



Planning of Groundwater Anomalies Associated with the Earthquake and Case study in Taiwan

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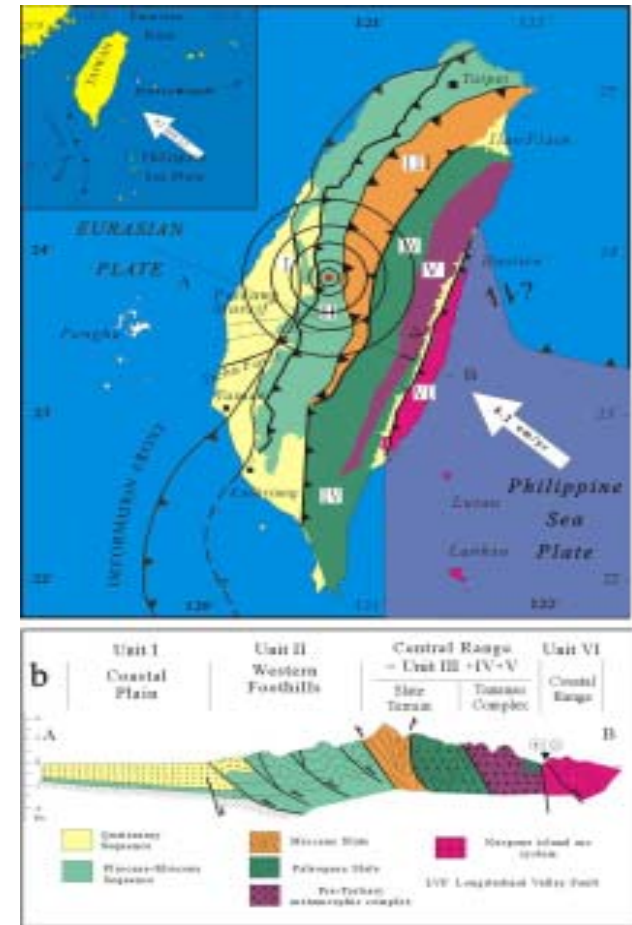
Introduction

- **Tectonic Setting of Taiwan**
- **Information from Chi-Chi earthquake (Sep. 21st, 1999; Mw:7.6)**
- **Groundwater Monitoring Network of Taiwan**

Tectonic Environment of Taiwan

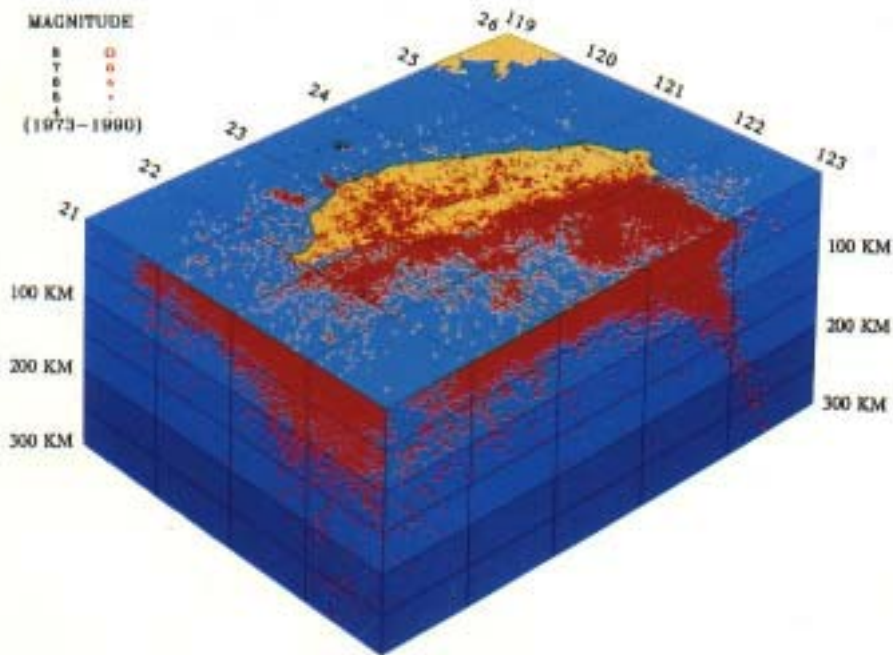


Tectonic environment of Taiwan

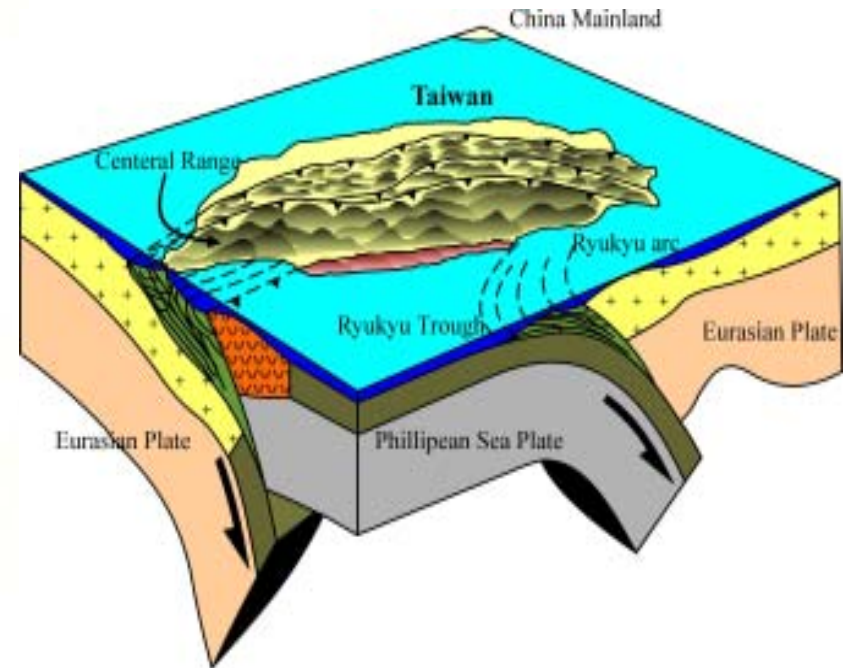


Geological map of Taiwan and east-west cross section along central Taiwan

Lithospheric Structure of Taiwan

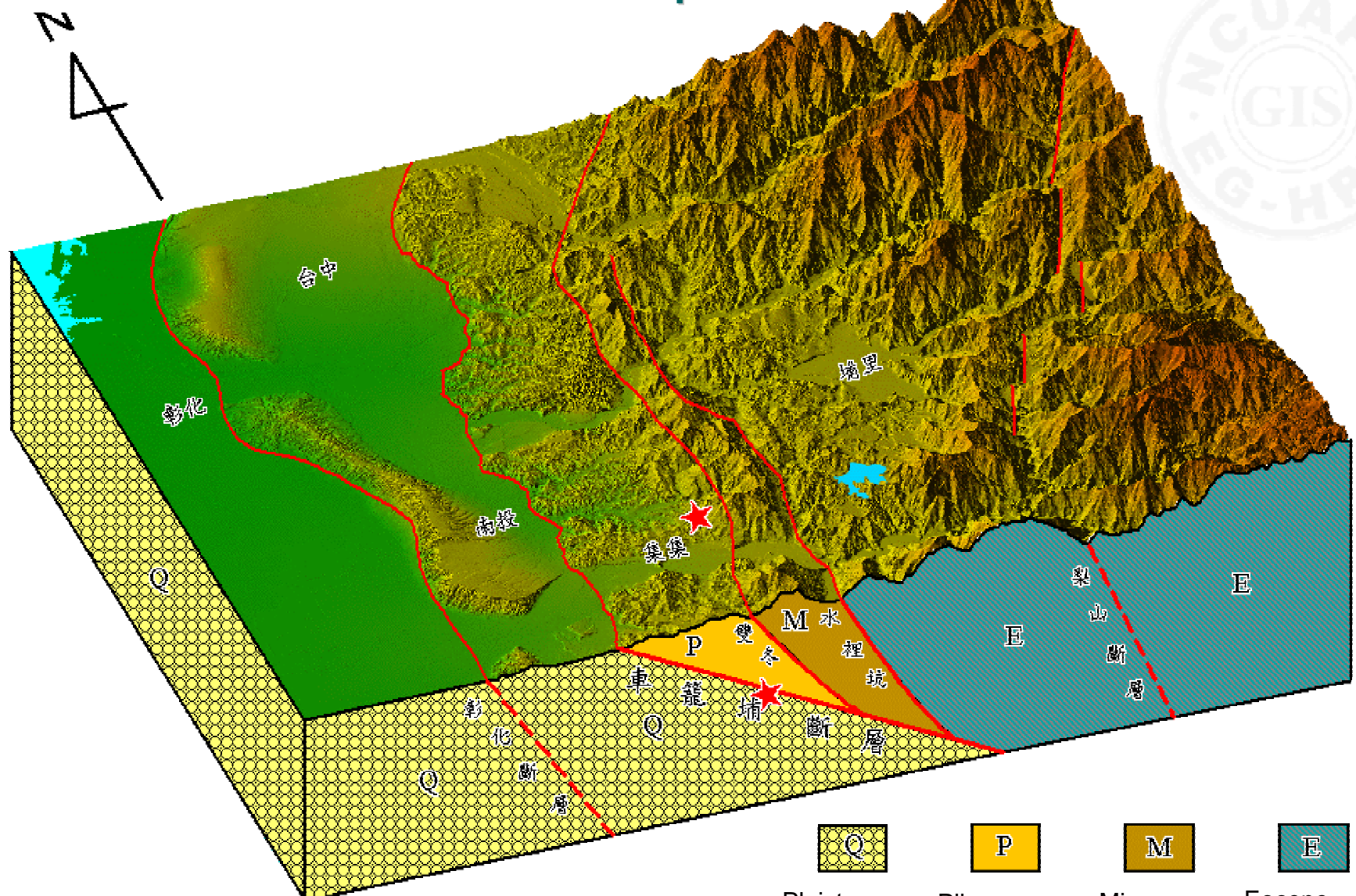


Spatial Distribution of Earthquake in the Taiwan region



Tectonic Explanation of Taiwan region(Anglier, 1986)

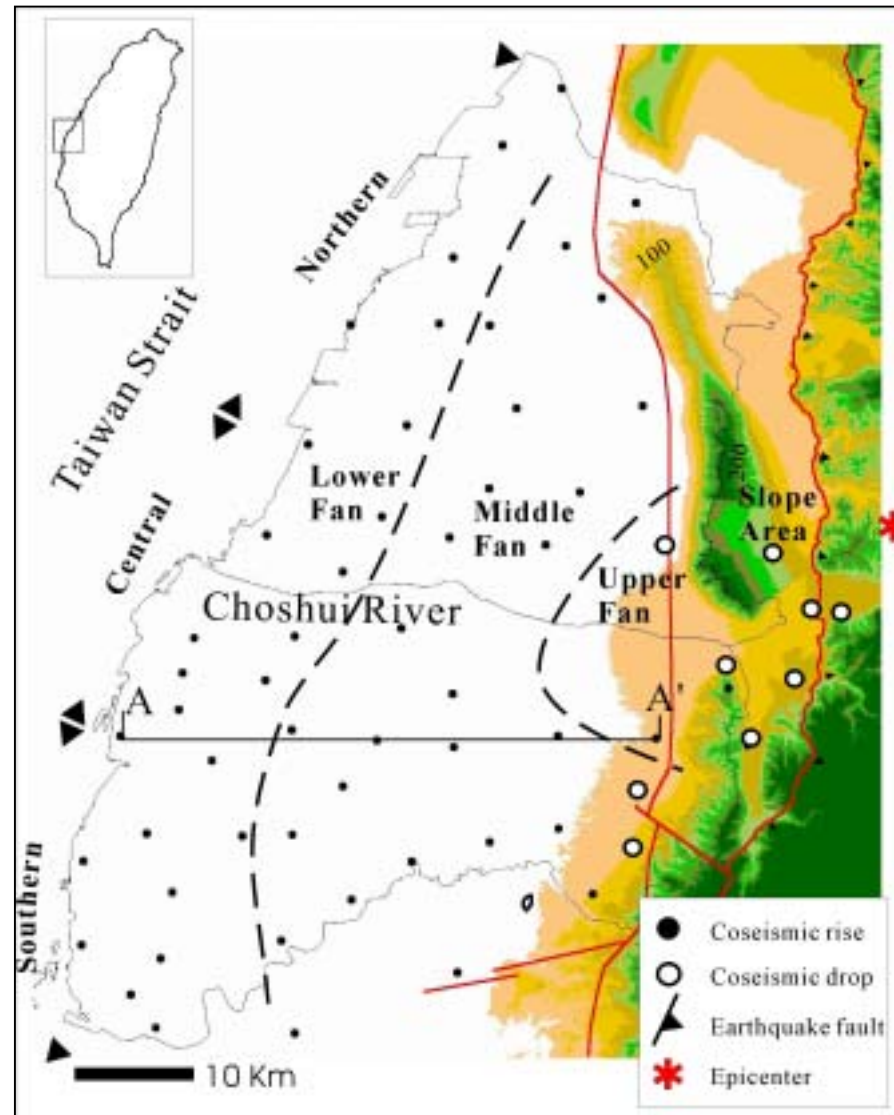
Structural Section of Chi-Chi earthquake Fault



影像繪製：中央大學應用地質研究所
 工程地質與防災科技研究室
 (<http://gis.geo.ncu.edu.tw>)

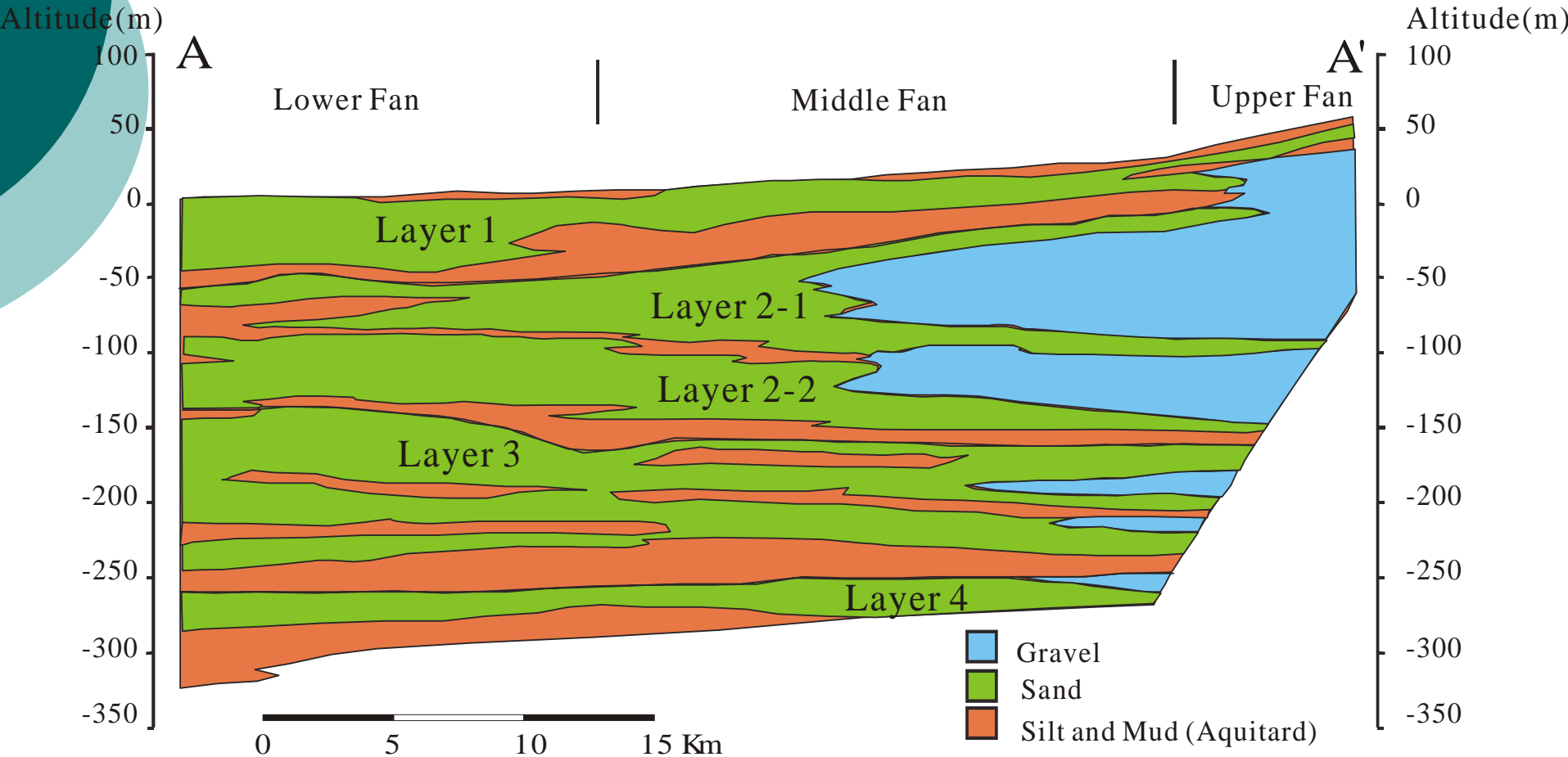
Pleistocene-Holocene Formation	Pliocene Formation	Miocene Formation	Eocene-Oligocene Formation

Earthquake-induced Groundwater Variations in the Choushuishi Alluvial Fan

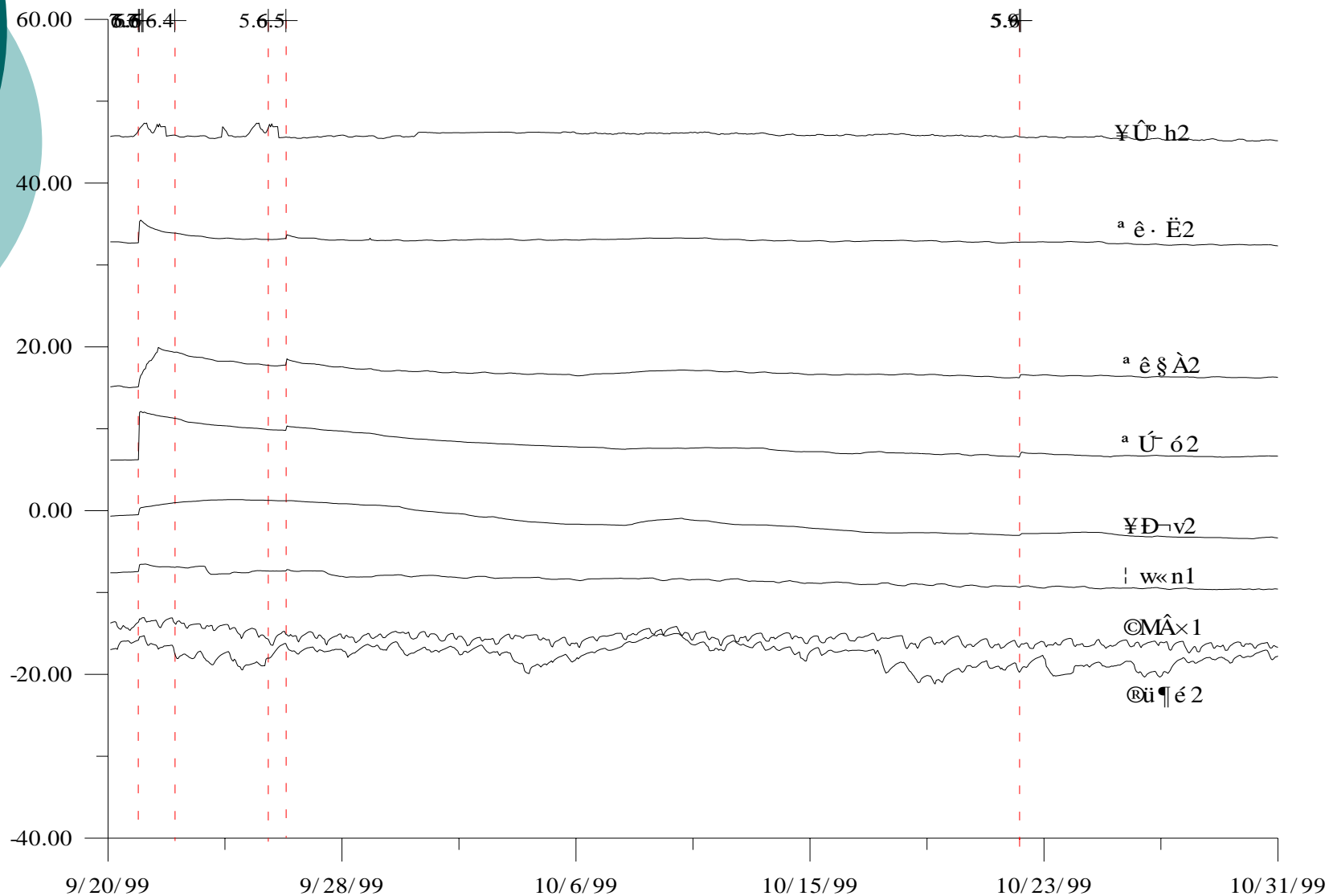


Location of Choushuishi Alluvial Fan

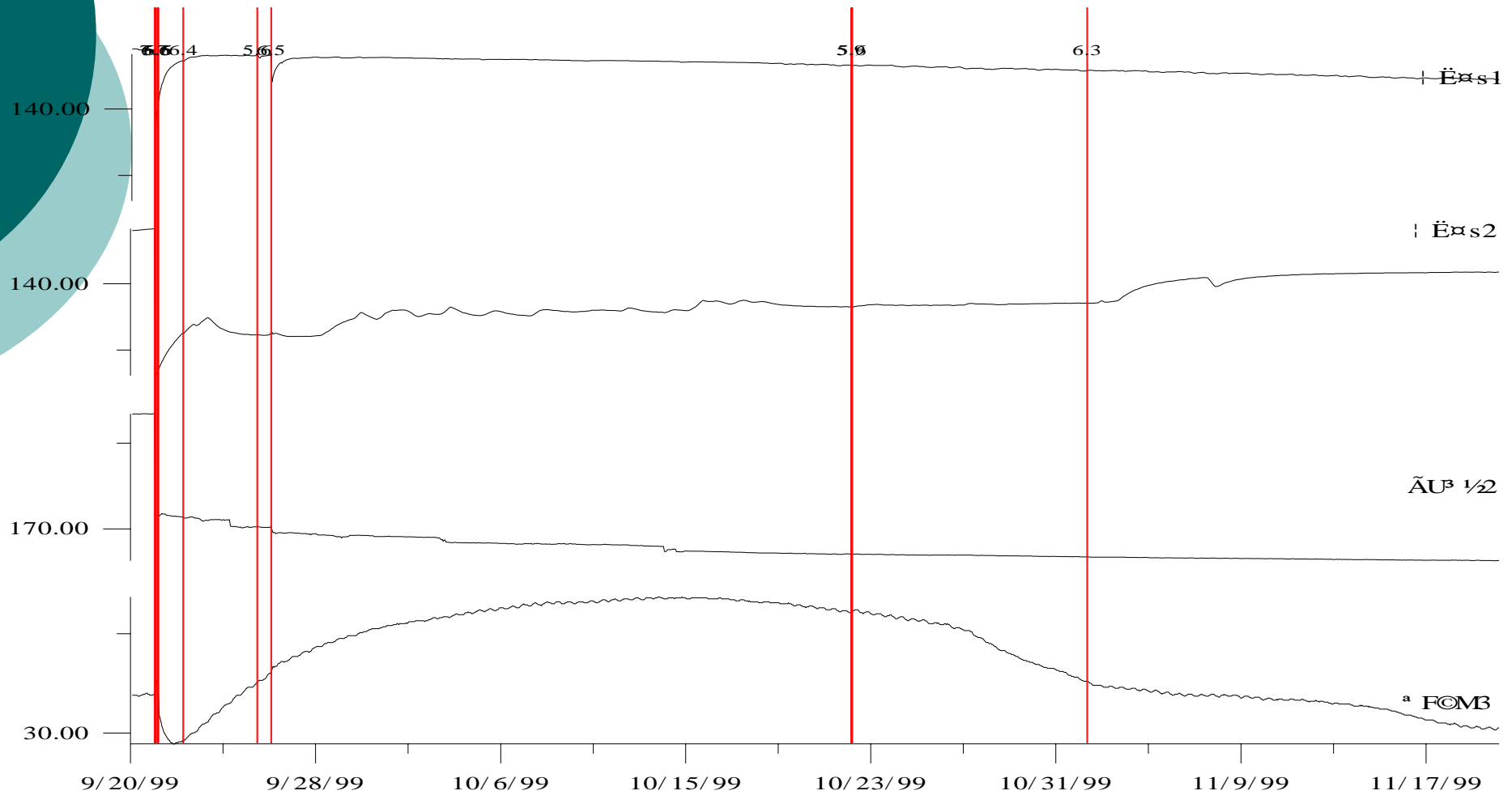
Hydrogeology Model of Choushuichi Alluvial Fan



