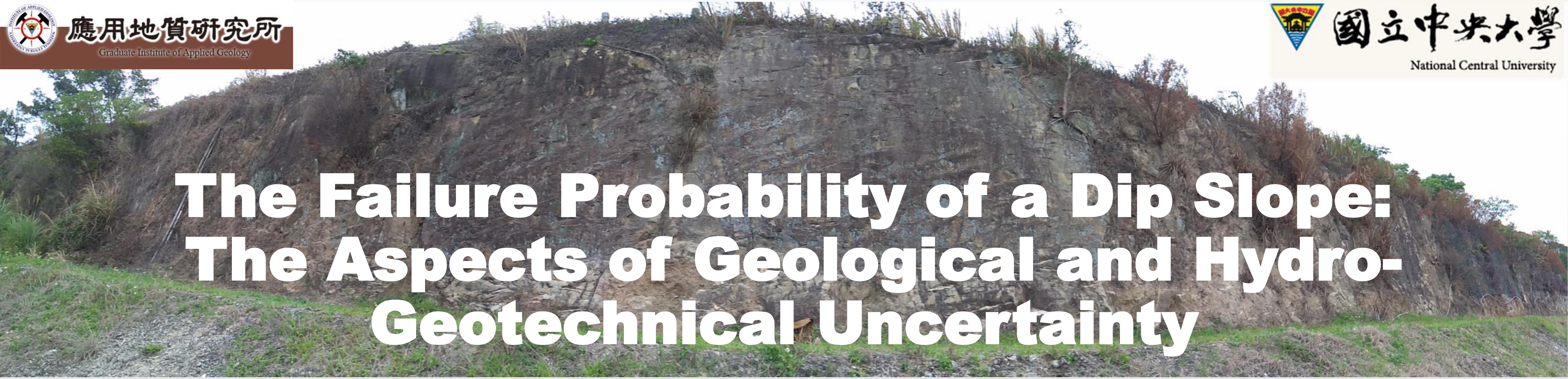

The Failure Probability of a Dip Slope: The Aspects of Geological and Hydro-Geotechnical Uncertainty

Geological Condition

Possibility Of Rock Mass Movement Below Main Campus

Hydrogeological Condition and Multi-Tank Model of M1

Presenter:

Alvian Rizky Yanuardian 楊安庭

109684601

Advisor:

Prof. Jia-Jyun Dong

April 15, 2022

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Introduction

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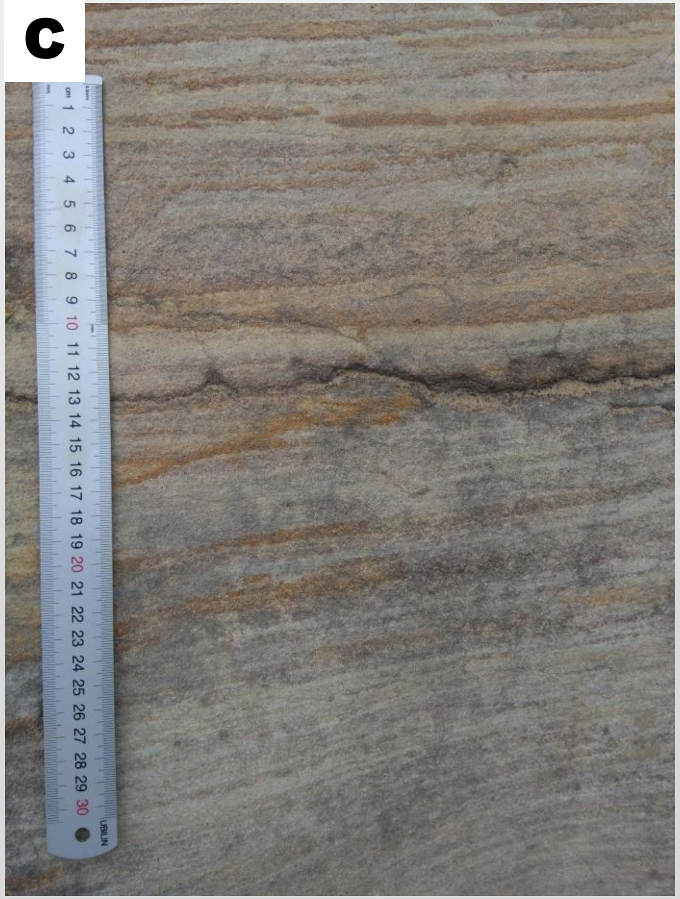
What do we face in NYCU ???

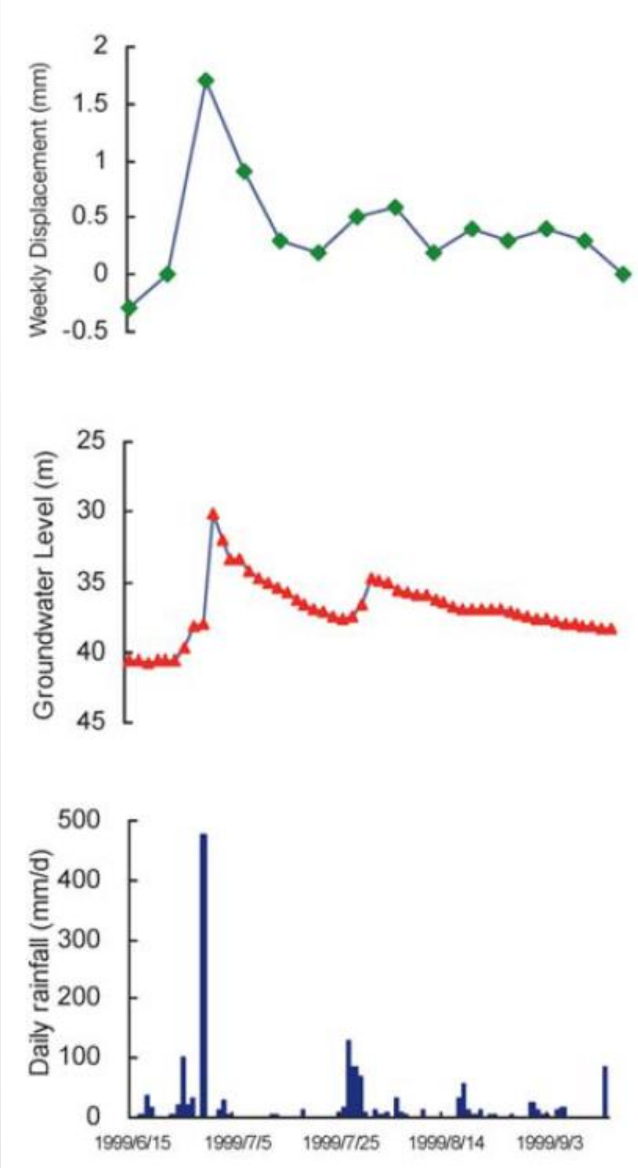
Opened joints



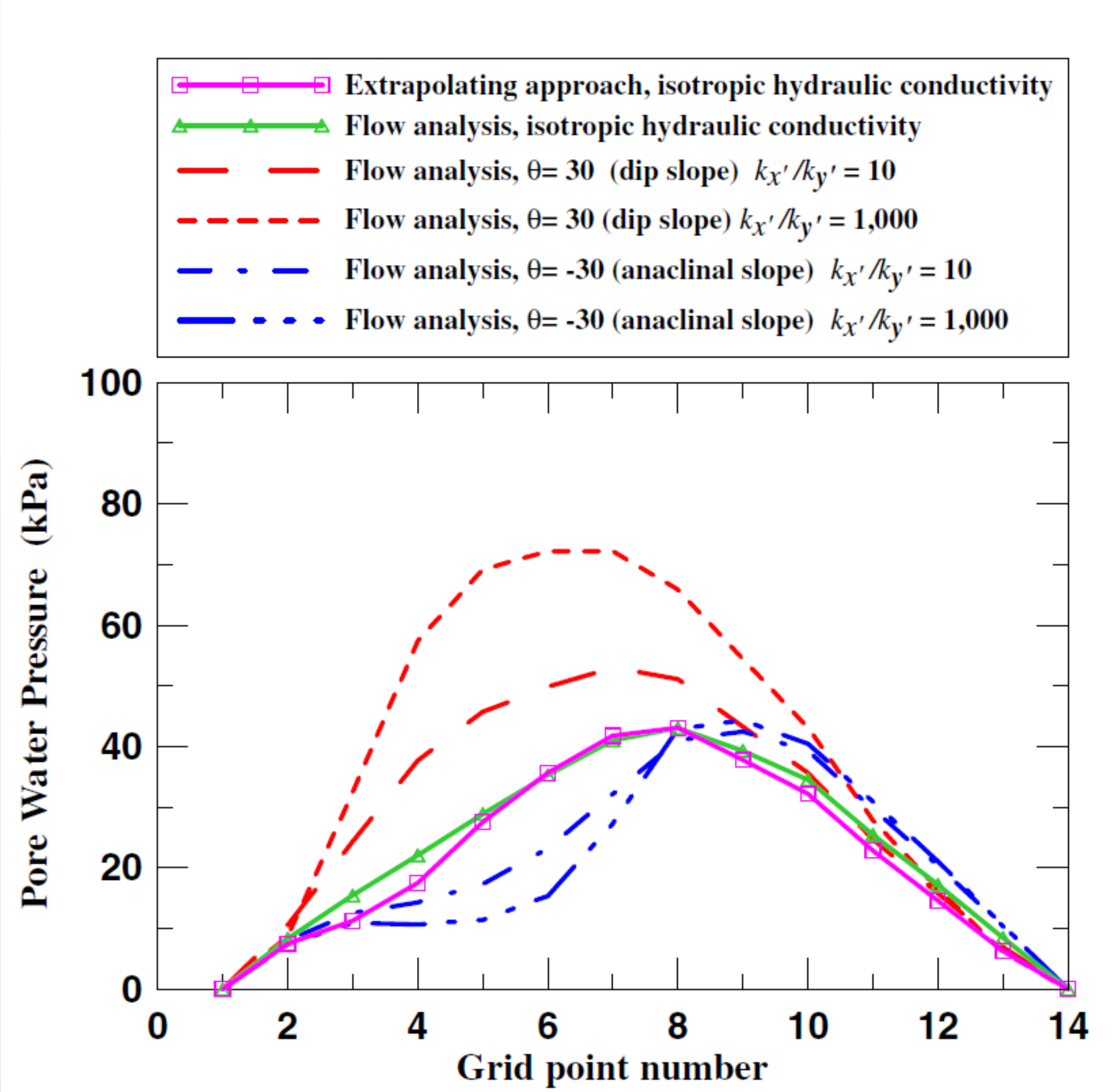
Anisotropic rock layer

Slightly-moderately weathered rock

Introduction



Hong *et al.*, (2005)



Estimated PWP at grid points from anisotropic issues (Dong *et al.*, 2006)

Predicting the rainfall-induced displacement is a challenge

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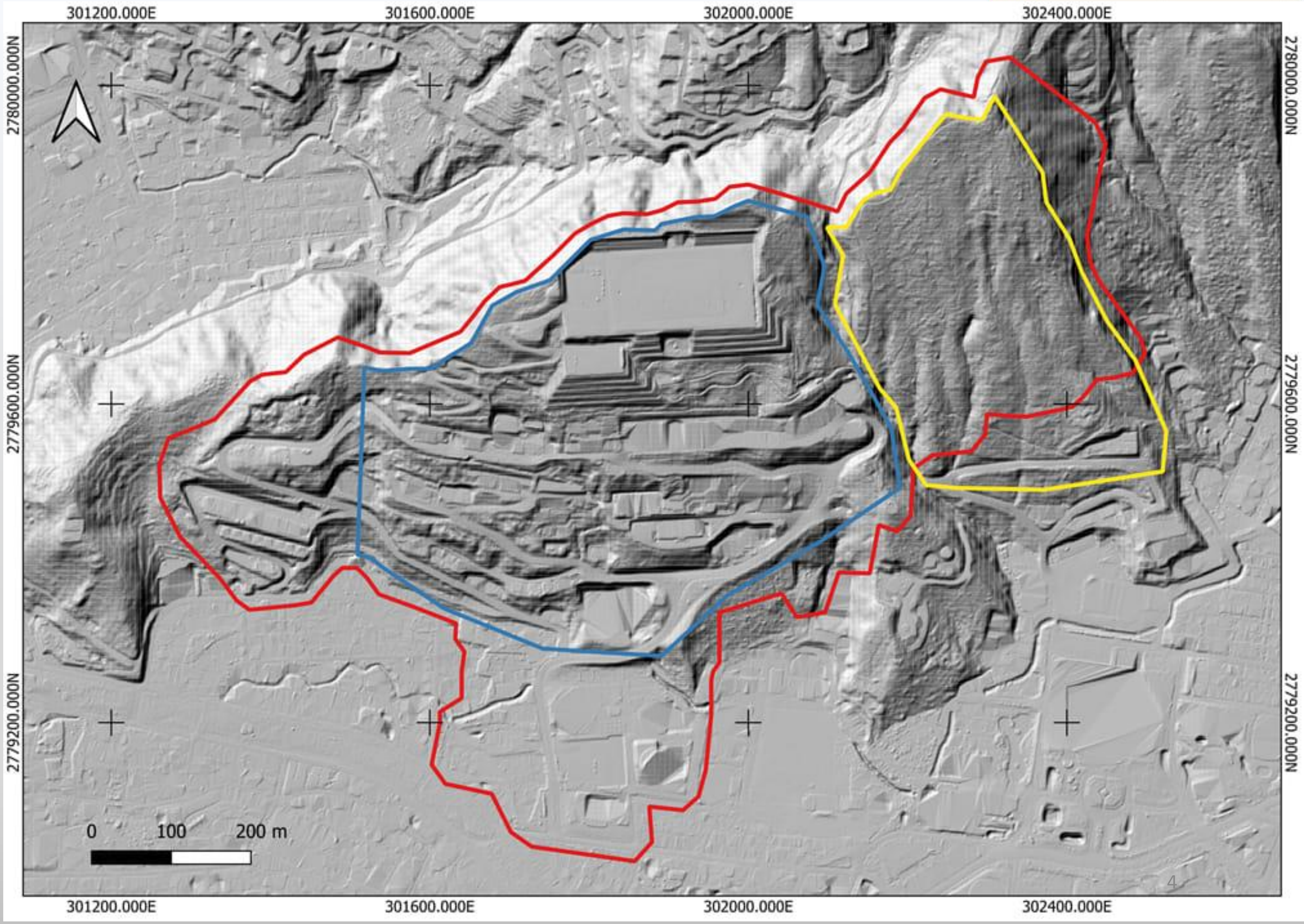
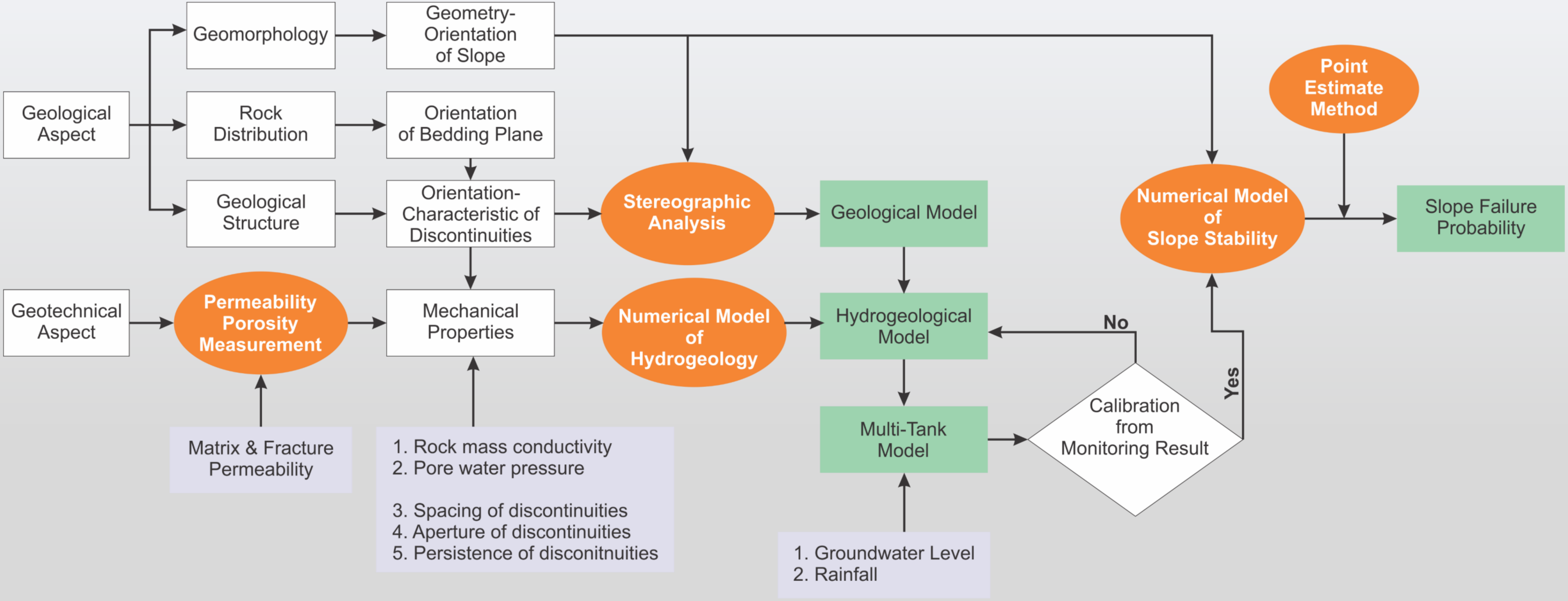
NYCU Map



