Rapid deformation rates due to development of diapiric anticline in southwestern Taiwan from geodetic observations

Ching, K. E., Gourley, J. R., Lee, Y. H., Hsu, S. C., Chen, K. H., & Chen, C. L.

Tectonophysics 692 (2016): 241-251.

Adviser : Wen-Jeng Huang
Speaker : Liang-Jie Yuan
Date : 2023/01/06

Outline

- **Introduction**
- **Methods & Results**
- **Discussion**
- **Conclusions**

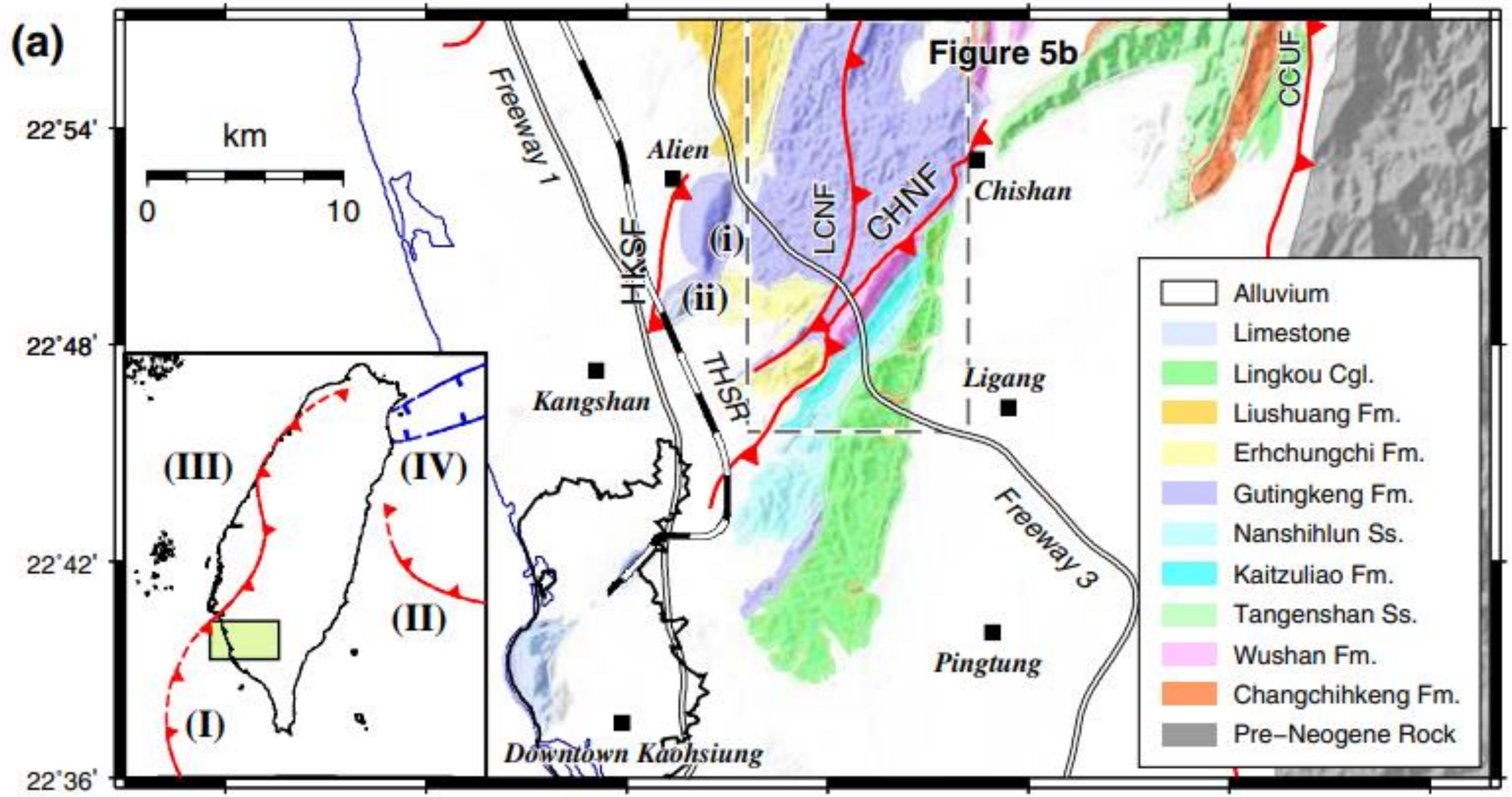
Introduction

- The stress accumulated will cause the high surface shortening rate. Southwest Taiwan has the high contraction rate of ~ 1.0 μstrain/yr.

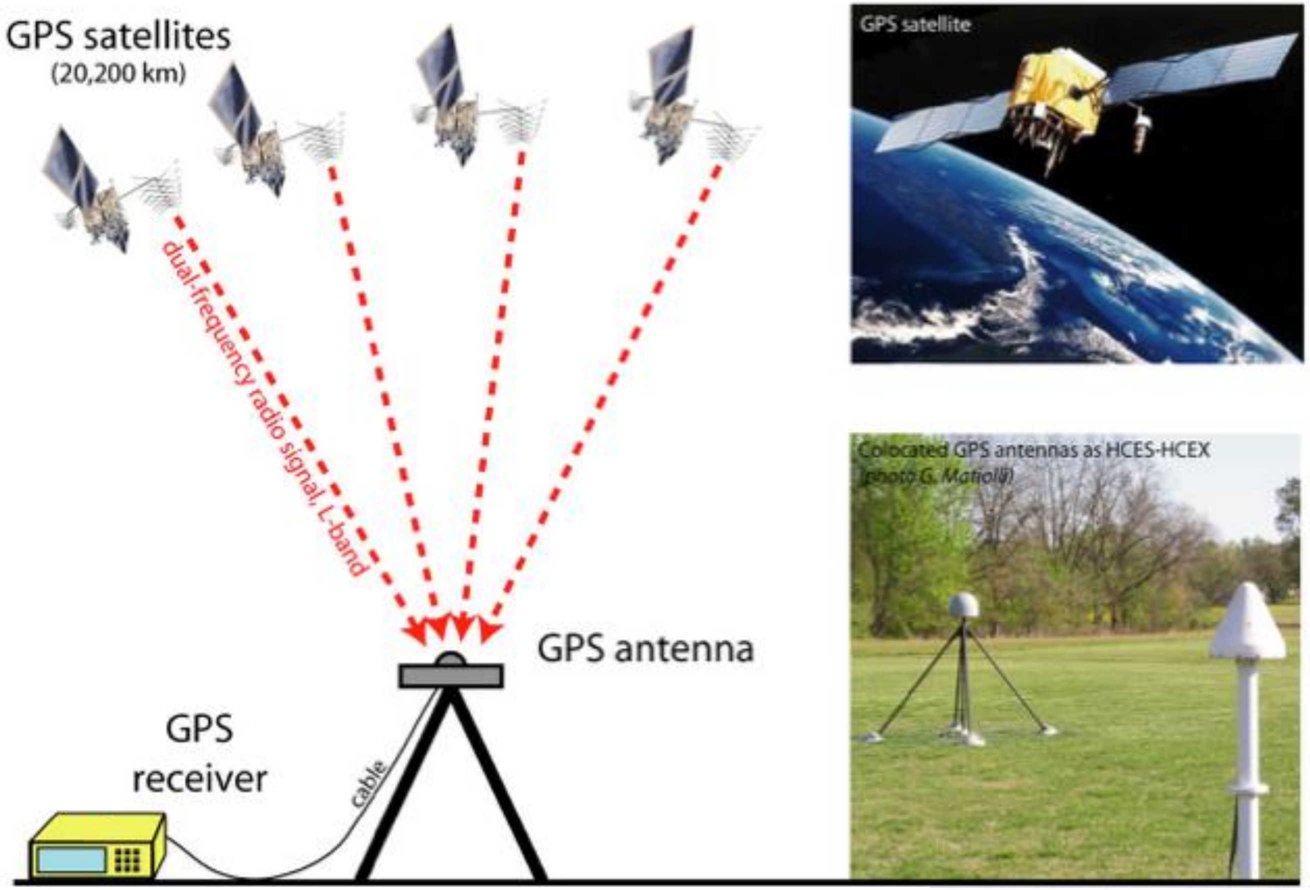
- The area with seldom earthquakes usually accumulates high seismic strain. Therefore does it mean a large earthquake being coming in southwest Taiwan in the near future?

