Normal faults in Bitou - Longdong area, northeastern Taiwan

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outline

01 Introduction

02 Methodology

03 Results

04 Discussion

05 Conclusions

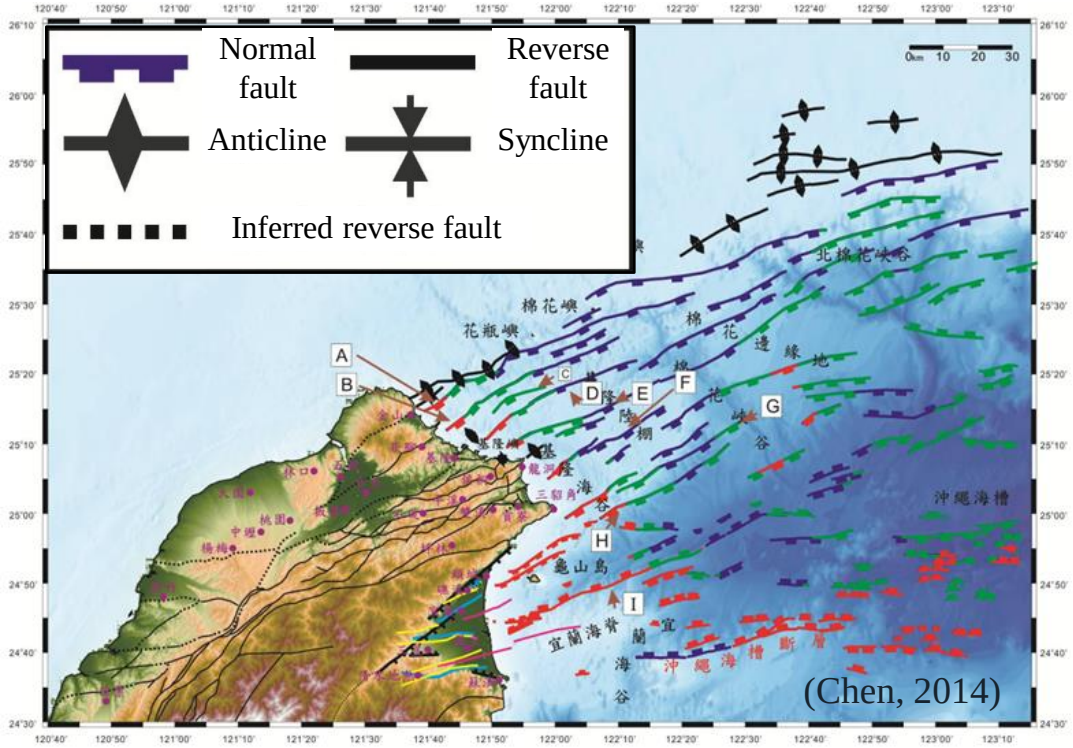
06 Future work

Introduction

Motivation & Purpose
Geological setting

Introduction

Northeastern Taiwan is being subject to post-collisional collapse and under an extensional regime. A series of normal faults have been formed offshore (Huang, 2007; Chen, 2014; Lin, 2022).



(Chen, 2014)

What's the continuation of these normal faults into onshore ?

Some normal faults can be observed in the Bitou and Longdong areas.

Are they related to offshore normal faults?

Motivation & Purpose

Motivation:

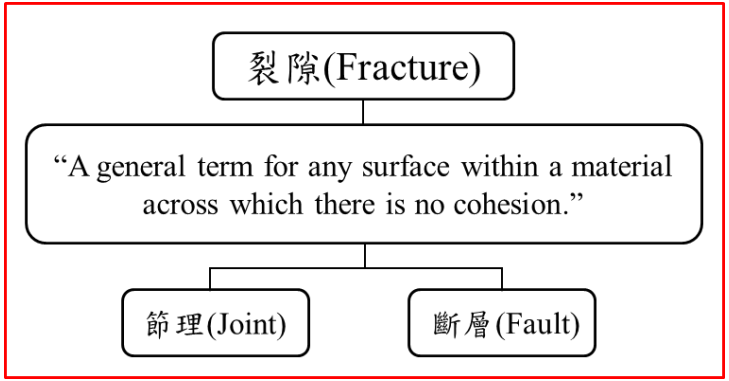
1. Some previous studies and reports have proposed that some normal faults can be observed in the Bitou and Longdong areas. However, few of them have focused on the properties and evolution of those normal faults.

2. The stratigraphic age is quite different between the Bitou and Longdong areas. It's interesting to know the relationship of the normal faults in these two areas.

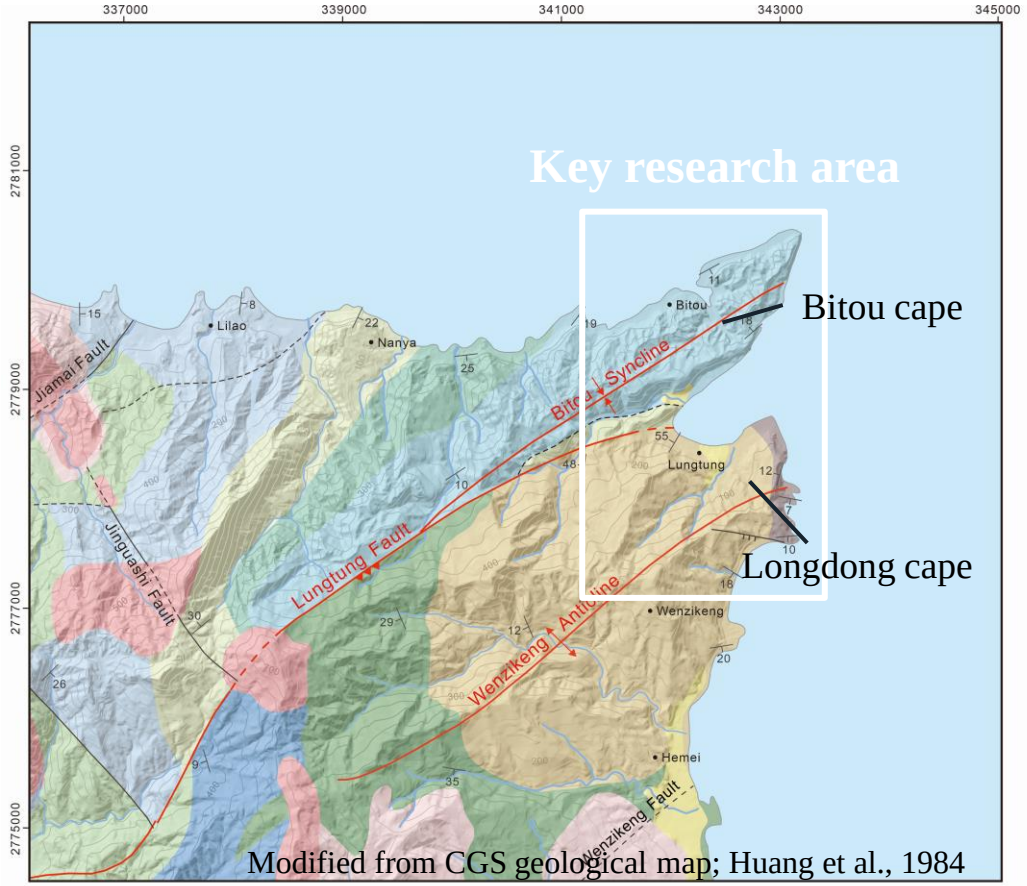
Purposes :

1. To infer the evolution of the normal faults.

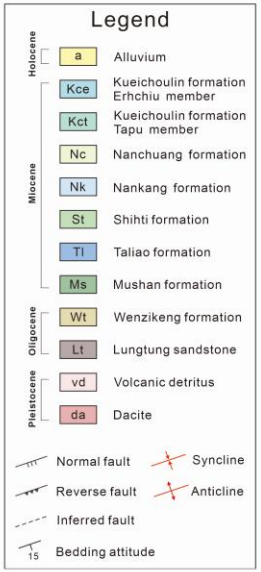
2. To understand the relationship between the normal faults in the Bitou and Longdong areas.



Geological setting



Modified from CGS geological map; Huang et al., 1984



Main structures:

Longdong Fault (龍洞斷層)
Bitou Fault(鼻頭斷層)
Bitou Syncline (鼻頭向斜)
Wenzukeng Anticline (蚊子坑背斜)

Formation:

Bitou:

Kueichulin formation
→ Late-Miocene formation ~4Ma

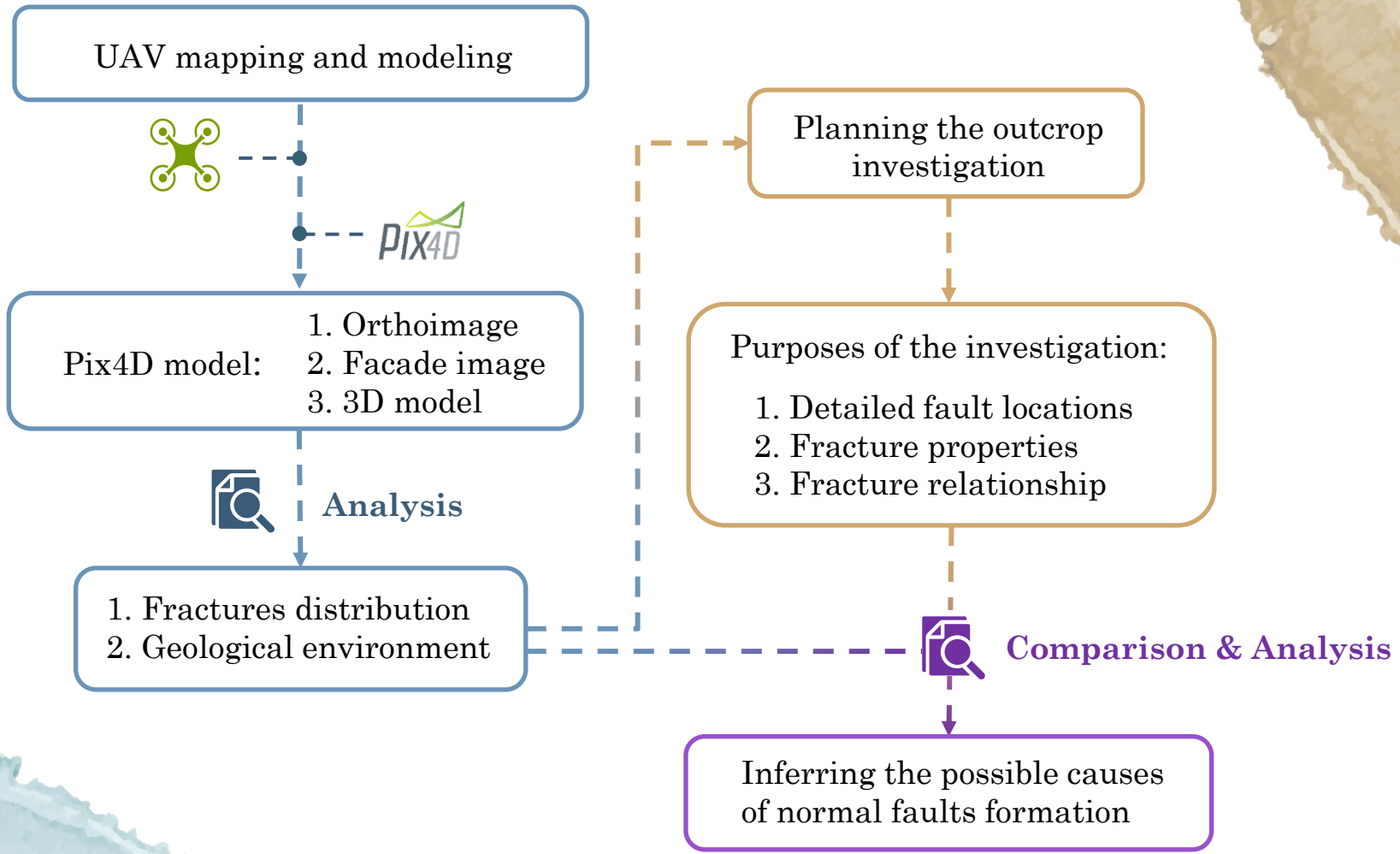
Longdong:

Wenzukeng formation
→ Oligocene formation ~30Ma

Longdong sandstone
→ Eocene - Oligocene formation ~35Ma

Methodology

UAV mapping and modeling
Field investigation


UAV mapping and modeling
Pix4D model:
1. Orthoimage
2. Facade image
3. 3D model
Analysis
1. Fractures distribution
2. Geological environment
Planning the outcrop investigation
Purposes of the investigation:
1. Detailed fault locations
2. Fracture properties
3. Fracture relationship
Comparison & Analysis
Inferring the possible causes of normal faults formation

Advantages of UAV mapping in the geological studies

1. Low GSD value: 3~5cm/pixel

The Ground Sampling Distance (GSD) is the distance between two consecutive pixel centers measured on the ground.

