Mixed-Mode Formation of Amorphous Materials in the Creeping Zone of the Chihshang Fault, Taiwan, and Implications for Deformation Style

Wu, W.-J., Kuo, L.-W., Ku, C.-S., Chiang, C.-Y., Sheu, H.-S., Aprilniadi, T. D., Dong, J.-J.
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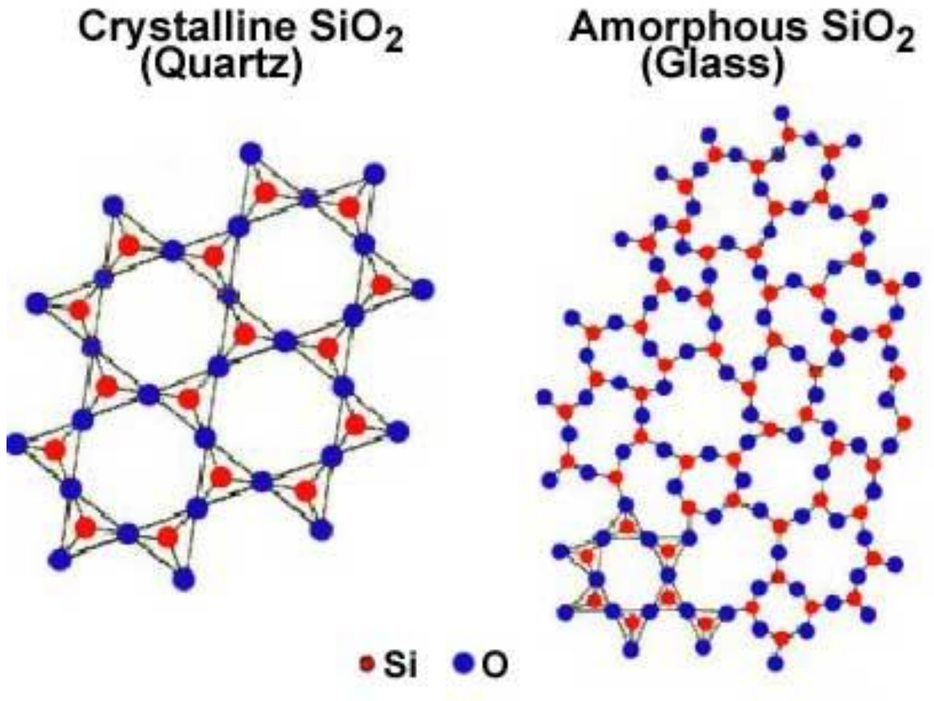
Date: 2024/04/19

Introduction

Fault rocks develop due to a **variety of deformation mechanisms** and **styles**, ranging from localized **brittle deformation** to distributed **ductile deformation**

Producing **distinct microstructures** and phase changes at **aseismic** (Ikari & Kopf, 2017) to **seismic** (Heaton, 1990) strain rates.



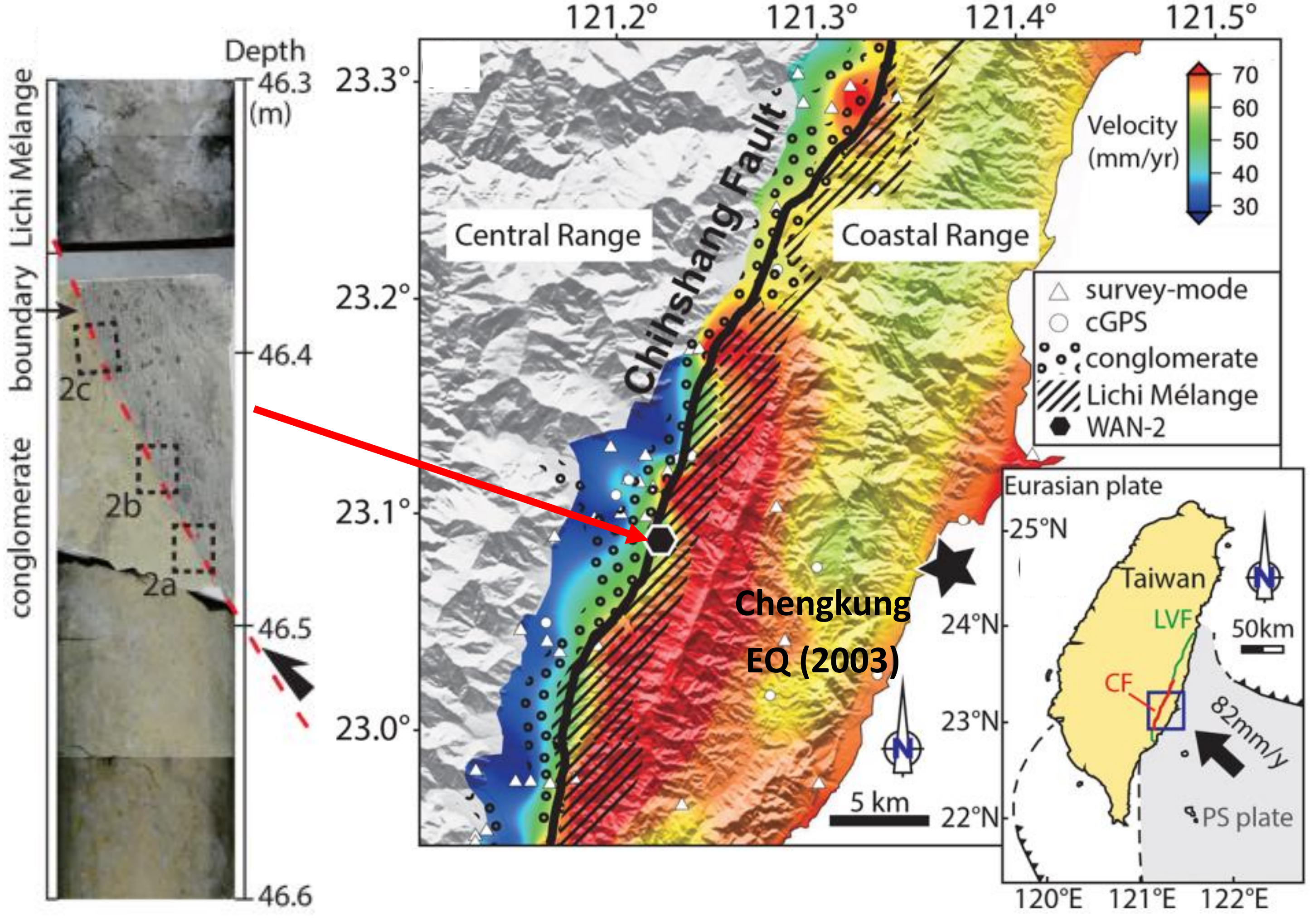
Amorphous materials (AMs) are materials in which the atoms and molecules are **NOT** organized in a definite lattice

It has been recognized that **AMs** can occur in faults and simulated **creeping zones** that formed at **aseismic deformation** conditions (Janssen et al., 2010; Pec et al., 2012)

Despite progress in **understanding the role of AMs** in **fault mechanics**, examples **from within the slip zones of natural faults** remain **limited**, and the related **mechanisms of formation** are **not well understood**.

Introduction

This paper reports the first occurrence of AMs in the creeping zone of the Chihshang Fault in Taiwan