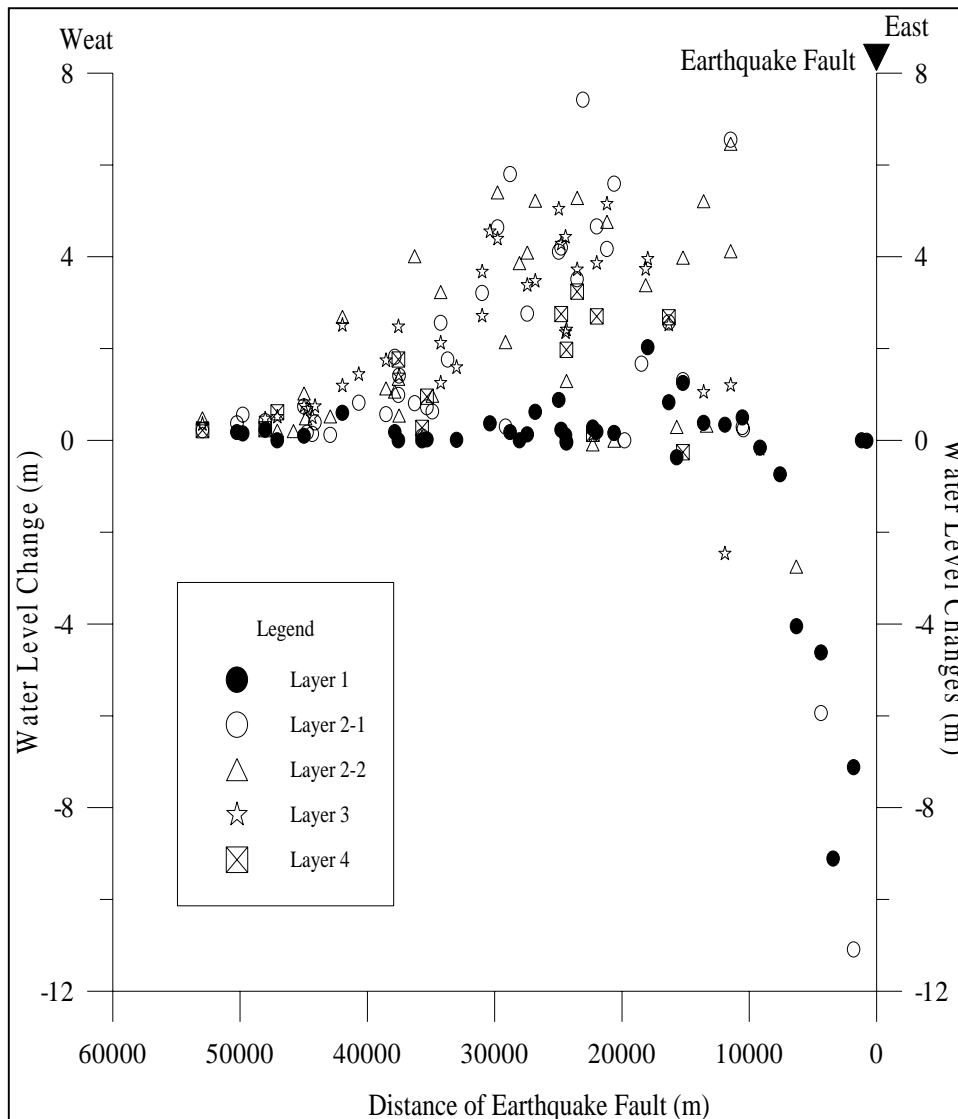
Coseismic Groundwater Level Changes in Alluvial Fan Area



Coseismic Groundwater Level Changes in Hill Slope Area



Coseismic Changes in Different Aquifer

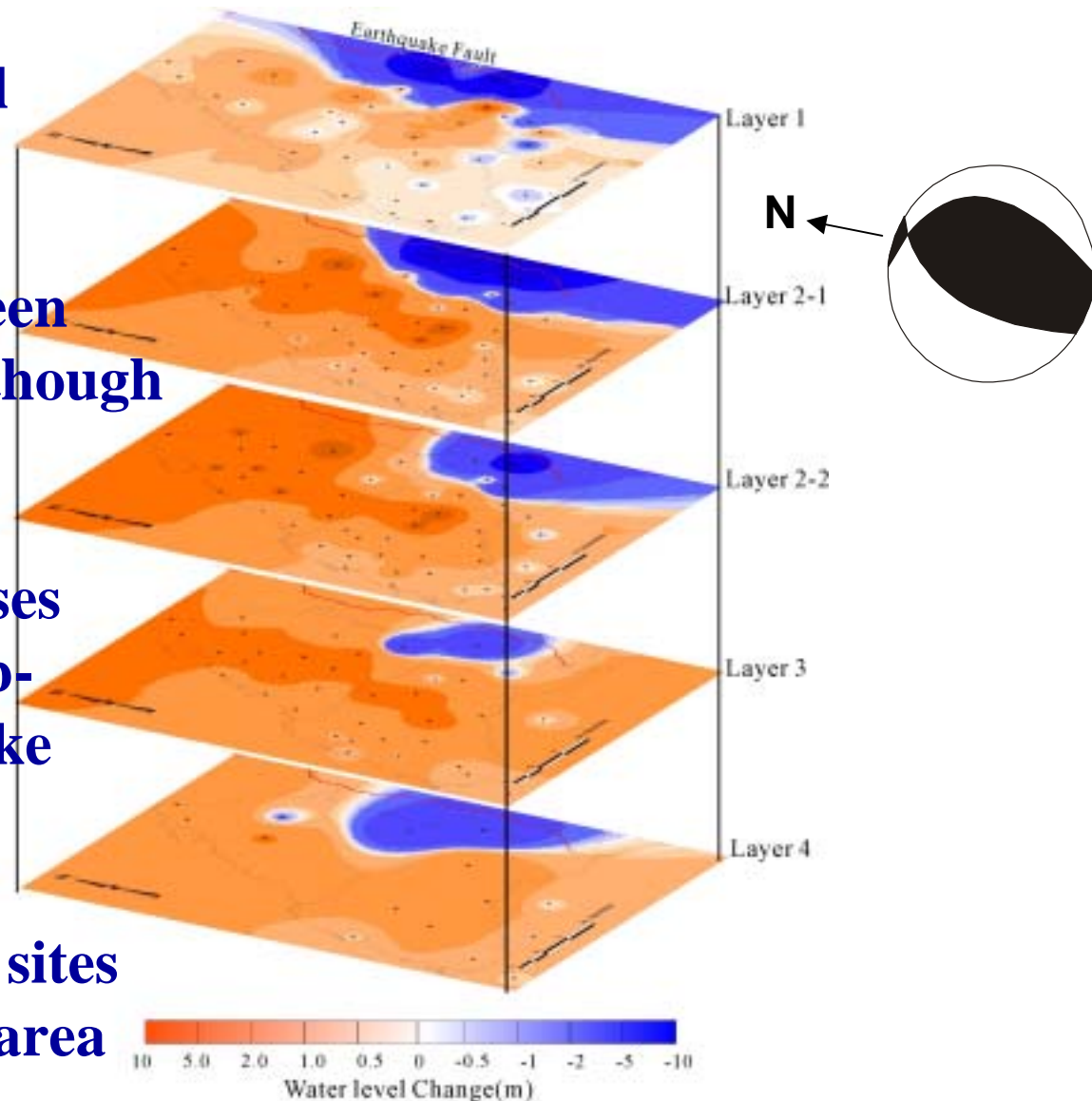


Groundwater level changes of main shock

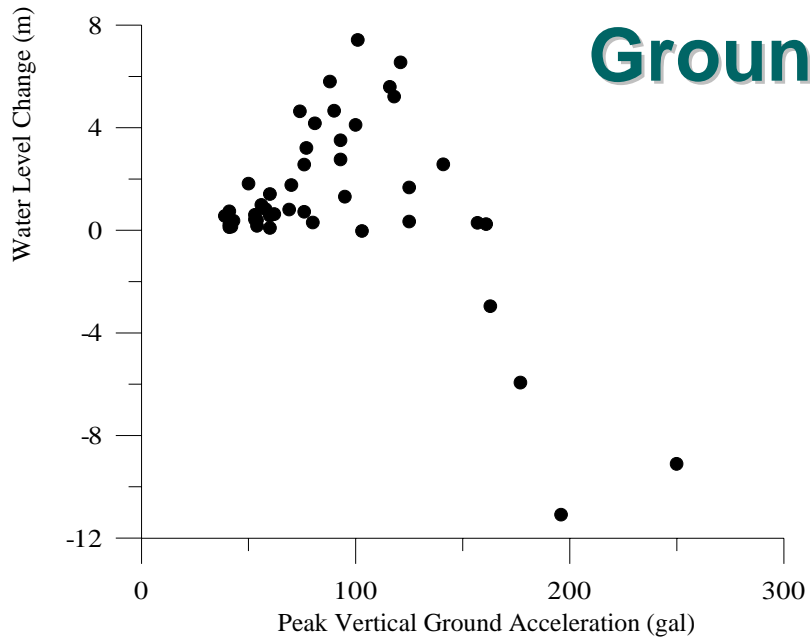
- **Confinement of aquifer**
- **Structural position**
- **Crust strain**
- **Ground motion**
- **Liquefaction**
- **Permeability enhancement**
- **Responses to seismic wave**

Distribution maps of the coseismic water level changes and the monitoring wells in different aquifers

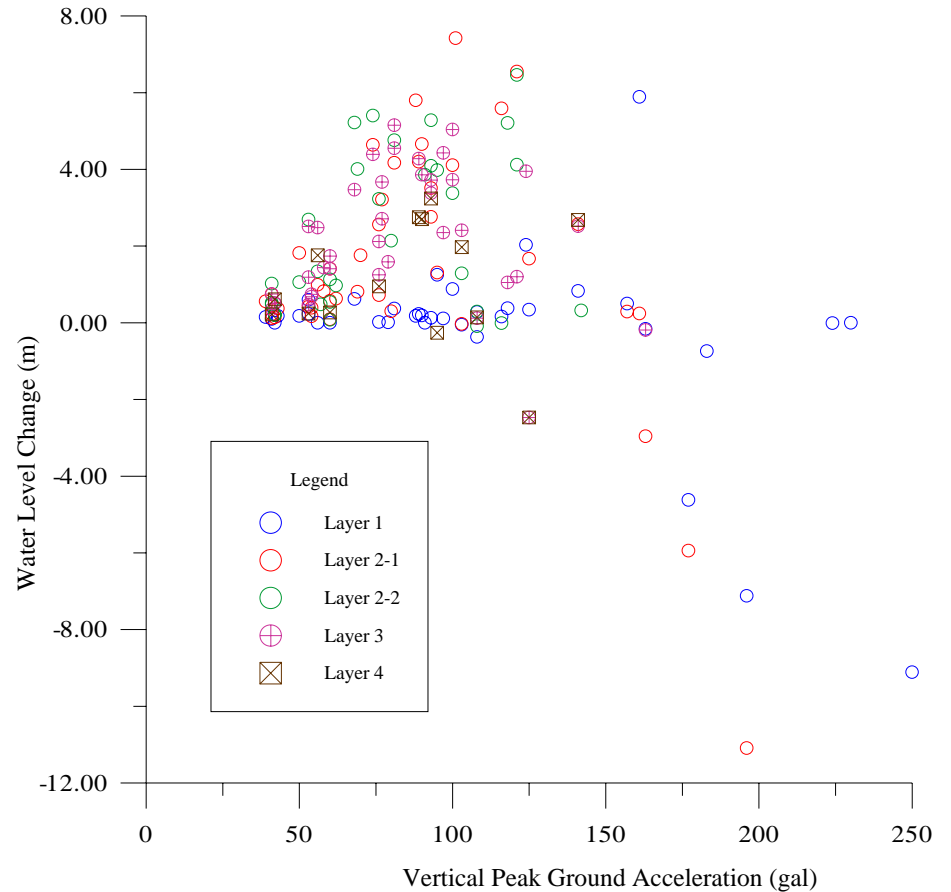
- ❑ Not fit to expected focal mechanism
- ❑ Large difference between different aquifers even though in the same site
- ❑ The larger coseismic rises made a narrow zone sub-parallel to the earthquake fault
- ❑ The coseismic decrease sites locates on the hill slope area



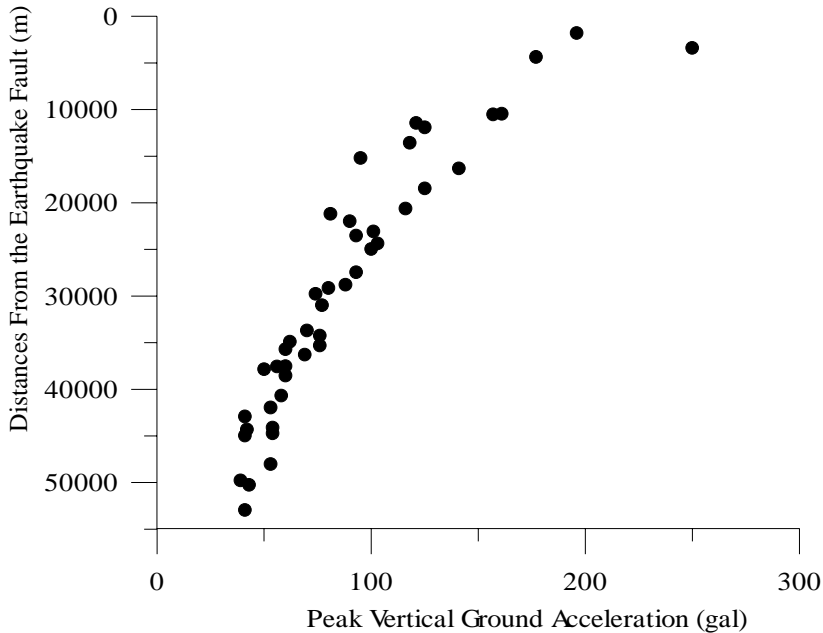
Groundwater Level Changes and Ground-motion



(a)



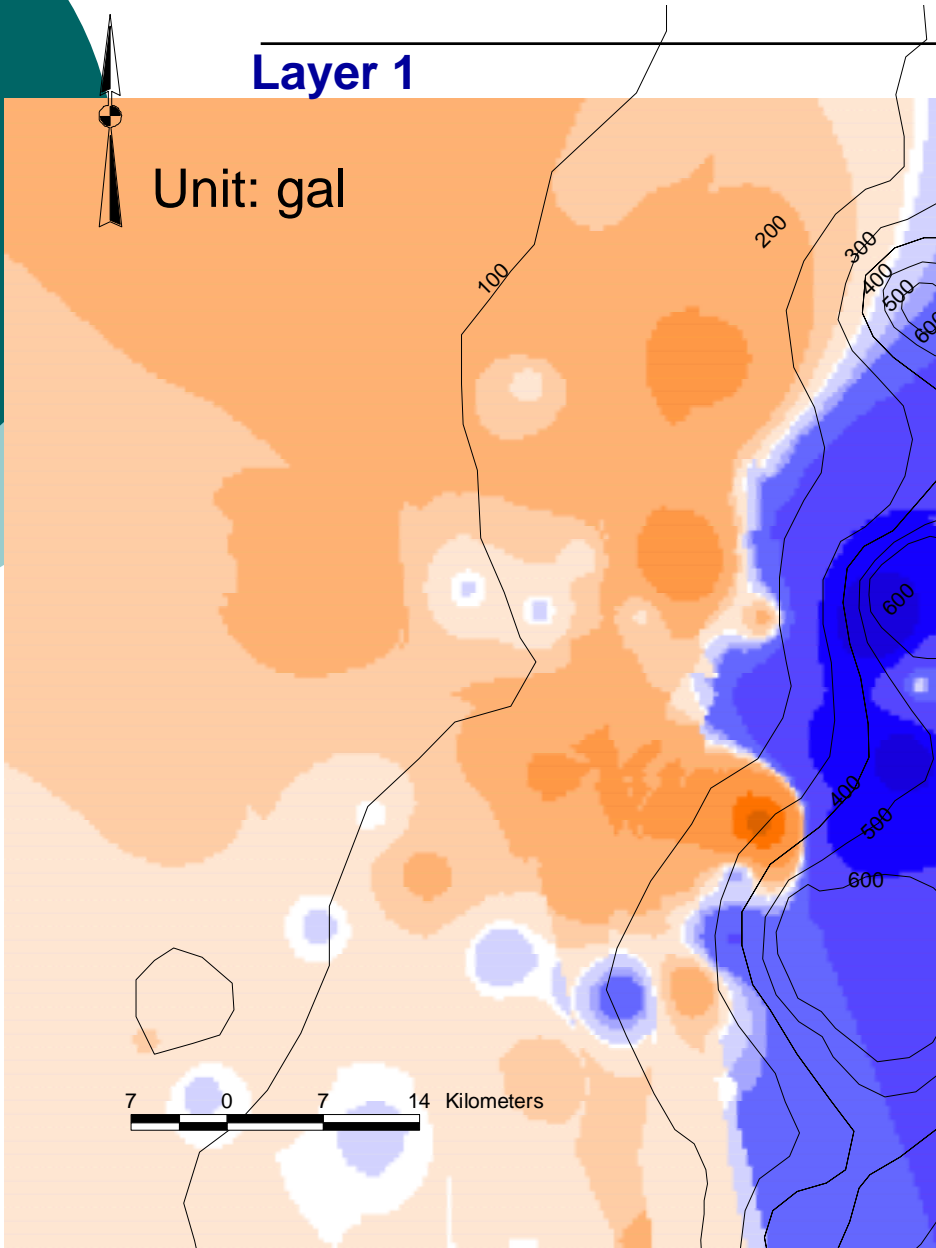
(b)



