An Introduction to Turbidites in the Deformed Retrowedge Foredeep Basin, Coastal Range of Eastern Taiwan

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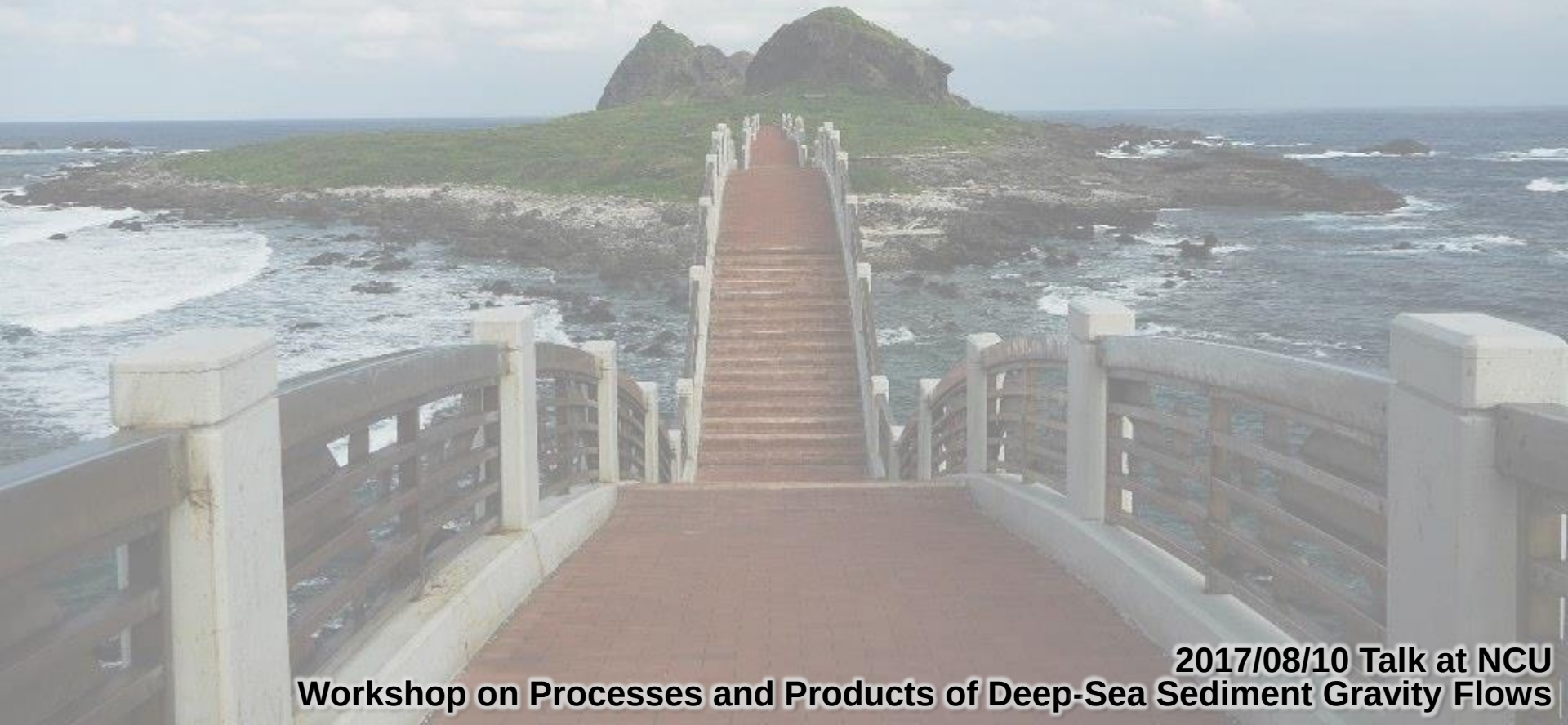
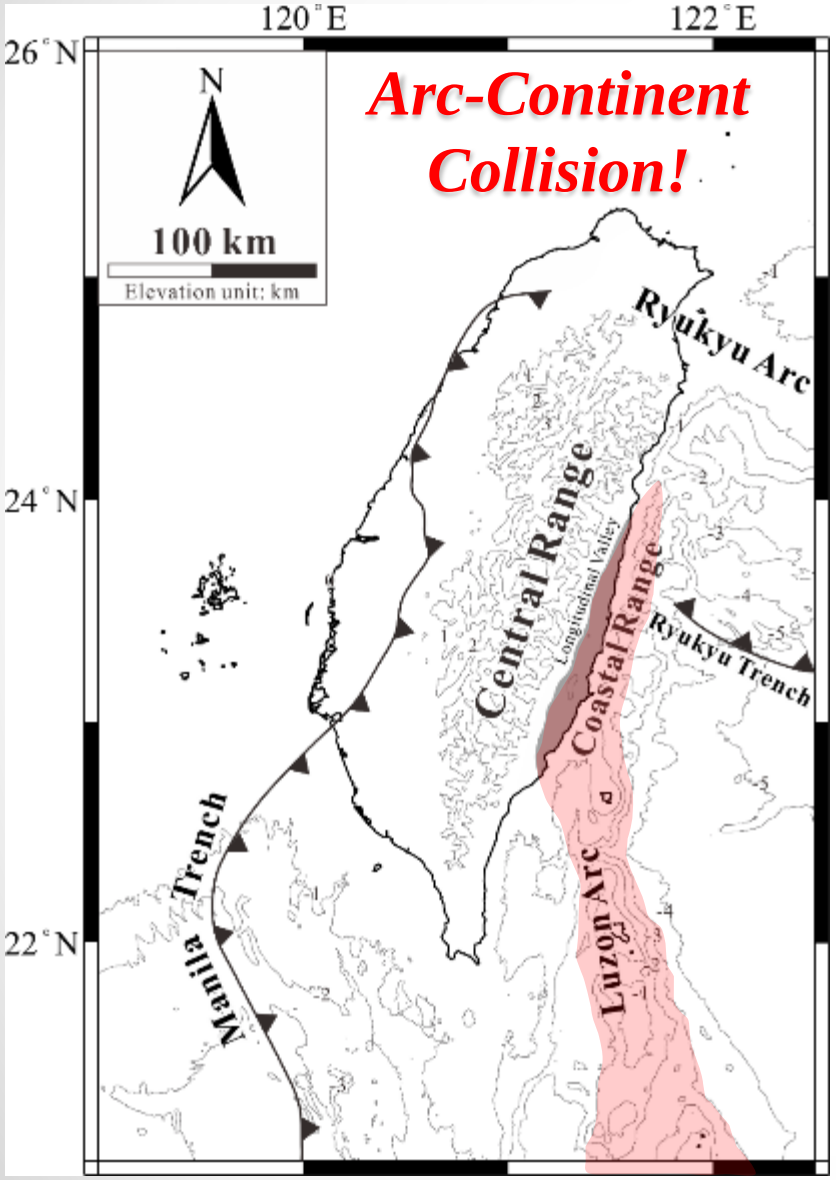
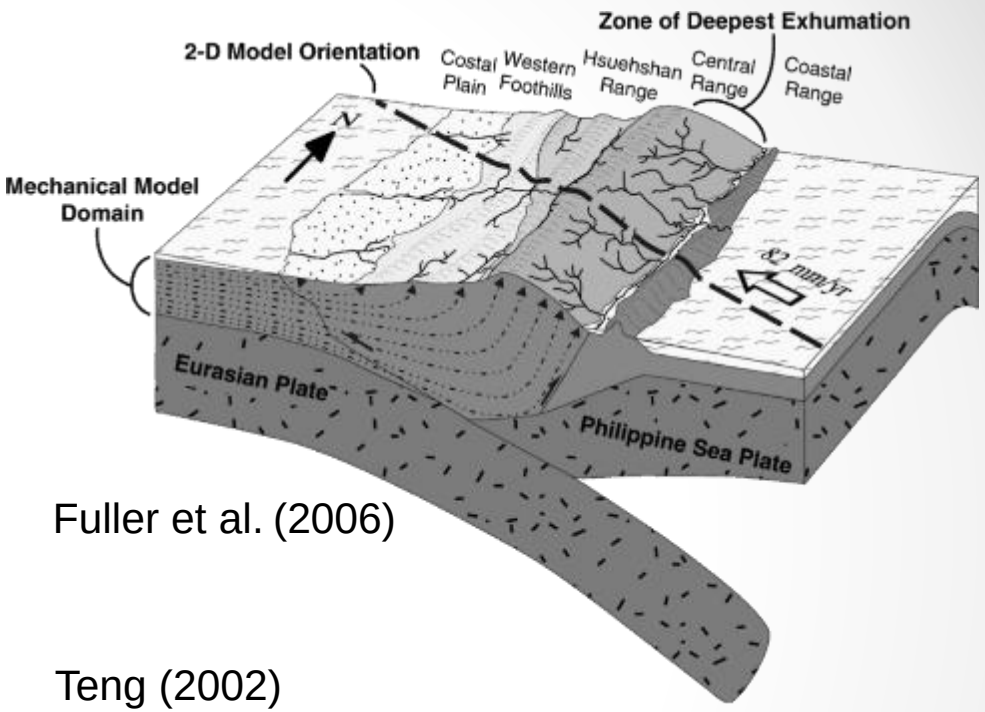


2017/08/10 Talk at NCU
Workshop on Processes and Products of Deep-Sea Sediment Gravity Flows

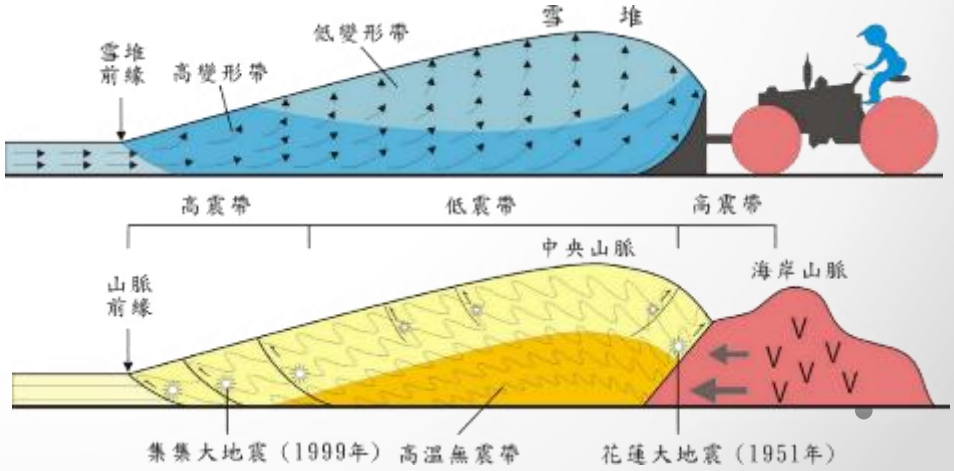
Geological Background





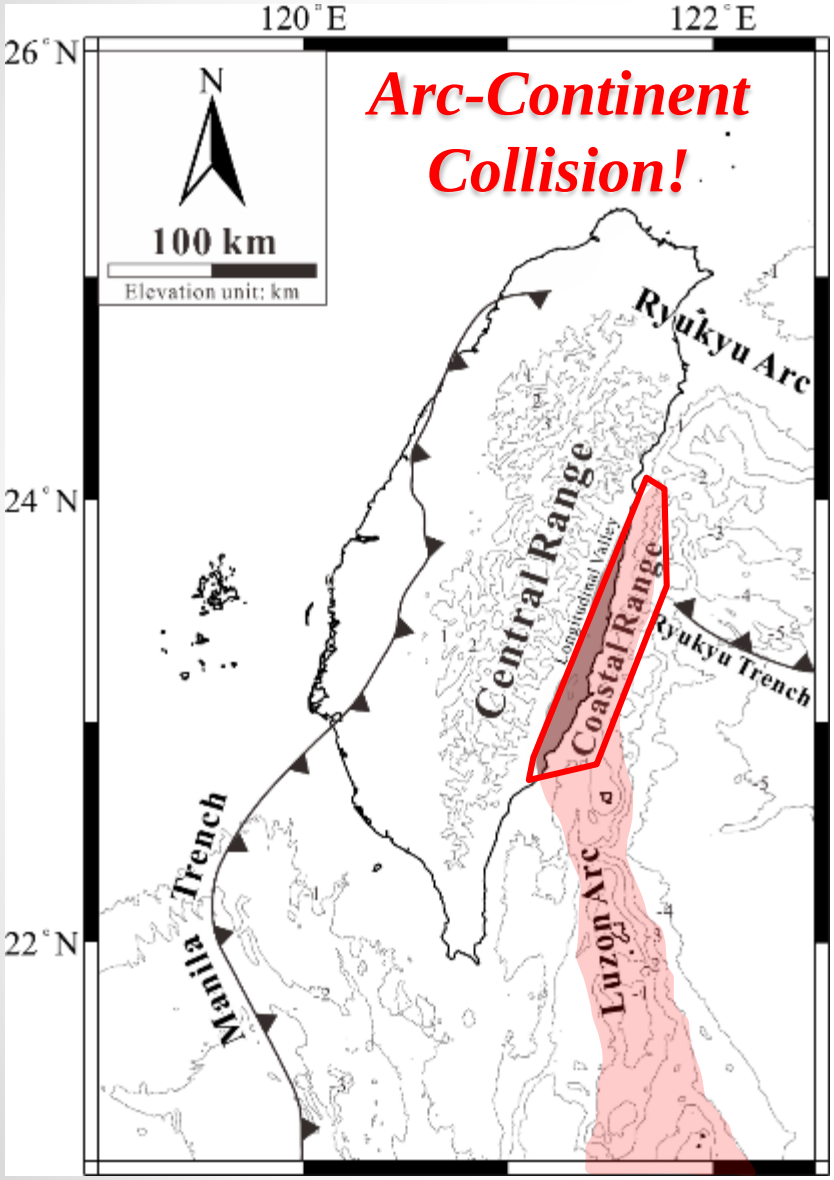
Fuller et al. (2006)

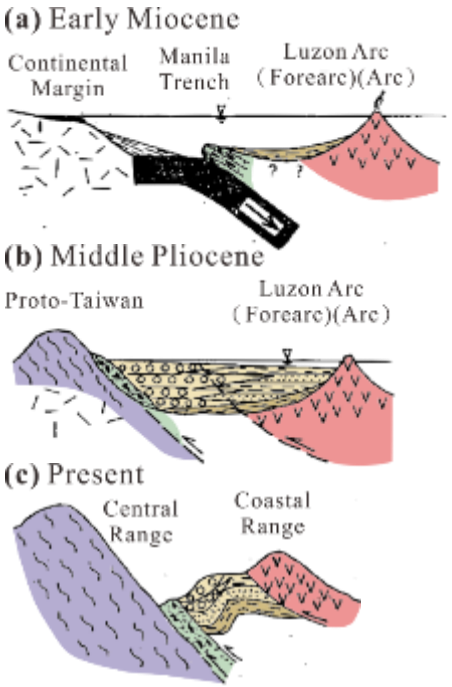
Teng (2002)
Originated by Dr. Suppe



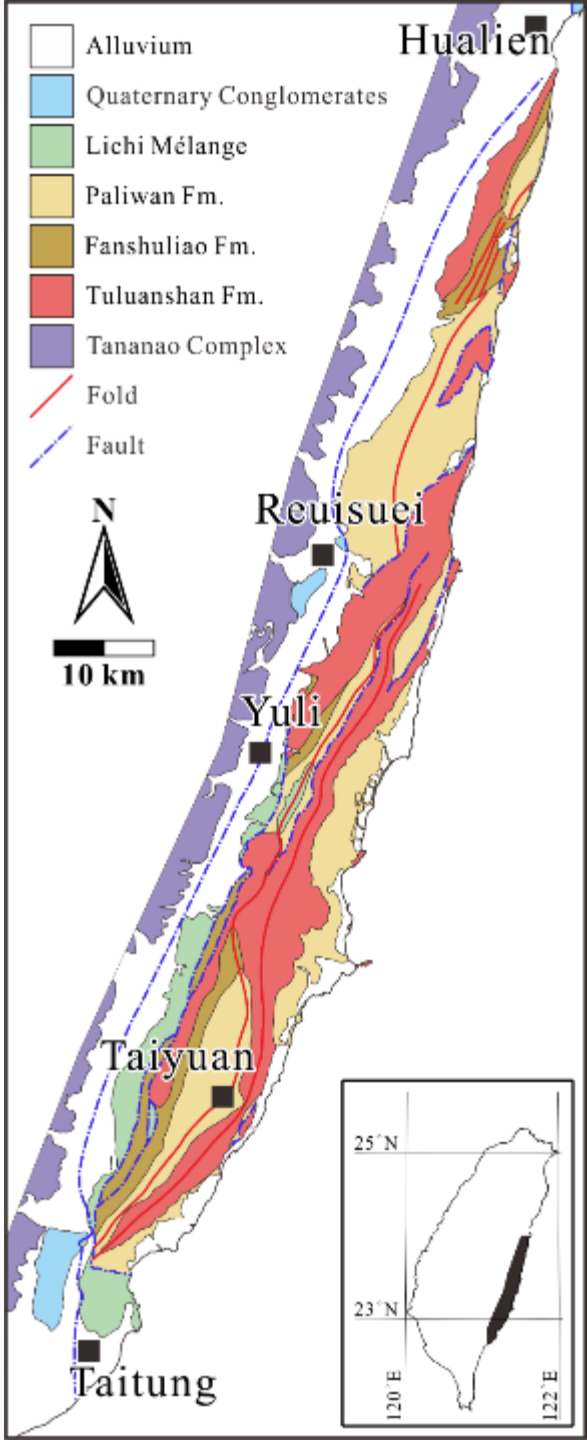
The Coastal Range

Deformed northern Luzon Arc





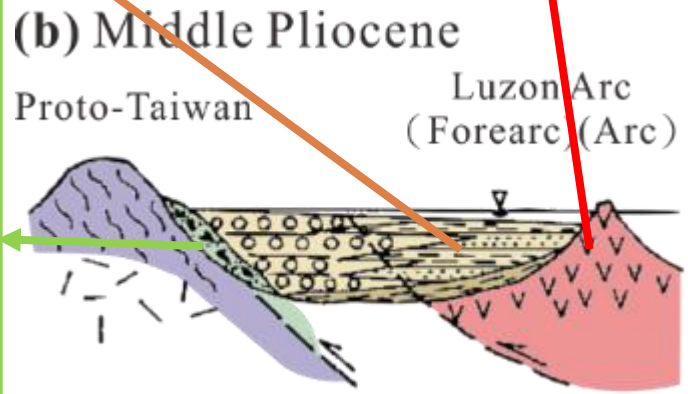
Modified from
Teng & Wang (1981)



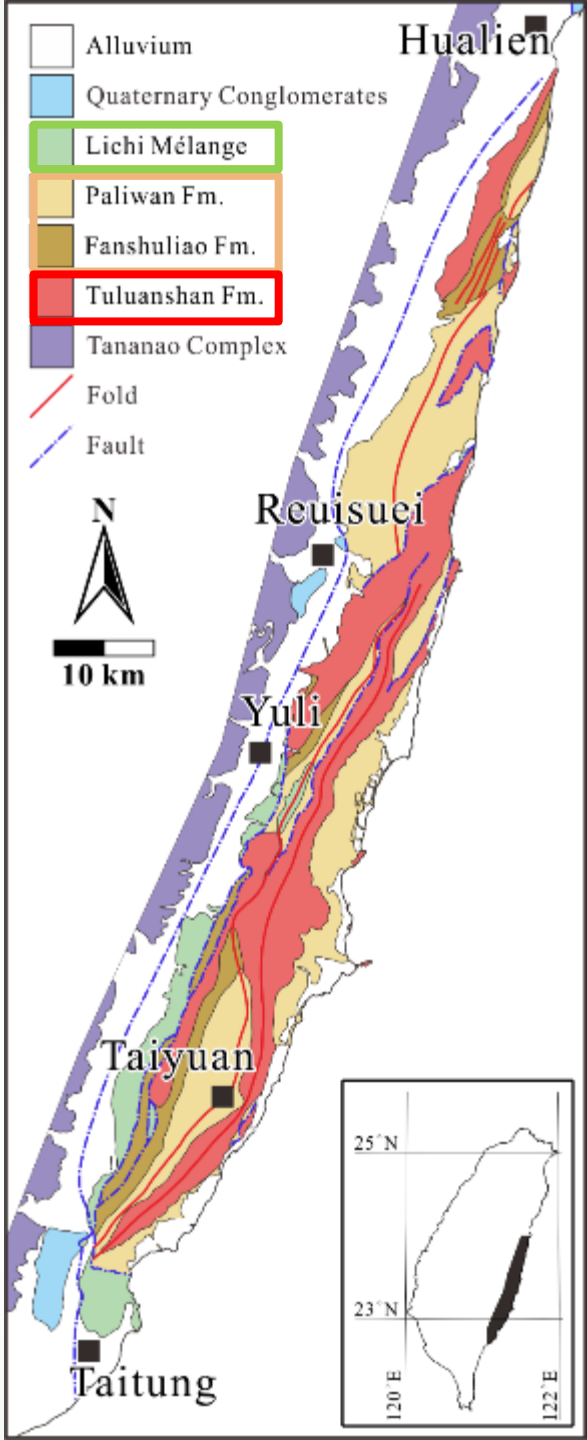
Modified from
Wang and Chen (1993)

The Coastal Range

Main rocks of the Coastal Range



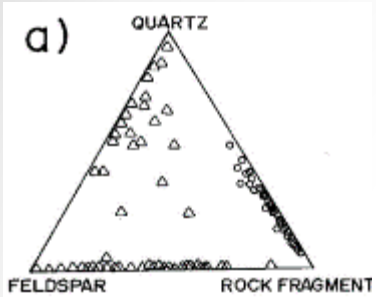
Teng and Wang (1981)



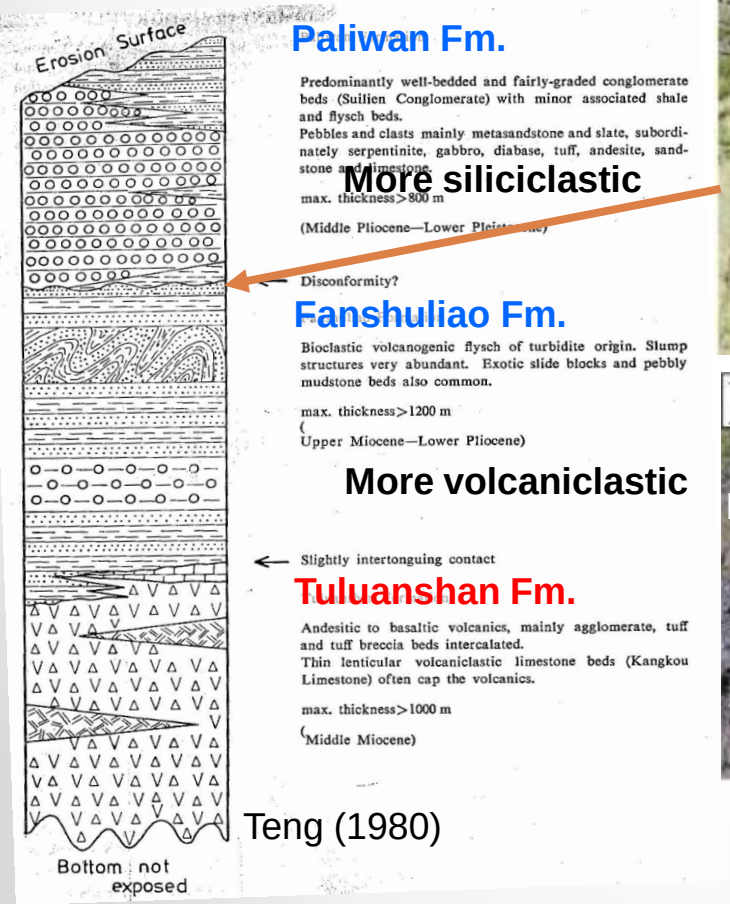
Modified from
Wang and Chen (1993)

The Coastal Range

Type Section in the northern Coastal Range



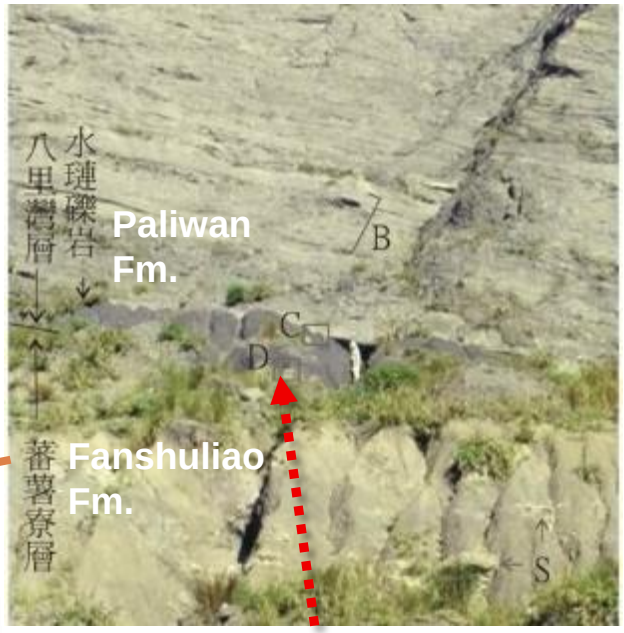
Divided by lithology of sandstone
Teng (1987)