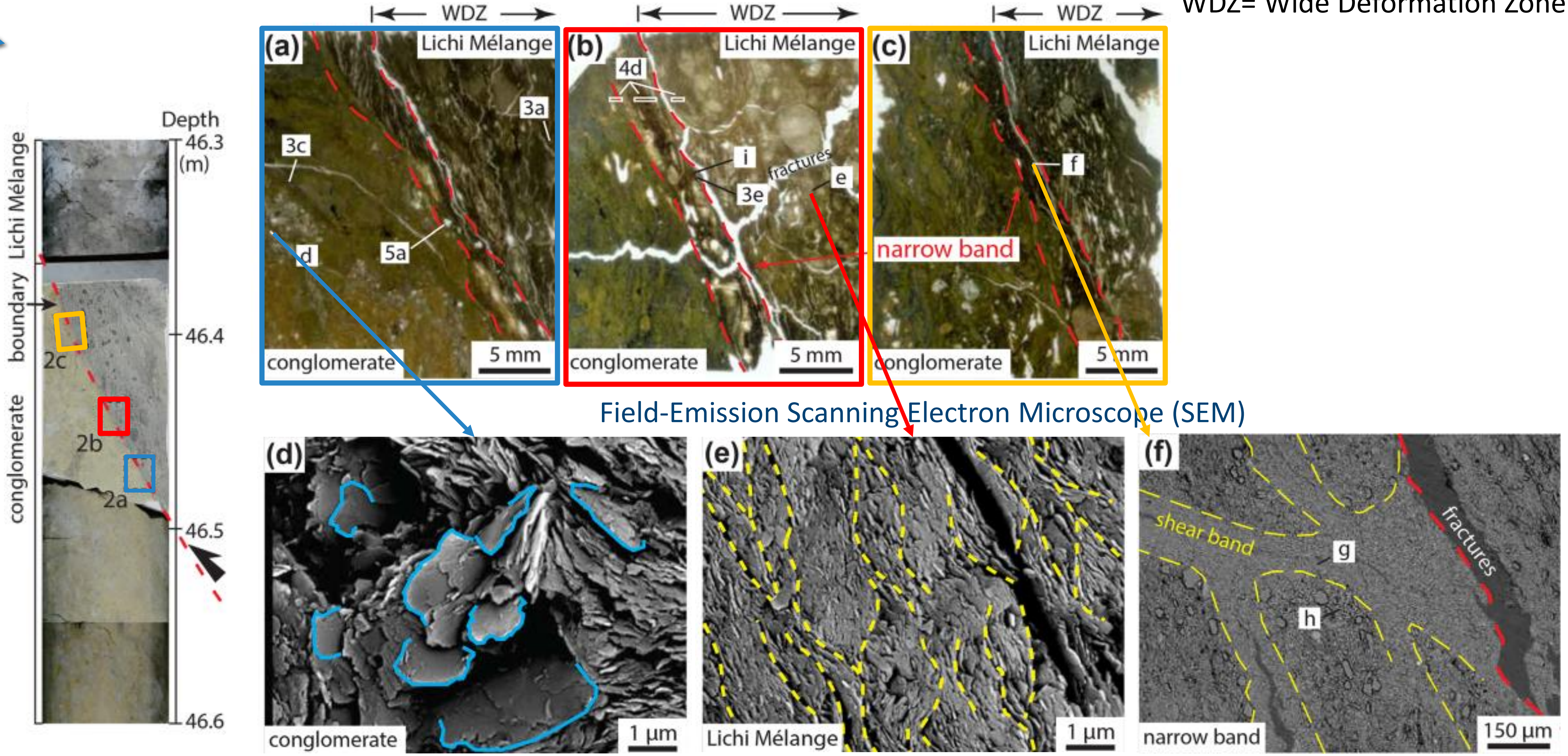
Horizontal displacement from GPS data collected from 2007- 2015

- **The Chihshang Fault** is an **oblique thrust fault** with a significant component of **left-lateral strike-slip**
- The **shallow creeping segment** lies within the **Lichi Mélange in its hanging wall** (Angelier et al., 2000; Lee et al., 2006; Thomas et al., 2014)
- The **fault zone materials** were characterized at a depth of **46.45 m** from the **WAN-2 borehole**, which is considered to be **principal slip zone** of the **Chihshang Fault**

Methods and Results

Optical Microscope Observations

WDZ= Wide Deformation Zone



Field-Emission Scanning Electron Microscope (SEM)