Groundwater Level Changes and Ground Motion

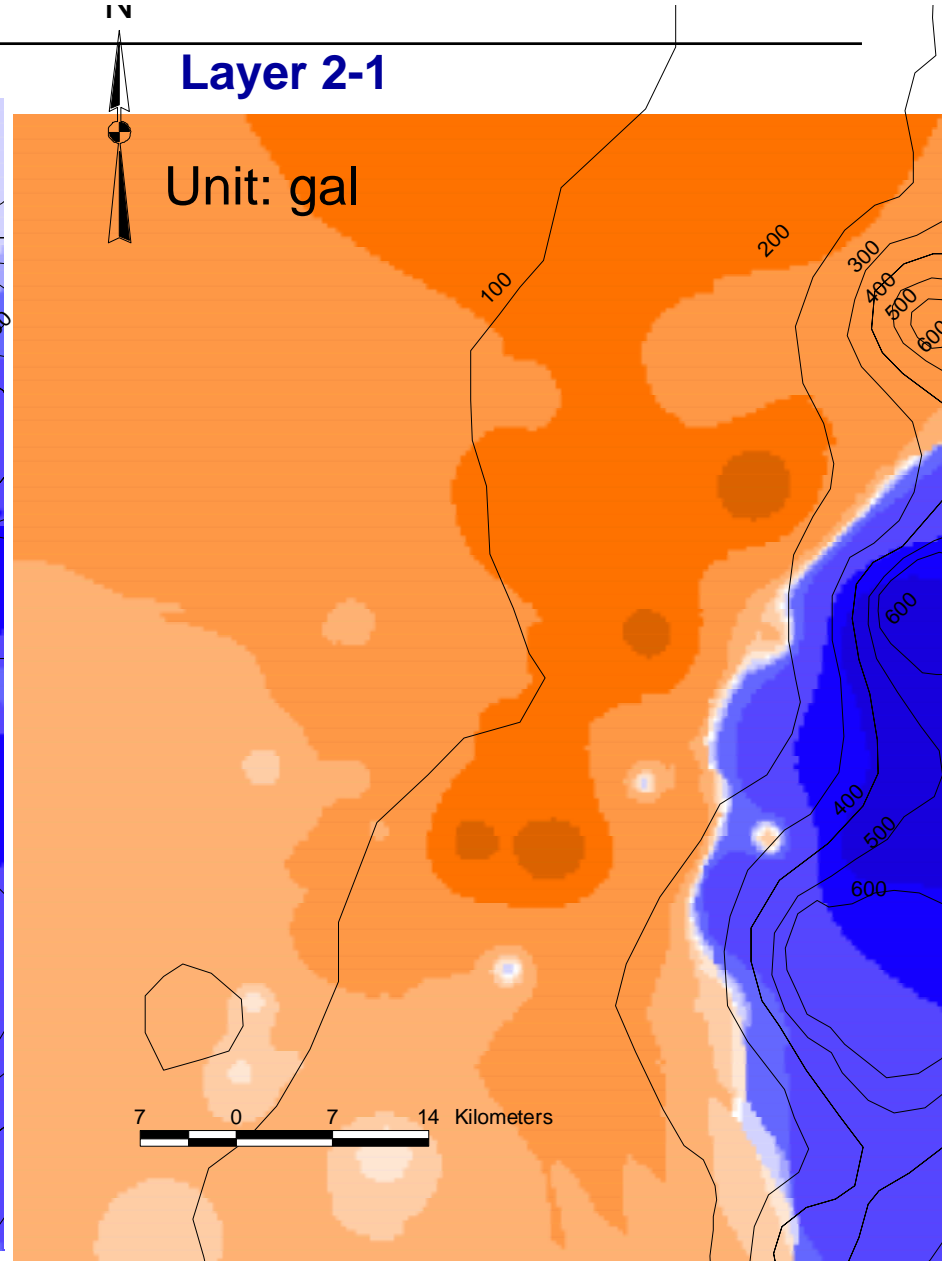
Layer 1

Unit: gal

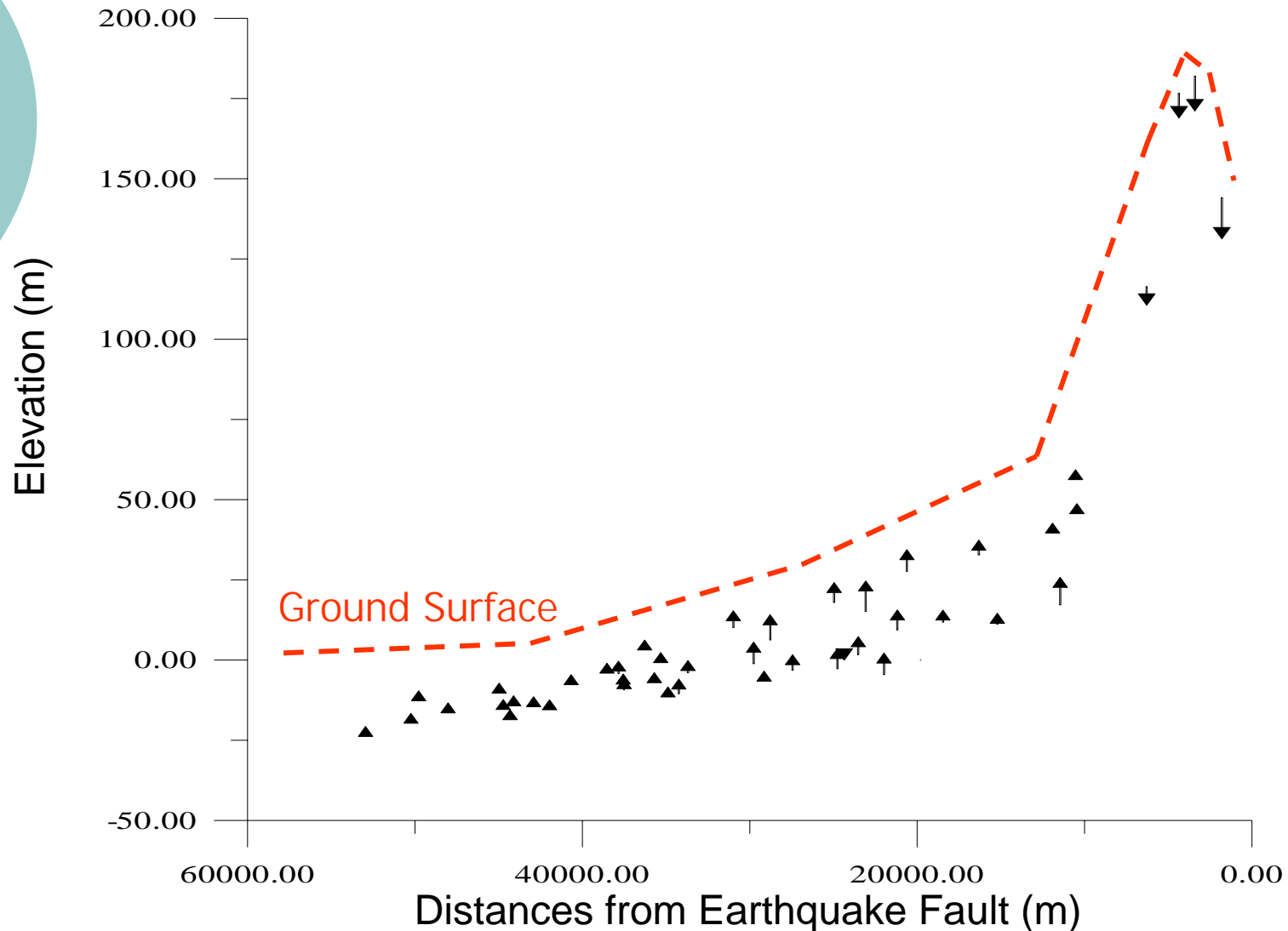


Layer 2-1

Unit: gal

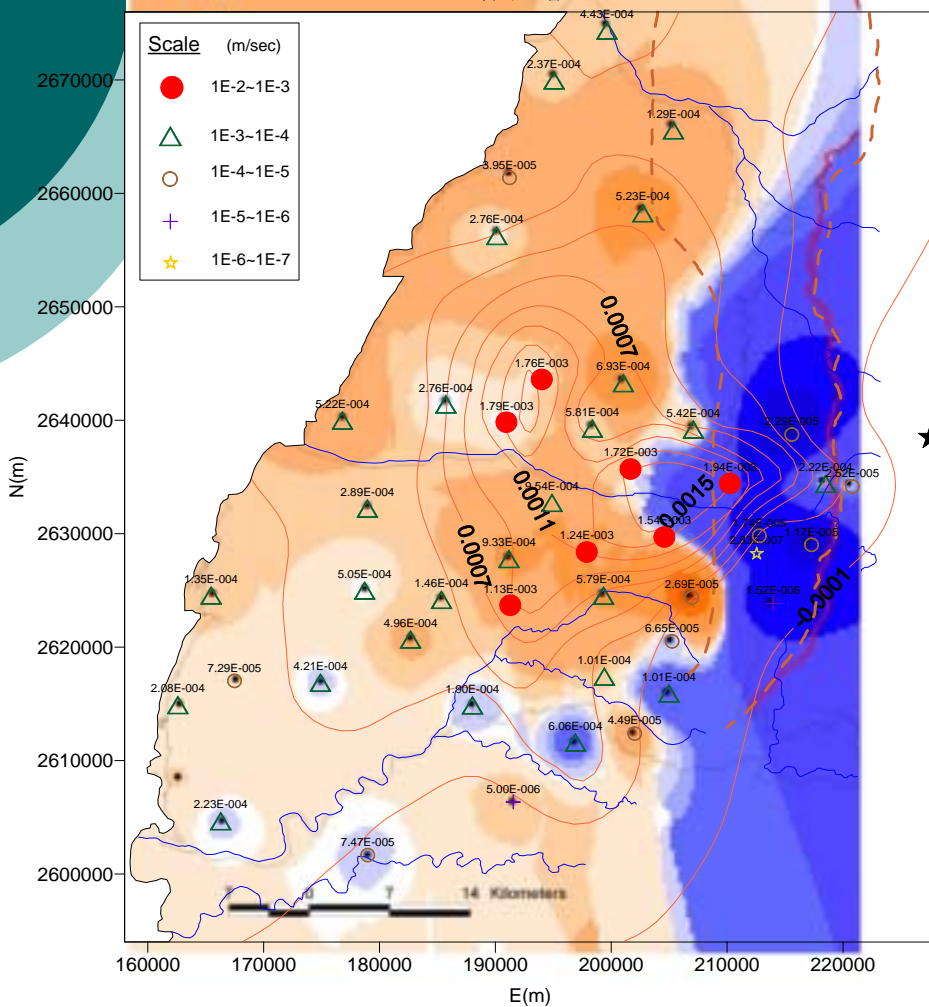


Permeability Enhancement: Groundwater Level Changes and Topography

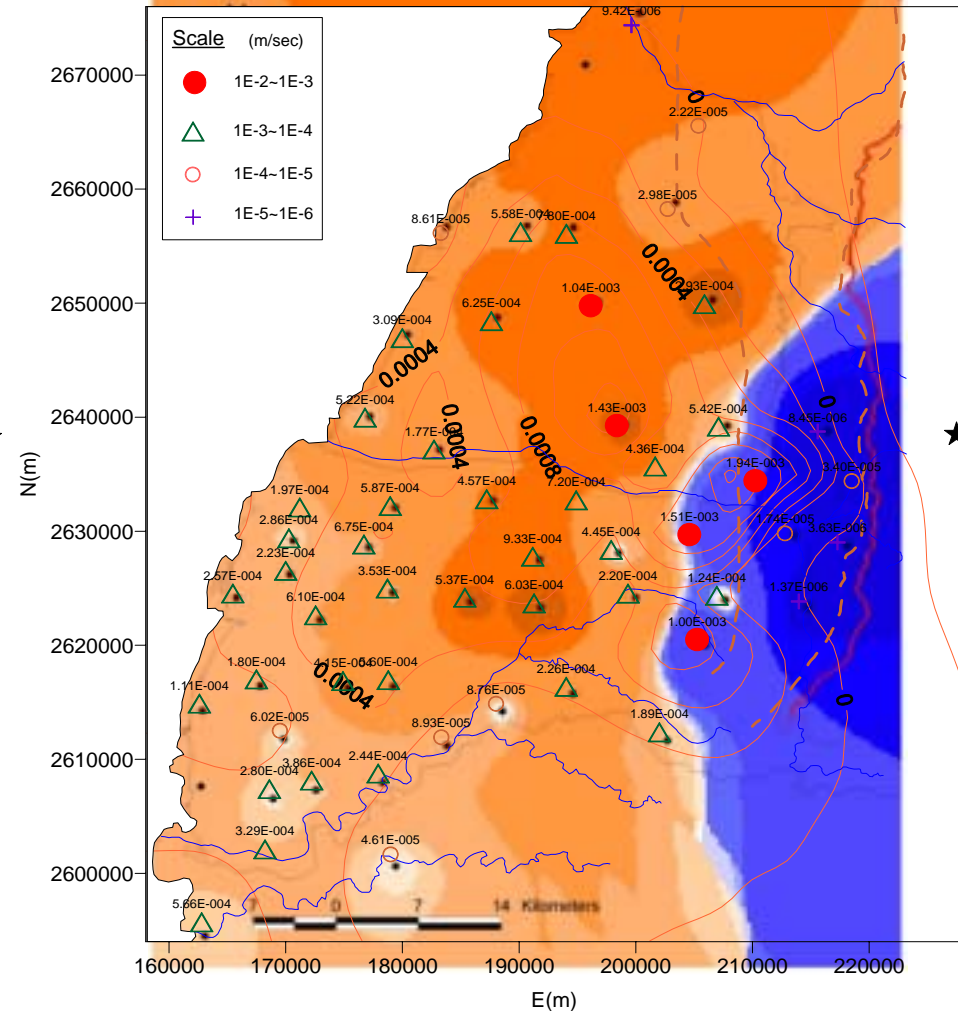


Groundwater Level Changes and Conductivity of Aquifer

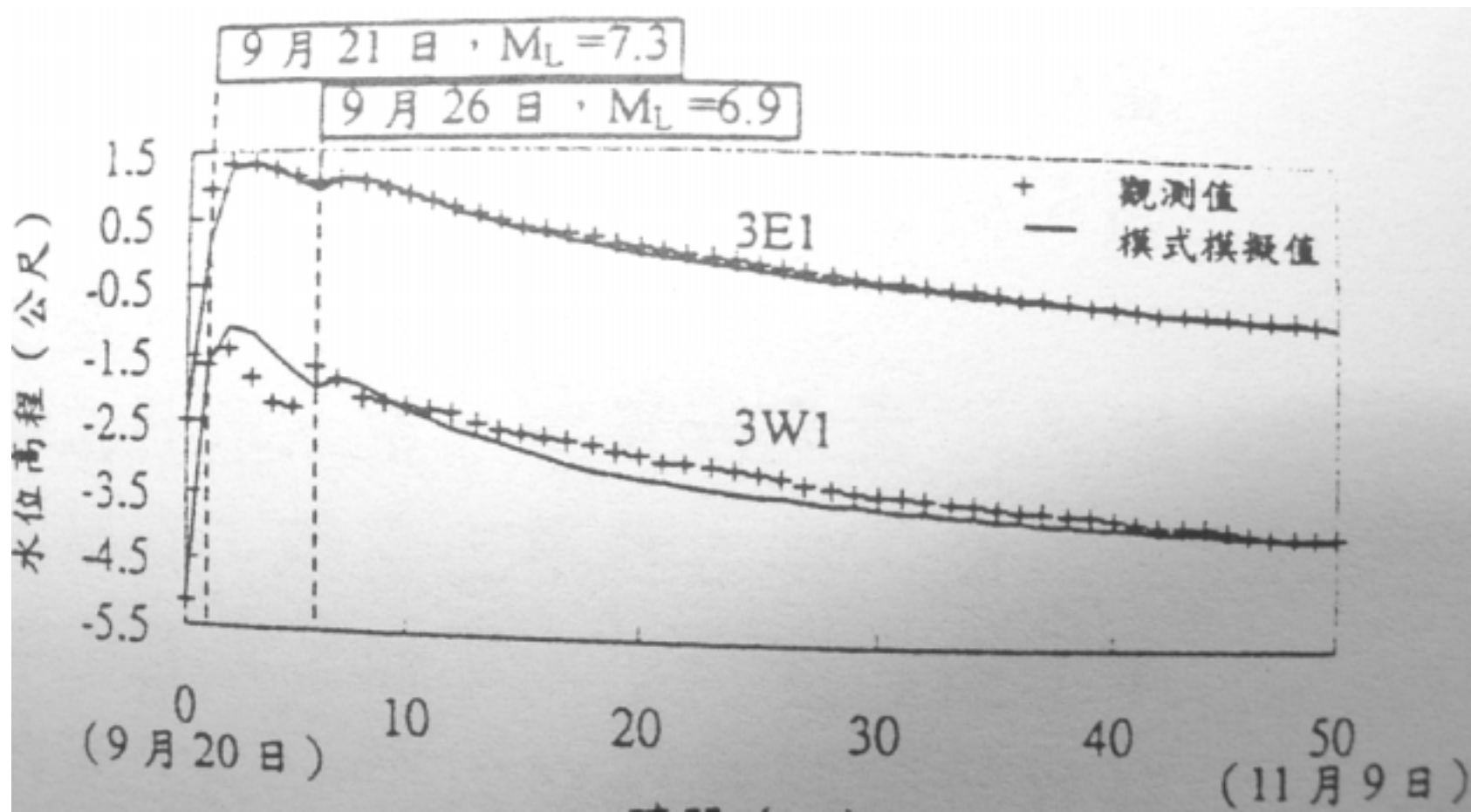
Layer 1



Layer 2-1



Response to Seismic Wave(Lin et al., 2001)

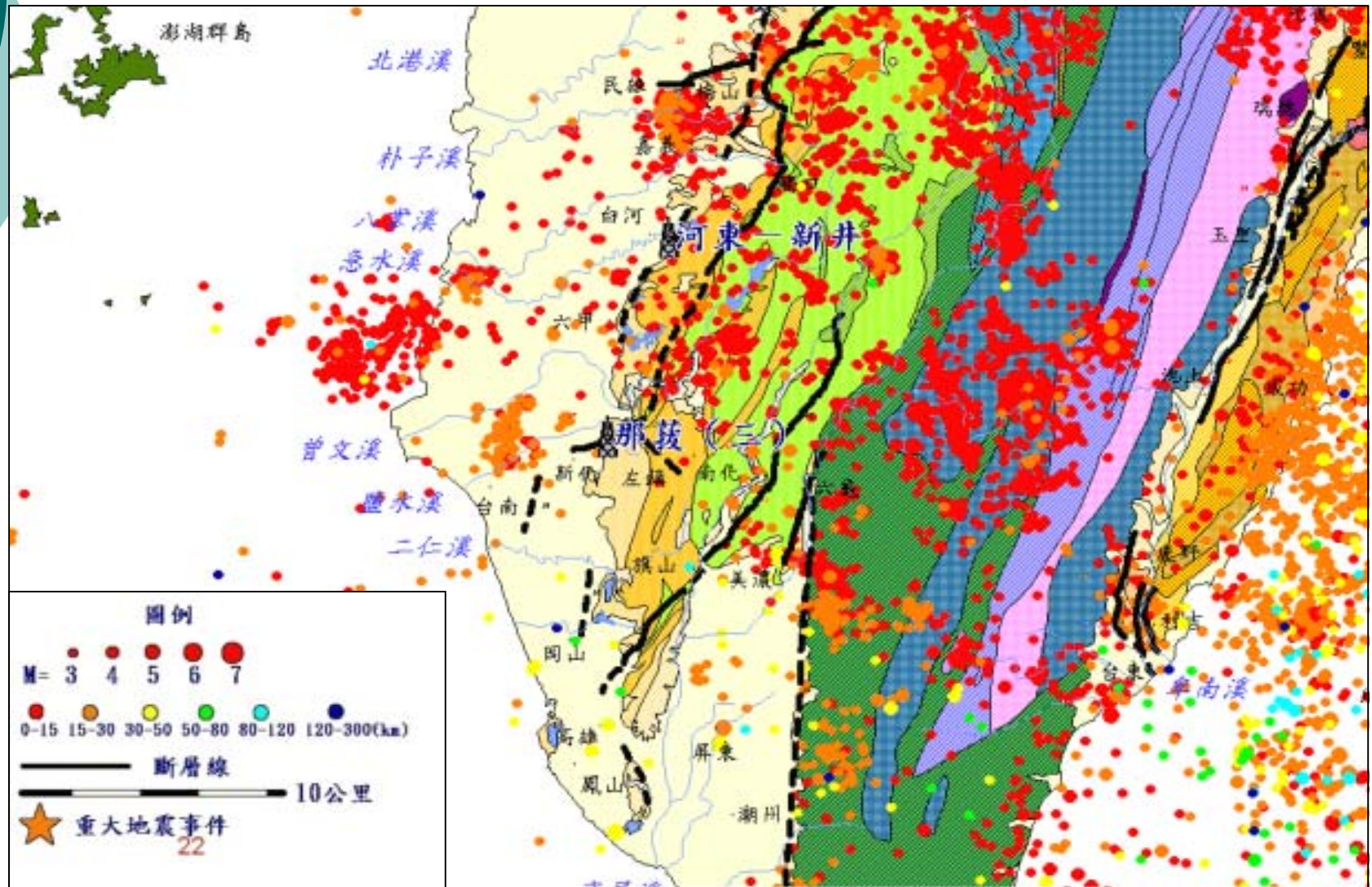


Spatial distribution of disastrous earthquake

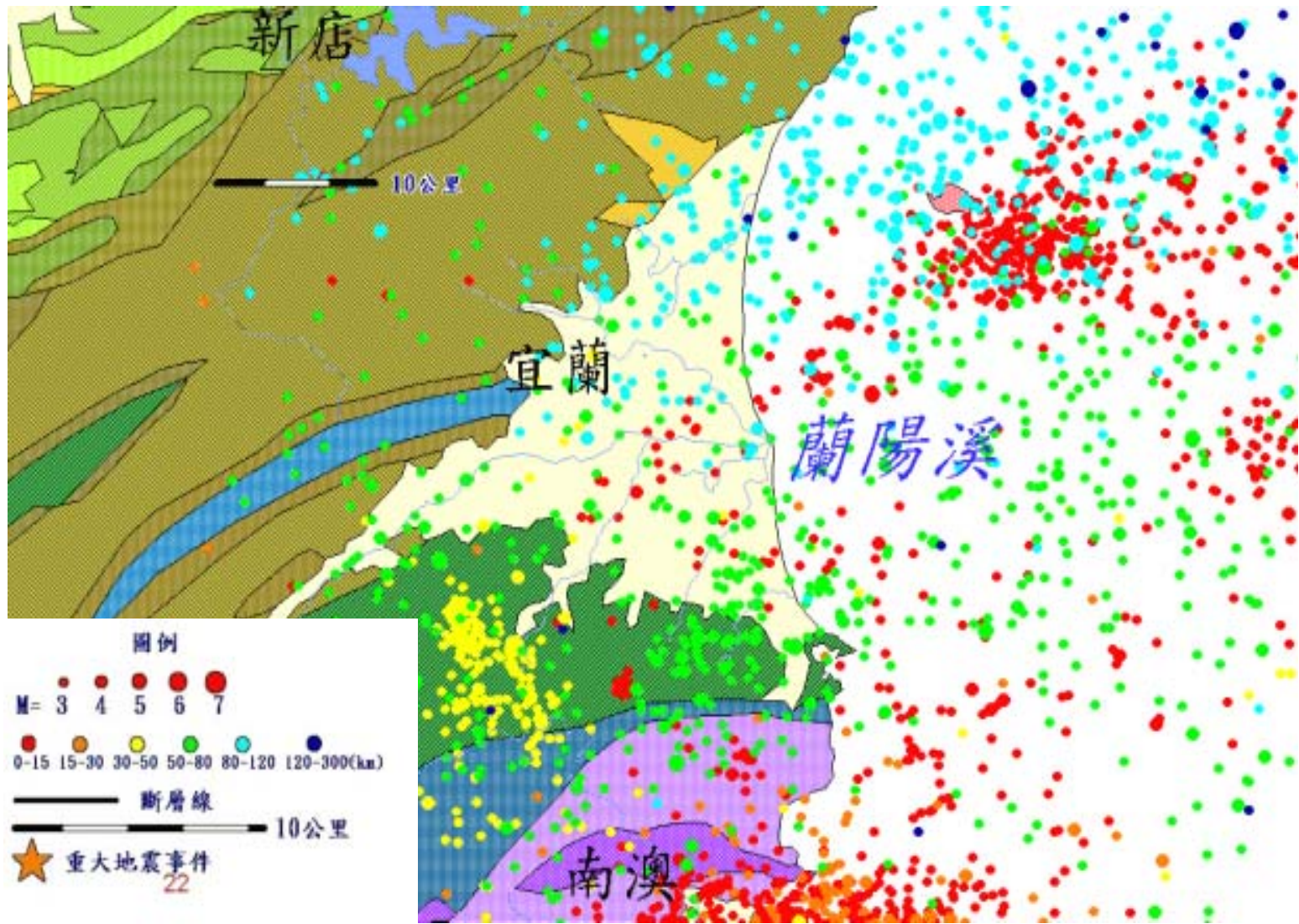
- Western foothill area
- Ilan offshore area
- Huliien offshore area
- Longitudinal Valley
- Liutao-Lanyu island



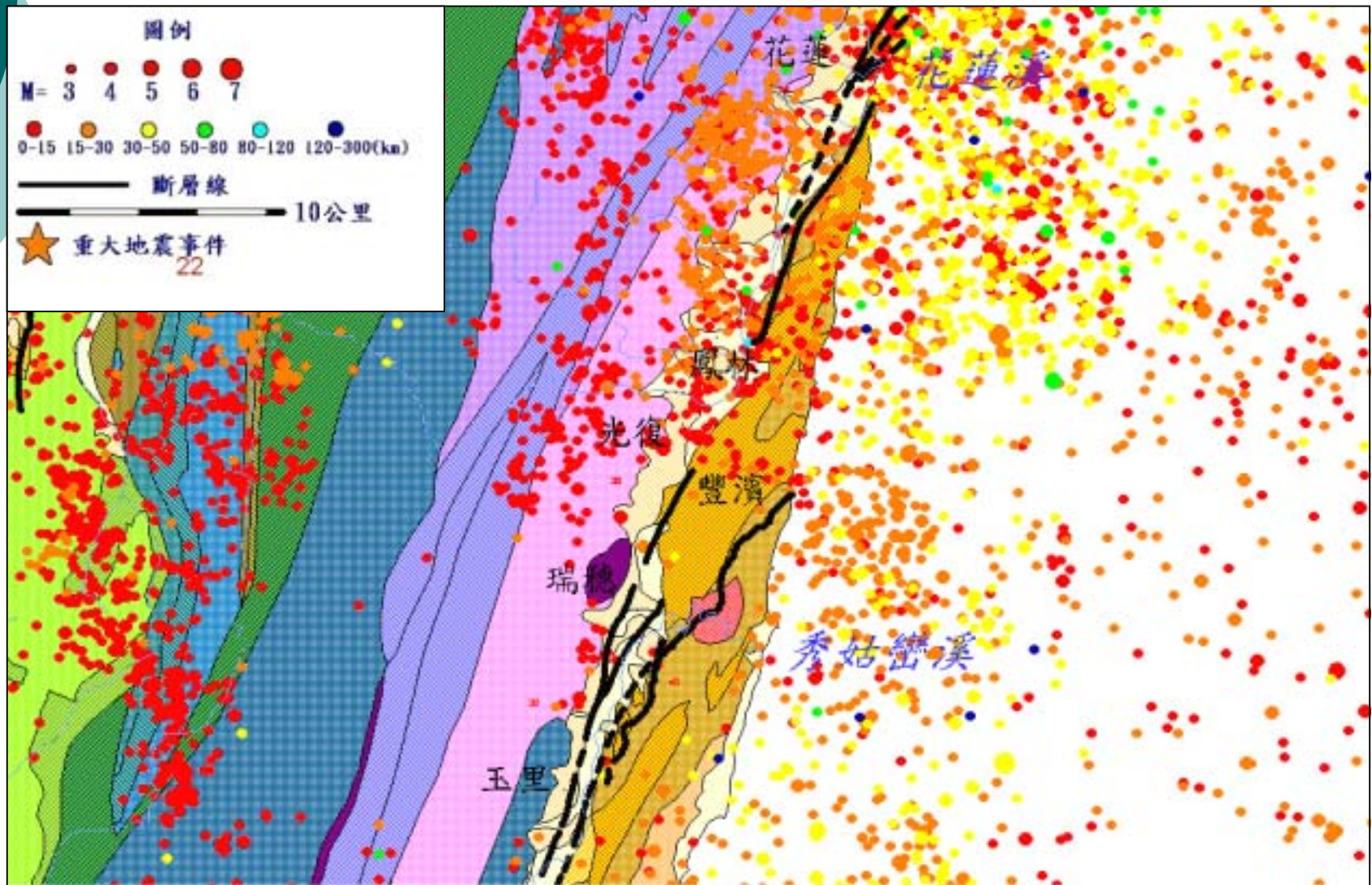
Seismic environment of southern Taiwan



Seismic environment of Ilan Plain

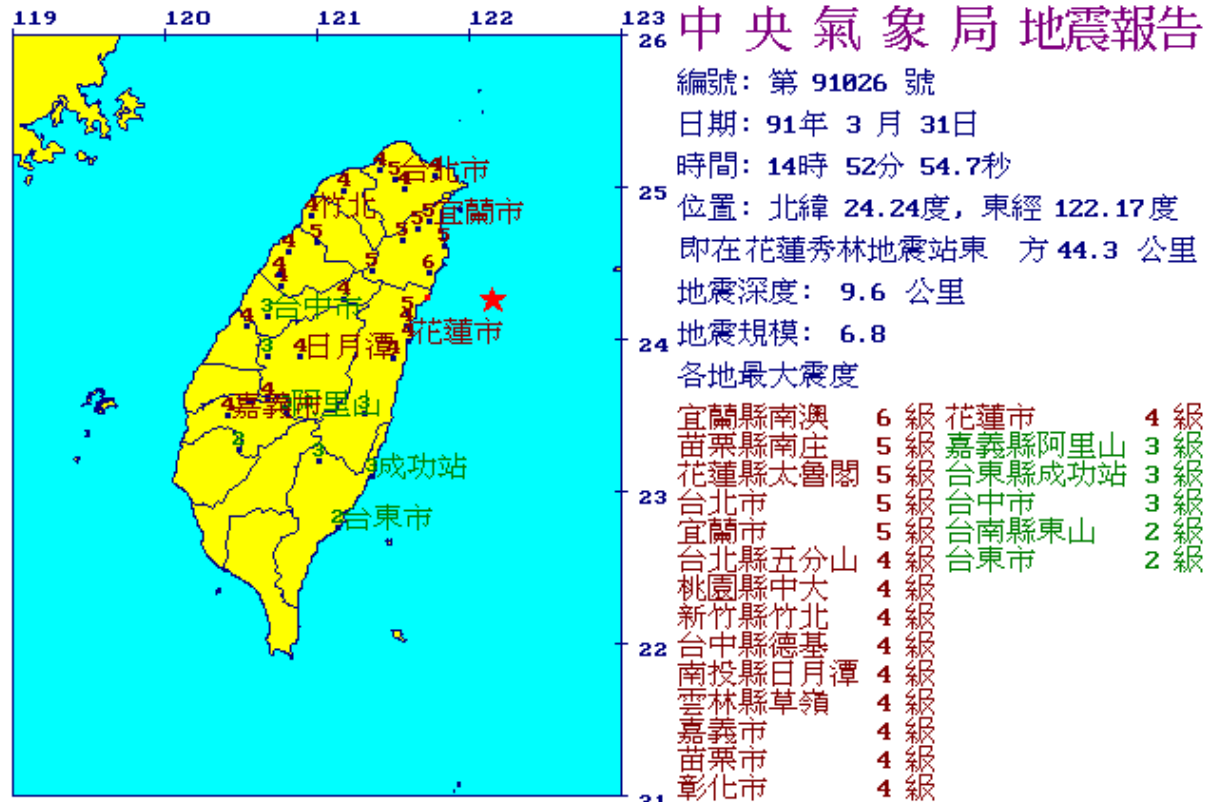


Seismic environment of Huli and Longitudinal Valley



Hulien Offshore Earthquake (M: 6.8) March 31st, 2002

□ Central Weather Bureau's Quick-Release Earthquake Information



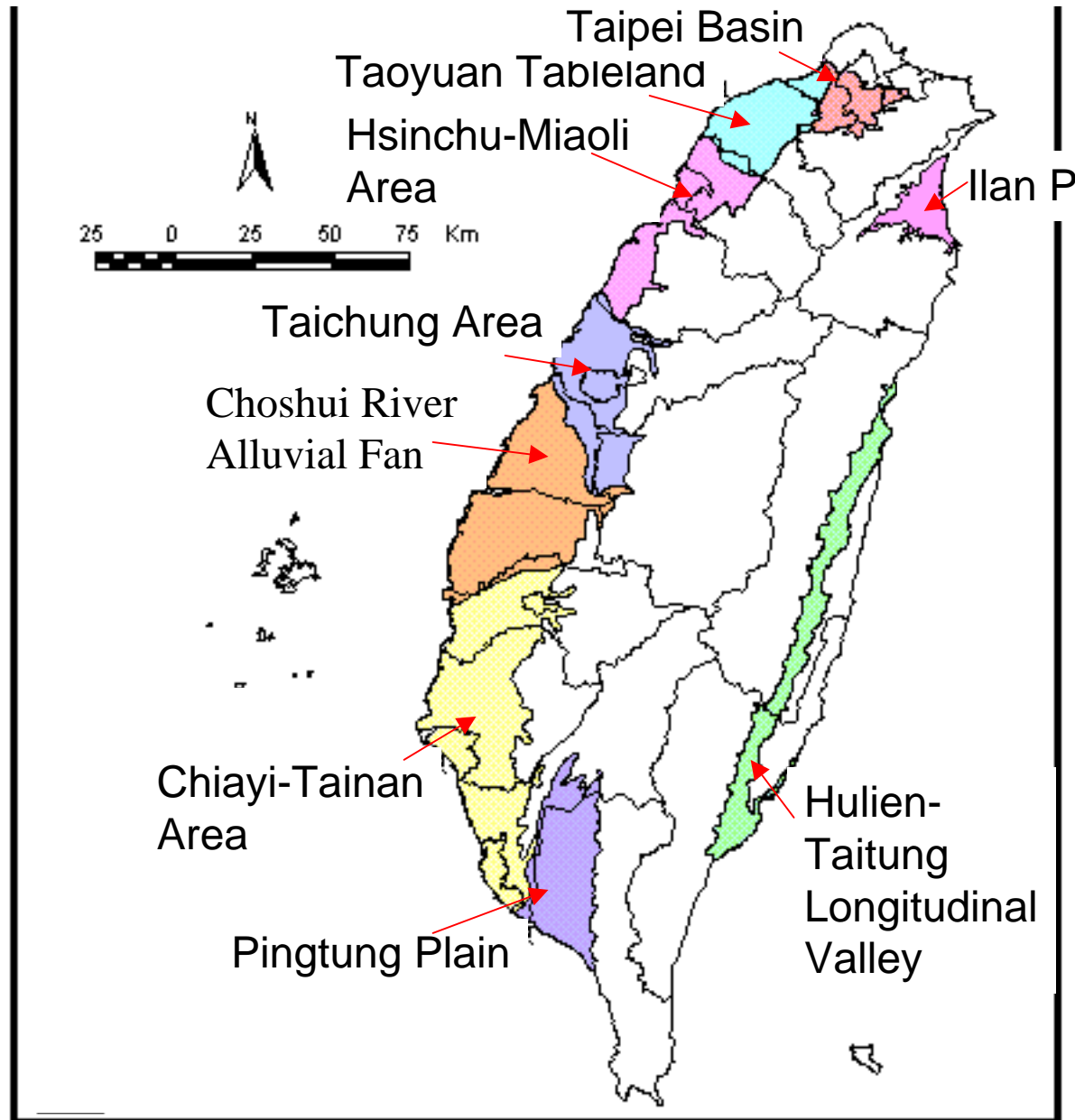
圖說：★ 表震央位置，數字表測站震度

Newly Risk from offshore Earthquake (March 31st, 2002; M: 6.8)



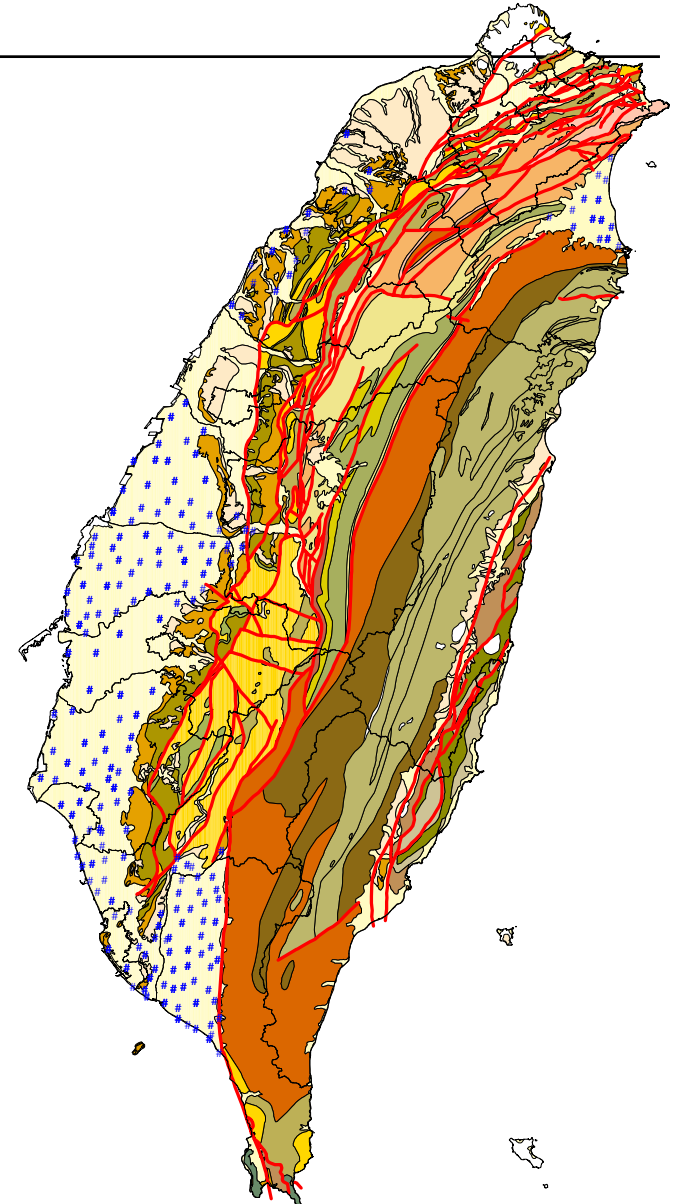
Groundwater Monitoring Network of Taiwan

Total of 517 hydro geological survey stations and 990 groundwater monitoring wells will be constructed in 8 sub-groundwater provinces during 17 years (1992-2008).