→ We can observe structures that larger than 5cm

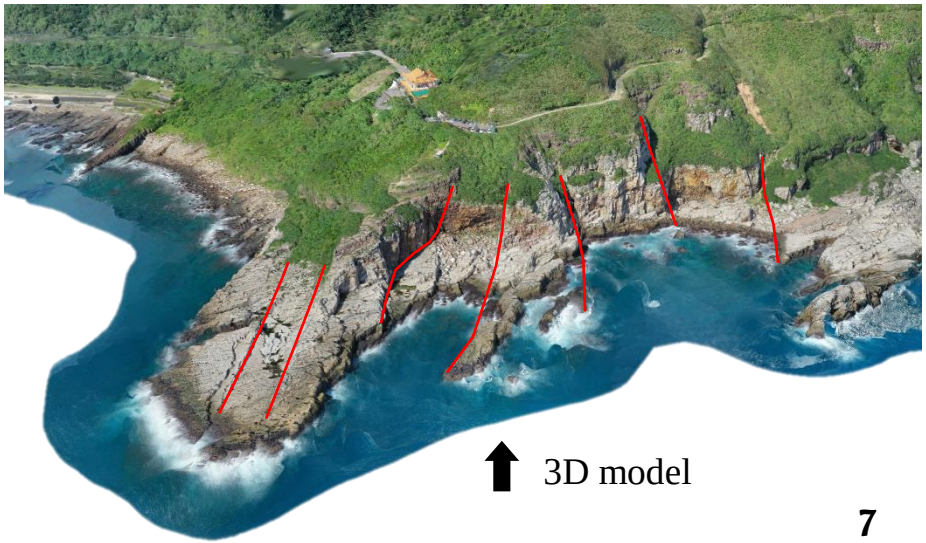
2. Easy to identify structures

- Fractures distribution
- Approximate locations of faults
- Base maps of field investigation

→ It's helpful for us to plan outcrop investigation

Orthoimage (map view)

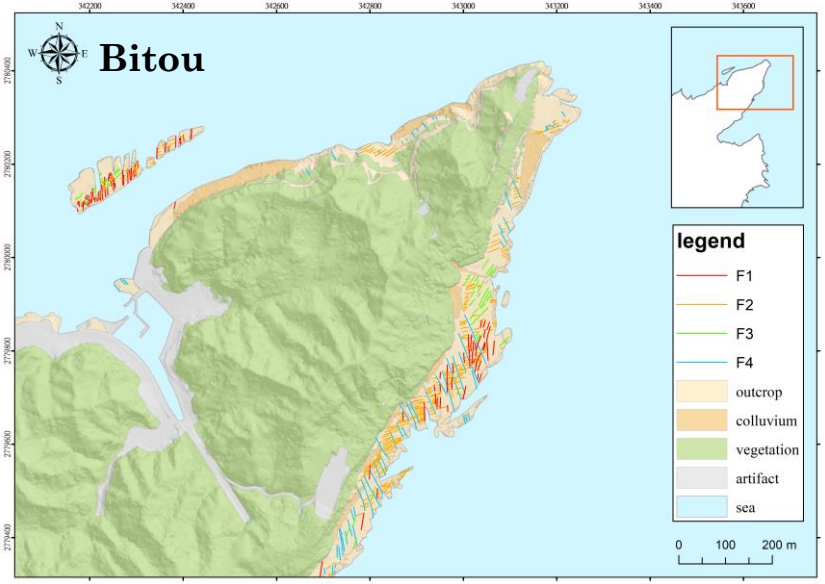
Facade image (elevation view)



3D model

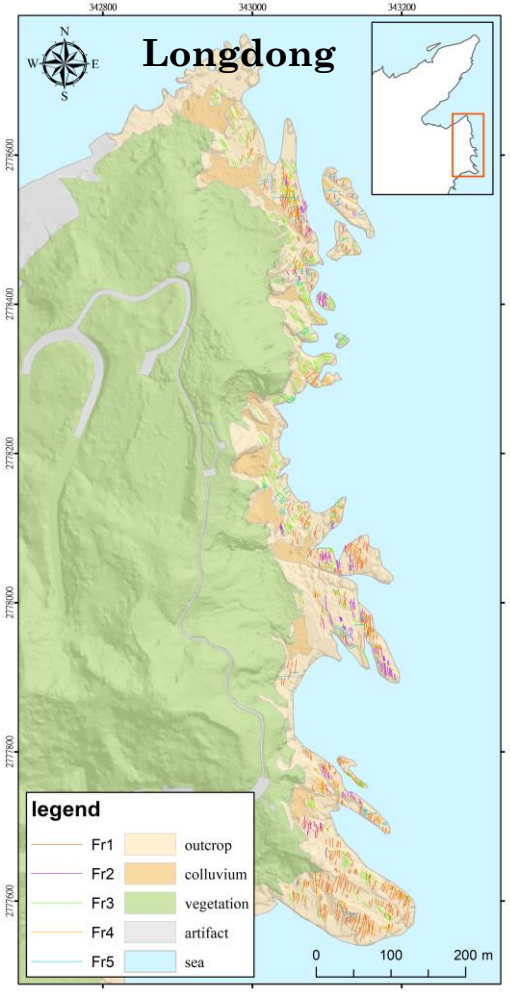
Results

Fractures distribution

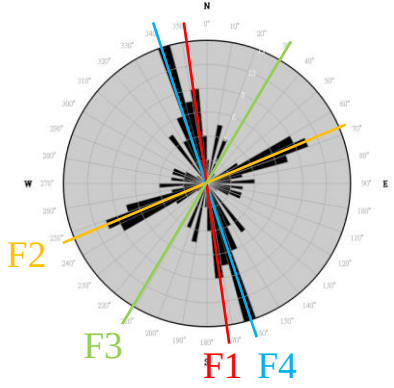


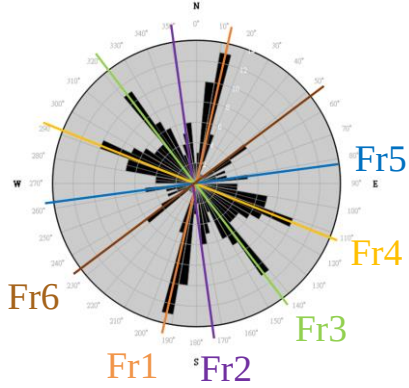
Some faults can be developed along pre-existing fractures.

Fracture	Strike	dip
Fr1	195˚	80˚W
Fr2	350˚	85˚E
Fr3	320˚	74˚NE
Fr4	290˚	83˚NE
Fr5	263˚	75˚N
Fr6	235˚	80˚NW

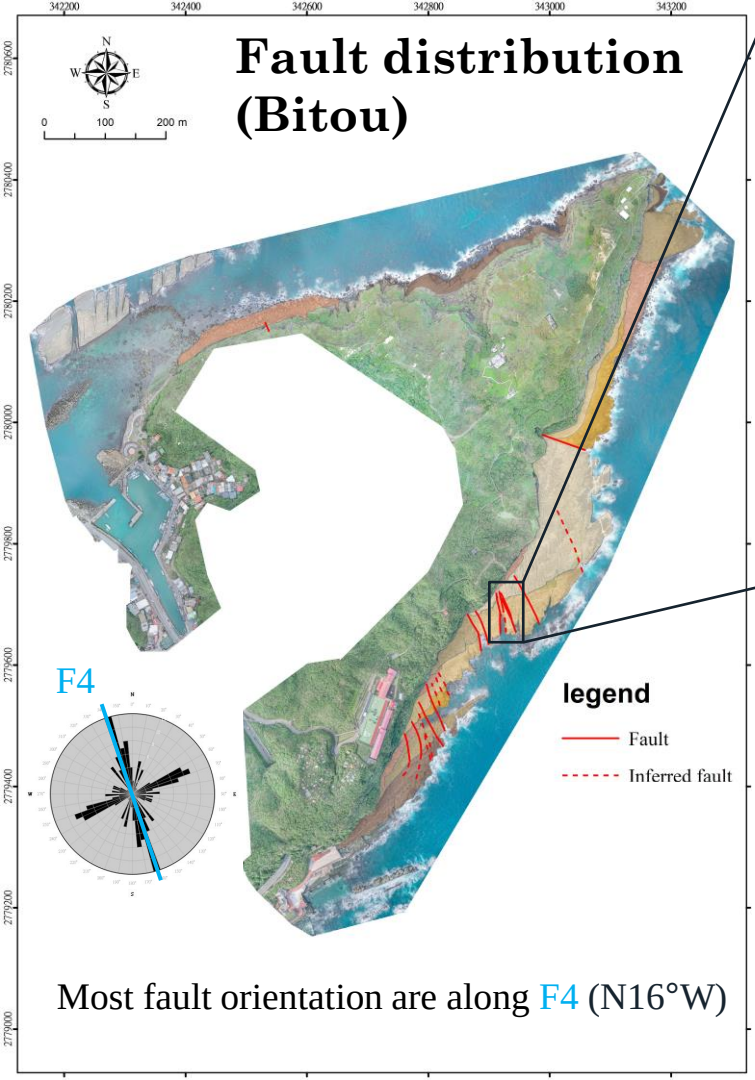


Fracture	Strike	dip
F1	175˚	84˚W
F2	247˚	78˚NW
F3	035˚	74˚SE
F4	164˚	74˚SW

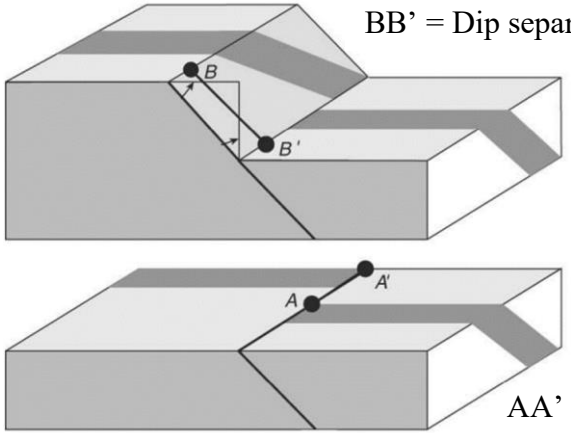




Fault distribution (Bitou)



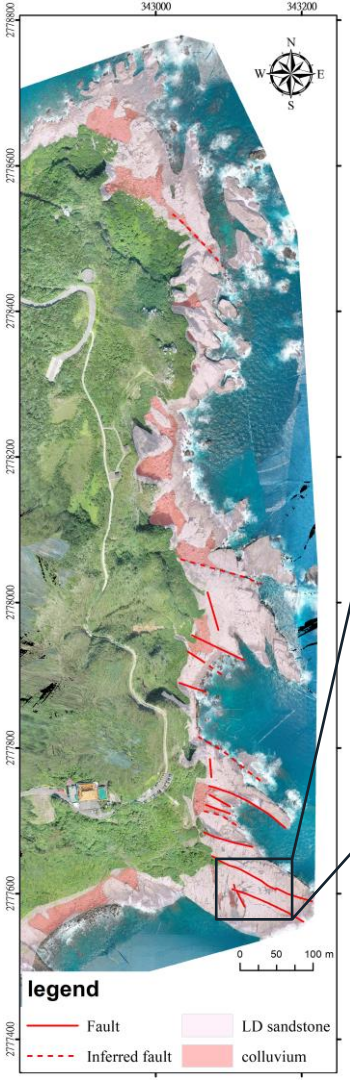
Most fault orientation are along F4 (N16°W)

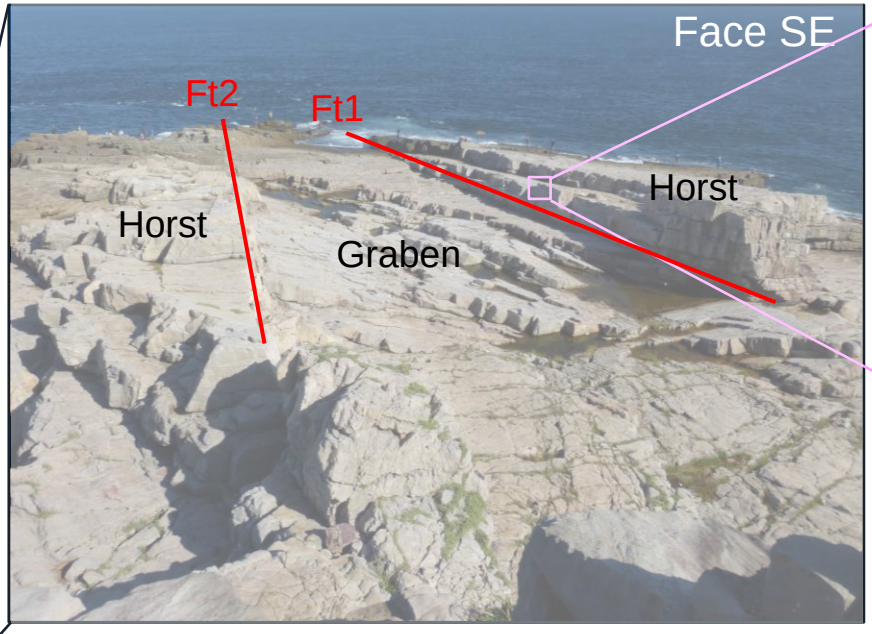


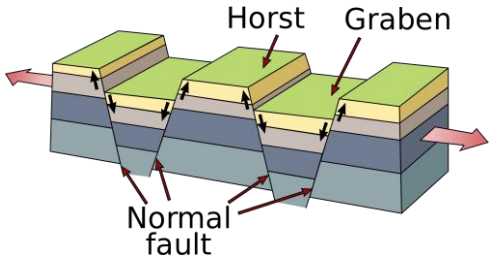
Separation: the offset observed along fault outcrops in 2D views.

