國立中央大學
National Central University

NATIONAL CENTRAL UNIVERSITY - COLLEGE OF EARTH SCIENCES
GRADUATE INSTITUTE OF APPLIED GEOLOGY

Scale effect of the spatial correlation factor used in Markov random fields: A case study in Taipei Basin

Presenter: Le Hoai Han
Advisor: Prof. Jia-Jyun Dong
Co-Advisor: Dr. Yu-Chen Lu
Date: 2023/03/03

CONTENT

1. INTRODUCTION

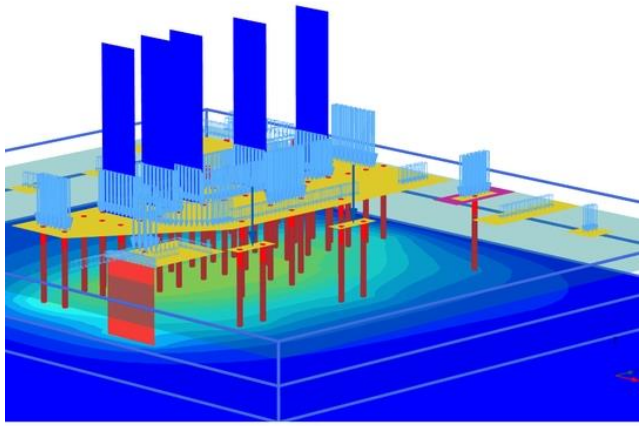
Geological model

Important in geotechnical systems (foundations, tunnels, slopes, hydrological..)

Basis for the analysis, simulation, evaluation

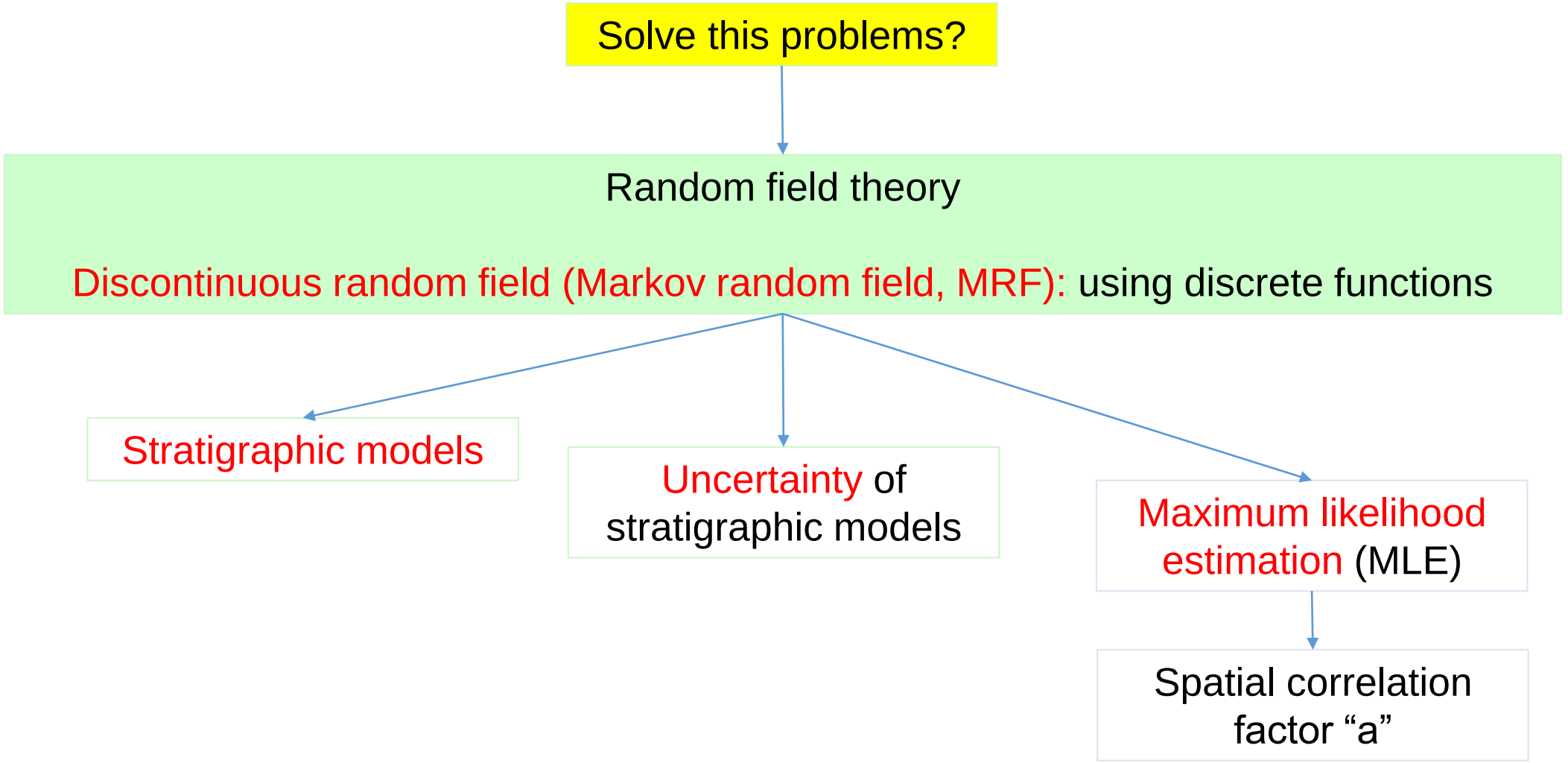
The derived geological model and geo-material properties could be highly uncertain, especially at a complex deposits site and limit data

Source: World Construction Today

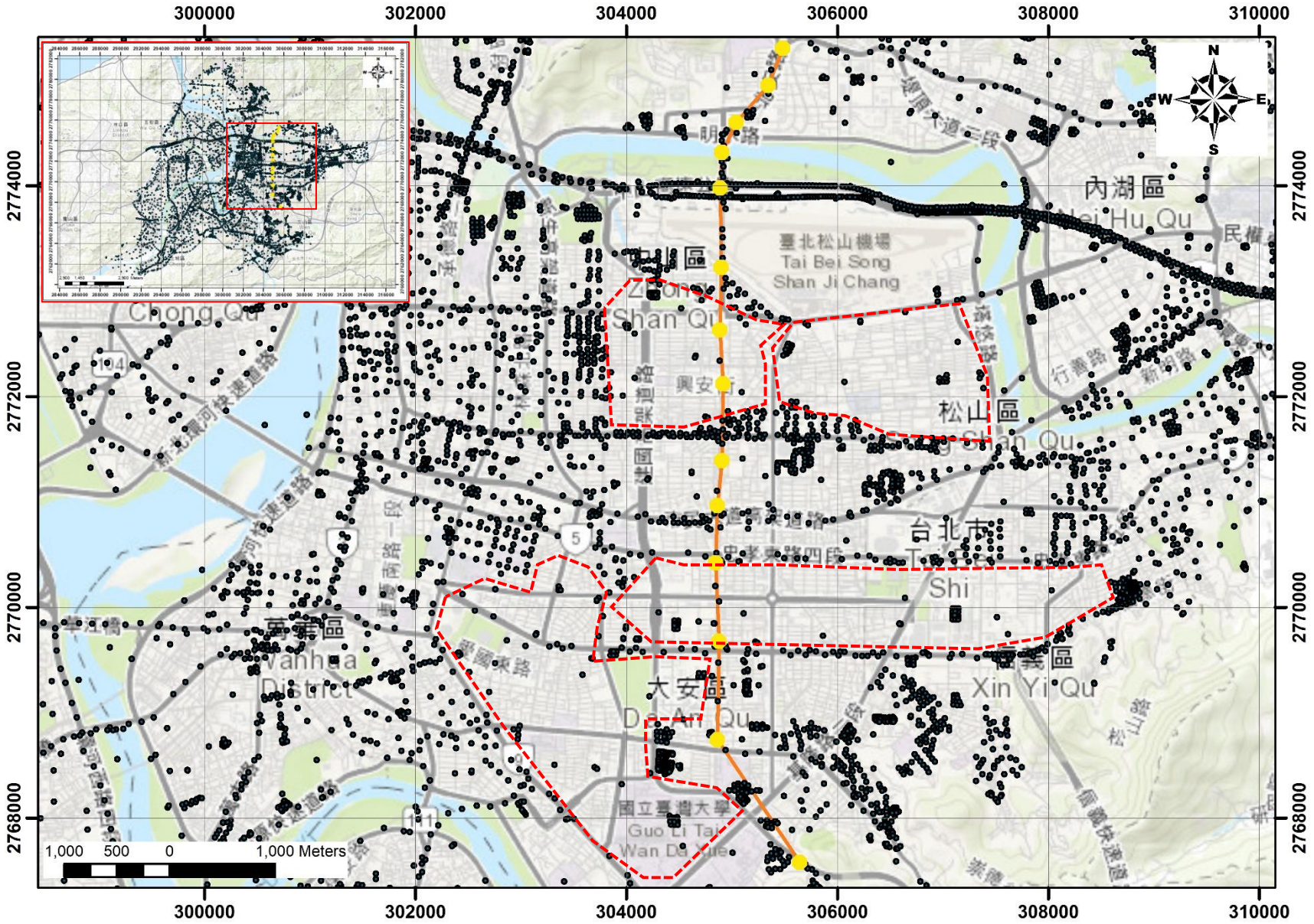


Source: CMW Geosciences

1. INTRODUCTION



1. INTRODUCTION



LEGEND

- NS-1 section (CGS, 2011)
- Boreholes in NS-1 section
- Boreholes from CGS databank

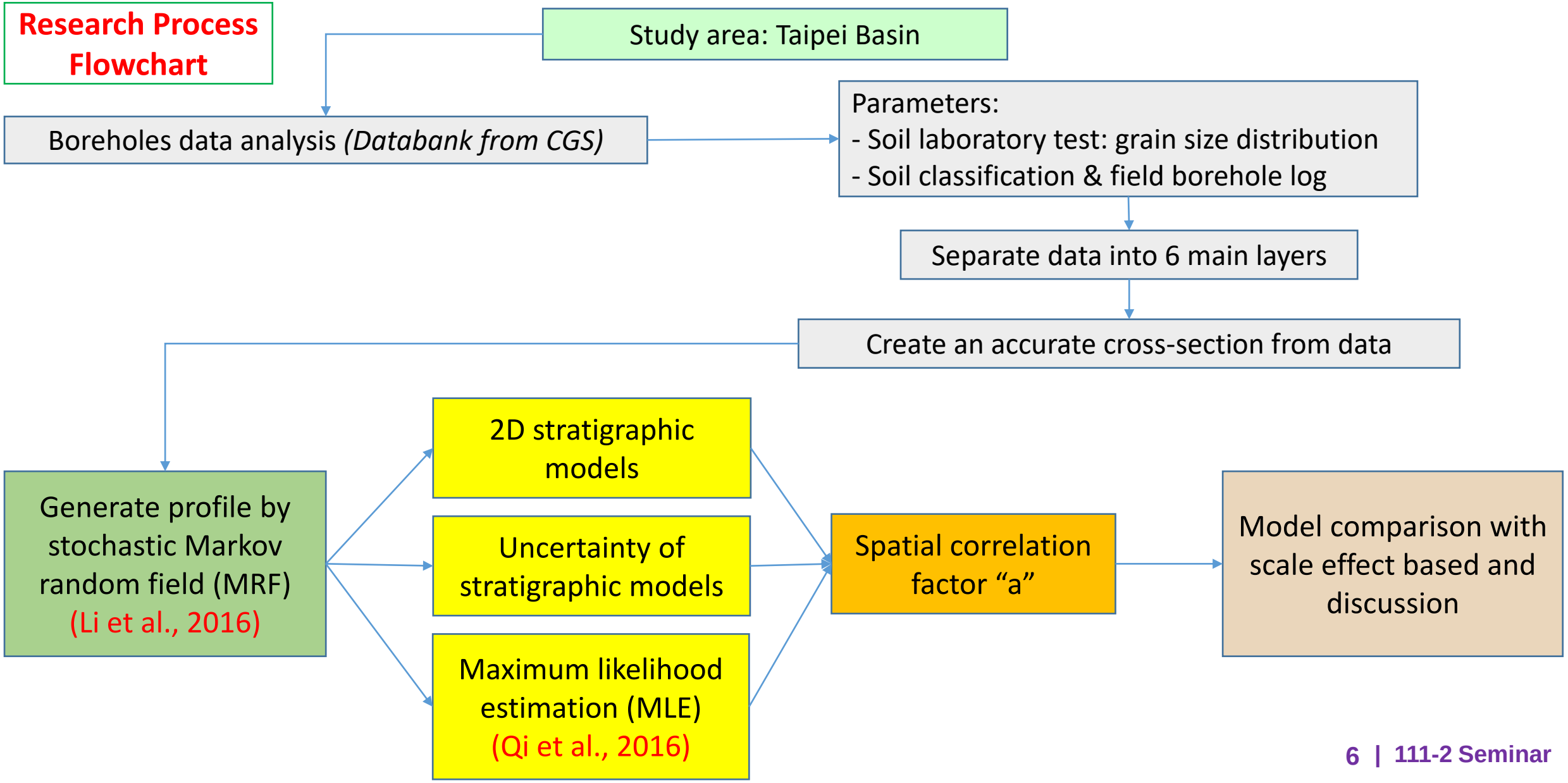
How to use MRF in an area of empty boreholes data?