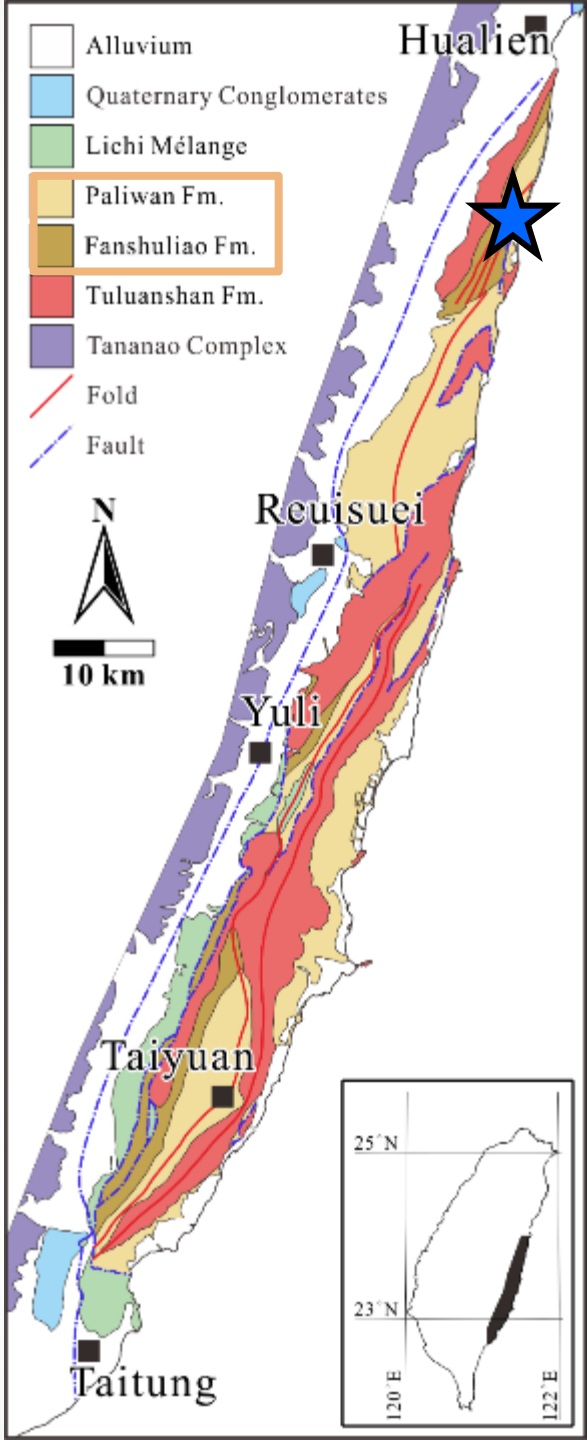
Teng (1980)

More siliciclastic

More volcaniclastic

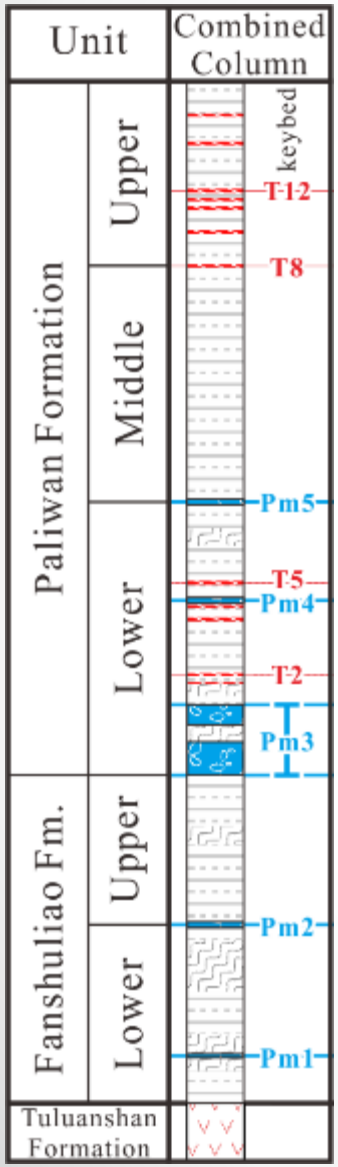


Modified from Wang and Chen (1993)



The Coastal Range

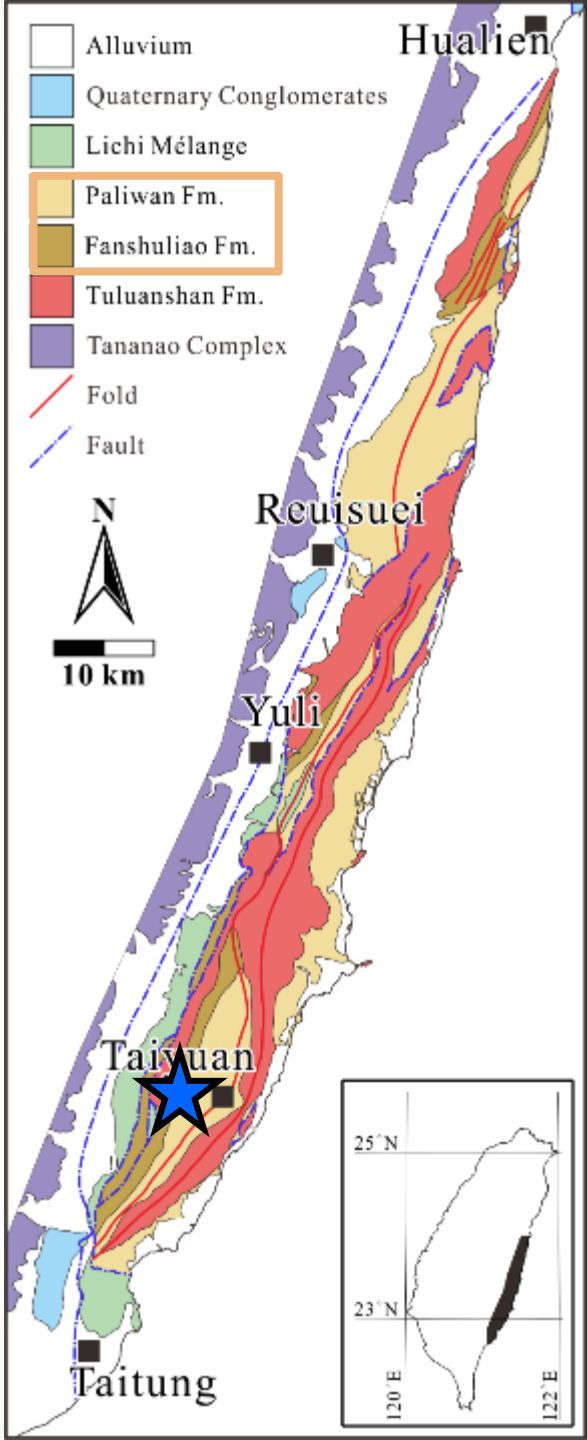
Type Section in the southern Coastal Range



Differences of Fanshuliao Formation from south to north:

- **Color:** gray in south, brown in north
- **Definition of formation boundary:** base of pebbly mudstone in south, sharply contact (disconformity?) in north.
- **Age:** ~3.5-2 Ma in south, ~4-3 Ma in north

Modified from Lai & Teng (2016)

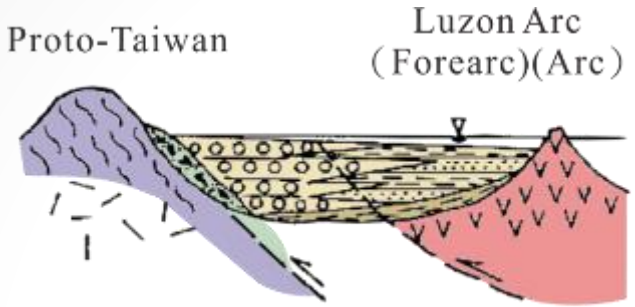


Modified from Wang and Chen (1993)

The Coastal Range

Deformed northern Luzon Arc

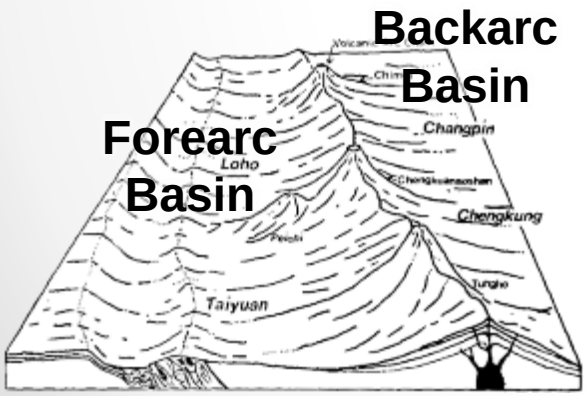
Forearc (Collisional) Basin Teng 1988; Dorsey (1988); Chen (2009)



Teng & Wang (1981)

Backarc Basin (?)

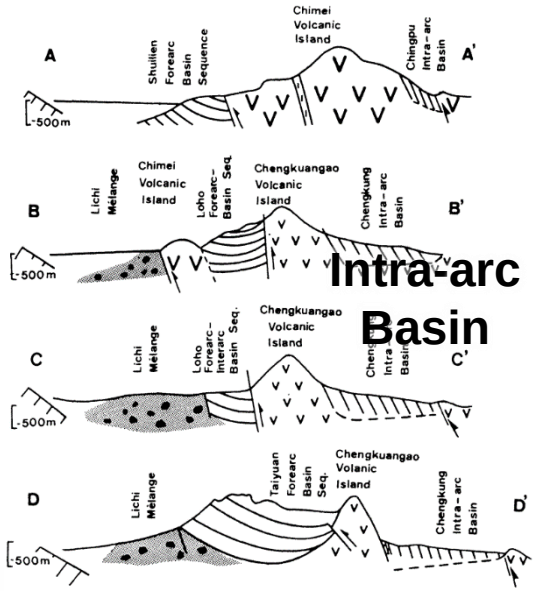
Chen (1988); Song & Lo (2002)
Lai & Song (2013)



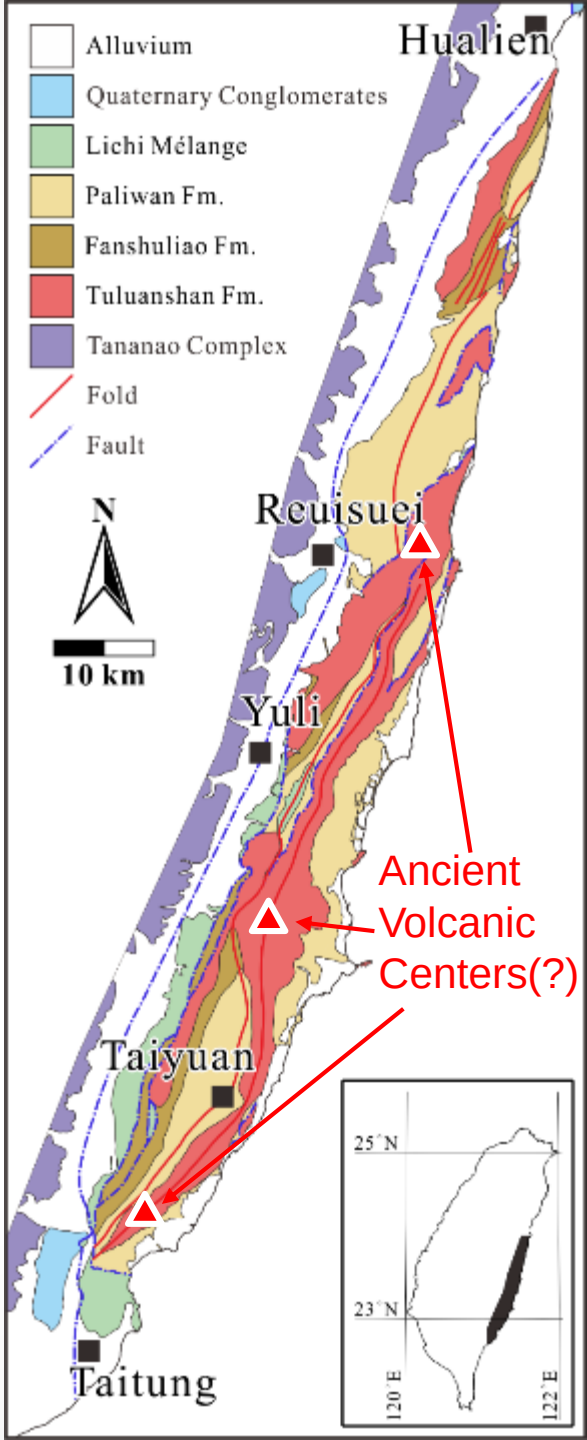
Chen (1988)

Intra-arc Basin (?)

Huang *et al.* (1995);(2006)



Huang *et al.* (1995)

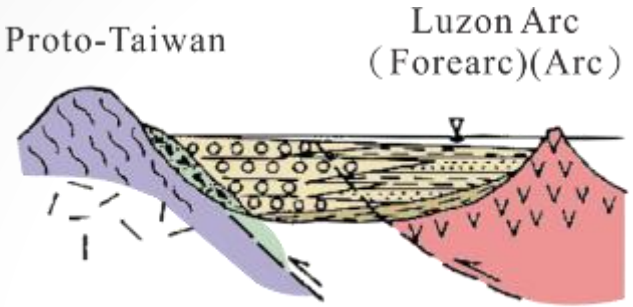


Modified from
Wang and Chen (1993)

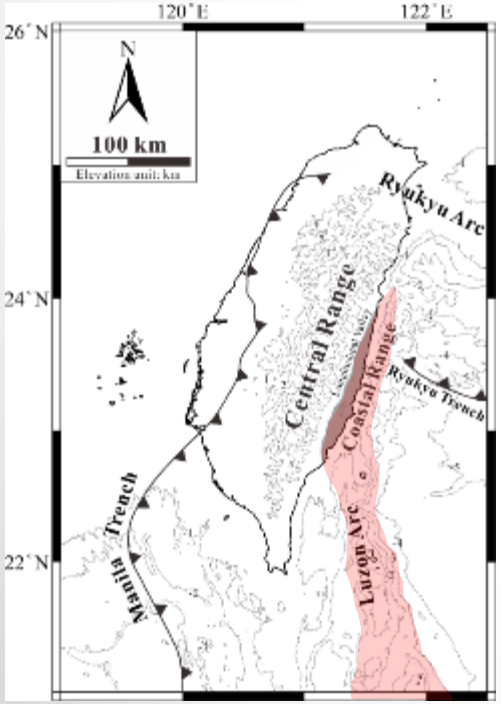
The Coastal Range

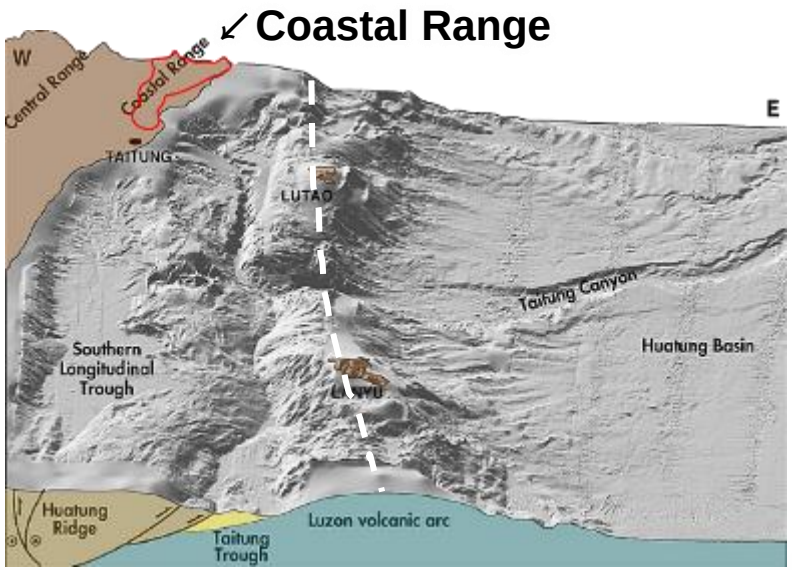
Deformed northern Luzon Arc

Forearc (Collisional) Basin Teng 1988; Dorsey (1988); Chen (2009)

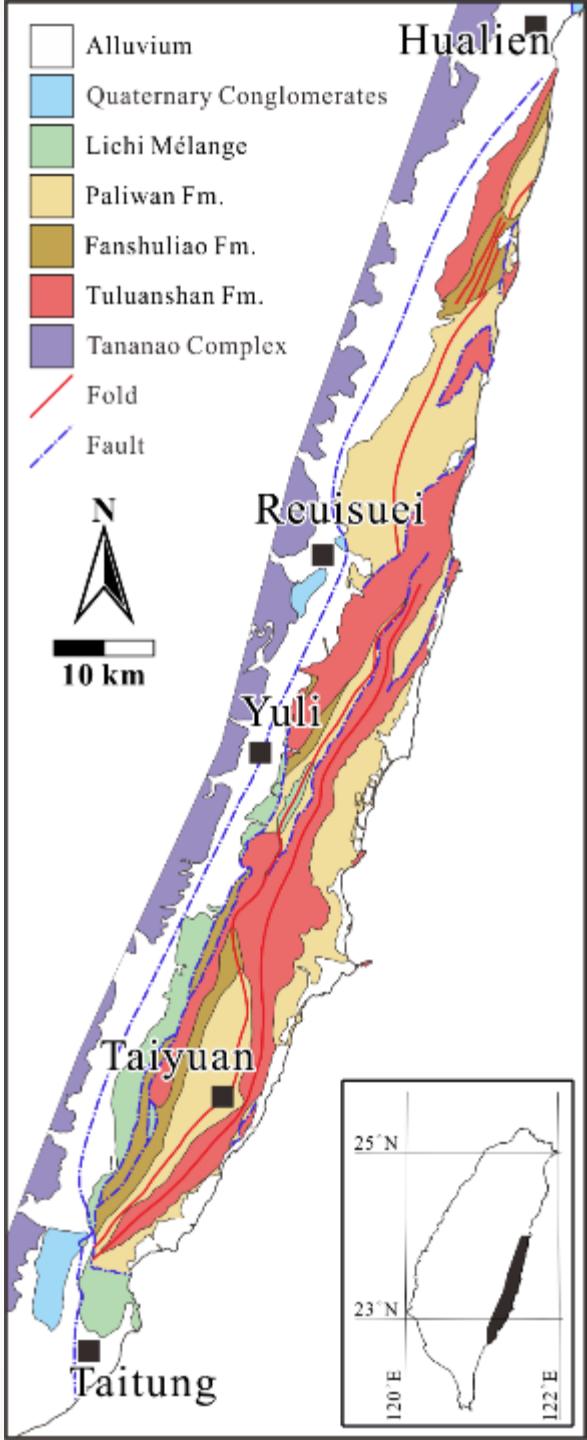


Teng & Wang (1981)





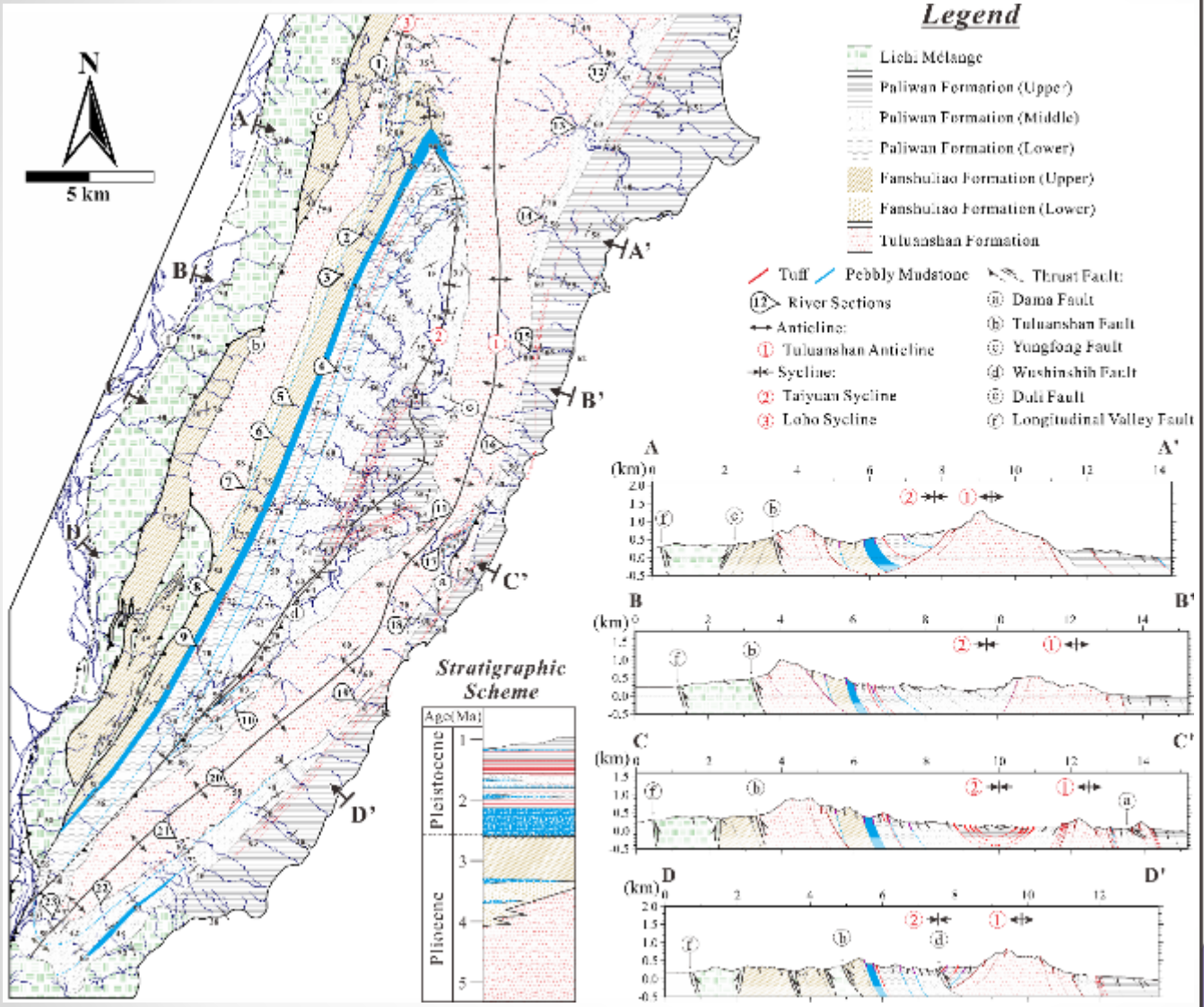
Malavieille *et al*. (2002)



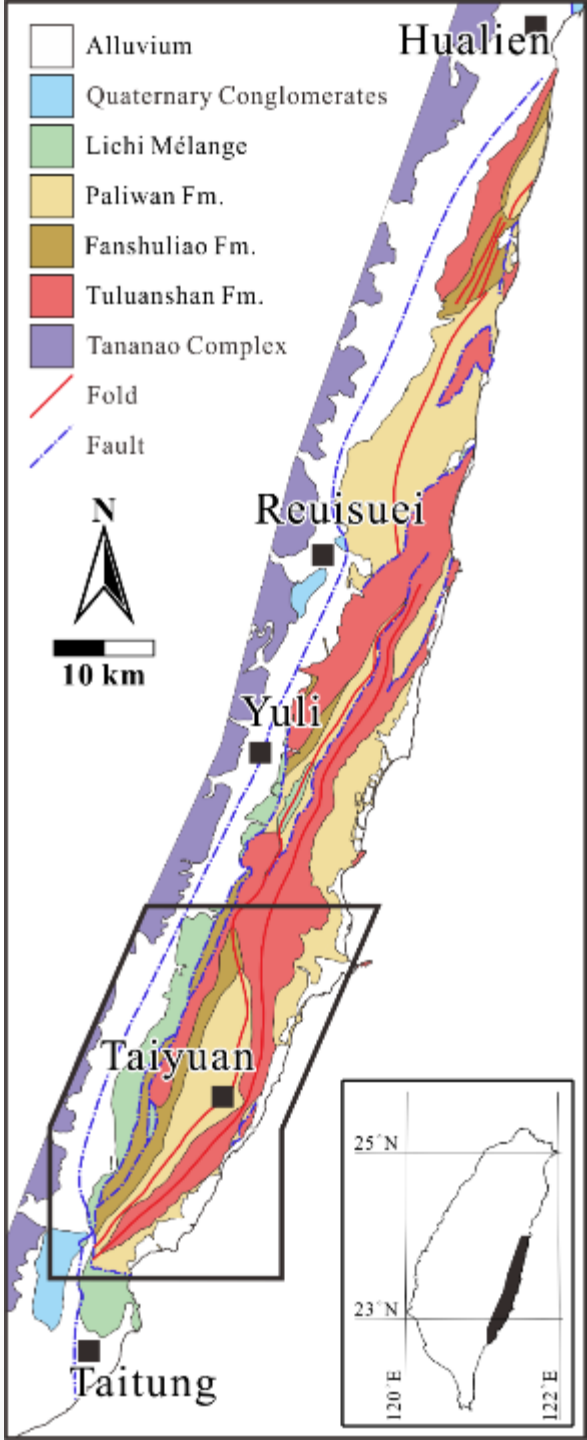
Modified from
Wang and Chen (1993)