- Is this high strain being accommodated by the development of mud diapir with low potential for major seismicity?

Geological background and study area



Campaign-Mode GPS



Campaign-Mode GPS

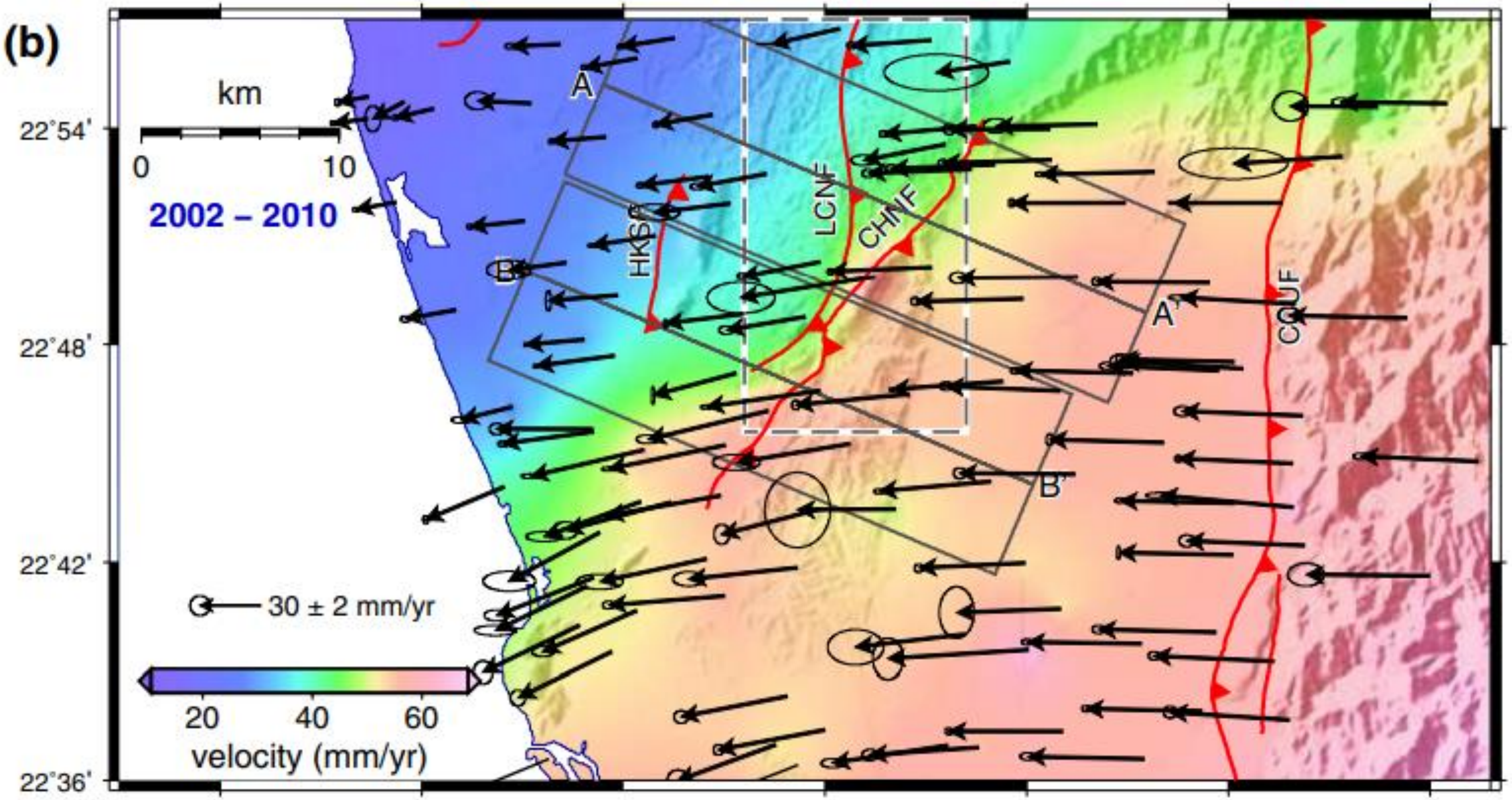
- 106 GPS stations data from 2002 to 2010.
- Each session is record 6 to 14 hours and all available satellites are tracked.
- Elevation angle rising higher than a 15°.
- The sampling interval for data logging is 15 second.

Campaign-Mode GPS

Data Processing

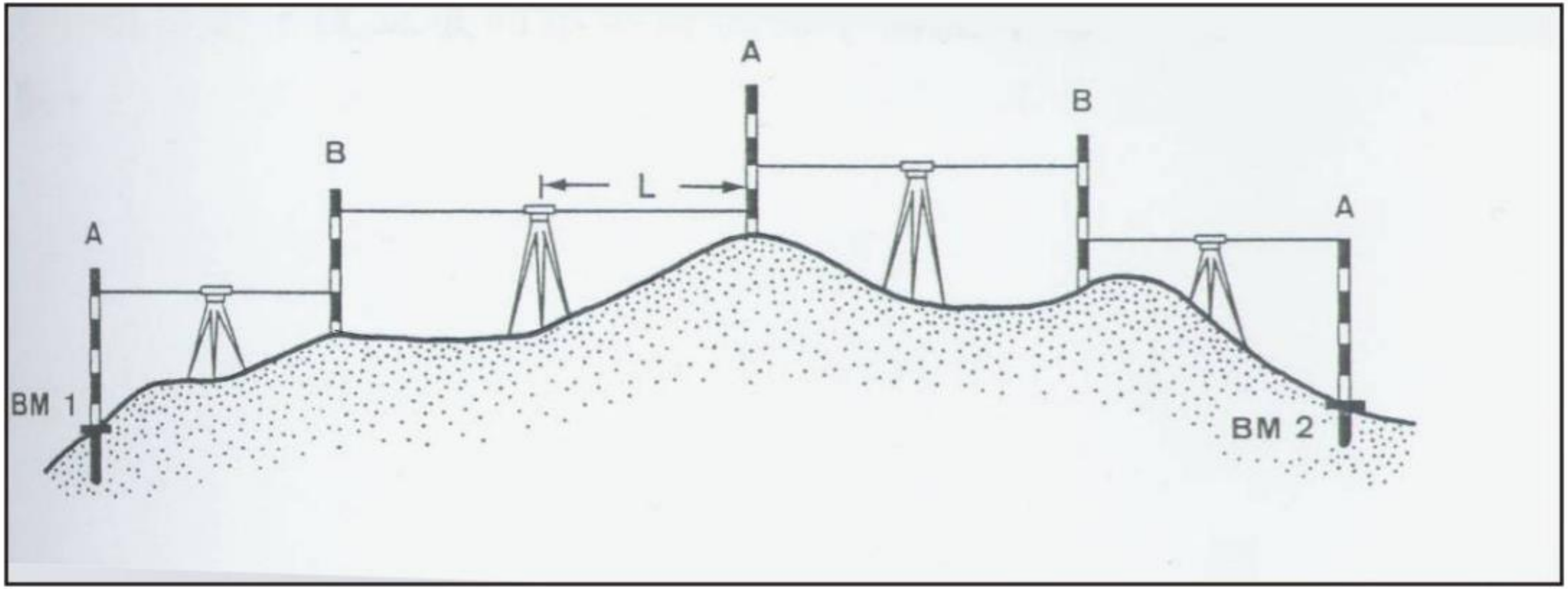
- Bernese software v.5.0 to obtain the precise station coordinates.
- The precise ephemerides provided by International GNSS Service (IGS) were employed and fixed during the processing.
- The horizontal uncertainties of station coordinates are estimated to be 2 ～ 5 mm.