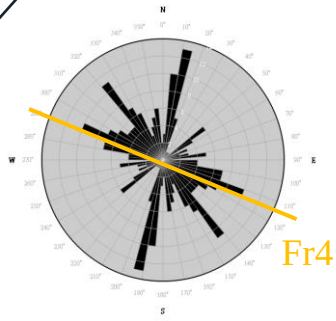
The separation of faults in Bitou area is about 0.2 ~3m

Fault distribution (Longdong)

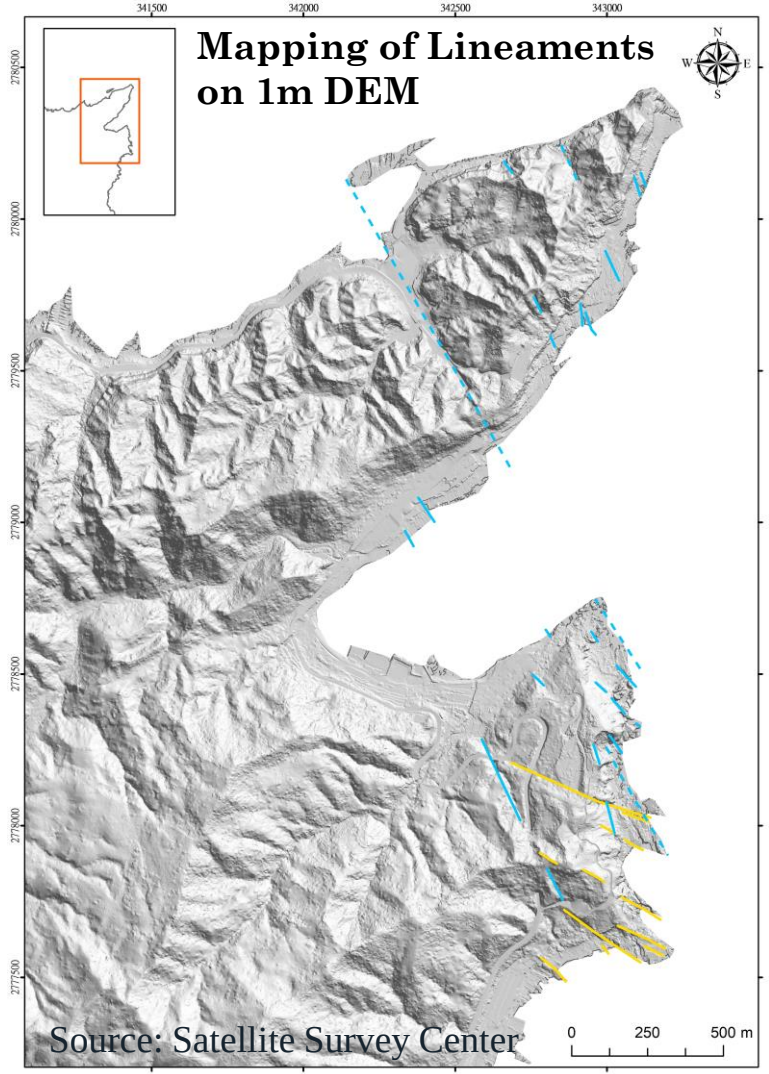








- Most faults are along Fr4 (N70°W)
- Few faults with orientation about N10°W~ N40°W
- The separation of major faults in Longdong area can be larger than 3m.



- The orientation of the two main lineaments(blue and yellow lines) is similar to that of the faults in the research areas. (F4 in **Bitou**； Fr4 in **Longdong**)

- Both normal faults and strike slip faults could be observed in Bitou and Longdong areas along these two orientation. (F4 : N16°W ; Fr4: N70°W)

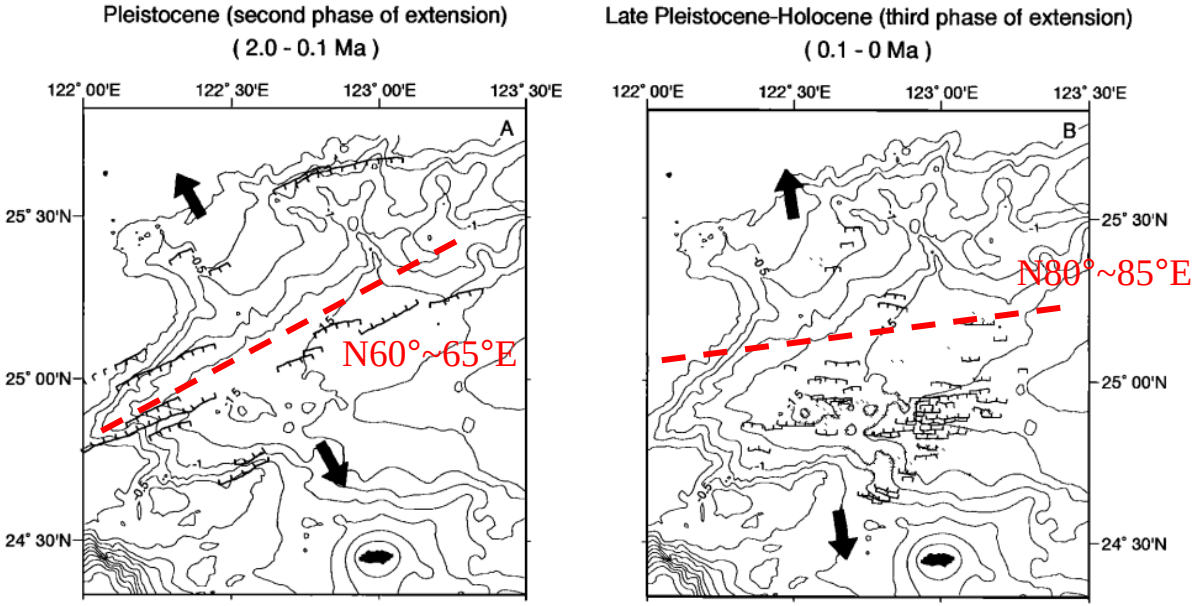
Discussion

Some opinion of the normal faults development

Okinawa Trough rifting

There are two phases of recent extension in the southwestern Okinawa Trough (Sibuet et al., 1998 ; Chen, 2014)

1. Pleistocene (2~0.1 Ma) : Normal fault traces are oriented N60°~65°E
2. Late Pleistocene – Holocene (0.1~0 Ma) : Normal fault traces are oriented N80°~85°E



(Sibuet et al., 1998)

Normal fault orientation

Normal fault orientation is quite different!

(Normal faults

Fr4 (N70°W)

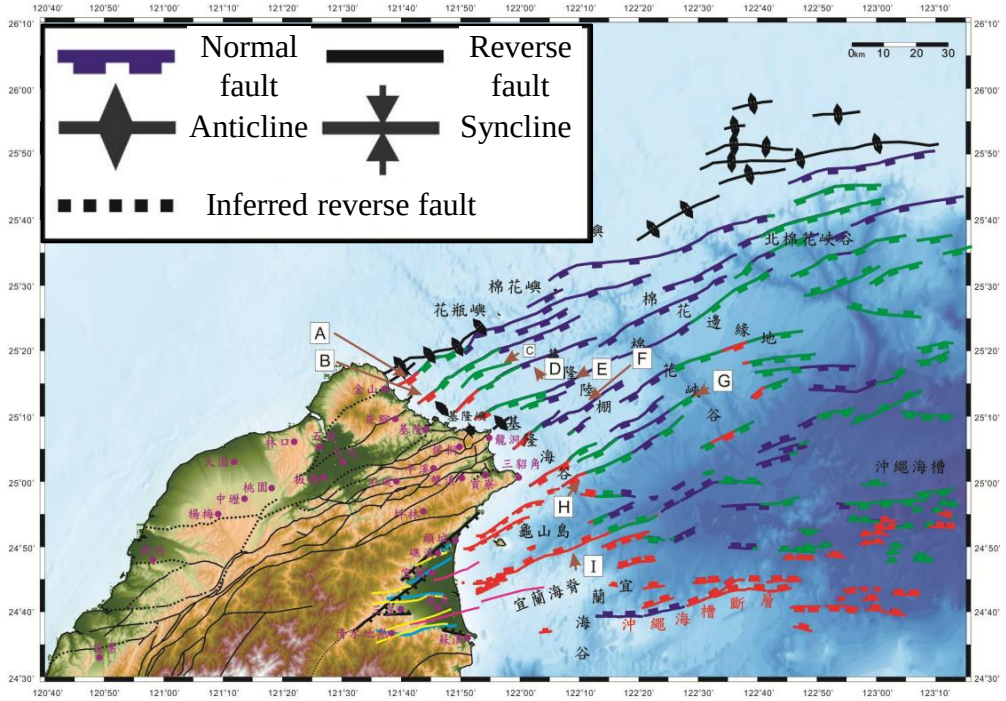
F4 (N16°W)

(Normal faults in Bitou)

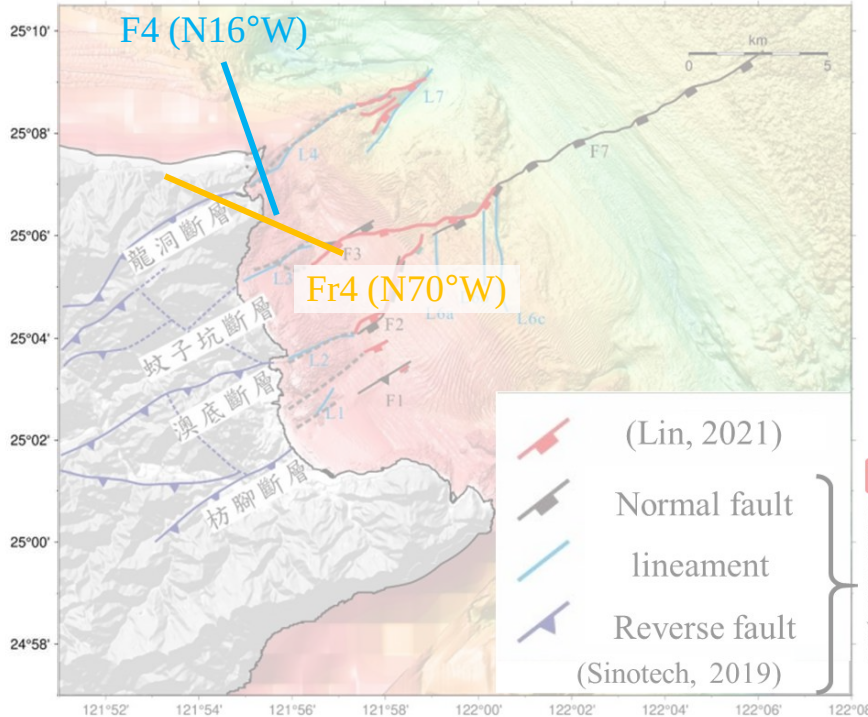
Offshore lineaments and normal faults

The orientation of offshore lineaments and normal faults is mainly NE-SW.