…considering the sedimentary environment
&
calibrate the spatial correlation factor related to the scale effect

CONTENT

2. METHODOLOGY

Research Process Flowchart

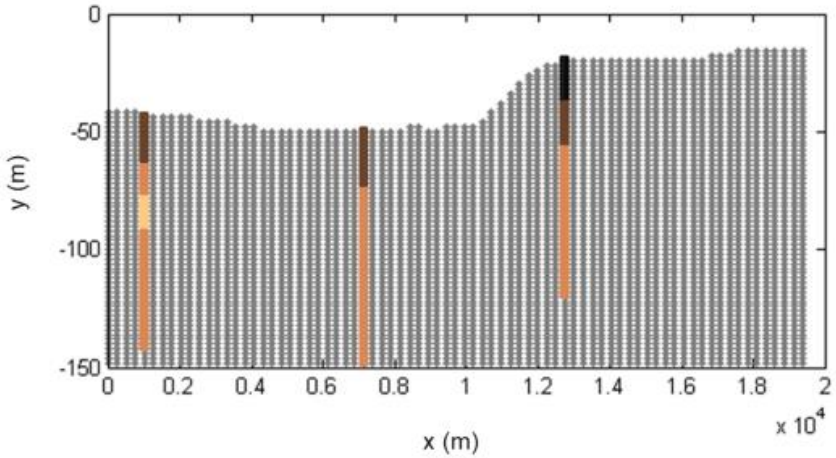


2. METHODOLOGY

The process of MRF

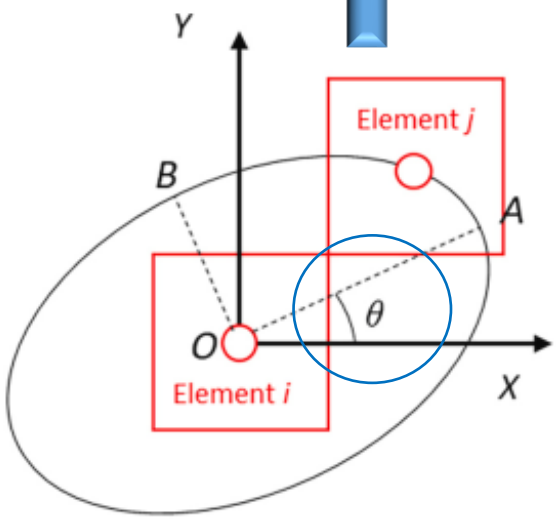
2.1 Spatial Correlation Model Used in MRF

Discritized mesh of cross-section



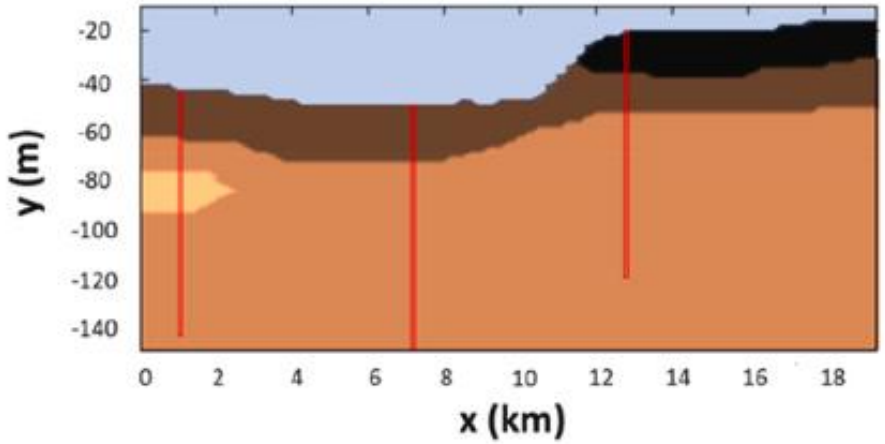
(Hsu et al., 2022)

MRF simulation



Spatial Correlation Model
(after Li et al., 2016)

1 realization generated by MRF



(Hsu et al., 2022)

Two parameters should be determined

$\overline{OA} = a$

$\overline{OB} = 1$

spatial correlation factor, a

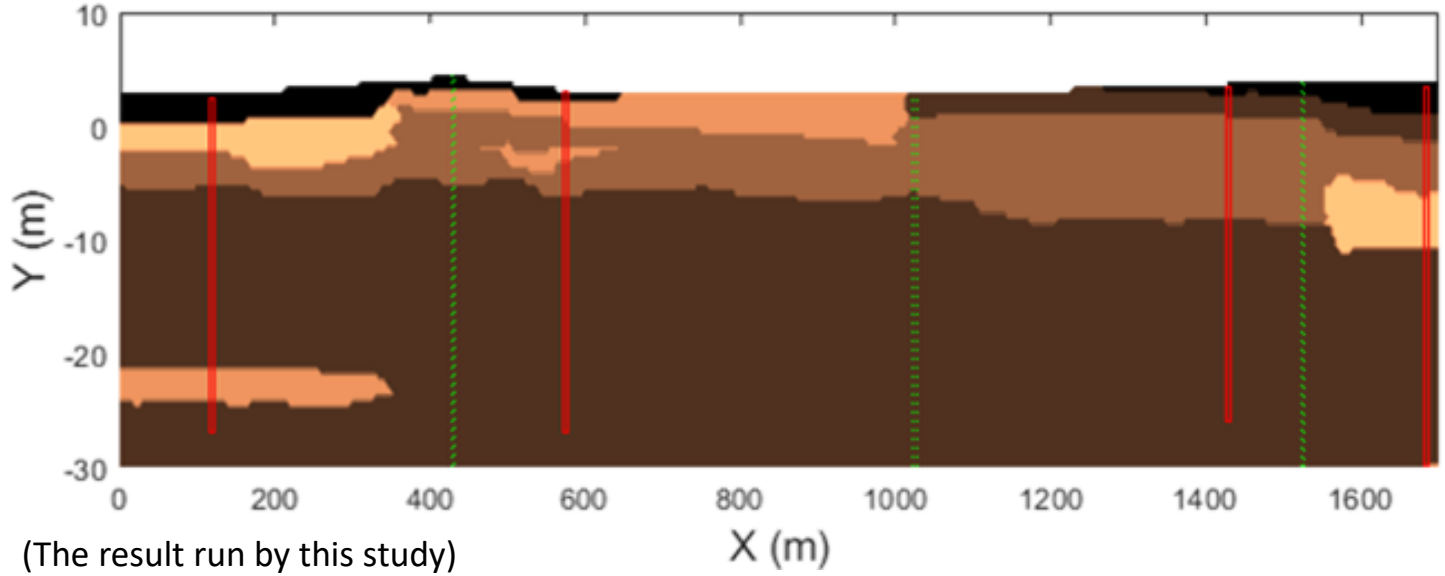
spatial correlation dip, θ

2. METHODOLOGY

The process of MRF

2D Stratigraphic Model: Stochastic MRF Simulation

a = 12 (1000 realizations)



(The result run by this study)

LEGEND

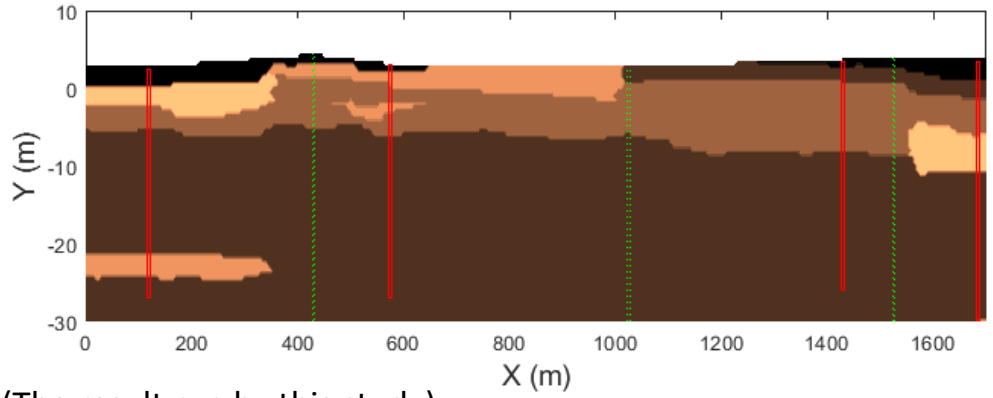
- Backfilling
- Clay
- Sand
- Silt with plasticity
- Silt without plasticity
- Borehole for MRF simulation
- Observation borehole

2. METHODOLOGY

The process of MRF

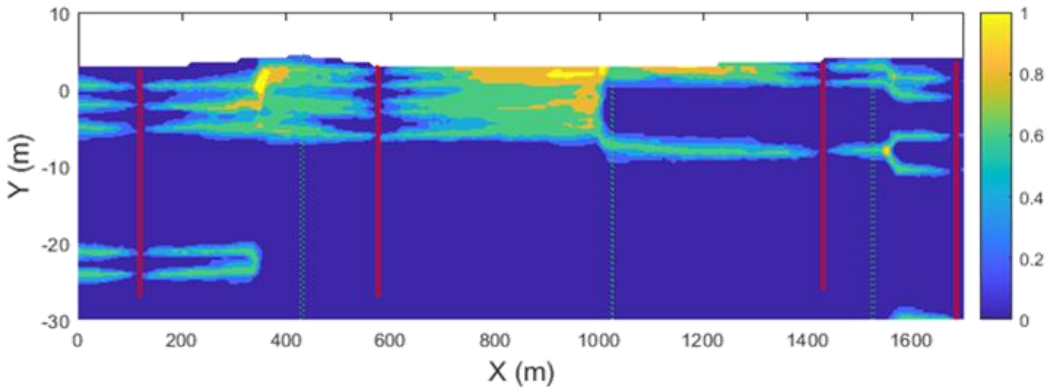
2.2 The Uncertainty of Stratigraphic model

a = 12



(The result run by this study)

Information entropy



LEGEND

- Backfilling
- Clay
- Sand
- Silt with plasticity
- Silt without plasticity
- Borehole for MRF simulation
- Observation borehole

