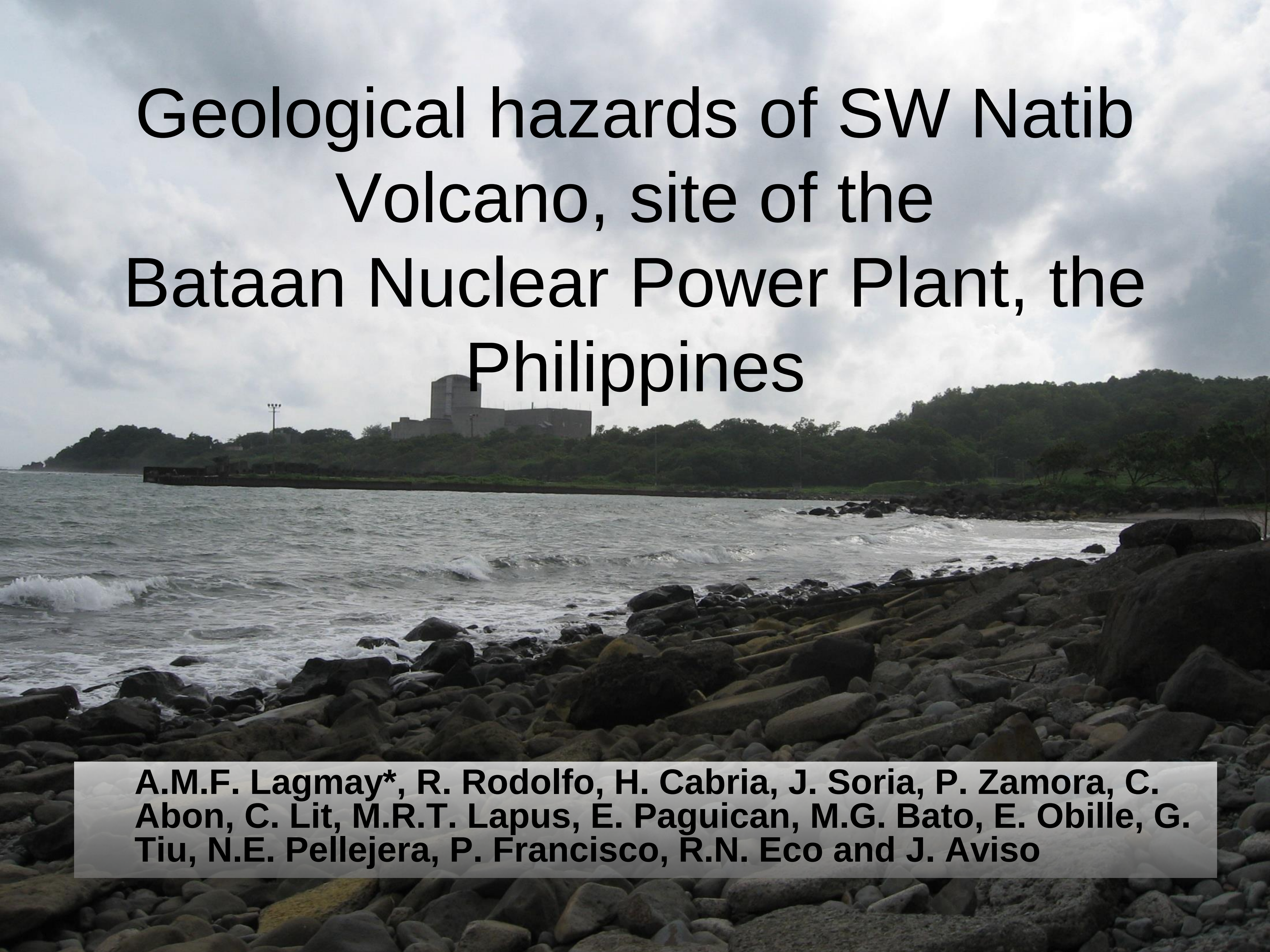
Geological hazards of SW Natib Volcano, site of the Bataan Nuclear Power Plant, the Philippines

A.M.F. Lagmay*, R. Rodolfo, H. Cabria, J. Soria, P. Zamora, C. Abon, C. Lit, M.R.T. Lapus, E. Paguican, M.G. Bato, E. Obille, G. Tiu, N.E. Pellejera, P. Francisco, R.N. Eco and J. Aviso




~33 km
Natib Volcano
BNPP
~25 km
Mariveles Volcano

Knowledge

- Much of scientific understanding of volcanism was learned only in the past 35 years.
  - Eruption columns
  - Pyroclastic Density currents

St. Pierre after the 8 May 1902 disaster

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Geological Society, London, Special Publications 2012; v. 361; p. 151-169
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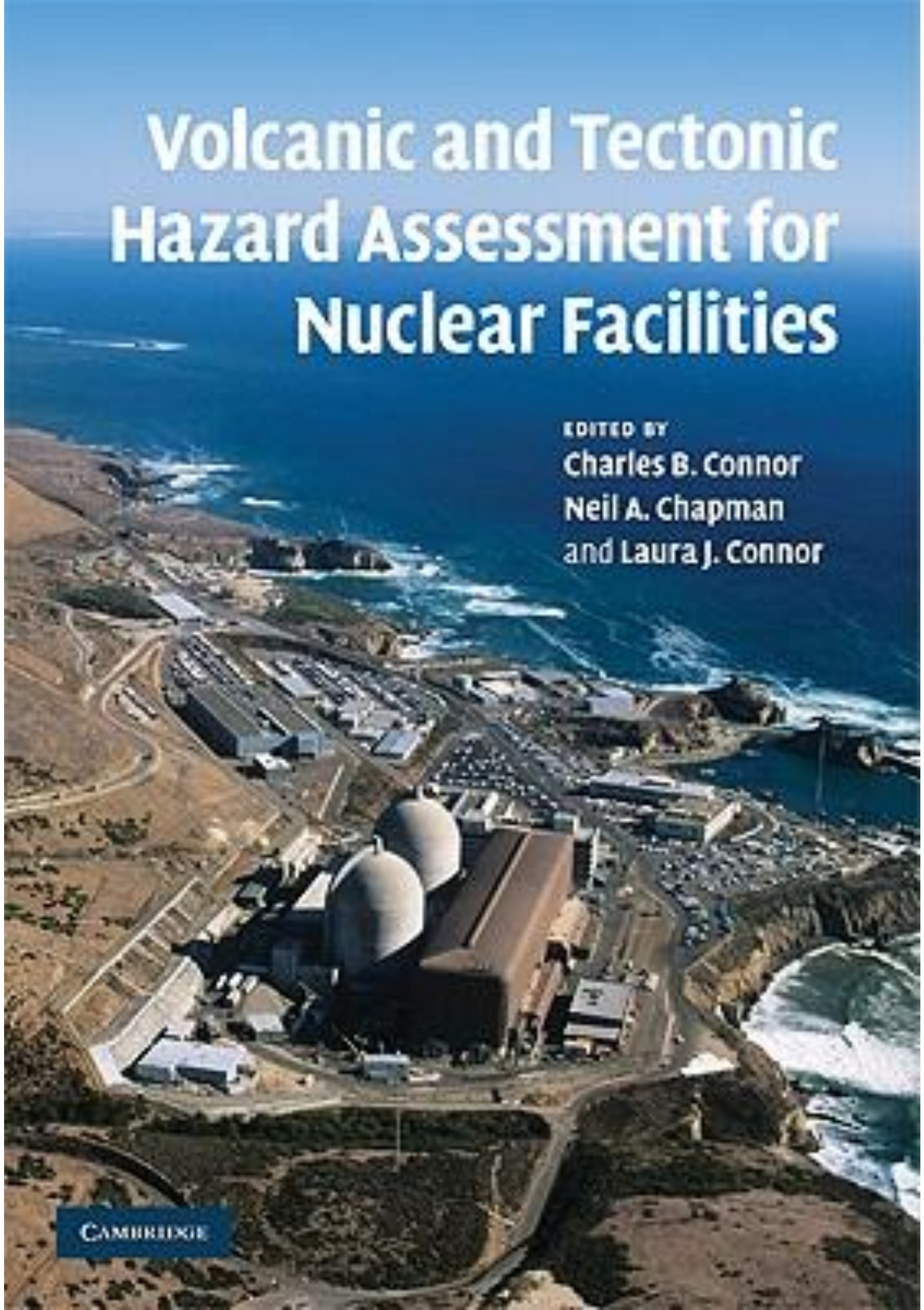
Notes


Volcanic and Tectonic Hazard Assessment for Nuclear Facilities
EDITED BY
Charles B. Connor
Neil A. Chapman
and Laura J. Connor
CAMBRIDGE