The Coastal Range

Deformed northern Luzon Arc



Lai *et al.* (2017) FACET II Poster



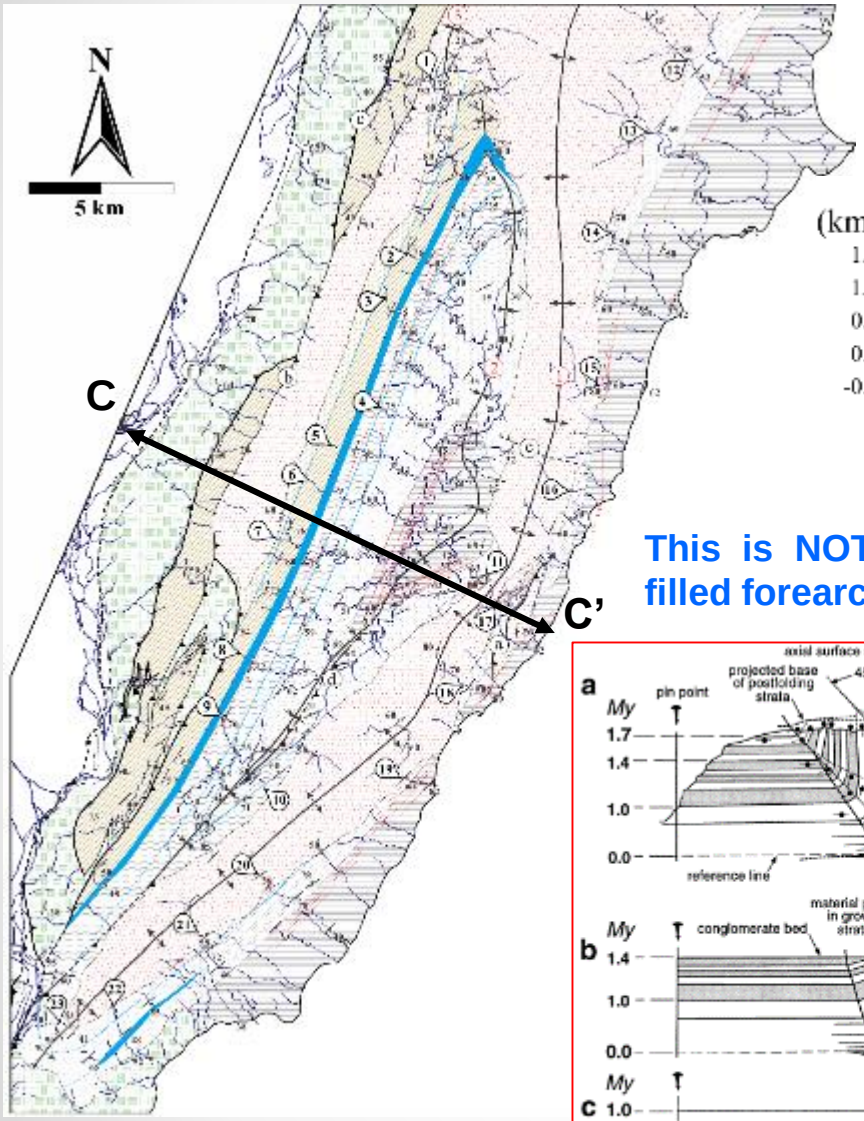
Modified from
Wang and Chen (1993)

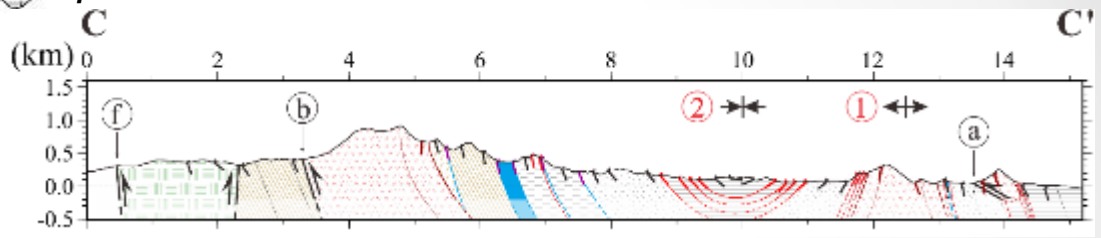
The Coastal Range

Deformed northern Luzon Arc

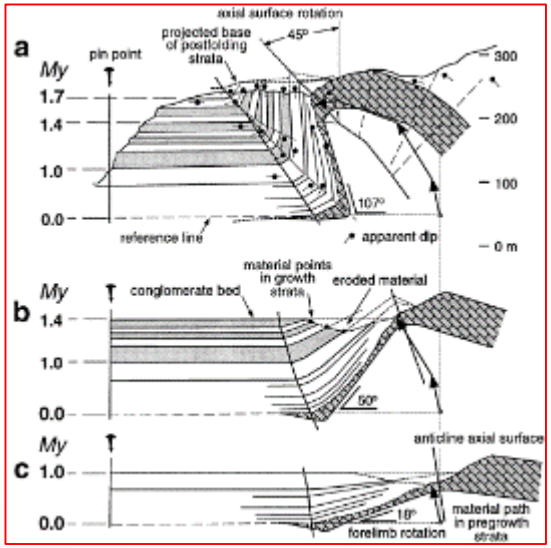
Growth Strata *formed by syn-depositional tilting and folding in a thrust-related syncline-anticline pair.*

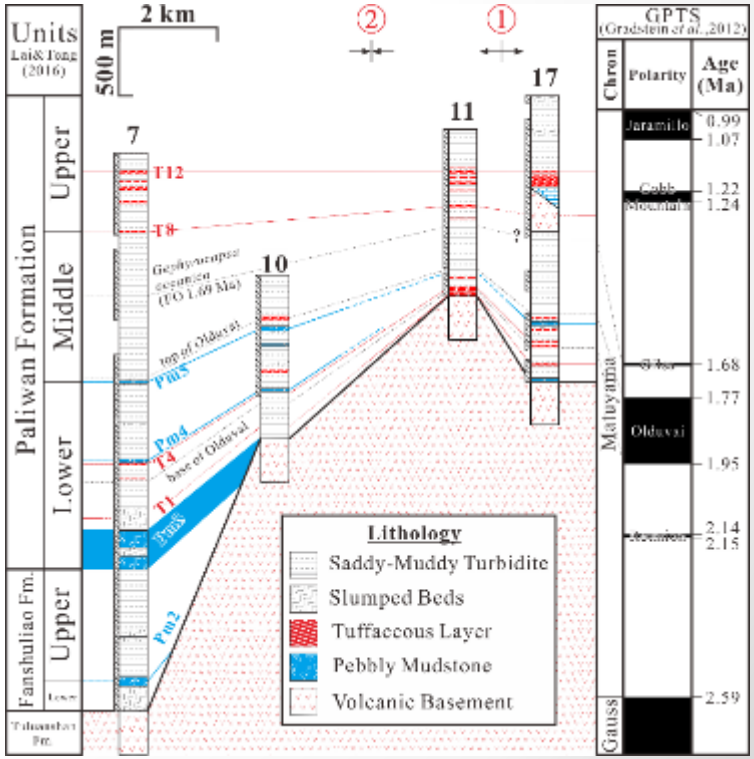
Lai *et al.* (2017) GSA Abstract





This is NOT a passively filled forearc basin!!!





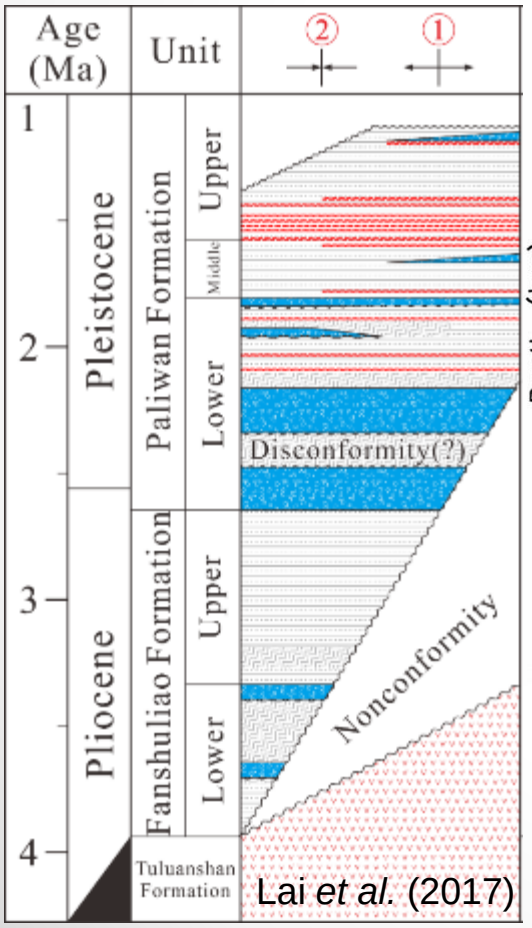
Lai *et al.* (2017) FACET II Poster

Burbank *et al*. (1996)

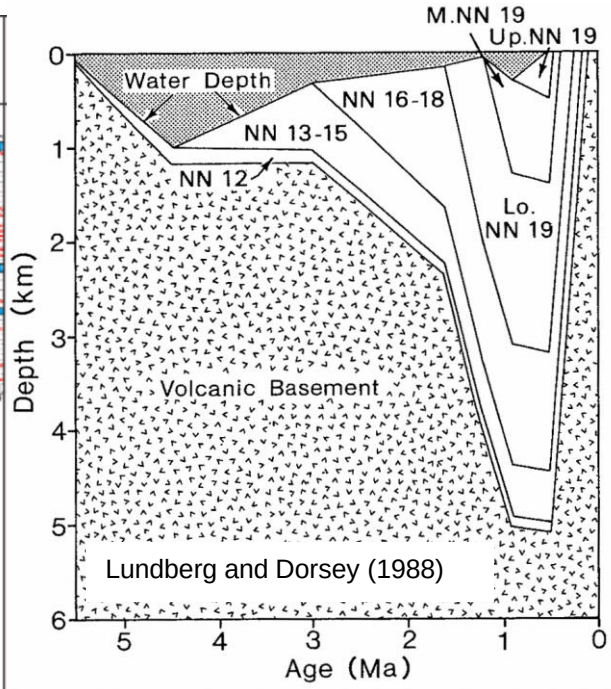
The Coastal Range

Deformed northern Luzon Arc

- **Erosional Unconformity** at base.
- **Stratal Onlap**: Basin moved toward thrust-belt load.
- **Subsidence**: Started slow, accelerated through time.
- **Abrupt Uplift at End**: Basin incorporated into orogen.



Lai *et al.* (2017)

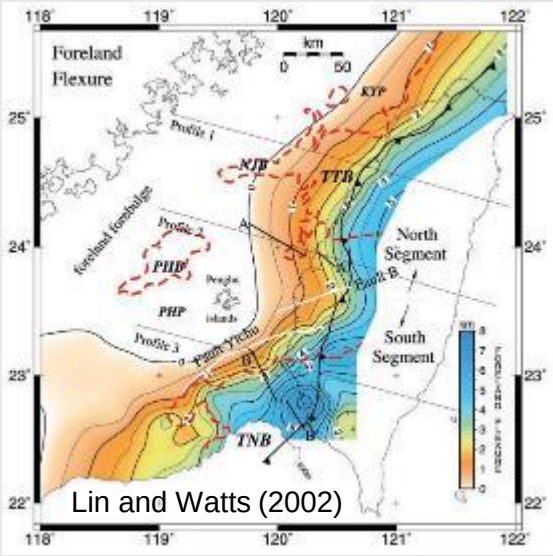


Lundberg and Dorsey (1988)

↑ Accelerated subsidence rate

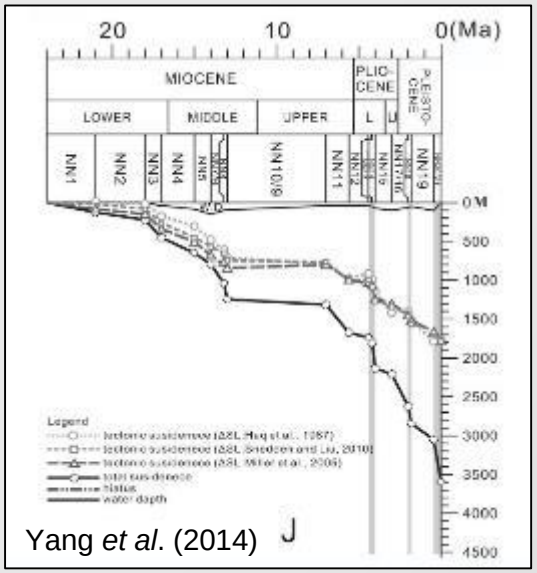
← Eastward younging basal mudstone

More similar to foreland basins in prowedge of Taiwan Orogen



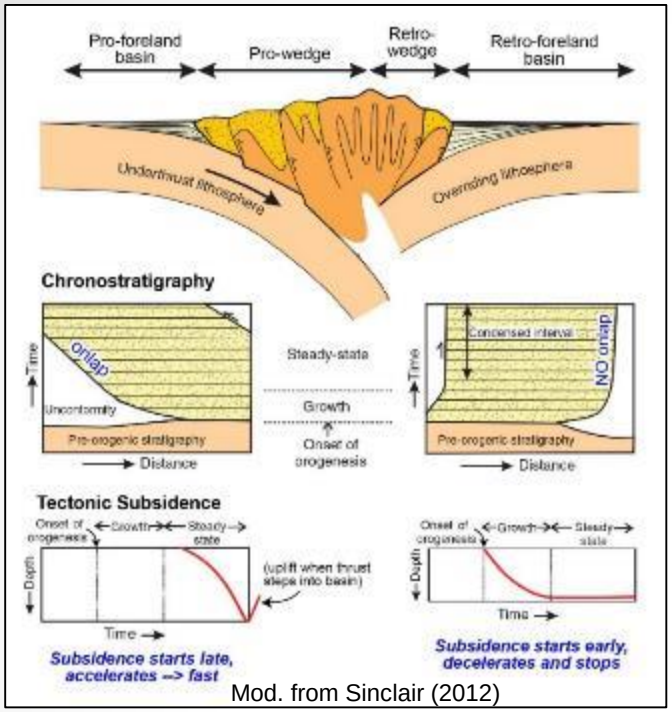
Lin and Watts (2002)

Depth to base of foreland basin sequence, west Taiwan

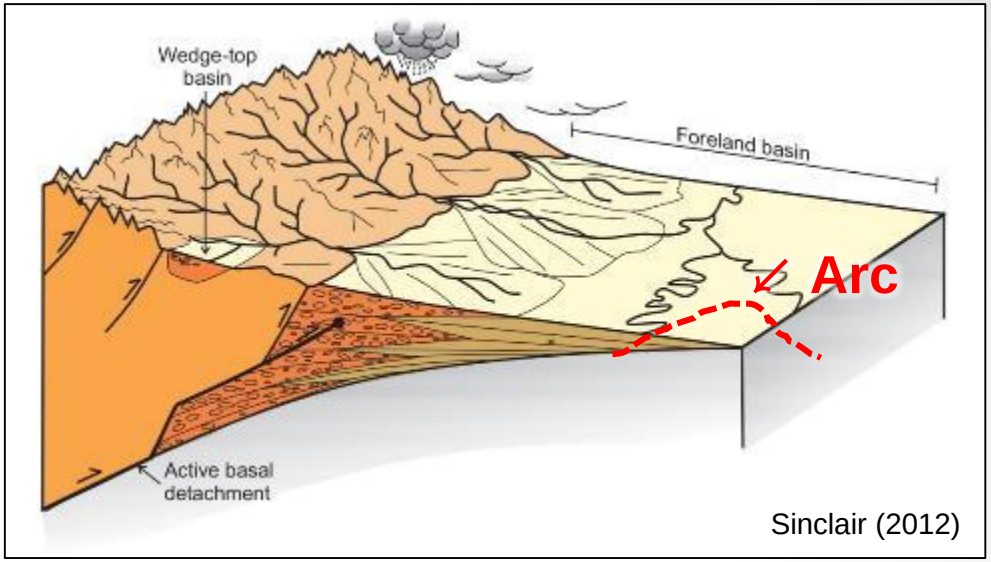


Yang *et al.* (2014)

Eastern Collisional Basin – Formed and Evolved as a Marine Foredeep



Mod. from Sinclair (2012)



Sinclair (2012)

	Predicted	Predicted	Observed
Basin Response:	**Pro**-foreland basin	**Retro**-foreland basin	**Eastern Taiwan Retrowedge Basin**
Stratal Onlap?	Yes	No	**Yes**
Subsidence Starts	Late: ***after*** onset of orogenesis	Early: ***at*** onset of orogenesis	**Early: *at* onset of orogenesis**
Subsidence Evolution	Accelerating, Rapid	Decelerating, Slow	**Accelerating, Rapid**
Steady-state subsidence?	Yes	No	***Uncertain***
Uplift at End?	Yes	No	**Yes**

Courtesy of Rebecca Dorsey

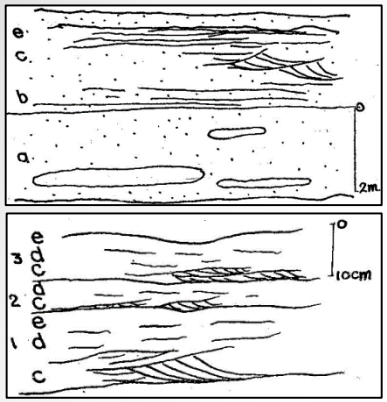
Turbidites in the Coastal Range

Before the concept of turbidite was established in 1960s……

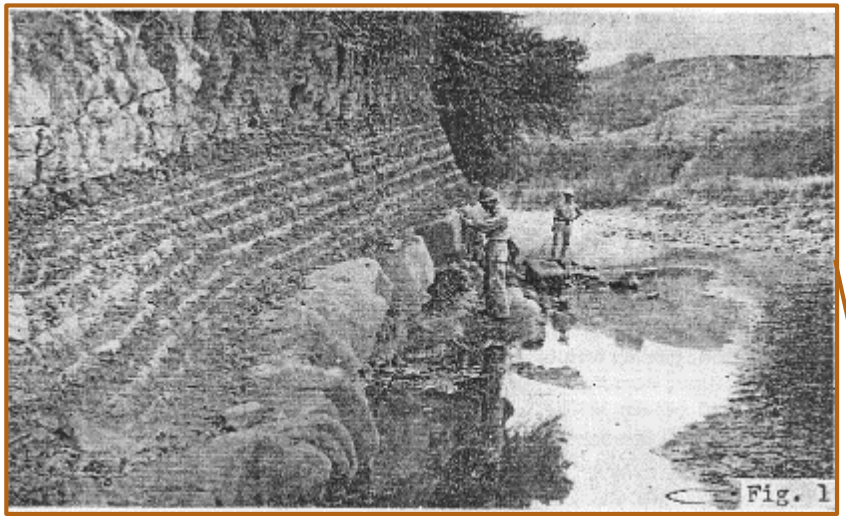
“Pebbly mud beds with slumping features.” (Hsu, 1954)
“Glacial pebbles bearing beds.” (Wang, 1956)

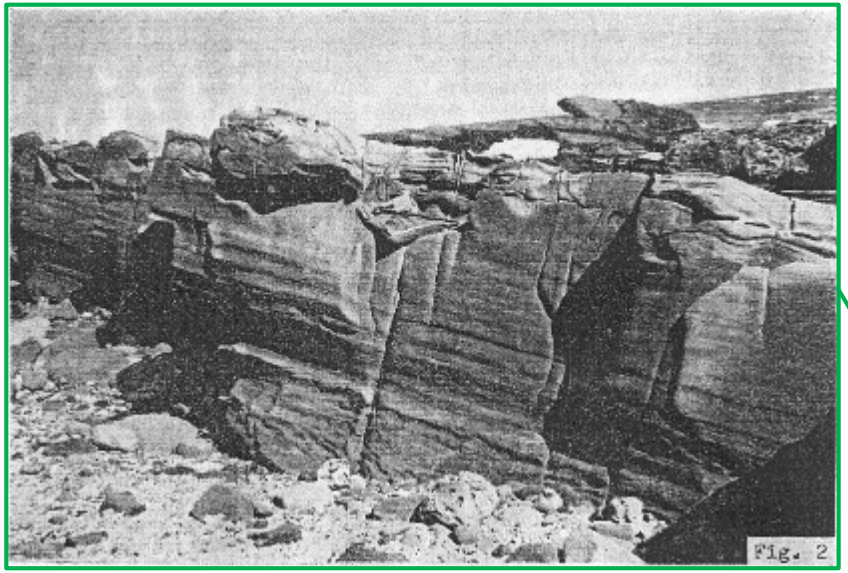
Turbidites in the Coastal Range

First report: Wang & Chen (1966)

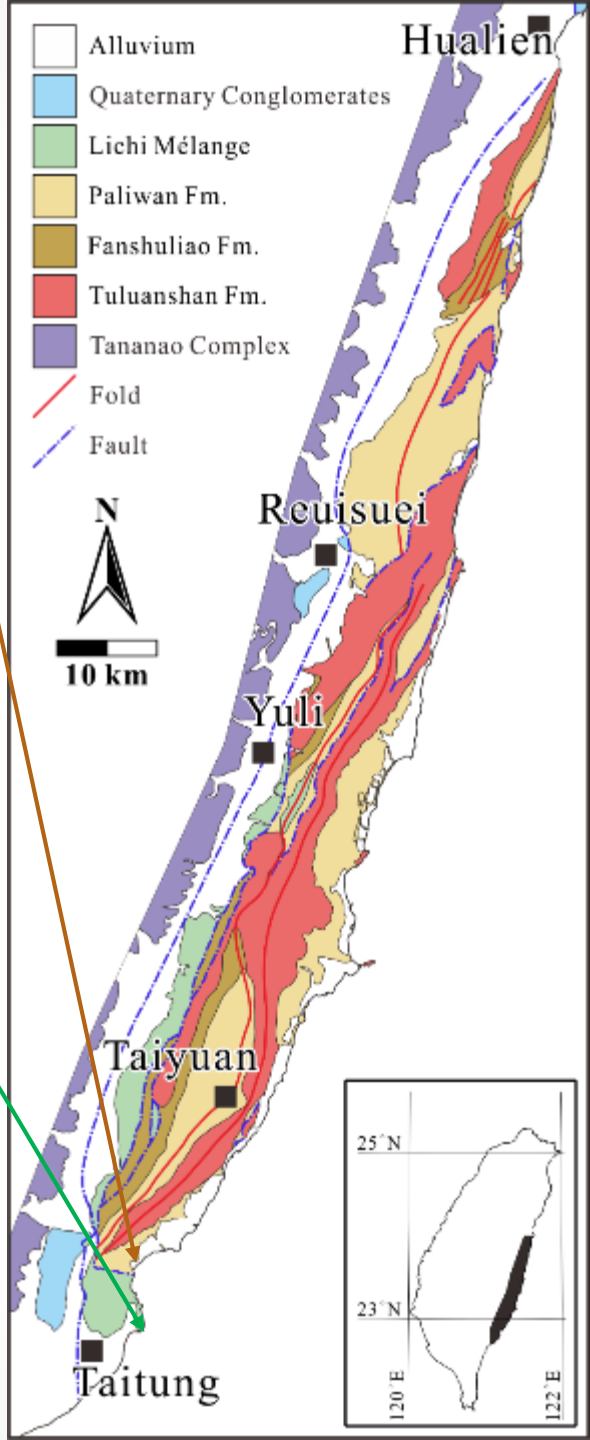


Deep-sea flysch deposits →





Overturned sandy turbidite **block** within Lichi Mélange →



Modified from Wang and Chen (1993)

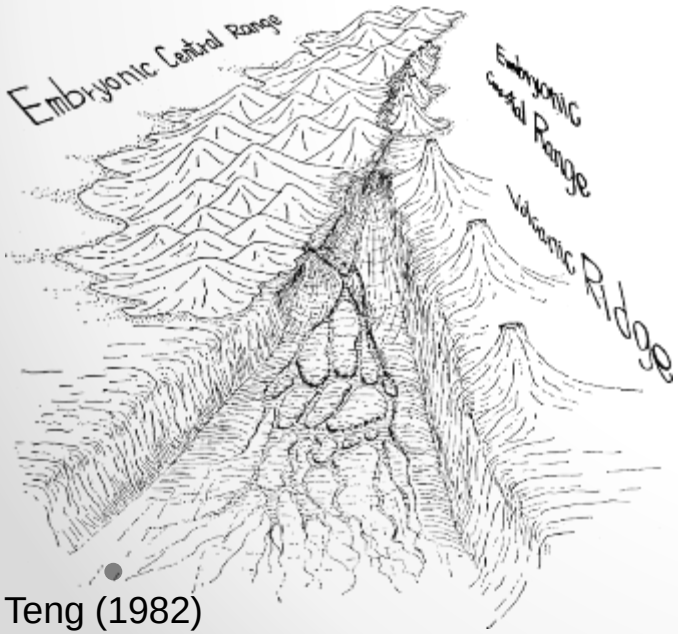
Turbidites in the Coastal Range

Orogen-derived deposits: *Paliwan / Fanshuliao Fm.*

- Dominated by coarse-grain to fine-grain turbidites.
- Associated with pebbly sandstone or mudstone beds, which deposited by the debris flow (or slurry flows).

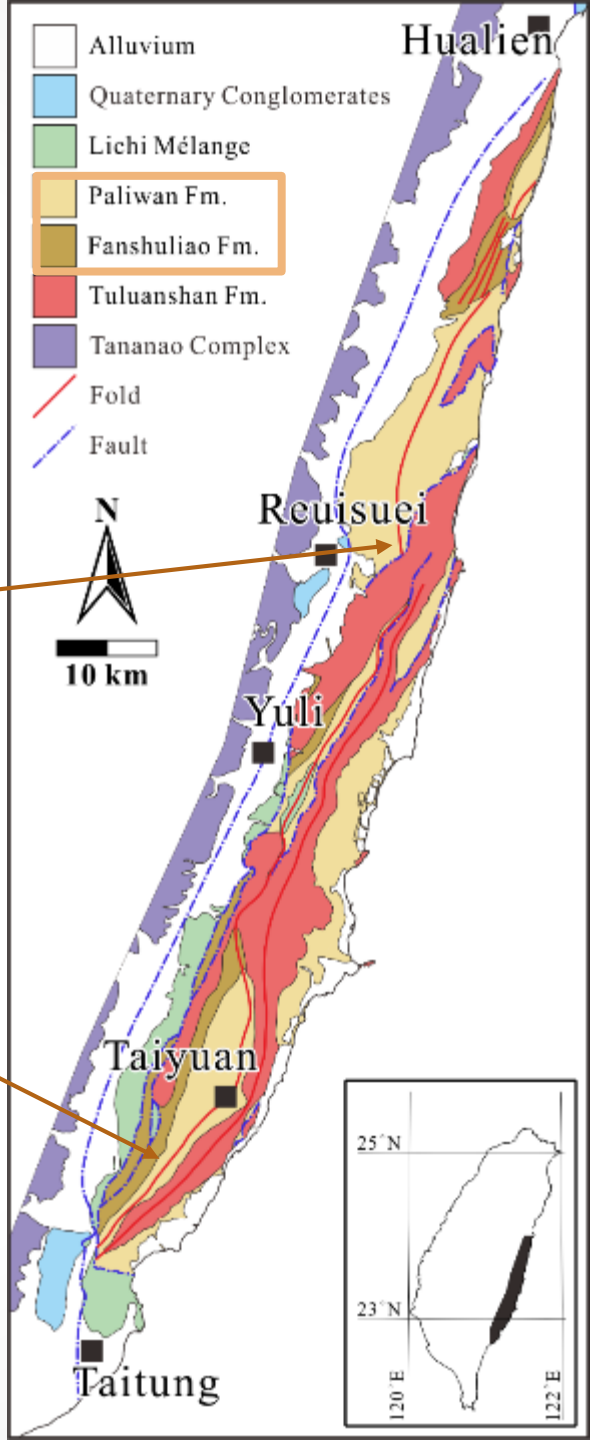

Coarse-grain turbidite


Sandy-muddy turbidite



Teng (1982)


Pebbly mudstone



Modified from
Wang and Chen (1993)

Turbidites in the Coastal Range

Orogen-derived deposits(?): *Lichi Mélange*

- Turbidites and olistostrome features.

