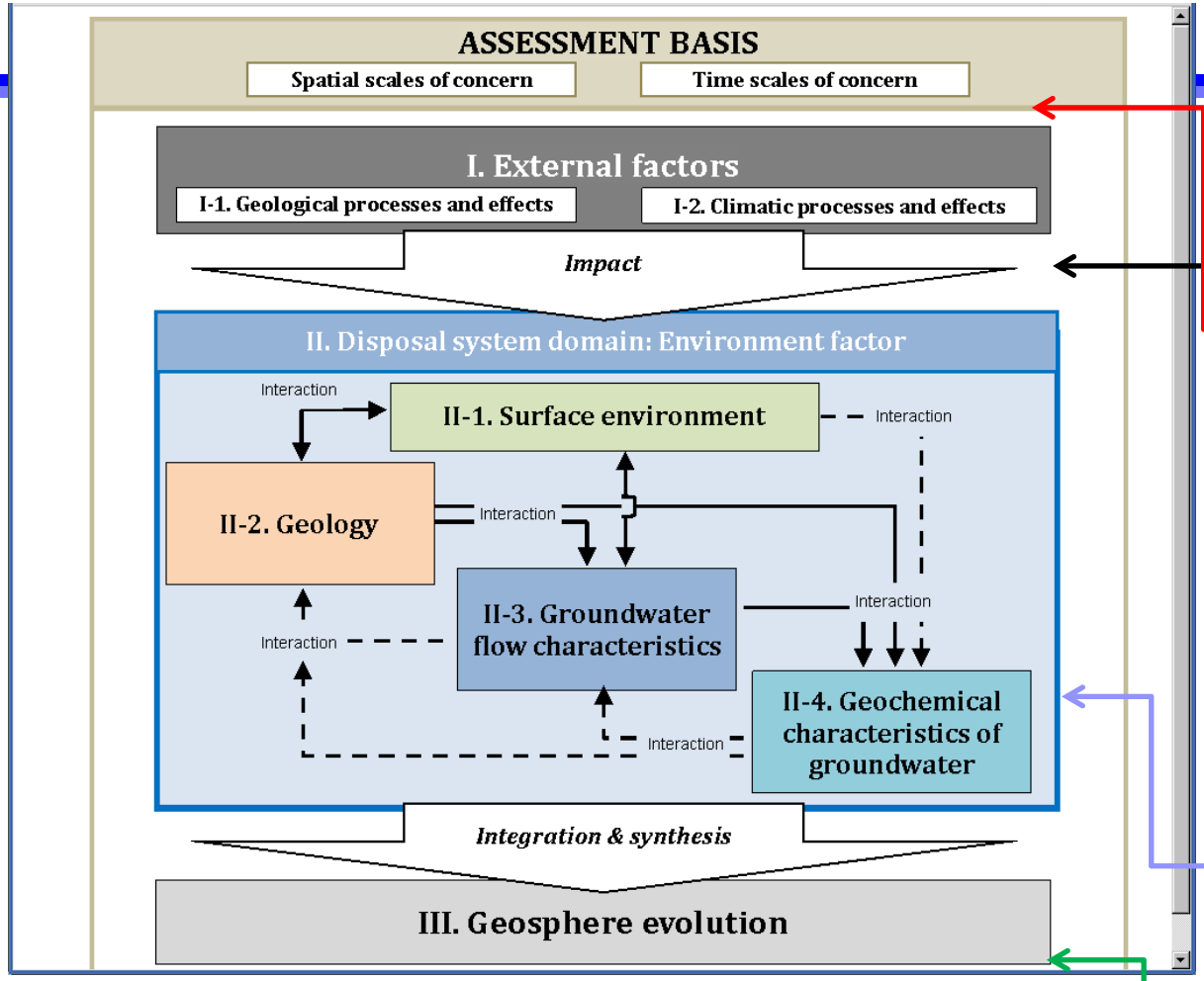
Table 1. Natural Events and Processes in the Coastal Field in the Horonobe Area, Hokkaido, Japan since 130 ka
LGM; Last Glacial Maximum, LIG; Last Interglacial.



Age	Geology	Descriptions
Present		**Events:** - Transgression by global-scale sea-level change - Deposition of alluvium with 40 to 80 m thickness in the Sarobetsu Lowland in the past 14ky (Sakai et al., 2011) **Features:** - Distribution of major fracture and minor fractures around the URL area (Ishii et al., 2011)
Last Glacial Maximum (ca. 1.8 ka)		**Events:** - Regression caused by global-scale sea-level change (Niizato et al., 2007) - Development of permafrost with 20 m in thickness in land (no data for sub-seabed permafrost)
Last Interglacial (ca. 125 ka)		**Events:** - Transgression caused by global-scale sea-level change (Niizato et al., 2007) - Initiation of Horonobe Hill due to differential erosion - Sea level: +7 m to the present (Oba et al., 2006)
ca. 1000 ka		**Events:** - Maximum burial of the Wakkanai, Koetoi, and Yuchi Formations in the present coastal area. See the results of subsidence analysis - Deposition of fluvial and lagoonal deposits in the coastal area (the present Sarabetsu Formation) - Periodical isolation of Sea of Japan caused by global-scale sea-level change (Tada, 1994) **Features:** - Sarabetsu Fomarion: geological anisotropy but no hydrogeological anisotropy (internal report of Geol. Survey of Hokkaido, 2009 in Japanese)
ca. 2000 ka		**Events:** - Initiation of the fault movement of the Sarobetsu Fault Zone in the present coastal area and of the Omagari Fault in the vicinity of the present URL area (Ito, 1999; Ishii et al., 2008). Such fault movement result in the formation of fold structure in the Horonobe area (Ishii et al., 2008) - Deposition of sand (the Yuchi Formation) and burial of siliceous rocks (the Koetoi and Wakkanai Formations in descending order) **Features:** - Burial depth of the Wakkanai Formation is ca. 2.5 – 1.5 km in the west and 1.9 – 0.9 km in the east based on the subsidence analysis (data source; AIST, 2006 and JNOC,1995), then the porosity is the range of ca. 30%? (deeper; JNOC, 1995) – 38% (1.5km; Fukusawa, 1987) – 46% (shallower; Fukusawa, 1987) - Wakkanai Formation: siliceous mudstone, Koetoi Formation: diatomaceous mudstone, Yuchi Formation: Sand (shallow marine environment)

FEPs-like database for Horonobe palaeohydrogeology (1/4)