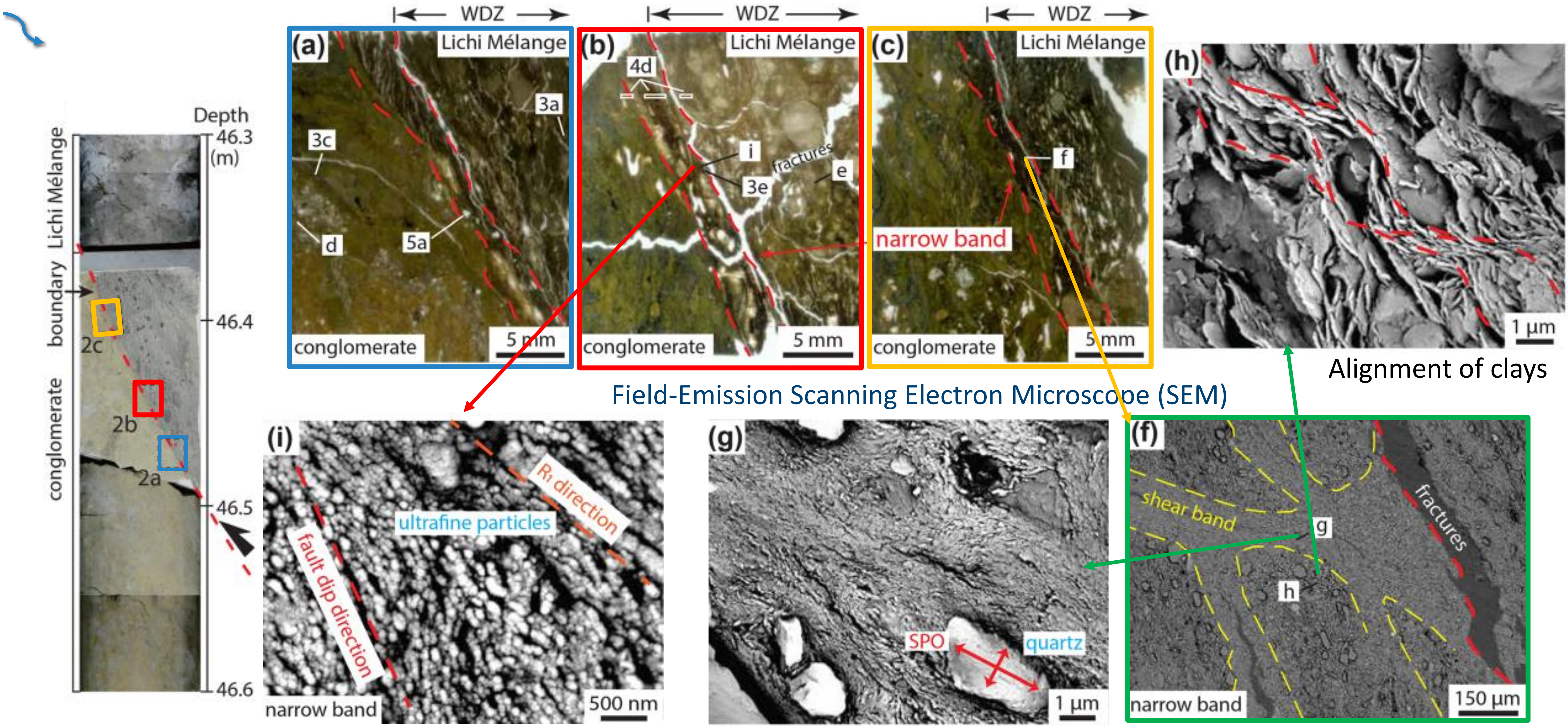
Random oriented

Scaly clay fabrics

Divided by small quartz clast

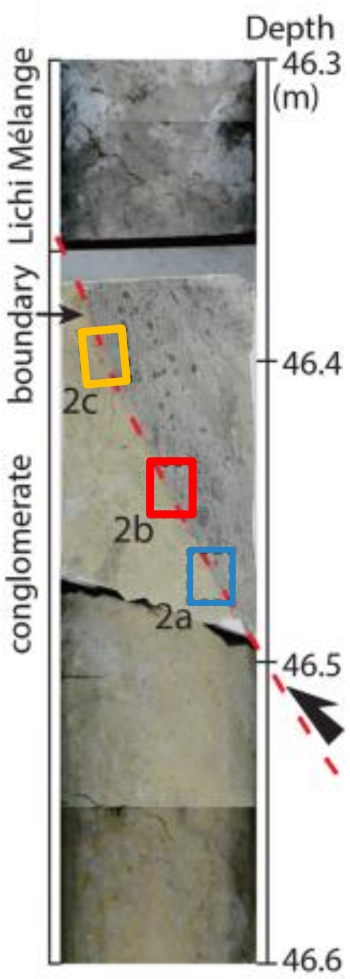
Methods and Results

Optical Microscope Observations

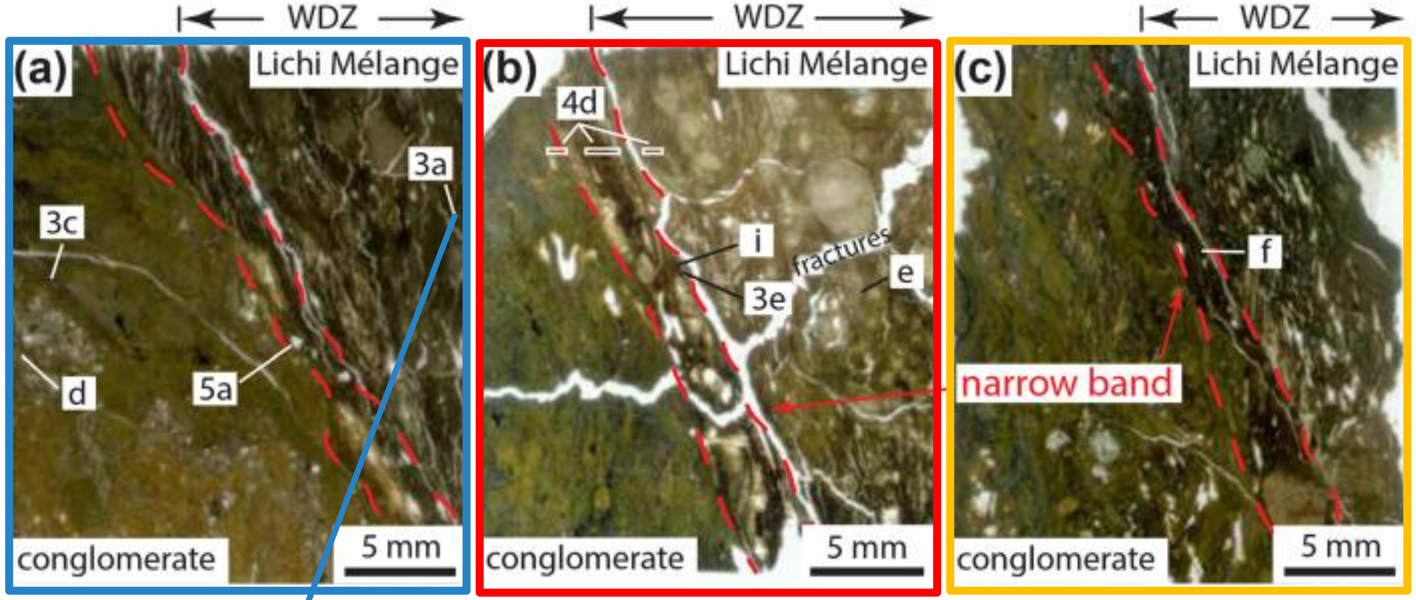


SPO= Shape Preferred Orientation

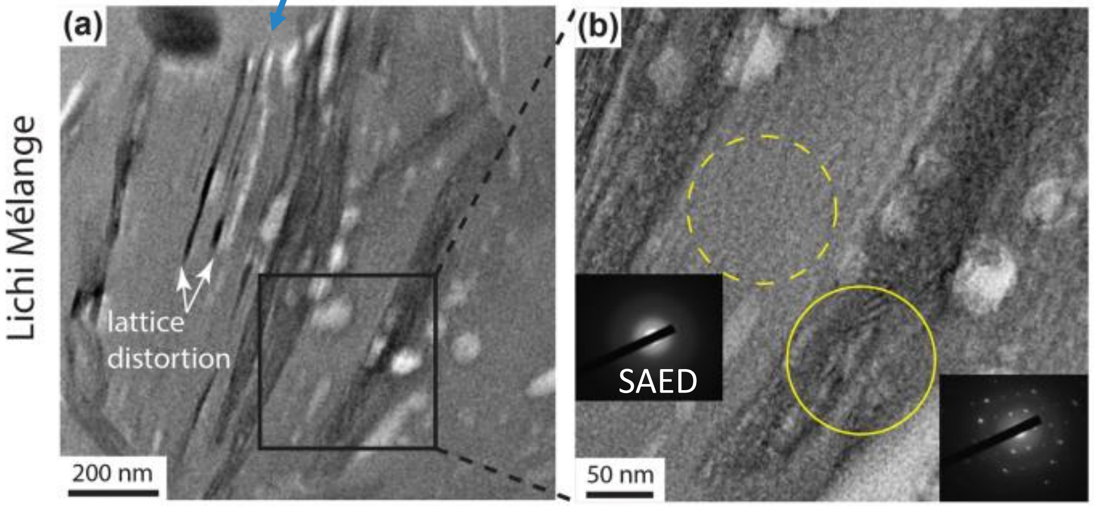
Methods and Results



Optical Microscope Observations



Focused Ion Beam-Transmission Electron Microscope (FIB-TEM)