IAEA
International Atomic Energy Agency

IAEA Safety Standards

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Description

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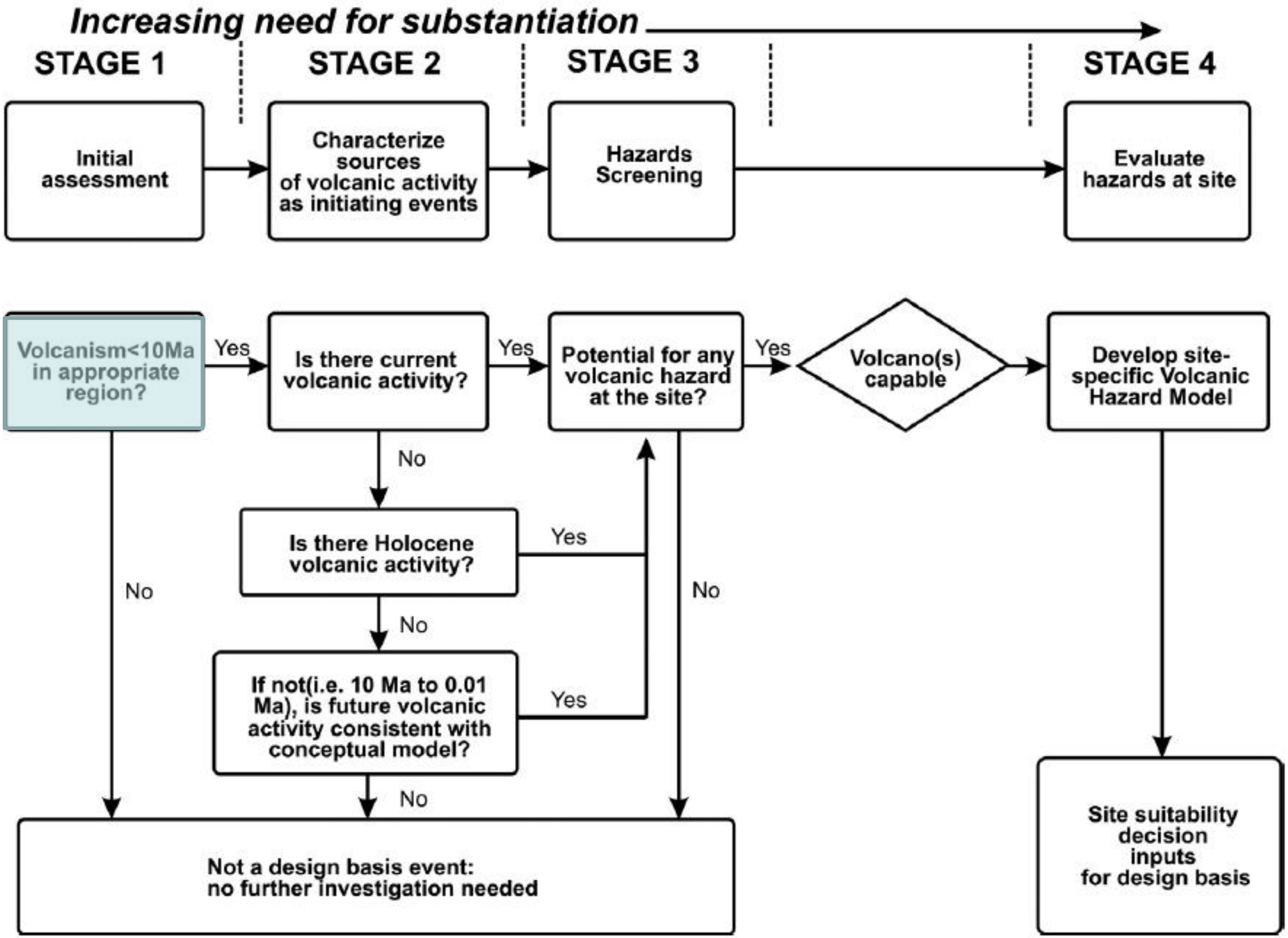
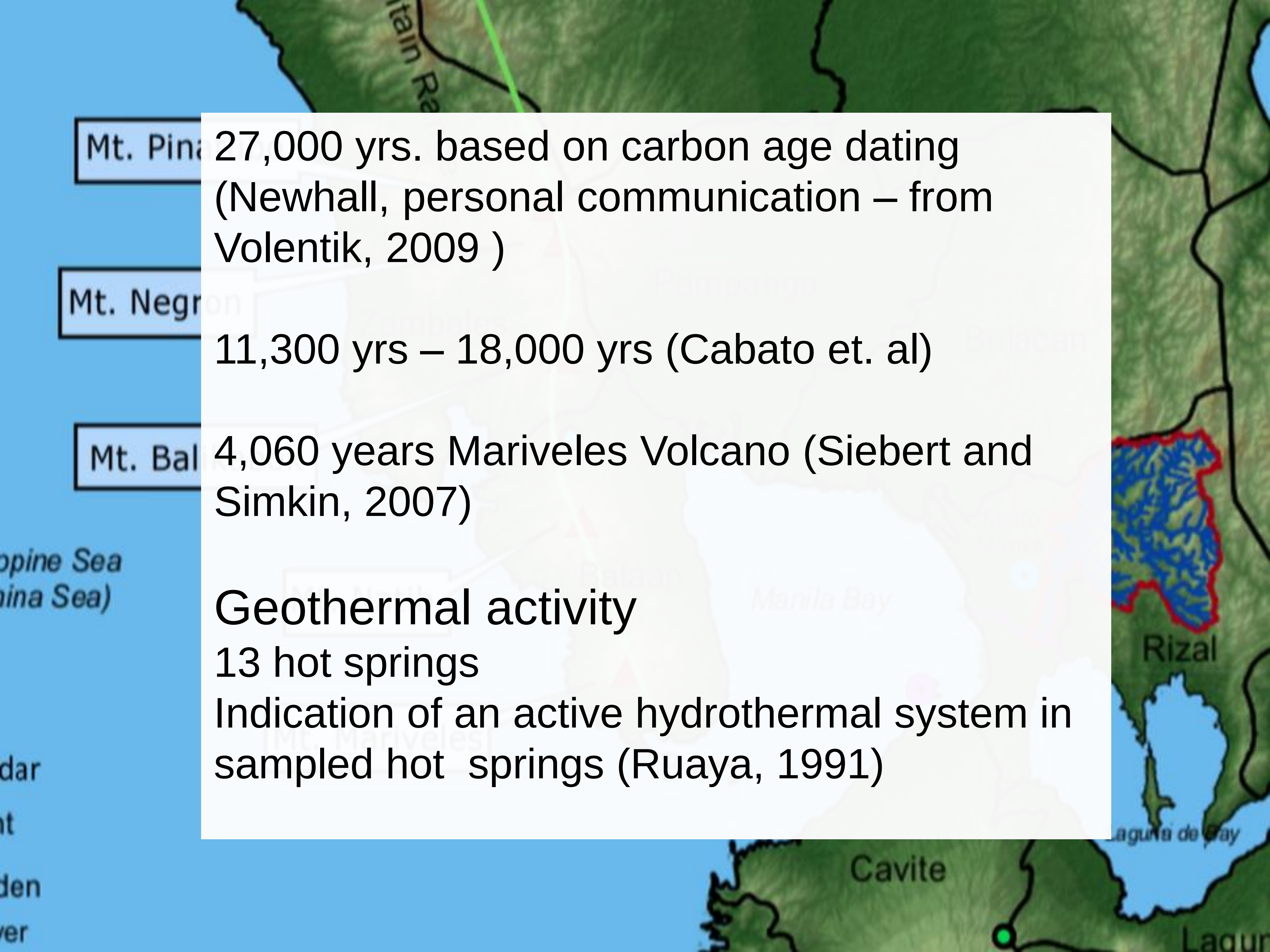
Volcanic Hazard Assessments for Nuclear Installations: Methods and Examples in Site Evaluation

Released in October 2016



Increasing need for substantiation
STAGE 1
STAGE 2
STAGE 3
STAGE 4
Initial assessment
Characterize sources of volcanic activity as initiating events
Hazards Screening
Evaluate hazards at site
Volcanism<10Ma in appropriate region?
Yes
Is there current volcanic activity?
Yes
Potential for any volcanic hazard at the site?
Yes
Volcano(s) capable
Develop site-specific Volcanic Hazard Model
No
Is there Holocene volcanic activity?
Yes
No
No
No
If not(i.e. 10 Ma to 0.01 Ma), is future volcanic activity consistent with conceptual model?
Yes
No
Not a design basis event: no further investigation needed
Site suitability decision inputs for design basis



27,000 yrs. based on carbon age dating (Newhall, personal communication – from Volentik, 2009)

11,300 yrs – 18,000 yrs (Cabato et. al)

4,060 years Mariveles Volcano (Siebert and Simkin, 2007)

Geothermal activity

13 hot springs

Indication of an active hydrothermal system in sampled hot springs (Ruaya, 1991)

A capable volcano or volcanic field is one that:

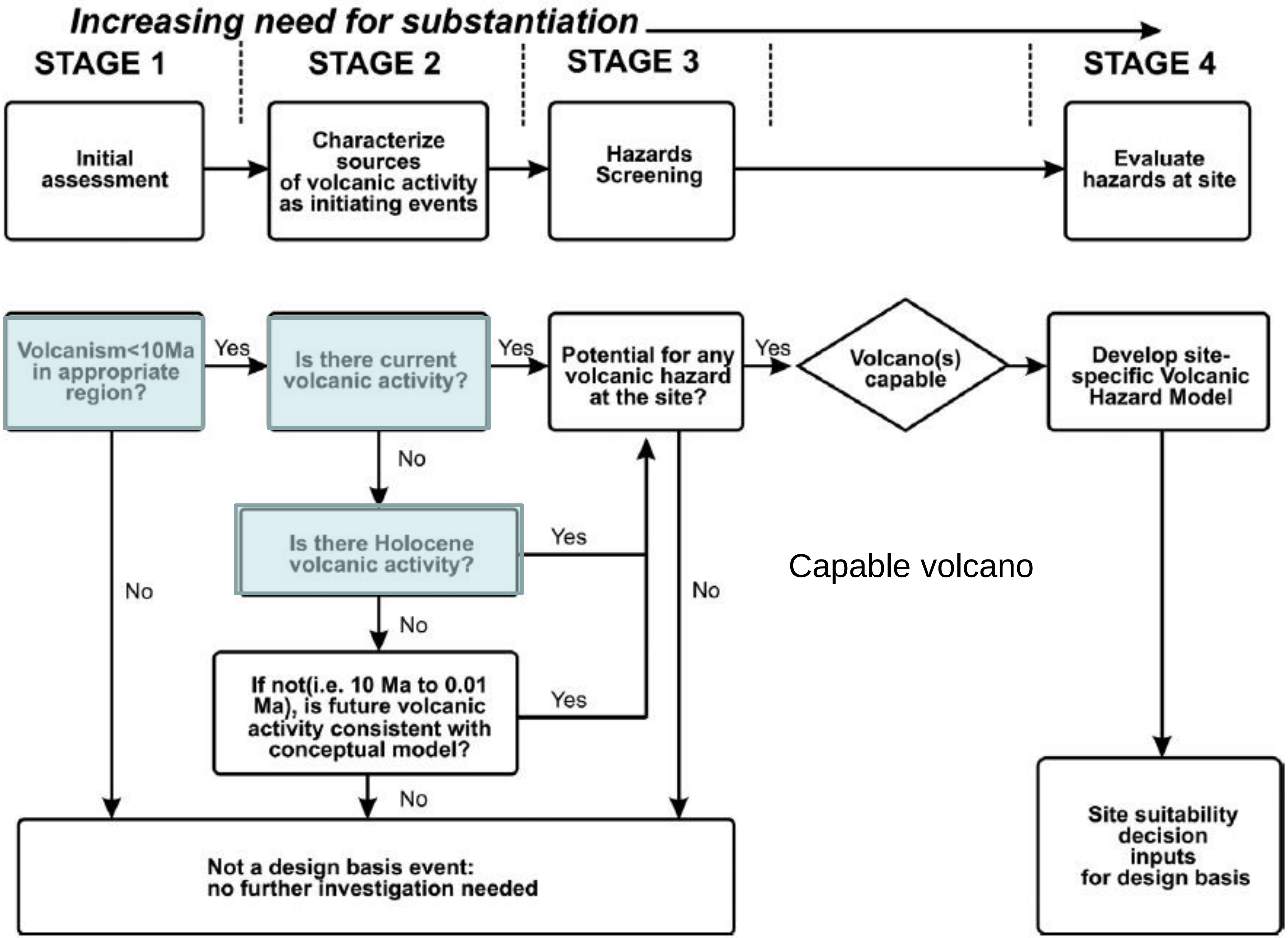
(i) has a credible likelihood of experiencing future activity during the lifetime of the installation

(ii) has the potential to produce phenomena that may affect the site of the installation. The designation of a volcano as capable is not dependent only on the time elapsed since the most recent eruption of the volcano, but rather is dependent on the credibility of the occurrence

IAEA, 2012

What probability constitutes serious radiological consequences

In some States a value for the annual probability of 10^{-7} is used in the hazard assessment for external events as a reasonable basis to evaluate whether a volcano in the region could produce any type of activity in the future that could lead to serious radiological consequences(IAEA 2012).



Capable volcano

Potential sources of future volcanic activity

- Evidence of current volcanic activity includes historical volcanic eruptions, ongoing volcanic unrest, an active hydrothermal system (e.g. the presence of fumaroles) and related phenomena.
- Evidence of an eruption in the past 2 Ma generally indicates that future volcanic activity remains possible

IAEA, 2012

Potentially active

www.phivolcs.dost.gov.ph/html/update_VMEPD/Volcano/VolcanoList/natib.htm

NATIB

Name of Volcano: NATIB

Classification: Potentially Active
Lat (deg-min) 14°43'
Long (deg-min) 120°24'
Province Bataan
Region III
Nearby Cities/Towns Olongapo, Morong, Bagac, Pilar, Balanga, Abucay, Samal, Orani, Hermosa, Dinalupihan
Topo Sheets 3064 II, 3063 I

Natib Volcano

- 27,000 years (Newhall)
- 11,000 years (Cabato et al.)
- Active Hydrothermal activity

Dearth of information on eruptive activity but enough information to consider to proceed to stage 3

