國立中央大學
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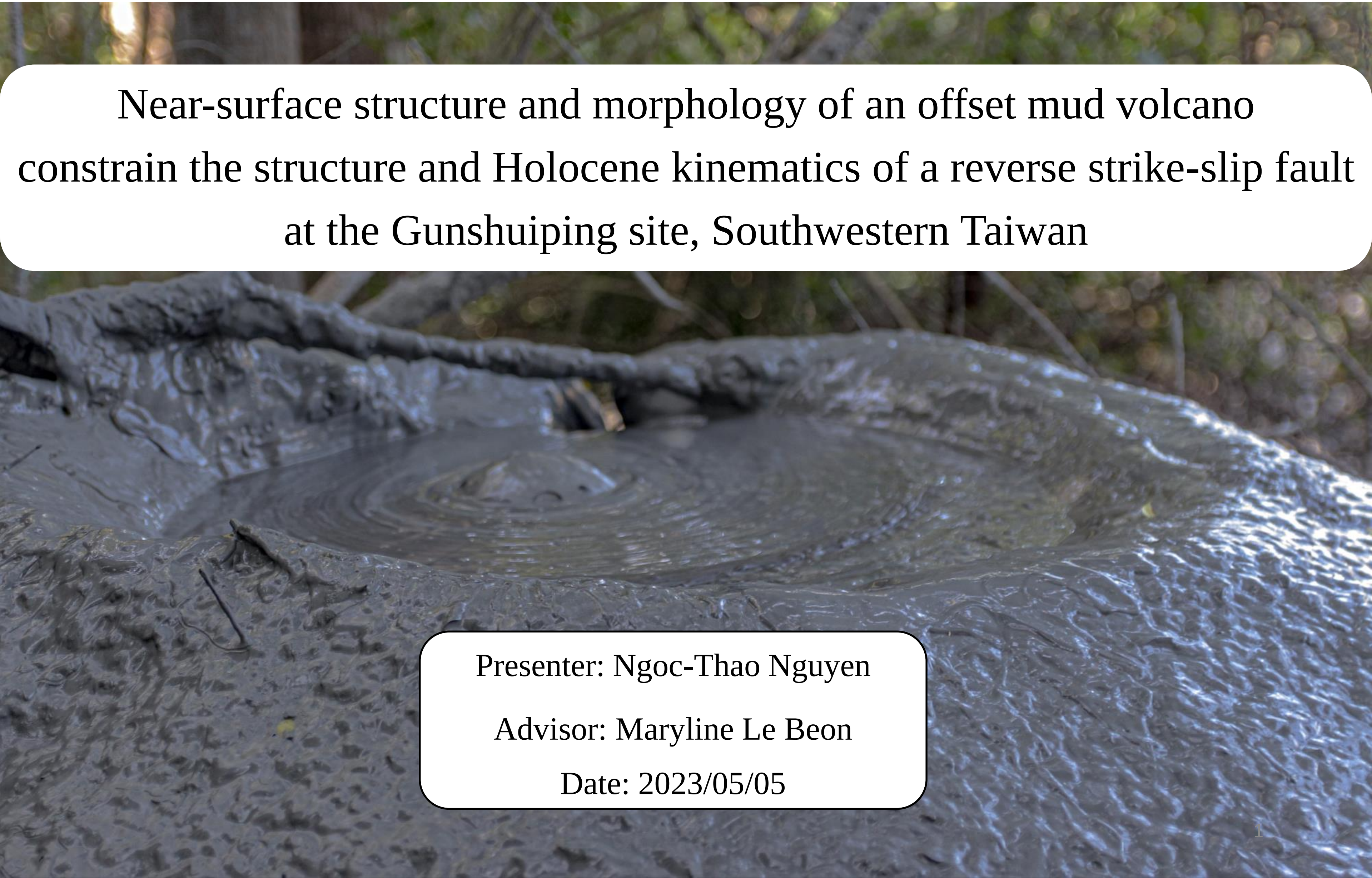
Near-surface structure and morphology of an offset mud volcano constrain the structure and Holocene kinematics of a reverse strike-slip fault at the Gunshuiping site, Southwestern Taiwan



Presenter: Ngoc-Thao Nguyen

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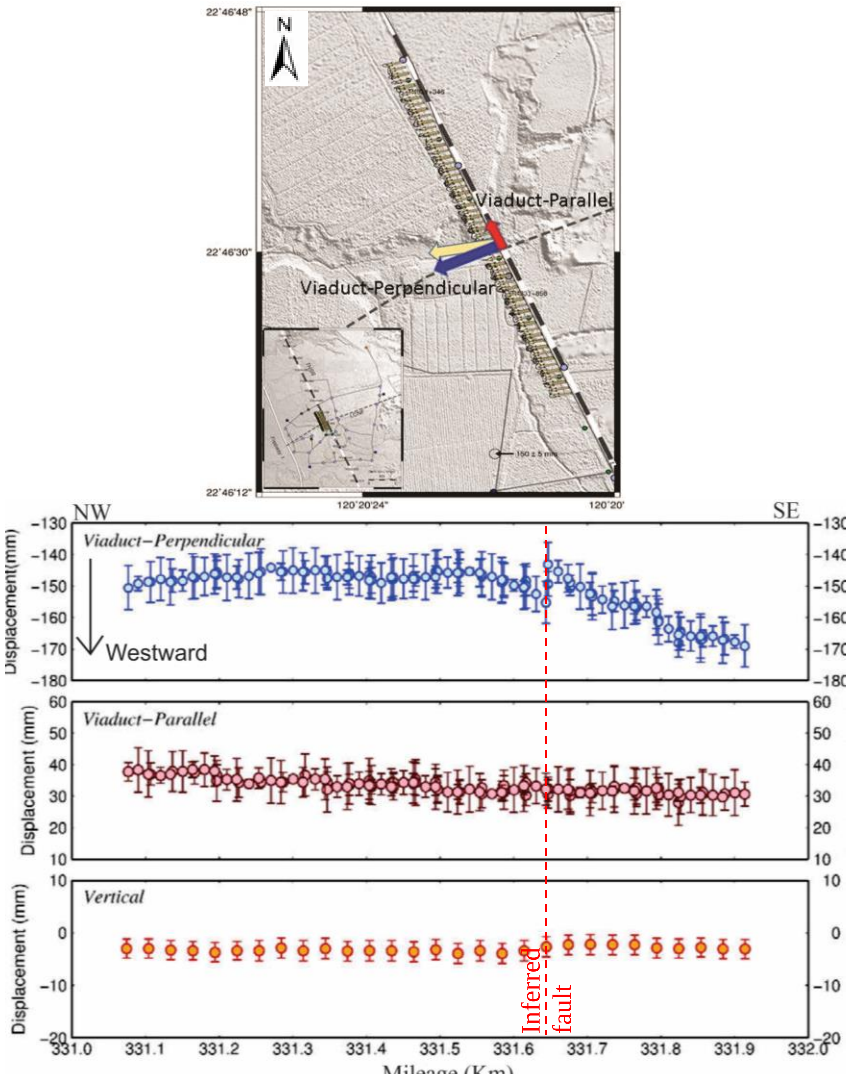
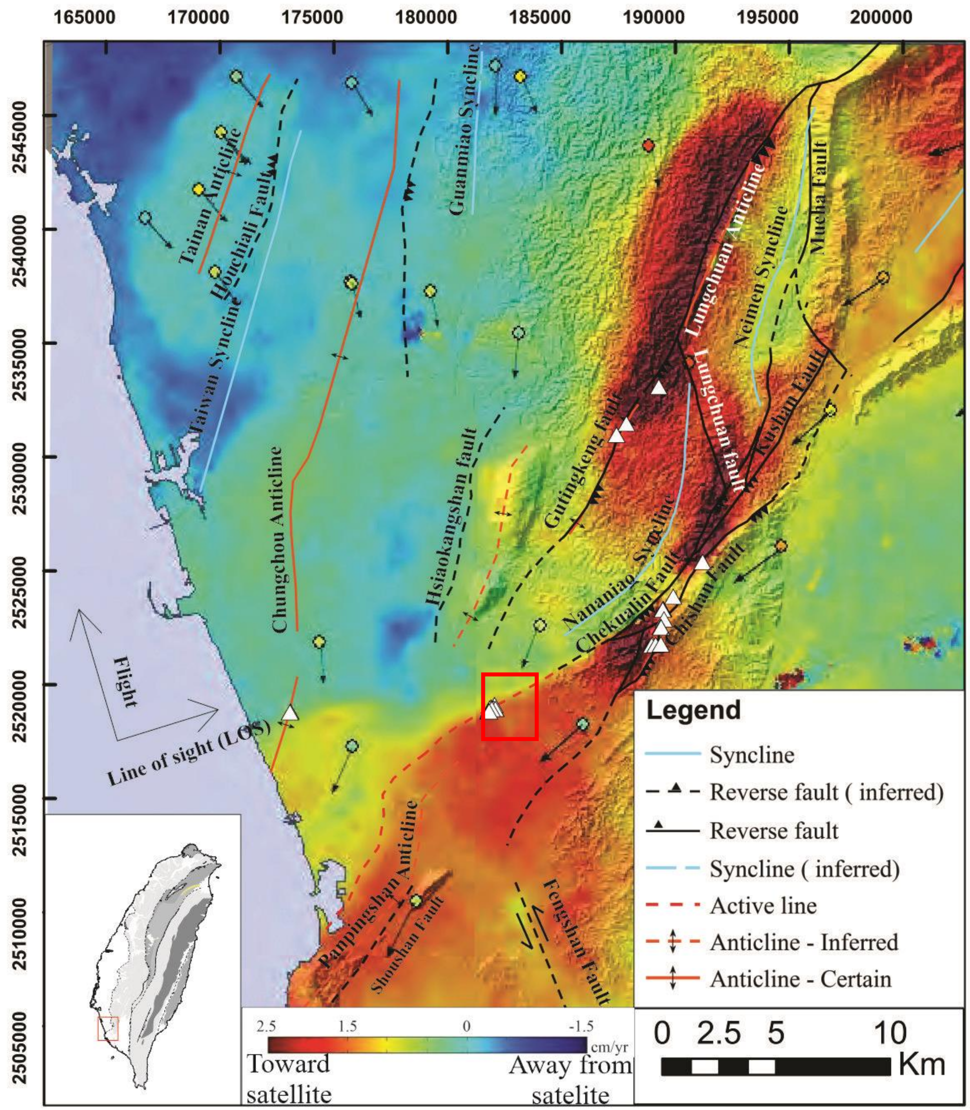
Date: 2023/05/05

Geodetic observations

- Geodetic observations suggest the existence of a <u>right-lateral strike-slip fault</u> connecting to the Chegualin fault (*Pathier et al, 2014; Chao, 2019*)



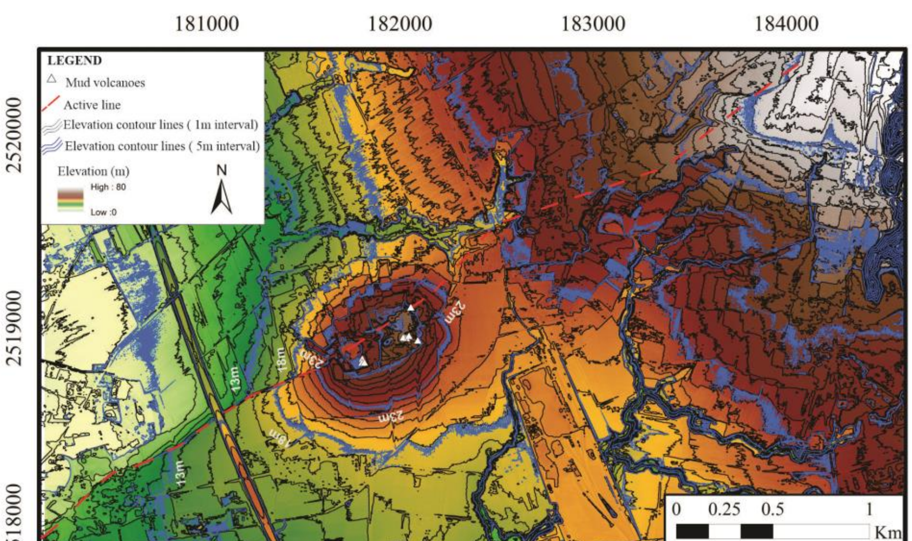
The displacement of GPS continuous station along Taiwan High Speech Rail from October 2015 to June 2018 *(Chao, 2019)*