Taiwan Groundwater Monitoring Network (1992~2001)

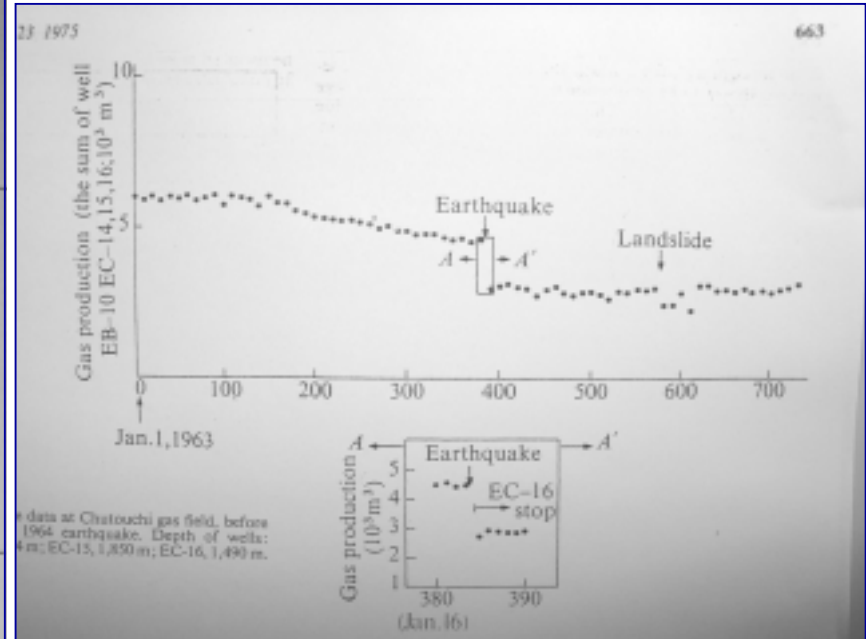
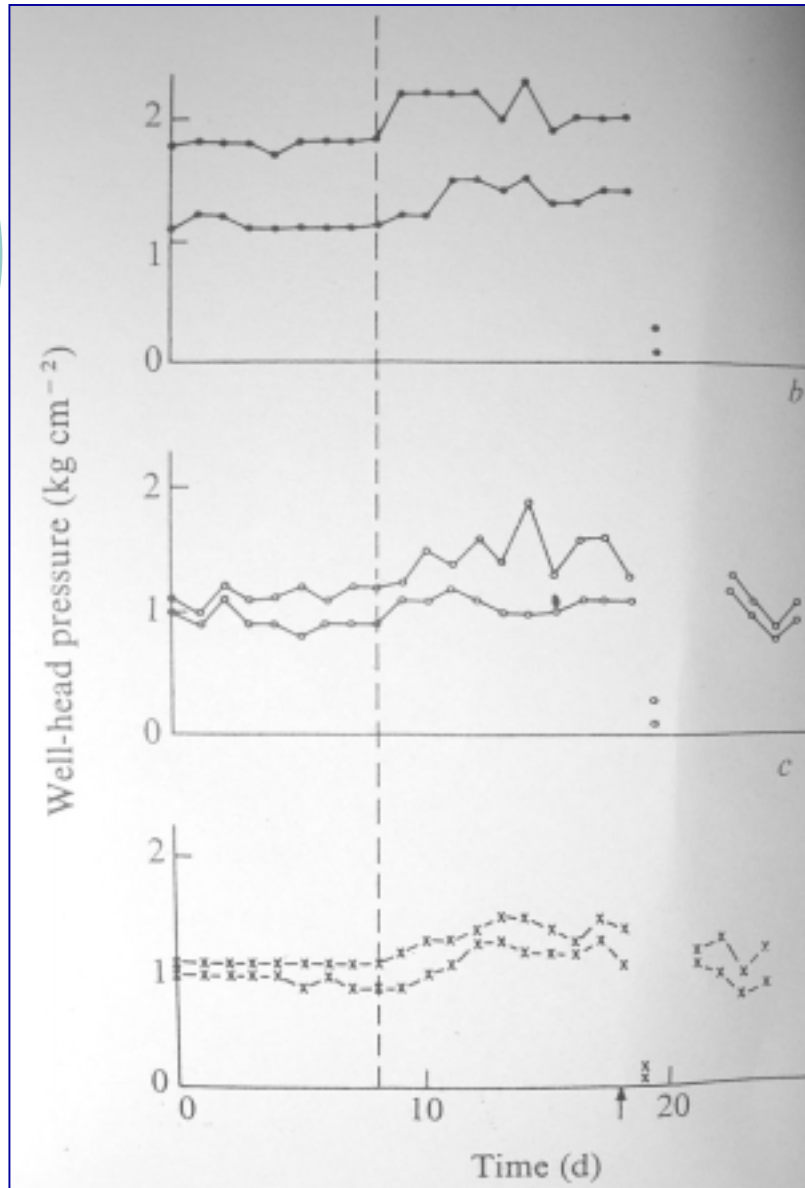
Sub-Province	Site	Well
Taipei Basin	2	4
Taoyuan Tableland	1	2
Hsinchu-Miaoli Area	16	35
Choshui River Alluvial Fan	70	193
Chiayi-Tainan Area	39	104
Pingtung Plain	55	132
Ilan Plain	13	29
Total	196	499



Previous Study: Groundwater anomalies associated with Earthquake

- A significant rise in well head pressure in Niushan gas field 9 days prior to the Jan. 18th,1964 Tainan-Chiayi earthquake(Wu,1975; Wu and Feng,1975)**
- Good agreement of groundwater level fluctuation associated large earthquake at a deep well at Ilan area (Yu et al.,1984)**
- Groundwater level fluctuation correlated with local seismicity and focal mechanism (Yu and Luh, 1988)**
- In 1980~1984 several spike-like anomalies of radon content could be related to several moderate earthquake.**
- Studies of Groundwater level changes associated with Chi-Chi earthquake (Chia et al., 2000; Wang et al., 2000; Lin et al., 2001; Lee, 2001; Lai et al., 2002)**

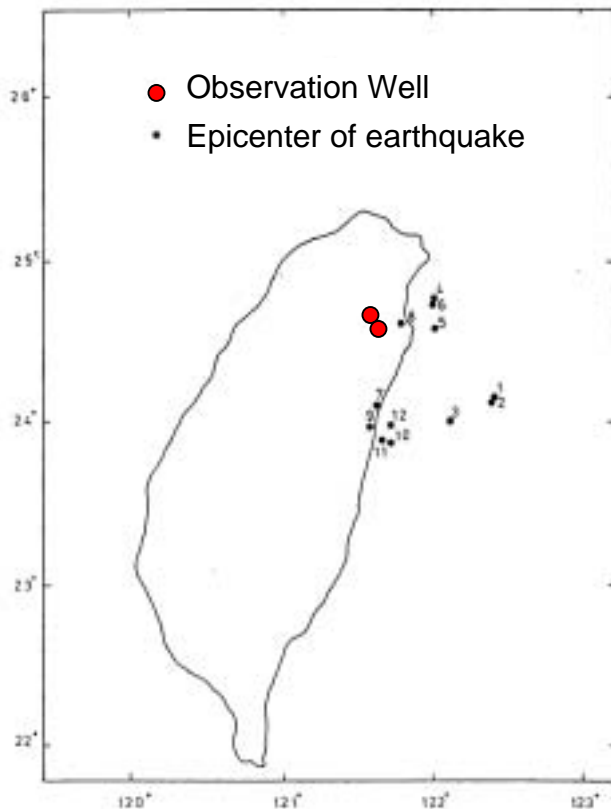
Jan. 18th, 1964 Tainan-Chiayi earthquake



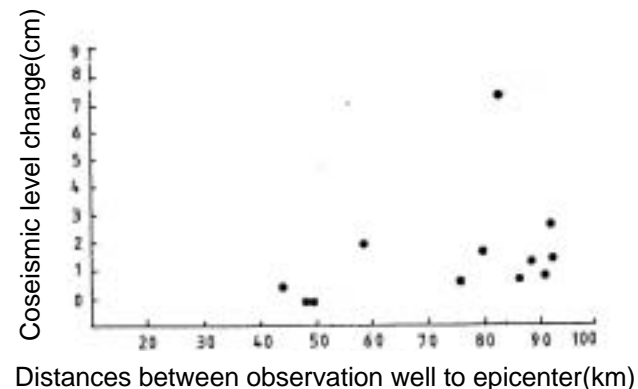
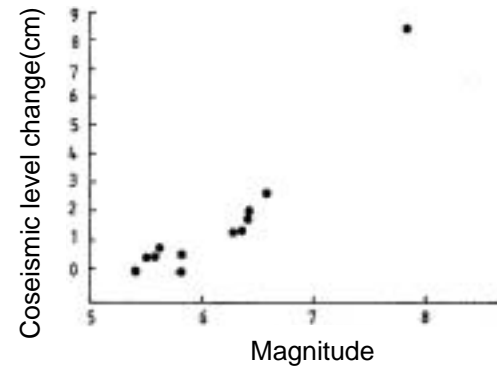
(Wu, 1975; Wu and Feng, 1975)

A case study at a deep well in Ilan area (Yu et al., 1984)

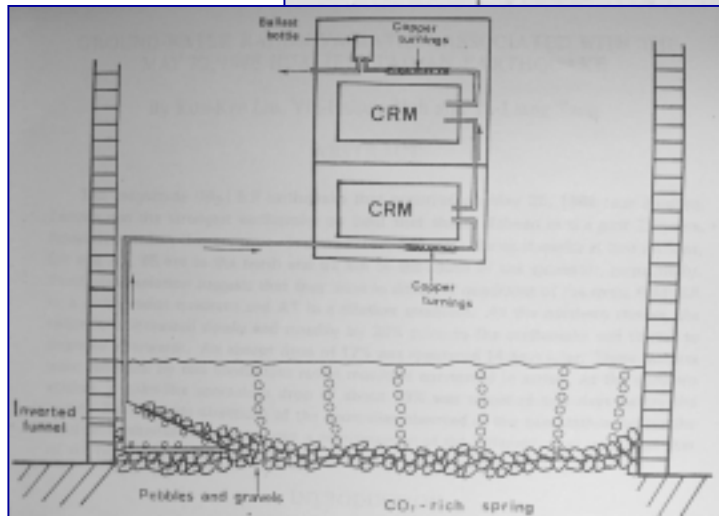
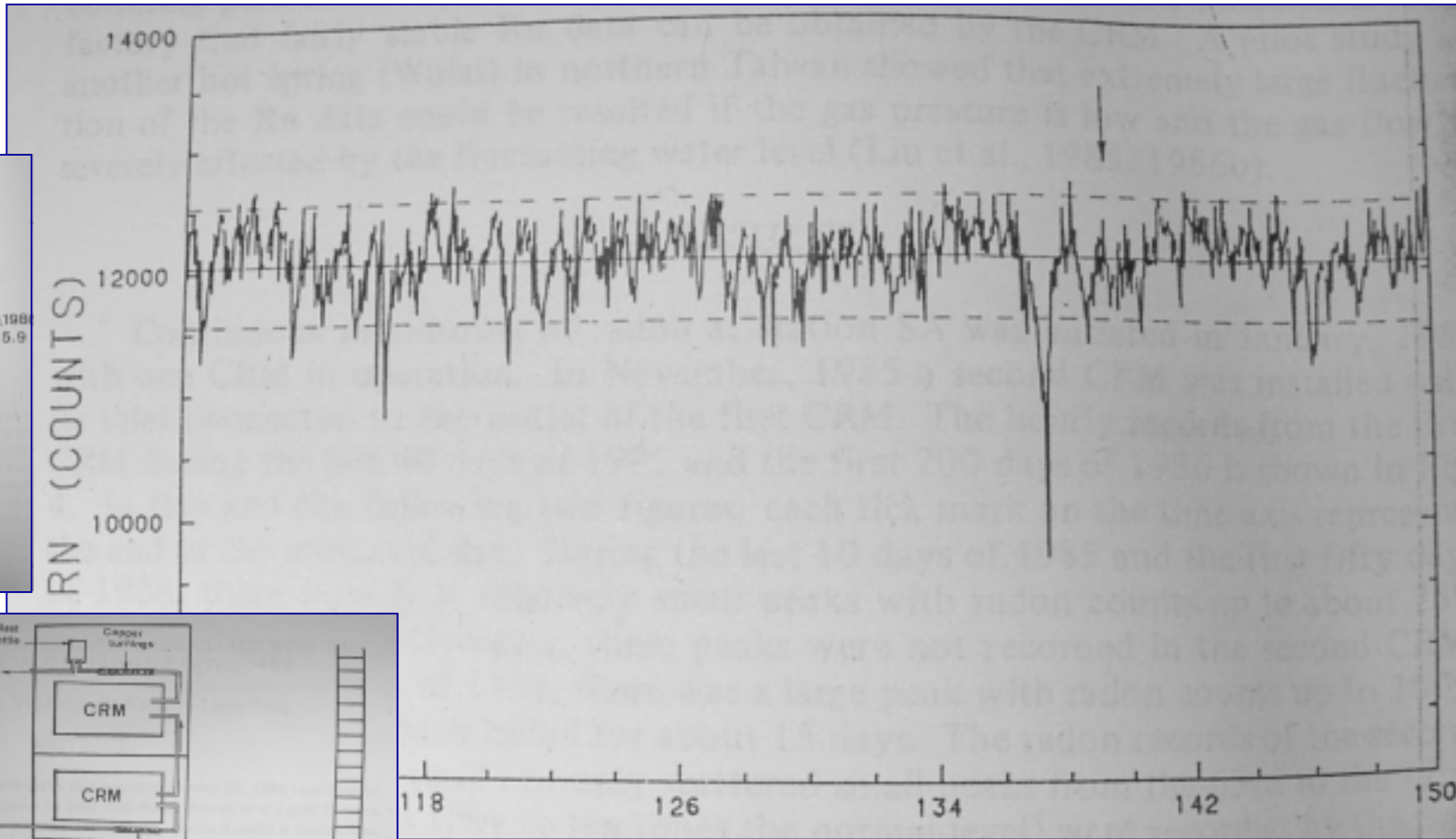
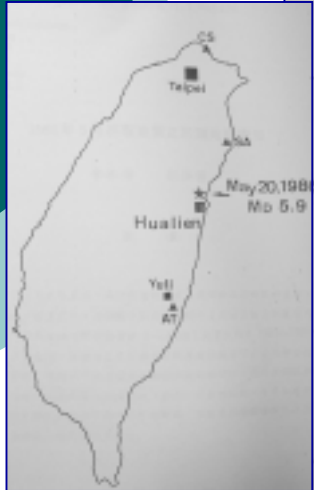
Two geothermal observation wells, depth are 500 m, when situated at the dilation quadrant of focal mechanism coseismic changes are increase, and when situated at the compression quadrant of focal mechanism coseismic changes are decrease



Position of observation well and epicenter of earthquakes used in the study



Radon Anomalies in Hualien Earthquake, May 20, 1986 (Liu et al., 1987)



Background Information of Groundwater Monitoring Network in Taiwan

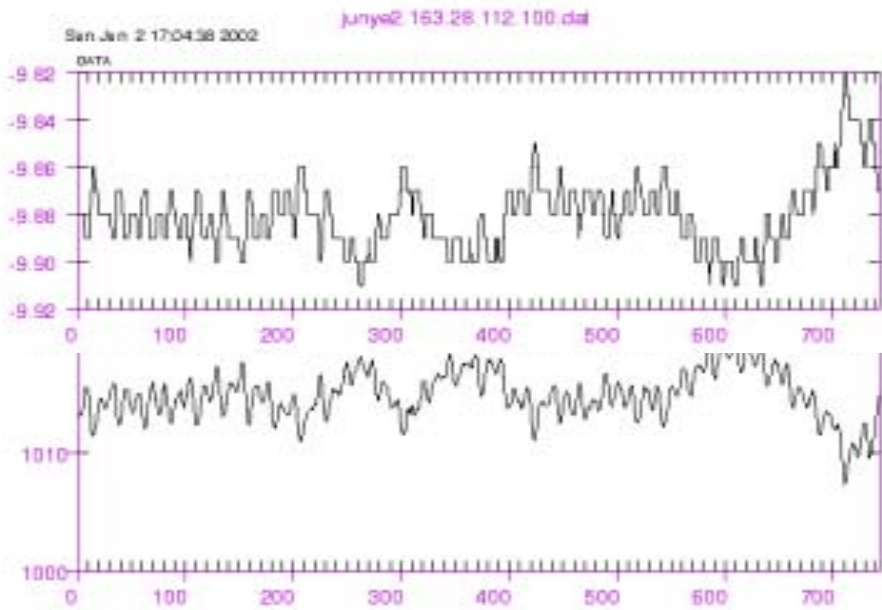
❑ Disadvantage

- The depth of the observation wells are shallow than 300m
- Mostly effect by pumping and surface water circulation
- Resolution of existing data are too low for analysis tidal and coseismic change

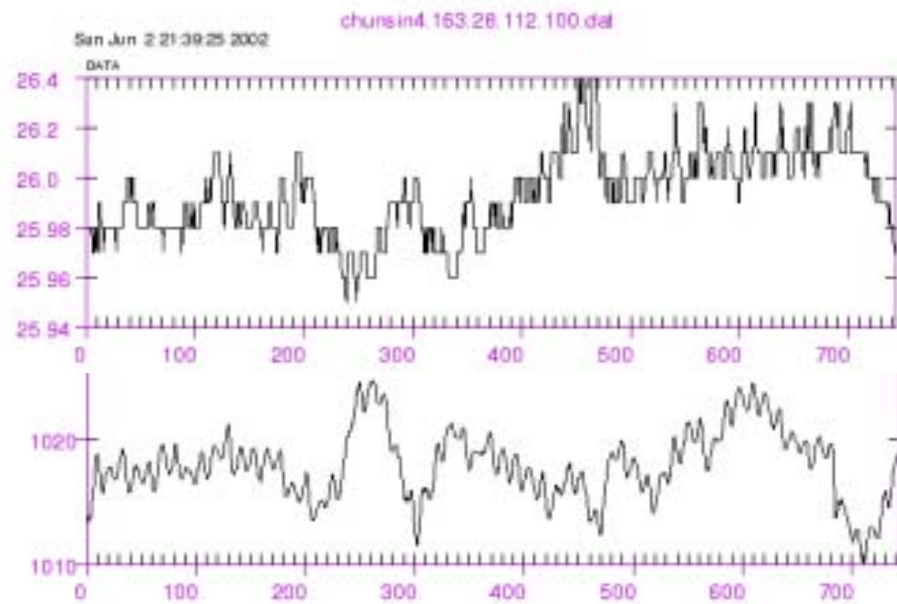
❑ Advantage

- Different screened aquifers in one site
- Detail hydrology and geology study
- Large number of the observation wells around the island

Barometric Response of Groundwater Level

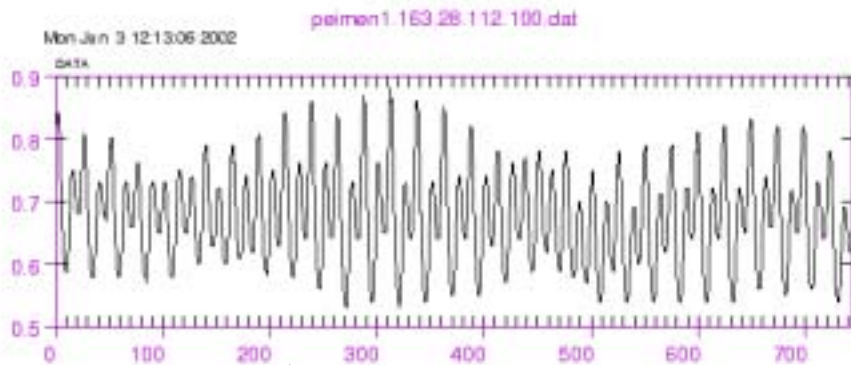


總爺(二)

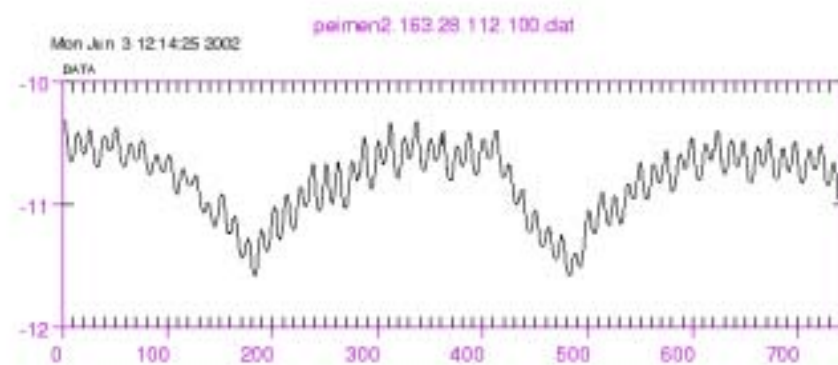


中興(四)

Oceanic Tide Effect

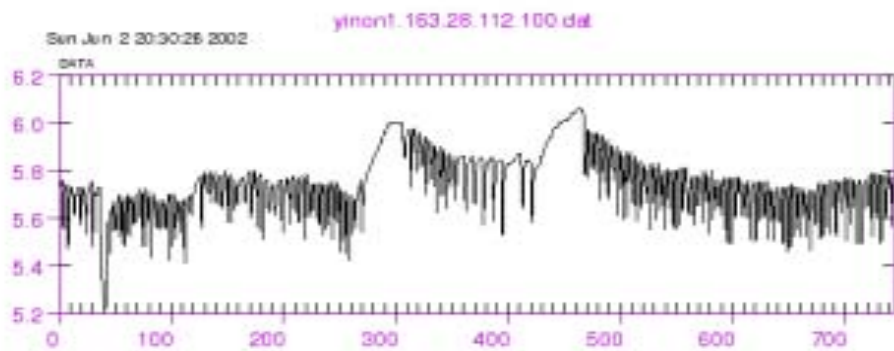


北門 (一)

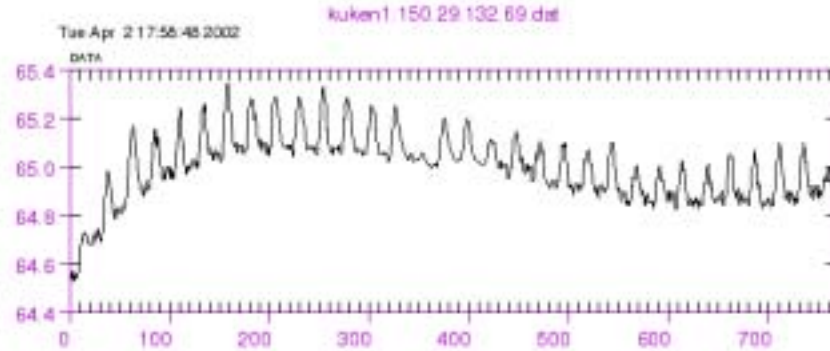


十份 (一)