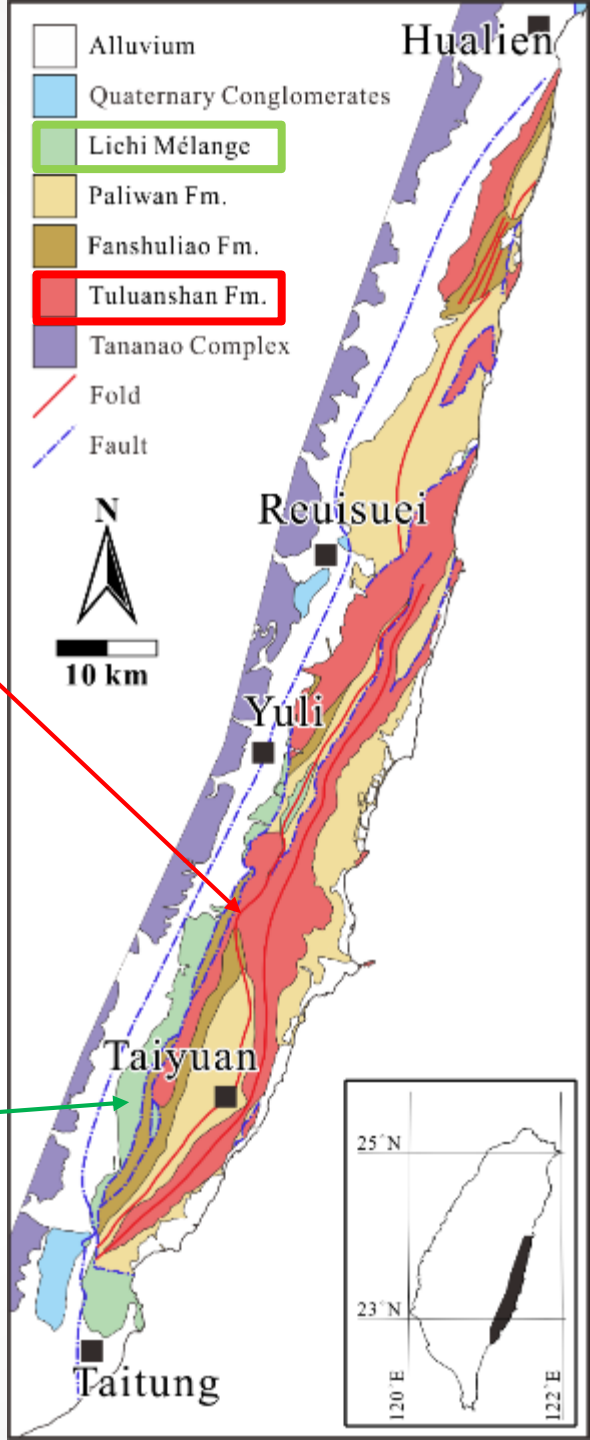
Arc-derived deposits: *Tulaunshan Fm.* *(& Paliwan Fm.)*

- Subaquaeous gravity flow (probably transformed from subaerial epiclastic/pyroclastic flow) deposits.


Coarse-grain turbidite


Turbidites


Turbidite-olistostrome in Lichi Mélange



Modified from Wang and Chen (1993)

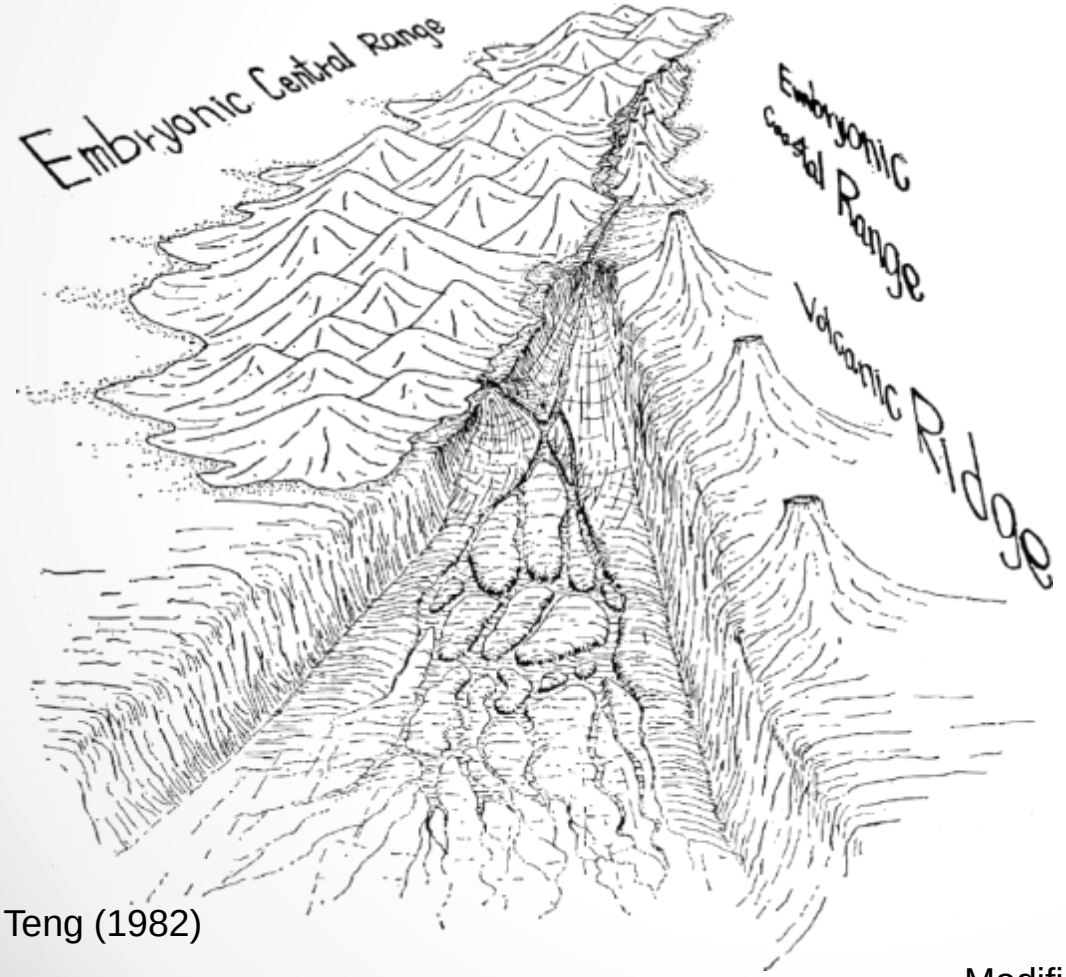
Turbidites in the Coastal Range

Orogen-derived gravity flow deposits:

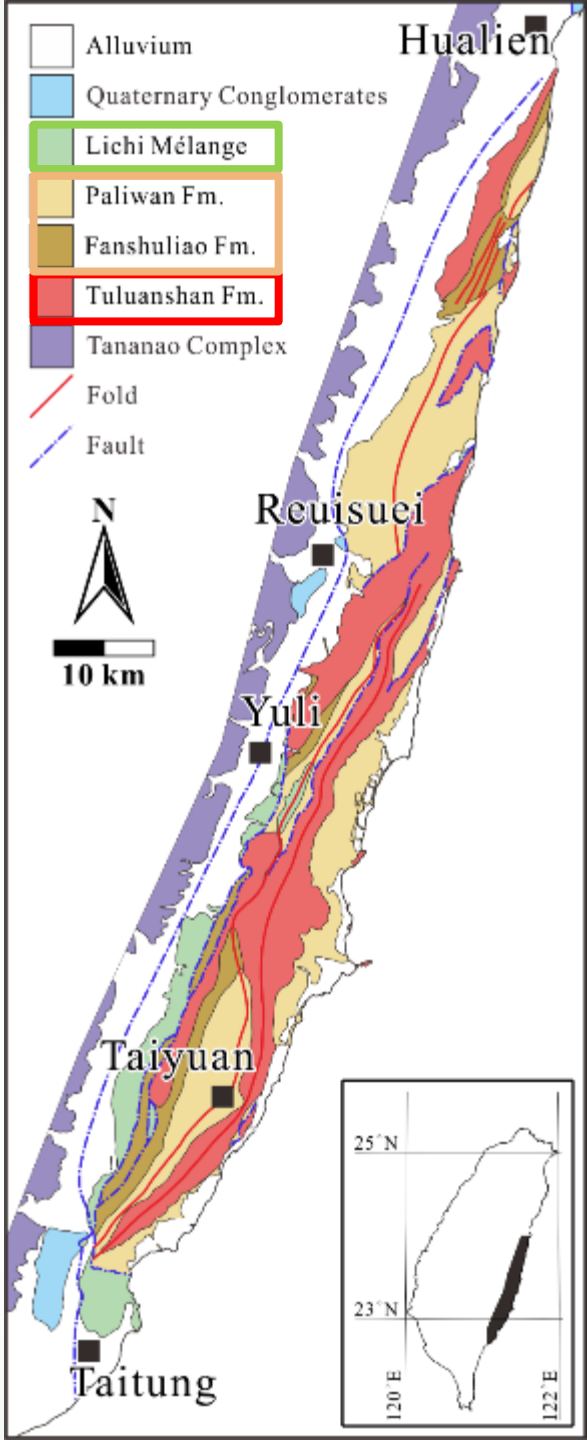
- *Paliwan / Fanshuliao Fm.*
- *Lichi Mélange*

Arc-derived gravity flow deposits:

- *Tulaunshan Fm.*
- *Embedded in Paliwan Fm.*



Teng (1982)



Modified from Wang and Chen (1993)

Orogen-derived gravity flow deposits

Paliwan/Fanshuliao Fm.

- The **Paliwan Fm.** can be divided into three divisions in accordance with the fan morphological settings. (Teng, 1982)
- **Fanshuliao Fm.** originally constituted the lower fan of an Asian deep-sea fan system. (Chen, 1988)

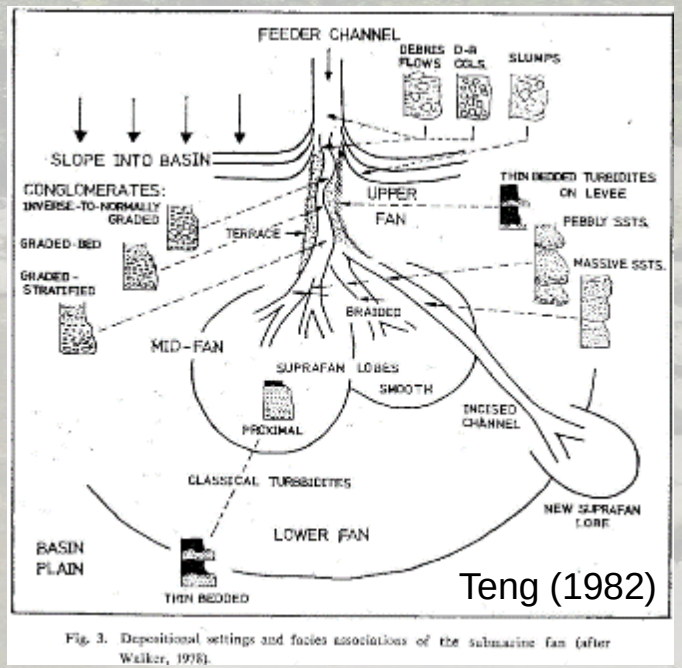
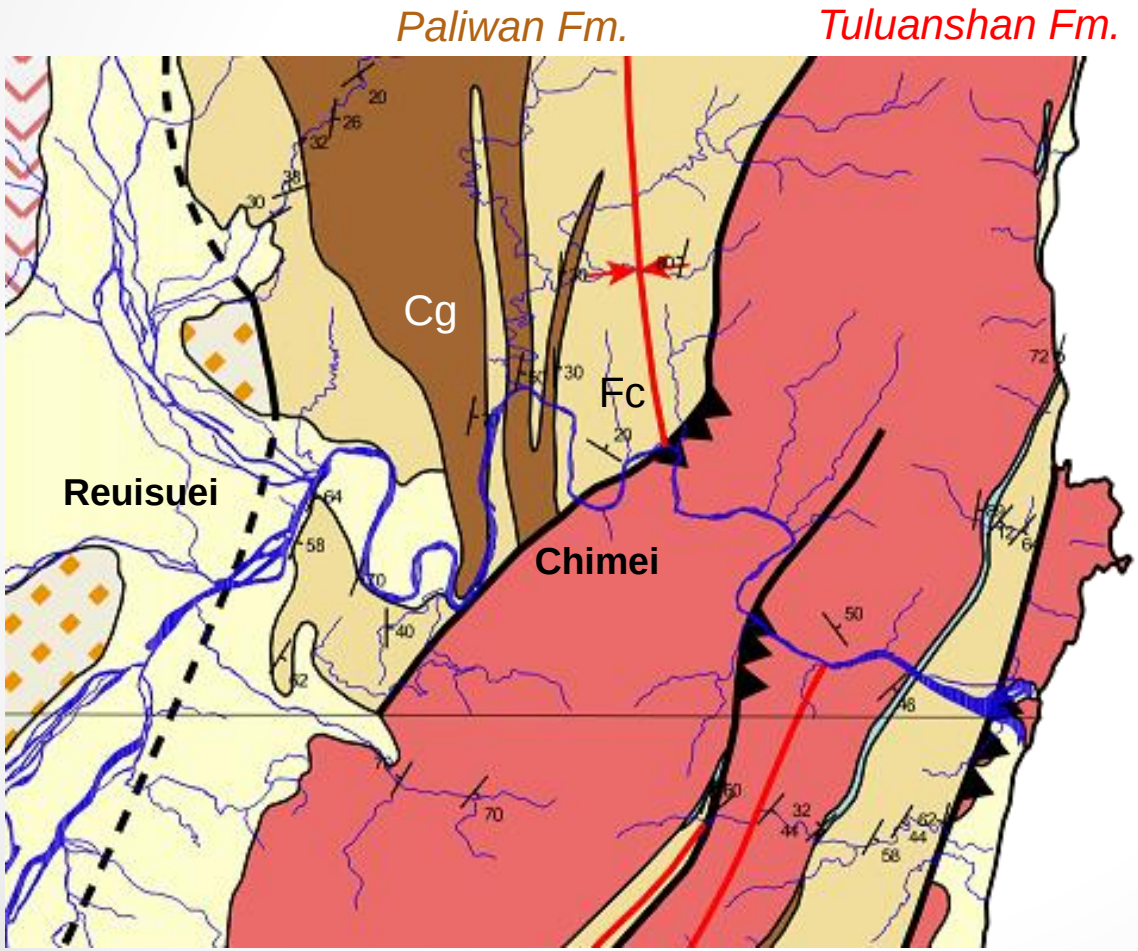


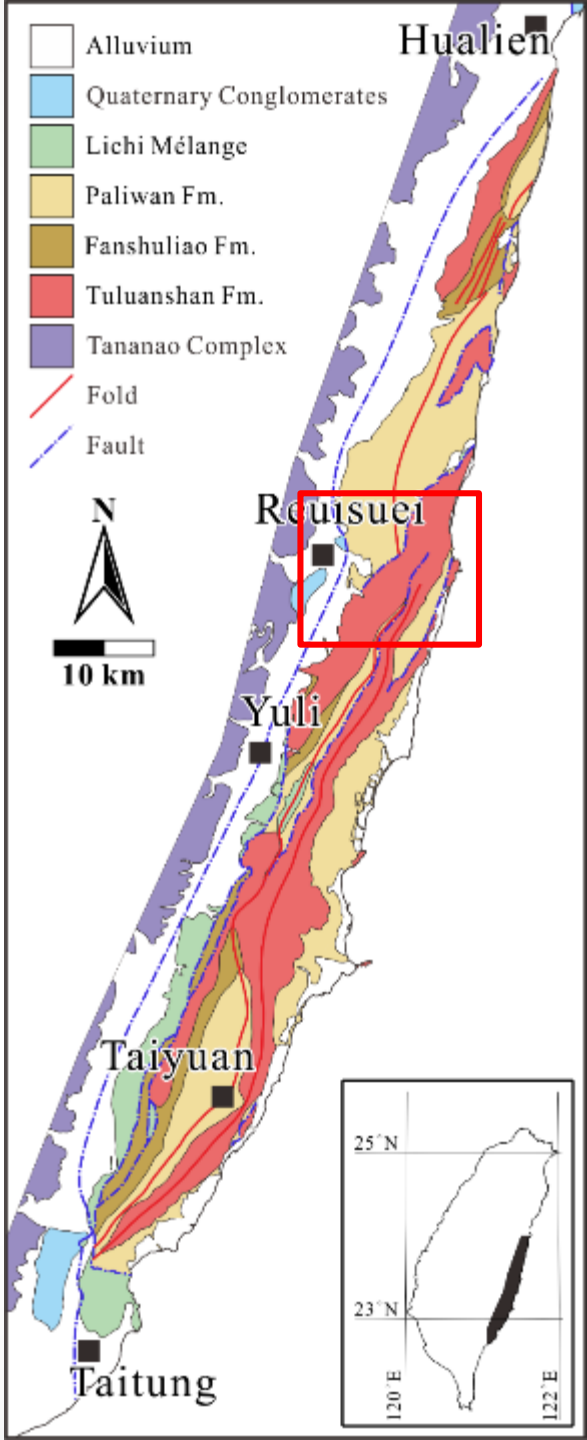
Fig. 3. Depositional settings and facies associations of the submarine fan (after Walker, 1978).

Submarine fans/canyon system

Well exposed example of coarse gravelly and sandy turbidites of a deep-sea submarine canyon and base-of-slope submarine fan complex in the **Hsiukuluan-chi section.** (Dorsey & Lundberg, 1988)

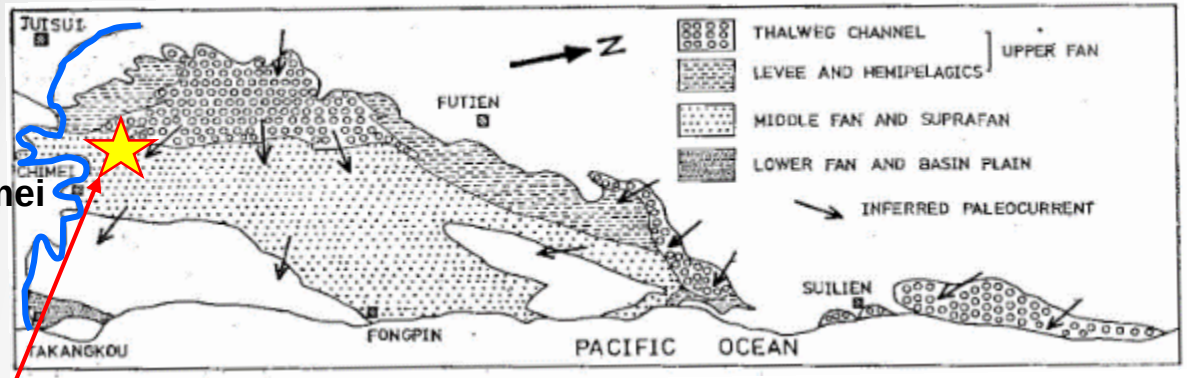


Modified from
Wang and Chen (1993)



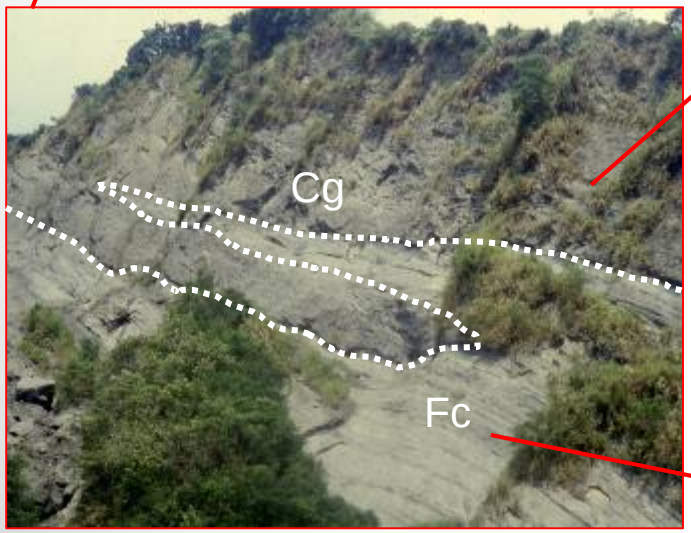
Submarine fans/canyon system

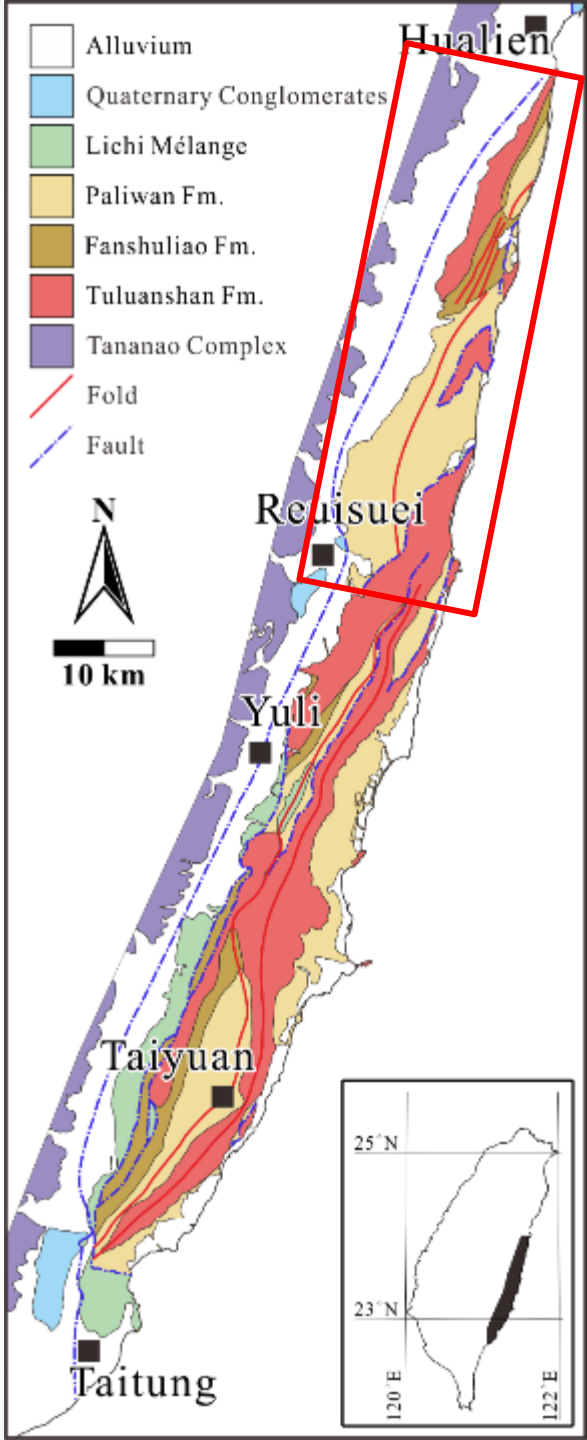
Two fan system well exposed in northern Coastal Range: **Chimei Fan**, Shuilien-Chichi Fan (Teng, 1982; Chen,1988)



Chimei

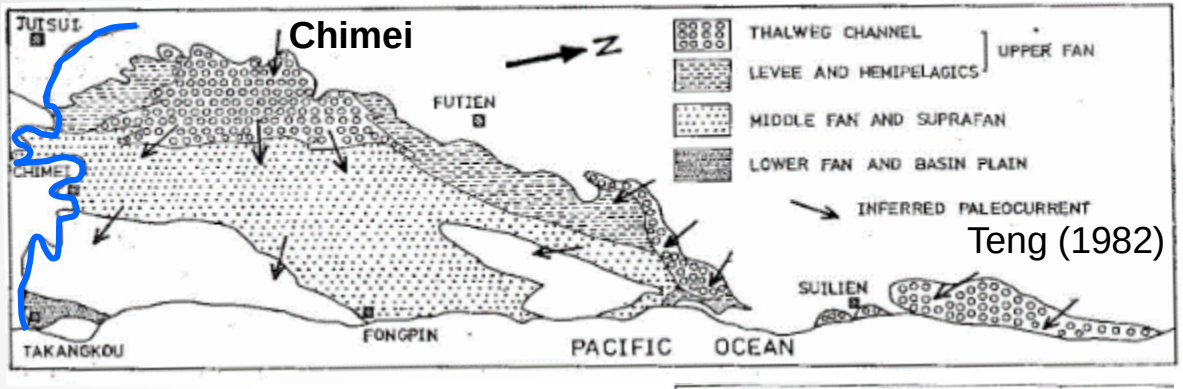
Teng (1982)





Submarine fans/canyon system

2 fan system well exposed in northern Coastal Range: **Chimei Fan**, **Shuilien-Chichi Fan** (Teng, 1982; Chen,1988)

