Taiwan Power Company

Geological Survey for the Sites of Operating Nuclear Power Plants

Geotechnical Engineering Department

中興工程顧問股份有限公司

SINOTECH ENGINEERING CONSULTANTS, LTD.

2013/9/24

Stage

1. Supplemental Geological Survey
   - Performance Period : *November 2010~August 2012*

2. Continuity Geological Survey
   - Performance Period : *June 2013~October 2014*

1. Supplemental Geological Survey

(November 2010~August 2012)

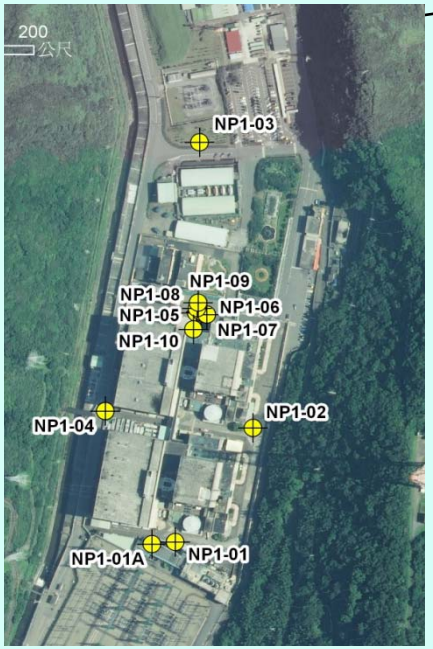
Outline

- Additional geological investigations for the (three) Operating Nuclear Power Plants sites
- Geological survey for the Shanchiao Fault at Jinshan area, and the offshore area within a radius of 40 km centered in NPP1 or NPP2 site
- Geological survey for the Hengchun Fault at Hengchun Valley area, and the offshore area within a radius of 40 km centered in NPP3 site, and explored the relationship between Chaochou Fault and Hengchun Fault

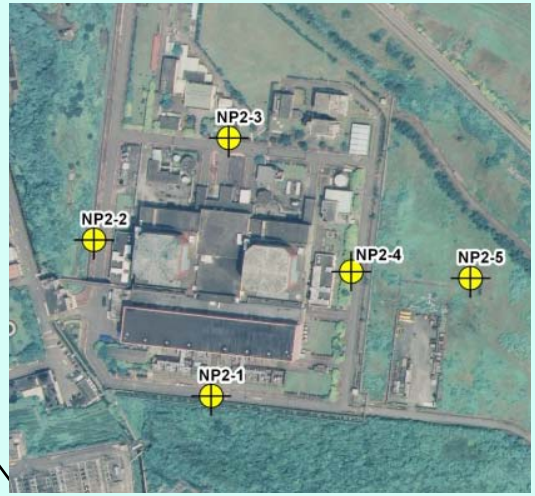
Additional geological investigations for the sites of (three) operating NPPs

- Geological borings
- Suspension P-S velocity logging

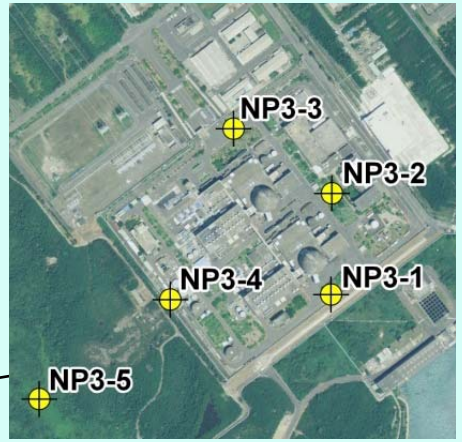
NPP4 (Lungmen)



NPP1(Chinshan)



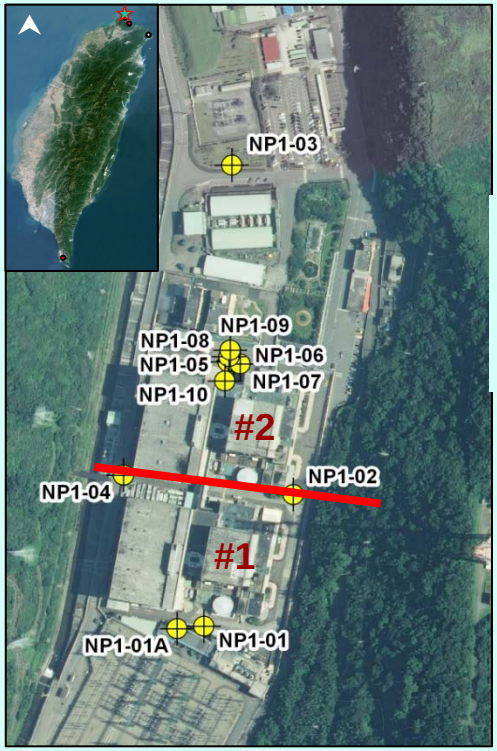
NPP2(Kuosheng)



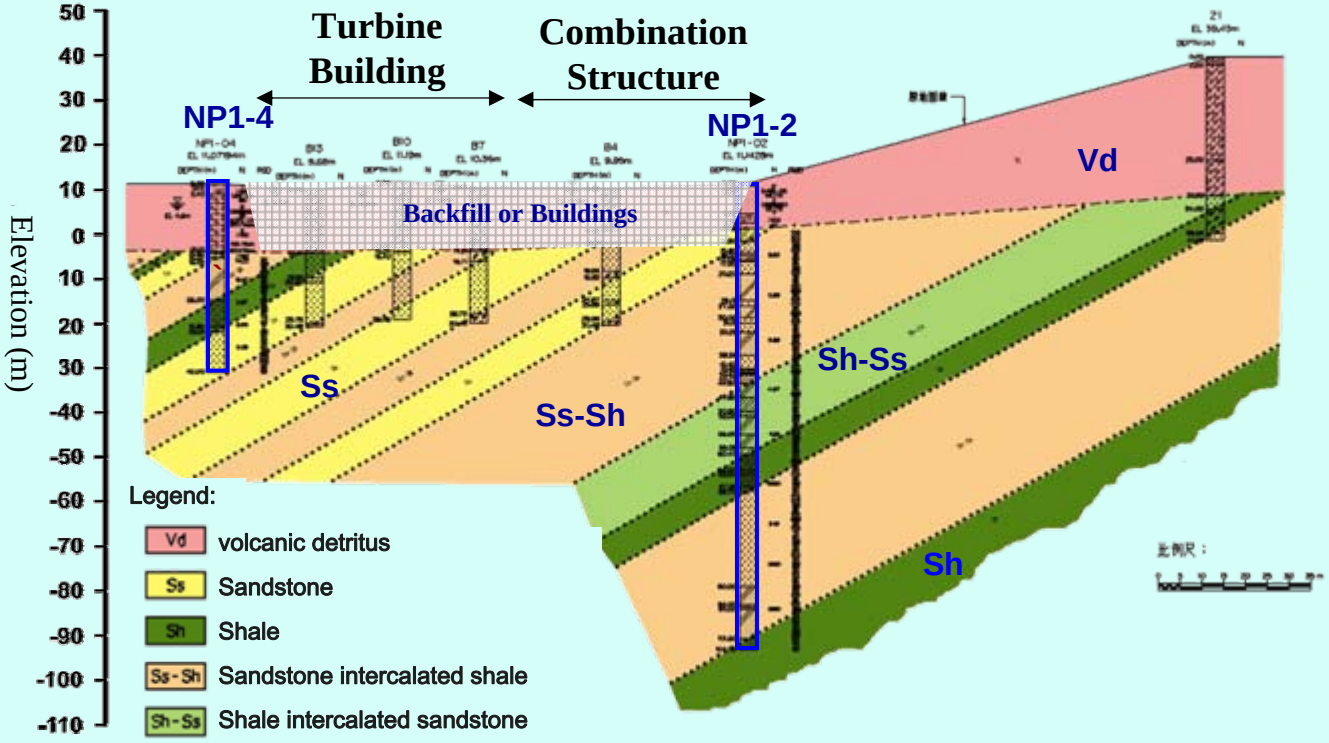
NPP3(Maanshan)

Geological and geophysical characteristic of the NPP1 site

- Stratigraphy and Lithology
  - Unconsolidated sediments : thickness of 2~12m
  - Volcanic detritus (pyroclastic or epiclastic) rocks (Vd) : thickness of 2~14.7m
  - Rockmass : Tapu (or lower Kueichoulin) Formation (Late Miocene)



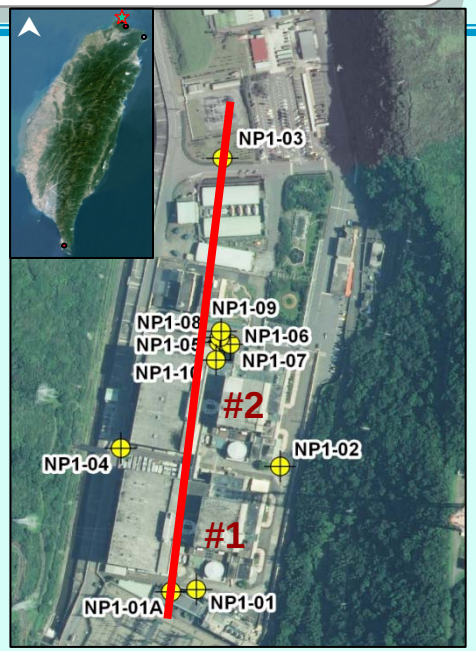
NPP1(Chinshan)

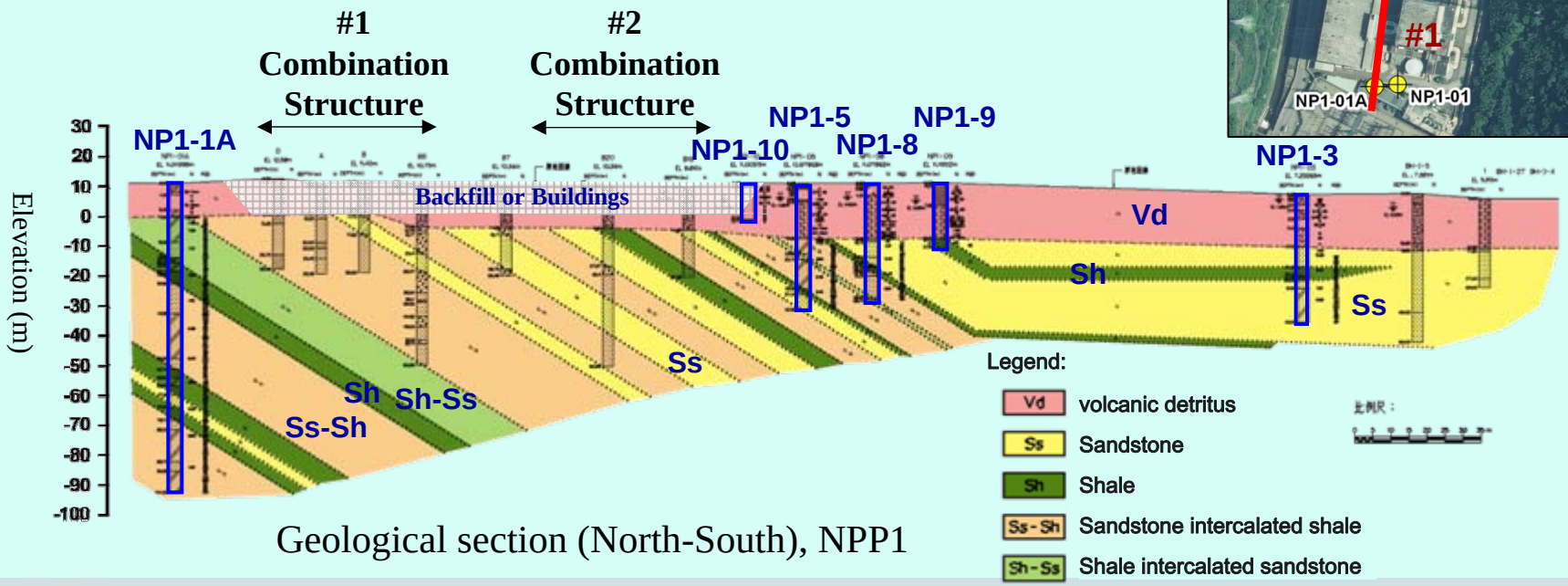


Geological section (West-East), NPP1

NPP1

- Geological Structure
  - Bedding plane : Attitude N58°E/ 38°N
  - Bedding shears : locally well-developed along the bedding-plane
  - No large shear zone or fault structure found (from the core logging)





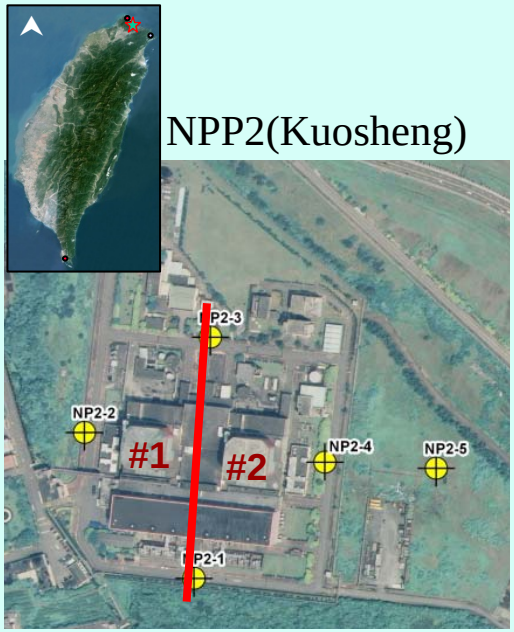
Geological section (North-South), NPP1

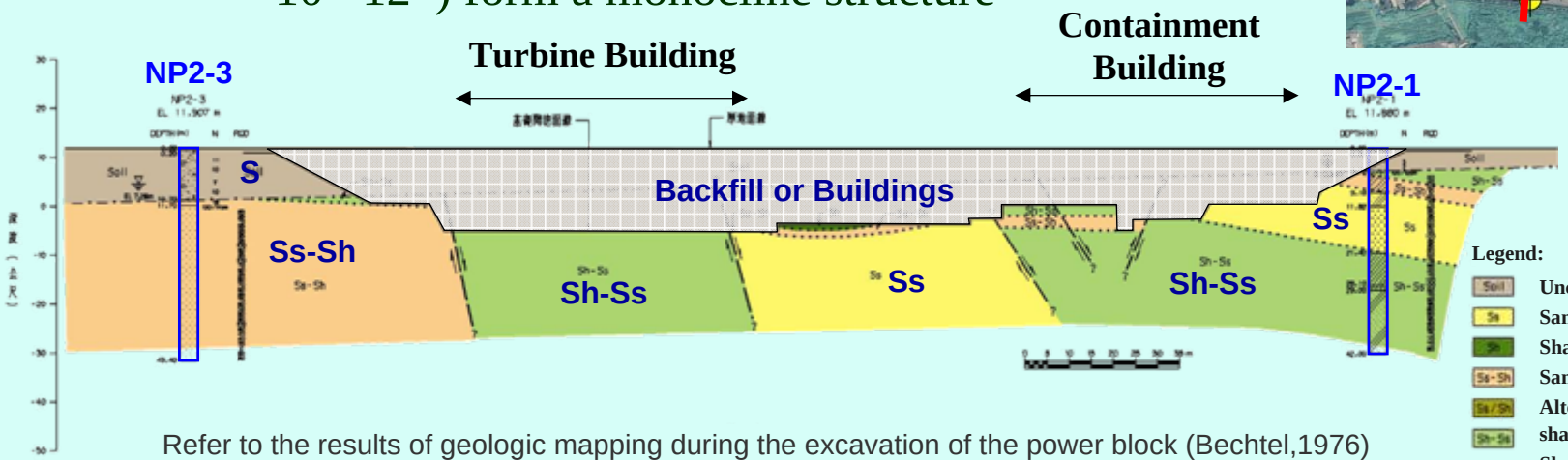
- Geophysical characteristic

Item	Stratigraphy (Material)	Vp (m/sec)	**Vs (m/sec)**	Poisson's Ratio υ d	Shear Modulus Gd (kg/cm^2)	Young's Modulus Ed (kg/cm^2)	Bulk Modulus Kd (kg/cm^2)	Remarks
1	gravels (unsaturated)	630 (2,100 ft/sec)	210 (700 ft/sec)	0.438	1.26 x 10^4	3.6 x 10^4	-	FSAR
	gravels (saturated)	1,500 (5,000 ft/sec)	210 (700 ft/sec)	0.487	1.26 x 10^4	3.75 x 10^4	-	
	Tapu Formation	1,905 (6,350 ft/sec)	**420** (1,400 ft/sec)	0.475	5.0 x 10^4	1.48 x 10^5	-	
2	Unconsolidated sediments	870~2,041	246~719	0.413~0.486	1,145~9,454	3,352~26,956	11,323~67,589	This Project
	Rockmass	1,493~2,326	**391~840**	0.384~0.476	2,737~16,573	8,008~46,808	33,618~111,627	

Geological and geophysical characteristic of the NPP2 site

- Stratigraphy and Lithology
  - Unconsolidated sediments : thickness of 1.1~12.45m
  - Rockmass : Mushan Formation (Early Miocene)
- Geological Structure
  - Bedding plane : Attitude generally flat to gentle dipping (vary up to about 20°) in the power block area
    - South part tilted and dipping to the southeast (about 10°~12 °) form a monocline structure



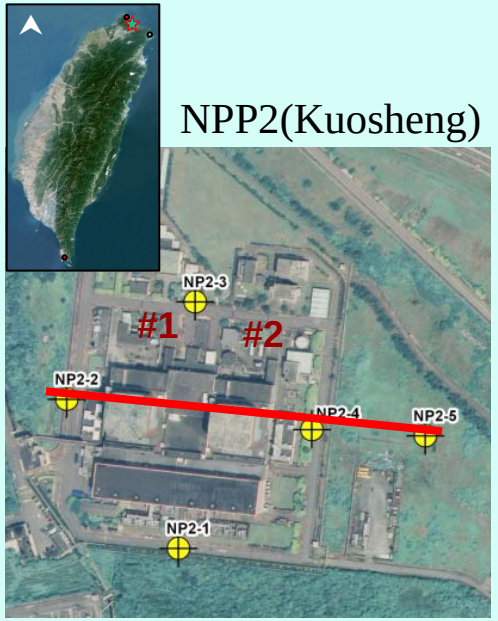


Refer to the results of geologic mapping during the excavation of the power block (Bechtel,1976)

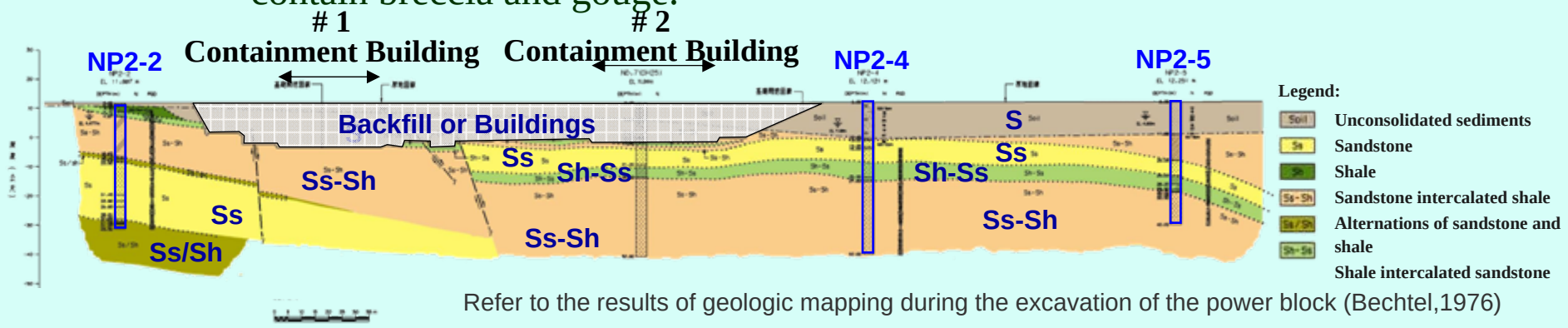
Geological section (North-South), NPP2

NPP2

- Geological Structure
  - Bedding shears : locally well-developed along the bedding-plane and contain gouge (width several centimeters)
  - Joints: locally closely spaced but contain no gouge (from the core logging)
  - No large shear zone or fault structure found from the core logging
  - Geological mapping during the excavation
    - Two prominent northeast-trending shear zones, dip towards each other, forming a graben, and locally contain breccia and gouge.