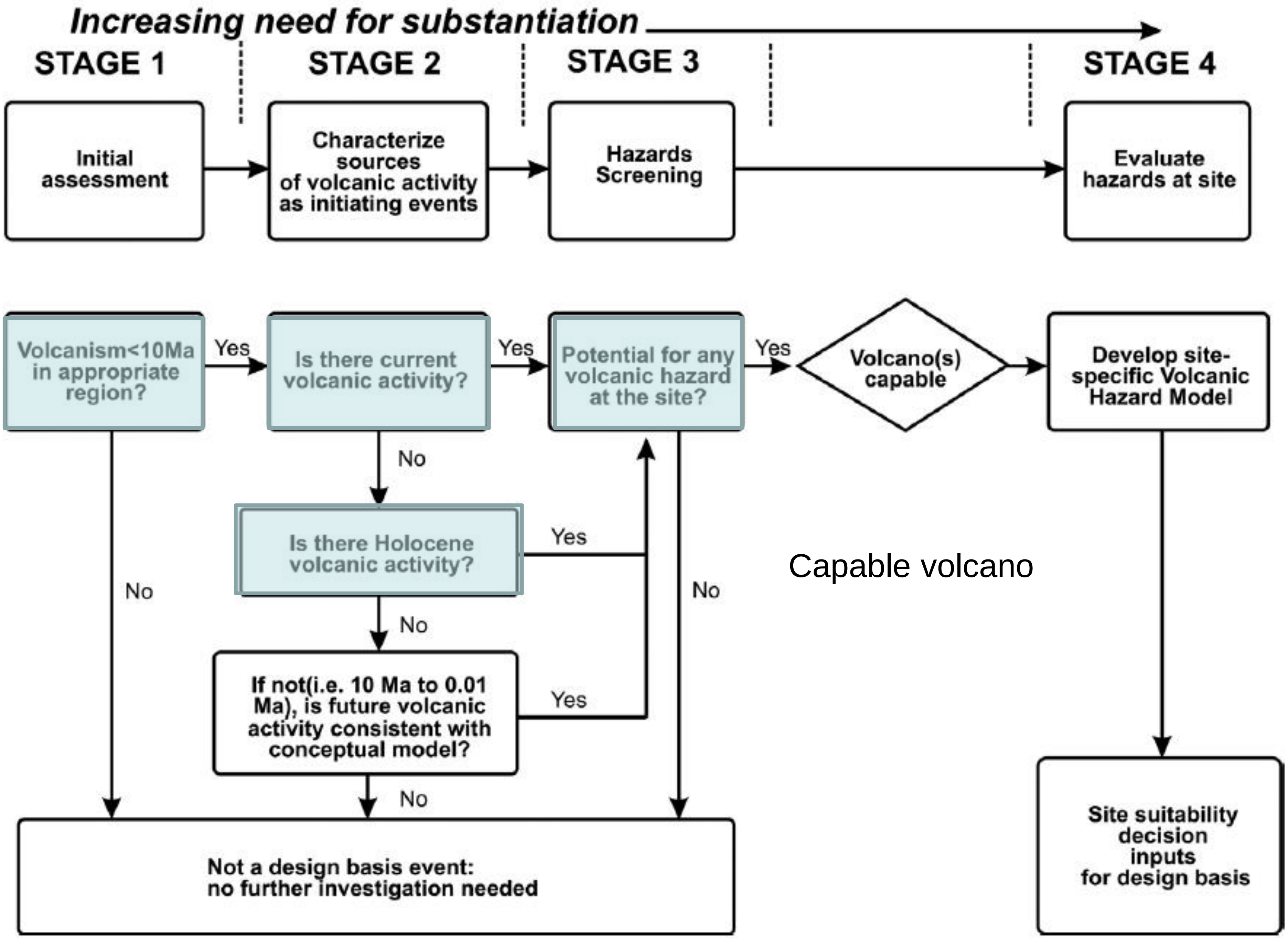
Mariveles Volcano

- 5000 years (Siebert and Simke, 2002)

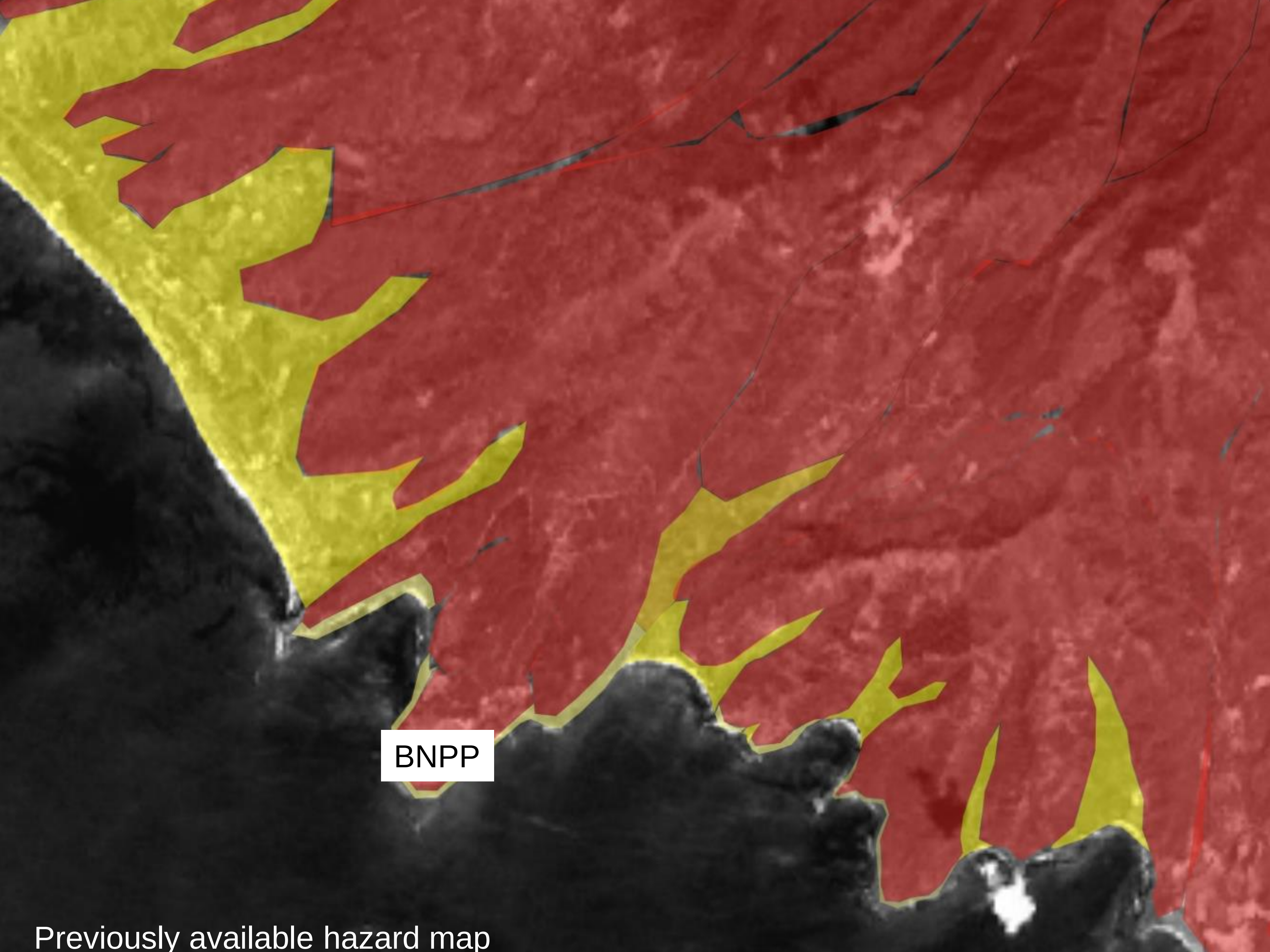
Modern Pinatubo eruptions

- ~33,000 BC
- ~15,000 BC (Sacobia Eruptive Period)
- ~7000 BC (Pasbul Eruptive Period). Its eruptions were as energetic, if not as voluminous as the Inararo eruptions.
- ~4000–3000 BC (Crow Valley Eruptive Period). This and the Maraunot period's eruptions were smaller than the Inararo eruption but about 2 to 3 times as big as that of 1991 based on the pyroclastic flow runout distances and depths of valley filling.
- ~1900–300 BC (Maraunot Eruptive Period)
- ~AD 1500 (Buag Eruptive Period). Its eruptions were roughly the same size as those of 1991.
- 1990 eruption