InSAR line-of-sight velocity from 2007-2011 *(Pathier et al, 2014)*

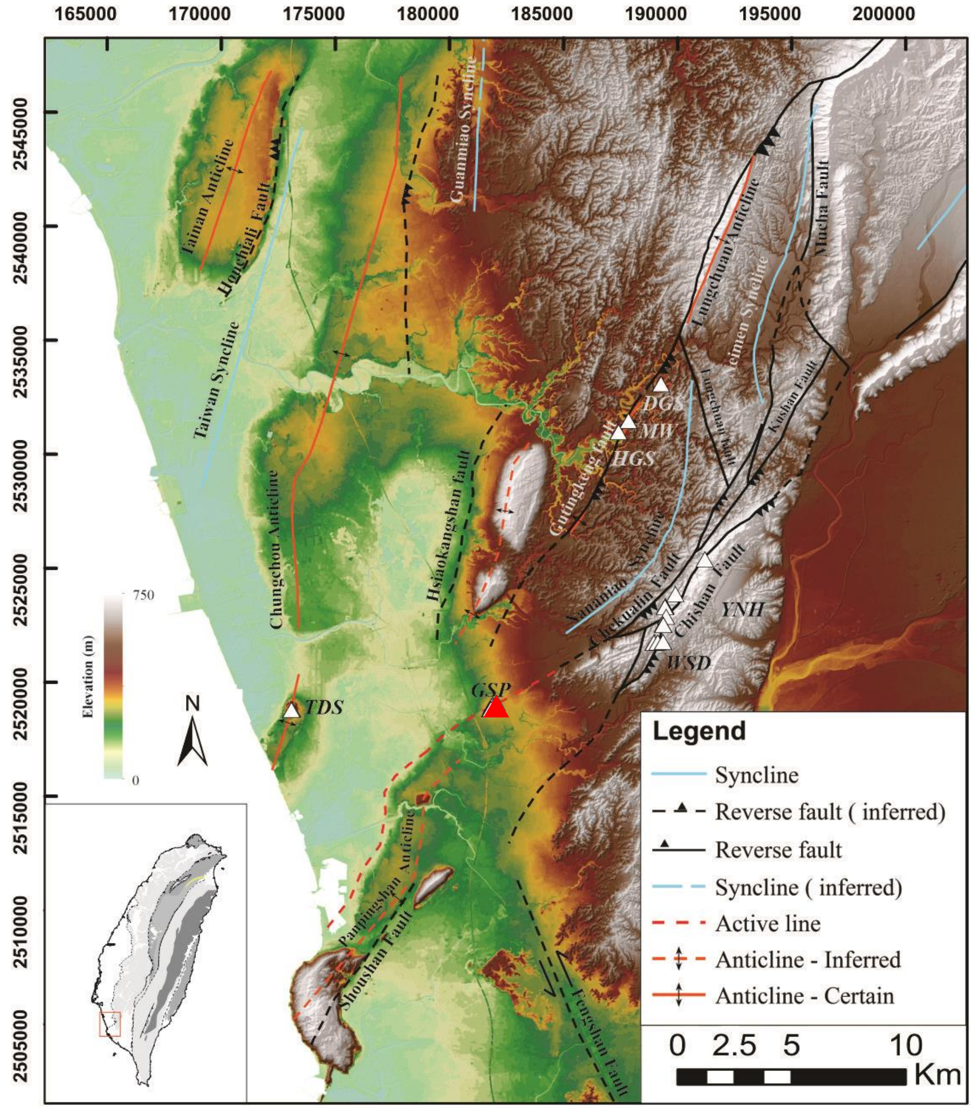
Geomorphology

- Geodetic observations suggest the existence of a right-lateral strike-slip fault connecting to the Chegualin fault *(Pathier et al, 2014; Chao, 2019)*
- The inferred fault path is presented as correlated with a topographic scarp on the southwestern flank of the Chegualin fault
- Along this inferred fault have the presence of the Gunshuiping mud volcano



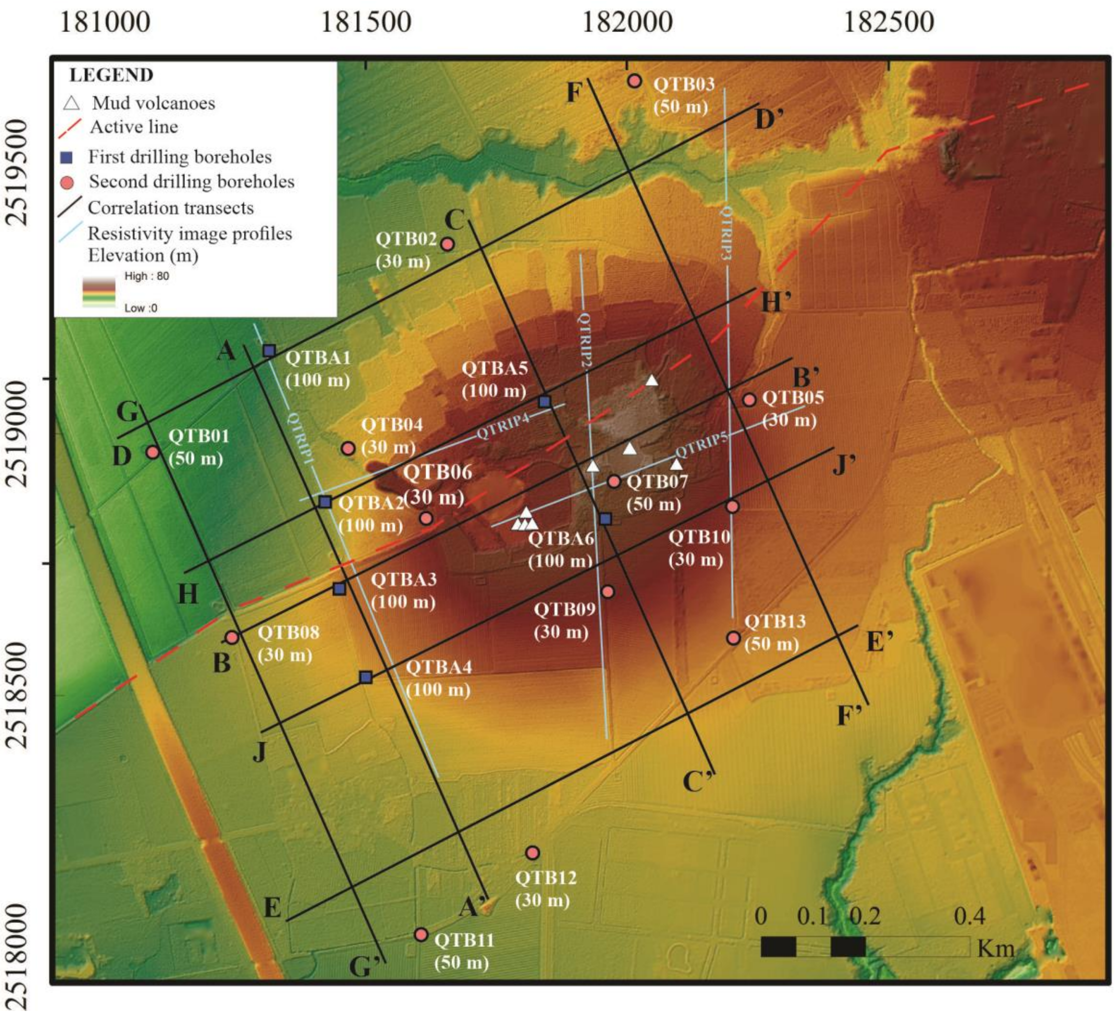
The dome-shaped morphology of Gunshuiping with 1m interval topographic contour lines

▲ Gunshuiping mud volcano



Gunshuiping mud volcanoes in Yanchao, Kaohsiung, Taiwan

The <u>geometry</u> and the <u>Holocene kinematics</u> of this inferred fault?



The distribution of boreholes and resistivity profiles at the Gunshuiping site

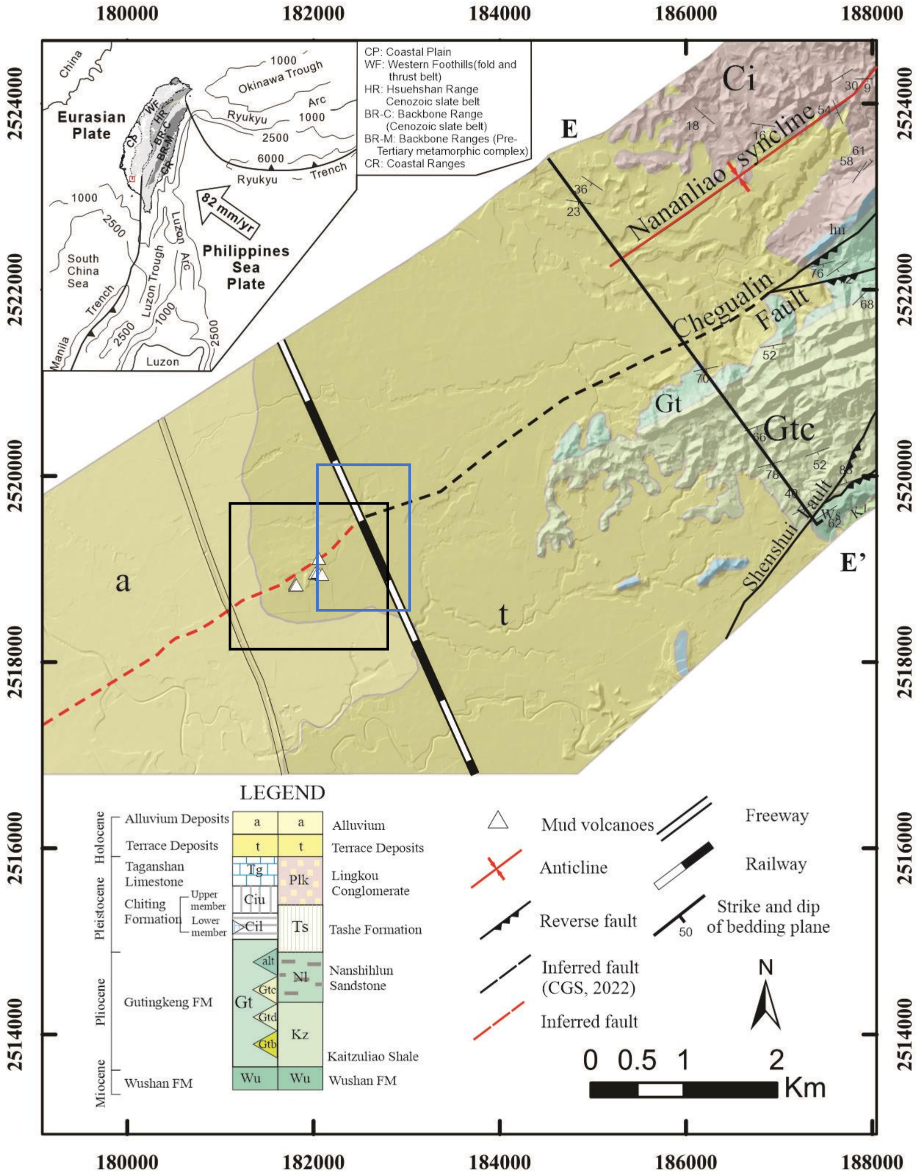
❑ Datasets:

- 19 boreholes
- 5 resistivity image profiles
- Radiocarbon dating
- U-Th dating
- Nannofossil

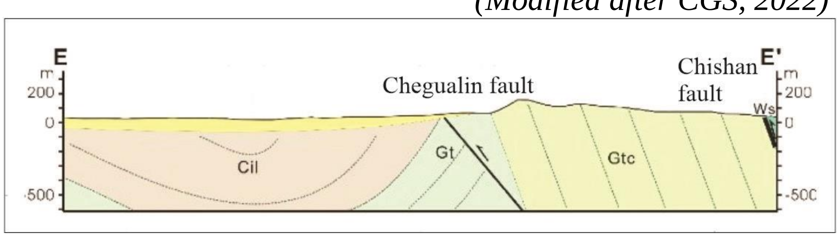
❑Quantify the Holocene kinematics of the fault based on the <u>buried layers</u> and <u>geomorphology</u>

$$Slip\ rate\ (mm/yr) = \frac{(Cumulative\ slip)}{(Time\ period)}$$

Acknowledgments to the Southern Taiwan Science Park for sharing the data; Consulting project conducted by Sinotech.



