Is there a Fault **Beneath** the Bataan Nuclear Power Plant? A systematic study using Electrical Resistivity, Seismic Refraction and Radon Gas Detection

By

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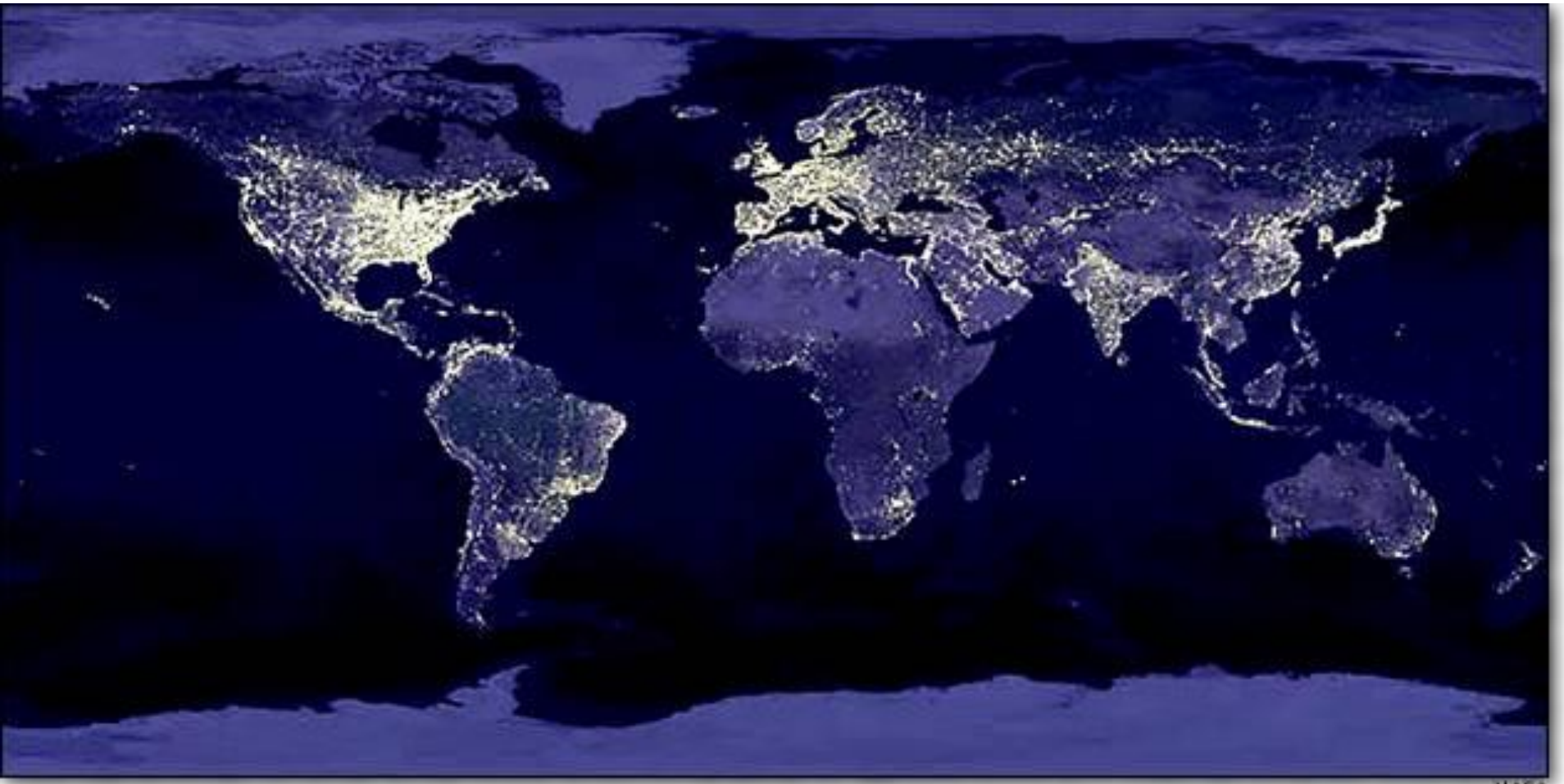
Mario Collado

Benjamin Punay



NASA

Bataan Nuclear Power Plant or Philippine Nuclear Power Plant

- We inherited this ‘white elephant”
- Proven corruption in procurement and construction
- Not the best location (understatement)
- Is it really unsafe?

Fukushima

- Tsunami and nuclear disaster has had sobering effect on revival of BNPP
- Considering Japanese discipline, BNPP would have done much worse had an accident like that happened

But consider…

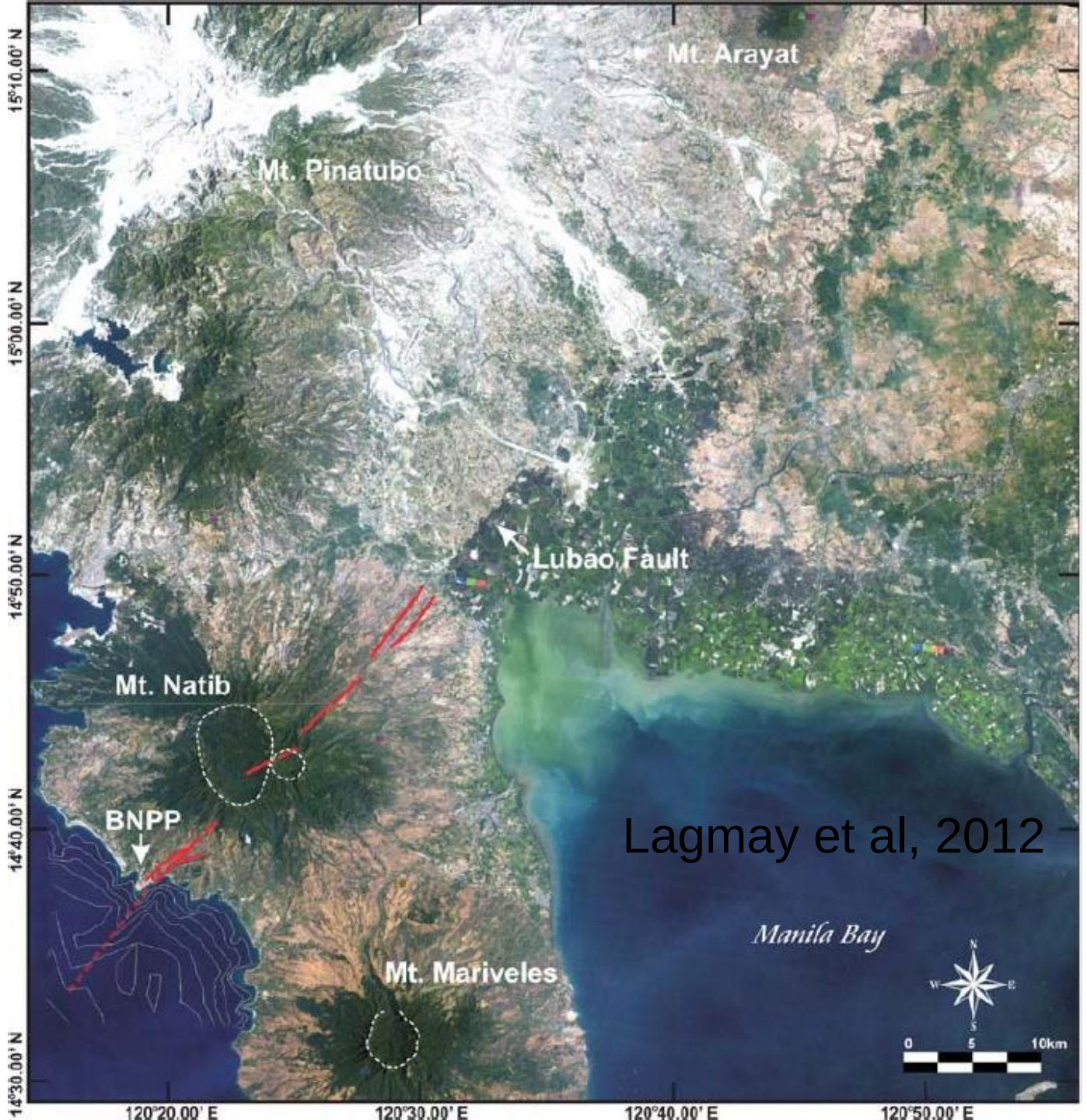
- BNPP is NEWER and better designed thank Fukushima plants (oldest in Japan)
- Located 18 meters above sea level, so tsunami like that in Japan would not have happened
- Back-up generators are above sea level, so hydrogen buildup when power failure and subsequent explosion would not have happened

Bataan Nuclear Power Plant

- Built at cost of US$ 2.3 billion
- Corruption by Marcos government AND Westinghouse Corporation
- Completed but closed nearly 20 years ago, mainly due to "safety reasons"--not 1 watt produced
- **Situated close to (or on) a “dormant” volcano and a fault**

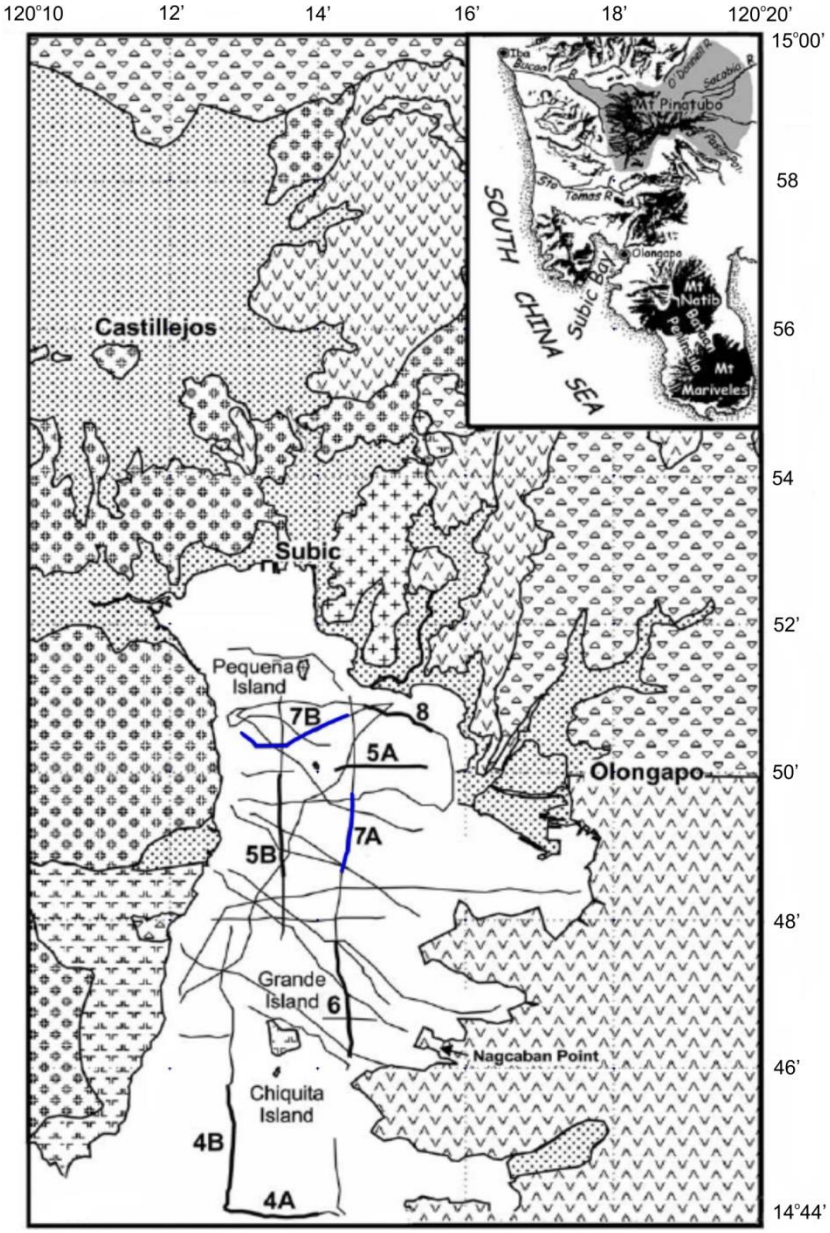
This study only aims to test if the BNPP is located ON TOP of an active fault

- It does not seek to study location of faults BESIDE or CLOSE to the structure (covered by engineering design?)
- An active fault BENEATH the BNPP will condemn the structure immediately AND absolutely.

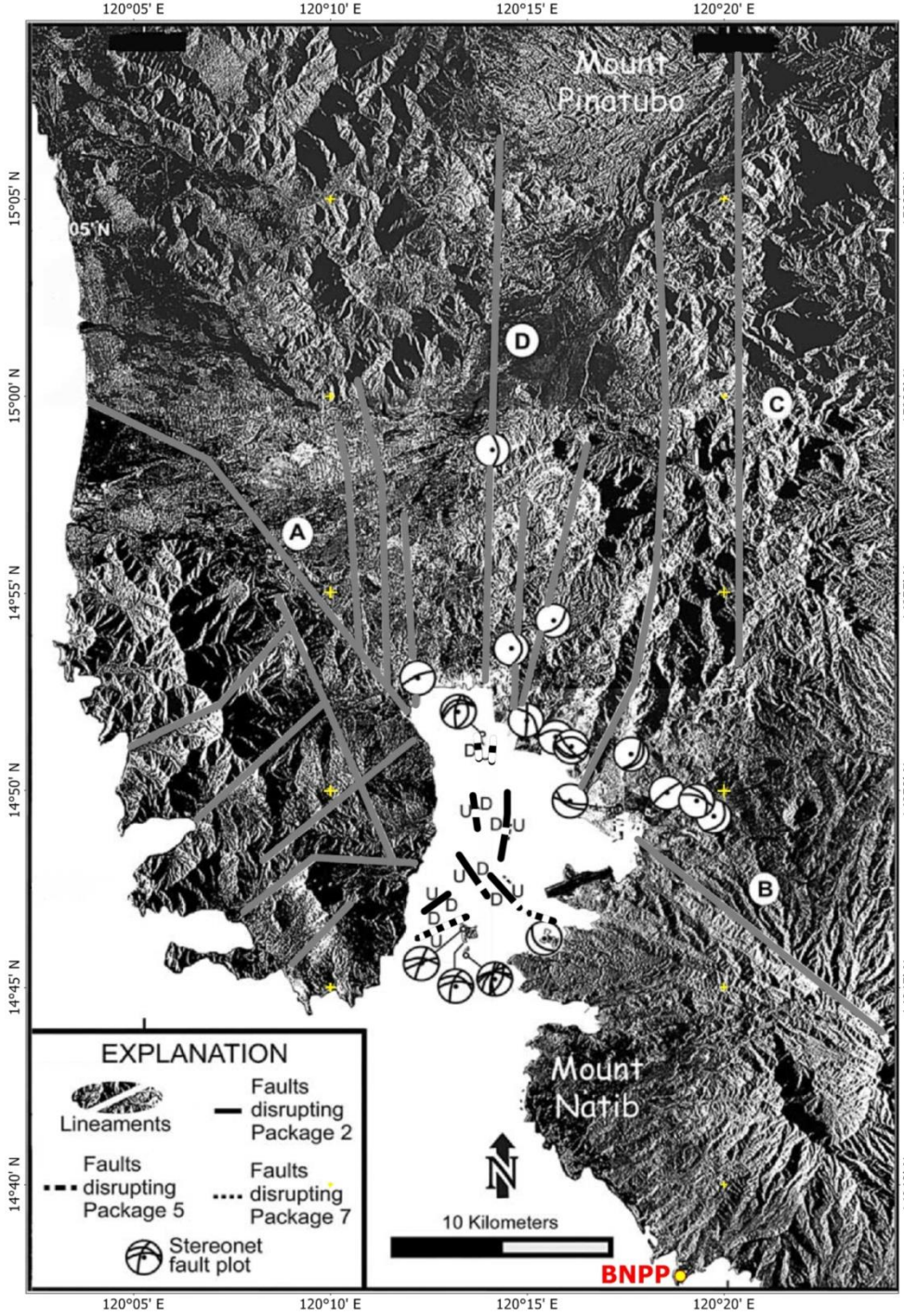

Mt. Arayat
Mt. Pinatubo
Lubao Fault
Mt. Natib
BNPP
Mt. Mariveles
Manila Bay
Lagmay et al, 2012
15°10.00' N
15°00.00' N
14°50.00' N
14°40.00' N
14°30.00' N
120°20.00' E
120°30.00' E
120°40.00' E
120°50.00' E
N
W
E
S
0
5
10km

The Fault Issue

- Is there an ACTIVE fault beneath BNPP? -- this can be tested
- Lubao Fault appears to transect BNPP from satellite observations
- There is active faulting in Subic Bay (cf Cabato et al., 2005), but do these faults extend to the vicinity of BNPP?
- Did the very strong earthquake of 1990 damage BNPP?
- Is the BNPP designed to resist earthquakes?



Cabato et al, 2005



Cabato et al, 2005

Active Faults

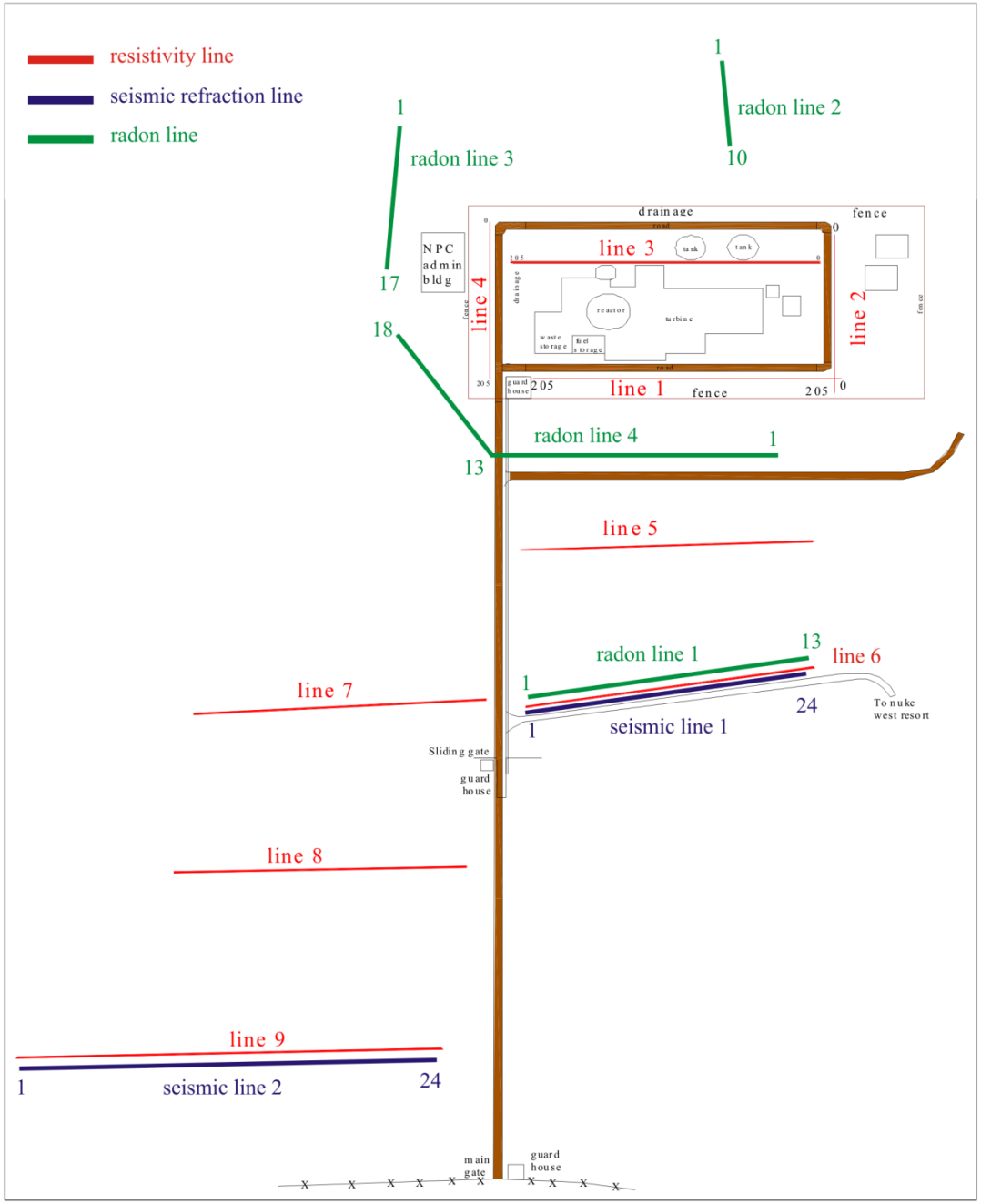
- By definition, *active faults MUST have surficial manifestations* (e.g., stream displacements, damaged structures, etc.)
- The active fault map of the Philippines by PHIVOLCS **does not** list an active fault in the vicinity of the BNPP

Examples of structures with faults beneath them

If there was an active fault beneath the BNPP,
Surface manifestations would have been
observed within the >20-year period
it has been mothballed.