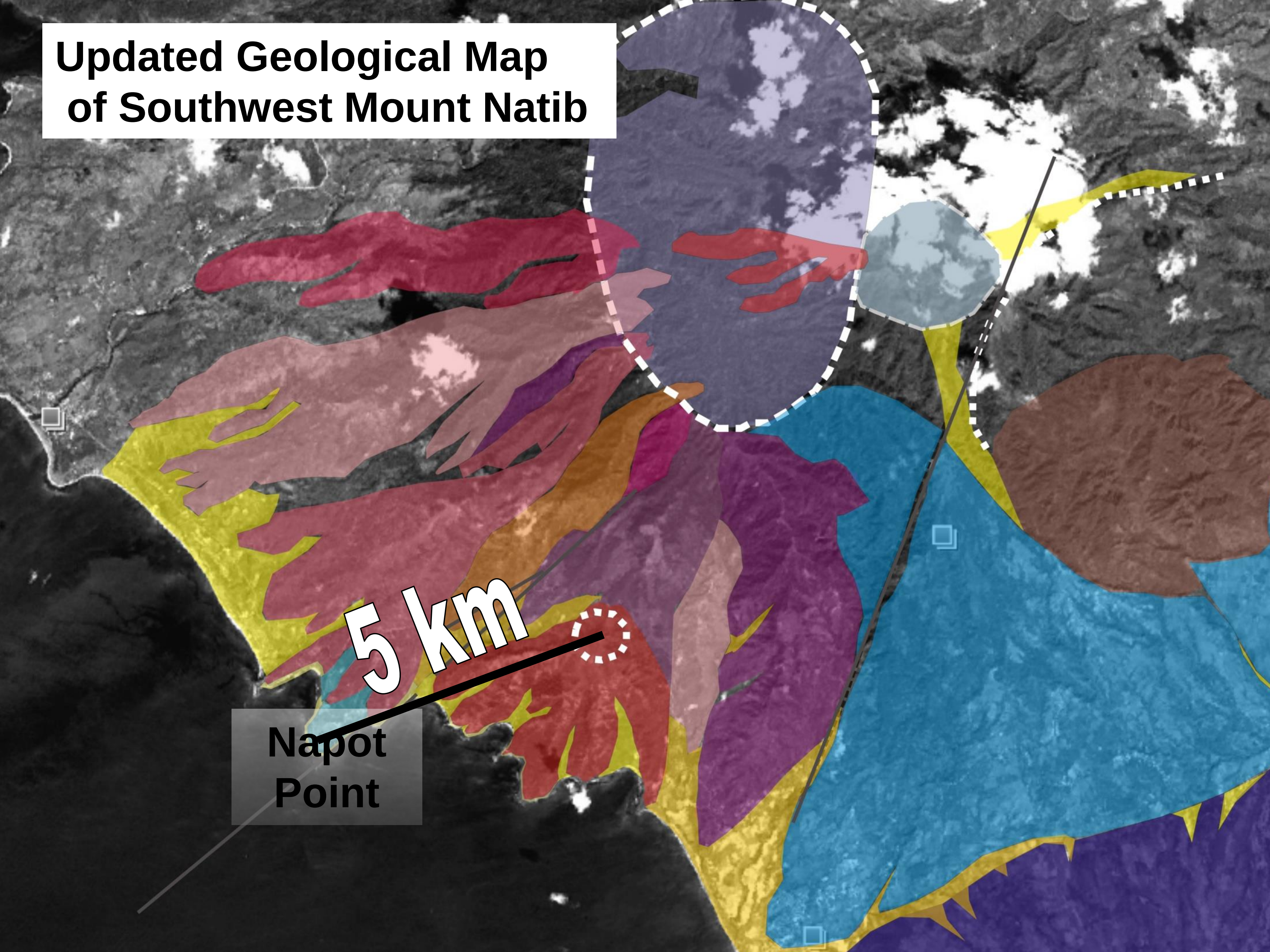
Newhall and Punongbayan, 1996



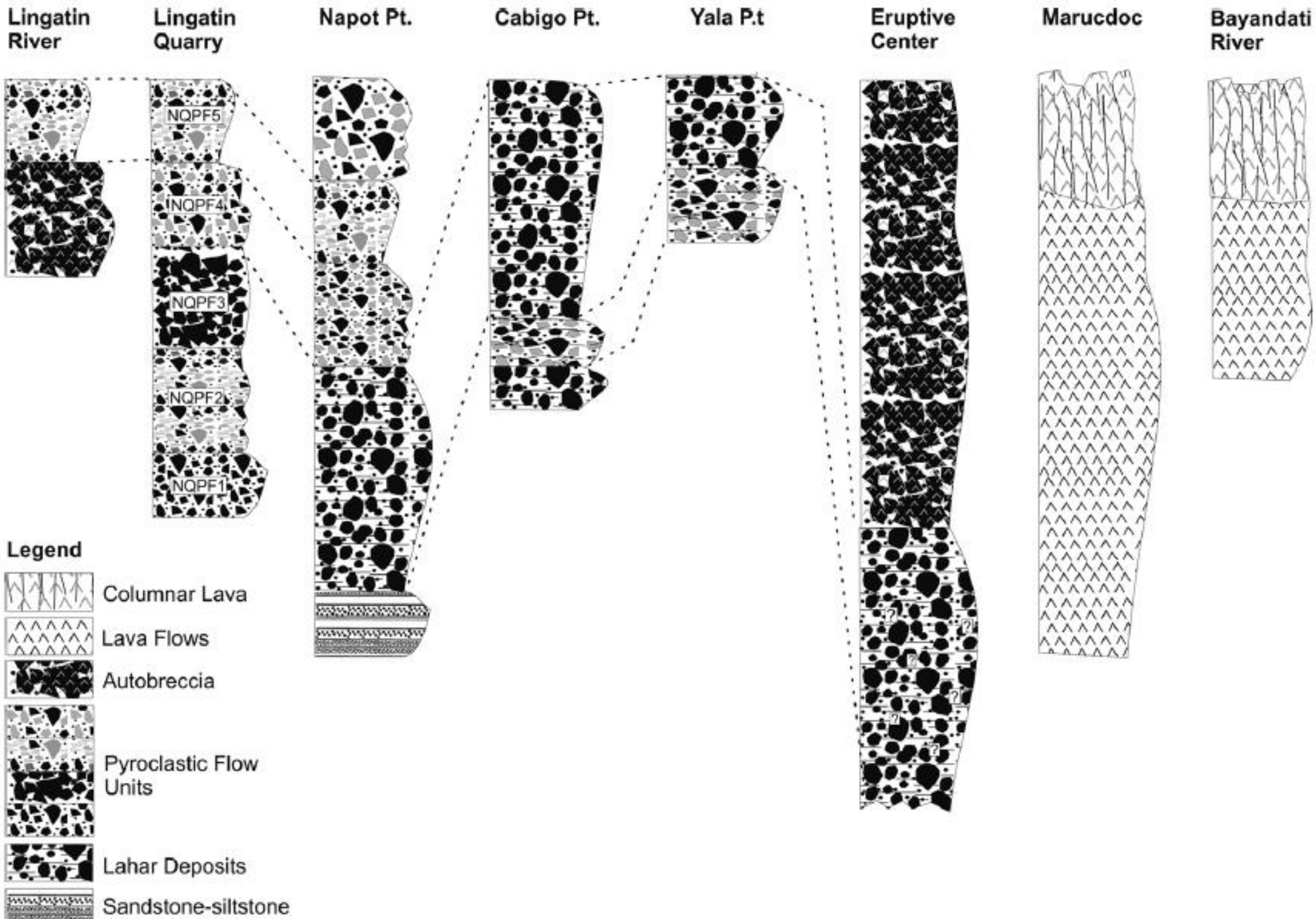
Capable volcano

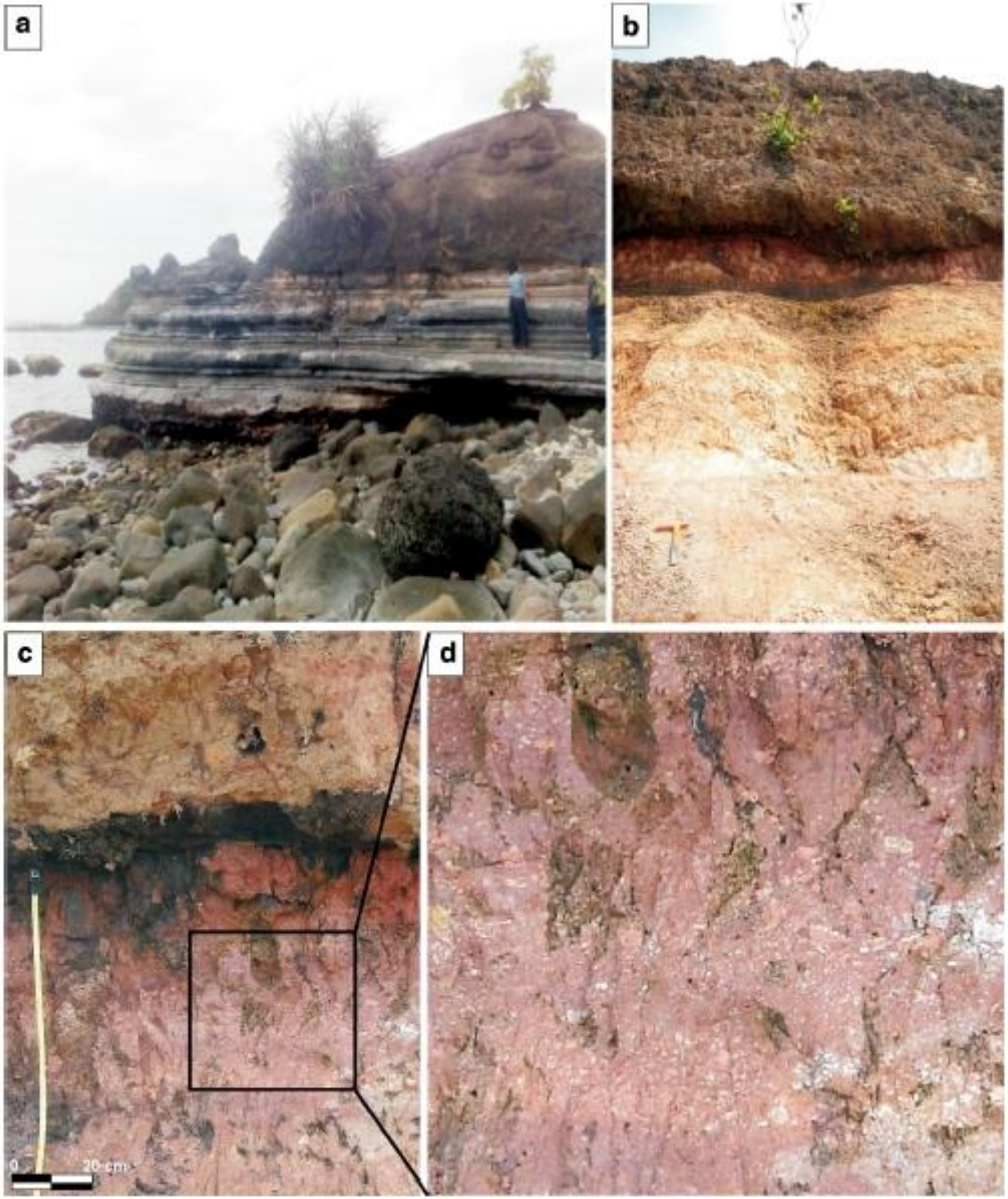


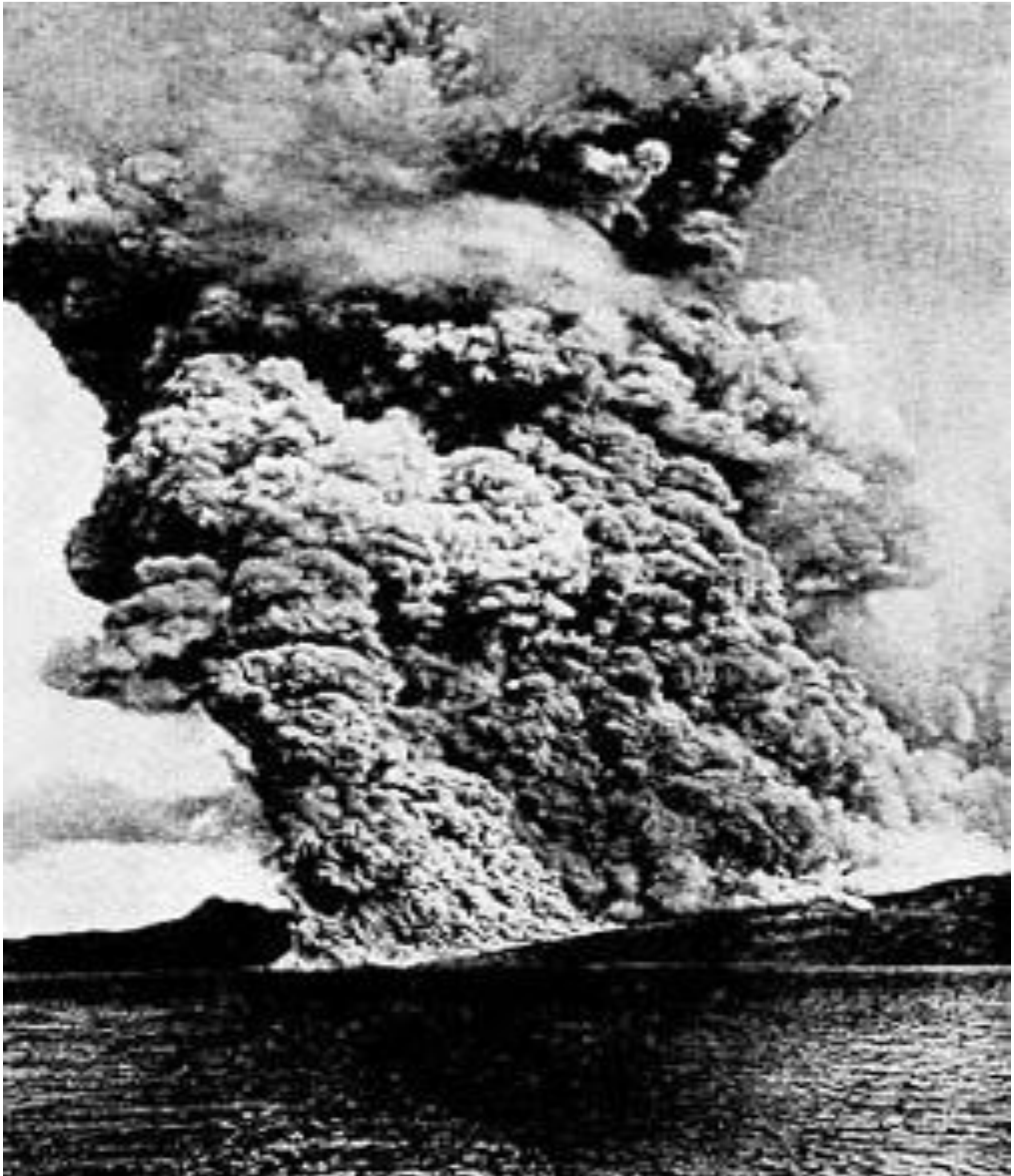
Previously available hazard map


Updated Geological Map
of Southwest Mount Natib
5 km
Napot
Point

Volcanic deposits




a
b
c
d
0
20 cm



Surge

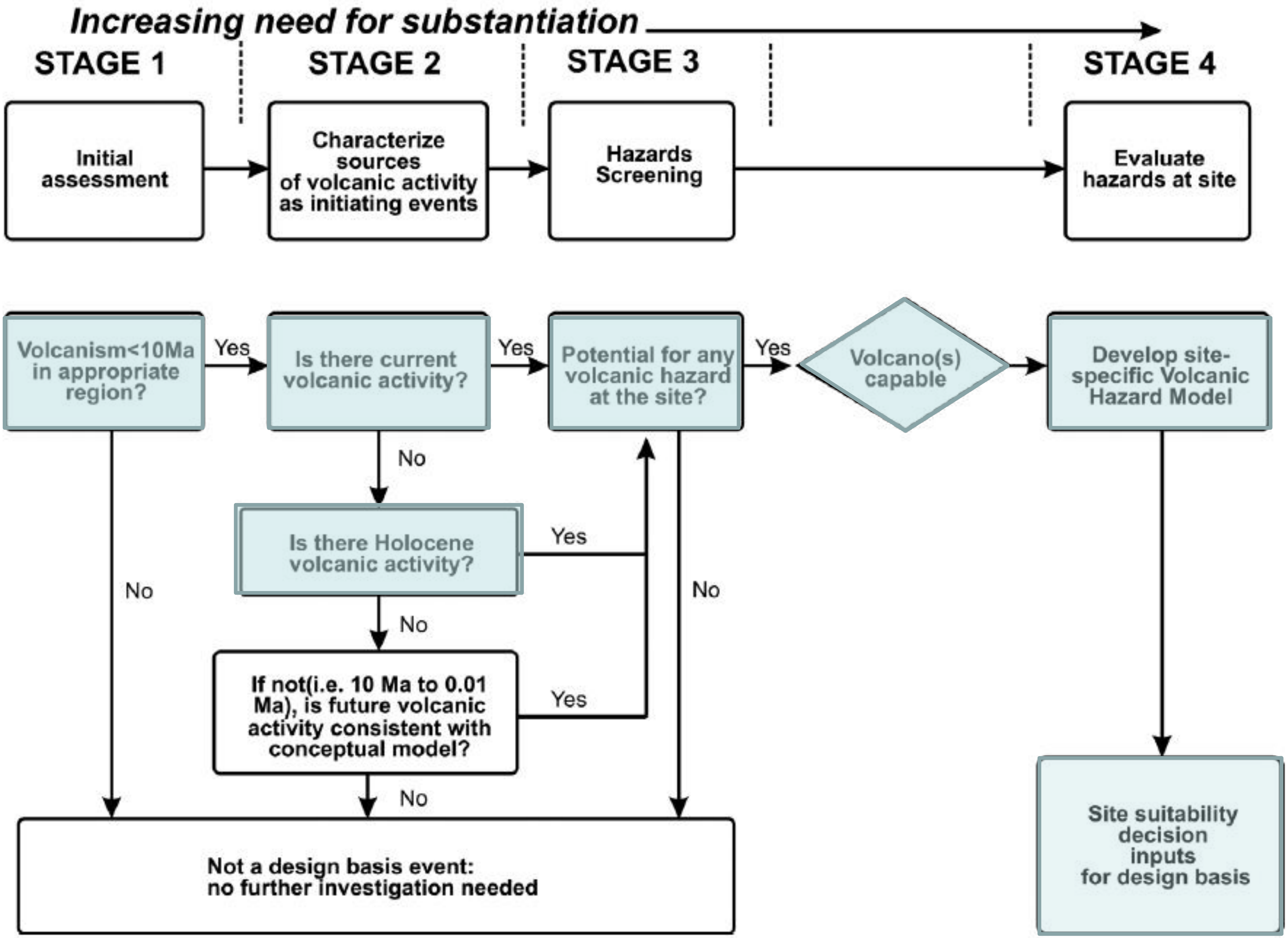

2.5X vertical exaggeration


a
0
10 cm

Hazards

- Lava flows
- Pyroclastic flows – at least 5 pyroclastic flow deposits
- Pyroclastic surge
- Lahars