(Modified after CGS, 2022)



Geological setting

- Research area: Yanchao, Kaohsiung (black rectangle on geological map)
- The research area is covered by **thick Holocene sediment:**

  Marine sediments

  Terrace deposits (t)

  Alluvial deposits (a)
- **Gutingkeng formation:** which from late Miocene to Pleistocene in age (Lin, 2013)

  Massive mudstone (Gt)

  Alternated sandstone and mudstone (alt)

  Alternated bedded sandstone and mudstone, conglomerate, and limestone (Gtc)

  Alternated thick-bedded sandstone and mudstone (Gtl)

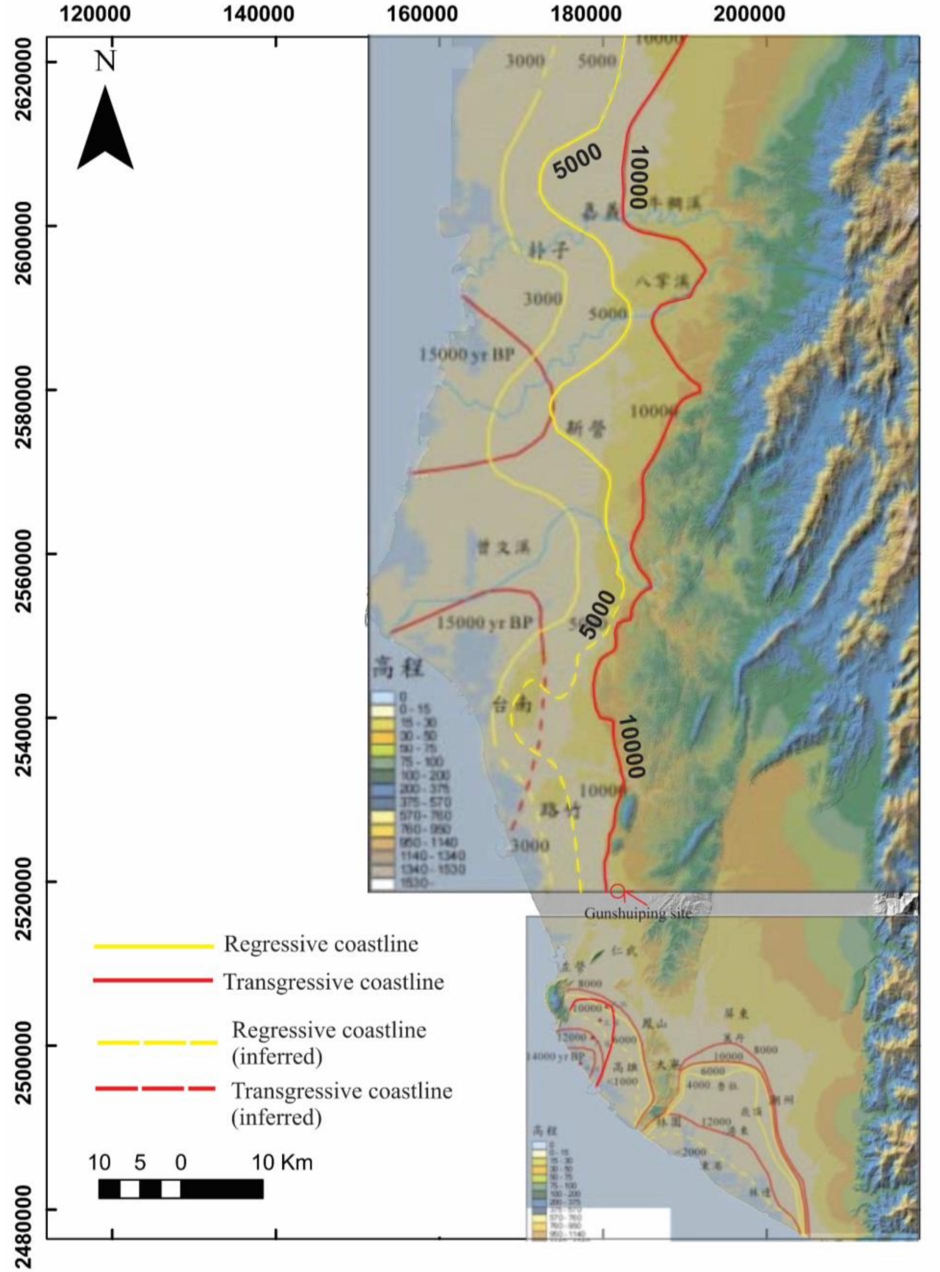
- **Chegualin fault**

✓ In the **foothills**, the **Chegualin fault** is an **oblique thrust fault** striking northeast *(Chang, 2014)* with a low dip angle *(Liu, 2013; Liu, 2019; Chen,2015)*

✓ However, **in the plain** the fault is proposed to strike N68ºE and has mainly **a strike-slip component** based on geodetic data *(Pathier et al, 2014; Chao, 2019 (blue rectangle))*

Holocene sediment

- **About 10000 years ago**, the **Chianan Plain** was completely **submerged by seawater**, and **the coastline was migrating landward** at 3-5 m per year *(Chen et al, 2004)*
- **After 6000 years ago**, the sea level stopped rising, the foothills area gradually rose and the basin filling continued, causing **the seaward migration of the coastline** *(Chen et al, 2004).*
- About 1000 years ago, the coastline was approximately 5-15 km east of the current coastline with a regression rate was about 1.4 – 2.8 m per year *(Chen et al, 2004)*
- The depositional environment was changed from the shallow marine environment to the coastal environment in this period



The distribution of coastline in the western foothills since 15 ka
(modified from Chen et al., 2004)

Unit subdivision

Core analysis

Unit 1 Backfill material

Unit 2 Silty clay, occasionally observe flow pattern

Unit 3 Dark grey loose coarse to fine sand, rich in shell

Unit 4 Grey clay and silt are interbedded with horizontally laminated sandy silt and thin gravel layers in certain places. Several parts have bioturbation

^{14}C dating

Unit subdivision

Core analysis

Unit 5 Mudstone with sandstone; bedding dip angle around 50-65^{o}, occasionally observes 70^{o} shearing texture

Mudstone

Mudstone with sandstone

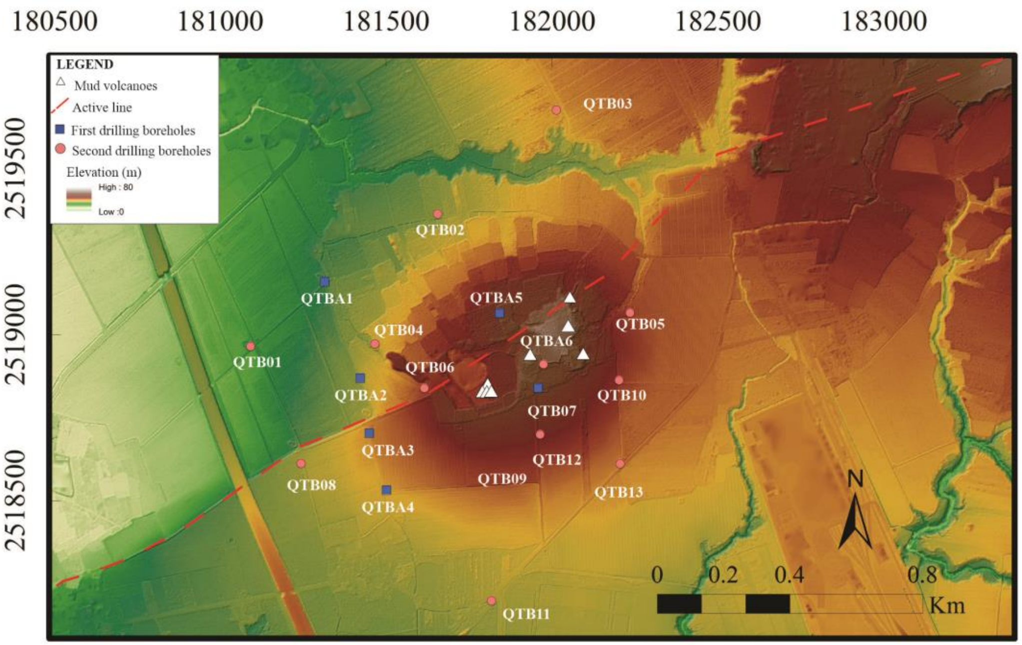
Nannofossil

Top NN-15

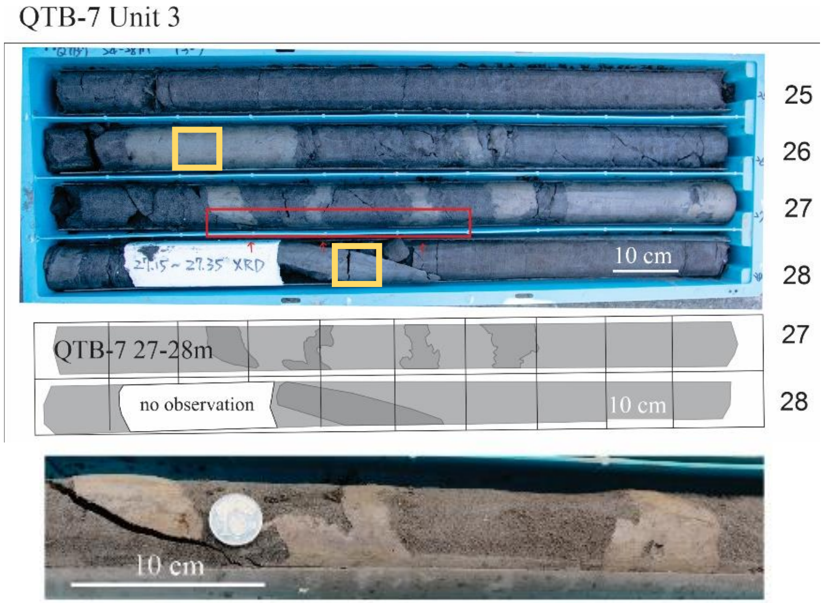
Upper part of Nanshihlun SS

Lower Part of Lower Gutingkeng Fm

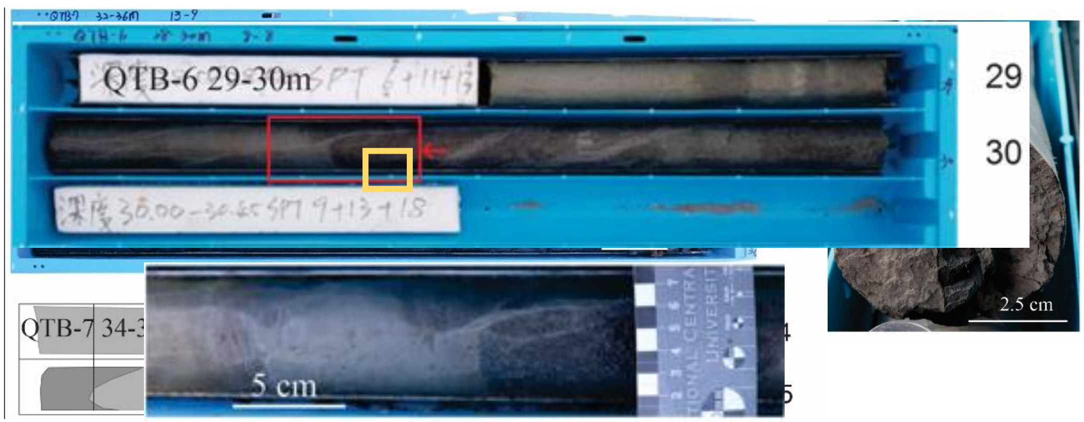
Other special strata



Mud conduit (mud infiltration)



Minor fault in Unit 3



Nannofossil

Q07-25.20N
Q07-27.45N
Q07-34.50N

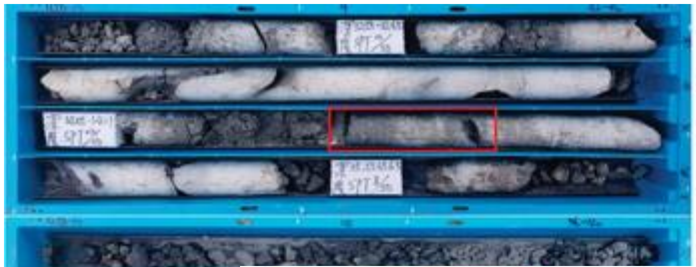
NN-11&NN-14

Mucha/Wushan
Lower Gutingkeng Fm

Other special strata

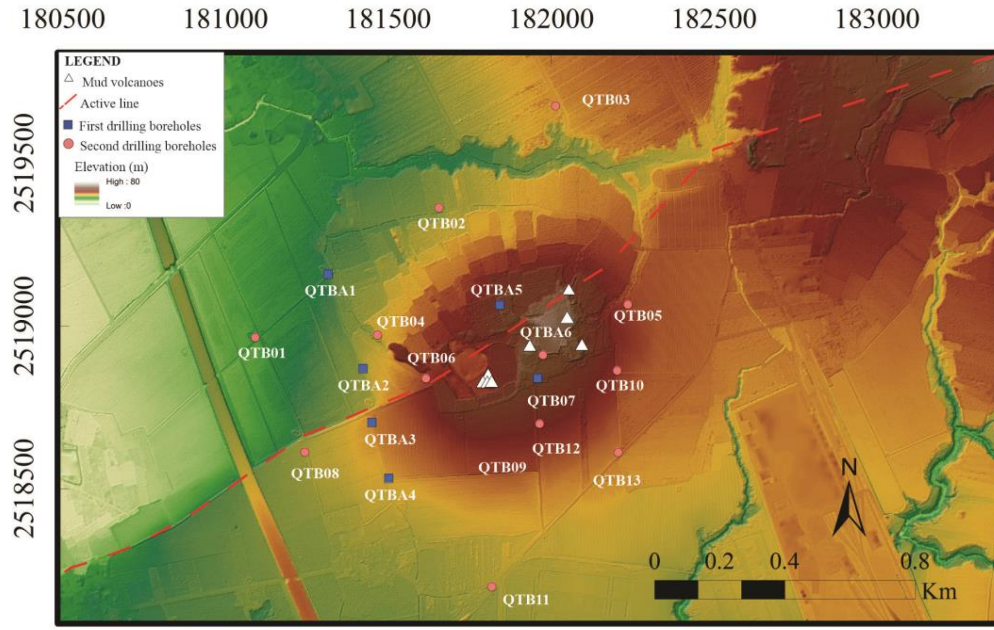
Coral reefs

QTB-13 Coral reefs Depths (m)