Pumping and Injection Effect



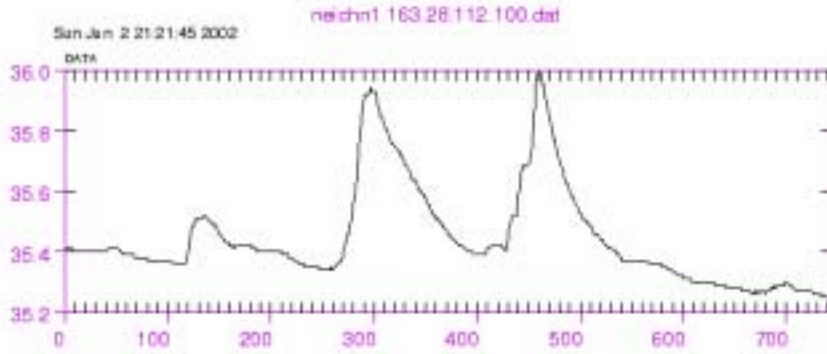
宜農 (一)



古坑 (一)

Rainfall Effect

Discharge Effect by River Flow



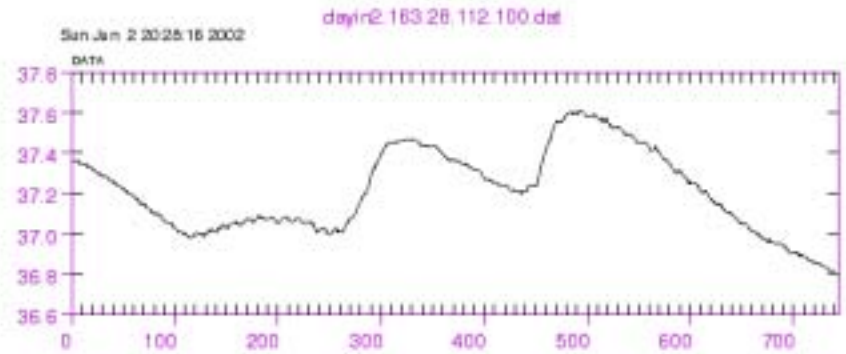
城(一)



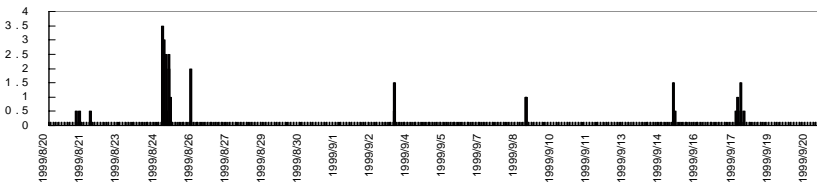
自強國小(一)



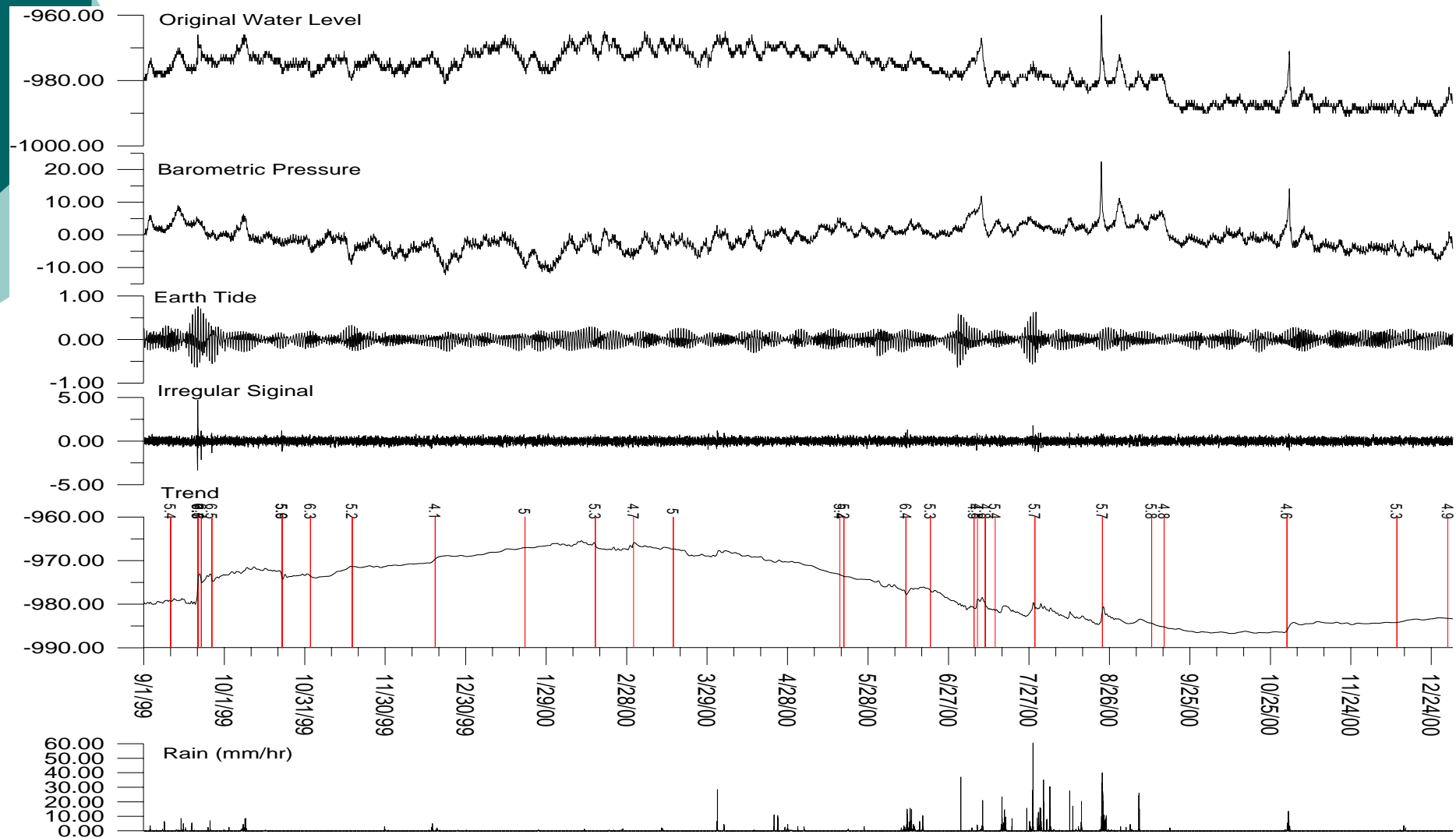
三和(一)



大隱(一)

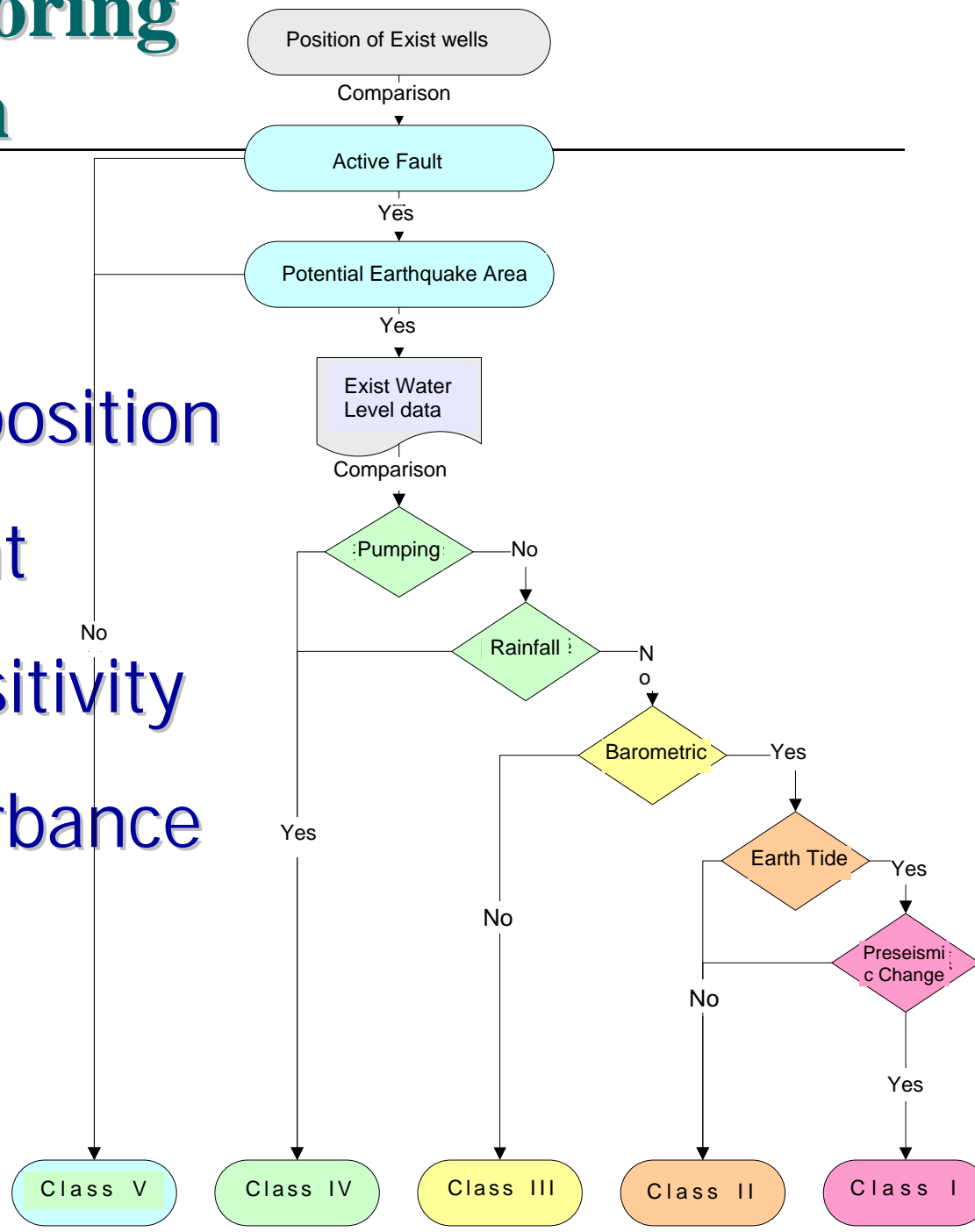


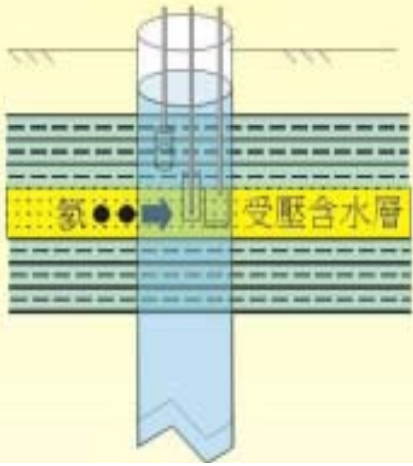
Exist Water level data analysis and site selection



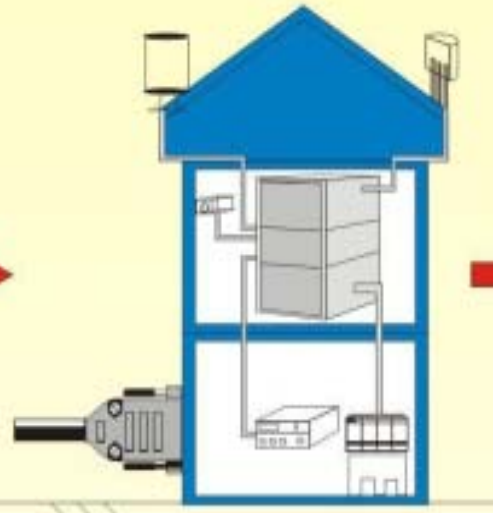
Criteria in Monitoring Site Selection

- ❑ Good Structural position
- ❑ Good confinement
- ❑ Highly strain sensitivity
- ❑ No artificial disturbance

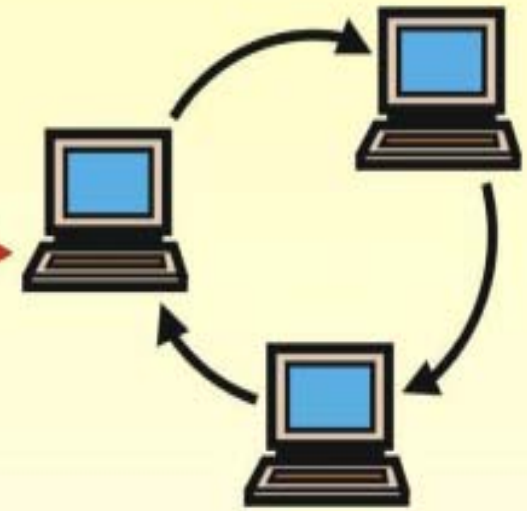




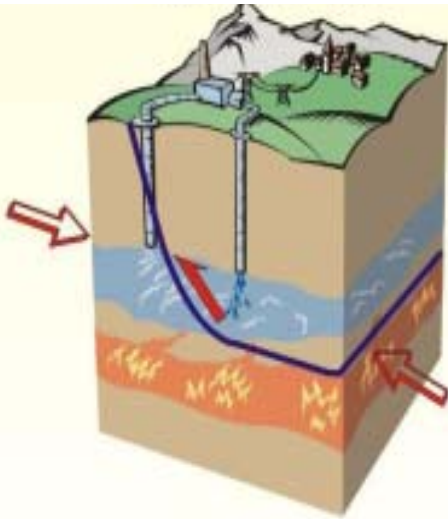
Observation well selection



Observation instruments installation



Data transfer and record network



Related earthquake prediction study



Data publish
Information system



Data correction and
analysis technique

Result of sites selection

□ 2001

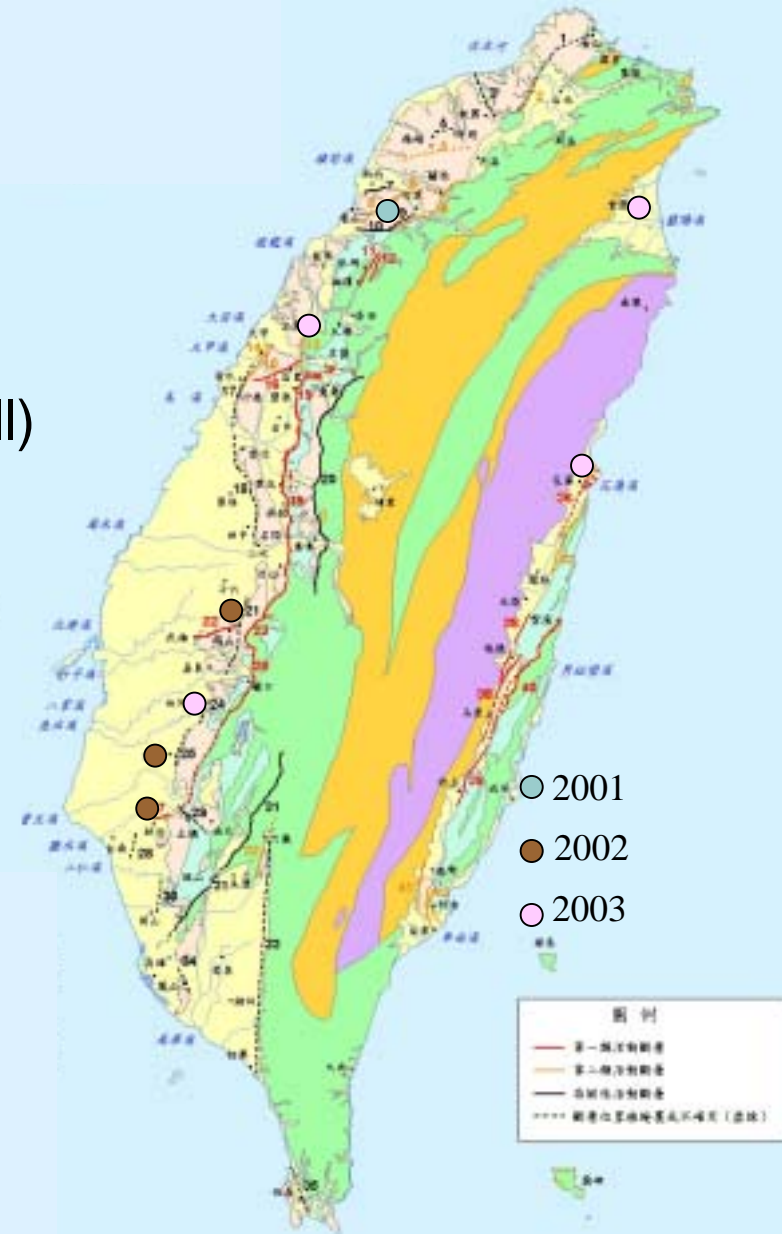
- Hsinchu area (1 well)

□ 2002

- Choushuichi alluvial fan (1 well)
- Tainan-Chiayi area (2 well)

□ 2003

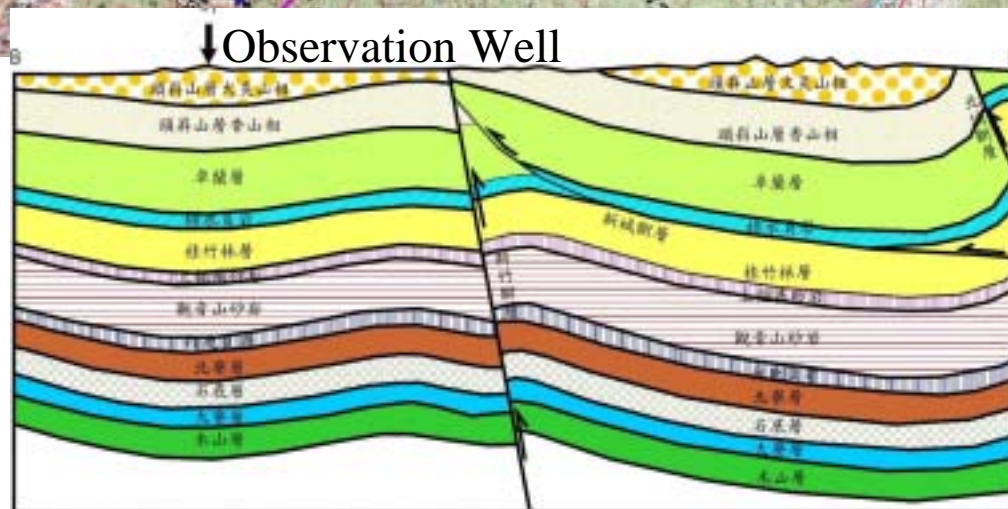
- Miaoli area (1 well)
- Tainan-Chiayi area (1 well)
- Ilan plain (1 well)
- Hulien area (1 well)



Observation Well in Hsinchu area: Sinpu Primary School



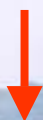
- Locate on the fold axis of syncline and close to the fault