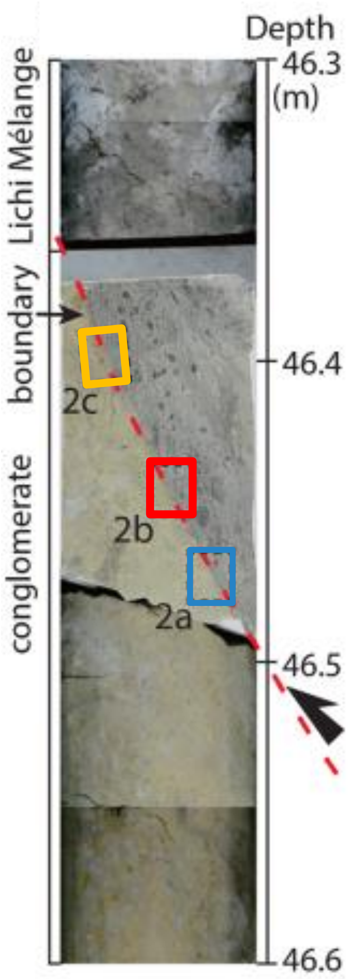
- SAED showed Amorphous textures

- Lattice distortion
- AMs/Crystalline phase (Clays): Sharp boundary

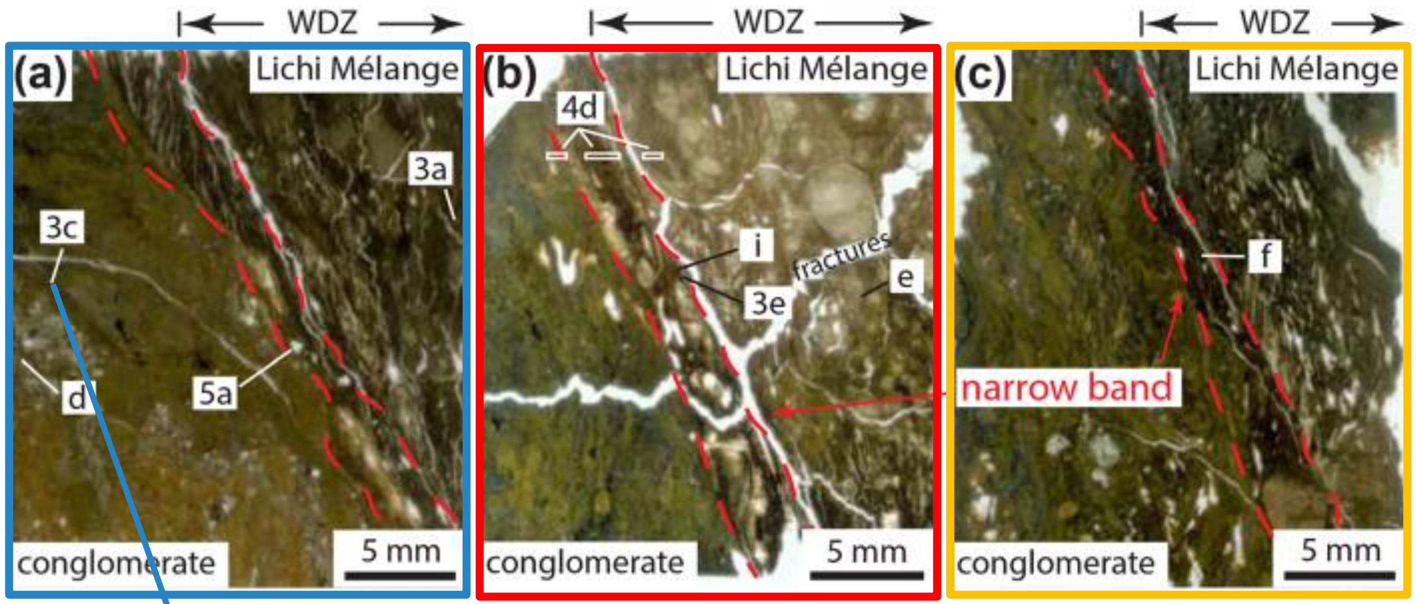
↳ Scaly clay fabrics

SAED= Selected Area Electron Diffraction

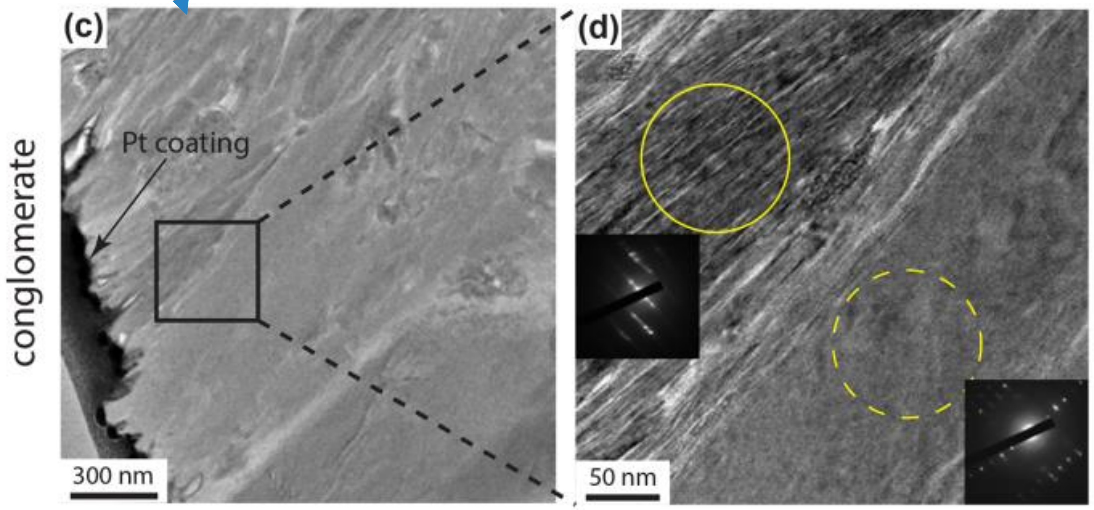
Methods and Results



Optical Microscope Observations

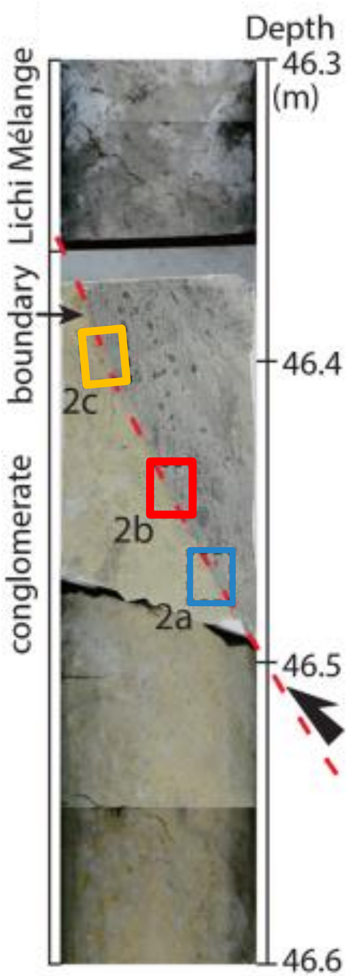


Focused Ion Beam-Transmission Electron Microscope (FIB-TEM)

