Areal Source Modeling
(Shallow Zones, Deep Zones and Subduction Zones)

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Taiwan SSHAC Level 3 PSHA Study
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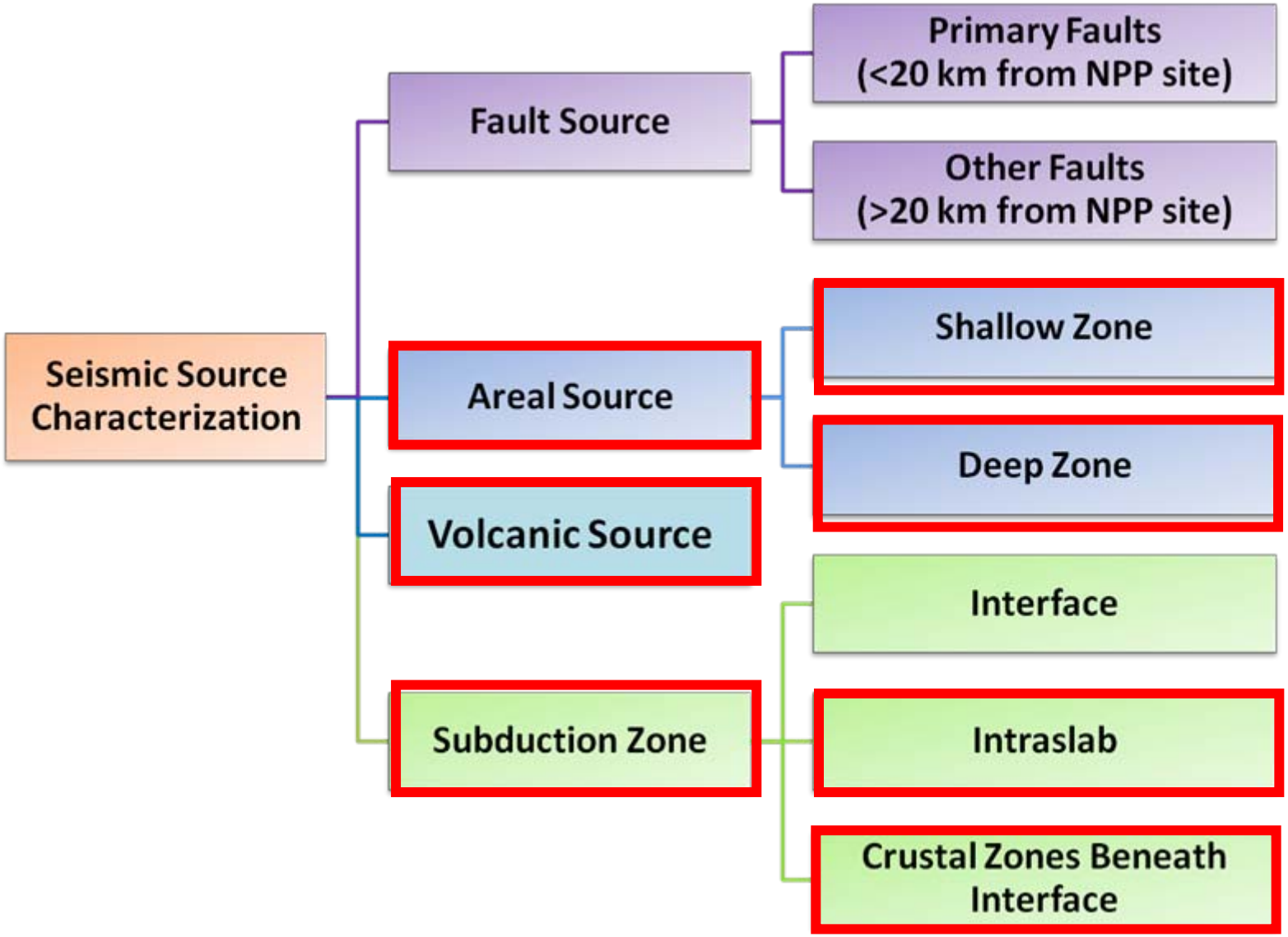
Taipei, Taiwan

Seismic Source Characterization in Taiwan



Areal Source Style of Logic Tree Node

- **Geometry**

  Seismic Zoning

- **Activity**

  b-value & Activity Rate

  Max Magnitude (for TE model)

  Focal Mechanism

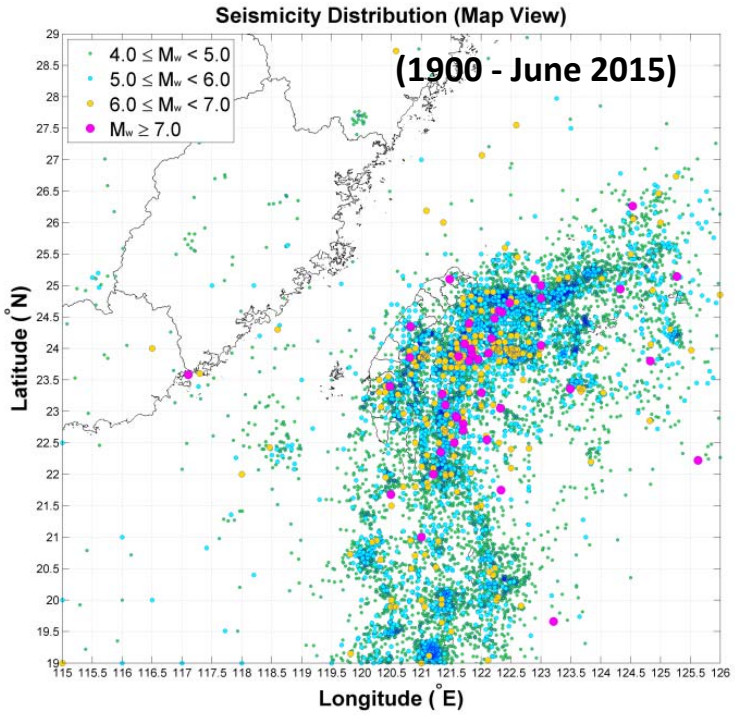
*Note:
•Method of estimating b-value and activity rate: Maximum Likelihood Estimation
•Magnitude pdf Model: G-R Truncated Exponential Model
•Depth pdf Model: Normal Distribution for Shallow Zones Triangular Distribution for Deep Zones
•Crustal GMPE: NGA-West2 (for Shallow Zones)
•Intraslab GMPE: BCHydro, LL08 (for Deep Zones)
•Max Magn. = Char. Magn. + 0.25
•Char. Magn. is calculated from Magnitude Scaling Law: Strasser et al (2010) and Blaser et al (2010).

Outline

- Zoning Scheme Overview
- Explanation of Zoning Setting
- Weighting for Zoning Scheme

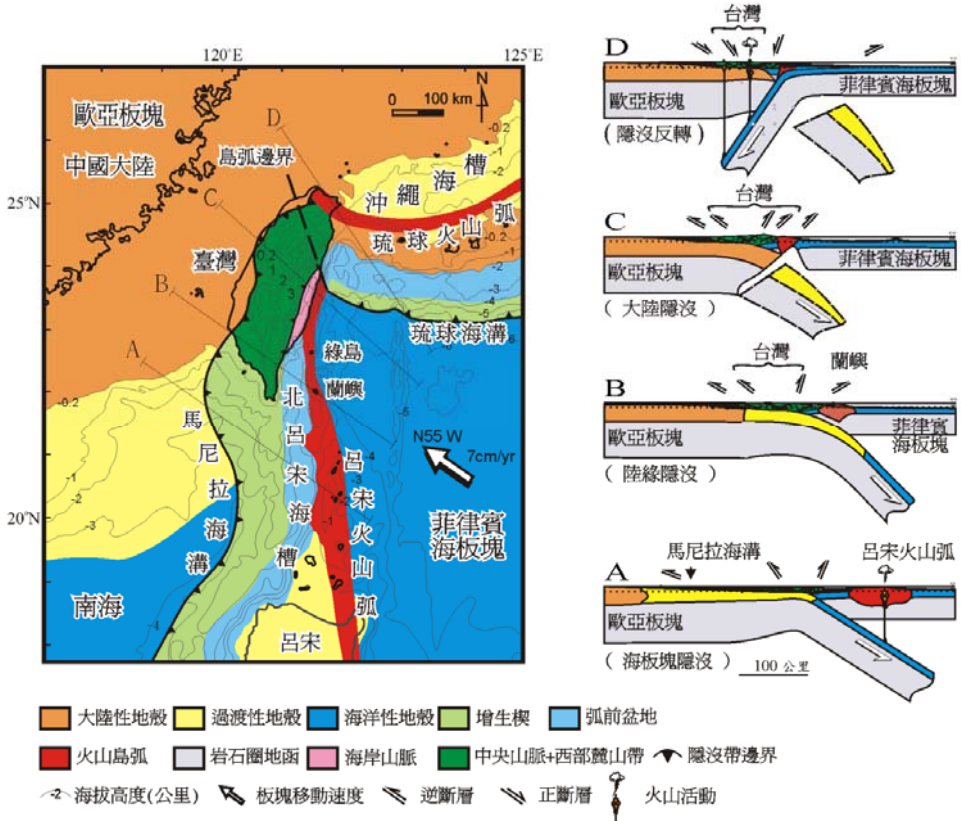
Zoning Schemes Consideration

- **Modeling Reference:**
  - Seismicity Distribution
  - Tectonic Structures
- **Three Zoning Schemes:**
  - Scheme B
  - Scheme S
  - Scheme Z (Zoneless Model)
- **Range of Zoning Scheme:**
  - Area Coverage: 115°E ~ 126°E, 19°N ~ 29°N
  - Cover the region of the study sites with a 320-kilometer radius according to nuclear regulation

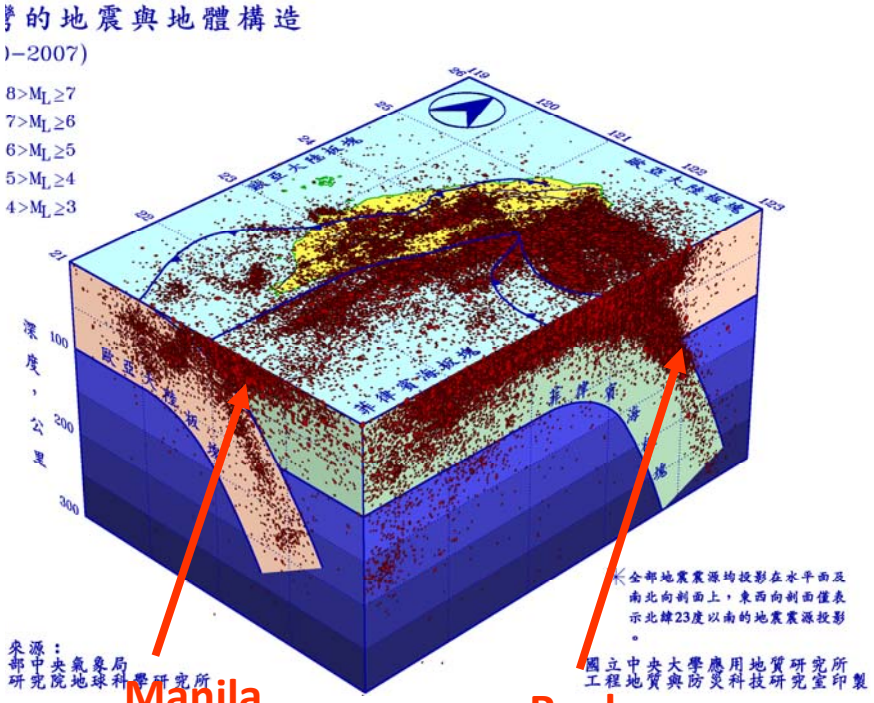


Earthquake Catalog provided by Y.M. Wu

Zoning Boundary Reference for Taiwan Area (Tectonic Structure)

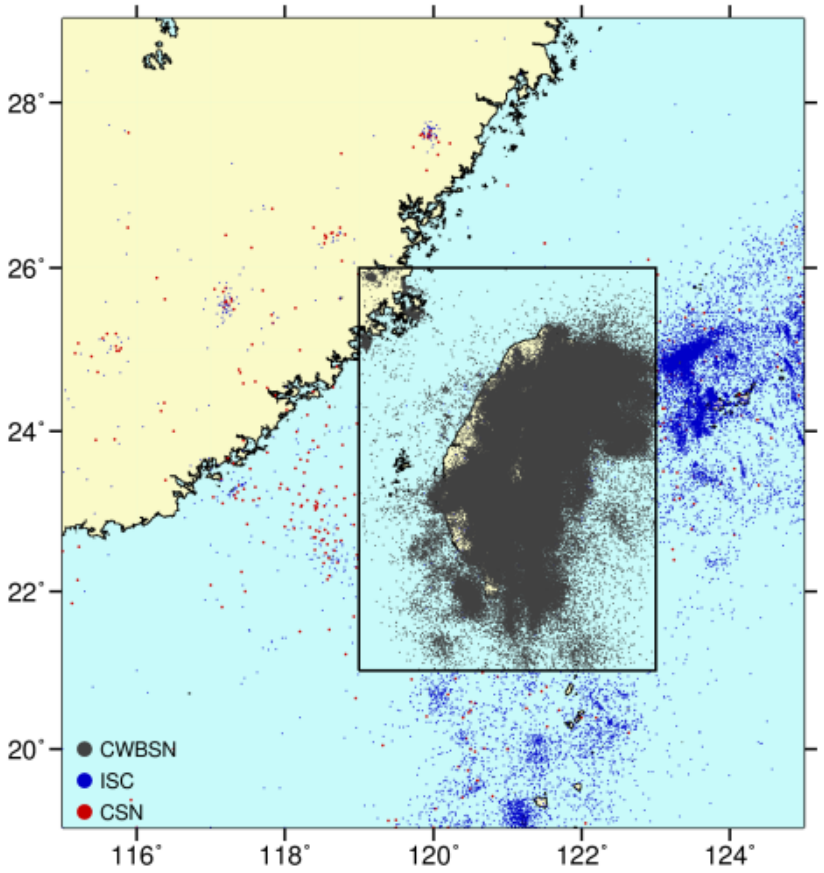


Teng, L.S. (2007). "Quaternary Tectonics of Taiwan," Special Publication of the Central Geological Survey, No.18, pp1-24.



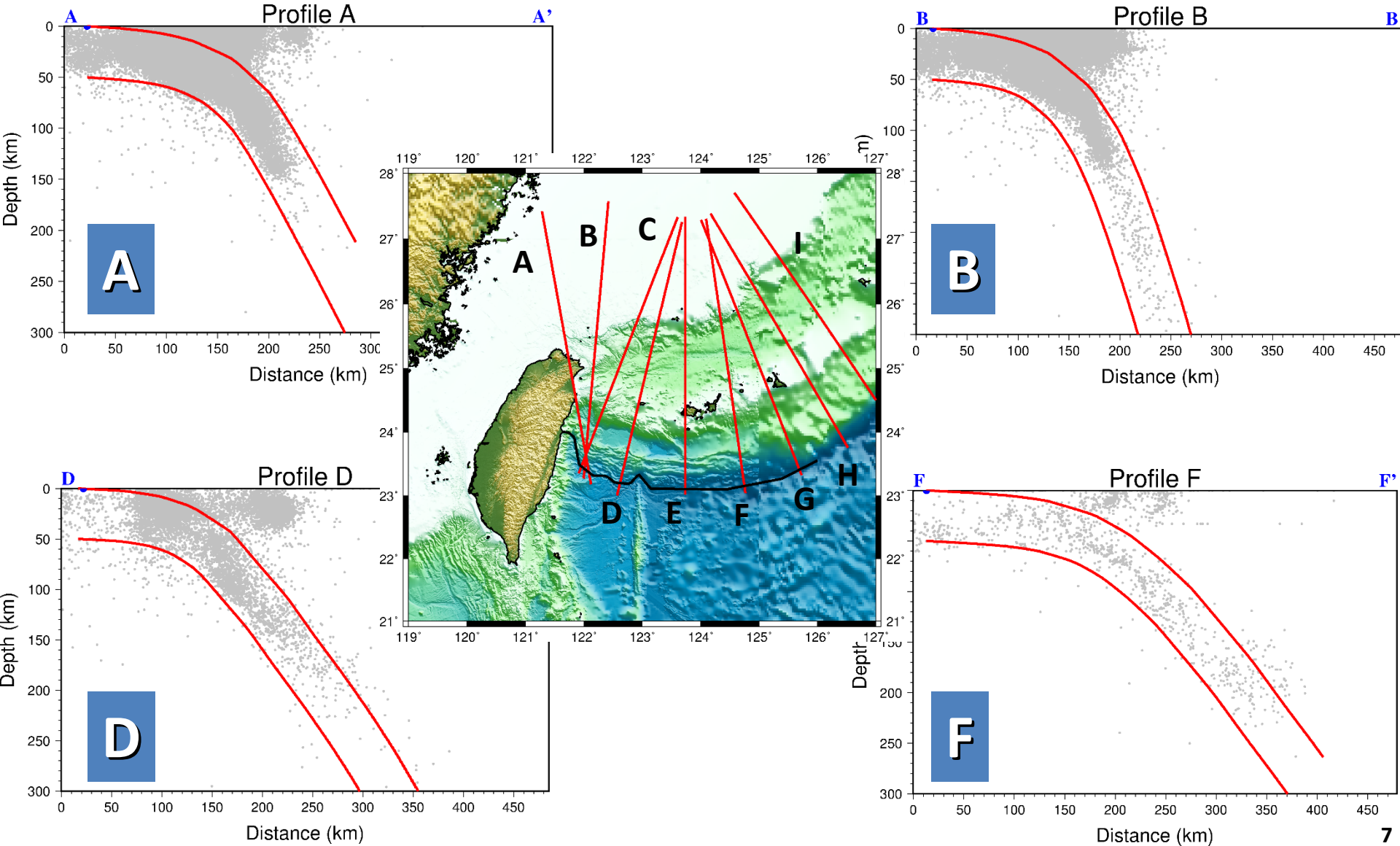
Zoning Boundary Reference for Taiwan Area (Earthquake Catalog)