Close View of the observation wells

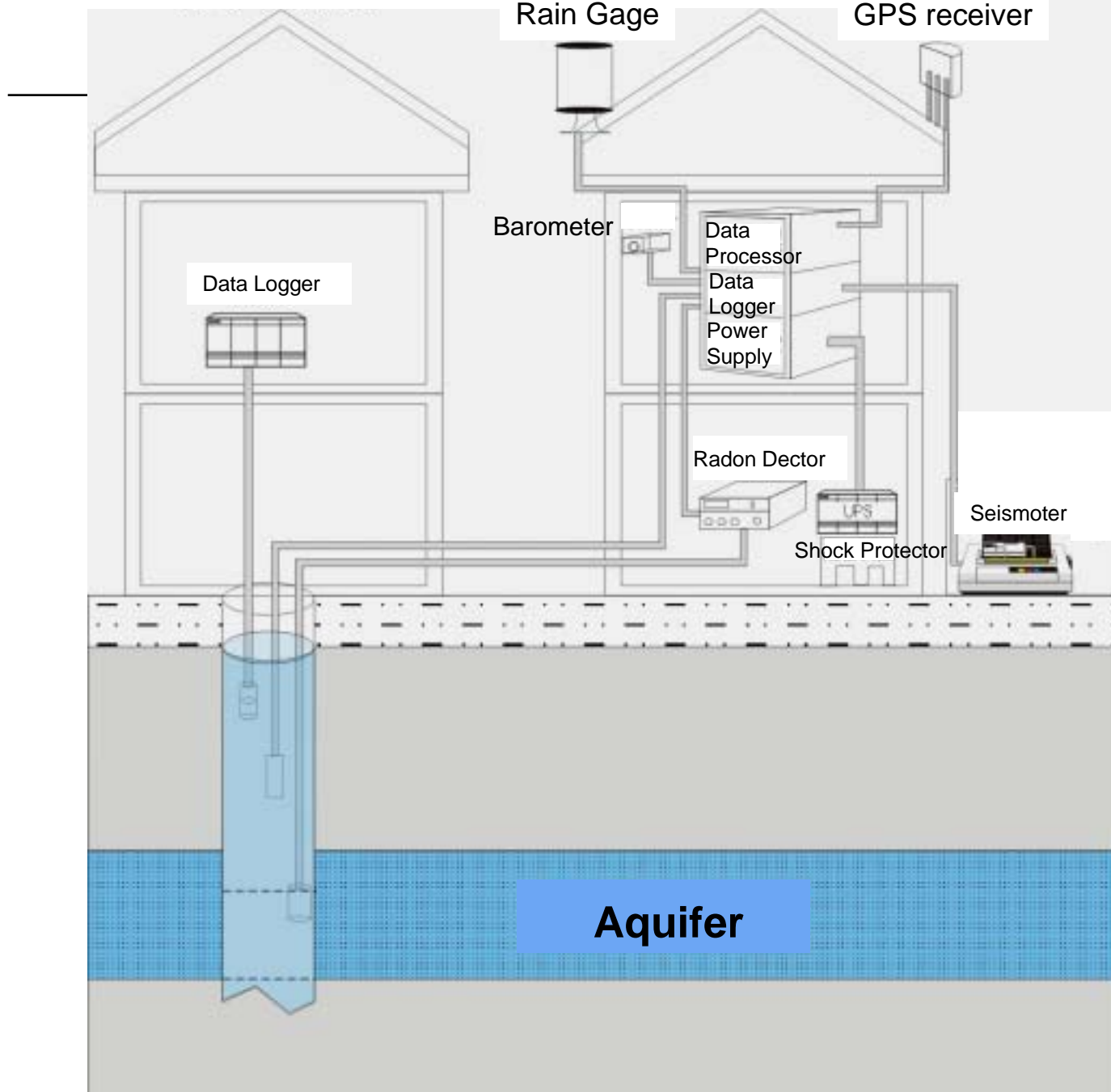


Sinpu observation well



Original surveillances

New surveillances

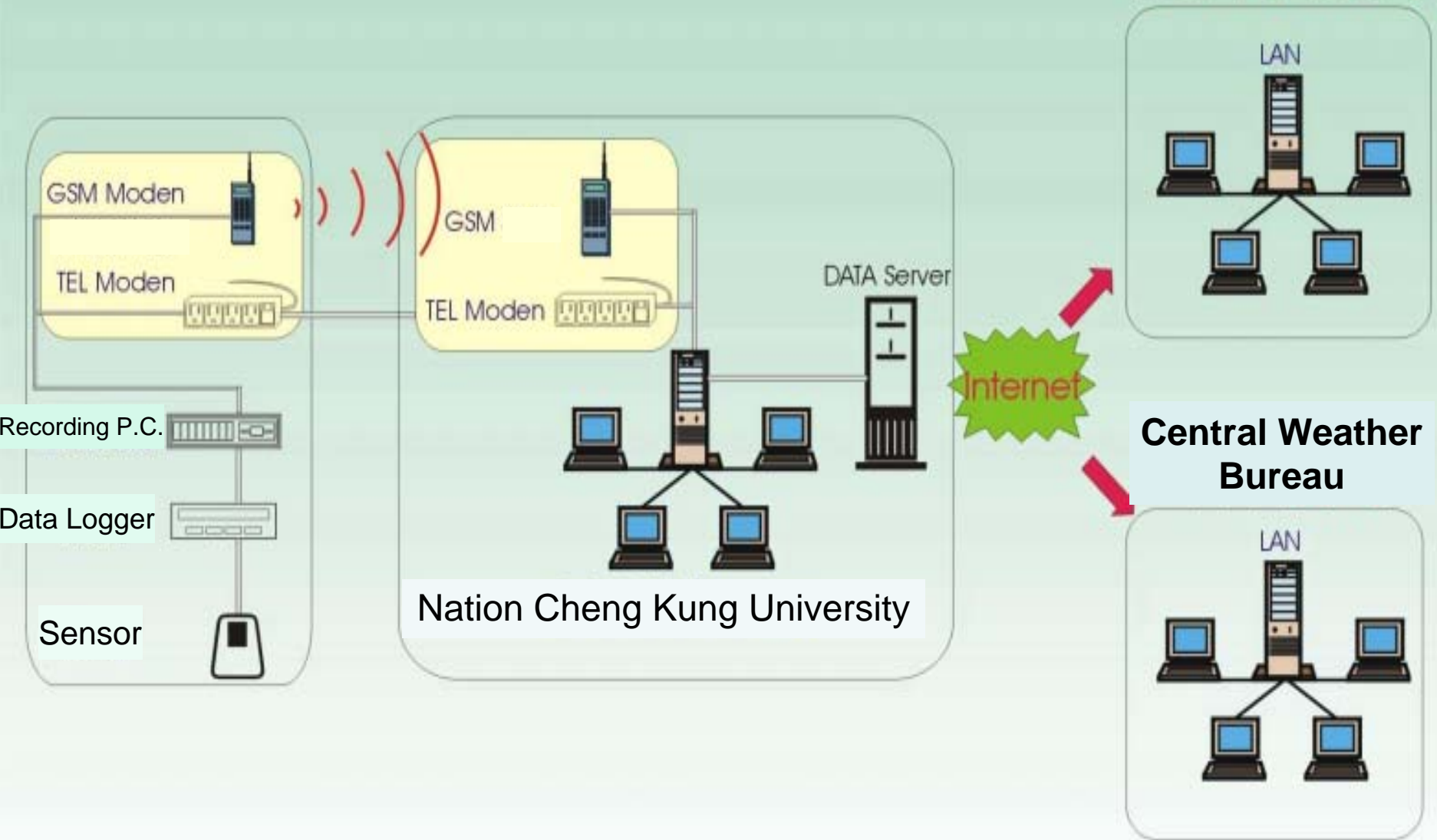


Instruments of Sinpu Observation Well



Data Transfer and Record Network

Water Resource Agency



Observation Well

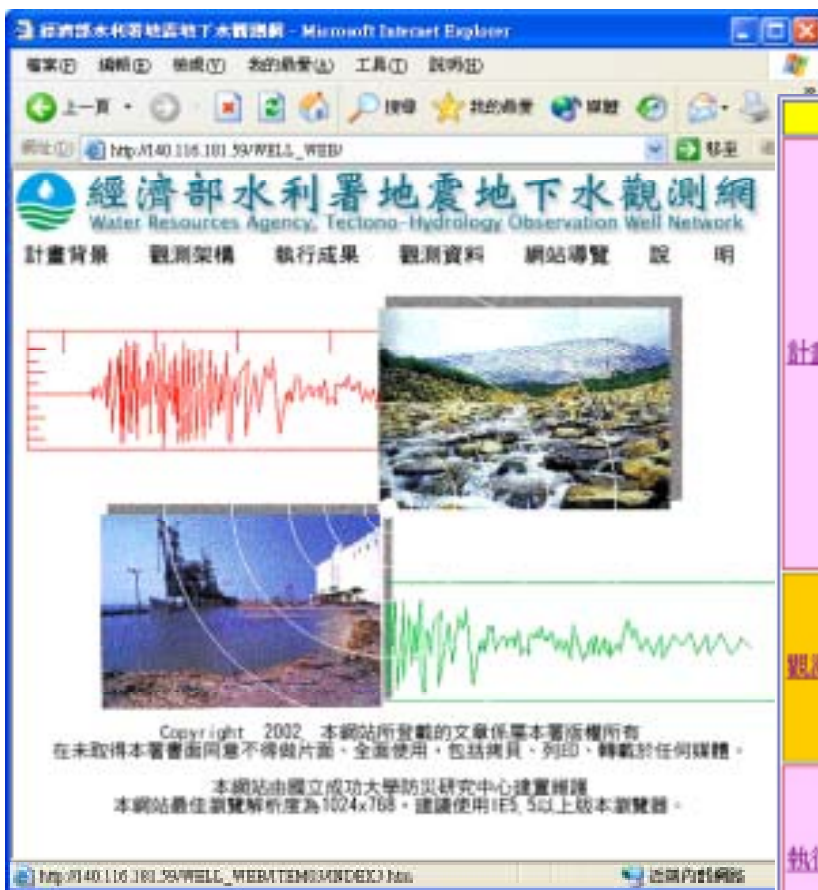
Phone Line

Monitoring Center

Internet

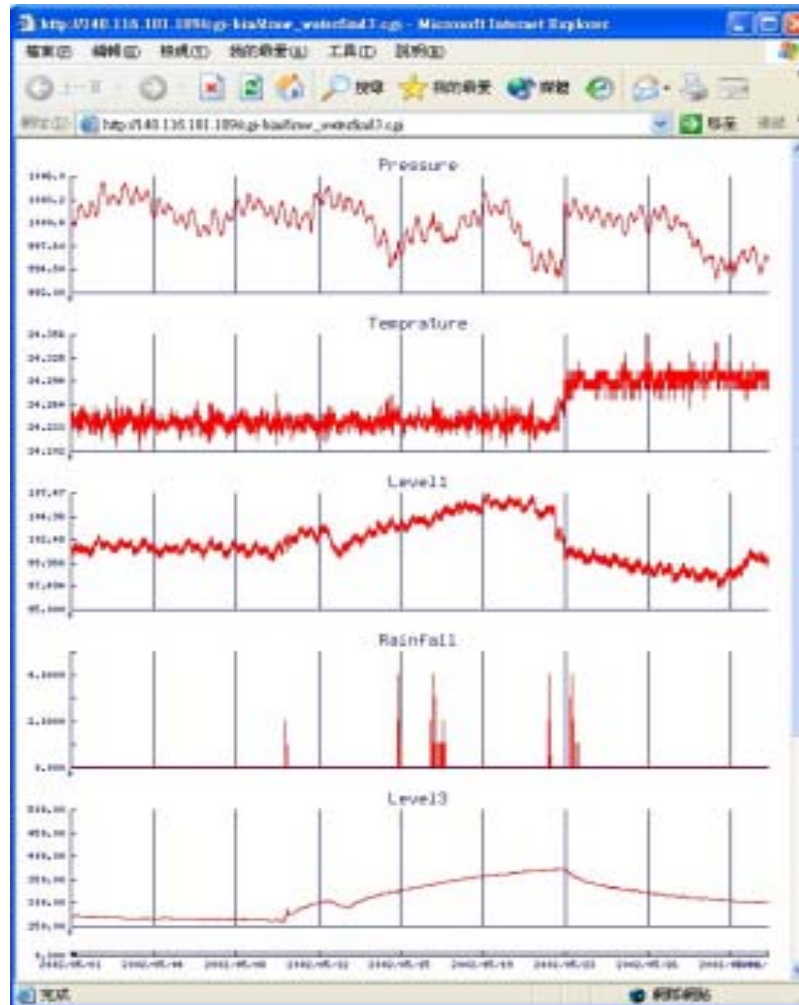
Government Agency

Observation Data Publish System



經濟部水利署地震地下水觀測網			
計畫背景	計畫源起		
	理論背景	理論依據 膨脹-擴散模式 含水層彈性應變 模式岩體破裂模式	
	觀測網建置	直接目標	
		最終目標	
		階段性目標	第一期計畫目標
第二期計畫目標			
第三期計畫目標			
第四期計畫目標			
第五期計畫目標			
觀測架構	方法及流程		
	儀器設備	測站現場狀況	
		資料觀測儀器	
資料收錄設備			
資料傳輸系統			
執行成果	第一期計畫成果		
	第二期計畫成果		
	第三期計畫成果		
	第四期計畫成果		
	第五期計畫成果		
觀測資料			
網站導覽			
說明			

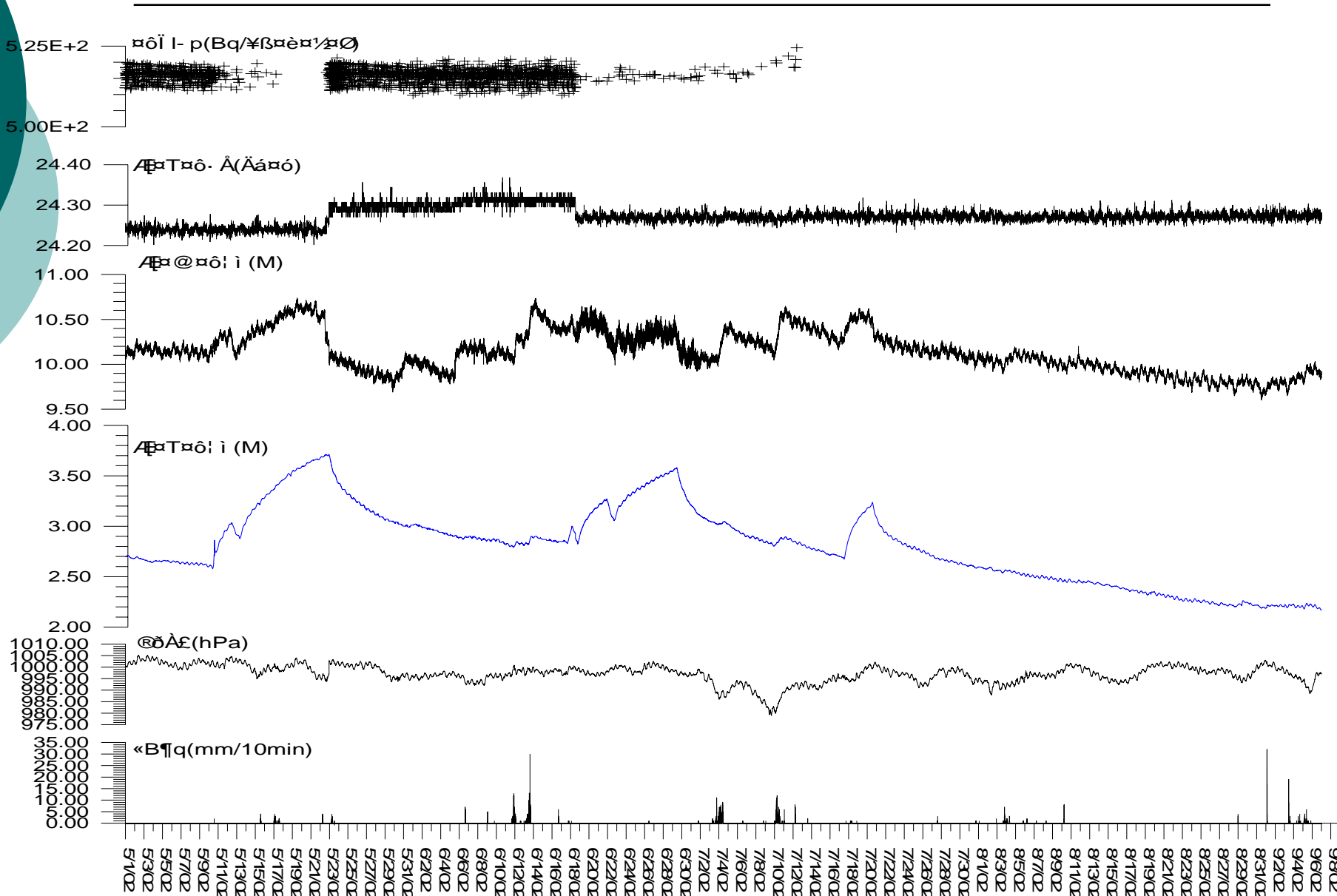
Publish the Observation Data on Internet Homepage



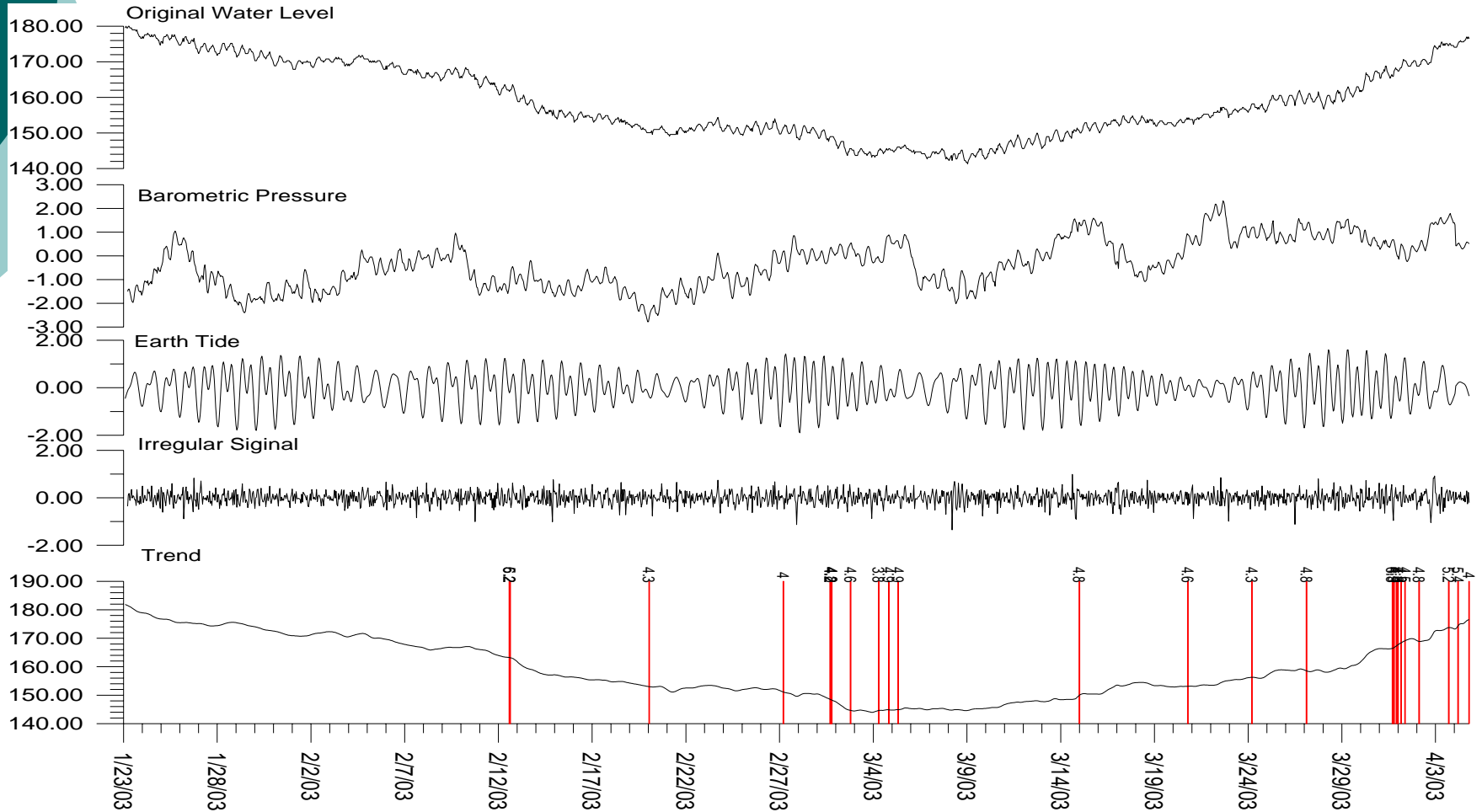
The screenshot shows a web browser window displaying a data table with the following columns: 記錄時間 (Recording Time), 觀測時間 (Observation Time), 氣壓計 (Pressure), 水溫計 (Water Temperature), 觀一水位 (Water Level 1), 雨量計 (Rainfall), 觀二水位 (Water Level 2), and 水質 (Water Quality). The table contains 16 rows of data.

記錄時間	觀測時間	氣壓計 (hPa)	水溫計 (°C)	觀一水位 (m)	雨量計 (MM)	觀二水位 (CM)	水質 (Bq/m ³)
2002/06/13 AM 00:00:00	2002/06/12 16:01:09	998.34	24.319	101.82	0	280.88	0 ++ 0
2002/06/13 AM 00:10:00	2002/06/12 16:11:11	998.26	24.319	102.65	0	281.88	0 ++ 0
2002/06/13 AM 00:20:00	2002/06/12 16:21:10	998.04	24.307	102.6	0	281.88	0 ++ 0
2002/06/13 AM 00:30:00	2002/06/12 16:31:11	997.82	24.319	102.6	0	281.88	0 ++ 0
2002/06/13 AM 00:40:00	2002/06/12 16:41:10	997.68	24.307	102.81	0	281.88	5.17854 ++ 2
2002/06/13 AM 00:50:00	2002/06/12 16:51:11	997.31	24.307	101.98	0	281.88	0 ++ 0
2002/06/13 AM 01:00:00	2002/06/12 17:01:09	997.02	24.307	102.13	0	281.88	5.160605 ++ 2
2002/06/13 AM 01:10:00	2002/06/12 17:11:11	996.72	24.319	102.81	0	281.88	5.162607 ++ 2
2002/06/13 AM 01:20:00	2002/06/12 17:21:11	996.58	24.295	103.07	0	281.89	0 ++ 0
2002/06/13 AM 01:30:00	2002/06/12 17:31:09	996.58	24.319	102.24	0	281.89	5.155390 ++ 2
2002/06/13 AM 01:40:00	2002/06/12 17:41:11	996.58	24.307	103.07	0	281.89	0 ++ 0
2002/06/13 AM 01:50:00	2002/06/12 17:51:11	996.43	24.307	102.55	0	281.89	5.160569 ++ 2
2002/06/13 AM 02:00:00	2002/06/12 18:01:11	996.21	24.307	102.71	0	281.89	5.166658 ++ 2
2002/06/13 AM 02:10:00	2002/06/12 18:11:10	996.21	24.319	102.45	1	281.89	0 ++ 0
2002/06/13 AM 02:20:00	2002/06/12 18:21:10	996.36	24.282	103.12	0	281.89	5.161659 ++ 2
2002/06/13 AM	2002/06/12	996.43	24.307	102.6	0	281.89	0 ++ 0

Observation Data (5/1~9/8, 2002)

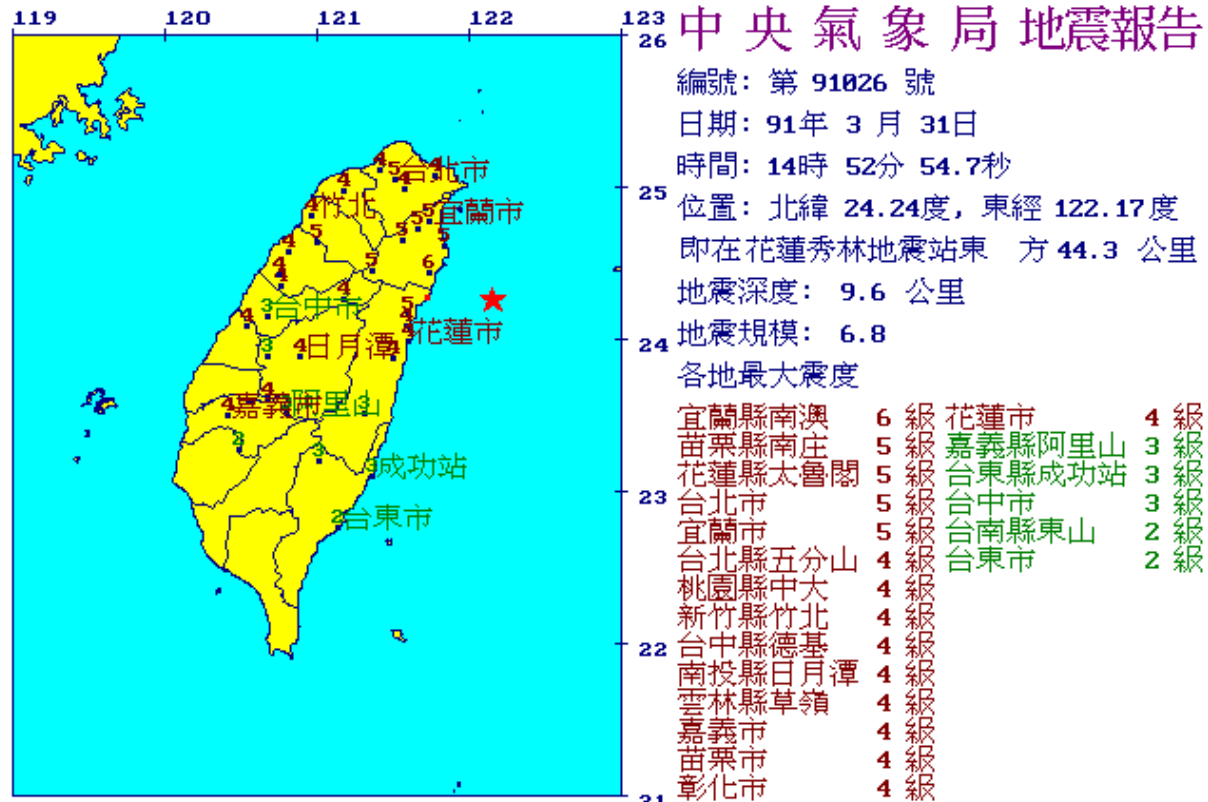


Comparison with locally and distant earthquakes



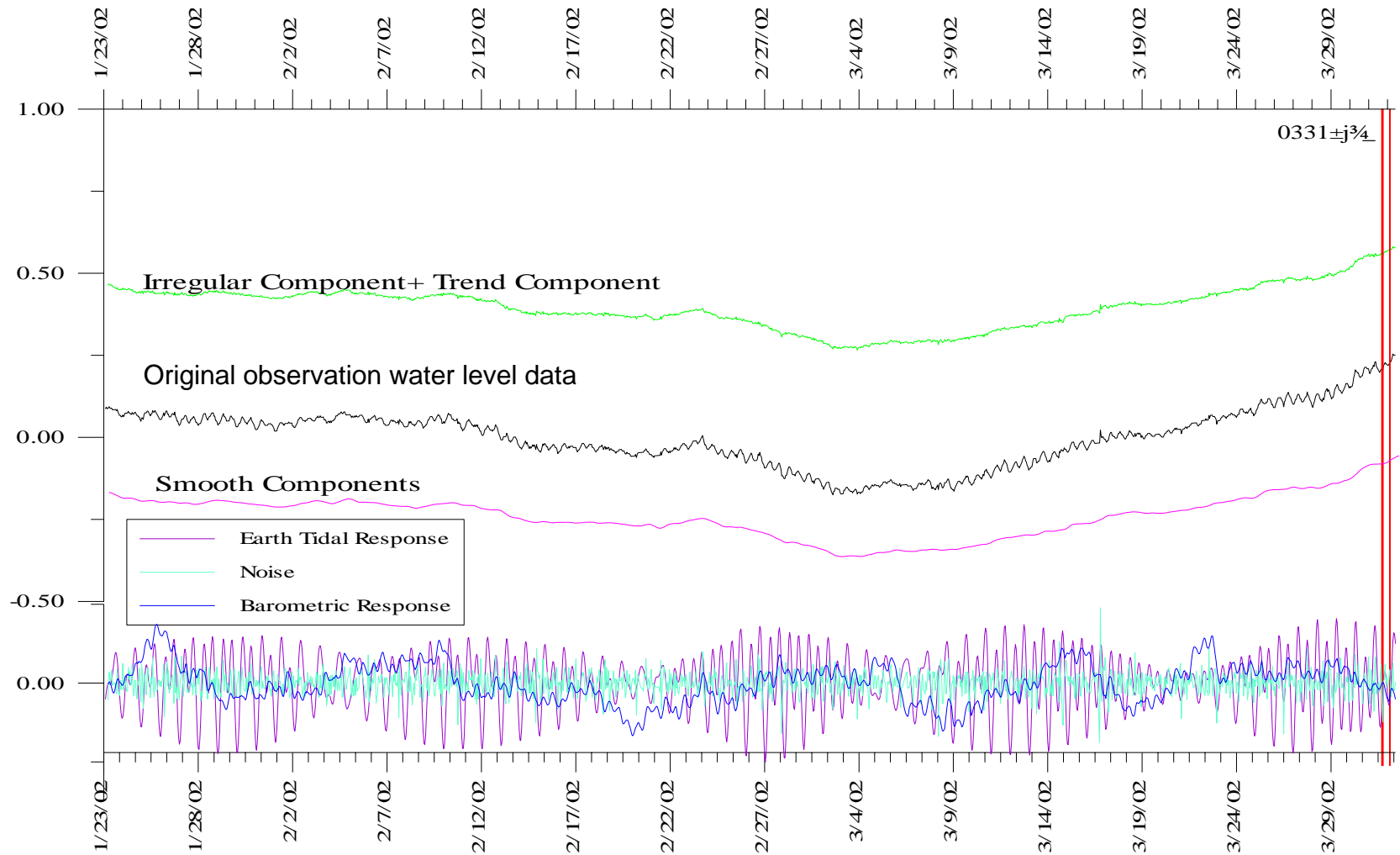
Hulien Offshore Earthquake (M: 6.8) March 31st, 2002