NPP2(Kuosheng)



Refer to the results of geologic mapping during the excavation of the power block (Bechtel,1976)

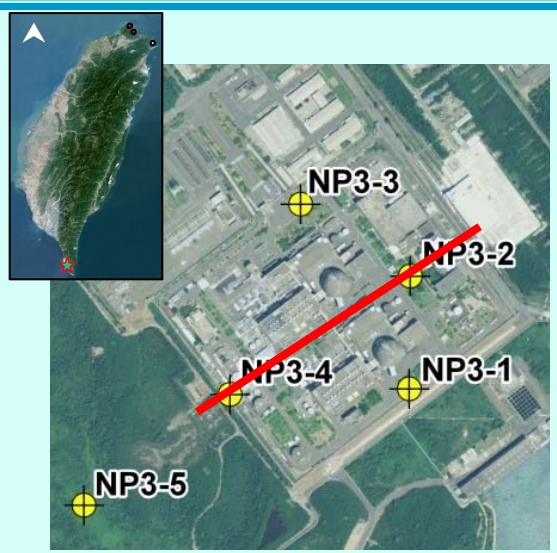
Geological section (West-East), NPP2

- Geophysical characteristic

Item	Stratigraphy (Material)	Vp (m/sec)	**Vs (m/sec)**	Poisson's Ratio υ d	Shear Modulus Gd (kg/cm^2)	Young's Modulus Ed (kg/cm^2)		Bulk Modulus Kd (kg/cm2)		Remarks
1	Top of rock	1,950 (6,500 ft/sec)	540 (1,800 ft/sec)	0.40	6,327 (90,000 psi)	28,120 (400,000 psi)		14,060 (200,000 psi)		FSAR
	10 feet Into rock	2,100 (7,000 ft/sec)	**690** (2300 ft/sec)	0.35	10,545 (150,000 psi)	Turbine Area	Reactor Area	Turbine Area	Reactor Area	
	20 feet into rock	2,100 (7,000 ft/sec)	**690** (2300 ft/sec)	0.35	10,545 (150,000 psi)	56,943 (810,000 psi)	58,349 (830,000 psi)	41,477 (590,000 psi)	49,562 (705,000 psi)	
2	Unconsolidated sediments	926~1,852	209~741	0.400~0.489	743~13,493	2,211~37,795		14,167~64,343		This Project
	Rockmass	1,538~3,846	**402~1,408**	0.349~0.476	2,732~48,986	8,066~133,460		36,002~311,498		

Geological and geophysical characteristic of the NPP3 site

- Stratigraphy and Lithology
  - Unconsolidated sediments : thickness of 0.3~4.2m, sandy clay contained broken fragments of coral reef limestone and cobble
  - Rockmass : Maanshan Formation (late Pliocene to Pleistocene)



Legend :

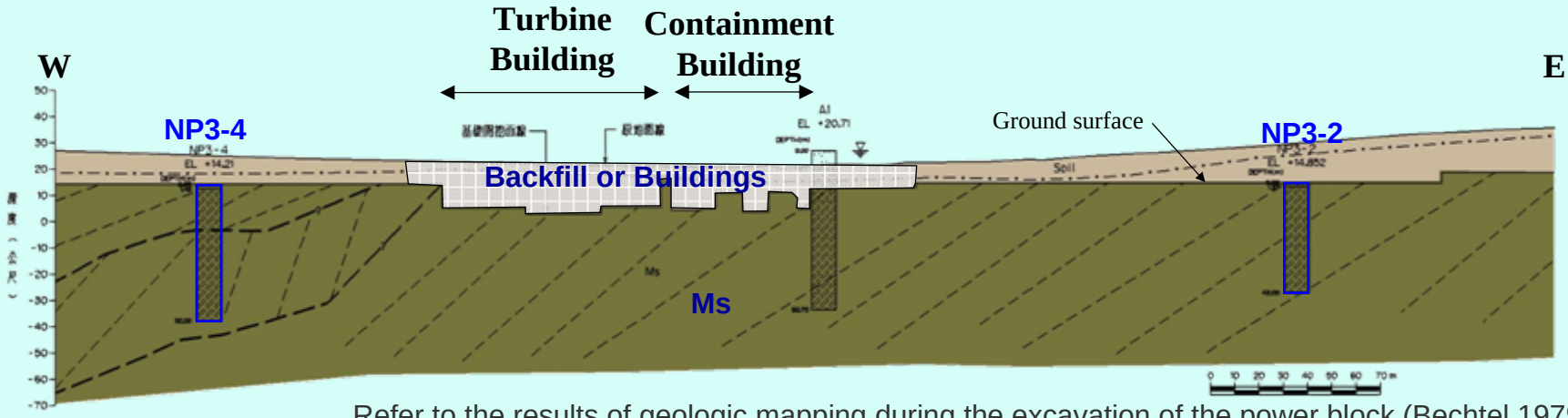
S — Unconsolidated sediments

Ms — Mudstone

Inferred rock line

Inferred bedding

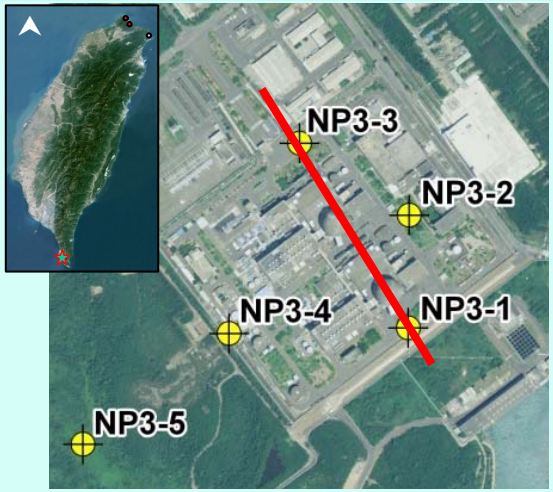
Inferred shear

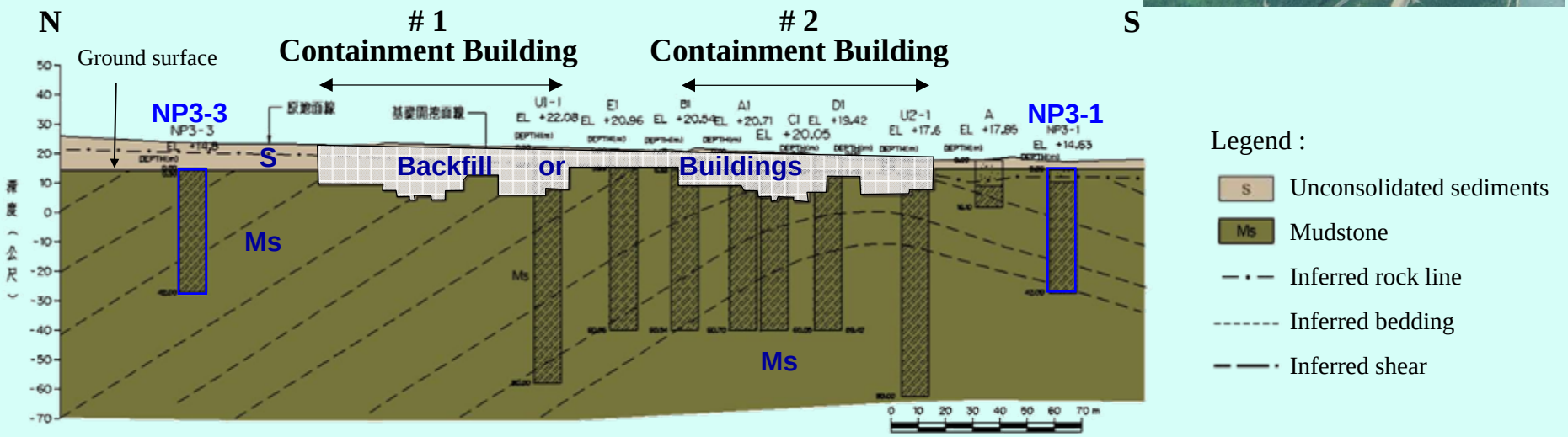


Refer to the results of geologic mapping during the excavation of the power block (Bechtel,1979)

Geological section (West-East), NPP3

- Geological Structure
  - Bedding plane : Attitude striking approximately N30 ° E and dipping 10°~70° NW, south part dipping to south and form anticline structure (Ref. to FSAR)
  - Shear zone : well-developed shearing, and easily found from the core logging and FSAR report





Refer to the results of geologic mapping during the excavation of the power block (Bechtel,1979)

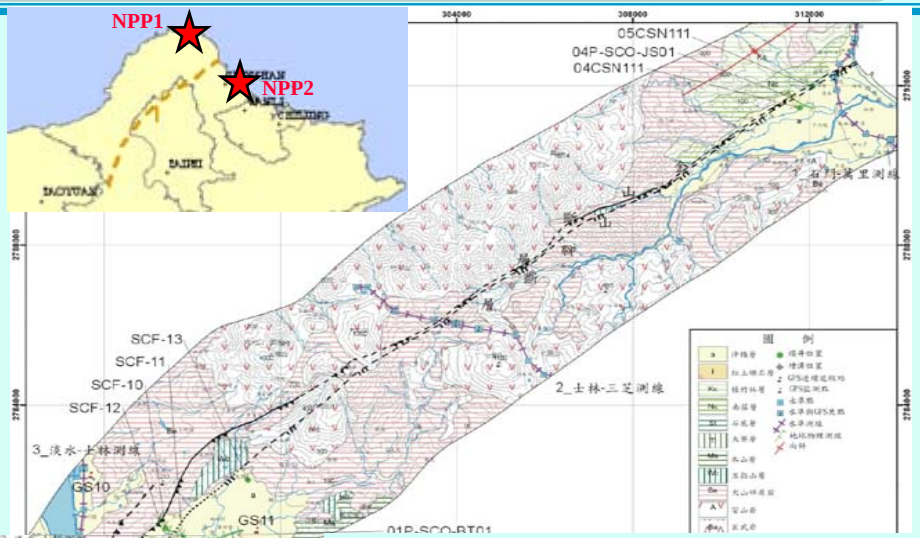
Geological section (North-South), NPP3

- Geophysical characteristic

Item	Stratigraphy (Material)	Vp (m/sec)	**Vs** (m/sec)	Poisson's Ratio υ d	Shear Modulus Gd (kg/cm^2)	Young's Modulus Ed (kg/cm^2)	Bulk Modulus Kd (kg/cm^2)	Remarks
1	mudstone	1,200 (4,000~5,000 ft/sec)	555 (1,850 ft/sec)	0.3~0.4	-	3.0 x 10^5	-	FSAR
2	Rockmass	1,299~2,083	392~637	0.420~0.474	3,201~8,486	9,283~24,321	30,841~82,952	This Project

Shanchiao Fault_Literature Review

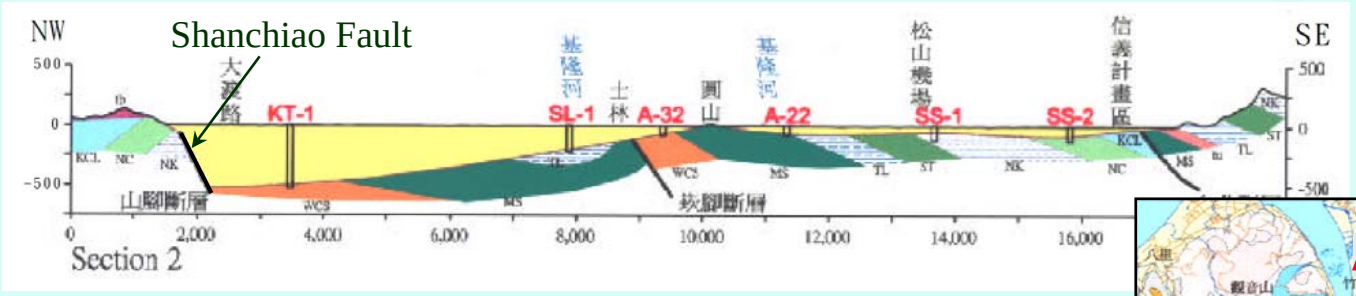
- Normal Fault
  - Strike NNE
    - Northern part : length of about 21 km
    - Southern part : length of about 13 km
  - Horizontal displacement unapparent from the GPS measurement on both side of fault
  - Hanging wall obvious subsidence
  - Recent activity about a ten thousand years ago



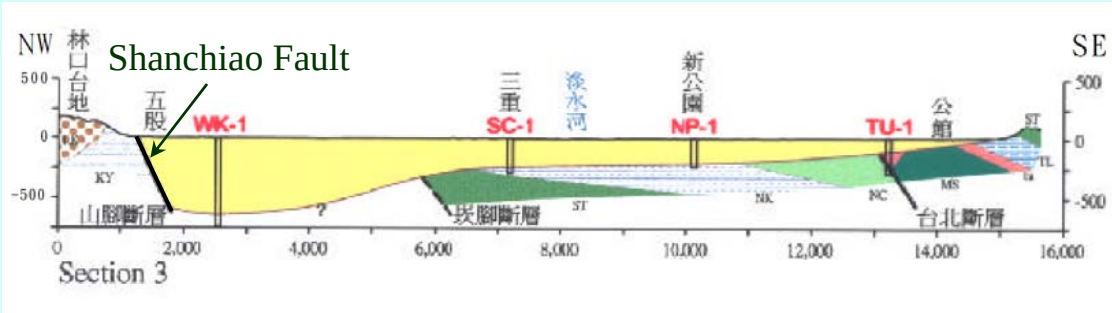
Refer to the Central Gelogical Survey, MOEA (2007)

Literature Review

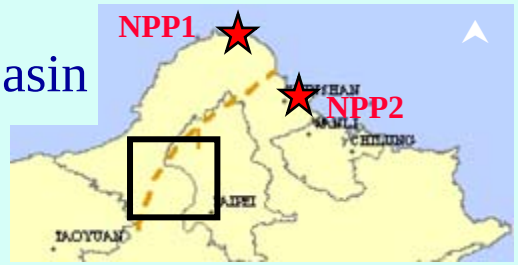
- Southern part of Shanchiao Fault (in Taipei Basin)
  - Hanging wall subsidence
  - Depth of at least 700 m the Tertiary basement in Taipei Basin

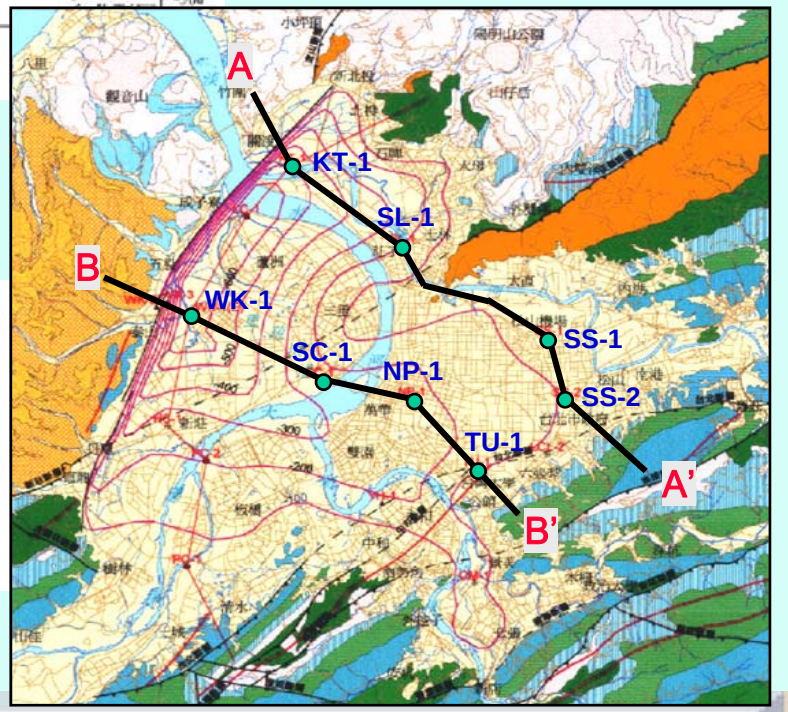


Geological section (A-A'), Taipei Basin



Geological section (B-B'), Taipei Basin

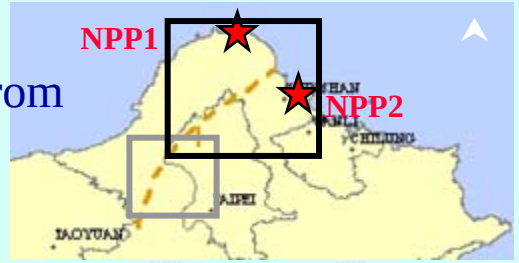


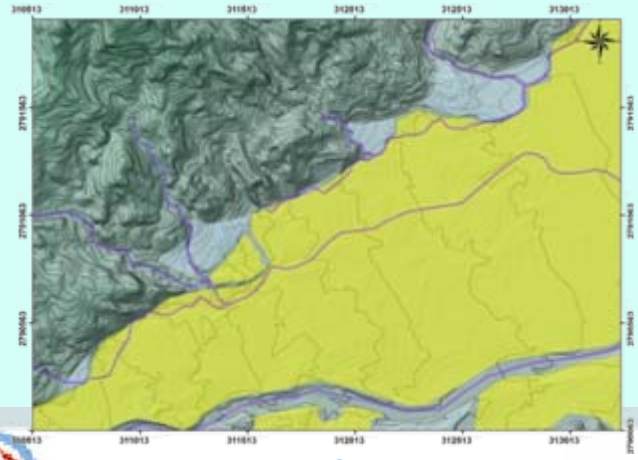


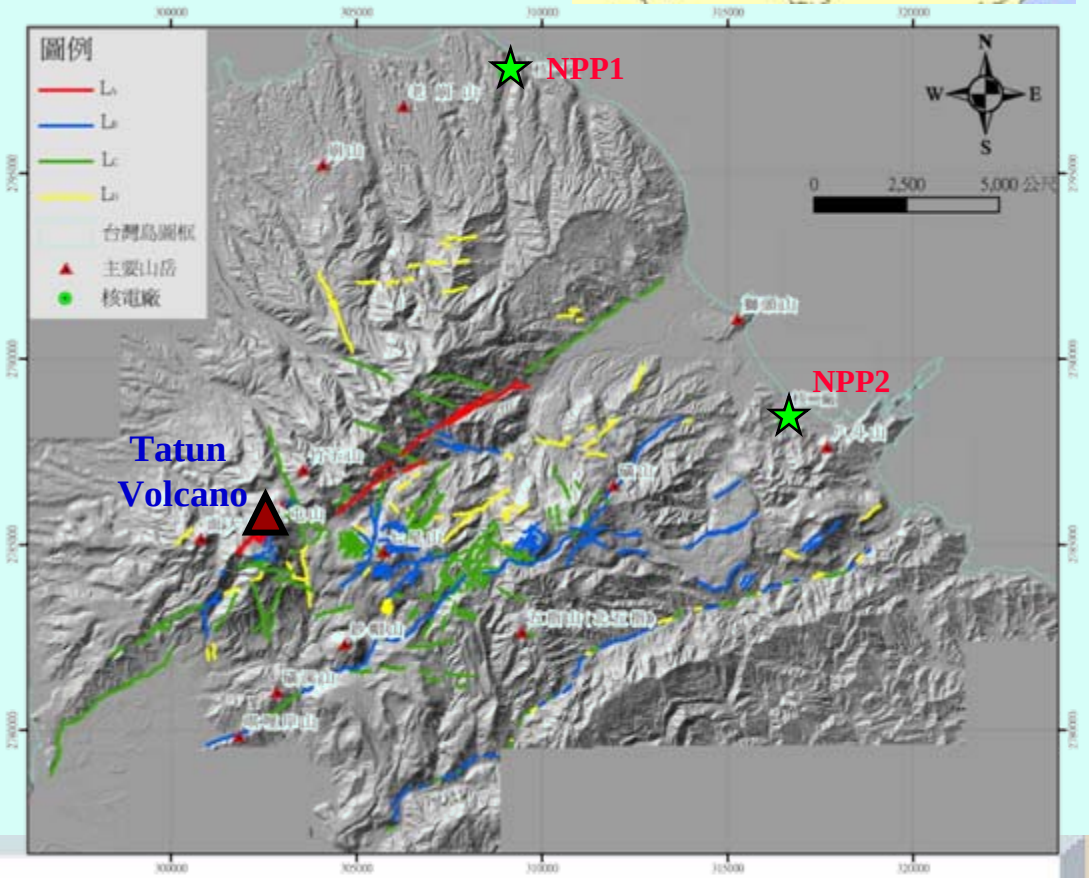
Refer to the Central Gelogical Survey, MOEA (1999)