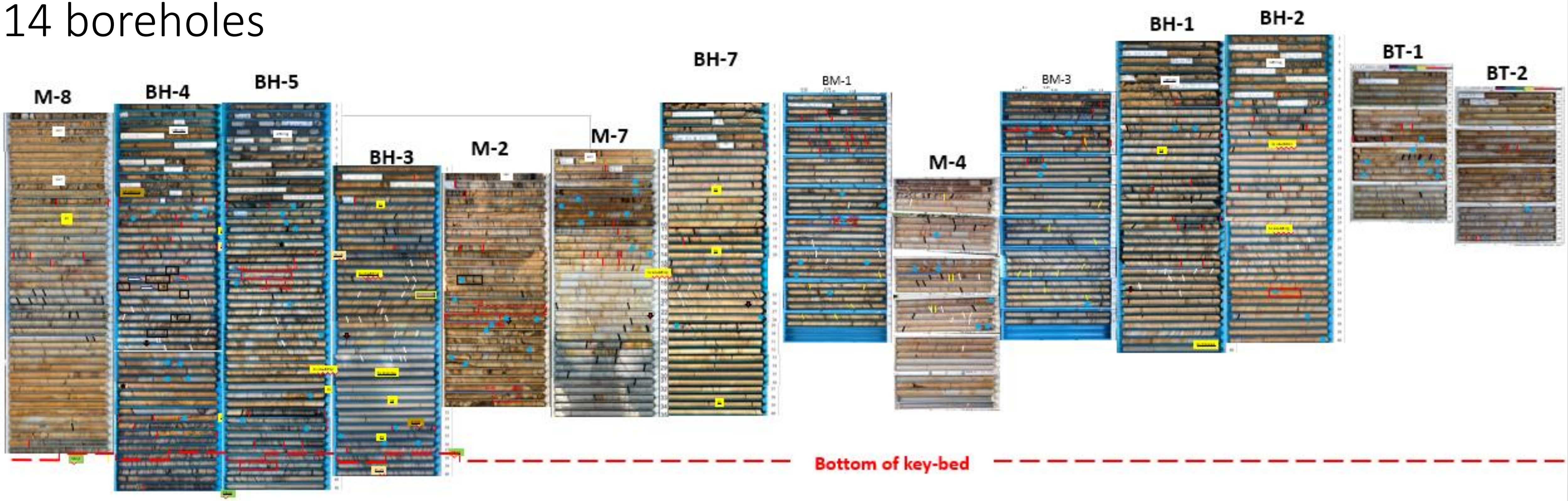
Flow Chart


Geological Aspect
Geomorphology
Geometry-Orientation of Slope
Rock Distribution
Orientation of Bedding Plane
Geological Structure
Orientation-Characteristic of Discontinuities
Stereographic Analysis
Geological Model
Point Estimate Method
Numerical Model of Slope Stability
Slope Failure Probability
Geotechnical Aspect
Permeability Porosity Measurement
Mechanical Properties
Numerical Model of Hydrogeology
Hydrogeological Model
No
Yes
Multi-Tank Model
Calibration from Monitoring Result
Matrix & Fracture Permeability
1. Rock mass conductivity
2. Pore water pressure
3. Spacing of discontinuities
4. Aperture of discontinuities
5. Persistence of disconitnuities
1. Groundwater Level
2. Rainfall

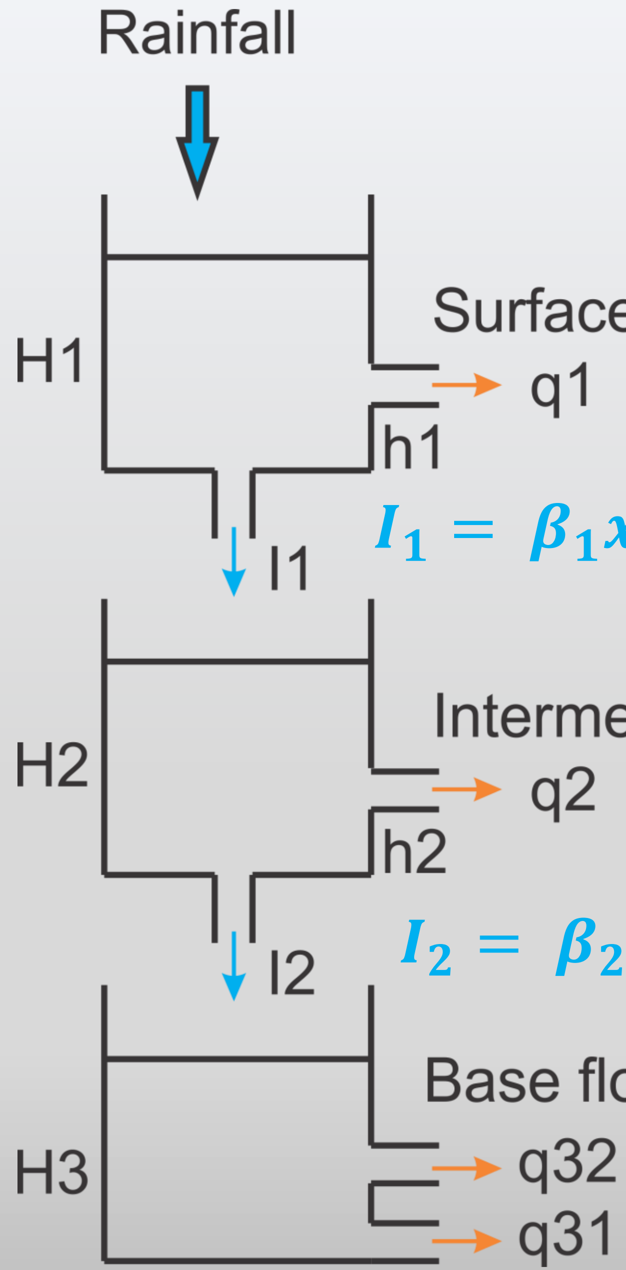
Methods

Boreholes Comparison

14 boreholes



Multi-Tank Model



$$q_1 = \alpha_1 x (H_{1(t)} - h_1)$$

$$I_1 = \beta_1 x \, H_{1(t)}$$

$$q_2 = \alpha_2 x (H_{2(t)} - h_2)$$

$$I_2 = \beta_2 x \, H_{2(t)}$$

$$q_{32} = \alpha_{31} x (H_{3(t)} - h_{32})$$

$$q_{31} = \alpha_{31} x H_{3(t)}$$

q : discharge (mm)

I : infiltration (mm)

H : water tank or water storage (mm)

h : height of side outlet(mm)

α : coefficient of side outlet

β : coefficient of side outlet

13 of 14 parameters are unknown

Multi-Tank Model

$H_{1(t)}$: Changing height of water in Tank 1(mm)

$H_{1(o)}$: Initial height of water in Tank 1 (mm)

R : Rainfall intensity (mm)

A : Adjustment number

I_1 : infiltration in Tank 1 (mm)

q_1 : Surface runoff discharge (mm)

$H_{2(t)}$: Changing height of water in Tank 2 (mm)

$H_{2(o)}$: Initial height of water in Tank 2 (mm)

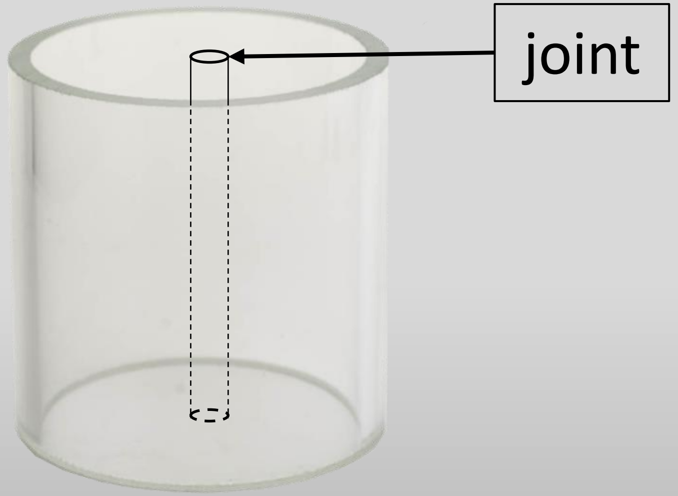
I_1 : infiltration from Tank 1 (mm)

q_2: Base flow discharge (mm)

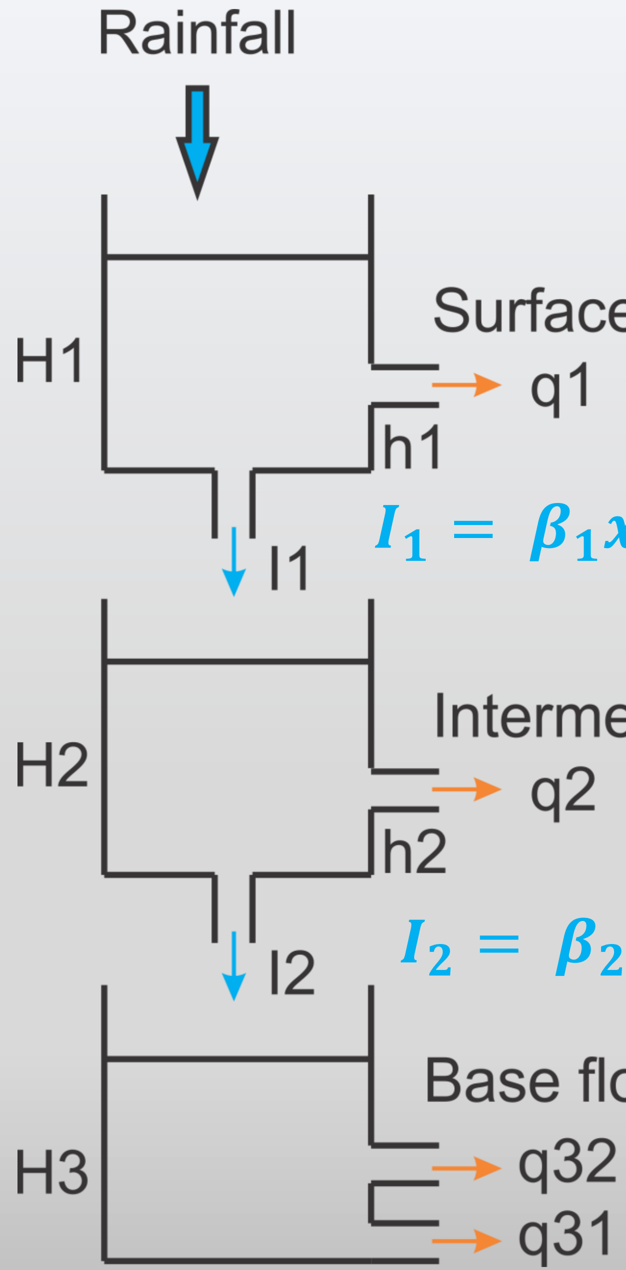
$$H_{1(t)} = H_{1(to)} + A.R - I_1 - q_{1(t)}$$

$$H_{2(t)} = H_{2(to)} + I_1 - I_2 - q_{2(t)}$$

$$H_{3(t)} = H_{3(to)} + I_2 - q_{31(t)} - q_{32(t)}$$



Multi-Tank Model



$$q_1 = \alpha_1 x(H_{1(t)} - h_1)$$

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$$q_2 = \alpha_2 x(H_{2(t)} - h_2)$$

$$I_2 = \beta_2 x\, H_{2(t)}$$

$$q_{32} = \alpha_{31} x(H_{3(t)} - h_{32})$$

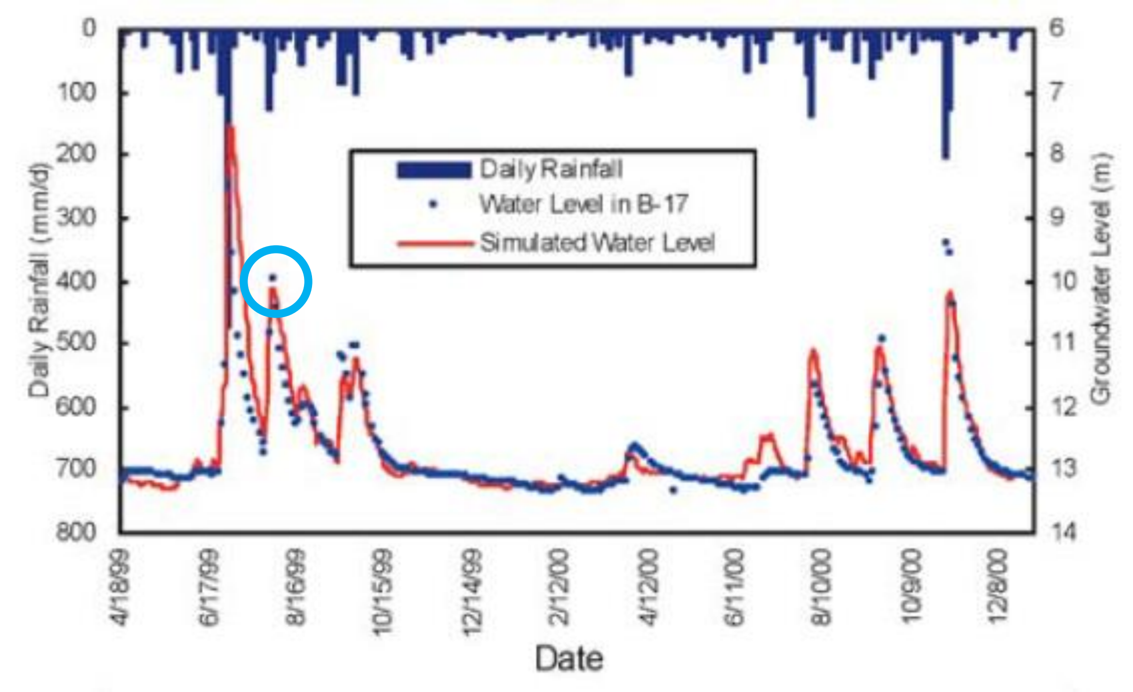
$$q_{31} = \alpha_{31} x H_{3(t)}$$

$$H_{1(t)} = H_{1(o)} + A.R - I_1 - q_{1(t)}$$

$$H_{2(t)} = H_{2(o)} + I_1 - I_2 - q_{2(t)}$$

$$H_{3(t)} = H_{3(o)} + I_2 - q_{31(t)} - q_{32(t)}$$

What we want to see from Multi-Tank Model



Hong *et al.,* (2005)

Simulating the model:

1. Simulated groundwater fluctuation trend
2. Simulated maximum groundwater level
3. Simulated groundwater fluctuation slope

