Insights into active tectonics of eastern Taiwan from analyses of geodetic and geologic data

by Wen-Jeng Huang¹,², Kaj M. Johnson², Junichi Fukuda² and Shui-Beih Yu¹

¹.Academia Sinica  ².Indiana University

Presenter: Wen-Jeng Huang

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AGU
After Ching et. al., 2007

(Ruptures according to Hsu, 1962)
Three major faults

(After Ching et al., 2007)
Geodetic and Geologic Data

Vertical GPS

Horizontal GPS

Holocene Uplifted marine terraces

InSAR-inferred differential vertical motion

(Hsieh et al., 2004)
Geodetic and Geologic Data

Vertical GPS

Holocene Uplifted marine terraces

Yu, unpublished

(Hsueh et. al., 2004)

(Hsu and Bürgmann, 2006)

Horizontal GPS

InSAR-inferred differential vertical motion

Yu and Kuo, 2001
Geodetic and Geologic Data

Horizontal GPS

(Yu and Kuo, 2001)
Geodetic and Geologic Data

Horizontal GPS

Northern Profile

Southern Profile

(Yu and Kuo, 2001)
Geodetic and Geologic Data

Horizontal GPS

Northern Profile

Southern Profile
Geodetic and Geologic Data

- Vertical GPS
- Horizontal GPS

Holocene Uplifted marine terraces

InSAR-inferred differential vertical motion

(Hsu and Bürgmann, 2006)
Geodetic and Geologic Data

**Vertical GPS**

InSAR - inferred differential vertical motion

(Derived from Hsu and Bürgmann, 2006)

(Yu, unpublished)

(Hsieh et. al., 2004)

**Horizontal GPS**

InSAR-inferred differential vertical motion

(Yu and Kuo, 2001)

**Interseismic deformation**

**Long-term deformation**

**Holocene Uplifted marine terraces**
Buried dislocation model by Hsu et al. (2003)

Plate-block model by Johnson et al. (2005)
$t_R = 2\eta/\mu$, relaxation time

$W(t) = (F_0*S) \exp(-\alpha t/t_R)$

$S$: displacement
$t$: time
$\alpha$: scalar

Plate-block Model
Plate-block Model

\[ T_i/T_R < 1 \]

steady deformation
ignore earthquake timing

\[ V(t) = V_s \exp\left( -\frac{t}{T} \right) \frac{(T/T_R)}{t} \]

V: velocity on the ground

CRF: 65° W
(Hsu, 1976; Shyu et al, 2006)

LVF: ~55° E;
(Kuo Chen, 2004)

OSF: 30° W
(Malaveille et al, 2002)

H = 30 km

elastic \( \mu \)

viscoelastic \( \eta, \mu \)

\[ t_R = 2\eta/\mu, \text{ relaxation time} \]
Plate-block Model

creep at constant resistive stress

long-term slip

τ = constant

imposed back-slip

τ = constant

interseismic slip

τ = constant

![Diagram of plate-block model with various stress conditions and color scale](image)
Solving for parameters: inverting data through viscoelastic collision model

**Forward problem**: Interseismic and long-time velocities are solved, given model parameters

\[ V_{\text{long}} = [G_{\text{block}} + G_c B_{\text{cancel}} + G_f B_{\text{forward}}] \cdot \Omega \]

\[ V_{\text{int}} = [G_{\text{block}} + G_c B_{\text{cancel}} + G_f B_{\text{forward}} + G_b B_{\text{backslip}}] \cdot \Omega \]

- \( V_{\text{int}} \): vector of interseismic geodetic data
- \( V_{\text{long}} \): vector of long-term geologic data
- \( G \): Green function
- \( B \): corresponding matrix
- \( \Omega \): vector of Euler poles

\[ d = g(m) + \varepsilon \]

- \( m \): vector of parameters
- \( \varepsilon \): vector of errors
Monte Carlo Inversion
- Metropolis method

Bayes’ Theorem

\[ P(m / d) = \frac{P(d / m)P(m)}{P(d)} = \alpha P(d / m) \]

- \( m \): vector of parameters
- \( d \): vector of data
- \( \alpha \): constant scalar

By definition

\[ P(d / m) = C \exp \left[ -\frac{1}{2} (d - g(m))^T \sum_d^{-1} (d - g(m)) \right] \]