Survey results

- Shanchiao Fault at Tatun Volcano Group
  - Tectonic geomorphology analysis according DEM ascend from LiDAR
    - 2 sets of major lineaments
      - Strike NE-SW
      - Strike NNW-SSE
    - In Tatun Volcano area
      - Deformed feature of lineaments obvious
    - In Jinsahn area
      - Deformed feature of lineaments unobvious

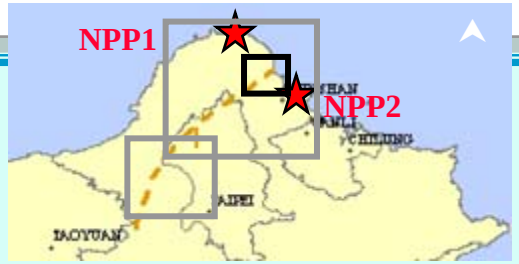


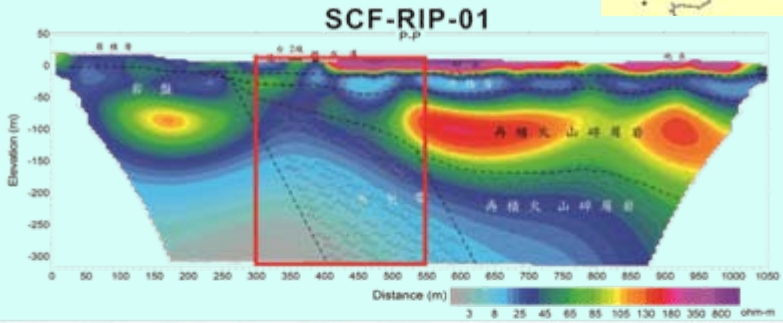


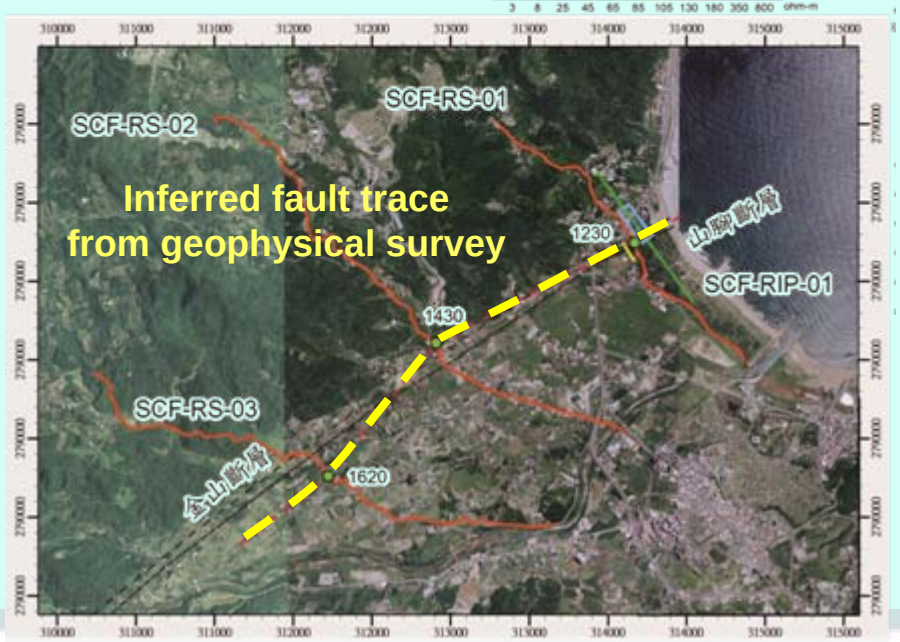


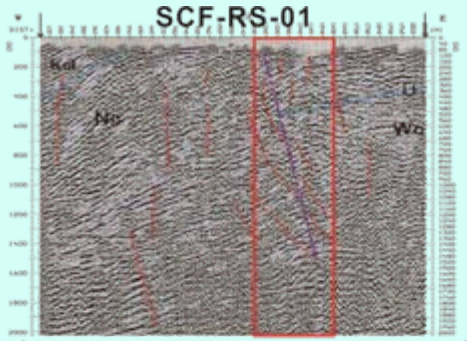
Survey results

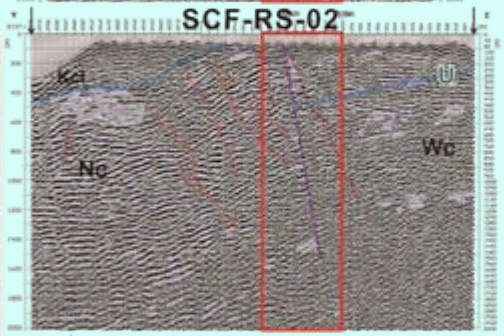
- Shanchiao Fault at Jinshan area
  - Resistivity image profiling method
  - Seismic reflection method

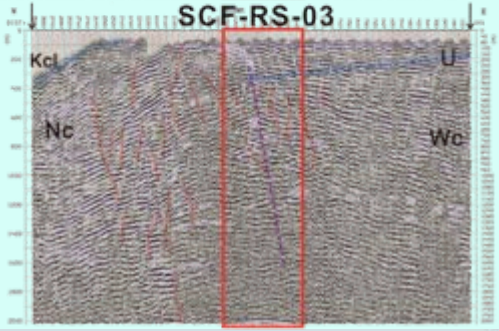






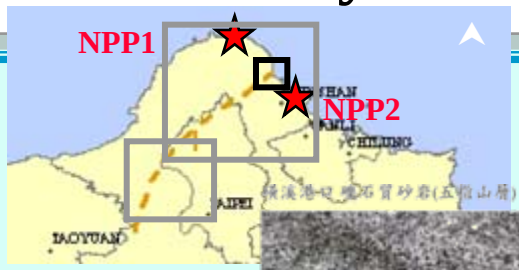


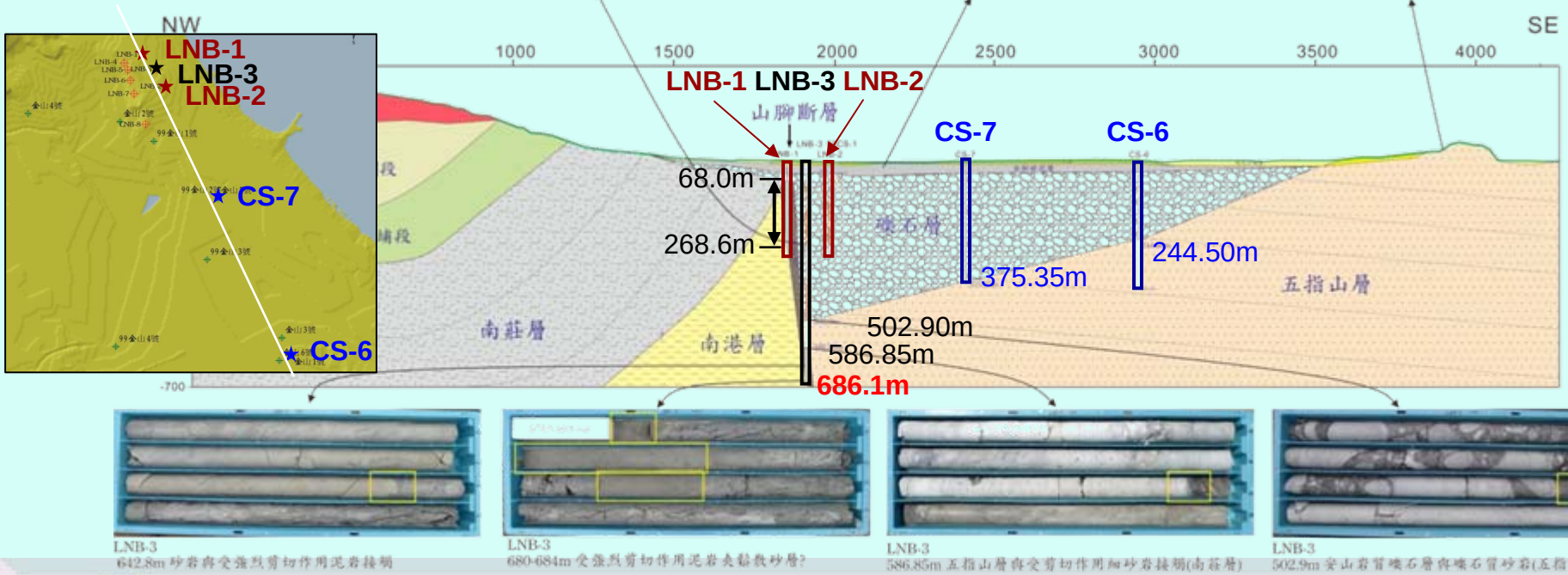




Survey results

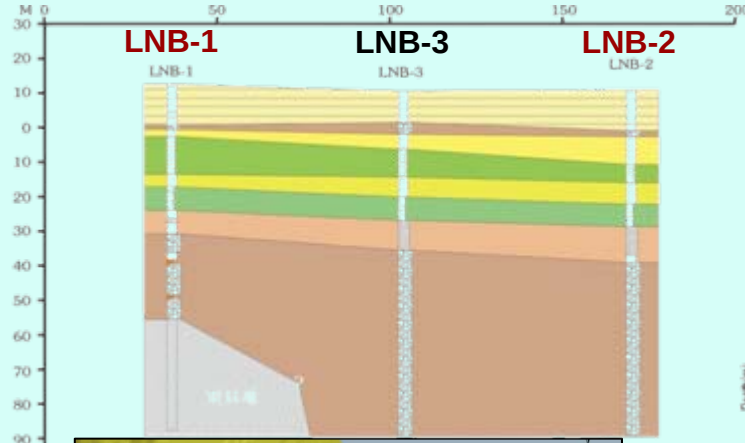
- Shanchiao Fault at Jinshan area (deep borehole drilling)
  - Located between LNB-1 and LNB-3
  - Hanging wall subsidence, dip separation about 518.85m
  - Dipping >82° toward southeastern

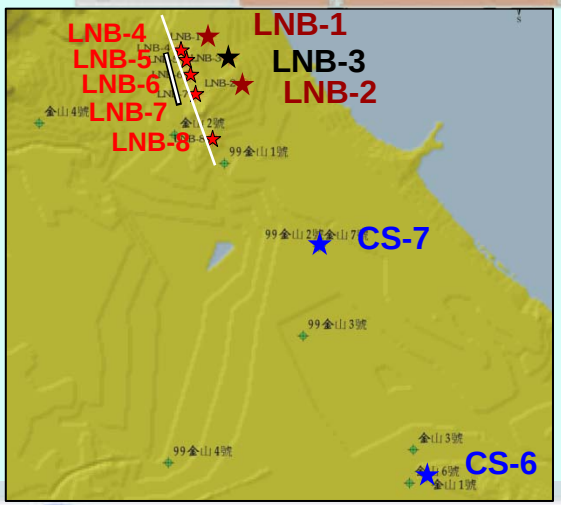


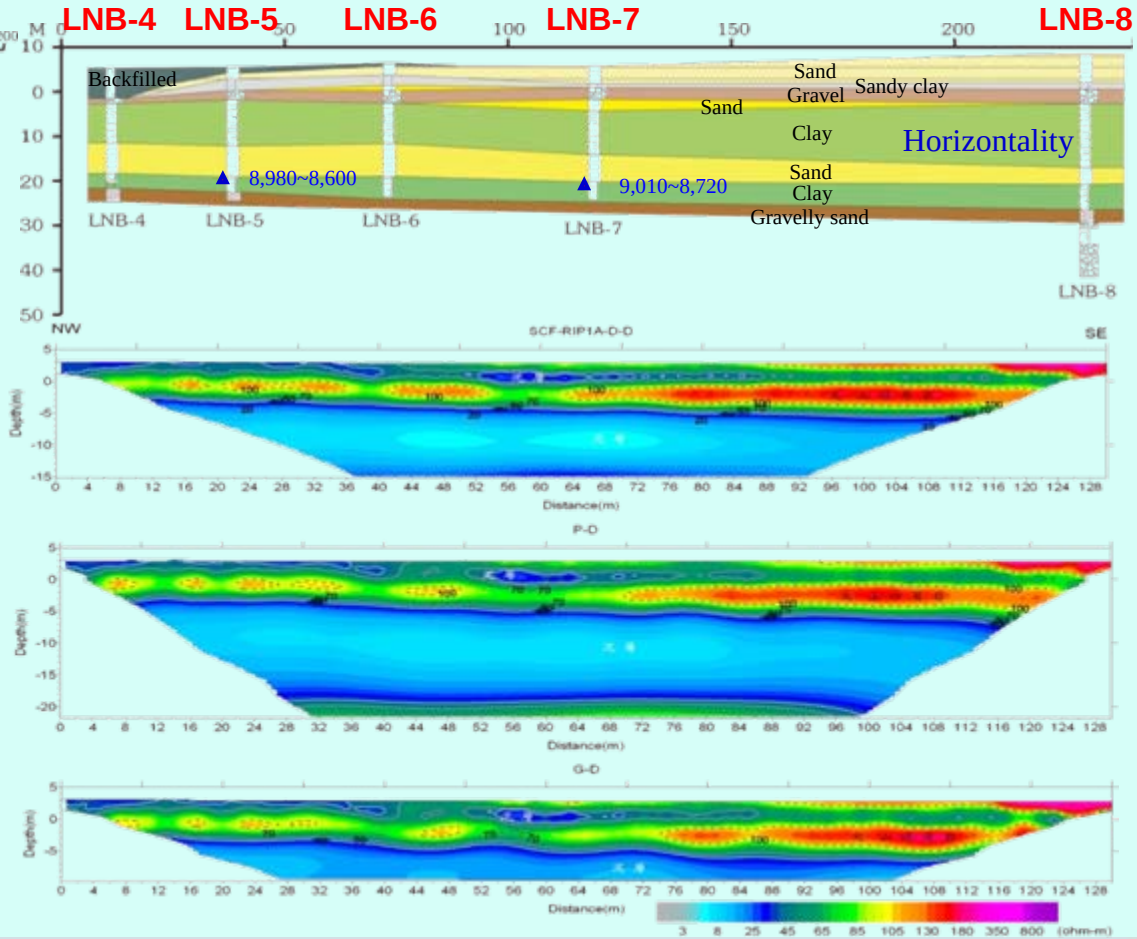


Survey results

- Shanchiao Fault at Jinshan area (shallow borehole drilling)
  - Estuary deposits almost horizontal
  - Younger than 8,600-9,010 Cal BP



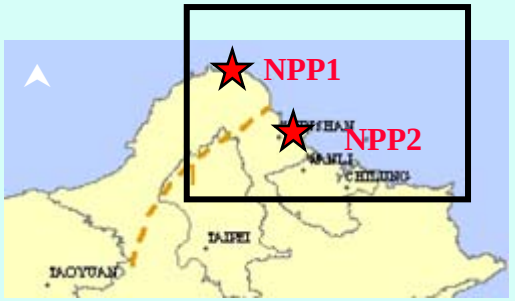


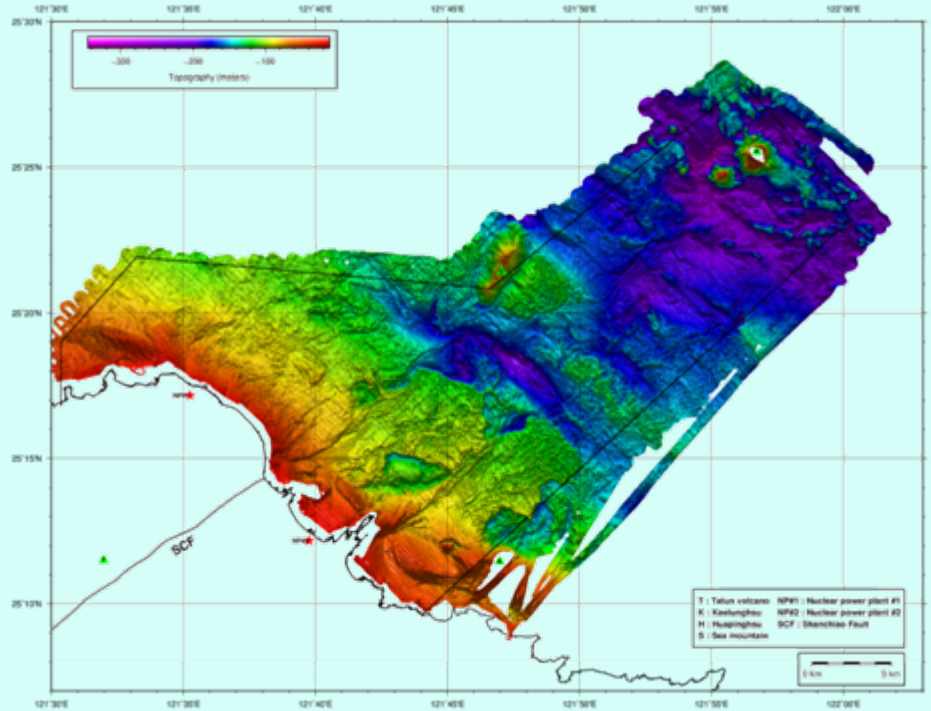


Resistivity image profile

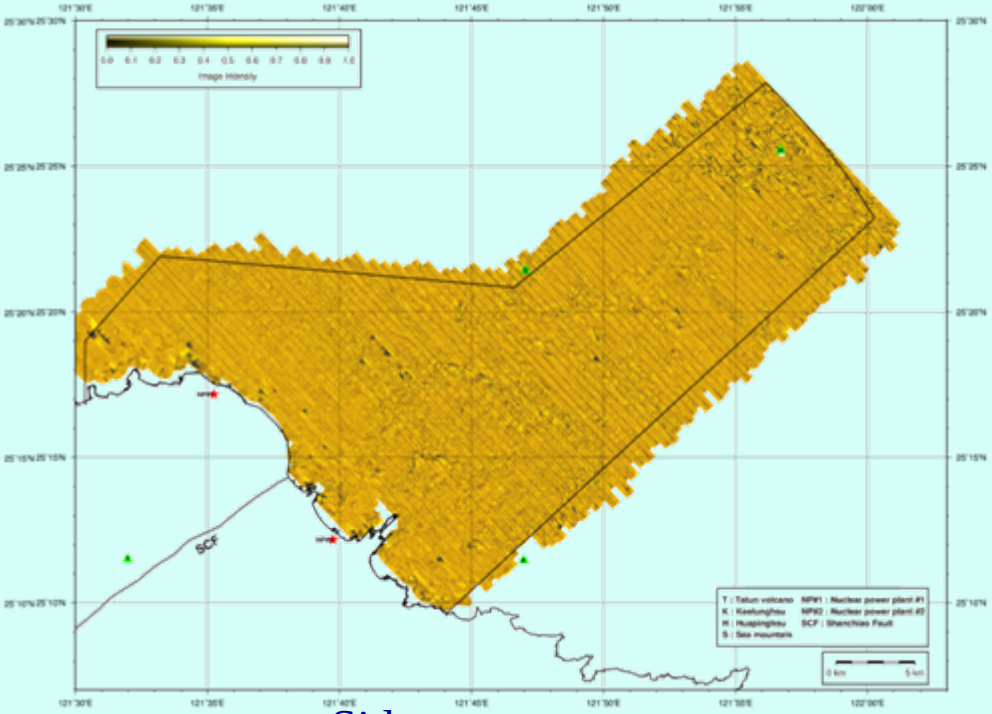
Survey results

- Marine survey between the Jinshan coastal and offshore area within a radius of 40 km
  - Multi-beam survey
  - Side-scan sonar survey
  - Multi-channel seismic reflection method
  - Sub-bottom profile method
  - Offshore magnetic survey