The probability of a future Natib eruption was calculated by Ebasco (1977) at **3×10^5 year^{-1}** and to be an order of magnitude greater by Volentik et al. (2009) at **1×10^{-4} – 2×10^{-4} year^{-1}**, with a confidence level of 95%. **These probabilities, together with Natib's active volcanic hydrothermal system (Ruaya & Panem 1991), means that Natib has credible potential for future eruption.** Volentik et al. (2009) estimated an even higher probability for a VEI (Volcanic Explosivity Index) 6 – 7 eruption of Mariveles Volcano: 3.5×10^{-4} – 6×10^{-4} year^{-1}, with a 95% confidence level.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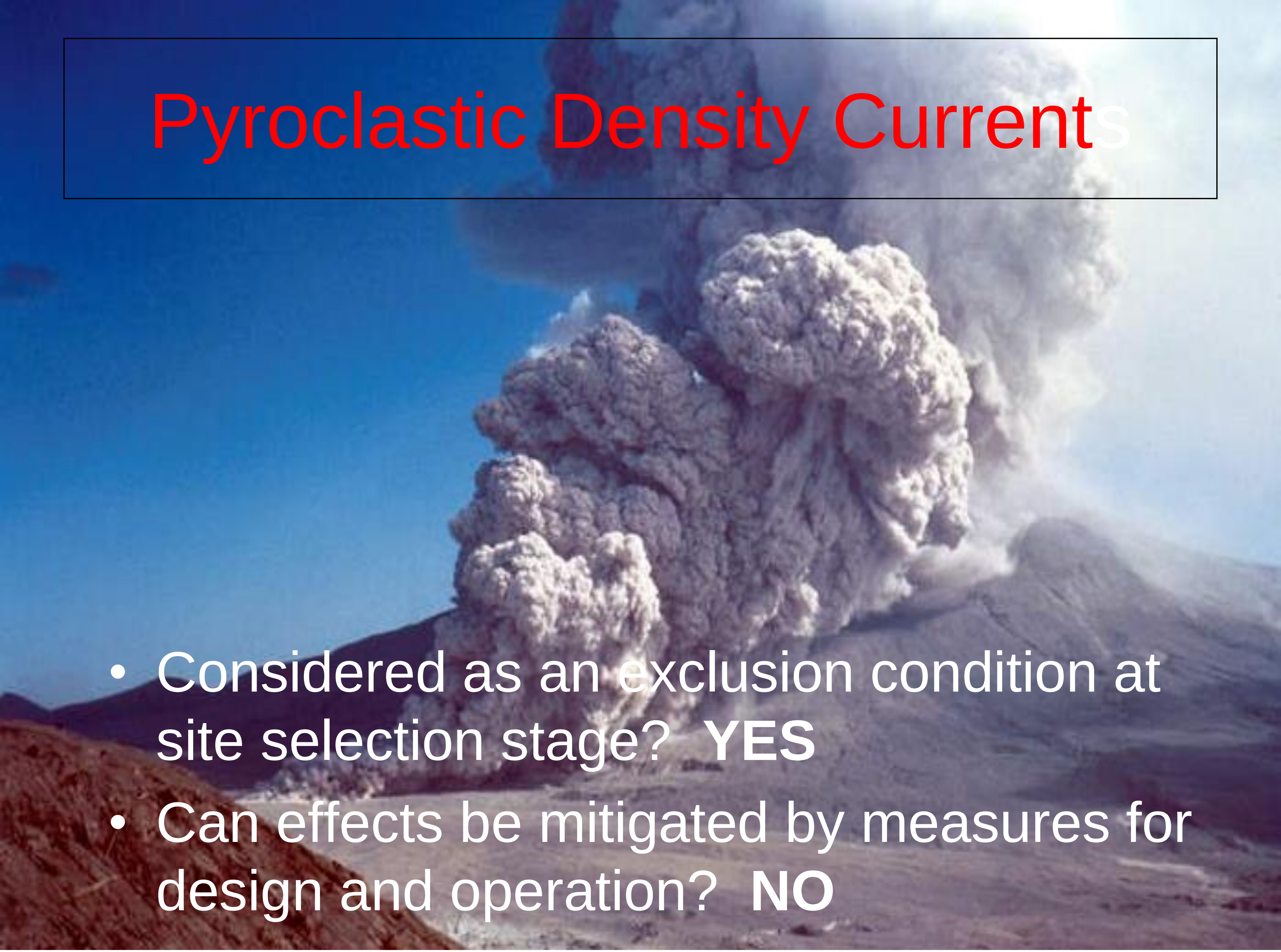
No
Not a design basis event: no further investigation needed
Site suitability decision inputs for design basis

TABLE 1. VOLCANIC PHENOMENA AND ASSOCIATED CHARACTERISTICS THAT COULD AFFECT NUCLEAR INSTALLATIONS, WITH IMPLICATIONS FOR SITE SELECTION AND EVALUATION AND DESIGN

Phenomena	Potentially adverse characteristics for nuclear installations	Considered an exclusion condition at site selection stage?	Can effects be mitigated by measures for design[2] and operation?
1. Tephra fallout	Static physical loads, abrasive and corrosive particles in air and water	No	Yes
2. Pyroclastic density currents: pyroclastic flows, surges and blasts	Dynamic physical loads, atmospheric overpressures, projectile impacts, temperatures >300°C, abrasive particles, toxic gases	Yes	No
3. Lava flows	Dynamic physical loads, floods and water impoundments, temperatures >700°C	Yes	No
4. Debris avalanches, landslides and slope failures	Dynamic physical loads, atmospheric overpressures, projectile impacts, water impoundments and floods	Yes	No
5. Volcanic debris flows, lahars and floods	Dynamic physical loads, water impoundments and floods, suspended particulates in water	Yes	Yes
6. Opening of new vents	Dynamic physical loads, ground deformation, volcanic earthquakes	Yes	No
7. Volcano generated missiles	Particle impacts, static physical loads, abrasive particles in water	Yes	Yes
8. Volcanic gases and aerosols	Toxic and corrosive gases, acid rain, gas charged lakes, water contamination	No	Yes