Methods

- Electrical Resistivity (Mario Collado)
- Seismic Refraction (Benjamin Punay)
- Geochemical Fault detection by Radon gas survey (with Jason Antonio, Peter Zamora, Tina Petrache)


resistivity line
seismic refraction line
radon line
1
radon line 2
10
1
radon line 3
17
NPC
admin
bldg
drainage
road
fence
line 3
tank
tank
reactor
turbine
waste
storage
fuel
storage
line 4
line 2
line 1
guard
house
205
0
18
radon line 4
1
13
line 5
radon line 1
13
line 6
1
24
seismic line 1
Tonuke
west resort
line 7
Sliding gate
guard
house
line 8
line 9
1
seismic line 2
24
main
gate
guard
house


BATAAN NUCLEAR POWER PLANT
OWNER: NATIONAL GOVERNMENT
UNDER THE DEPT. OF FINANCE
CARETAKER: NATIONAL POWER CORPORATION
ASSET PRESERVATION DEPT.-TECHNICAL MAINT. SERVICES
TEL. # 527-4873 — 527-4863 (FAX)
(BNPP NAPOT POINT MORONG, BATAAN)

NIGS Fieldwork at BNPP

Electrical resistivity survey in BNPP

Objective

- To identify geological structures like fault/fractures that could affect the stability of BNPP by using electrical resistivity survey.

Methodology

- Conducted 4 resistivity lines within the compound of main building and two lines at flat topography and sloping terrain outside the compound alight to the building at NW direction.
- Added five additional lines outside the compound particularly at the southern, northern, and eastern part.

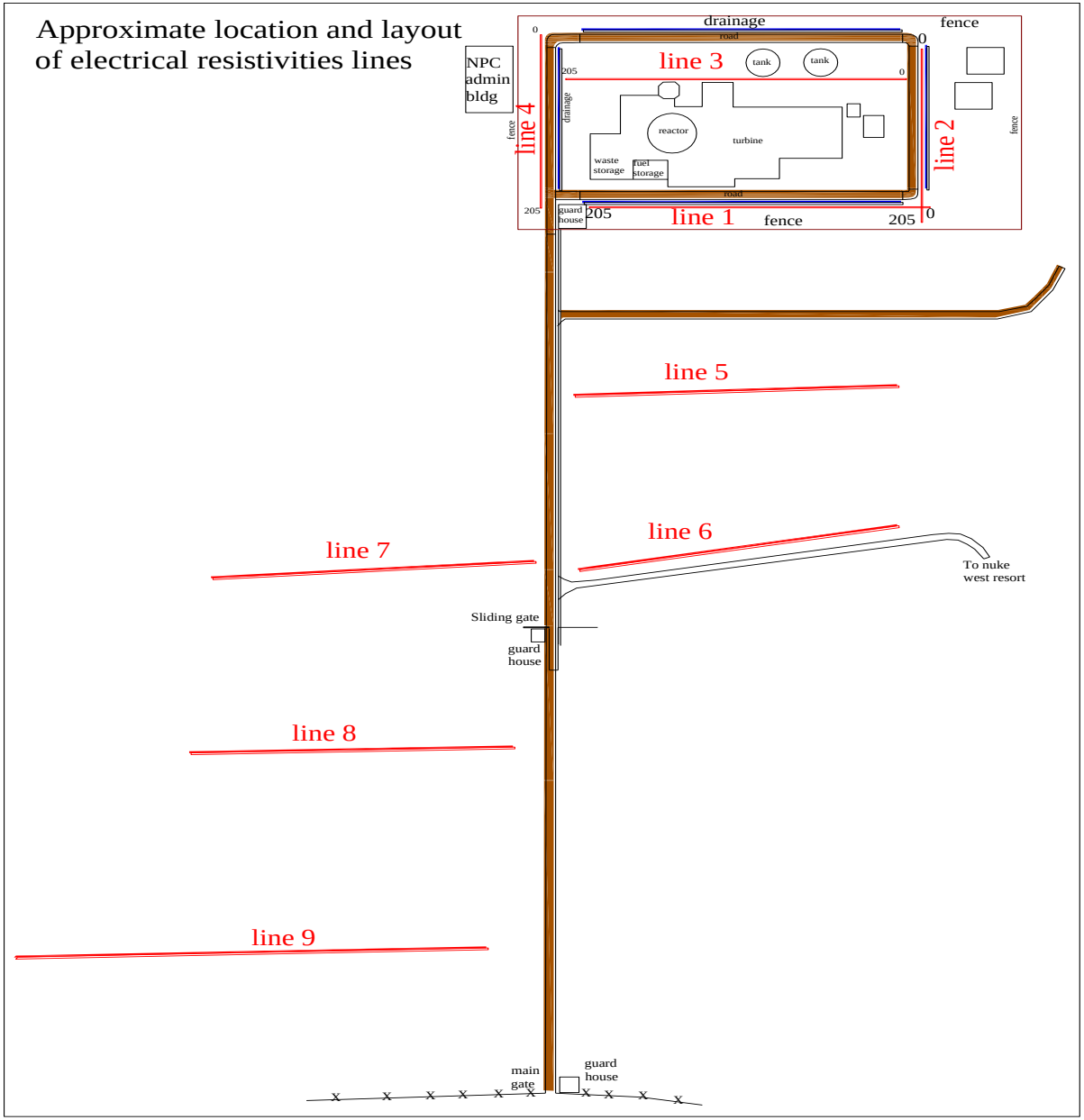
Field measurement

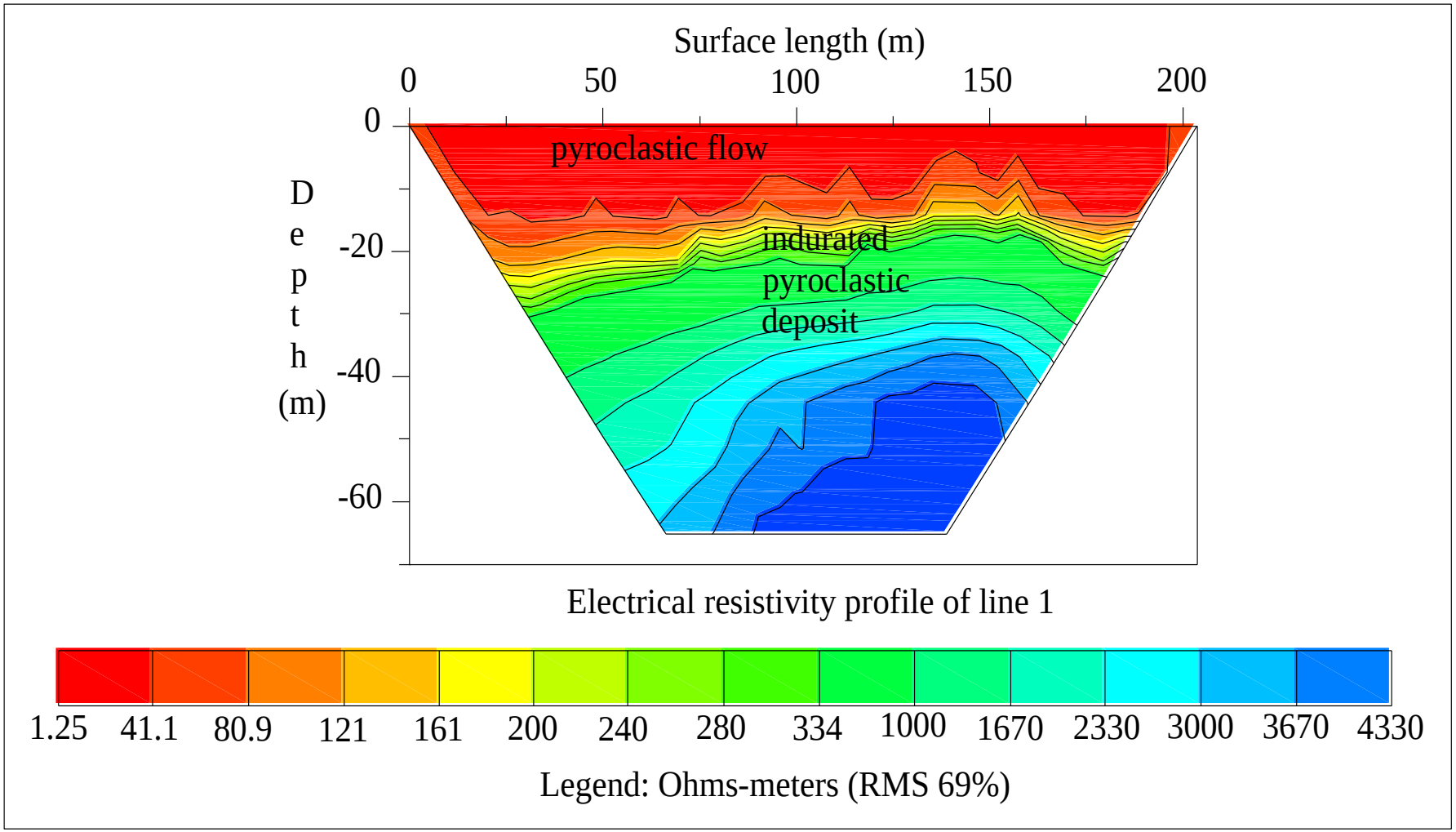

Resistivity

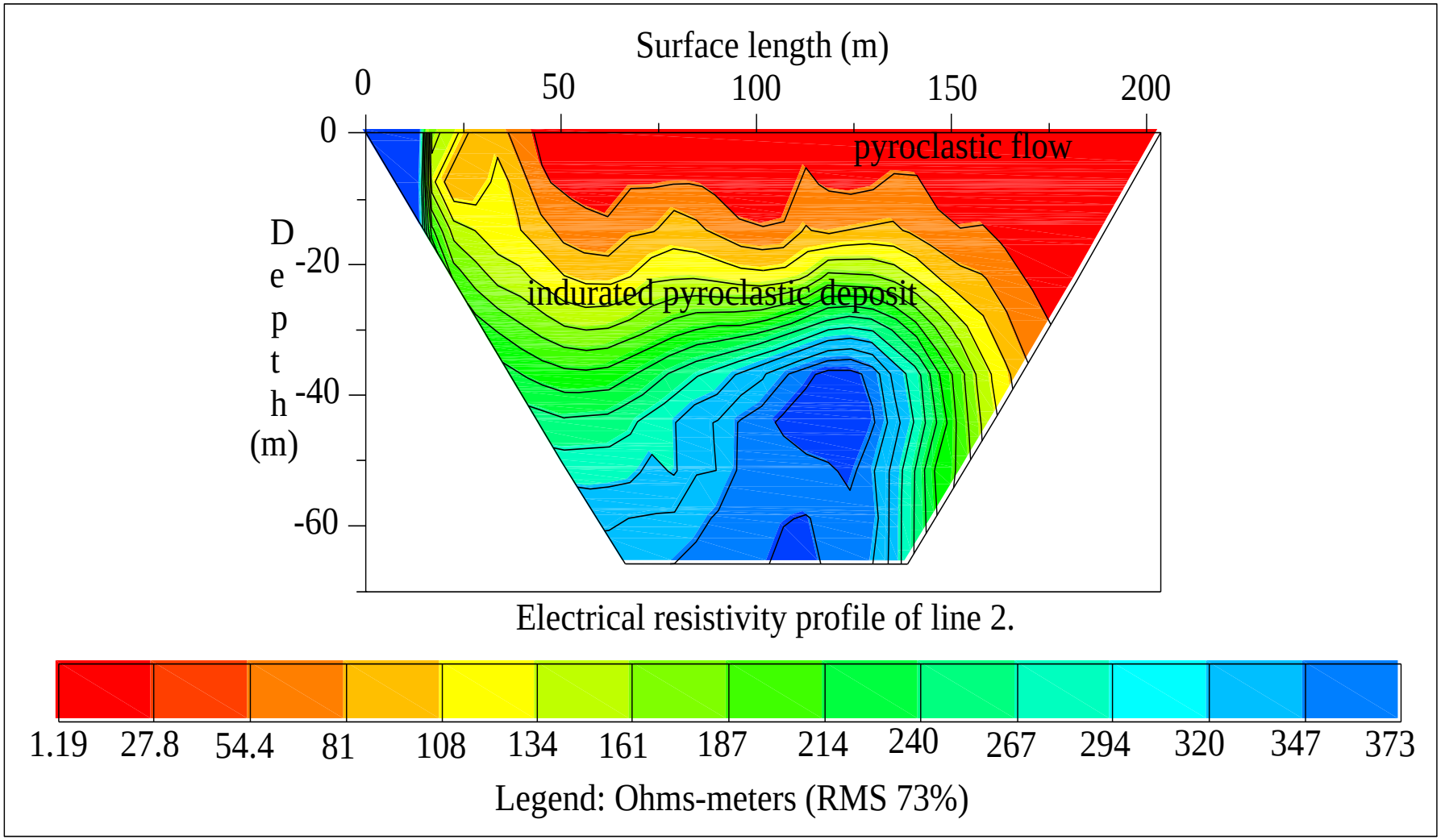

Resistivity line 6


Set of instrument used

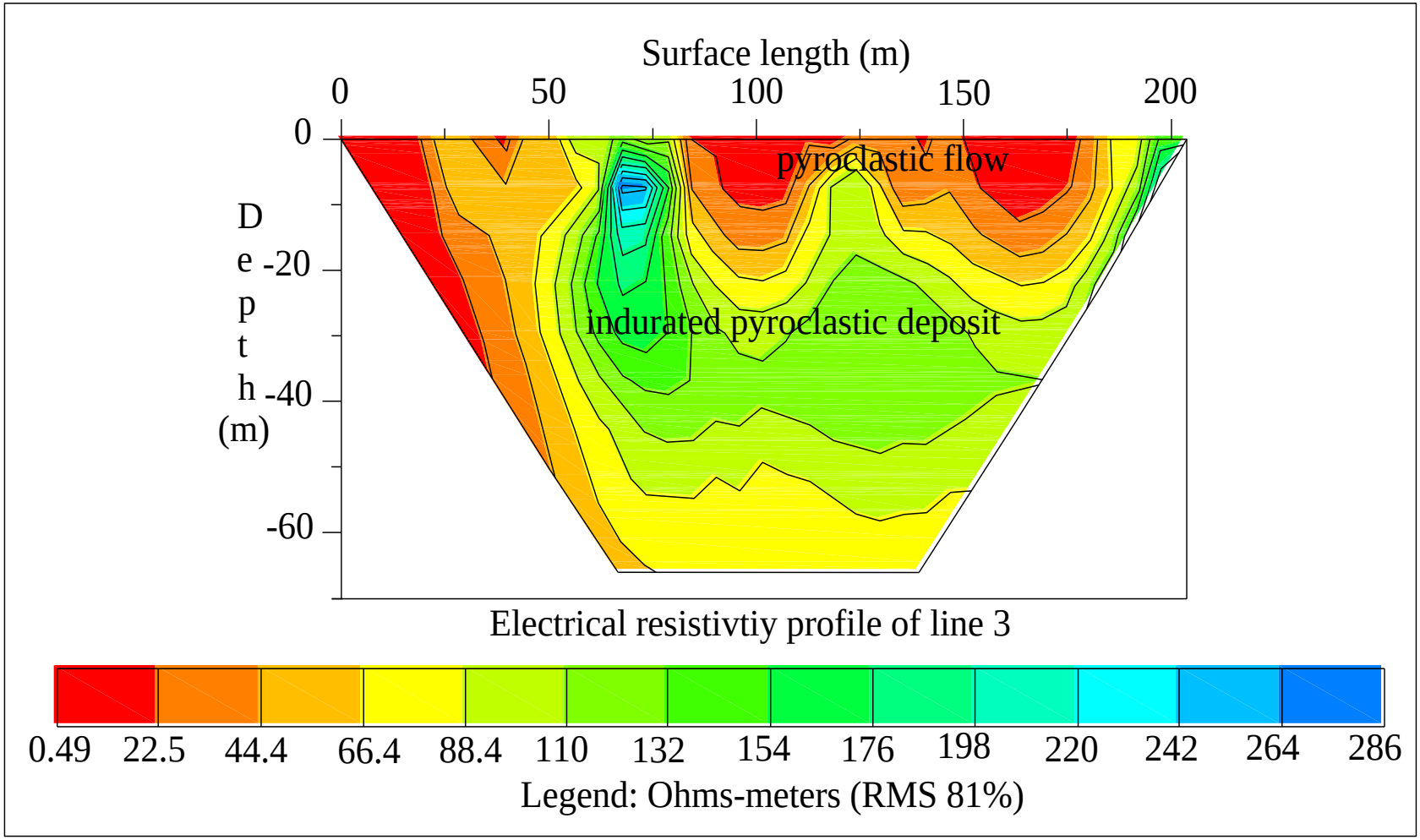
Approximate location and layout of electrical resistivities lines