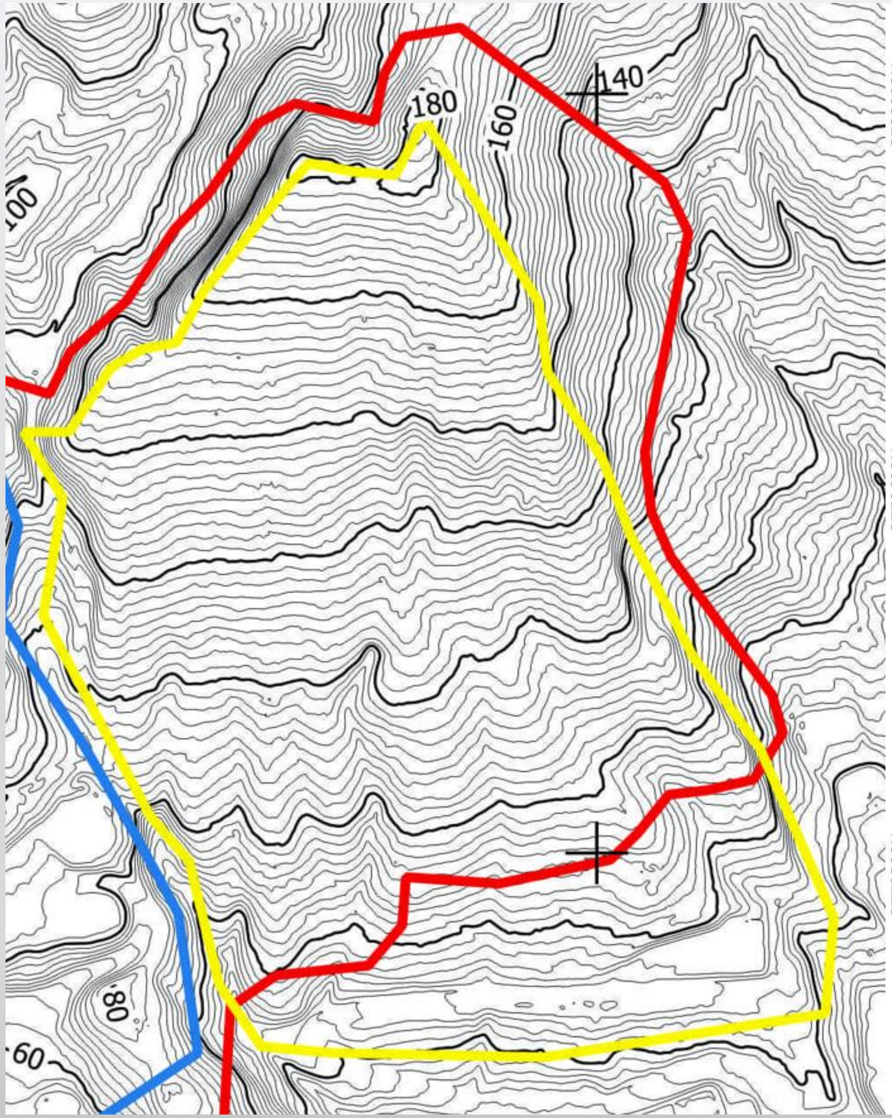
Result

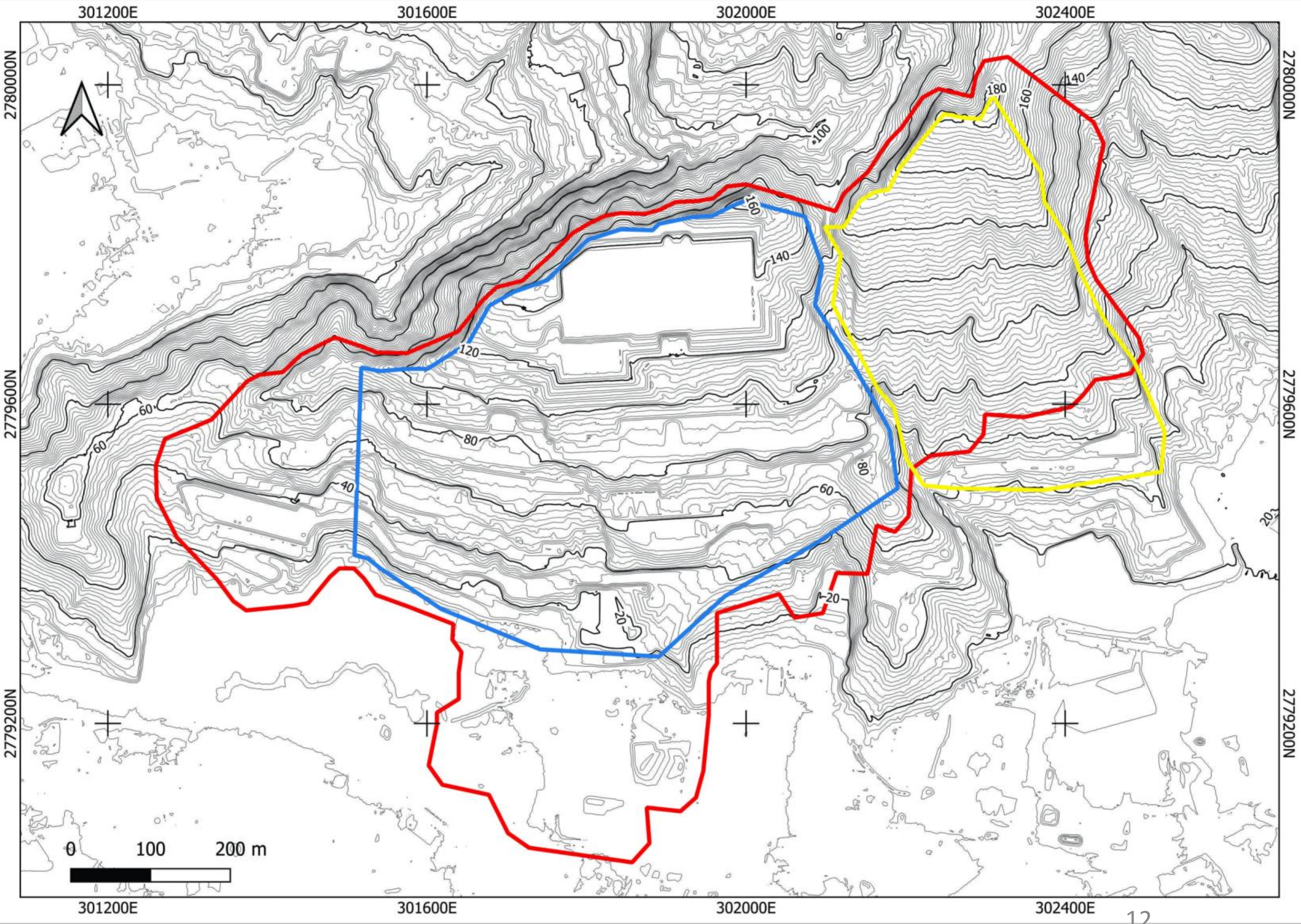
Orientation of Bedding Plane

- Large Scale → Yellow Zone Surface (hundreds meters)
- Medium Scale → Key-bed within Boreholes (tens meters)
- Small Scale → Outcrop Data (tens centimeters)