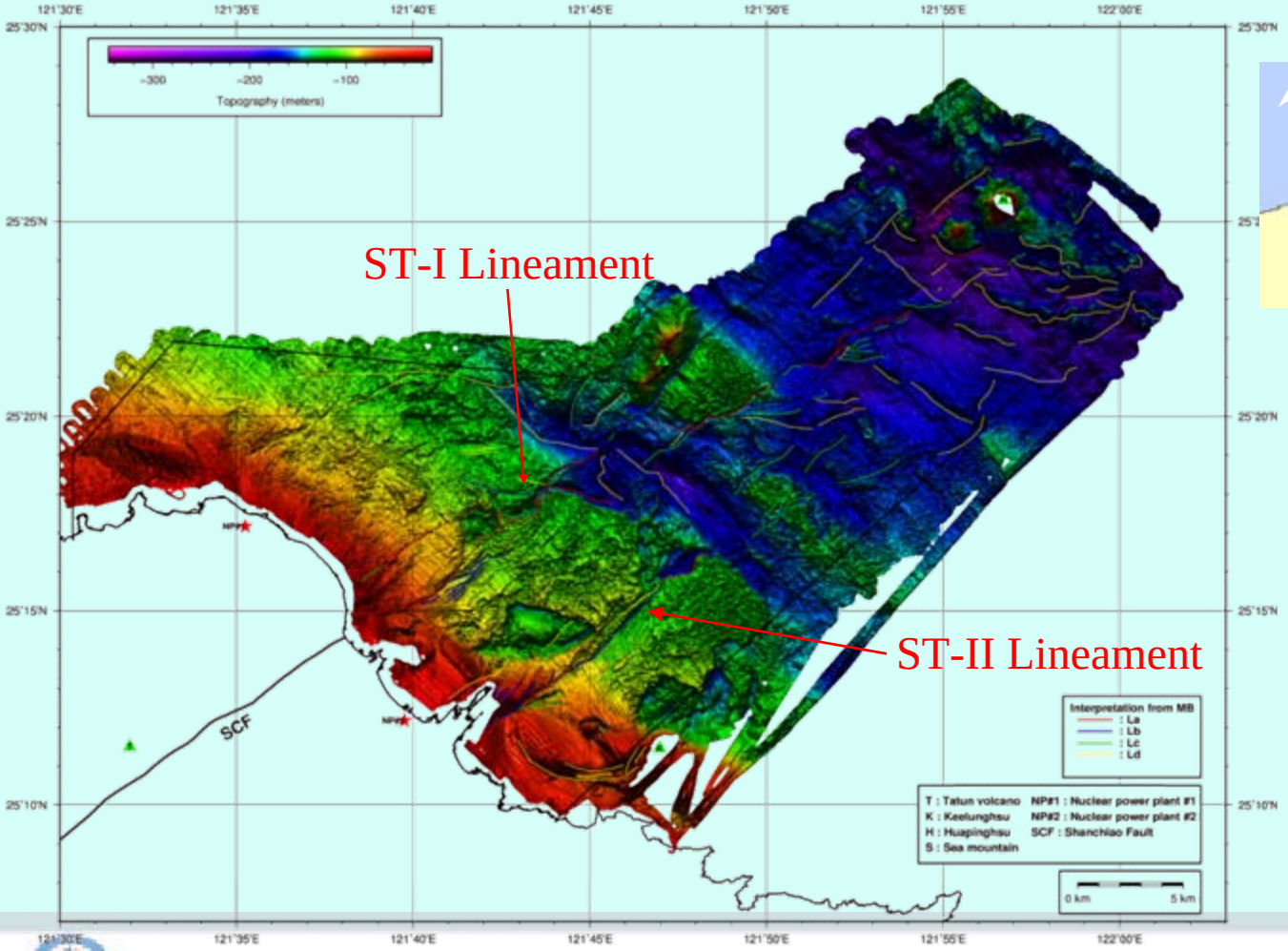
Multi beam survey

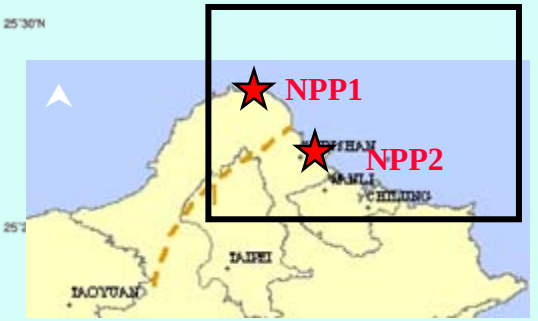


Side-scan sonar survey

Survey results

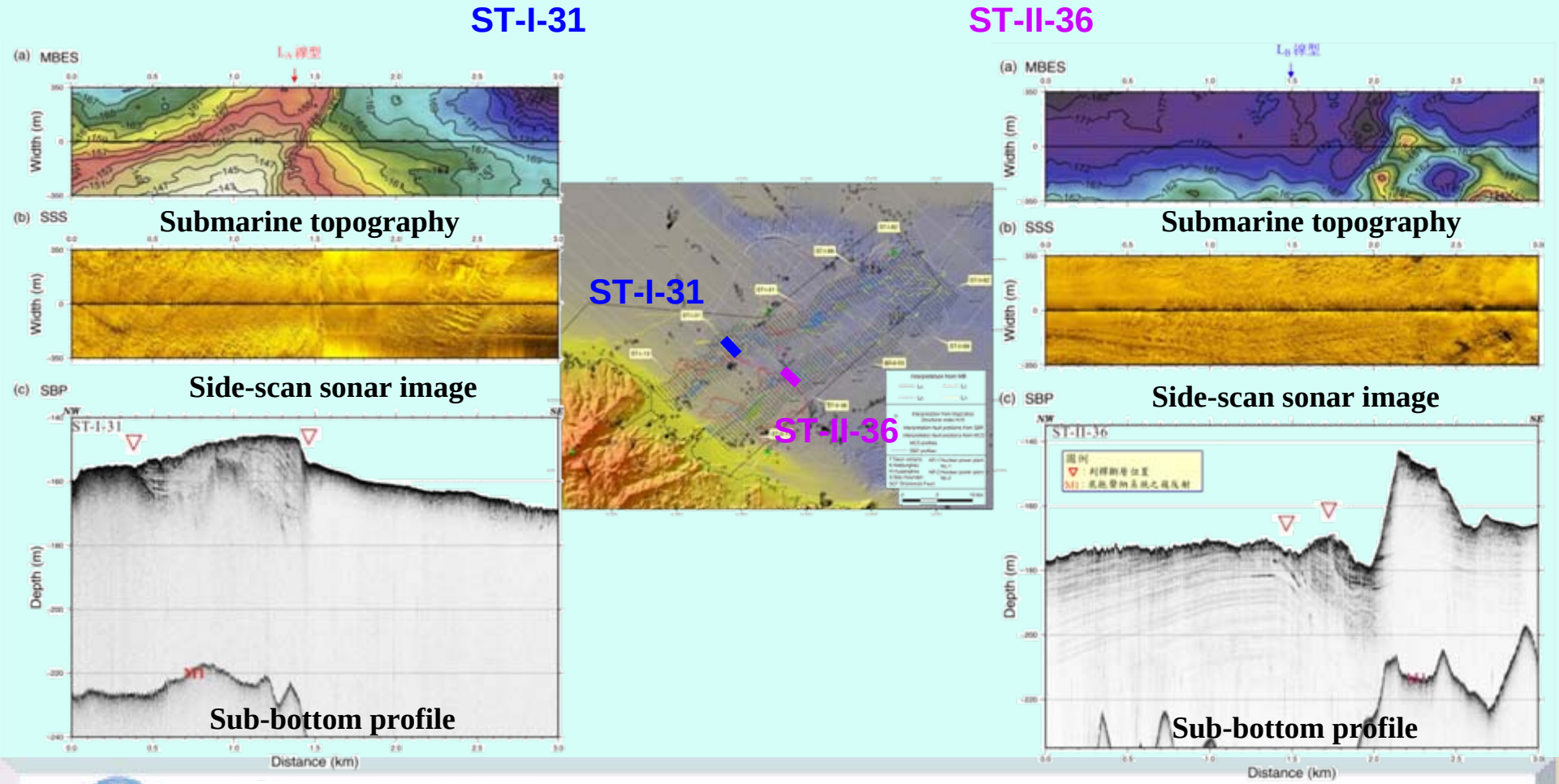
- Marine survey between the Jinshan coastal and offshore area within a radius of 40 km
  - Tectonic geomorphology analysis by DEM ascend from Multi-beam survey





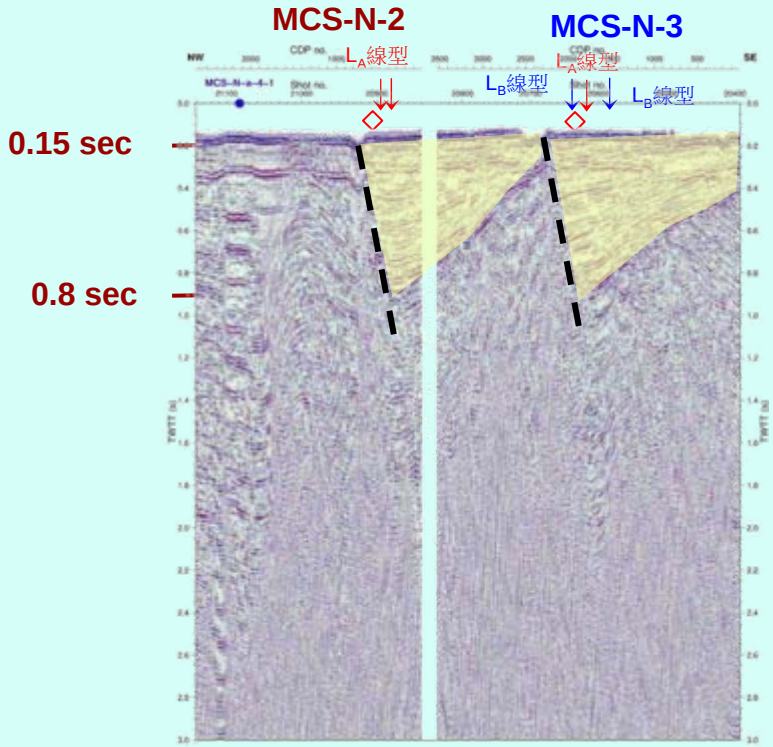
Survey results

- Marine survey between the Jinshan coastal and offshore area within a radius of 40 km
  - Analysis of lineaments

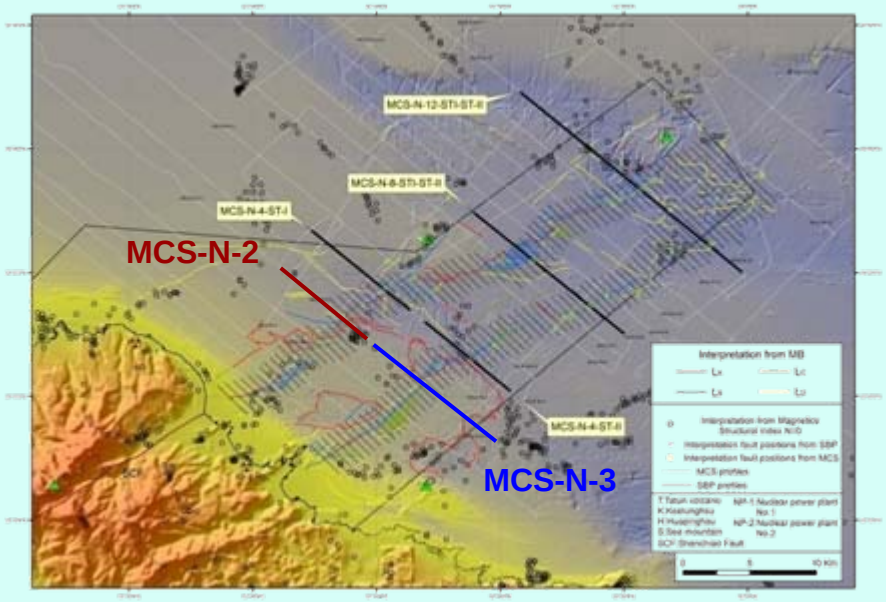


Survey results

- Marine survey between the Jinshan coastal and offshore area within a radius of 40 km
  - Analysis of lineaments
    - High-angle normal fault, dipping toward southeastern
    - Half-graben structure

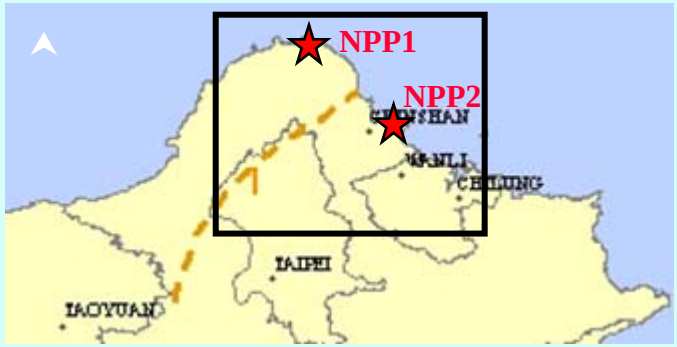


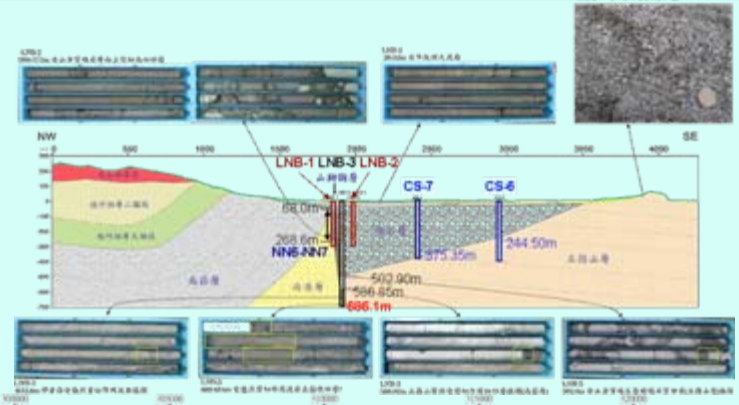
Multi-channel seismic reflection profile

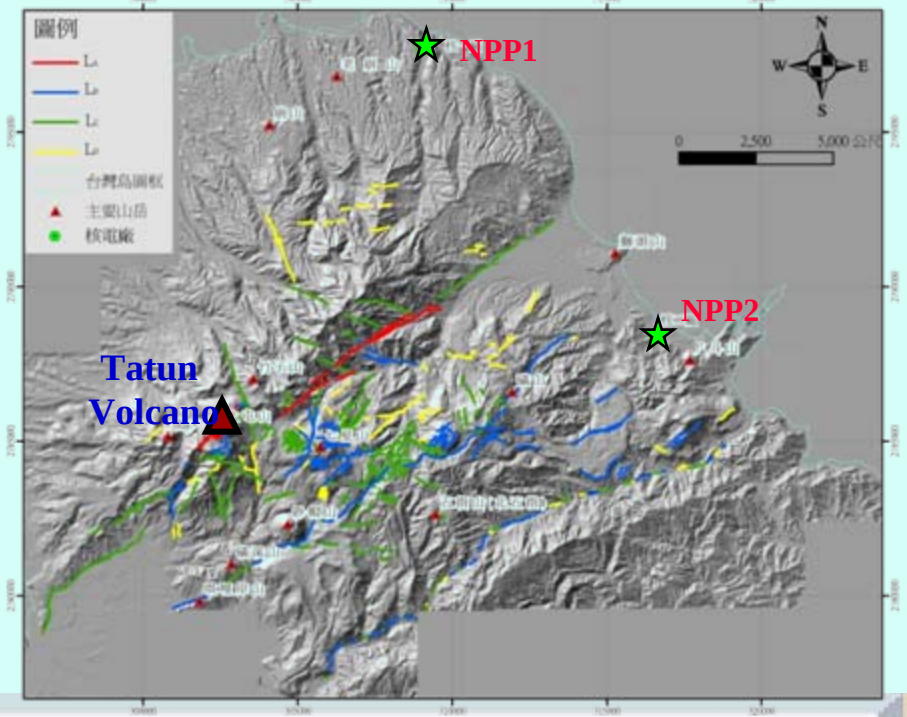


Summary

- Shanchiao Fault total length of at least 74 km
  - On landside
    - South part : length of 13 km
    - North part : length of 21 km
      - Tatun volcano group
        - Lineament obvious
      - Drilling at Jinshan area
        - Hanging wall subsidence
        - Dip separation about 518.85m
        - Dipping >82° to southeastern
        - Low activity since Holocene



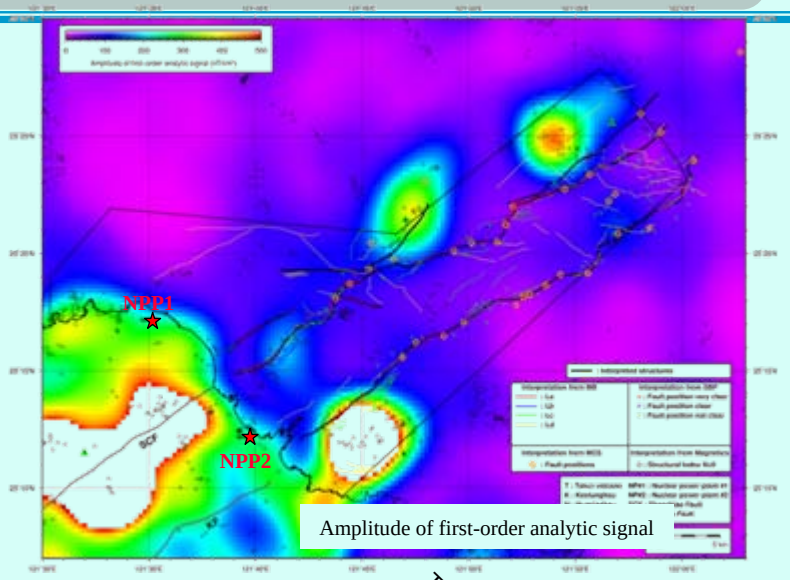


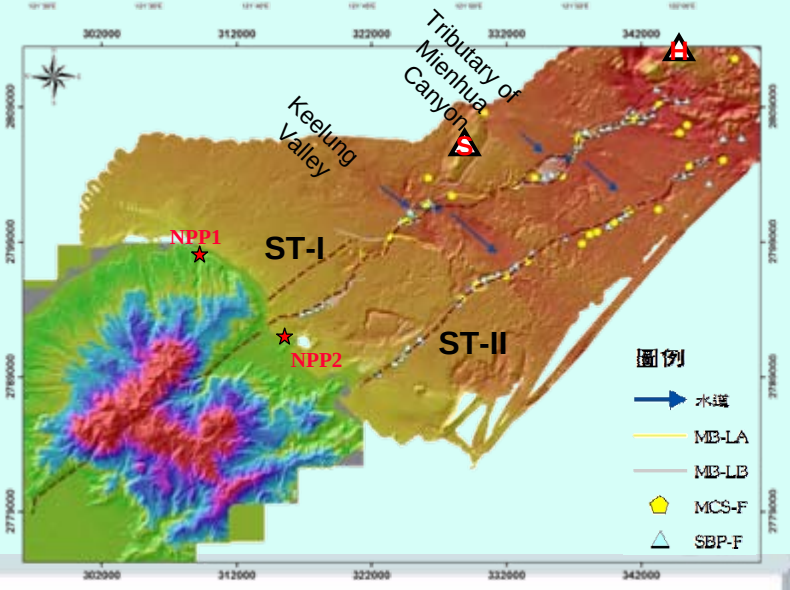


Summary

– Offshore area

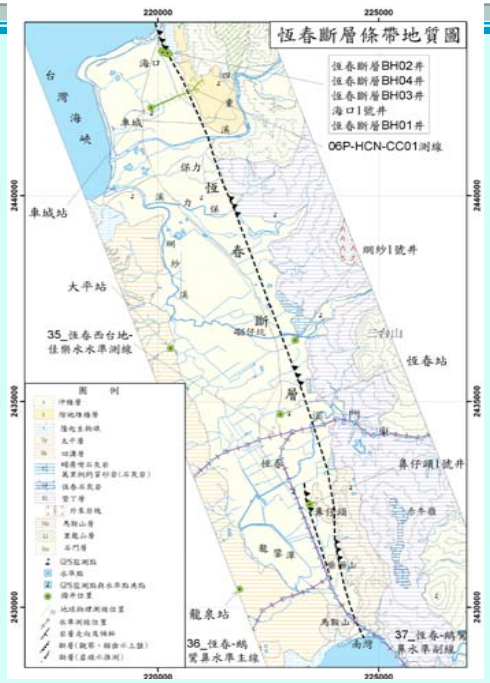
- Fault extension from land to the offshore length of at least 40km
- 2 sets of lineaments
  - ST-I
    - Normal with left-lateral fault
    - Half-graben structure
    - Extension from Shanchiao fault on land
  - ST-II
    - Normal fault
    - No corresponding normal fault on land