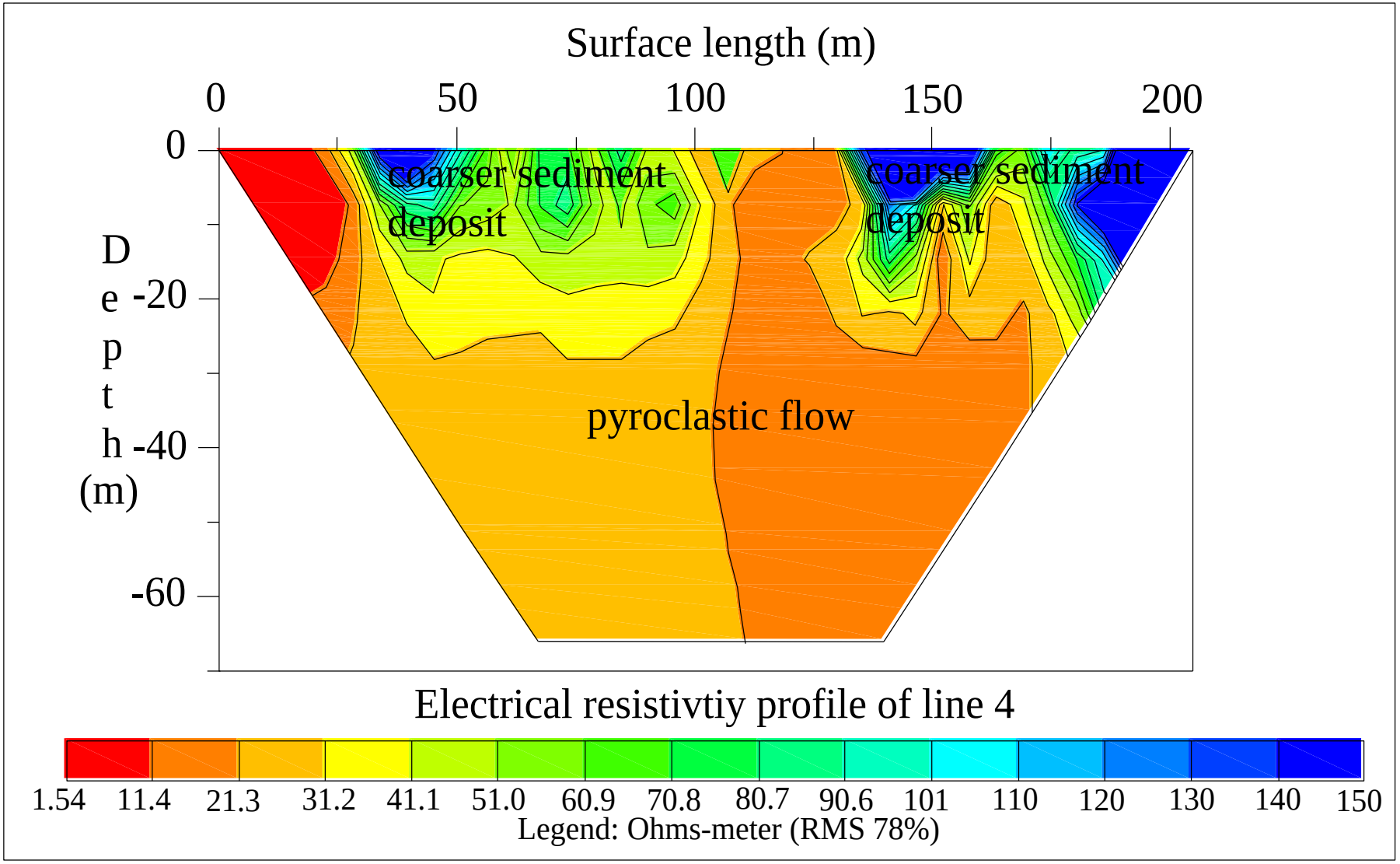


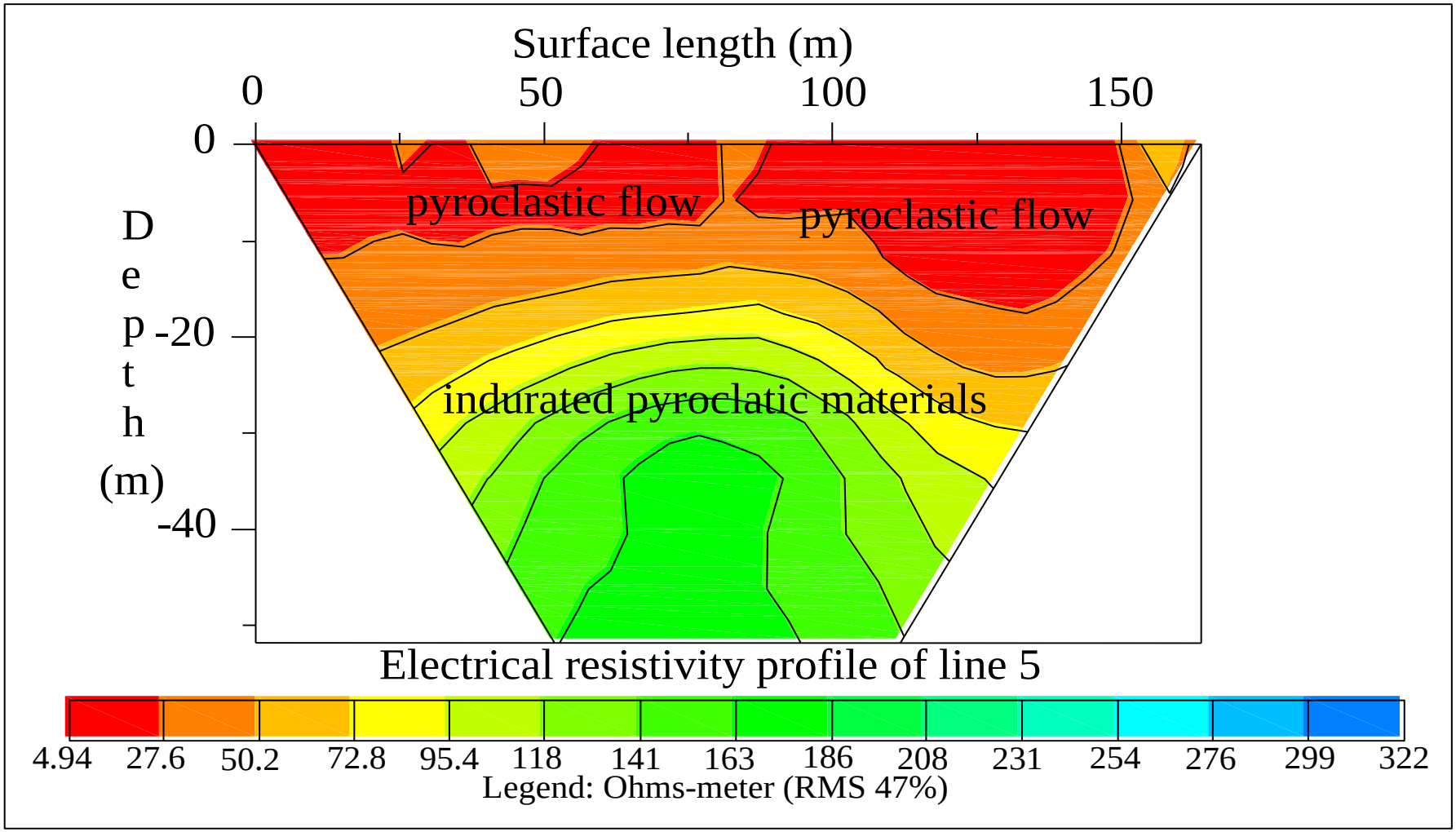

Surface length (m)
0
50
100
150
200
0
-20
-40
-60
Depth (m)
pyroclastic flow
indurated pyroclastic deposit
Electrical resistivity profile of line 1
1.25
41.1
80.9
121
161
200
240
280
334
1000
1670
2330
3000
3670
4330
Legend: Ohms-meters (RMS 69%)

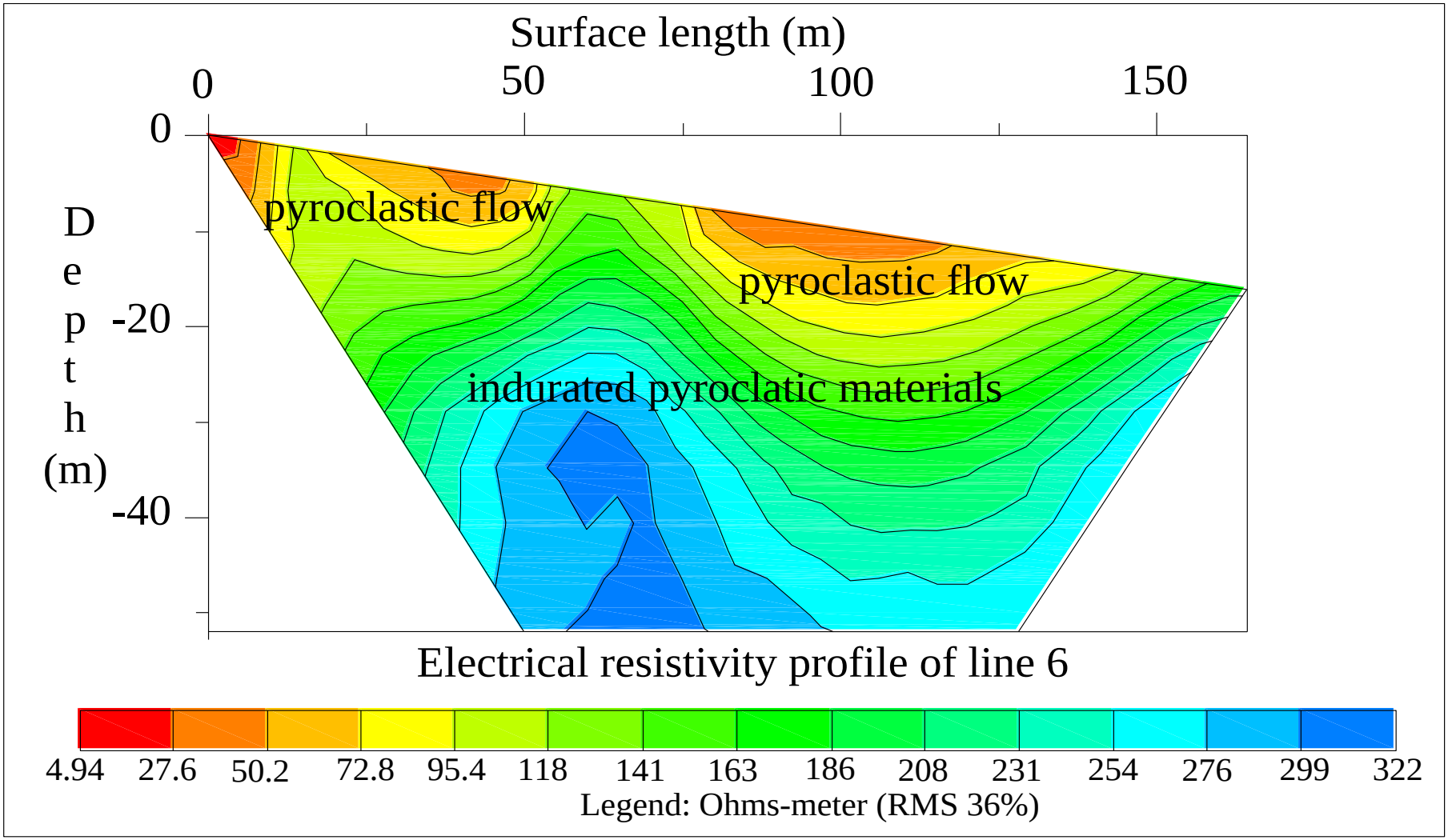


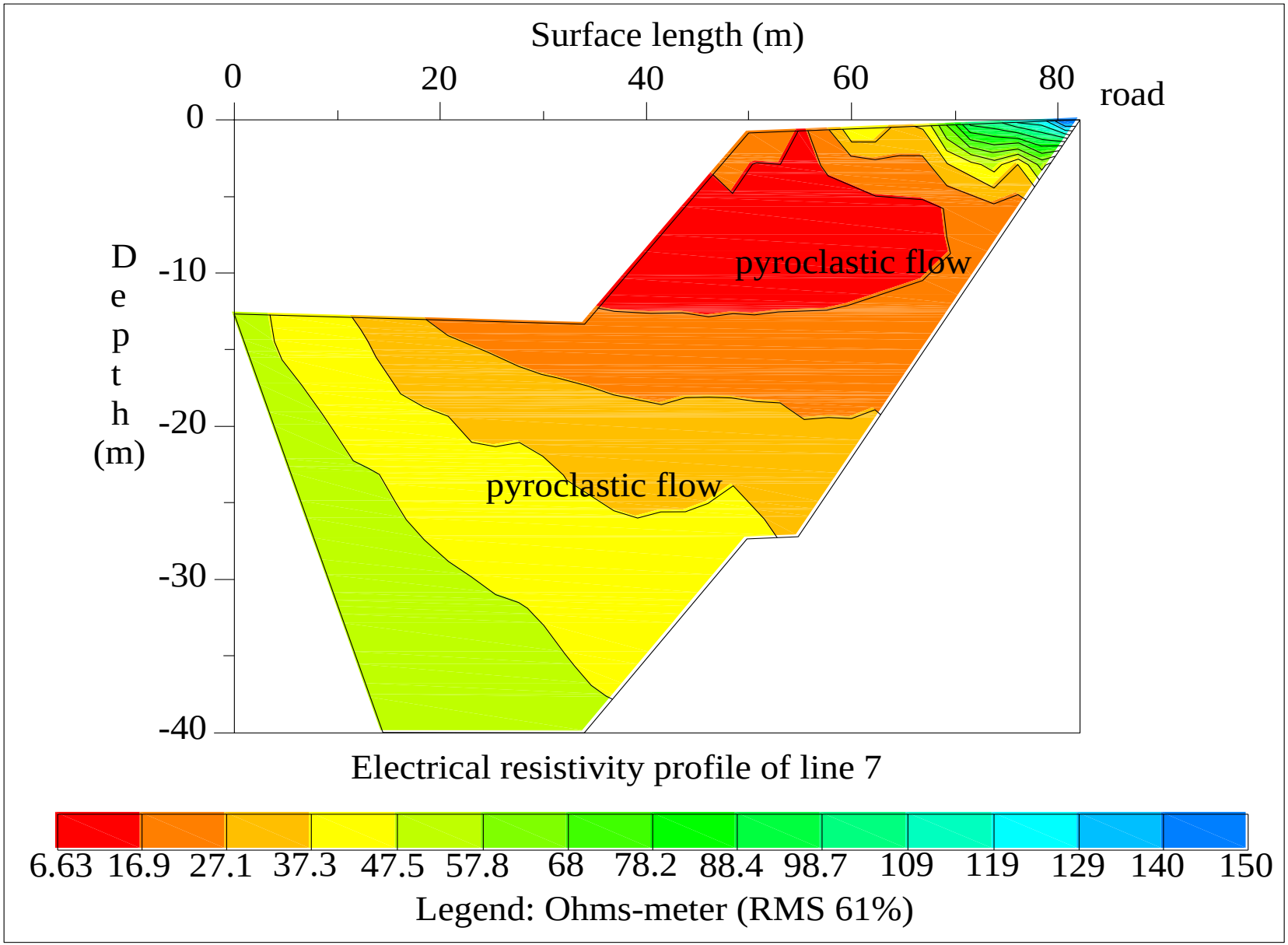
Electrical resistivity profile of line 2.

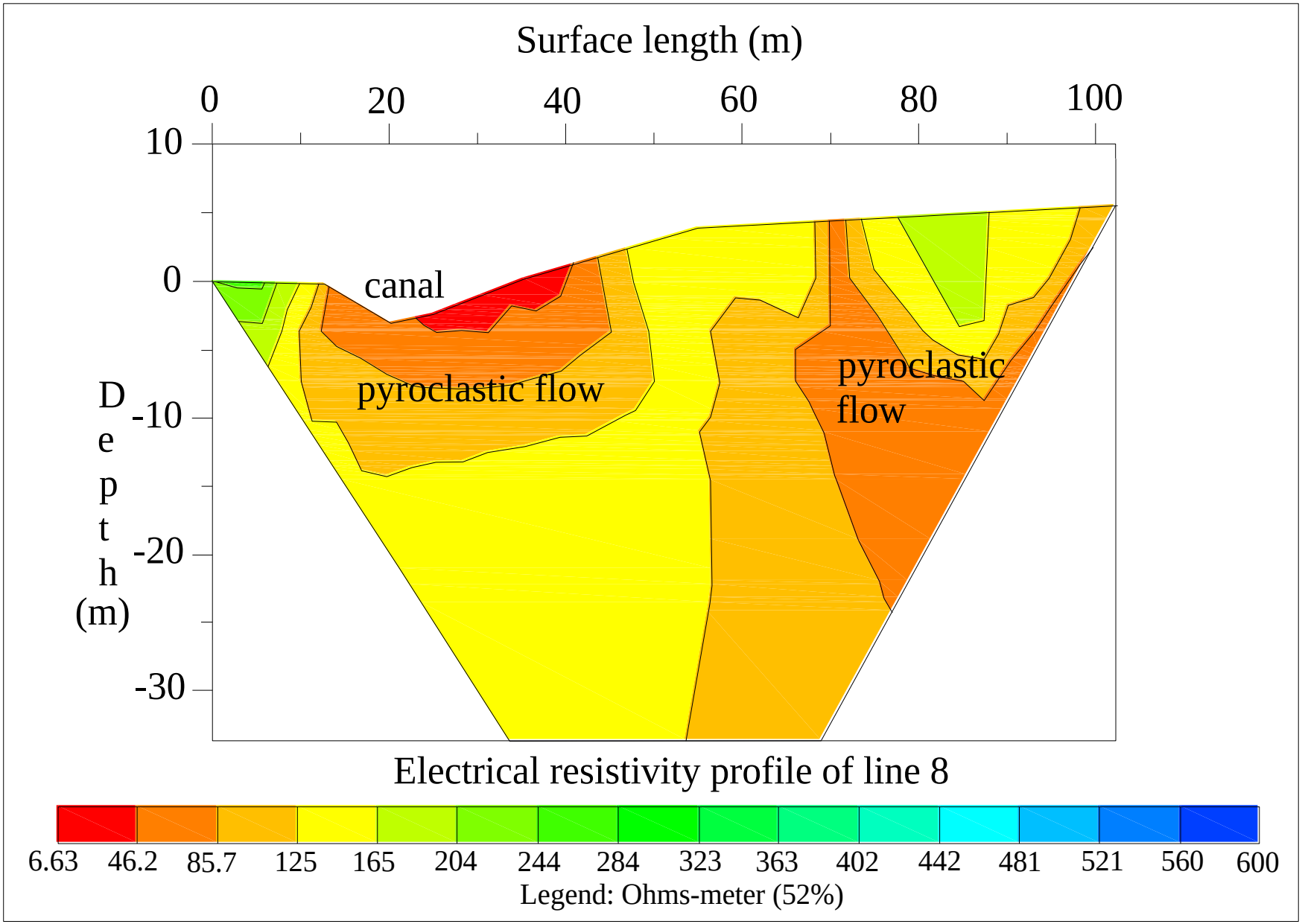

Surface length (m)
0
50
100
150
200
0
-20
-40
-60
Depth (m)
pyroclastic flow
indurated pyroclastic deposit
Electrical resistivtiy profile of line 3
0.49
22.5
44.4
66.4
88.4
110
132
154
176
198
220
242
264
286
Legend: Ohms-meters (RMS 81%)