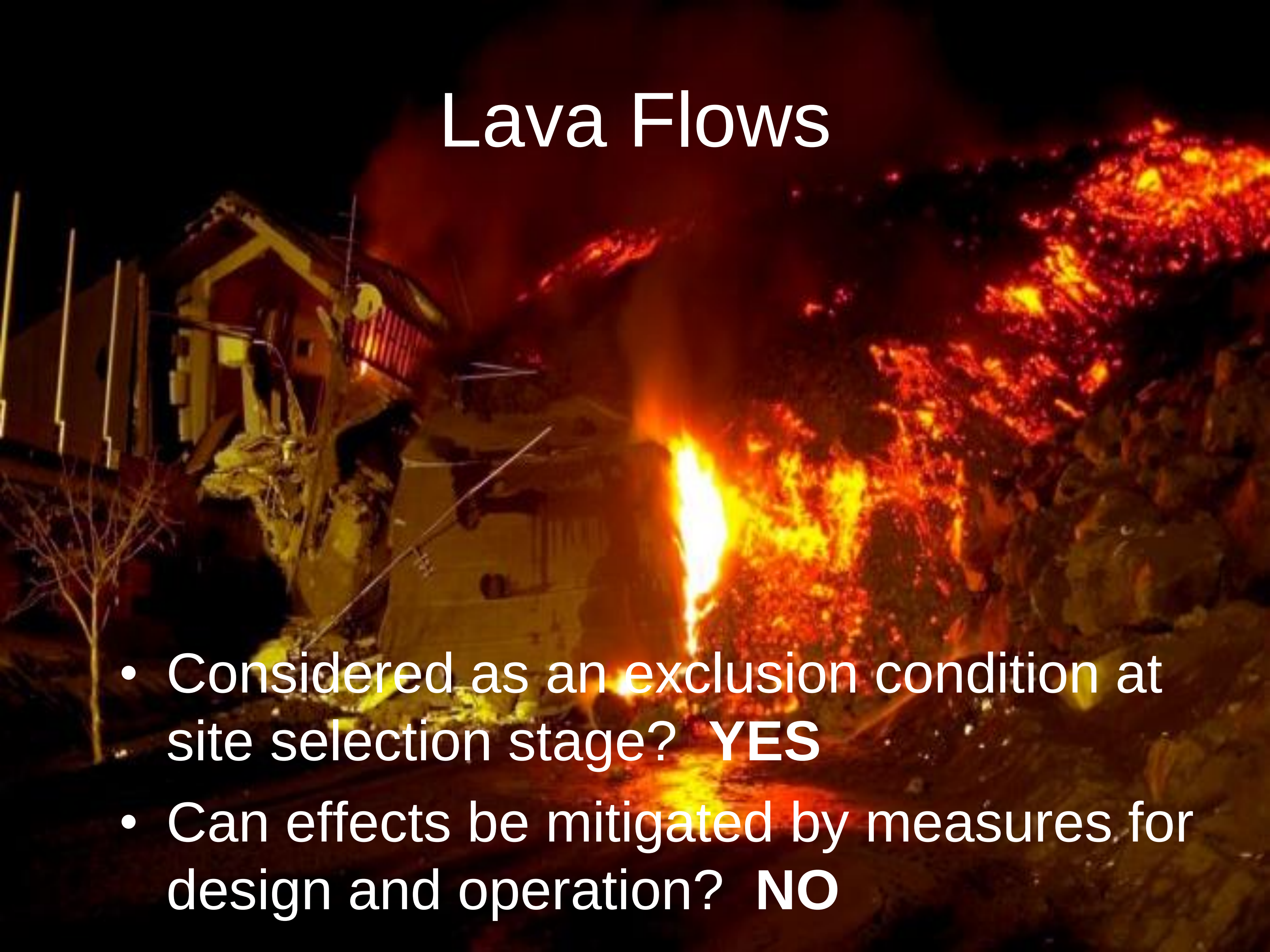
IAEA, 2012

Pyroclastic Density Currents

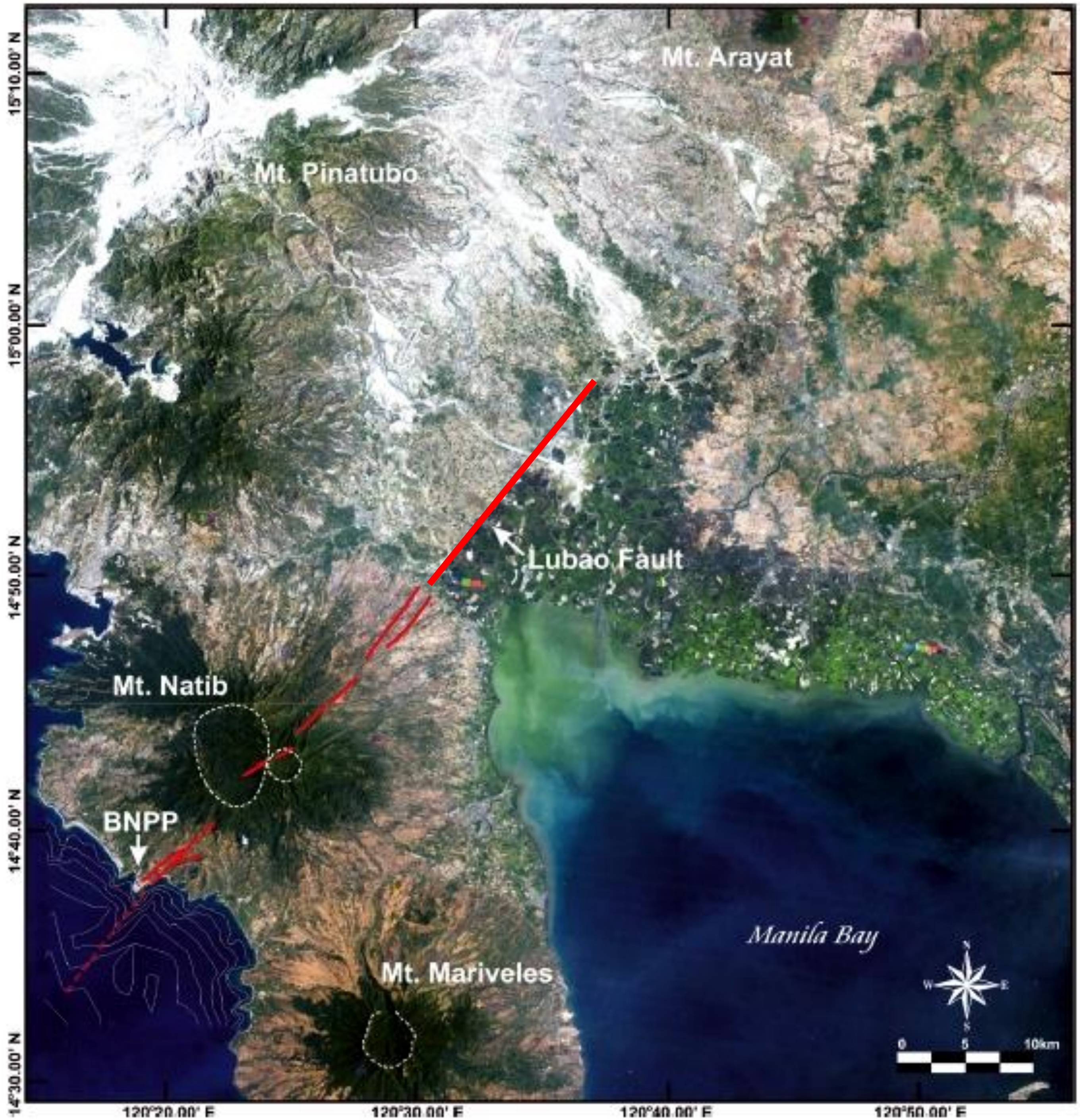


- Considered as an exclusion condition at site selection stage? **YES**
- Can effects be mitigated by measures for design and operation? **NO**

Lava Flows



- Considered as an exclusion condition at site selection stage? **YES**
- Can effects be mitigated by measures for design and operation? **NO**

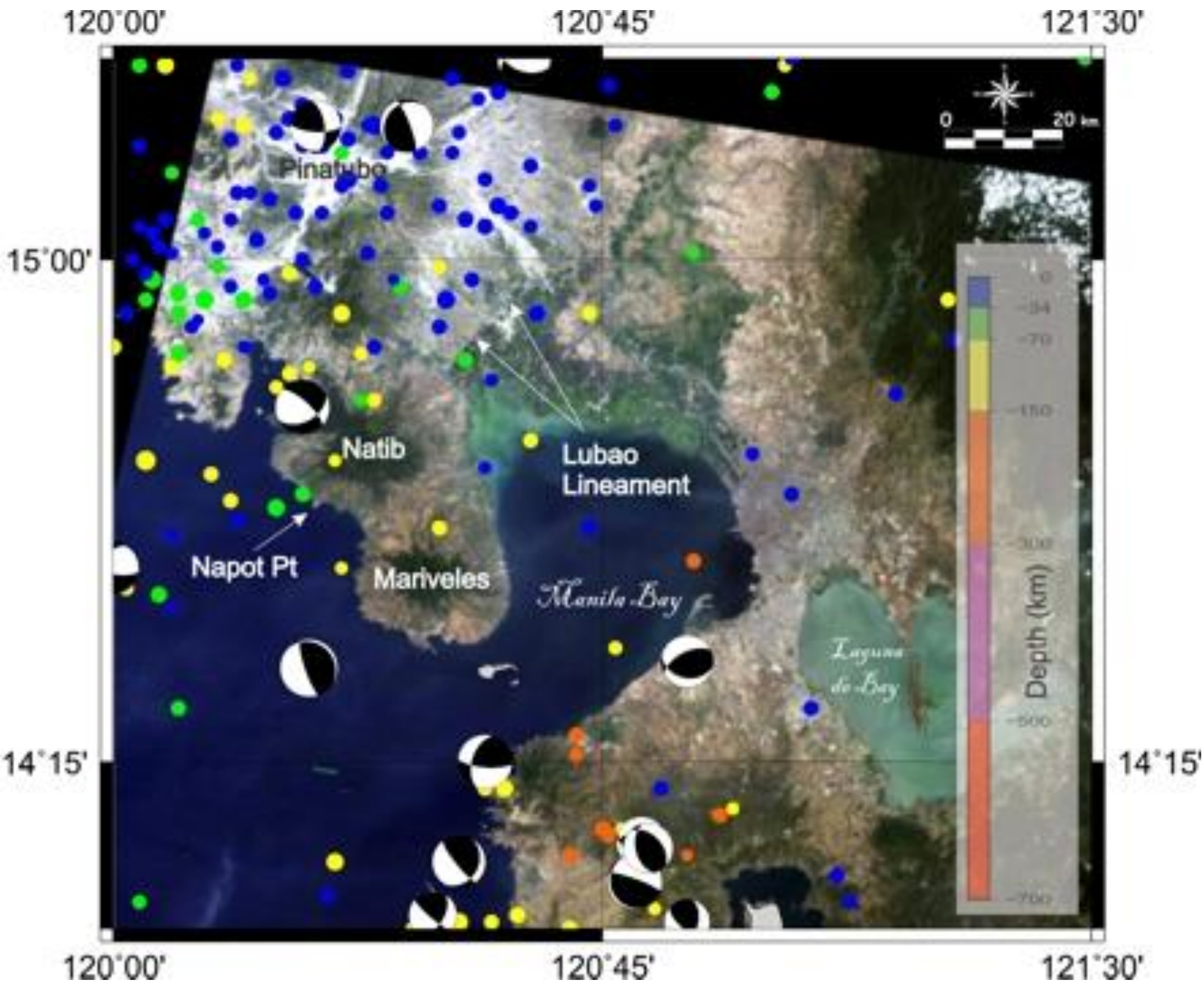


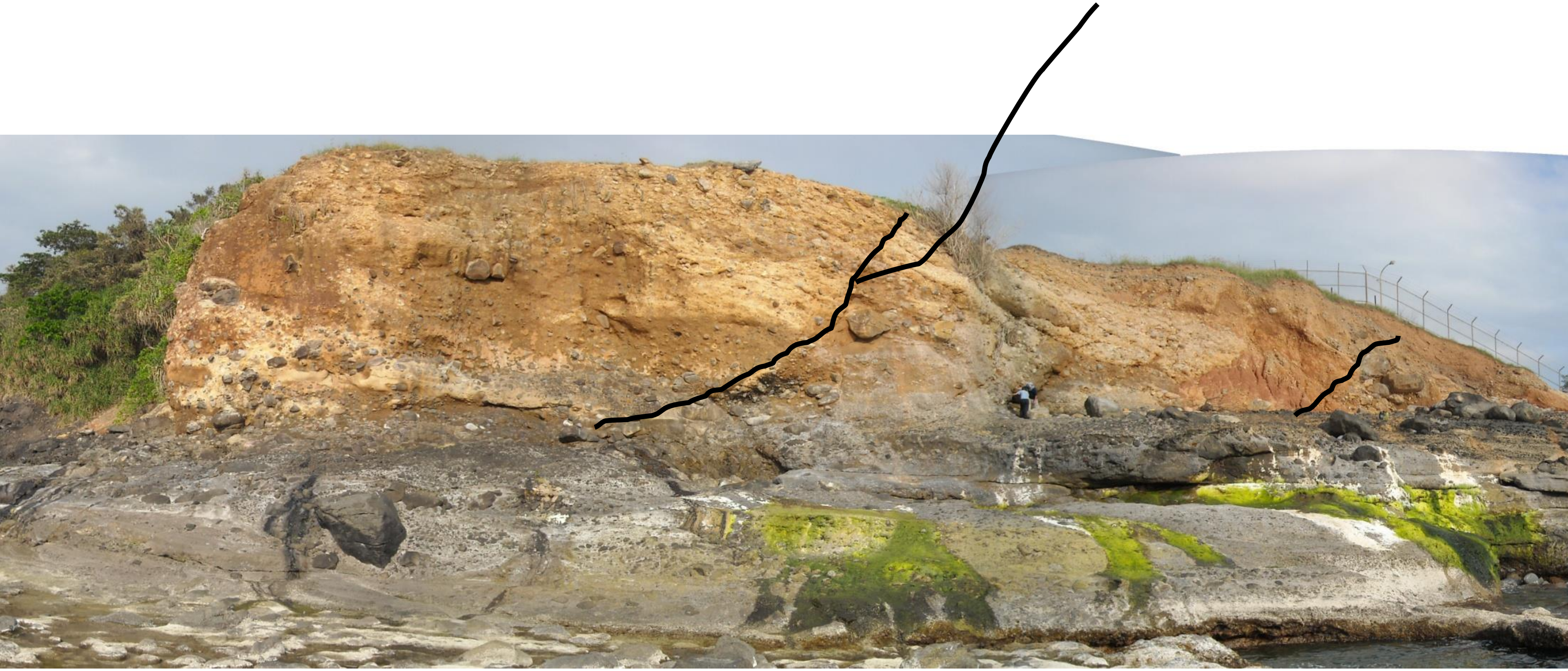
Mt. Arayat
Mt. Pinatubo
Lubao Fault
Mt. Natib
BNPP
Mt. Mariveles
Manila Bay
N
S
E
W
0
5
10km
15°10.00' N
15°00.00' N
14°50.00' N
14°40.00' N
14°30.00' N
120°20.00' E
120°30.00' E
120°40.00' E
120°50.00' E