→ Different with the normal fault orientation



(Chen, 2014)



(Lin, 2021)

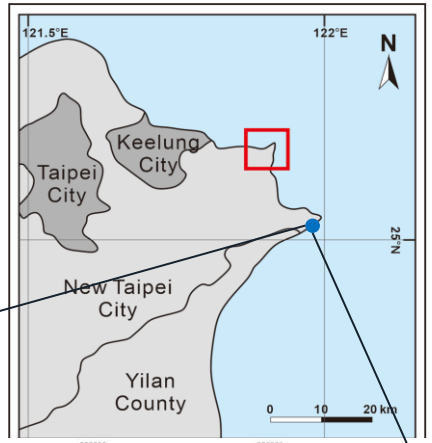
Late-Miocene extension of the crust

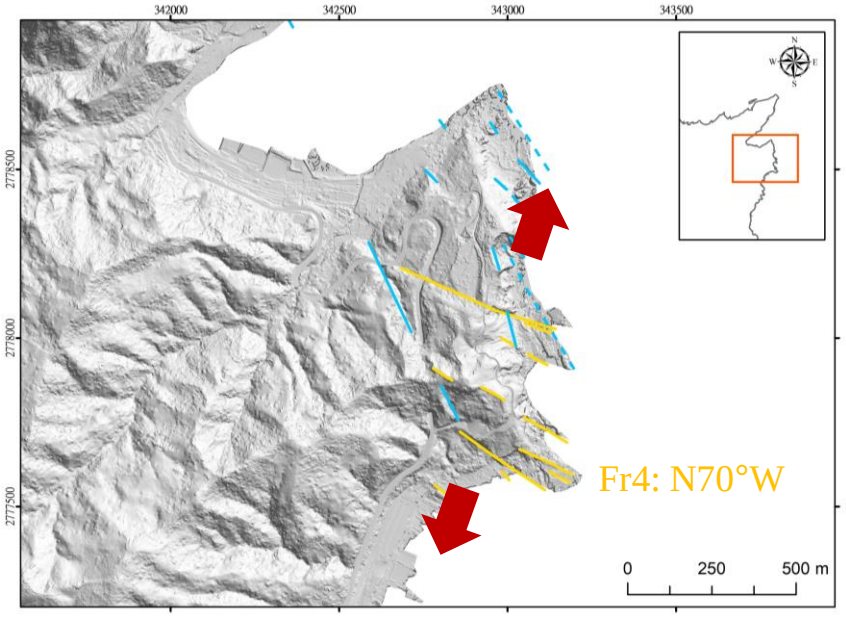
This study

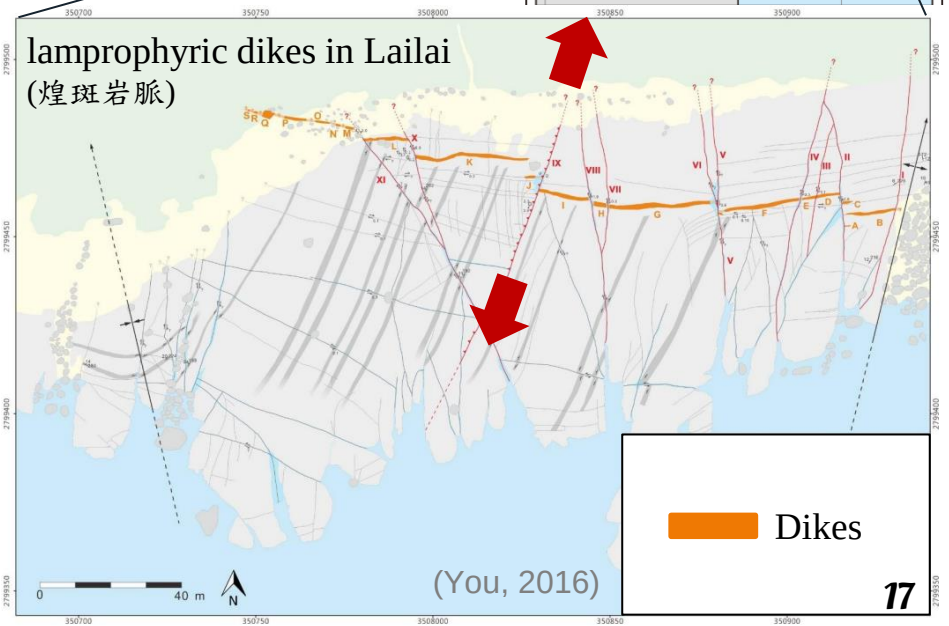
(You, 2016)

A study of lamprophyric dikes in Lailai area has concluded that the intrusive age of the dikes is Late-Miocene. (You, 2016)

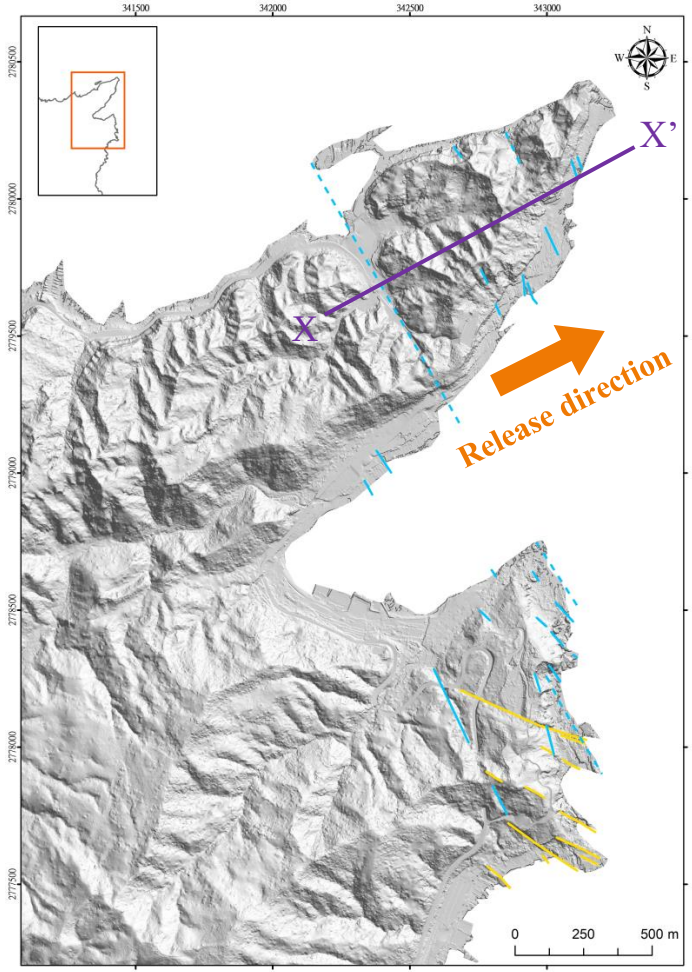
Dike orientation usually can indicate the extensional direction.



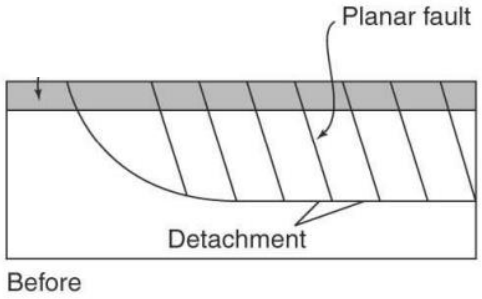


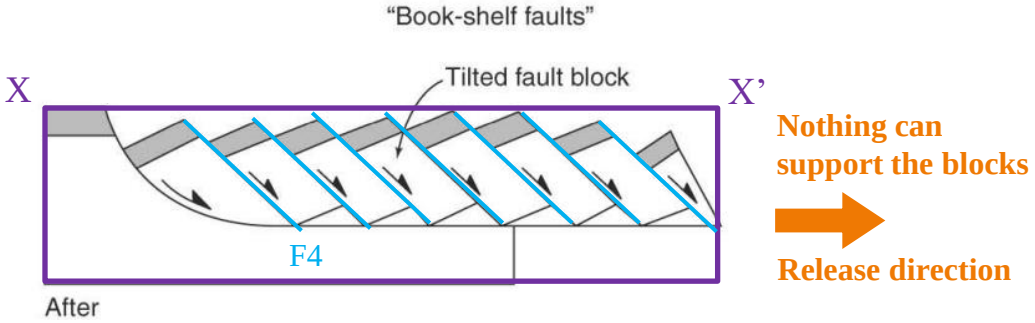


Lateral stress release at coastal area

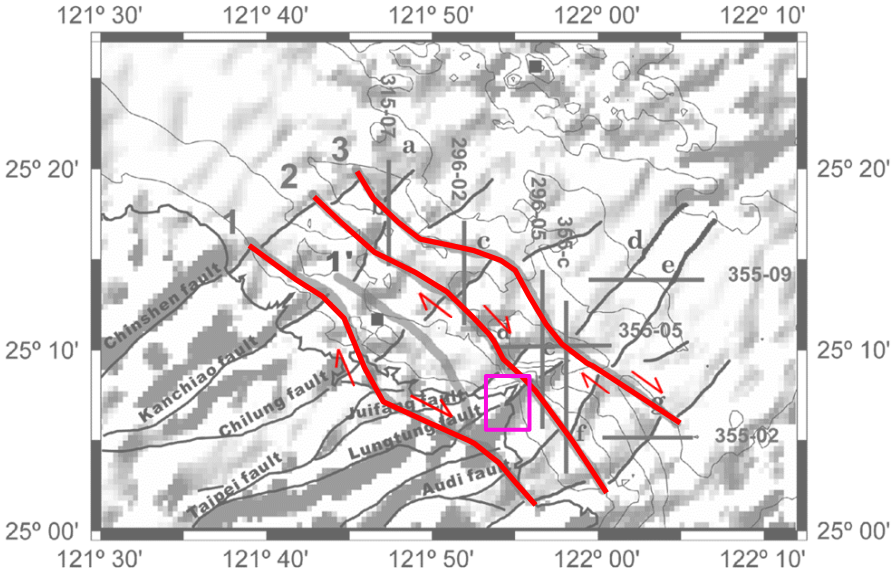


Normal faults parallel to F4 are more likely formed by lateral stress release in comparison to normal faults parallel to Fr4.





Right-lateral strike-slip faults in Bitou area



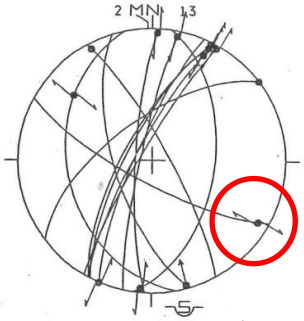
This study areas

(Song, 2000)

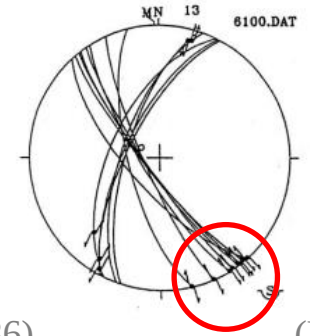
圖 4.12 第一組節理因剪切滑動而留下的擦痕面(slickenside)，其擦痕滑動方向為水平右移的現象(調查點：P07)。

Right-lateral motion

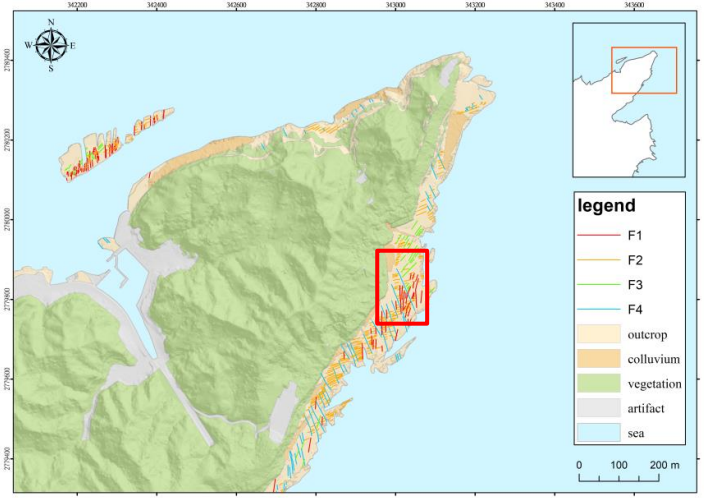
(You, 1998)

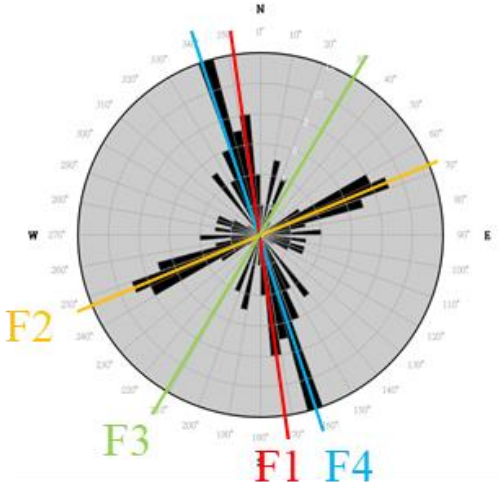


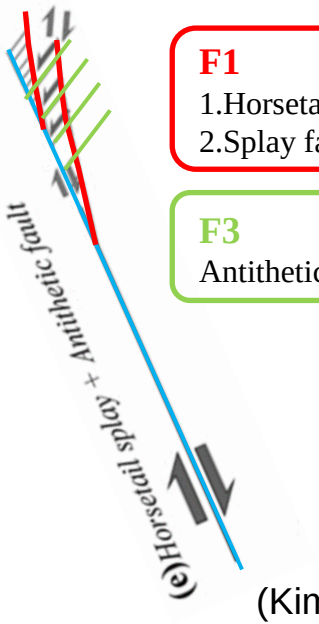
(Lee, 1986)



(Lee, 1989)







F1
1.Horsetail structure
2.Splay fault

F3
Antithetic fault

(Kim, 2004)

Normal faults can be caused by strike-slip faulting, in particular should be regarded as a sign of lateral faulting, even if no lateral displacement can be found.