Orientation of Bedding Plane

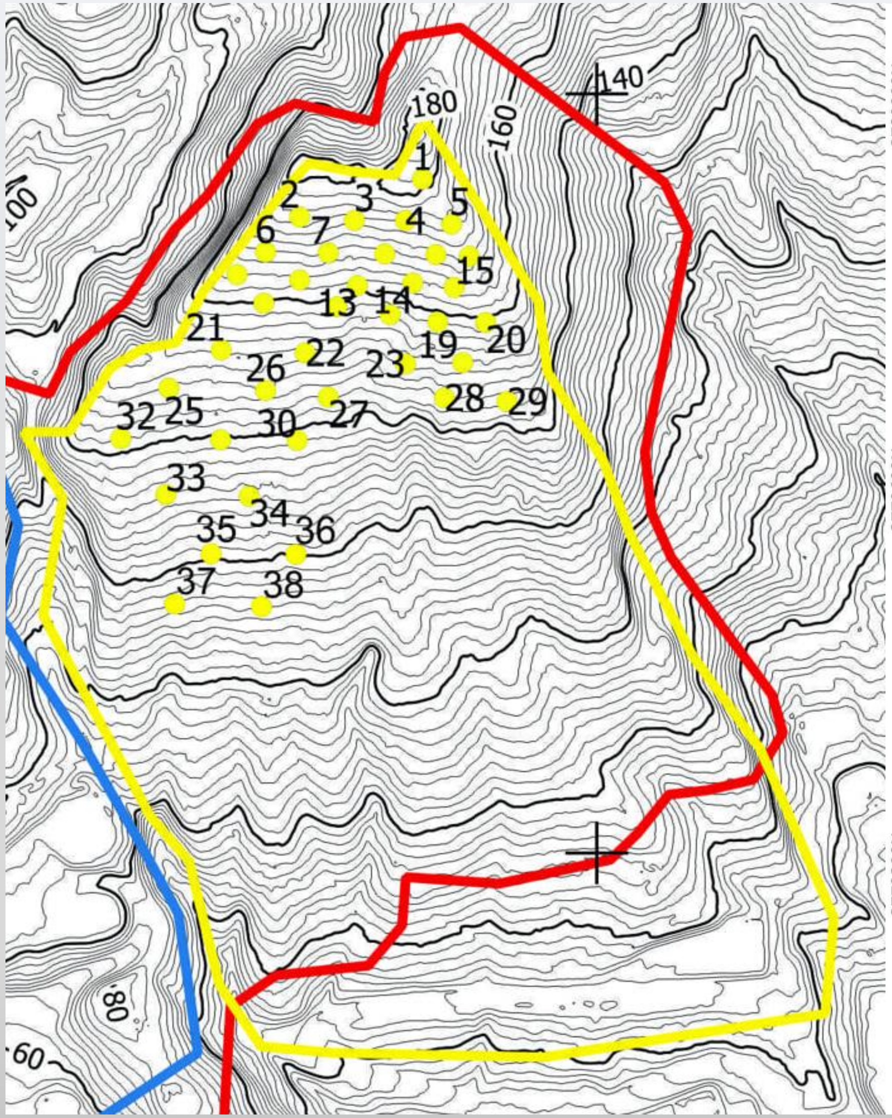
Large Scale → Yellow Zone Surface

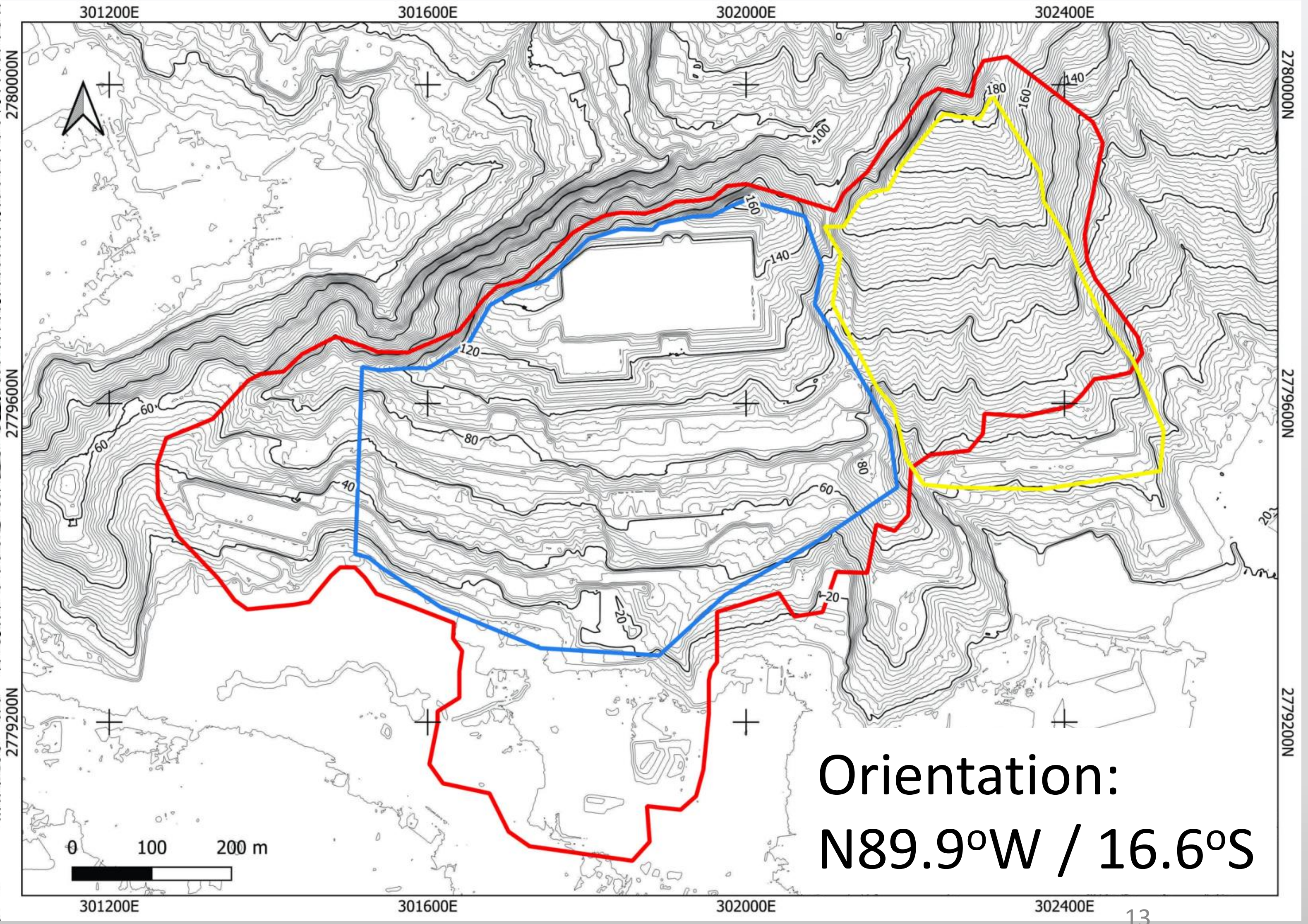




Orientation of Bedding Plane

Large Scale → Yellow Zone Surface



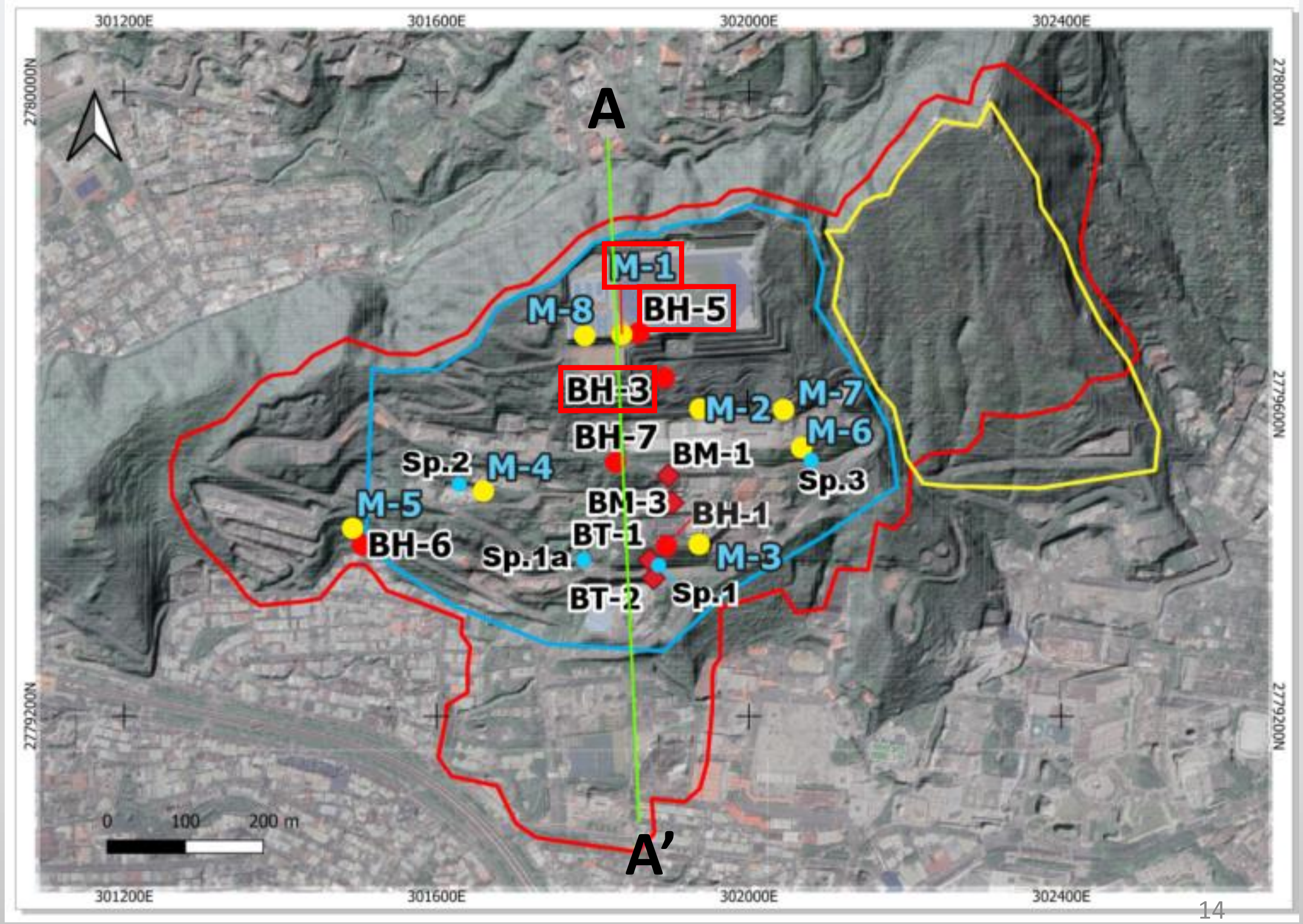


Orientation:
N89.9°W / 16.6°S

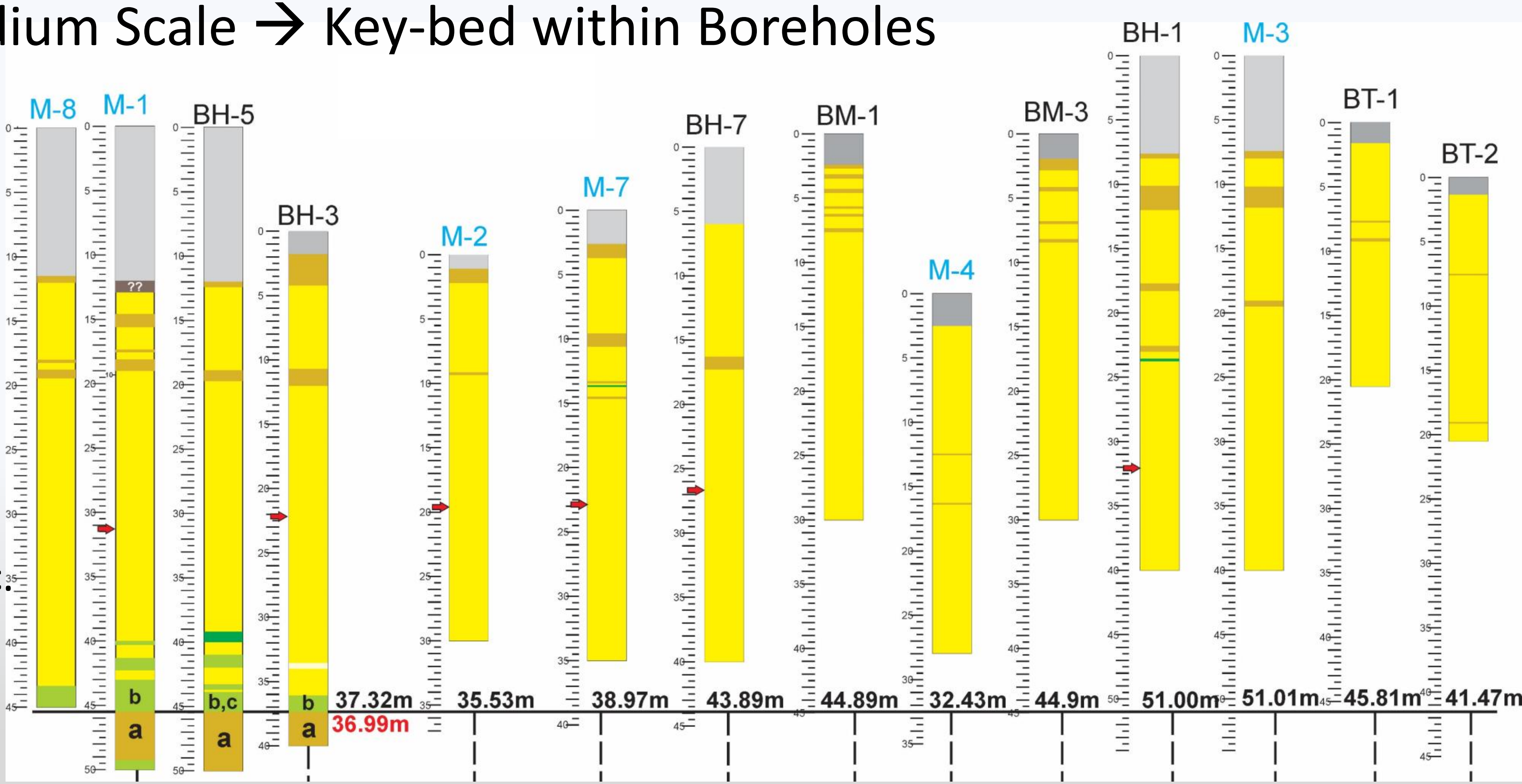
Orientation of Bedding Plane

Medium Scale → Key-bed within Boreholes

- BH-5 Boreholes (as key-bed)
- BH-1 Boreholes
- BM-1 CGS Boreholes
- M-1 Monitoring Wells
- A A' Cross sections



Medium Scale → Key-bed within Boreholes



a Flaser Structure

b Wavy Lamination Strc.

c Lenticular Strc.

Overburden & Colluvium

Mudstone

SS (massive sandstone)

SS-SH (mainly composed of ss with sh occasionally)

SS/SH (Interbedded of ss and sh)

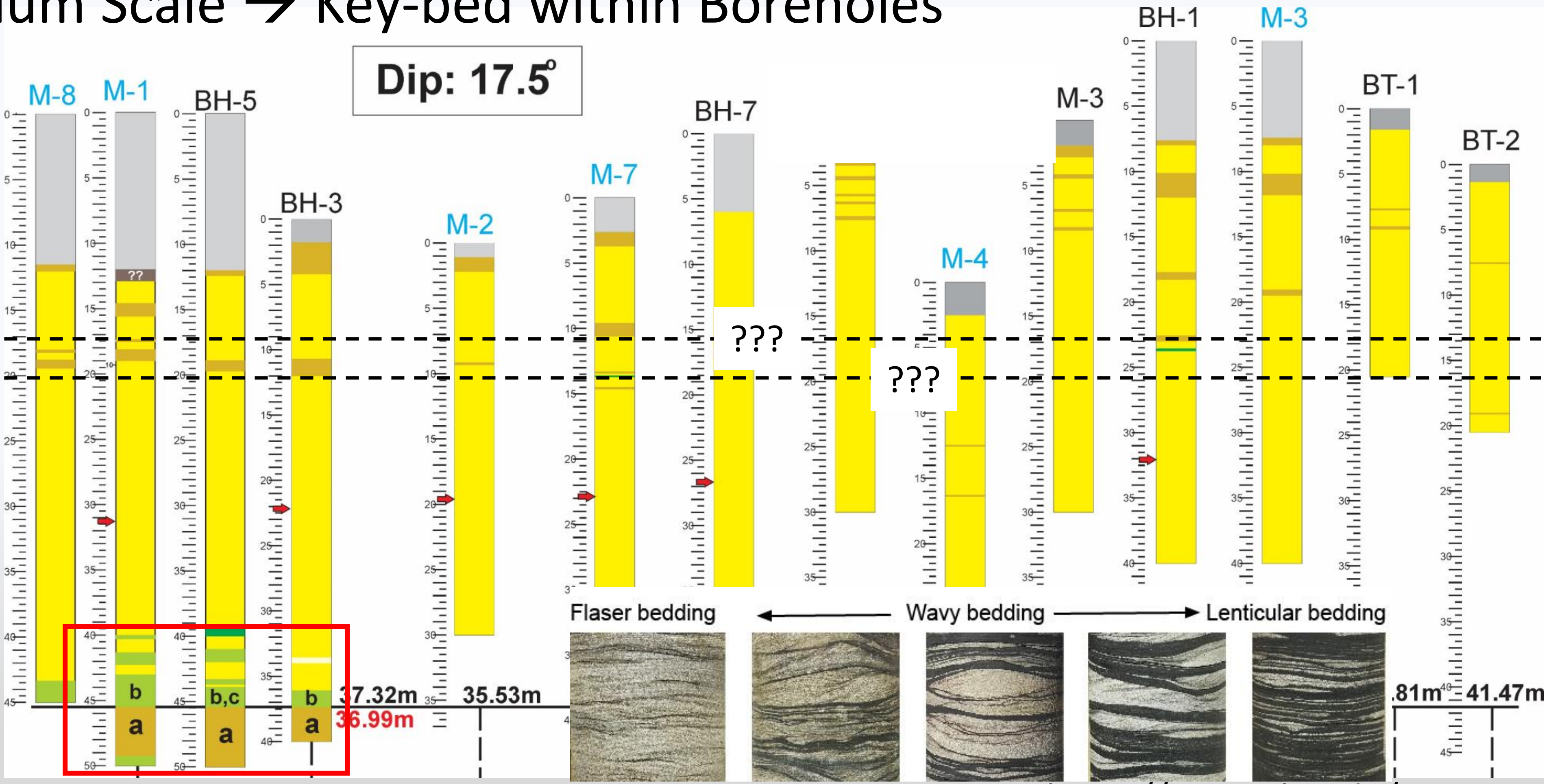
SH-SS (mainly composed of sh with ss occasionally)

SH (shale)

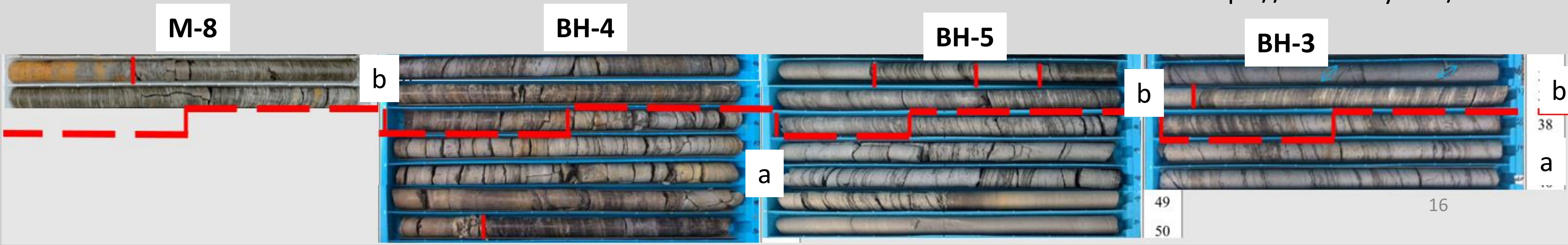
Medium Scale → Key-bed within Boreholes

Orientation:
N87.6°E / 17.5°S

a	Flaser Structure
b	Wavy Lamination Strc.
c	Lenticular Strc.