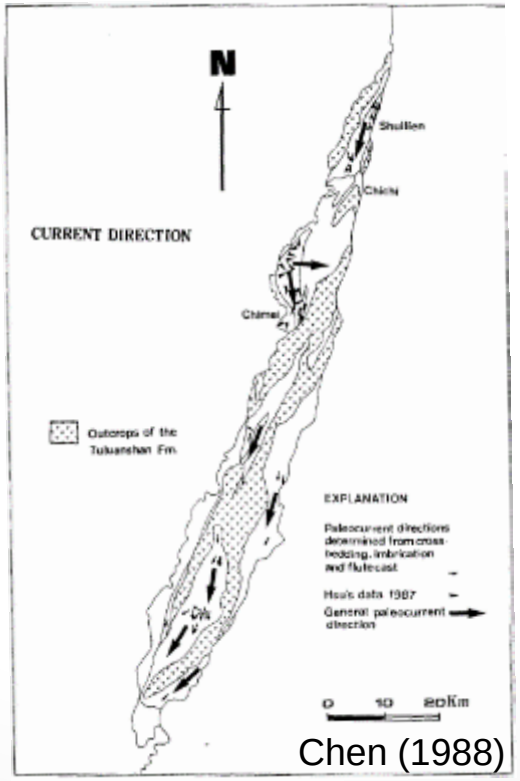


Teng (1982)

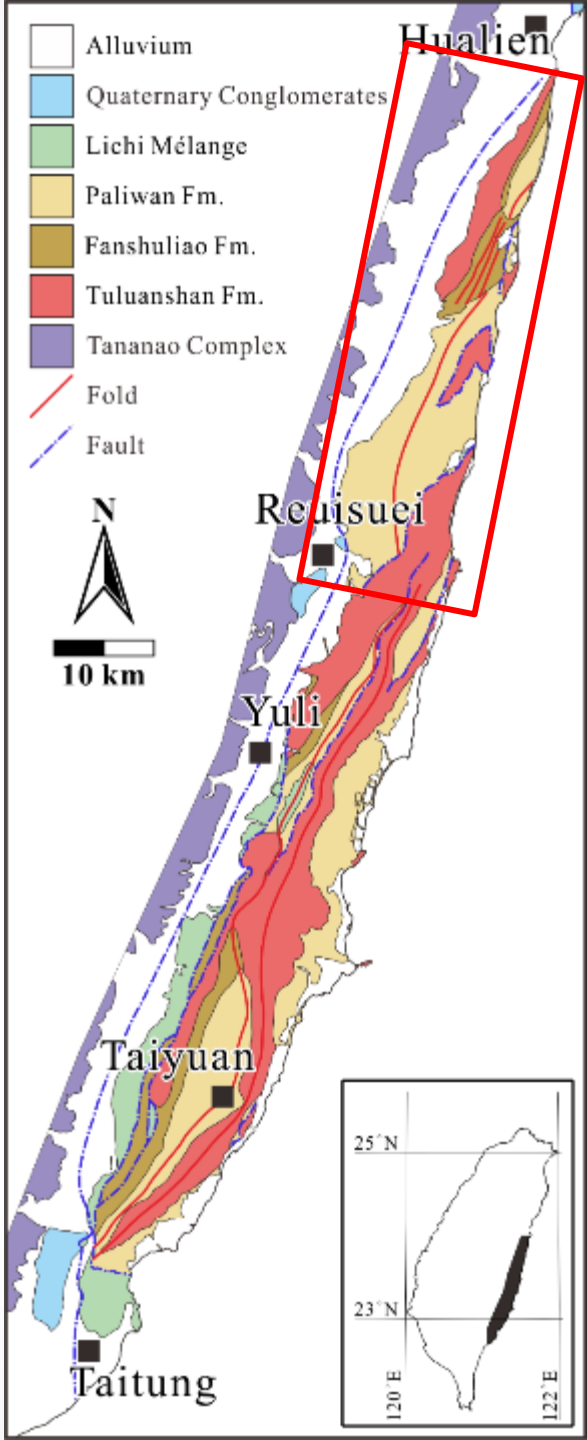
Three fan morphological settings

Deep-sea fan system:

- **Northern** Coastal Range: Upper-middle fan, canyon
- **Middle** Coastal Range: Middle or supra-fan
- **Southern** Coastal Range: Fan-fringe & basin plain

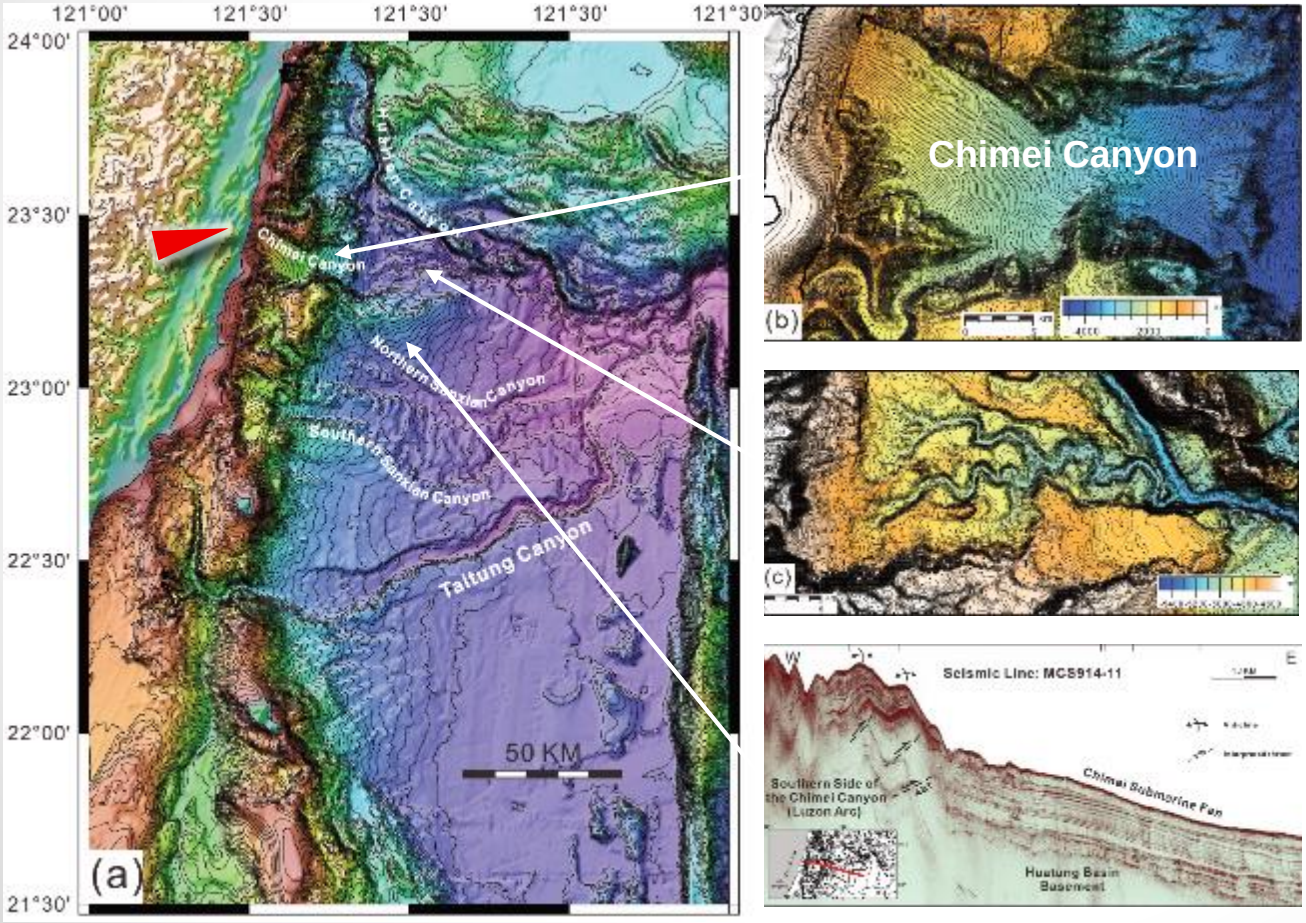


Chen (1988)

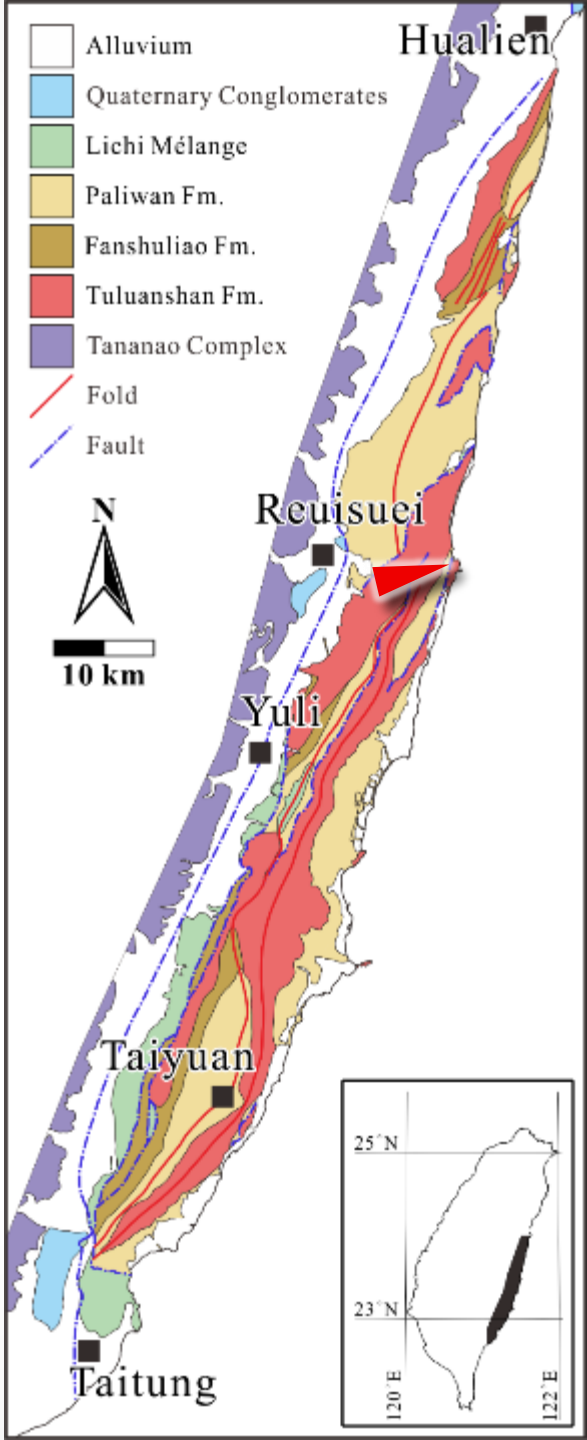


Submarine fans/canyon system

Modern analogue:
Building active deep see fans today in the Huatong basin immediately east of the mouth of the Hsiukuluan-chi.



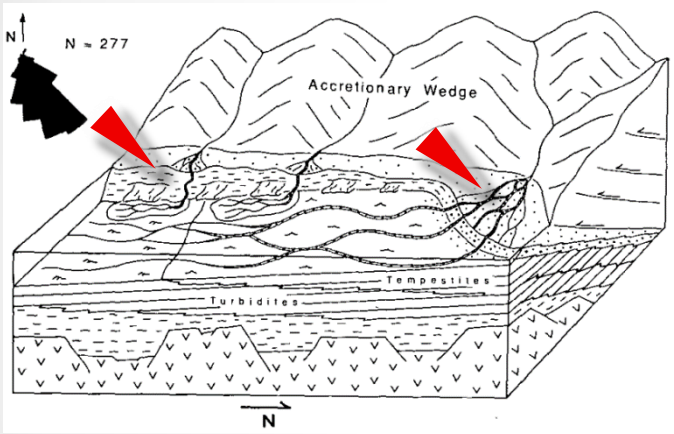
Hsieh (2014)



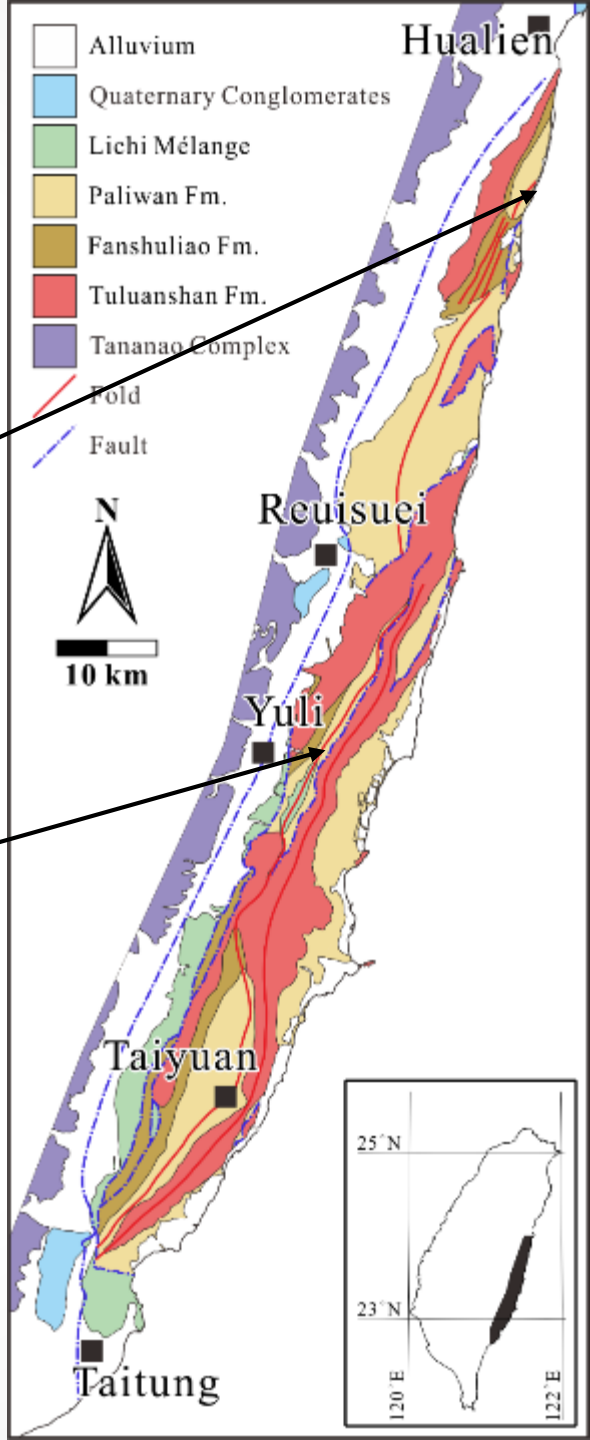
Modified from
Wang and Chen (1993)

Other proposed depositional systems

Shallow-Marine Tempestite Ramp Facies & **Wave-Reworked Braid-Delta Front** Facies (Dorsey & Lundberg,1988; Lin, 2011)



Dorsey & Lundberg (1988)

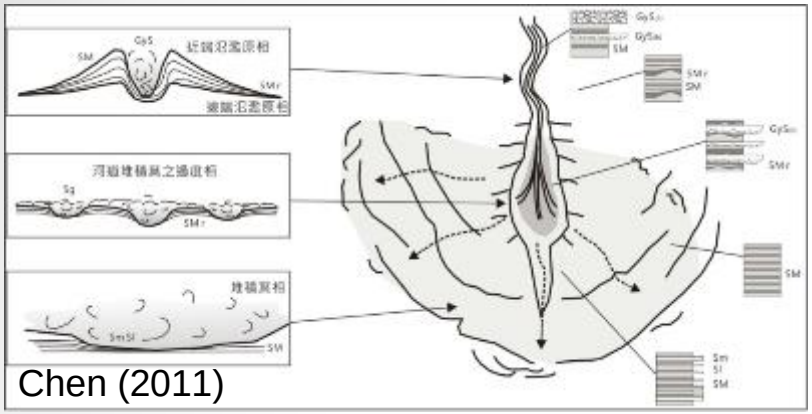


However…

- **Deep water benthic foraminifera:**
  Oridorsalis umbonatus, Cibicidoides spp., etc.
  (Huang *et al*., 1995; Chien, 2003 Chang,1967; 1968; 1969)
- **Bathyal-abyssal ichnofacies:**
  Nereites and *Zoophycos* groups (Chen, 1988)

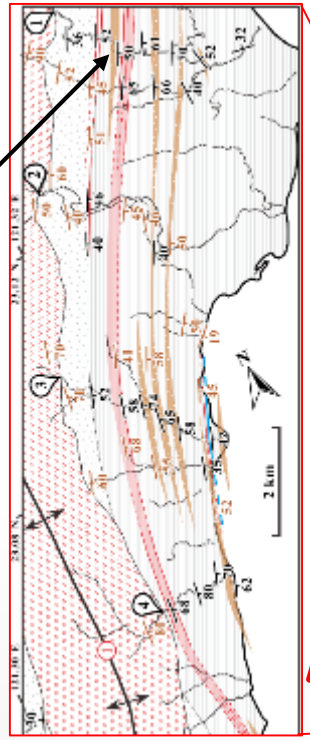
Other proposed depositional systems

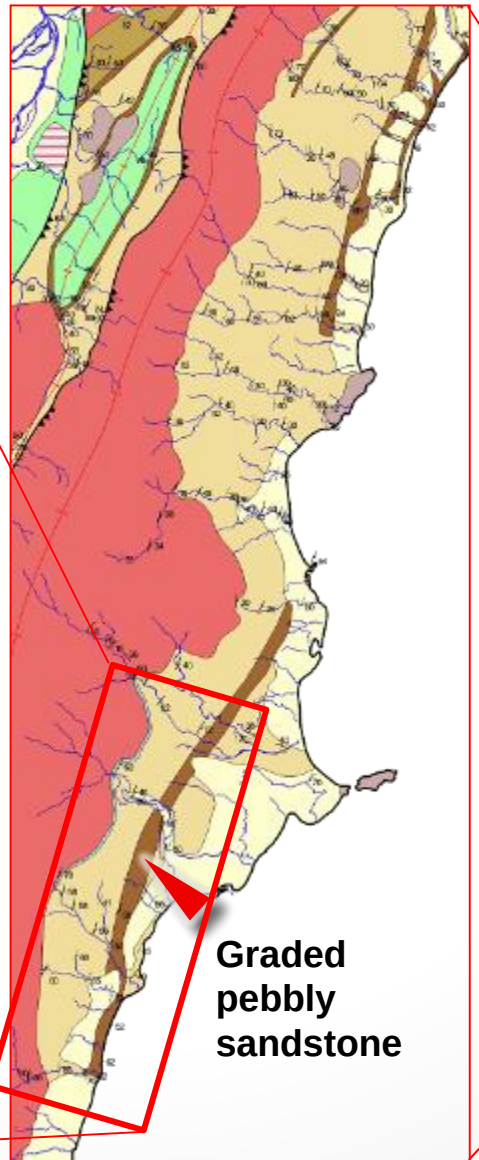
Submarine channel-levee system in the southern Coastal Range (Chen, 2011, Bachelor Thesis)



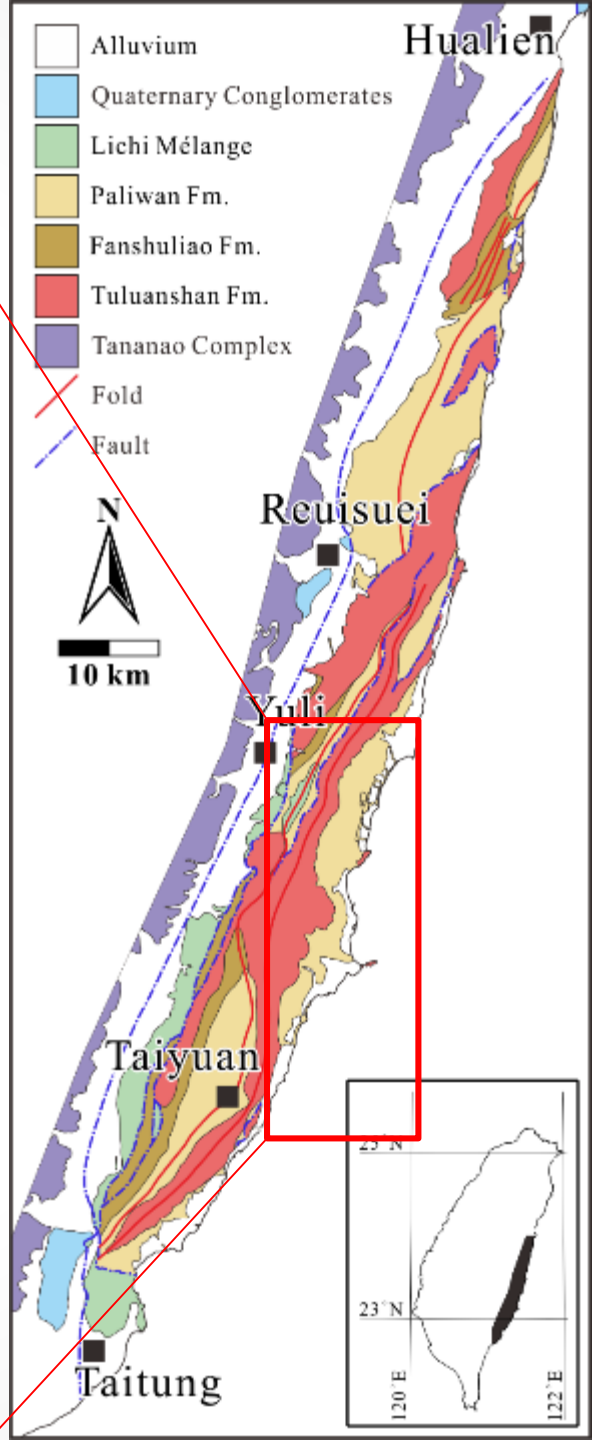
Chen (2011)

Lai *et al*. (2017) in review





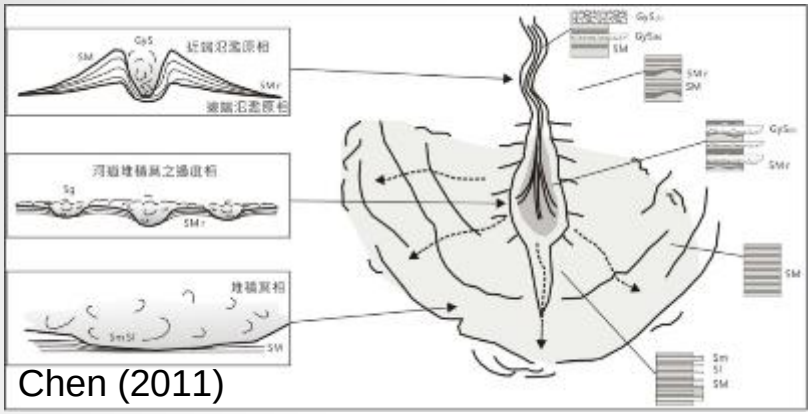
Graded pebbly sandstone



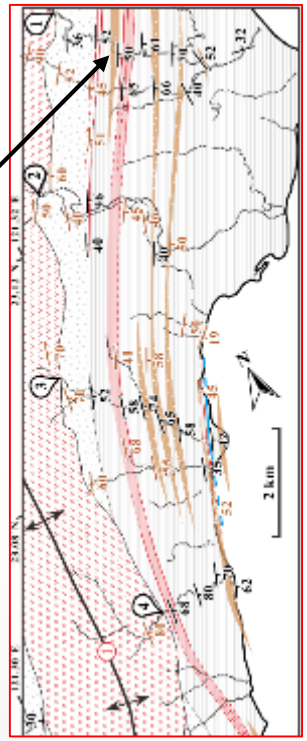
Other proposed depositional systems

Submarine channel-levee system in the southern Coastal Range (Chen, 2011, Bachelor Thesis)

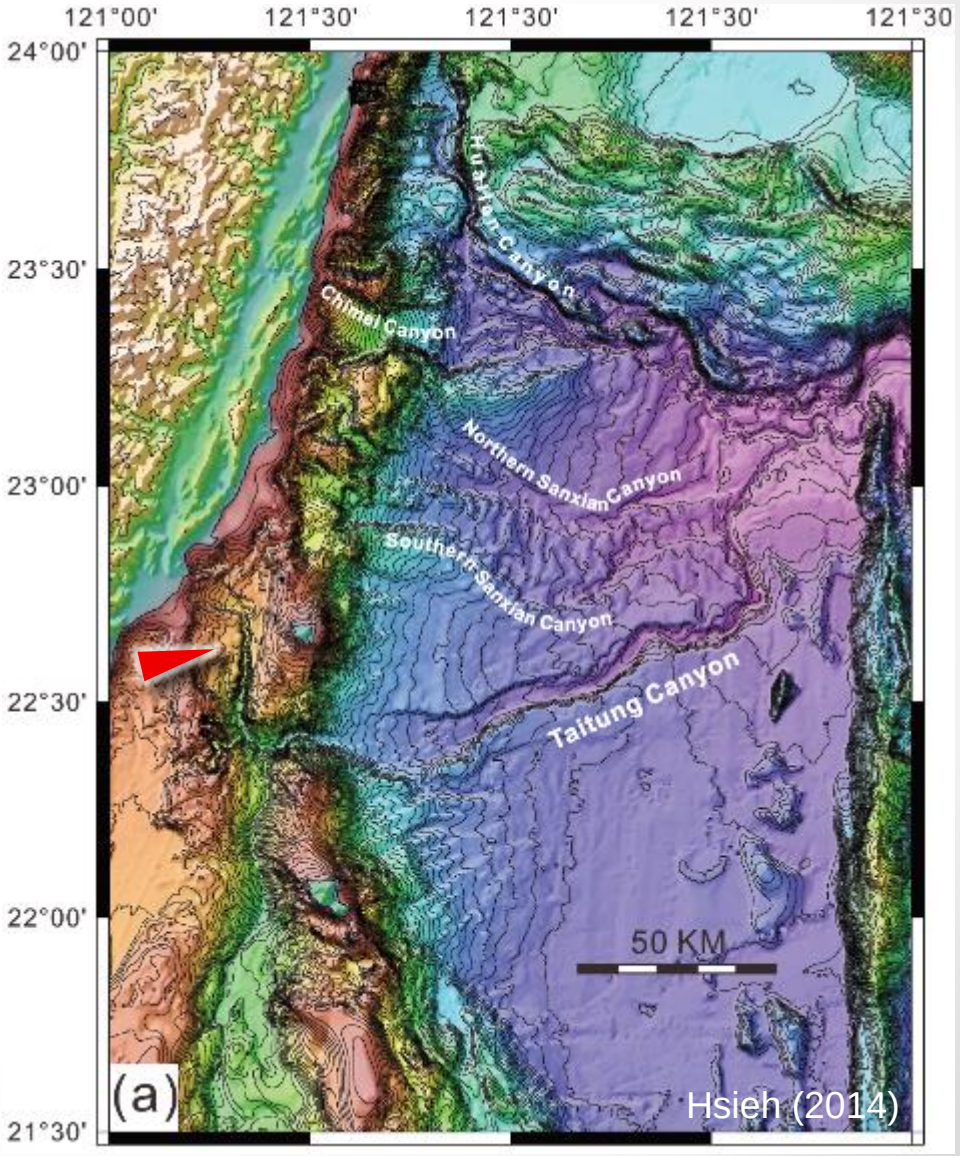
Modern analogue in Taitung Trough ↙ in the south



Chen (2011)



Lai *et al*. (2017) in review



Hsieh (2014)

Orogen-derived gravity flow deposits

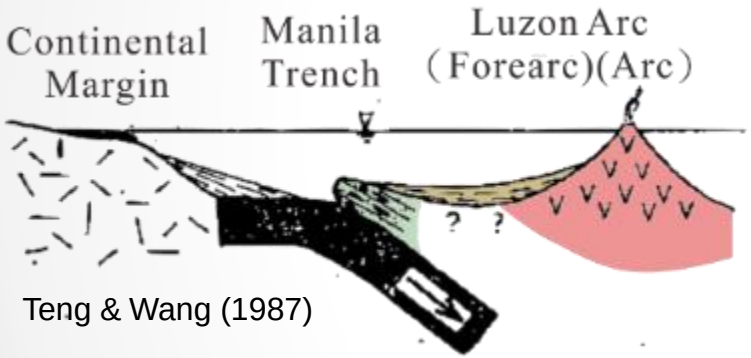
Lichi Mélange

- An **olistostrome origin** Mélange which went through sedimentary and/or structural mixing.
- The Lichi Melange consists principally of laminated to chaotic scaly mudstone, coarser clastic layers of flysch-like (turbiditic) sandstone, lenses of conglomerate and ubiquitous pebbly detritus and blocks of ophiolitic material.