- **Collecting 3 Earthquake Catalog from 1900/01/01 to 2015/06/30 (provided by Y.M. Wu as RE):**
  - The Central Weather Bureau Seismic Network (CWBSN)
  - The International Seismological Centre (ISC)
  - China Seismic Network (CSN)



Provided by Y.M. Wu as RE at WS#1

Zoning Boundary Reference for Ryukyu Subduction Zone



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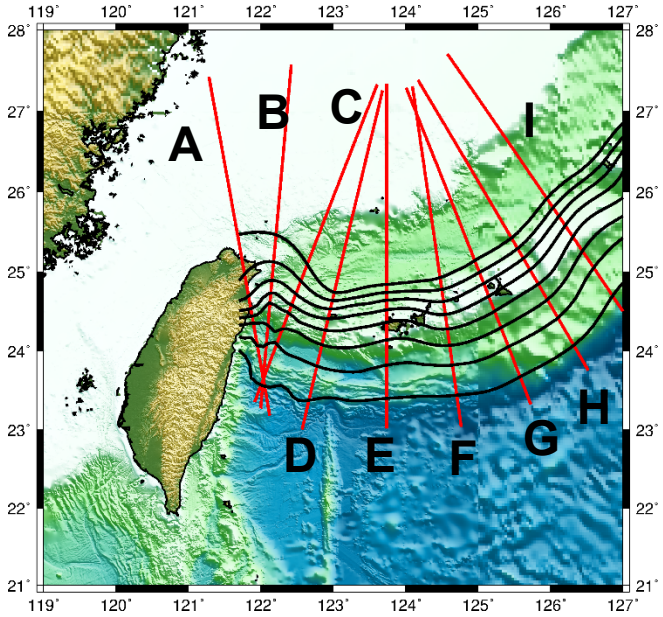
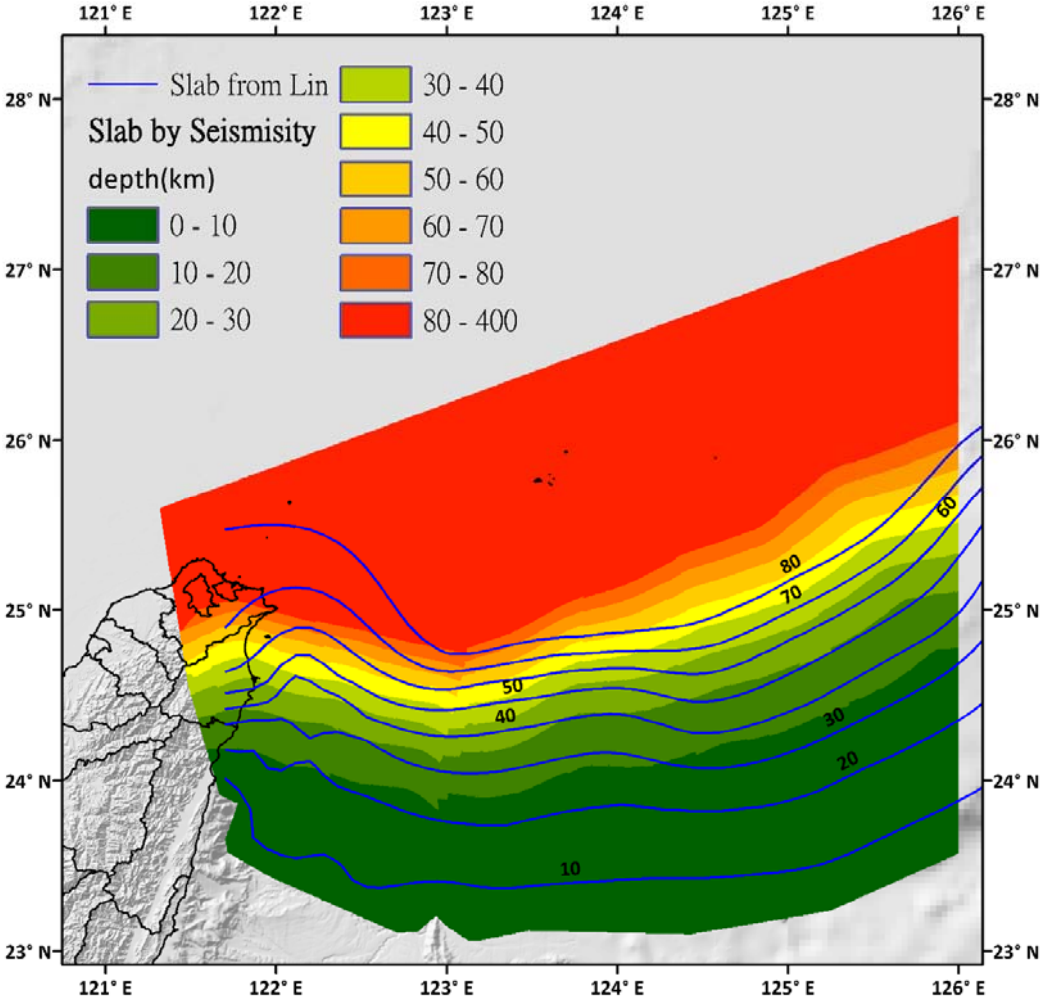
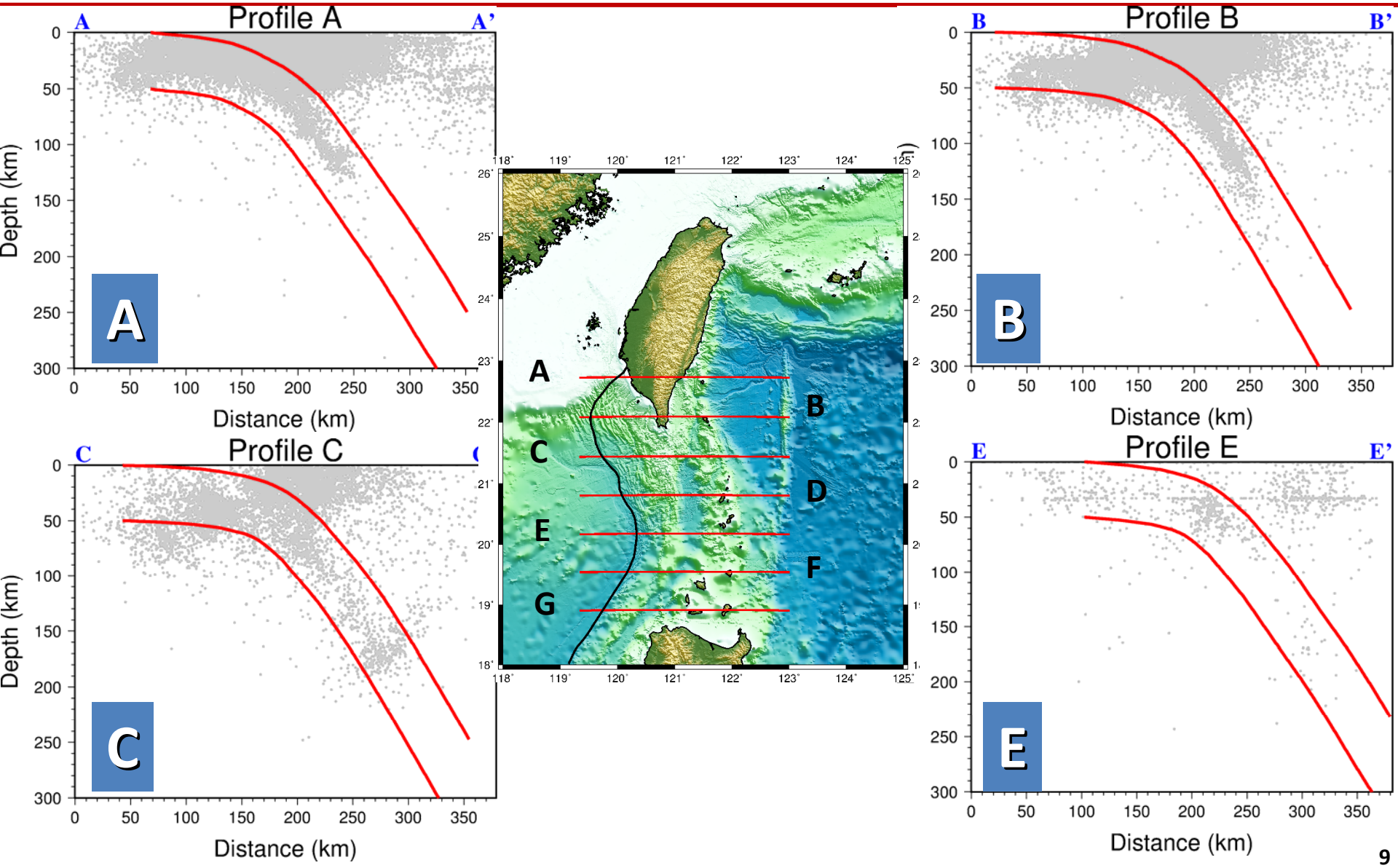


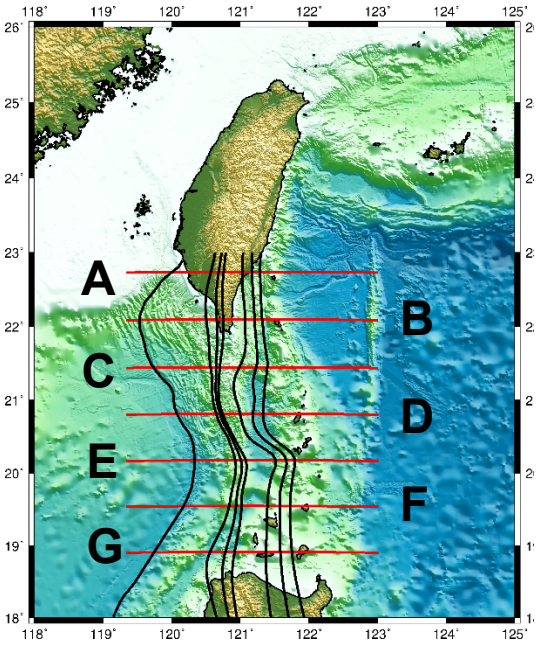


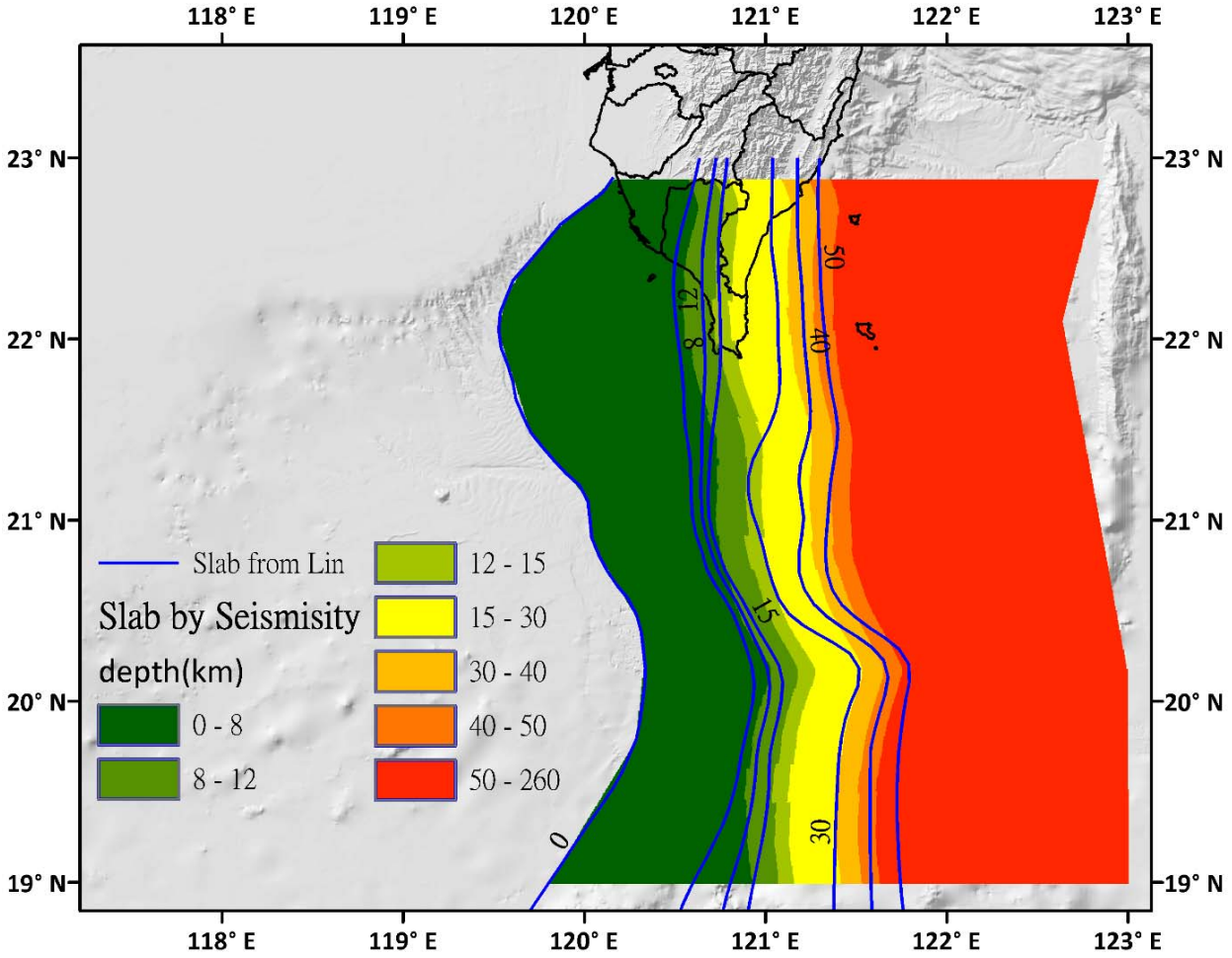
Hsu, Y. J. and Lin, J. Y. (2016). "Ryukyu, Manila Subduction Zone Model - Parameters for HID and Coupling," presentation at Working Meeting 2, Taiwan SSHAC Level 3 Project, July 13, 2016.

Zoning Boundary Reference for Manila Subduction Zone



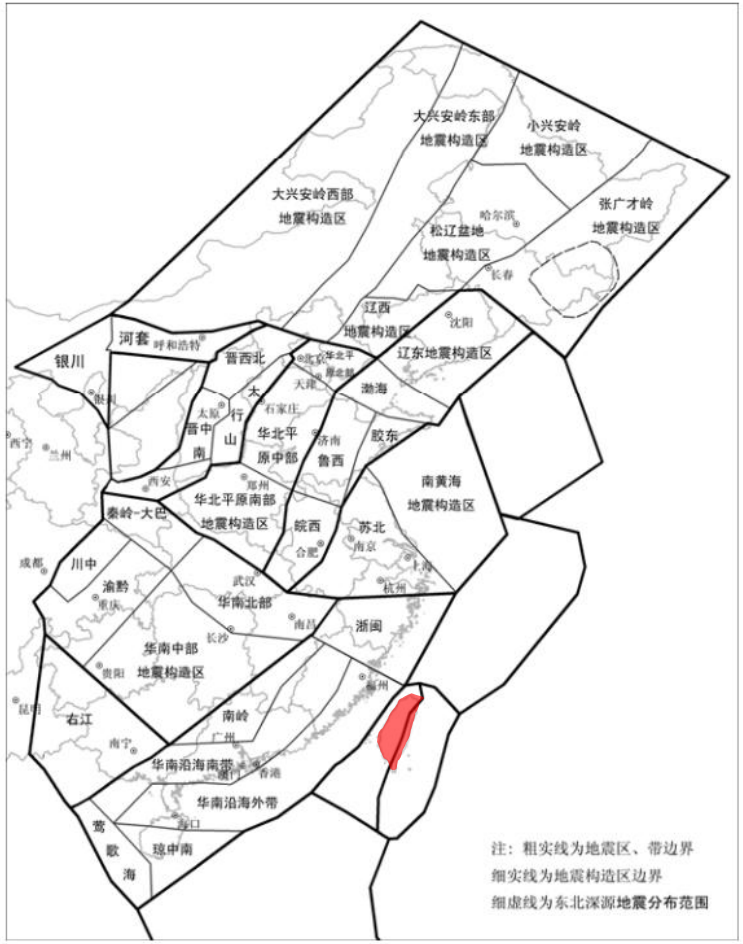
Zoning Boundary Reference for Manila Subduction Zone



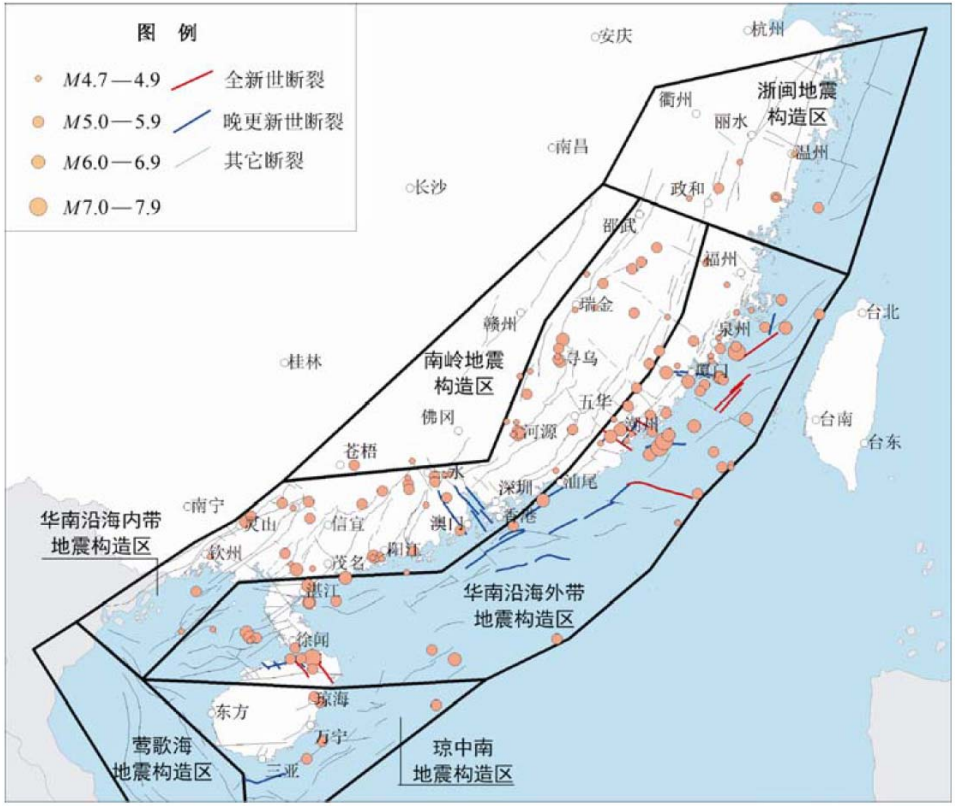


Hsu, Y. J. and Lin, J. Y. (2016). "Ryukyu, Manila Subduction Zone Model - Parameters for HID and Coupling," presentation at Working Meeting 2, Taiwan SSHAC Level 3 Project, July 13, 2016.