Source: https://www.uky.edu/

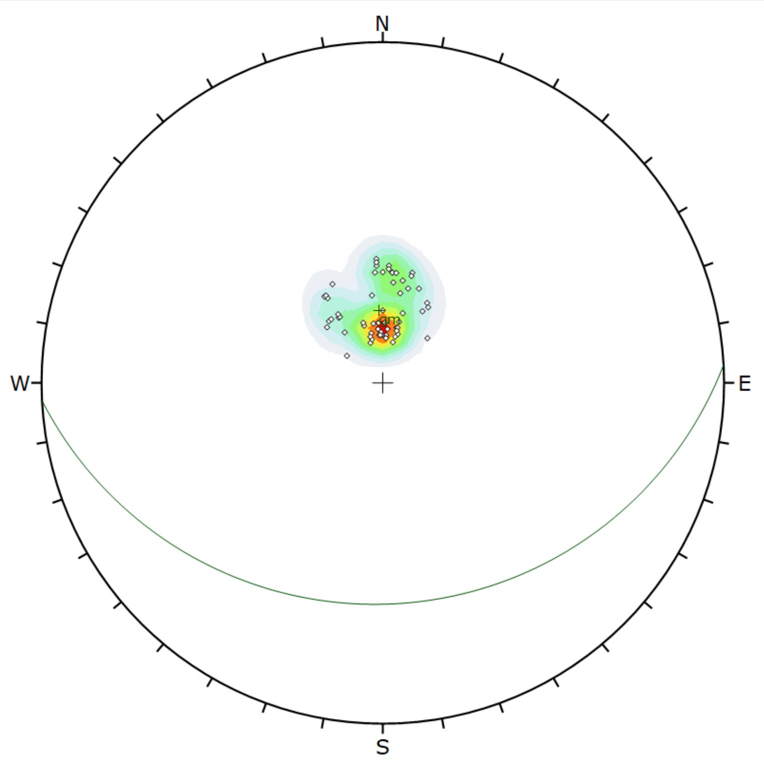


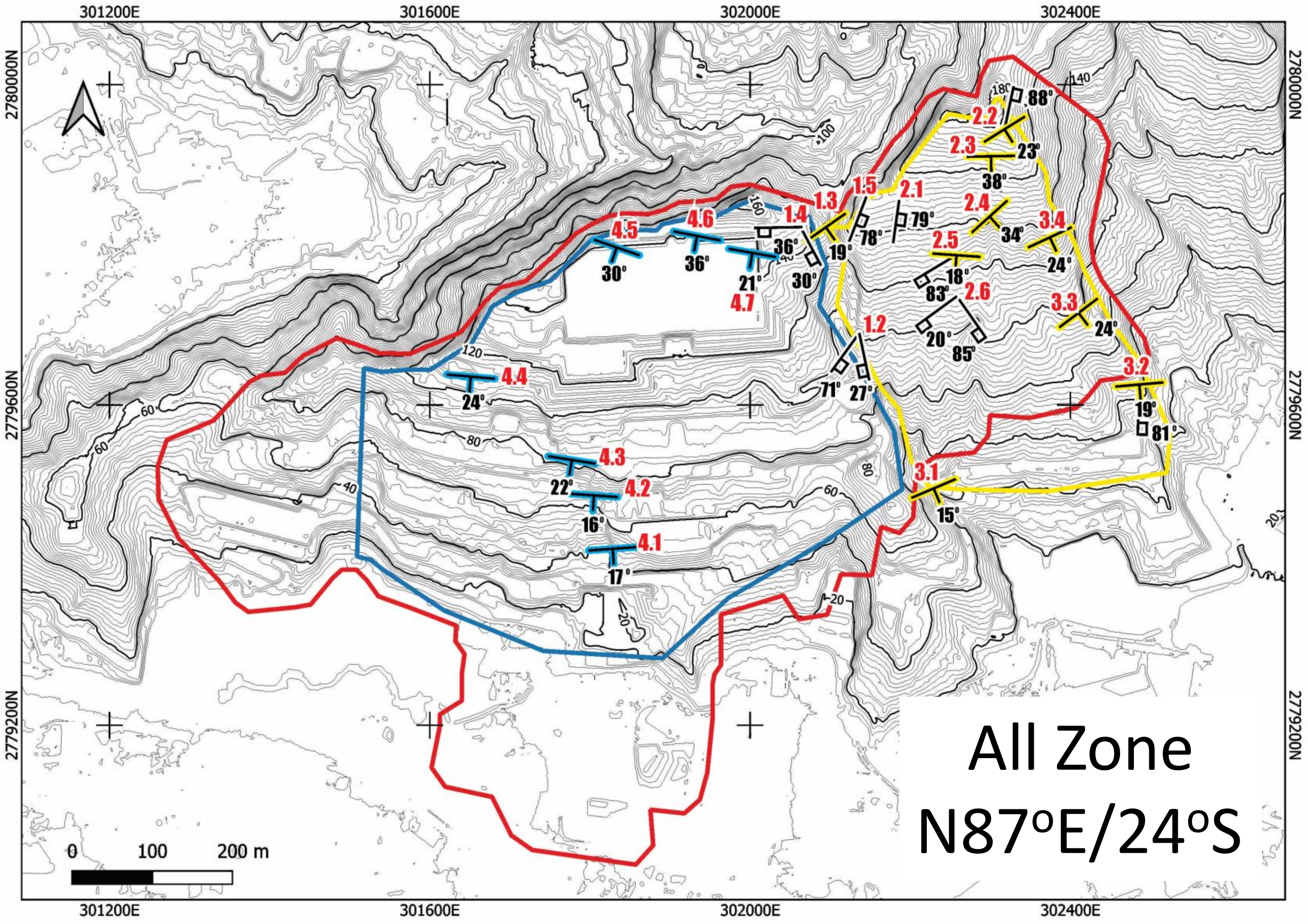
Orientation of Bedding Plane

Small Scale → Outcrops Data

17° Orientation of Bedding Plane

65° Orientation of Joints

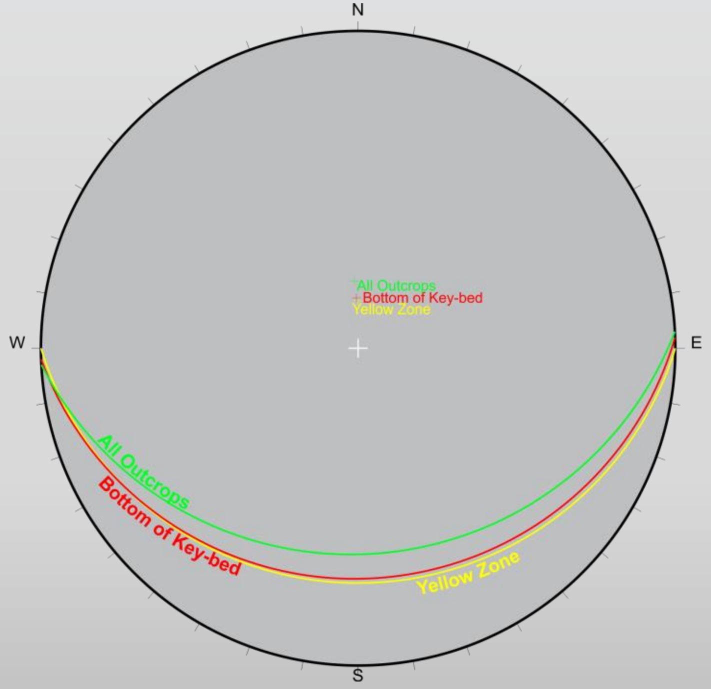




Orientation of Bedding Plane

Comparison of All Orientation

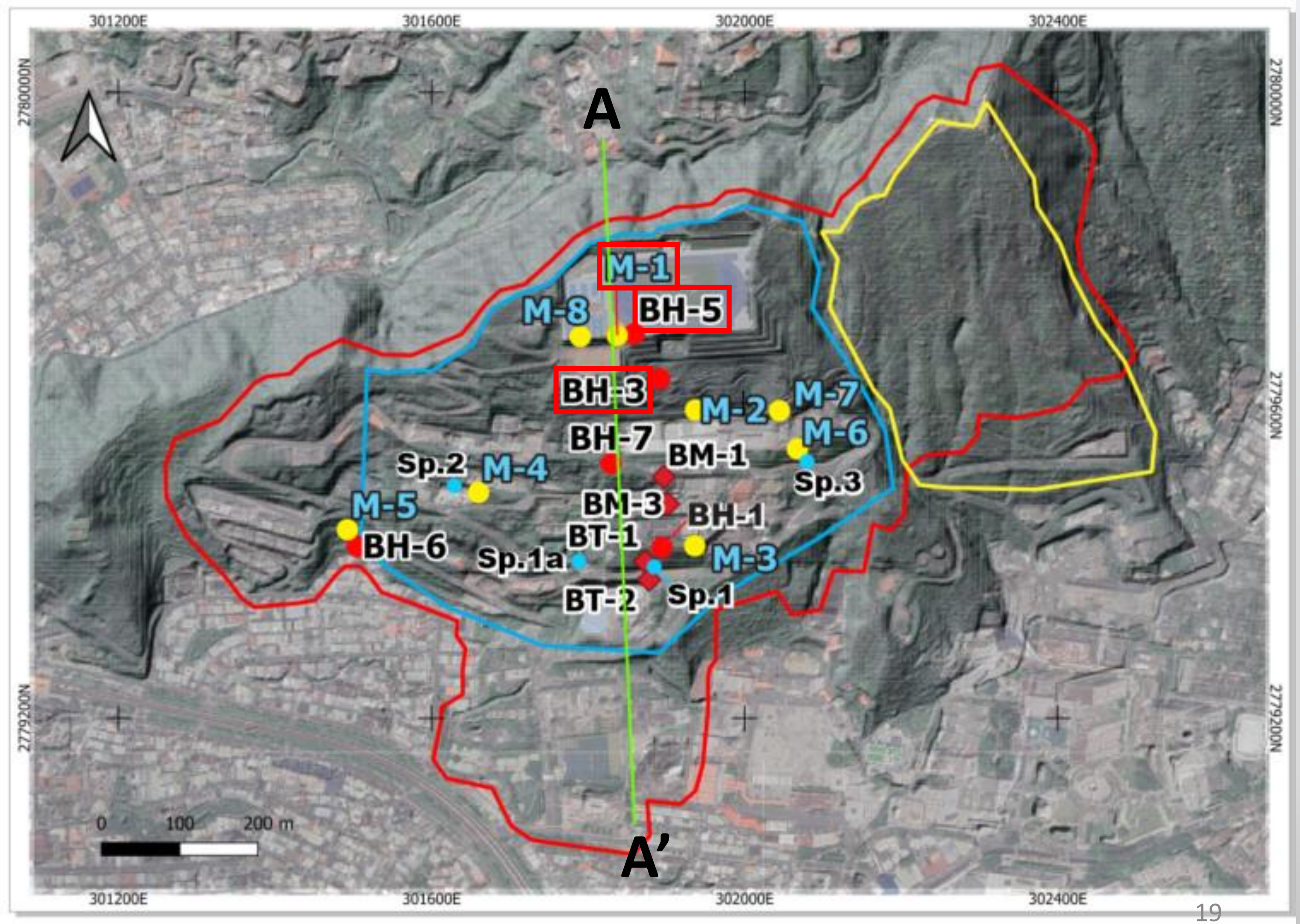
	Yellow Zone Surface's	Bottom of Key-bed's	All Outcrop's
Strike	N89.9^{o}W	N87.6^{o}E	N87^{o}E
Dip	16.6^{o}S	17.5^{o}S	24^{o}S



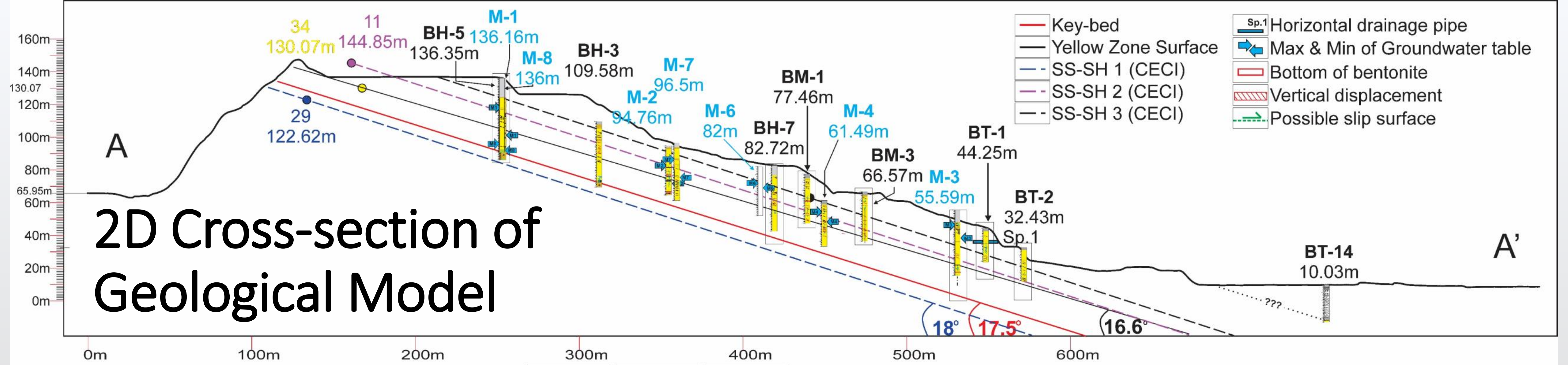
- ❖ Condition of geology in the Yellow Zone and Blue Zone is relatively the same
- ❖ Some measurements of the outcrop's orientation could be controlled by disturbances (such as cross-bedding, moving block, or creek feature)

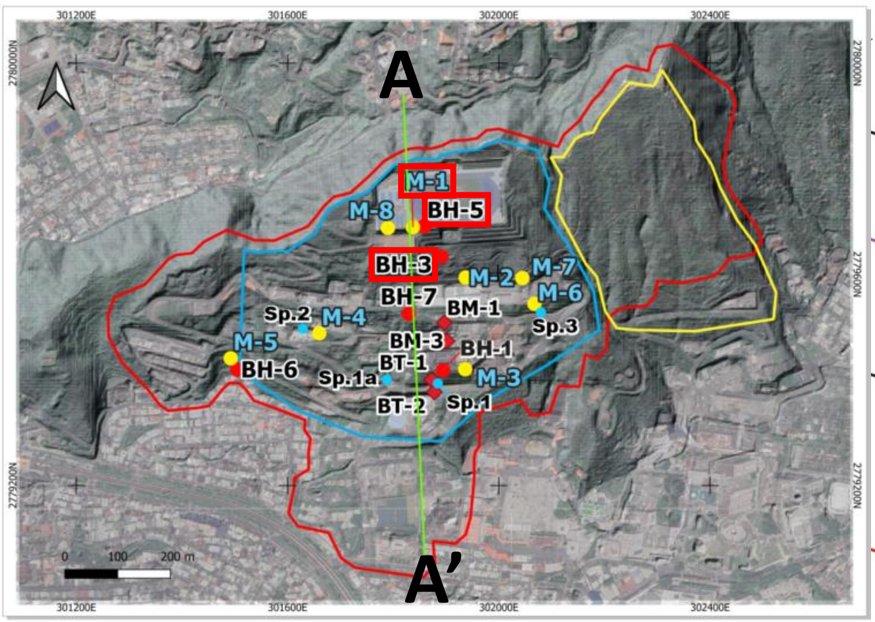
Geological Model

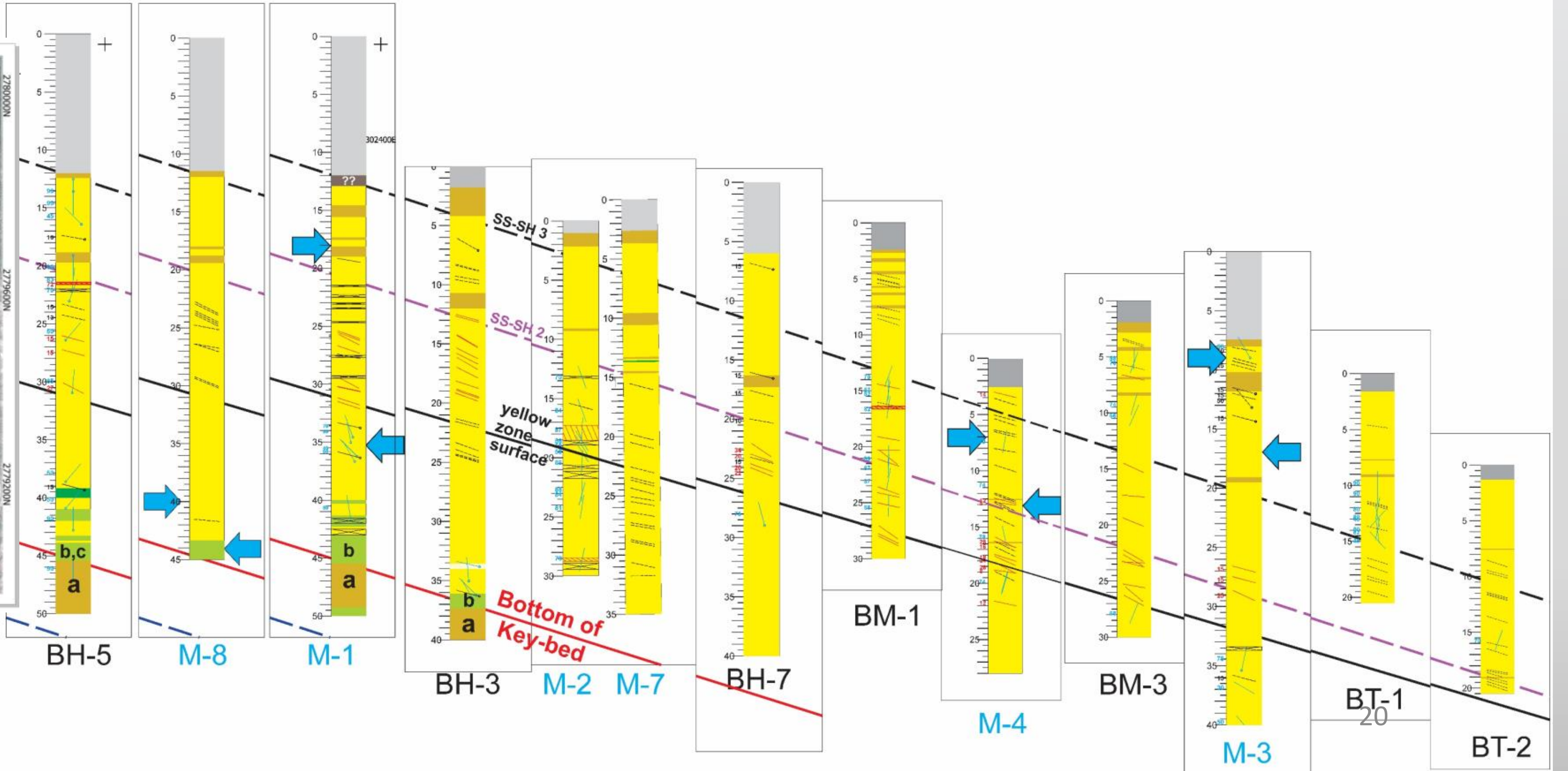
- BH-5 — Boreholes (as key-bed)
- BH-1 — Boreholes
- BM-1 — CGS Boreholes
- M-1 — Monitoring Wells
- A — A' — Cross sections



2D Cross-section of Geological Model







Location of Displacement

BH-5 Boreholes (as key-bed)