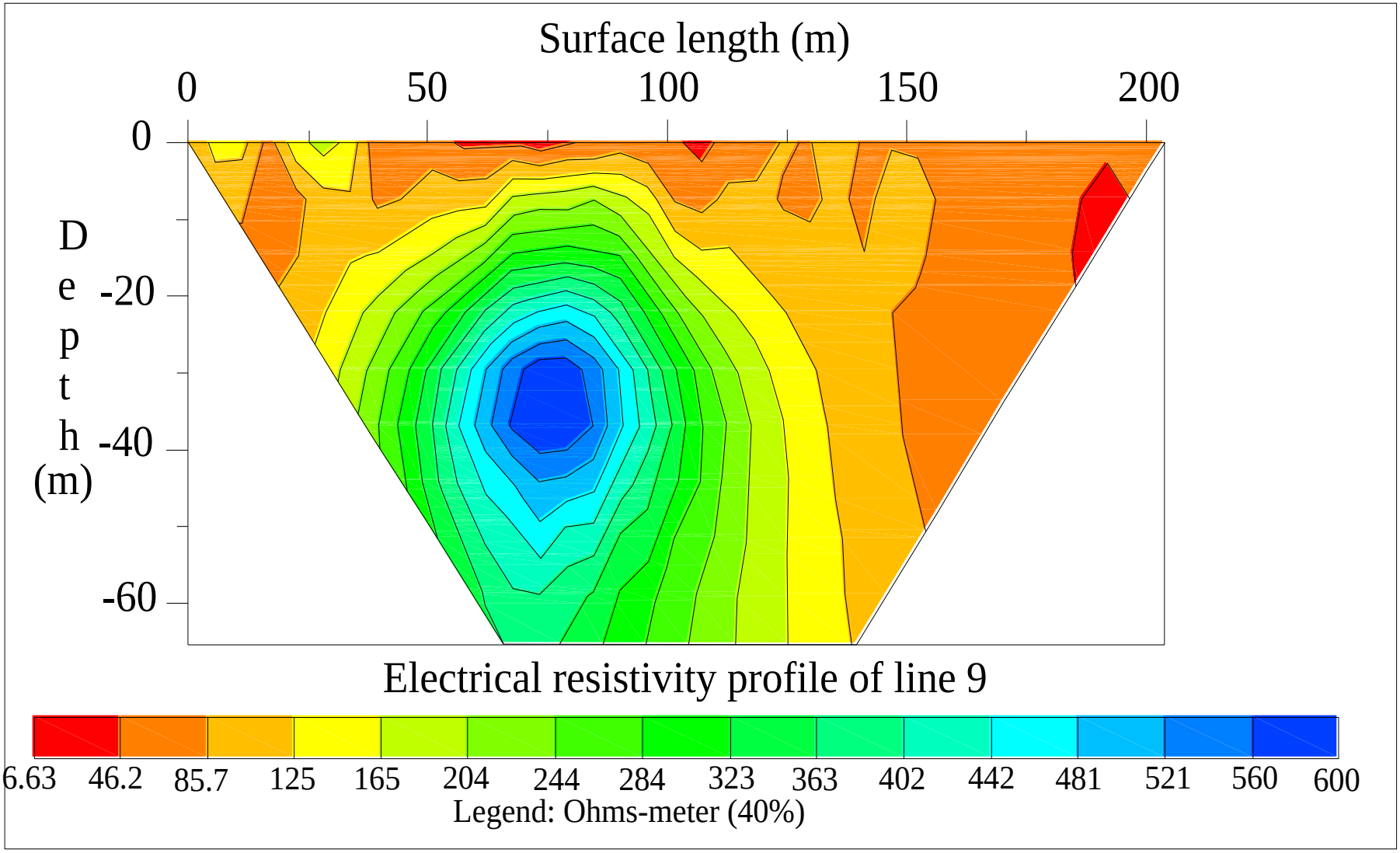

Surface length (m)
0
50
100
150
200
0
-20
-40
-60
Depth (m)
coarser sediment deposit
coarser sediment deposit
pyroclastic flow
Electrical resistivtiy profile of line 4
1.54
11.4
21.3
31.2
41.1
51.0
60.9
70.8
80.7
90.6
101
110
120
130
140
150
Legend: Ohms-meter (RMS 78%)


Surface length (m)
0
50
100
150
0
-20
-40
Depth (m)
pyroclastic flow
pyroclastic flow
indurated pyroclatic materials
Electrical resistivity profile of line 5
4.94
27.6
50.2
72.8
95.4
118
141
163
186
208
231
254
276
299
322
Legend: Ohms-meter (RMS 47%)


Surface length (m)
0
50
100
150
0
-20
-40
Depth (m)
pyroclastic flow
pyroclastic flow
indurated pyroclatic materials
Electrical resistivity profile of line 6
4.94
27.6
50.2
72.8
95.4
118
141
163
186
208
231
254
276
299
322
Legend: Ohms-meter (RMS 36%)


Surface length (m)
0
20
40
60
80
road
0
-10
-20
-30
-40
Depth (m)
pyroclastic flow
pyroclastic flow
Electrical resistivity profile of line 7
6.63 16.9 27.1 37.3 47.5 57.8 68 78.2 88.4 98.7 109 119 129 140 150
Legend: Ohms-meter (RMS 61%)

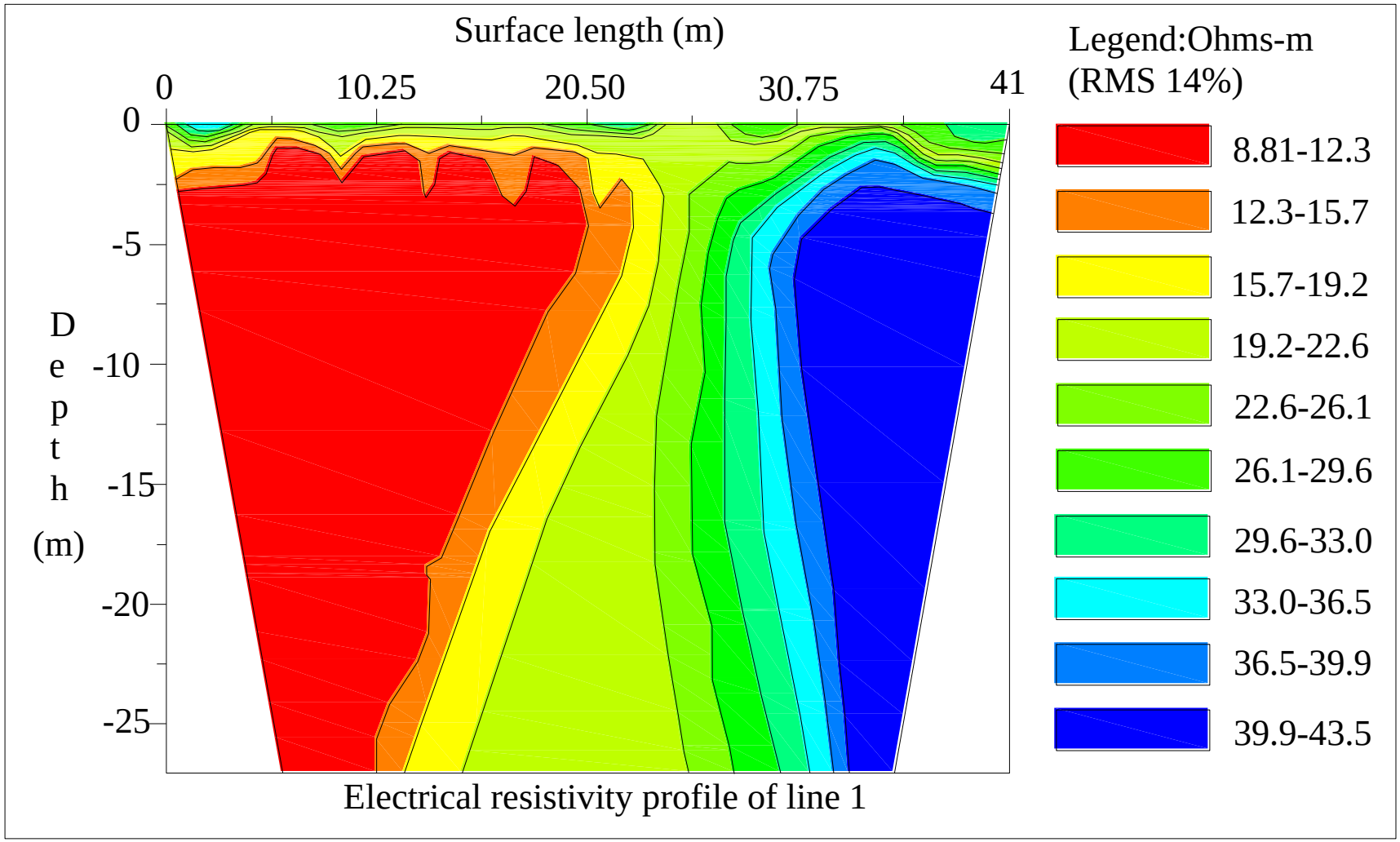

Surface length (m)
0
20
40
60
80
100
10
0
-10
-20
-30
Depth (m)
canal
pyroclastic flow
pyroclastic flow
Electrical resistivity profile of line 8
6.63
46.2
85.7
125
165
204
244
284
323
363
402
442
481
521
560
600
Legend: Ohms-meter (52%)

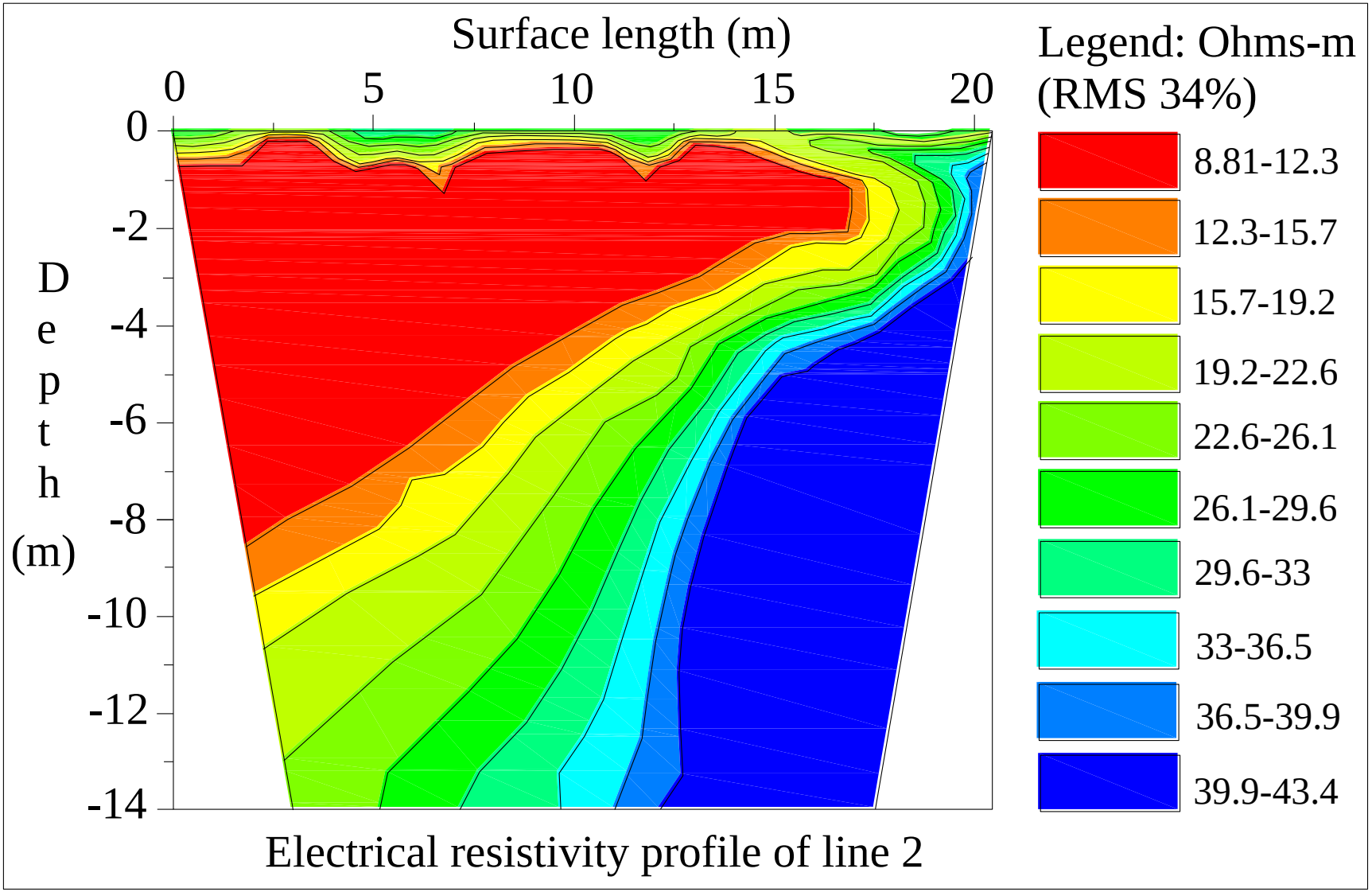

Surface length (m)
0
50
100
150
200
Depth (m)
0
-20
-40
-60
Electrical resistivity profile of line 9
6.63
46.2
85.7
125
165
204
244
284
323
363
402
442
481
521
560
600
Legend: Ohms-meter (40%)

- Resistivity Profiles across an ACTIVE

Fault for comparison…

Location site of Electrical Resistivity (ER) line 1 and 2, alignment of Fault at the University of Asia and Pacific Parking Lot.


Surface length (m)
0
10.25
20.50
30.75
41
0
-5
-10
-15
-20
-25
Depth (m)
Legend:Ohms-m
(RMS 14%)
8.81-12.3
12.3-15.7
15.7-19.2
19.2-22.6
22.6-26.1
26.1-29.6
29.6-33.0
33.0-36.5
36.5-39.9
39.9-43.5
Electrical resistivity profile of line 1


Surface length (m)
0
5
10
15
20
Depth (m)
0
-2
-4
-6
-8
-10
-12
-14
Legend: Ohms-m
(RMS 34%)
8.81-12.3
12.3-15.7
15.7-19.2
19.2-22.6
22.6-26.1
26.1-29.6
29.6-33
33-36.5
36.5-39.9
39.9-43.4
Electrical resistivity profile of line 2

Summary

- NINE (9) lines of electrical resistivity were laid out along the perimeter of the Bataan Nuclear Power Plant to determine if there is a fault beneath the building. Using close-spaced electrodes in a Wenner array, the four 2-D electrical resistivity sounding profiles show NO evidence of faults underneath the Bataan Nuclear Power Plant
-

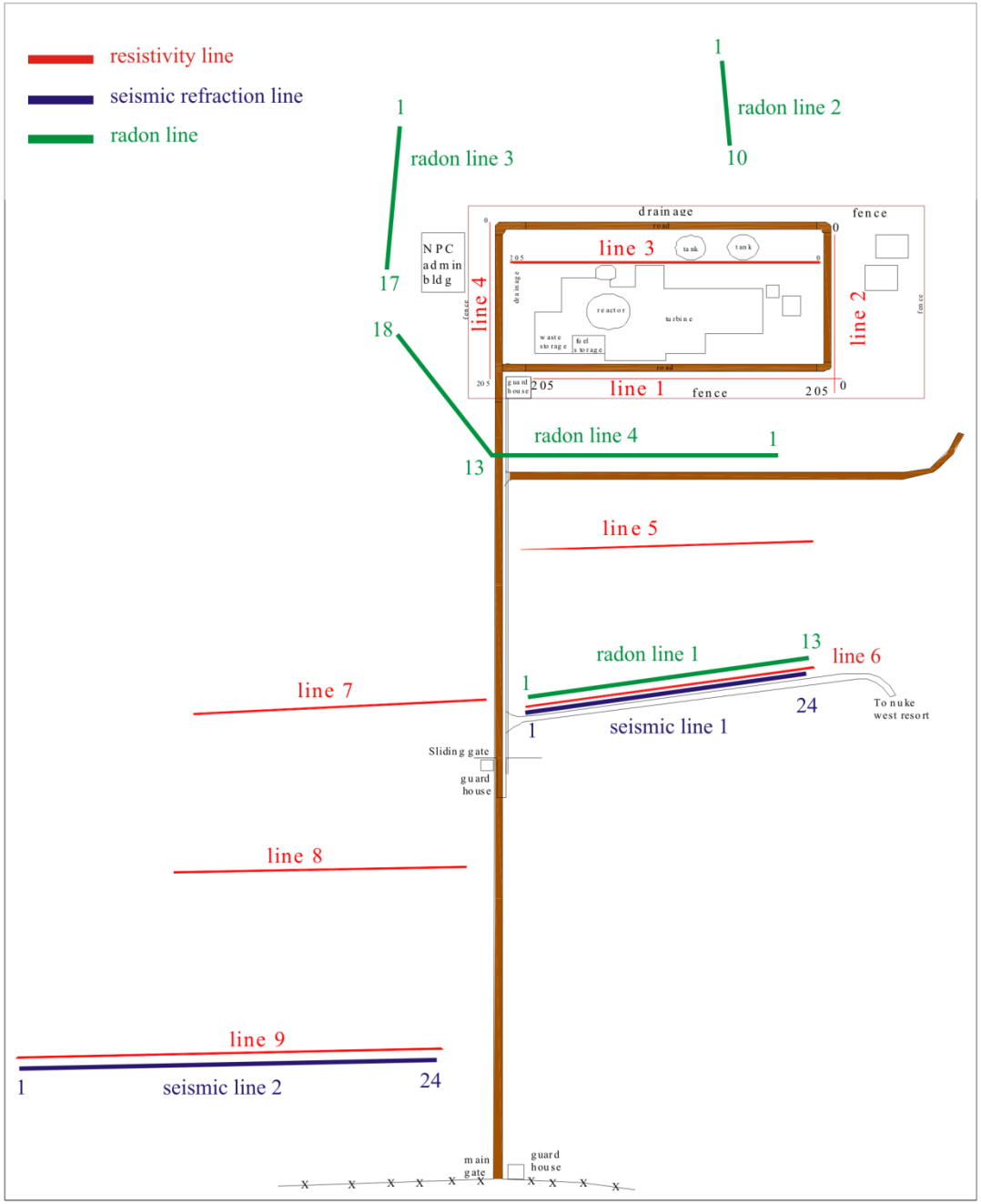
Occurrence of Fault

- The burden of proof lies with the people who say there is a fault.
- What kind of evidence and data?

BNPP Seismic Refraction Survey

- To verify independently the findings of electrical resistivity survey


Data Acquisition and
Processing system for
seismic prospecting
MaSES
16000
MaSES
AS-UNIT


resistivity line
seismic refraction line
radon line
1
radon line 2
10
1
radon line 3
17
NPC
admin
bldg
drainage
road
fence
line 3
tank
tank
reactor
turbine
waste
storage
fuel
storage
line 4
line 2
line 1
guard
house
205
0
18
radon line 4
1
13
line 5
radon line 1
13
line 6
1
24
seismic line 1
Tonuke
west resort
line 7
Sliding gate
guard
house
line 8
line 9
1
seismic line 2
24
main
gate
guard
house

REPORT ON THE SEISMIC REFRACTION SURVEY AT THE BATAAN NUCLEAR POWER PLANTSITE MORONG, BATAAN

1.0 OBJECTIVES

Seismic refraction survey was conducted at the plant site of the moth-balled Bataan Nuclear Power Plant (BNPP) at two lines for the following purposes:

a) to gain knowledge on the compressional wave velocities and corresponding depths to the various subsurface underlying the site and

b) to determine/detect the existence of geological structures, specially faults, and

c) to augment the findings/data of other geophysical/geological investigations recently conducted by the National Institute of Geological Sciences (NIGS).