(Lensen, 1958)

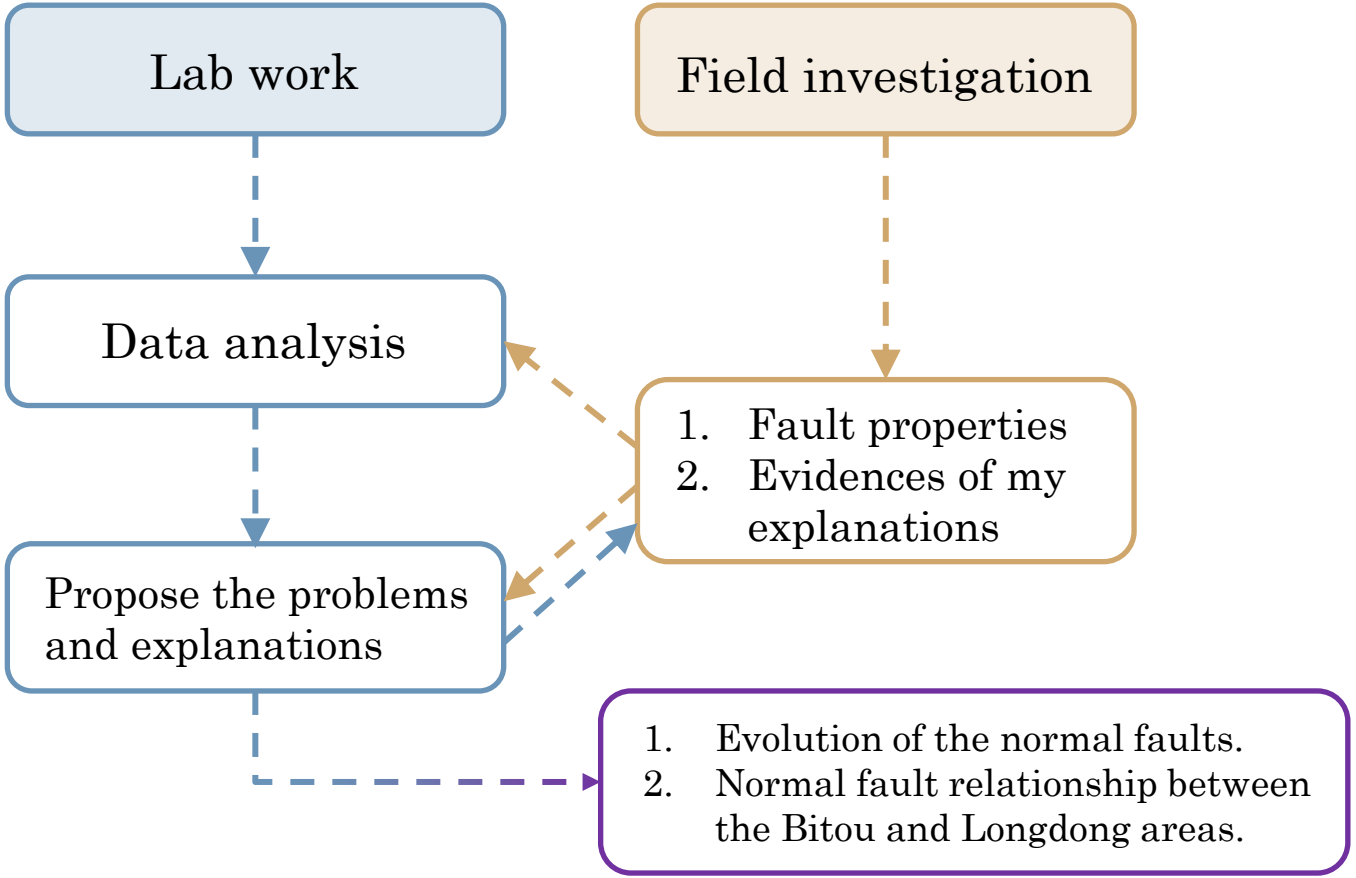
Conclusions

1. Normal faults in the Bitou and Longdong areas are mainly striking N16°W and N70°W, respectively.

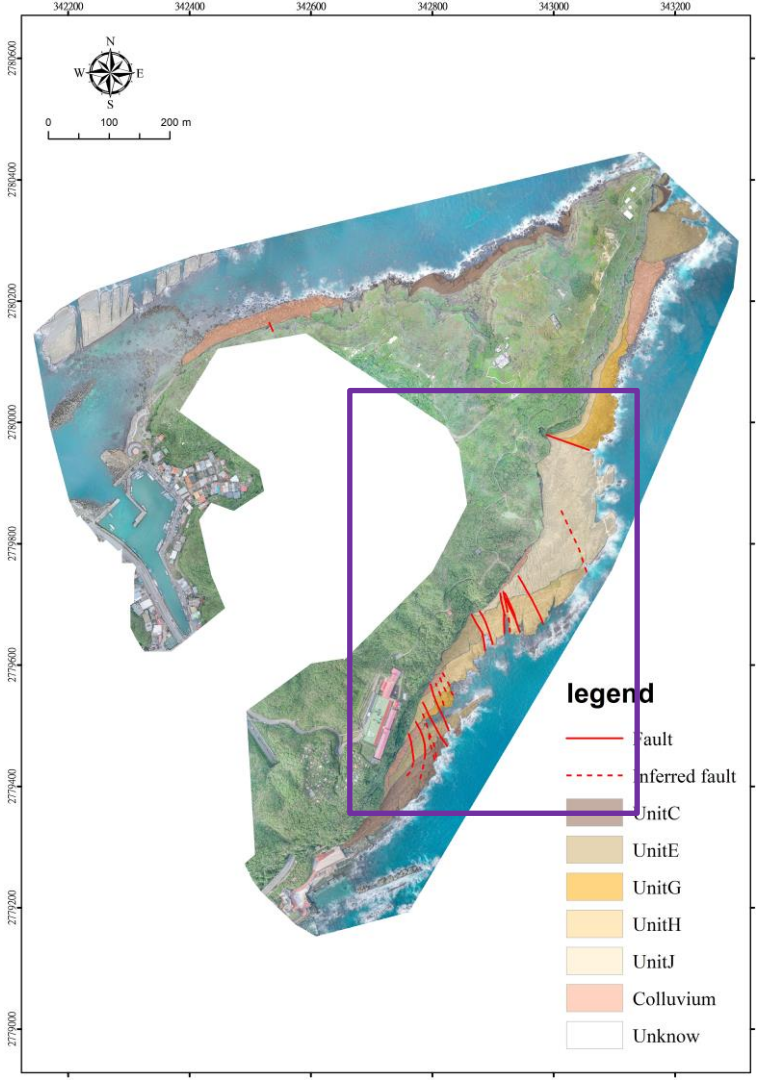
2. Both **normal faults** and **strike slip faults** could be observed in the Bitou and Longdong areas.

3. Normal faults may not be directly related to Okinawa Trough rifting and offshore normal faults with NE-SW trending.

Future work


Lab work
Field investigation
Data analysis
1. Fault properties
2. Evidences of my explanations
Propose the problems and explanations
1. Evolution of the normal faults.
2. Normal fault relationship between the Bitou and Longdong areas.

Thanks for your attention ~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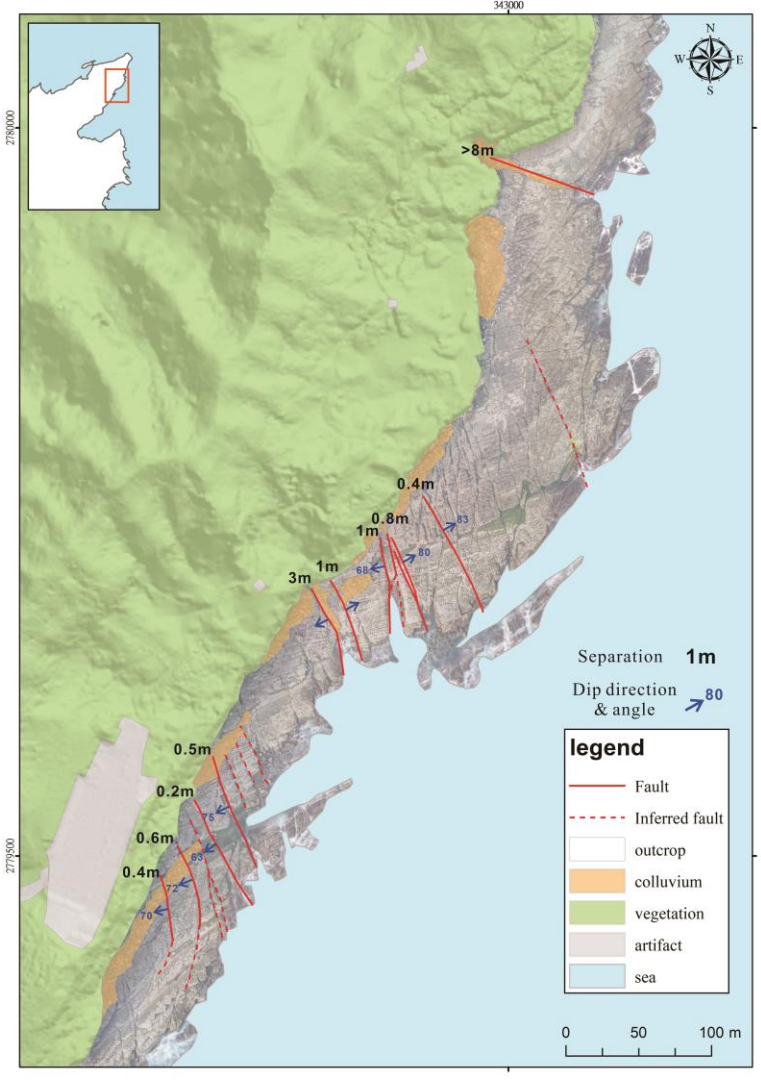
UnitC
UnitE
UnitG
UnitH
UnitJ
Colluvium
Unknow


343000
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0.8m
1m
1m
3m
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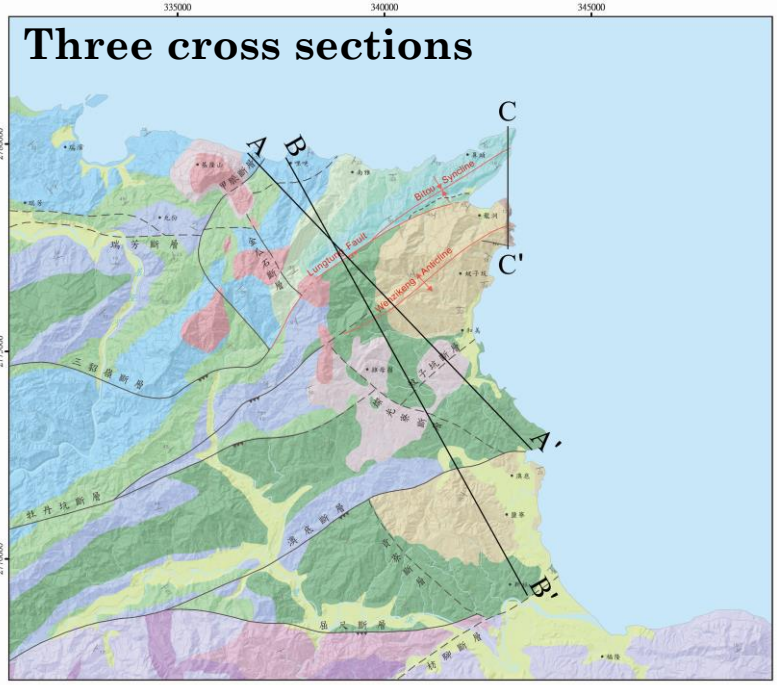
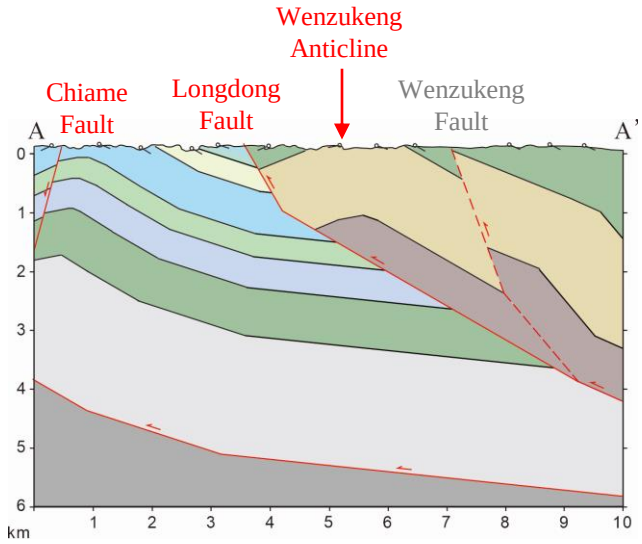
0.6m
0.4m
83
80
68
75
69
72
70
Separation 1m
Dip direction & angle 80
legend
Fault
Inferred fault
outcrop
colluvium
vegetation
artifact
sea
0
50
100 m