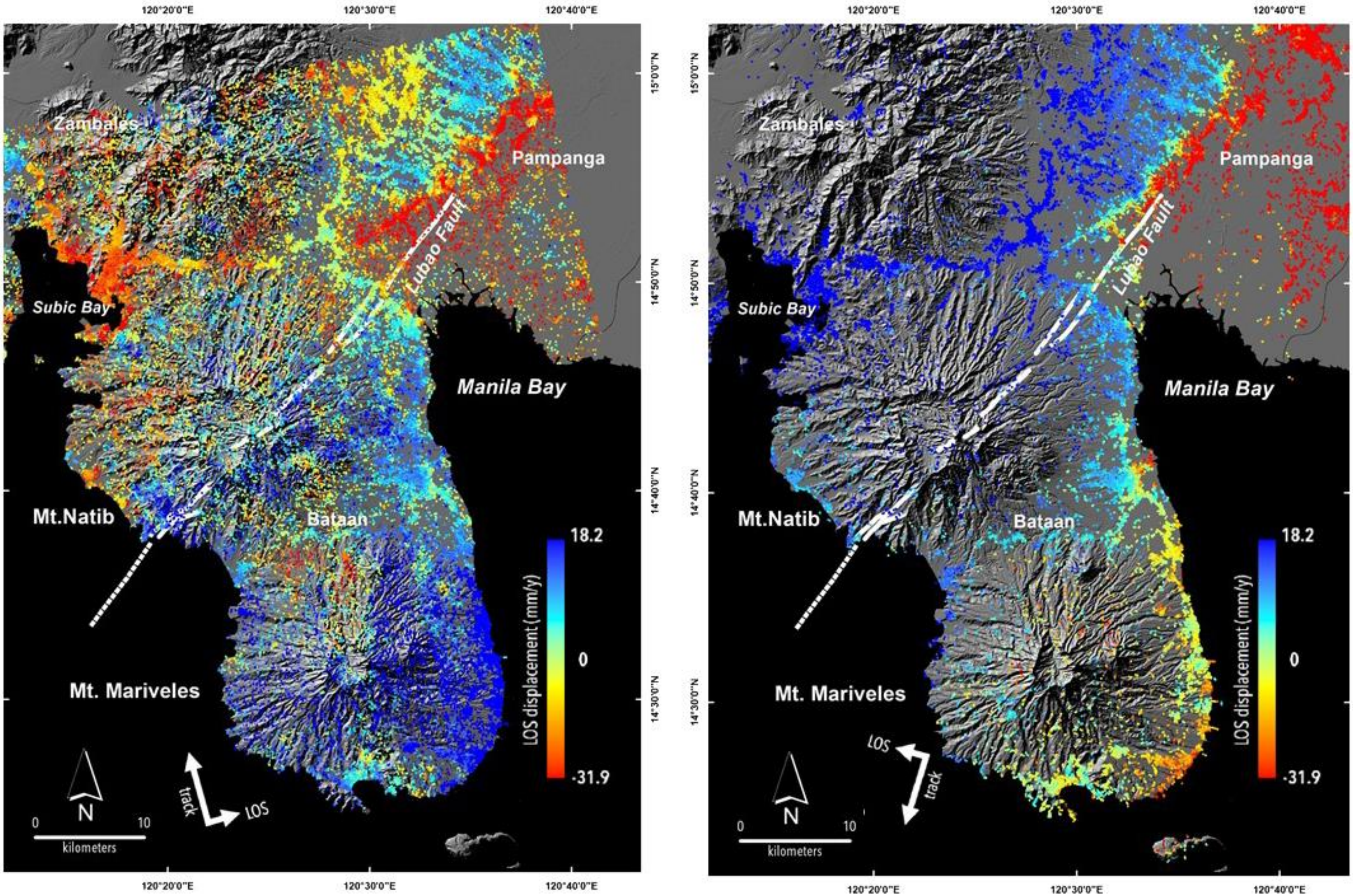
Lubao fault

Soria (2009) formally named it the Lubao Lineament after the municipality where it is best expressed and argued that despite high sedimentation due to the Holocene eruptions of Mt Pinatubo, the wetland–dryland boundary has been maintained because it is an active fault.

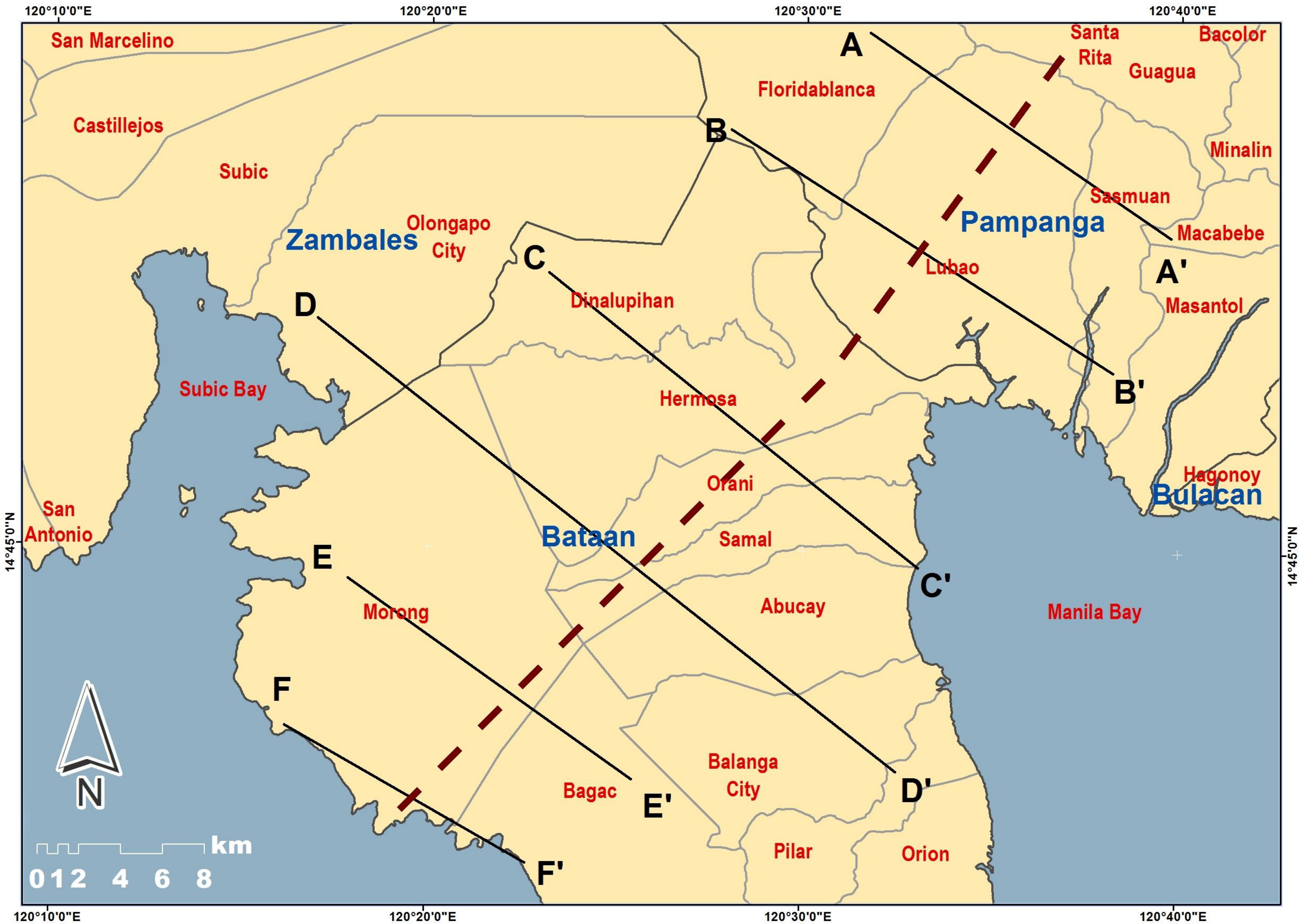
Soria (2009) estimated that vertical components of motion at the lineament have dropped the southeastern block by as much as 3.5 m over the past 1.5 ka, based on palaeosea-level reconstructions from a peat layer taken in Lubao.

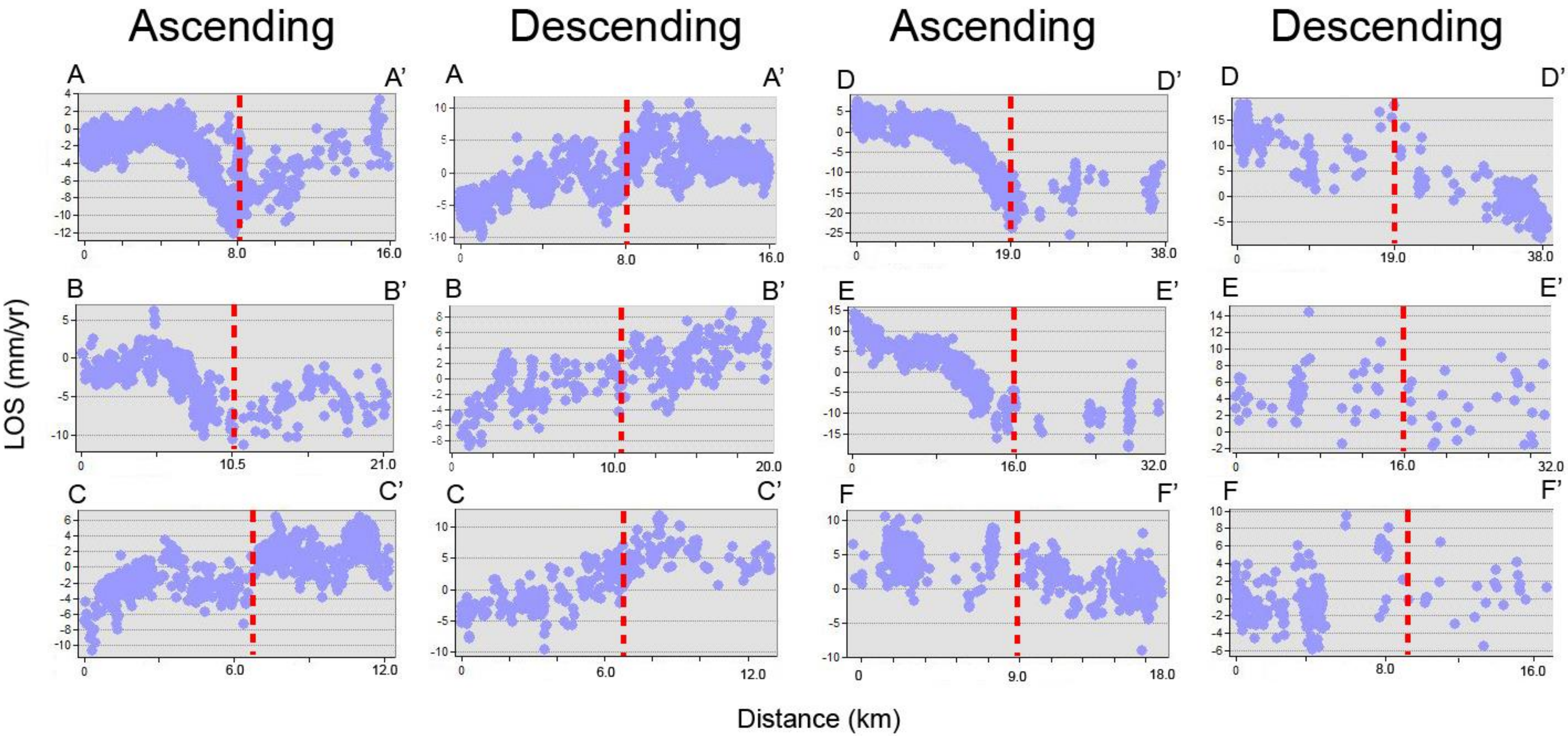

120°00'
120°45'
121°30'
15°00'
14°15'
0
20 km
Pinatubo
Natib
Lubao
Lineament
Napot Pt
Mariveles
Manila Bay
Laguna de Bay
Depth (km)
0
-34
-70
-150
-300
-500
-700





120°20'0"E
120°30'0"E
120°40'0"E
15°0'0"N
14°50'0"N
14°40'0"N
14°30'0"N
Zambales
Pampanga
Lubao Fault
Subic Bay
Manila Bay
Mt.Natib
Bataan
Mt. Mariveles
LOS displacement (mm/y)
18.2
0
-31.9
N
0
10
kilometers
track
LOS


120°10'0"E
120°20'0"E
120°30'0"E
120°40'0"E
14°45'0"N
San Marcelino
Castillejos
Subic
Olongapo City
Zambales
Subic Bay
San Antonio
Floridablanca
Santa Rita
Bacolor
Guagua
Minalin
Sasmuan
Macabebe
Pampanga
Lubao
Masantol
Dinalupihan
Hermosa
Orani
Samal
Bataan
Abucay
Morong
Bagac
Balanga City
Pilar
Orion
Hagonoy
Bulacan
Manila Bay
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
N
km
0 1 2 4 6 8


Ascending
Descending
Ascending
Descending
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
LOS (mm/yr)
Distance (km)