Zoning Boundary Reference for China Area



Delineation map of seismotectonic provinces in East China (高战武等，2014)



Delineation map of seismotectonic provinces of the costal seismic belt in Southeast China (高战武等，2014)

Criteria of Zoning Scheme Selection

- Practical Application in Engineering Purpose
- Based on Seismicity Distribution and Tectonic Structures
- Delineation Difference
- Fully Considering Shallow Zones, Deep Zones and Subduction Zones

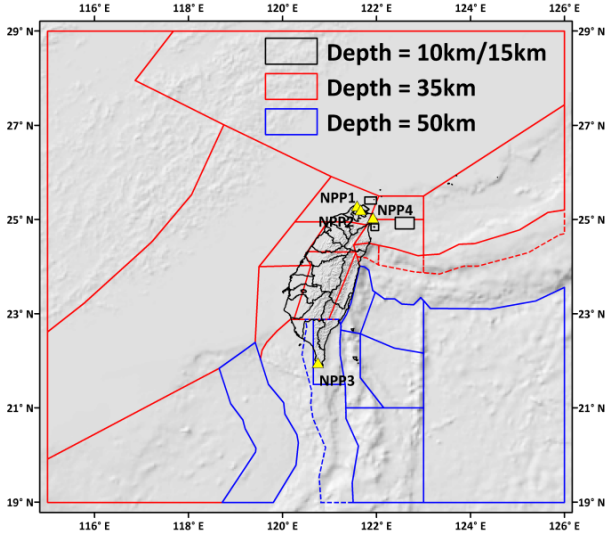
- **Zoning Scheme B (ZB)**
  → source from PSHA report of 4 NPPs (1994)
- **Zoning Scheme S (ZS)**
  → source from C.T. Cheng, 2002

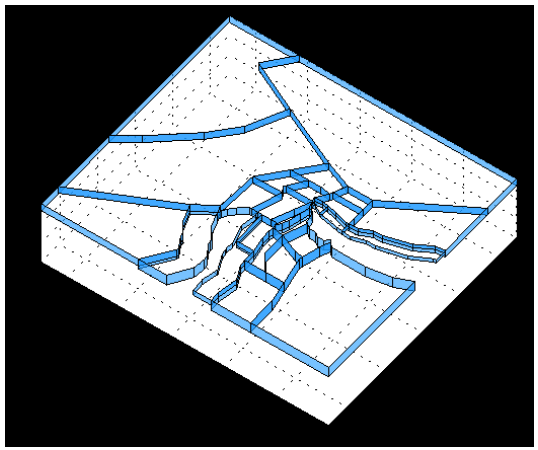
Zoning Schemes Overview

Zoning Scheme	Scheme B	Scheme S	Scheme Z
Boundary Reference	Based on NPPs' PSHA Report (Loh, 1994)	Based on C.T. Cheng's Thesis (2002)	New Creation (H.J. Liu)
Seismic Source Classify	• Shallow Zone • Beneath Interface Crust Zone • Deep Zone • Intraslab Zone • Volcanic Zone	• Shallow Zone • Deep Zone • Intraslab Zone • Volcanic Zone	• Shallow Zones • Beneath Interface Crust Zone • Deep Zone • Intraslab Zone • Volcanic Zone
Seismic Rate Distribution	Uniform	Uniform	Spatial Smoothed
Depth Ranges of Shallow Zones	0 – 35km 0 – 50km	0 – 35km	0 – 35km 0 – 50km
No. of Shallow Zone	25	38	6
No. of Beneath Interface Crust Zone	4	N/A	2
No. of Intraslab Zone	19	11	6
No. of Deep Zone	20	8	4

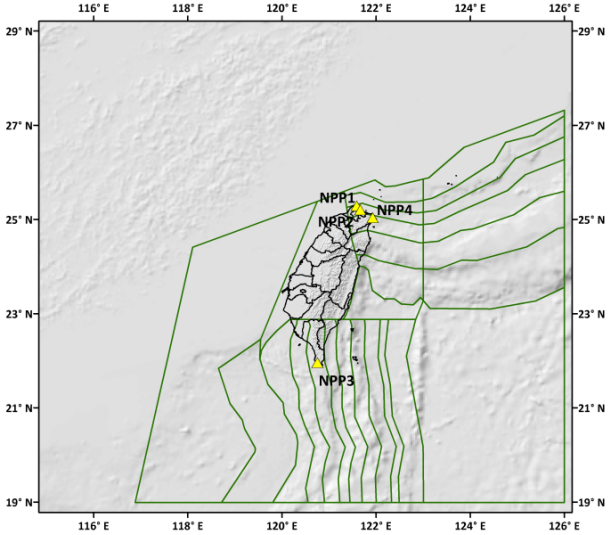
Zoning Scheme B

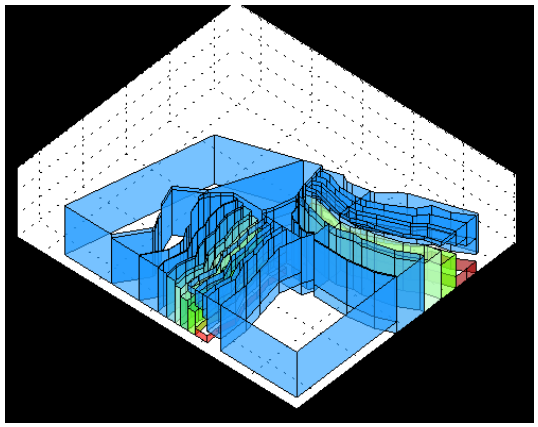
Shallow



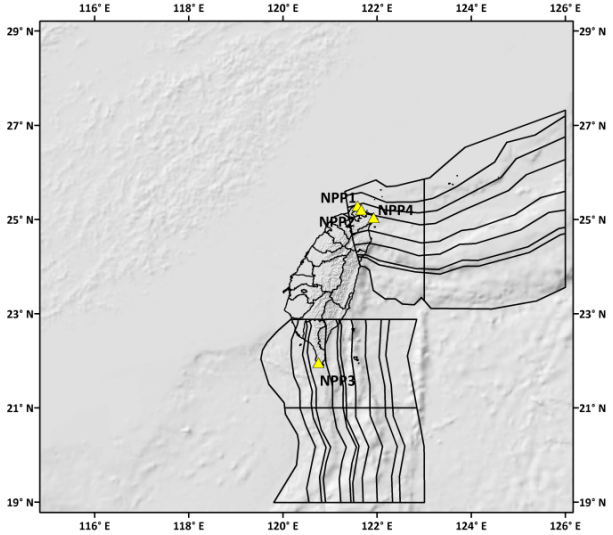


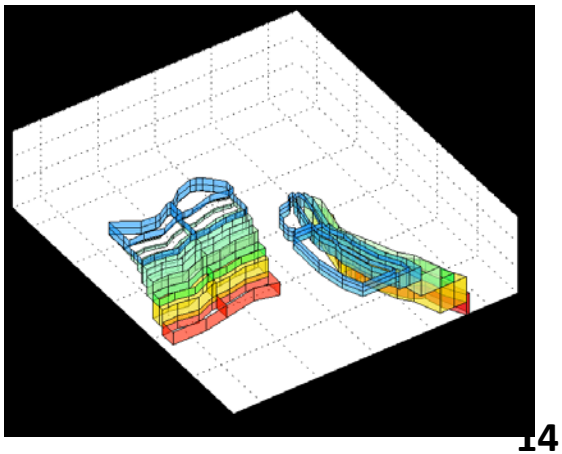
Deep





Subduction-zone

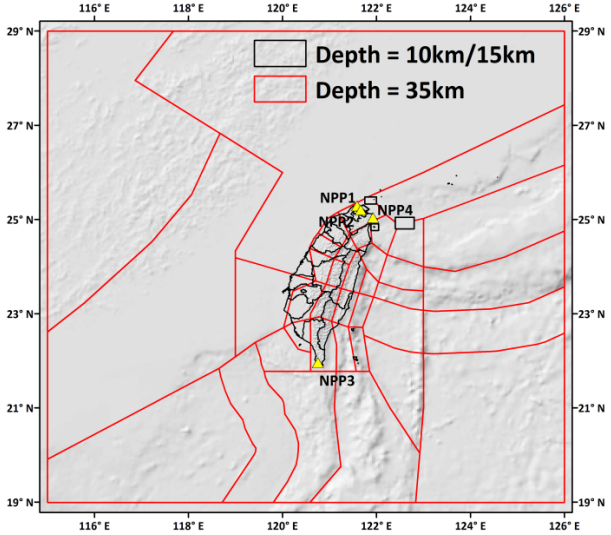


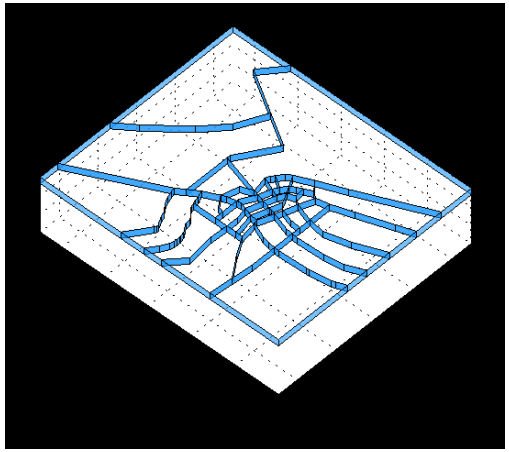


Zoning Scheme S

Shallow

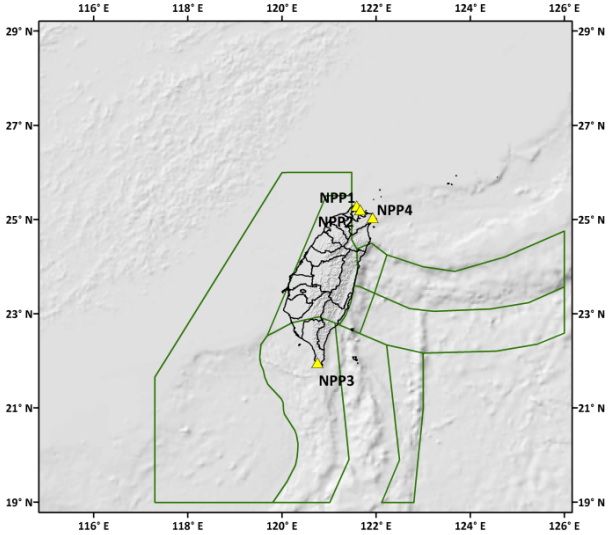
Zoning Scheme S, Shallow Zone

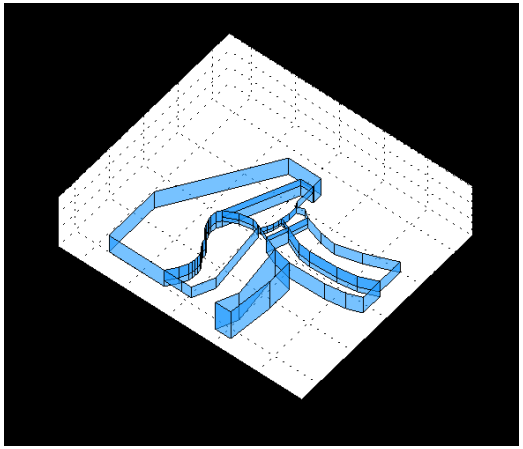




Deep

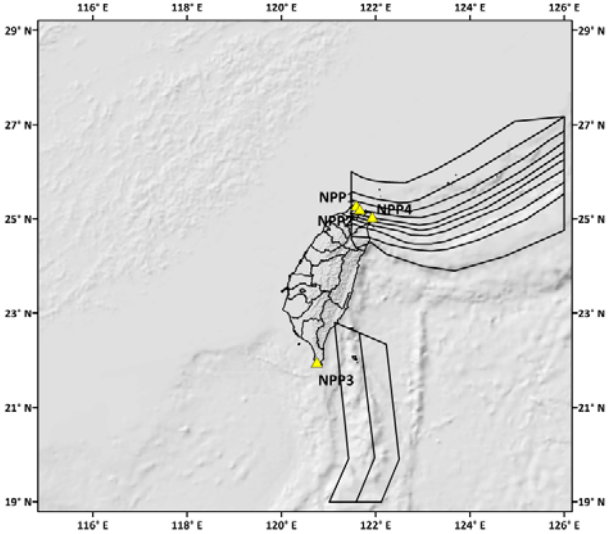
Zoning Scheme S, Deep Zone

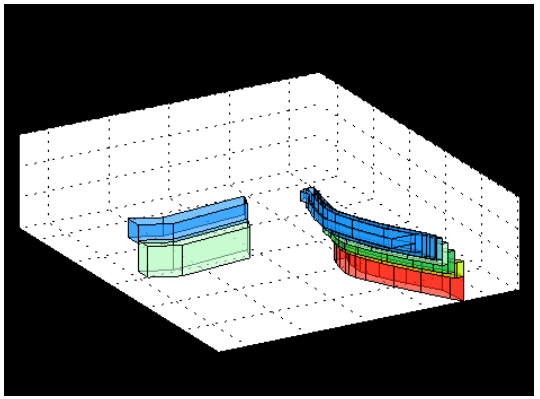




Subduction-zone

Zoning Scheme S, Subduction Zone

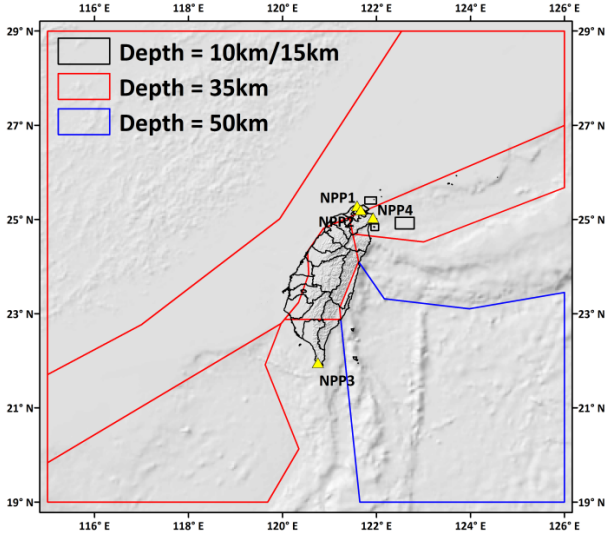


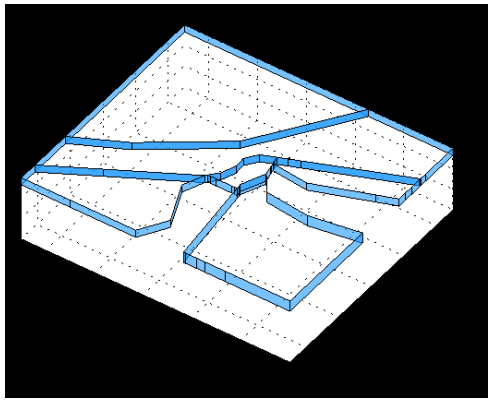


Scheme Z (Zoneless Model)