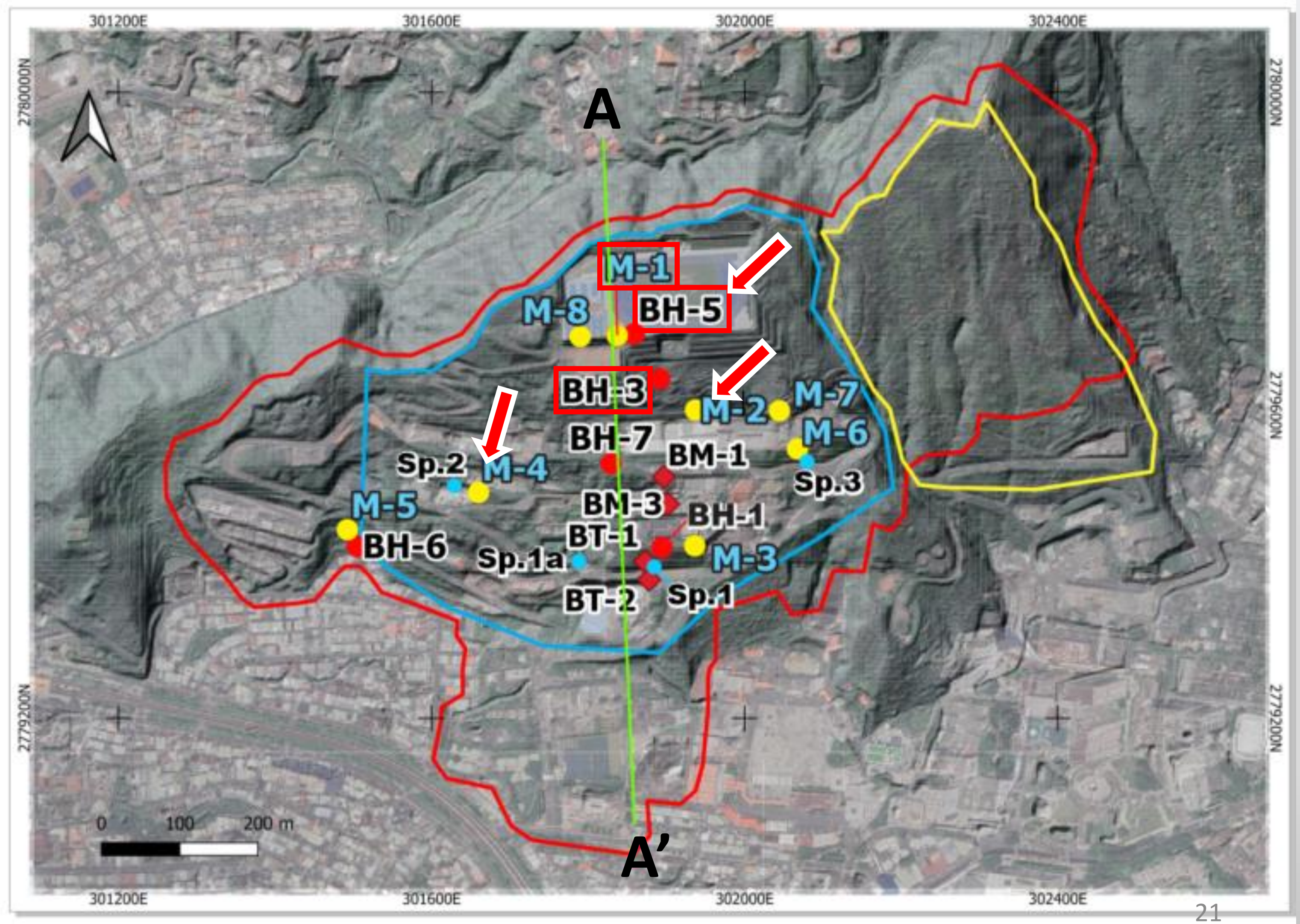
BH-1 Boreholes

BM-1 CGS Boreholes

M-1 Monitoring Wells

A A' Cross-sections

Position of displacements



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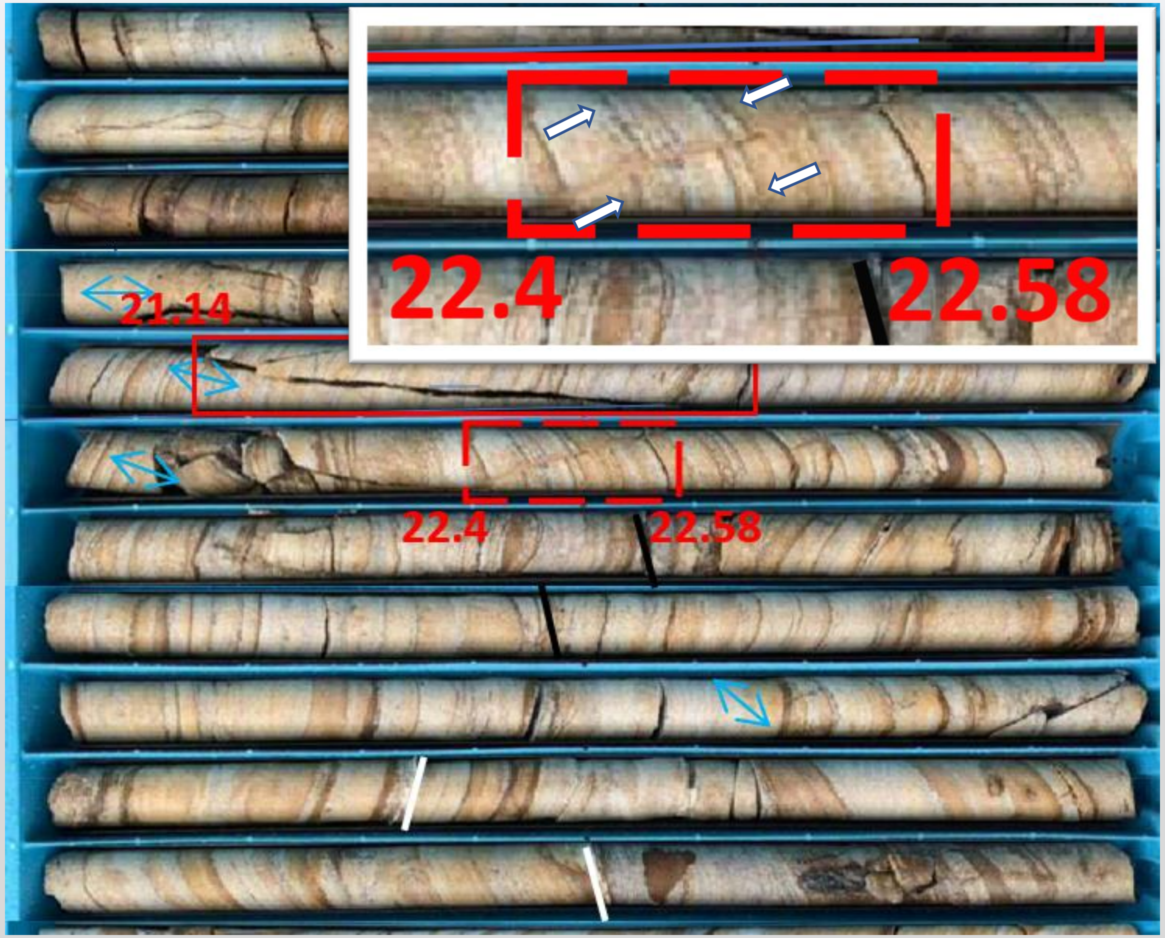
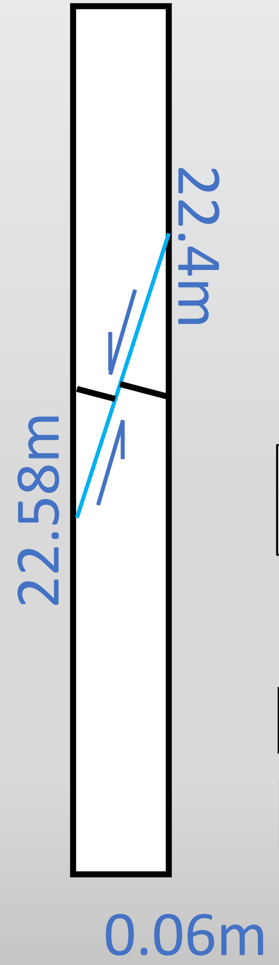
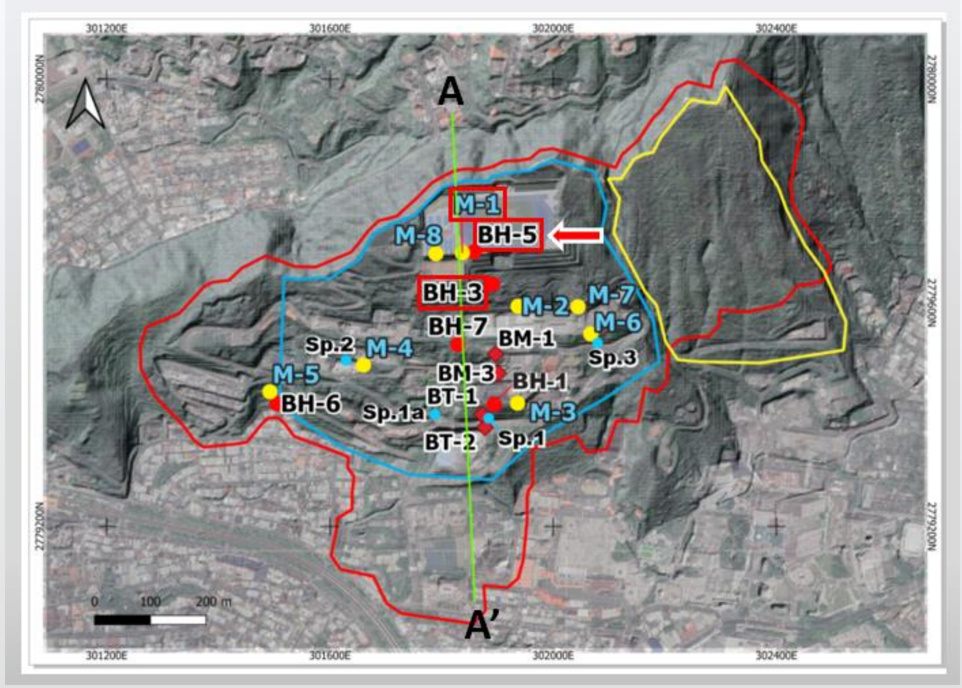
Vertical Displacement in BH-5







Dip angle ≈ 72º

Vertical joint

Vertical displacement

Joint (CECI)

Mud layer

Vertical displacement

Bedding plane

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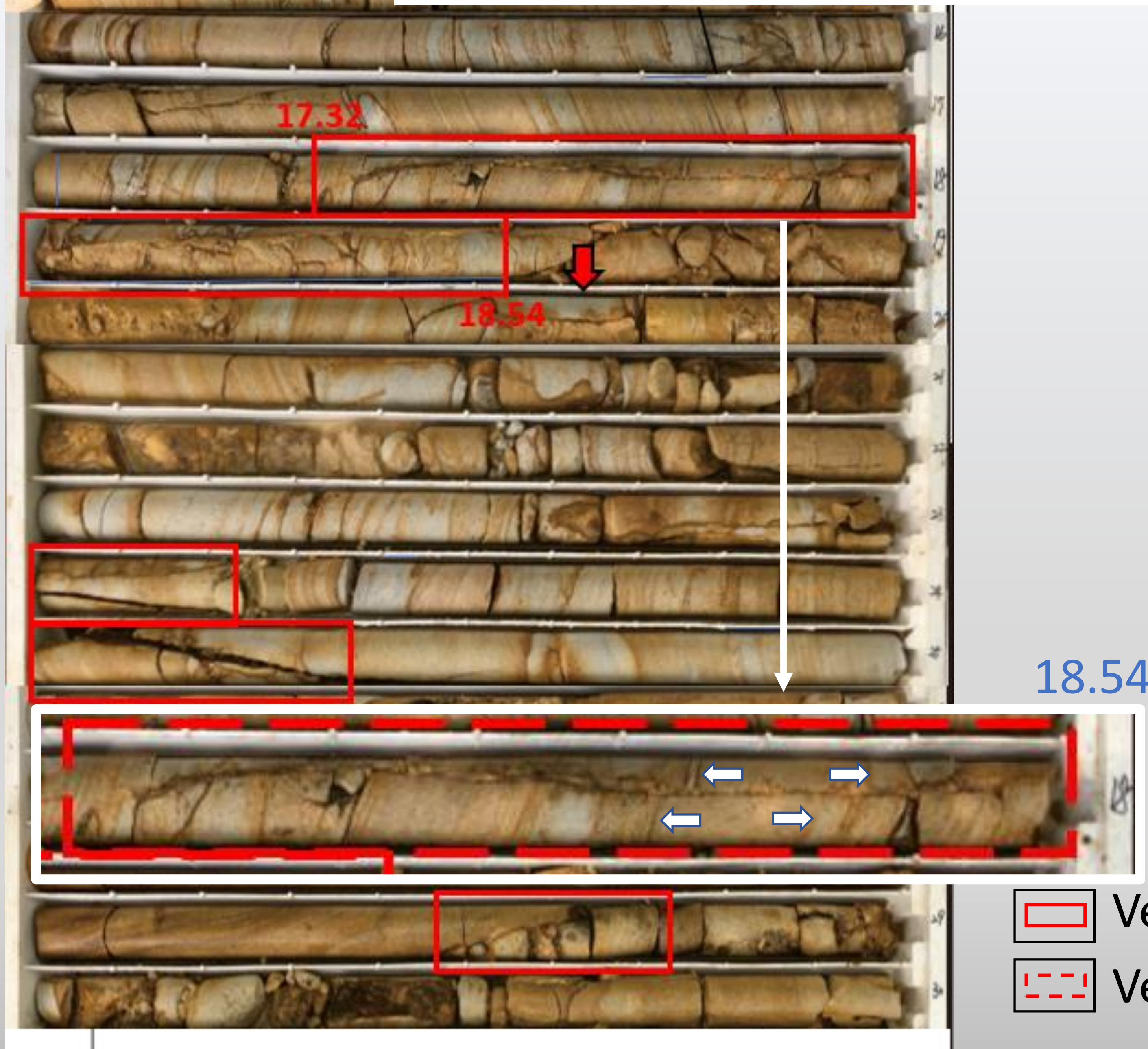
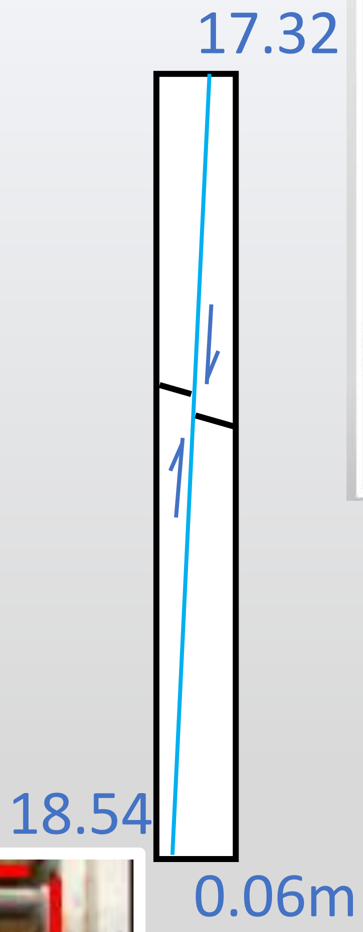
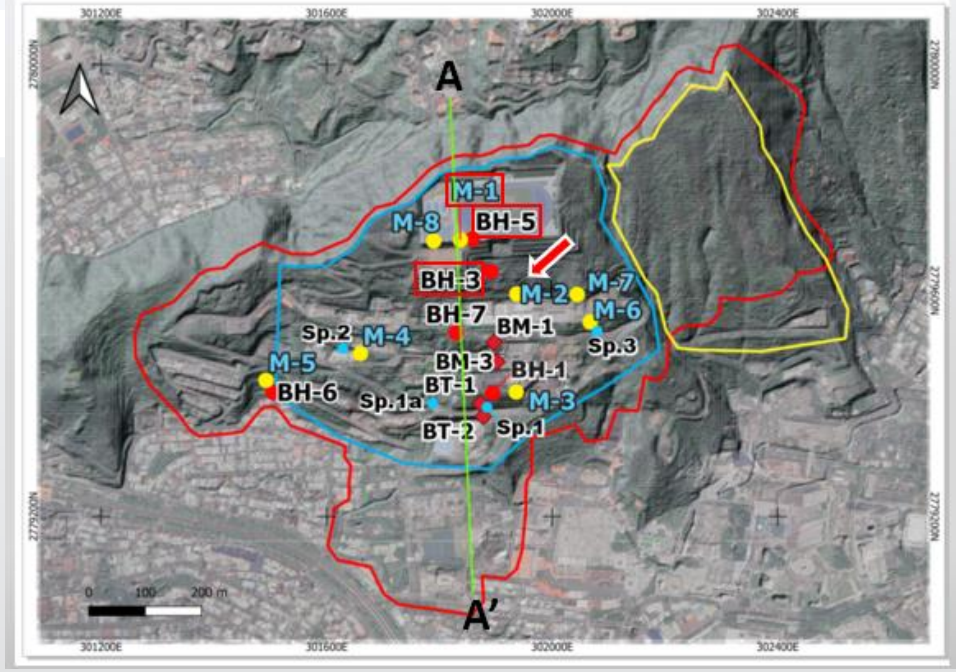
Vertical Displacement in M-2







Dip angle ≈ 87º

- Vertical displacement
- Bedding plane
- Vertical joint
- Vertical displacement
- Joint (CECI)
- Mud layer

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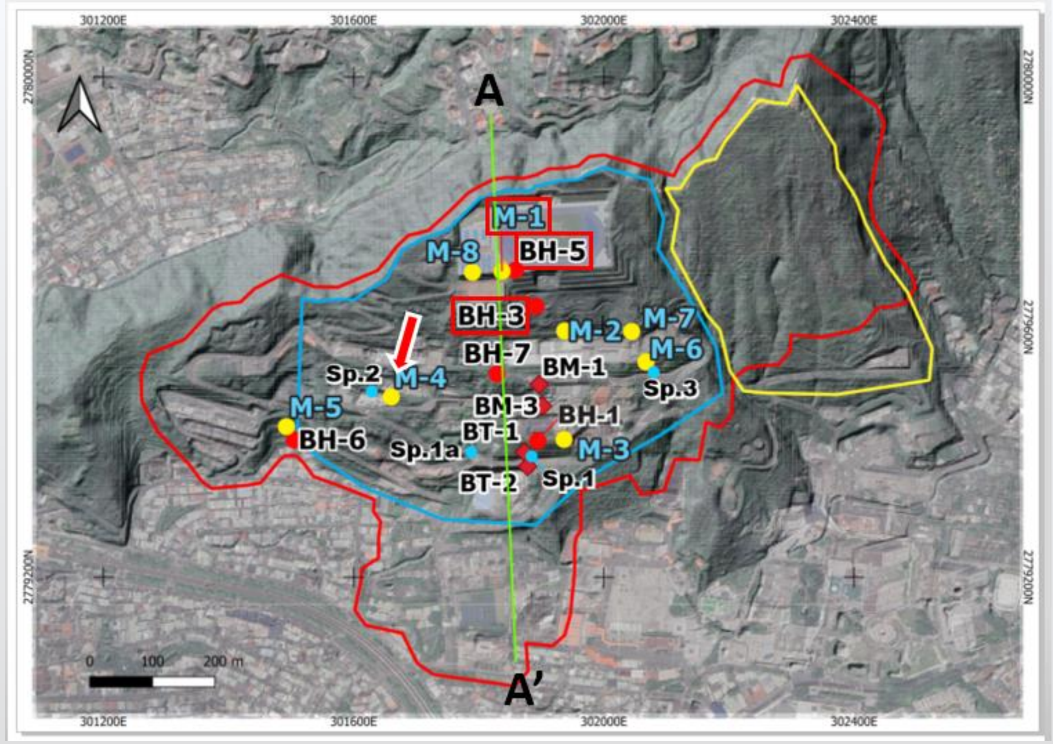
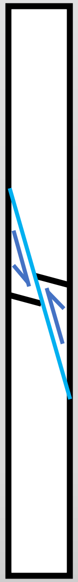
Vertical Displacement in M-4





