國立中央大學應地所專題討論110-2學期

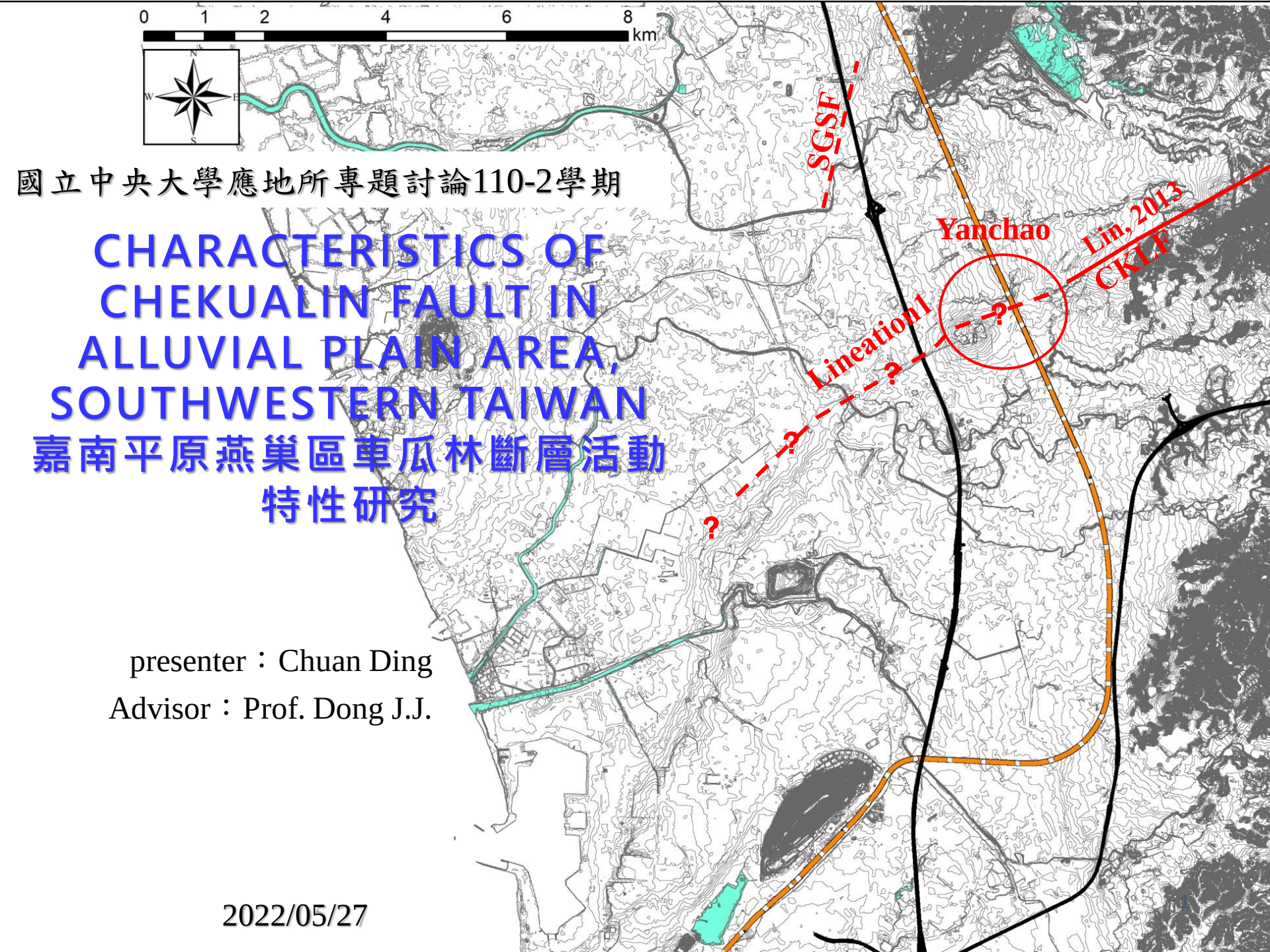
CHARACTERISTICS OF CHEKUALIN FAULT IN ALLUVIAL PLAIN AREA, SOUTHWESTERN TAIWAN

嘉南平原燕巢區車瓜林斷層活動特性研究

presenter：Chuan Ding

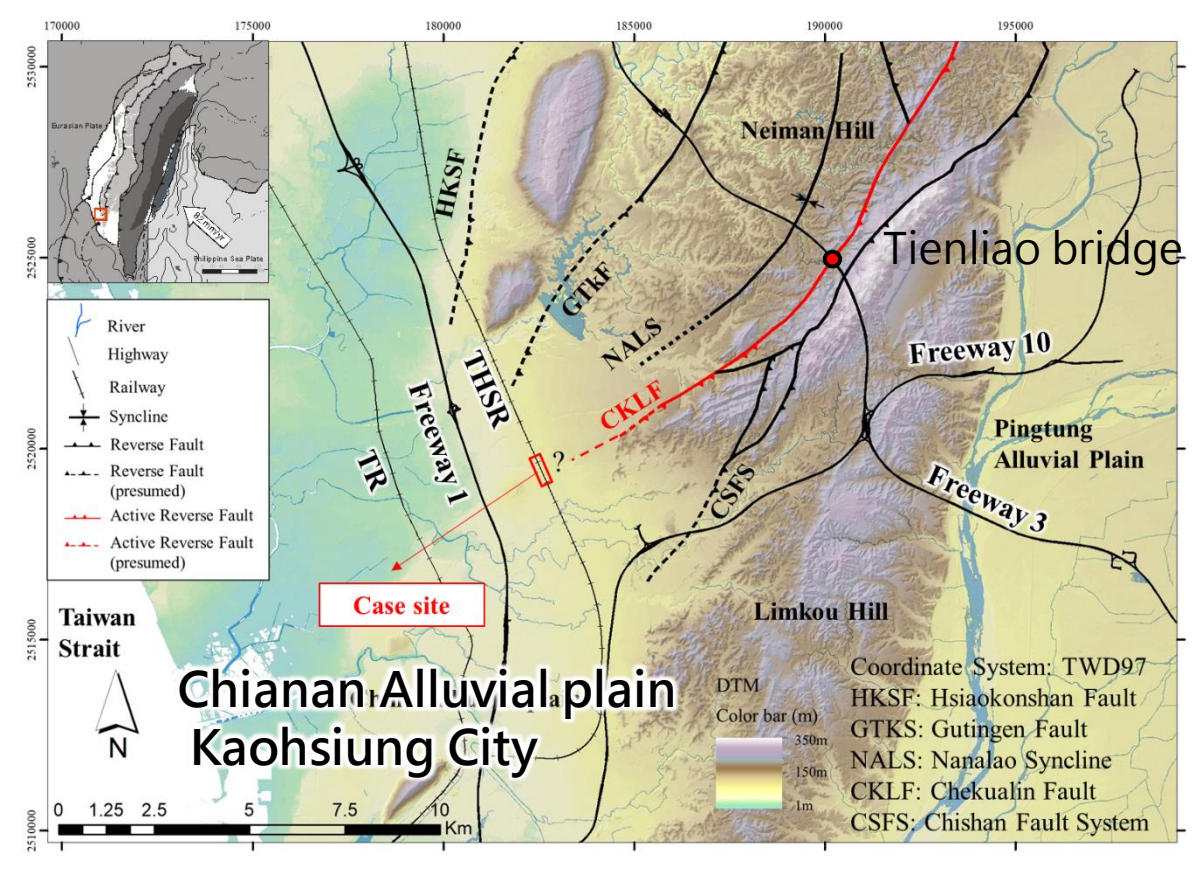
Advisor：Prof. Dong J.J.

2022/05/27

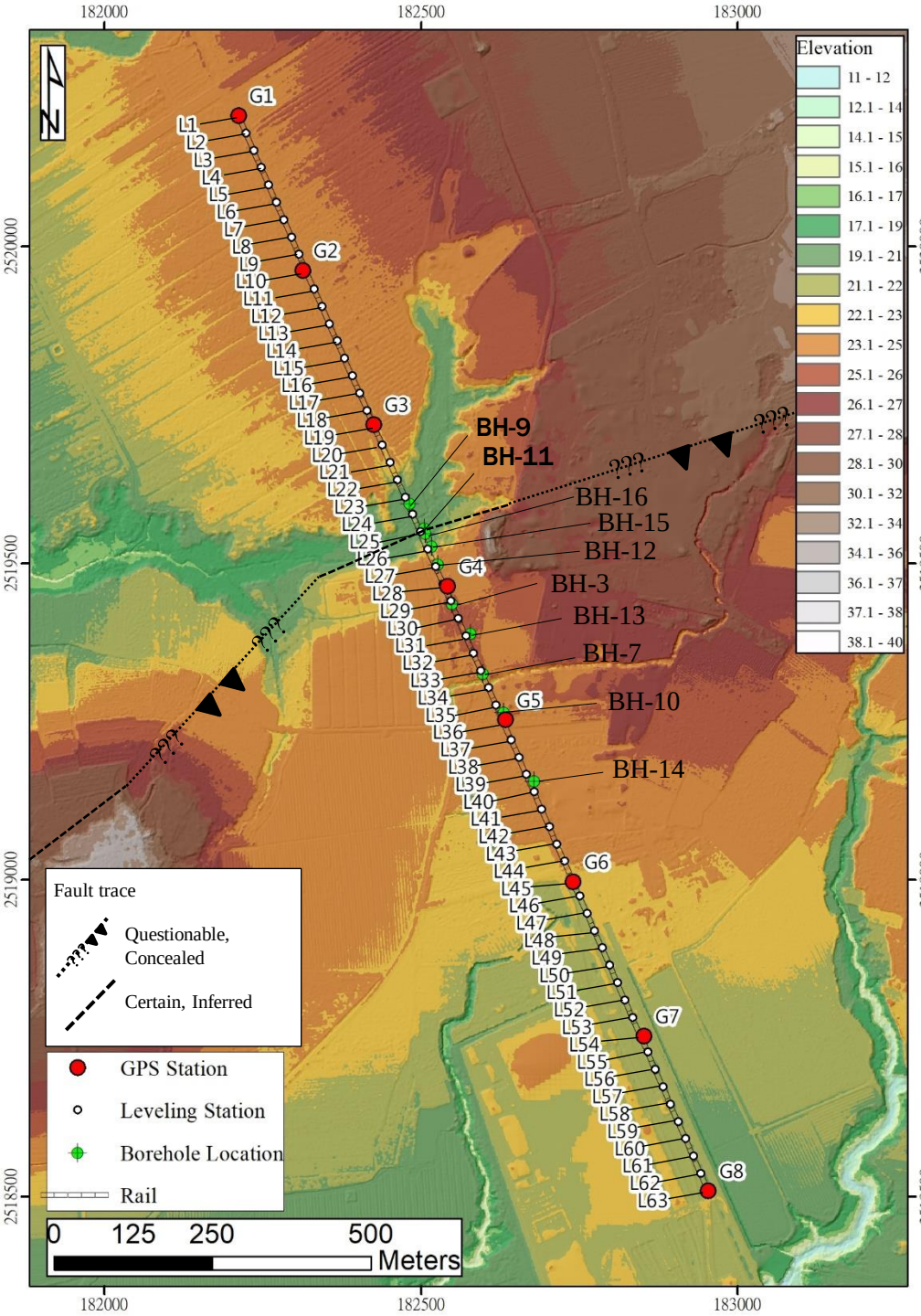


WHY?

- Creeping Active Fault Geohazard
- Metro Transits (Freeway, MRT)
- Still Unknown under Chianan Alluvial plain



CKLF = Chekualin fault


182000
182500
183000
2520000
2519500
2519000
2518500
N
Elevation
11 - 12
12.1 - 14
14.1 - 15
15.1 - 16
16.1 - 17
17.1 - 19
19.1 - 21
21.1 - 22
22.1 - 23
23.1 - 25
25.1 - 26
26.1 - 27
27.1 - 28
28.1 - 30
30.1 - 32
32.1 - 34
34.1 - 36
36.1 - 37
37.1 - 38
38.1 - 40
G1
G2
G3
G4
G5
G6
G7
G8
L1
L2
L3
L4
L5
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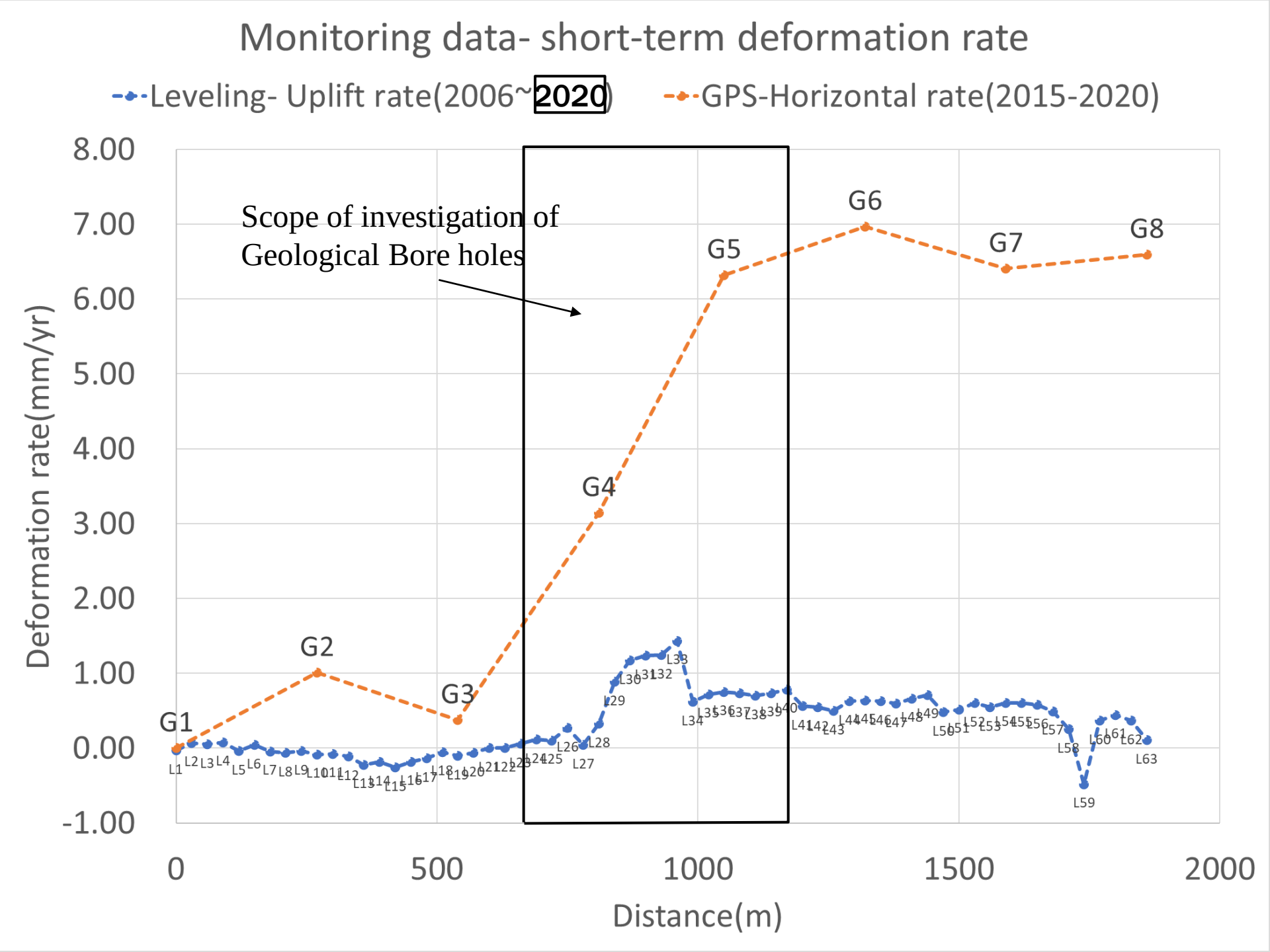
L54
L55
L56
L57
L58
L59
L60
L61
L62
L63
BH-9
BH-11
BH-16
BH-15
BH-12
BH-3
BH-13
BH-7
BH-10
BH-14
???
Fault trace
Questionable, Concealed
Certain, Inferred
GPS Station
Leveling Station
Borehole Location
Rail
0 125 250 500
Meters

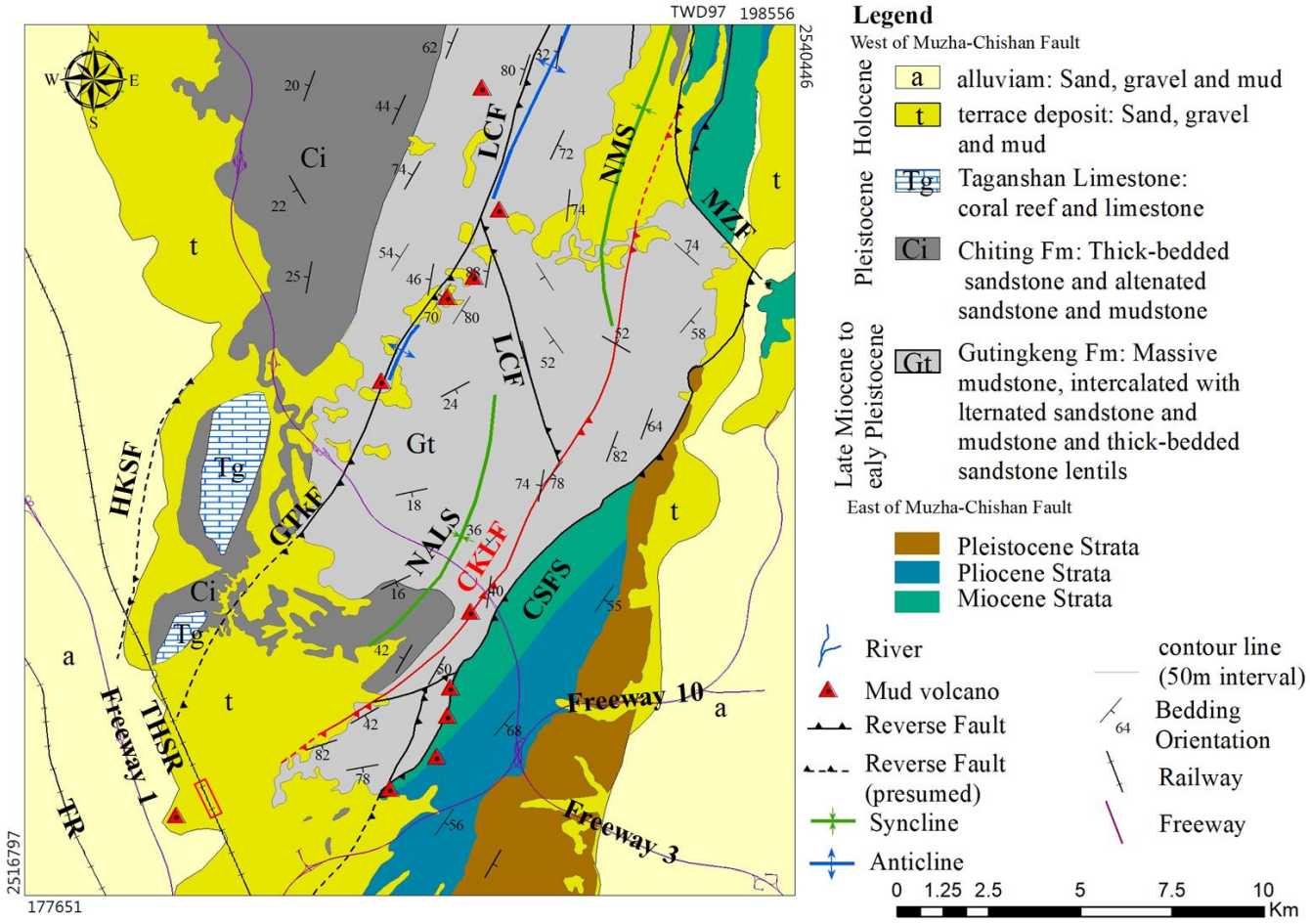

Monitoring data- short-term deformation rate
Leveling- Uplift rate(2006~2020)
GPS-Horizontal rate(2015-2020)
Scope of investigation of Geological Bore holes
Deformation rate(mm/yr)
Distance(m)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
0
500
1000
1500
2000
G1
G2
G3
G4
G5
G6
G7
G8

THE GOAL OF THIS STUDY

- Using Extensive detail site investigation to built complete time spectrum of active line/zone.
- Geological model were proposed to discuss temporal and spatial variation
- How a engineering project can earlier identify the possible active surface deformation zone according to this case history.