Top page



Description of time and spatial frame

Natural events and processes in Horonobe area

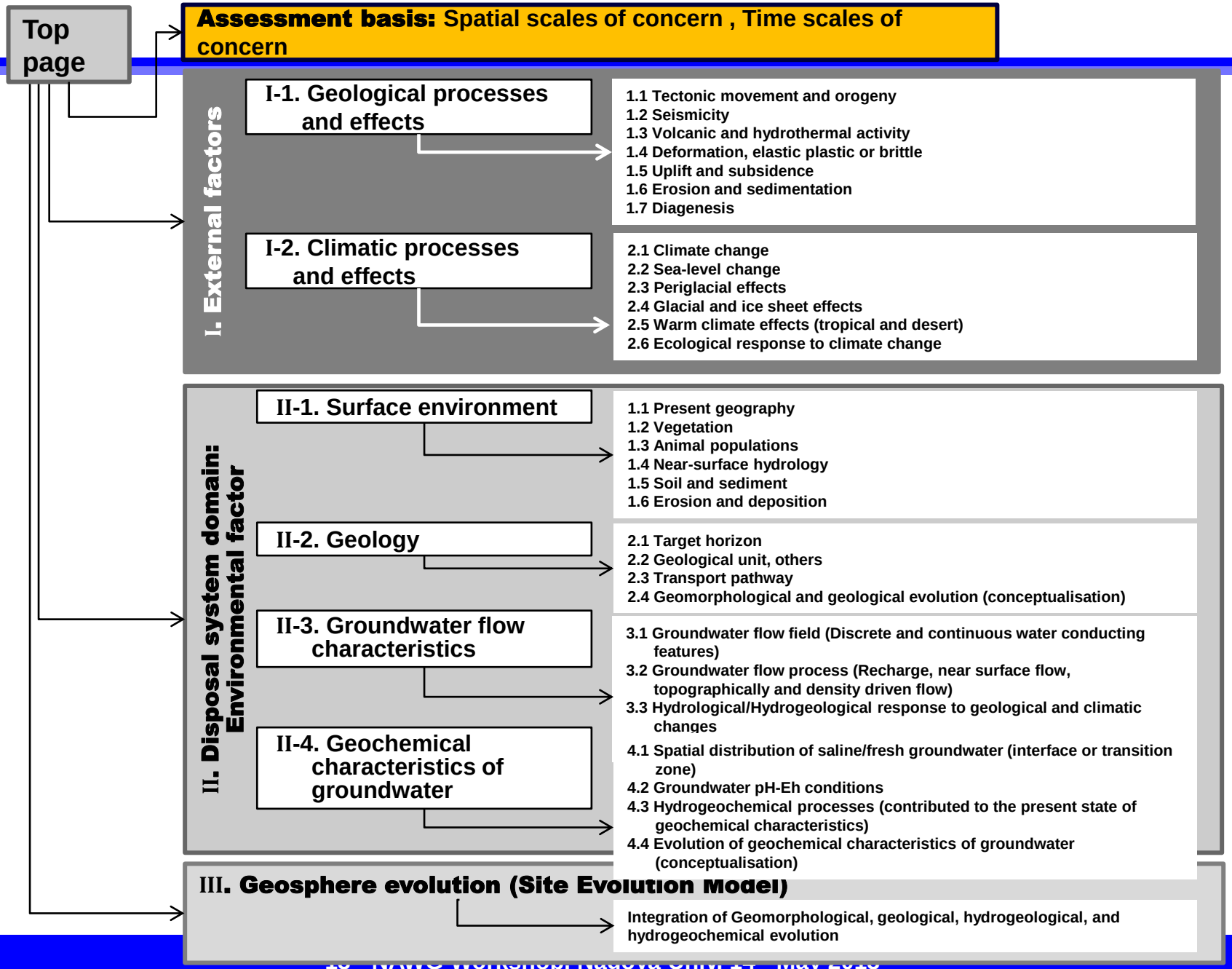
- Information on the characteristics of geological environments
- Site model of Horonobe area

Site evolution model in Horonobe area

Web-based data-structure

- ✓ This database do not intend to provide the full of raw data but outline of the properties and processes of geological environments (as FEPs report).
- ✓ This database will be able to prevent the data dispersion.
- ✓ Easily updatable (if you want to revise the data sheet, you have only to revise the relevant FEP sheet)
- ✓ Correspondence to Geosynthesis Data Flow diagram of Horonobe URL Project

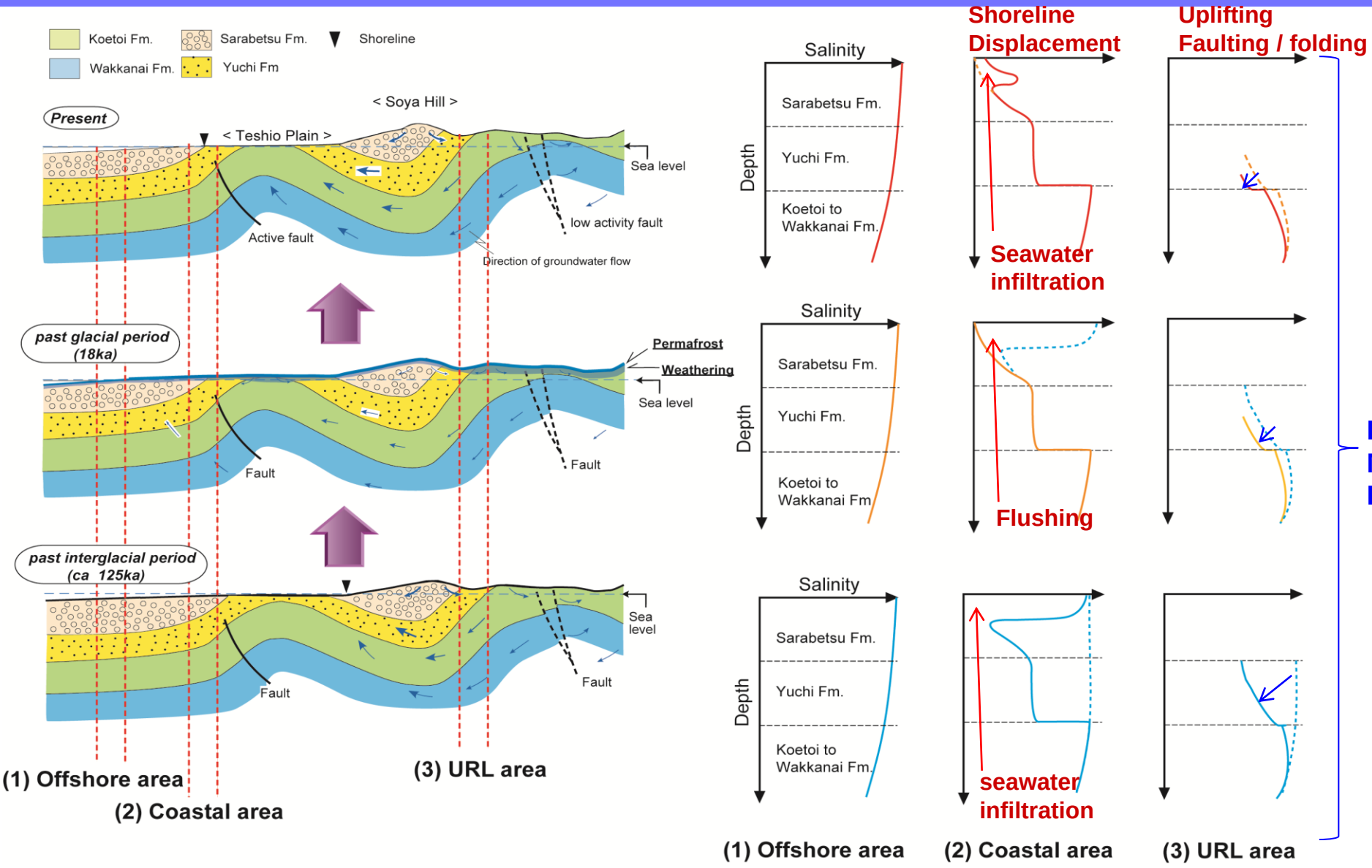
Structure of the FEPs-like database for Horonobe palaeohydrogeology (2/4)



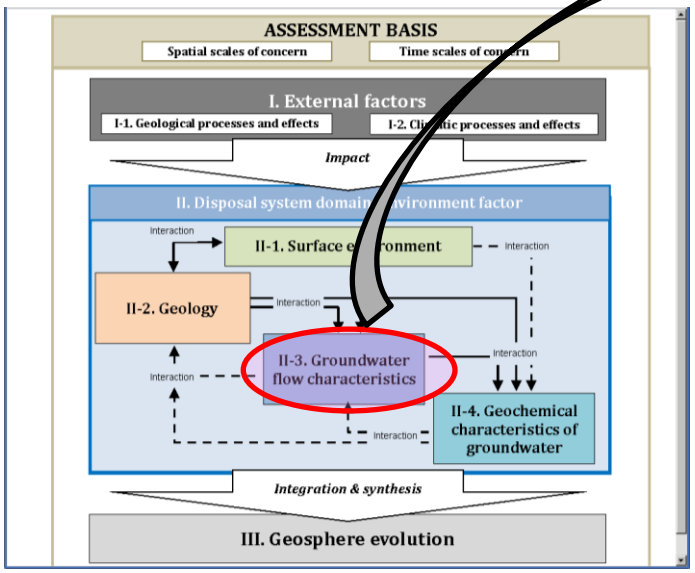
Description of uncertainties

Natural events & processes	Descriptions of uncertainty
Tectonics	Inhomogeneous nature of spatial distribution of uplift and subsidence
	Variations in the rate of uplift and subsidence
Topography	Height of mountain range in the past period
Hydrogeology	Variations of recharge rate through the Glacial-Interglacial cycles
	Changes in porosity and hydraulic conductivity over geological time
	Uncertainties about sea-levels in the Sea of Japan
	Uncertainties about location of former shoreline through the past glacial-interglacial cycles
Hydrogeochemistry	Variations in seawater chemistry (especially salinity and stable isotopes)
Hydrogeology & Hydrogeochemistry	Degree of coverage of the permafrost (i.e. just how discontinuous is discontinuous?) around the northern end of the Sea of Japan

Palaeohydrogeological Conceptual Model



FEPs-like database for the Horonobe palaeohydrogeology (3/4)



SOJ Framework (II-3)

FEPs number is after NEA (2000)"Features, Events and Processes (FEPs) for Ge

<OVERVIEW>

3 Groundwater Flow Characteristics

Correspondent FEPs no. 2.2.07 Hydraulic/hydrogeological processes and c

FEPs related to the hydraulic and hydrogeological processes that affect the host rock ar evolution of conditions with time. This includes the effects of changes in condition, excavation, construction and long-term presence of the repository.