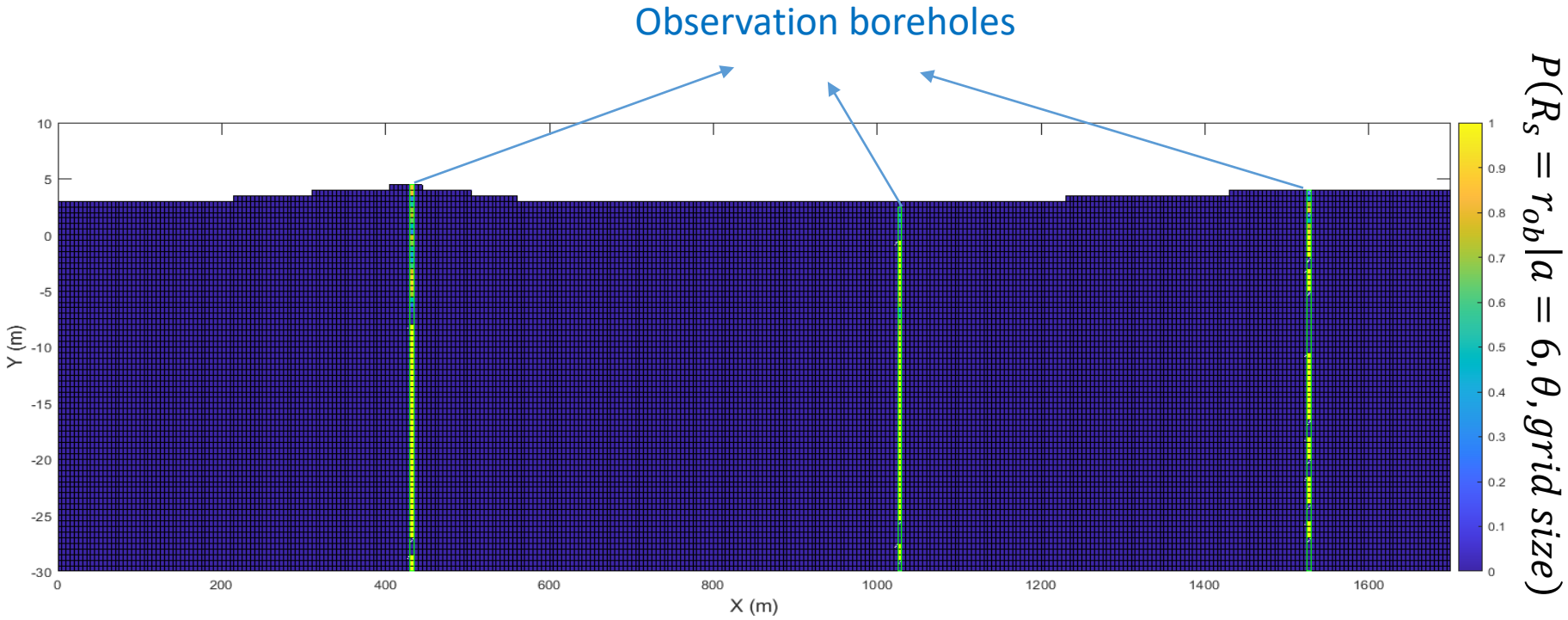
1000 realizations

- Calculate the probability of soil type existence
- Substitute the probability into equation of information entropy

2. METHODOLOGY

The process of MRF

2.3 Likelihood Value at the Observation Borehole



$P(R_s = r_{ob}|a = 6, \theta, grid\ size)$

Probability of the existence of the layer

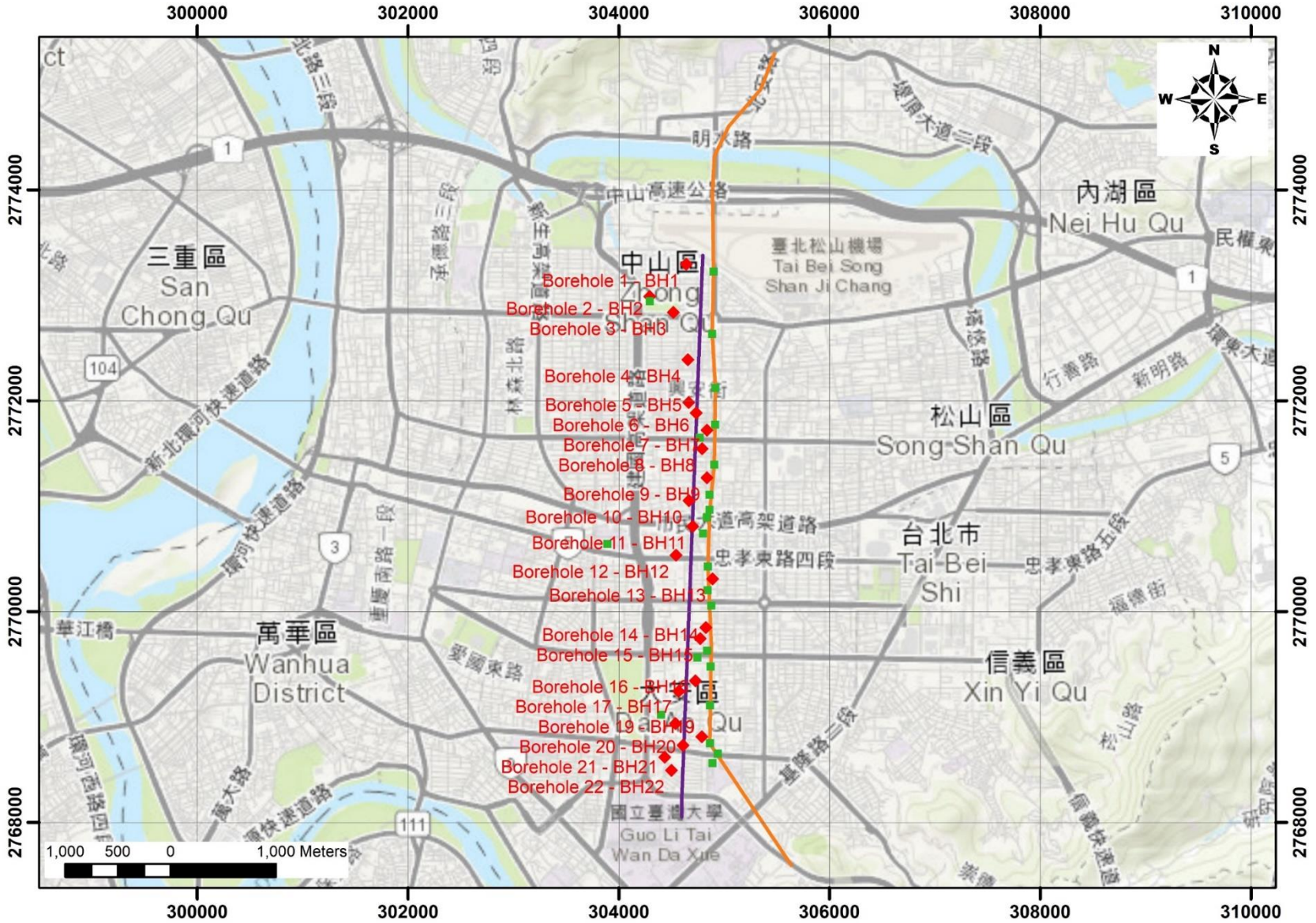
Likelihood value

(The result run by this study)

The probability of simulation equal to observation for spatial correlation, *a* equal to 12 (only compared with observation borehole)

2. METHODOLOGY

The study site

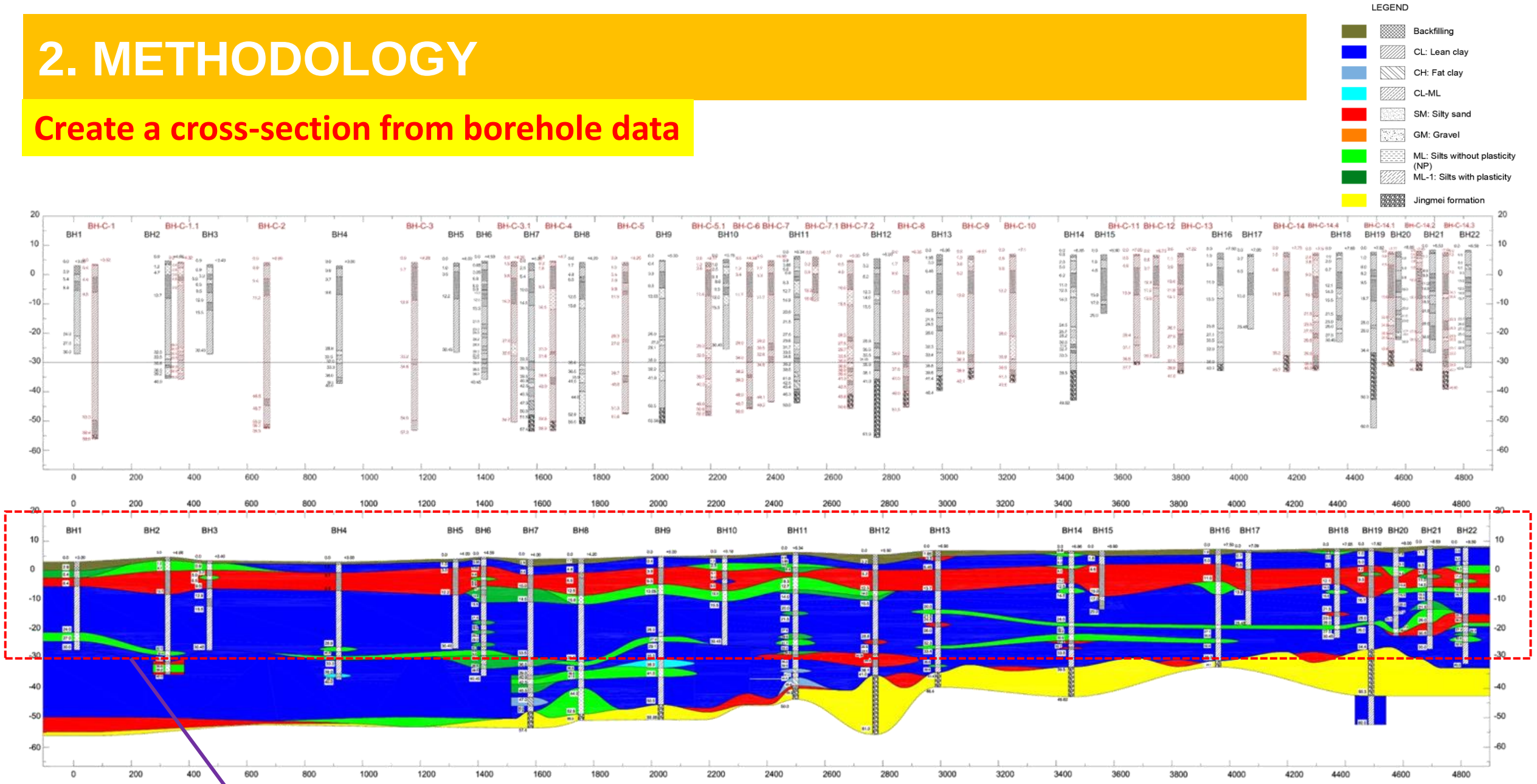


LEGEND

- NS-1 section (CGS, 2011)
- Boreholes used for analyzed (22 BHs)
- The line use for projected boreholes
- Boreholes used for checking information (23 BHs)

2. METHODOLOGY

Create a cross-section from borehole data



2. METHODOLOGY

Scale effect based

LEGEND
- Backfilling
- CL: Lean clay
- SM: Silty sand
- ML: Silts without plasticity
- ML-1: Silts with plasticity
- Jingmei formation

Model 1: Scale effect with the length ~800m

Section 1.1 BH1 - BH4

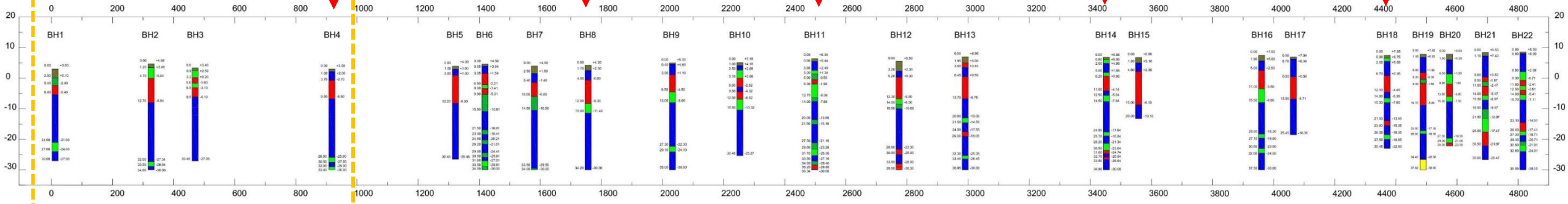
Section 1.2 BH4 – BH8

Section 1.3 BH8 – BH11

Section 1.4 BH11 – BH14

Section 1.5 BH14 – BH18

Section 1.6 BH18 – BH22

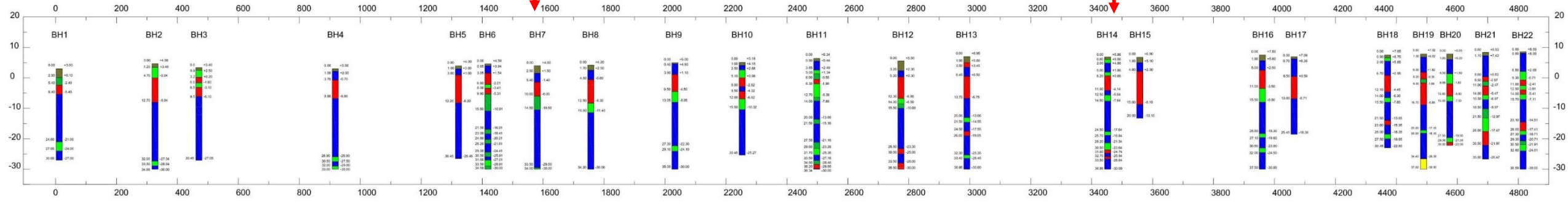


Model 2: Scale effect with the length ~1600m

Section 2.1 BH1 – BH7

Section 2.2 BH7 – BH14

Section 2.3 BH14 – BH22



Model 3: Scale effect with whole section (~5000m)