BACK GROUND GEOLOGICAL SETTING

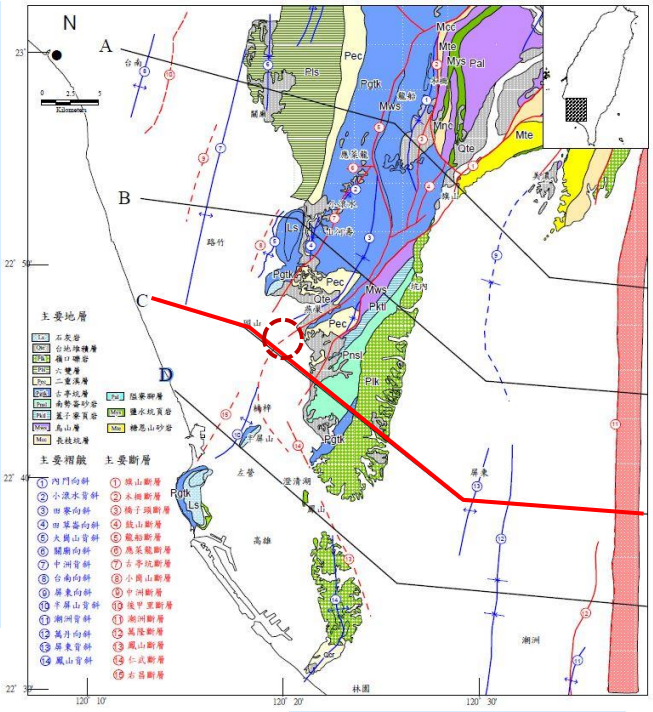
- Mudstone (Gt)
- Fold and thrust belt
- Mud volcanoes

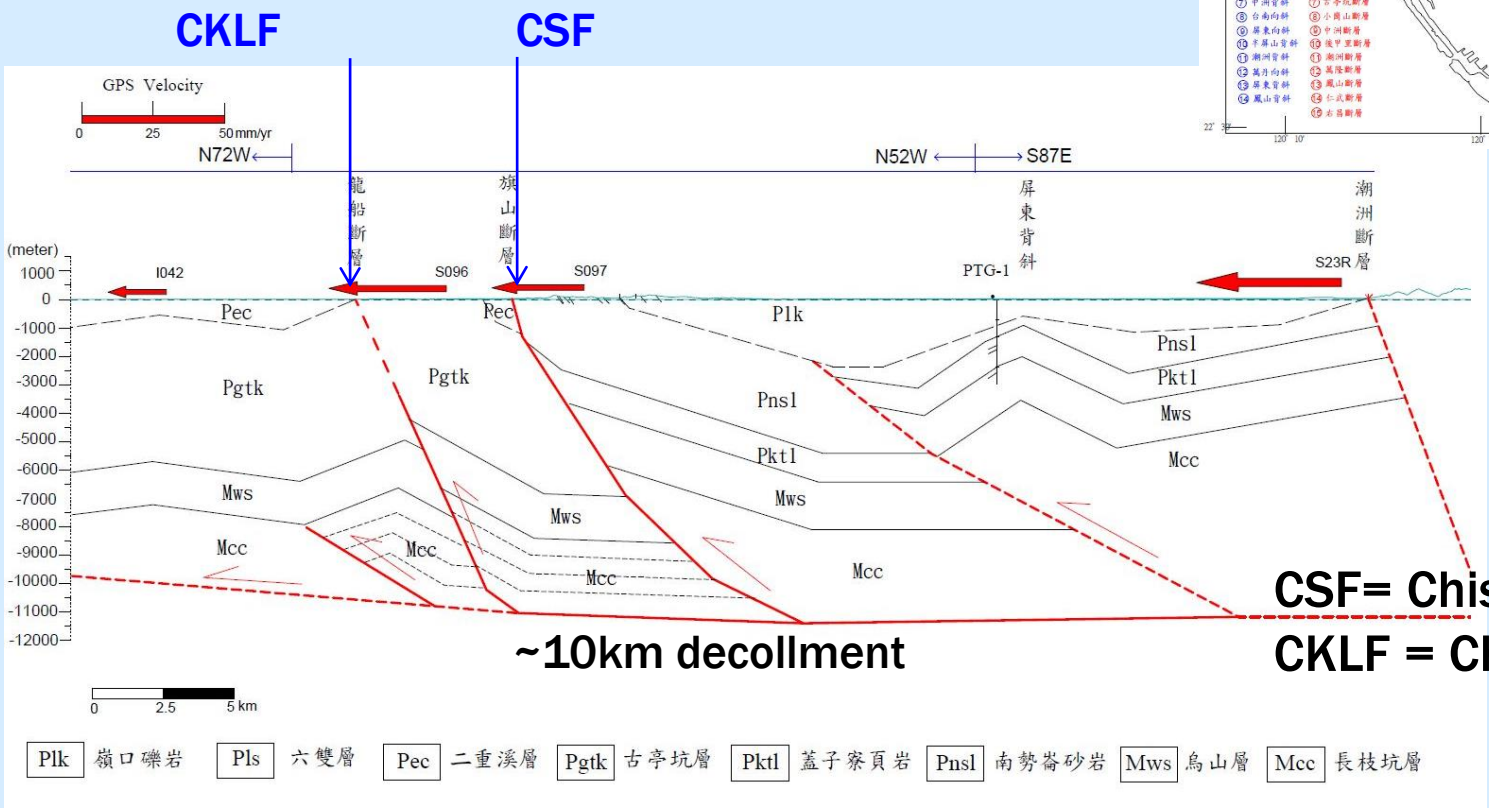


CKLF = Chekualin fault

- **High angle thrust fault**

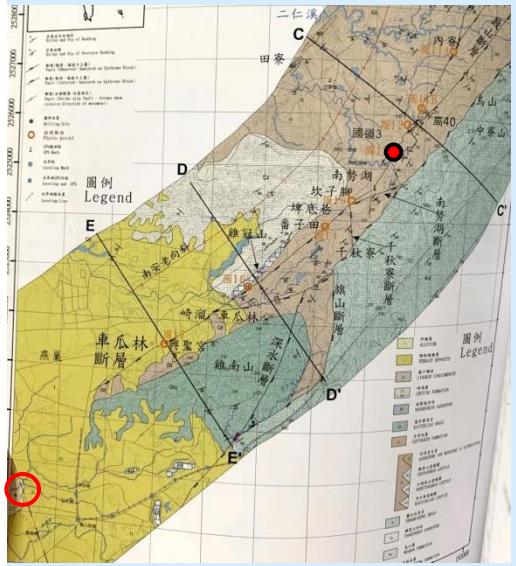
  Equilibrium Profile
  Cheng(2000)





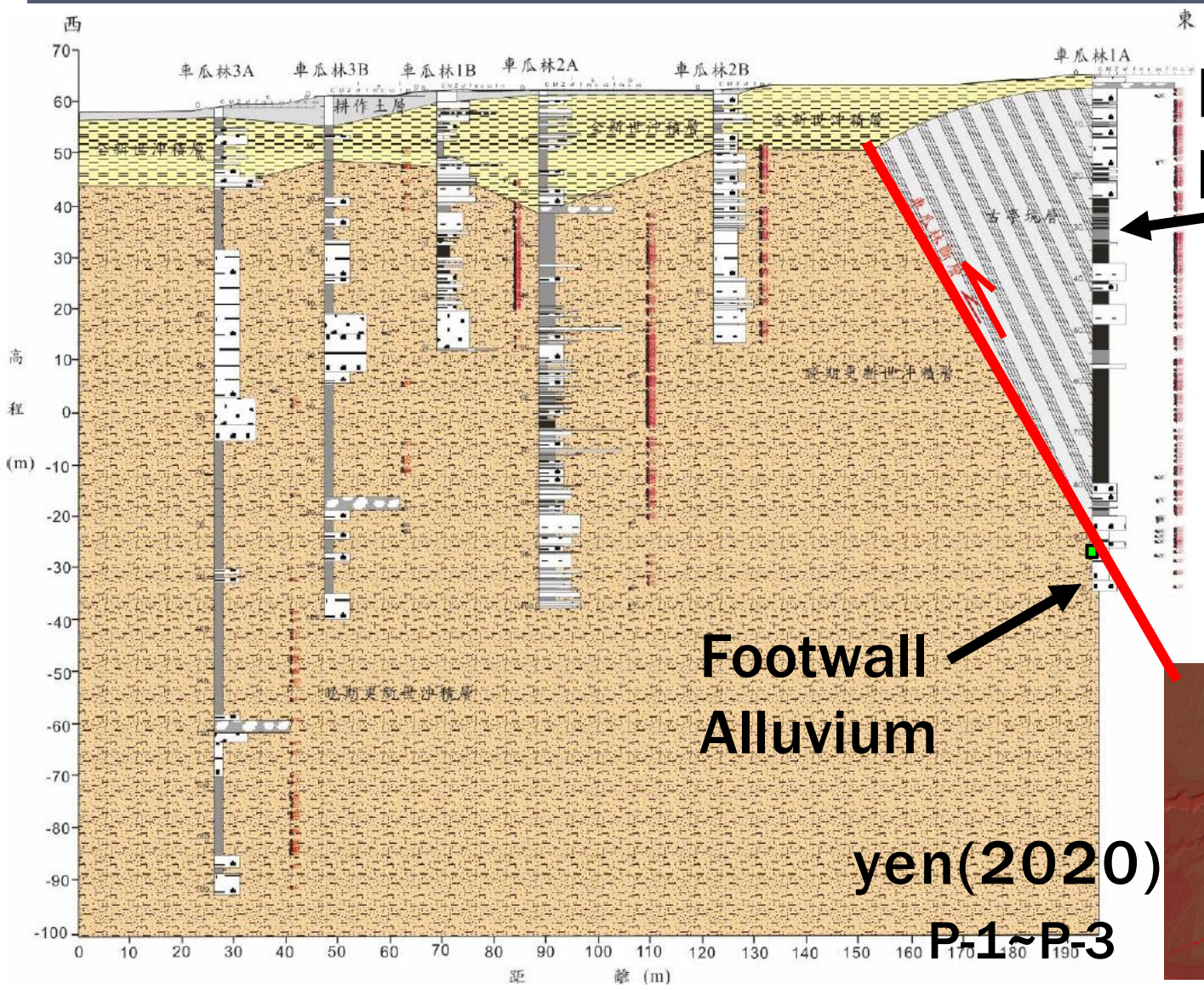
OUTCROPS FAULT ZONE FEATURES

- Widespread Shear Zone in hanging wall(>130m)
- Branch Faults
- Steeply hanging wall



Liu & Lin(2019)

BEDROCK THRUST ON OLDER ALLUVIUM(20~40KA)

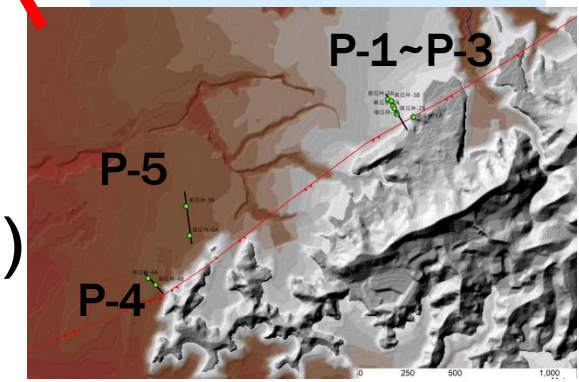


Hanging wall bedrock

Footwall Alluvium

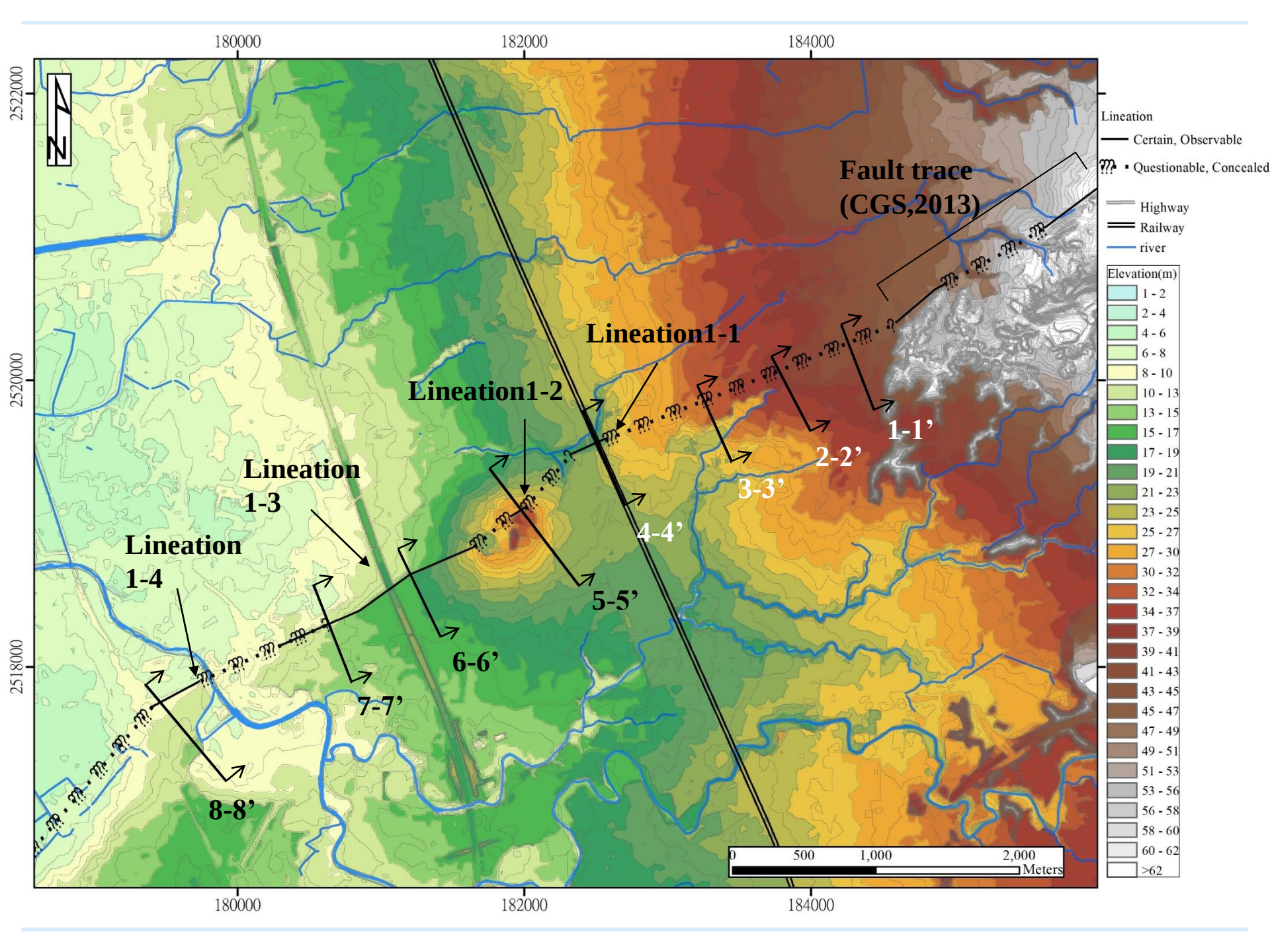
yen(2020)

P-1~P-3



STUDY METHOD

- Faut trace mapping
- Stratigraphic correlation, Boreholes
  - Bedding change, shear plane
  - ^{14}C, nannofossil and foraminifera
- Active line/zone
  - Long-term crustal uplift rate
  - Short-term crustal uplift rate


180000
182000
184000
2522000
2520000
2518000
N
Fault trace
(CGS,2013)
Lineation1-1
Lineation1-2
Lineation
1-3
Lineation
1-4
1-1’
2-2’
3-3’
4-4’
5-5’
6-6’
7-7’
8-8’
0
500
1,000
2,000
Meters
Lineation
Certain, Observable
Questionable, Concealed
Highway
Railway
river
Elevation(m)
1 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 13
13 - 15
15 - 17
17 - 19
19 - 21
21 - 23
23 - 25
25 - 27
27 - 30
30 - 32
32 - 34
34 - 37
37 - 39
39 - 41
41 - 43
43 - 45
45 - 47
47 - 49
49 - 51
51 - 53
53 - 56
56 - 58
58 - 60
60 - 62
>62

Position	Location	Certain Identity and Existence	Questionable Identity or Existence
Within zone of confidence	Observable	A Solid line	a Solid line+ ?
May not be within zone of confidence	Observable	B Long dash line	b Long dash line+ ?
	Inferred between outcrops or beneath rubble or vegetation	C Short dash line	c Short dash line+ ???
	Concealed beneath overlying map unit, ice, or water	D Dot	d Dot + ???