Methods & Results



Horizontal velocities relative to the station S01R at the Penghu Island

Precise Leveling



(YU, 1989)

Precise Leveling

- Two CGS precise leveling lines was repeatedly surveyed 6 times from 2004 to 2010. Two E–W trending precise leveling routes spacing of ～1 km.

- The first CGS leveling transect is 91 km length and crosses the northern side of Takangshan hill from Luzhu (蘆竹) to Maolin (茂林).

- The second CGS leveling transect is 50 km length and crosses the southern side of Hsiaokangshan hill from Kangshan (岡山) to Anpo (安坡).

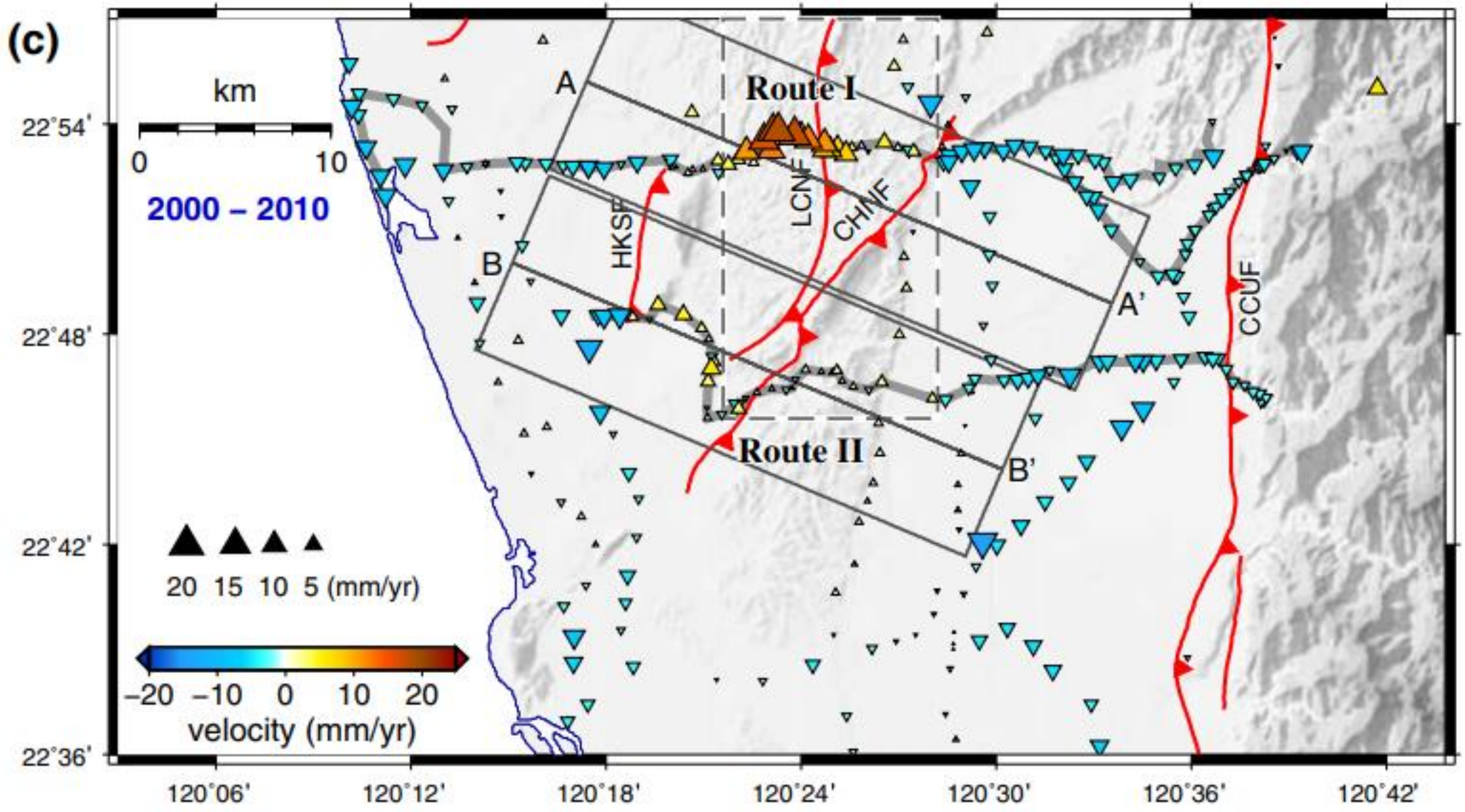
Precise Leveling

Data Processing

- The leveling data were mostly collected at night by Zeiss DiNi-12 digital leveling instruments.

- The systematic errors of various kinds were calculated and removed from the measurements.