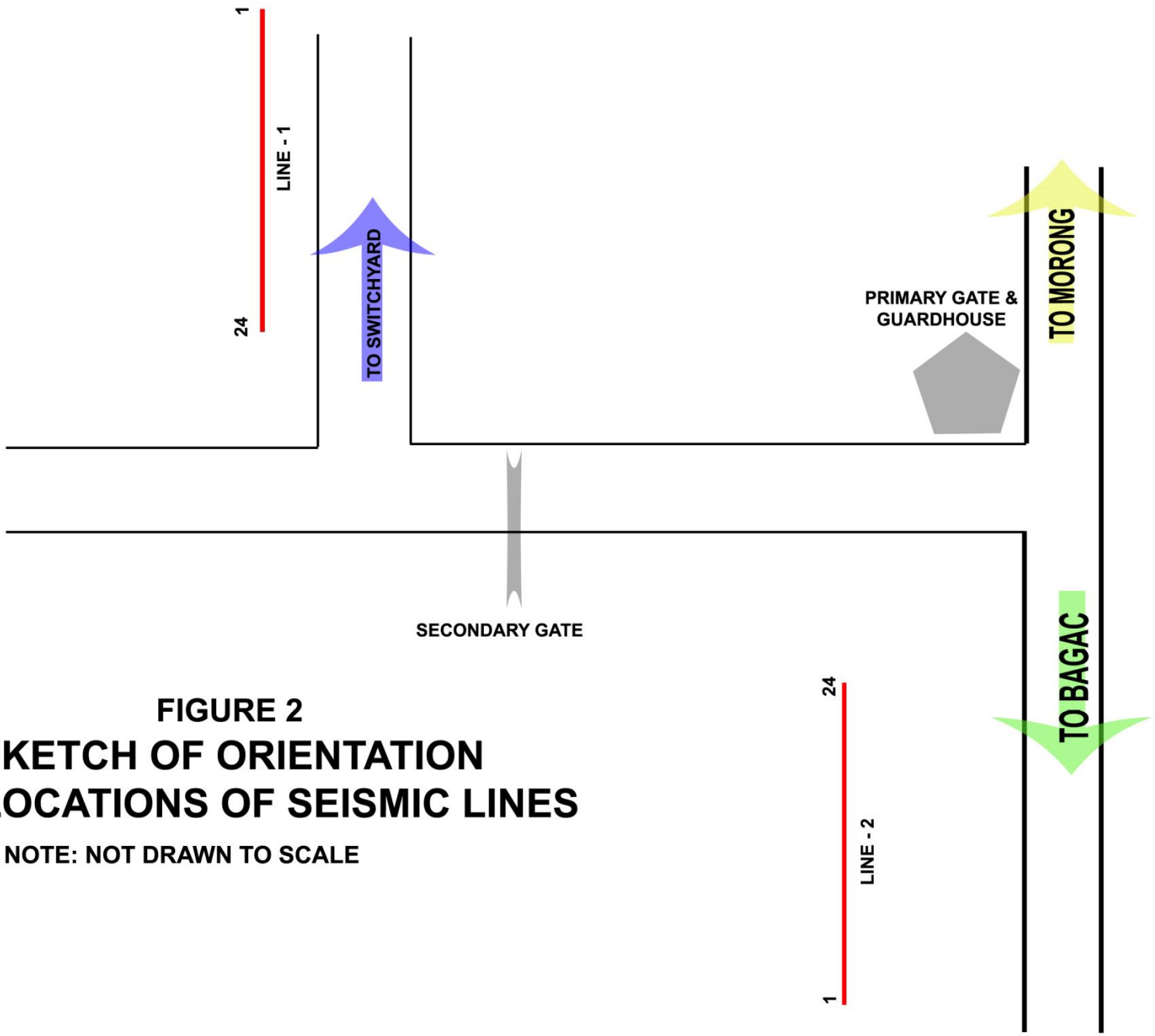


FIGURE 2

SKETCH OF ORIENTATION AND LOCATIONS OF SEISMIC LINES

NOTE: NOT DRAWN TO SCALE

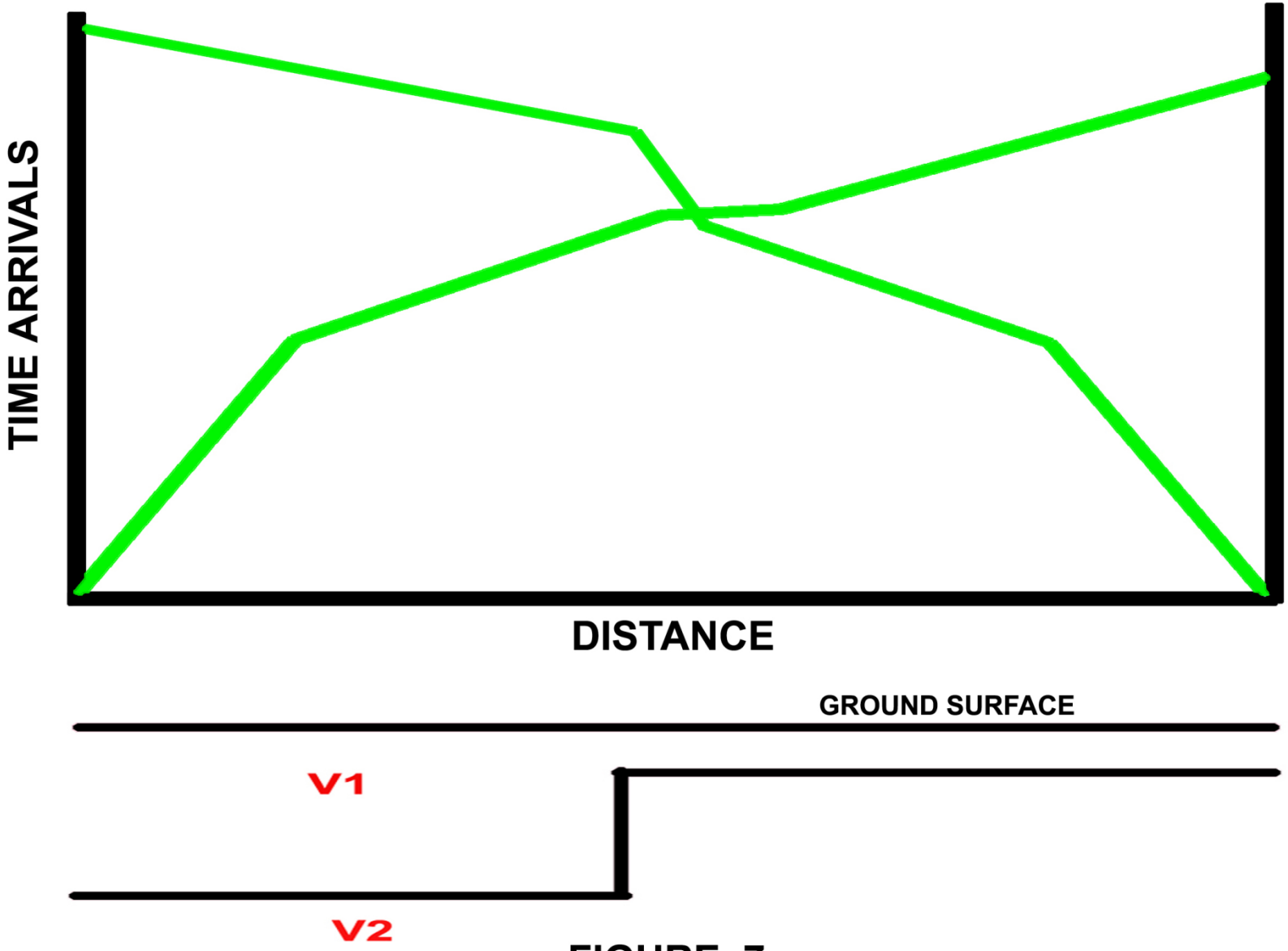
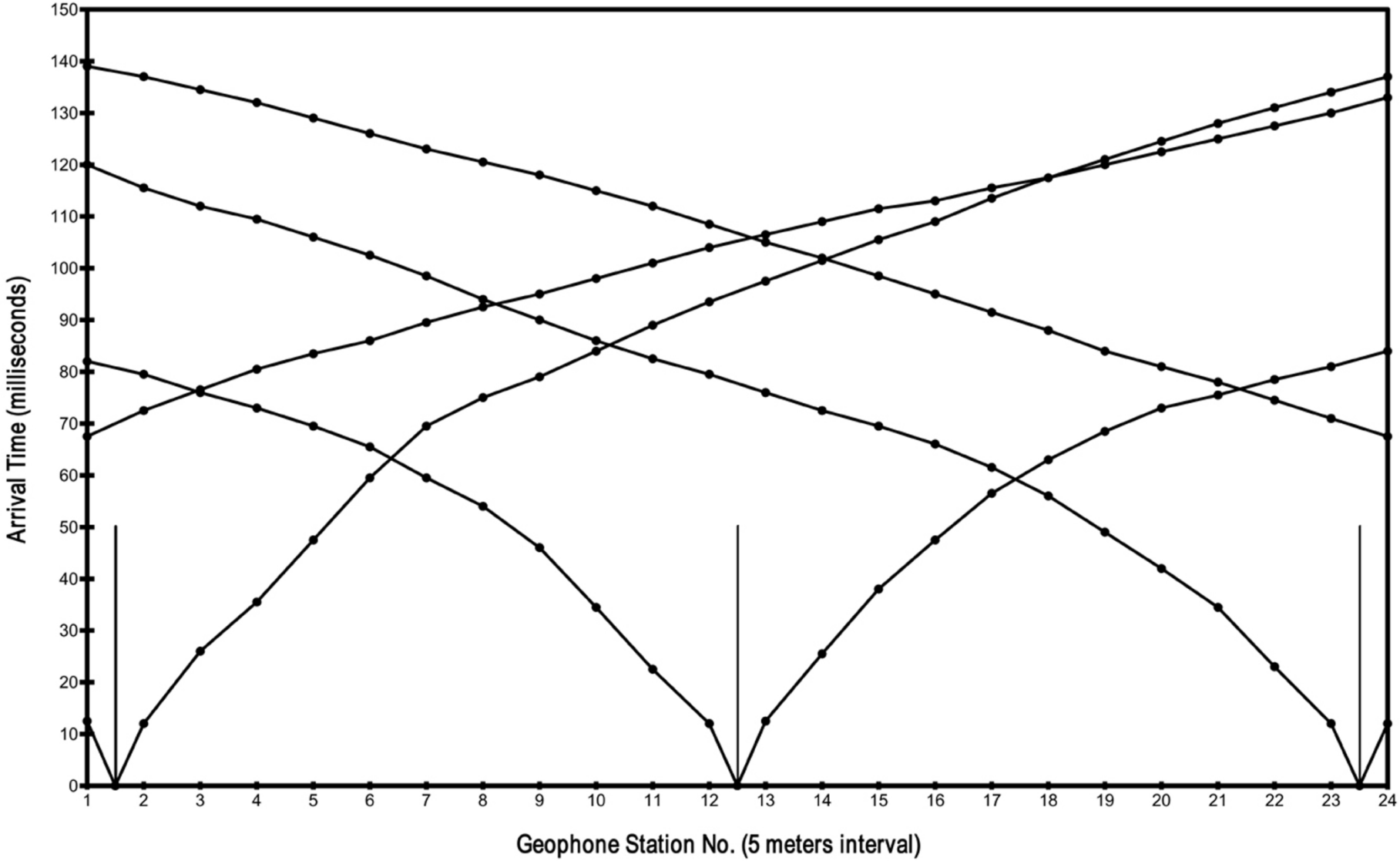


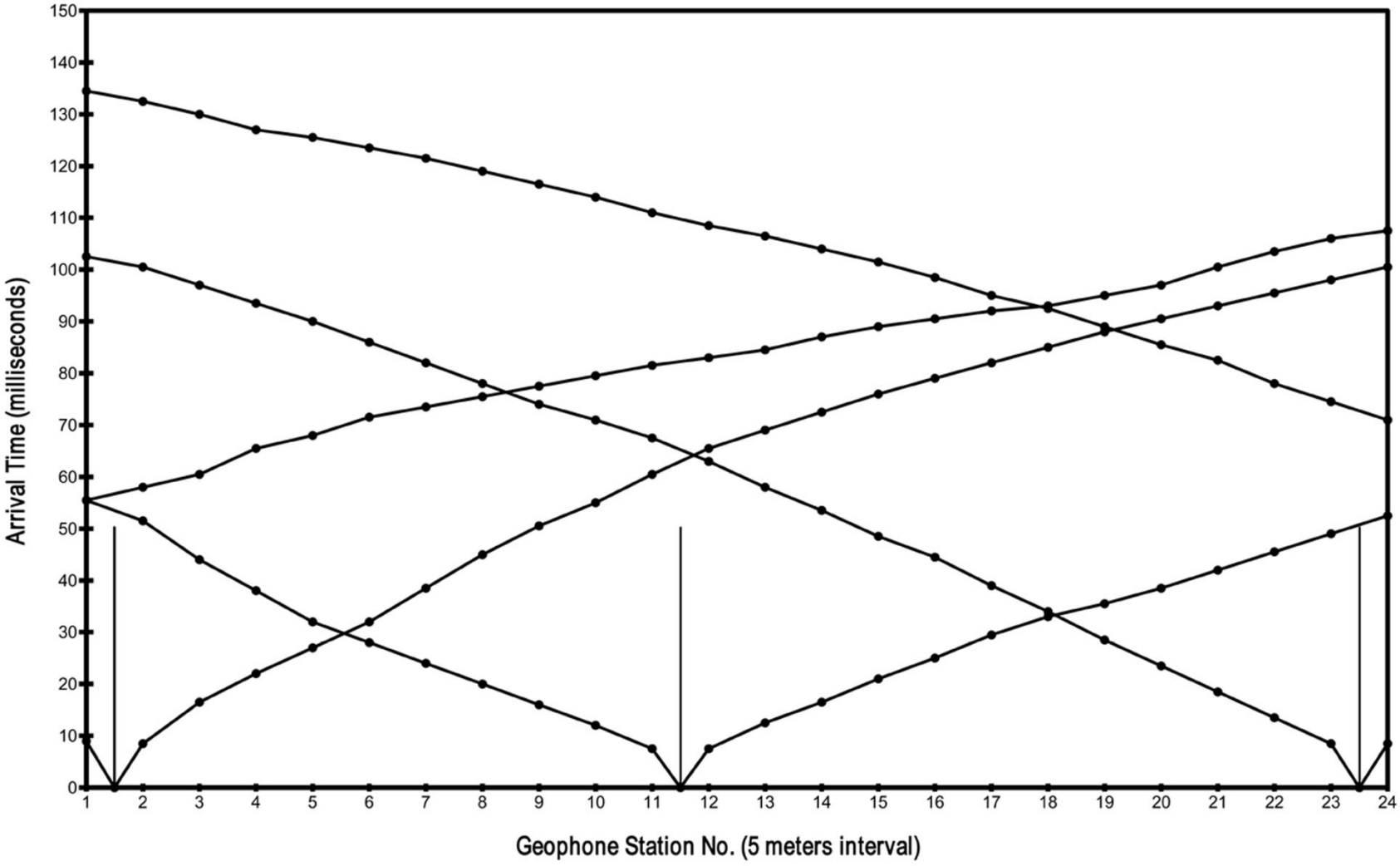
FIGURE 7

TYPICAL TIME DISTANCE GRAPH &
SEISMIC PROFILE FOR A FAULT STRUCTURE

TIME DISTANCE PLOT
LINE - 2
Figure 5



TIME DISTANCE PLOT
LINE - 1
Figure 3



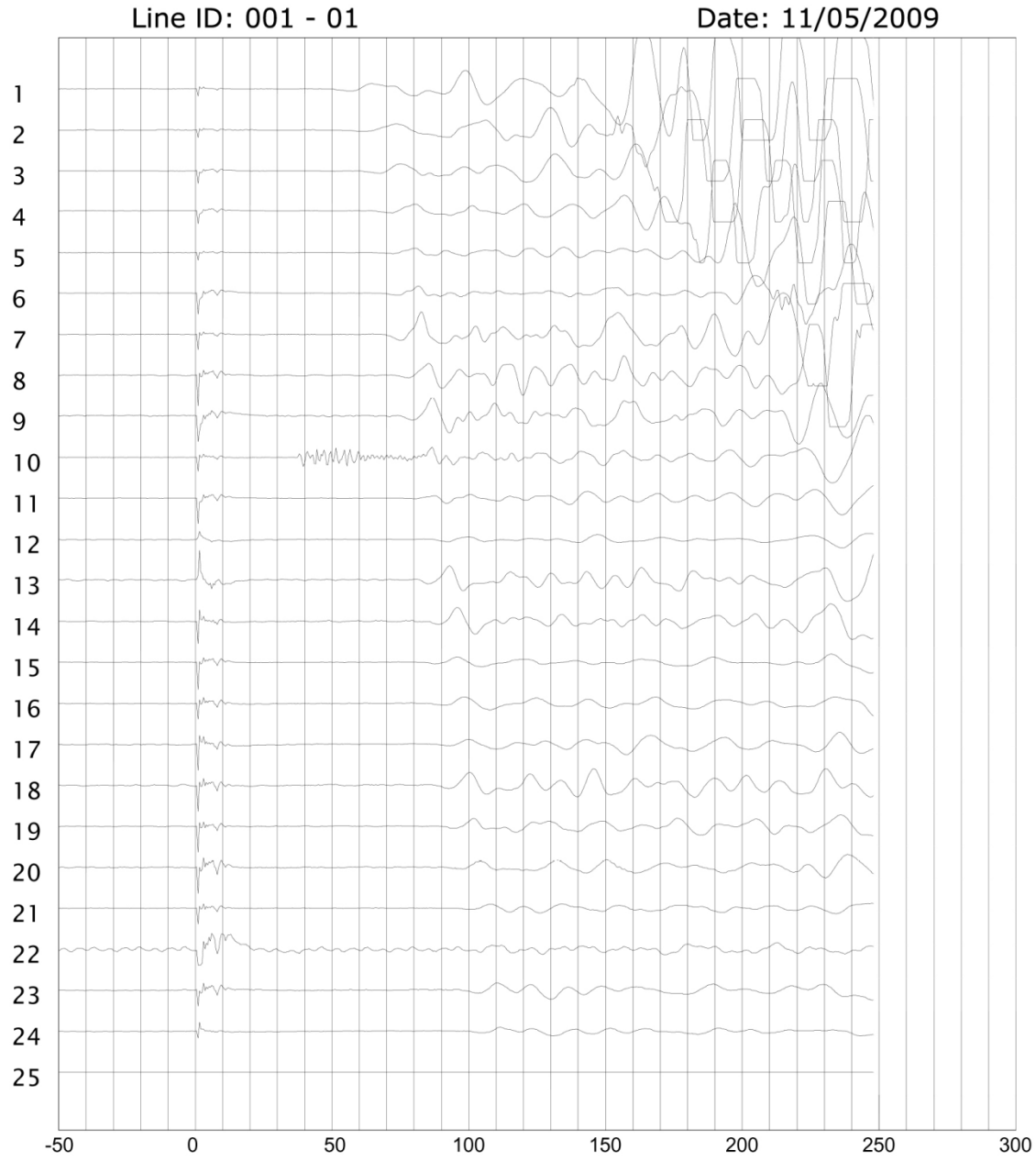


Figure 8
Line 1
Shot Point 1 (-50.0 m)