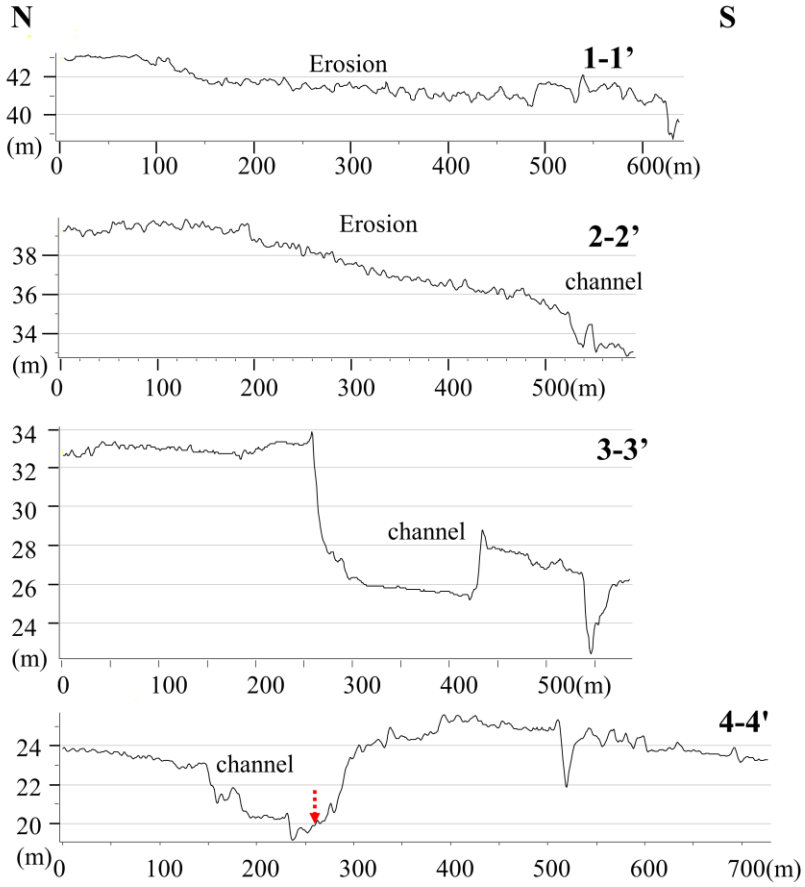
High

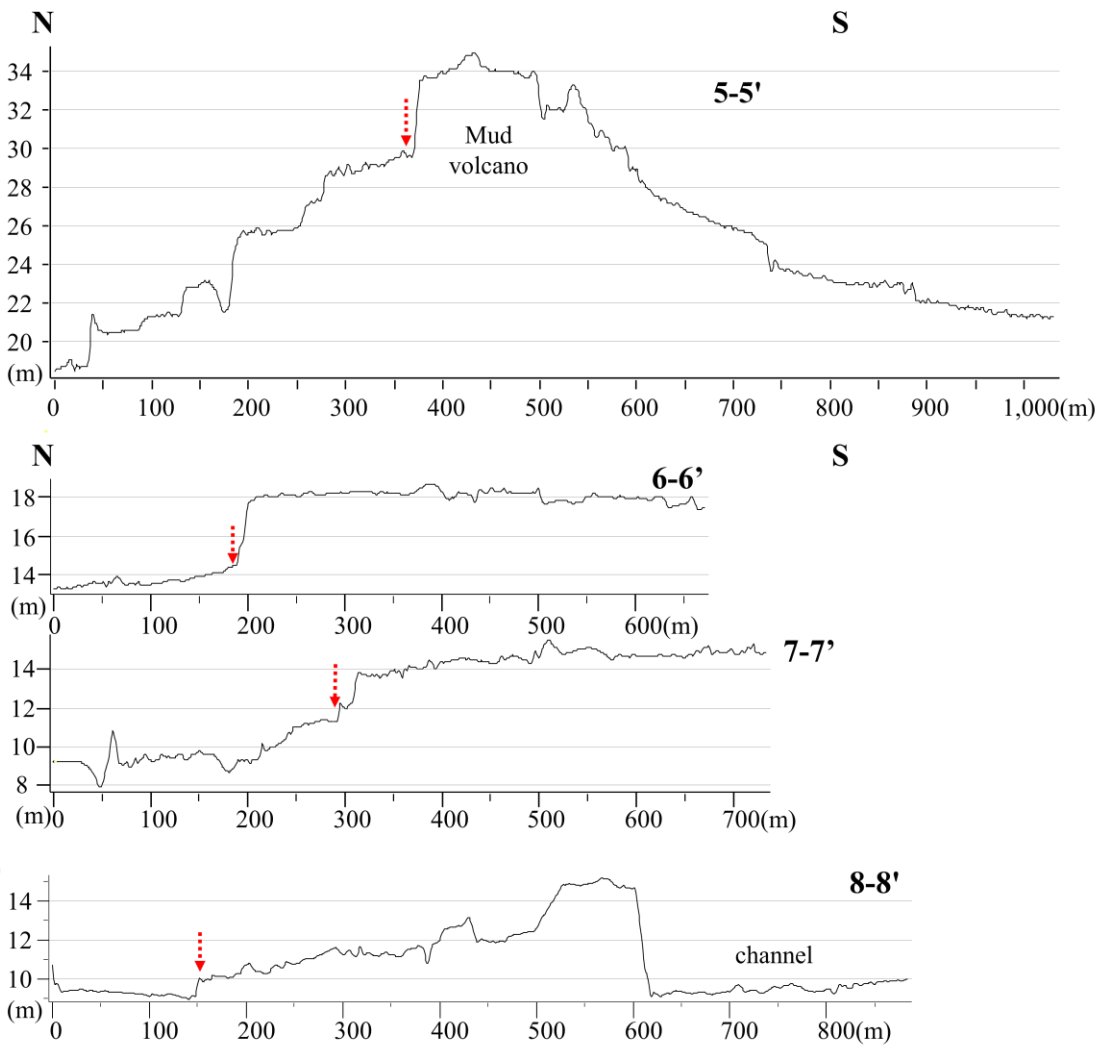
Degrees of precision

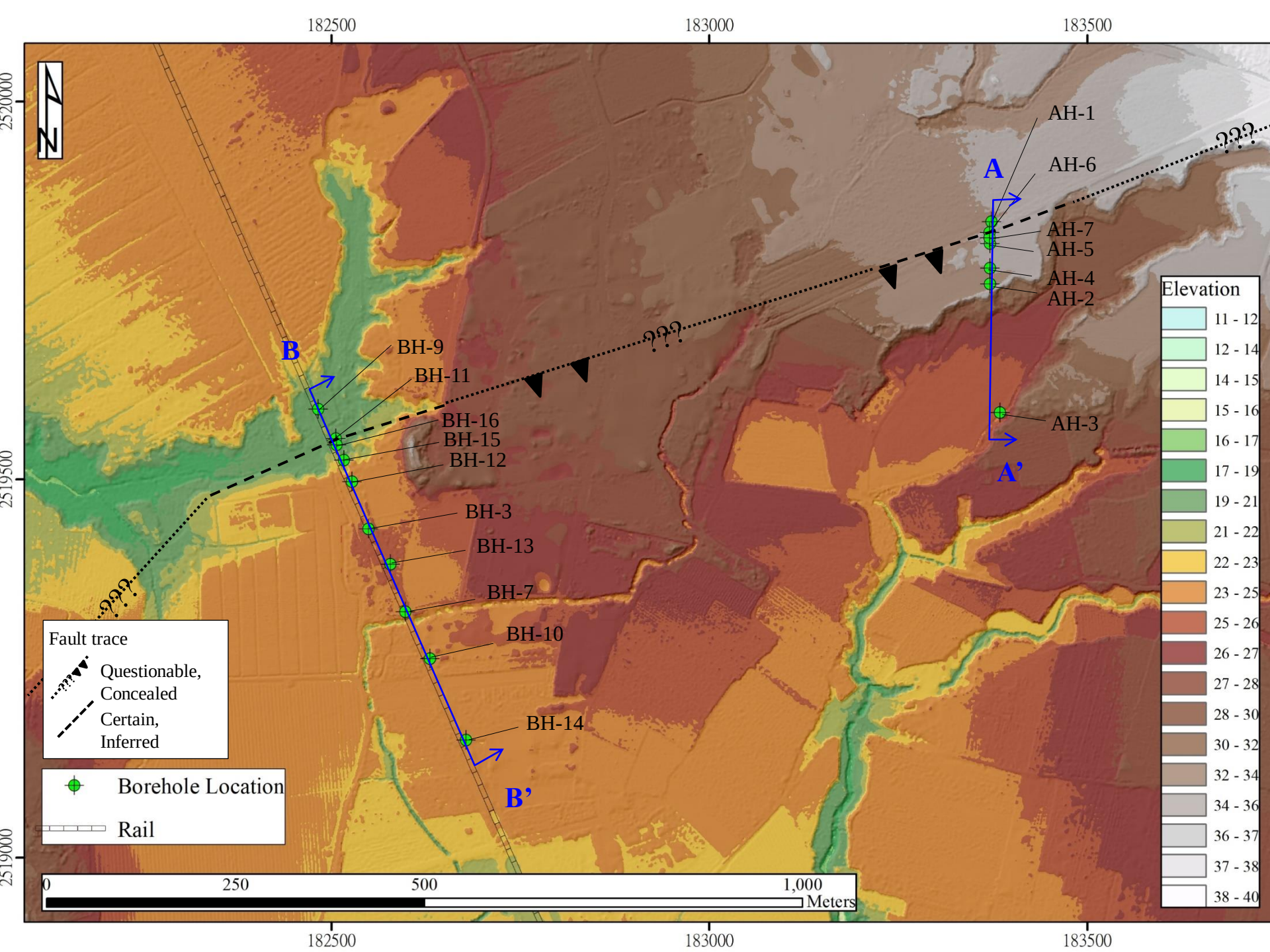
Low

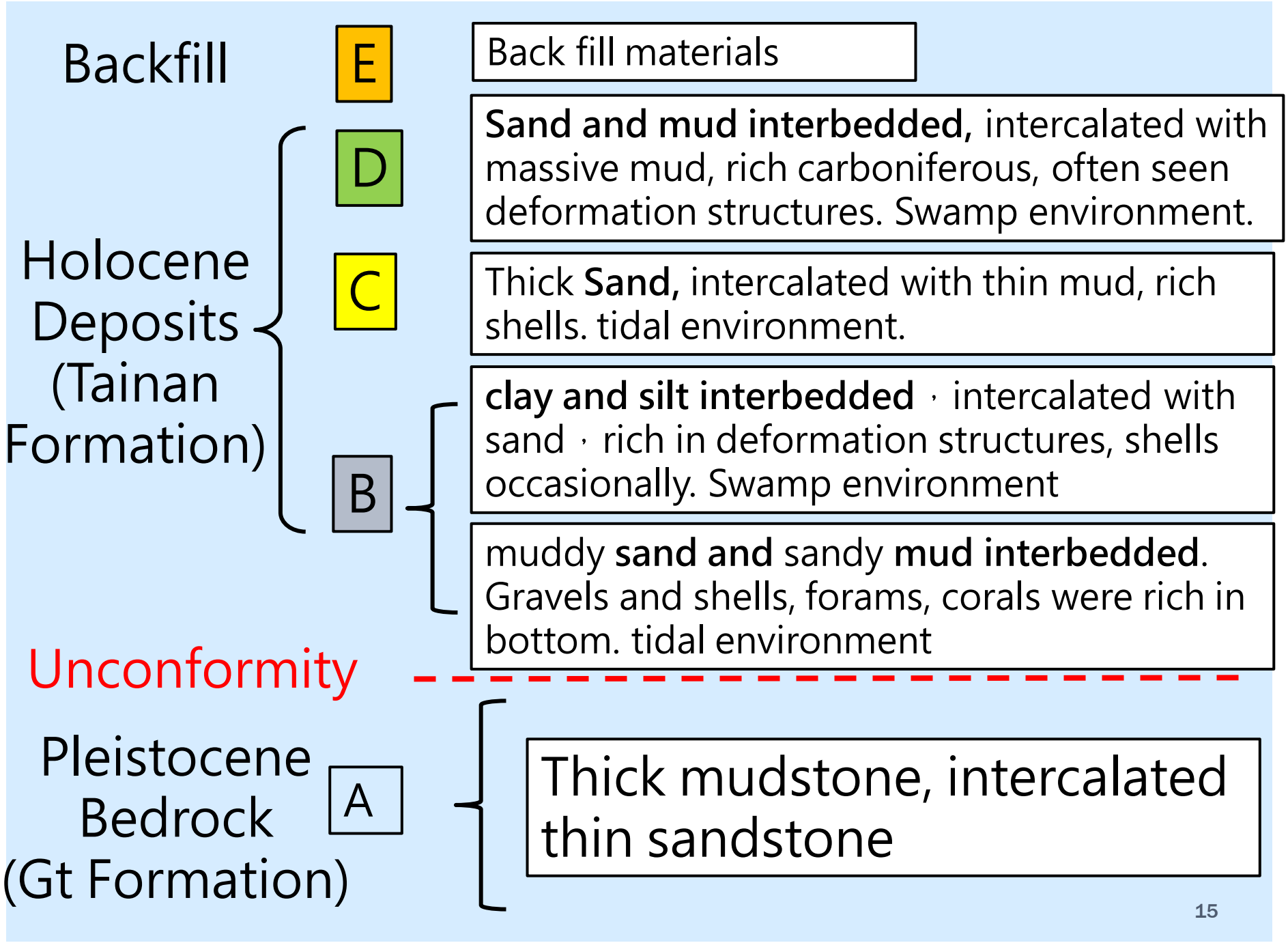
U.S. Geological Survey Open-File Report 02-370, 2002, p36-37