Dip angle ≈ 74º

Vertical displacement

Bedding plane

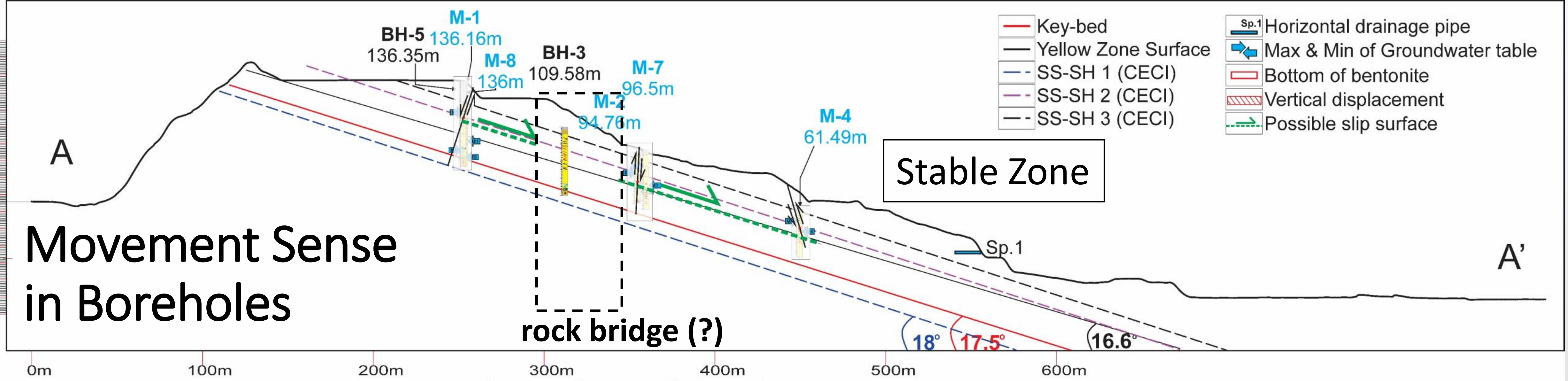
Vertical joint

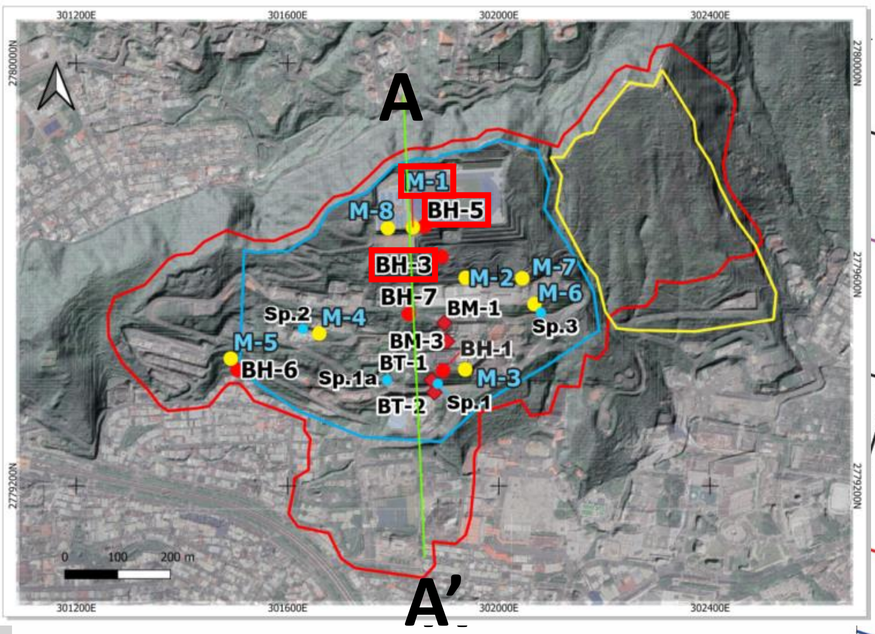
Vertical displacement

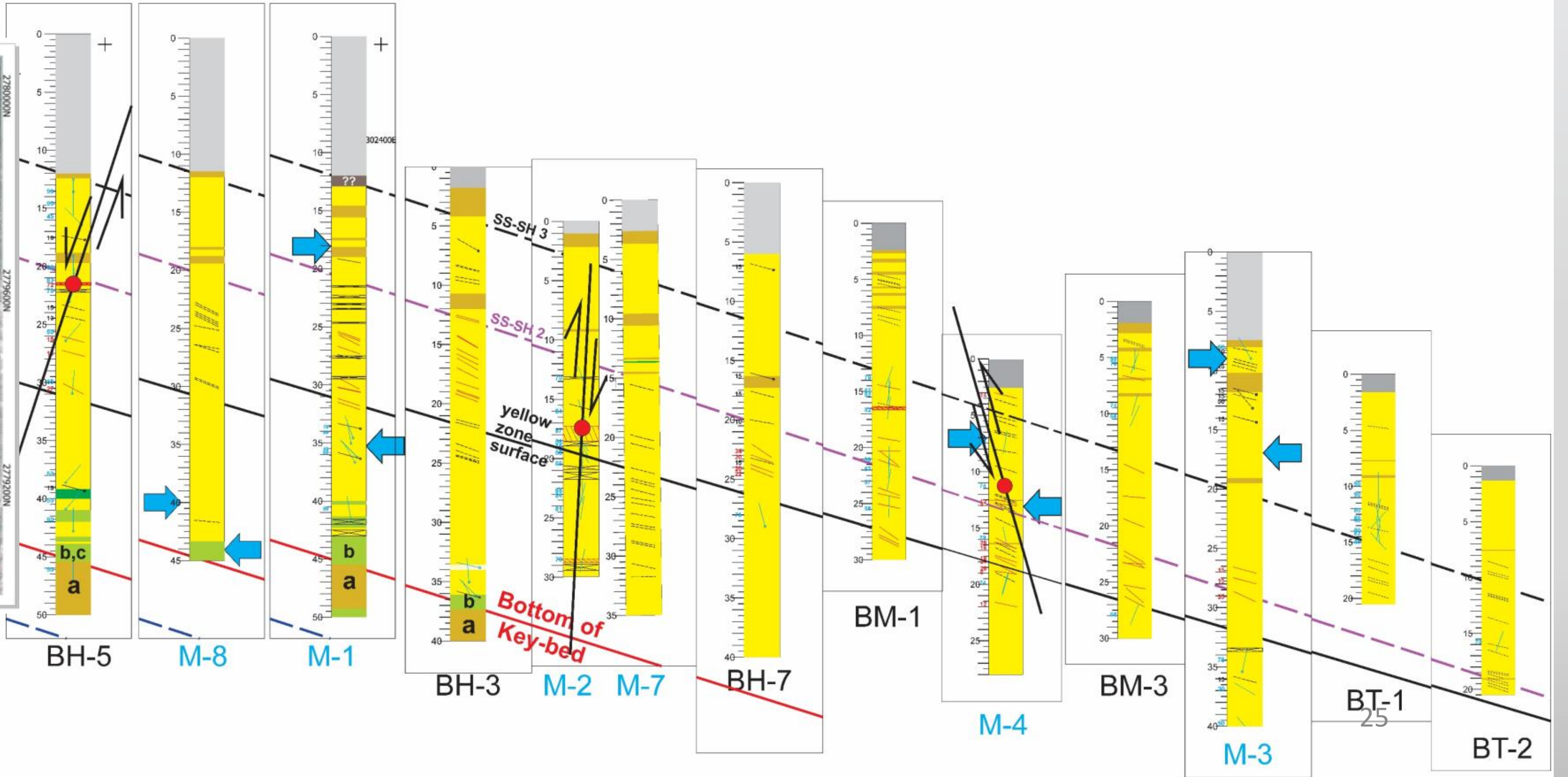
Joint (CECI)

Mud layer

Movement Sense in Boreholes

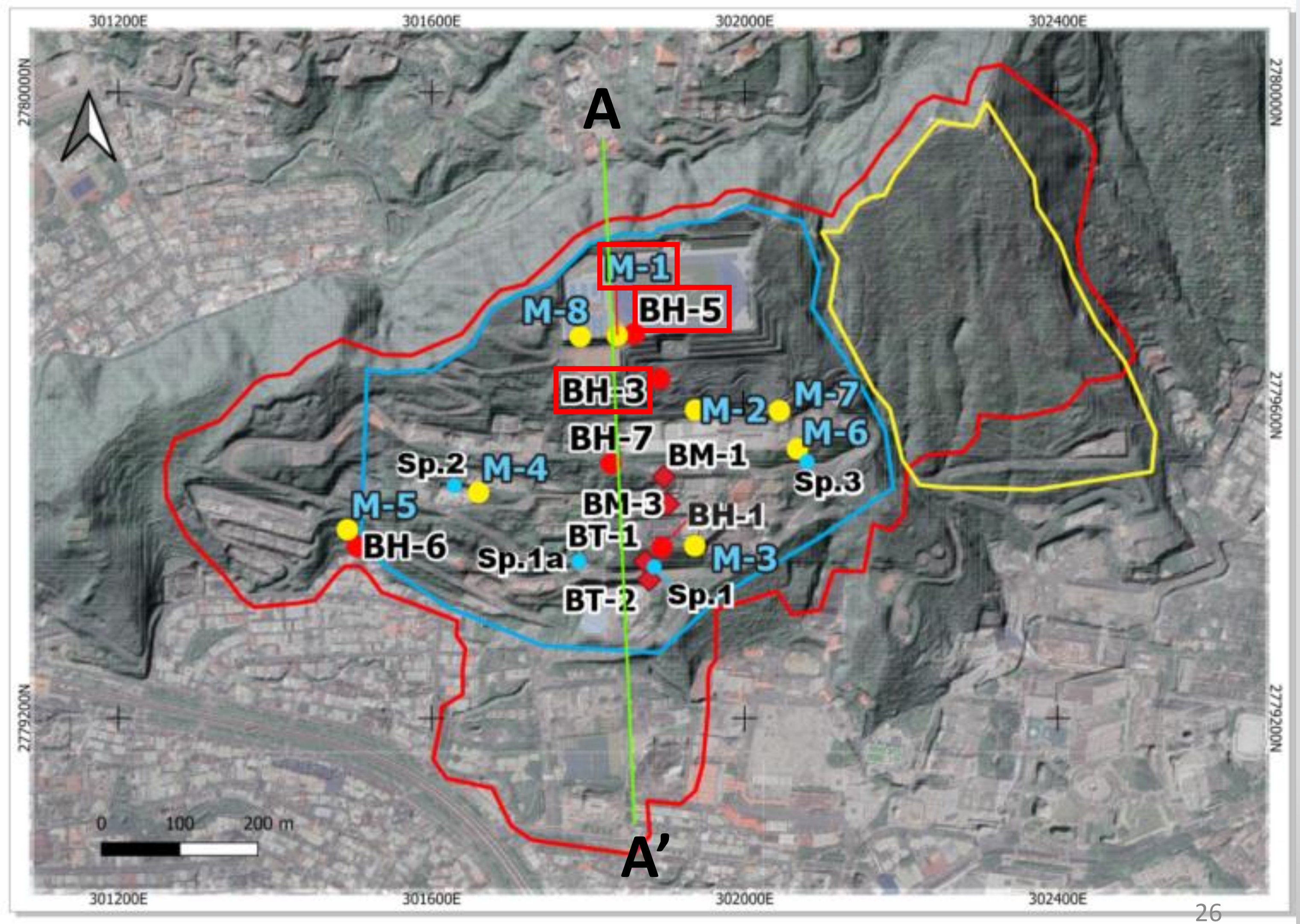






Monitoring Wells Location

- BH-5 Boreholes (as key-bed)
- BH-1 Boreholes
- BM-1 CGS Boreholes
- M-1 Monitoring Wells
- A A' Cross-sections



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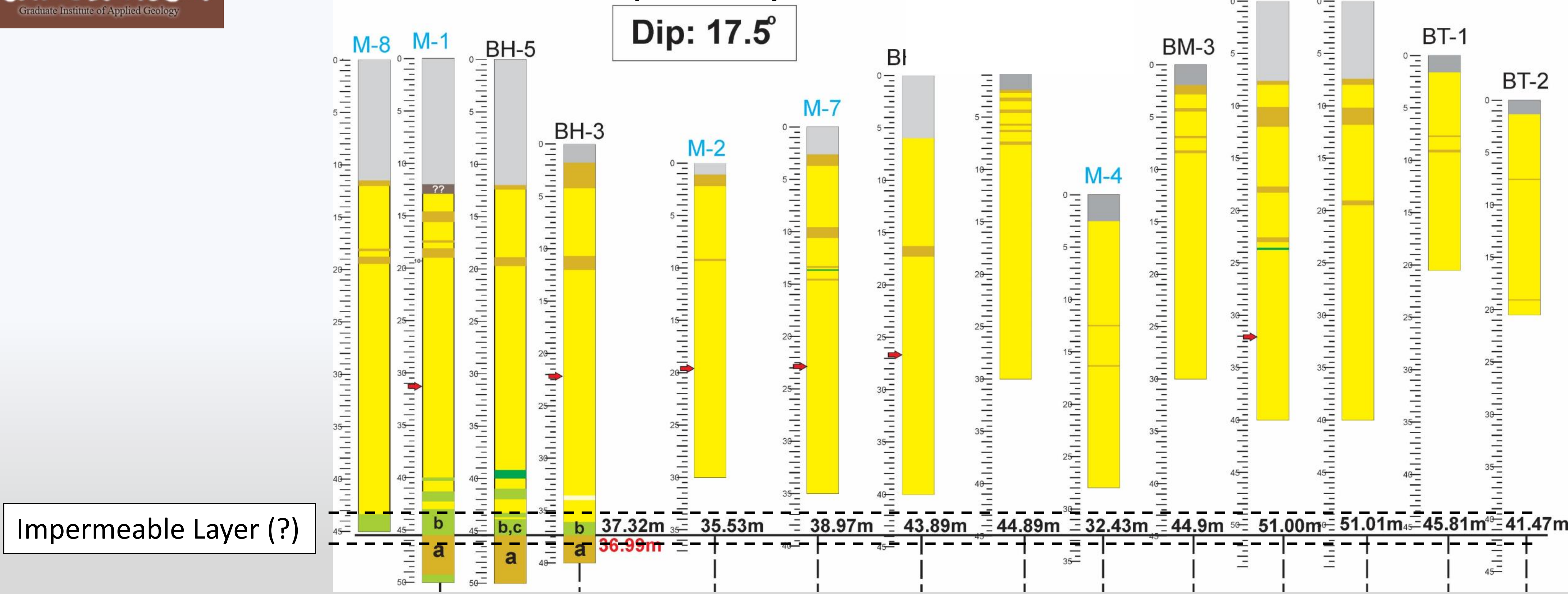
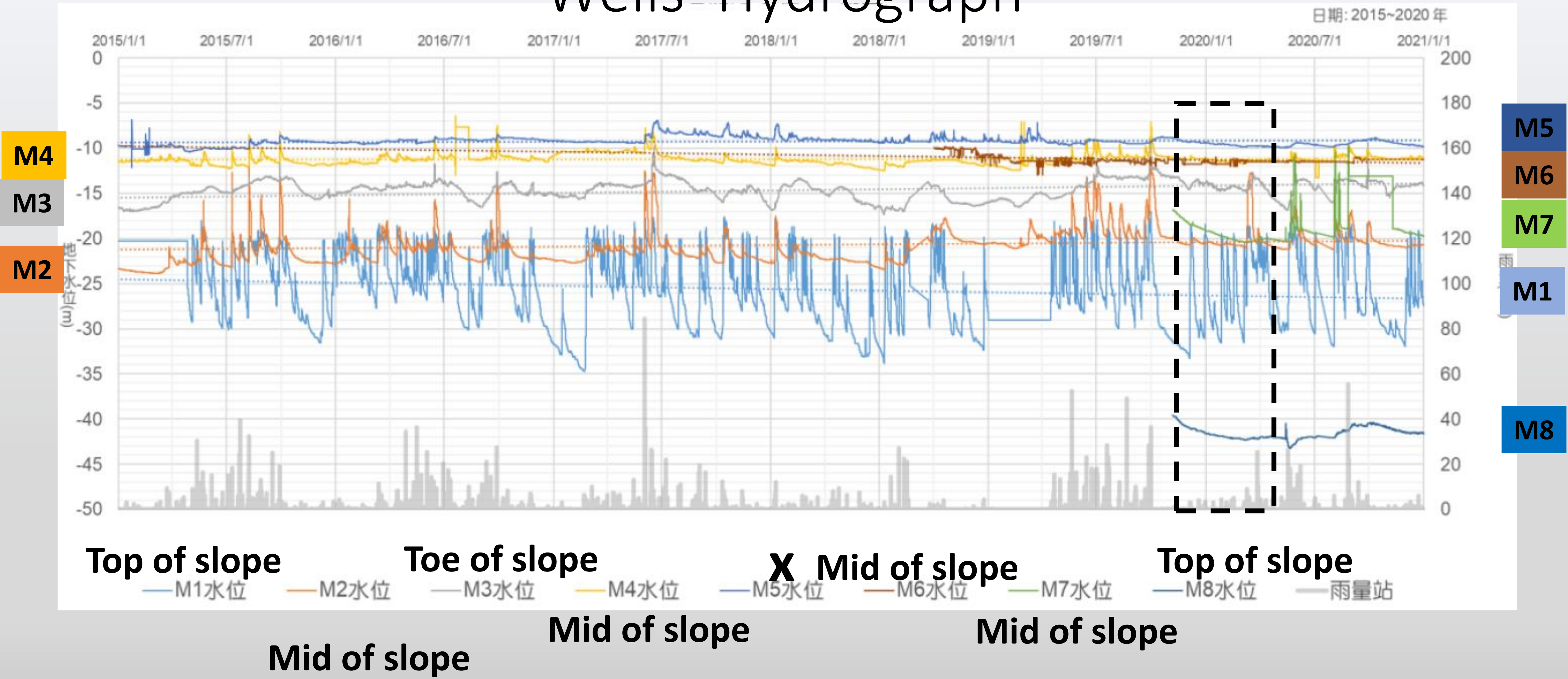
The Aquifer Systems



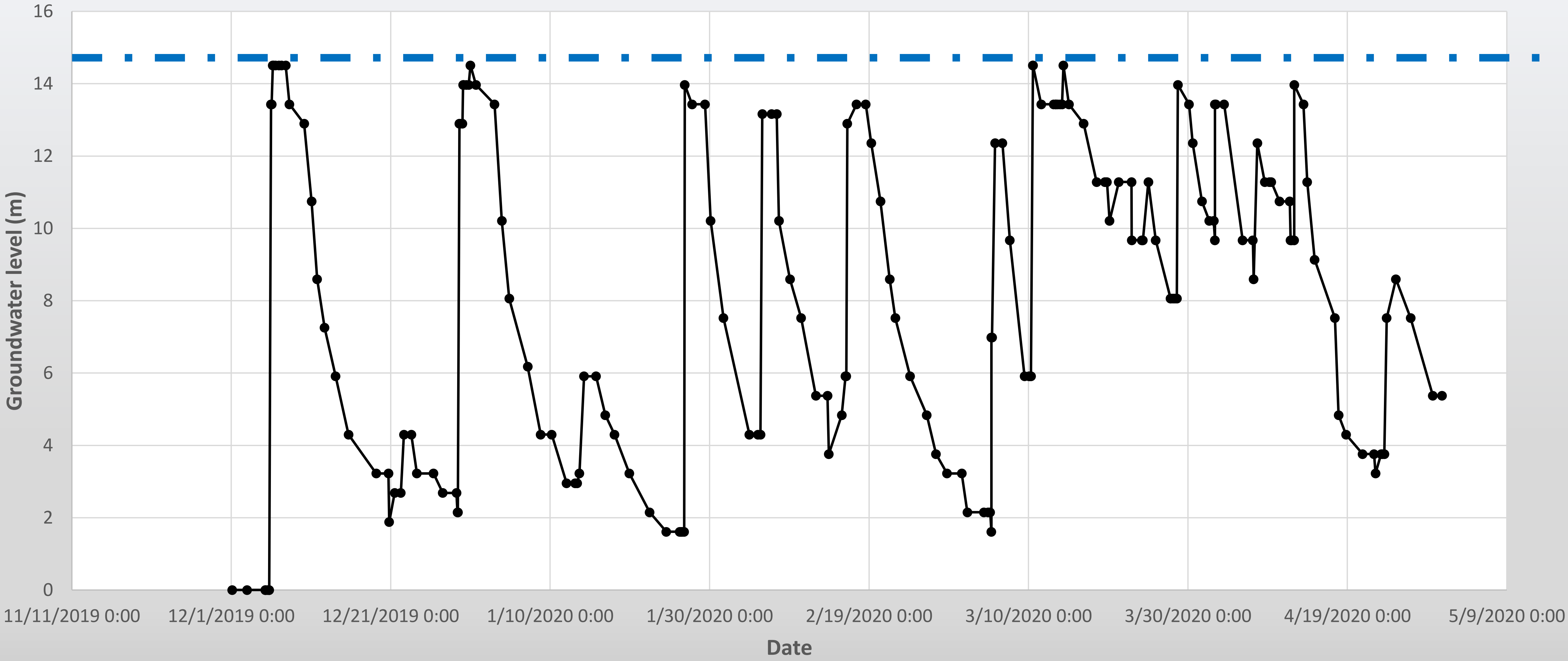
- Overburden & Colluvium
- Mudstone
- SS (massive sandstone)
- SS-SH (mainly composed of ss with sh occasionally)
- SS/SH (Interbedded of ss and sh)
- SH-SS (mainly composed of sh with ss occasionally)
- SH (shale)