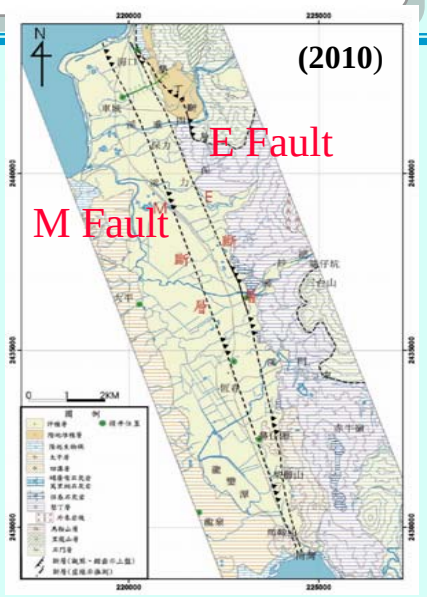




Hengchun Fault_Literature Review

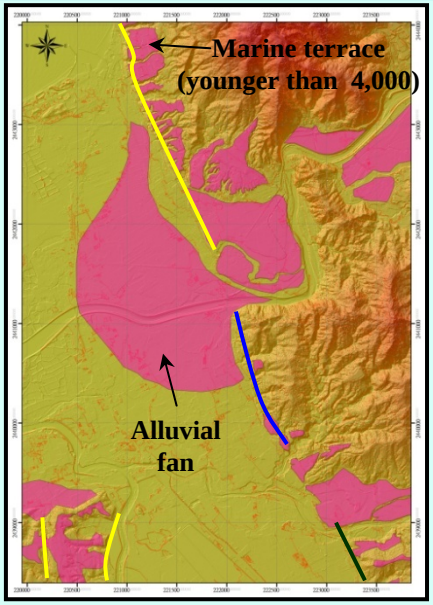
- Reverse Fault
  - Strike NNW
    - Total length about 16km
  - Vertical displacement of GPS between flanks of fault is unapparent
  - Topography in this area modified by 2006 Pingtung Earthquake Doublet
  - West Hengchun Platform is continuous tilting toward west
  - Recent activity about a ten thousand years ago
    - Late Pleistocene strata (reef platform or limestone) cut by Hengchun Fault

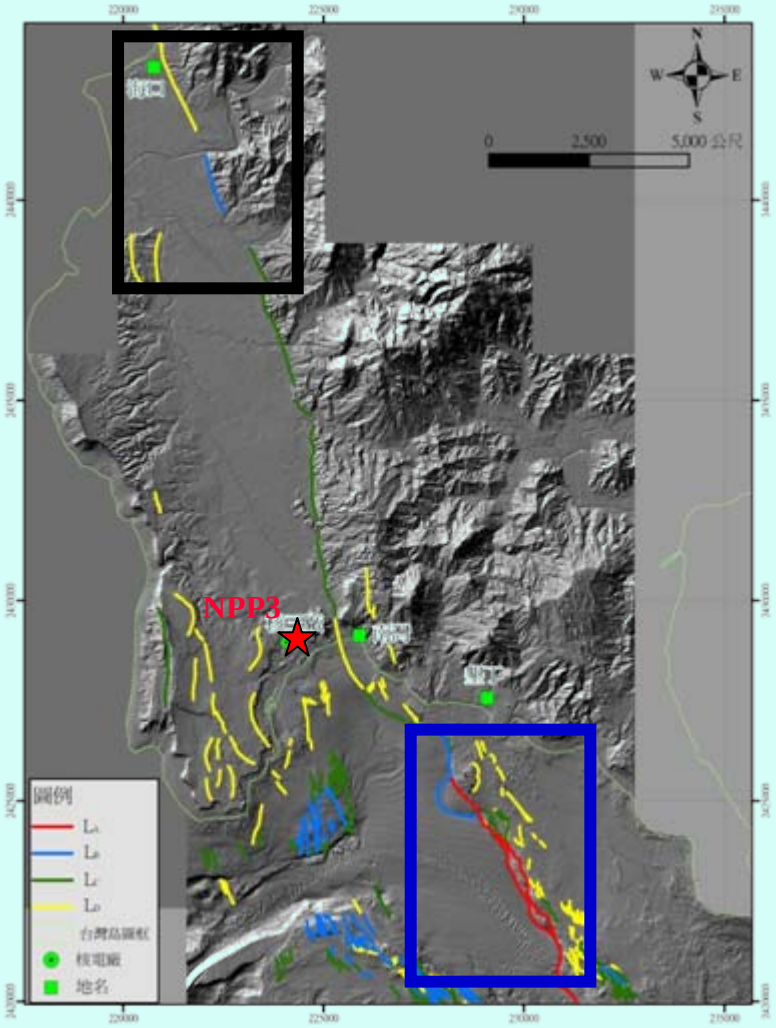




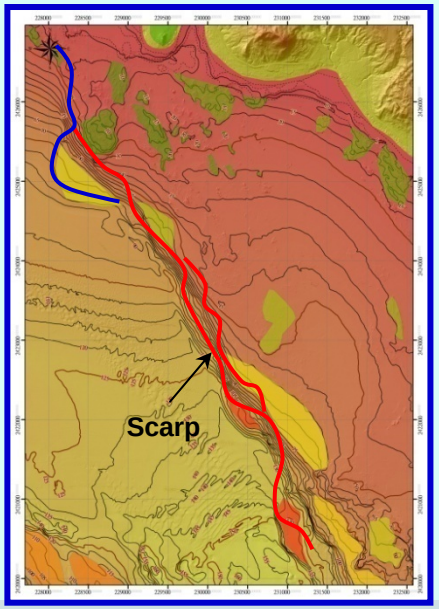
Refer to the Central Gelogical Survey, MOEA (2009)

Survey results





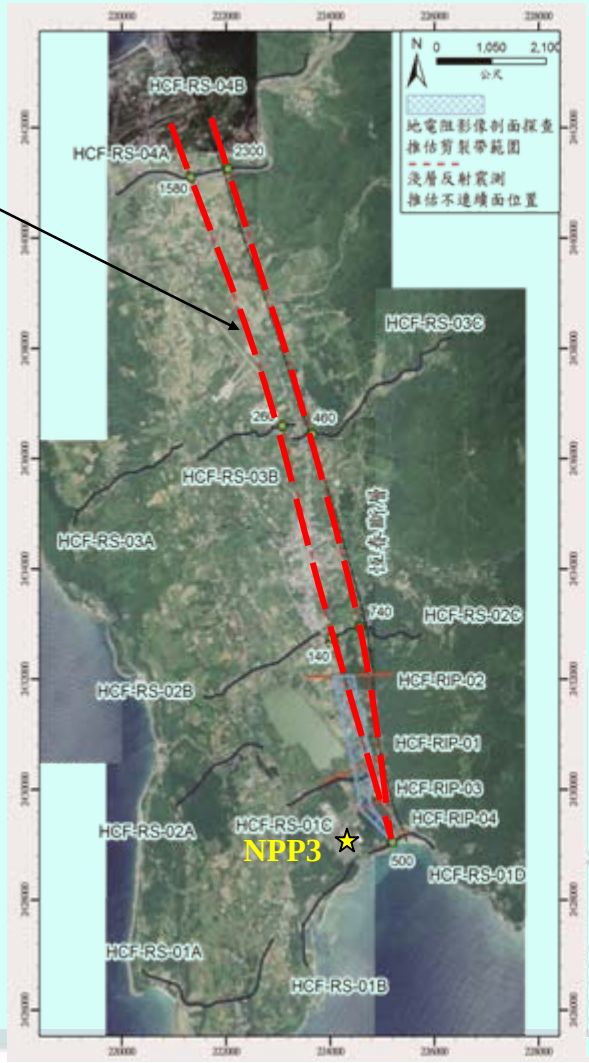
- Tectonic geomorphology analysis by DEM ascend from LiDAR survey
  - NNW-SSE trending lineaments unobvious

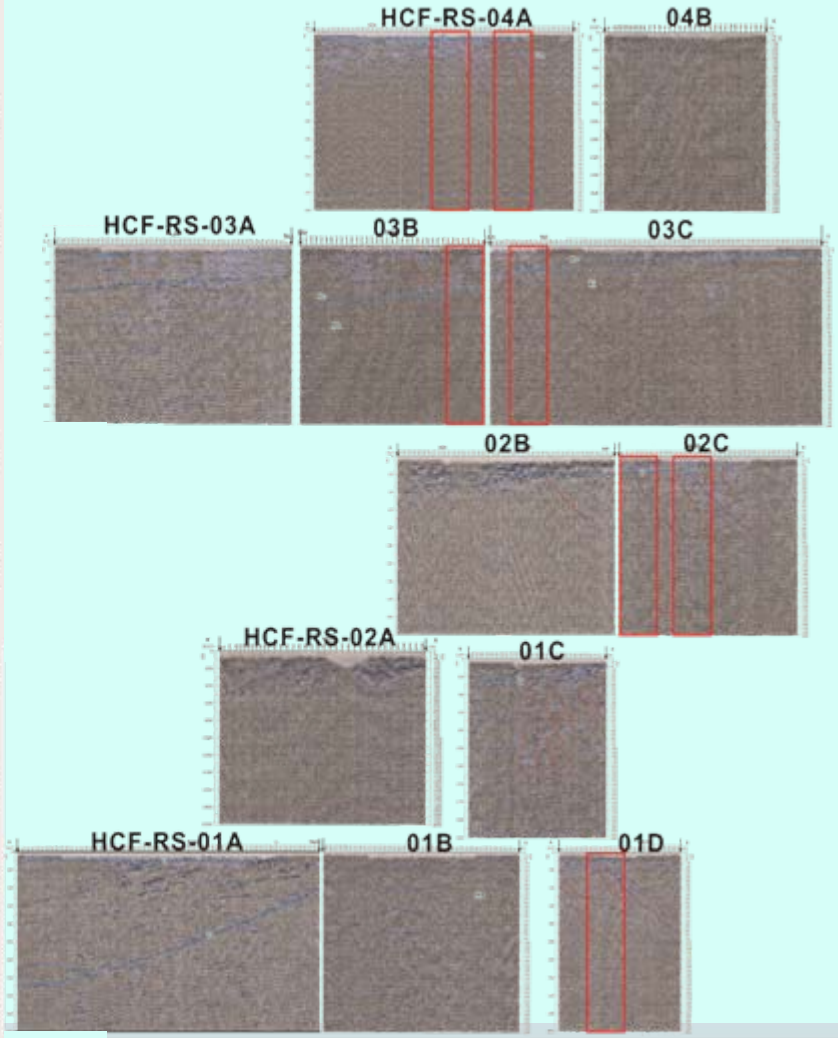


Survey results

- Seismic reflection method

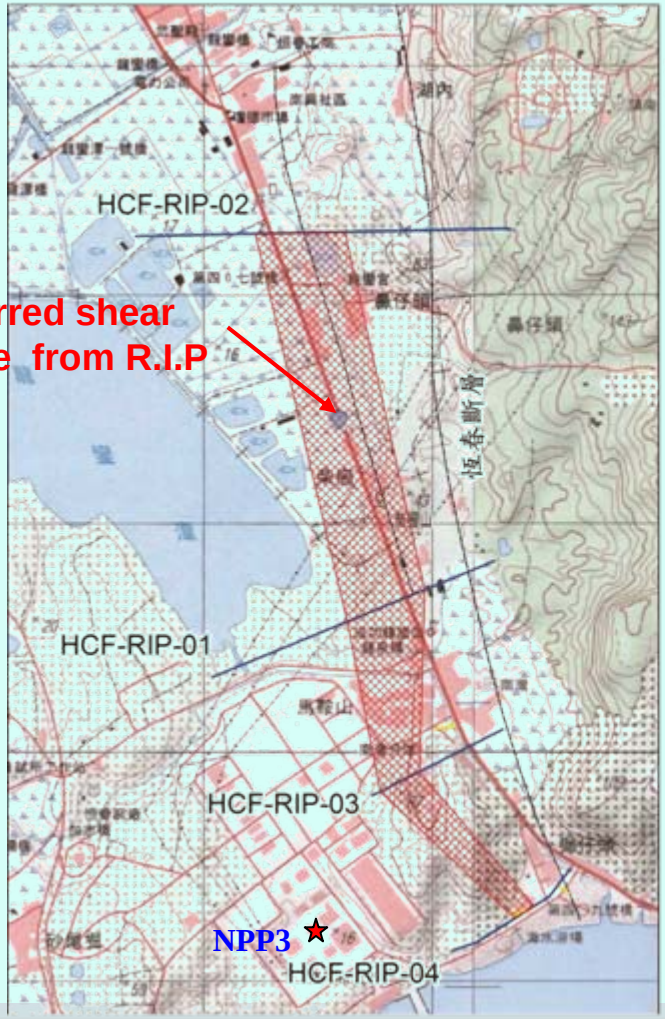
Inferred fault trace from Seismic reflection method

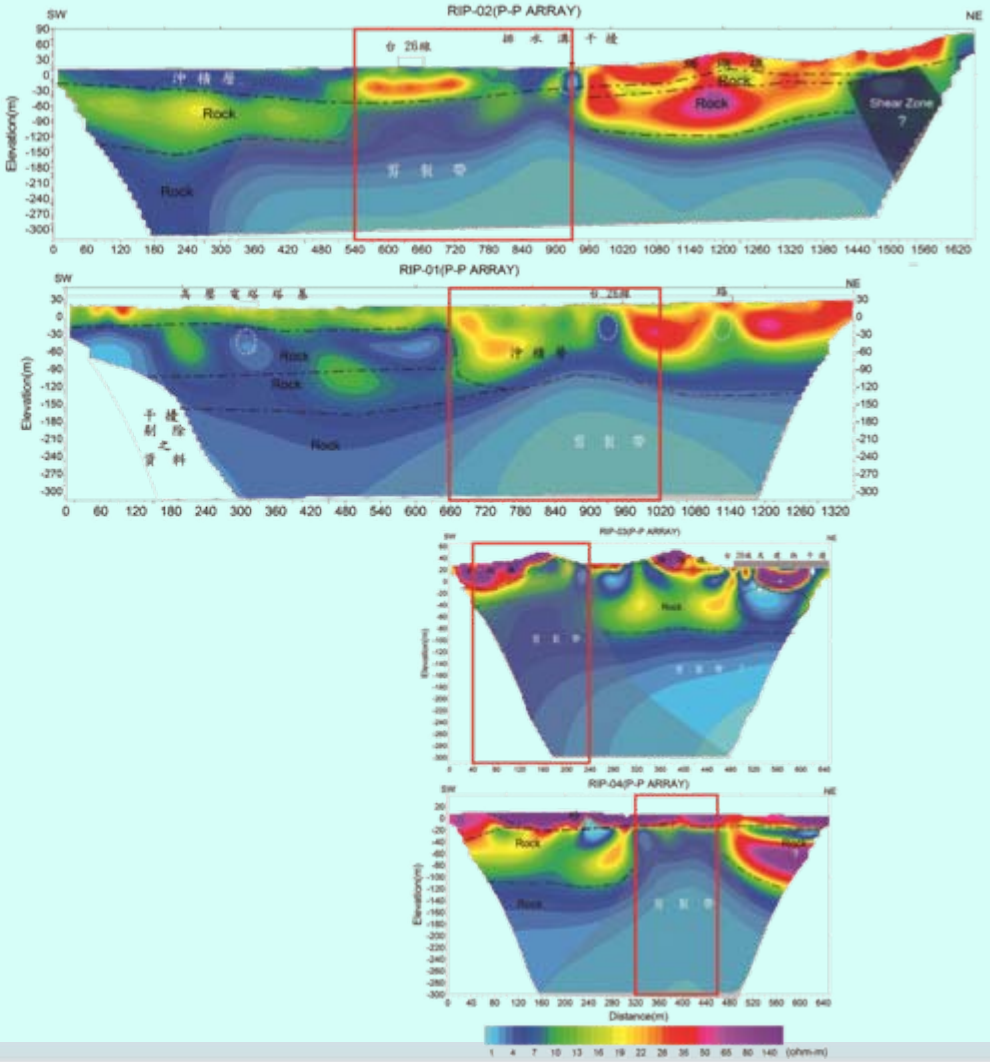




Survey results

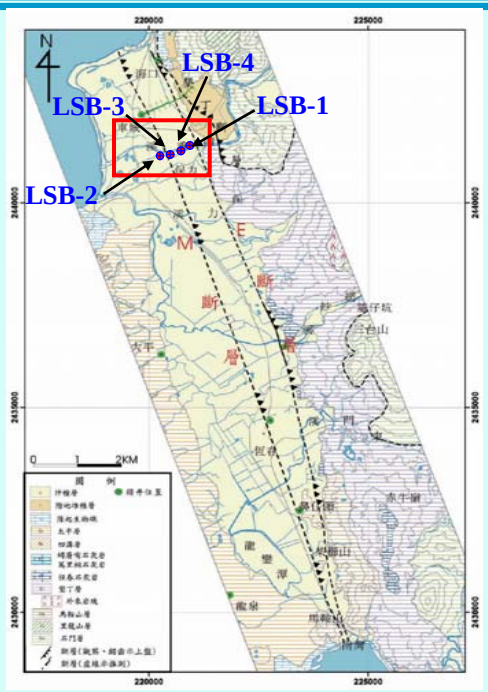
- Resistivity image profiling method

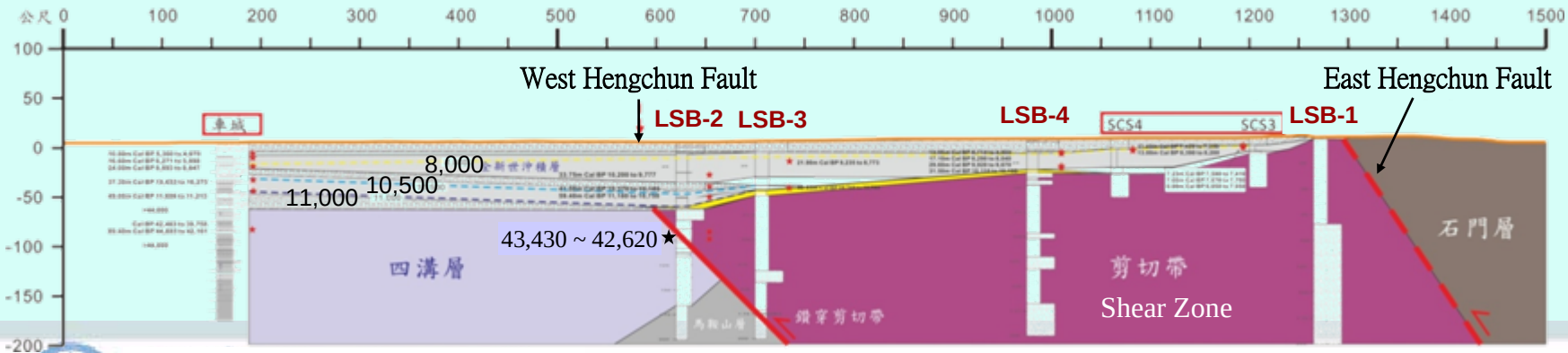




Survey results

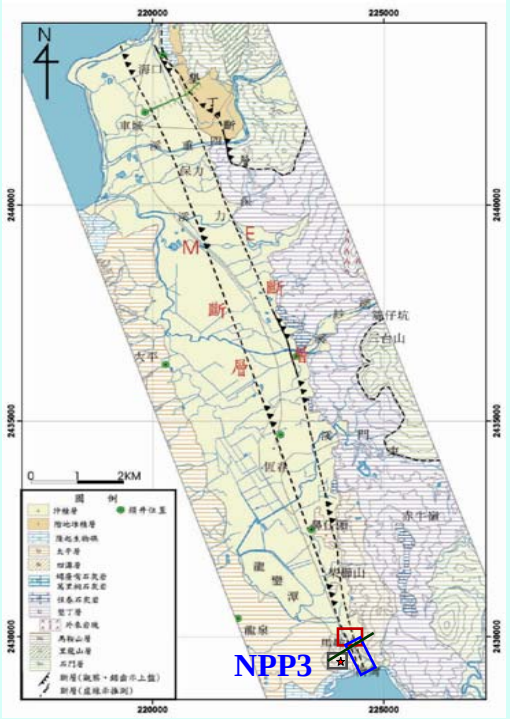
- North section (deep borehole drilling at the Sihjhong River area)
  - Recent activity older than 10,000 years ago (Holocene)
    - Holocene deposits no deformed or cut by Hengchun Fault
  - West Hengchun Fault
    - Fault plane found in depth of about 88.1m at borehole LSB-2
    - Recent activity younger than 42,000 years ago
      - ^{14}C dating result of depth of 96.25m at LSB-2
        - 43,430 ~ 42,620 Cal BP
  - East Hengchun Fault
    - Recent activity younger than 4,000 years ago
      - Dating result of reef terrace on the piedmont
        - approximately 4,000 years ago