Geomorphological setting -strongly eroded environment

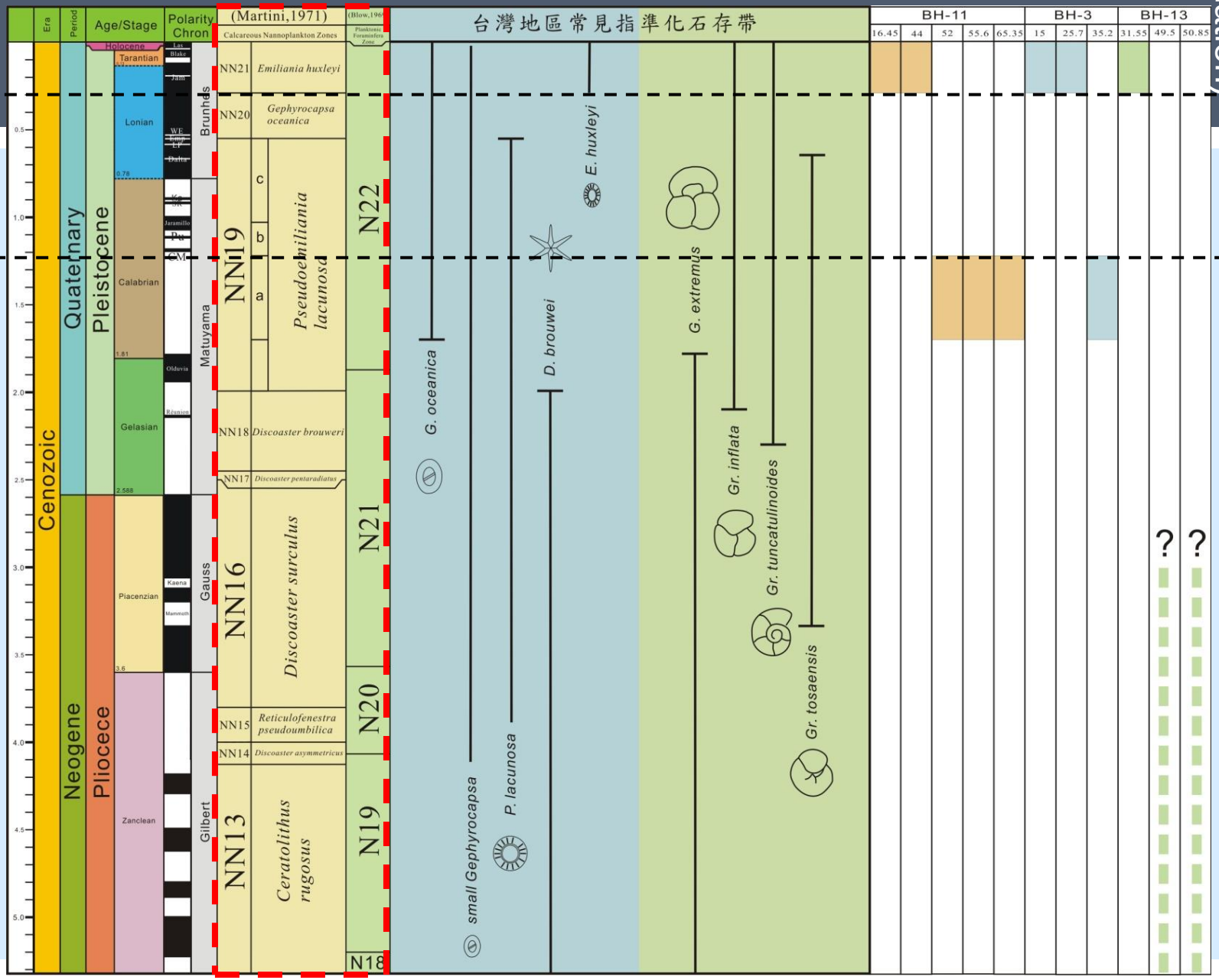




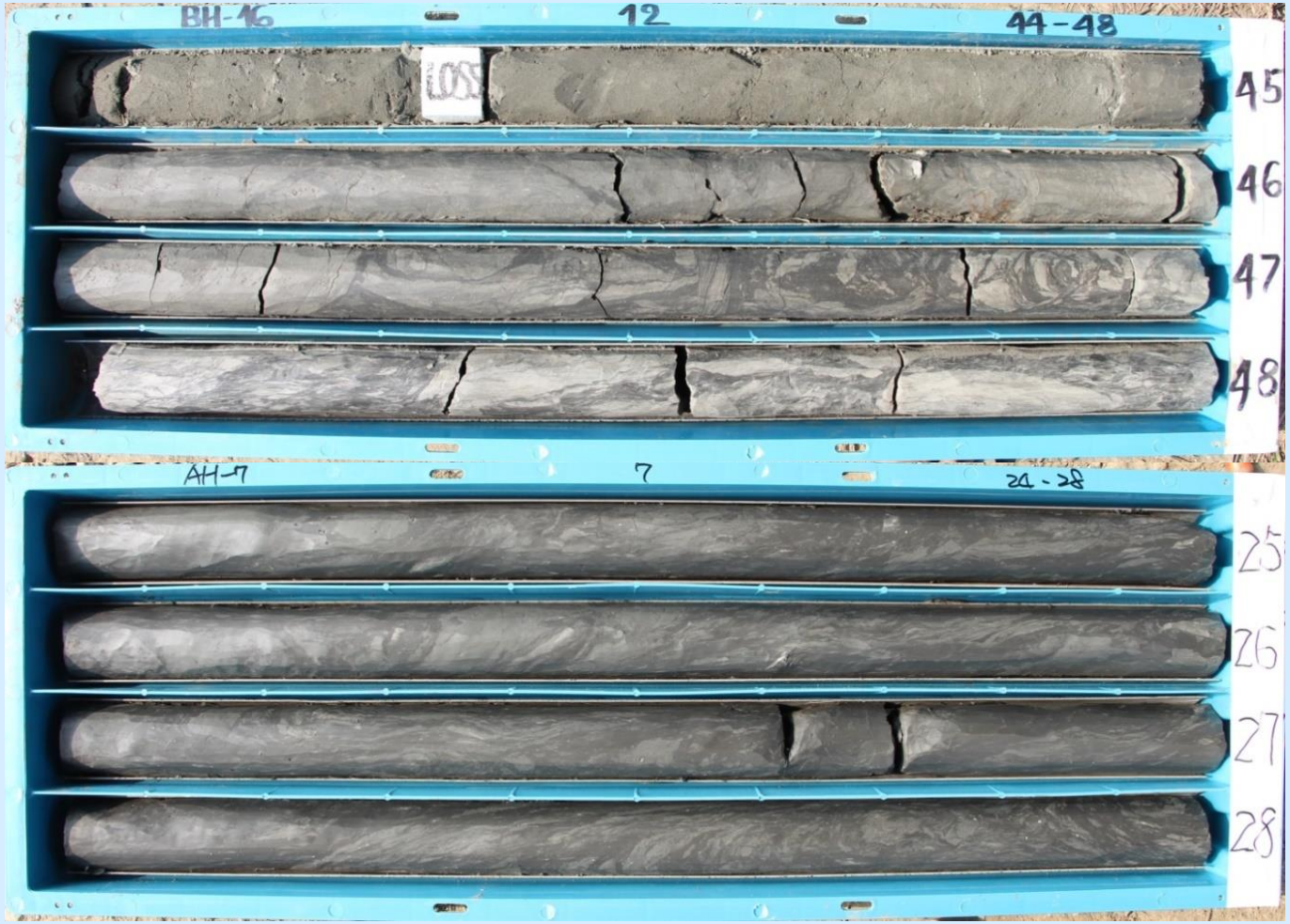

182500
183000
183500
2520000
2519500
2519000
N
AH-1
AH-6
AH-7
AH-5
AH-4
AH-2
AH-3
A
A'
B
B'
BH-9
BH-11
BH-16
BH-15
BH-12
BH-3
BH-13
BH-7
BH-10
BH-14
???
Elevation
11 - 12
12 - 14
14 - 15
15 - 16
16 - 17
17 - 19
19 - 21
21 - 22
22 - 23
23 - 25
25 - 26
26 - 27
27 - 28
28 - 30
30 - 32
32 - 34
34 - 36
36 - 37
37 - 38
38 - 40
Fault trace
Questionable, Concealed
Certain, Inferred
Borehole Location
Rail
0
250
500
1,000
Meters


Backfill
E
Back fill materials
Holocene Deposits (Tainan Formation)
D
Sand and mud interbedded, intercalated with massive mud, rich carboniferous, often seen deformation structures. Swamp environment.
C
Thick Sand, intercalated with thin mud, rich shells. tidal environment.
B
clay and silt interbedded · intercalated with sand · rich in deformation structures, shells occasionally. Swamp environment
muddy sand and sandy mud interbedded. Gravels and shells, forams, corals were rich in bottom. tidal environment
Unconformity
Pleistocene Bedrock (Gt Formation)
A
Thick mudstone, intercalated thin sandstone

NANNOFOSSIL AND FORAMINIFERA



Layer A, Hanging wall

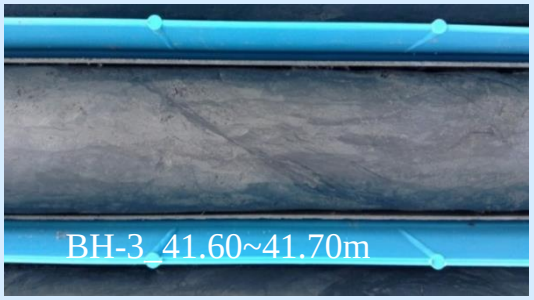


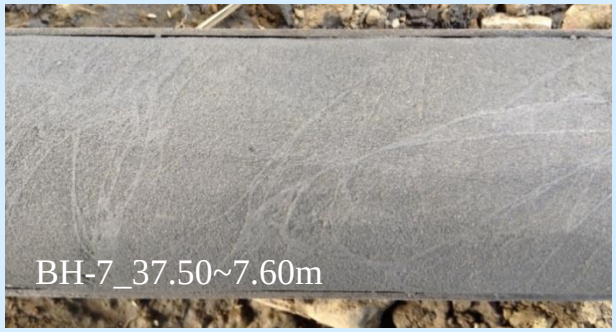
- Fault gauge
- Fault breccia

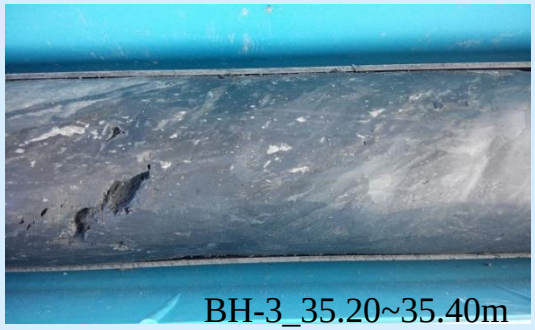
Thickness>4m

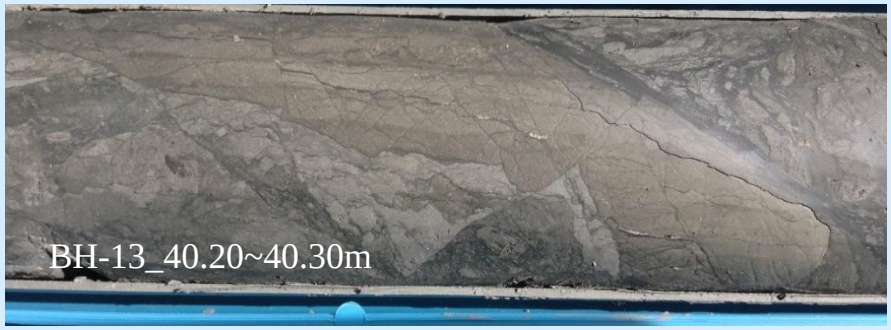
Ductile deformation

Layer A, Hanging wall









- Fault gauge
- Fault breccia
- Web Structure

- Multiple shearing events
- Low angle cut by high angle

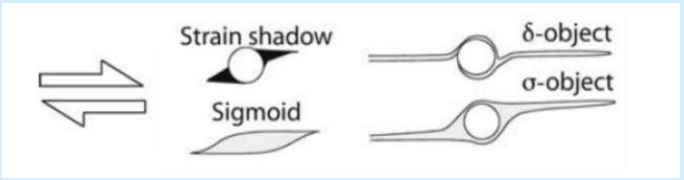
SLICKENSIDE

- Orientation shows high angle thrust mainly

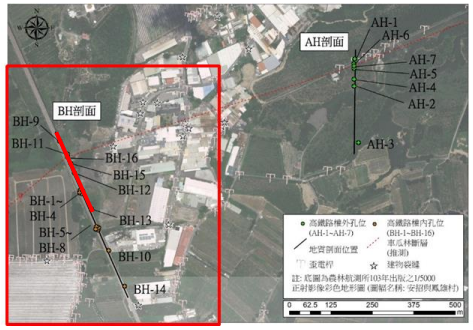
細拍AH-2(28-32)(5)

細拍AH-2(36-40)(7)

AH-4(33.8m)

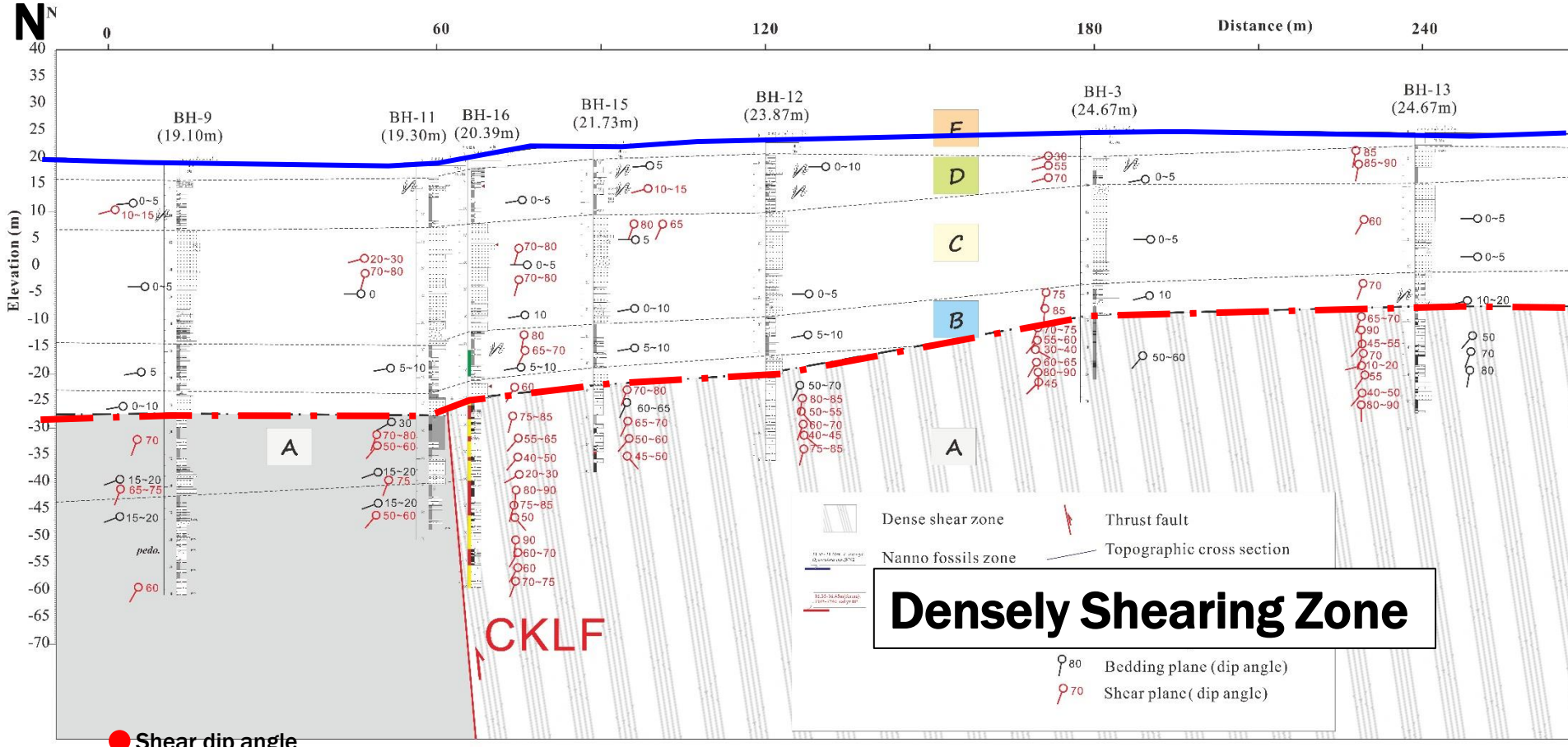


Passchier and Trouw,2005



B-B’

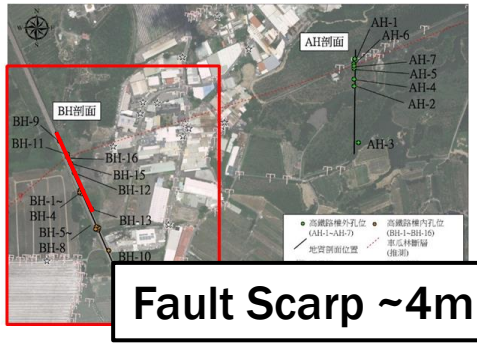
(1:1)



Shear dip angle

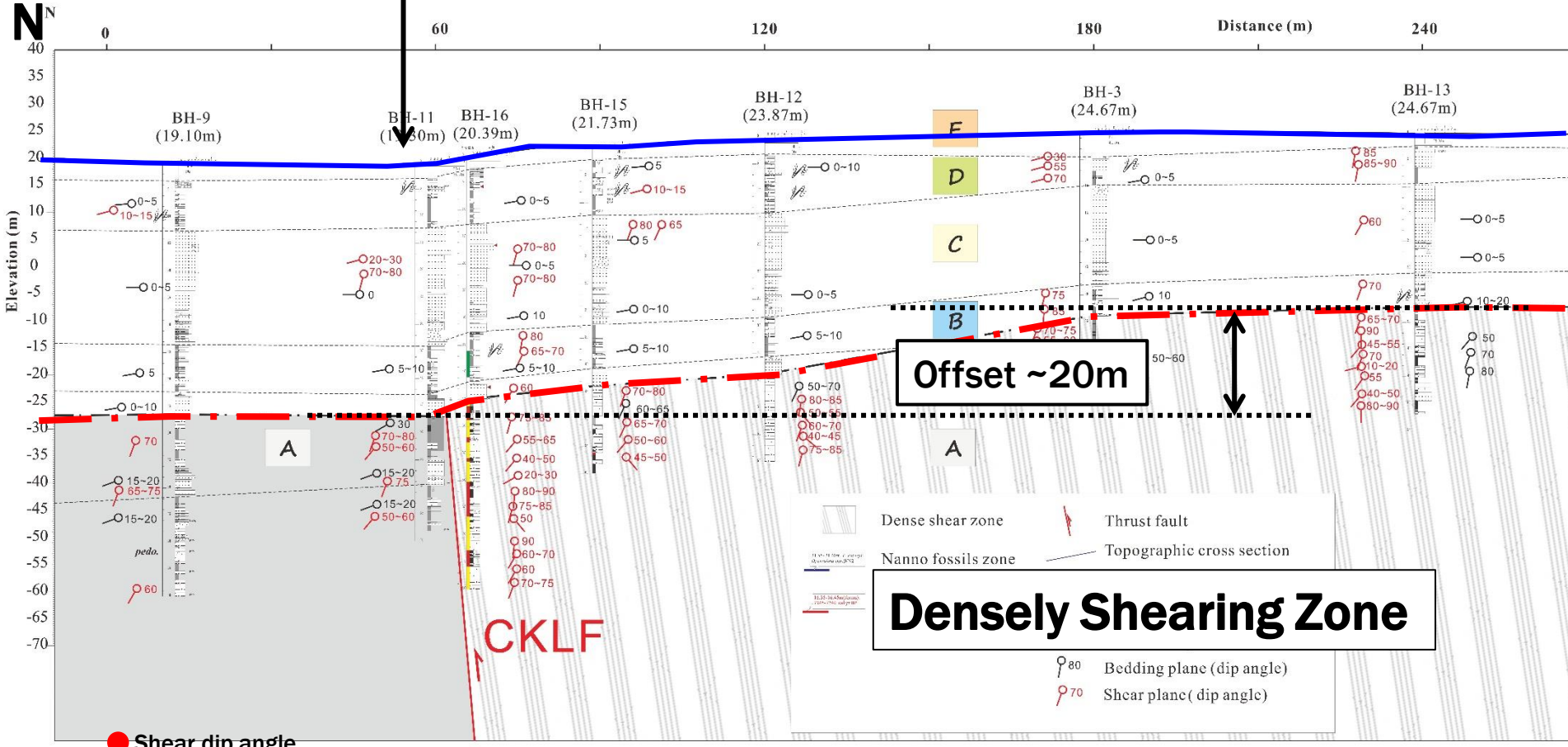
Bedding dip angle

CKLF = Chekualin fault



(1:1)