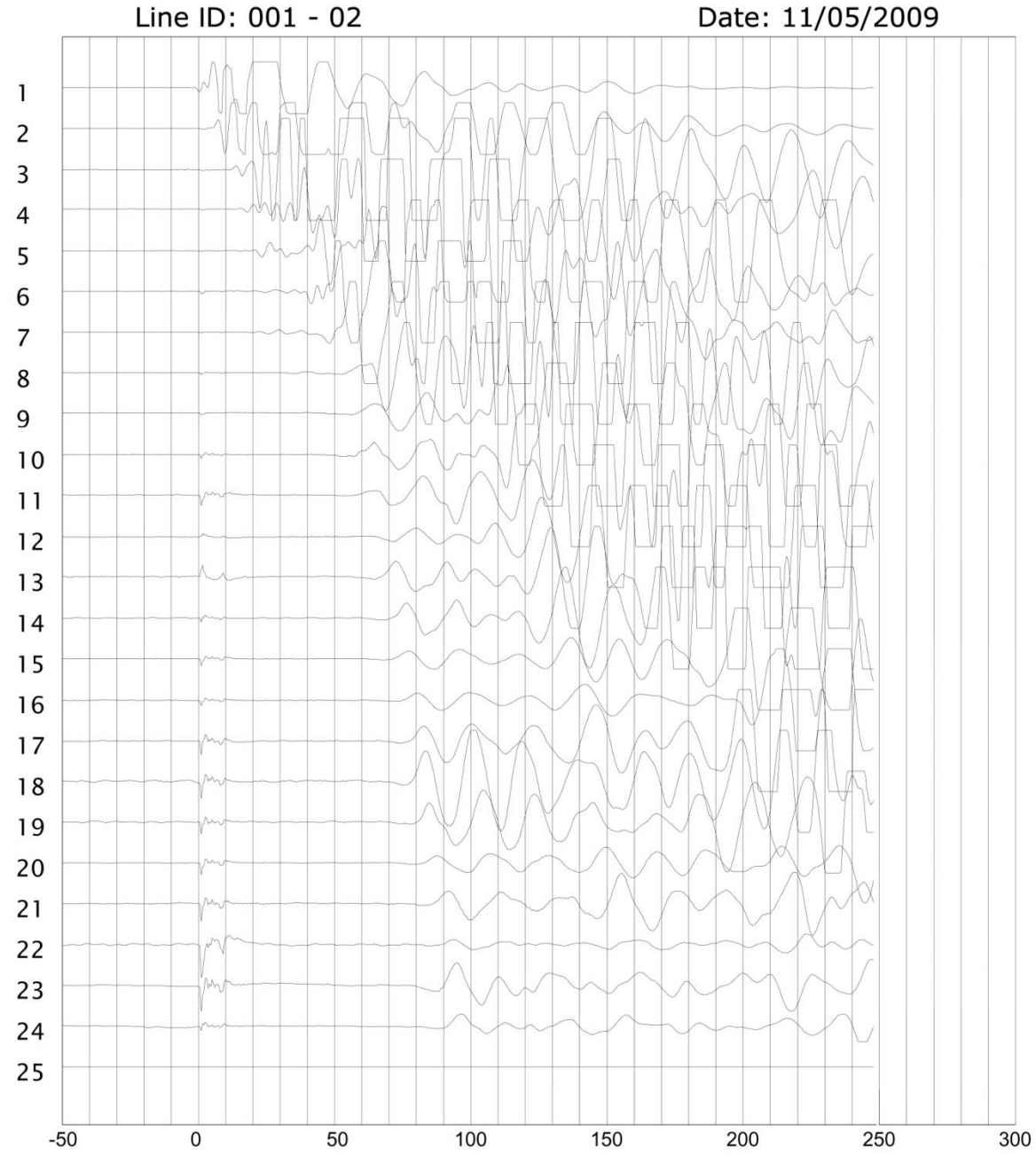


Figure 9
Line 1
Shot Point 2 (2.5 m)

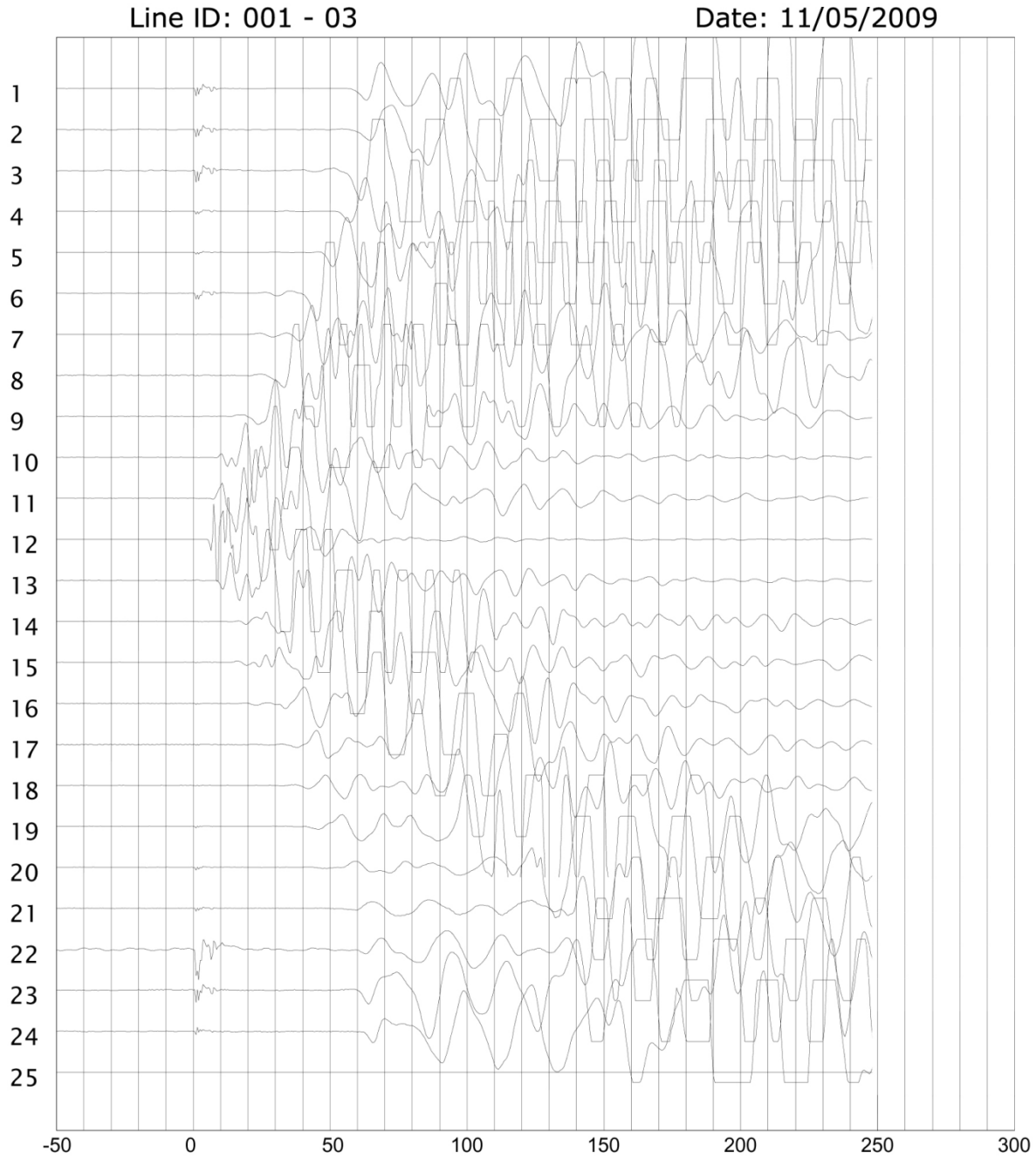
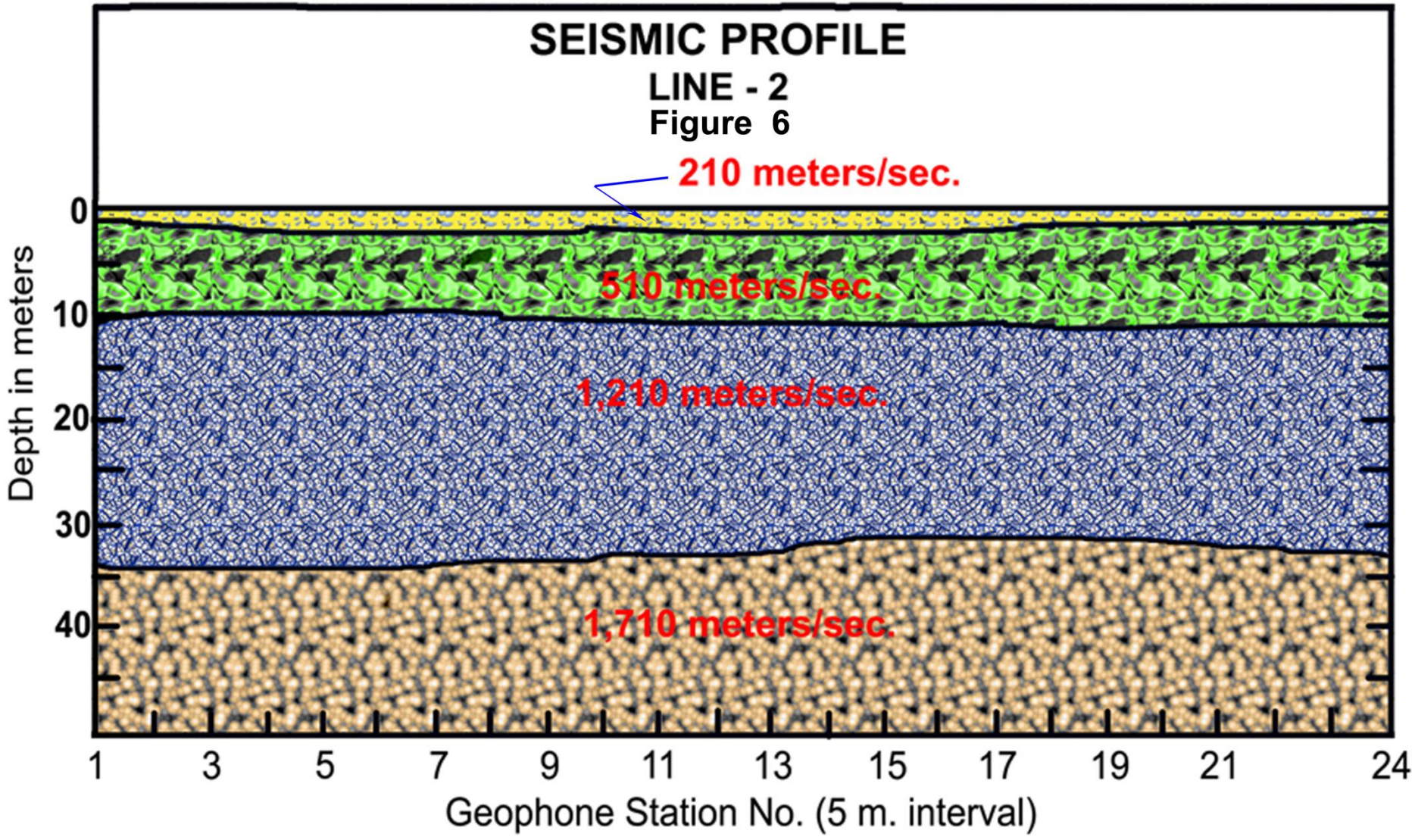
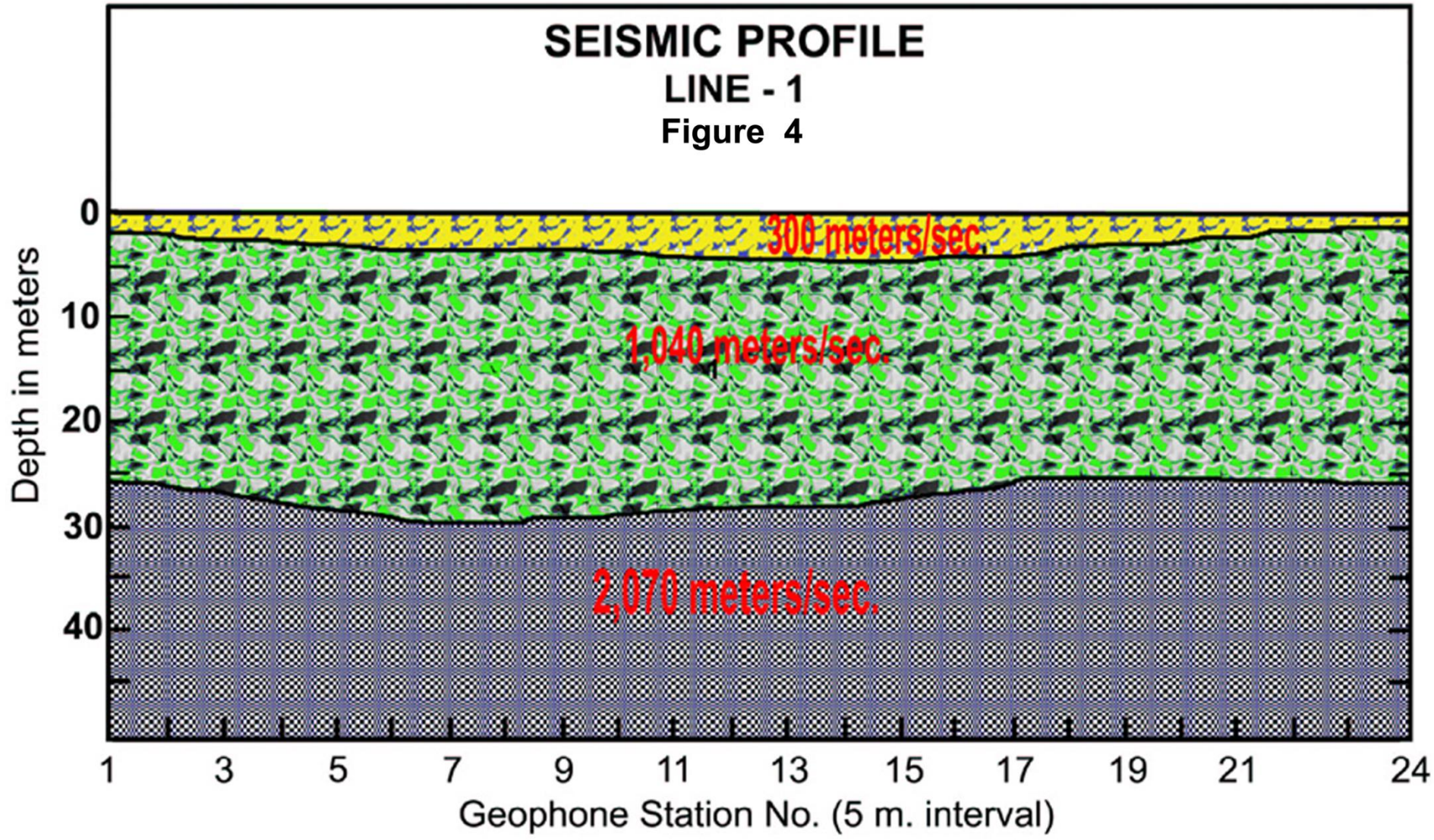


Figure 10
Line 1
Shot Point 3 (52.5 m)


SEISMIC PROFILE
LINE - 2
Figure 6
210 meters/sec.
510 meters/sec.
1,210 meters/sec.
1,710 meters/sec.
Depth in meters
0
10
20
30
40
1
3
5
7
9
11
13
15
17
19
21
24
Geophone Station No. (5 m. interval)


SEISMIC PROFILE
LINE - 1
Figure 4
300 meters/sec.
1,040 meters/sec.
2,070 meters/sec.
Depth in meters
0
10
20
30
40
1
3
5
7
9
11
13
15
17
19
21
24
Geophone Station No. (5 m. interval)

The seismic refraction data strongly support the findings of the electrical resistivity surveys:

No faults are detected beneath the BNPP

Radon and Thoron soil gas testing:

Geochemical detection of hidden faults

(another independent test)

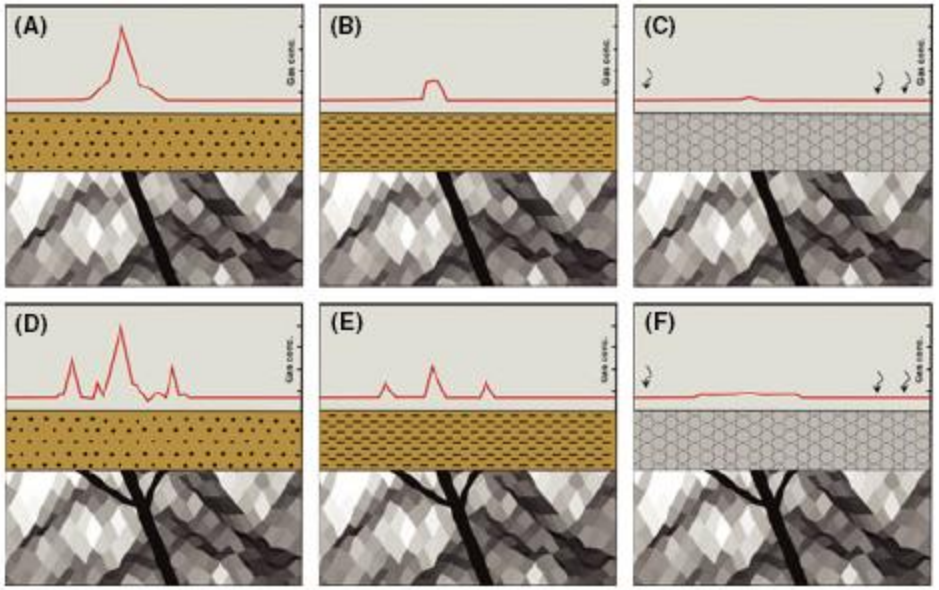


Fig. 4. Sketch of the soil gas variations across a fault zone (modified from Fu *et al.* 2005). (A)–(C) show the simple fault system. (D)–(F) are faults with branches close to the surface. (A) and (D) demonstrate that where sandy soils cover the fault (zones), then higher anomalous soil gas concentrations occur at the fault trace. (B) and (E) illustrate that where shaly soils with lower permeability cover the faults, lower soil gas concentration are observed even at the fault zone. (C) and (F) are the cases of conglomerate sediment cover above the basement. Elevated porosity in the soils and dilution by significant amount of atmospheric gas usually make it difficult to detect clear anomalous soil gas concentrations in this case.