CONTENT

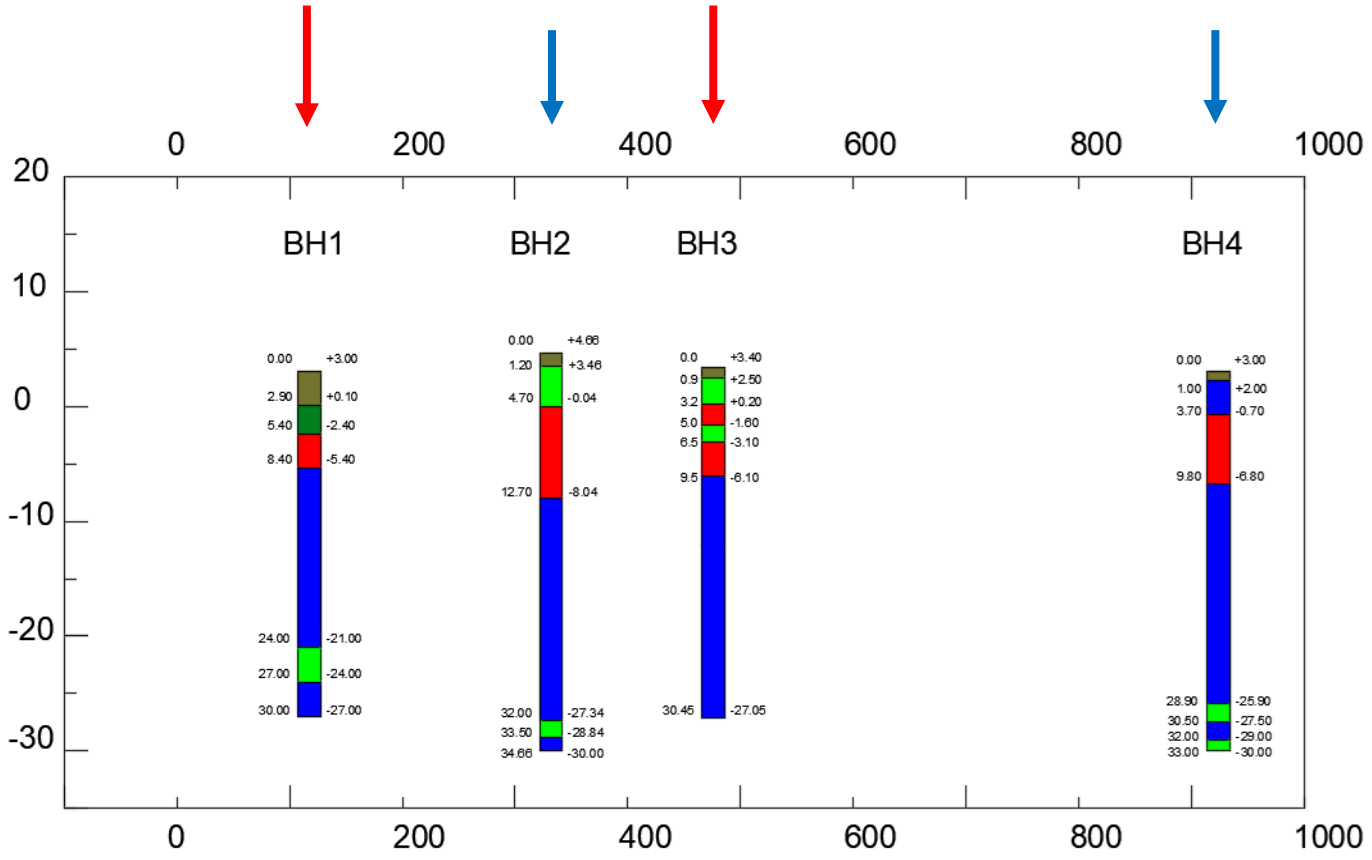
3. RESULTS AND DISCUSSION

Simulation results in Section 1.1 – Model 1

SECTION 1.1: BH1-BH4

Simulation borehole (2 boreholes)

Observation borehole (2 boreholes)



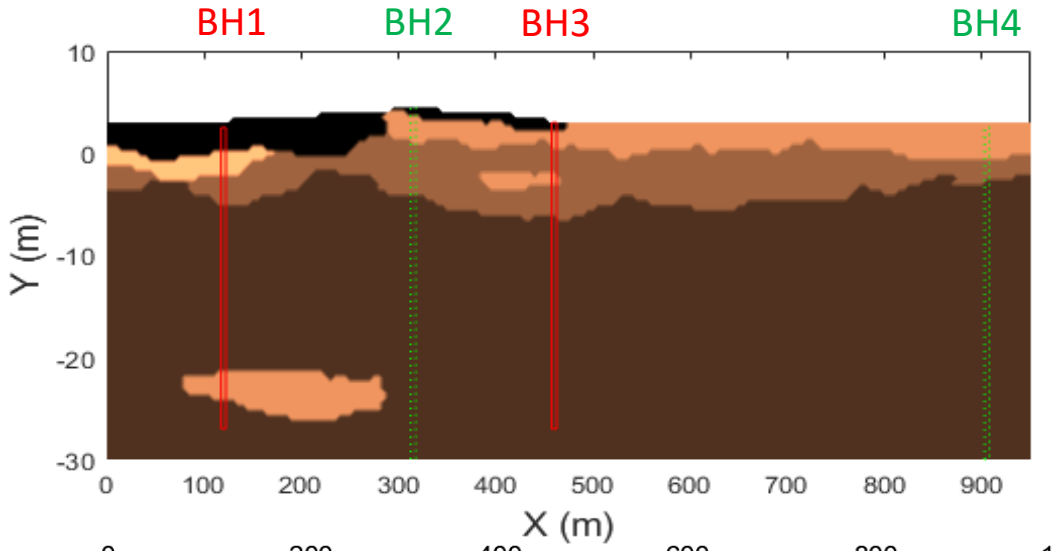
LEGEND

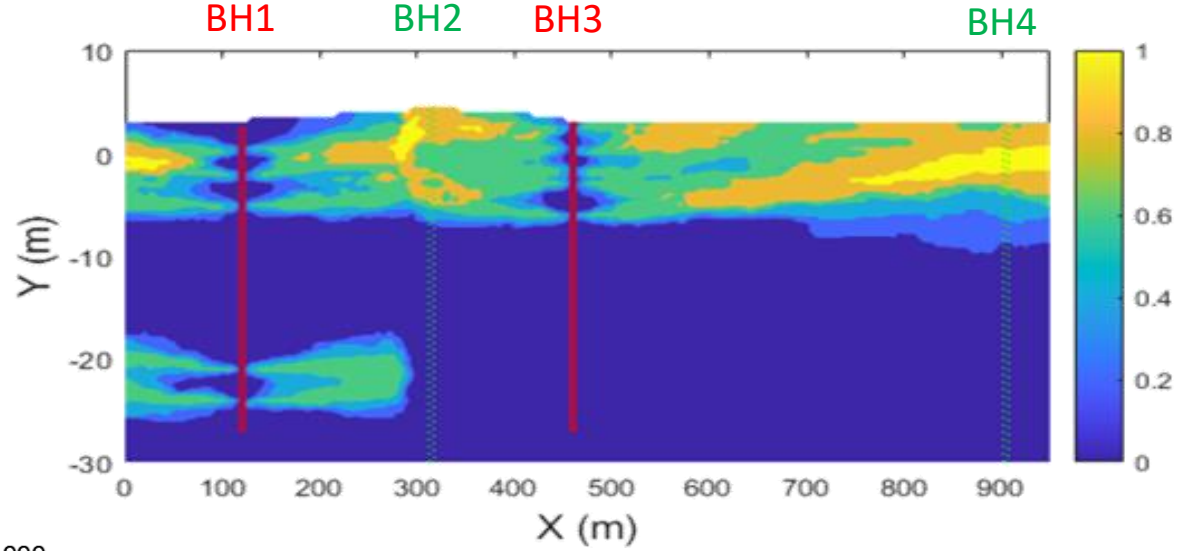
- Backfilling
- CL: Lean clay
- SM: Silty sand
- ML: Silts without plasticity
- ML-1: Silts with plasticity

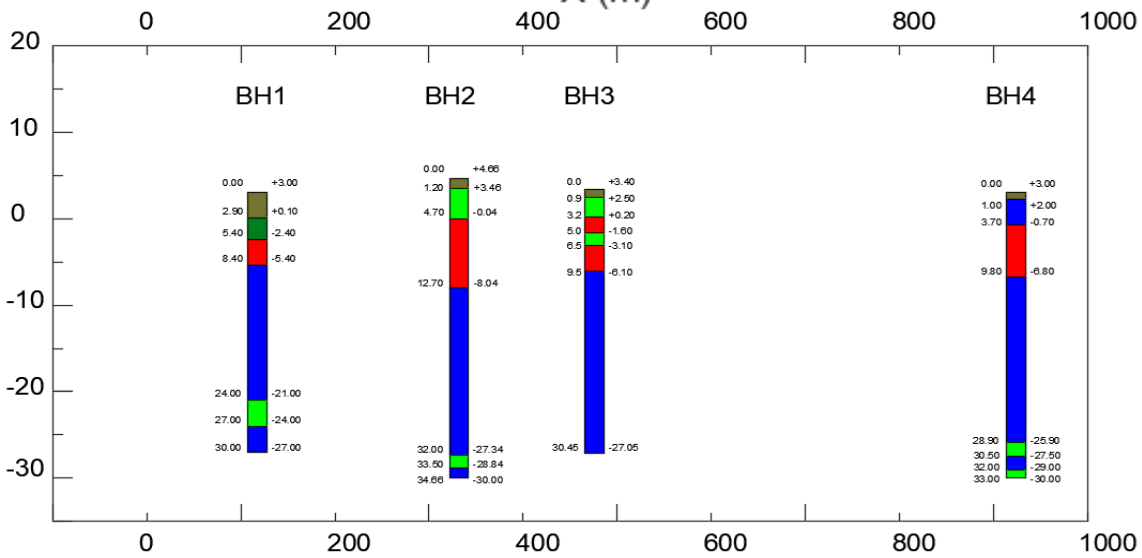
3. RESULTS AND DISCUSSION

Simulation results in Section 1.1 – Model 1: 2D stratigraphic model & Uncertainty of stratigraphic model

a = 7 (1000 realizations)







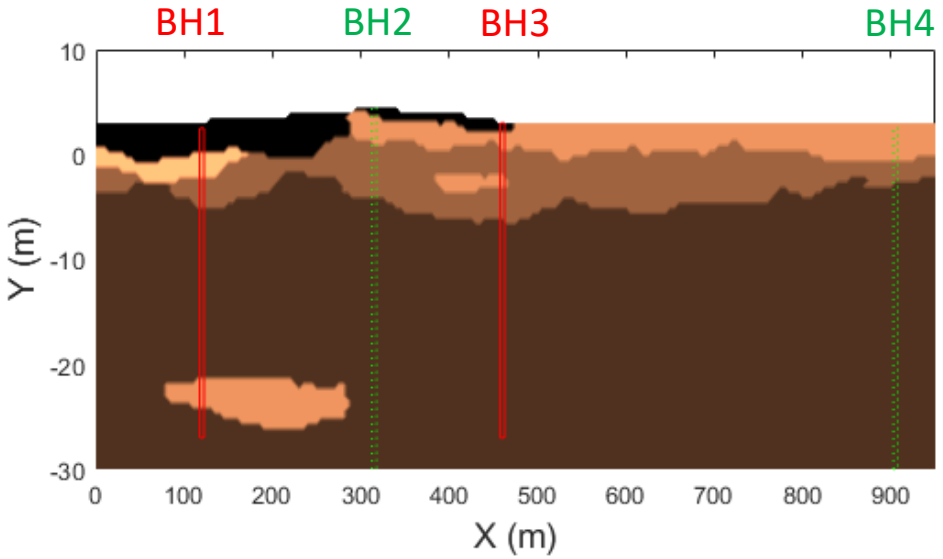
LEGEND

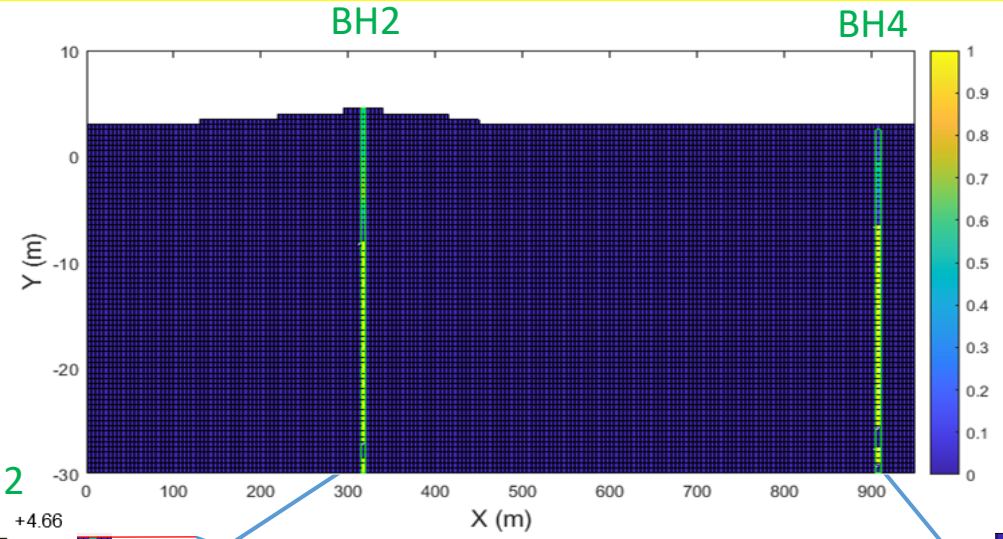
- Backfilling
- Clay
- Sand
- Silt with plasticity
- Silt without plasticity
- Borehole for MRF simulation
- Observation borehole