3.1 Groundwater Flow Field

Water Conducting Features

(1) Inventory of Discrete Water Conducting Features

- **Major Faults**: Omagari Fault, Horonobe Fault, Sarobetsu Fault Zone
- **Minor Faults**

(2) Inventory of Continuous Water Conducting Features (geological for

- **Al** : Alluvium & Terrace deposits
- **Sb** : Sarabetsu Formation
- **Yc** : Yuchi Formation
- **Kt** : Koetoi Formation
- **Wk** : Wakkanai Formation
- **Mi** : Miocene (except for Wk)
- **Cr**: pre-Tertiary

3.2 Groundwater Flow Process

Potential Processes

- Recharge
- Near surface flow
- Topographically driven flow
- Density driven flow

3.3 Hydrological/Hydrogeological Response and Climatic Changes

FEPs no. 1.2.10 Hydrological/hydrogeological response to geological char

FEPs arising from large-scale geological changes. These could include changes of hydr to effects of erosion on topography, and changes of hydraulic properties of geological uni

<FEPs SHEETs>

3.1 Groundwater Flow Field

Water Conducting Features

(1) Inventory of Discrete Water Conducting Features

(a) Omagari Fault

Description/interpretation	The Omagari Fault has a fault zone, about 120 m wid, that consists mainly of the damage zone, and has a permeable structure. The magnetotelluric survey shows several high-resistivity zones, one of which corresponds to the Omagari Fault inferred from the reflection seismic surveys. The high resistivity zones are correlative with the concentration zones of low-saline water, which suggests infiltration of groundwater through the permeable Omagari Fault zone. Please input the description
Source Da	Ishii et al. (2006) Three-dimensional distribution and hydrogeological properties of the Omagari Fault in the Horonobe area, northern Hokkaido, Japan., Jour.Geol.Soc.Japan, vol.112, pp.301-314. *(Japanese with English abstract)* *Method:* - Geometry of Omagari Fault: Surface geological survey, borehole geological survey, geophysical investigation - Direction of principle stress: Multiple inverse method
	Ishii, E., 2011. *JAEA_Research_2010-068_HOR-PhaseI_4.1_Geology* *Method: xxx*
	Ishii and Fukushima *Method: xxx*
Assumptions/premise	Geological characteristics of the Omagari Fault in the Horonobe URL area (northern part of the Horonobe Town) is same as that of the Fault in the southern part of the Horonobe Town.
Uncertainty	
References	Caine, et al. (1996) Petit (1987) Yamaji (2000)
Comments	
Correspondent FEPs (NEA 2000)	**1.2.02 Deformation, elastic, plastic or brittle** FEPs related to the physical deformation of geological structures in response to geological forces. This includes faulting, fracturing, extrusion and compression of rocks.
	2.2.04 Discontinuities, large scale The processes by which deposited sediments at or near the Earth's surface are formed into rocks by compaction, cementation and crystallisation, i.e. under conditions of temperature and pressure normal to the upper few kilometres of the earth's crust.

FEPs-like database for the Horonobe palaeohydrogeology (4/4)

SOJ Framework (II-3)

FEPs number is after NEA (2000) "Features, Events and Processes (FEPs) for Geologic Disposal of Radioactive Waste."

<OVERVIEW>

3 Groundwater Flow Characteristics

Correspondent FEPs no. 2.2.07 Hydraulic/hydrogeological processes and conditions

FEPs related to the hydraulic and hydrogeological processes that affect the host rock and other rock units, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g. hydraulic head, due to the excavation, construction and long-term presence of the repository.

3.1 Groundwater Flow Field

Water Conducting Features

(1) Inventory of Discrete Water Conducting Features

- Major Faults: Omagari Fault, Horonobe Fault, Sarabetsu Fault Zone
- Minor Faults

(2) Inventory of Continuous Water Conducting Features (geological formations/facies)

- Al : Alluvium & Terrace deposits
- Sb : Sarabetsu Formation
- Yc : Yuchi Formation
- Kt : Koetoi Formation
- Wk : Wakkanai Formation
- Mi : Miocene (except for Wk)
- Cr: pre-Tertiary

3.2 Groundwater Flow Process

Potential Processes

- Recharge
- Near surface flow
- Topographically driven flow
- Density driven flow

3.3 Hydrological/Hydrogeological Response to Geological and Climatic Changes

FEPs no. 1.2.10 Hydrological/hydrogeological response to geological change

FEPs arising from large-scale geological changes. These could include changes of hydrological boundary conditions due to effects of erosion on topography, and changes of hydraulic properties of geological units due to changes in rock stress or fault movements.

FEPs no. 1.3.07 Hydrological/hydrogeological response to climate change

FEPs related to changes in hydrology and hydrogeology, e.g. recharge, sediment load and seasonality in response to climate change in a region.

Response to geological change

- Fluid generation: gas
- Volume change: porosity change (compaction & diagenesis), density change (thermal and pressure dependent)
- Permeability change: compaction & diagenesis (cementation), cataclasis / fault smear

Response to climate change

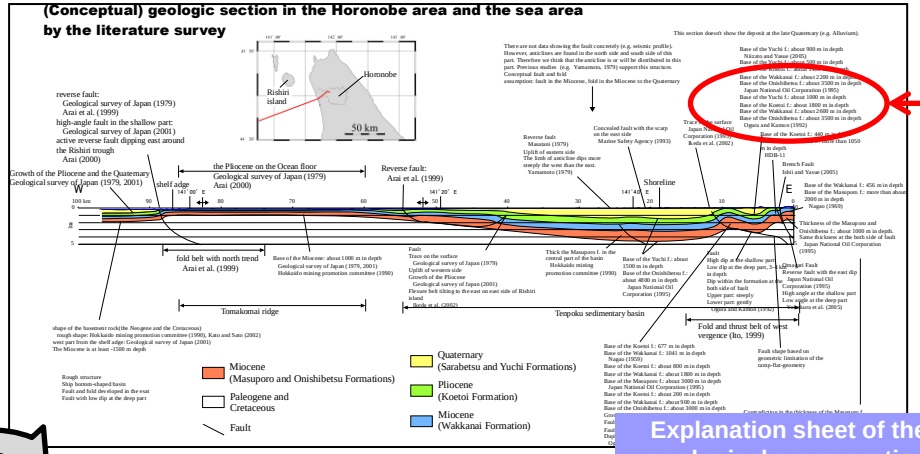
- Recharge rate
- Recharge and discharge area
- Hydraulic gradient