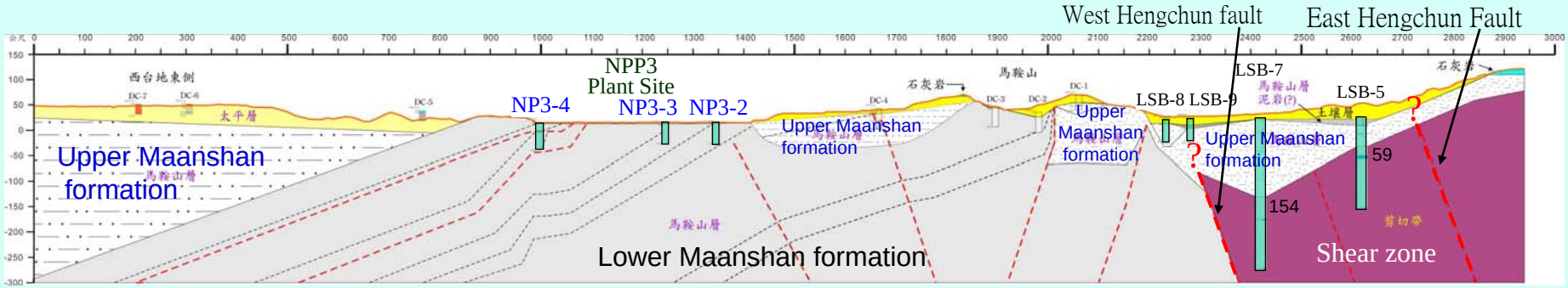




Survey results

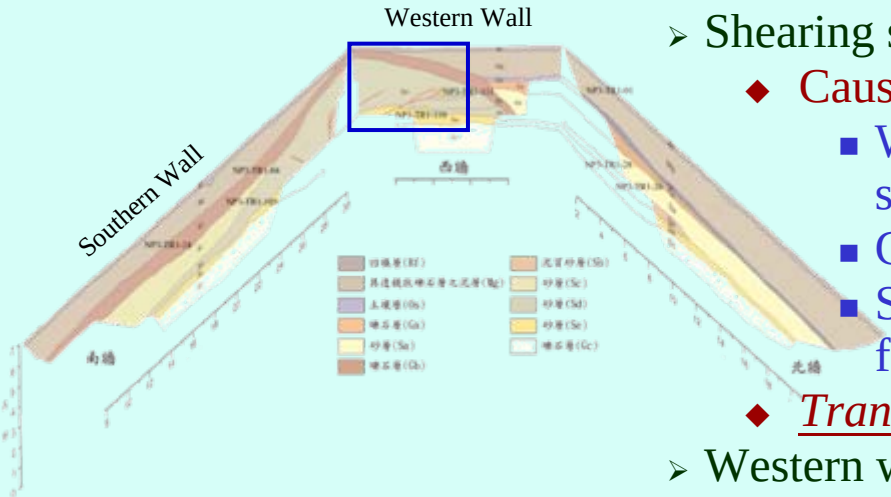
- South section (deep and shallow borehole drilling at the Nanwan area)
  - Recent activity older than 10,000 years ago (Holocene)
    - Holocene deposits no deformed or cut by Hengchun Fault
  - Hengchun Fault Zone
    - Recent activity younger than 46,500 years ago
      - ^{14}C dating result of depth of 21.8m at LSB-5
        - 46,500-44,400Cal BP
  - Recent activity between 10,000 and 40,000 years ago

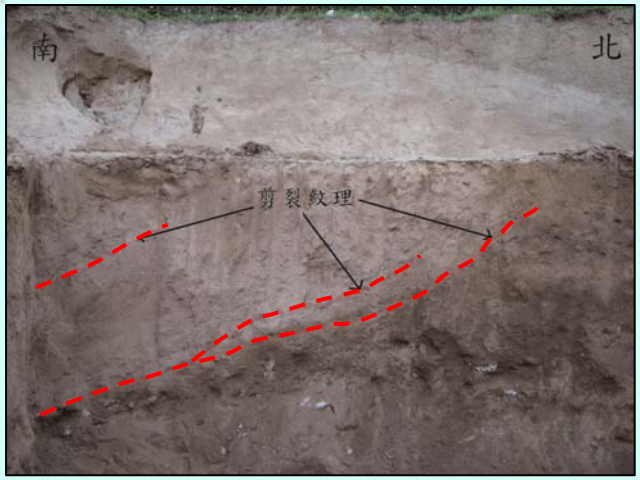




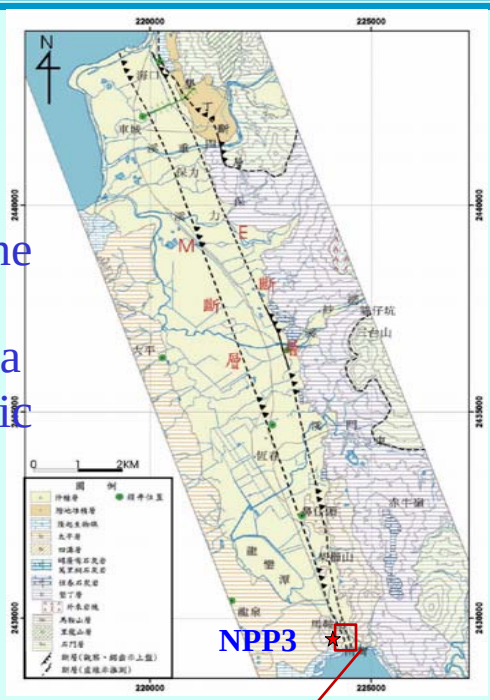
Survey results

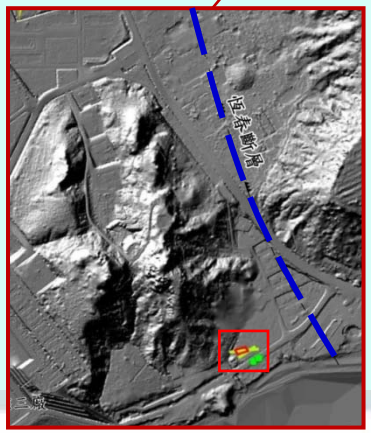
- South section (at the NPP3 site area)
  - Trench excavation



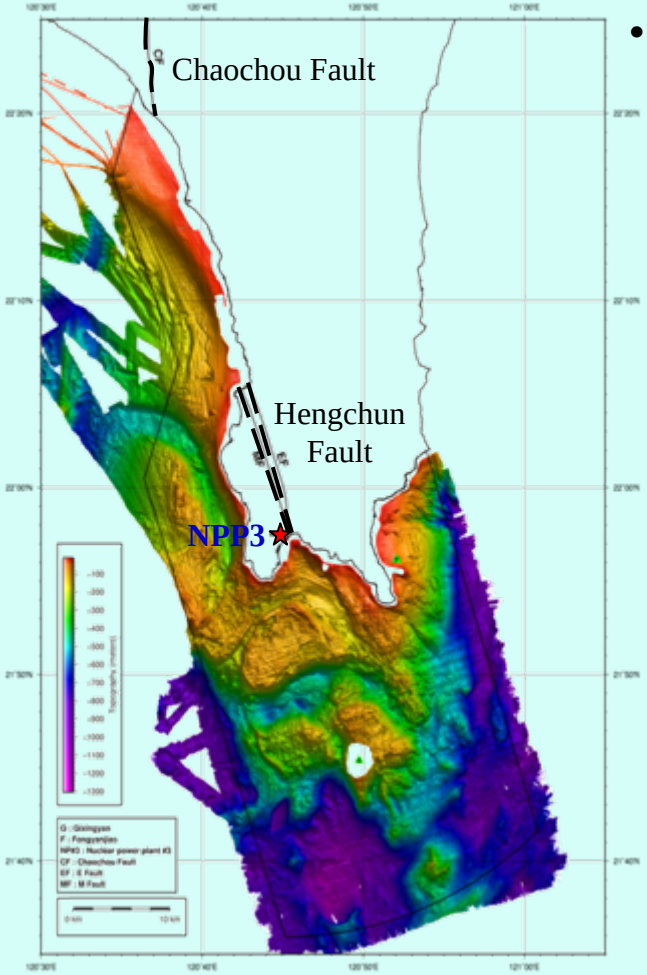


- Shearing structure found
  - Caused by reverse faulting
    - West southern corner of the strata is uplifted
    - Cuts through horizontal strata
    - Stretching bioclastic fragments remains
  - *Transverse flower structure*
- Western wall of excavated trench
  - A set of shearing structure
    - Shear plane angle 40~50°
- Southern wall of excavated trench
  - 2 sets of shearing structure
    - Shear plane angle 40~50° 45° and 80~90°
- Major shearing texture
  - Attitude N70°W/52°S
  - Recent activity
    - Older than 1530-1380 Cal BP



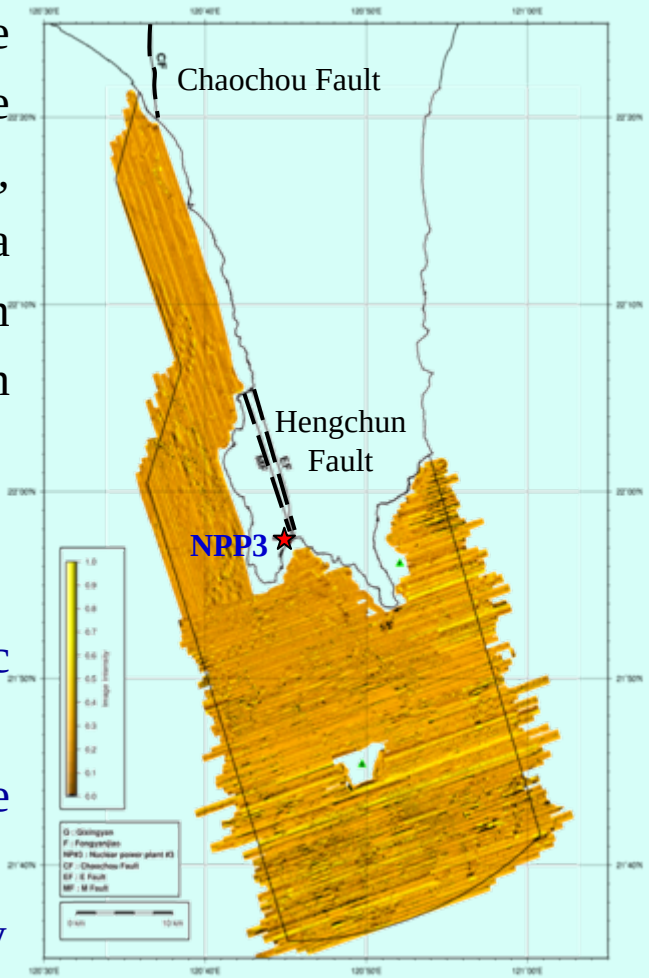


Survey results



Multi beam survey

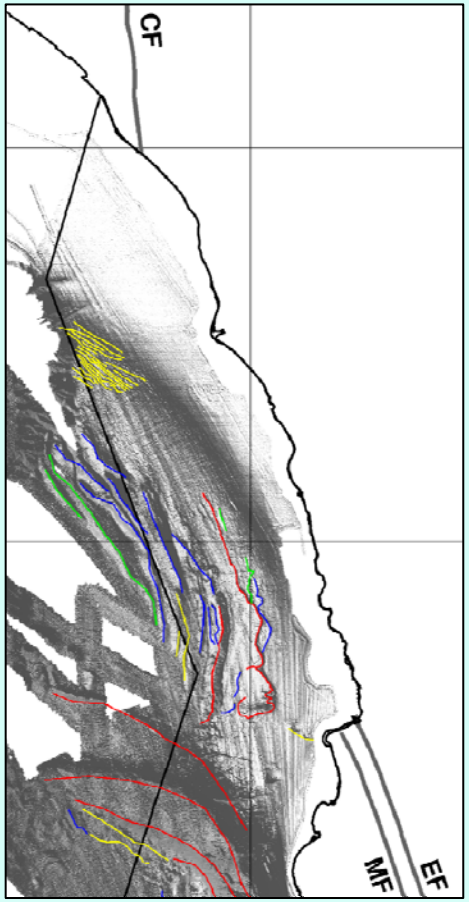
- Marine survey between the Nanwan coastal and offshore area within a radius of 40 km, and the offshore area in a direction extending between Chaochou Fault and Hengchun Fault
  - Multi-beam survey
  - Side-scan sonar survey
  - Multi-channel seismic reflection method
  - Sub-bottom profile method
  - Offshore magnetic survey

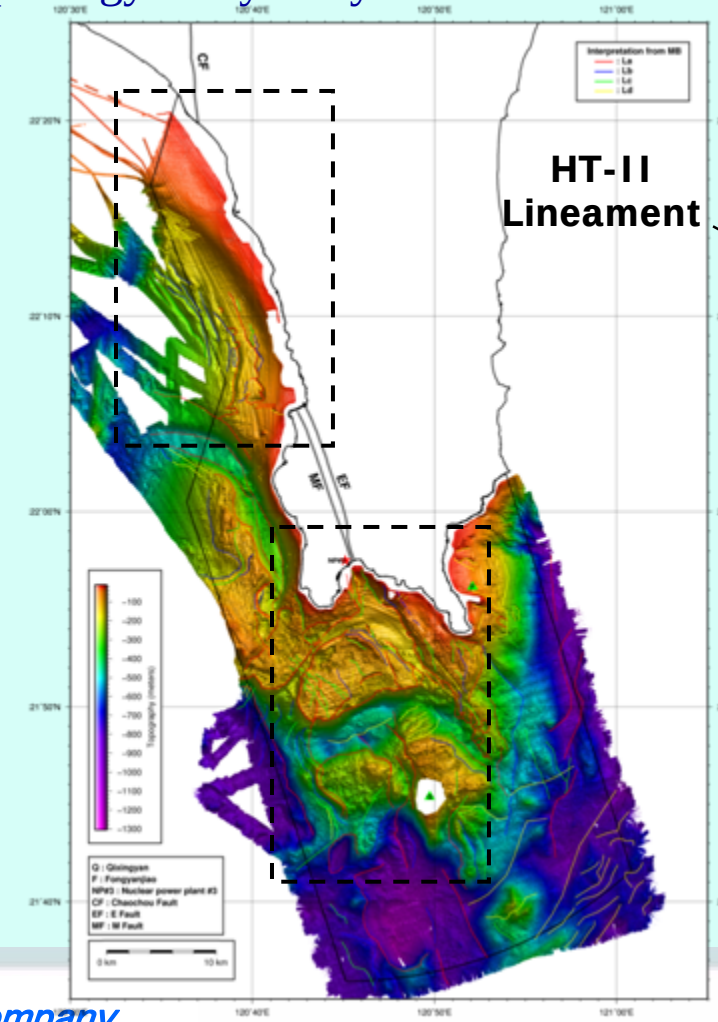


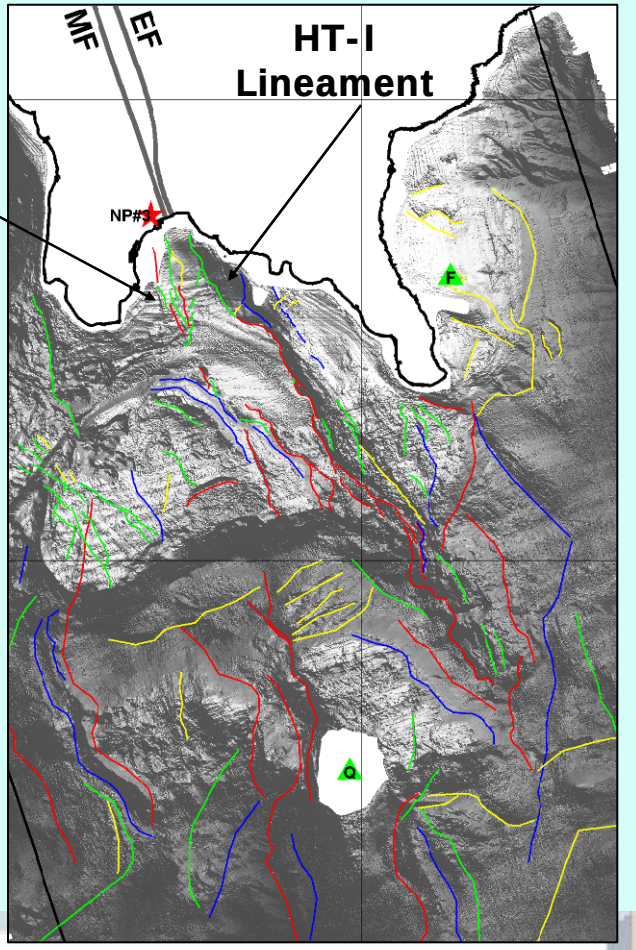
Side-scan sonar survey

Survey results

- Marine survey between the Nanwan coastal and offshore area within a radius of 40 km, and the offshore area in a direction extending between Chaochou Fault and Hengchun Fault
  - Tectonic geomorphology analysis by DEM ascend from Multi-beam survey

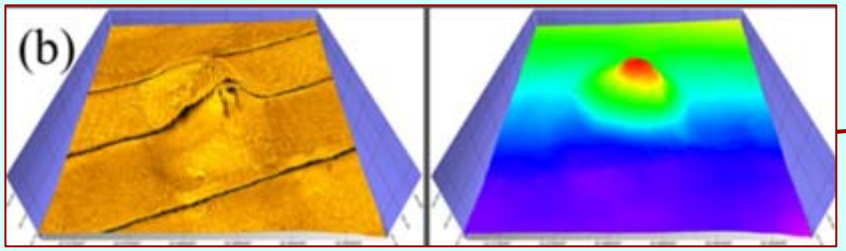






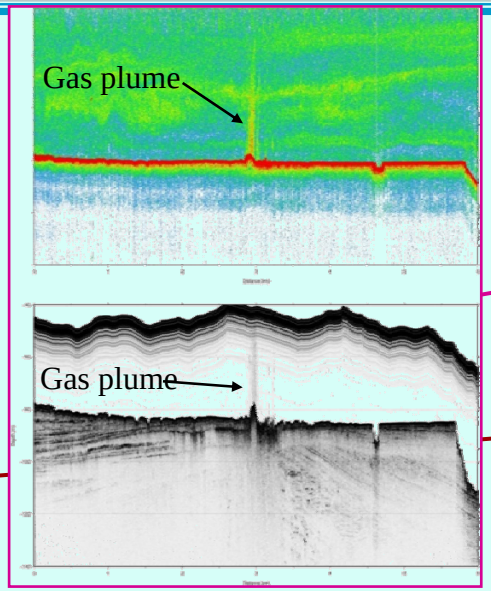
Survey results

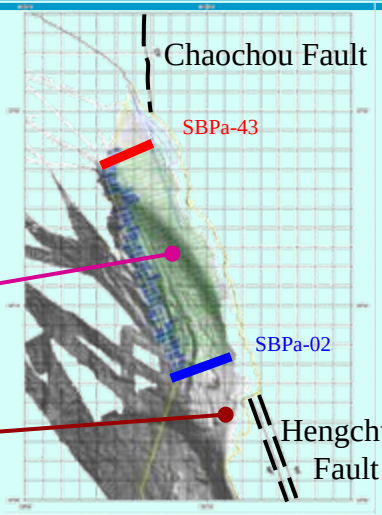
- On the offshore area in a direction extending between Chaochou Fault and Hengchun Fault
  - No obvious shear or fault track found
  - Gas plume found
  - Mud volcano found