Shallow

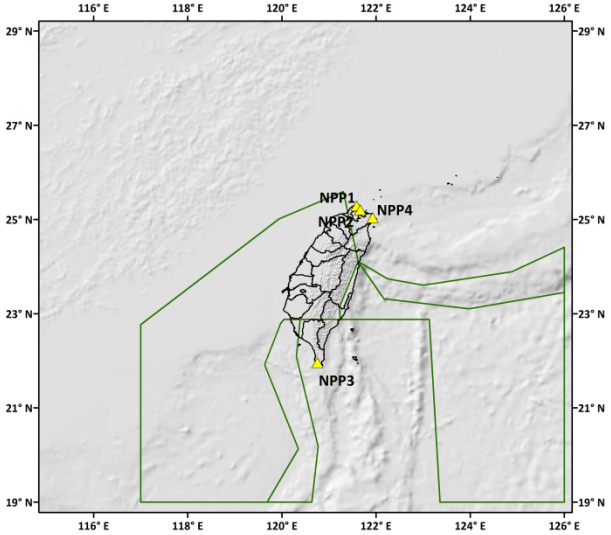
Zoneless, Shallow Zone

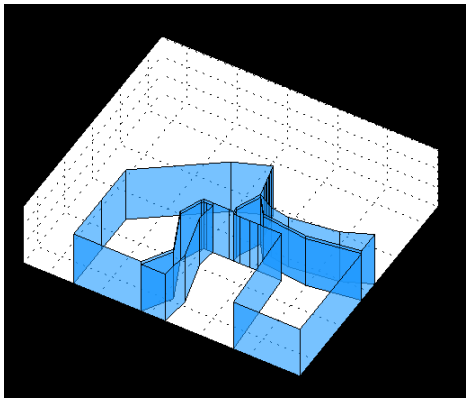




Deep

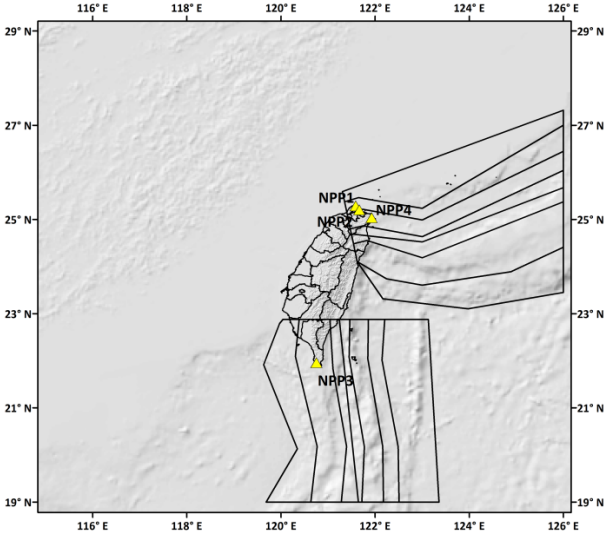
Zoneless, Deep Zone

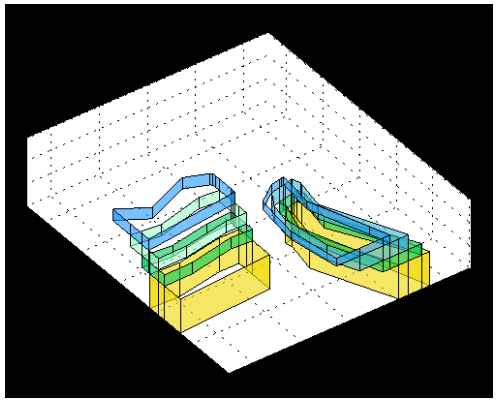




Subduction-zone

Zoneless, Subduction Zone





Outline

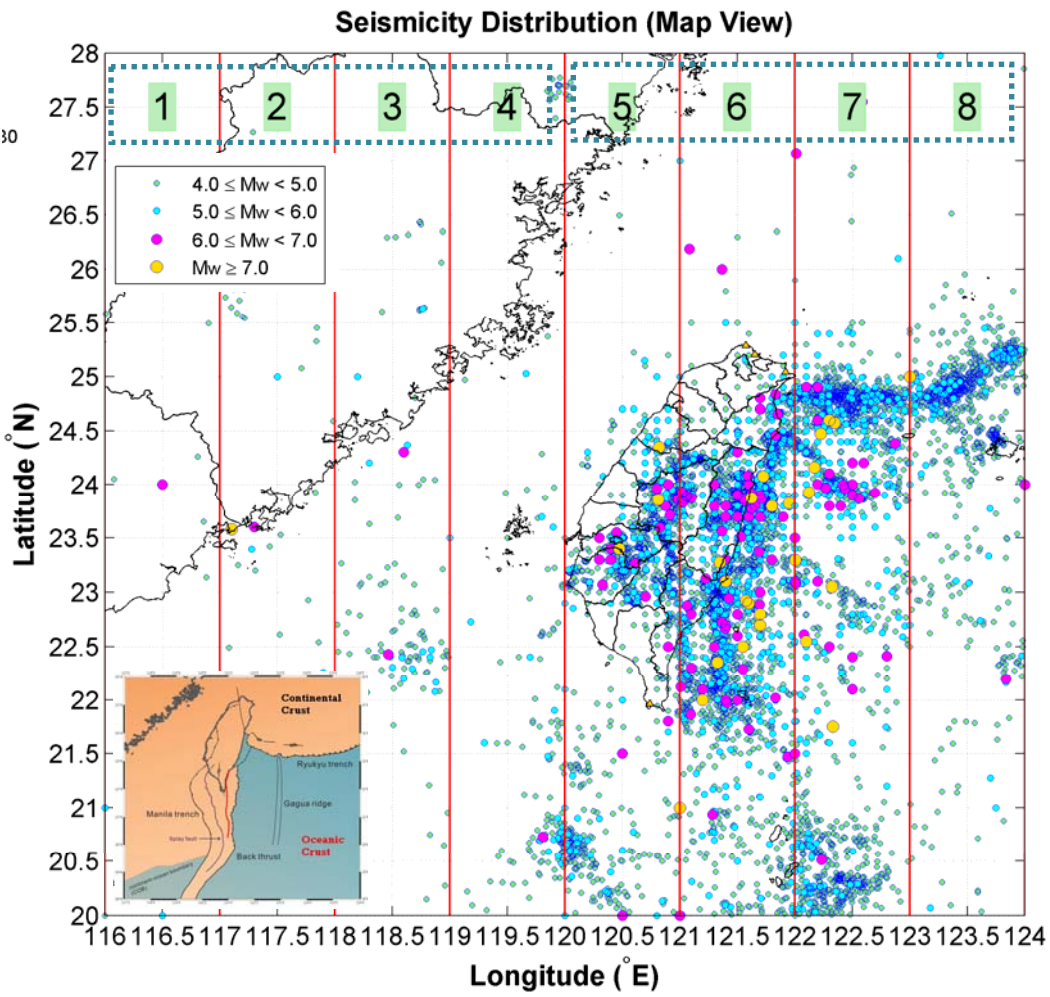
- Zoning Scheme Overview
- Explanation of Zoning Setting
- Weighting for Zoning Scheme

Explanation of Zoning Setting

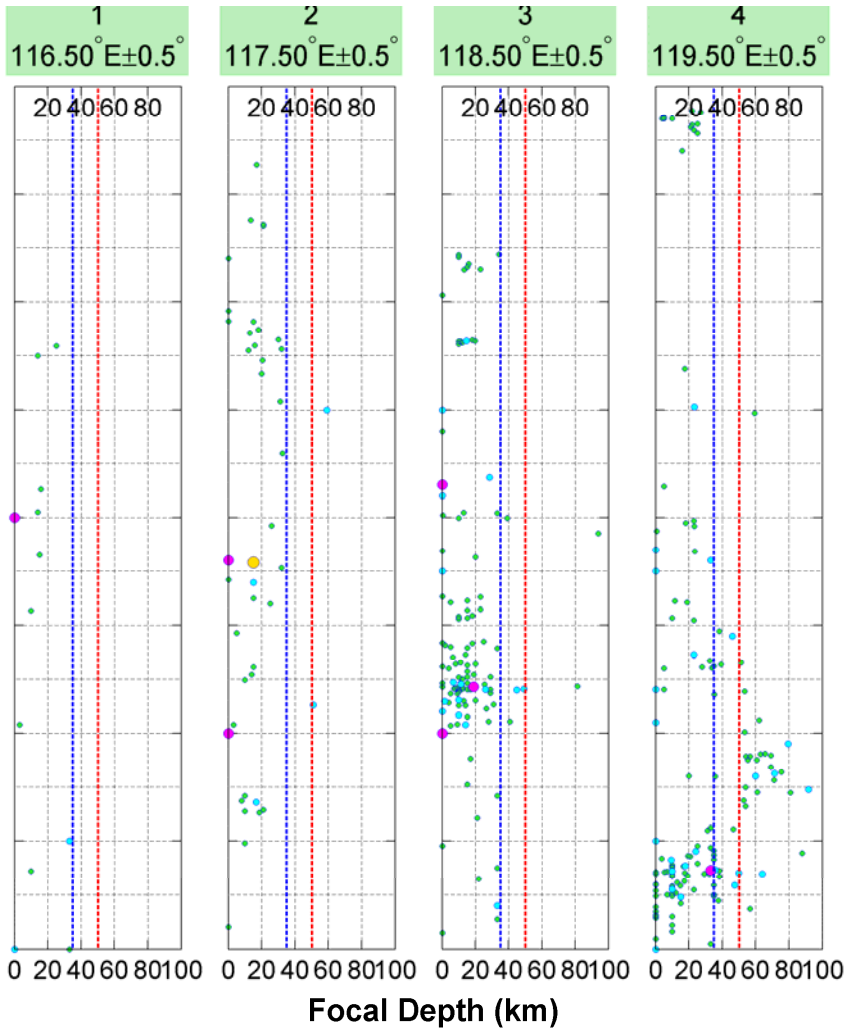
- **Seismogenic Depth of Shallow Zones**
  - 0 - 35km, 0 - 50km
- **Seismic Source Definition**
  - Shallow seismicity
  - Deep Seismicity
  - Subduction Seismicity
    - Beneath Interface Crustal Seismicity
    - Intraslab Seismicity
- **Zoning Delineation**
  - Based on Seismicity and Tectonic Structure
- **Subduction Zones**
- **Volcanic Zones**
- **Seismicity Nearby Each NPP Site**

Seismogenic Depth of Shallow Zones

Removal of subduction-zone earthquakes



Blue Line: 35km **Red Line: 50km**



➢ **Depth Range of Shallow Seismicity: 0 – 35km / 0 – 50km**

Explanation of Zoning Setting

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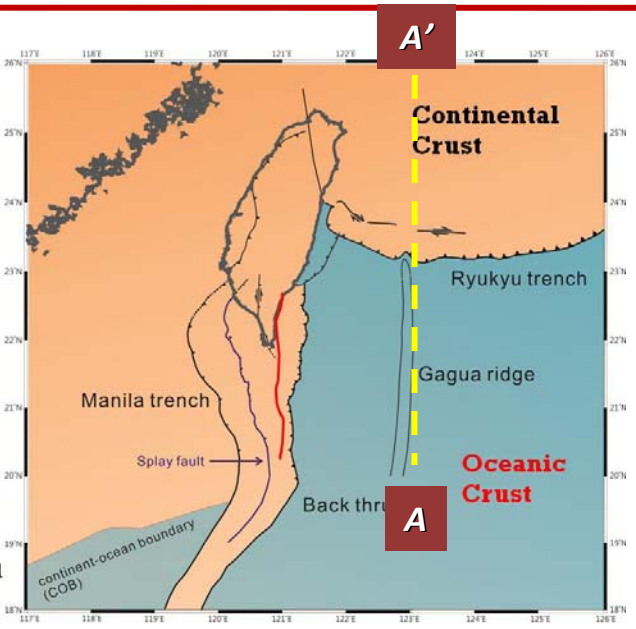
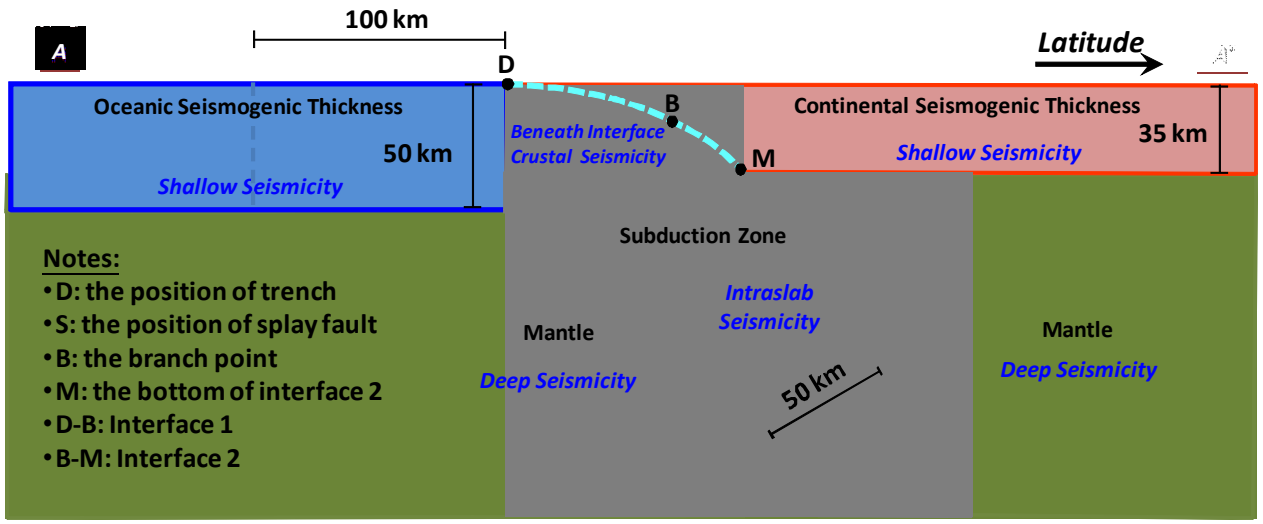
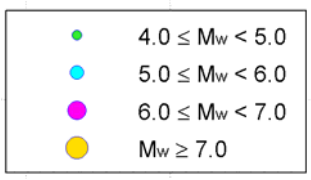
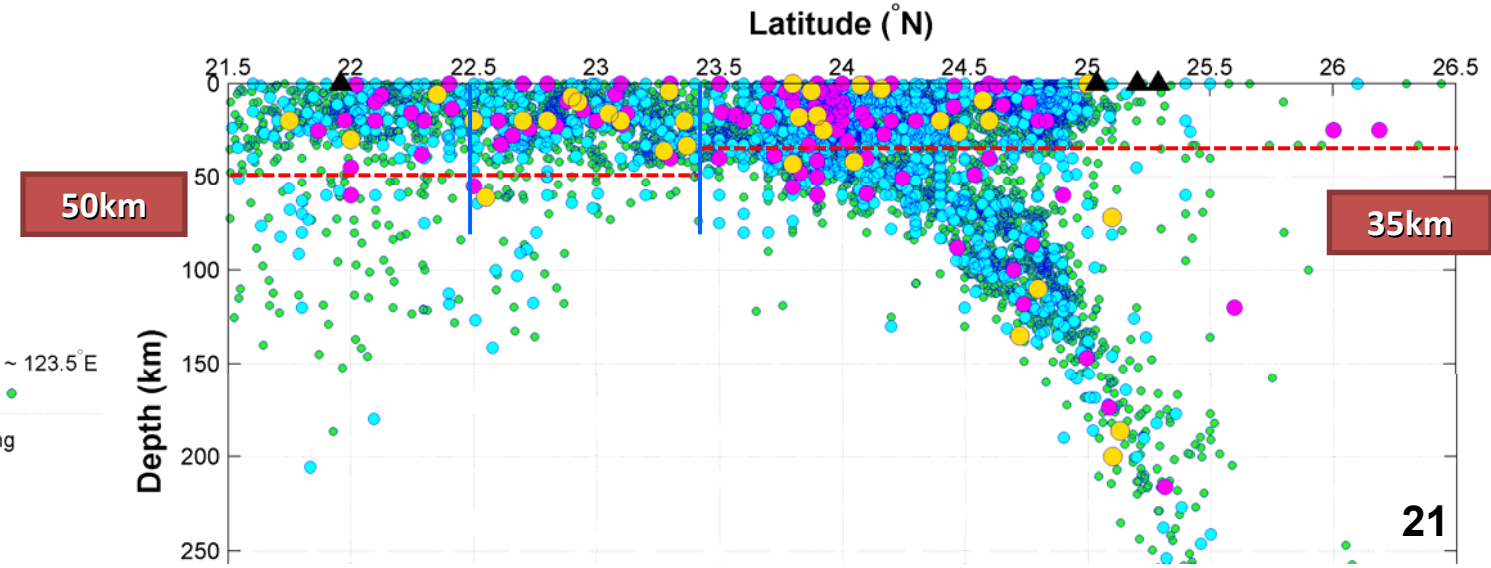
Definition of Seismic Source Type (Ryukyu Trench)



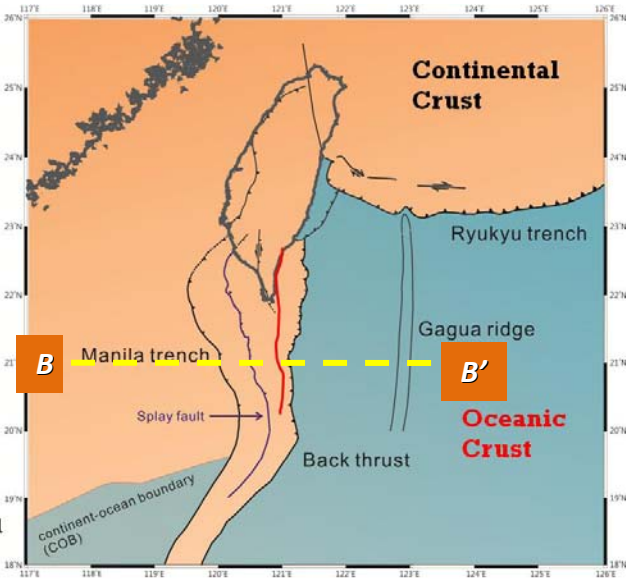


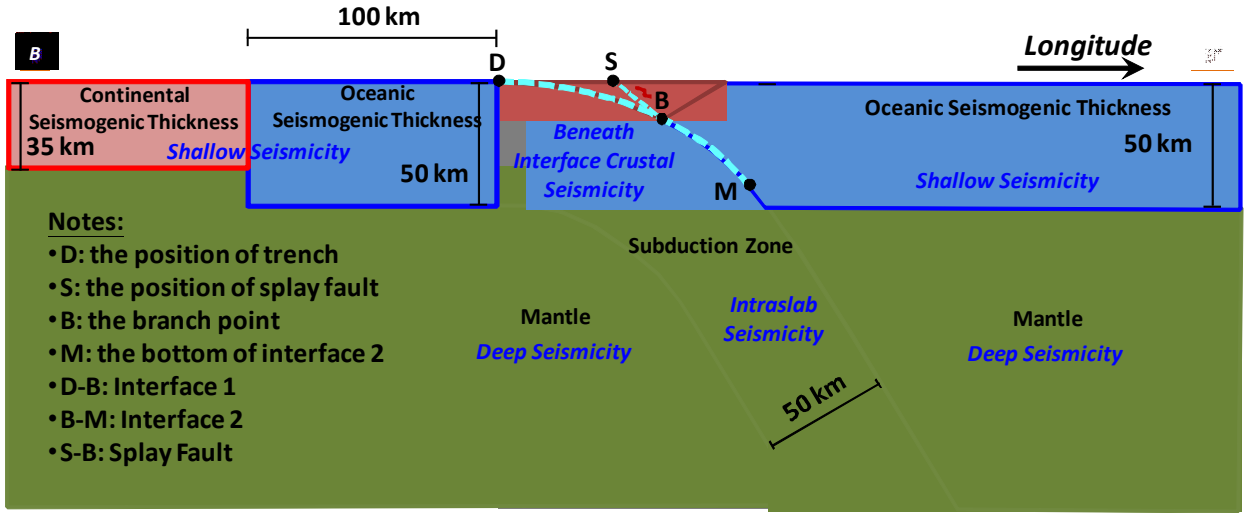


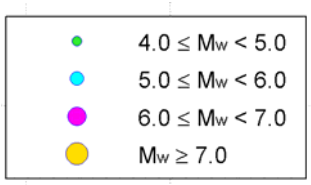
* Info of Earthquake Catalog:
- range of data: 21.5°N ~ 26.5°N / 121°E ~ 123.5°E
- period of time: 1900 ~ 2015/06/30
- Mw ≥ 4.0
- foreshocks and aftershocks declustering
- Total Earthquake Events: 7647