Three cross sections
335000
340000
345000
2780000
2775000
2770000
C
C'
A
B
A'
B'
Bitou Syncline
Lungtung Fault
Wenzukeng Anticline


Wenzukeng Anticline
Chiame Fault
Longdong Fault
Wenzukeng Fault
A
A'
0
1
2
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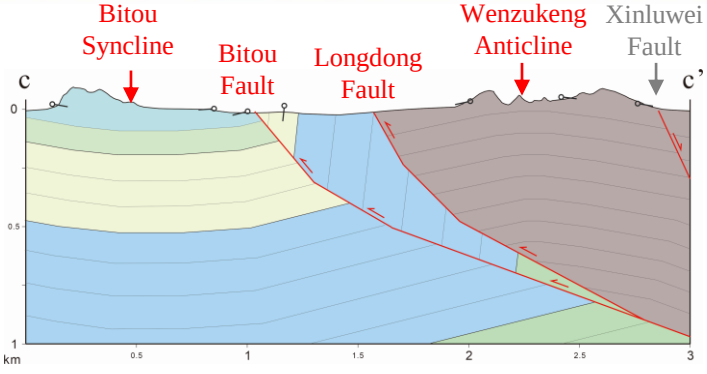
Bitou Syncline
Bitou Fault
Longdong Fault
Wenzukeng Anticline
Xinluwei Fault
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1
1.5
2
2.5
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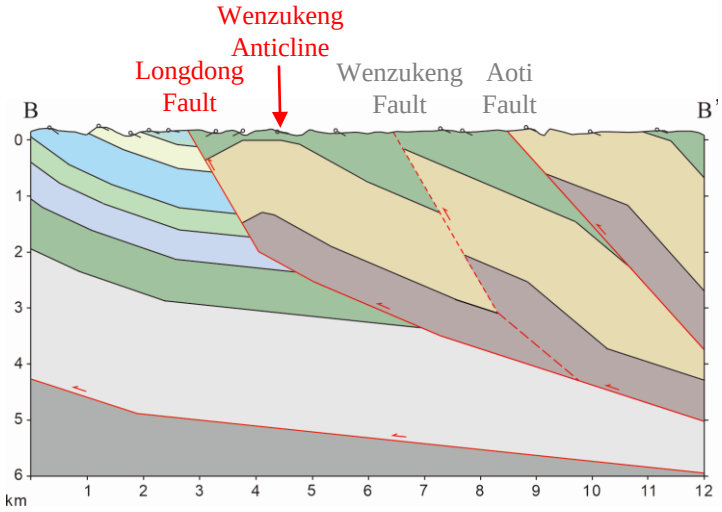
Wenzukeng Anticline
Longdong Fault
Wenzukeng Fault
Aoti Fault
B
B'
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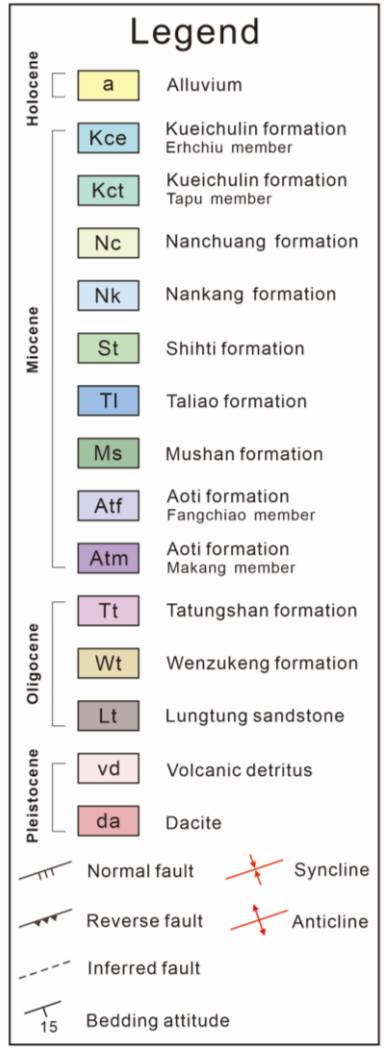
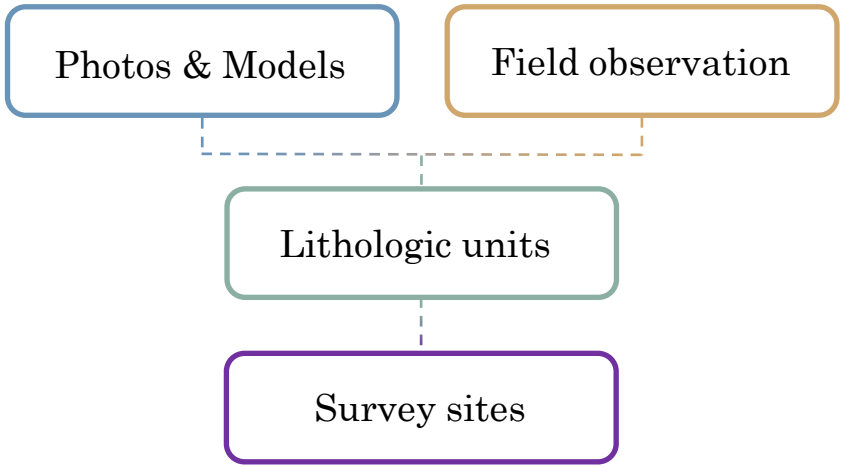
12

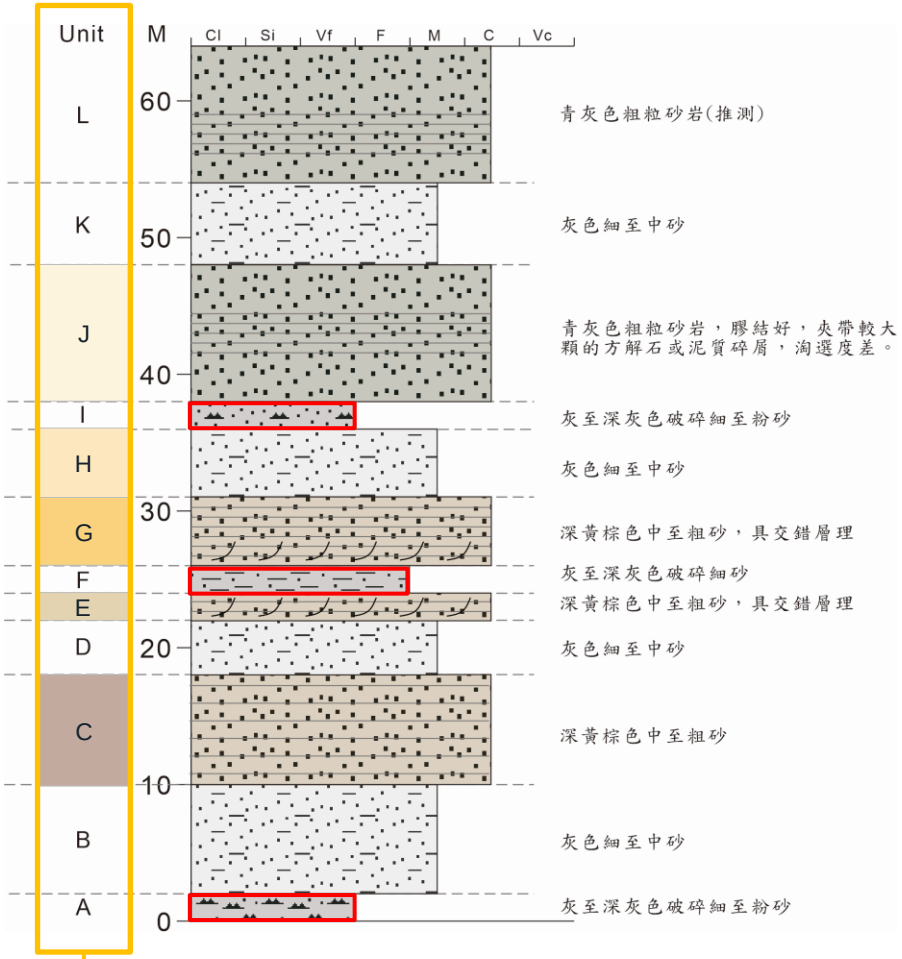

Legend
Holocene
a
Alluvium
Miocene
Kce
Kueichulin formation
Erhchiu member
Kct
Kueichulin formation
Tapu member
Nc
Nanchuang formation
Nk
Nankang formation
St
Shihti formation
Tl
Taliao formation
Ms
Mushan formation
Atf
Aoti formation
Fangchiao member
Atm
Aoti formation
Makang member
Oligocene
Tt
Tatungshan formation
Wt
Wenzukeng formation
Lt
Lungtung sandstone
Pleistocene
vd
Volcanic detritus
da
Dacite
Normal fault
Syncline
Reverse fault
Anticline
Inferred fault
15
Bedding attitude

Separate different lithological units

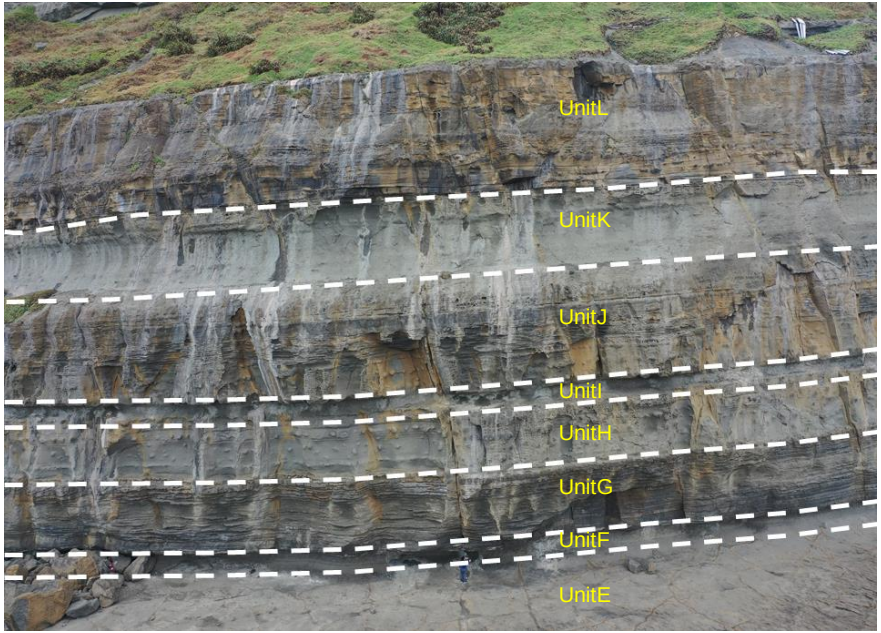
Stress discontinuities arising from contrasts in mechanical properties at **lithologic contacts** act as **a barrier to joint propagation** and thus confine joints to specific layers. (Gross,1993)