- Backfilling
- CL: Lean clay
- SM: Silty sand
- ML: Silts without plasticity
- ML-1: Silts with plasticity

3. RESULTS AND DISCUSSION

Simulation results in Section 1.1 – Model 1: 2D stratigraphic model & Maximum likelihood estimation

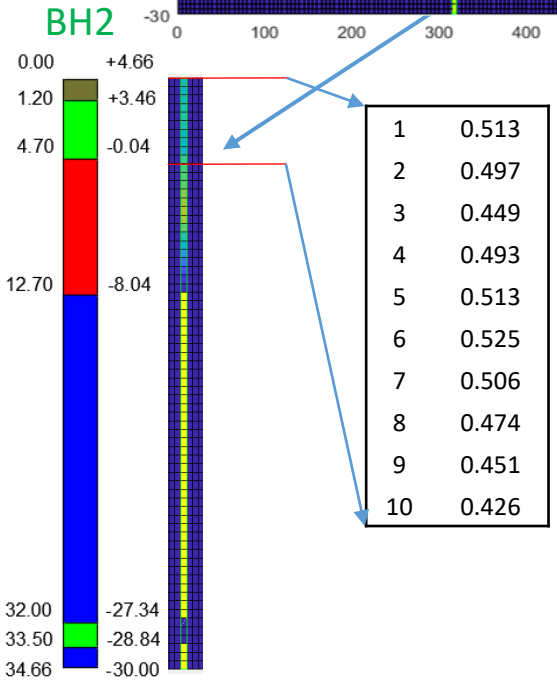




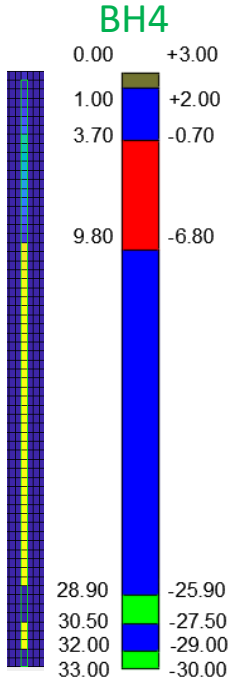
LEGEND

- Backfilling
- Clay
- Sand
- Silt with plasticity
- Silt without plasticity
- Borehole for MRF simulation
- Observation borehole

- Backfilling
- CL: Lean clay
- SM: Silty sand
- ML: Silts without plasticity
- ML-1: Silts with plasticity



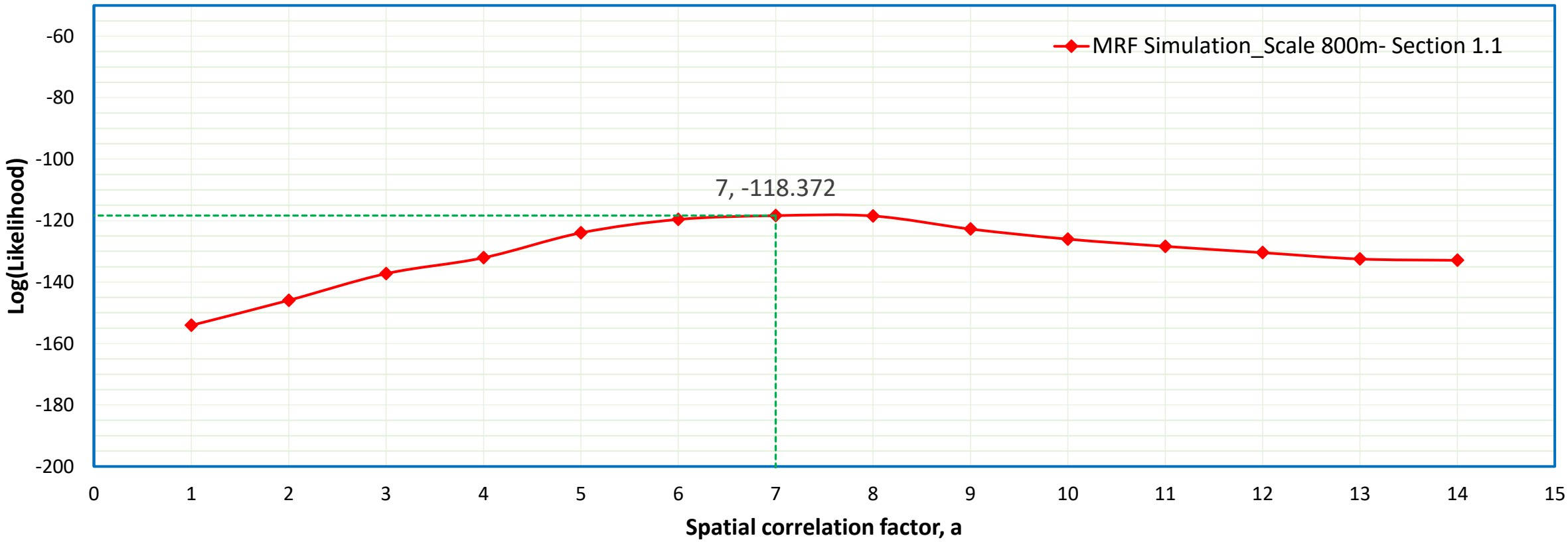
1	0.513
2	0.497
3	0.449
4	0.493
5	0.513
6	0.525
7	0.506
8	0.474
9	0.451
10	0.426



3. RESULTS AND DISCUSSION

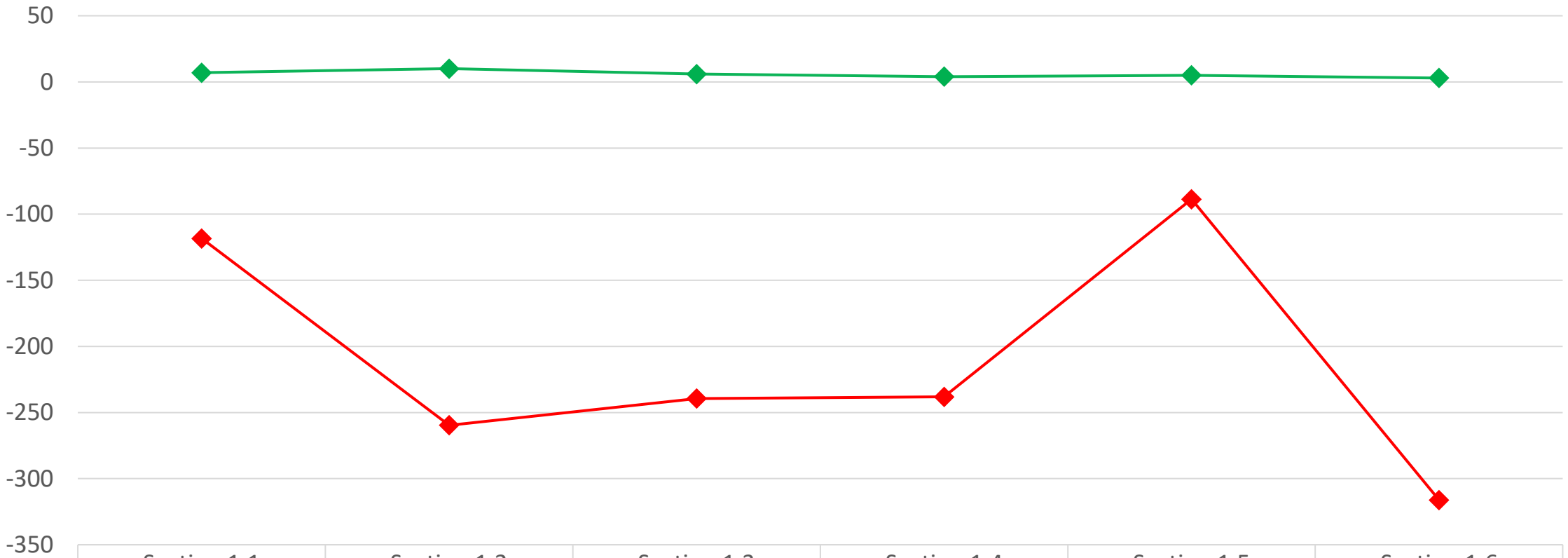
Simulation results in Section 1.1 – Model 1

Relationship between Log(Likelihood) and Spatial correlation factor



3. RESULTS AND DISCUSSION

Simulation results in Model 1

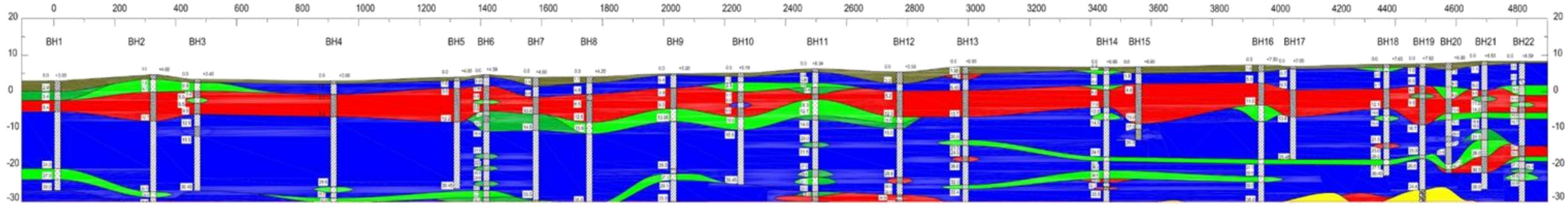


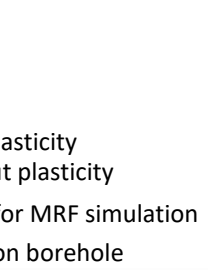
	Section 1.1	Section 1.2	Section 1.3	Section 1.4	Section 1.5	Section 1.6
a value	7	10	6	4	5	3
Log(Likelihood)	-118.372	-259.5801	-239.3648	-238.1021	-88.6695	-316.1605