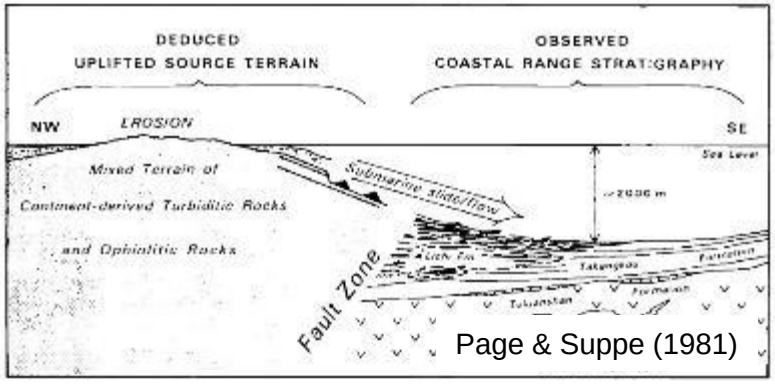
Ernst (1977)

Different explanation of the origin of Lichi Mélange:

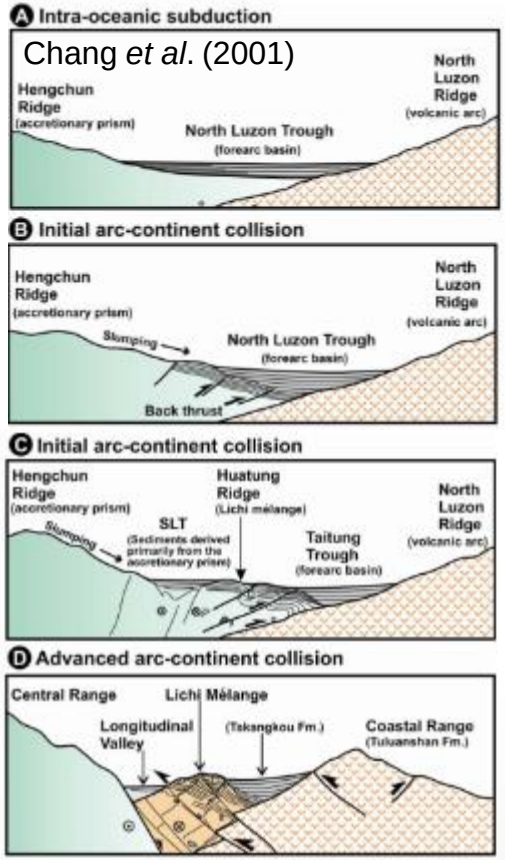
1. **Subduction Complex** (Biq, 1971; Karig, 1973; Hsu, 1988)
2. **Olistostrome** (Wang, 1976; Ernst, 1977; Ho, 1977; Liou *et al*., 1977; Page & Suppe, 1981; Barrier & Muller, 1984)
3. **Collision Complex** (Chang *et al*., 2000, 2001; Huang *et al*., 2008)

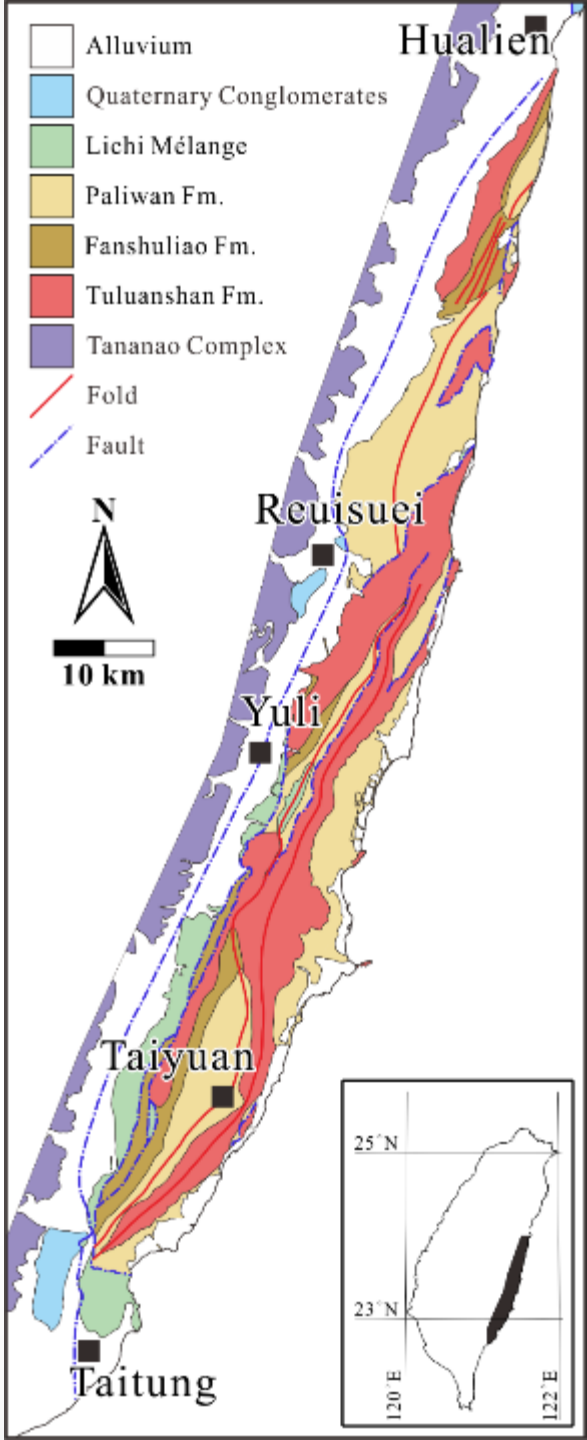


Teng & Wang (1987)

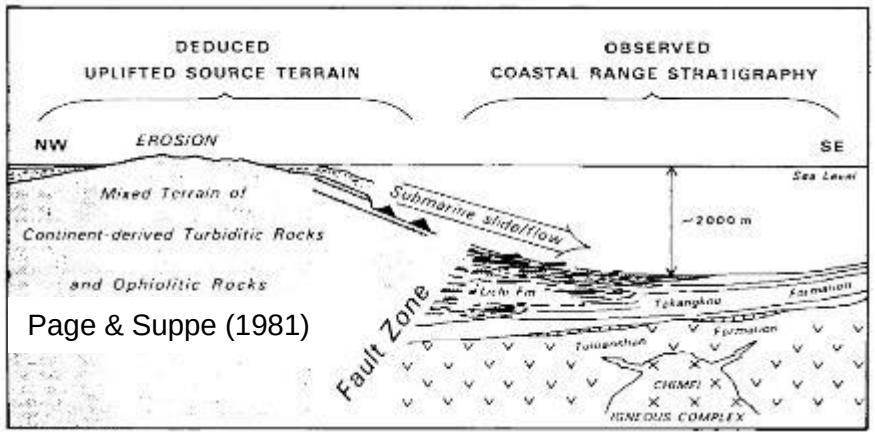


Page & Suppe (1981)

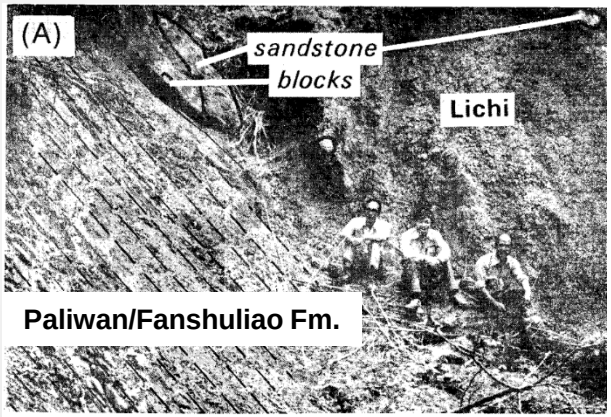




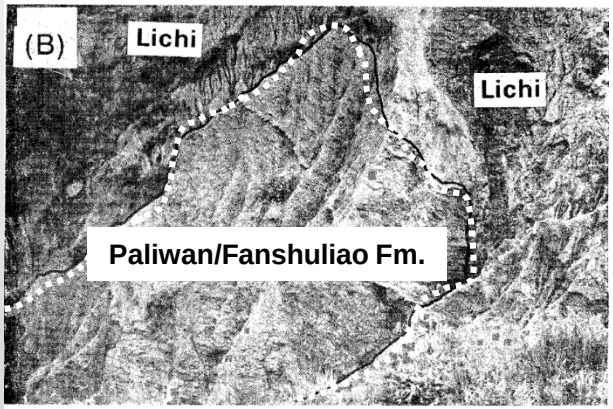
Olistostromal features in Lichi Melange:



Page & Suppe (1981)

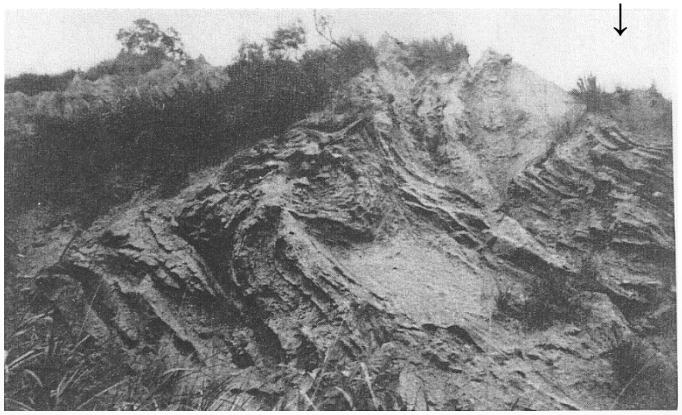


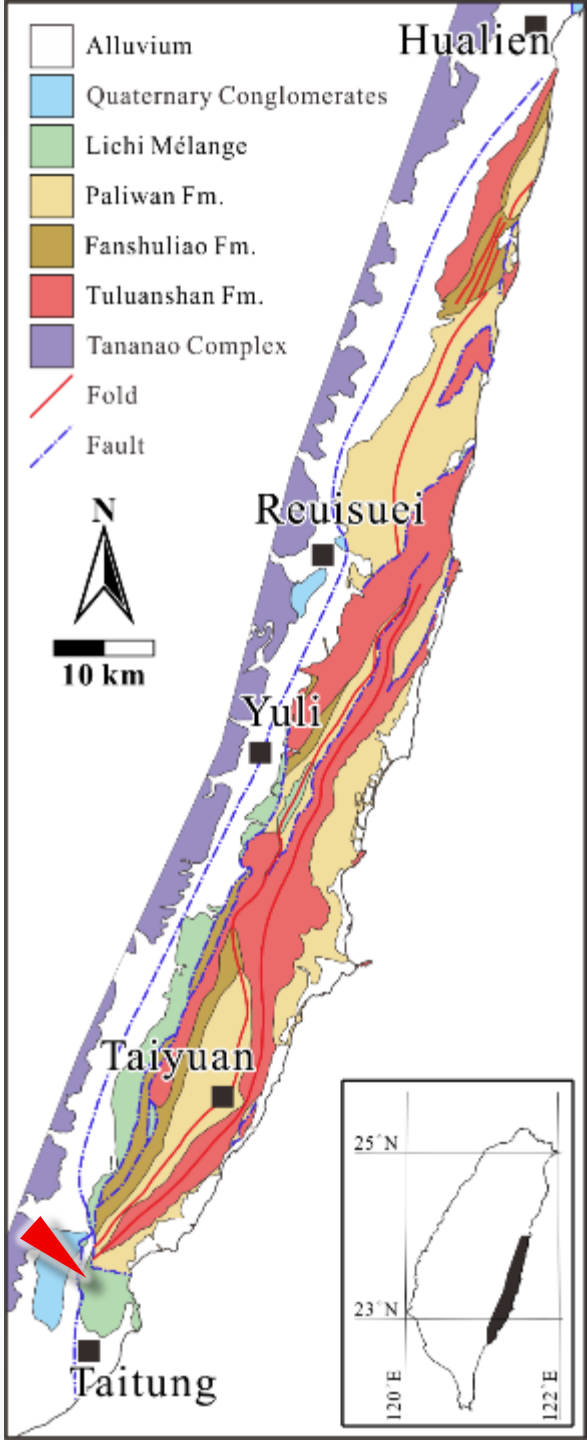
←Lichi Mélange and overlying mudstones of Fanshuliao or Paliwan Fm. (Page & Suppe, 1981)



Typical slump structures in the Lichi Mélange (Barrier & Muller, 1984)

↓

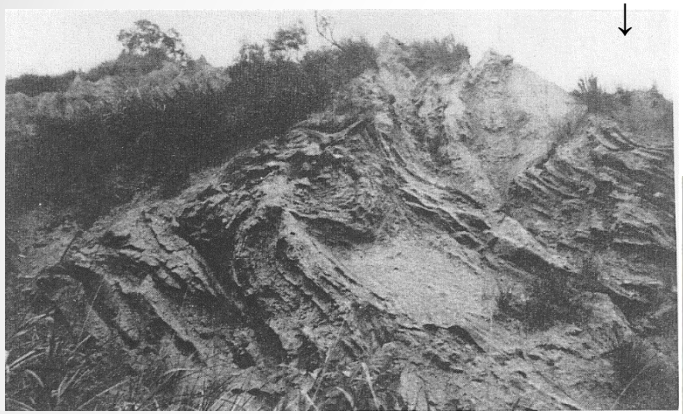




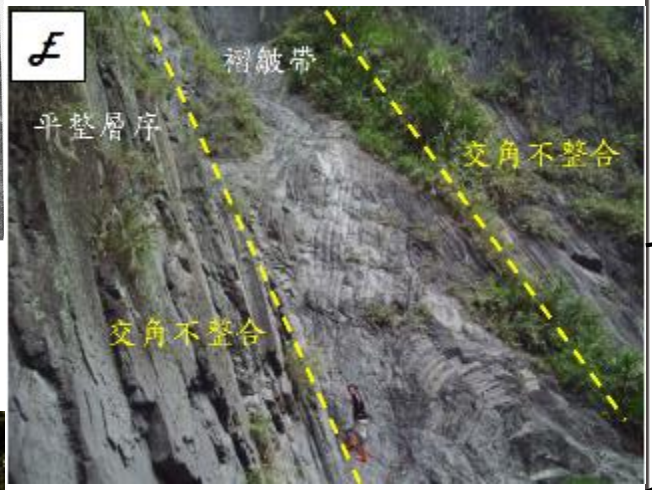
Olistostromal features in Lichi Melange:

Such mega-slumped structures are also abundant in nearby Fanshuliao / Paliwan Fm.

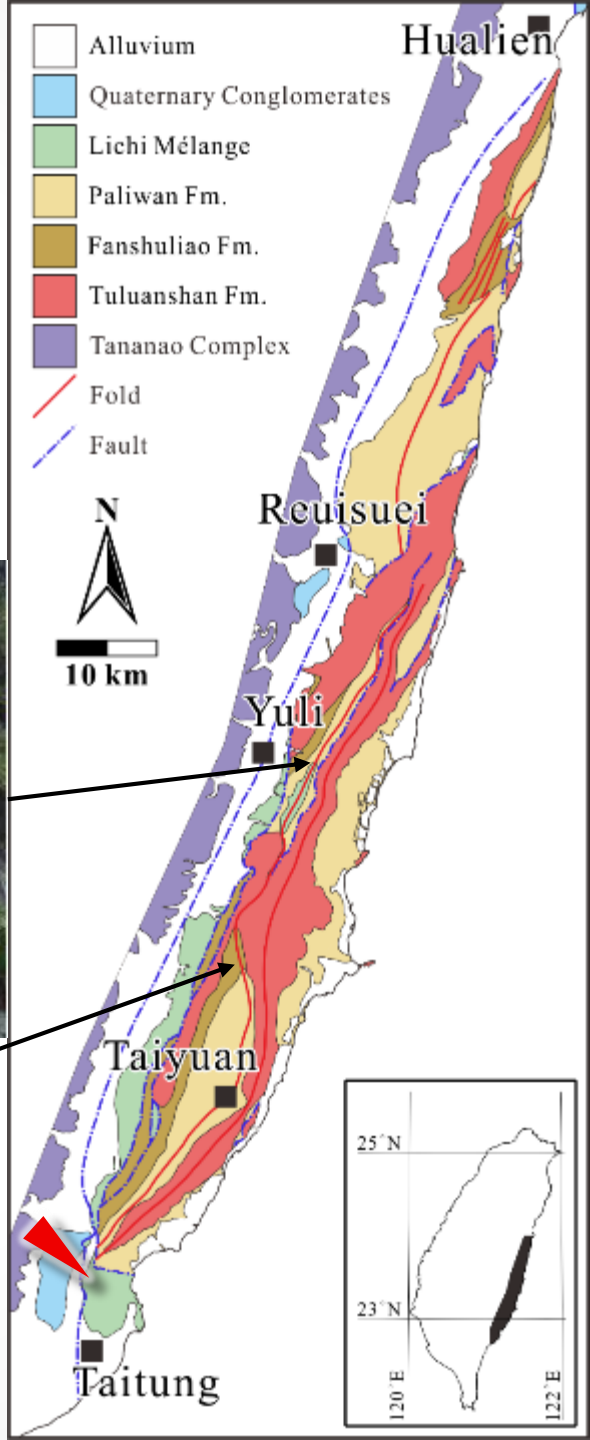
Typical slump structures in the Lichi Mélange (Barrier & Muller, 1984) ↓



Slump structures in the Paliwan Fm. (Chen, 2011) ↓

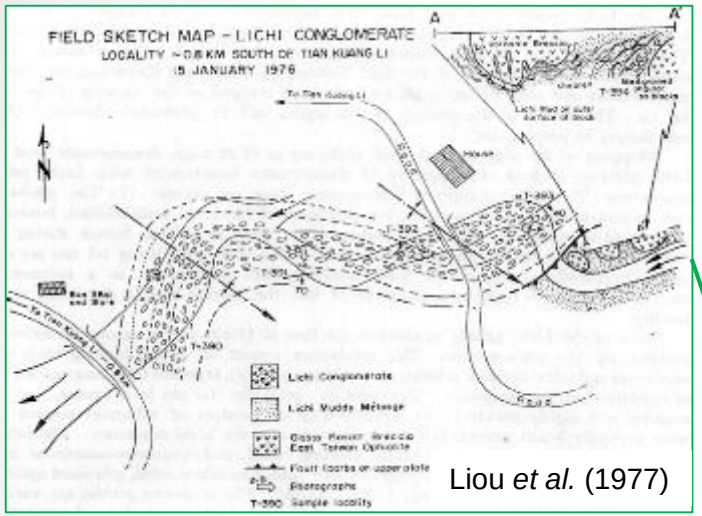


← Slump structures in the Fanshuliao Fm.

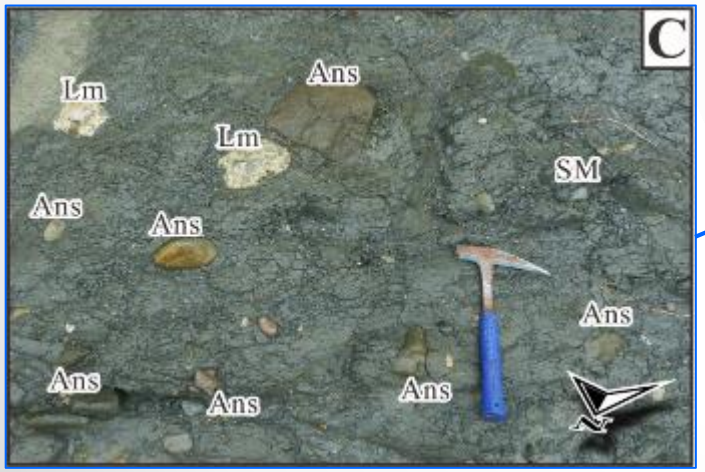


Olistostromal features in Lichi Melange:

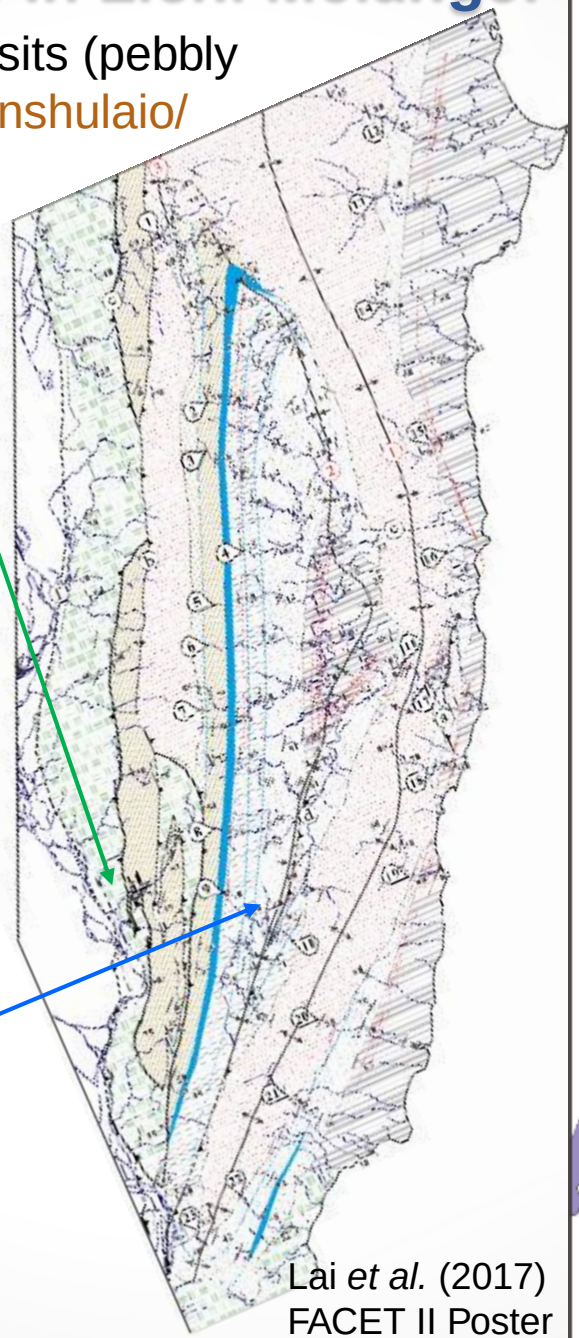
Similar submarine debris flow deposits (pebbly mudstone) in Lichi Mélange and Fanshulaio/ Paliwan Fm.