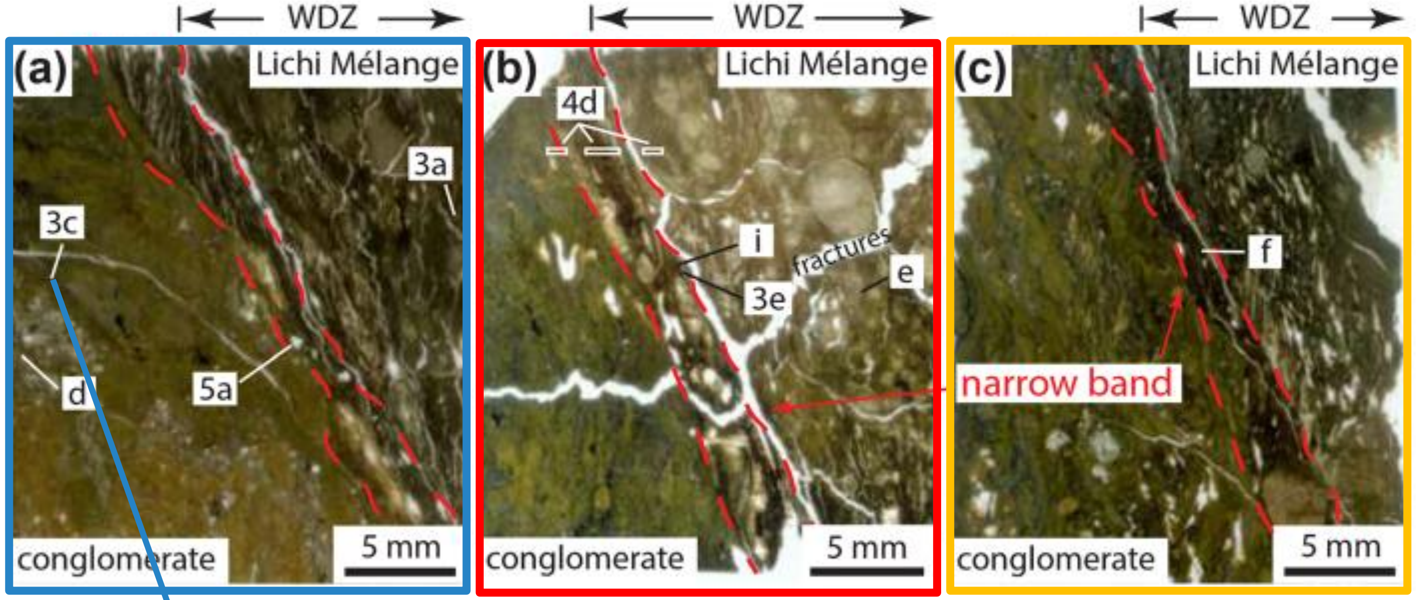


- It is less oriented compared with those from the Lichi Mélange

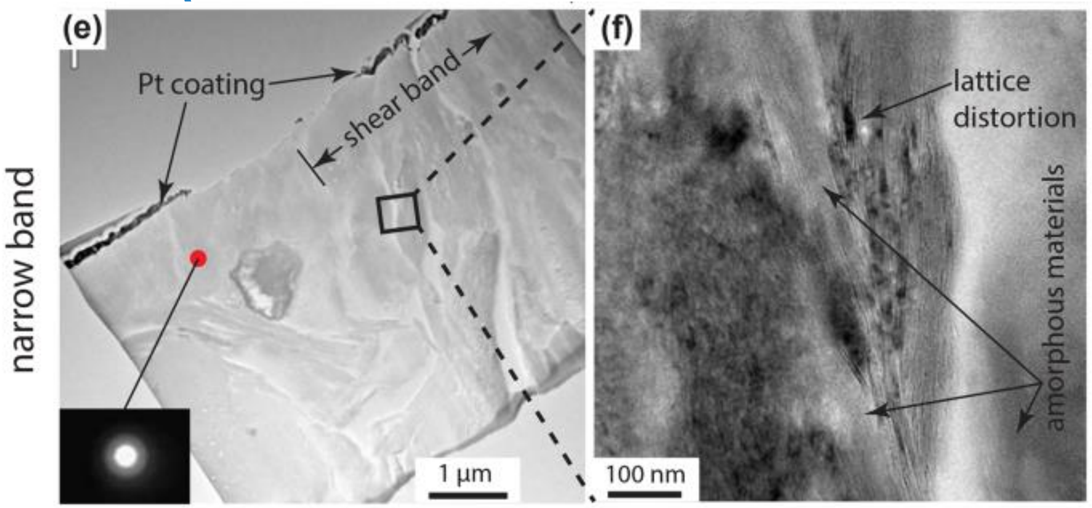
Methods and Results



Optical Microscope Observations



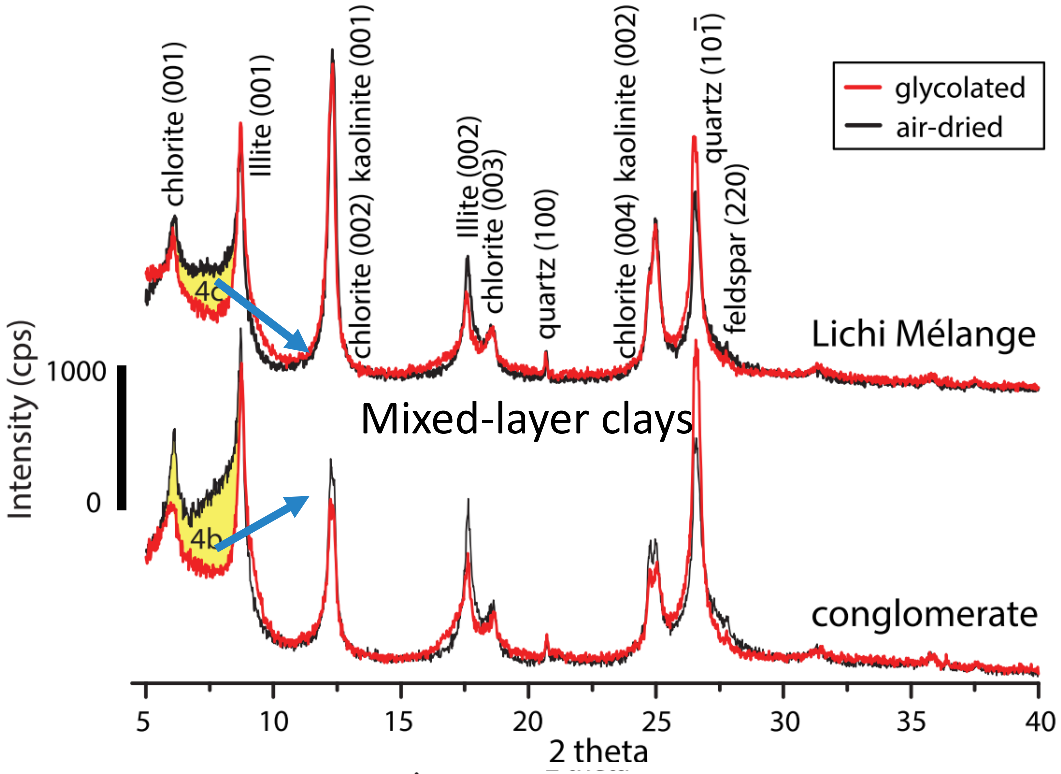
Focused Ion Beam-Transmission Electron Microscope (FIB-TEM)

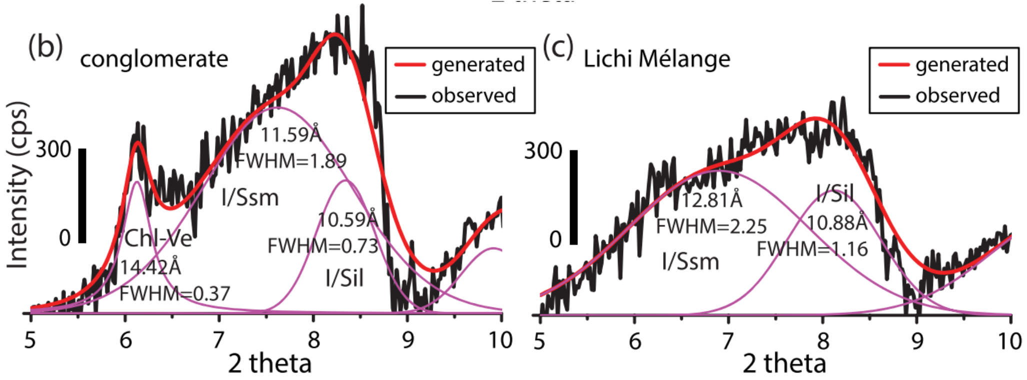


- AMs: Matrix (SAED), along shear bands, together with lattice distortions

SAED= Selected Area Electron Diffraction

Methods and Results





Monochromatic XRD

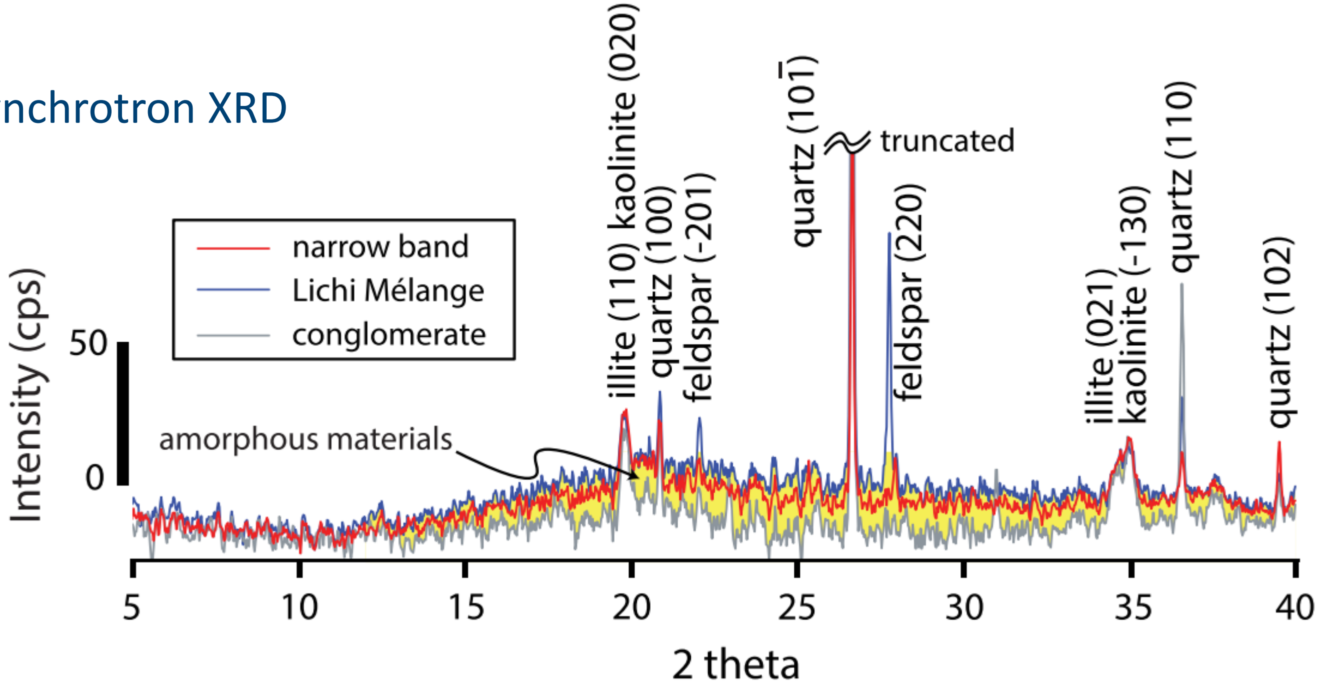
- Mixed-layer clays:

I/Sil: Illite/smectite mixed-layer mineral with low smectite content

I/Ssm: Illite/smectite mixed-layer mineral with high smectite content

Chl/Ve: Chlorite/vermiculite mixed-layer mineral

Synchrotron XRD



- Lichi Mélange and narrow band: illite, kaolinite, quartz, **feldspar**
- Conglomerate: illite, kaolinite, quartz
- **Amorphous materials**

Better crystallization

Extra smectite content in I/Ssm

FWHM= Full width at half maximum

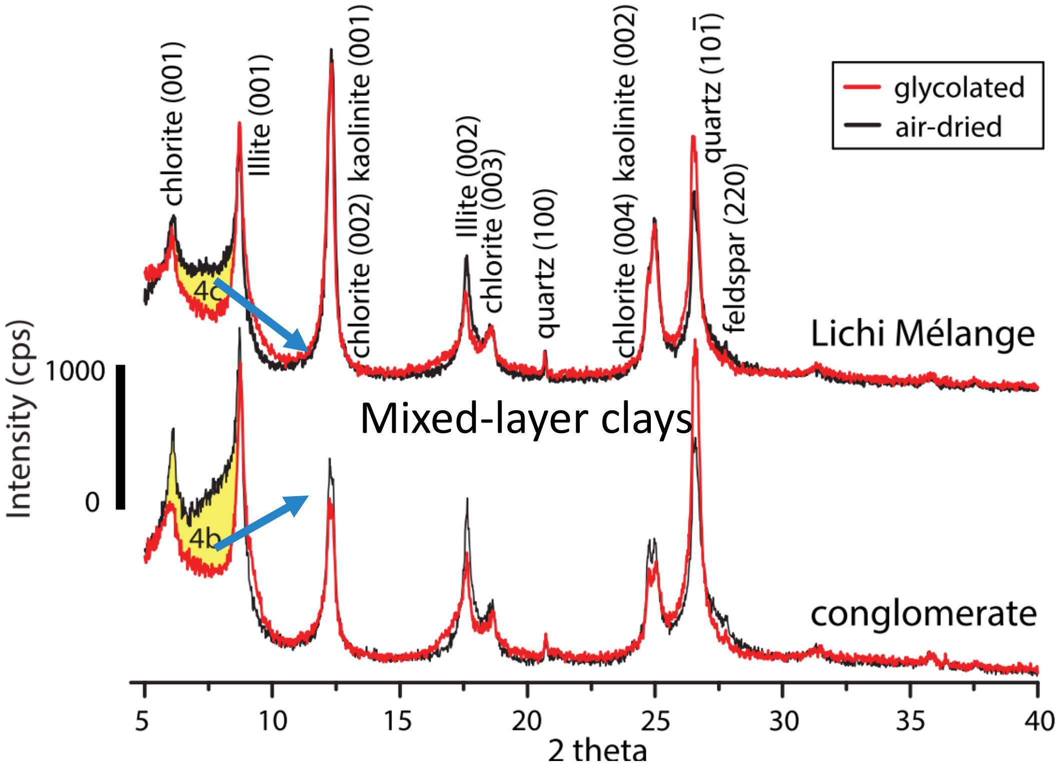
Discussions (+Methods and Results)