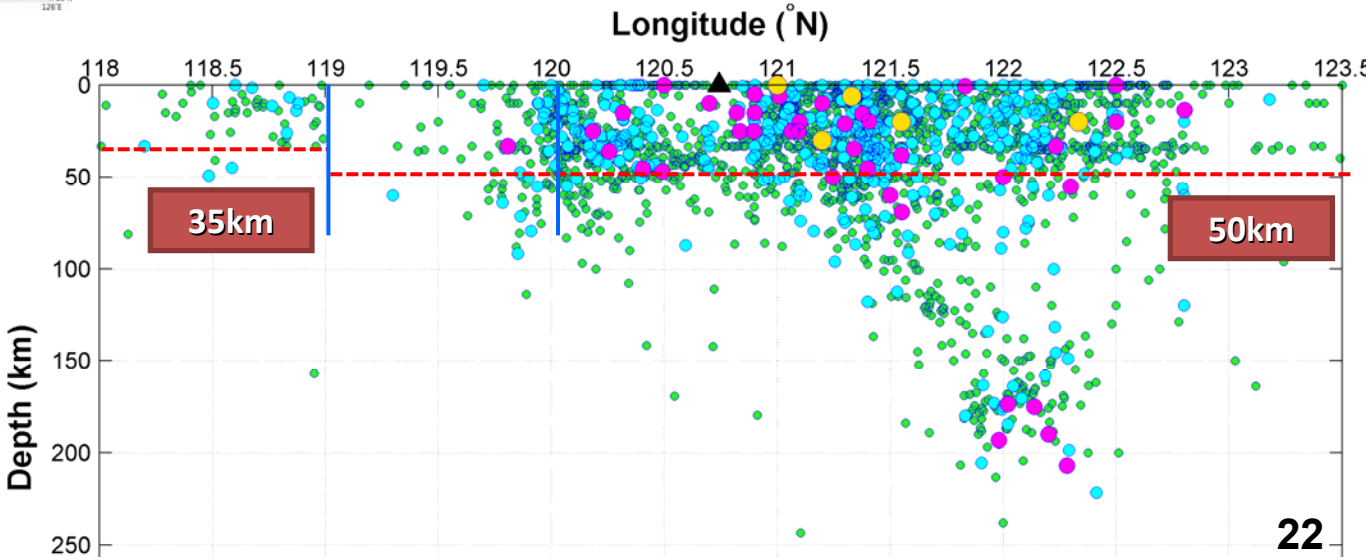
Definition of Seismic Source Type (Manila Trench)







* Info of Earthquake Catalog:
- range of data: 20°N ~ 22.5°N / 118°E ~ 123.5°E
- period of time: 1900 ~ 2015/06/30
- Mw ≥ 4.0
- foreshocks and aftershocks declustering
- Total Earthquake Events: 2305



Explanation of Zoning Setting

- **Seismogenic Depth of Shallow Zones**
  - 0 - 35km, 0 - 50km
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  - Deep Seismicity
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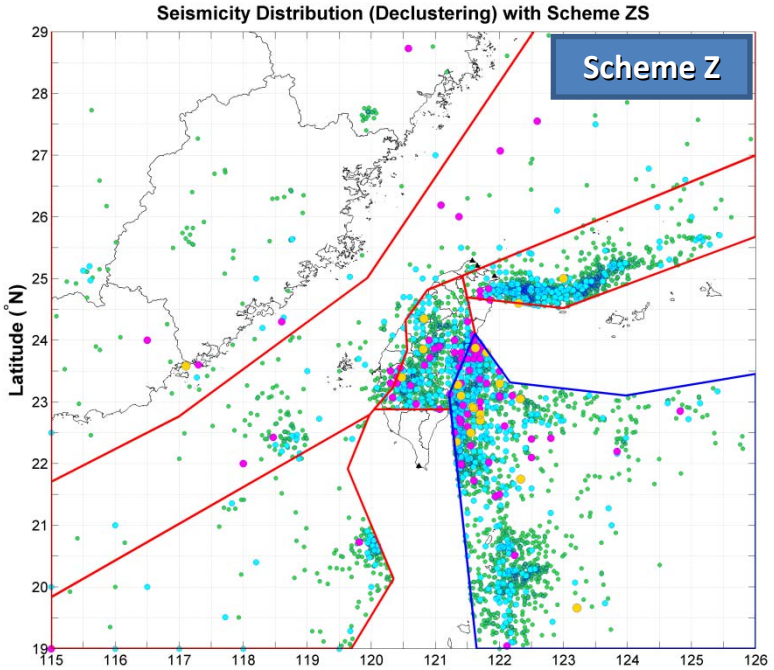
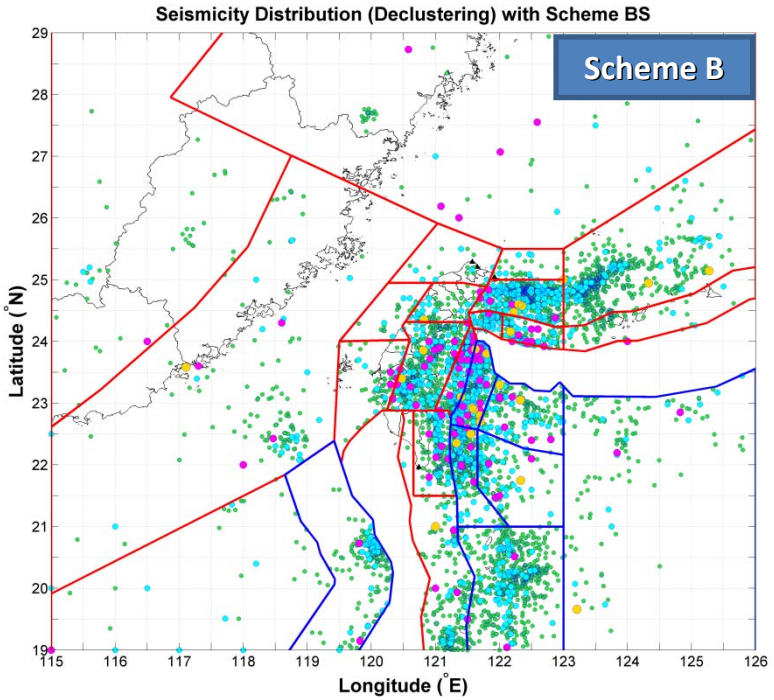
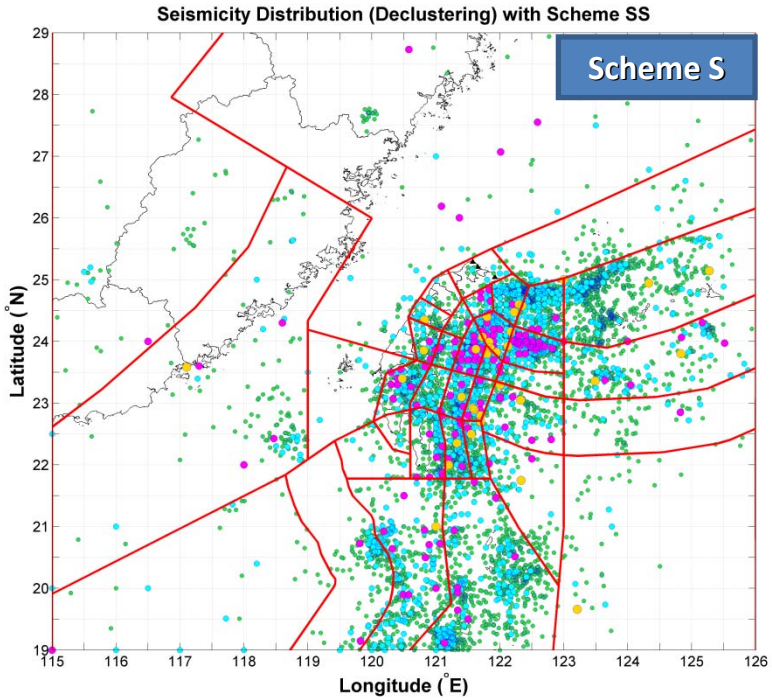
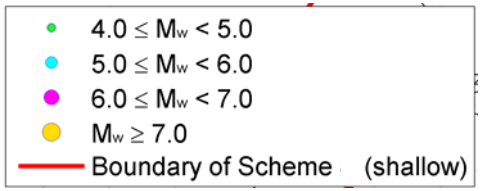
- **Volcanic Zones**
- **Seismicity Nearby Each NPP Site**

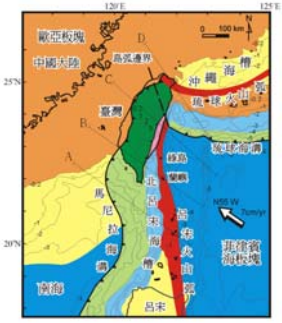
Shallow Zones with Seismicity





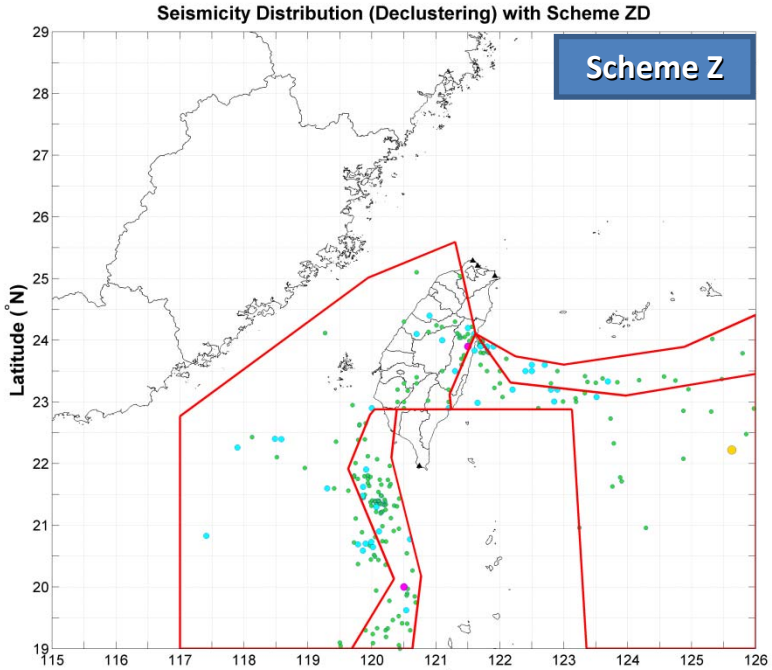


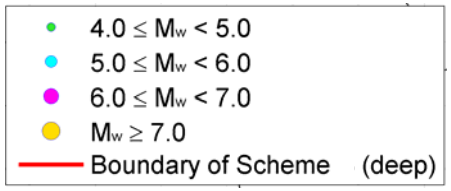


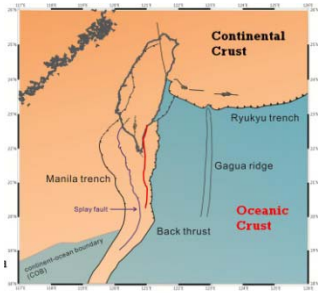


* Info of Earthquake Catalog:
- period of time: 1900 ~ 2015/06/30
- $M_w \geq 4.0$
- depth of seismicity (km): 0 ~ 35 (red-zone) / 0 ~ 50 (blue-zone)
- foreshocks and aftershocks declustering
- removal of subduction-zone earthquakes

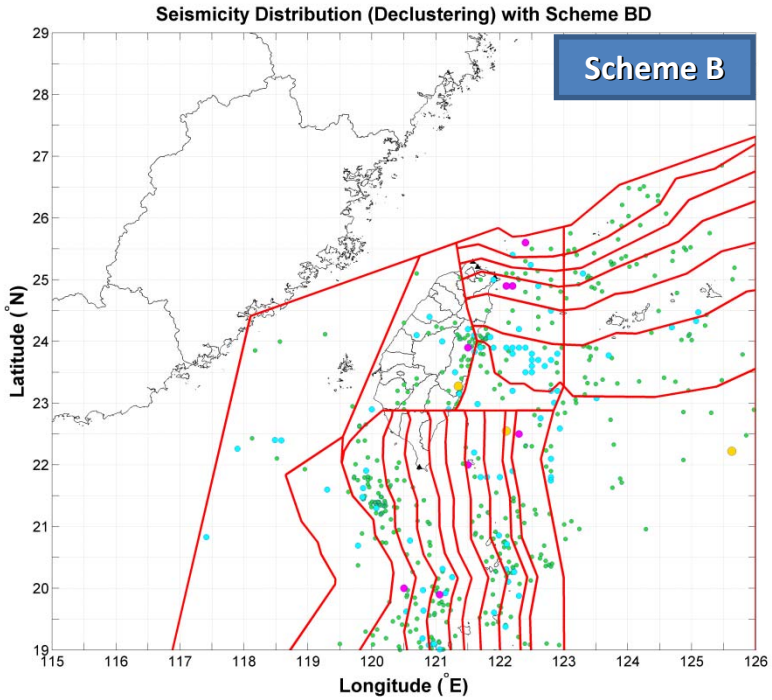
Deep Zones with Seismicity

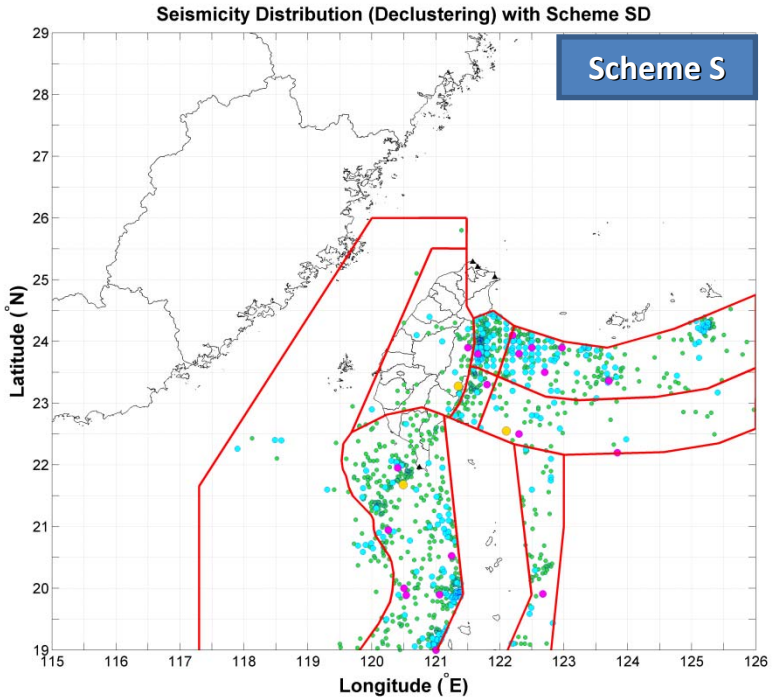




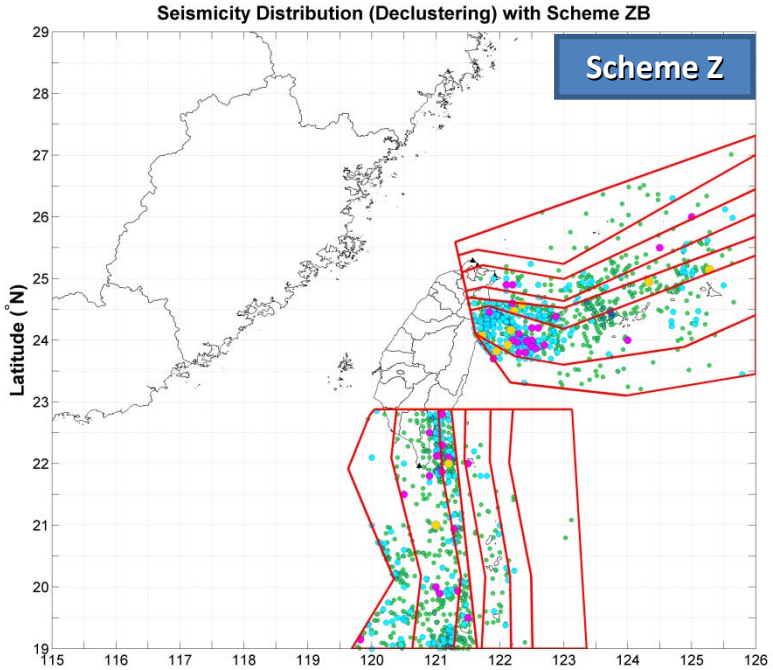


* Info of Earthquake Catalog:
- period of time: 1900 ~ 2015/06/30
- $M_w \geq 4.0$
- foreshocks and aftershocks declustering
- removal of subduction-zone earthquakes

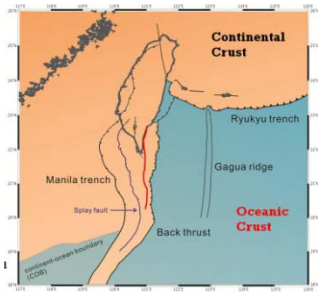




Subduction Zones with Seismicity



$4.0 \le M_w < 5.0$
$5.0 \le M_w < 6.0$
$6.0 \le M_w < 7.0$
$M_w \ge 7.0$
Boundary of Scheme (subduction-zone)