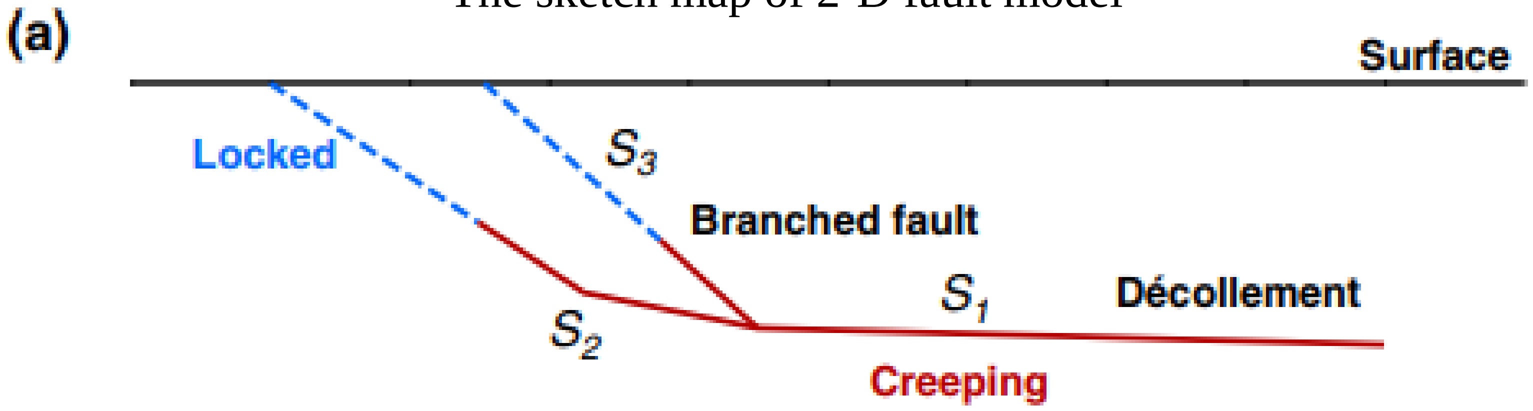
Methods & Results

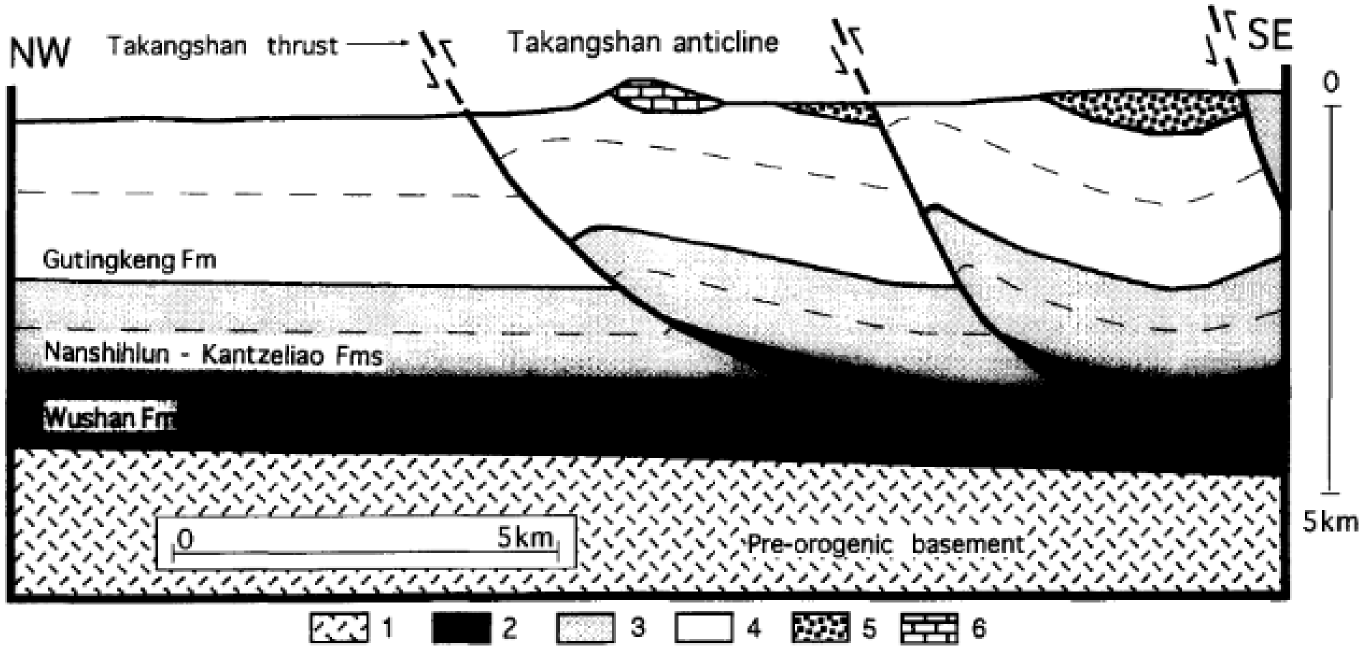


Vertical velocity field

2D- fault model

The sketch map of 2-D fault model





(Johnson et al., 2005)

Fault parameters

Table 1
Fault parameters of profiles AA′ and BB′.

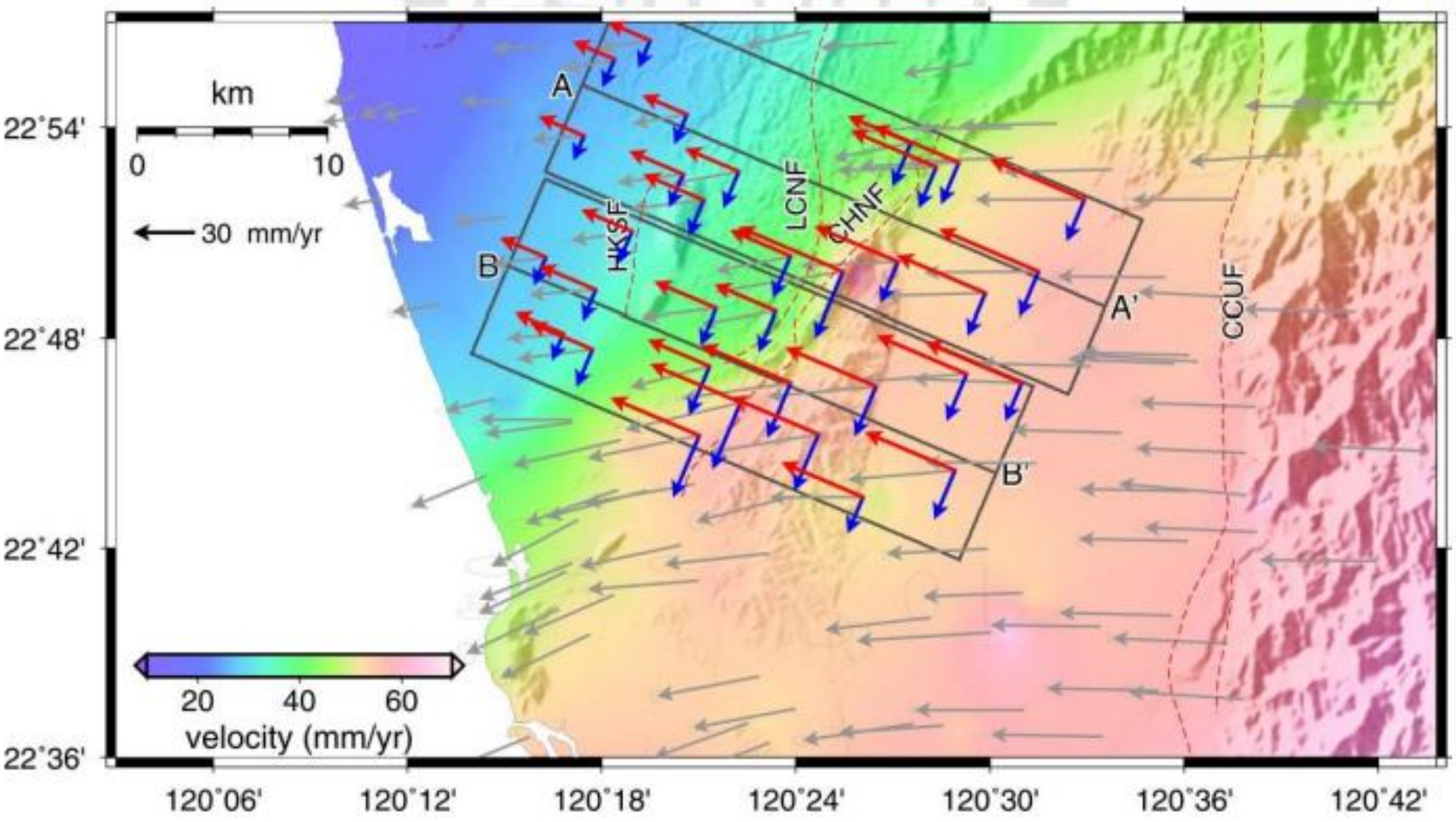
Fault name	Profile AA′					
	Dip angle (°)	Depth (km)	Locking depth (km)	Location (km)	Slip rate (mm/yr)	Rake (°)
HKSF	52.9 ± 4.1	6.2 ± 0.1	2.3 ± 0.2	6.7 ± 0.2	24.3 ± 1.6	107.9 ± 2.1
CHNF	63.8 ± 8.5	6.7 ± 0.1	3.6 ± 1.8	21.0 ± 1.1	1.1 ± 0.9	133.2 ± 8.2
Décollement	~0	–	–	–	25.3 ± 1.5	109.2 ± 1.9
	Profile BB′					
HKSF	34.0 ± 2.5	6.1 ± 0.1	1.9 ± 0.2	5.6 ± 0.3	14.4 ± 0.8	133.6 ± 3.7
CHNF	74.9 ± 6.4	6.7 ± 0.1	5.8 ± 0.5	18.2 ± 0.8	8.4 ± 0.3	96.7 ± 3.7
Décollement	~0	–	–	–	22.8 ± 0.8	120.9 ± 2.3