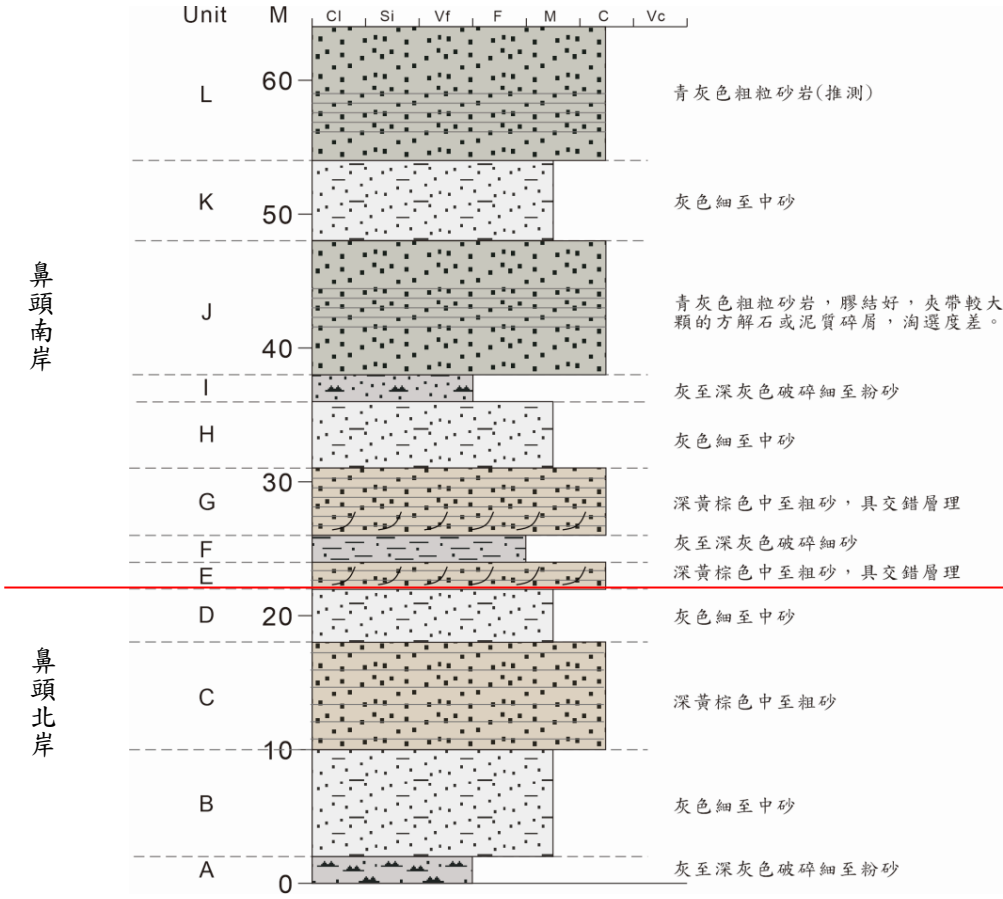
→ Lithology differences may affect joint development.



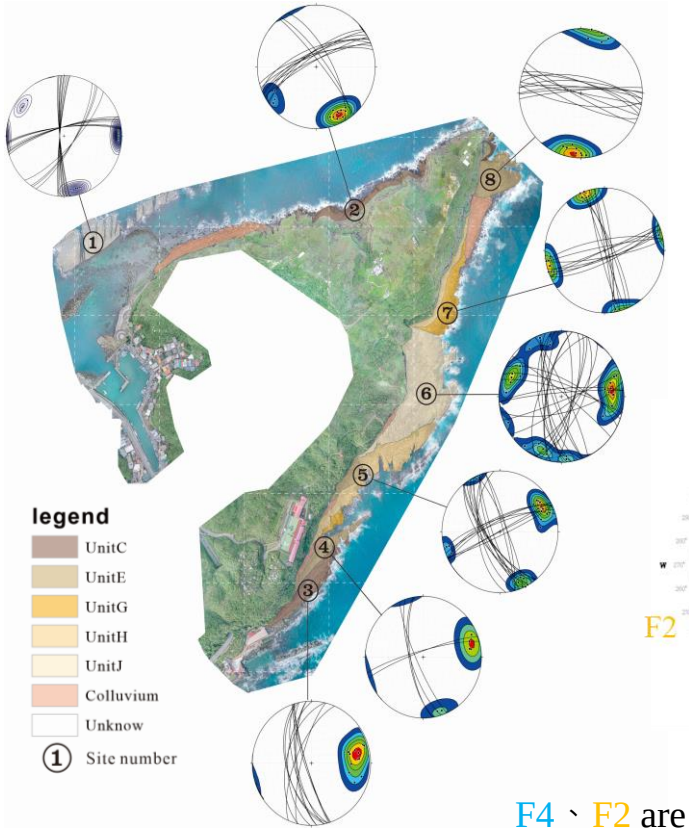


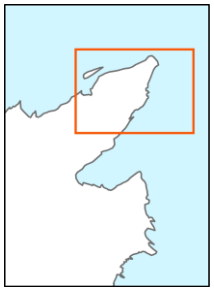
UnitA ~ UnitL in Bitou area

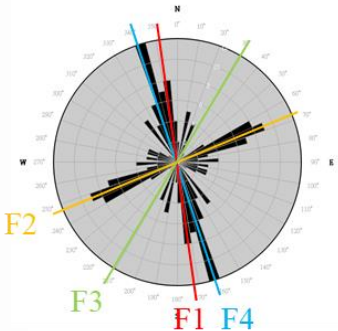

UnitL
UnitK
UnitJ
UnitI
UnitH
UnitG
UnitF
UnitE


Unit
M
Cl
Si
Vf
F
M
C
Vc
60
50
40
30
20
10
0
L
K
J
I
H
G
F
E
D
C
B
A
青灰色粗粒砂岩(推測)
灰色細至中砂
青灰色粗粒砂岩，膠結好，夾帶較大顆的方解石或泥質碎屑，淘選度差。
灰至深灰色破碎細至粉砂
灰色細至中砂
深黃棕色中至粗砂，具交錯層理
灰至深灰色破碎細砂
深黃棕色中至粗砂，具交錯層理
灰色細至中砂
深黃棕色中至粗砂
灰色細至中砂
灰至深灰色破碎細至粉砂
鼻頭南岸
鼻頭北岸

8 survey sites in Bitou area

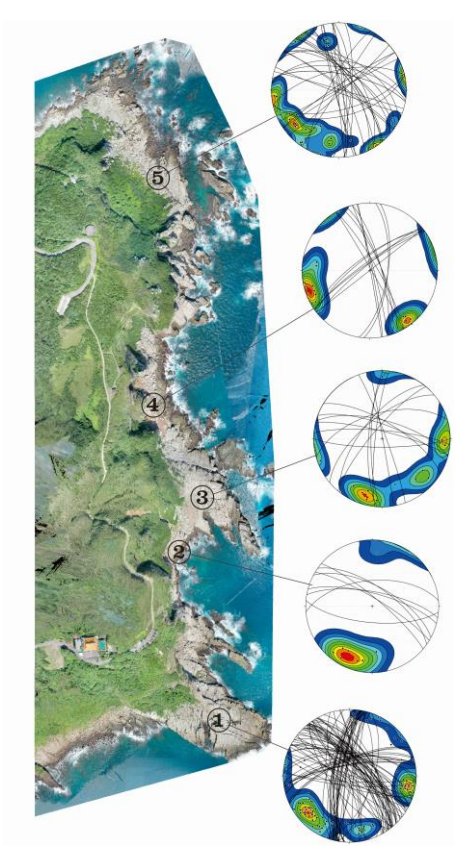


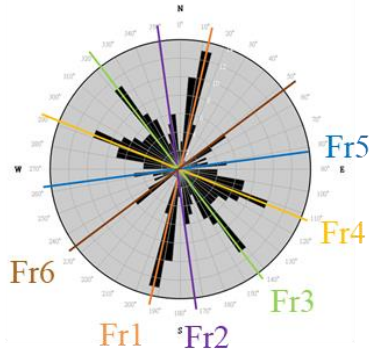




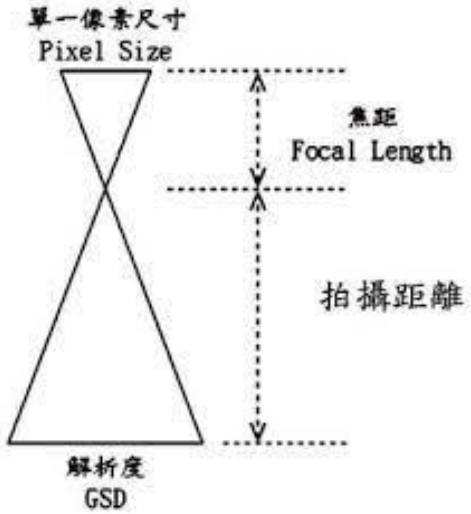
F4、F2 are regional fractures

5 survey sites in Longdong area





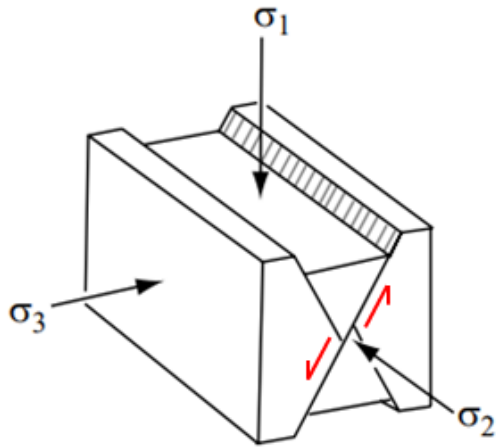
Fr4、Fr2、Fr1 are regional fractures



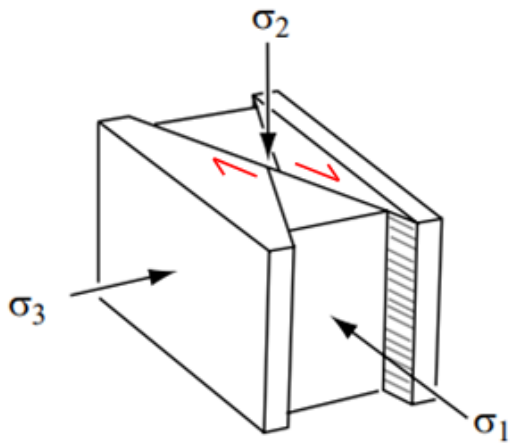
Low GSD value: 3~5cm/pixel

The Ground Sampling Distance (GSD) is the distance between two consecutive pixel centers measured on the ground.

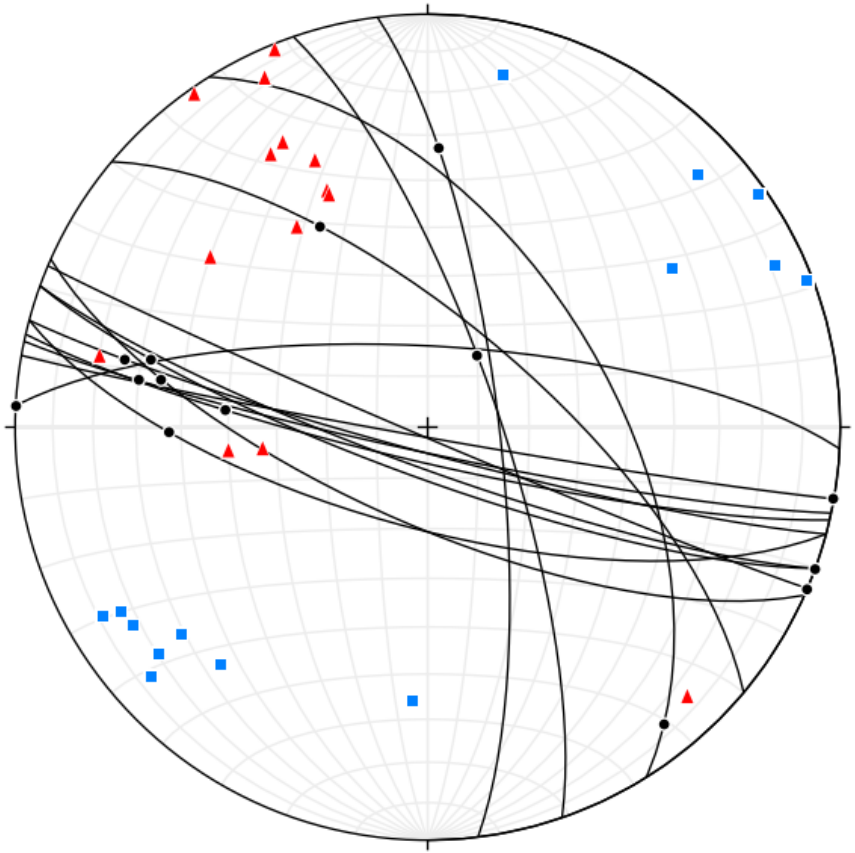
Normal fault

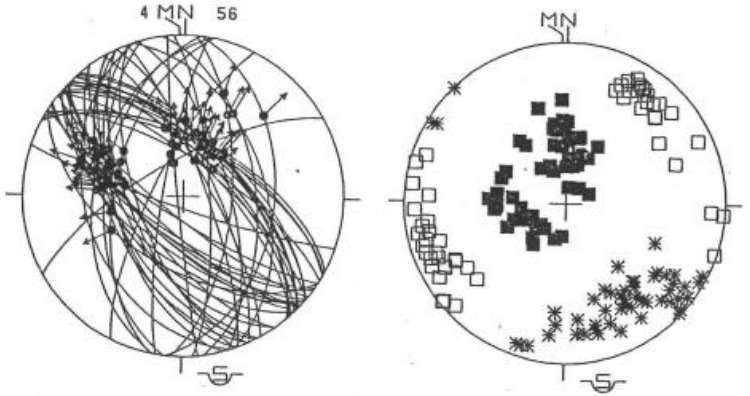


Strike slip fault



Fault data analysis





(李錫提, 1986)