* Info of Earthquake Catalog:
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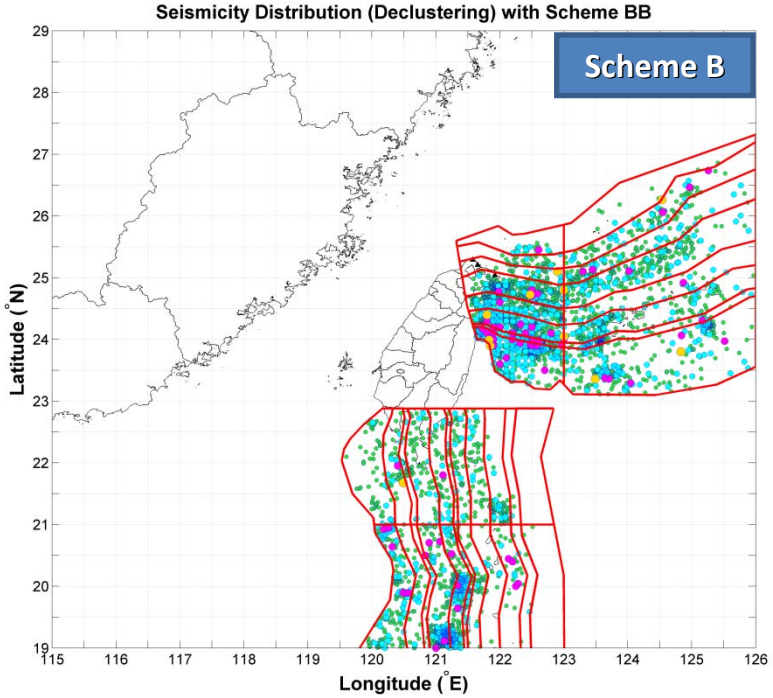
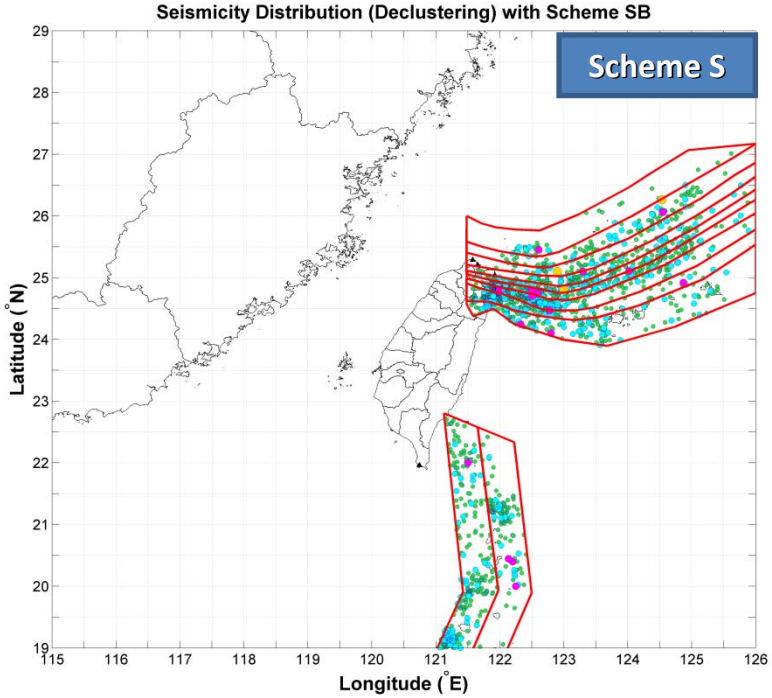
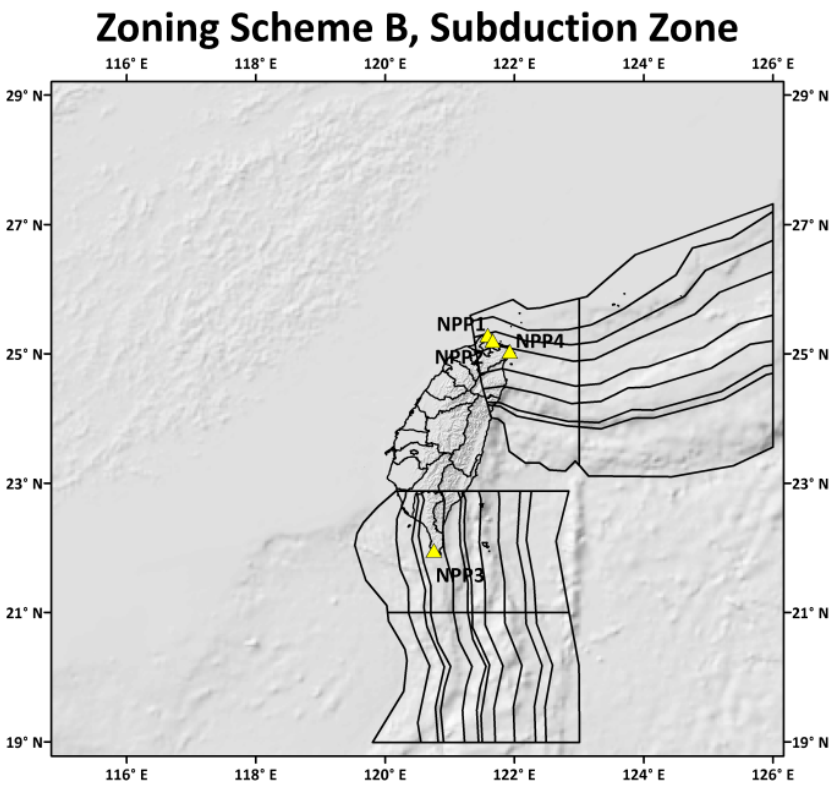


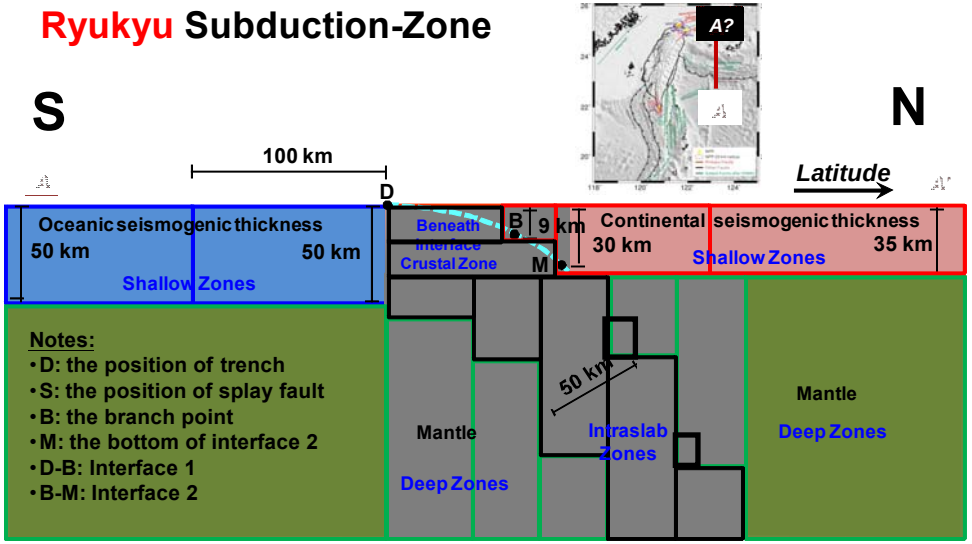


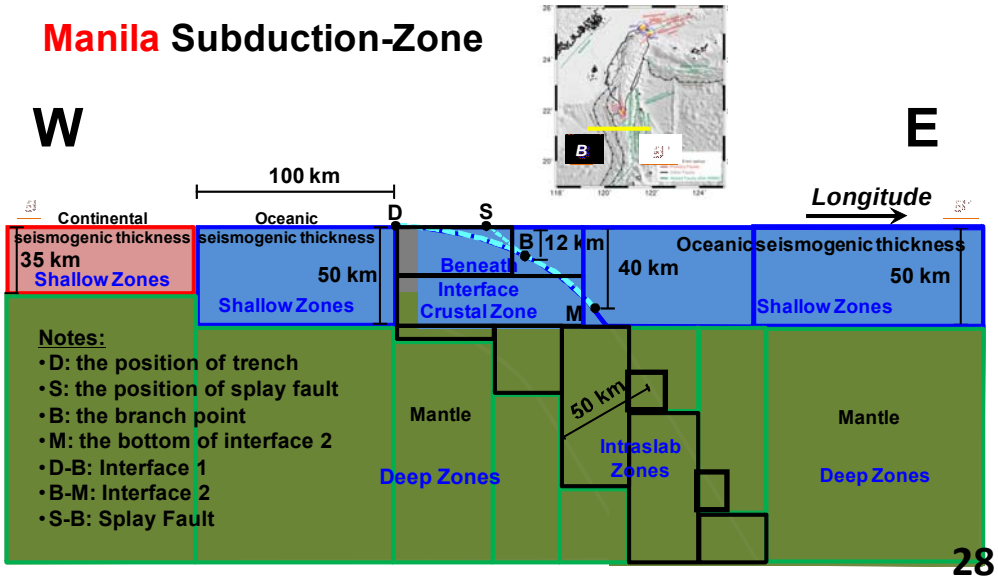
Explanation of Zoning Setting

- **Seismogenic Depth of Shallow Zones**
  - 0 - 35km, 0 - 50km
- **Seismic Source Definition**
  - Shallow seismicity
  - Deep Seismicity
  - Subduction Seismicity
    - Beneath Interface Crustal Seismicity
    - Intraslab Seismicity
- **Zoning Delineation**
  - Based on Seismicity and Tectonic Structure
- **Subduction Zones**
- **Volcanic Zones**
- **Seismicity Nearby Each NPP Site**