- Three clay groups

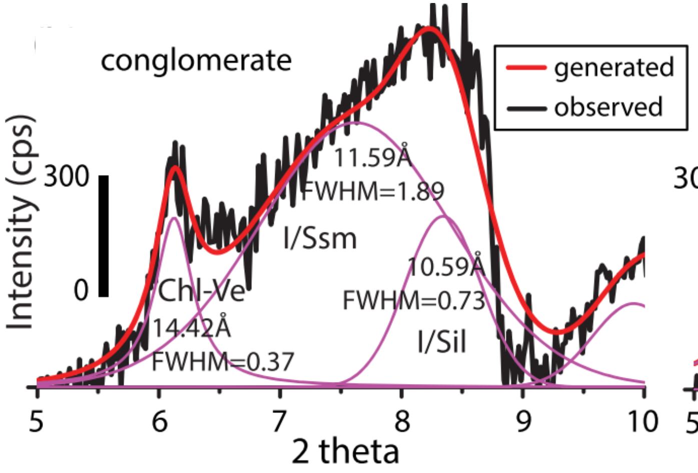
I. Chlorite and Illite (**Detrital**) (Kubler index "KI"(~0.3 to 0.5 in °Δ2θ) is consistent with clay minerals (as detrital phase) in Taiwan sedimentary rocks)

II. Chl/Ve, I/Ssm, I/Sil, and kaolinite in **conglomerate**

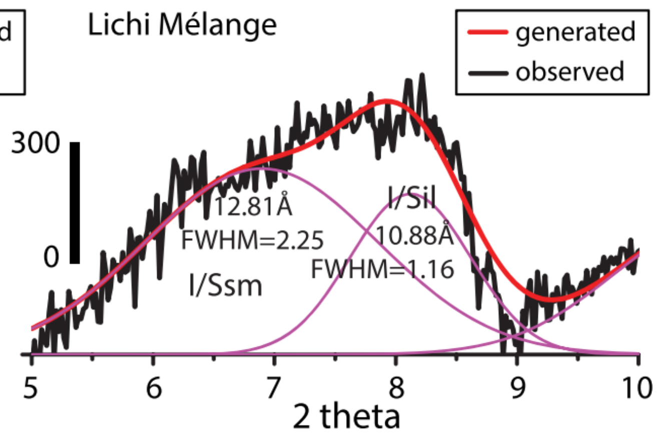
III. I/Ssm, I/Sil, and kaolinite in **Lichi Mélange**



Monochromatic XRD



Group II

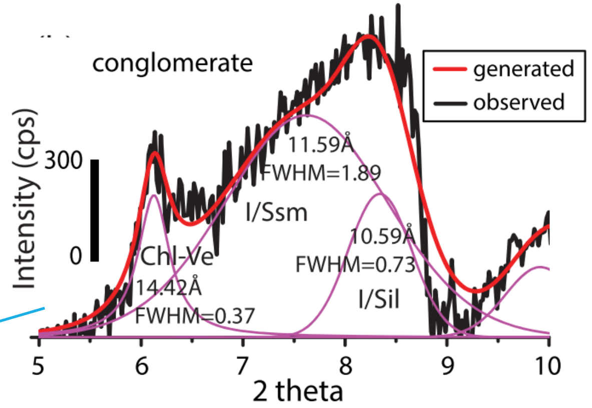


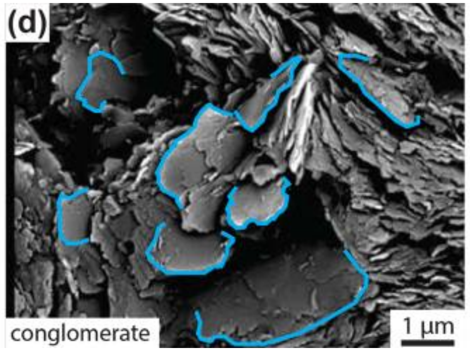
Group III

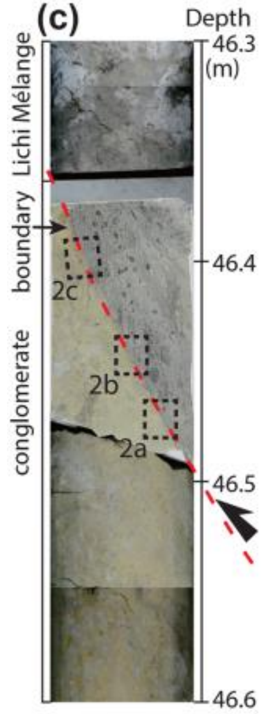
Discussions (+Methods and Results)