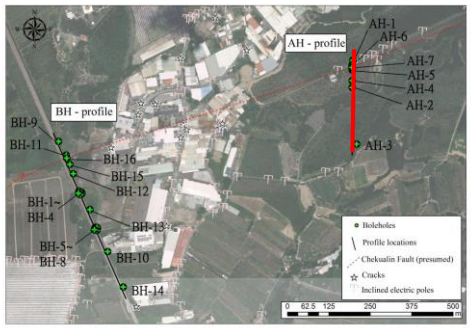
Fault Scarp ~4m



Shear dip angle

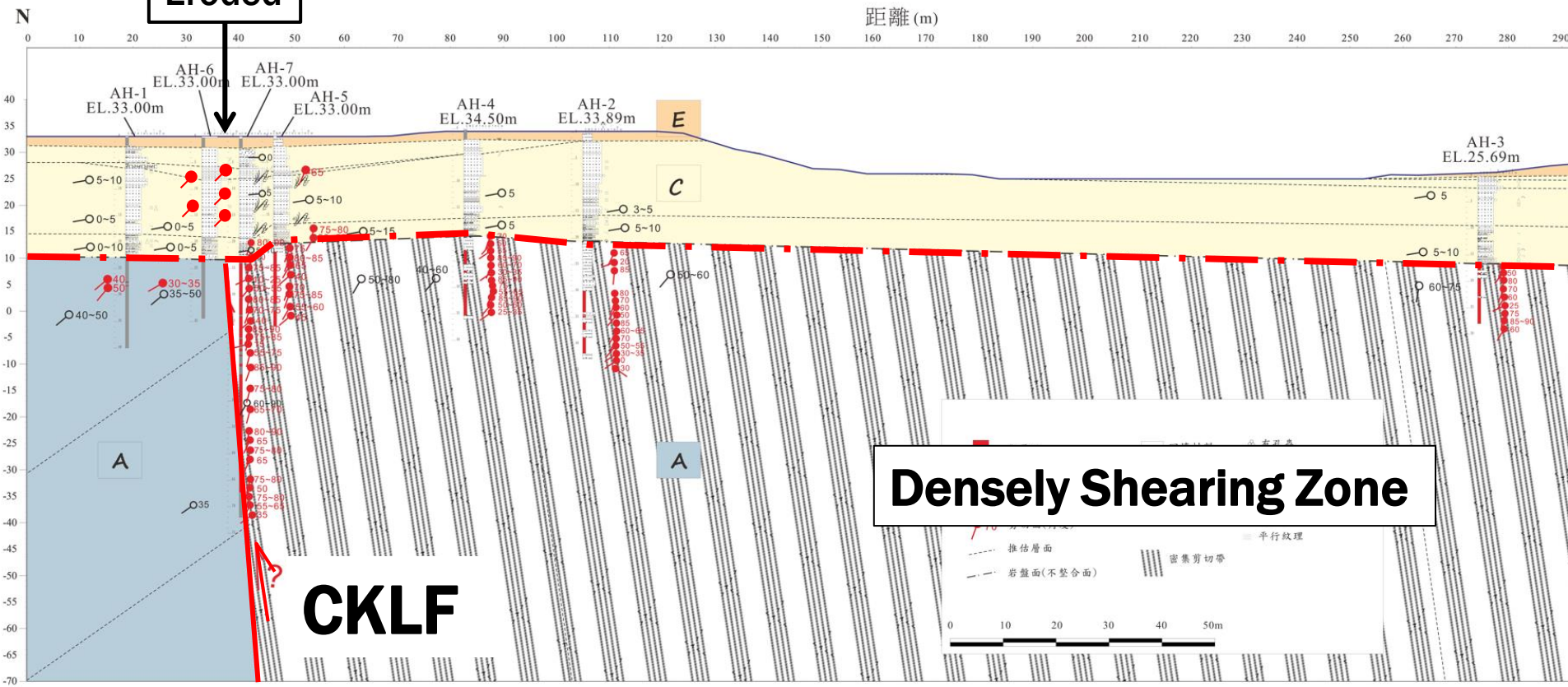
Bedding dip angle

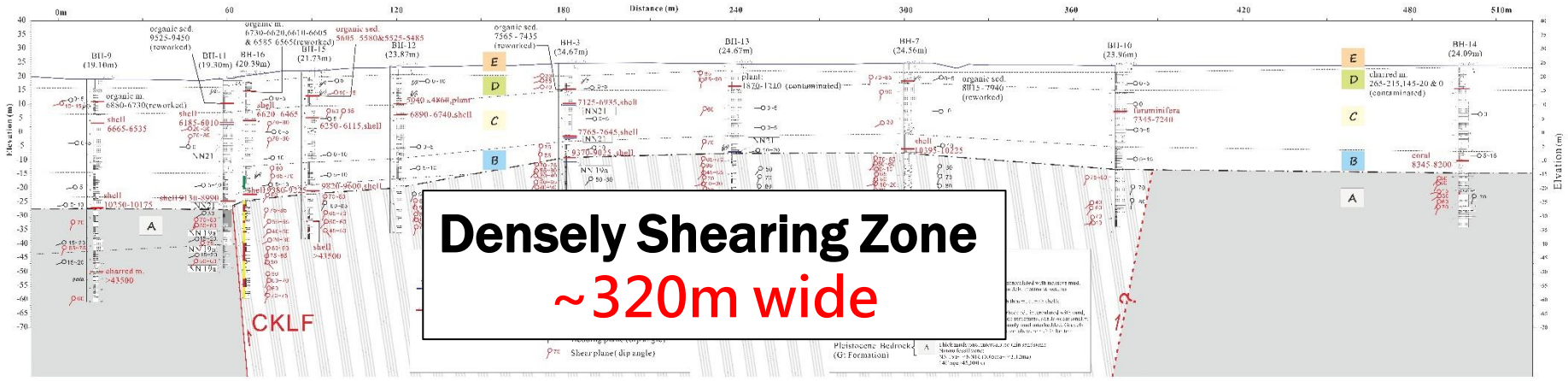
CKLF = Chekualin fault

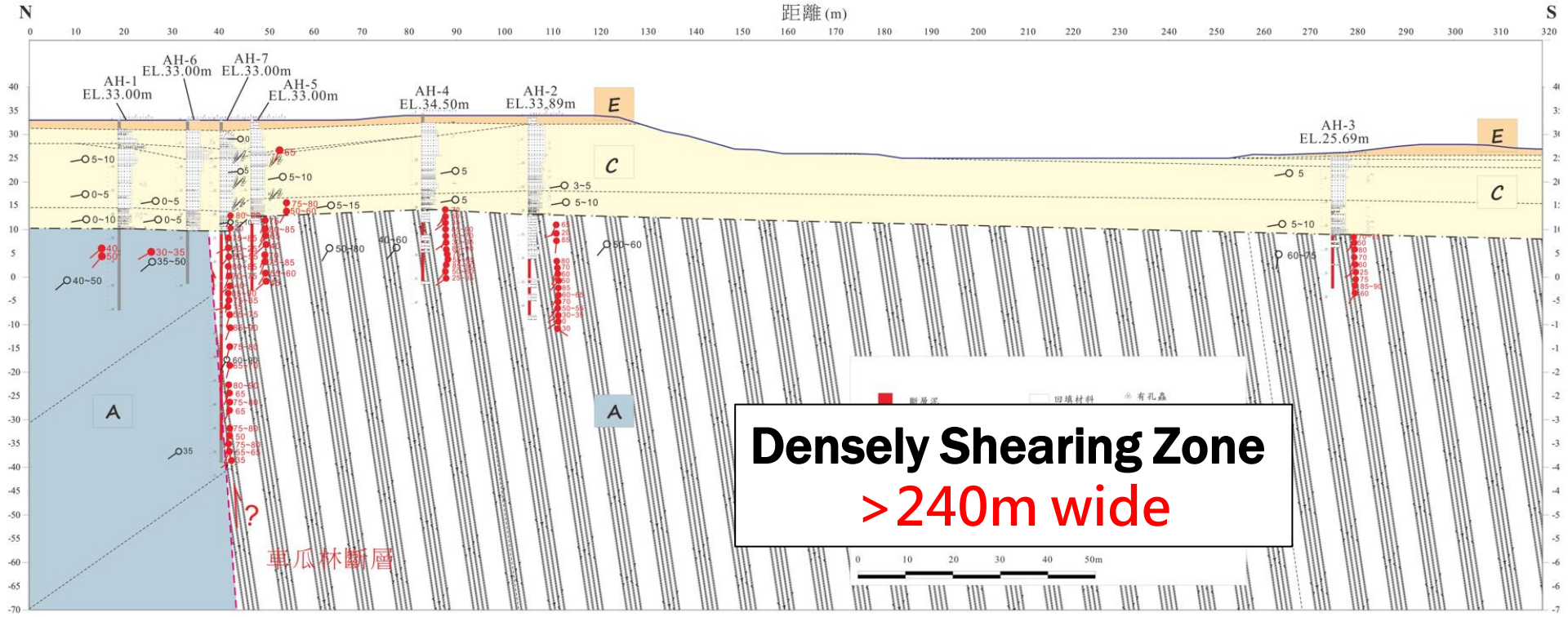

AH - profile
AH-1
AH-6
AH-7
AH-5
AH-4
AH-2
AH-3
BH - profile
BH-9
BH-11
BH-16
BH-15
BH-12
BH-1~
BH-4
BH-13
BH-5~
BH-8
BH-10
BH-14
Boleholes
Profile locations
Chekualin Fault (presumed)
Cracks
Inclined electric poles

A-A’ (1:1)

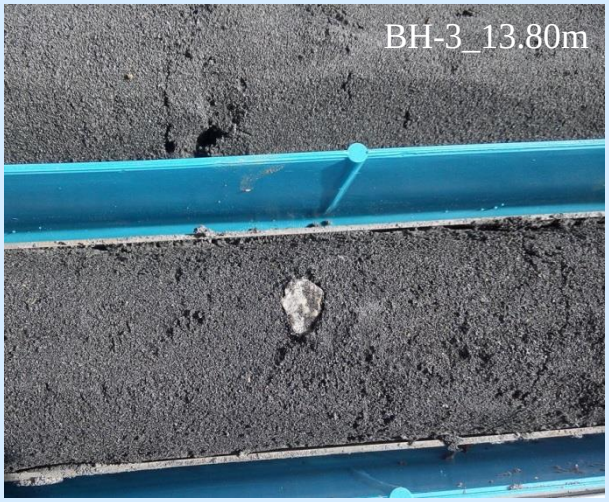
Eroded


N
距離 (m)
AH-1 EL.33.00m
AH-6 EL.33.00m
AH-7 EL.33.00m
AH-5 EL.33.00m
AH-4 EL.34.50m
AH-2 EL.33.89m
AH-3 EL.25.69m
E
C
A
A
CKLF
Densely Shearing Zone
推估層面
岩盤面(不整合面)
密集剪切帶
平行紋理
0 10 20 30 40 50m


Distance (m)
Elevation (m)
CKLF
Densely Shearing Zone
~320m wide


N
S
距離 (m)
AH-1 EL.33.00m
AH-6 EL.33.00m
AH-7 EL.33.00m
AH-5 EL.33.00m
AH-4 EL.34.50m
AH-2 EL.33.89m
AH-3 EL.25.69m
華瓜林斷層
Densely Shearing Zone
>240m wide

HOLOCENE DEPOSITS (TAINAN FORMATION)