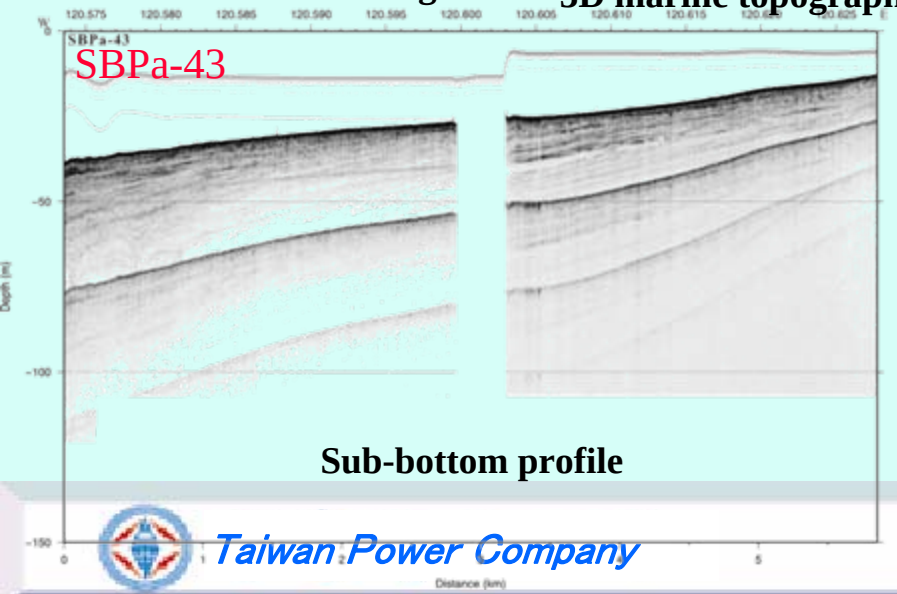


3D Side-scan image

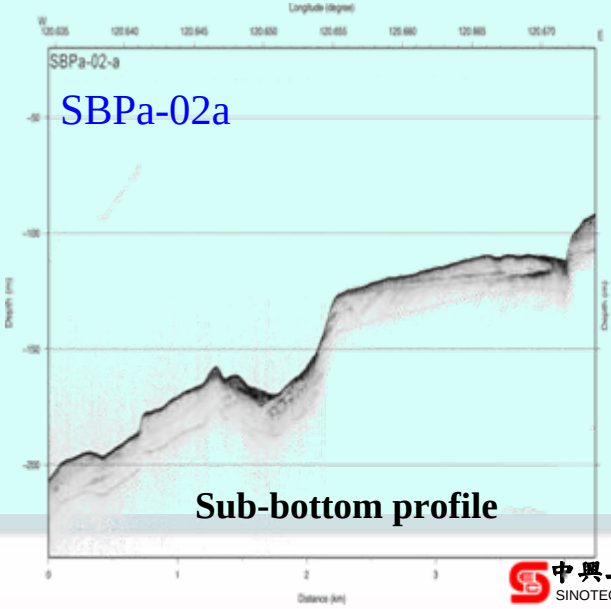
3D marine topography

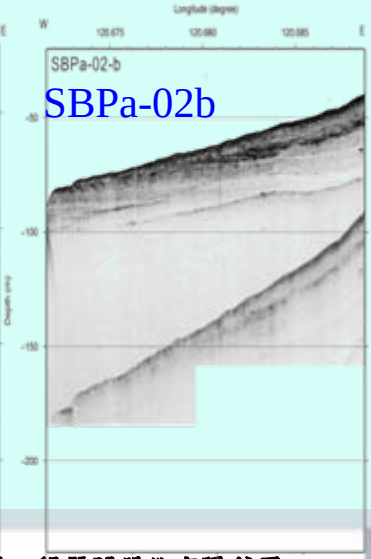






Sub-bottom profile

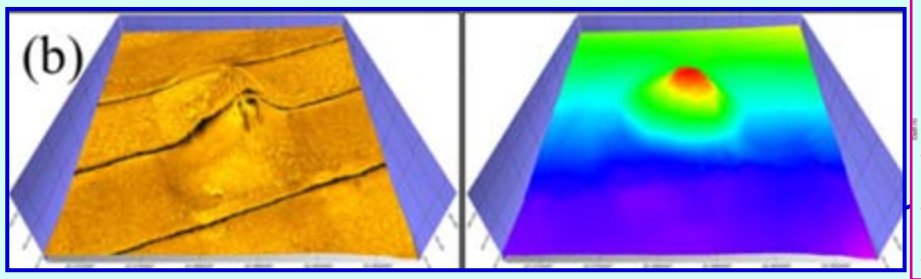




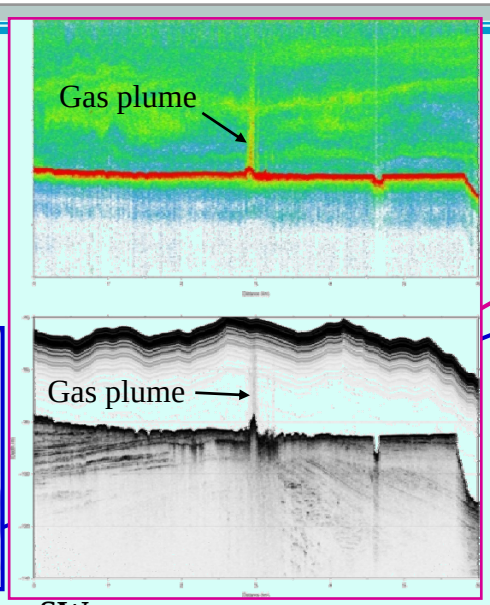
Sub-bottom profile

Survey results

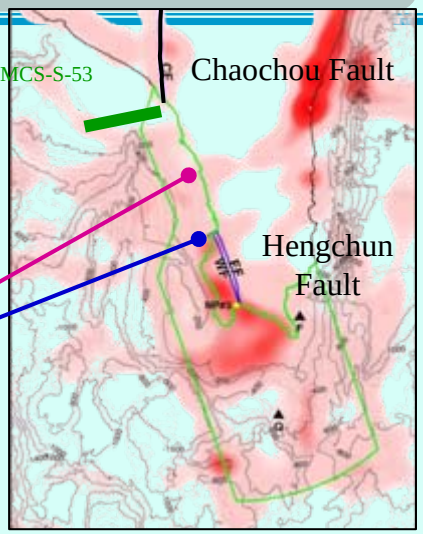
- On the offshore area in a direction extending between Chaochou Fault and Hengchun Fault
  - No obvious shear or fault found
  - Mud diapir found



3D Side-scan image　　3D marine topography

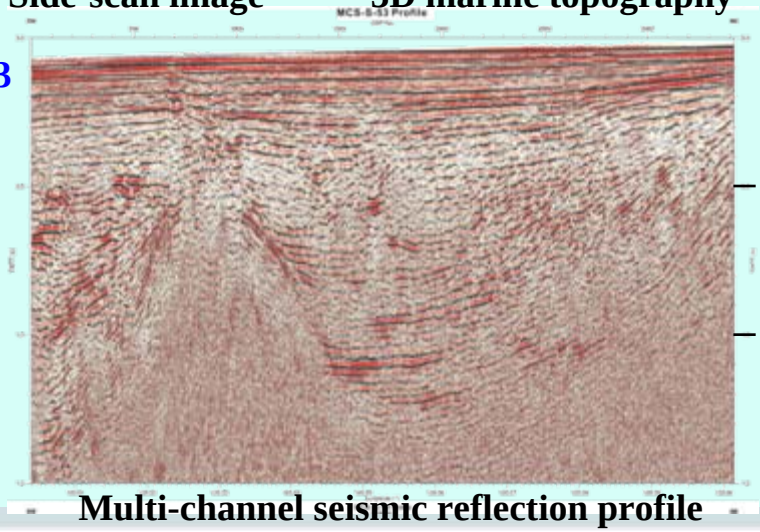


SW　　NE

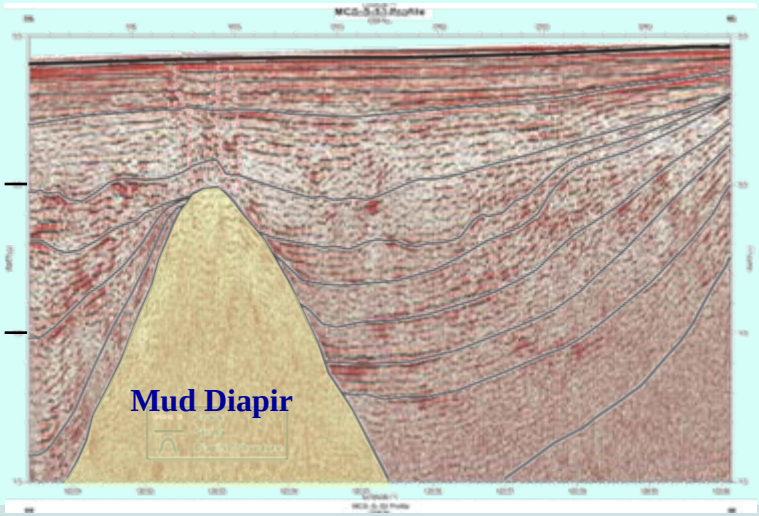


Amplitude of first-order analytic signal

MCS-S-53

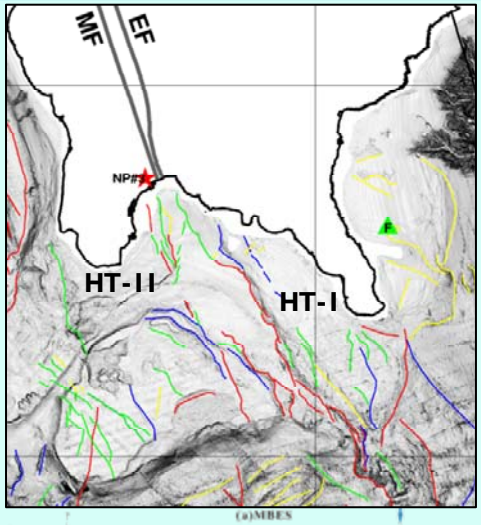


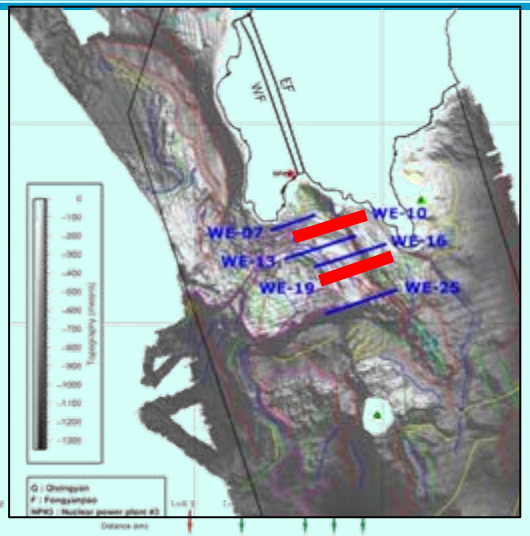
Multi-channel seismic reflection profile

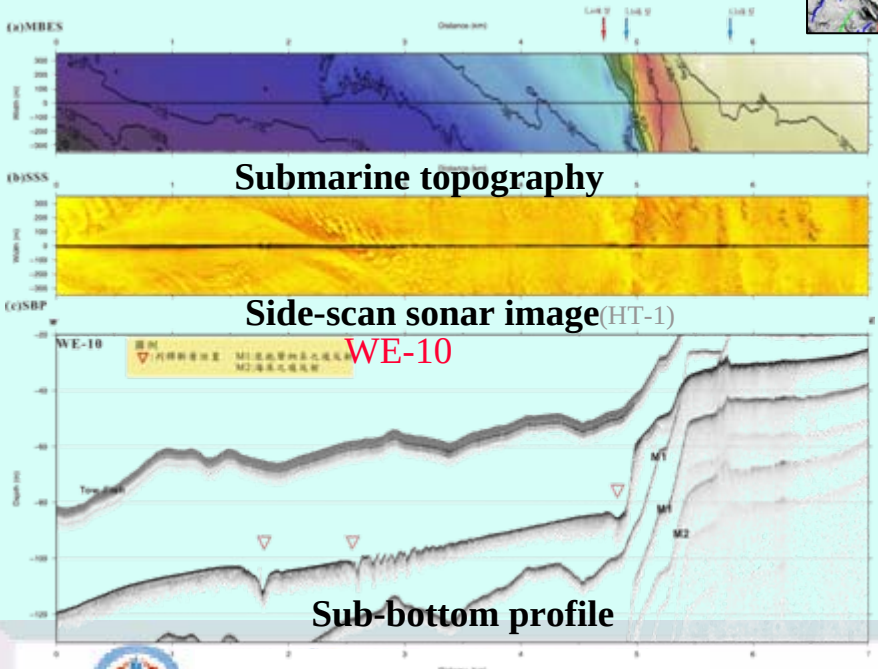


Survey results

- Marine survey between the Nanwan coastal and offshore area within a radius of 40 km





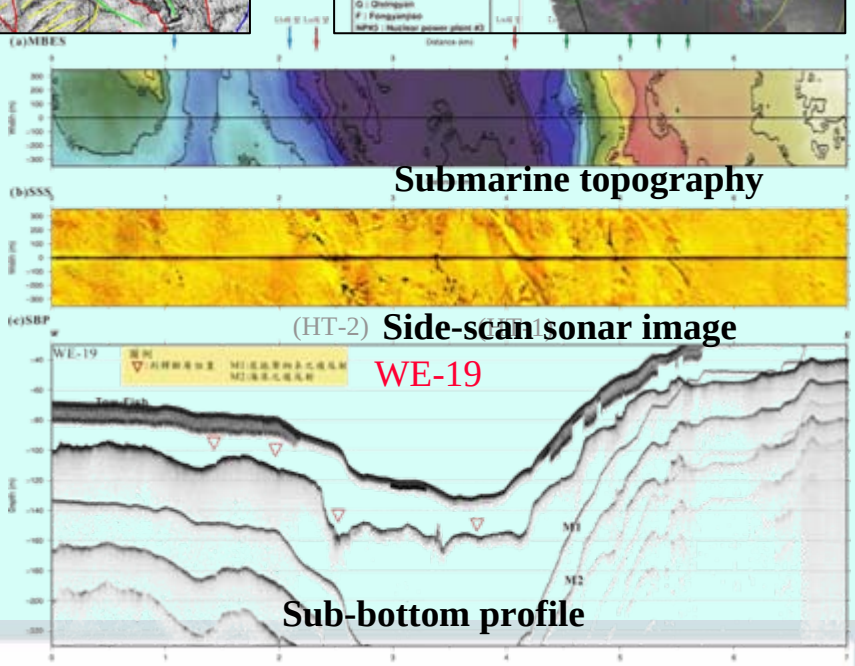


Submarine topography

Side-scan sonar image (HT-1)

WE-10

Sub-bottom profile



Submarine topography

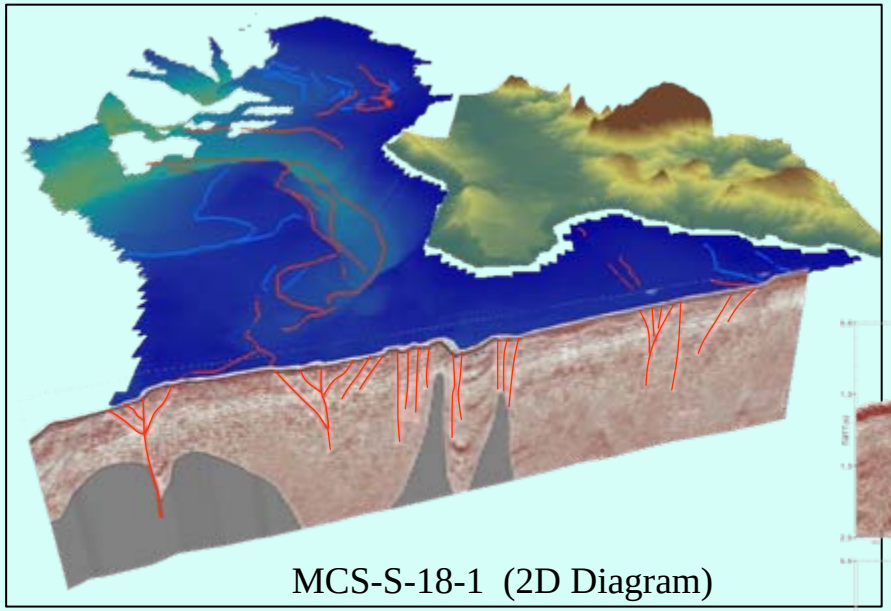
(HT-2) Side-scan sonar image

WE-19

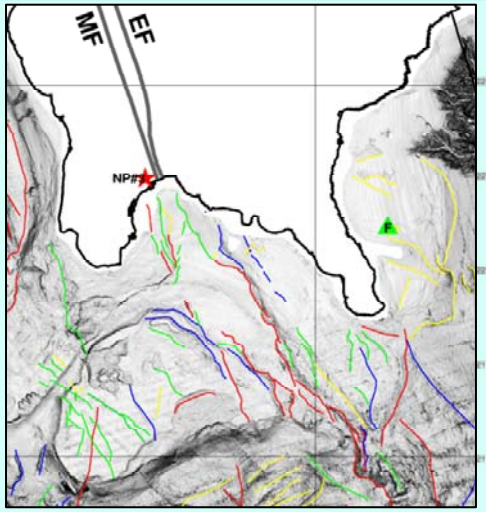
Sub-bottom profile

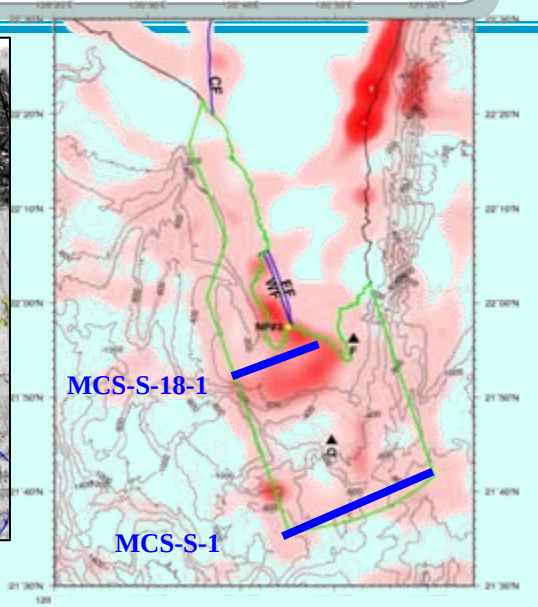
Survey results

- Marine survey between the Nanwan coastal and offshore area within a radius of 40 km

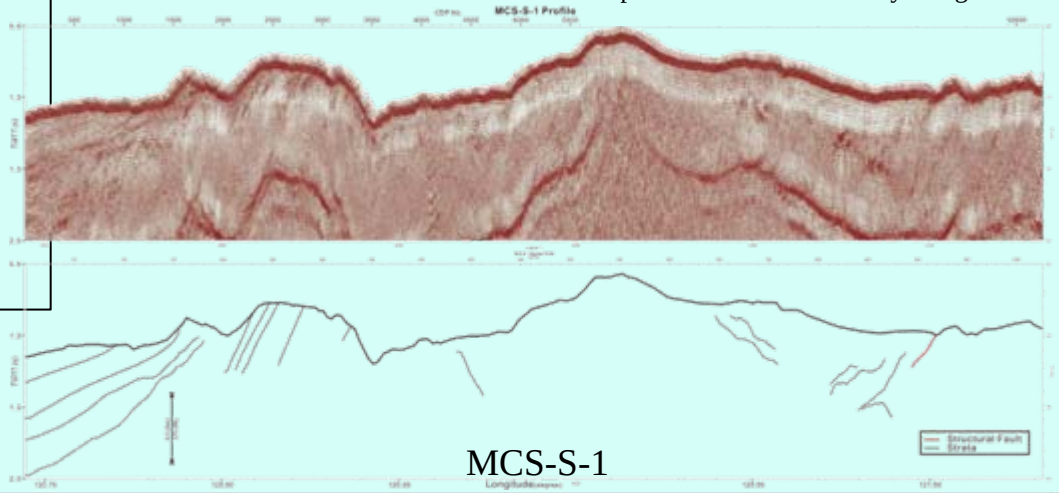


MCS-S-18-1 (2D Diagram)