HKSF: the Hsiaokangshan fault; CHNF: the Chishan fault.

$$\mathrm{RMS} = \sqrt{\frac{(\mathbf{As} - \mathbf{data})^2}{dof}}$$

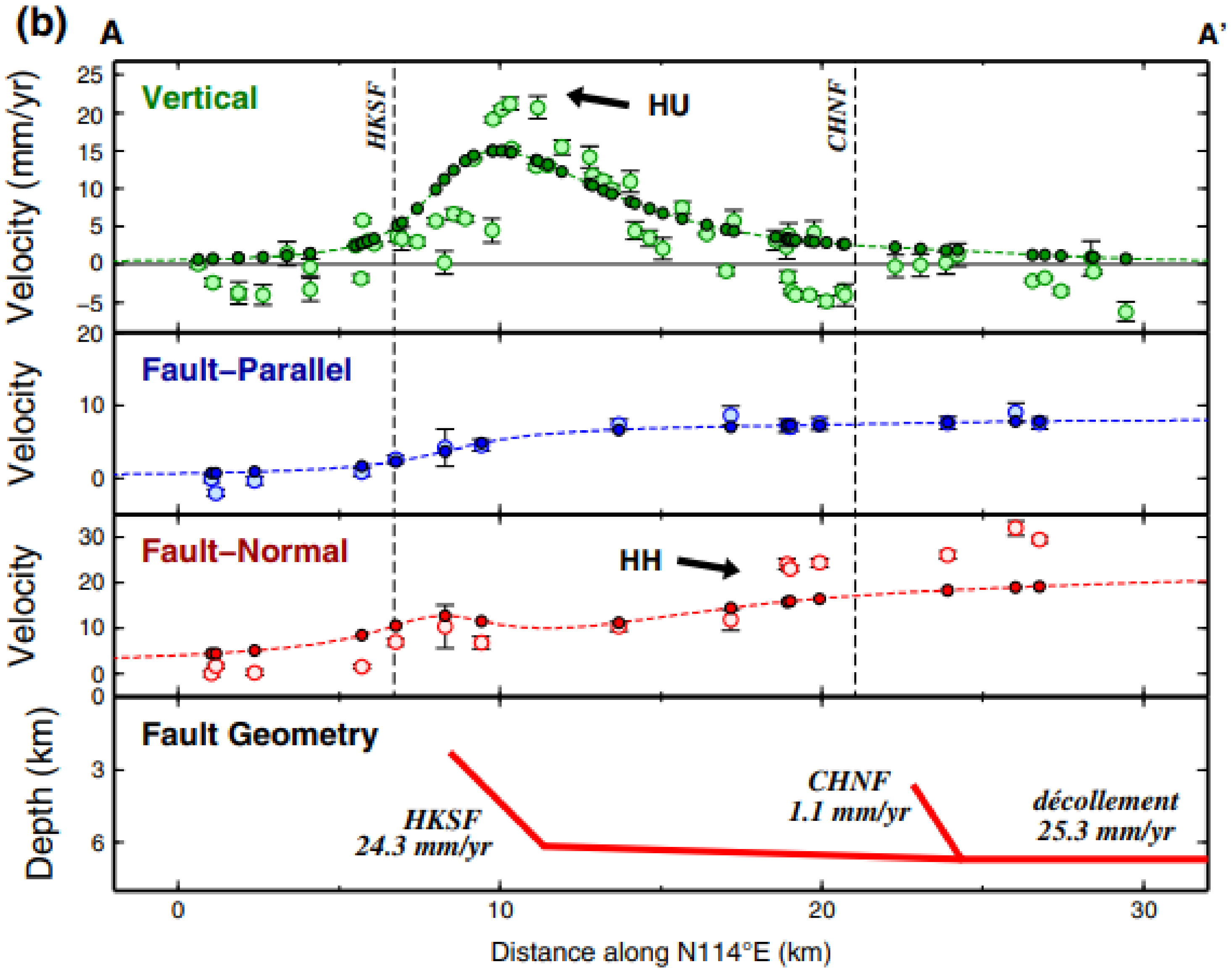
A = Green's function from Okada (1985)
s = slip rates on faults
data = observed velocities
dof = degree of freedom

Locations of the two profiles

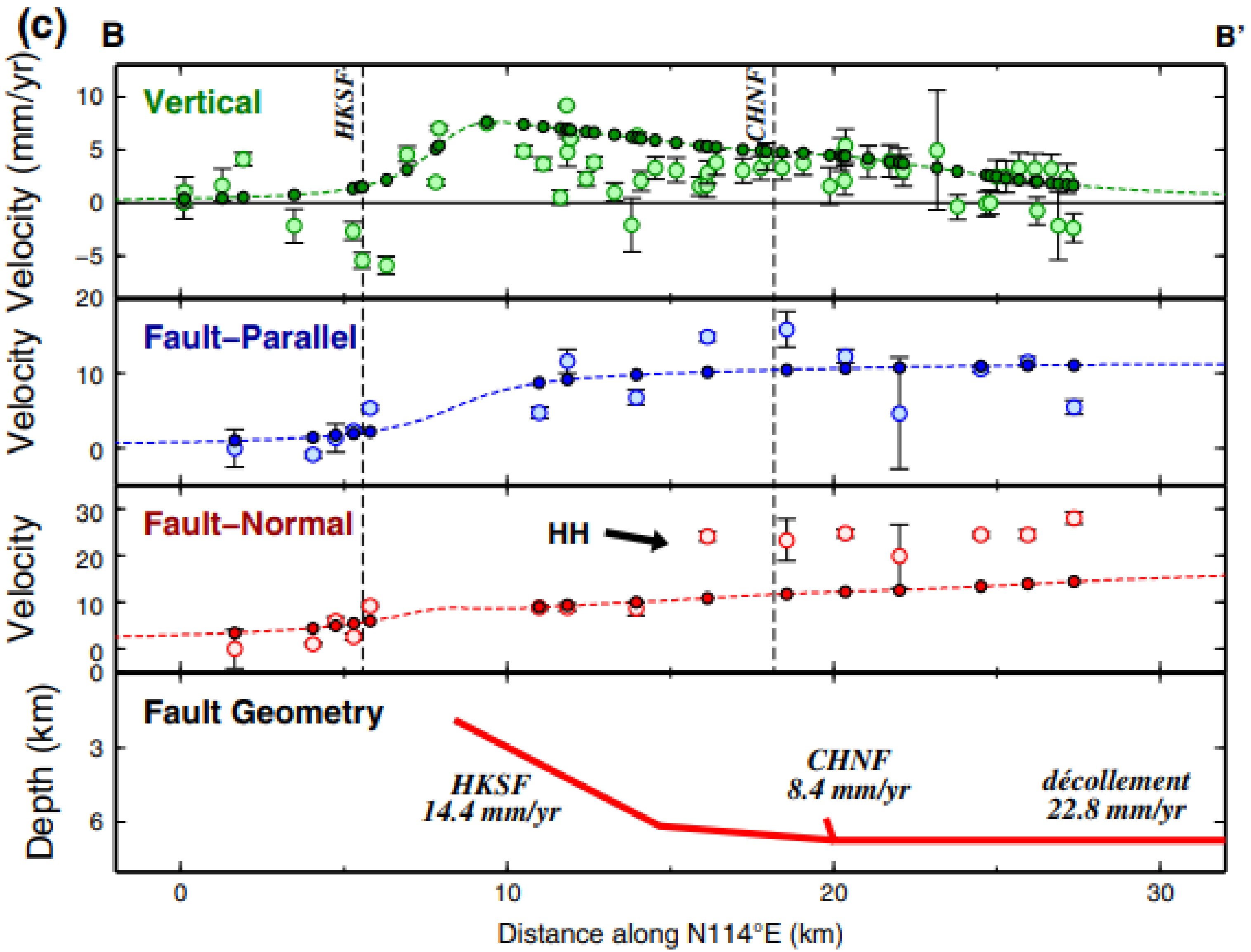


(Hsu, 2012)