QTB-13 34.5-34.7m

QTB-12 Coral reefs

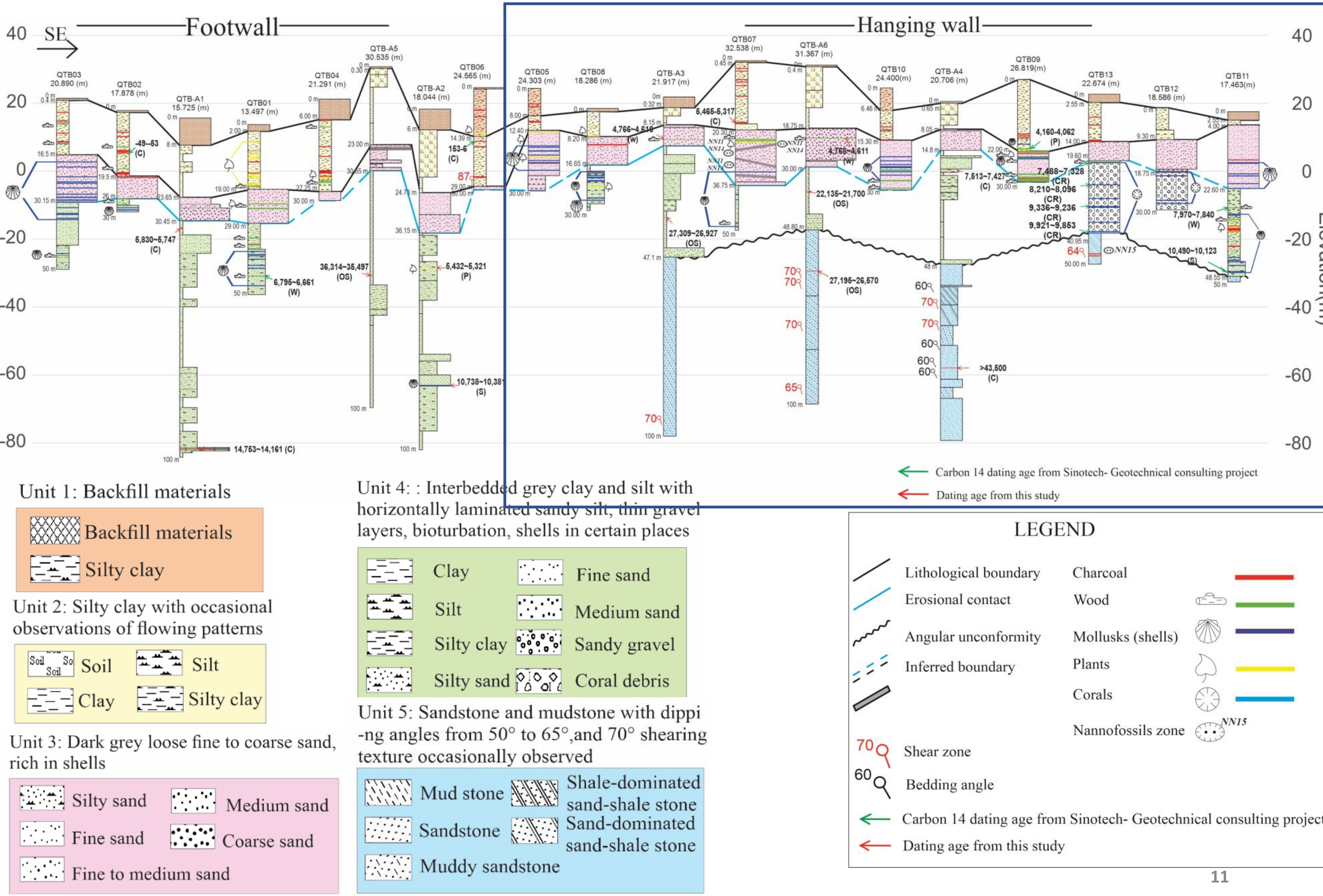


U-Th dating

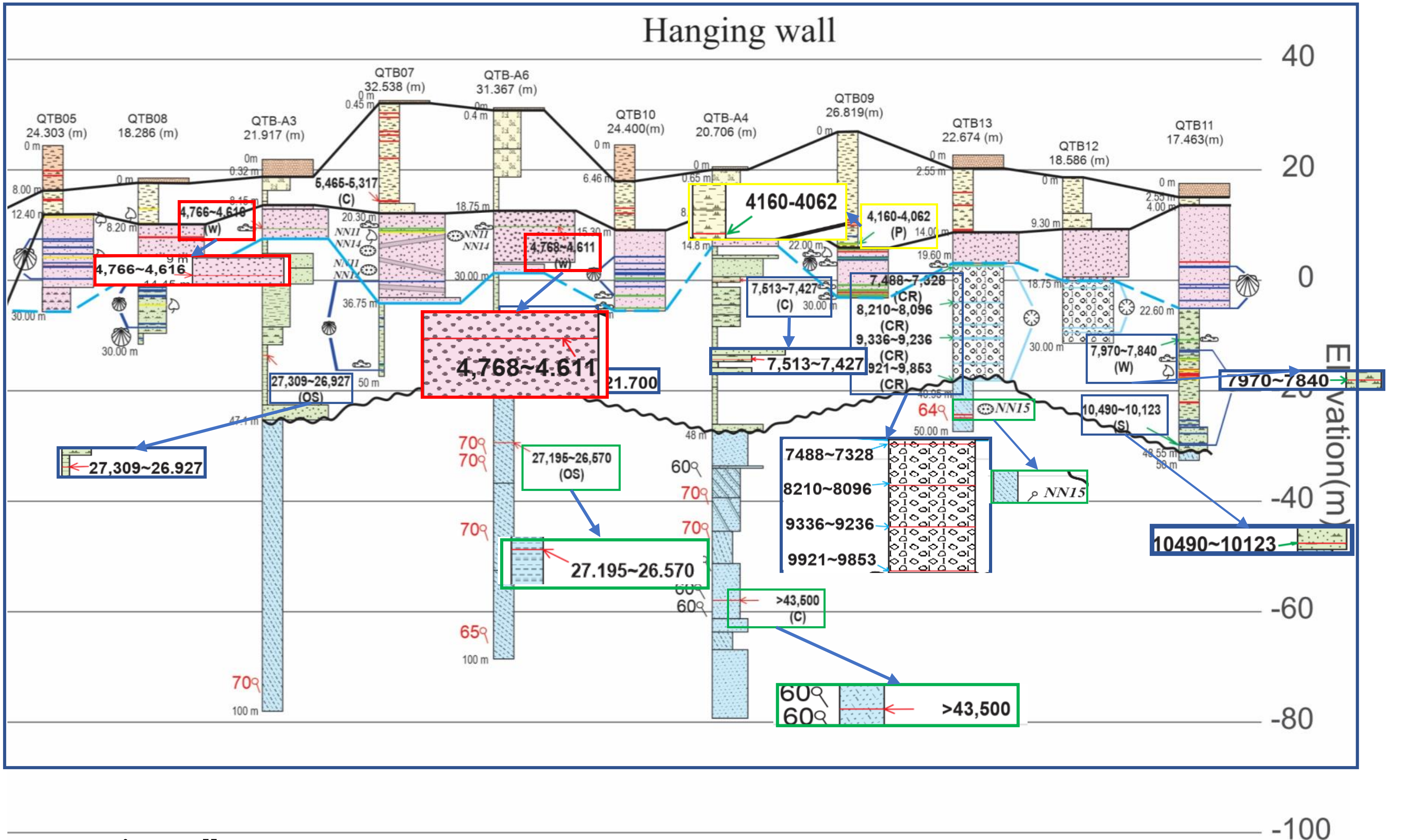
QTB13 37.8-38

QTB13 33.45

Stratigraphic correlation



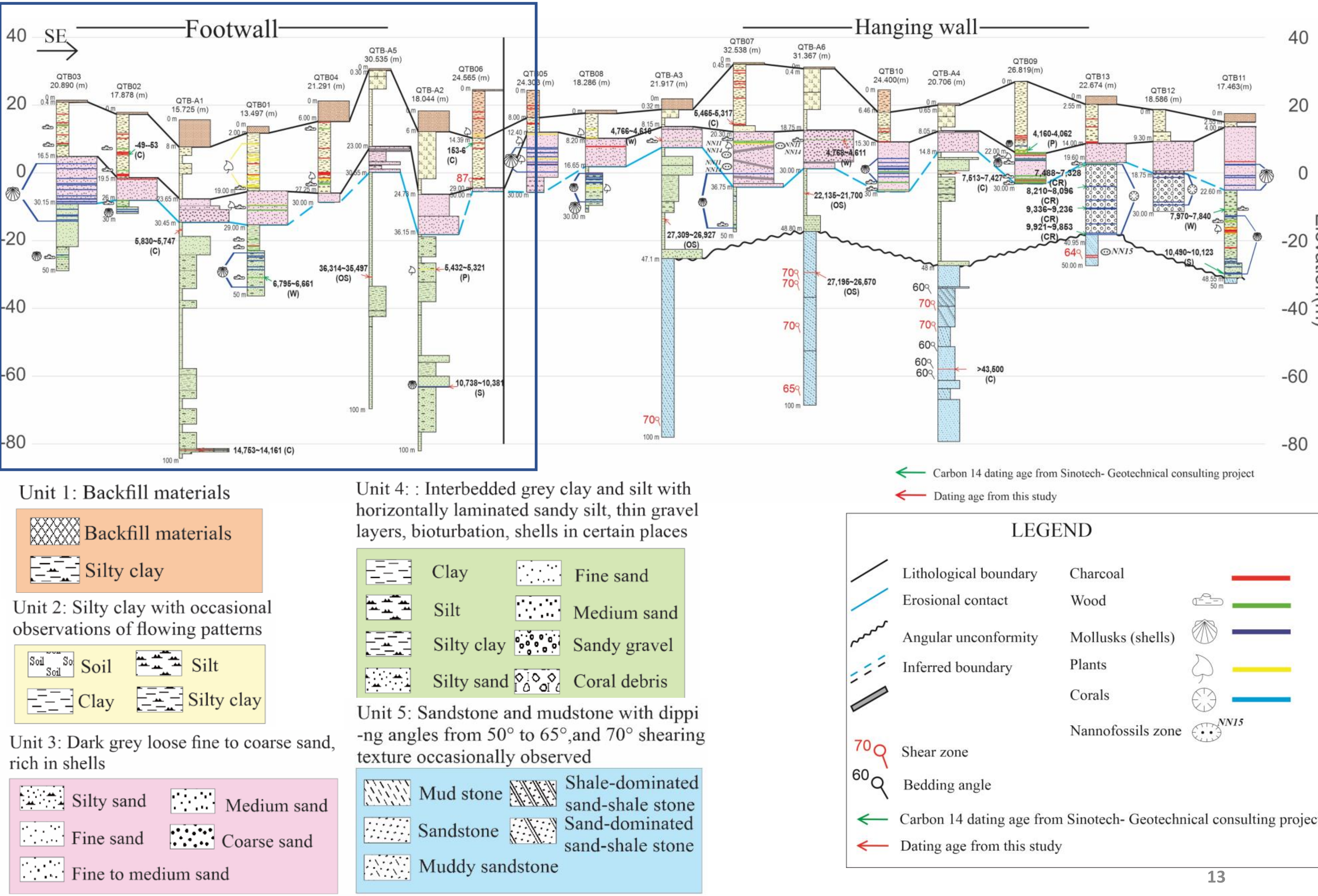
Stratigraphic correlation



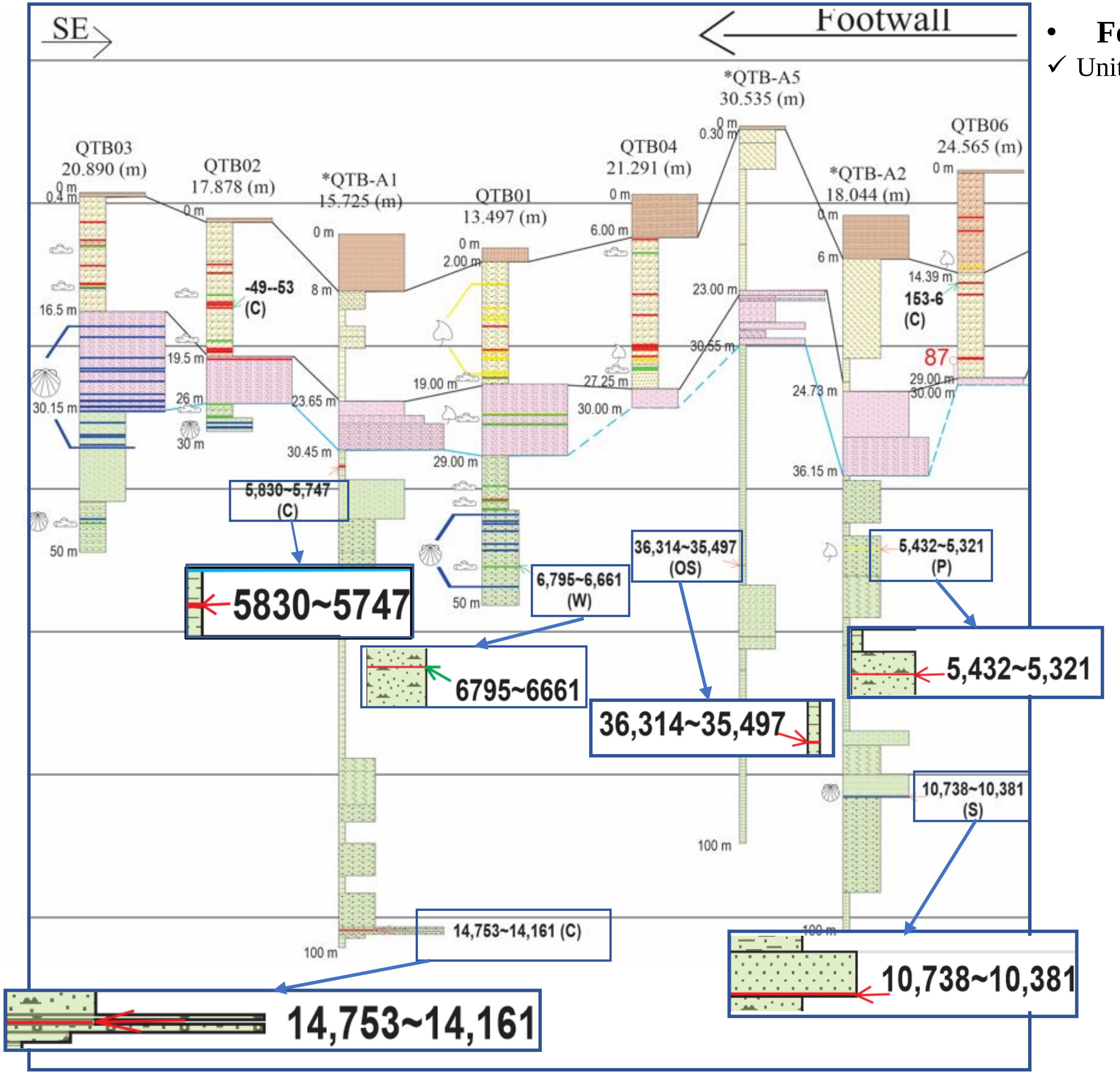
- **Hanging wall**

✓ Unit 5: Bedrock (Gutingkeng formation)
✓ Unit 4: Holocene deposits (10 ka- 7.5 ka)
✓ Unit 3: Holocene deposits (4.7 ka)
✓ Unit 2- Unit 1: Holocene deposits (4.1 ka- present)

Stratigraphic correlation



Stratigraphic correlation

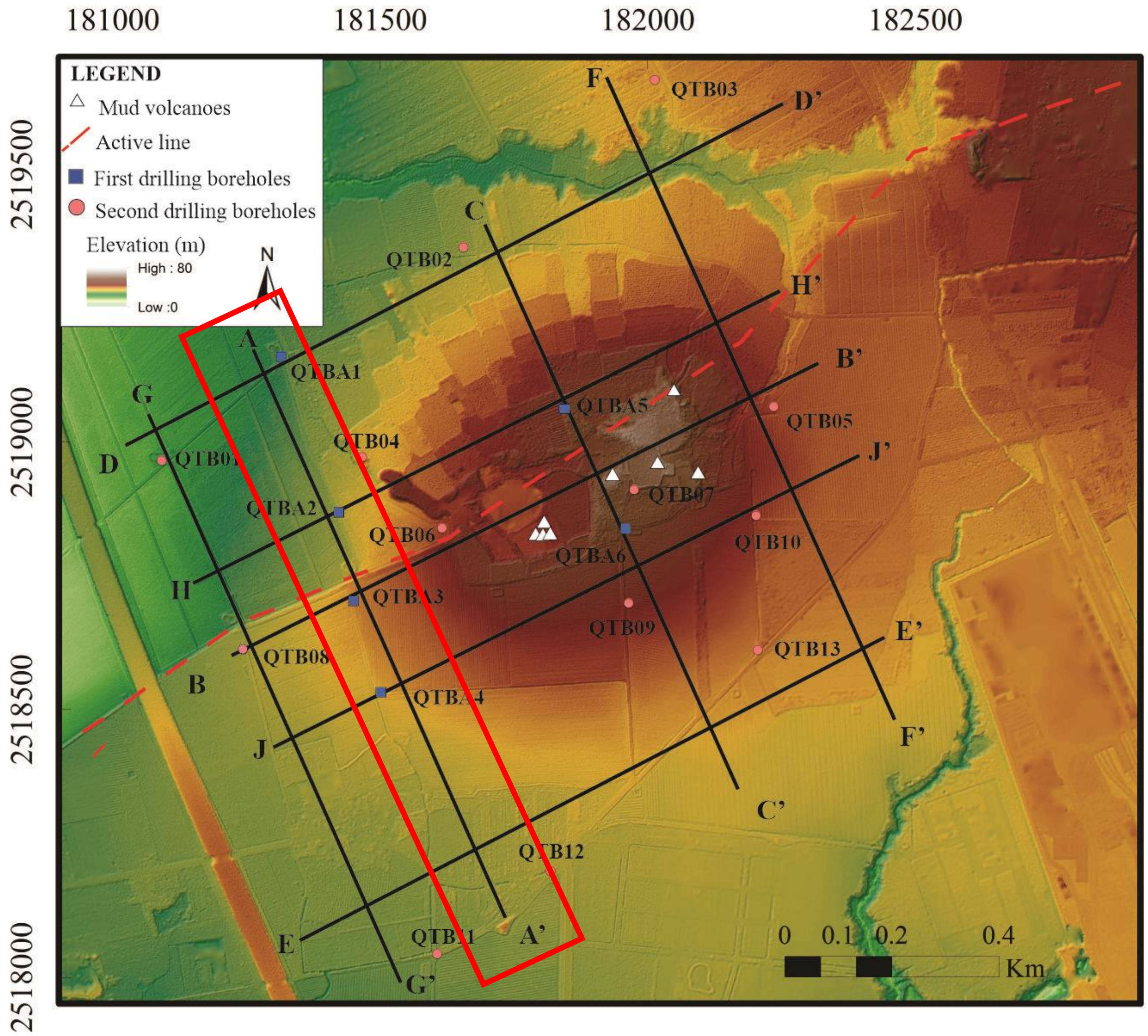


- **Footwall**
- ✓ Unit 4: Holocene deposits (10 ka- 5.4 ka)

Near-surface geometry

- Borehole data: 19 boreholes