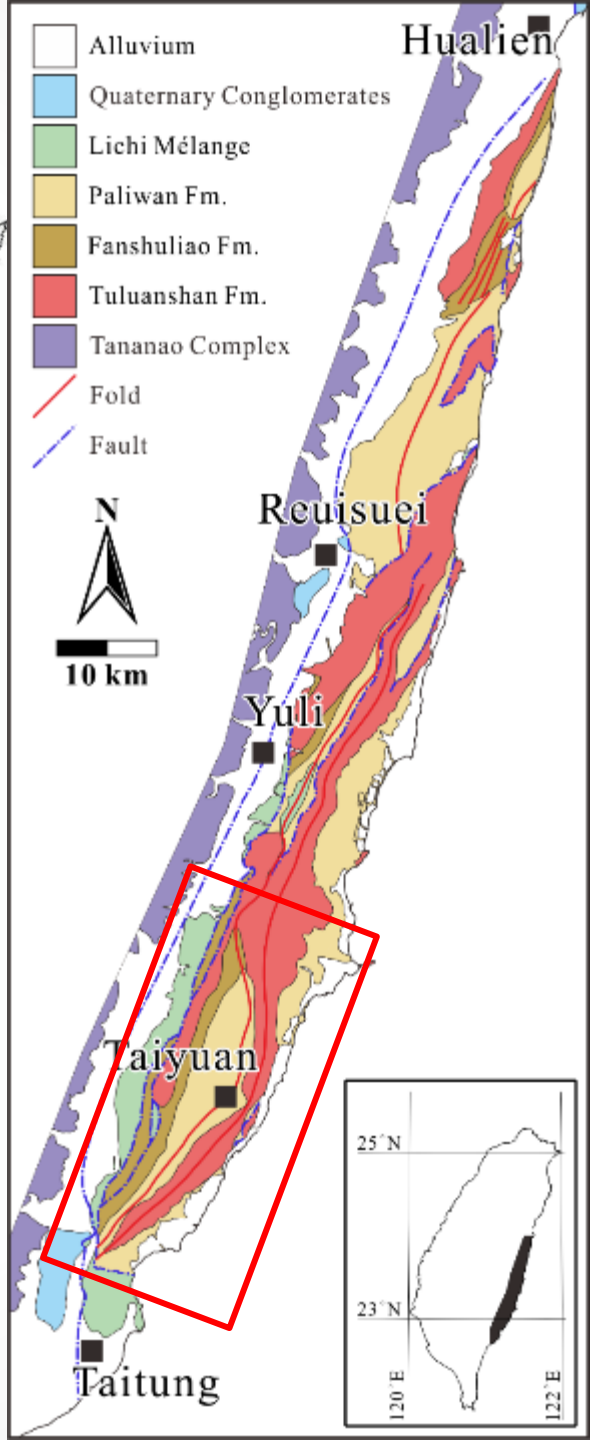
Liou *et al.* (1977)



Lai & Teng (2016)



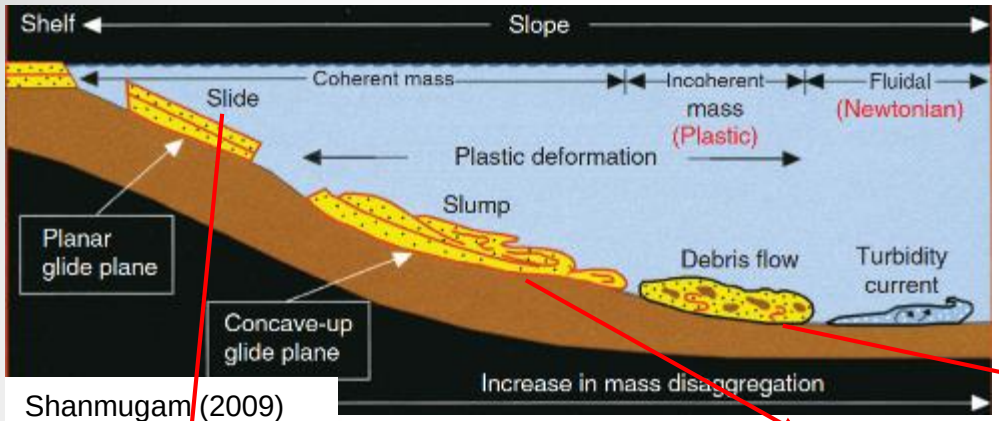
Lai *et al.* (2017)
FACET II Poster



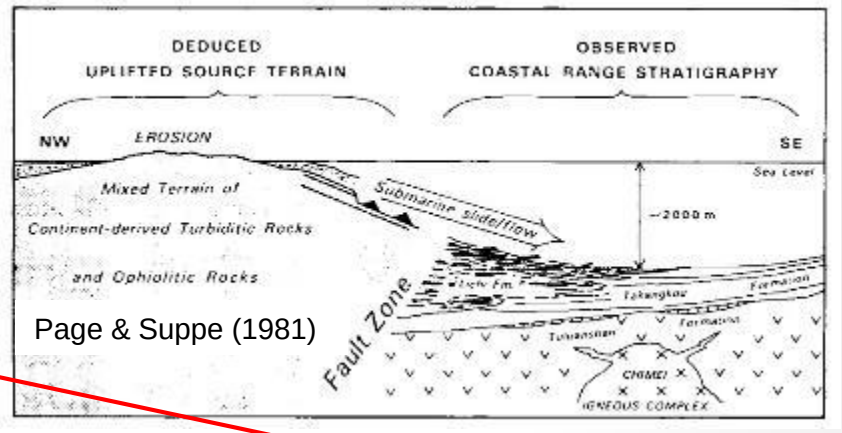
Hypothesis

Olistostromal features in Lichi Melange:

Steep sandy-muddy slope to basin plain facies association (Dorsey & Lundberg, 1988)

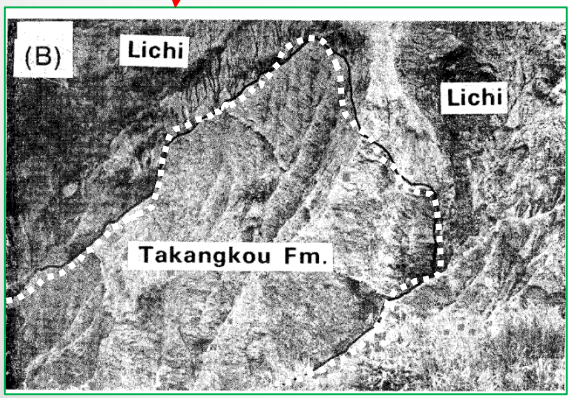


Shanmugam (2009)



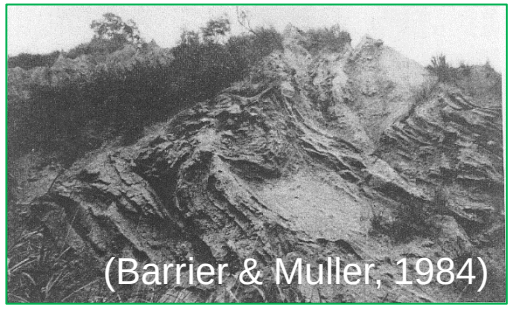
Page & Suppe (1981)

Lichi Mélange



(Page & Suppe, 1981)

Slide blocks



(Barrier & Muller, 1984)

Slump structures

Liou *et al*., 1977)

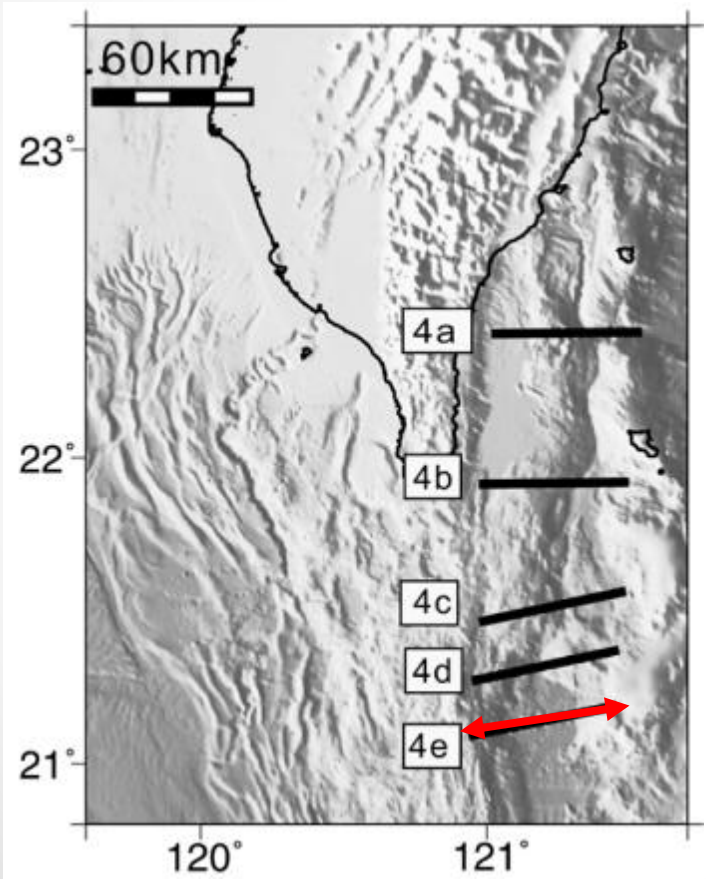
Pebbly Mudstones

Fanshuliao/Paliwan Fm.

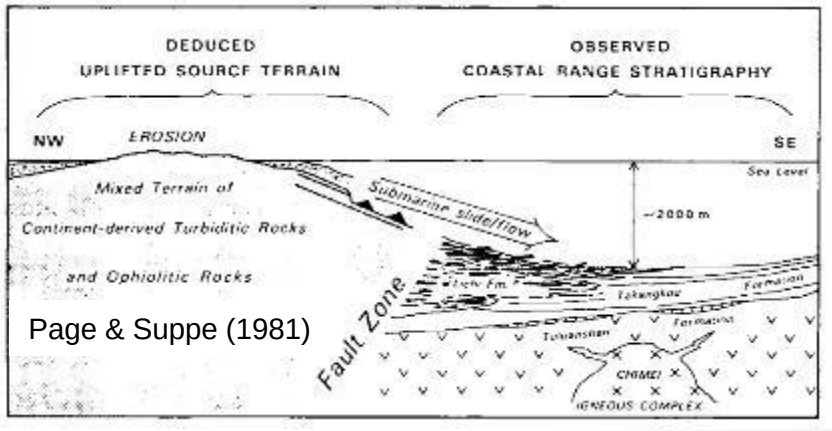
Olistostromal features in Lichi Melange:

Modern analogue:

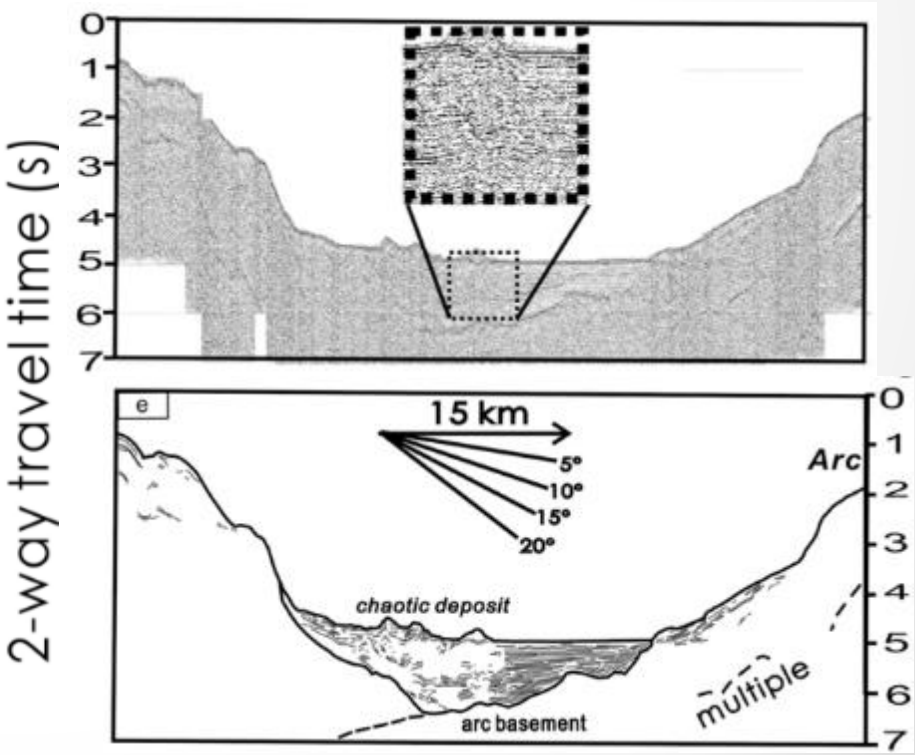
Lateral changing from western chaotic olistostromal deposits to eastern flysch beds (turbidites?) in the Taitung Trough.



Hirtzel *et al.* (2009)

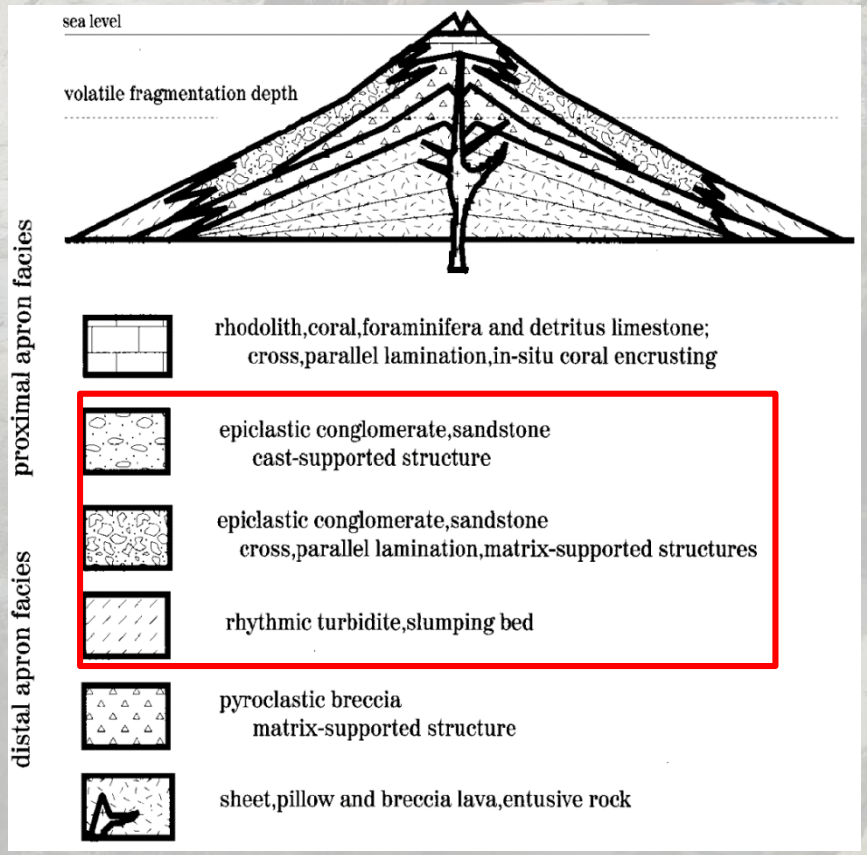


Page & Suppe (1981)



Arc-derived gravity flow deposits

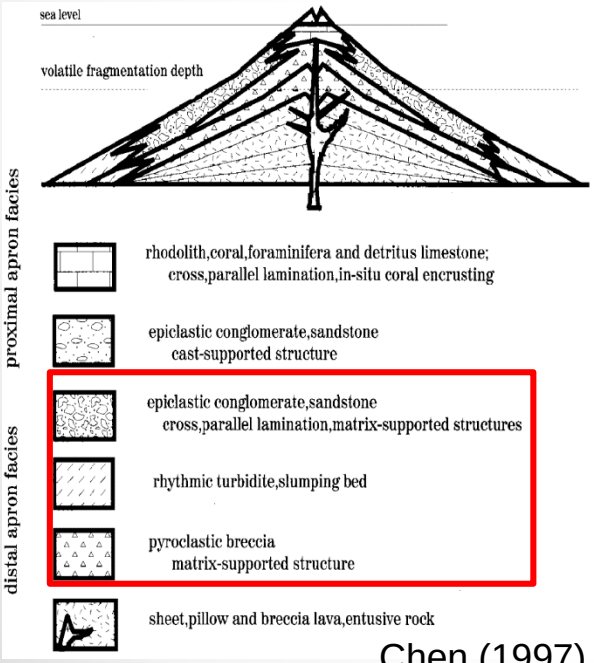
Tuluanshan Fm.



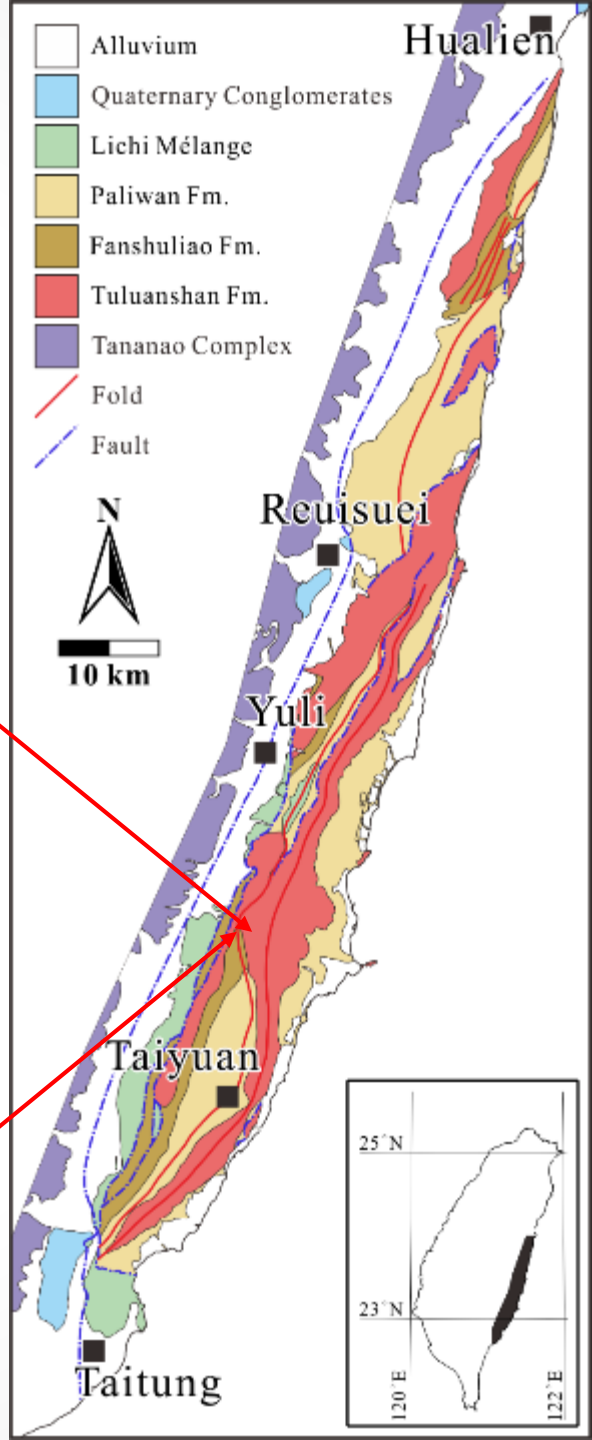
Chen (1997)

Submarine volcano apron facies in Tuluanshan Fm.

Beishi epiclastic flow deposits:
Lateral changing from eastern conglomerate to western rhythmic turbidites and slumping beds.



Chen (1997)

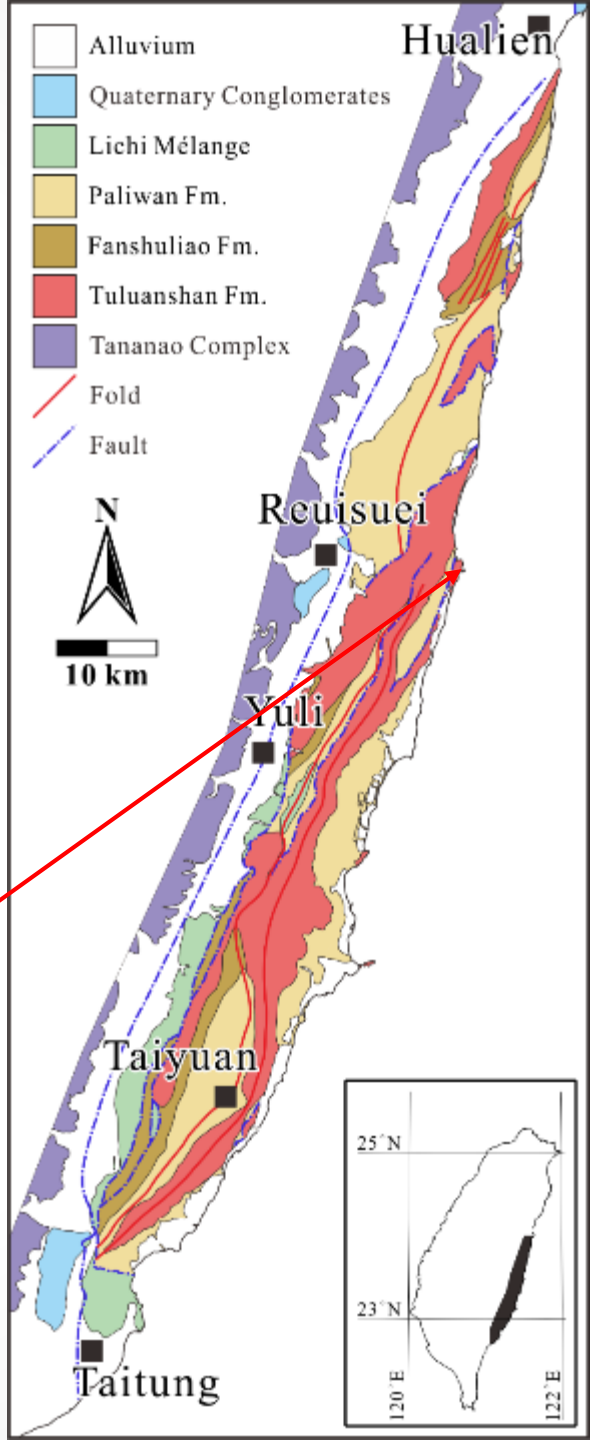


Submarine volcano apron facies in Tuluanshan Fm.

Shihtiping ignimbrites:

- It carries a whole spectrum of pyroclastic rocks.
- Many depositional structures such as cross laminations, parallel laminations, normal and reverse graded beddings, impacted sag blocks, plastic deformations and erosion surface.

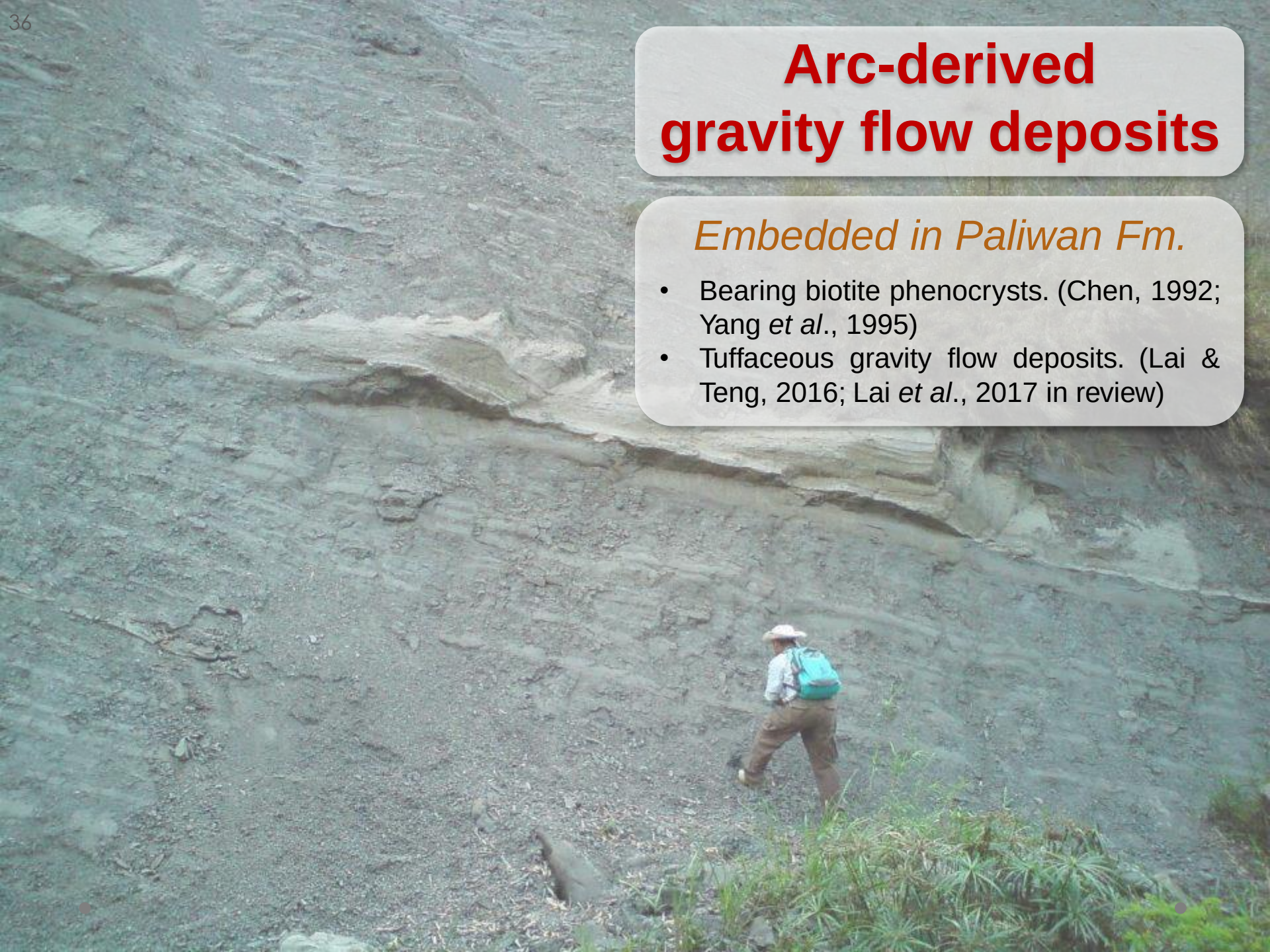
Song & Lo (1988)



Arc-derived gravity flow deposits

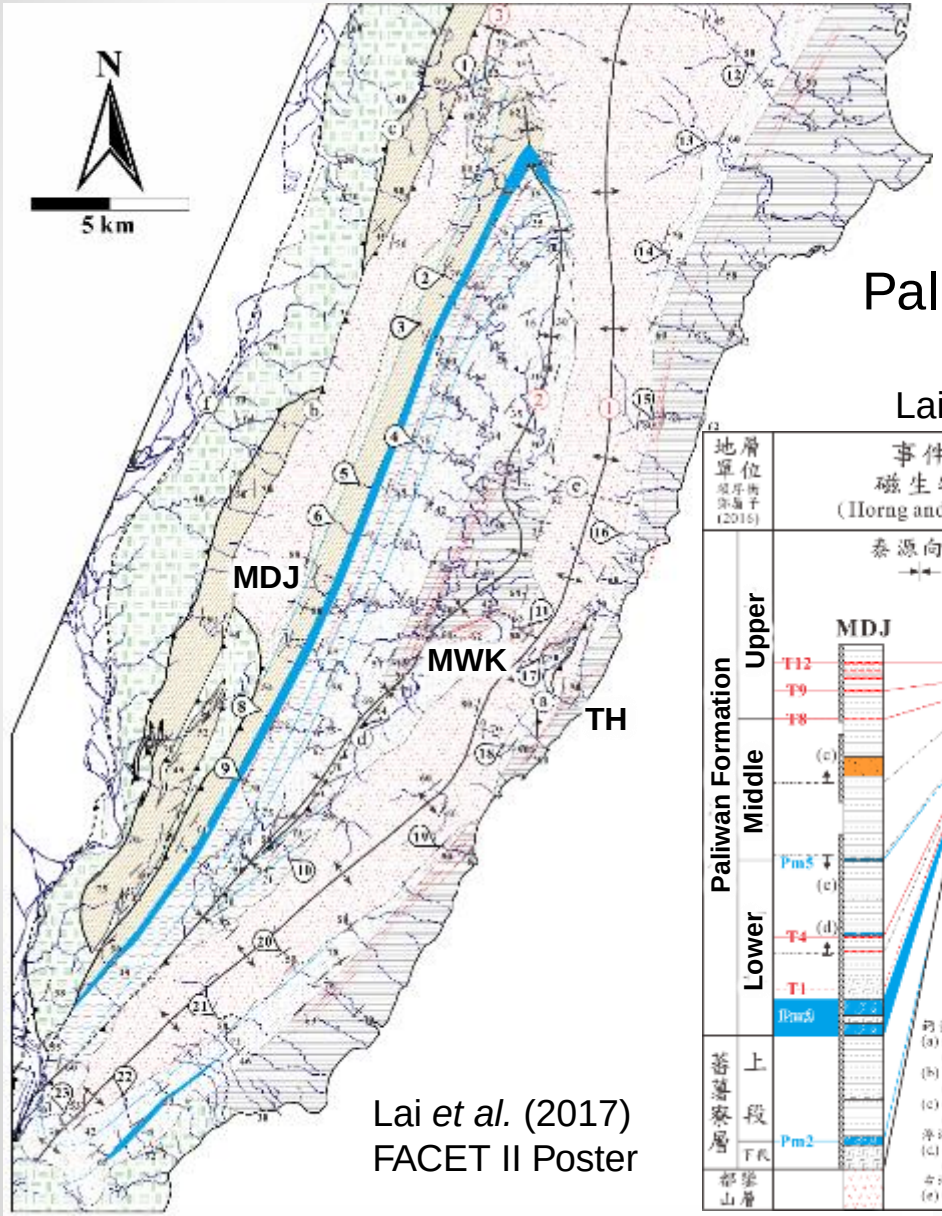
Embedded in Paliwan Fm.