3.4 Evolution of Groundwater Flow Characteristics (conceptualisation)

- Xxx

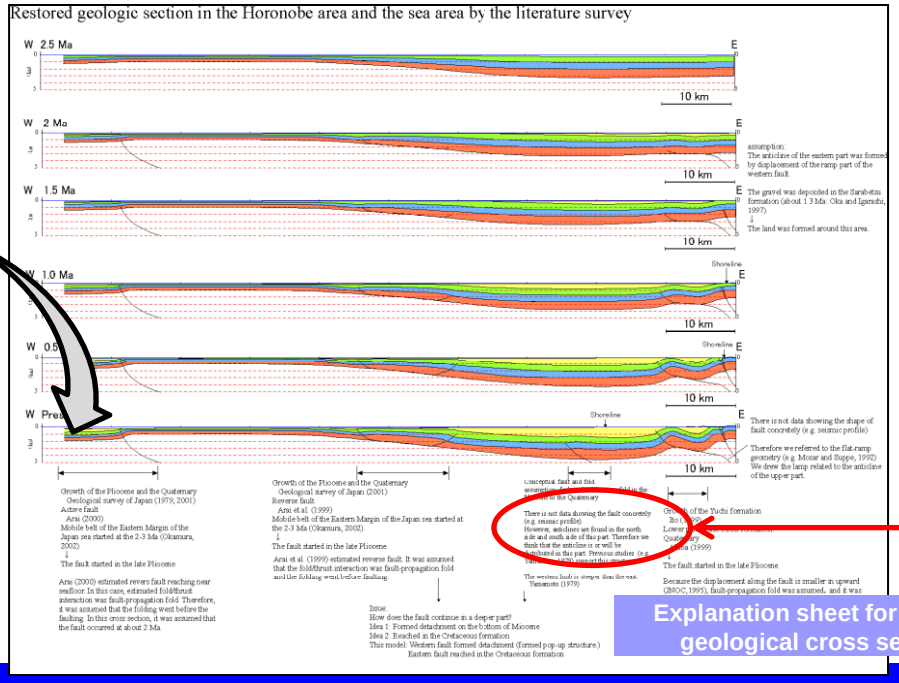
<Explanation sheet of conceptual model>

(Conceptual) geologic section in the Horonobe area and the sea area by the literature survey



Explanation sheet of the geological cross section

Restored geologic section in the Horonobe area and the sea area by the literature survey



Explanation sheet for restored geological cross sections

Description of the data source for modelling

Modularization of the groundwater flow simulation

Module 1: Sequential restoration of geological structure

- ✓ Balanced cross-section method
- ✓ Subsidence analysis
- ✓ Analogue model experiment

Module 2: Parameter setting

- ● Variation of Hydraulic parameters of each hydrogeological unit with time
  - ✓ Hydraulic conductivity
  - ✓ Specific storage
  - ✓ porosity
- ● Variation of recharge rate associated with climate change

Input : Boundary and initial conditions

Input : Geosphere evolution

Module 3: Data-transfer

- ✓ This module relate a sequential restoration of the geological structure to a analysis mesh
- ✓ Transferring the previous analytical results to the next time-step.and setting the hydraulic parameters in the each time-step

Module 4:
Saturated-unsaturated unsteady groundwater flow simulation

Advection-dispersion transport analysis (Dtrans-3D･EL; Finite element method)

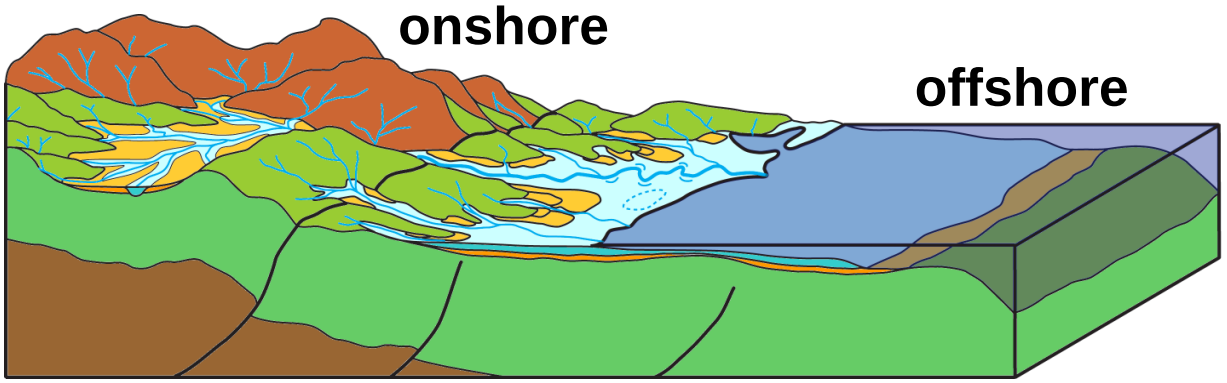
Long-term Groundwater Flow Simulations

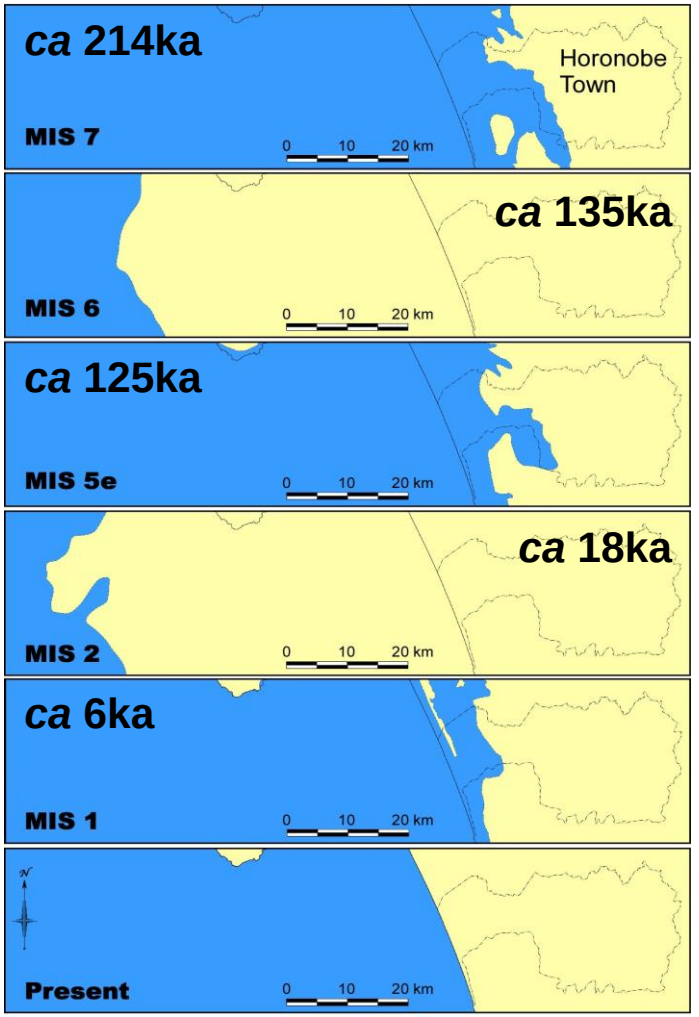
- *Geology*
  - Evolution of geological structure: Vertical 2D model
  - Rate of crustal movement (uplift, etc.): the same order of magnitude as the rate estimated by geo-history analysis

- *Hydrogeology*
  - Hydrogeological unit is almost the same as the geological unit
  - Porous media, no consideration of hydraulic anisotropy
  - Hydraulic parameters is based on the output of hydrogeological investigation
  - Major faults are assumed to have higher hydraulic conductivity than surrounding sedimentary formations (act as permeable faults)

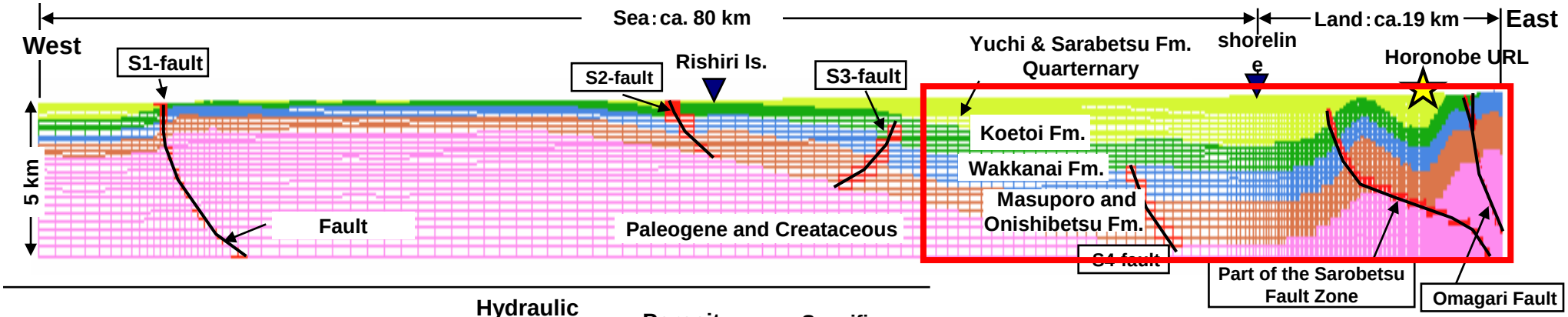
Boundary conditions

- Relevant implementation stage: PI – (DI)
- Relevant disposal concept: offshore and onshore disposal
- Investigation area: shallow marine to recharge – discharge area
- Characterisation depth: *~2,000* m
- Timeframe: 2Ma ~ present