II. Chl/Ve, I/Ssm, I/Sil, and kaolinite in **conglomerate** (Weathering authigenic)

Monochromatic XRD

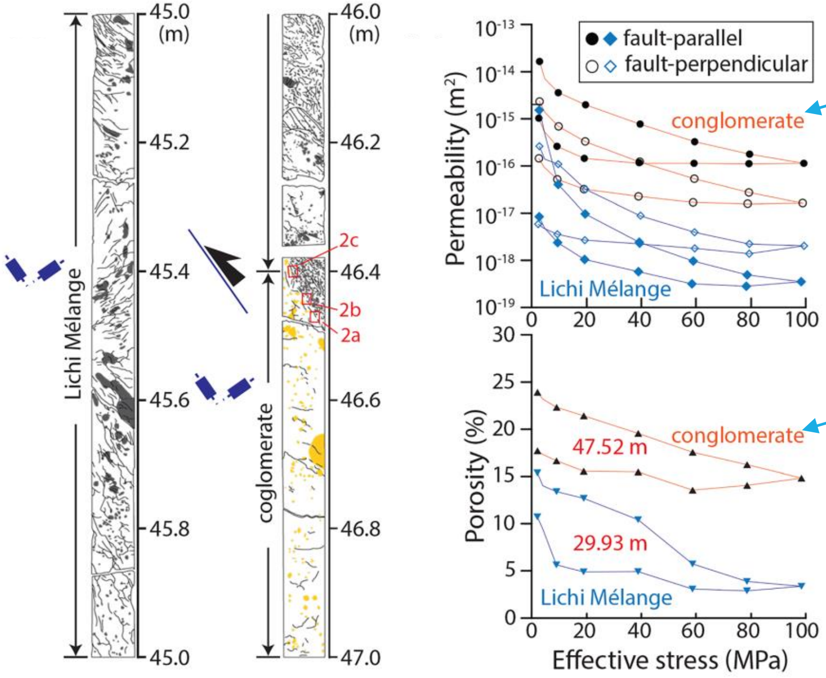


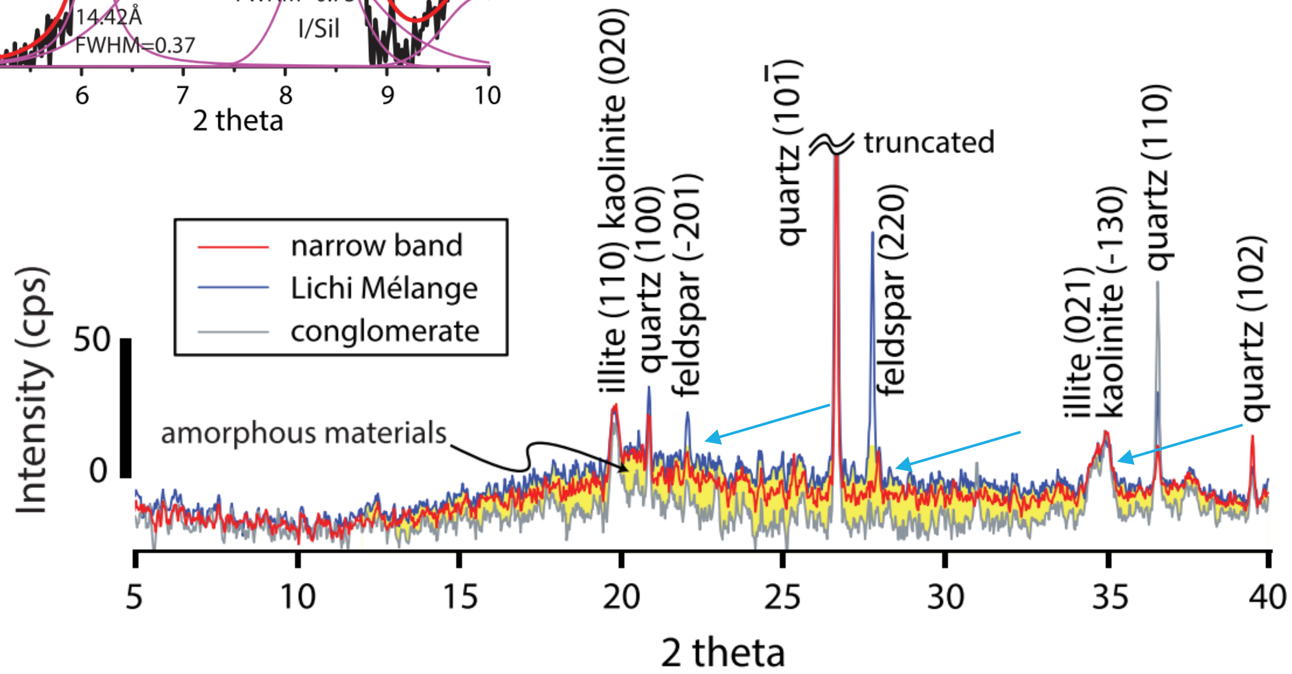




SEM

Permeability and Porosity





Synchrotron XRD

K-feldspar→illite+kaolinite

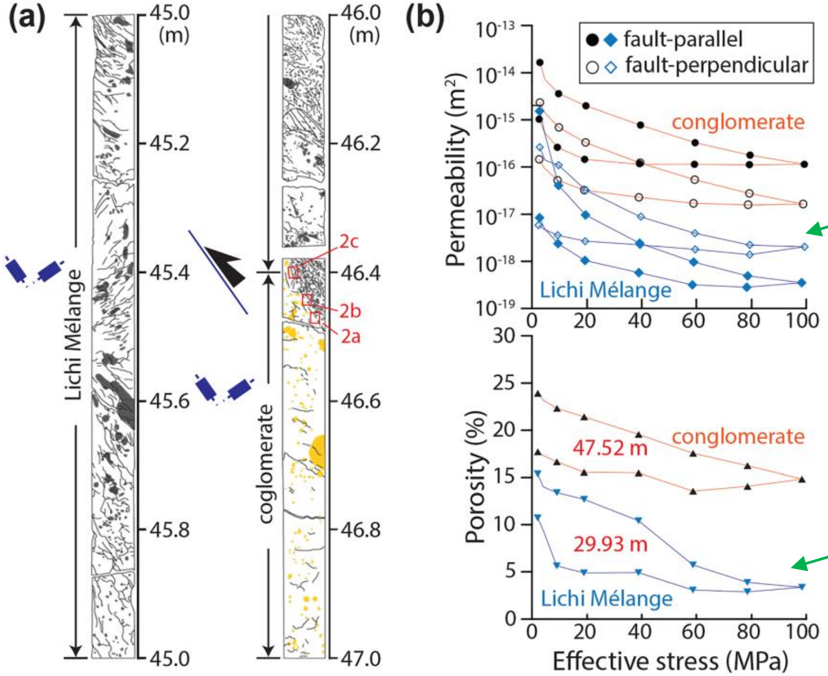
K-feldspar→(illite) + smectite+kaolinite

➯ Group II was formed by weathering and alteration of Group I (Chlorite and Illite)

Discussions (+Methods and Results)

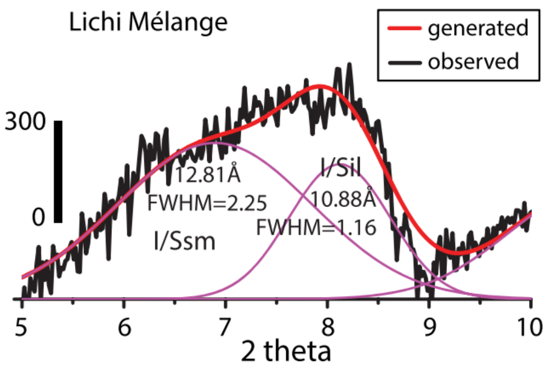
III. I/Ssm, I/Sil, and kaolinite in **Lichi Mélange** (Synfaulting authigenic)

Permeability and Porosity

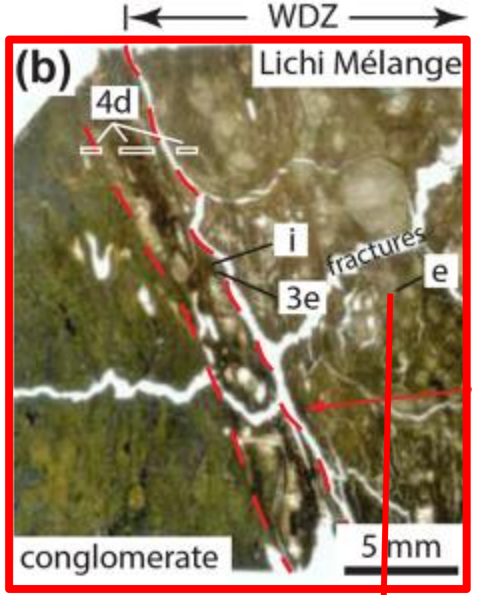


- Unfavorable environment for weathering process

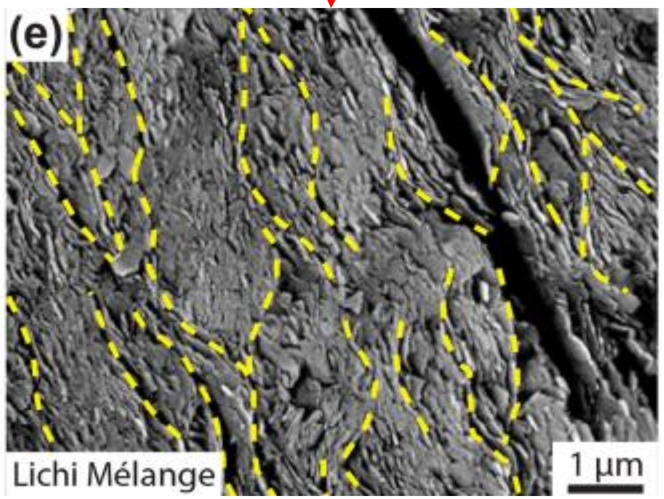
Monochromatic XRD



- Poor crystallinity of I/S
- An increase of smectite interlayer in I/S



SEM



- Group 3 is deformed and occurs in shear zones

The **difference in crystallinity** between group II and group III:

➯ Presumably due to **shearing** and **weathering** of Group I (chlorite and illite)