- Bearing biotite phenocrysts. (Chen, 1992; Yang *et al*., 1995)
- Tuffaceous gravity flow deposits. (Lai & Teng, 2016; Lai *et al*., 2017 in review)



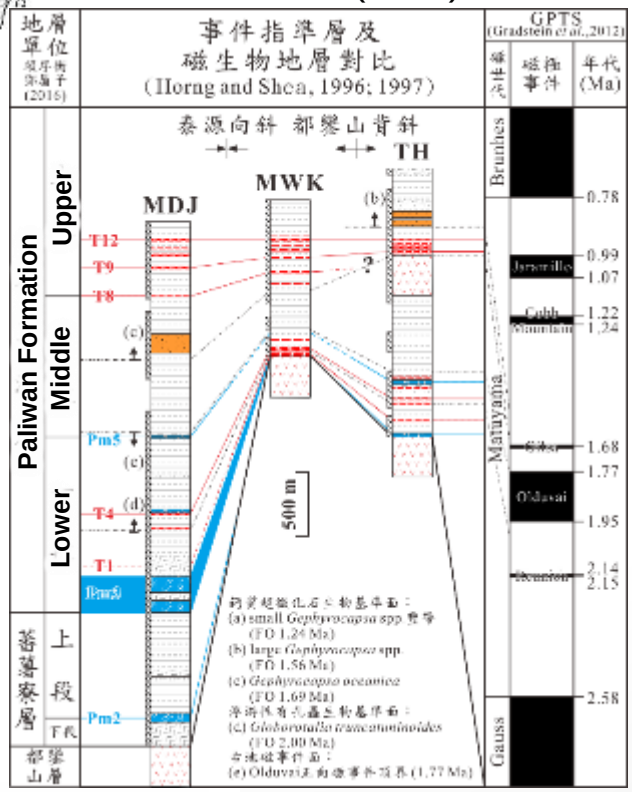
Tuffaceous turbidites embedded in Paliwan Fm.

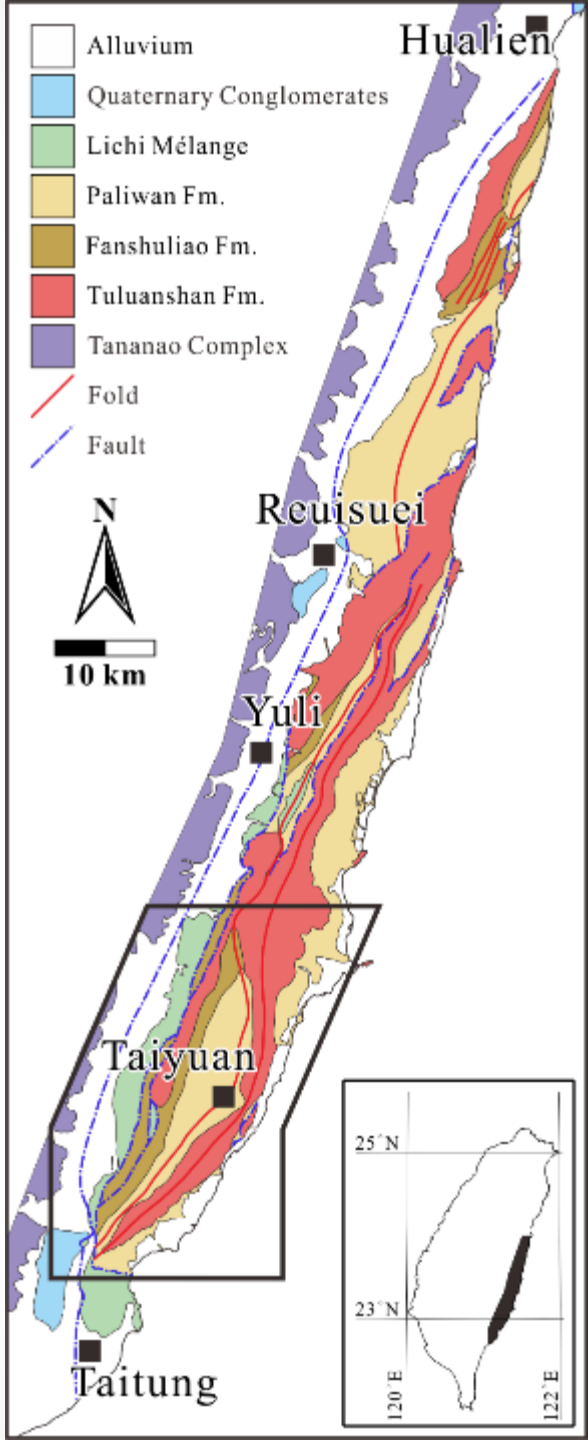
15 tuff layers could be used as event marker beds in Paliwan Formation.



Lai *et al.* (2017)
FACET II Poster

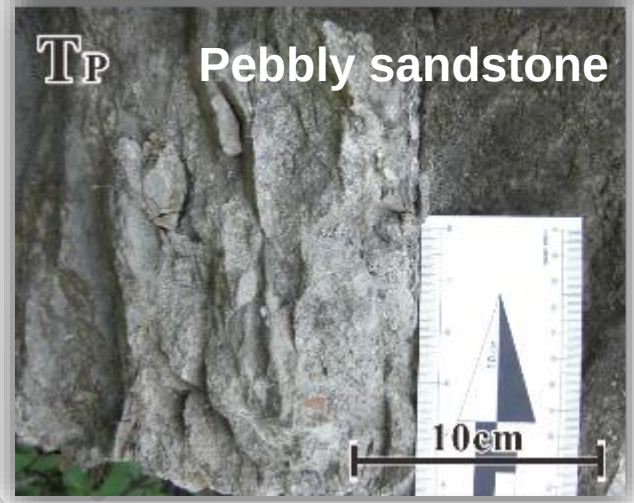
Lai *et al.* (2017) in review

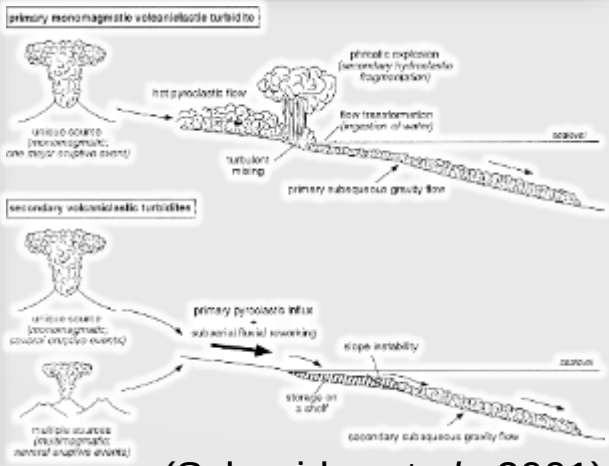




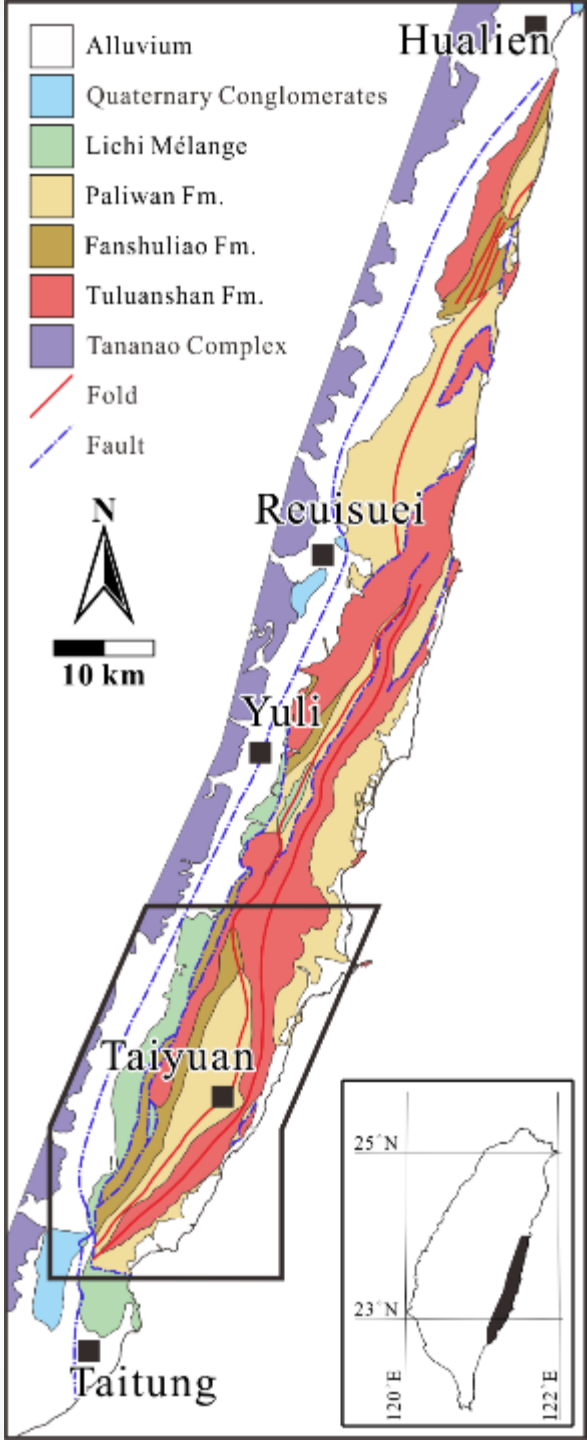
Tuffaceous turbidites embedded in Paliwan Fm.

These tuffs probably generated from pyroclastic flow which transformed into subaqueous gravity flows.





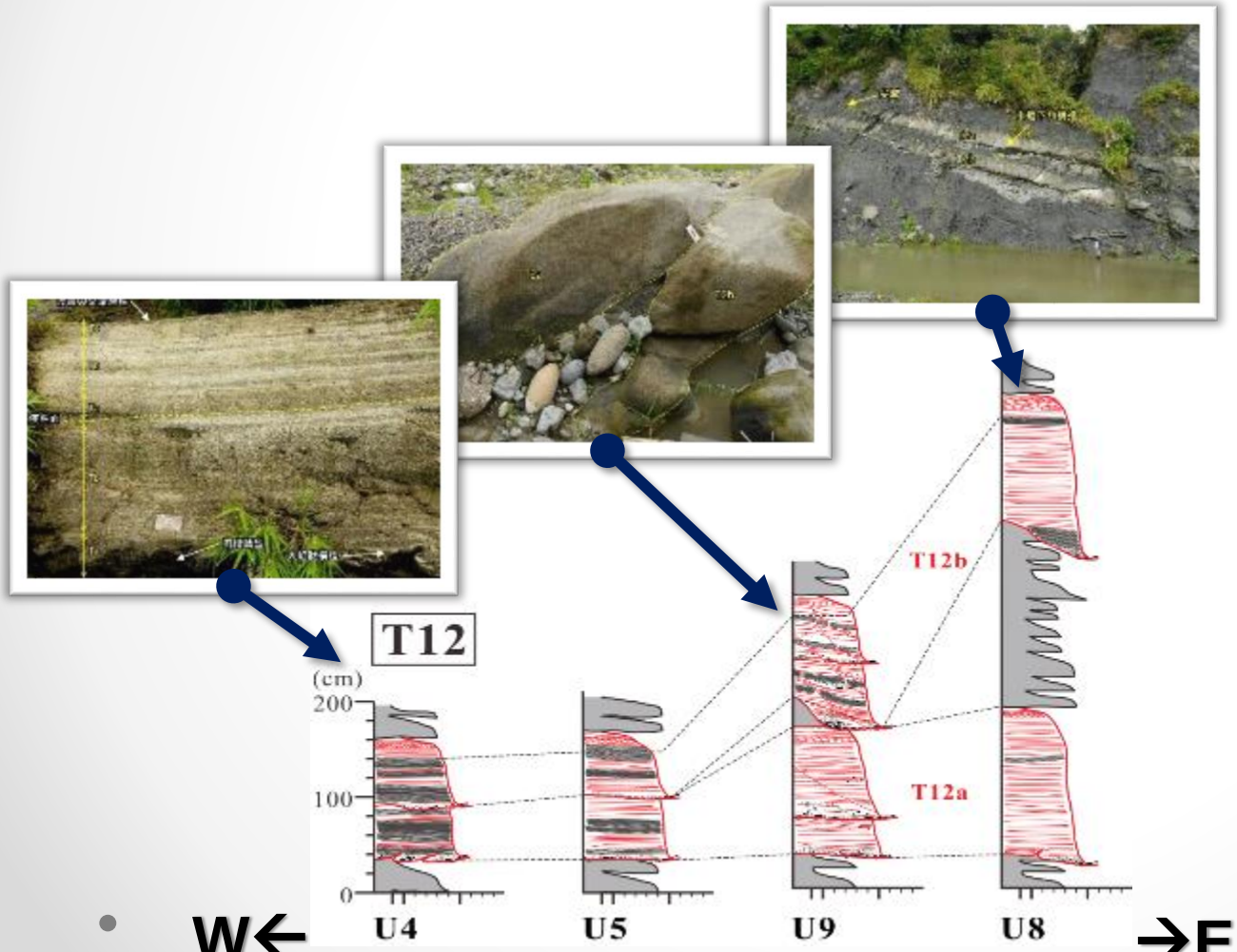
(Schneider *et al*., 2001)

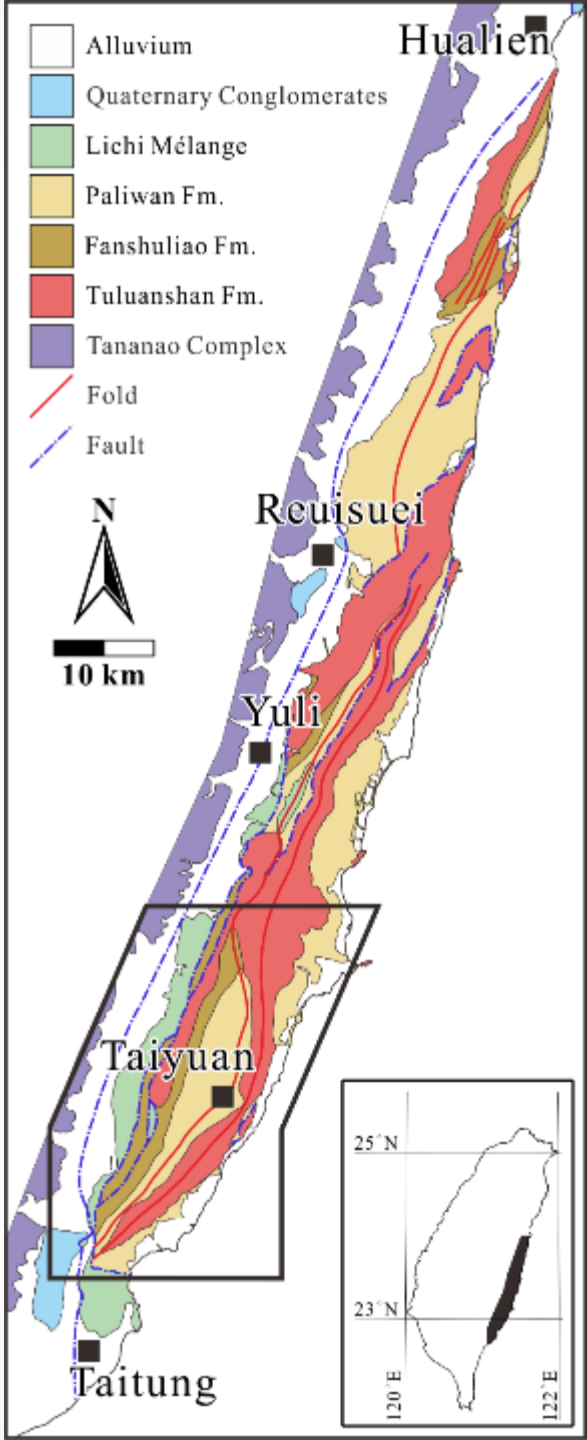


Tuffaceous turbidites embedded in Paliwan Fm.

Lateral changing:

- Thickness: thicker in the east
- Grain size: coarser in the east



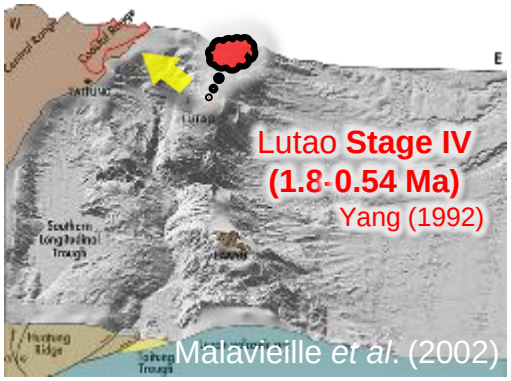


Tuffaceous turbidites embedded in Paliwan Fm.

These tuffs were widely considered as eruptional products from Lutao island in the south-eastward.

- *Similar depositional age of biotite-contained andesite & tuffs.*

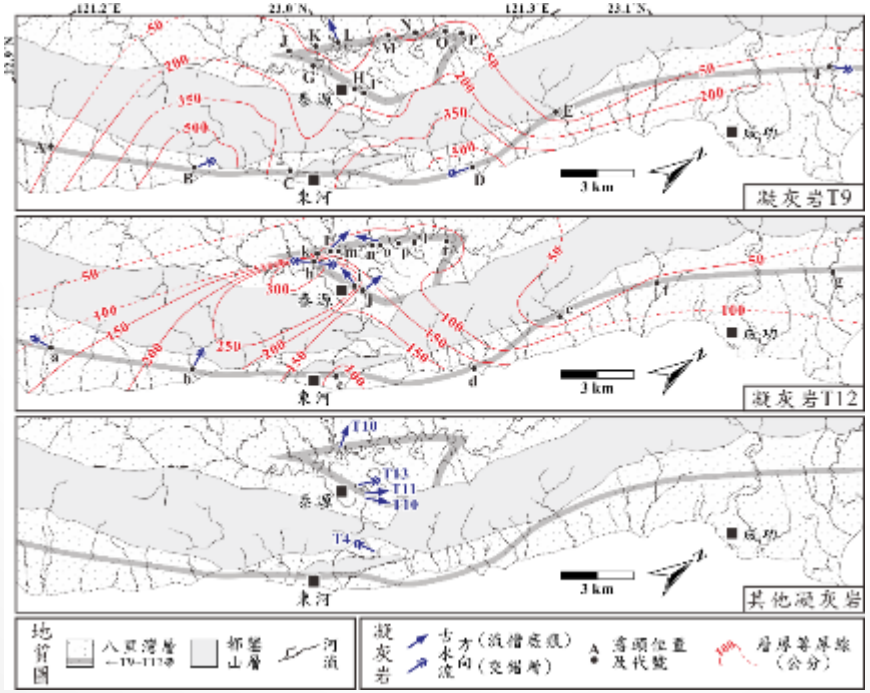
Yang *et al*. (1995)
Honrg and Shea (1997)

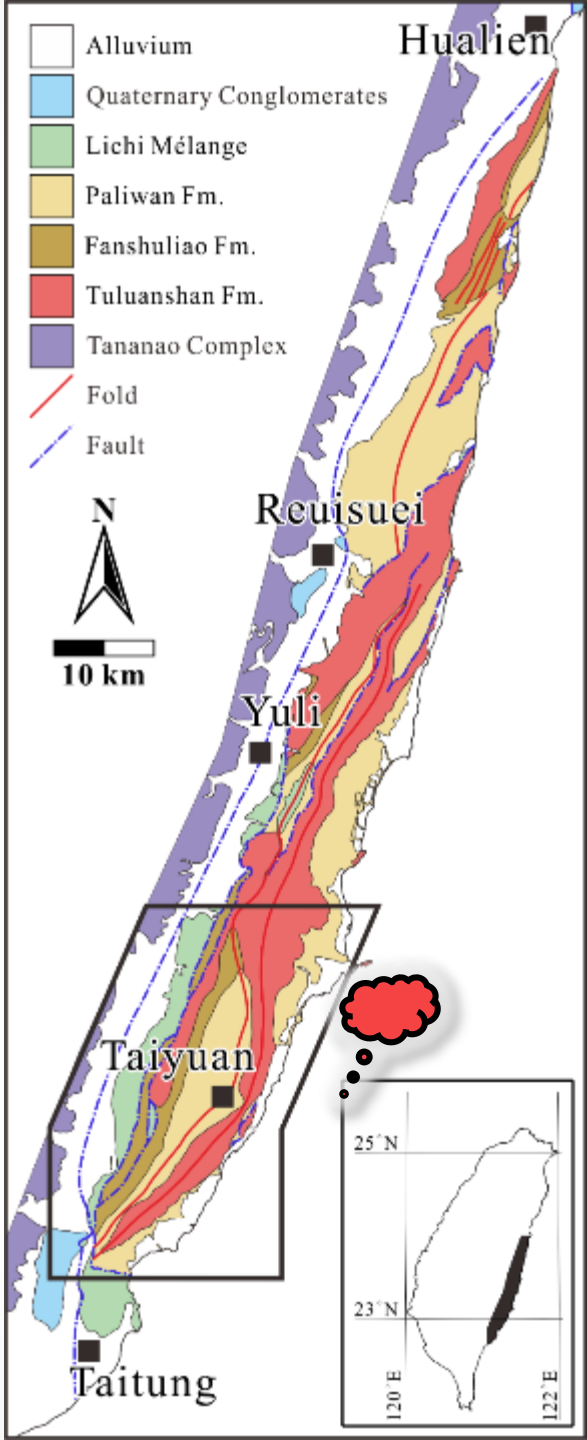


However...

- Largest thickness and grain size in the east.
- Paleocurrent directions radiate from the east. (Lai *et al.*, 2017, in review)

A possible source lying eastern offshore, which is undiscovered!





Summary

Turbidites in the Deformed Retrowedge Foredeep Basin, Coastal Range of Eastern Taiwan

Orogen-derived gravity flow deposits

Paliwan/Fanshuliao Fm.

- Coarse-grain to fine-grain turbidites
- Deep-sea fans/canyon system (partial channel-levee system?)

Lichi Mélange

- Consist olistostrome-slump beds-debrites (pebbly mudstone) assn.
- Overprinted by late quaternary east-vergent thrust system then transform into collisional complex.

Arc-derived gravity flow deposits

Tuluanshan Fm.

- Gravity flow deposits derived from epiclastic or pyroclastic flow.
- Submarine volcano apron system

Embedded in Paliwan Fm.

- Tuff generated by pyroclastic flow which transformed into subaqueous gravity flows.
- Originated from eastern offshore source, probably not Lutao.