Yang et al., 2008

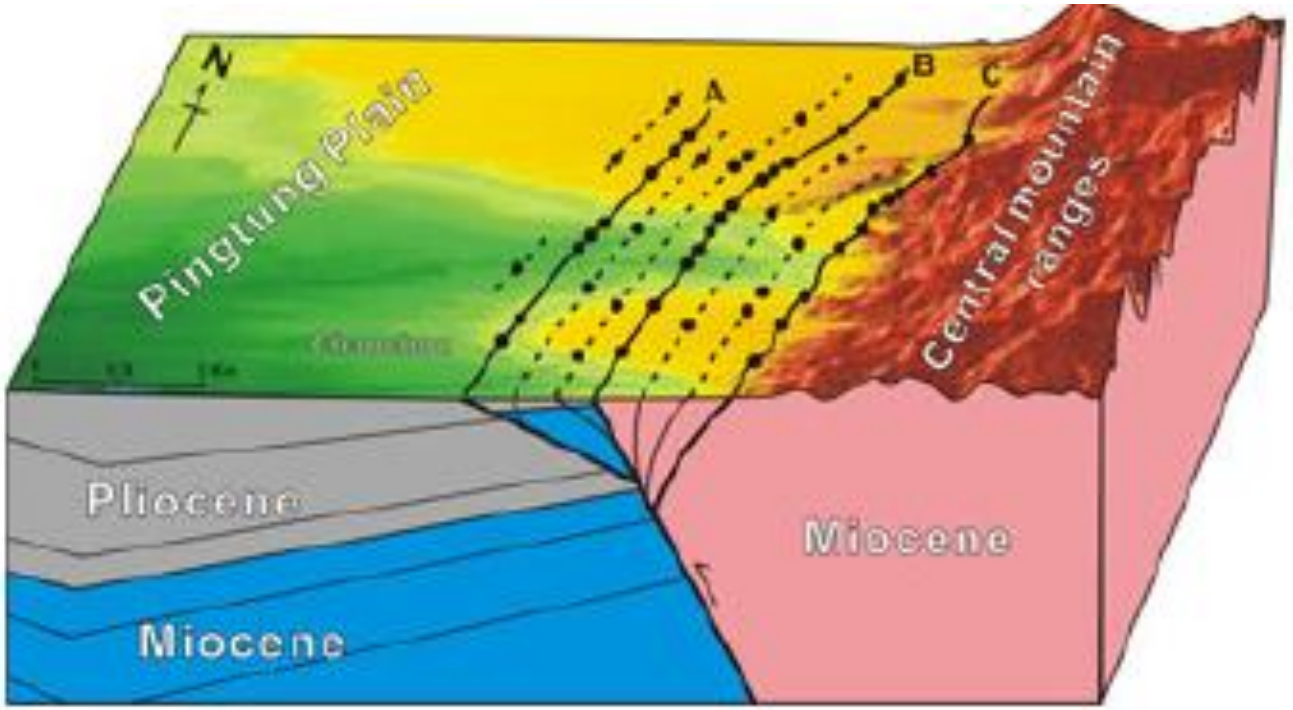
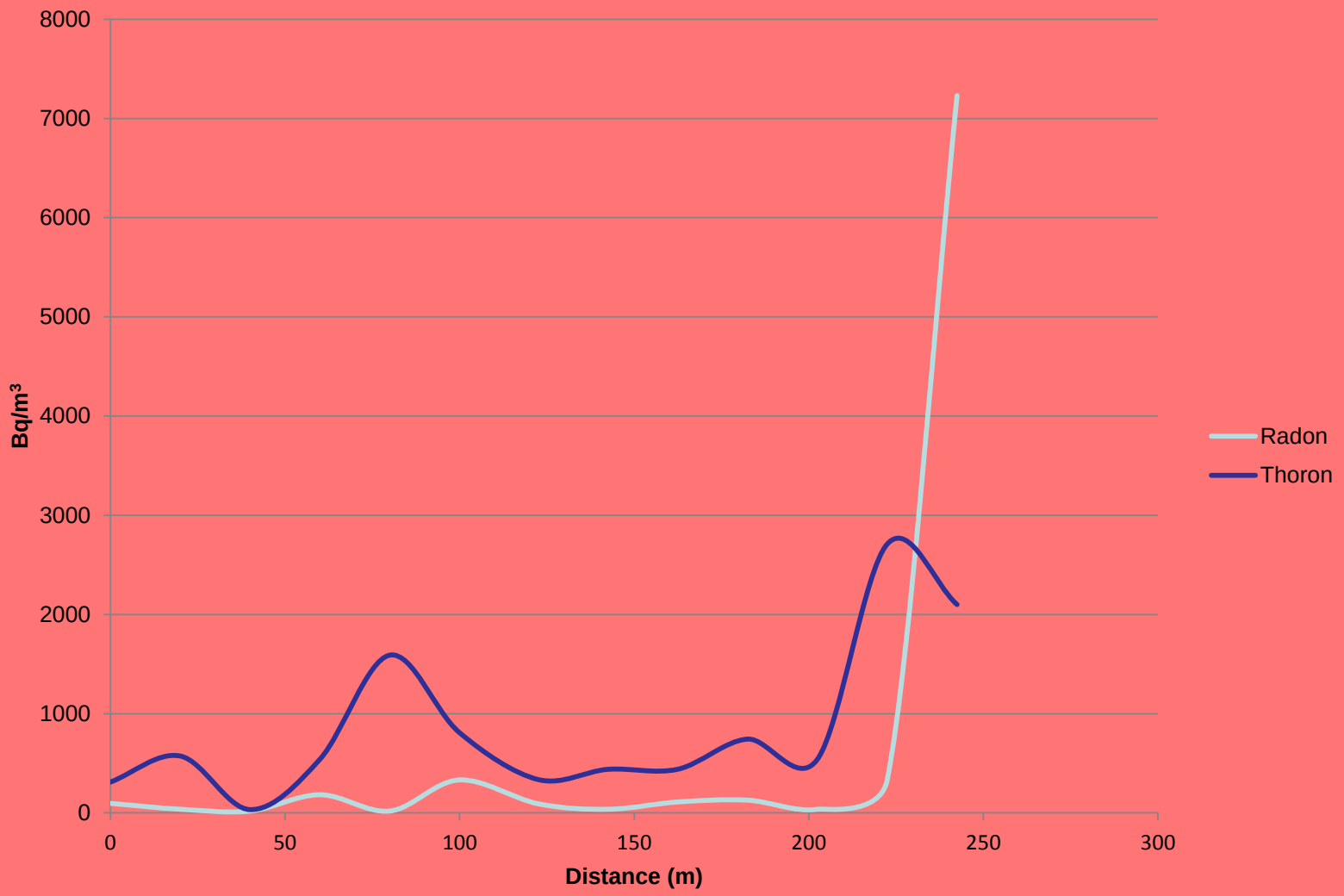


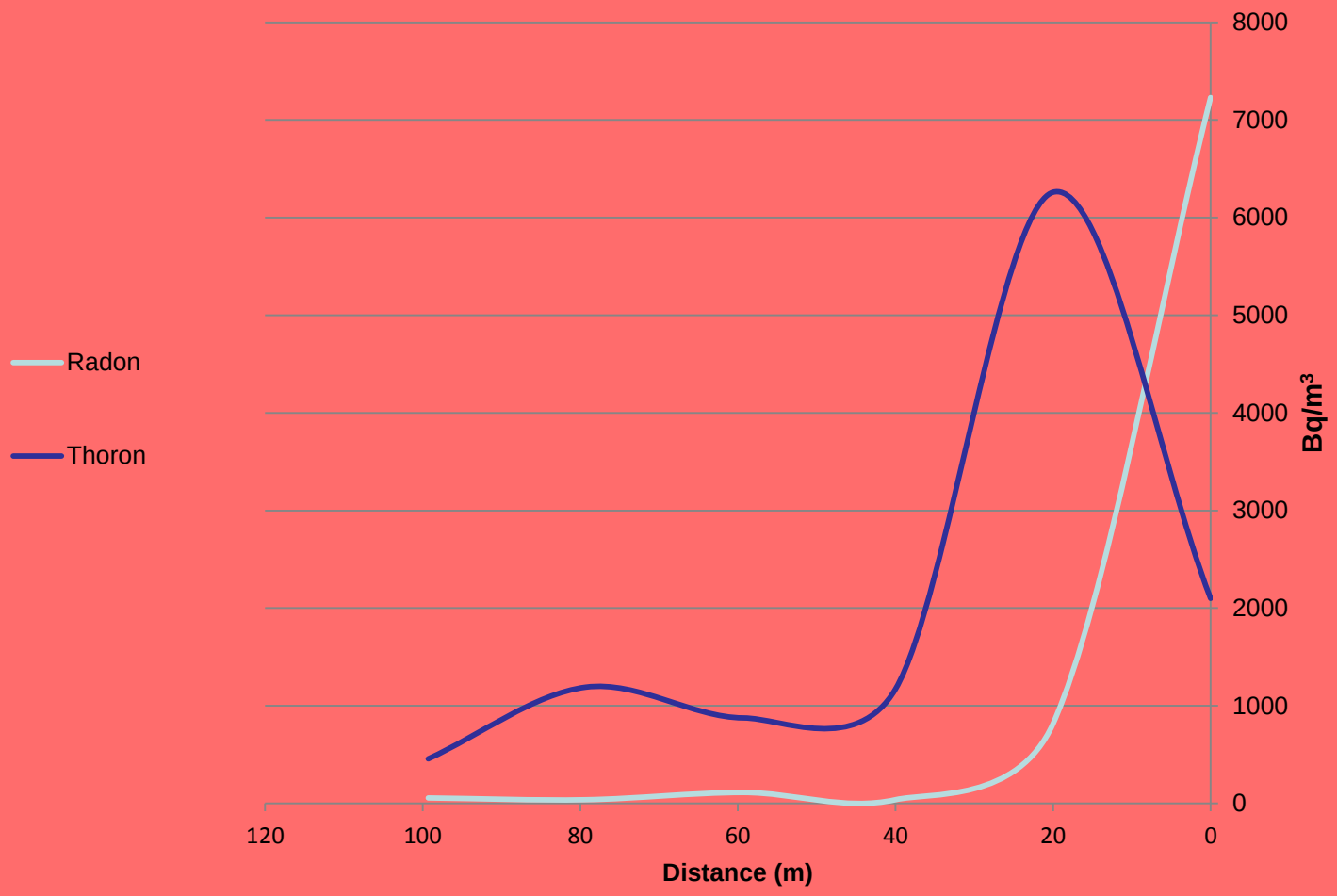
Fig. 5. Example for the delineation of the surface trace of a fault zone by soil gas survey in southern Taiwan (modified from Fu *et al.* 2005). Black circles indicate the sites with anomalous soil concentrations; those sites can delineate the surface traces of the faults/fractures.

Yang et al., 2008

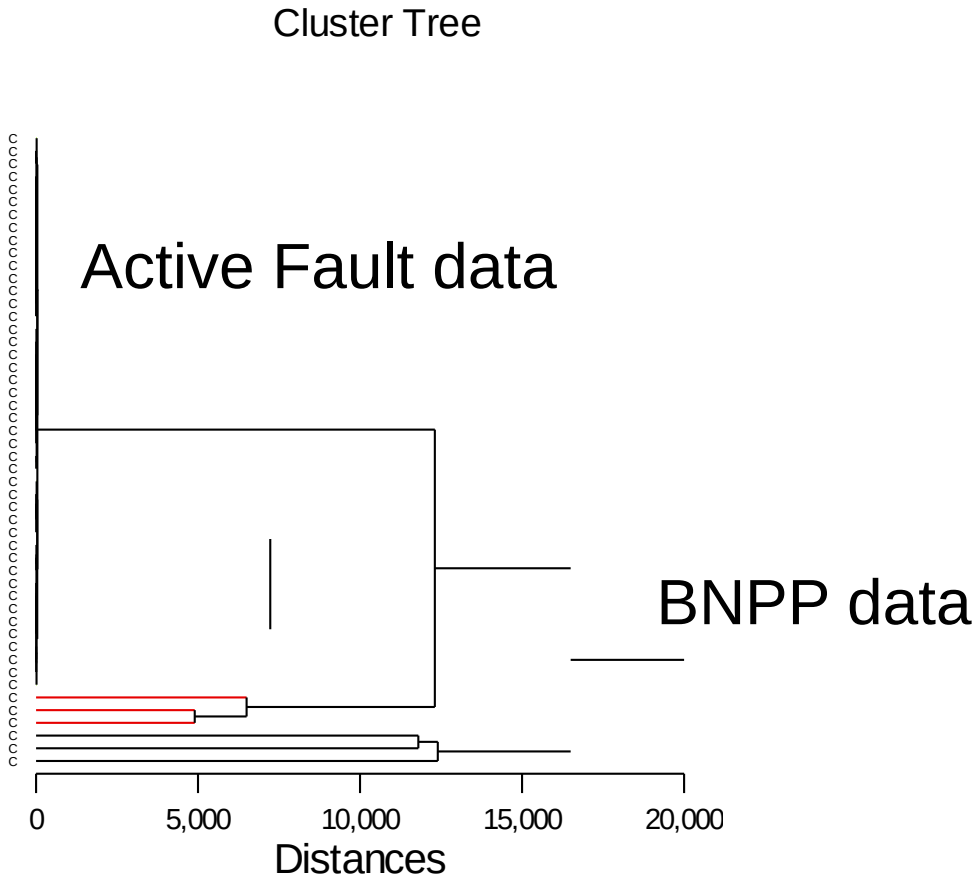

RAD7
radon detector
menu
enter
DURRIDGE
professional
DURRIDGE Co.
on
off
inlet
outlet
RAD7
Electronic Radon Detector
DURRIDGE Co.


RAD7

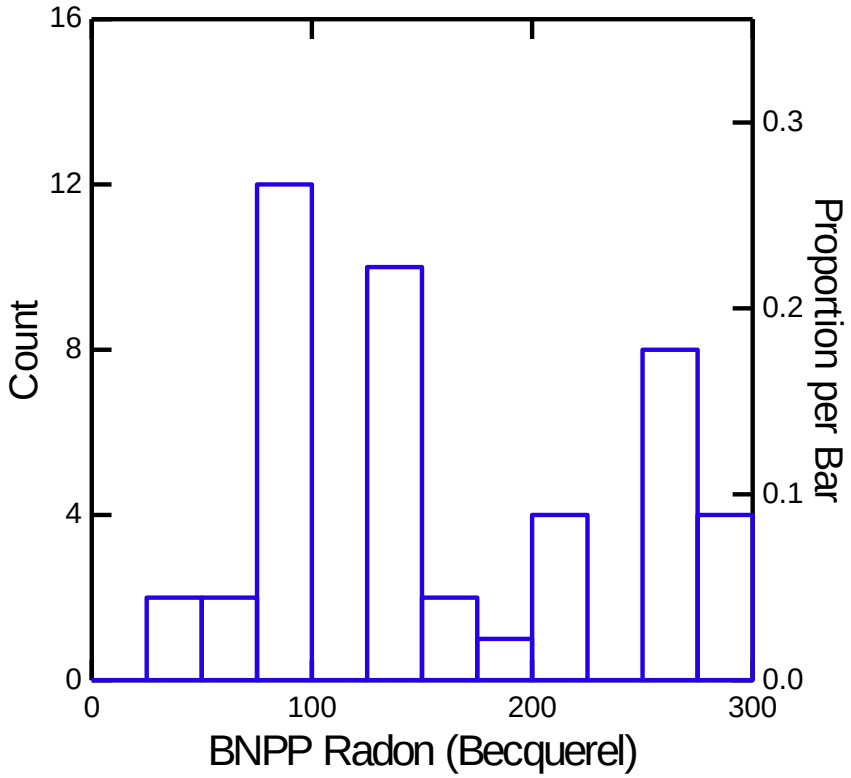

8000
7000
6000
5000
4000
3000
2000
1000
0
Bq/m3
0
50
100
150
200
250
300
Distance (m)
Radon
Thoron

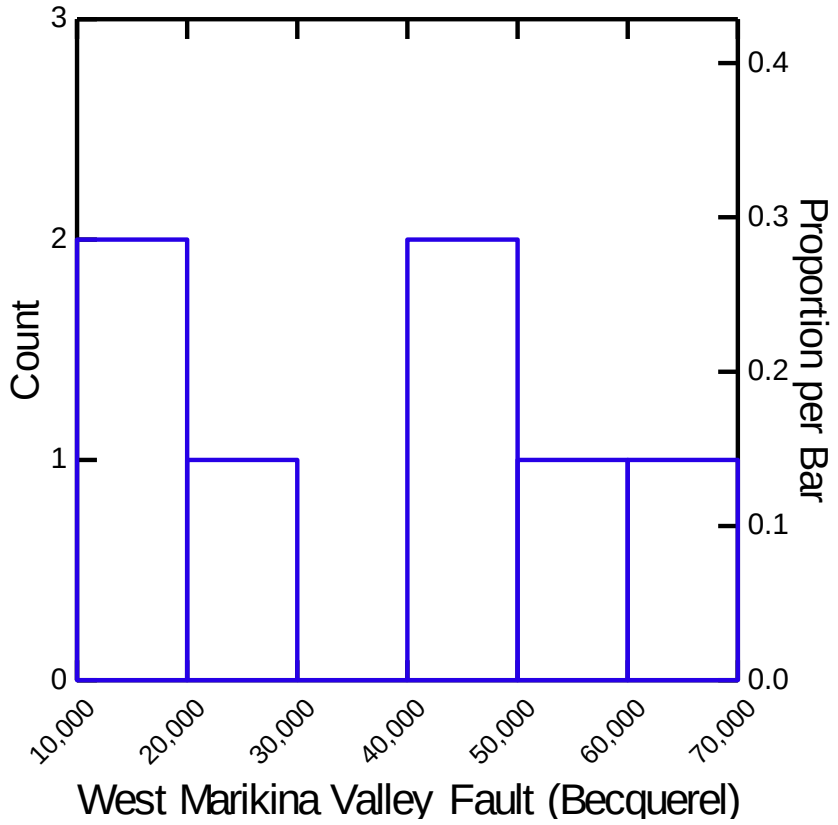

Radon
Thoron
8000
7000
6000
5000
4000
3000
2000
1000
0
Bq/m³
120
100
80
60
40
20
0
Distance (m)