3. RESULTS AND DISCUSSION

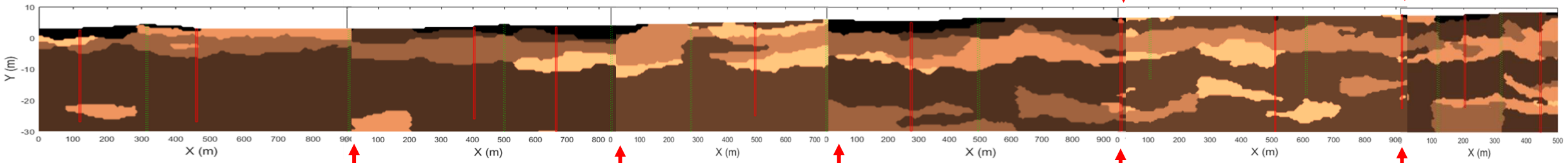
Model 1 – Scale 800m

Original cross - section

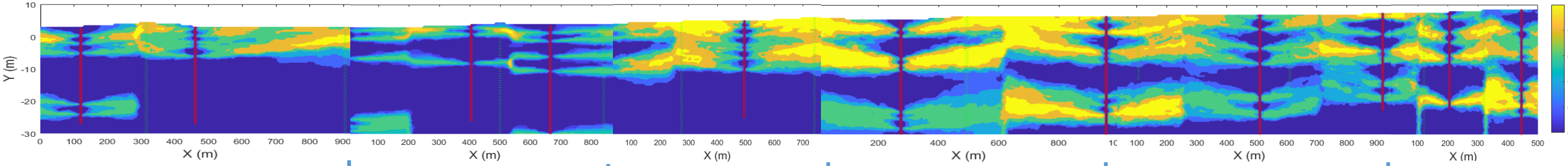




Stochastic Markov Random Field Simulation



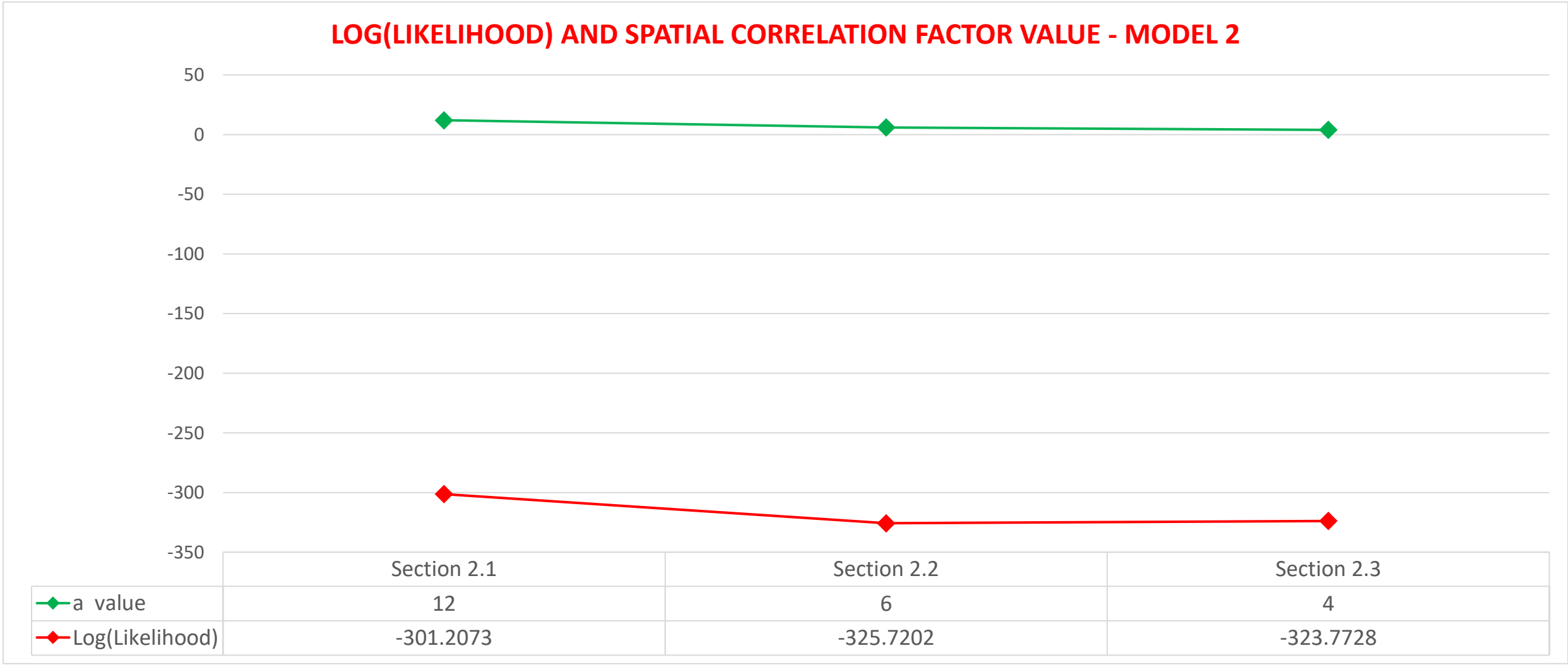
Information entropy



a = 7 | a = 10 | a = 6 | a = 4 | a = 5 | a = 3

3. RESULTS AND DISCUSSION

Model 2 – Scale 1600m

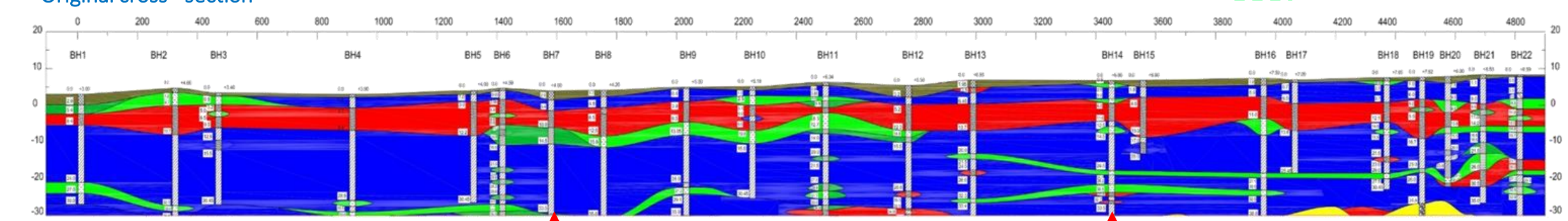


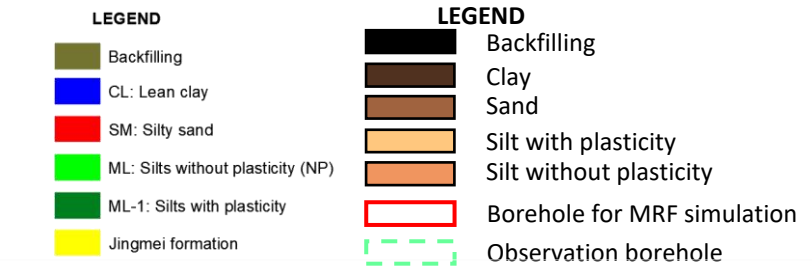
	Section 2.1	Section 2.2	Section 2.3
a value	12	6	4
Log(Likelihood)	-301.2073	-325.7202	-323.7728