- ^{14}C dating: 19 samples (12 samples from Sinotech report)
- U-Th dating: 4 samples

Fault-perpendicular transect



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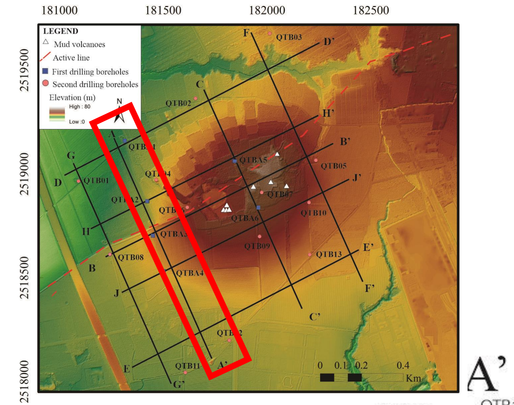
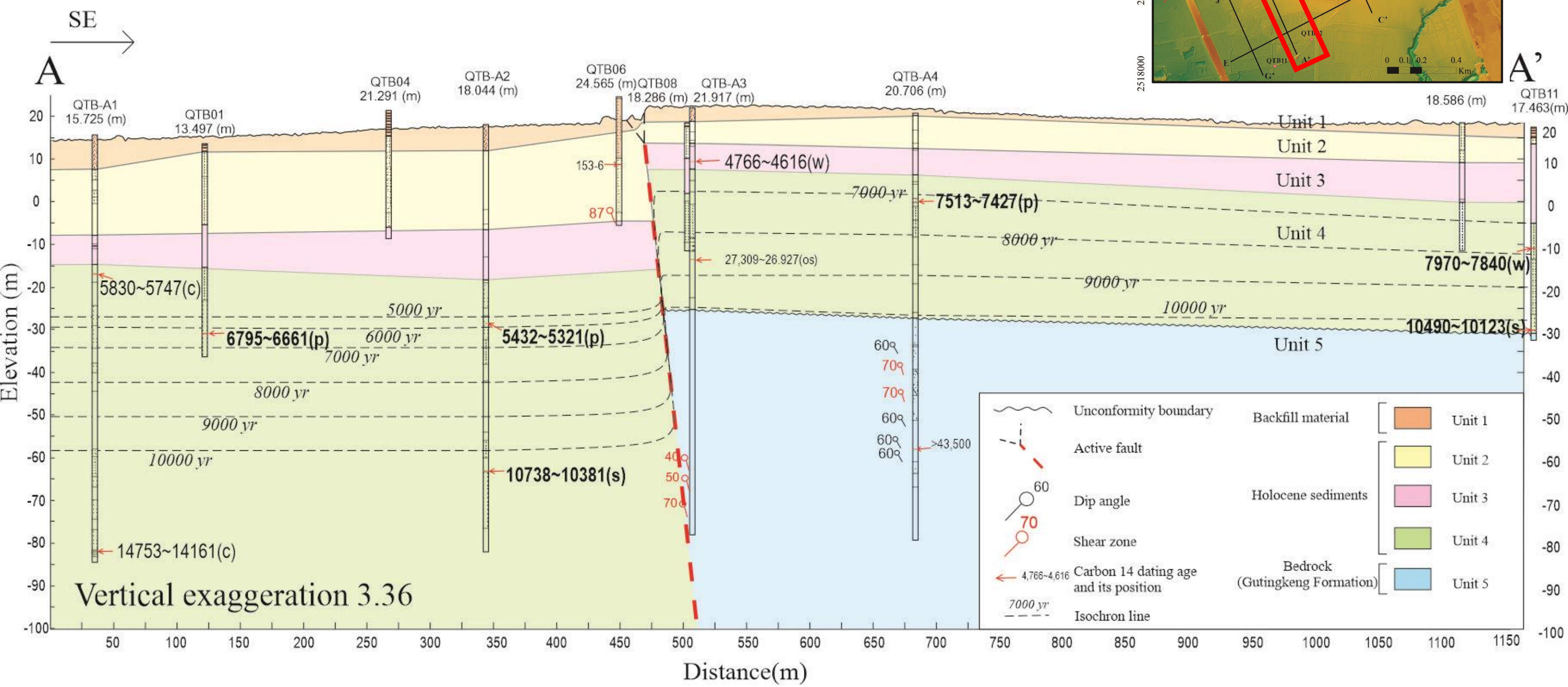
Near-surface geometry



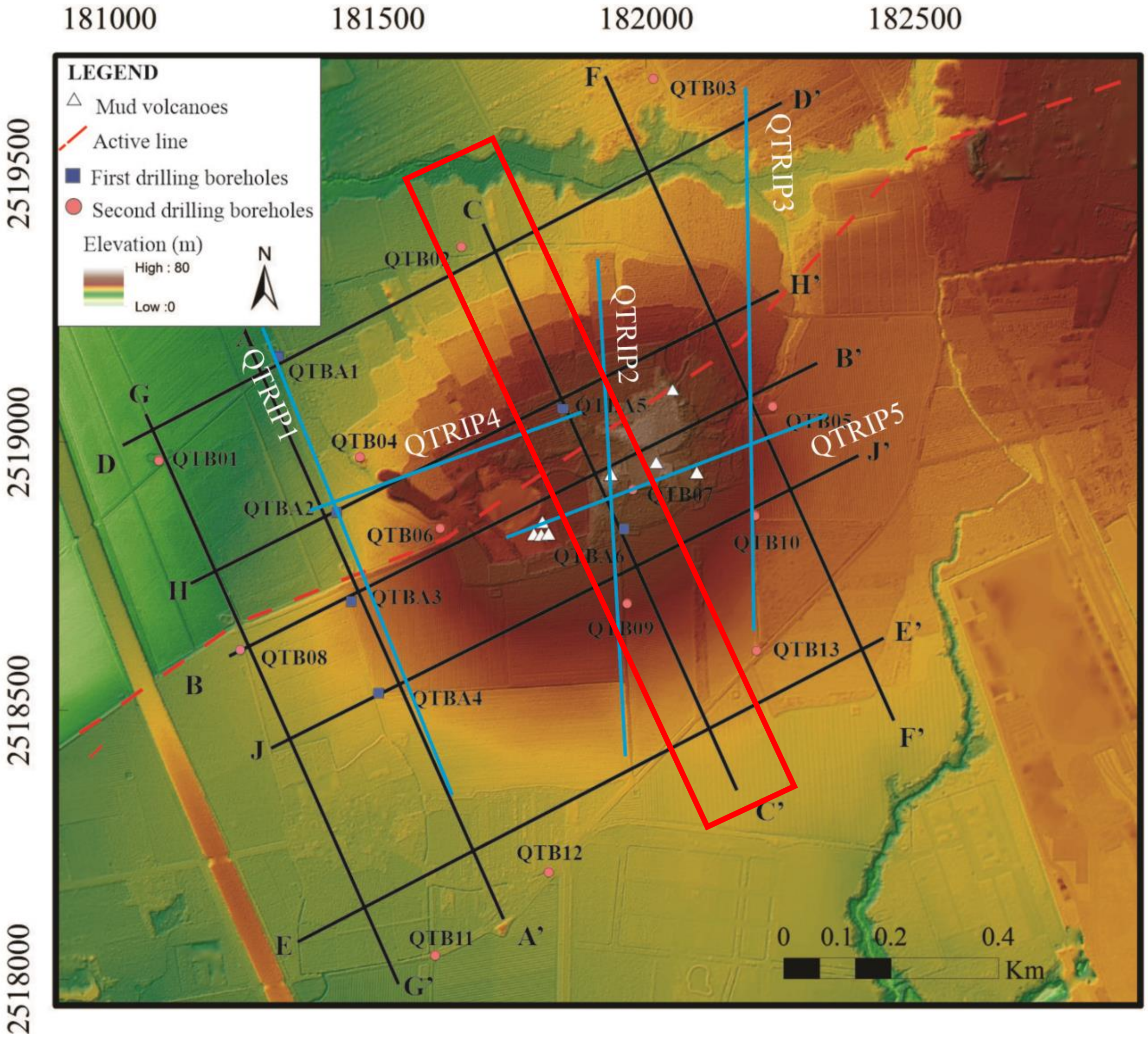


- **Chegualin fault** is associated with **displaced Holocene** strata
- The **thickness** of **Unit 2** and **Unit 4 changes** through the **fault zone**, which relates to **growth strata** on the footwall or **erosion** on the hanging-wall
- The **thickness change of Unit 3** indicates a **slower deformation stage** during this time or it was **rapidly deposited**