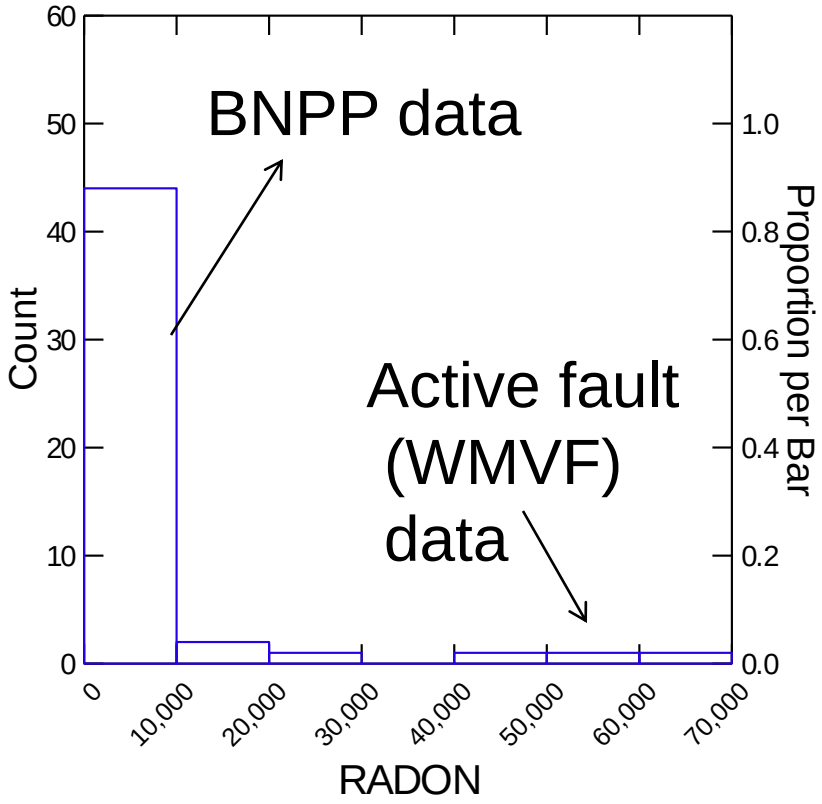
RADON GAS DATA SHOW BIMODAL DISTRIBUTION: ACTIVE FAULTS AND BNPP

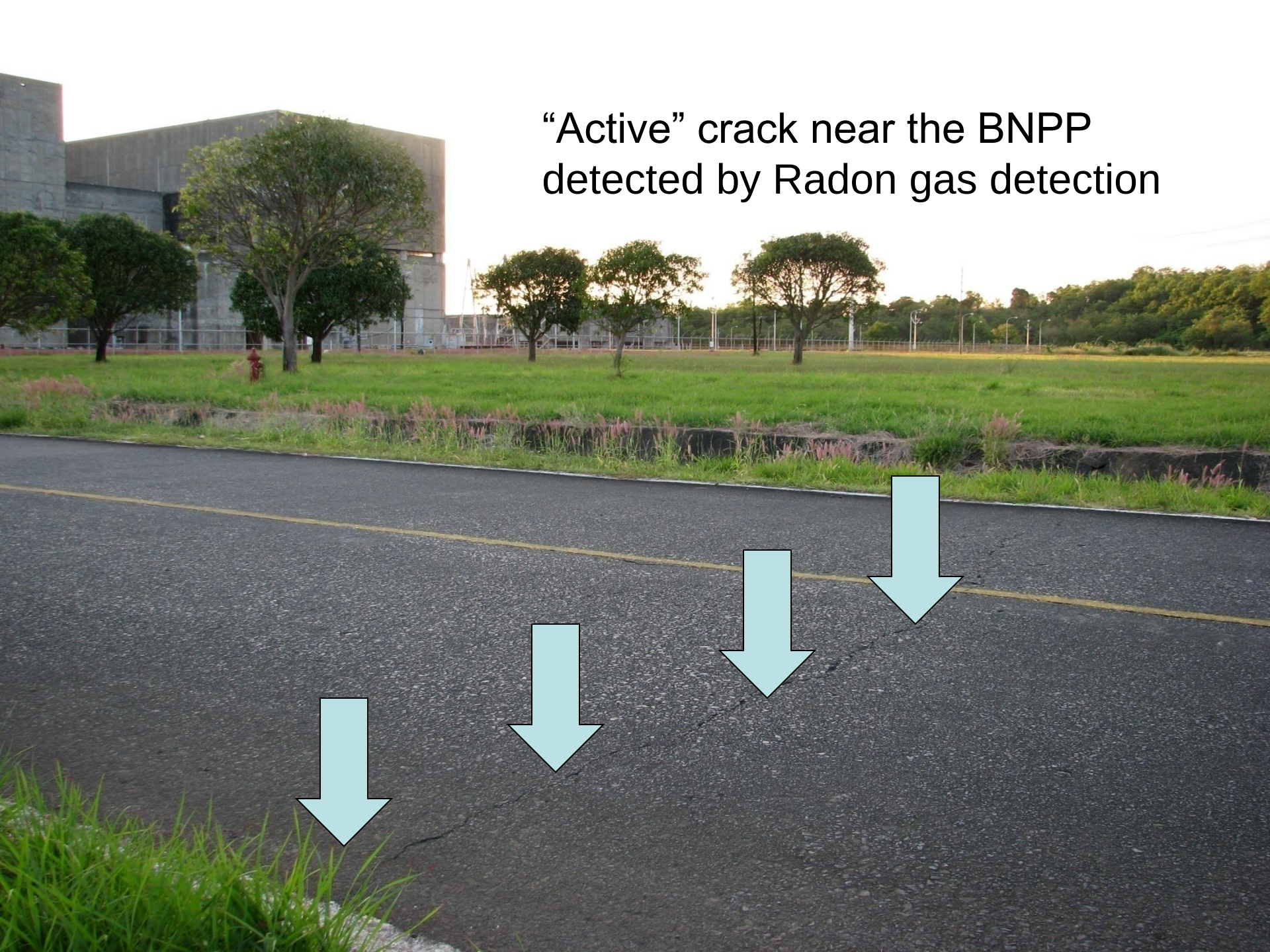


Radon gas comparisons of Active Marikina Valley Fault and BNPP surroundings






BNPP data
Active fault
(WMVF)
data
Count
Proportion per Bar
RADON
0
10
20
30
40
50
60
0.0
0.2
0.4
0.6
0.8
1.0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000


“Active” crack near the BNPP detected by Radon gas detection

Concluding Statements

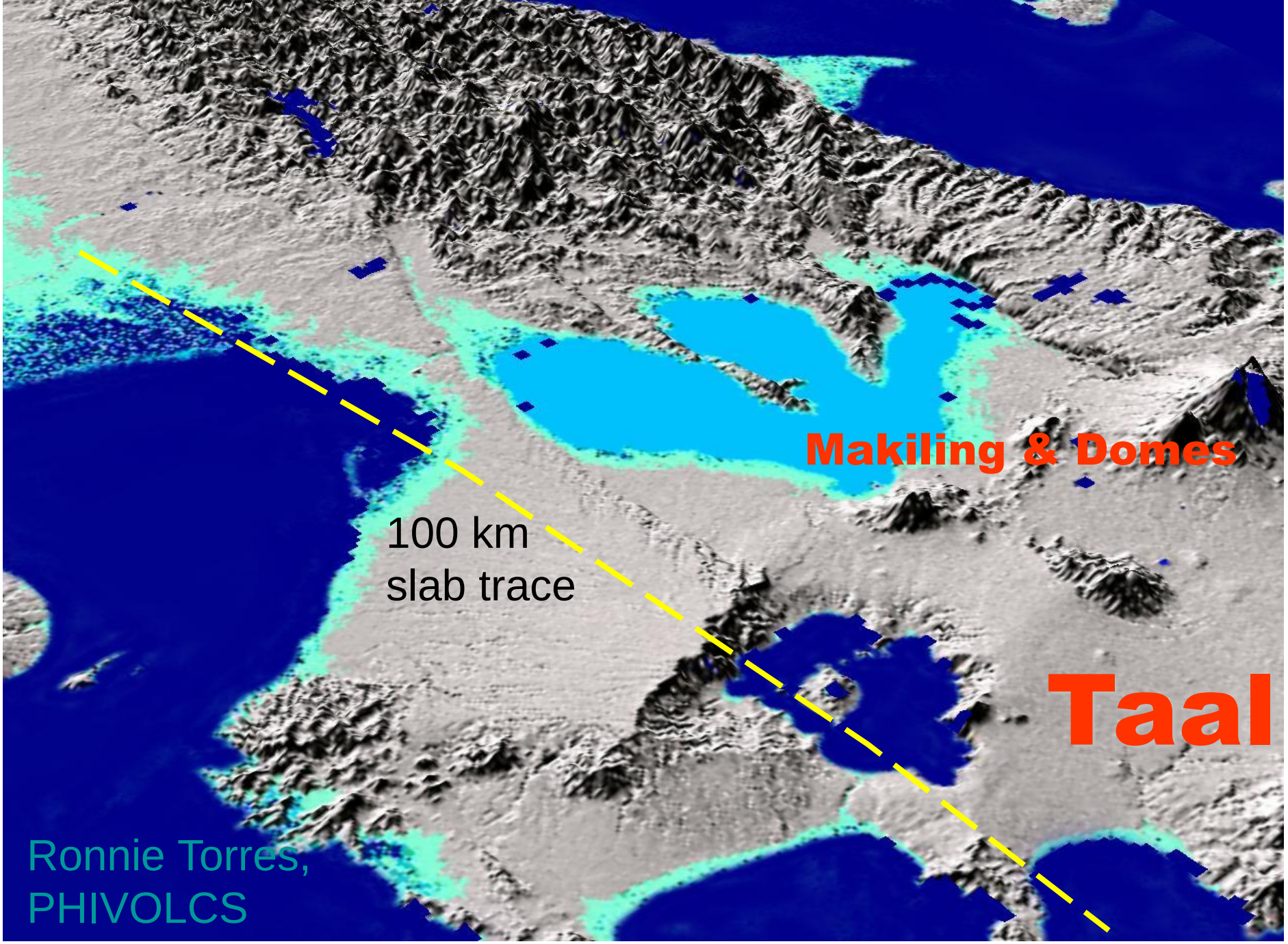
- Geologic mapping, electrical resistivity, seismic refraction, radon gas mapping all suggest there is NO fault beneath the BNPP
- There could be faults/fractures at some distance from the BNPP but these will have to be studied in detail.
- The volcanic risk will still have to be studied, with precise Age dates

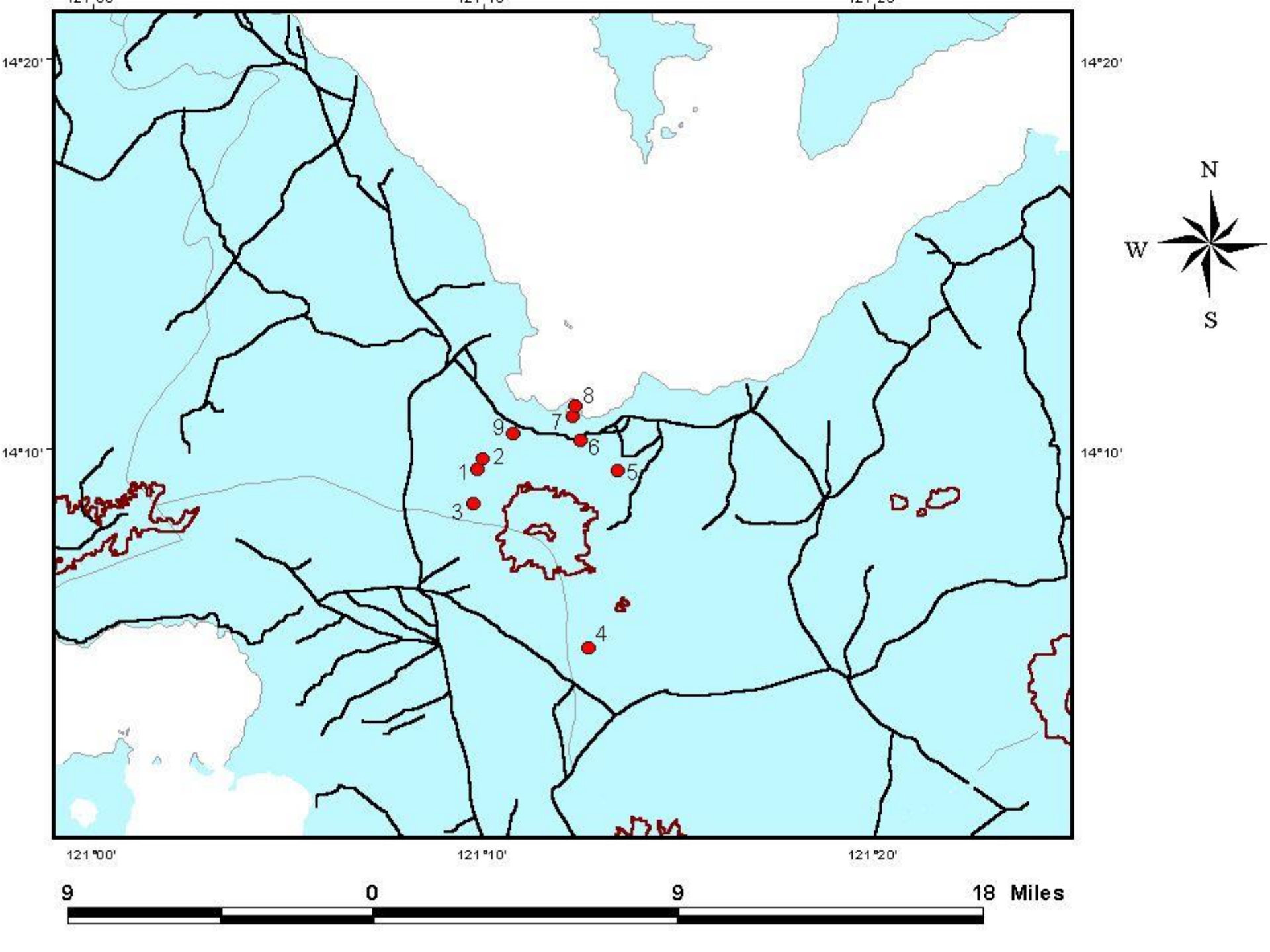
Volcanic Risk

- Age of the volcano in question
- Pyroclastic flows from Mt Natib have been mapped very close to the BNPP
- ONLY TWO reliable age dates by Carbon 14: 27,000 and 60,000 years
- Currently searching and testing for charcoal from latest eruption.

Metro Manila and volcanoes

- >10 million people within 50 km radius of a Laguna de Bay volcanoes, which is YOUNGER than Mt. Natib, and much more explosive in the past
- Located < 80 km Taal volcano, which is active, and most deadly Philippine volcano
- Most of city is built on pyroclastic flows from Laguna de Bay volcanoes


Makiling & Domes
100 km
slab trace
Taal
Ronnie Torres,
PHIVOLCS


14°20'
14°10'
121°00'
121°10'
121°20'
1
2
3
4
5
6
7
8
9
N
W
S
9
0
9
18 Miles

Manila and Clark would not have passed risk criteria imposed by earthquake and volcanic factors!

- If we follow the (defective) reasoning for closing the Bataan Nuclear plant, then the cities of Manila and Angeles (Clark) should have never been built in the first place

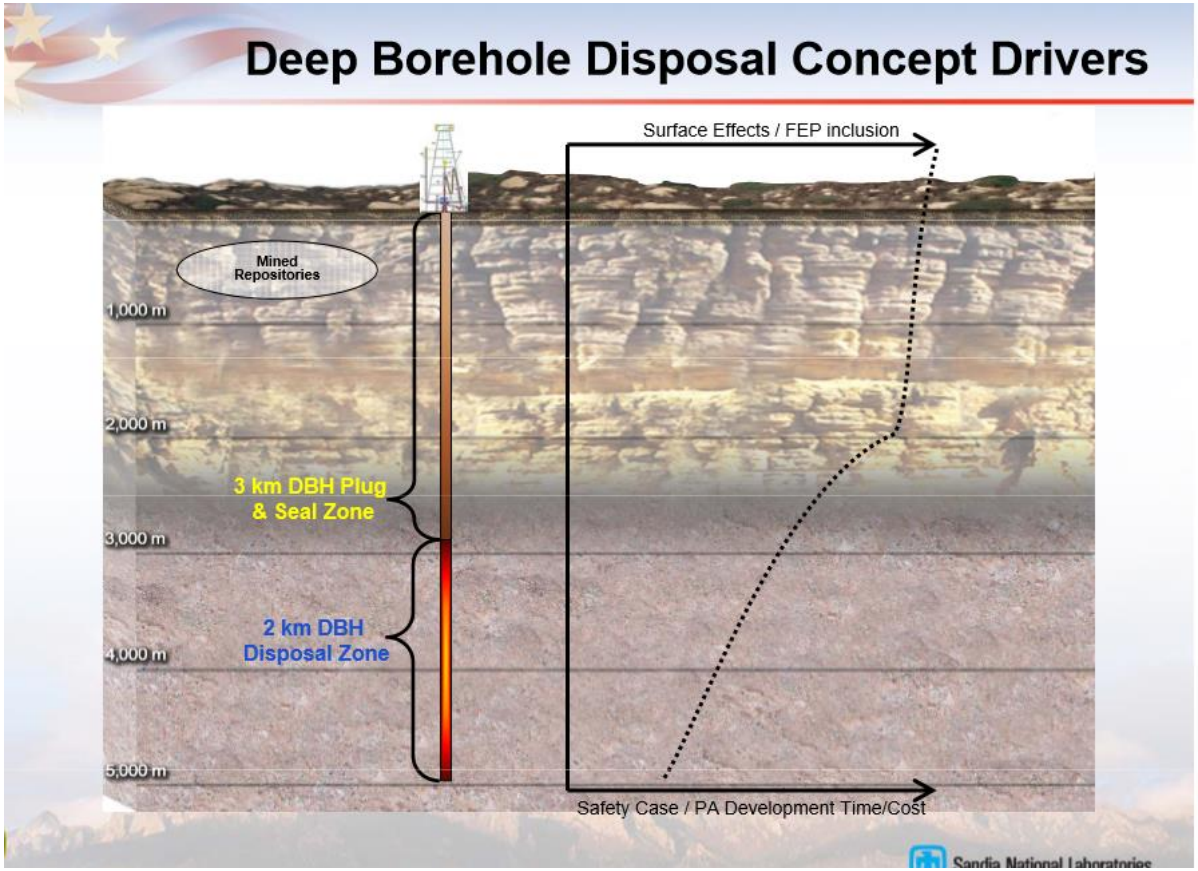
Concluding Statements

- If indeed an active fault is beneath BNPP, this immediately disqualifies its reopening.
- If, however, the active fault is beside or proximate, it must be mapped ON THE GROUND and estimate peak ground acceleration if an earthquake happens.
- Our data need to be disproven by facts

IAEA draft guidelines on nuclear power plant siting in volcanic terrane

IAEA will vet the BNPP if it is safe to open because an accident anywhere is an accident everywhere, but there must be an actual verification of the suggested fault and volcano dangers

Disposal of nuclear waste?



Deep borehole disposal

Asserted Benefits of DBH Disposal Concepts

- **Crystalline basement rocks are relatively common at depths of 2 km to 5km**
- **Disposal could occur at multiple locations, reducing waste transportation costs and risks**
  - Greater potential for site to site performance comparability, possibly avoiding 'best site' contentions, fostering equity and fairness issues.
- **Low permeability and high salinity in the deep crystalline basement suggest extremely limited interaction with shallow groundwater resources; high assurance isolation**
- **Thermal loading issues are minimized**
- **Geochemically reducing conditions limit solubility and enhance the sorption of many radionuclides**
- **Retrievability is difficult**
- **Compatible with multiple waste forms and types (e.g. CANDU bundles)**
- **The deep borehole disposal concept is modular, with construction and operational costs scaling approximately linearly with waste inventory**
- **Existing drilling technology permits construction of boreholes at a cost of about $20 million each**
  - Low cost facilitates abandonment of emplacement-ready holes that fail to meet minimum criteria, limits 'make it work' perceptions
- **Disposal capacity of ~950 boreholes would allow disposal of projected US SNF inventory**
  - Dry Rod Consolidation (demonstrated at INL in the 80's) could reduce this by ~1/2, or possibly further reduce costs for smaller hole bottom diameter
- **May be amenable to a COL approach (separate licensing for technology and siting)**

Conclusion

- The point here is not that Deep Borehole Disposal is the best or only solution for geologic disposal. The point is that the concept holds such significant promise that it warrants consideration of an effort to accelerate its pilot demonstration, and to vet its true feasibility and viability.
- As the concept has such merit for the US, and potentially Mexico and Canada as well, it may be worth considering a multinational collaborative effort similar to the EU technology platform for Implementing Geologic Disposal.
- Lastly, as a concept which could yield patentable technology that would have direct and indirect applications (e.g. enhanced geothermal), industry RD&D participation is conceivable, and could be a precursor to alternative waste management models such as FedCorp.