3. RESULTS AND DISCUSSION

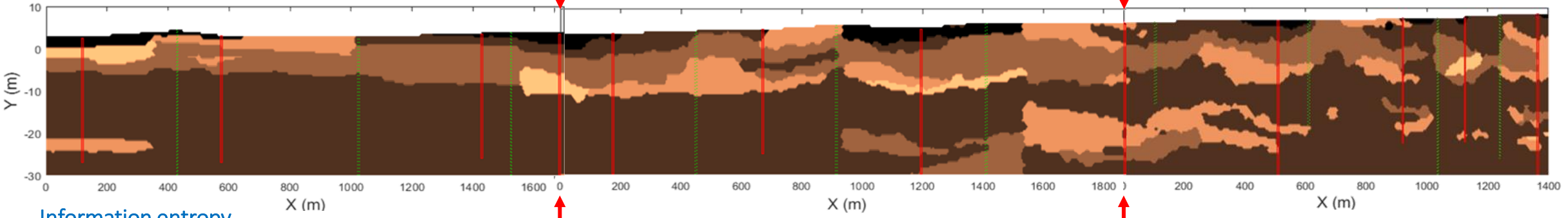
Model 2 – Scale 1600m

Original cross - section

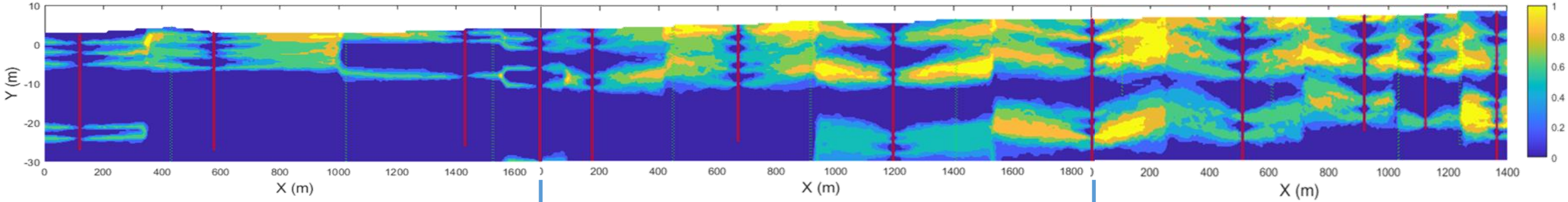




Stochastic Markov Random Field Simulation



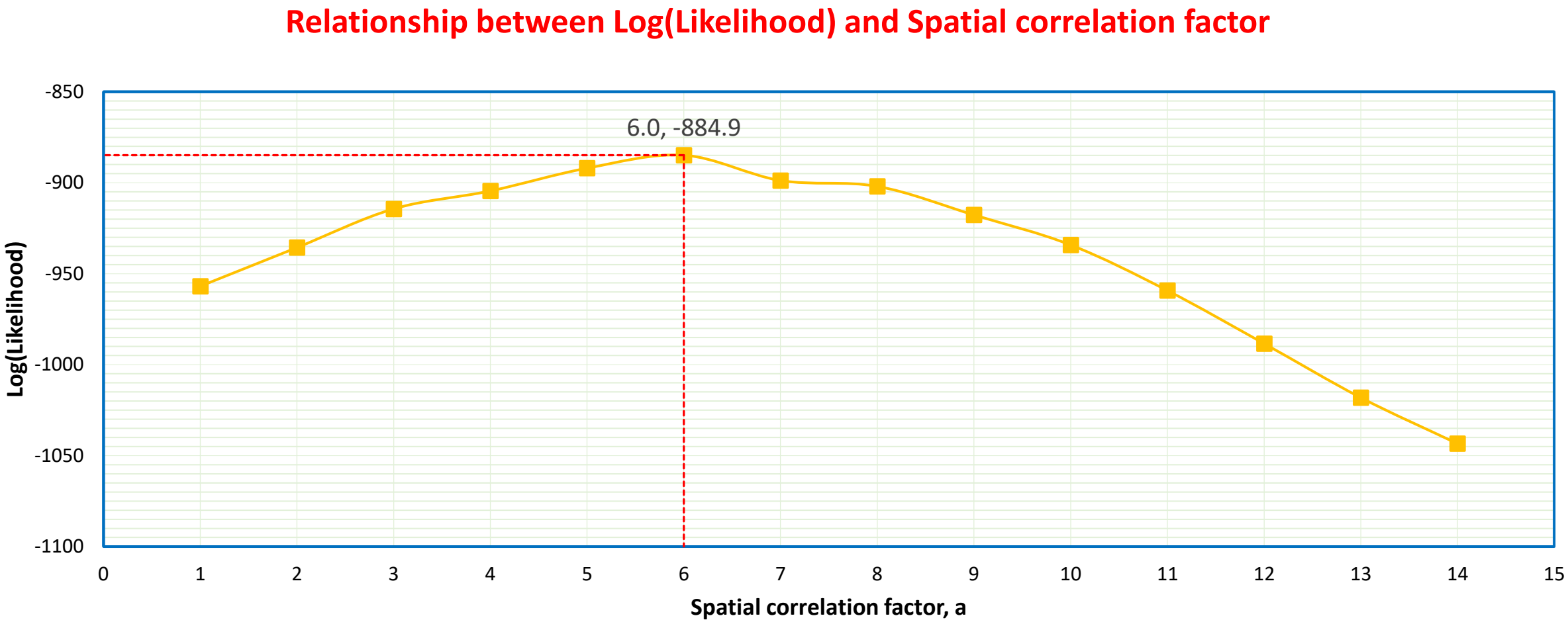
Information entropy



a = 12 a = 6 a = 4

3. RESULTS AND DISCUSSION

Model 3 – Scale 5000m



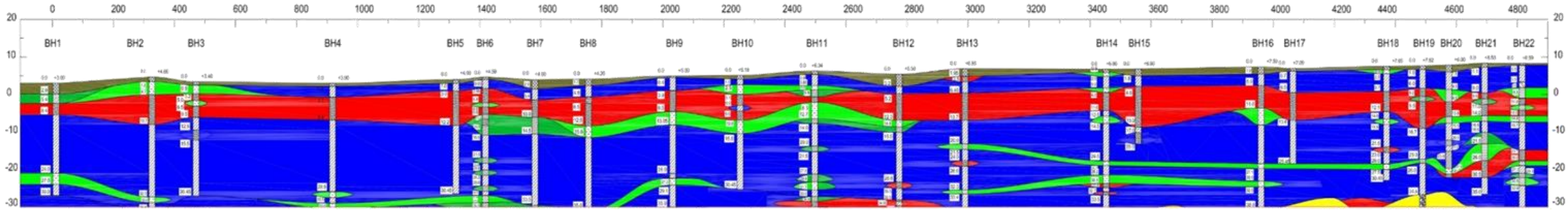
3. RESULTS AND DISCUSSION

Model 3 – Scale 5000m

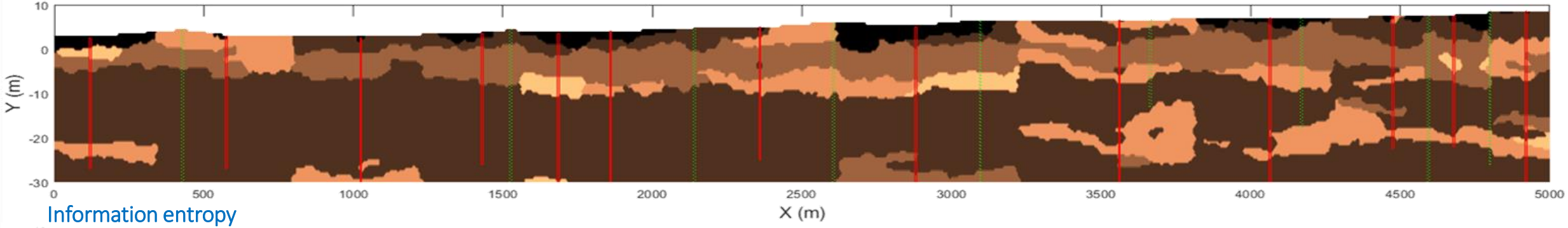
LEGEND
- Backfilling
- CL: Lean clay
- SM: Silty sand
- ML: Silts without plasticity (NP)
- ML-1: Silts with plasticity
- Jingmei formation

LEGEND
- Backfilling
- Clay
- Sand
- Silt with plasticity
- Silt without plasticity
- Borehole for MRF simulation
- Observation borehole

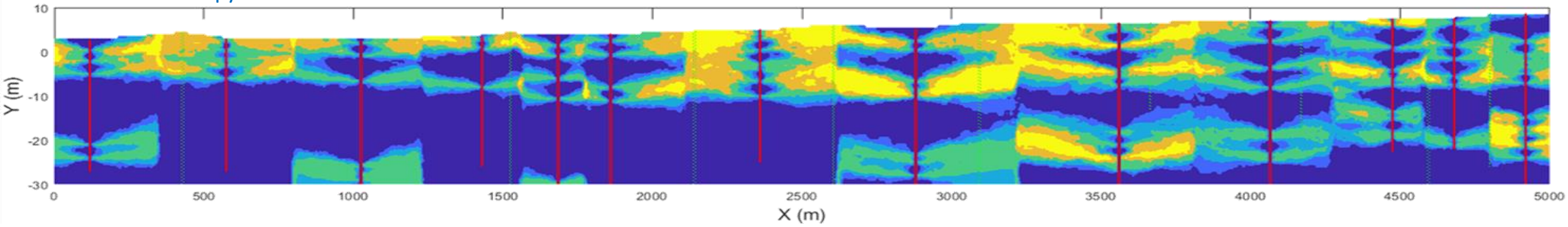
Original cross - section



Stochastic Markov Random Field Simulation



Information entropy

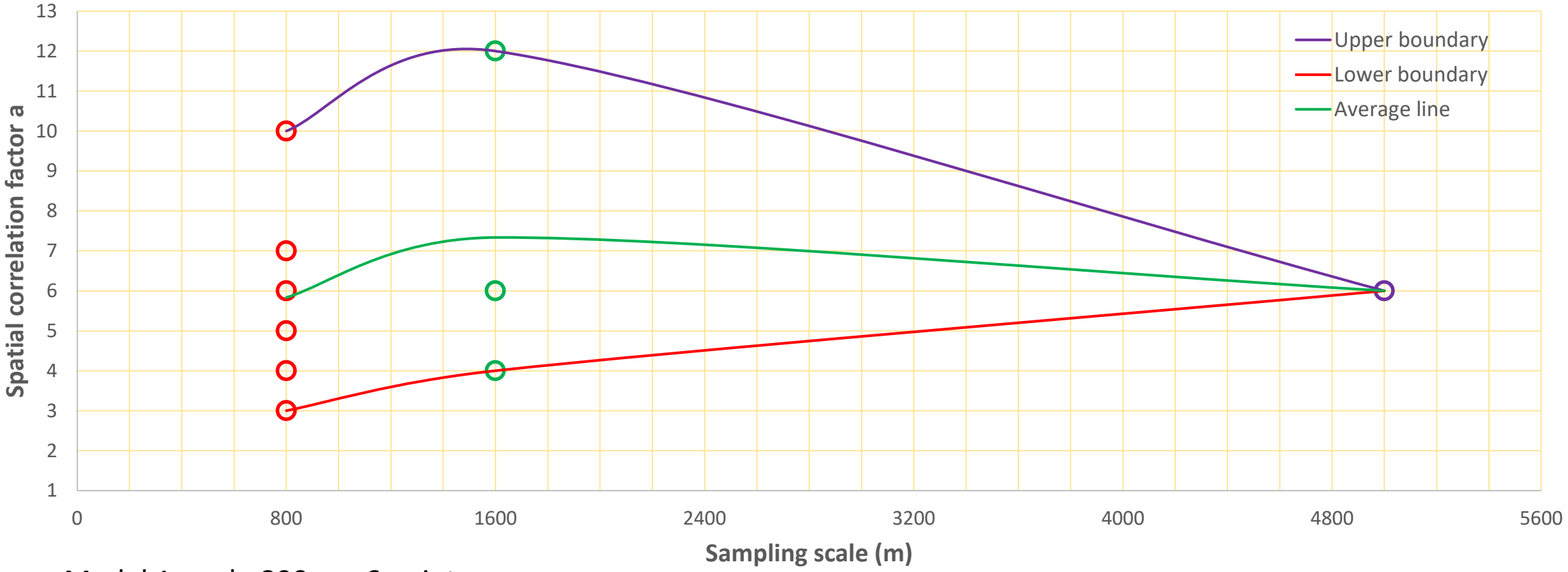


a = 6

CONTENT

4. CONCLUSIONS

Evaluation scale effect of sample



Model 1: scale 800m – 6 points

Model 2: scale 1600m – 3 points

Model 3: scale 5000m – 1 points

CONTENT

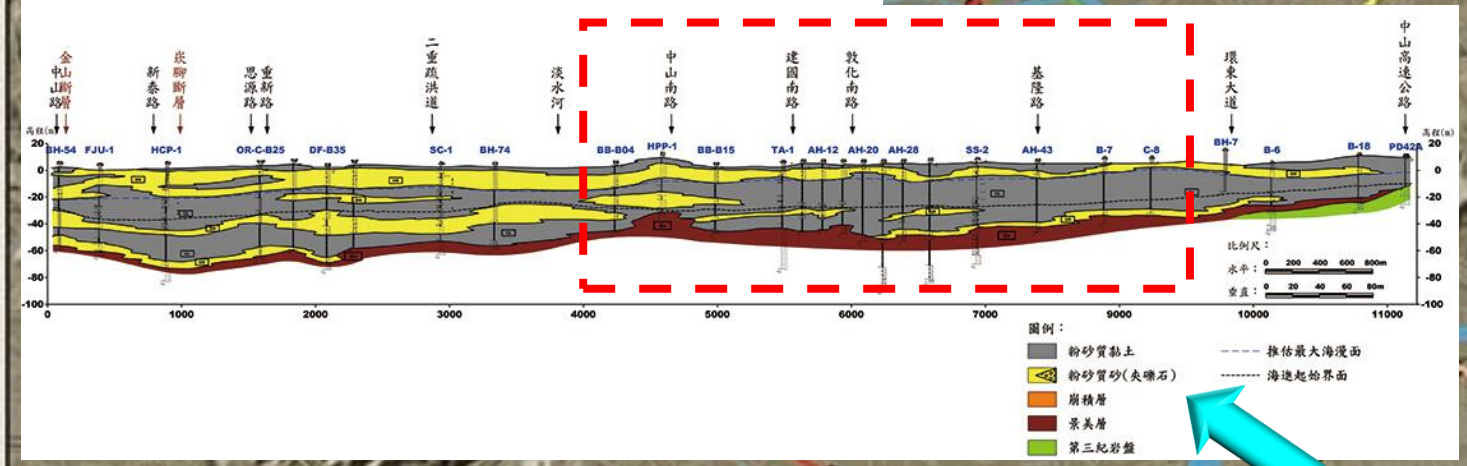
5. FUTURE WORKS

1. Choose another cross-section in the E-W direction to see the scale effect;

2. Apply 3D simulation with considering the spatial orientation distribution. Then, comparing with 2D simulation results.

5. FUTURE WORKS

The study site 2 (EW-2)



(CGS, 2011)

THANK YOU

To transfer the geological data to numerical models

It’s an interesting process..

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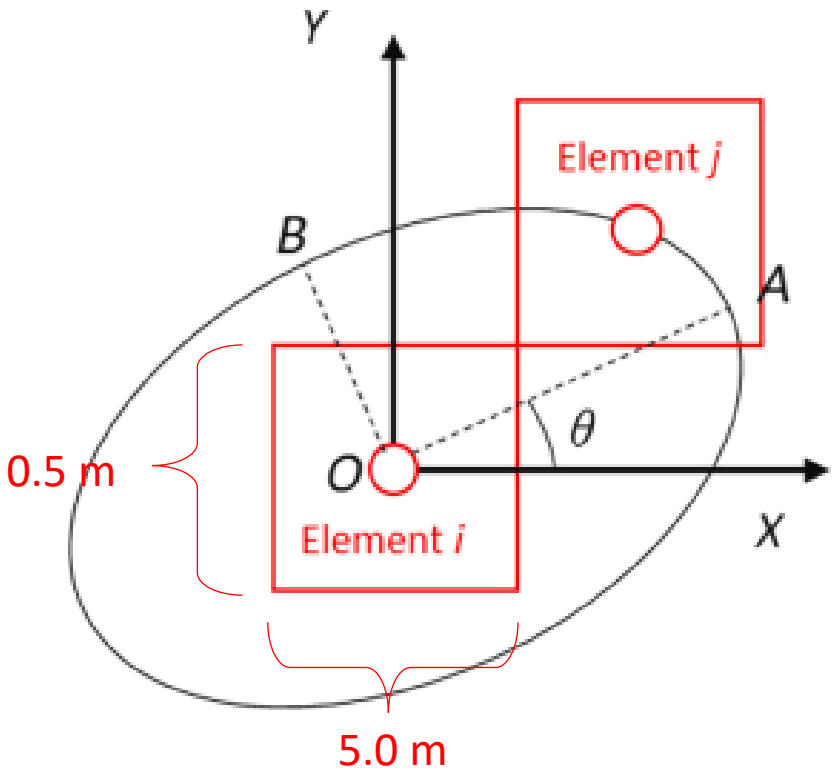
Advisor: Prof. Jia-Jyun Dong
Co-Advisor: Dr. Yu-Chen Lu
Date: 2023/03/03

Grid Size Used in This Study

element_number_x = ….; model_length_x = ….;
element_number_y = ….; model_length_y = ….;