Near-surface geometry

- Borehole data: 19 boreholes
- ^{14}C dating: 19 samples (12 samples from Sinotech report)
- U-Th dating: 4 samples

Fault-perpendicular transect



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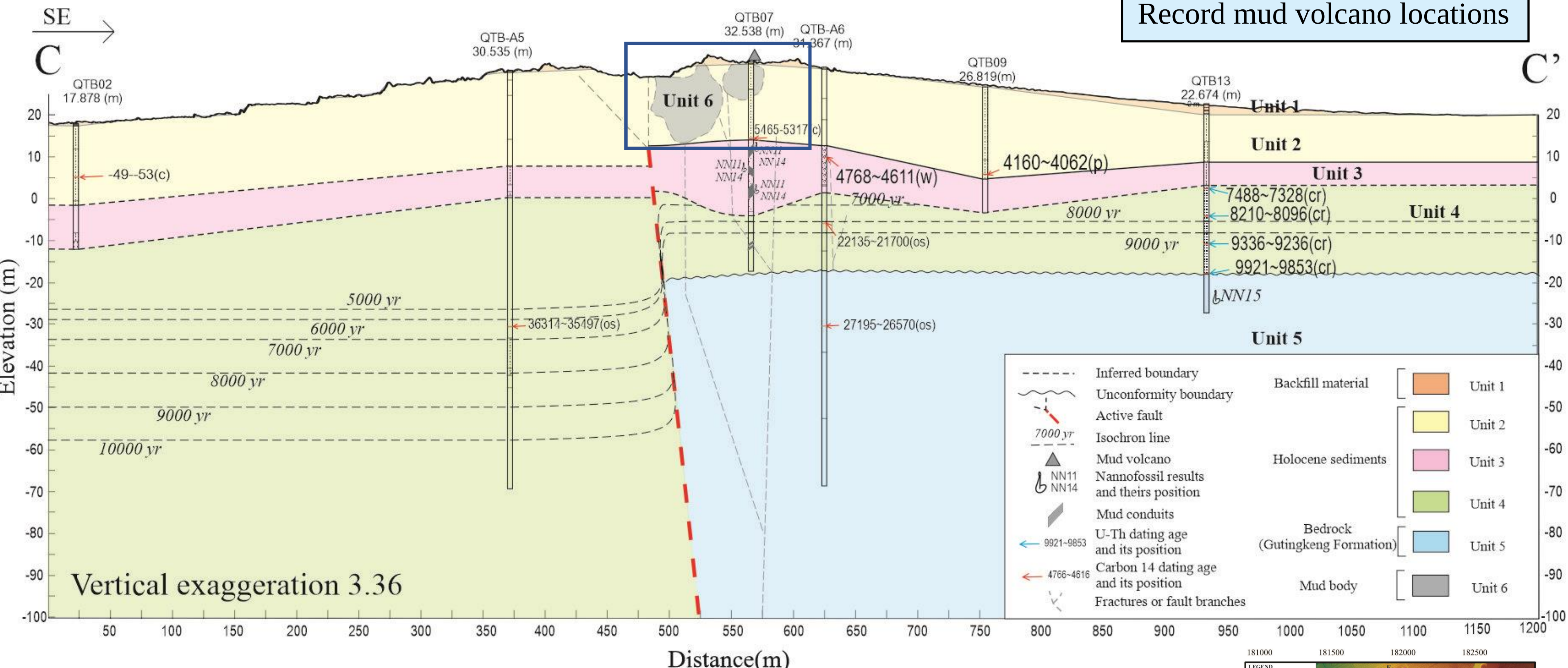
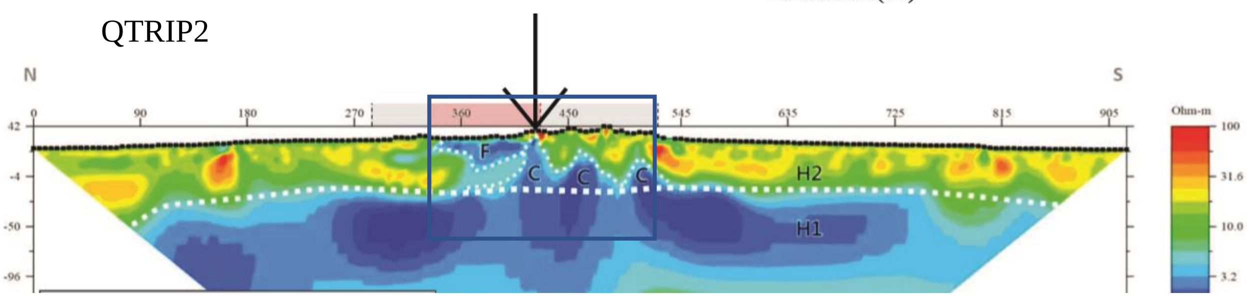
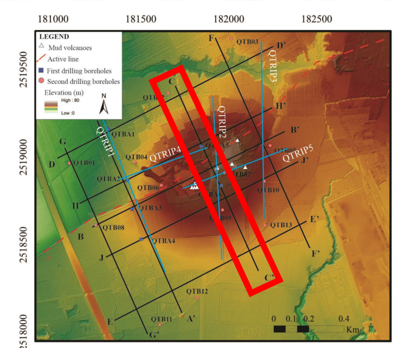
Near-surface geometry

Resistivity Image Profiling
Record mud volcano locations



QTRIP2



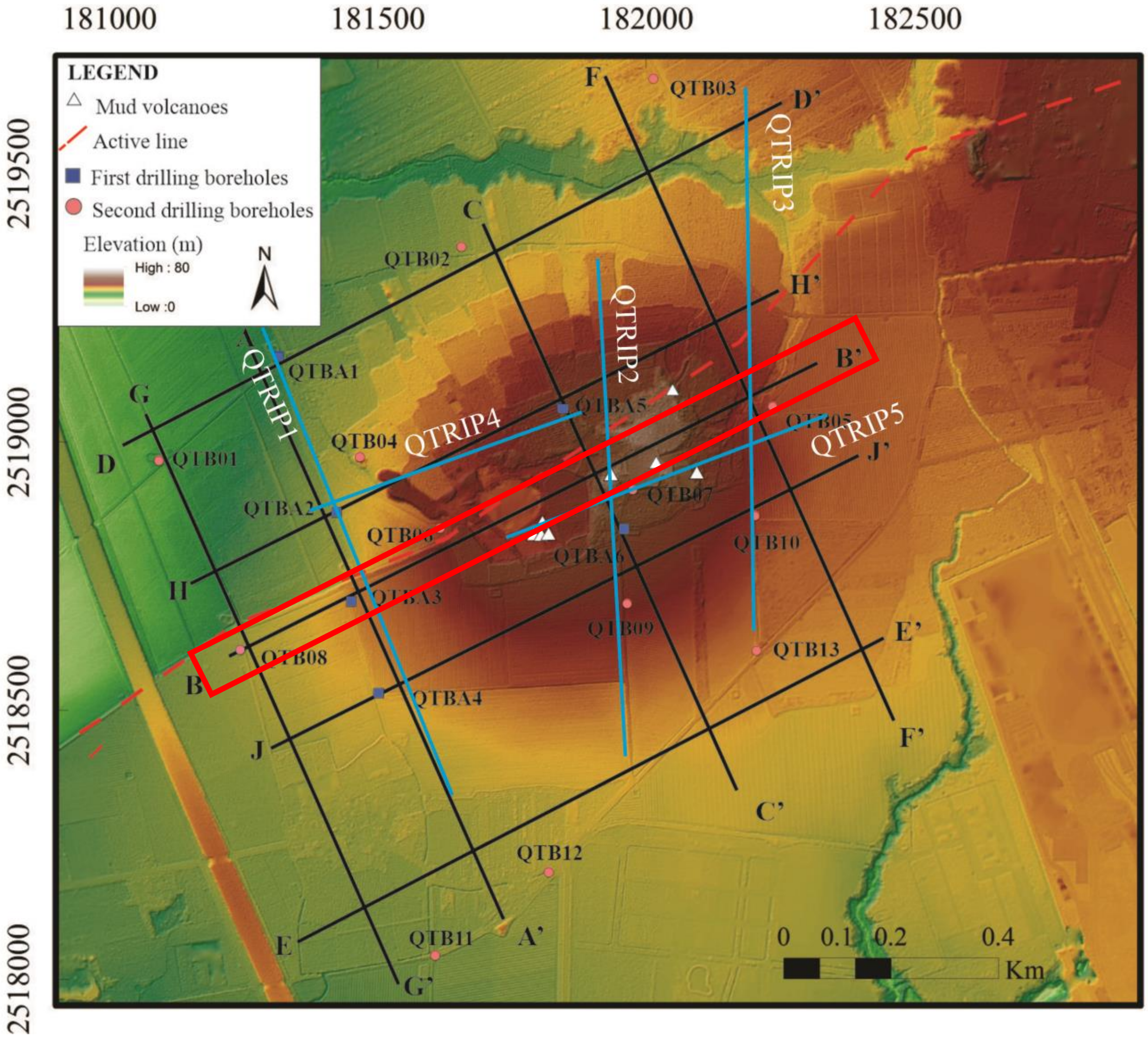


- The presence of **mud intrusion** in QTB07 causes the **thickening** of Unit 3
- **Mud conduit** creates a way to form **mud bodies** in the **near-surface** which is **a factor** that **changes the morphology**

Near-surface geometry

- Borehole data: 19 boreholes
- ^{14}C dating: 19 samples (12 samples from Sinotech report)
- U-Th dating: 4 samples