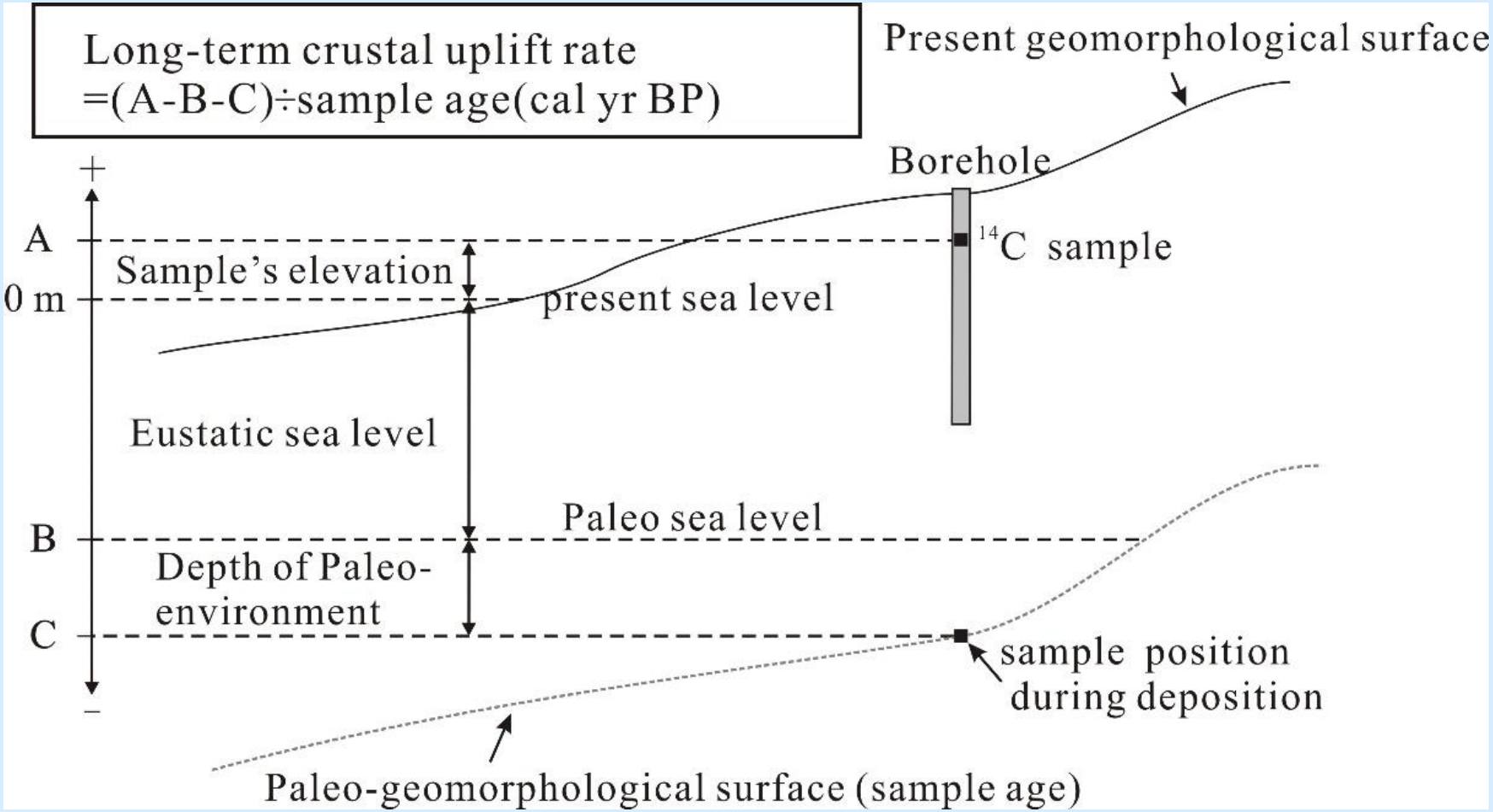


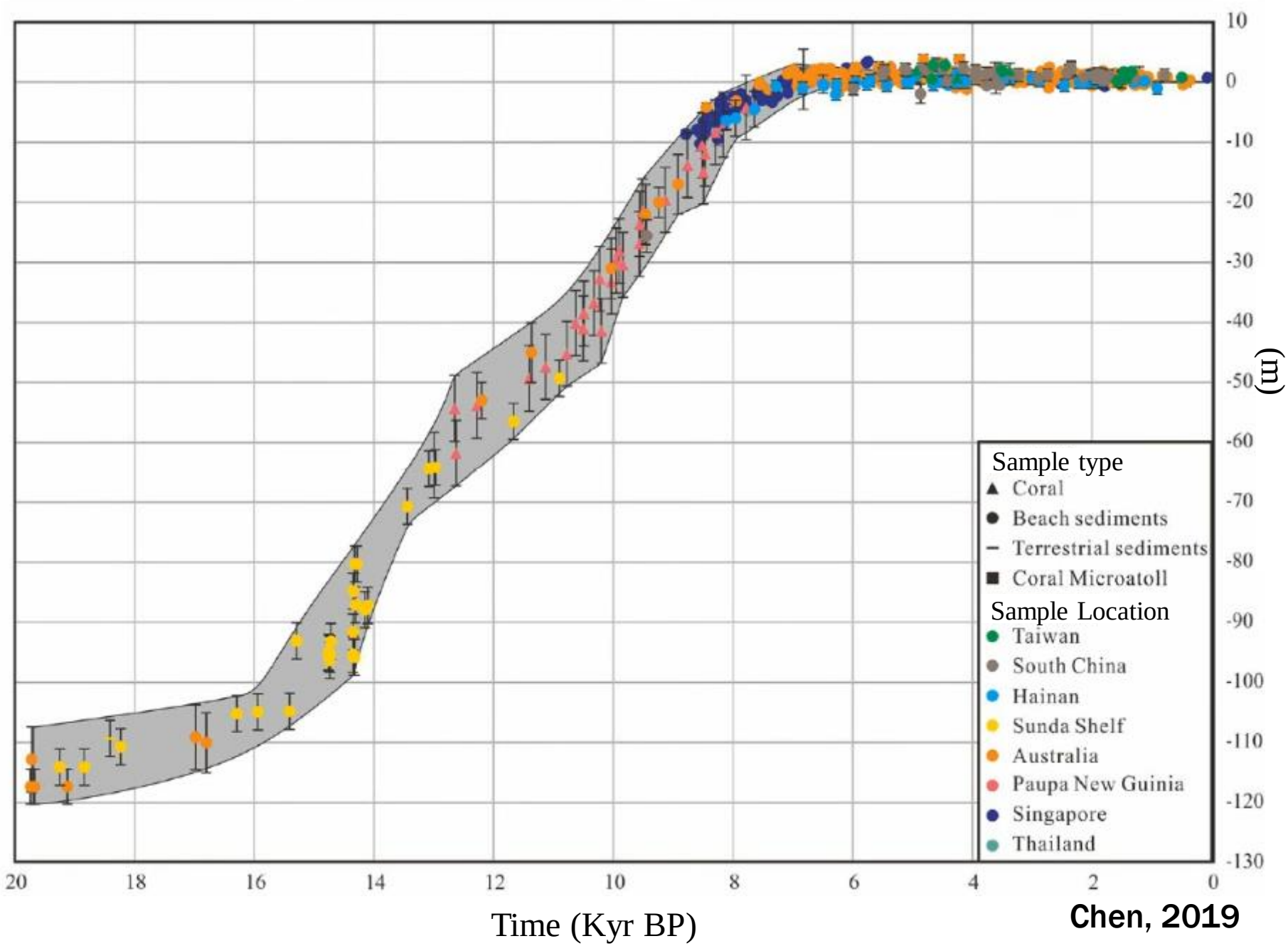
Deformed Holocene strata
Shear band

BH-3_31.75~32.00m
Layer B, shear plane 85~90°

BH-13_3.35~3.65m
Layer **D shear plane** 80°

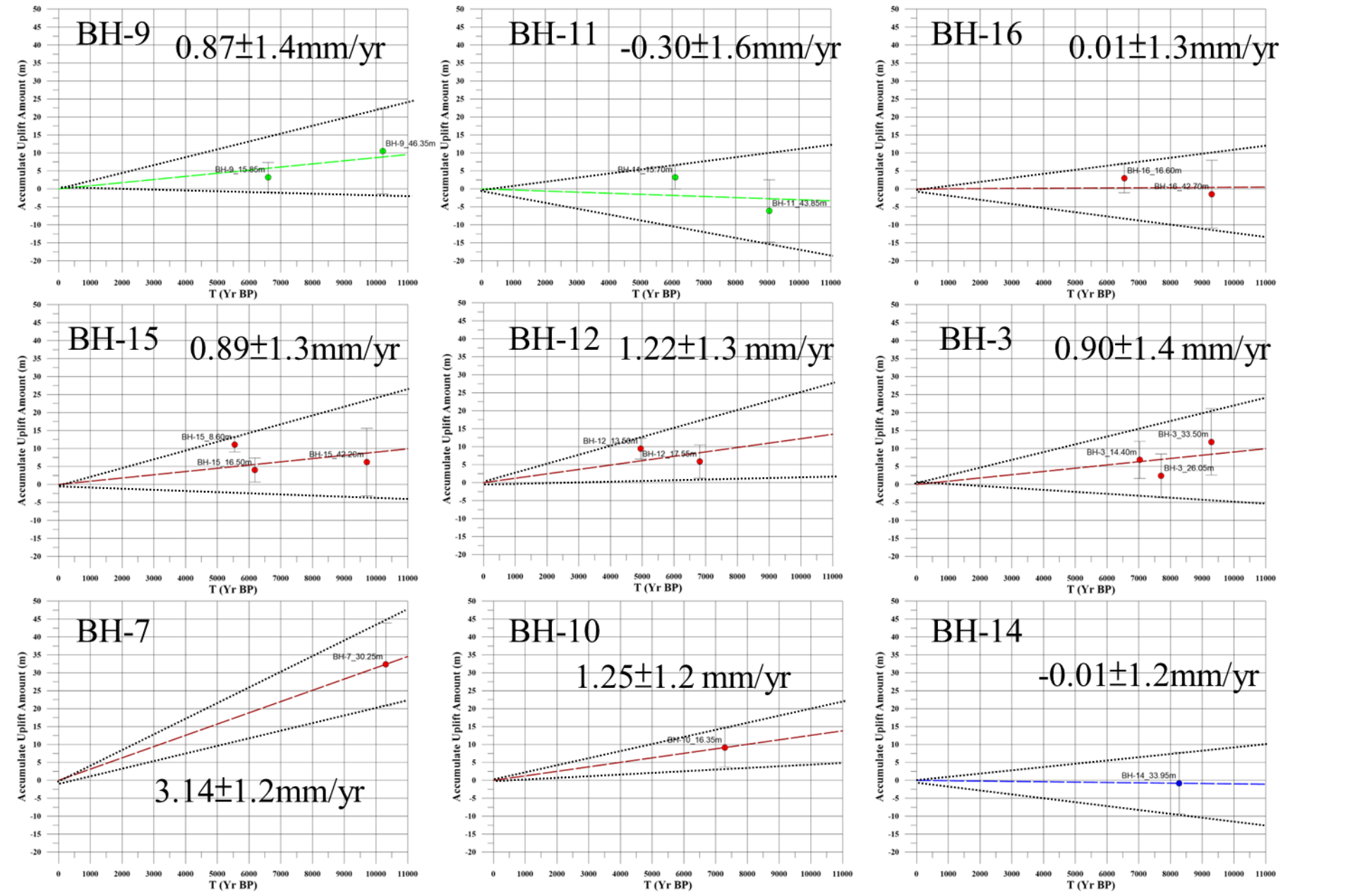
AH-7_10.00-10.25m · Layer **C shear plane**

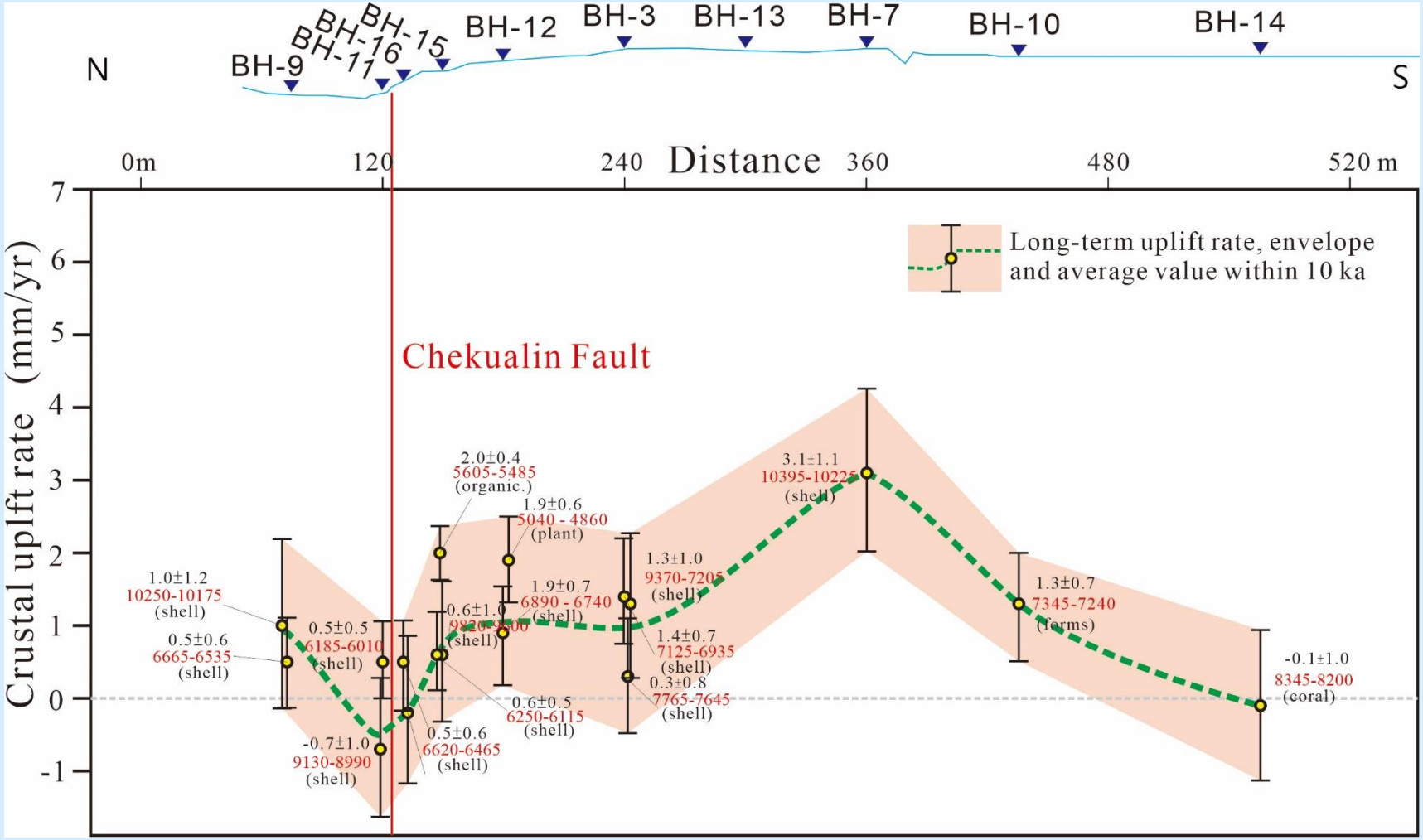

Long-term crustal uplift rate
=(A-B-C)÷sample age(cal yr BP)
Present geomorphological surface
Borehole
+
A
0 m
Sample's elevation
present sea level
^{14}C sample
Eustatic sea level
Paleo sea level
B
Depth of Paleo-
environment
C
sample position
during deposition
–
Paleo-geomorphological surface (sample age)

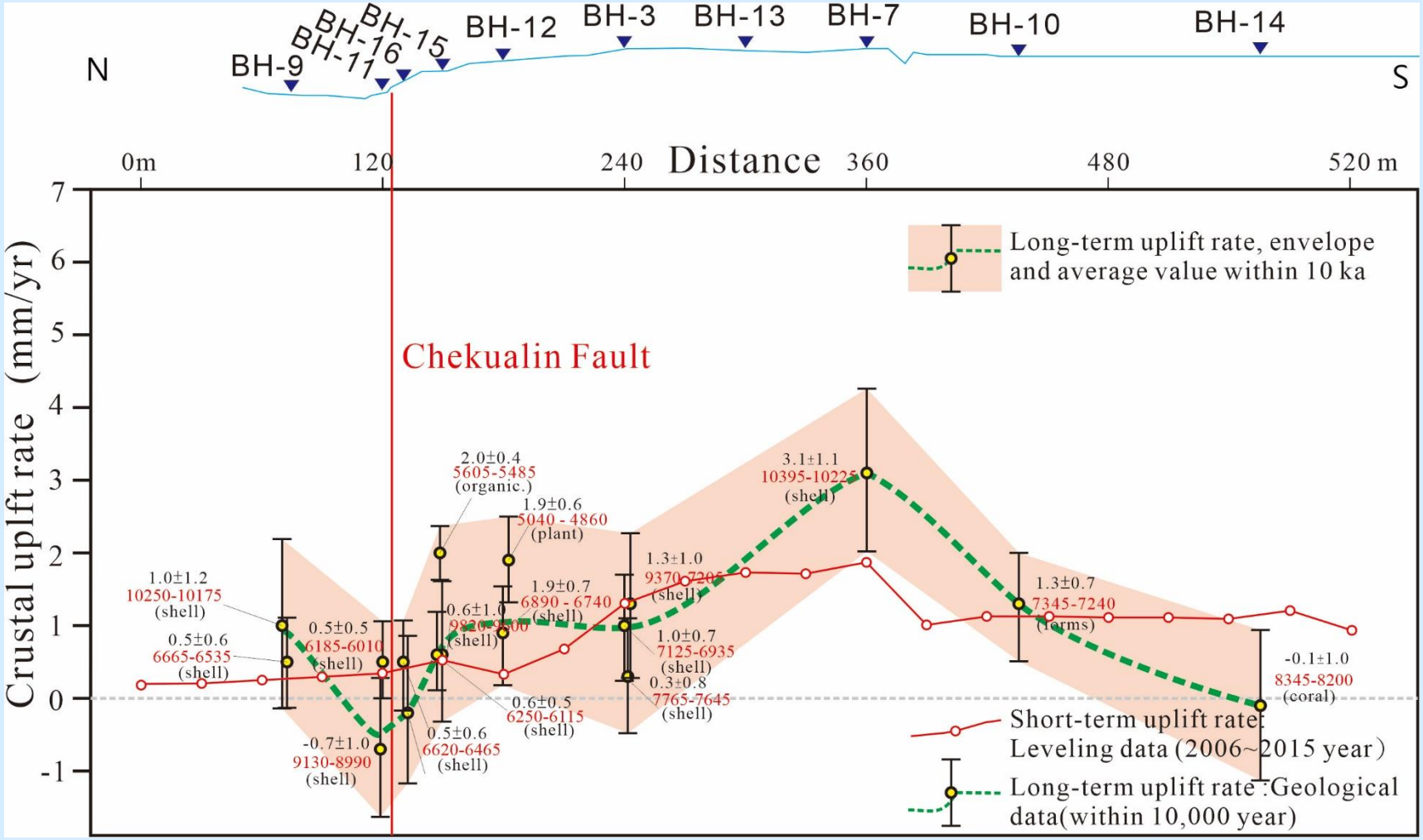

Eustatic Sea level Elevation (m)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
20
18
16
14
12
10
8
6
4
2
0
Time (Kyr BP)
Sample type
Coral
Beach sediments
Terrestrial sediments
Coral Microatoll
Sample Location
Taiwan
South China
Hainan
Sunda Shelf
Australia
Paupa New Guinia
Singapore
Thailand
Chen, 2019

Sample Number	Sample Material	Borehole Elevation (m)	Sample Depth (m)	Sample Elevation (m)	Paleo Sea Level Elevation(m)	Paleo Environmental Depth(m)	Carbon-14 Dating (Calibrated yr BP)	Vertical Displacement(m)	Uplift rate(mm/yr)
BH-3_14.40m	Shell	24.67	14.40	10.27	-0.1± 3.1	2~ -2	7030 ± 95	10.42 ± 5.15	1.48 ± 0.73
BH-3_26.05m	Shell	24.67	26.05	-1.38	-3.7± 4.0	2~ -2	7705 ± 60	2.40 ± 6.08	0.31 ± 0.79
BH-3_33.50m	Shell& Foraminifera	24.67	33.50	-8.83	-20.6± 7.2	2~ -2	9288 ± 83	11.83 ± 9.23	1.27 ± 0.99
BH-7_30.25m	Foraminifera	24.56	30.25	-5.69	-38.0± 9.5	2~ -2	10310 ± 85	32.38 ± 11.54	3.14 ± 1.12
BH-9_15.85m	Shell	19.89	15.85	4.04	0.8± 2.1	2~ -2	6600 ± 65	3.24 ± 4.10	0.49 ± 0.62
BH-9_46.35m	Shell	19.89	46.35	-26.46	-36.9± 9.8	2~ -2	10213 ± 38	10.49 ± 11.89	1.03 ± 1.16
BH-11_15.70m	Shell	20.17	15.70	4.47	1.2± 1.2	2~ -2	6098 ± 88	3.22 ± 3.25	0.53 ± 0.53
BH-11_43.85m	Shell	20.17	43.85	-23.68	-17.5± 6.6	2~ -2	9060 ± 70	-6.13 ± 8.67	-0.68 ± 0.96
BH-14_33.95m	Coral	24.09	33.95	-9.86	-9.0± 6.5	2~ -2	8273 ± 73	-0.81 ± 8.58	-0.10 ± 1.04
BH-10_16.35m	Foraminifera	23.96	16.35	7.61	-1.5± 3.4	2~ -2	7293 ± 53	9.16 ± 5.45	1.26 ± 0.75
BH-12_17.55m	Shell	23.87	17.55	6.32	0.4± 2.6	2~ -2	6815 ± 75	5.86 ± 4.64	0.86 ± 0.68
BH-12_13.50m	Plant material	23.87	13.50	10.37	0.9± 0.9	2~ -2	4950 ± 90	9.46 ± 2.91	1.91 ± 0.59
BH-15_42.20m	Shell	21.73	42.20	-20.47	-26.6± 7.3	2~ -2	9710 ± 110	6.23 ± 9.38	0.64 ± 0.97
BH-15_16.50m	Shell	21.73	16.50	5.23	1.2± 1.3	2~ -2	6183 ± 68	4.02 ± 3.37	0.65 ± 0.54
BH-15_8.60m	Organic sediment	21.73	8.60	13.13	1.0± 1.0	2~ 0	5545 ± 60	11.08 ± 2.05	2.00 ± 0.37
BH-16_42.70m	Shell	20.39	42.70	-22.31	-20.8± 7.4	2~ -2	9303 ± 78	-1.47 ± 9.43	-0.16 ± 1.01
BH-16_16.60m	Shell	20.39	16.60	3.79	0.84± 2.0	2~ -2	6543 ± 78	2.95 ± 4.04	0.45 ± 0.62

- Tidal flat-swamps. half fresh water and half salty - very shallow marine deposits


BH-9
0.87±1.4mm/yr
BH-9_46.35m
BH-9_15.85m
BH-11
-0.30±1.6mm/yr
BH-11_15.70m
BH-11_43.85m
BH-16
0.01±1.3mm/yr
BH-16_16.60m
BH-16_42.70m
BH-15
0.89±1.3mm/yr
BH-15_8.60m
BH-15_16.50m
BH-15_42.20m
BH-12
1.22±1.3 mm/yr
BH-12_13.50m
BH-12_17.55m
BH-3
0.90±1.4 mm/yr
BH-3_33.50m
BH-3_14.40m
BH-3_26.05m
BH-7
3.14±1.2mm/yr
BH-7_30.25m
BH-10
1.25±1.2 mm/yr
BH-10_16.35m
BH-14
-0.01±1.2mm/yr
BH-14_33.95m
Accumulate Uplift Amount (m)
T (Yr BP)
Hanging-wall sample inside shear zone samples
Hanging-wall sample outside shear zone samples
Footwall samples
Hanging-wall sample inside shear zone fit-lines
Hanging-wall sample outside shear zone fit-line
Footwall fit-lines