- \( C \): constant scalar
- \( P(m / d) \): posterior probability
Markov Chain random walk

Sample distribution

Probability contour
Two-fault Model

Long-term slip rate

LVF slip rate high – badly over-predicted coastal uplift

Central Range fault

Longitudinal Valley fault

Long-term coastal uplift rates

Predicted data in red
Observed data in black
Three-fault Model

long-term coastal uplift rates

long-term fault slip rate  uncertainty
Three-fault Model

long-term fault slip rate

uncertainty
Three-fault Model

horizontal residual  model vertical  vertical GPS

interseismic fault slip rate  uncertainty

view direction
Three-fault Model

slip deficit per year on Longitudinal Valley fault

(long-term slip rate minus interseismic slip rate)

1951 earthquakes surface ruptures (Hsu, 1962)
Three-fault Model

slip deficit on Longitudinal Valley fault

2003 Mw 6.8 Cheng-Kung earthquake coseismic slip (Ching et al, 2007)
Conclusion

1. Holocene uplift rates (long-term uplift rates) along eastern coast can only be reproduced if a significant amount of convergence is accommodated offshore on the OSF.

2. Including the OSF in the model reduces the estimate of long-term slip rate on the LVF by a factor of about two and changes the LVF from a nearly pure dip-slip reverse fault to an oblique reverse, left-lateral fault, consistent with independent observations.

3. The LVF is largely locked north of Yuli and is creeping to the south.

4. The transition from creeping to locked on the southern segment of LVF corresponds with the hypocenter of the 2003 Chengkung earthquake.
Thank you for your attention!
Talk Outline

• Tectonic setting and research interests

• Method
  • Forward model
    • Plate collision model
  • Inverse model
    • Inverse scheme
    • Resolution test

• Results
  • Two-fault model
  • Three-fault model

• Conclusion
M~6 Earthquakes
Plate-block model

\[ V_p/2 = \dot{s} \cos \delta \]

\[ \delta, \text{ fault dip: } 30^\circ \]

H, thickness: 30 km

**Vertical velocity**

- Long-term
- Interseismic

![](vertical_velocity.png)

**Horizontal velocity**

- Long-term
- Interseismic

![](horizontal_velocity.png)
Effect of elastic layer thickness

- Vertical/slip rate
  - Distance from fault tip (km)

- Long-term
- Interseismic

- Plate-block model
  - H, thickness of elastic layer
  - \( \eta, \mu \)

- Vertical velocity
- Horizontal velocity

- \( H \), thickness of elastic layer
  - 40 km
  - 30 km
  - 20 km

- Vertical velocity
  - Interseismic
  - Long-term

- \( \delta \), fault dip: 30°
Viscoelastic Earthquake cyclic model

When $T/\tau \approx 0$, i.e. $T << \tau$ and $\eta >> \mu$, $\mathbf{v}^{\text{EQ}} = -B^s \mathbf{v}$

Then $\mathbf{v}^{\text{in}} = \mathbf{v}^{\text{lt}} + B^s \mathbf{v}$, where $\mathbf{v}^{\text{lt}} = f(\mathbf{S} \cdot x_i)$

$\mathbf{S}$ is fault slip rate and $x_i$ is a coordinate.

velocity on the ground

interseismic

long-term (steady)

back-slip rate

effect after EQ

slip on fault

slip history

steady creep

black: back-slip
red: coseismic slip
Resolution Test

There are three types of continuity: low, moderate, and high. The images show how the specified view direction affects the continuity of different areas. The specified areas are CRF, LVF, and OSF.
Earthquake cycle

- **T**: earthquake recurrence time
- **t_R**: relaxation time (η/μ)
- **t**: time since last earthquake

**Horizontal velocity**
- \( T/t_R = 10 \)
- \( T/t_R = 1 \)
- \( T/t_R = 0.1 \)

**Vertical velocity**
- \( T/t_R = 10 \)
- \( T/t_R = 1 \)
- \( T/t_R = 0.1 \)

**Distance from fault tip (km)**

- \( H: 30\text{km} \)
- Fault dip: 30°
Three-fault Model

Patch distribution

Fit of InSAR-inferred differential vertical motion

Predicted data in red
Observed data in black