Fault-parallel transect



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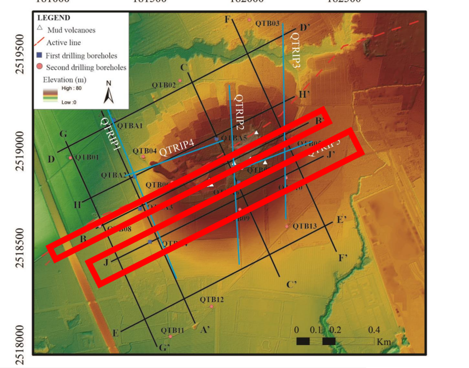
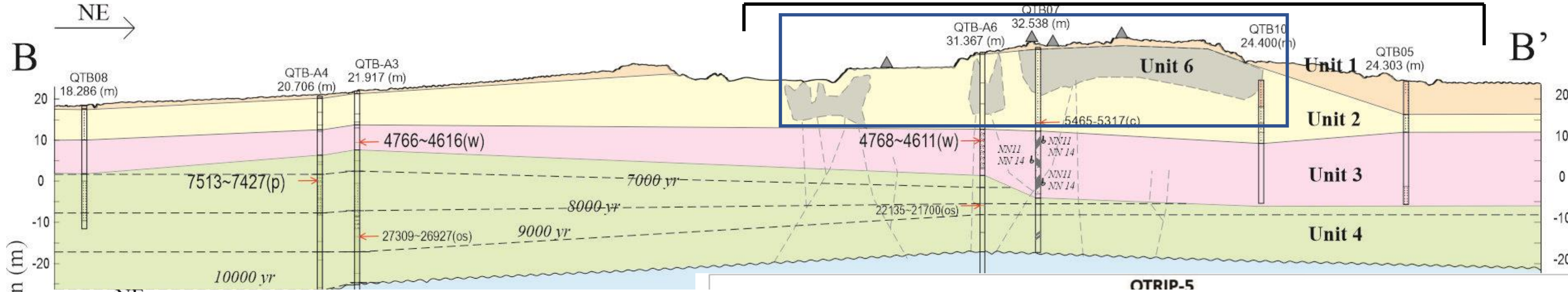
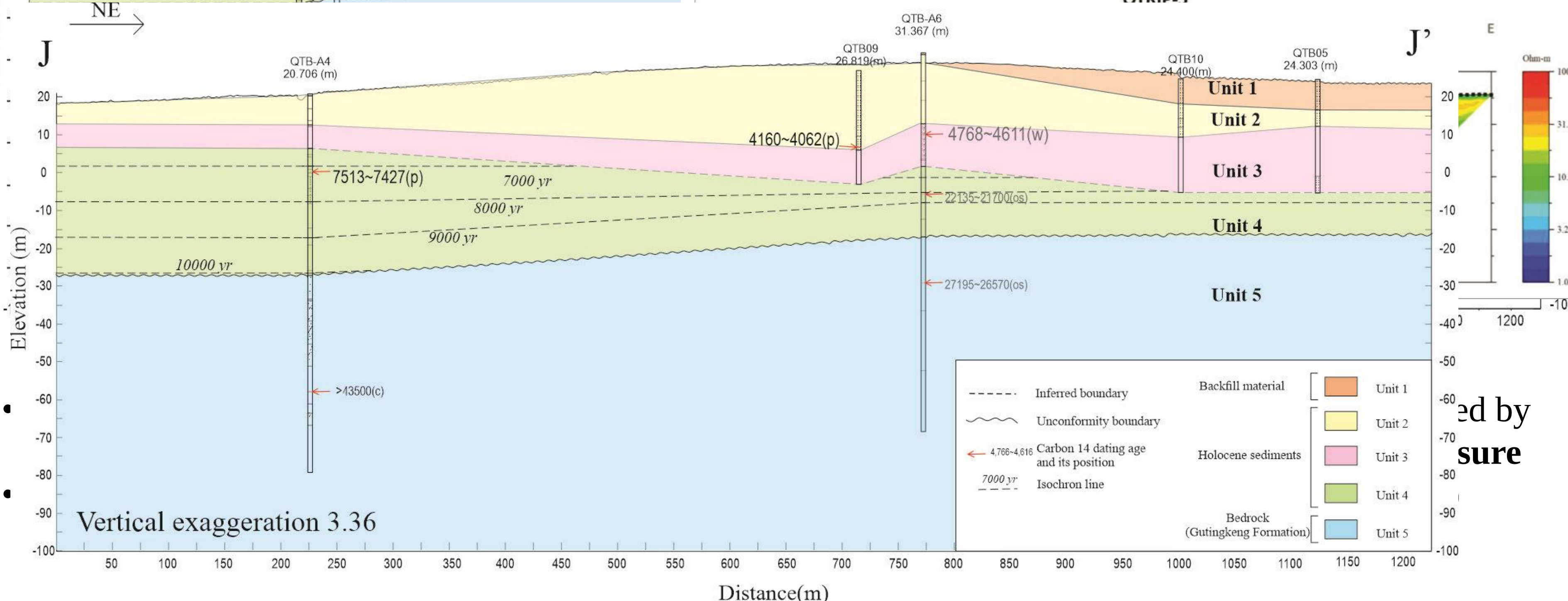
Near-surface geometry

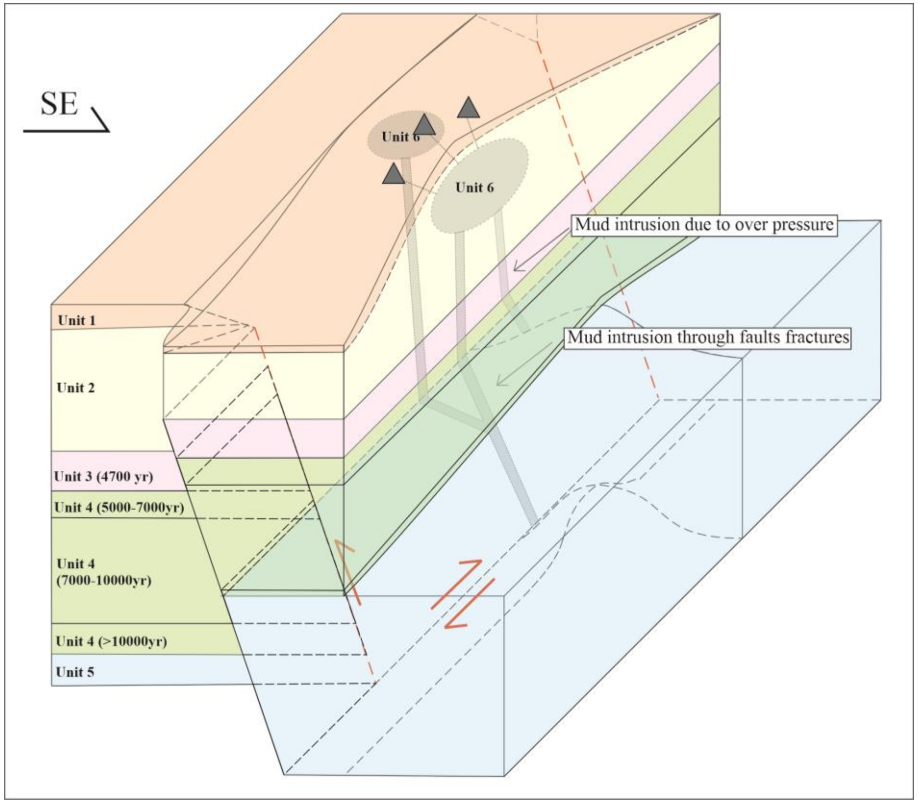
Resistivity Image Profiling
Record mud volcano locations

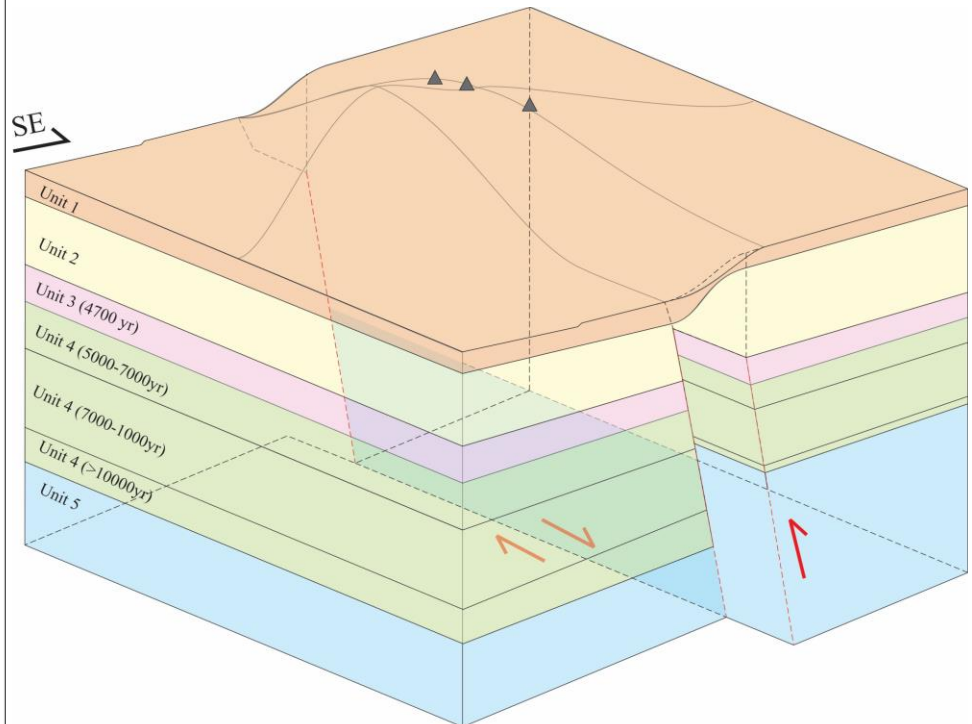






Near-surface geometry



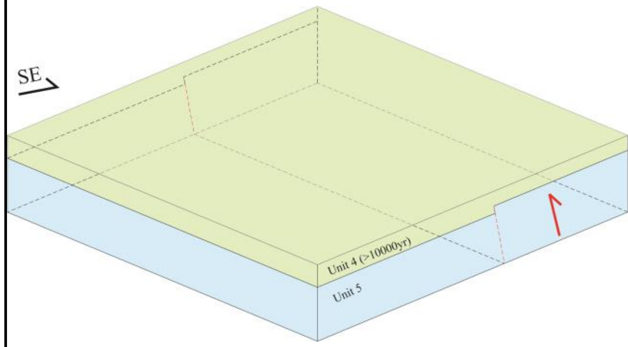


Near-surface geometry at the Gunshuiping site

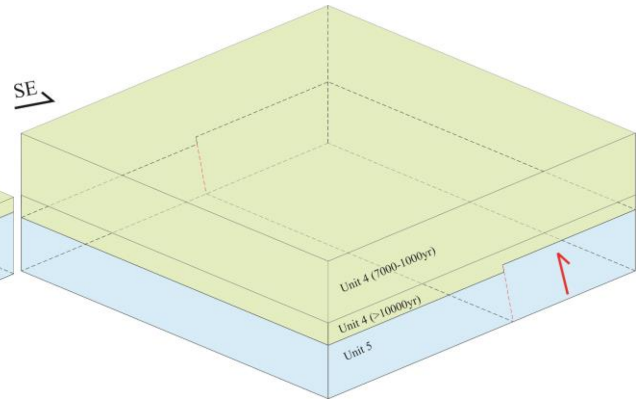
- The observation that **Unit 3 remains sub-horizontal** in the fault-parallel sections, while the **topography is dome-shaped** is the markable point suggesting **the formation of Gunshuiping mud volcanoes** in relation to **mud migrating upwards through faults, and fractures**.
- The configuration of Unit 3 is irrelevant to the topography suggested the **maximum age** of the t**opography** is the age of the base of **Unit 2 (4160-4067)**
- The **formation** of this **topography** was formed by **mud bodies** near the surface and **mudflow** on the surface