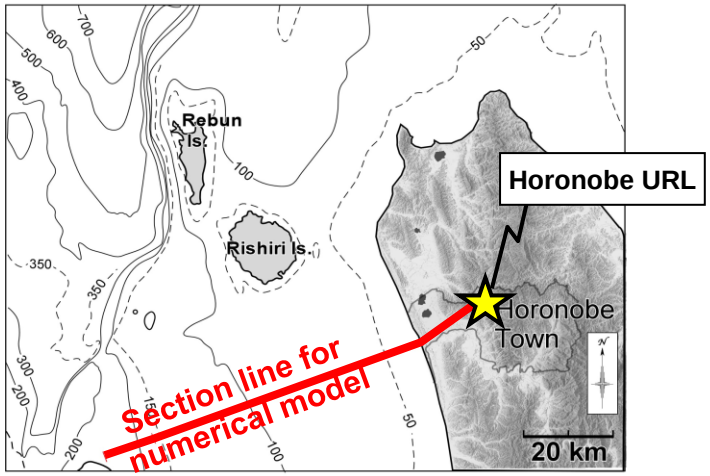




Modell Setting (1)



Units	Hydraulic conductivity (m/s)	Porosity (%)	Specific storage (1/m)
Surface deposits (ca. 10 m depth from surface)	1.0E-06	60	1.0E-05
Yuchi & Sarabetsu Fm. and Quaternary	*Depth_Yt* *	60	1.0E-05
Koetoi Formation	*Depth_Kt* *	60	1.0E-05
Wakkanai Formation	*Depth_Wk* *	40	1.0E-05
Masuporo & Onishibetsu Fm.	5.0E-10	30	1.0E-05
Paleogene & Cretaceous	1.0E-11	20	1.0E-05
Faults (Omagari Fault, part of the Sarobetsu Fault Zone, and S1- to S4-faults)	1.0E-07	50	1.0E-05



*** *Depth_Yt*, *_Kt*, and *_Wk* are hydraulic conductivities of each formation as a function of depth. K: hydraulic conductivity (m/s), Z: depth (m)**

***Depth_Yt* : $log_{10}(k) = - 0.0034Z - 8.3665$** [upper limit : 1 x 10^{-8} m/s, lower limit : 1 x 10^{-11} m/s]

***Depth_Kt* : $log_{10}(k) = - 0.0039Z - 7.5935$** [upper limit : 1 x 10^{-7} m/s, lower limit : 1 x 10^{-11} m/s]

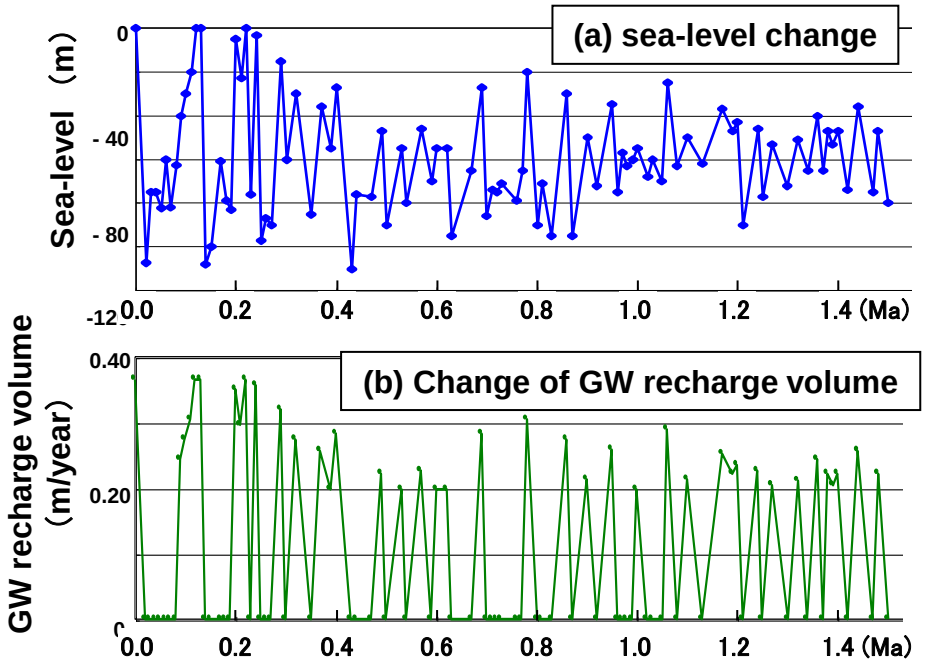
***Depth_Wk* : $log_{10}(k) = - 0.0061Z - 5.5626$** [upper limit : 1 x 10^{-6} m/s, lower limit : 1 x 10^{-11} m/s]

Modell Setting (2)

Simulation case

✓ **Period of simulation is past 1.5 million years, Unsteady analysis, vertical 2-dimentional analysis**

Variant	Case 1	Case 2	Case3
Sea-level, groundwater recharge volume (same as present topography and geological structure)	○	○	○
Evolution of topography & geological structure (Time step : ten thousand year)	×	○	○
Hydraulic conductivity (assumed that hydraulic conductivity at 1.5Ma is higher than that at present)	×	×	○

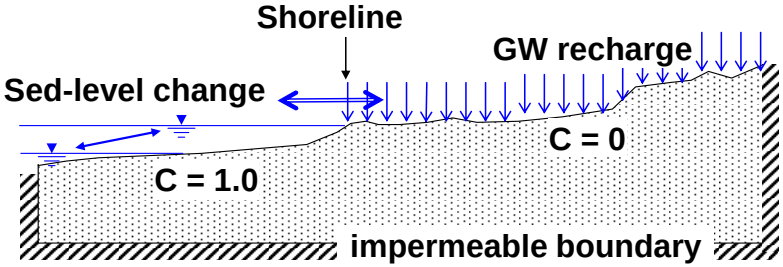


Initial conditions

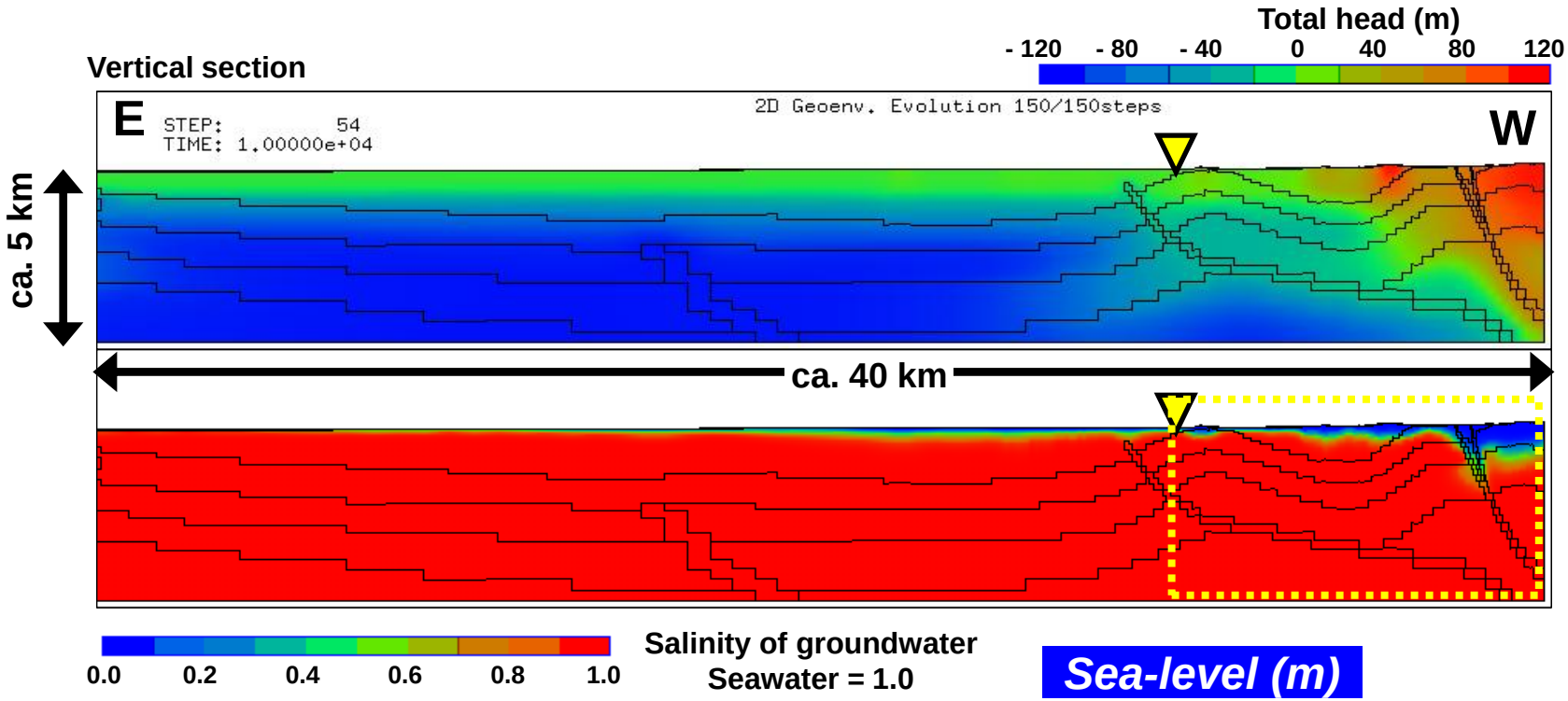
✓ **GW flow simulation: Distribution of hydraulic head at 1.5 Ma (steady-state analysis with the sea-level, GW recharge rate, and geological structure at 1.5 Ma)**