Rainfall Data and Monitoring Wells' Hydrograph



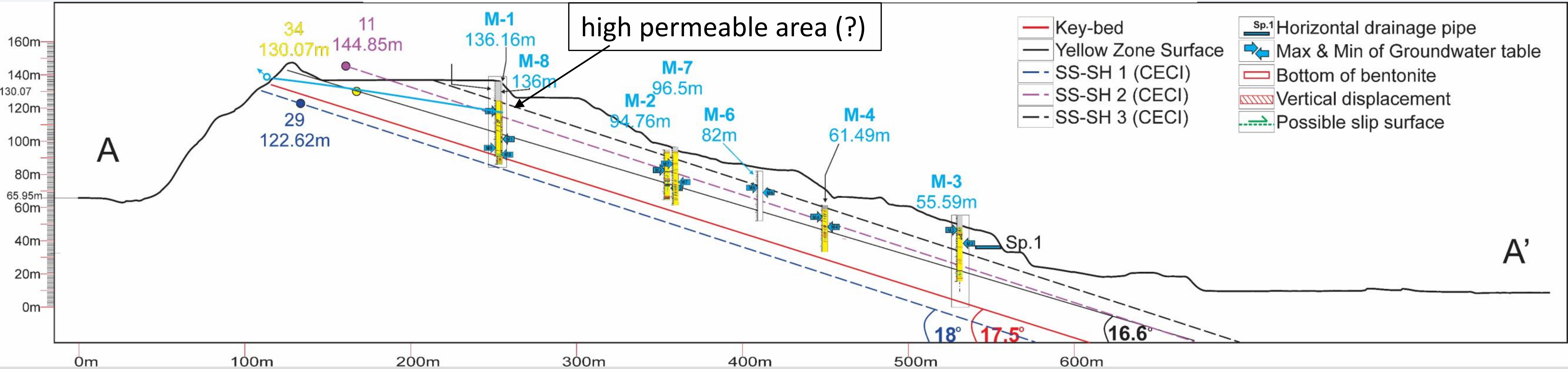
x : m.w. is too far

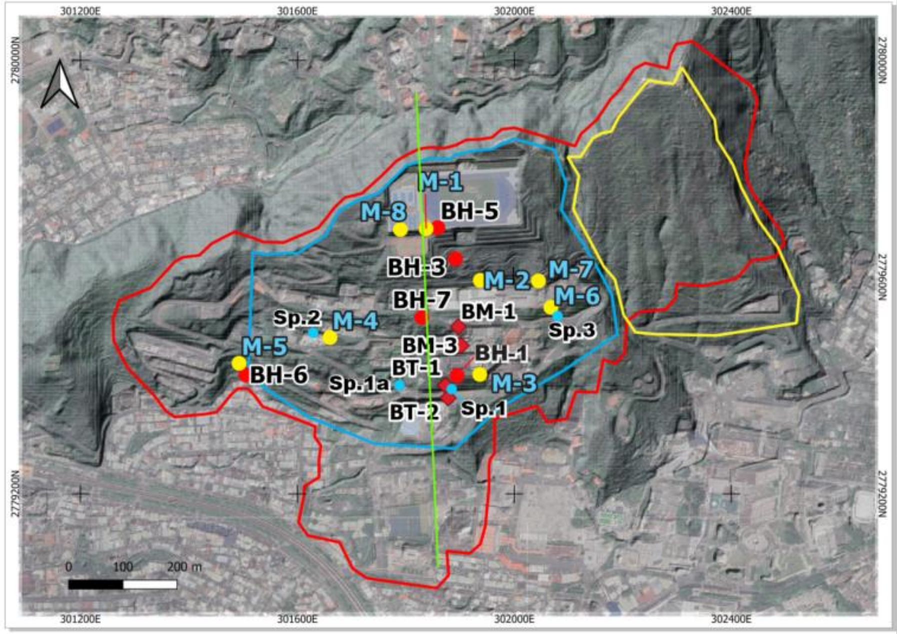
Groundwater Fluctuation of M1 (Dec 2019 – Apr 2020)

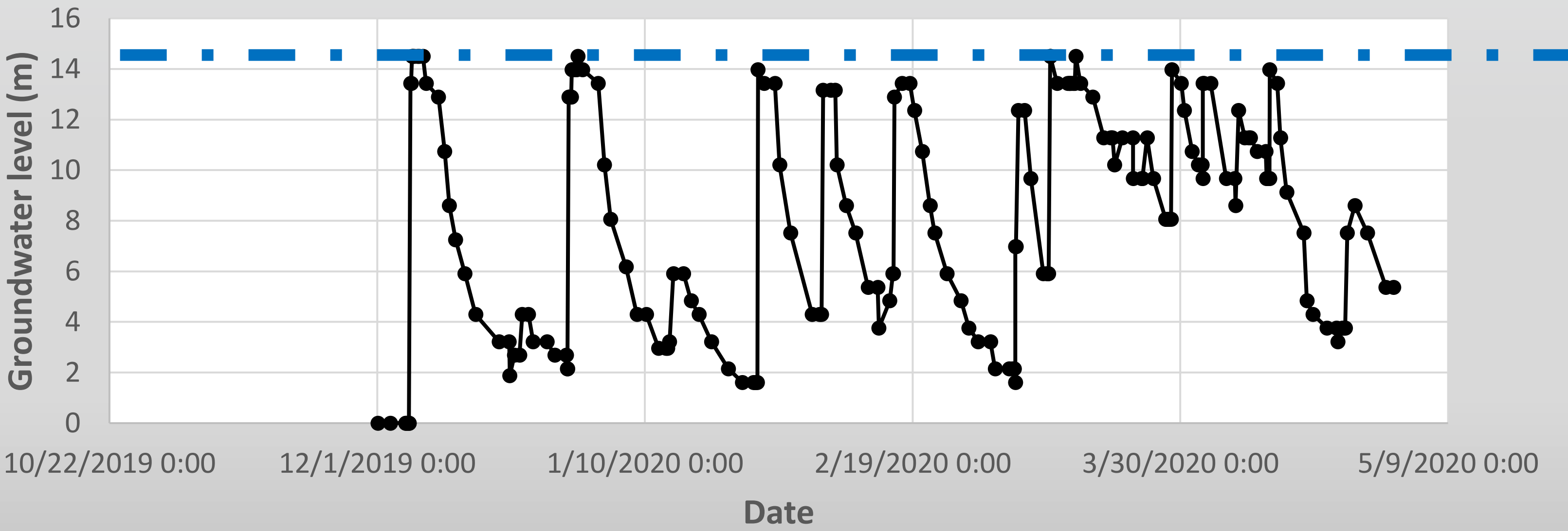


x : m.w. is too far

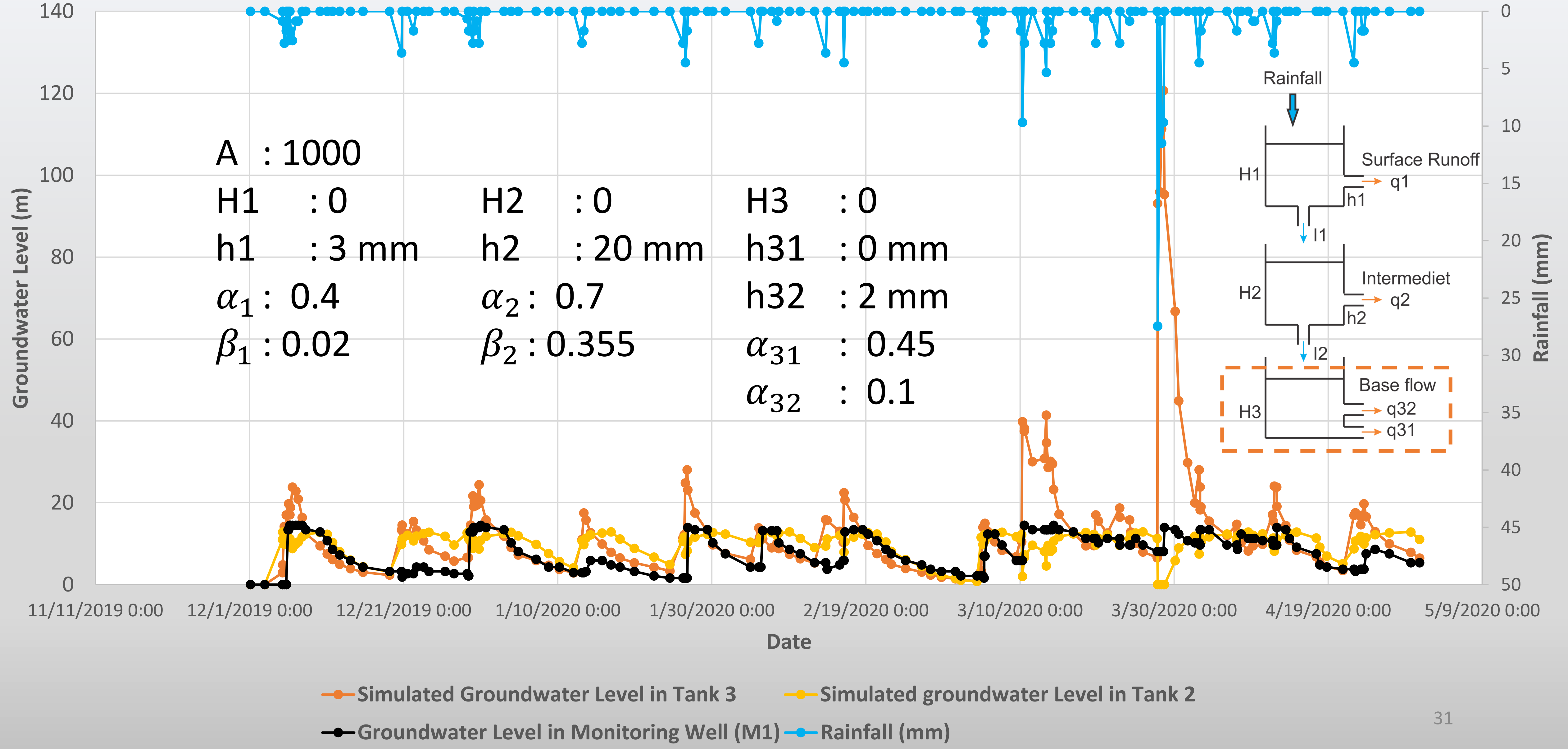
Monitoring Wells Cross-Section



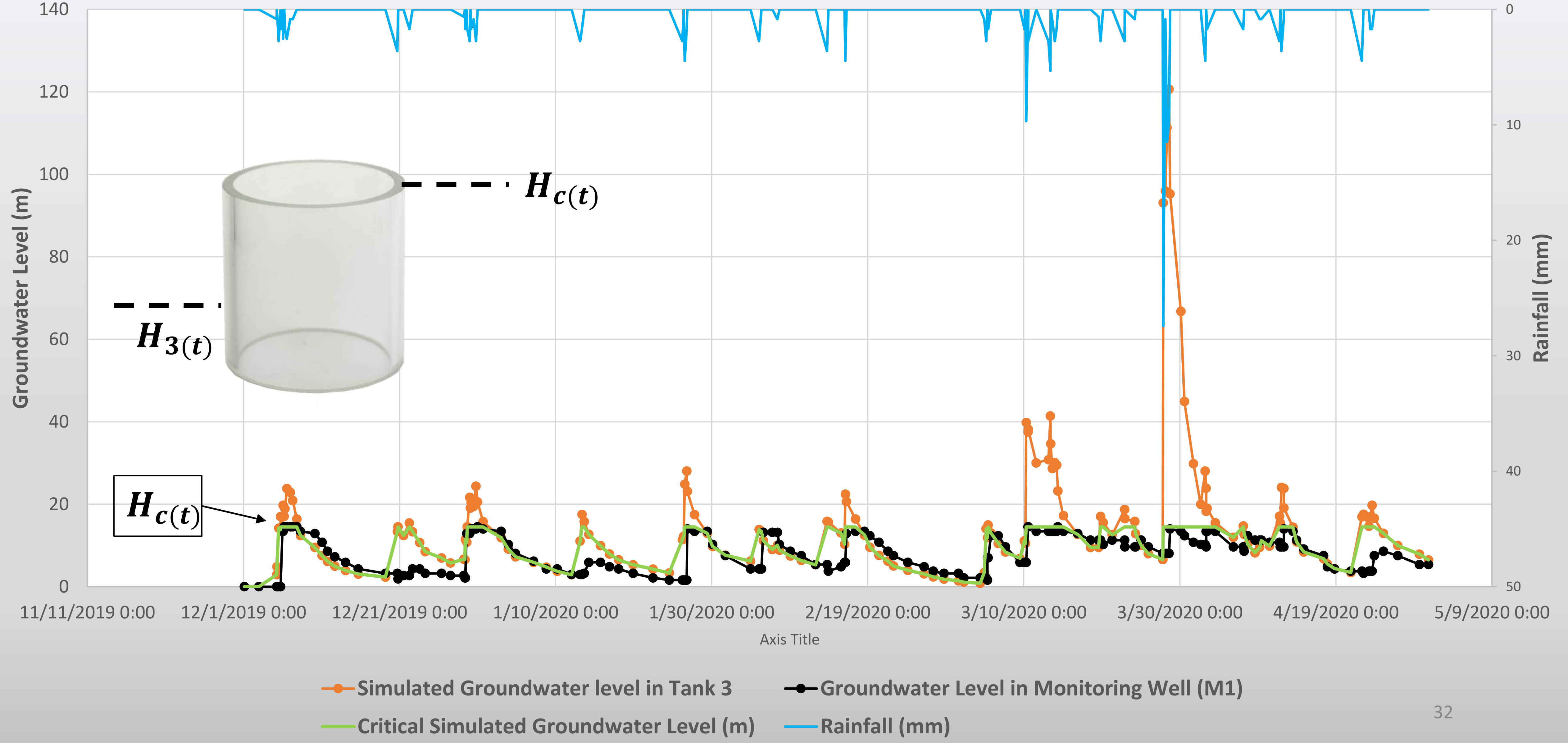




Simulated vs Factual Groundwater Fluctuation



Critical Simulated vs Factual Groundwater Fluctuation



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Conclusions

- Both orientation of the bottom of the key-bed and projected yellow zone surface are relatively the same as factual data in the boreholes.
- Upper and middle slopes of NYCU could have moved; the type of slip surface may be a step slip surface. However, the slope toe holds them and makes them still stable.
- Trend of groundwater fluctuation of the multi-tank model shows a corresponding good relation to the factual data of monitoring well.
- Bottom outlet will control significantly the increasing and decreasing of groundwater level in the below and above tank, respectively.

Future Works

- Finding the evidence of vertical movement in the field.
- Calibrating the simulated groundwater level to the different time periods in M1
- Proposing the multi-tank model for other monitoring wells.
- Identifying the critical groundwater level based on multi-tank models
- Identifying the slope stability and slope failure probability

References

Dong, J.J., Tzeng, J.H., Wu, P.K., & Lin, M.L.(2006).Effects of anisotropic permeability on stabilization and pore water pressure distribution of poorly cemented stratifiedrock slopes. *International journal for numerical and analytical methods in geomechanics*, *30*(15), 1579-1600.

Hong, Y., Hiura, H., Shino, K., Sassa, K., & Fukuoka, H. (2005). Quantitative assessment on the influence of heavy rainfall on the crystalline schist landslide by monitoring system-case study on Zentoku landslide, Japan. Landslides, 2(1), 31-41.

THANK YOU
FOR
YOUR ATTENTION