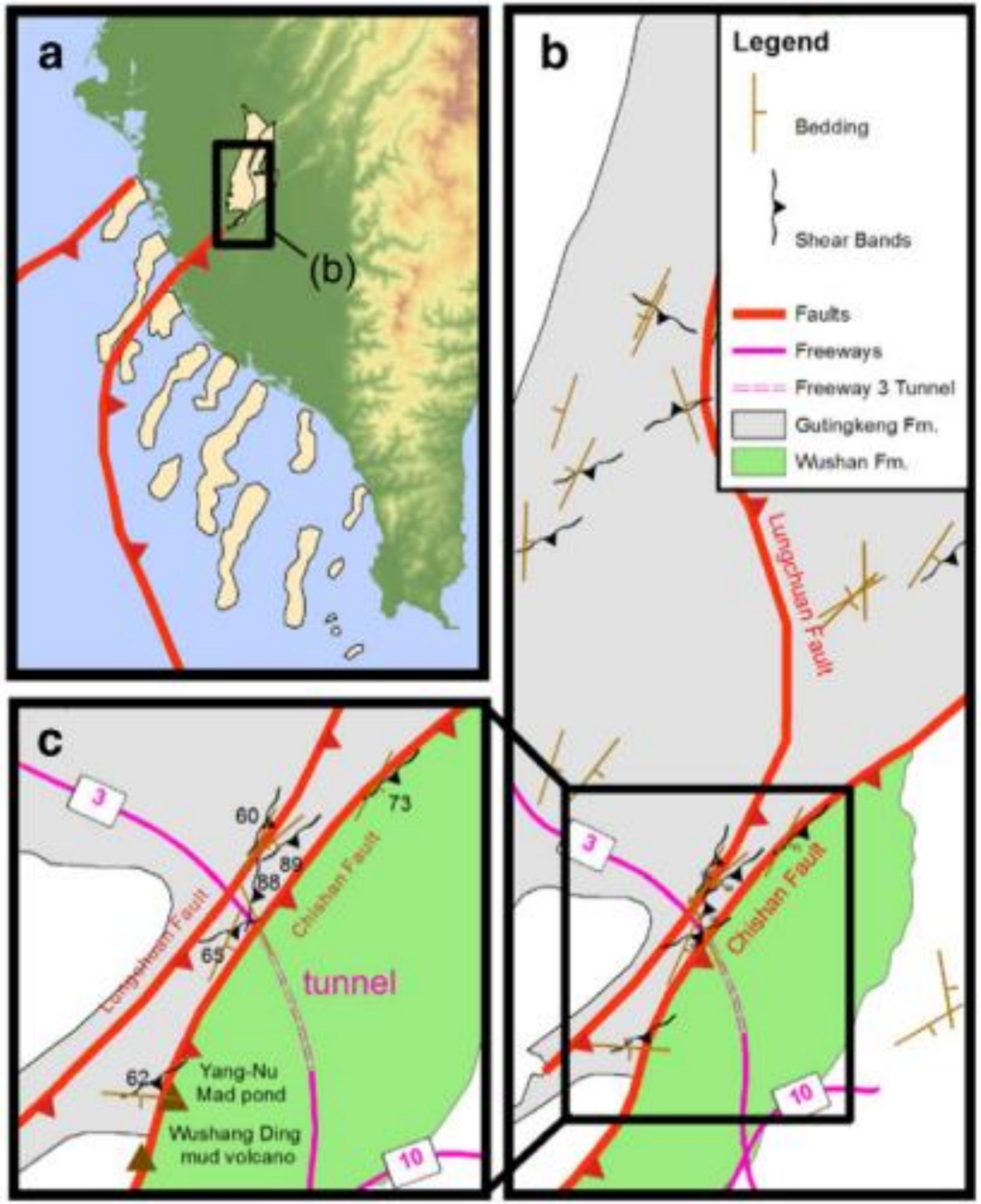
A-A′ profile


(b)
A
A'
Vertical
HKSF
CHNF
HU
Velocity (mm/yr)
25
20
15
10
5
0
−5
Fault−Parallel
Velocity
20
10
0
Fault−Normal
HH
Velocity
30
20
10
0
Fault Geometry
Depth (km)
0
3
6
HKSF
24.3 mm/yr
CHNF
1.1 mm/yr
décollement
25.3 mm/yr
0
10
20
30
Distance along N114°E (km)

B-B′ profile


(c)
B
B'
Vertical
HKSF
CHNF
Velocity (mm/yr)
10
5
0
−5
Fault−Parallel
Velocity
20
10
0
Fault−Normal
HH
Velocity
30
20
10
0
Fault Geometry
Depth (km)
0
3
6
HKSF
14.4 mm/yr
CHNF
8.4 mm/yr
décollement
22.8 mm/yr
0
10
20
30
Distance along N114°E (km)

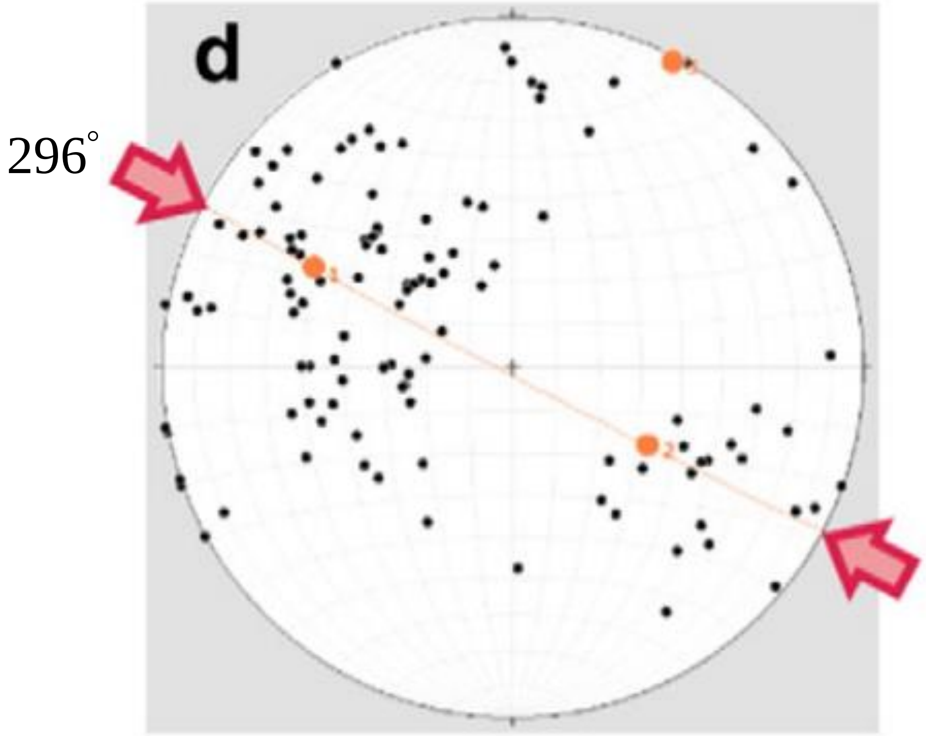
Discussion



a
(b)
b
Legend
Bedding
Shear Bands
Faults
Freeways
Freeway 3 Tunnel
Gutingkeng Fm.
Wushan Fm.
Lungchuan Fault
Chishan Fault
3
10
c
3
60
73
89
88
65
Lungchuan Fault
Chishan Fault
tunnel
62
Yang-Nu
Mad pond
Wushang Ding
mud volcano
10