✓ **GW salinity: Entire simulation area was sea at 1.5 Ma based on the palaeogeography, and hence salinity was same as sea water at 1.5Ma in the area.**

Boundary conditions



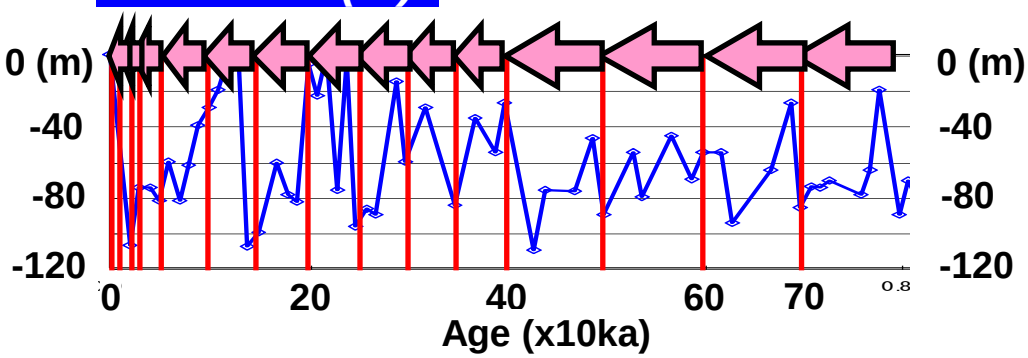
Simulation Results



Total head (m)

Salinity of groundwater

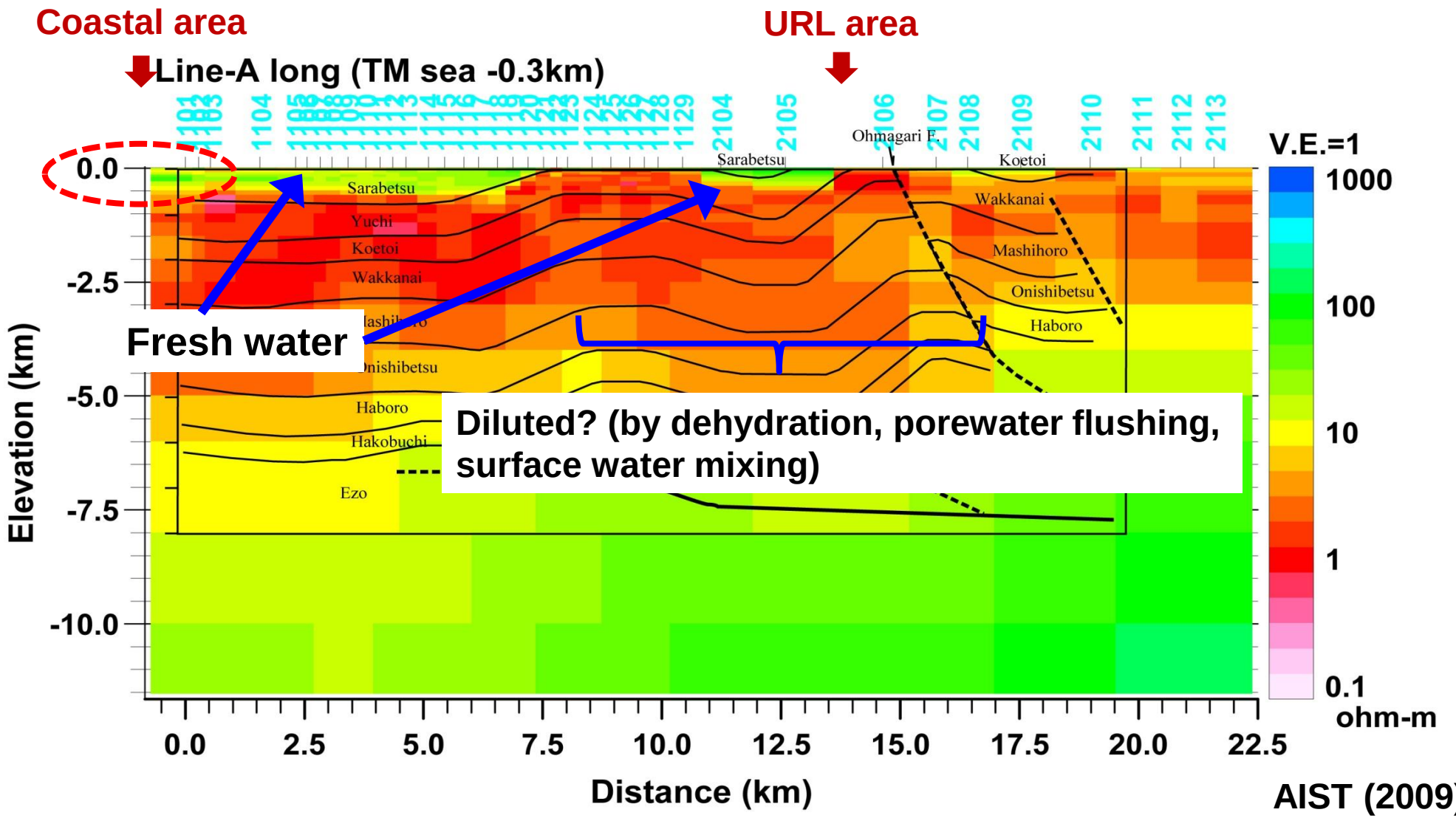
Sea-level (m)



Case 2 :