extension

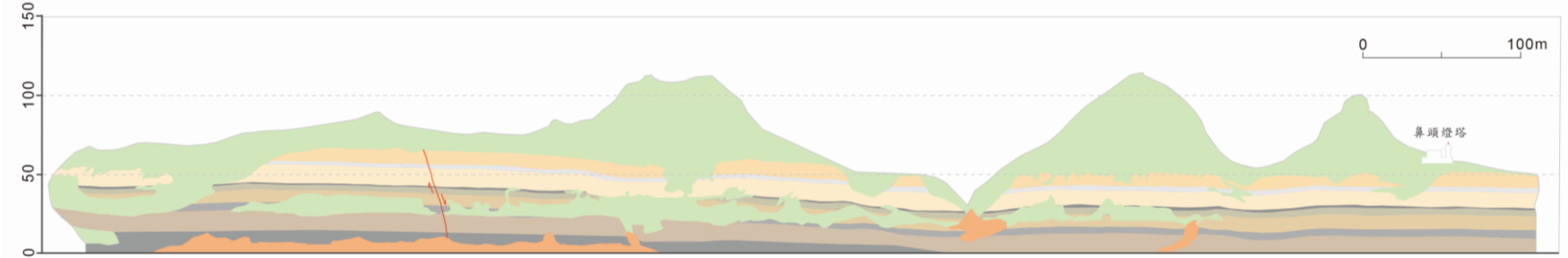
shortening

Facade images

SW

North shore of Bitou cape

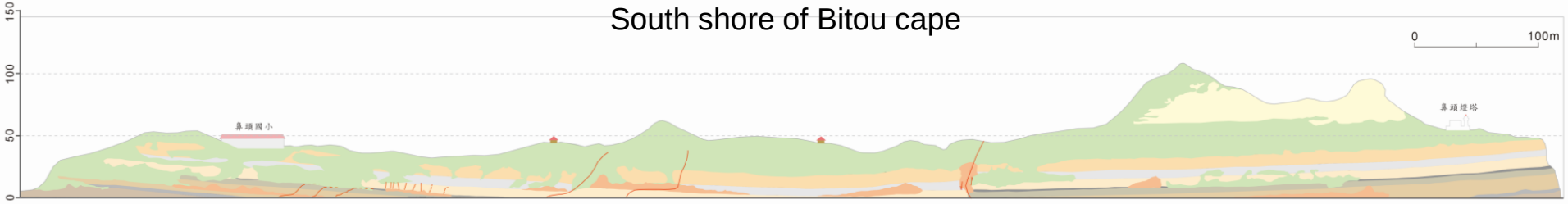
NE

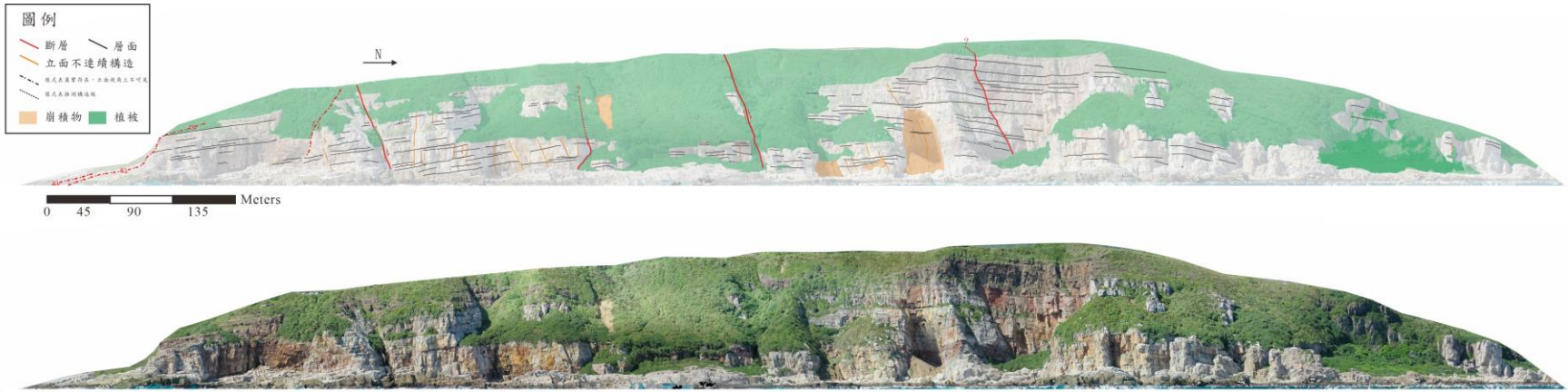


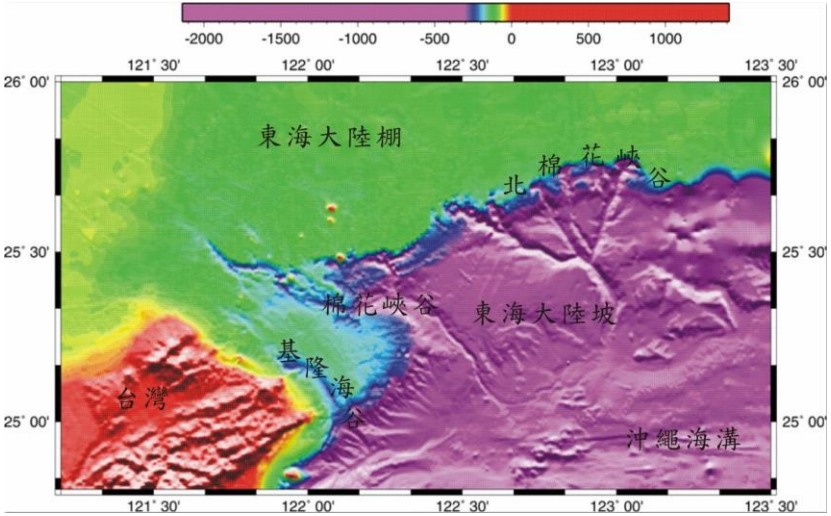
SW

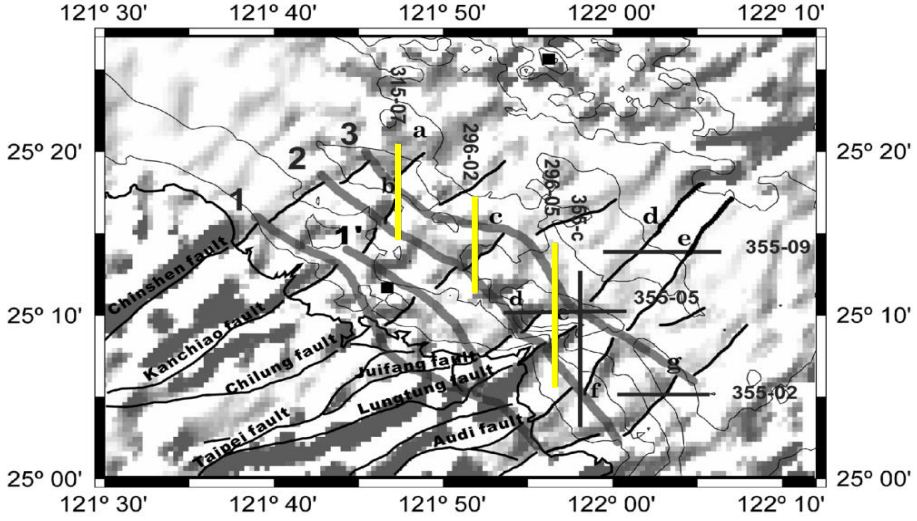
South shore of Bitou cape

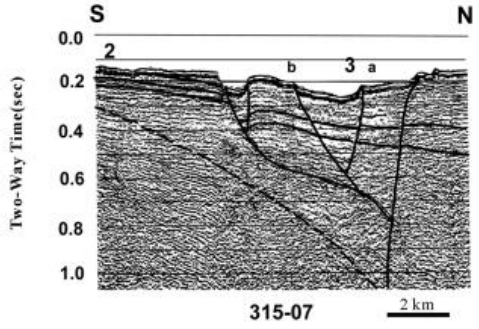
NE

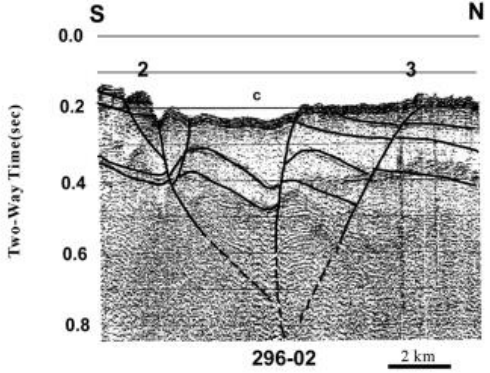


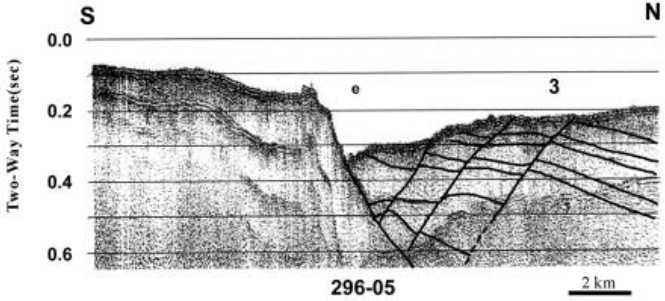

圖例
斷層
層面
立面不連續構造
崩積物
植被
N
0 45 90 135
Meters


-2000
-1500
-1000
-500
0
500
1000
121° 30'
122° 00'
122° 30'
123° 00'
123° 30'
26° 00'
25° 30'
25° 00'
東海大陸棚
北棉花峽谷
棉花峽谷
東海大陸坡
基隆海谷
台灣
沖繩海溝


121° 30'
121° 40'
121° 50'
122° 00'
122° 10'
25° 20'
25° 10'
25° 00'
315-07
296-02
296-05
355-c
355-09
355-05
355-02
a
b
c
d
e
f
g
1
1'
2
3
Chinshen fault
Kanchiao fault
Chilung fault
Juifang fault
Lungtung fault
Taigei fault
Audi fault


S
N
Two-Way Time(sec)
0.0
0.2
0.4
0.6
0.8
1.0
2
3
a
b
315-07
2 km

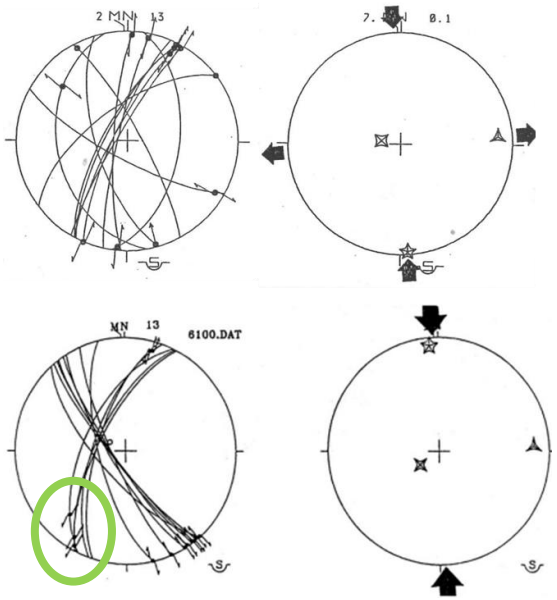

S
N
Two-Way Time(sec)
0.0
0.2
0.4
0.6
0.8
2
3
c
296-02
2 km


S
N
Two-Way Time(sec)
0.0
0.2
0.4
0.6
e
3
296-05
2 km

F3(*Antithetic faults*)、F1(*Horsetail fractures or pinnate fractures*)

↓ ↓

These fractures possibly show left-lateral slip sense



Because these two types of tip damage zone fracture propagate as mode I cracks, a fault tends to grow along a curved or kinked path, which is locally parallel to the direction of maximum compressive stress at the time of faulting. (Kim, 2004)

One of investigated fracture with orientation N5°W showed plumose structure, indicating mode I cracks（You, 1998）

圖 4.11 第一組節理面上之羽毛狀條紋，其羽狀裂形長軸為水平南北方向(調查點：P17)。