□ Central Weather Bureau's Quick-Release Earthquake Information



圖說：★ 表震央位置，數字表測站震度

Hulien Offshore Earthquake (M: 6.8) March 31st, 2002

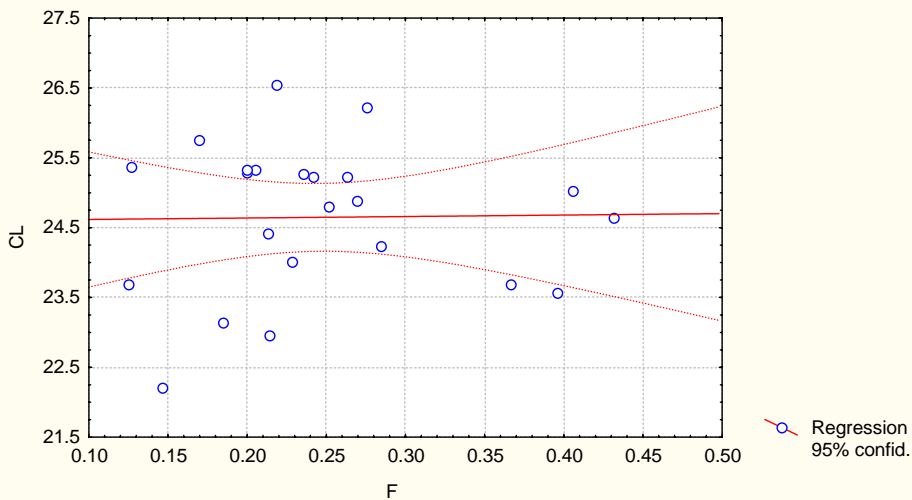


Monthly Sampled groundwater geochemistry analysis

F vs. CL

$$CL = 24.596 + .20985 * F$$

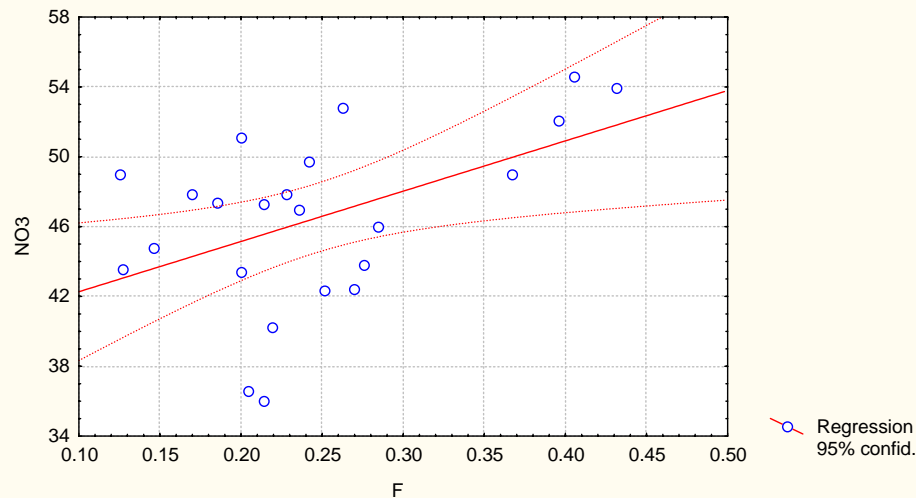
Correlation: $r = .01657$



F vs. NO3

$$NO3 = 39.390 + 28.806 * F$$

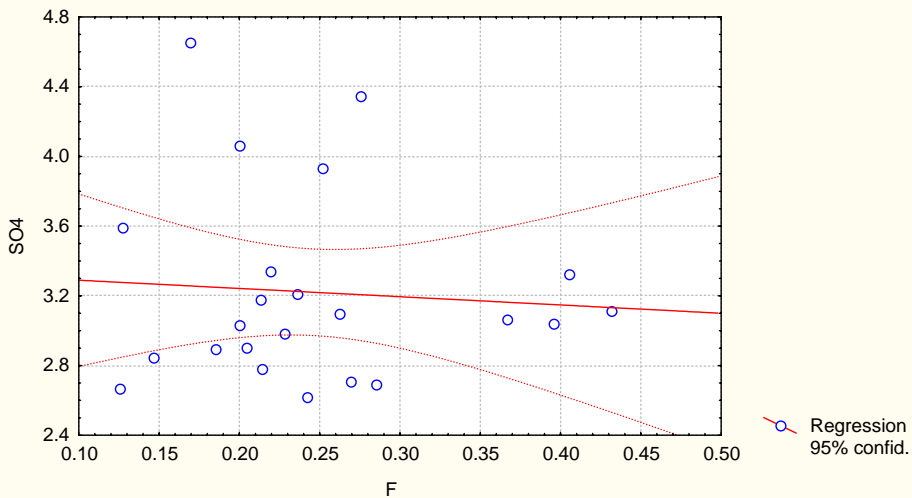
Correlation: $r = .48777$



F vs. SO4

$$SO4 = 3.3371 - .4738 * F$$

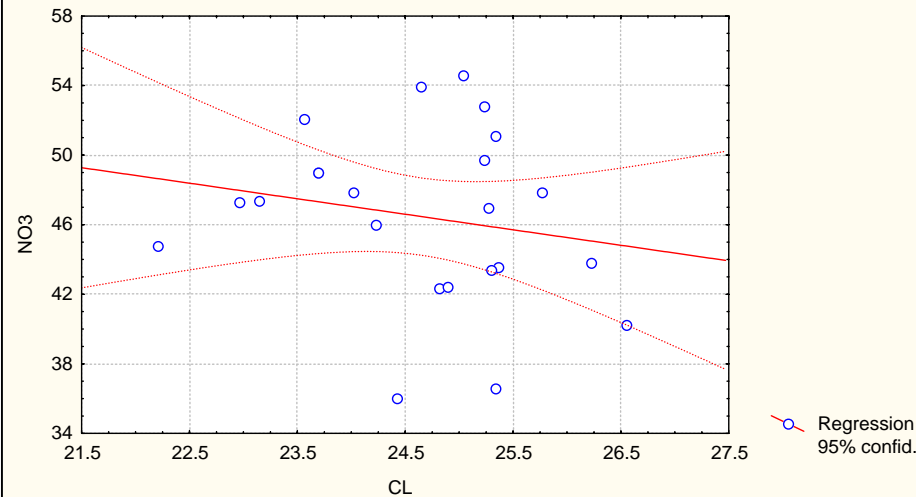
Correlation: $r = -.0730$



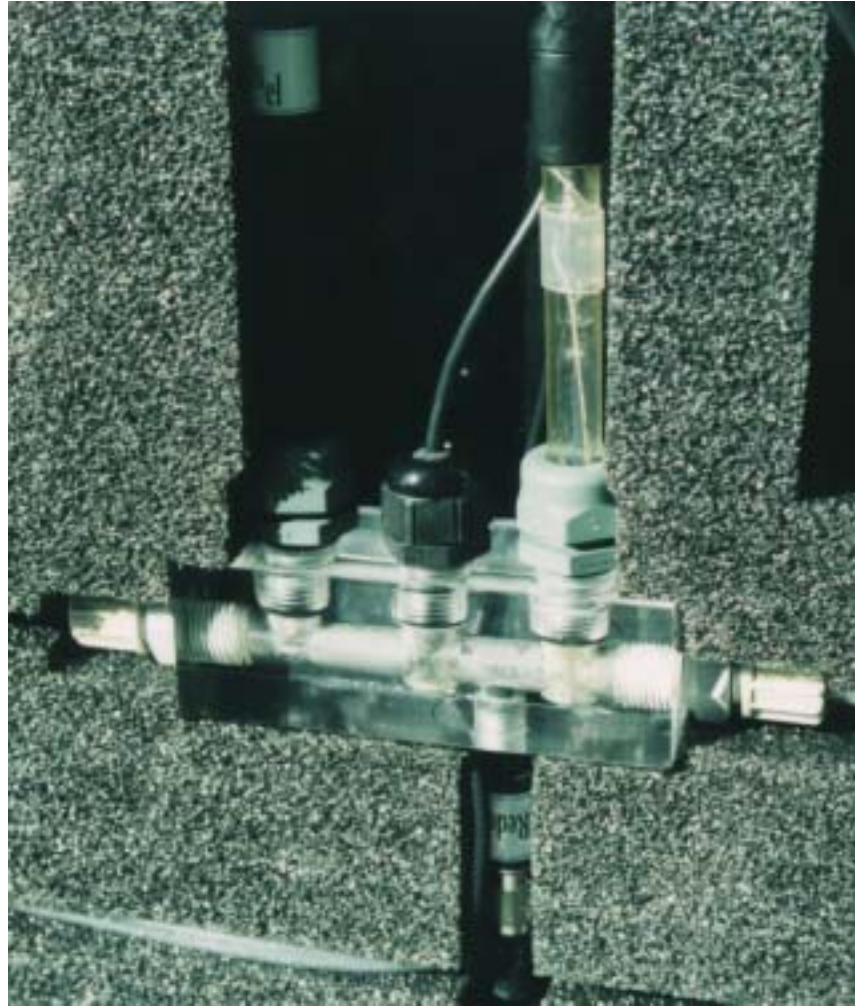
CL vs. NO3

$$NO3 = 68.466 - .8924 * CL$$

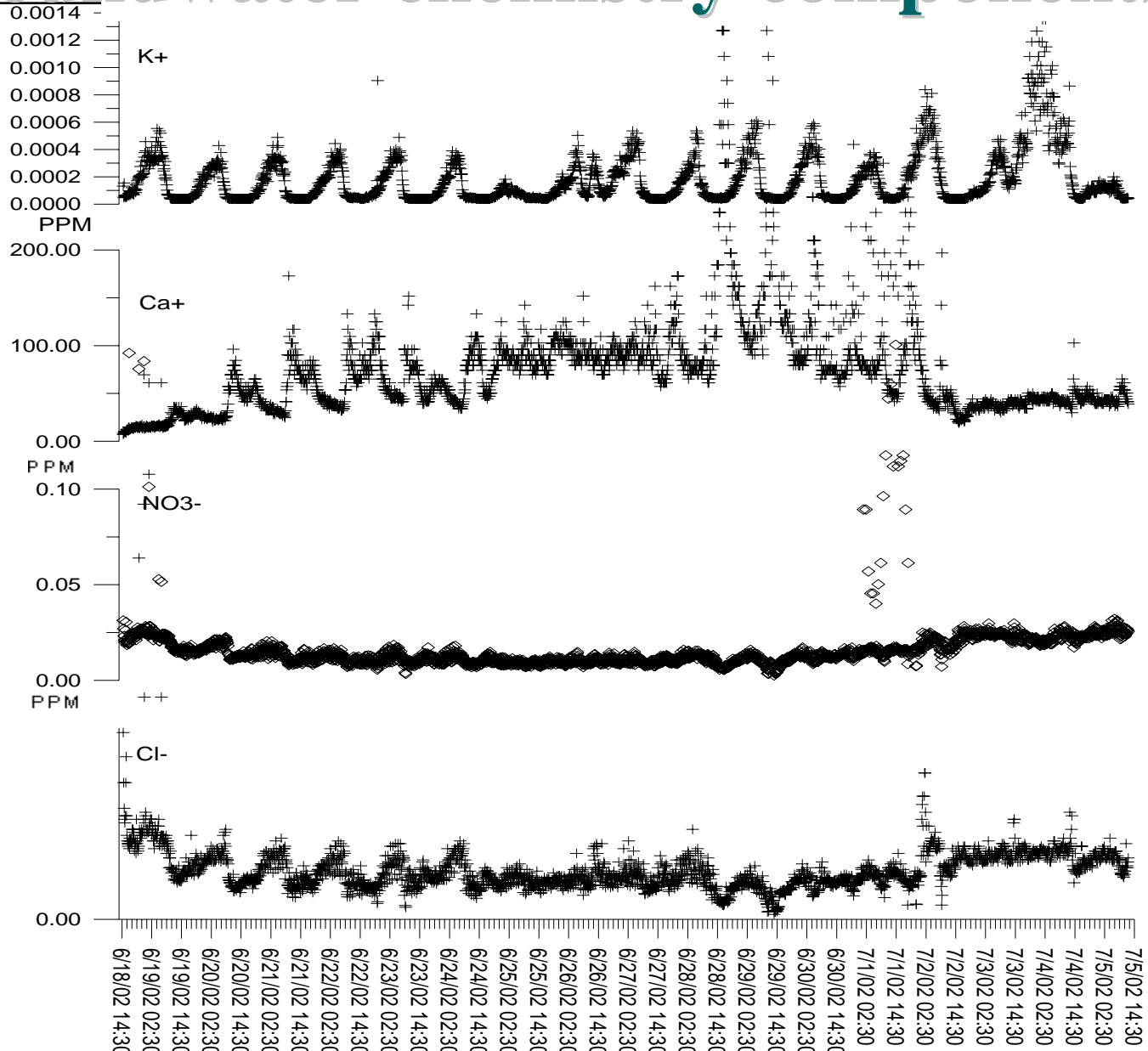
Correlation: $r = -.1914$



Continuously Geochemistry Monitoring



Continuously monitoring of groundwater chemistry components



Preliminary Conclusion

- ❑ **Improve the resolution and sampling interval of the highly dense groundwater observation network in Taiwan will offer more information for faulting or earthquake induced groundwater anomalies.**
- ❑ **Seriously noises made by artificial disturbances and surface water circulation will be rigorous challenge to our study.**
- ❑ **Except to purpose of earthquake prediction, our observation also offer more helpful information to groundwater hydrology and geosciences (ex. Earth tide fluctuation by oceanic loading).**
- ❑ **The groundwater level changes of Choushuishi Alluvial Fan in Sep. 21st 1999, show multi-effects of earthquake. The ground motion, liquefaction, permeability enhancement, crust strain also surface rupture of the earthquake fault induced the groundwater level changes. To clarify each effect should be done carefully and consider the characteristics of each well.**



— Thank You —

Abstract

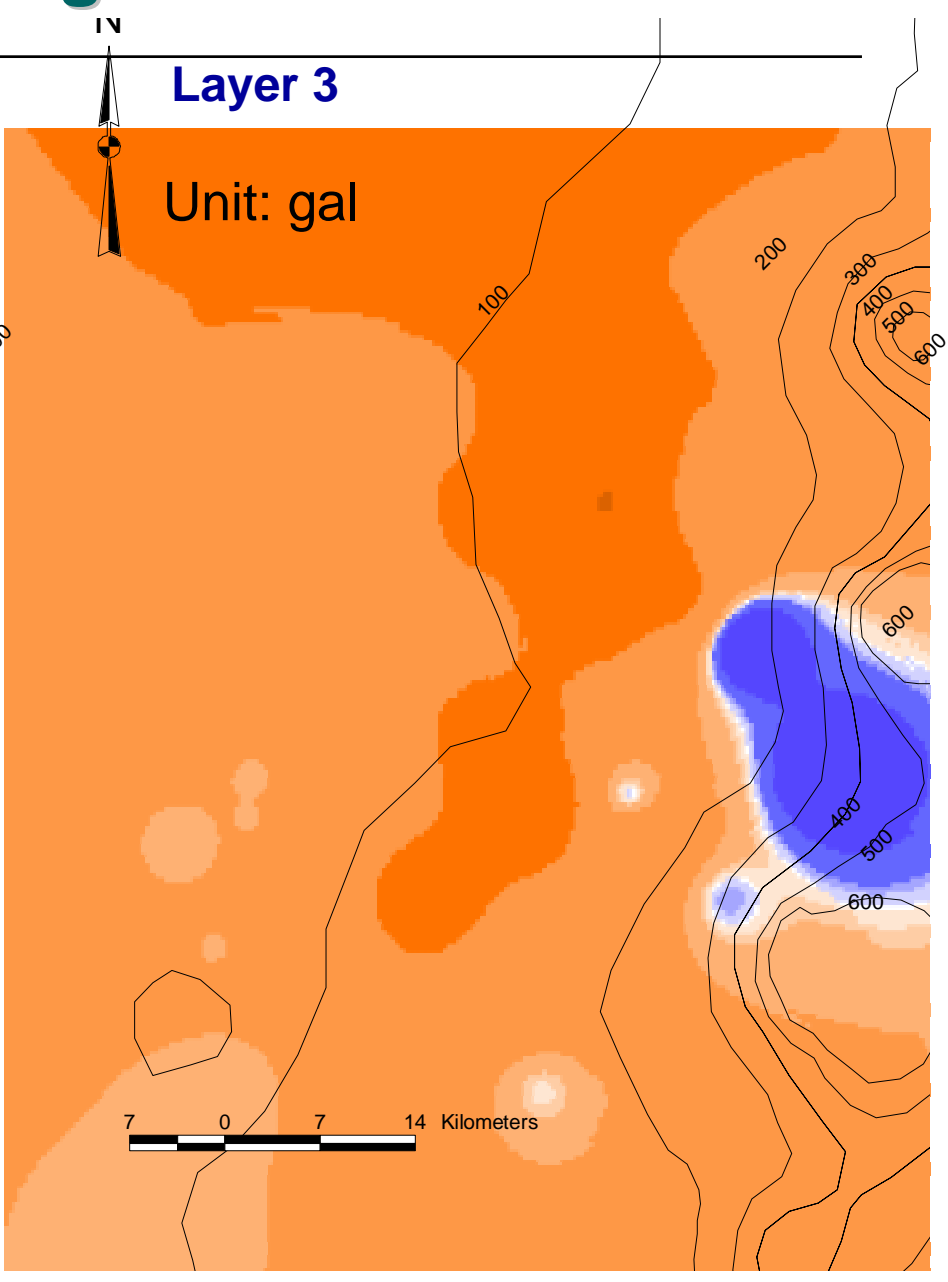
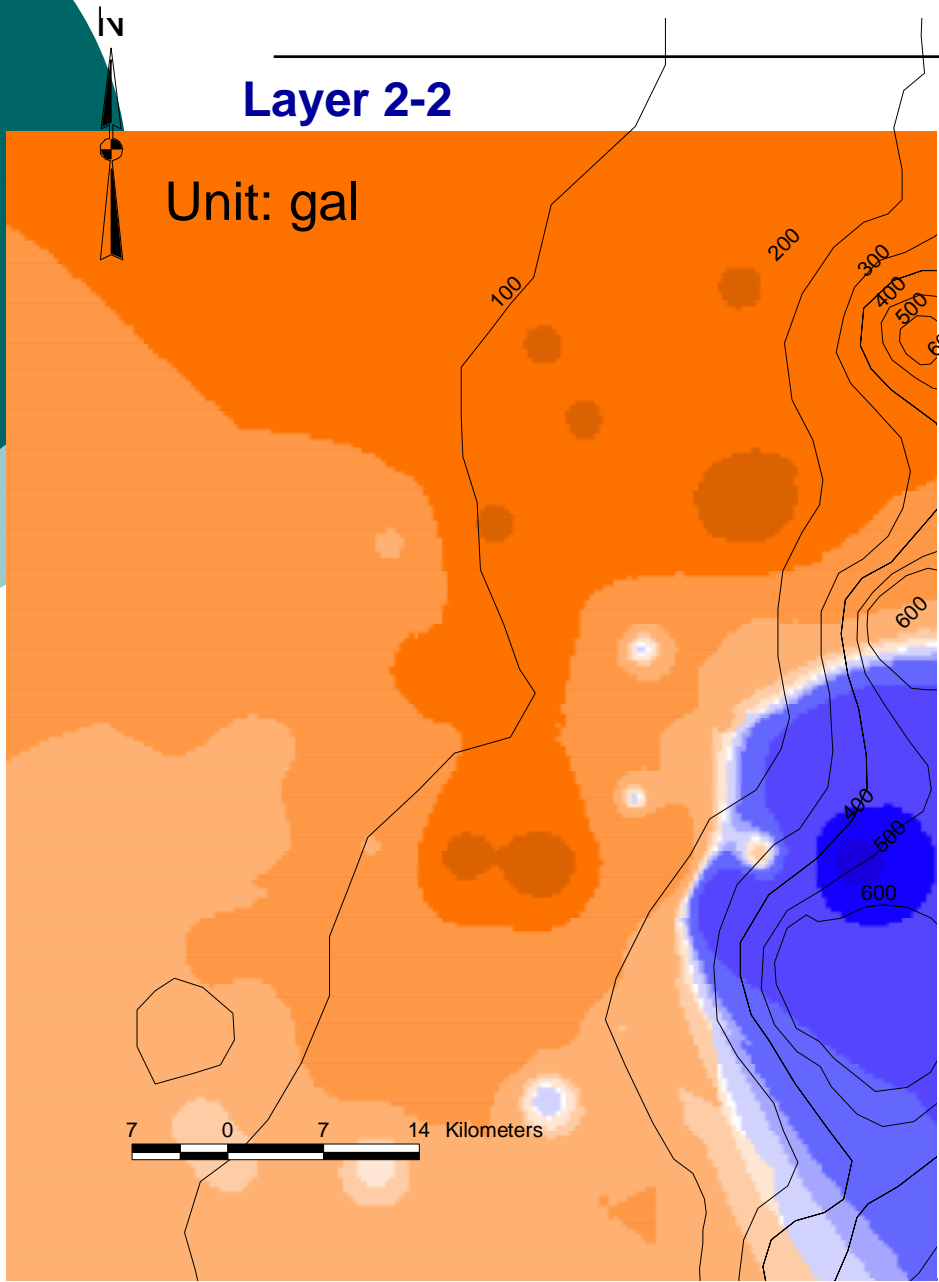
The main purpose of this five-years project is to study the earthquake-induced changes of the level, temperature, and chemical components of ground water. Through monitoring the physical and chemical characteristics of ground water, we hope can find some anomalies in ground water level, ground water temperature, and chemical components that can help identify the precursor of hazardous earthquakes in the near future.

In the first year, a monitoring system including the sensors of ground water level meter, ground water thermometer, Radon detector, atmosphere pressure meter, and GPS, has been set up at Shin-Pu primary school in Shin-Pu, Shinchu. In the system, data are measured every ten minutes, and they are automatically recorded. The recorded data will transfer to the information center at National Cheng Kung University through telephone every 12 hours.

To identify the anomalies of ground water that properly can indicate the precursor of hazardous earthquakes, the original recorded data need to be calibrated. The soft wares that developed by Geological Survey of Japan for calibrating the effects of earth tide and atmosphere pressure were used to analyze the recorded data. Besides, previous data that covered the Choushuichi alluvial fan and the Chiayi-Tainan area, and related to the Chi-Chi earthquake were also analyzed by the soft wares. The preliminary result shows that the groundwater level changes at most places after the Chi-Chi earthquake. It indicated the coseismic and postseismic changed of hydraulic parameters of aquifer occurred.

In order to build up 16 ground water monitoring systems in five years, three sites need to be selected for next year's project. According to the regional geological and

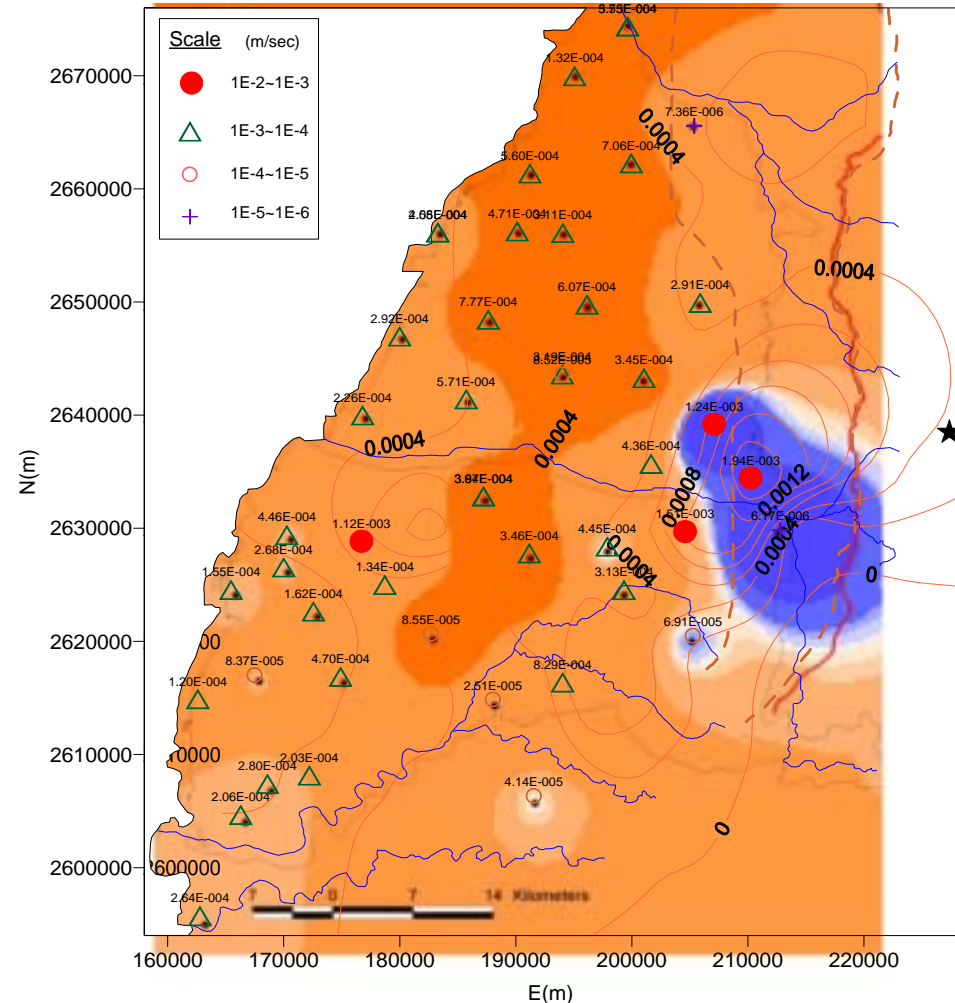
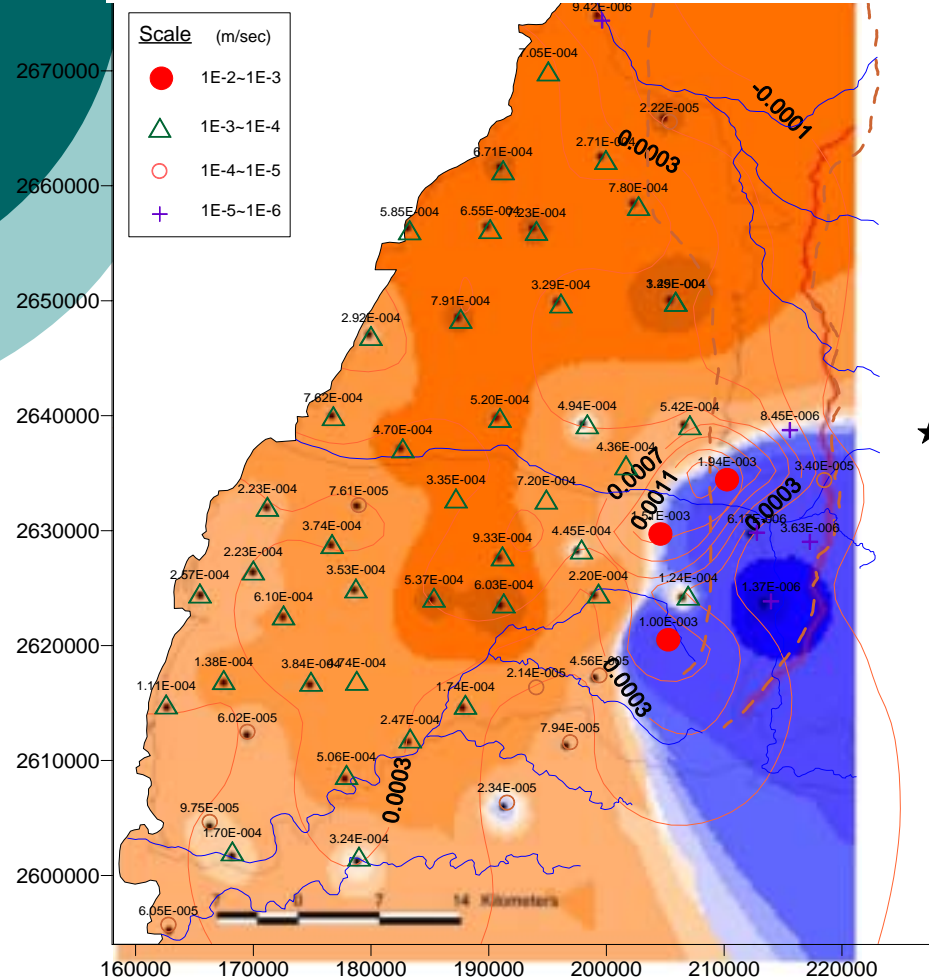
Groundwater Level Changes and Ground Motion