N
S
BH-9
BH-11
BH-16
BH-15
BH-12
BH-3
BH-13
BH-7
BH-10
BH-14
0m
120
240
Distance
360
480
520 m
Crustal uplft rate (mm/yr)
7
6
5
4
3
2
1
0
-1
Chekualin Fault
Long-term uplift rate, envelope
and average value within 10 ka
1.0±1.2
10250-10175
(shell)
0.5±0.6
6665-6535
(shell)
0.5±0.5
6185-6010
(shell)
-0.7±1.0
9130-8990
(shell)
2.0±0.4
5605-5485
(organic.)
0.6±1.0
9820-9500
(shell)
0.5±0.6
6620-6465
(shell)
1.9±0.6
5040 - 4860
(plant)
1.9±0.7
6890 - 6740
(shell)
0.6±0.5
6250-6115
(shell)
1.3±1.0
9370-7205
(shell)
1.4±0.7
7125-6935
(shell)
0.3±0.8
7765-7645
(shell)
3.1±1.1
10395-10225
(shell)
1.3±0.7
7345-7240
(forms)
-0.1±1.0
8345-8200
(coral)


N
BH-9
BH-11
BH-16
BH-15
BH-12
BH-3
BH-13
BH-7
BH-10
BH-14
S
0m
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(shell)
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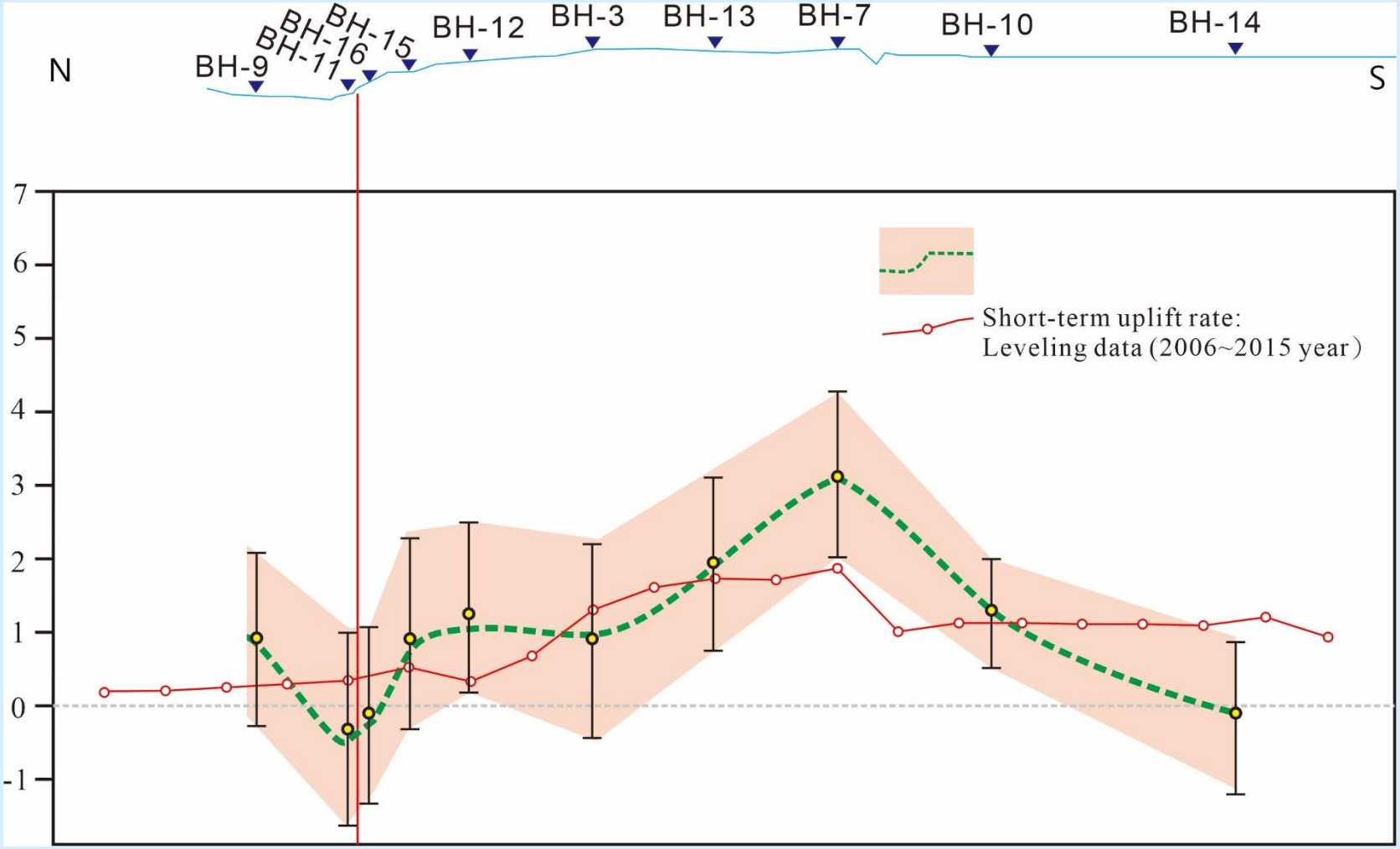
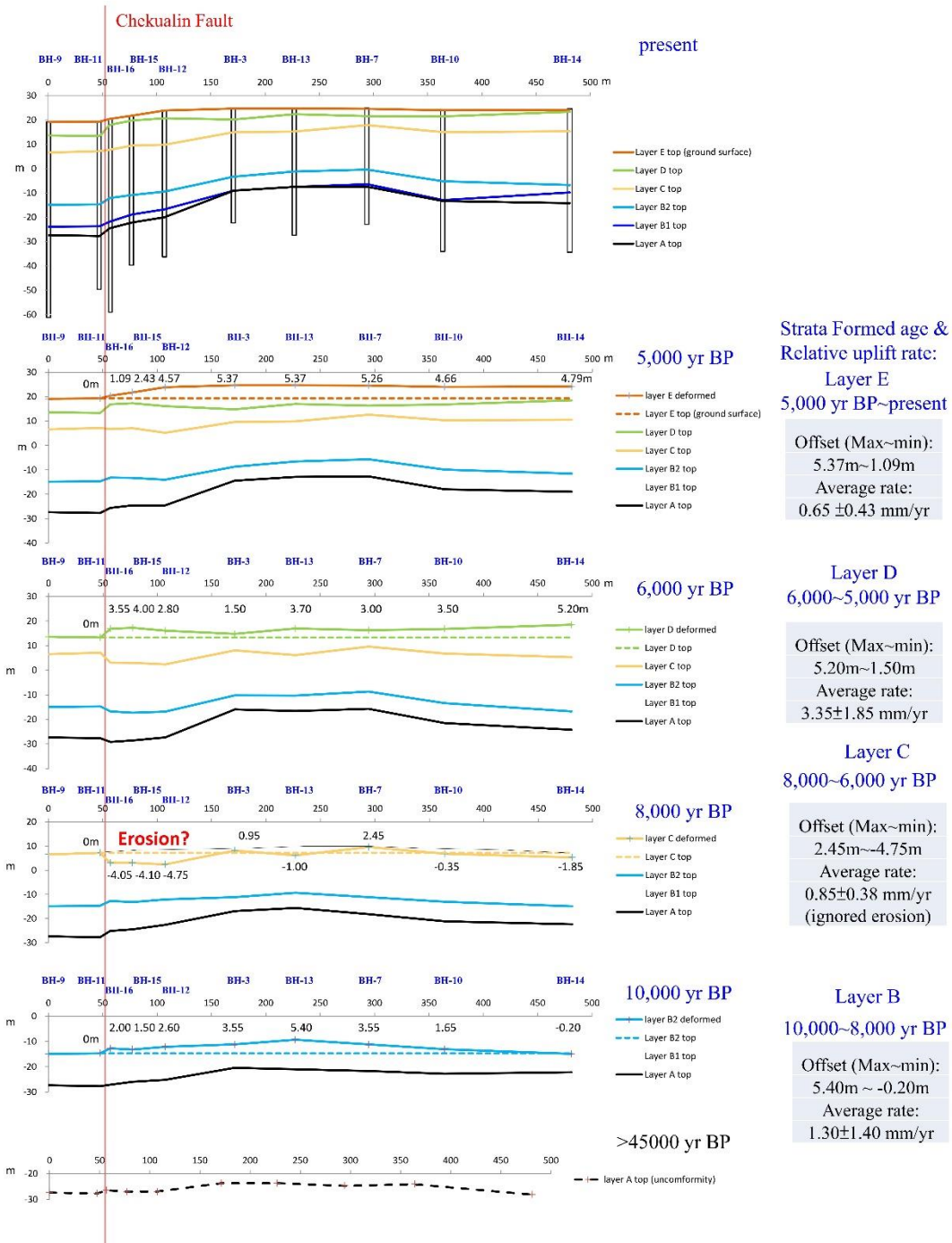
9130-8990
(shell)
2.0±0.4
5605-5485
(organic.)
0.5±0.6
6620-6465
(shell)
1.9±0.6
5040 - 4860
(plant)
0.6±1.0
9820-9500
(shell)
1.9±0.7
6890 - 6740
(shell)
0.6±0.5
6250-6115
(shell)
1.3±1.0
9370-7205
(shell)
1.0±0.7
7125-6935
(shell)
0.3±0.8
7765-7645
(shell)
3.1±1.1
10395-10225
(shell)
1.3±0.7
7345-7240
(terms)
-0.1±1.0
8345-8200
(coral)
Short-term uplift rate: Leveling data (2006~2015 year)
Long-term uplift rate: Geological data(within 10,000 year)

future work- footwall as base point to redraw



DISCUSSION- THE CHANGE OF ACTIVE ZONE THROUGH TIME



Strata Formed age & Relative uplift rate:

Layer E
5,000 yr BP~present

Offset (Max~min):
5.37m~1.09m
Average rate:
0.65 ±0.43 mm/yr

Layer D
6,000~5,000 yr BP

Offset (Max~min):
5.20m~1.50m
Average rate:
3.35±1.85 mm/yr

Layer C
8,000~6,000 yr BP

Offset (Max~min):
2.45m~-4.75m
Average rate:
0.85±0.38 mm/yr
(ignored erosion)

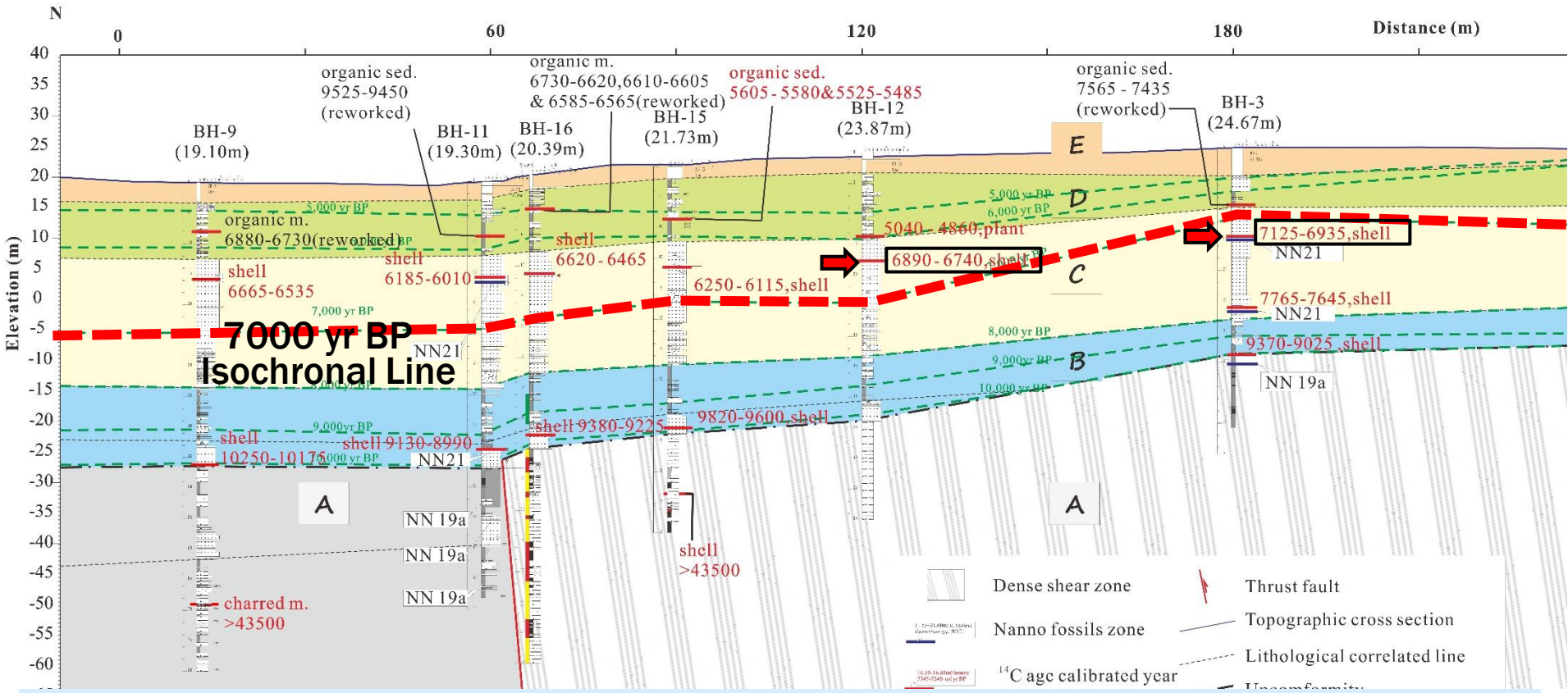
Layer B
10,000~8,000 yr BP

Offset (Max~min):
5.40m ~ -0.20m
Average rate:
1.30±1.40 mm/yr

FUTURE WORK
EXTRACT EVERY POINT TO DETERMINE DEFORMATION RATE

- Thrust(Pleistocene)
- Strike slip fault(Holocene, present)
- Different Time scale

DISCUSSION-THE CHANGE OF ACTIVE ZONE THROUGH TIME



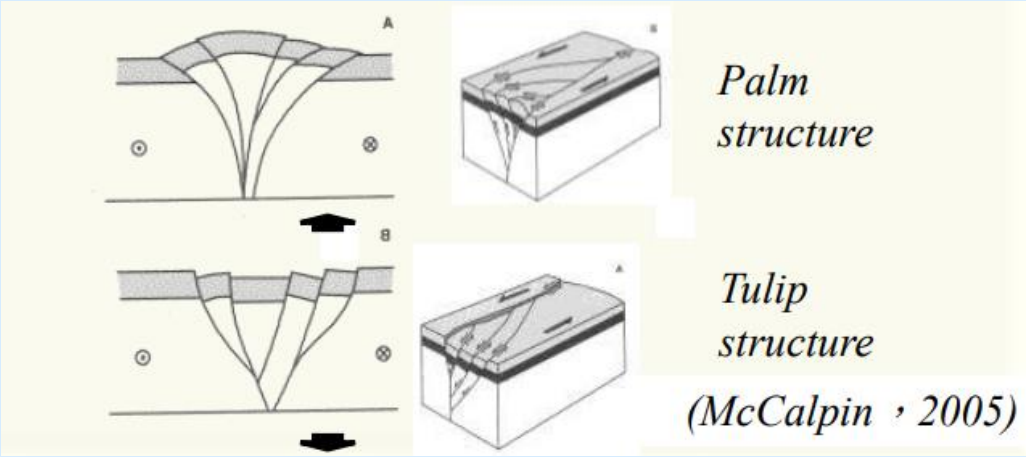
Growth Strata

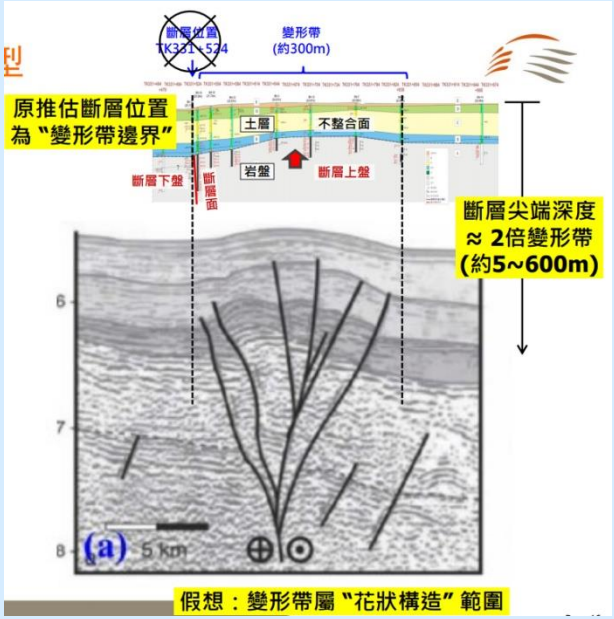
- B、C、D bottom: more shallower, more gentler for Layer B~25°，C~20°，D~5°
- Footwall thickening

DISCUSSION
STRIKE SLIP FAULT?