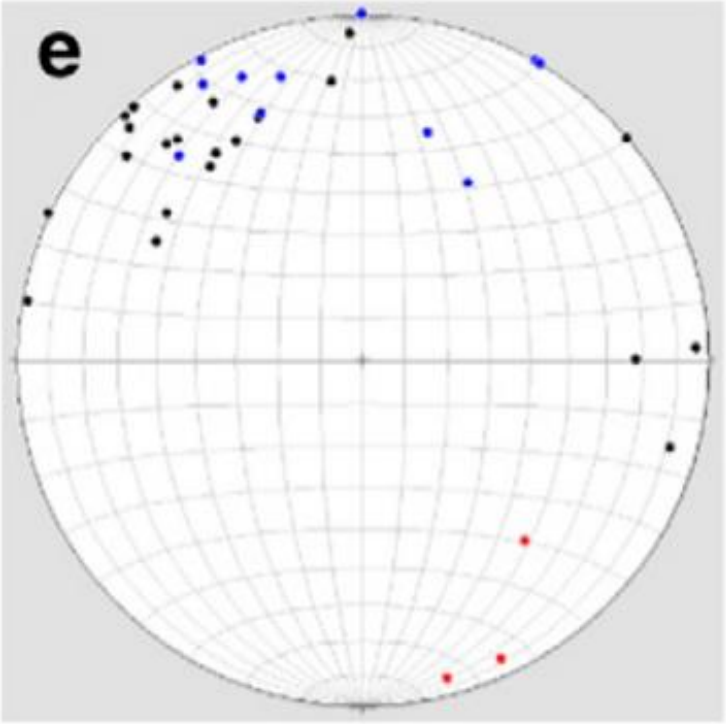
Stereonet

Bedding



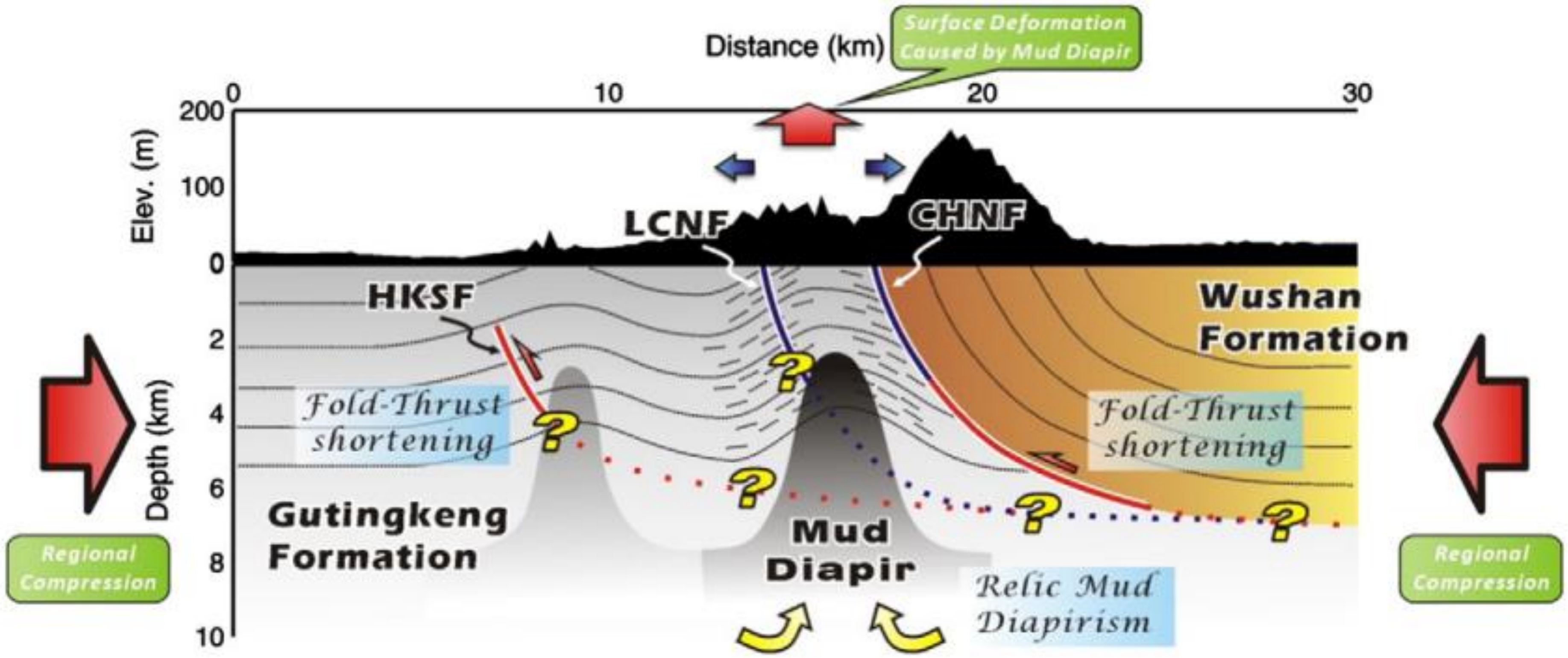
n = 113;
trend and plunge of fold axis = 028/02