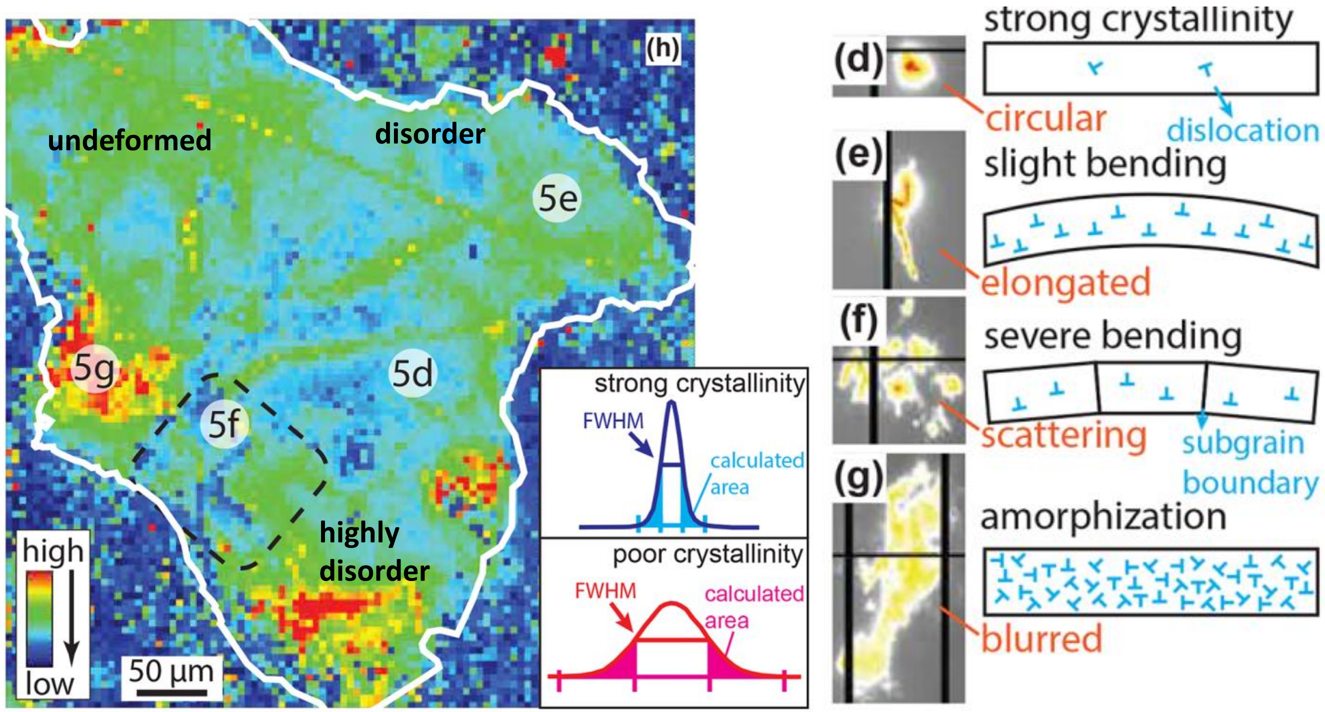
The **poor crystallinity** of Group III:

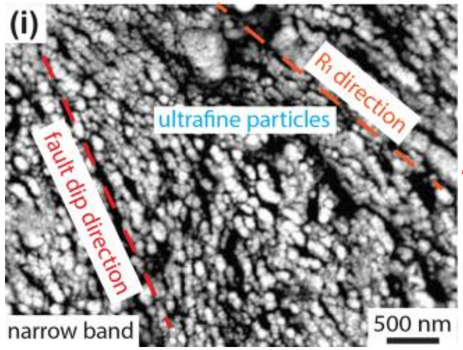
➯ **Stress and intense deformation**

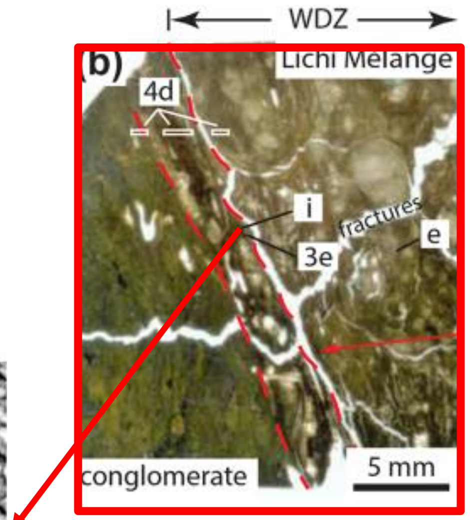
Discussions (+Methods and Results)

Shear-induced Amorphization in the Lichi Mélange

Laue diffraction pattern and mapping on the quartz grain within the narrow band







The narrow band was derived from strain localization and represents the PSZ of the Lichi Mélange

➯ Suggesting strain localization and associated **shear-induced amorphization** within the narrow band

Narrow band (both in matrix and quartz)

AMs

Interface of scaly clays fabrics

Discussions

Implications of Mixed Deformation Styles in Chihshang Fault

Narrow band (both in matrix and quartz)

Distributions of AMs

Interface of scaly clays fabrics

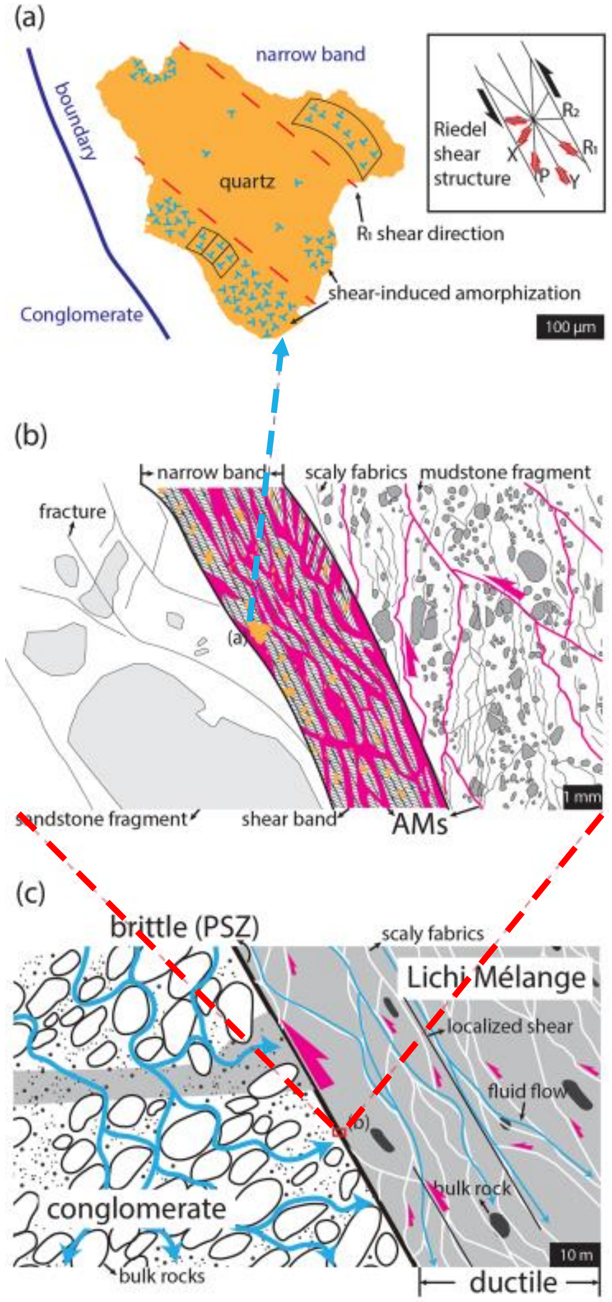
➢ The **creeping zone** of the **Chihshang Fault** was by both **brittle** and **ductile deformation styles** to **produce AMs** within **the narrow band** and **along scaly clay fabrics**

K^+ rich fluids → I/S, Chl /Ve (K-felspar)

Reduce fault strength

Increase of smectite phase in I/S

Shear-induced amorphization



- Authors proposed that the formation of AMs by shear-induced amorphization can be likely considered as precursors for the formation of I/Ssm
- The transformation of fault-zone materials by gouge amorphization could potentially modify the mechanical, physical, and chemical properties of the fault zone and promote the currently observed creeping behavior at shallow depths

Conclusions

- Authors demonstrate the presence of AMs in the actively creeping Chihshang Fault in Taiwan and suggest that the AMs were derived from shear-induced amorphization process.
- The occurrence of AMs in two structural locations (a localized narrow shear band and within distributed networks of scaly clay fabrics) as a likely consequence of the dissipation of strain during mixed brittle to ductile deformation.
- Because AMs are kinetically unstable in low-temperature environments at depth, their presence within the Chihshang Fault suggests recent and ongoing on-fault amorphization driven by tectonic loading and stress relaxation.
- Integrated with data on the populations of phyllosilicates within the creeping fault zone (in particular, an increase of smectite content in I/S mineral; Group III), they propose that shear-induced amorphization gradually modifies the physical, chemical, and mineralogical characteristics of a fault by amorphous phase and subsequent neomineralization
- Shear-induced amorphization likely serves as a mechanism that influences the dynamic fault strength and seismogenesis at shallow depths during the seismic cycle.

Thank you for listening