- Thrust(Pleistocene)
- Strike slip fault(Holocene, present)
- Different Time scale

- Main Fault of Strike slip fault Occurred at **Central of shear zone**





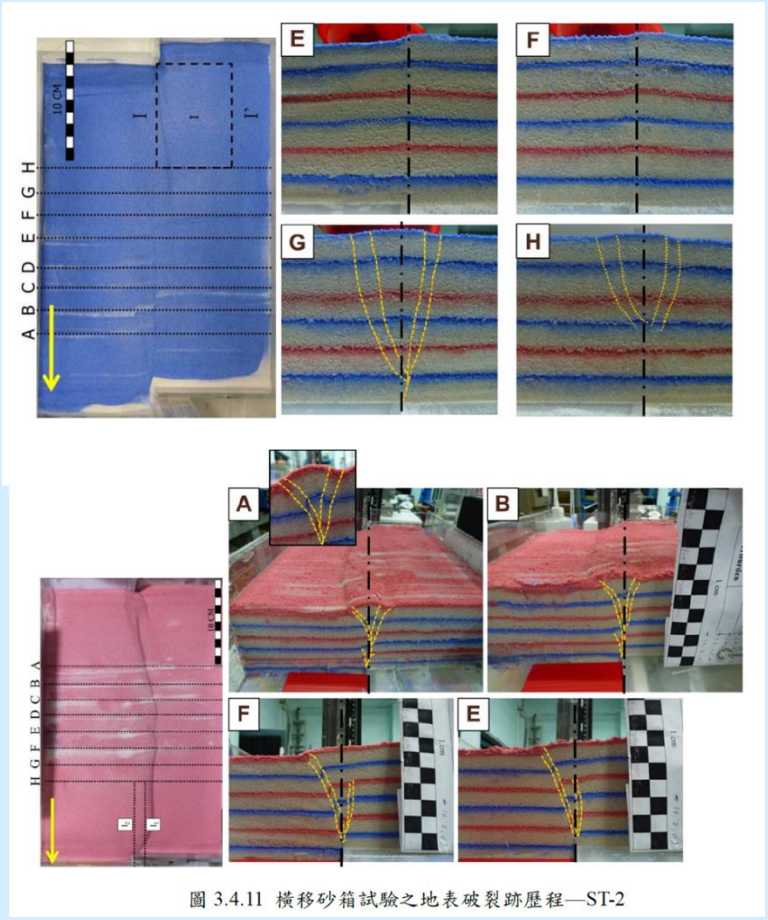
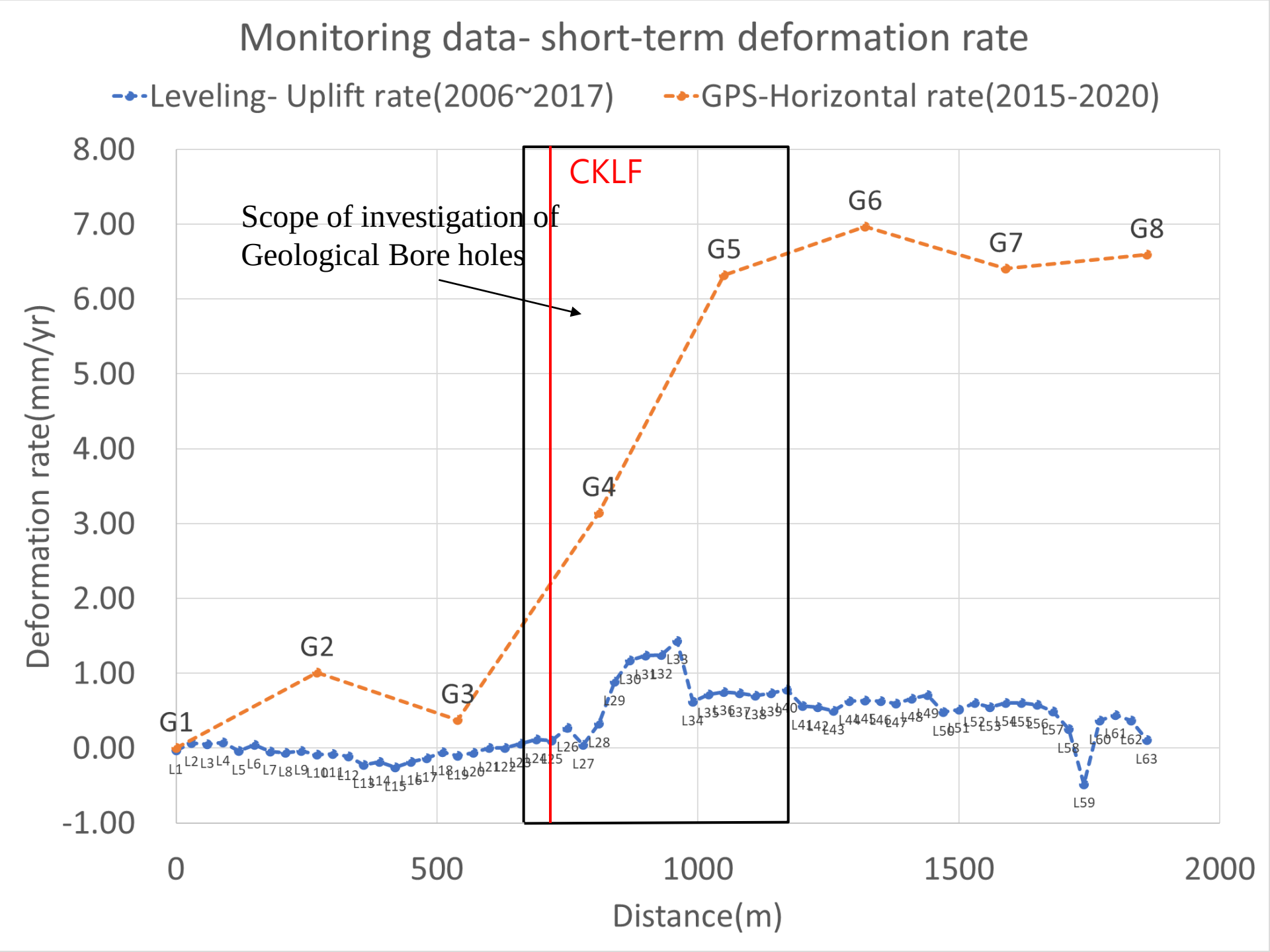
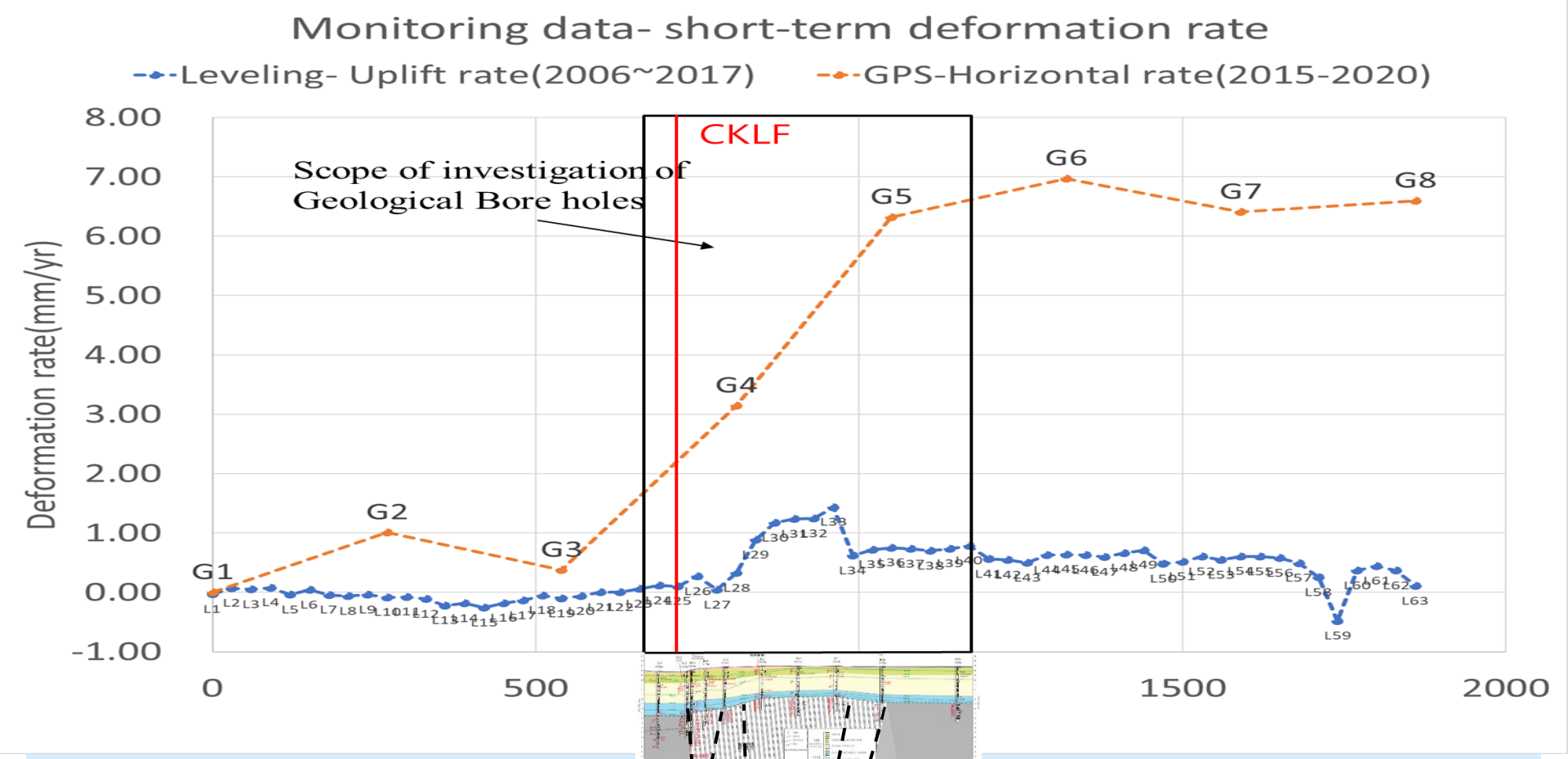


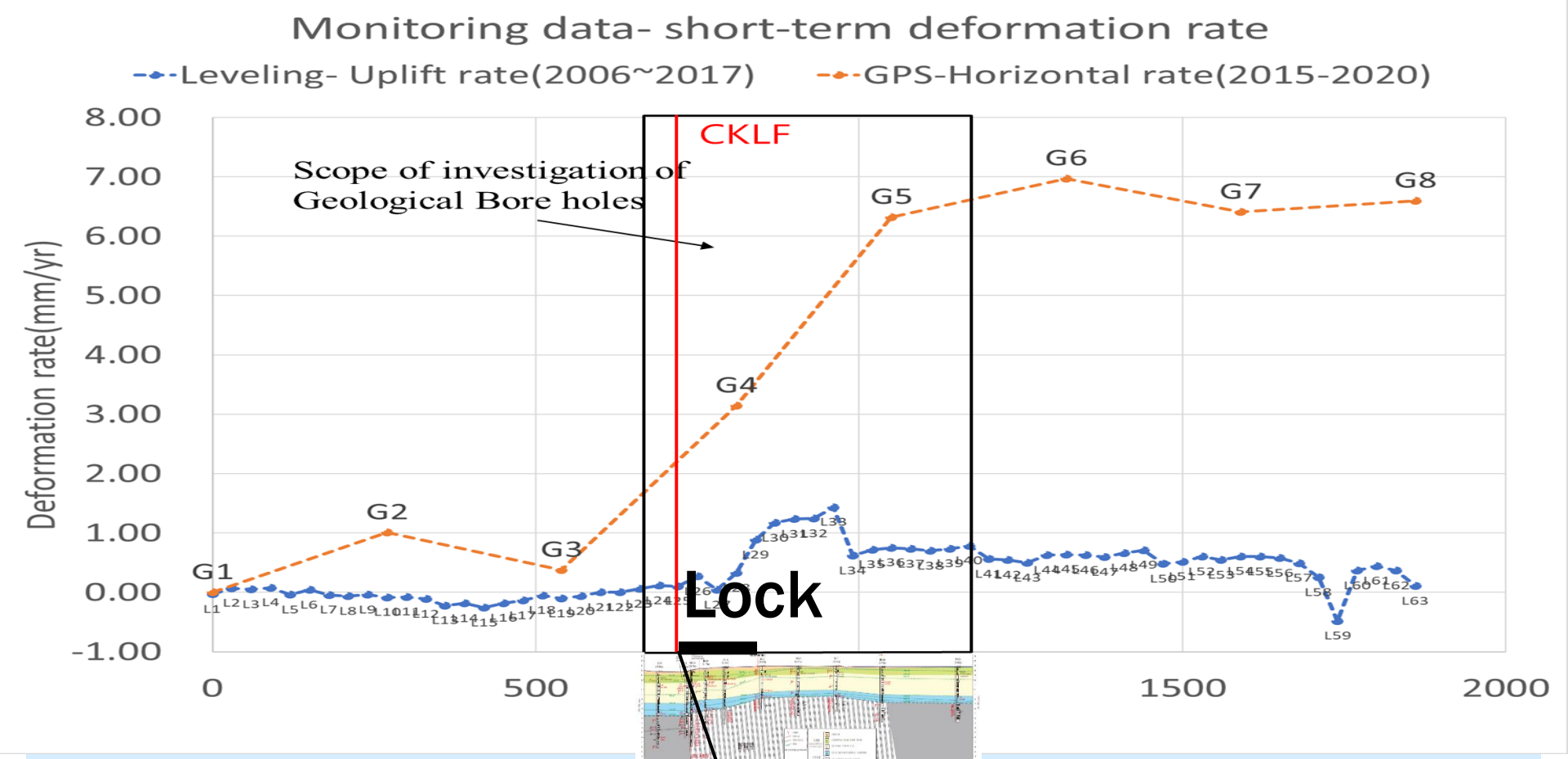
圖 3.4.11 橫移砂箱試驗之地表破裂跡歷程—ST-2


Monitoring data- short-term deformation rate
Leveling- Uplift rate(2006~2017)
GPS-Horizontal rate(2015-2020)
CKLF
Scope of investigation of Geological Bore holes
G1
G2
G3
G4
G5
G6
G7
G8
Deformation rate(mm/yr)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
0
500
1000
1500
2000
Distance(m)



Model A
Flower structure
Control by strike slip fault

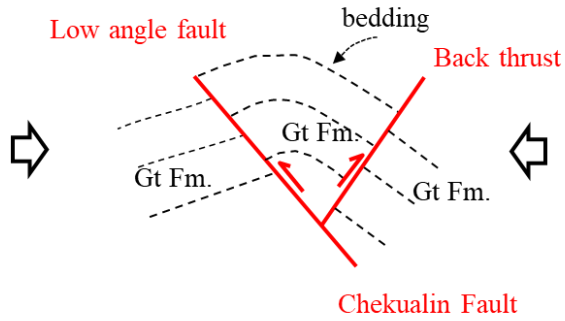
Shifting of central fault zone?



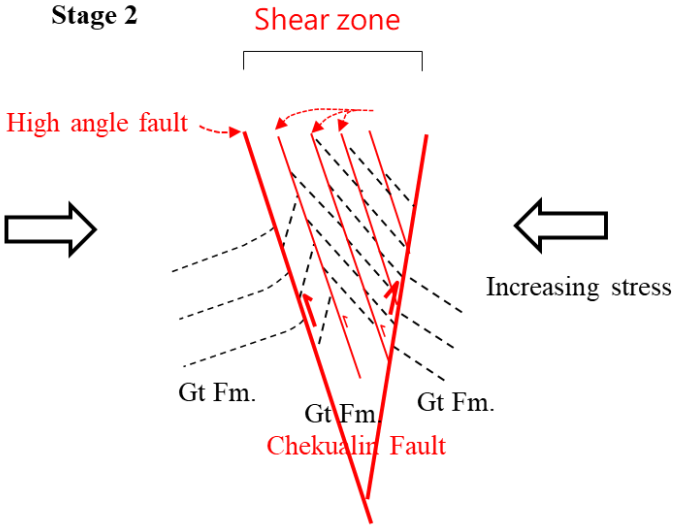
Model B

- Partially Locking
  by Fault Angle change?
  by lithology?

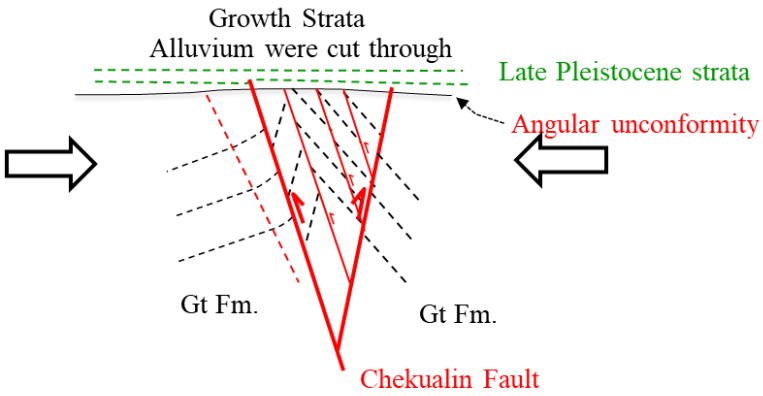
Stage 1



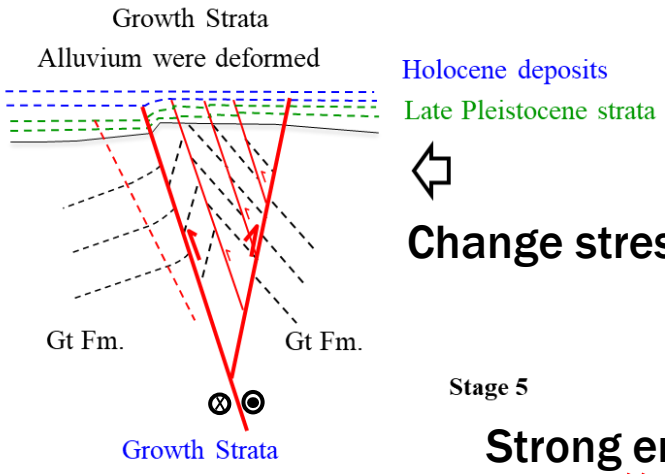
Stage 2



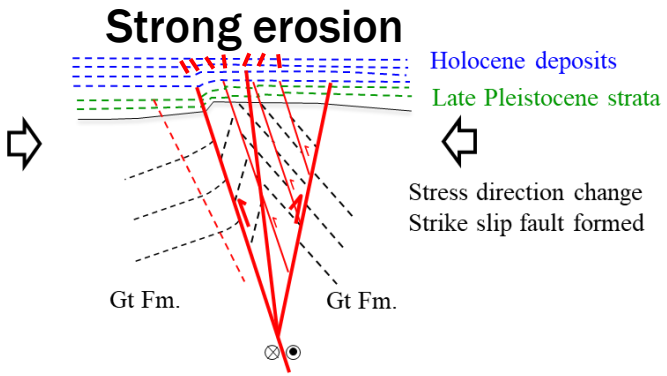
Stage 3



Stage 4



Stage 5



CONCLUSION

1. Study site was identified which located within **highly shear zone which extend ~300m wide** of Chekualin Fault in alluvial plain.
2. **Active deformation zone is highly relative to the shear zone**, which was not only related to the boundary between the shear zone and the intact part, but also fit to entire shear zone.
3. The deformation characteristics might be a **thrust fault** record by geological data, but **turn into a strike- slip fault nowadays** measured via geodetic data.

CONCLUSION

4. The present active line correspond uplift position of old active line since 7,000 yr isochrone.

THANK YOU!