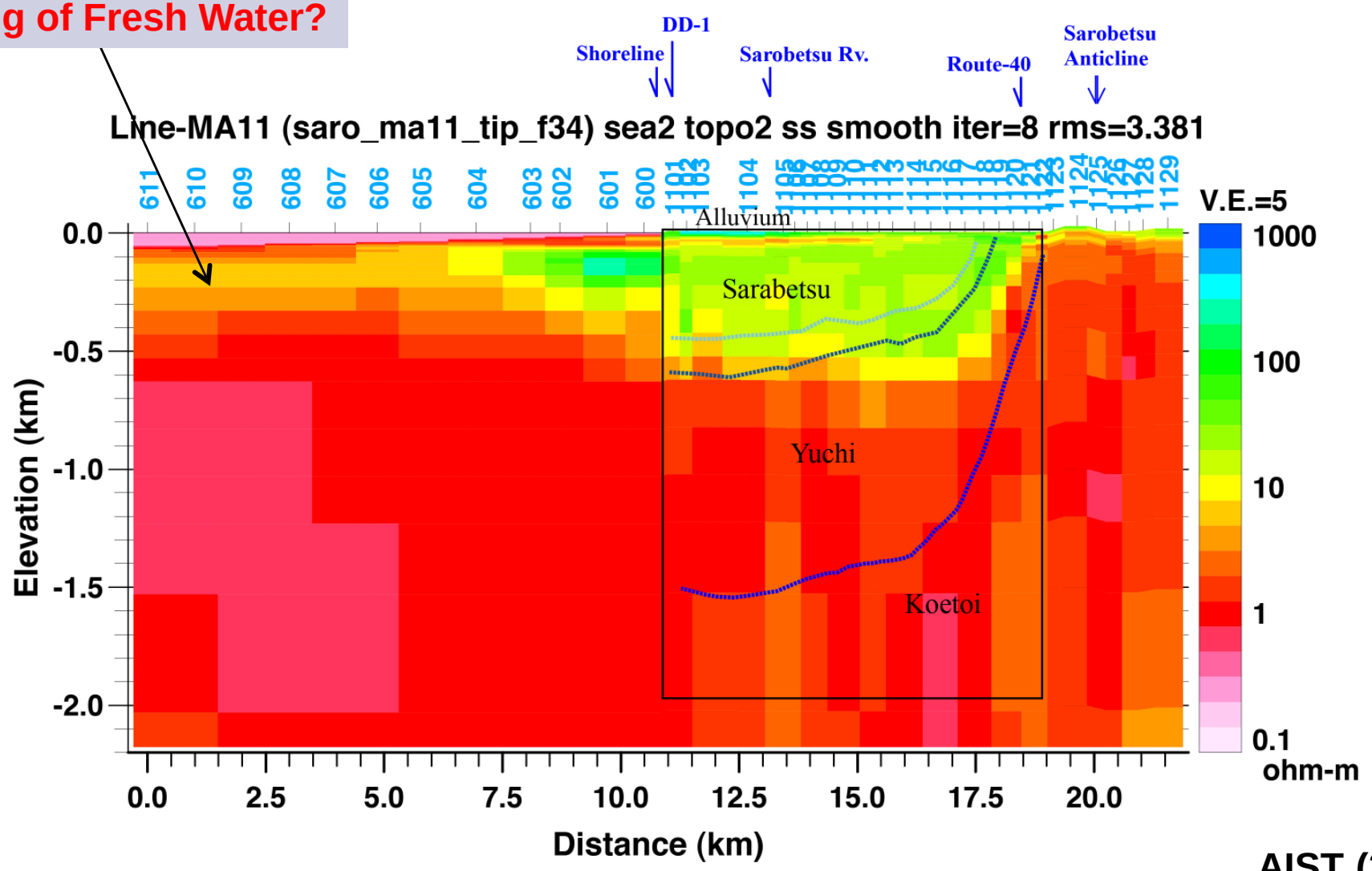
- Sea-level, change of groundwater recharge volume ····· Considered
- Evolution of geological structure··· Considered

Resistivity Profile by MT Survey (2009)



Sea-ward Expansion of Exploration Lines (2012)

Existing of Fresh Water?



AIST (2012)

Conclusions

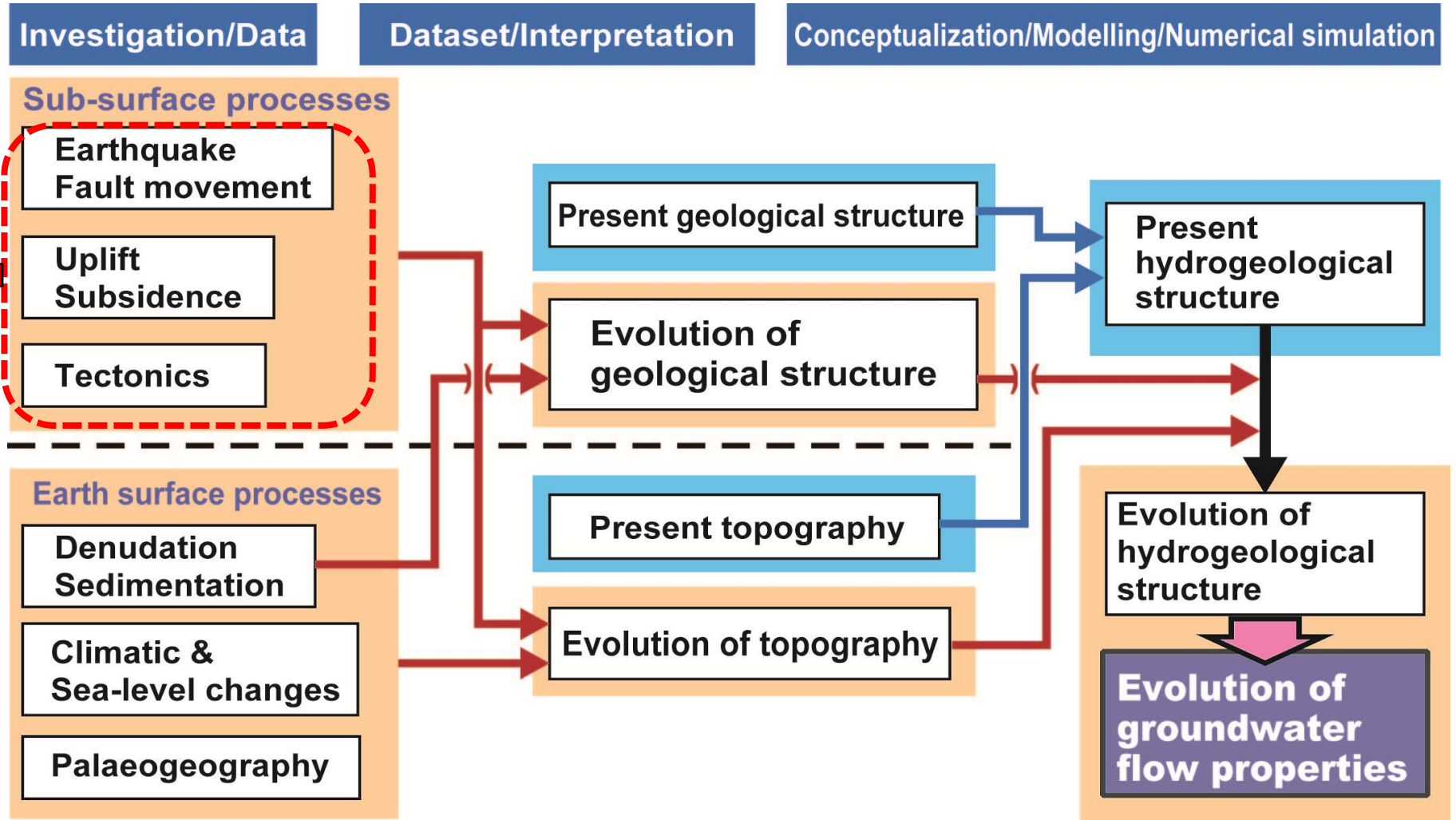
- A palaeohydrogeological conceptual model in the coastal area around the Horonobe was constructed suitably (i.e. without inconsistency) based on the available existing information.
- Although this model might be primitive and hence with considerable uncertainty, major hydrogeological and hydrochemical impacts caused by natural events and processes were identified for future long-term groundwater flow simulations.
- The results could be foundational information for putting forward to evaluate long-term geological stability in a realistic way.