Amplitude of first-order analytic signal

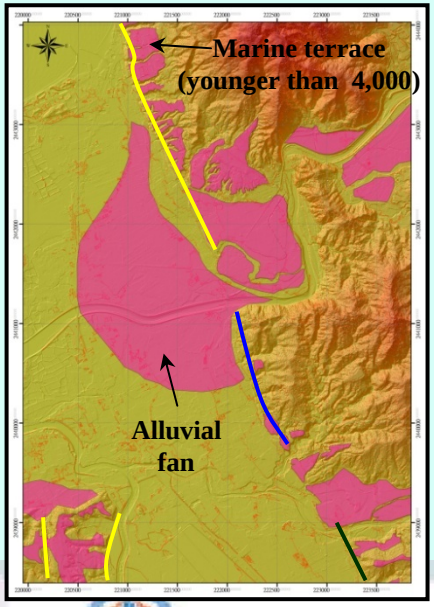


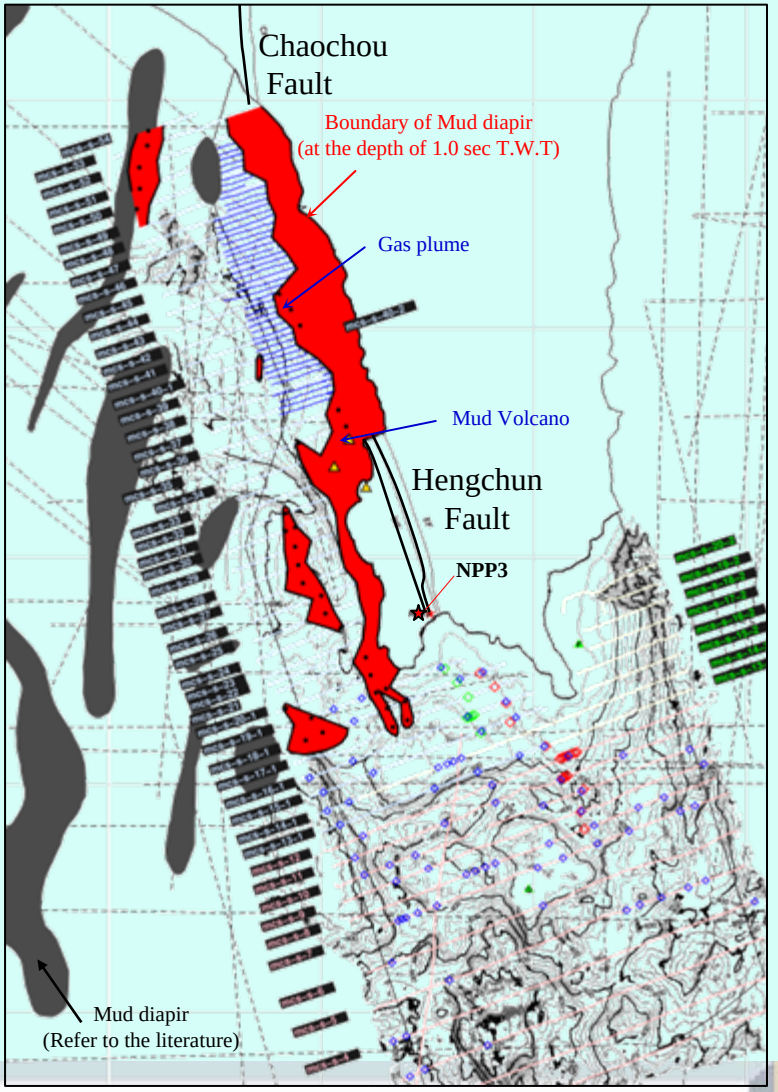
Multi-channel seismic reflection profile

MCS-S-1

Summary

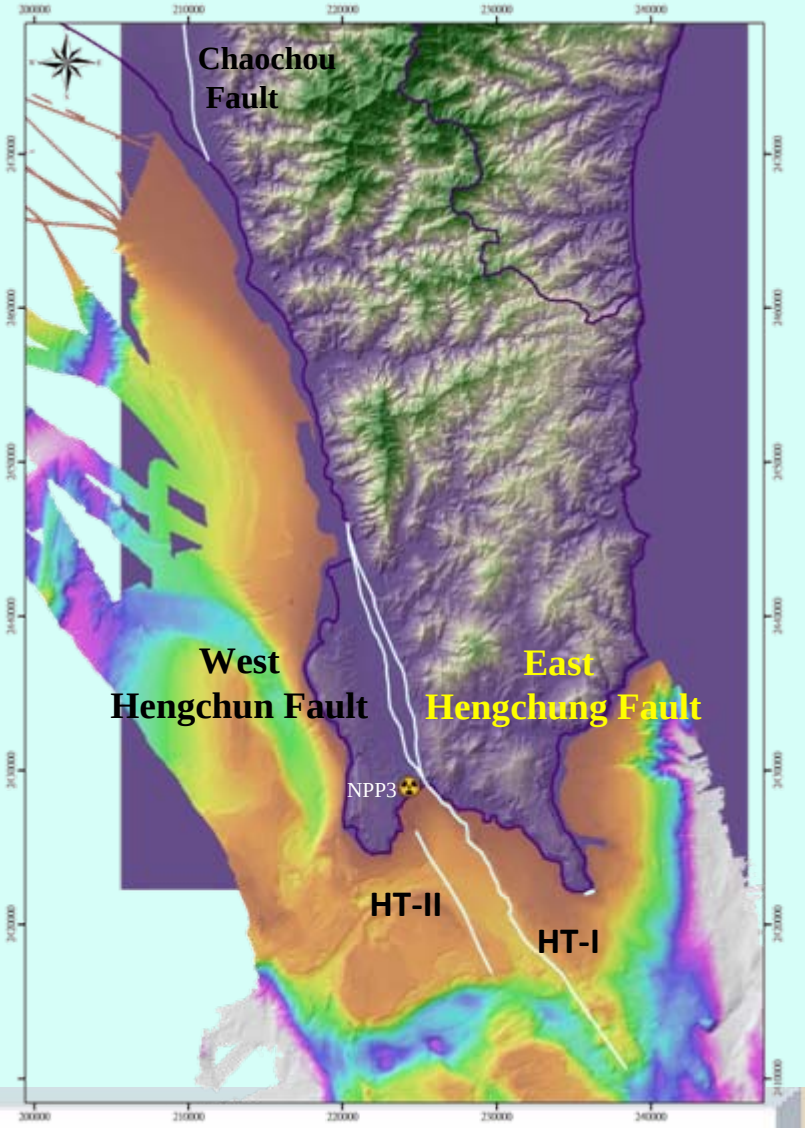
- On offshore area in a direction extending between Chaochou Fault and Hengchun Fault
  - No obvious shear or fault track found
  - Gas plume found
  - Mud volcano and mud diapir found
- Hengchun Fault total length of 41km
  - The coastal area of northern Hengchun Valley
    - Length of about 2 km
      - Marine terrace found along the western piedmont
      - Younger than 4,000 years ago
      - Activity of Hengchun Fault still continued on the north part of Hengchun Valley





Summary

- On landside (Hengchun Valley)
  - Fault zone width of about 200-1,000m
  - Total length of 16 km in the valley area
    - East Hengchun fault
      - Recent activity younger than 4,000 years ago
    - West Hengchun fault
      - Recent activity between 10,000 and 40,000 years ago
- On offshore area between the Nanwan coastal and offshore area within a radius of 40 km
  - Fault track length of about 23km
  - 2 sets of major lineaments
    - HT-I lineament
      - Extension from Hengchun Fault on land
      - Length of 23 km
    - The HT-II lineament
      - Length of 12 Km
      - No corresponding fault on land

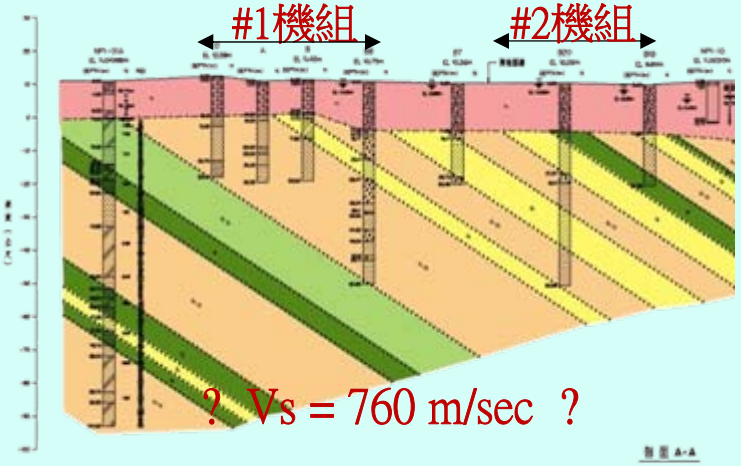


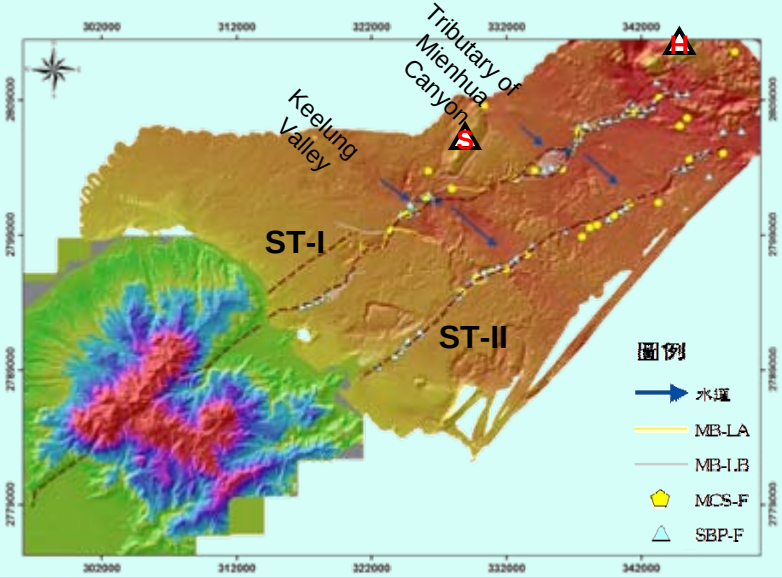
2. Continuity Geological Survey

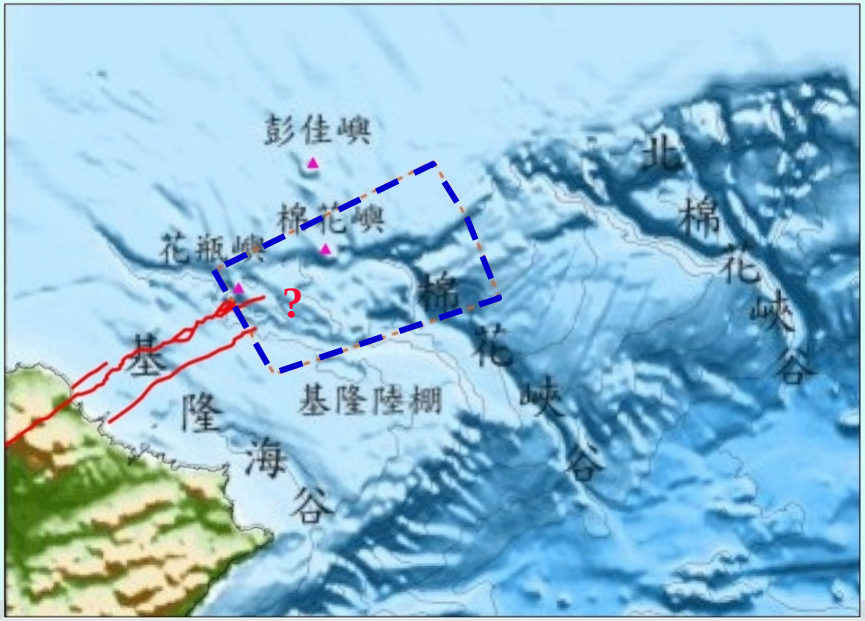
(June 2013~October 2014)

Key Issues

- Where is the depth of reference rock basement (Vs=760 m/sec）for the NPP1 and NPP3 site?
- Is the length of Shanchiao Fault extension from land to the offshore more than 74 (21+13+40) km ?

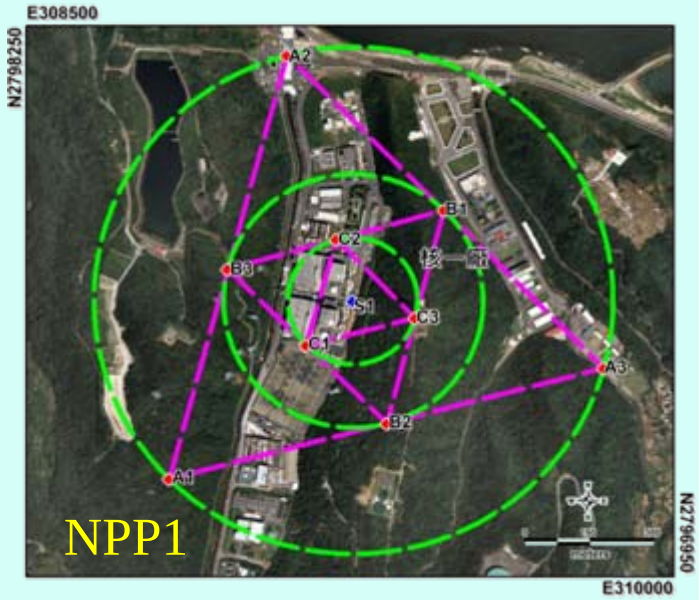




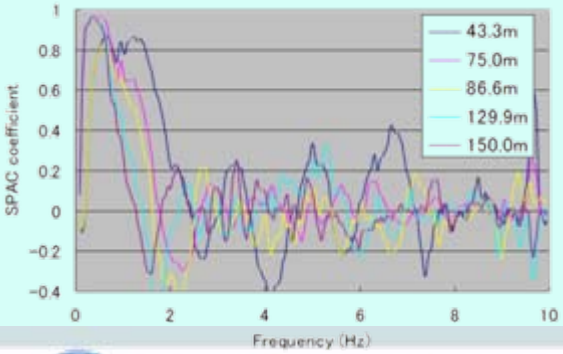


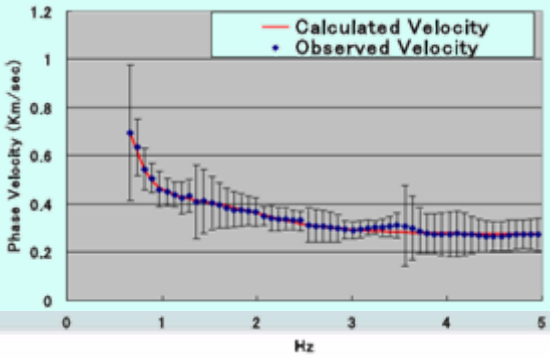
Array Records of Microtremors

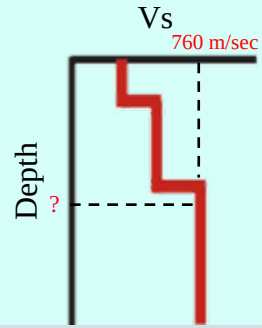
- Estimated the Shear Wave Velocity Structures of NPPs Site from Array Records of Microtremors



Being Performed

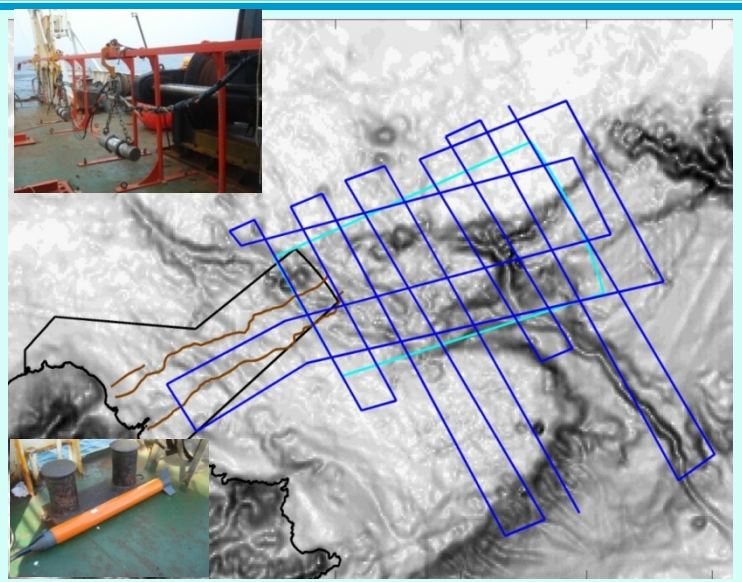


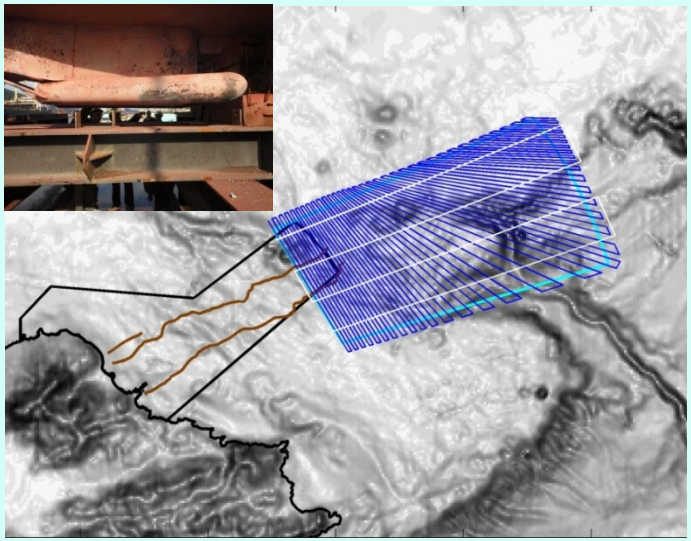




Investigating the northward extension characteristic of Shanchiao Fault

- Multi-beam survey
- Side-scan sonar survey
- Multi-channel seismic reflection method
- Sub-bottom profile method
- Offshore magnetic survey
- *Short-term observation of Ocean-Bottom Seismometer to investigate the activity of Shanchiao Fault*





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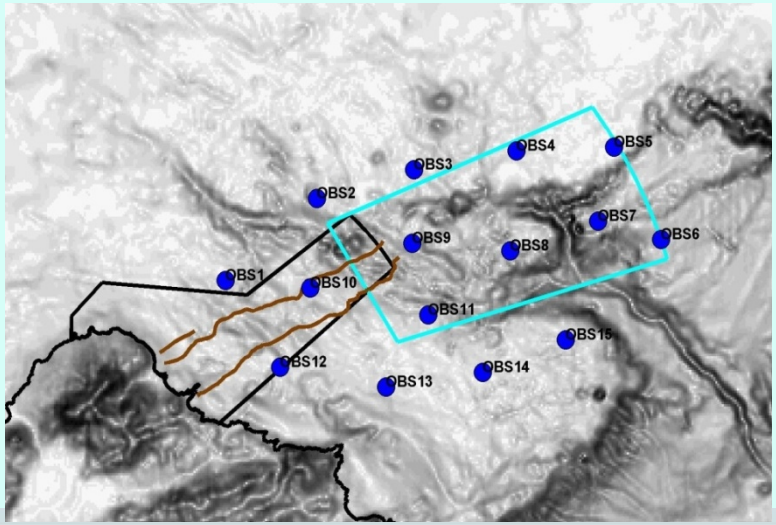

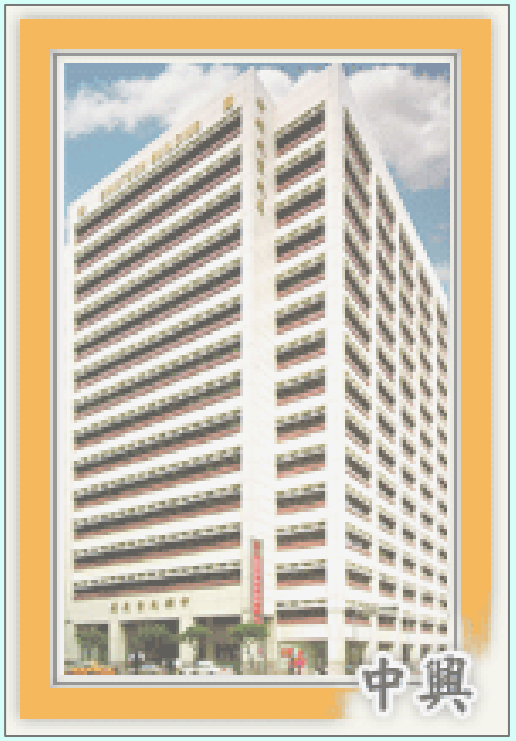

Thank you

For your attention