Shear band

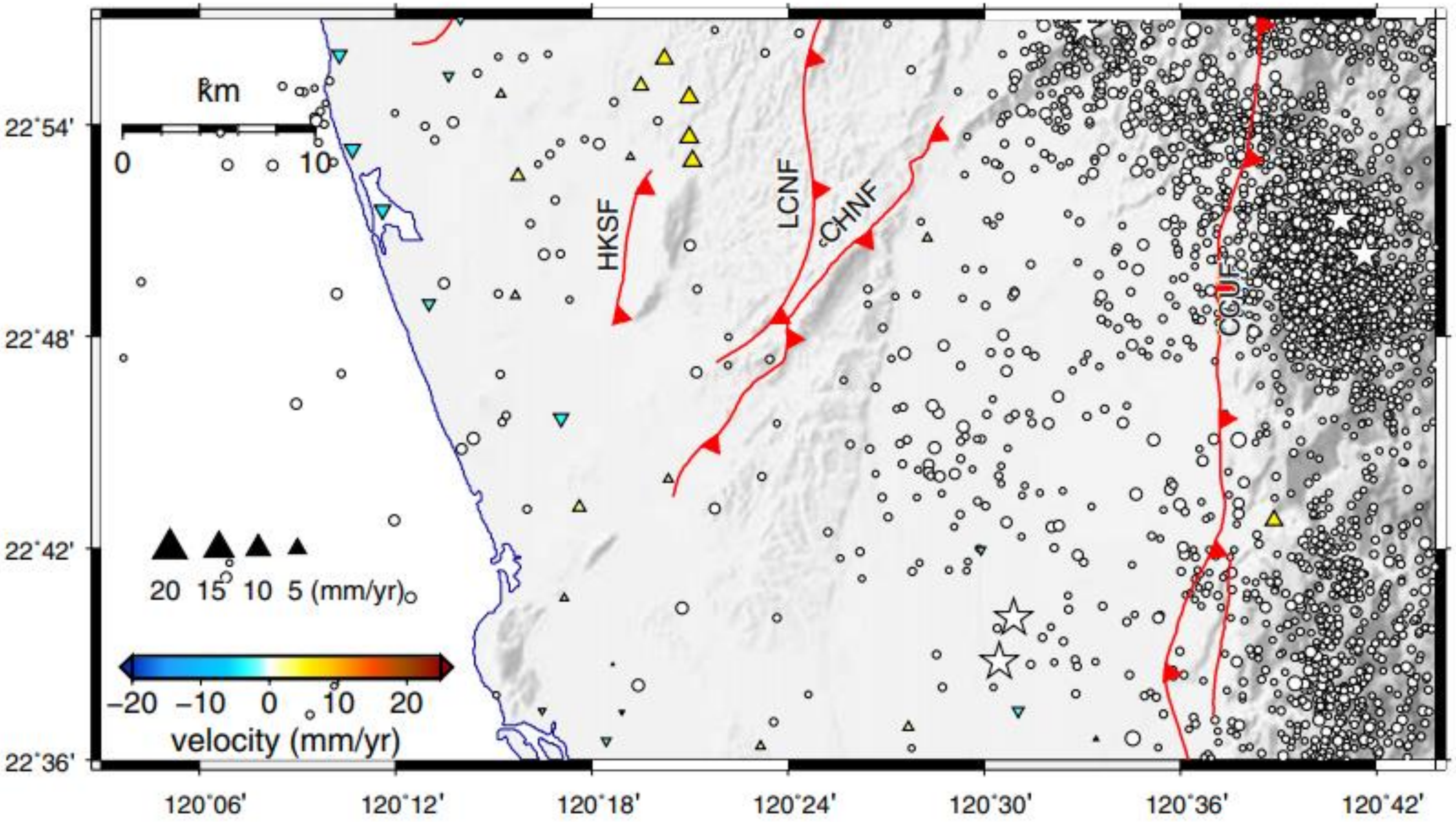


black poles = Eastern region, n = 22
blue poles = western region, n = 11
red poles = northern region, n = 3

Mud Diapir cause the uplift ?



High earthquake potential in SW Taiwan ?



High earthquake potential in SW Taiwan ?

- A high velocity gradient of ~15 mm/yr between the HKSF and the CHNF.
- High strain rates at the mudstone region of the Gutingkeng formation may not directly imply the accumulation of the seismic moment.
- The short-term uplift rates inferred in our study are very close to the longer-term uplift rates that are observed near the HKSF with the vertical velocities of ~ 5 mm/yr.

Conclusion

- The geodetic data does not fit the 2D dislocation model well. Therefore another mechanism must be considered in the result.

- In terms of our field investigations, the Gutingkeng formation has been rising relative to surrounding geologic units, which is interpreted as an onshore mud diapir dominated by vertical tectonics.

- The CHNF or the décollement here still has the possibility to generate destructive earthquakes in SW Taiwan in the future.

Thanks for your attention ~

Precise Leveling

- First, the maximum permissible difference in sight lengths between forward and backward sights is 0.5 m per set-up, and the cumulative difference is limited to 1.5 m per section.
- Second, the maximum length of sight is restricted to 30 m for greatly reducing the influence of atmospheric refraction. The minimum and maximum sight ground clearances are 0.3 m and 2.7 m, respectively.
- Third, the maximum standard deviation of each leveling reading in a set-up is ±0.2 mm.
- Finally, the maximum difference of the two height differences from the double readings at a set-up is limited to 0.4 mm. Besides, the maximum misclosure between forward and backward runs in a section is limited to ±2.0 mm $\sqrt{k}$ (k being the section distance in km).

Campaign-mode GPS

Horizontal velocity field

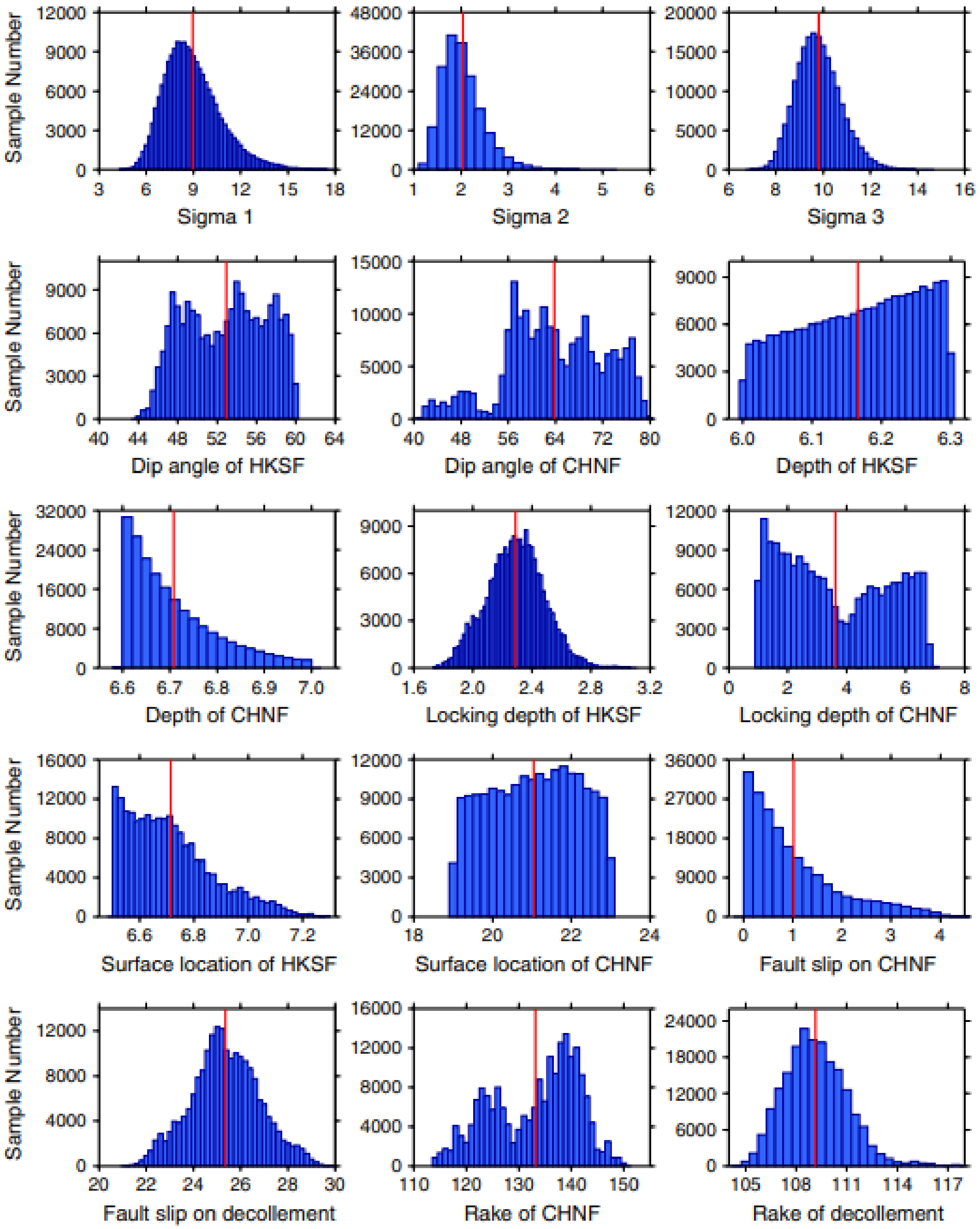
$$x_n^i(t) = a_n^i + b_n^i t + v_n^i$$

$x_n^i(t)$ ： observed displacement of each station
t ： units of year
a_n^i ： linear velocity of the station
b_n^i ： intercept
v_n^i ： residual

Precise Leveling

Vertical velocity field

Posterior probability distributions for the inversion of 2–D fault model in AA’ profile



Posterior probability distributions for the inversion of 2–D fault model in BB' profile