Issues to be Solved and Future Activities

- To validate and refine this approach by using the actual coastal borehole data (AIST DD-1 borehole, 1,500m)

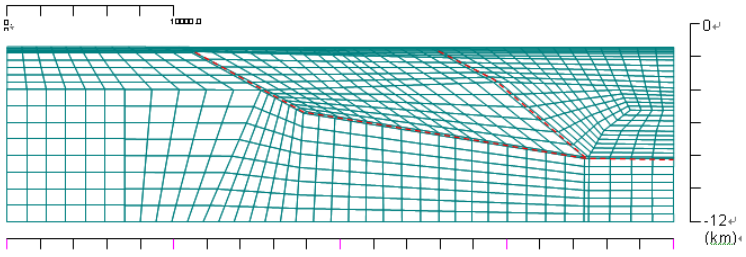
- Uncertainty analyses and their impact on safety assessment including extreme scenario case (eg. exceeds maximum regression and transgression levels)

Data Flow Diagram for Constructing Palaeohydrogeological Modell

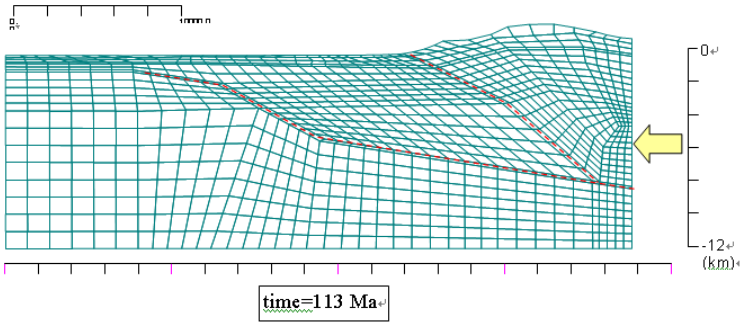


Numerical code modification was completed in FY2012.

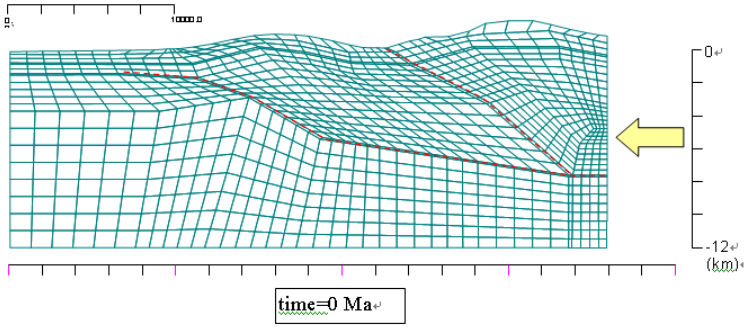
Deformed mesh systems with balanced cross sections



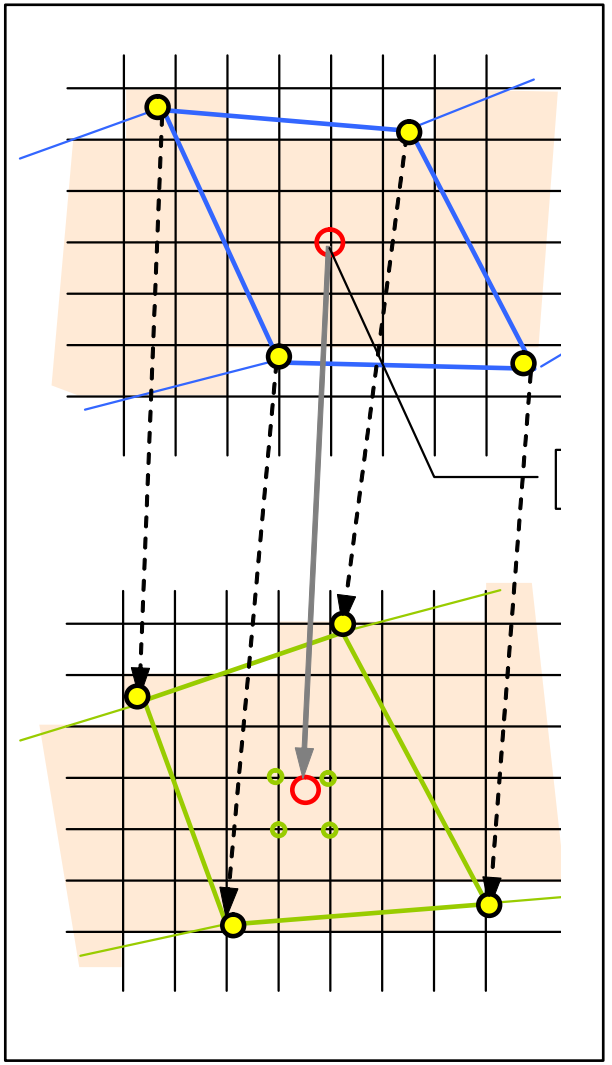
Time=2.3Ma

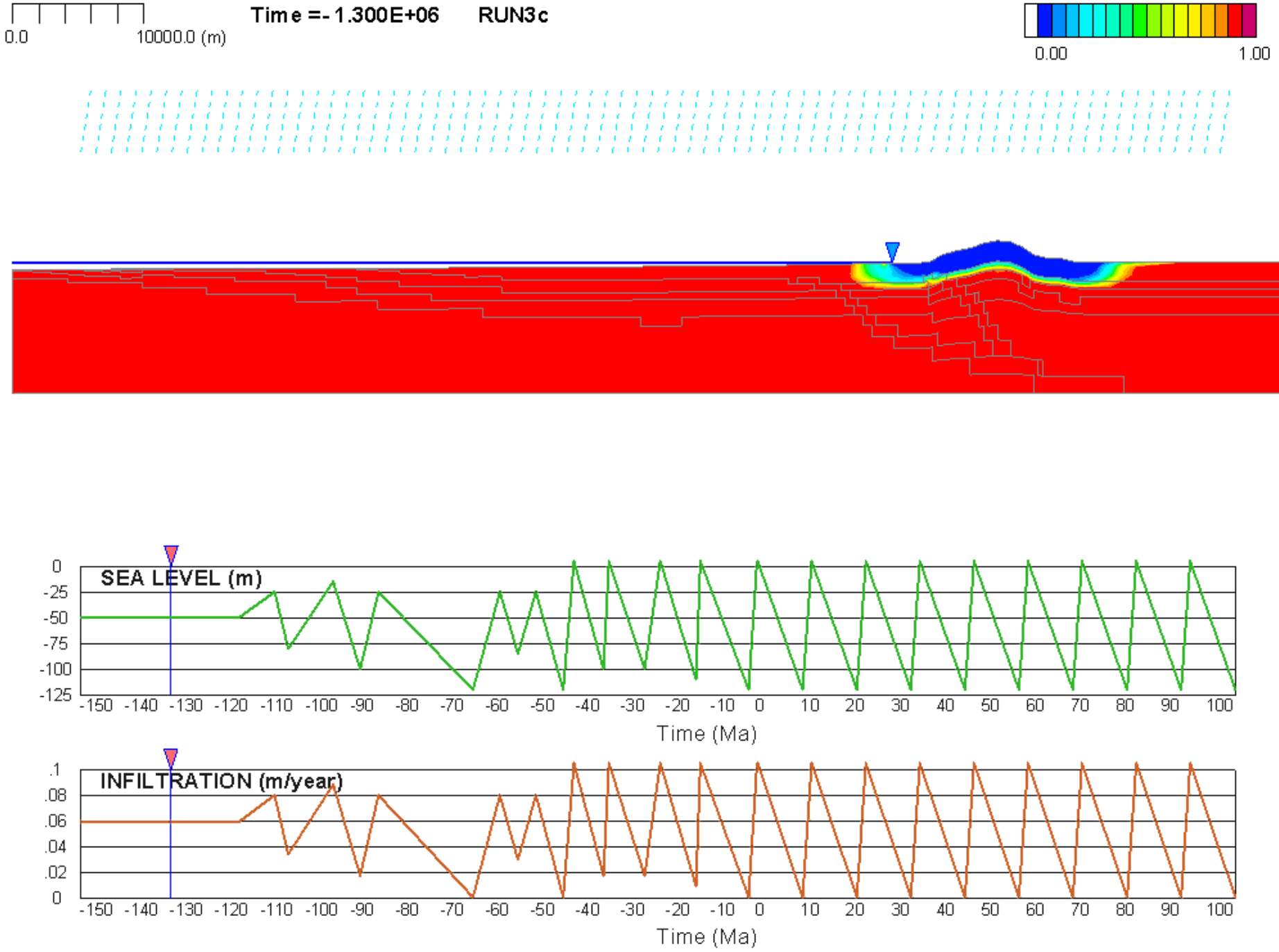


Time=1.14Ma



Time=0.0Ma




0.0
10000.0 (m)
Time =- 1.300E+06
RUN3c
0.00
1.00
SEA LEVEL (m)
0
-25
-50
-75
-100
-125
-150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
Time (Ma)
INFILTRATION (m/year)
.1
.08
.06
.04
.02
0
-150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
Time (Ma)