Groundwater Level Changes and Conductivity of Aquifer

Layer 2-2

Layer 3



Previous Study: Earthquake Seismology

- ❑ **First seismometer installed at Taipei in 1897**
- ❑ **1897~1935 Japanese seismologists constructed first seismic network composed by 17 stations.**
- ❑ **1972~1973 a network named “Taiwan Telemetered Seismographic Network (TTSN)” composed by 24 stations had constructed.**
- ❑ **1991~, a new seismic network “Taiwan Seismic Network (TSN)” upgrade from old network and merged with TTSN, totally composed by 72 stations.**
- ❑ **1980~1992 a island-wide strong-motion network consisting of 645 three-components accelerometers have been installed around the island.**

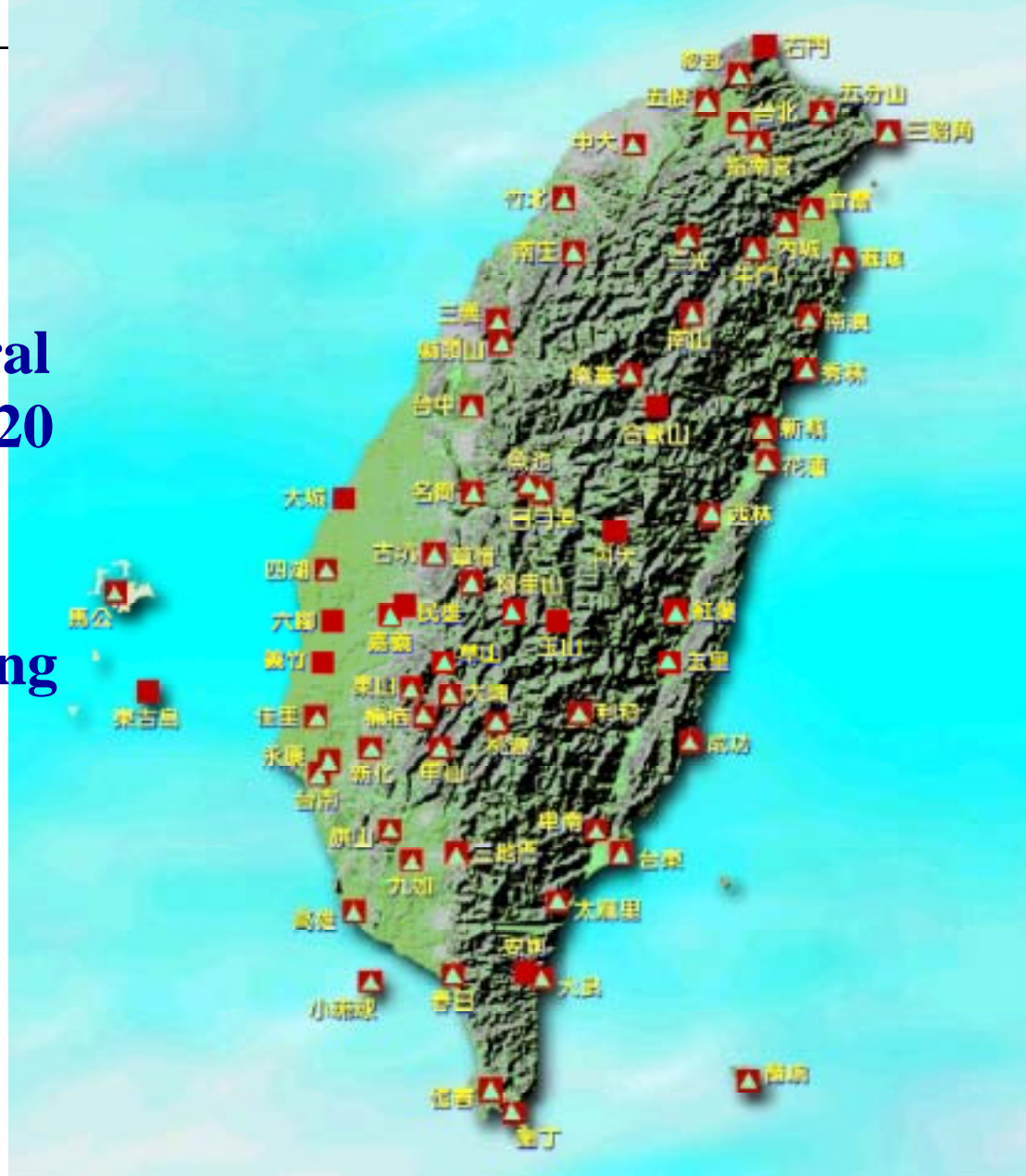
Taiwan Seismic Network

- 72 stations
- Locate the hypocentral data during the 60~120 sec.
- Roughly locate the hypocentral data during 30 sec.

Real Time Station
High Speed Station

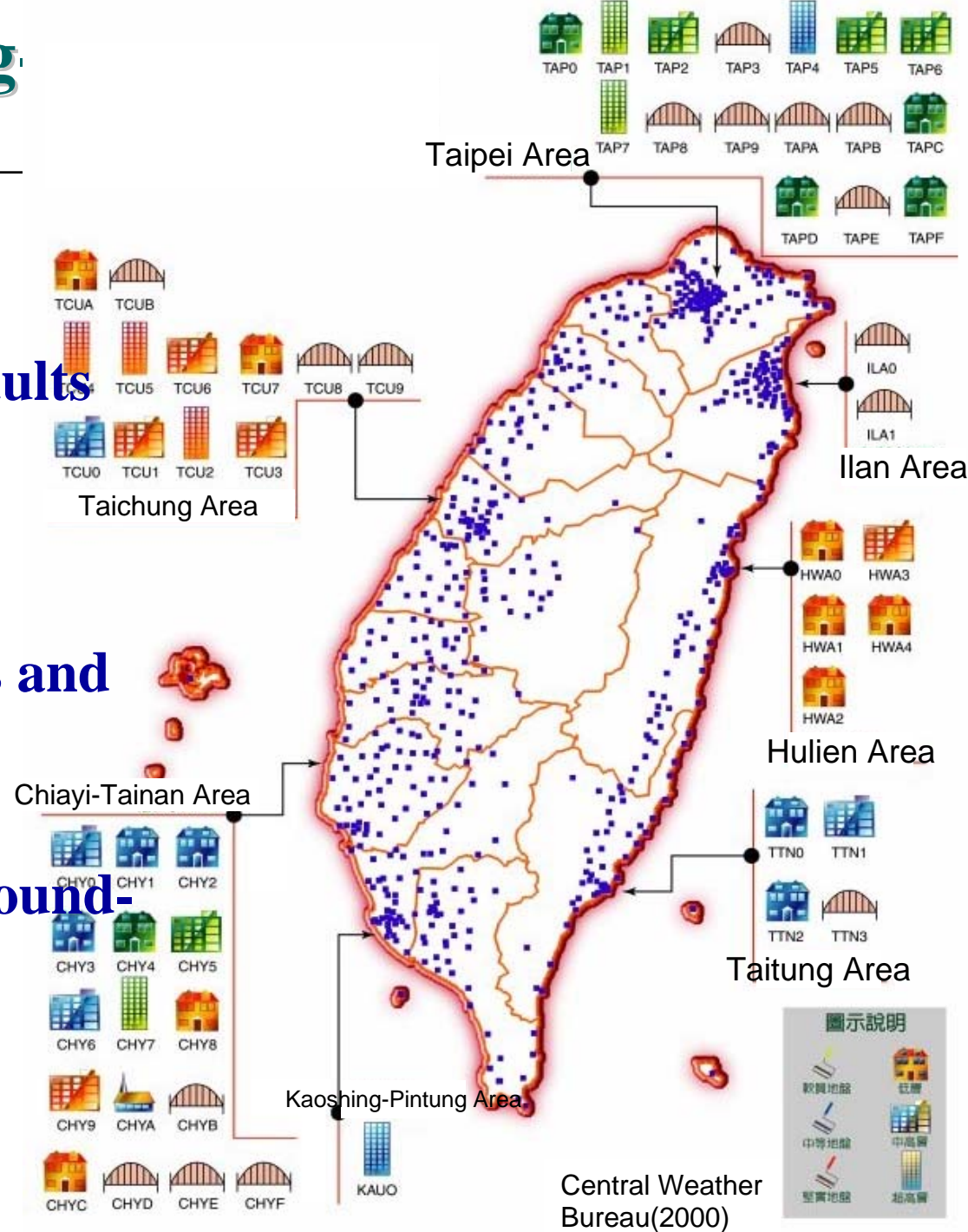


彭佳嶼



Island-Wide Strong Motion Network

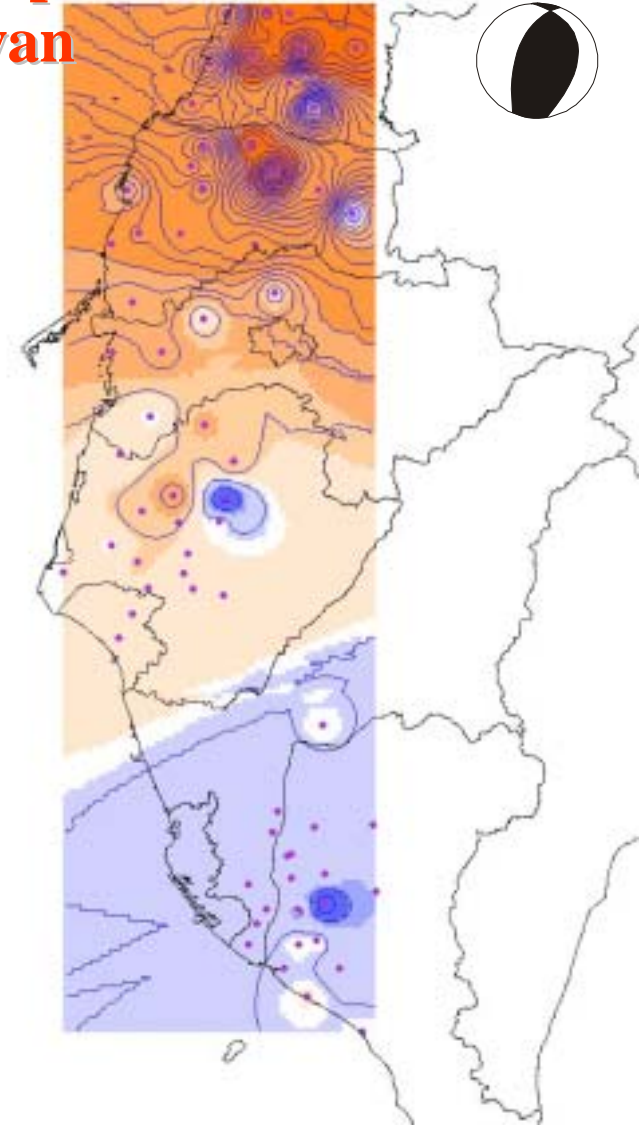
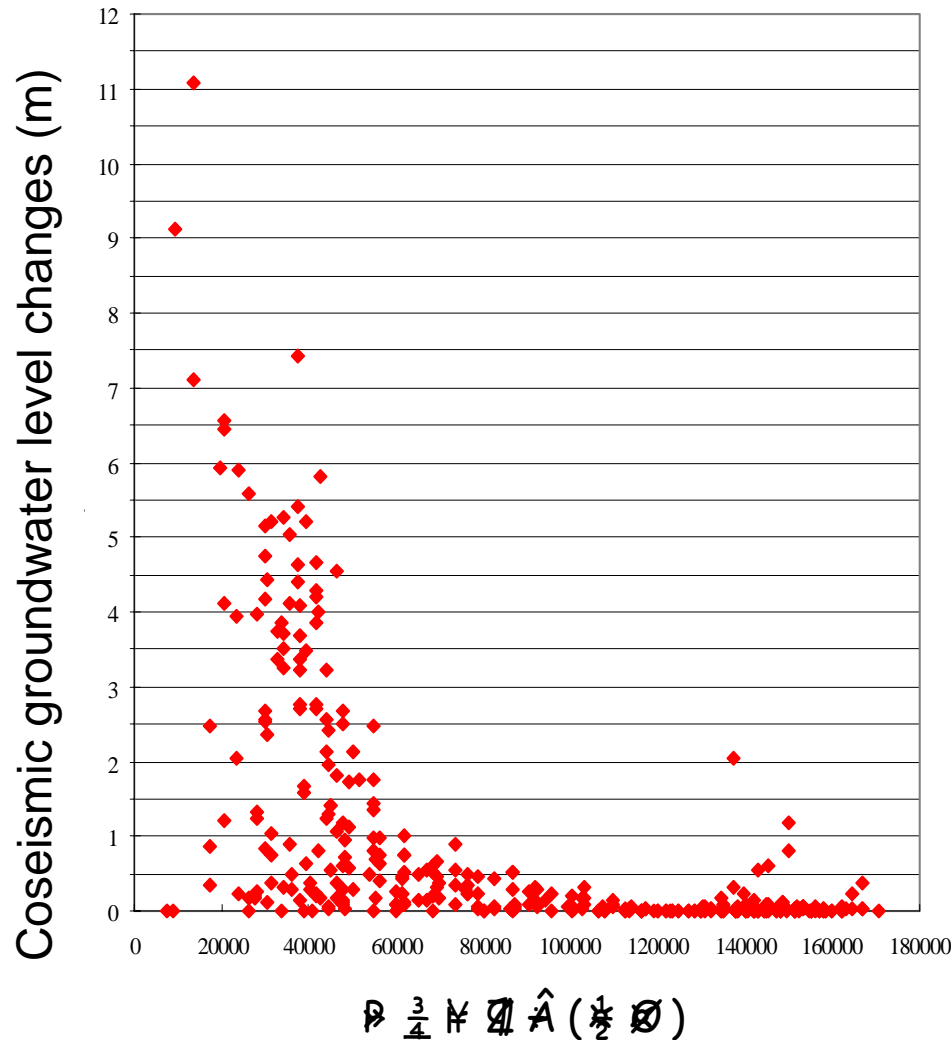
- 645 field sites in different areas, faults and geological conditions.
- 58 sites in public buildings, bridges and civil structures.
- Offer more information of ground-motion and rapid warning system



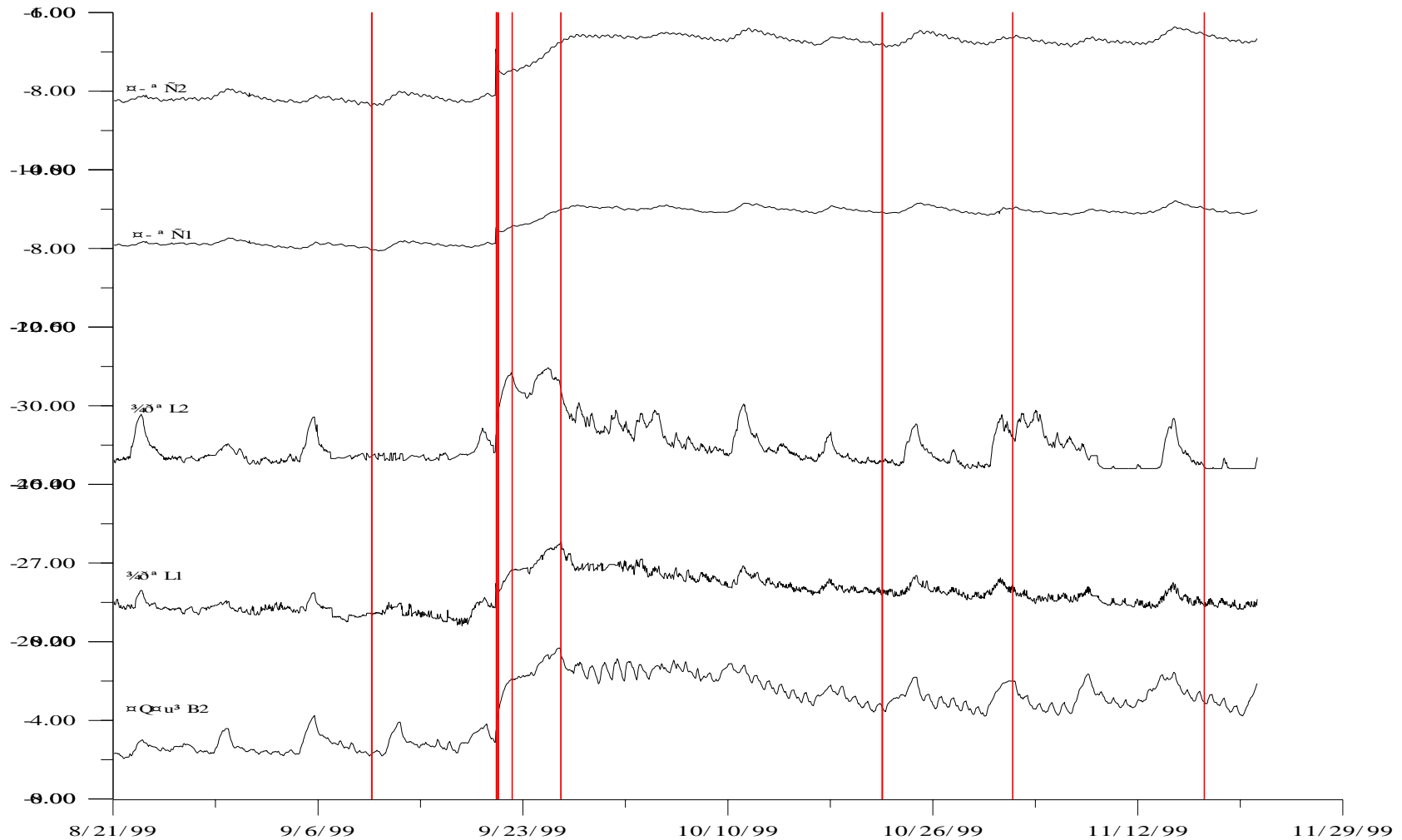
Coseismic groundwater level changes in other groundwater provinces

There are 190 wells coseismic changes larger than 10 cm

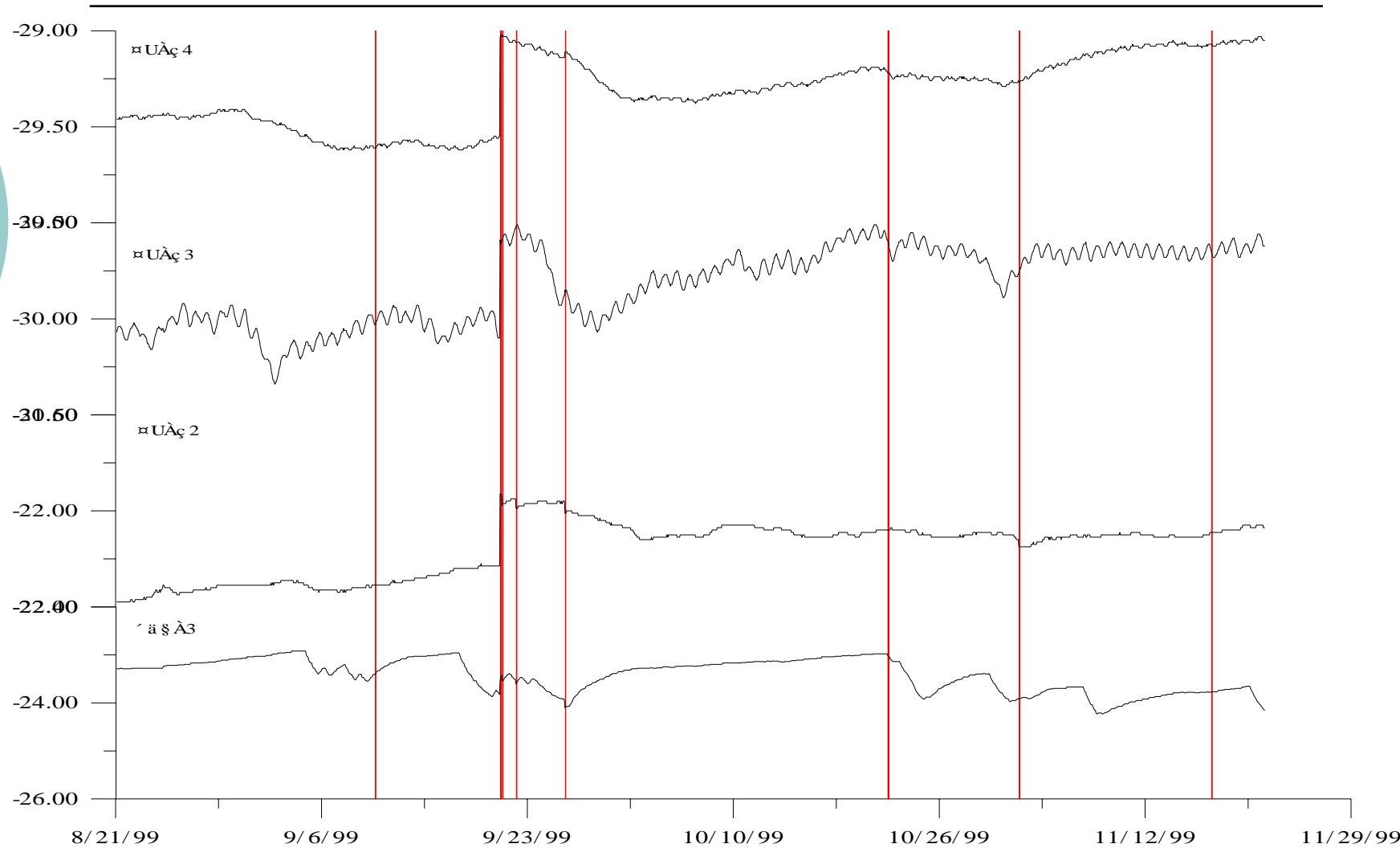
Example from south-western Taiwan



Coseismic Groundwater Level Changes in Northern Taiwan (Basin Amplifier Effect)



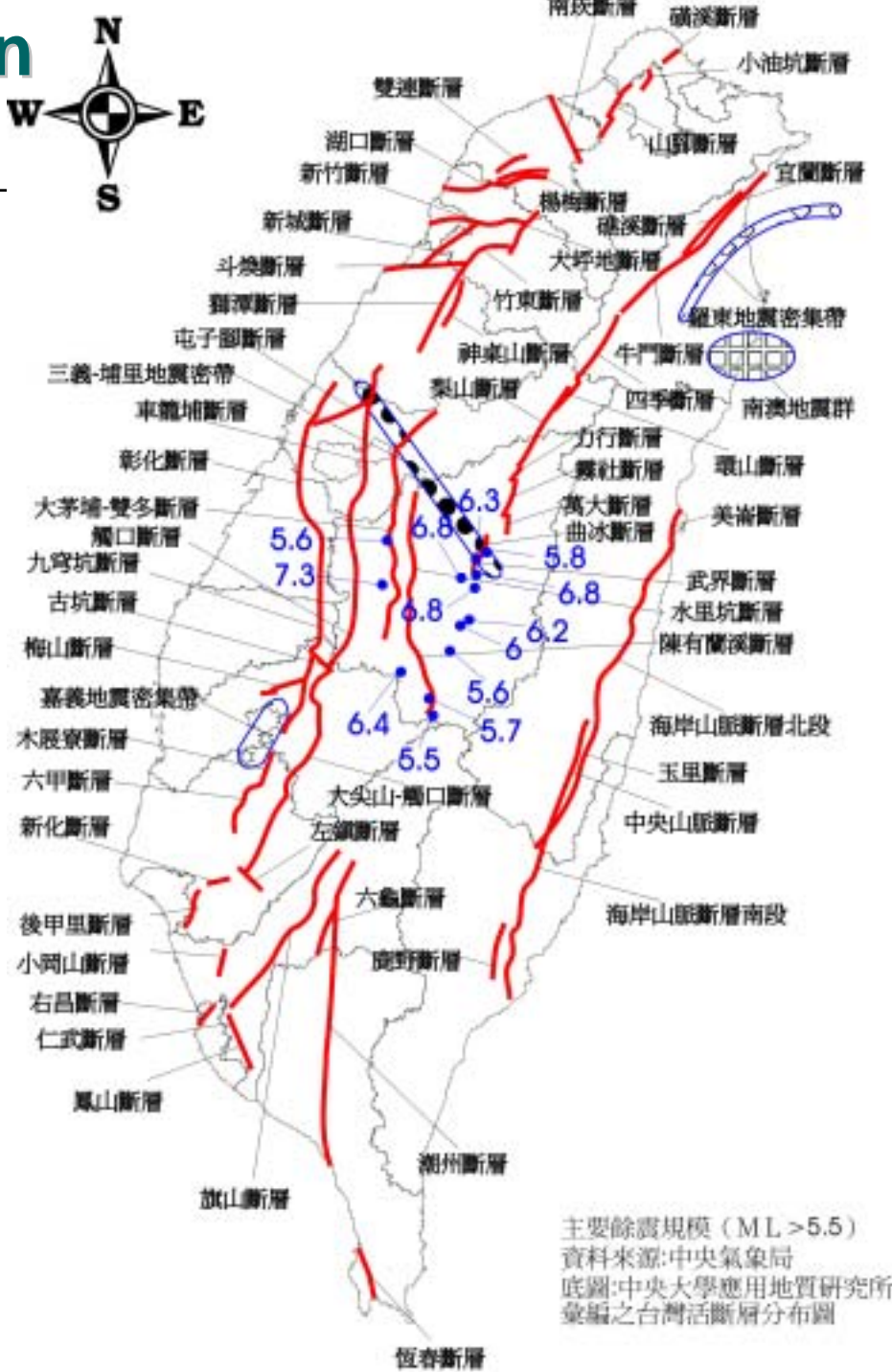
Coseismic Groundwater Level Changes in Southern Taiwan



Active Faults Distribution Map of Taiwan



- Northern Taiwan
- Southern Taiwan
- Ilan plain Area
- Huli city and Longitudinal Valley



Seismic environment of Northern Taiwan