Grid size = 5.0 m * 0.5 m

Horizontal grid size/vertical grid size = $A_R = 10$

$\overline{OA} = a$

$\overline{OB} = 1$

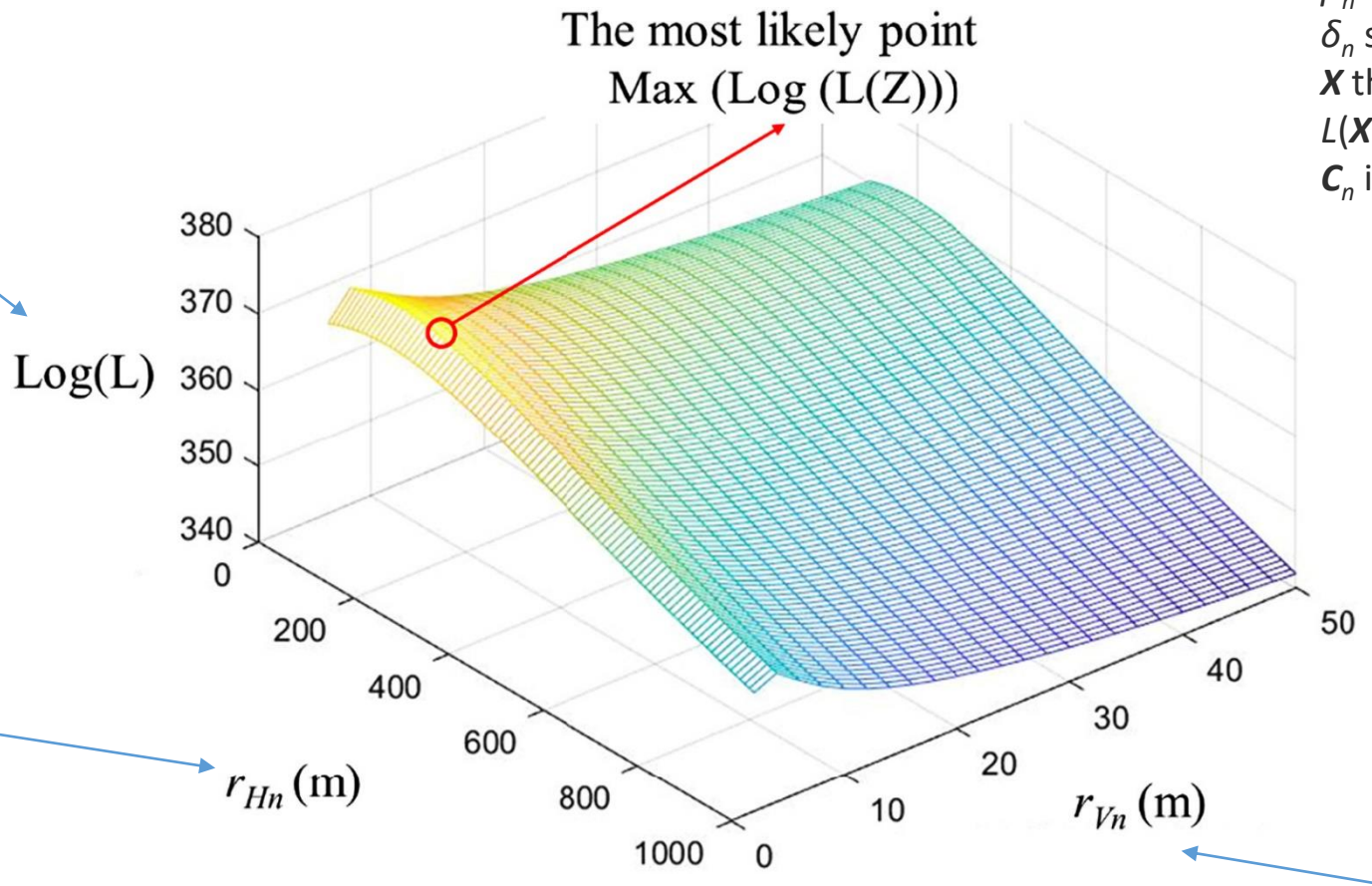
$$a' = A_R \times a$$

Maximum Likelihood Estimation

$$\begin{aligned} &\text{Find:} && \phi_n^T = \{\mu_n, \delta_n, r_{Vn}, r_{Hn}\} \\ &\text{Subject to:} && \boldsymbol{X} = \{X_1, X_2, \ldots, X_3\} \\ &\text{Objective:} && L(\boldsymbol{X}|\phi_n) = \frac{1}{(2\pi)^{m/2}|\boldsymbol{C}_n|^{1/2}} exp\left[-\frac{1}{2}(\boldsymbol{X}-\boldsymbol{\mu_n})^T \boldsymbol{C}_n^{-1}(\boldsymbol{X}-\boldsymbol{\mu_n})\right] \\ & && \text{Maximizing } L(\boldsymbol{X}|\phi_n) \end{aligned}$$

ϕ_n^T is the site parameter to be determined
μ_n mean value of the site parameter
δ_n standard deviation
$\boldsymbol{X}$ the detrended sample data
$L(\boldsymbol{X}|\ \phi_n)$ is the likelihood function
$\boldsymbol{C}_n$ is the covariance matrix

Likelihood function

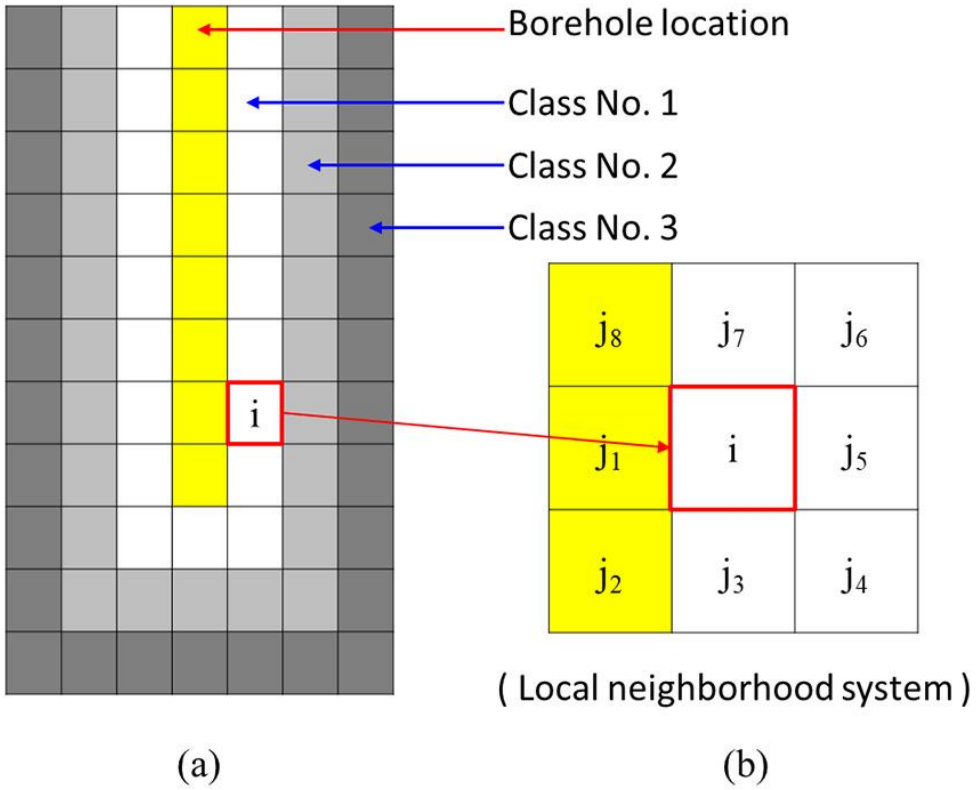


horizontal fluctuations

vertical fluctuations

Log-likelihood function of observational data I_c under different horizontal and vertical fluctuations

Neighborhood system



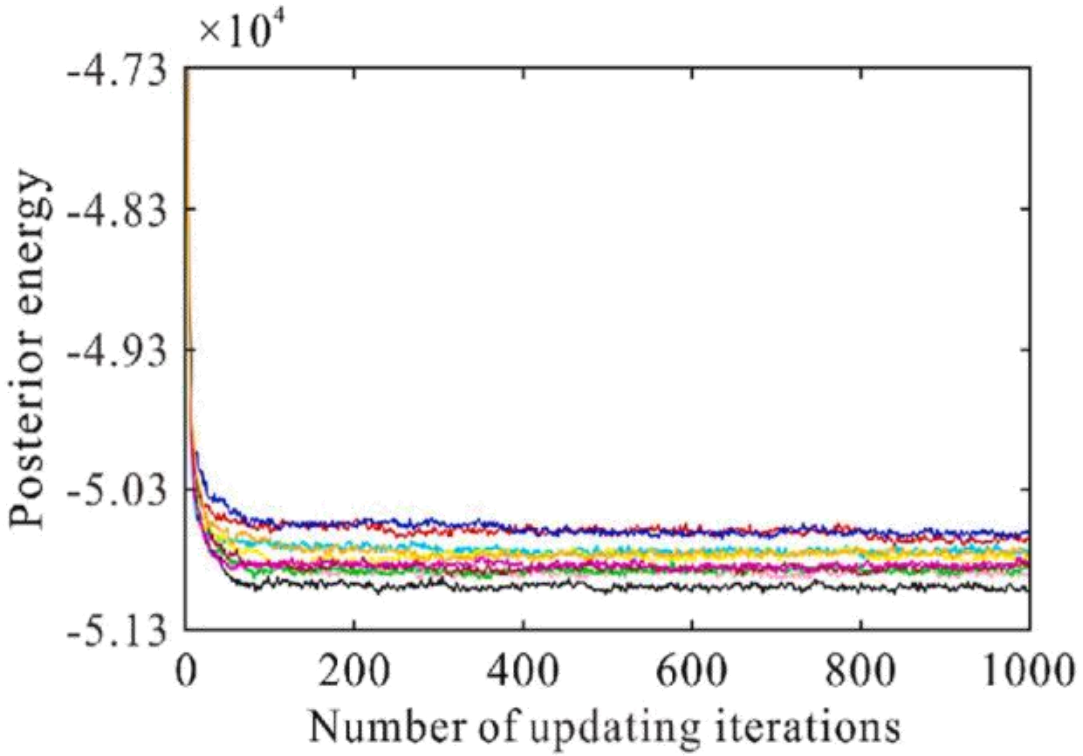
Neighborhood system and sampling order (After Gong et al., 2019)

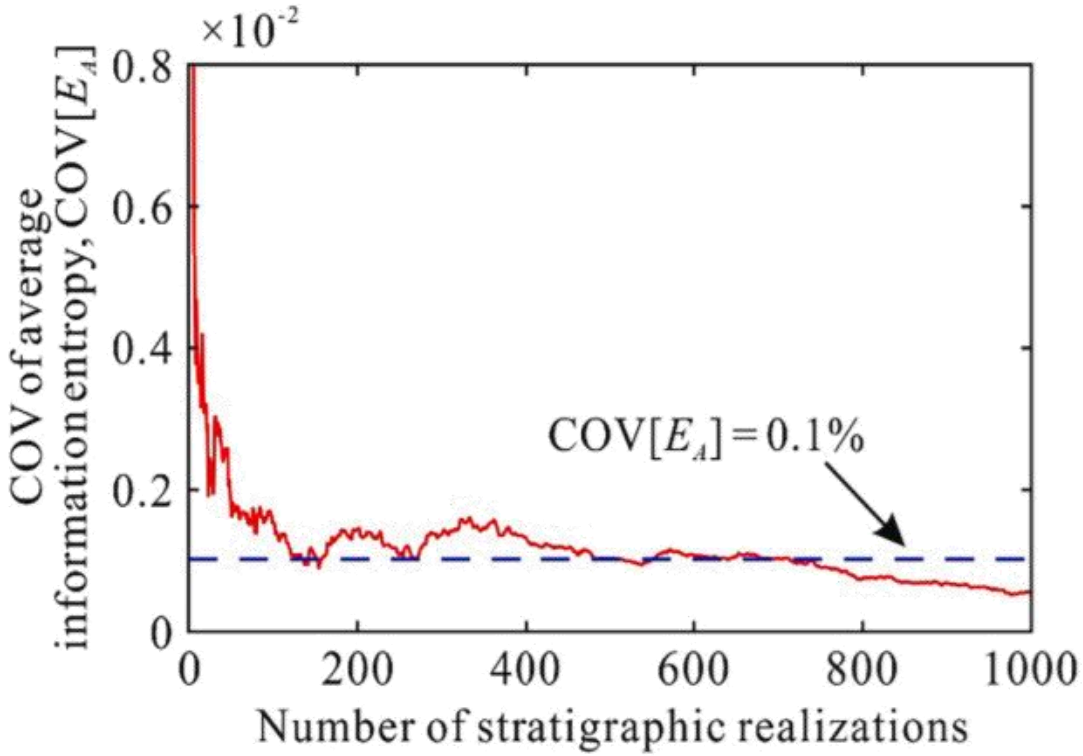
The analysis sequence starts by determining the soil types of the nearest neighbors and gradually expands outward.

The grid cells immediately adjacent to the borehole are defined as cells with the highest priority.

The grid cells adjacent to the first priority cells are defined as the cells with the second priority

How to know how many realization was applied in the simulation?





Determination of the number of iterations adopted in the MCMC updating and the number of sampled stratigraphic realizations (Chao Zhao, 2021)