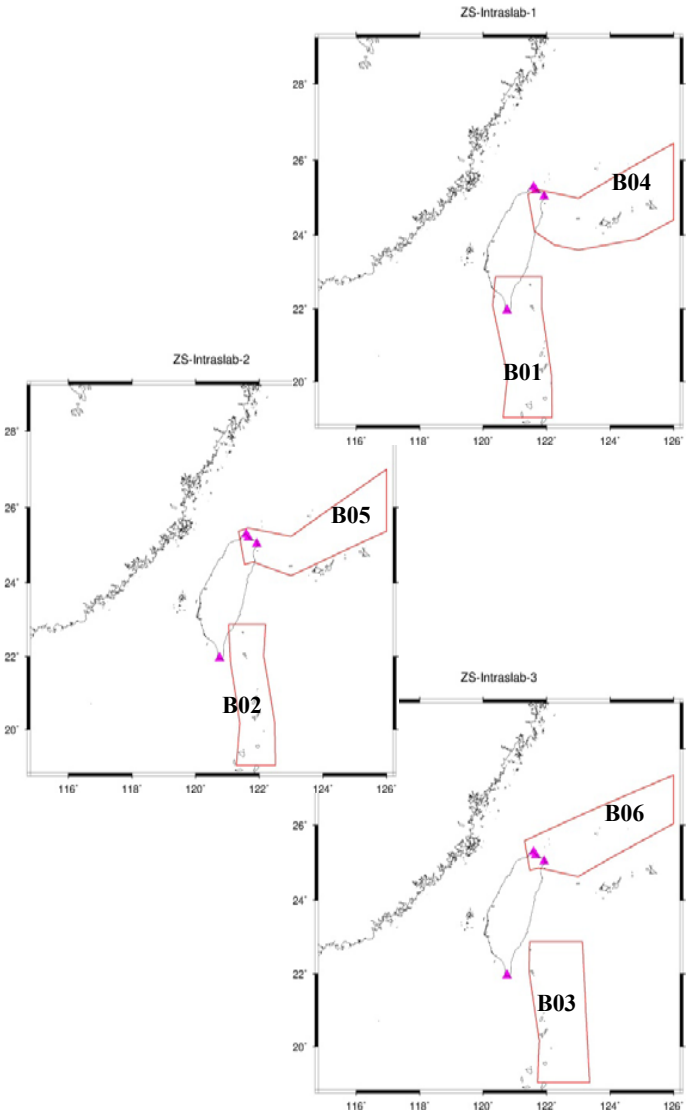
Scheme B for Subduction

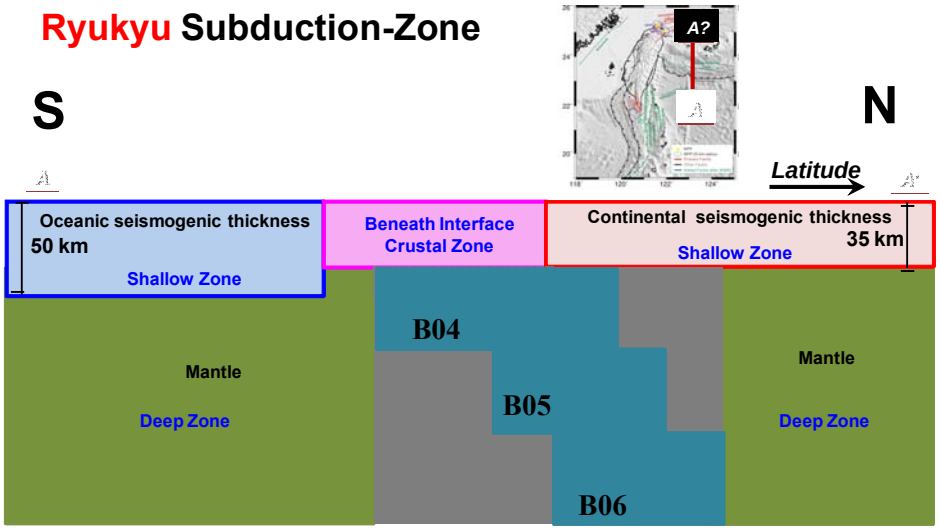


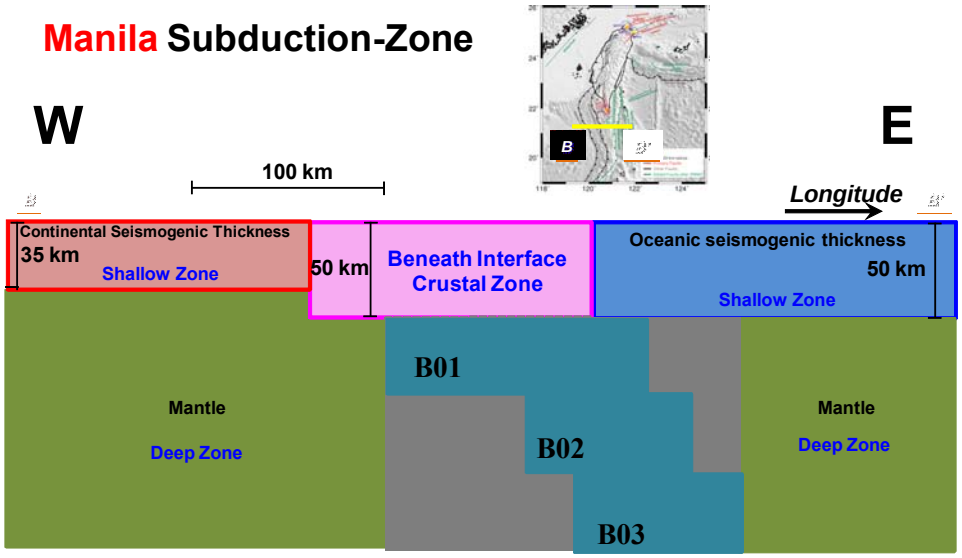




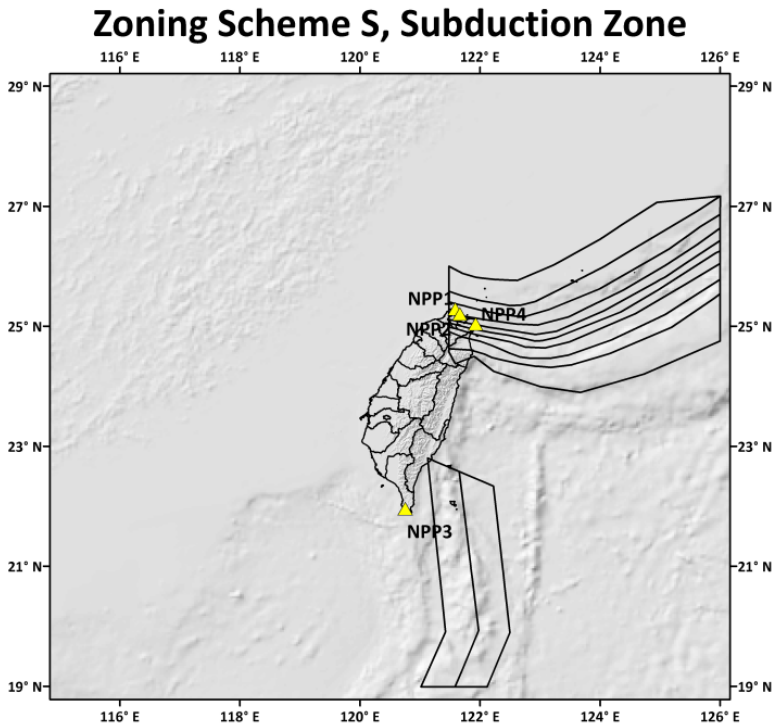
Scheme Z for Subduction Intraslab

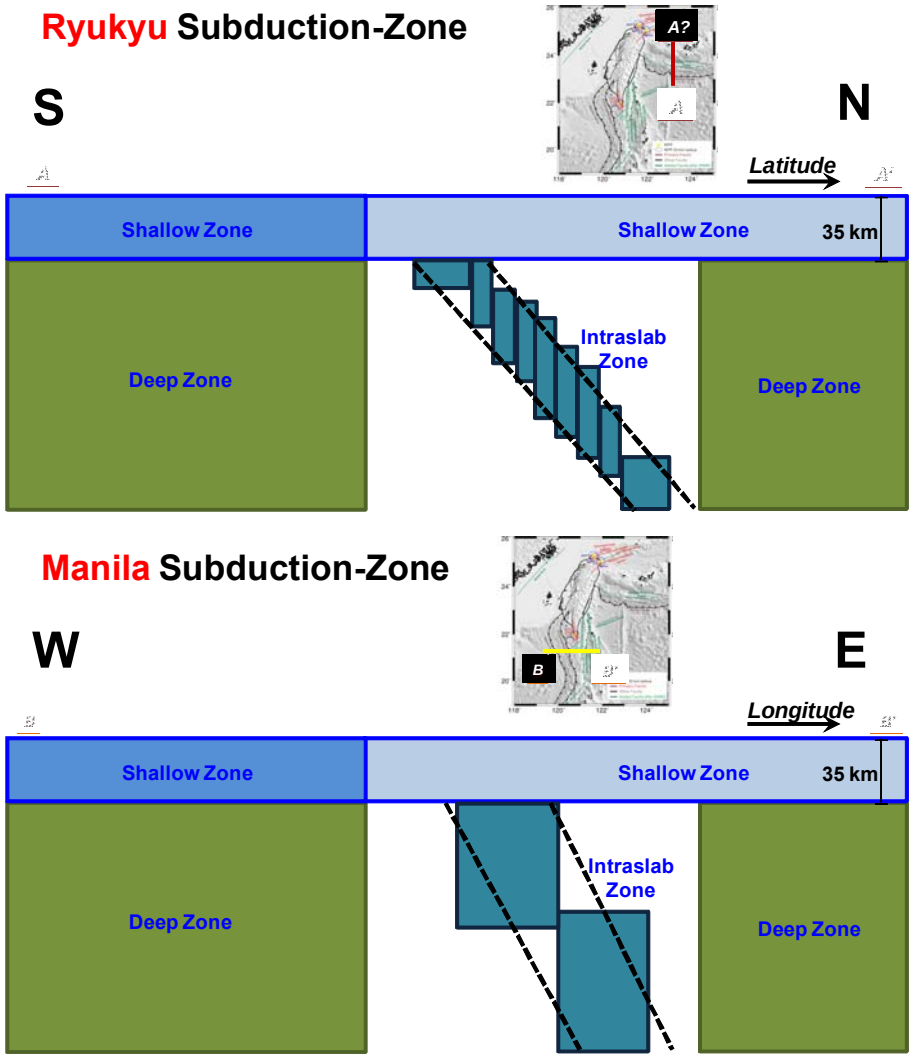






Scheme S for Subduction Intraslab





Explanation of Zoning Setting

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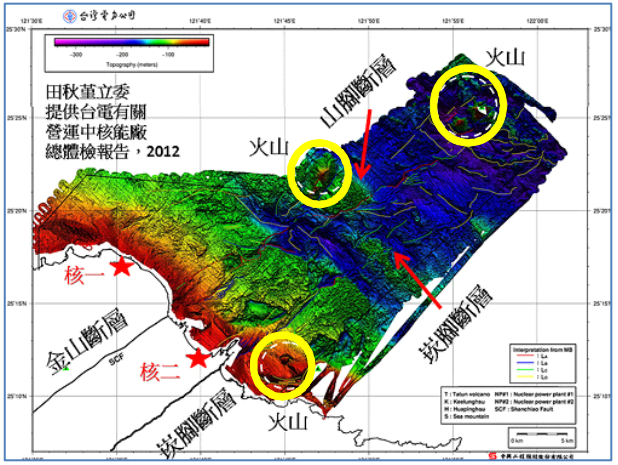
- **Seismicity Nearby Each NPP Site**

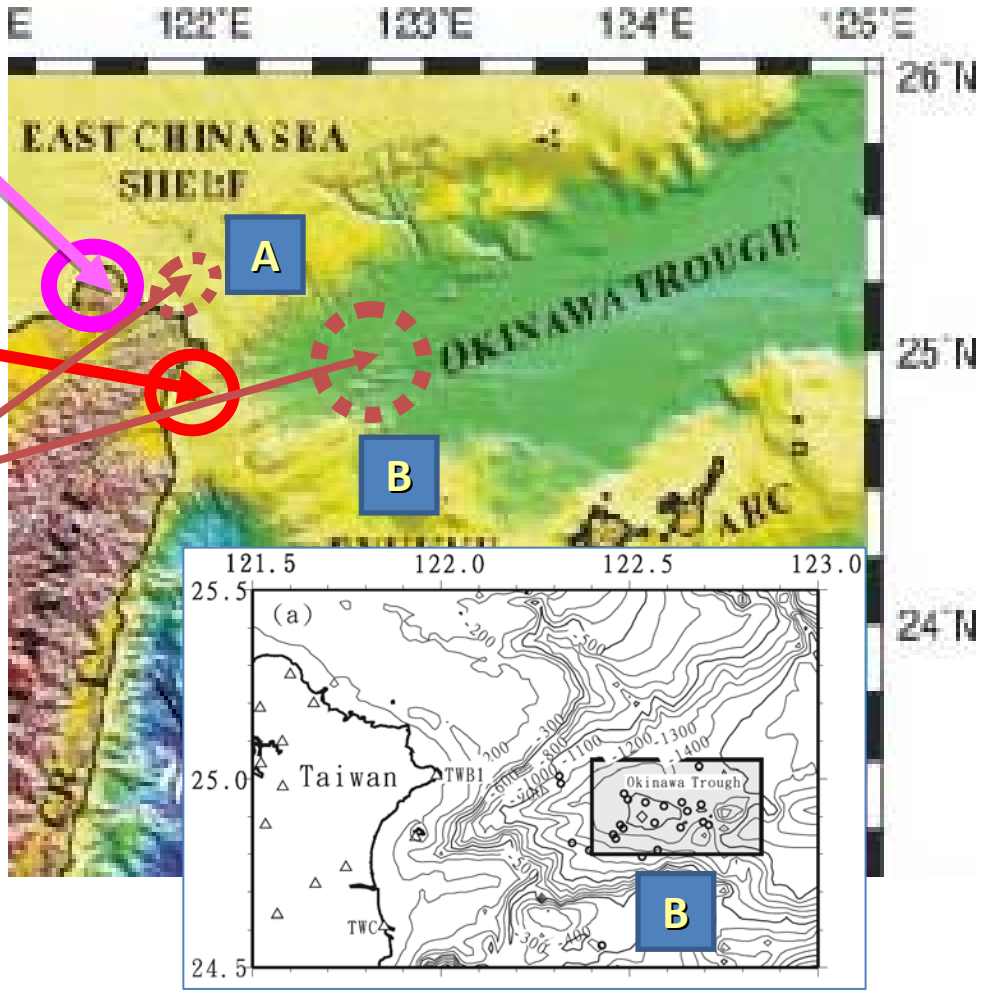
Volcanoes at Northern Taiwan (provided by Cheng-Horng Lin)

1. Tatun volcano group

2. Turtle Island

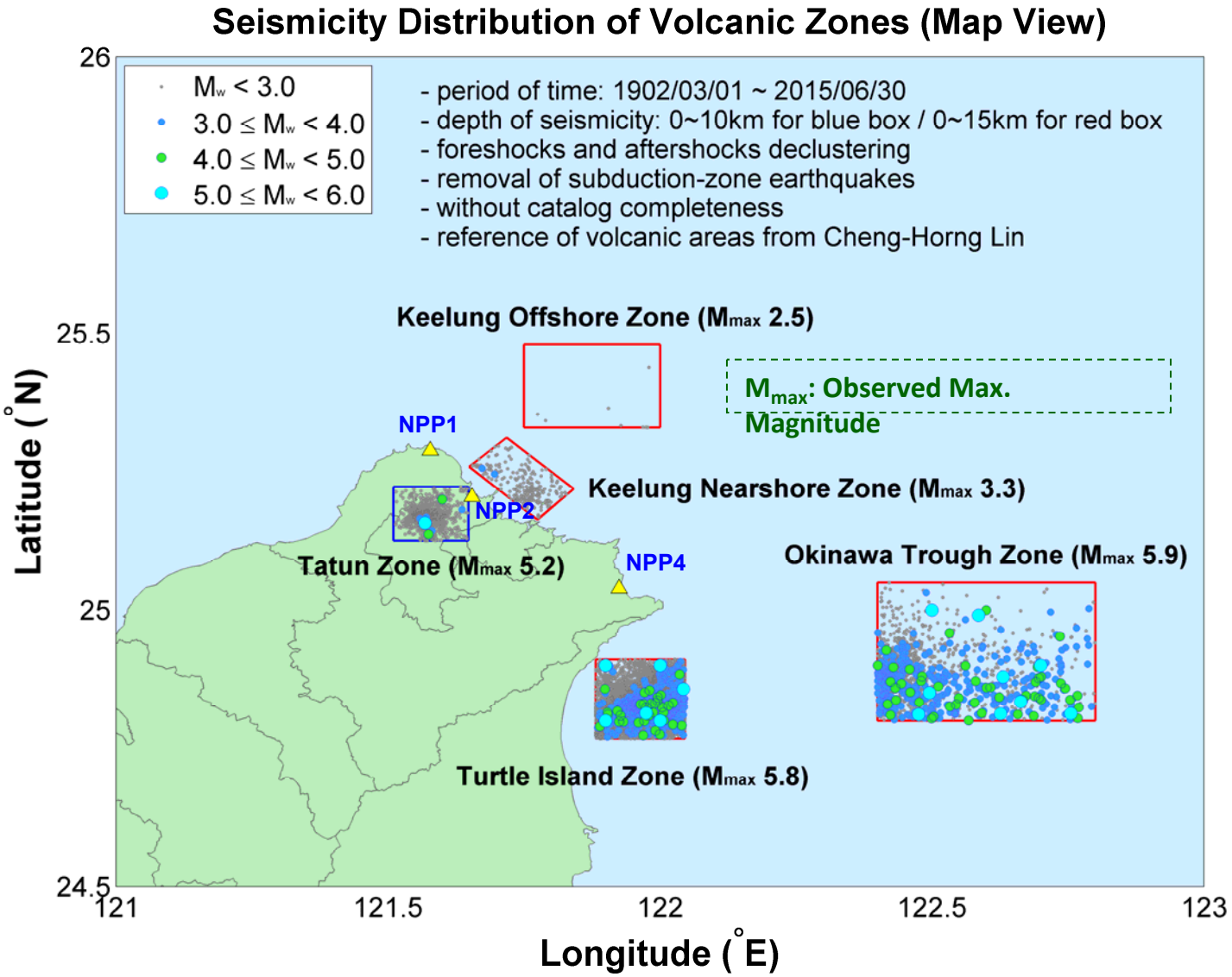
3. Submarine volcanoes





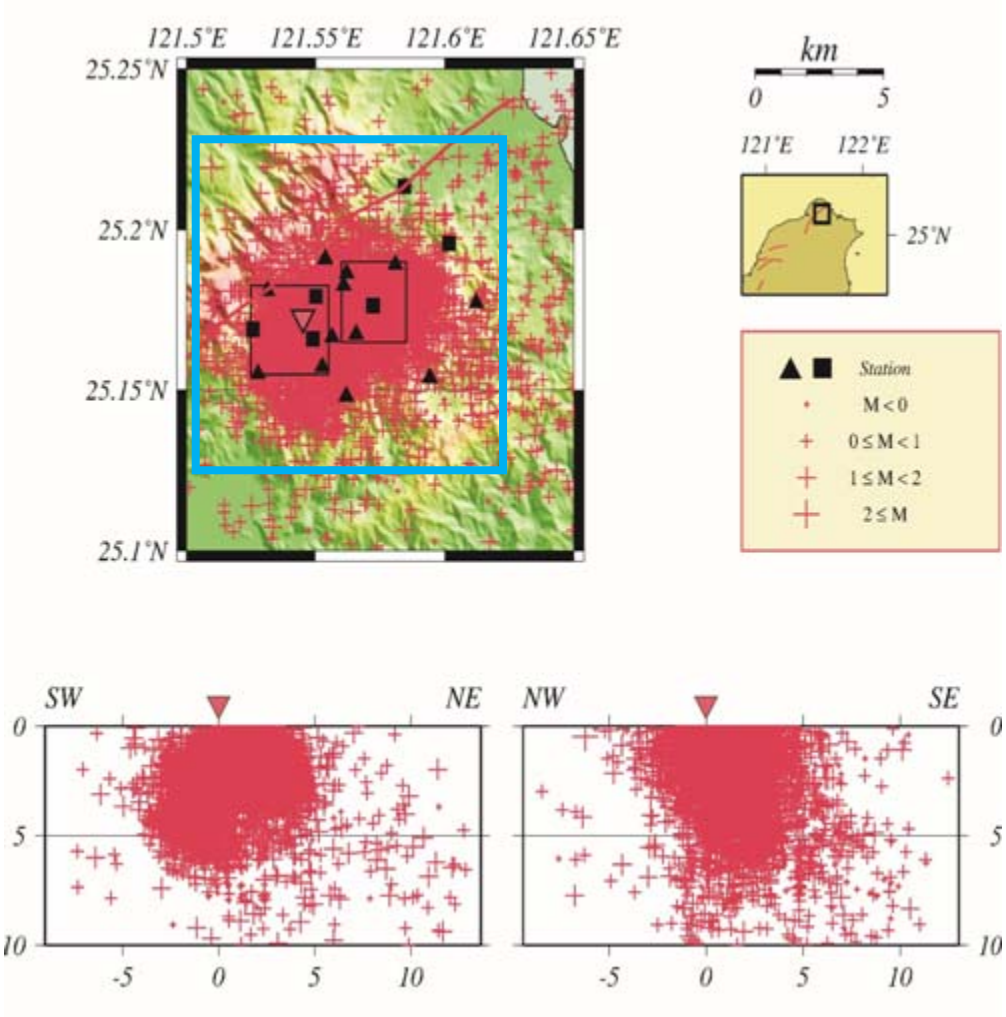
- Lin, C.H. (2016). "Volcanic Seismic Sources," presentation at Taiwan SSHAC Level 3 Project Workshop 1 , March 14.
- Lin, C.H. et al. (2007). "Low-frequency Submarine Volcanic Swarms at The Southwestern end of The Okinawa

The Volcanic Source Zones Nearby Taiwan



Depth Setting of Tatun Volcanic Zone

- Seismicity recorded by local stations from 2003/05 to 2013/12
- Setting Depth as **10 km**

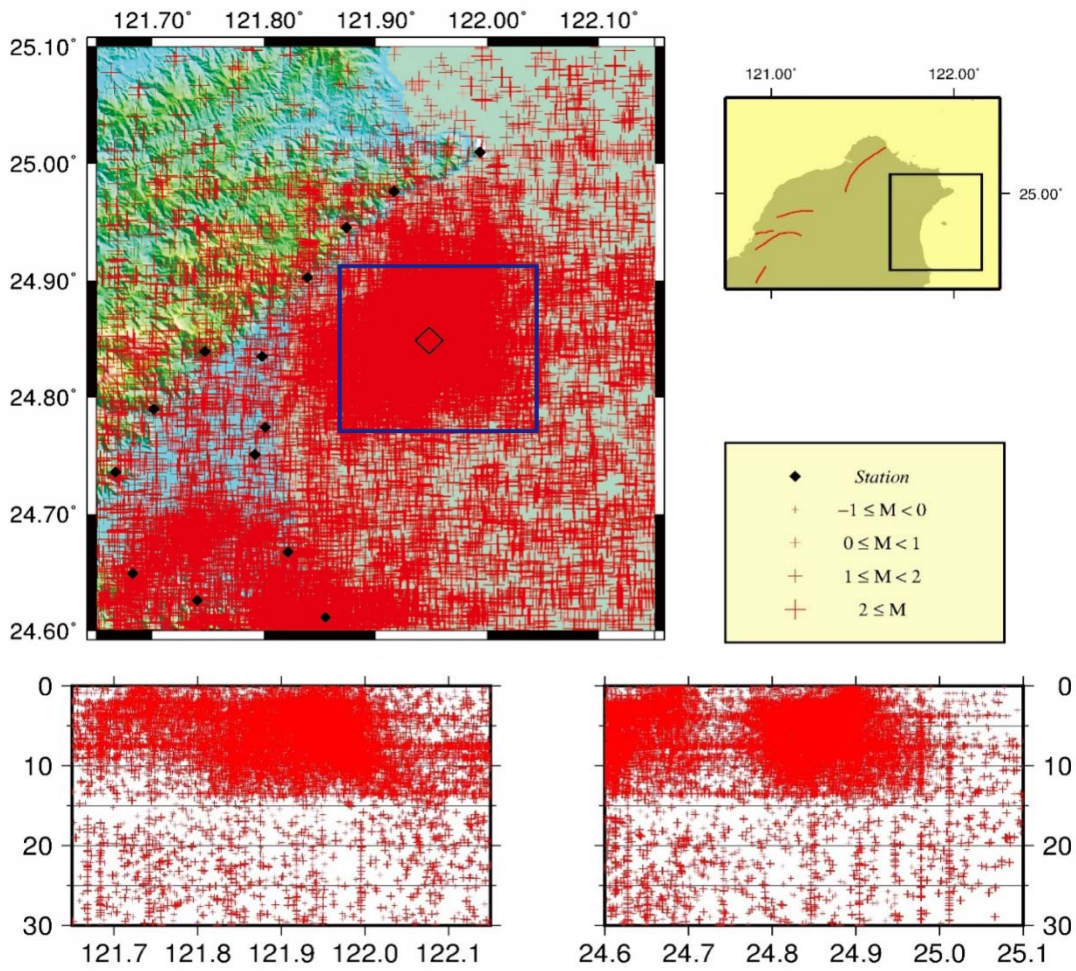


(provided by Prof. C.H. Lin as RE at WS#1)

Depth Setting of Turtle Island Zone

- **Seismicity recorded by local stations from 2007 to 2015**
- **Setting Depth as 15 km**