The evolution at the Gunshuiping site

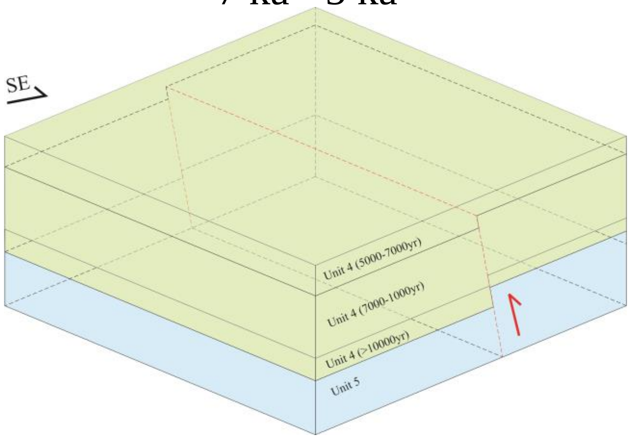
> 10ka



10 ka - 7 ka

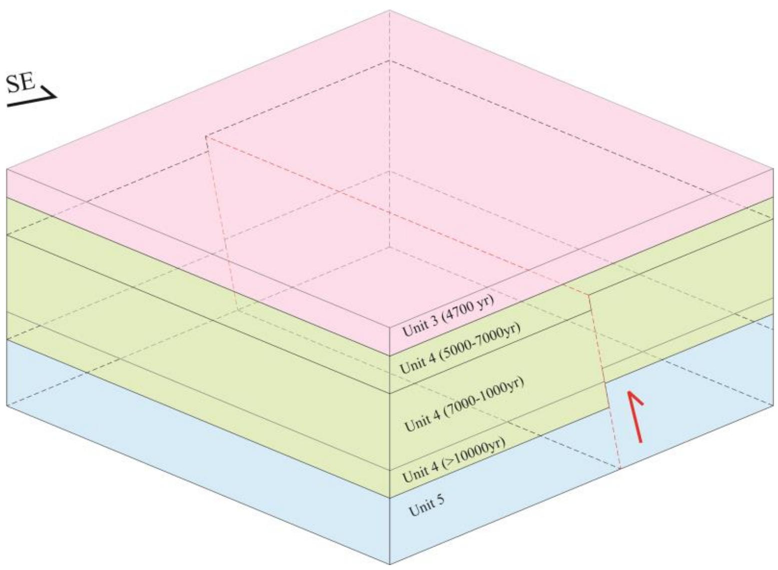


7 ka - 5 ka

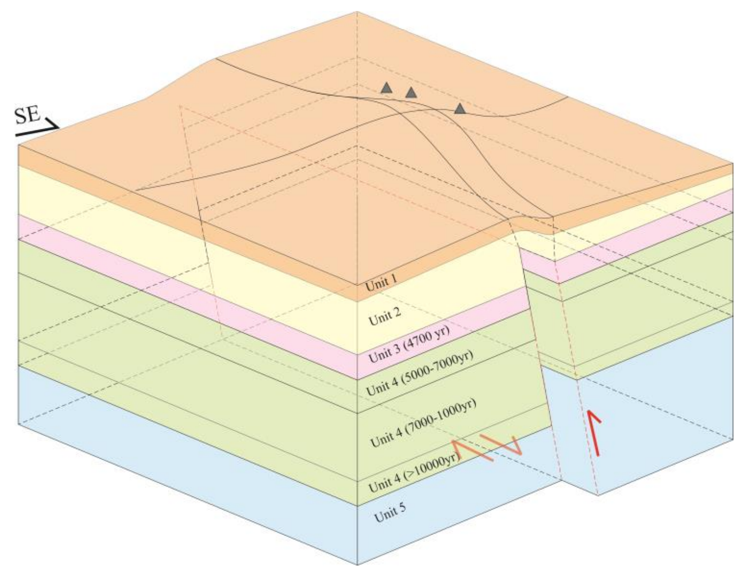


Transgressive coastline 10 ka

4.7 ka



4.1 ka - Present



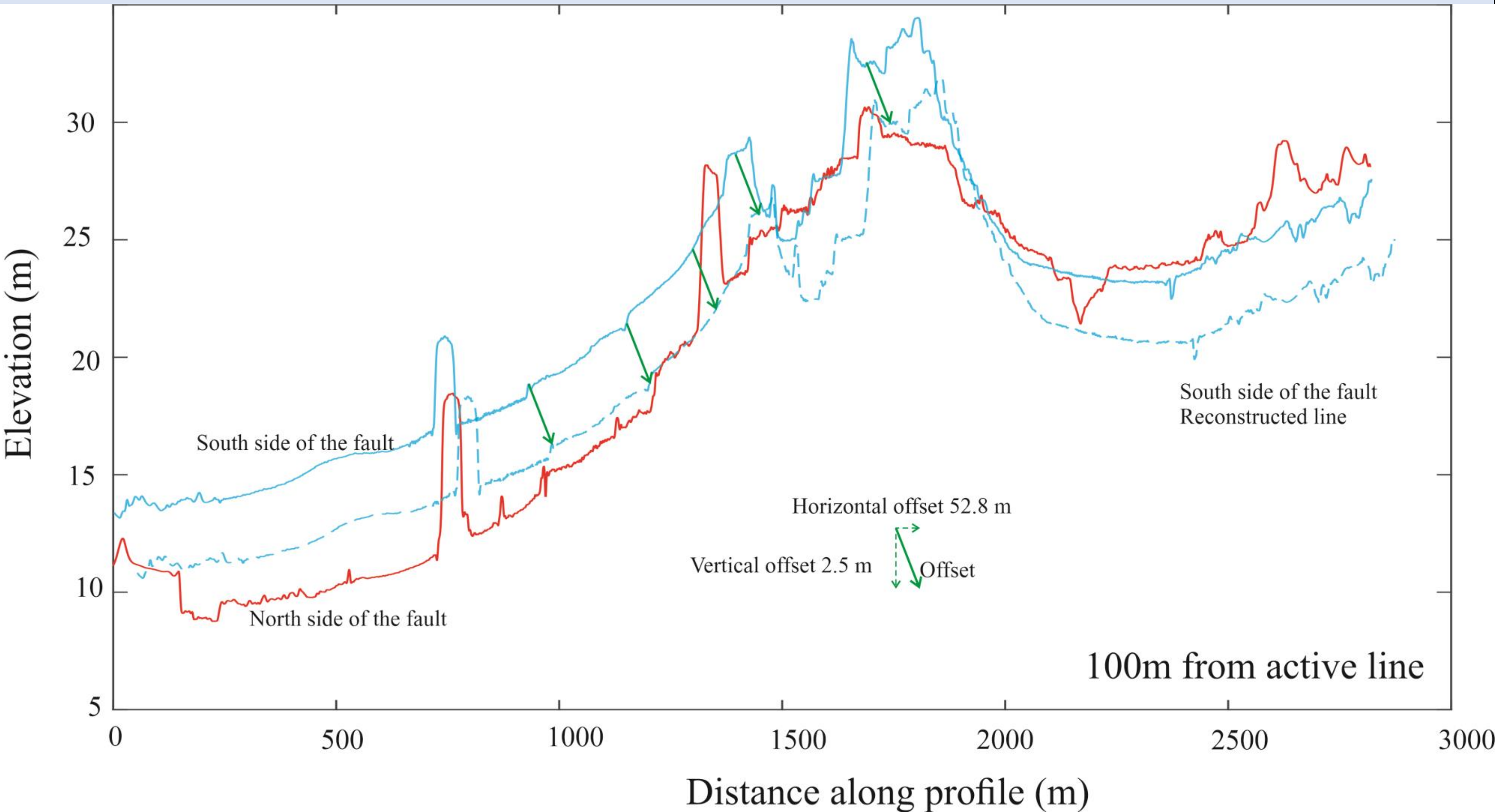
Regressive coastline 6 ka

The kinematics of the inferred fault

Horizontal slip rate

Geomorphology analysis

- Topographic Swath profiles



Vertical offset 2.5 m

Horizontal offset 52.8 m

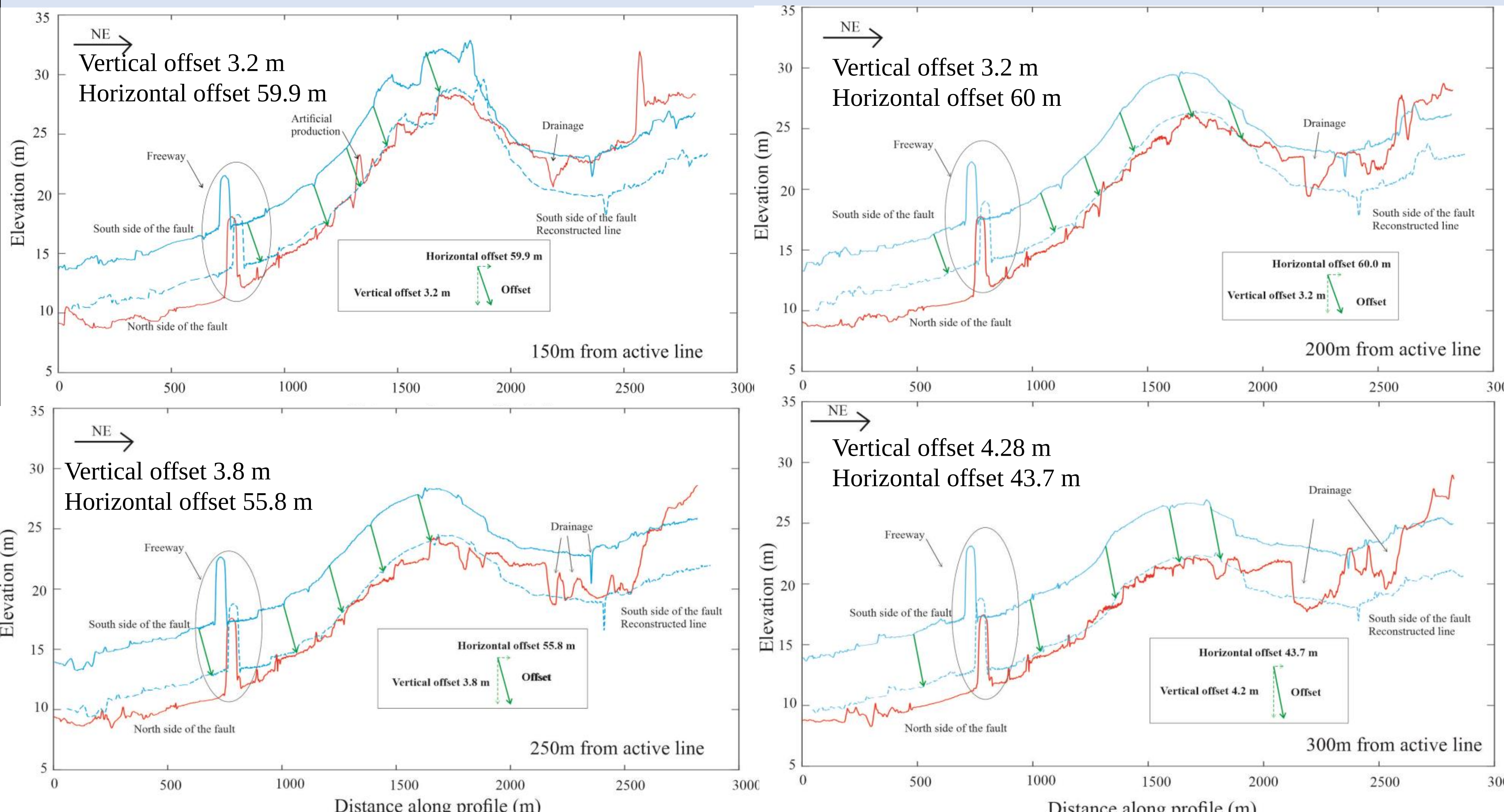
The kinematics of the inferred fault

Horizontal slip rate

Geomorphology analysis

- Topographic Swath profiles

The horizontal slip rate from GPS estimate in the period of 2015 to 2018 is around 10 mm/yr *(Chao, 2019)*

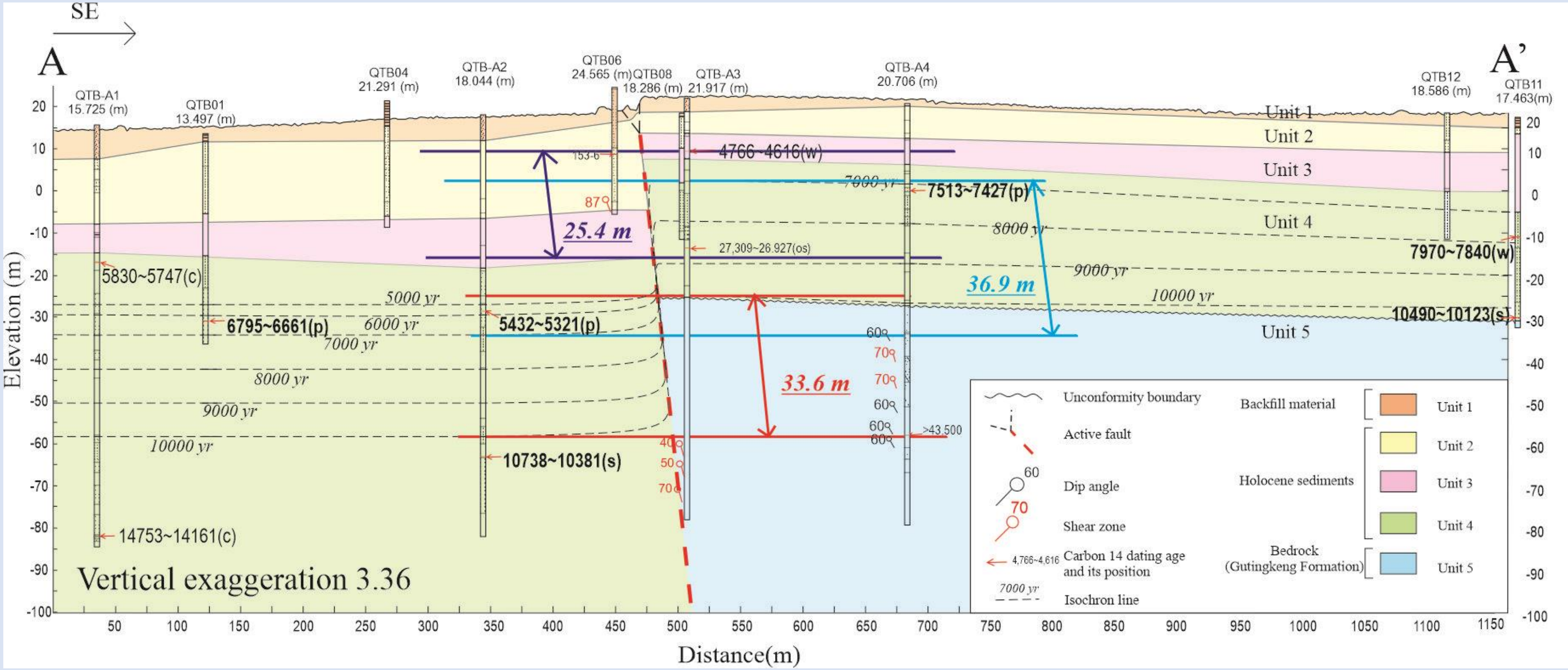


Vertical offset ≈ 3.4 ± 0.6 m
Horizontal offset ≈ 54.4 ± 6.7 m
The age of topography ≈ 4160 - 4062 years (Unit 2)

The vertical slip rate ≈ 0.8 ± 0.1 mm/yr
The horizontal slip rate ≈ 13.2 ± 1.6 mm/yr

The kinematics of the inferred fault

Vertical slip rate



- Using the vertical offset of the distinct layers along the fault-perpendicular correlation profile,
- The vertical fault slip rate of roughly 4.2 ± 1.8 mm/yr since 10ka
- The difference in vertical slip rate between using buried layer offset and morphology analysis indicates:

  The **uplift rate decreased** at the period of **4.1ka**

  The abnormal **topography** is caused mostly by the **lateral movement**

Conclusions

- **By the evidence from Holocene strata, the formation of Gunshuiping mud volcanoes in relation to mud migrating upwards through fractures in relation to fault activity**
- Gunshuiping site was in the shallow marine depositional environment from 10 ka to 5 ka. The 4.7 ka period marked the changing of the depositional environment in Gunshuiping, which has recorded coastline regression events until now.
- Unit 3 remains stable while the topography changes, implying that the topography here was formed after the forming of unit 3. Since that, the maximum age of topography in relation to the age of the base of Unit 2
- **As a result, the maximum age value for this topography will be 4160 - 4062 years. The horizontal slip rate has values of 13.2 ± 1.6 mm/yr**
- **The vertical fault slip rate was determined to be roughly 4.2 ± 1.8 mm/yr since 10ka**
- **The uplift rate reduced around 4700 years ago with the rising of the horizontal slip rate in relation to the formation of Gunshuiping mud volcanoes**
- The horizontal offset can be improved using other geomorphology analysis method.

Thank you for listening