➔ **The depth setting in other offshore volcanic zone refer to Turtle Island Zone as 15 km**



(provided by Prof. C.H. Lin as RE at WS#1)

Explanation of Zoning Setting

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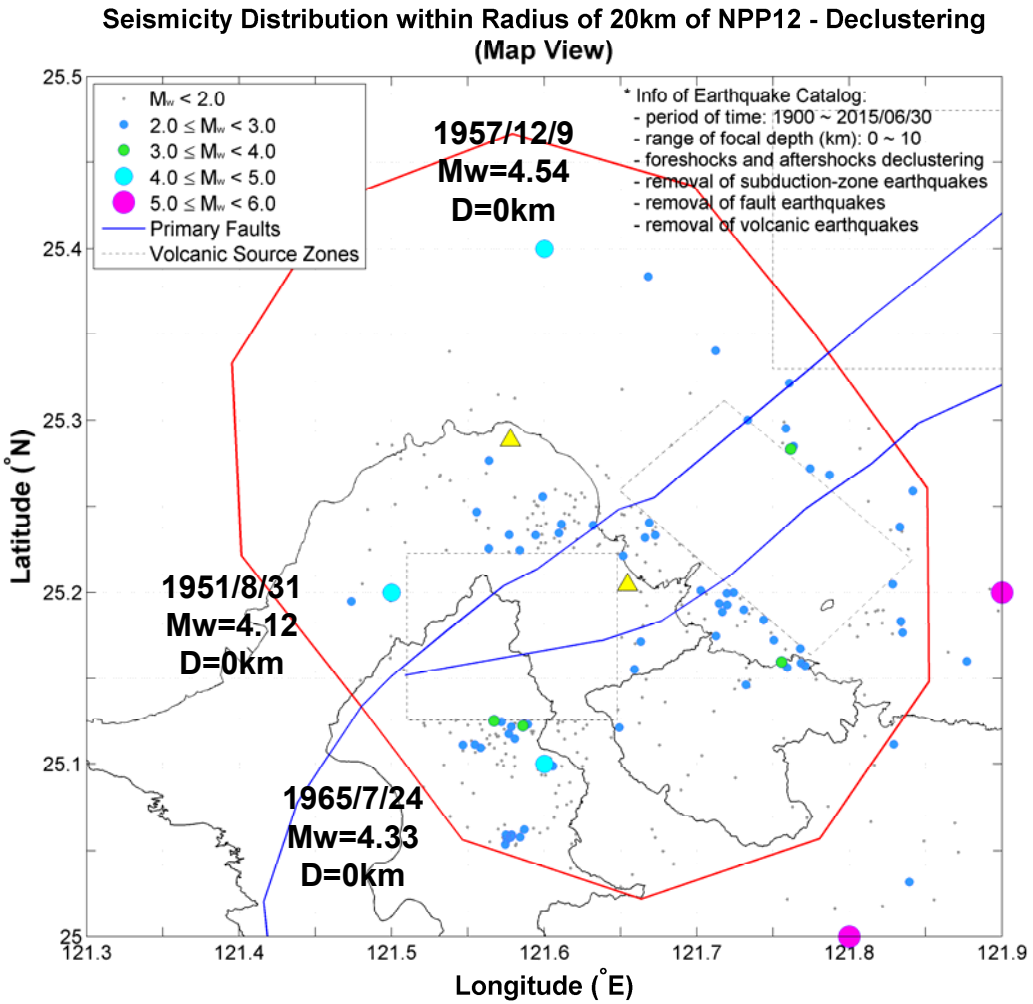
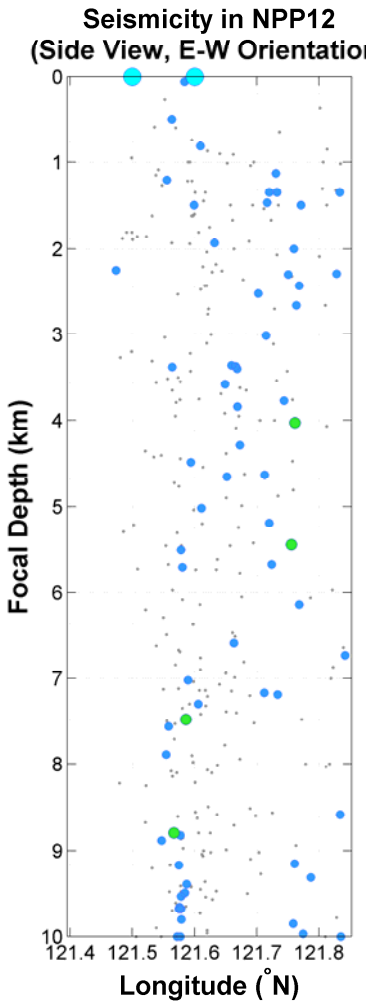
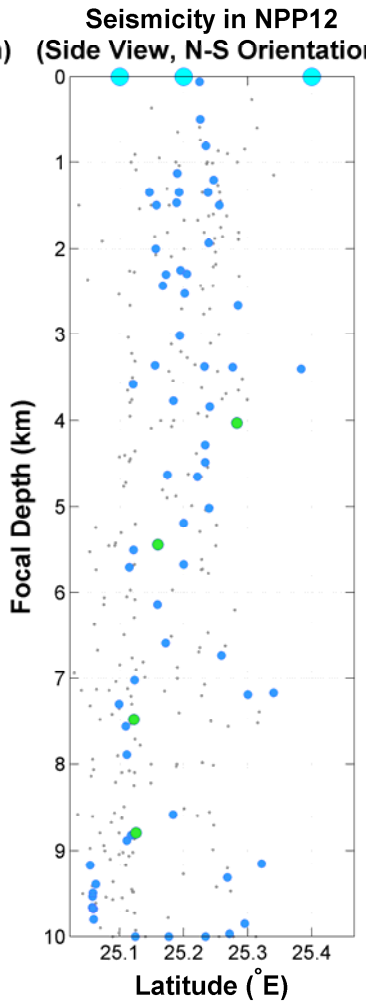
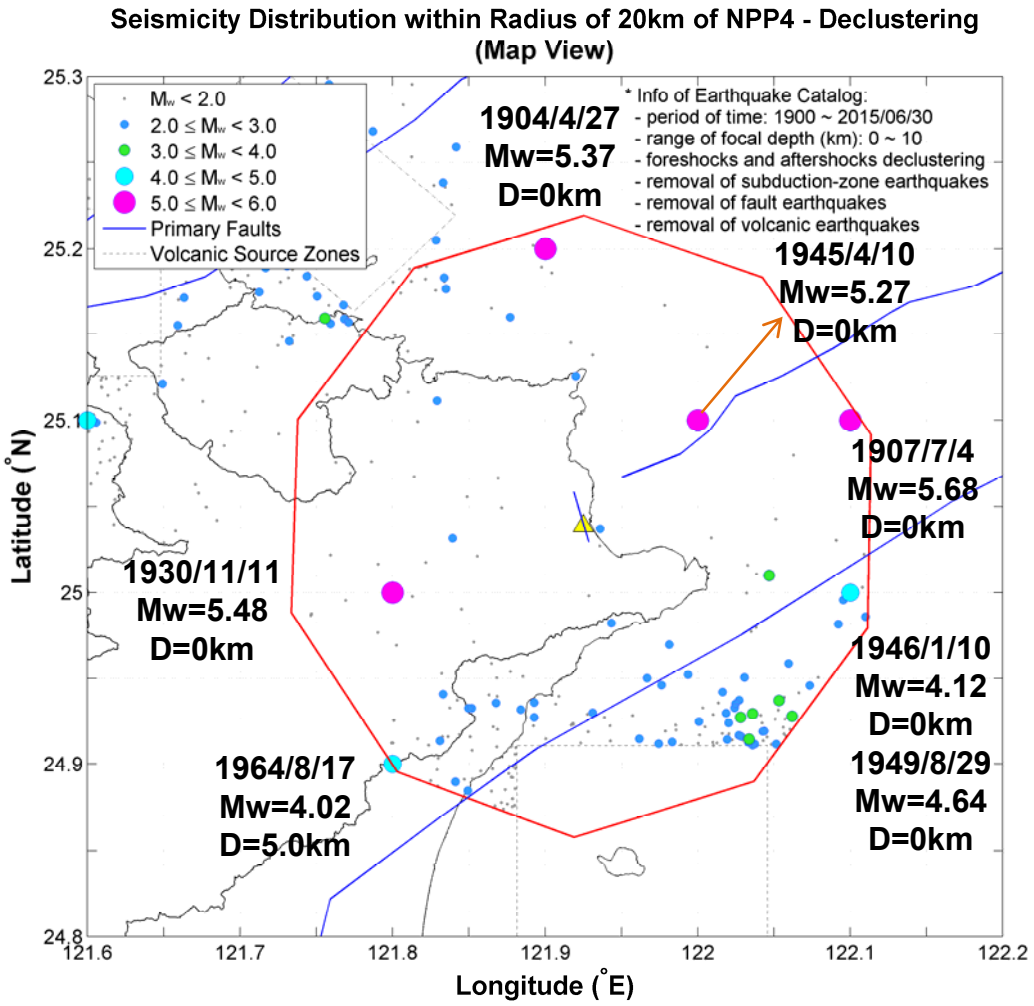
Seismicity within Radius of 20km and Depth of 10km - NPP1 and NPP2 Sites

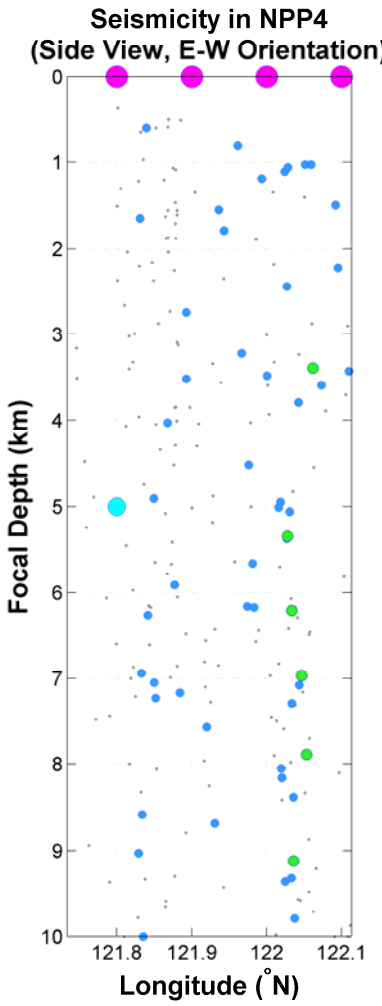


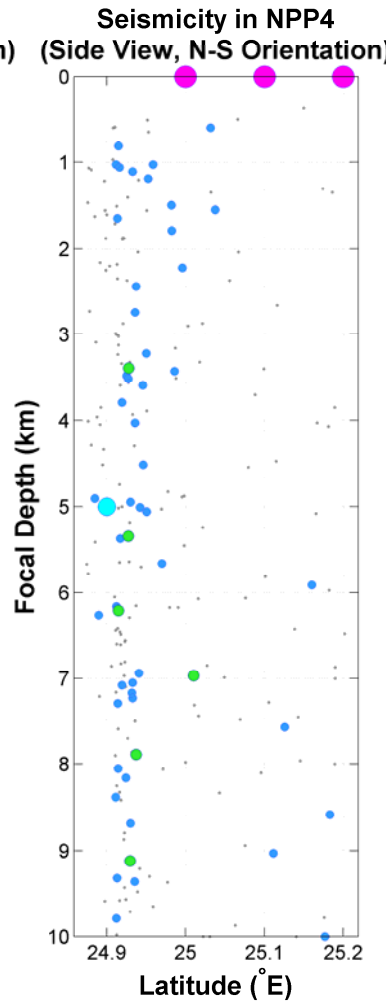




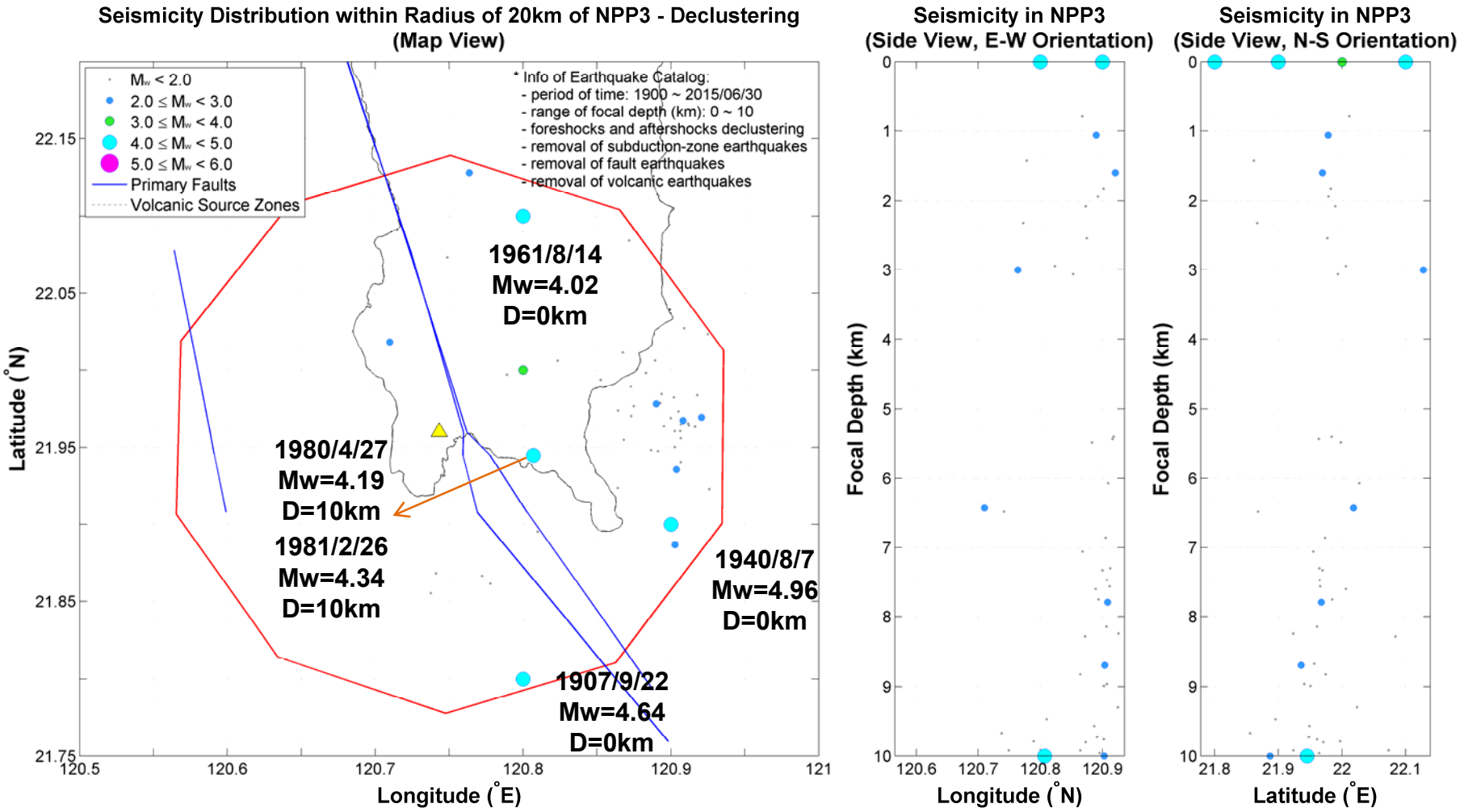
Seismicity within Radius of 20km and Depth of 10km - NPP4 Site







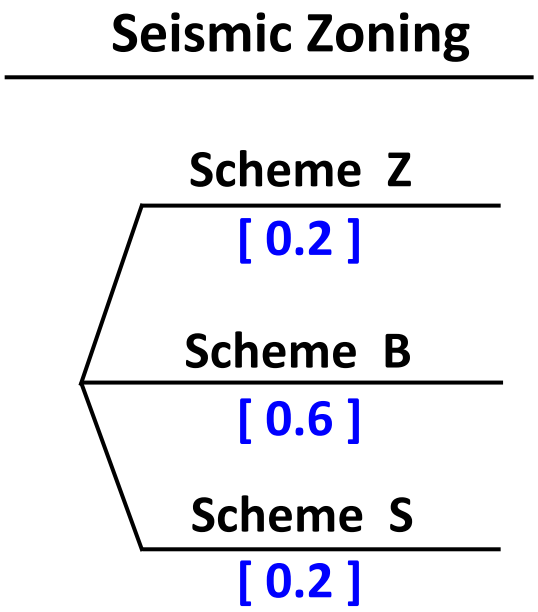
Seismicity within Radius of 20km and Depth of 10km - NPP3 Site



Outline

- Zoning Scheme Overview
- Explanation of Zoning Setting
- Weighting for Zoning Scheme

Explanation of Weighting Setting



- **Scheme B**
  - Based on the latest data to broaden the delineation region and readjust zonation
  - Subduction zone is separated by beneath interface crust zone and intraslab zone, and adopting interface and intraslab GMPE respectively
- **Scheme S**
  - Based on the latest data to broaden the delineation region, but no readjust zonation
  - No defining beneath interface crust zone. Adopting crustal GMPE in shallow zone only
- **Scheme Z**
  - New Creation
  - Larger-area zone to construct delineation

Thank You for Your Attention

Summary of Zoning Schemes

Zoning Scheme	Scheme B	Scheme S	Scheme Z
Be modified from prototype	Yes	Yes	No, new creation
Delineation fitted with the latest data and study area	Yes, delineation broaden to the study area and original zonation has been modified	Yes, delineation broaden to the study area, but keeping the original zonation	Yes, new creation
Considering both interface and intraslab parts in subduction zone	Yes, and the beneath interface crust zone is adopted interface GMPE	No, beneath interface crust zone is not considered	Yes, and the beneath interface crust zone is adopted interface GMPE
The prototype used in engineering practical purposes	Yes	Yes	No