Thank you

Geothermal Energy

Source: Youtube

Renewable Energy

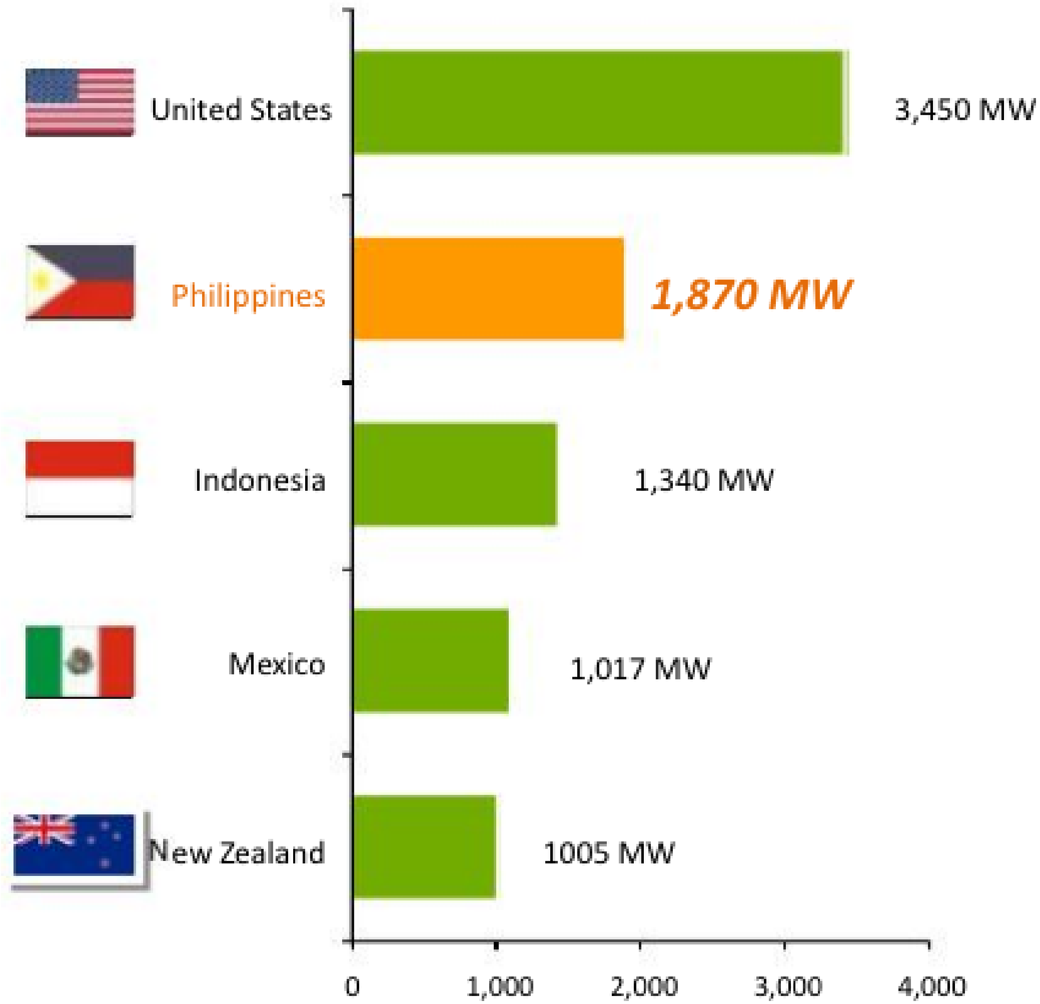
- Renewable Energy Act (2008)
  - "Accelerate the exploration and development of renewable energy resources such as, but not limited to, biomass, solar, wind, hydro, **geothermal** and ocean energy sources, including hybrid systems, to achieve energy self-reliance …"

Renewable Energy

- Climate Change Act (2009)
  - “It shall also be the policy of the State to incorporate a gender-sensitive, pro-children and pro-poor perspective in all climate change and **renewable energy efforts**”

Global Geothermal Energy Production (MW)

The Philippines is the 2ND largest geothermal producer in the world next to the US



Source: Bertani 2015
Source: Bertani 2015

Operating Geothermal Projects

	Project Name / Area	Province	Installed Capacity (MW)	Concession Holder
Luzon				
	MakBan	Laguna/Batangas	458	PGPC / AP
	Tiwi	Albay	234	PGPC / AP
	Maibarara	Laguna/Batangas	20	Maibarara Geothermal Inc
	BacMan	Sorsogon	130	EDC
Visayas				
	Tongonan	Leyte	701	EDC
	Palinpinon	Negros Oriental	221	EDC
Mindanao				
	Mindanao (Mt. Apo)	North Cotabato	108	EDC
TOTAL			**1,872**	

THERE ARE EXPANSION POTENTIALS WITHIN THE EXISTING FIELDS BUT WERE NOT YET DEVELOPED PRIMARILY DUE TO NON-COMPETITIVE ECONOMICS

Brownfield Geothermal Projects

	Project Name / Area	Province	Potential Capacity (MW)	Concession Holder	Remarks
Luzon					
	Bacman	Sorsogon			
	- Bacman 3 (Expansion)		30	EDC	Steam available. Project development on-hold due to unfavorable economics
	- Manito Lowlands (Binary)				Three wells drilled. Needs further drilling prior to development
	Maibarara	Laguna/Ba		ermal Inc	Planning stage
Mindanao					
	Mt. Apo 3	North Cotabato	20	EDC	Acidic resource requiring use of more expensive acid-resistant alloys
TOTAL			**80**		

80 MW

GEOTHERMAL EXPLORATION IN LUZON WERE FACED MOSTLY WITH TECHNICAL CHALLENGES, WHILE SOME SITES HAVE SOCIAL AND SECURITY ISSUES

	Prospect Name / Area	Province	Estimated Capacity (MW)	Concession Holder	REMARKS
Luzon	Kalinga	Kalinga Province	60-100	Chevron Philippines Inc	Surface exploration not completed yet. Issues with IPRA, security, community acceptance
	Cagua-Baua	Cagayan	25-40	Pan Pacific Power Philippines Corporation	2 deep exploration well drilled. Poor permeability. Acid fluids
	Sal-Lapadan-Boliney-Bucloc-Tubo	Abra	-		For further surface exploration
	Cervantes	Ilocos Sur/Mt Province/Benguet	-		For further surface exploration
	Mainit-Sadanga	Mt			with permeability, community, IPRA
	Bugias-Tinoc	Ifug			ther surface exploration
	Daklan	Ben			drilled. Poor permeability. Issues with ecurity
	Natib	Bat			wells drilled. Poor permeability. park
	East Mankayan	Ifug			ther surface exploration
	Mariveles	Bataan	-	Basic Energy Corporation	For further surface exploration
	Mabini	Batangas			
	Isarog Iriga	Albay/Sorsogon	-		For further surface exploration
	San Juan	Batangas	20	SKI Construction Group, Inc	For further surface exploration
	Tiaong	Laguna/Quezon/Batangas	-		For further surface exploration
	Tayabas-Lucban	Tayabas/Quezon	-		For further surface exploration
	Bulusan	Sorsogon	-		within Active volcano area
	Montelago	Oriental Mindoro	40	Constellation Energy Corp	two deep exploration wells drilled. Under evaluation for binary plant
	Mt. Labo	Quezon/Camarines Norte & Sur	54	-	Acid fluids
	Negron-Cuadrado	Zambales/Pampanga	-	AP Renewables Corp	For further surface exploration
TOTAL			143-494		

143-494 MW

FURTHER EXPLORATION IN THE VISAYAS ARE FACED WITH TECHNICAL ISSUES THAT MAKES PROJECTS UNECONOMICAL WITH CURRENT TARIFF

	Prospect Name / Area	Province	Estimated Capacity (MW)	Concession Holder	REMARKS
Visayas	Mandalagan	Negros Occidental			Within national park. For further surface exploration
	Dauin	Negros Oriental	20-40		2 wells drilled. Poor permeability
	Alto Peak	[illegible]	[illegible]	[illegible]	[illegible] wells drilled. Acid fluids. Development [illegible]ill require acid resistant alloys
	Mahagnao	[illegible]	[illegible]	[illegible]	[illegible] wells drilled. Poor permeability, possible binary
	Biliran	Biliran	50-94	Billiran Geothermal Inc	8 wells drilled. Acid fluids
	Cabalian	Southern Leyte	34	-	3 wells drilled. Poor permeability
TOTAL			**70-208**		

70-208 MW

THE CHALLENGE OF EXPLORATION IN MINDANAO ARE MOSTLY ON SECURITY, PARK AND SOCIAL ISSUES, WITH SOME TECHNICAL HURDLES

	Prospect Name / Area	Province	Estimated Capacity (MW)	Concession Holder	REMARKS
Mindanao	Mainit	Surigao del Norte	30	-	Low temperature, possible binary development
	Balingasag	Misamis Oriental	20		Issues with security
	Ampiro	Misamis Occidental	30		Issues with low permeability, IPRA, natural park, security
	Lakewood	Za			Low temperature, issues with IPRA, security, possible binary development
	Zion	N			Within National Park, For further surface exploration
	Amacan	Compostela Valley	40-100		1 well drilled. Low Permeability. Issues with IPRA, security. For further surface exploration
	Talomo-Tico	North Cotabato	-	AP Renewables Corp	For further surface exploration
	Sibulan-Kapatagan	Davao del Sur	-		For further surface exploration
TOTAL			**60-270**		

60-270 MW

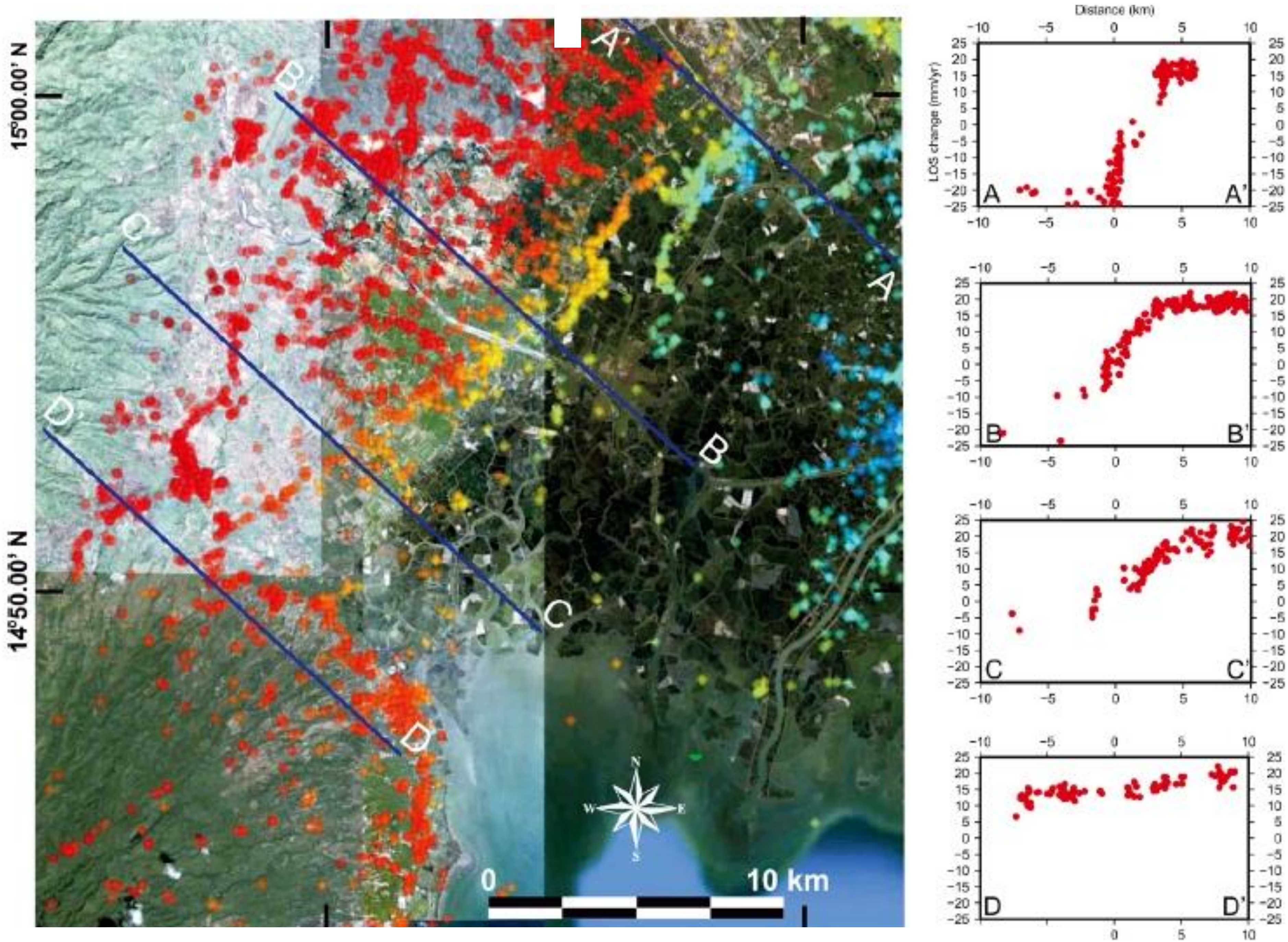
IN SUMMARY, THERE IS GROWTH IN THE GEOTHERMAL INDUSTRY IN THE COUNTRY BUT NEEDS FAVORABLE SUPPORT TO ADDRESS TECHNICAL AND NON-TECHNICAL ISSUES

SUMMARY	
TOTAL INSTALLED CAPACITY	1872 MW
TOTAL ADDITIONAL BROWNFIELD GEOTHERMAL POTENTIAL	80 MW
TOTAL ADDITIONAL GREENFIELD GEOTHERMAL POTENTIAL	273-972 MW

Advantages of Geothermal Energy to support industrialization

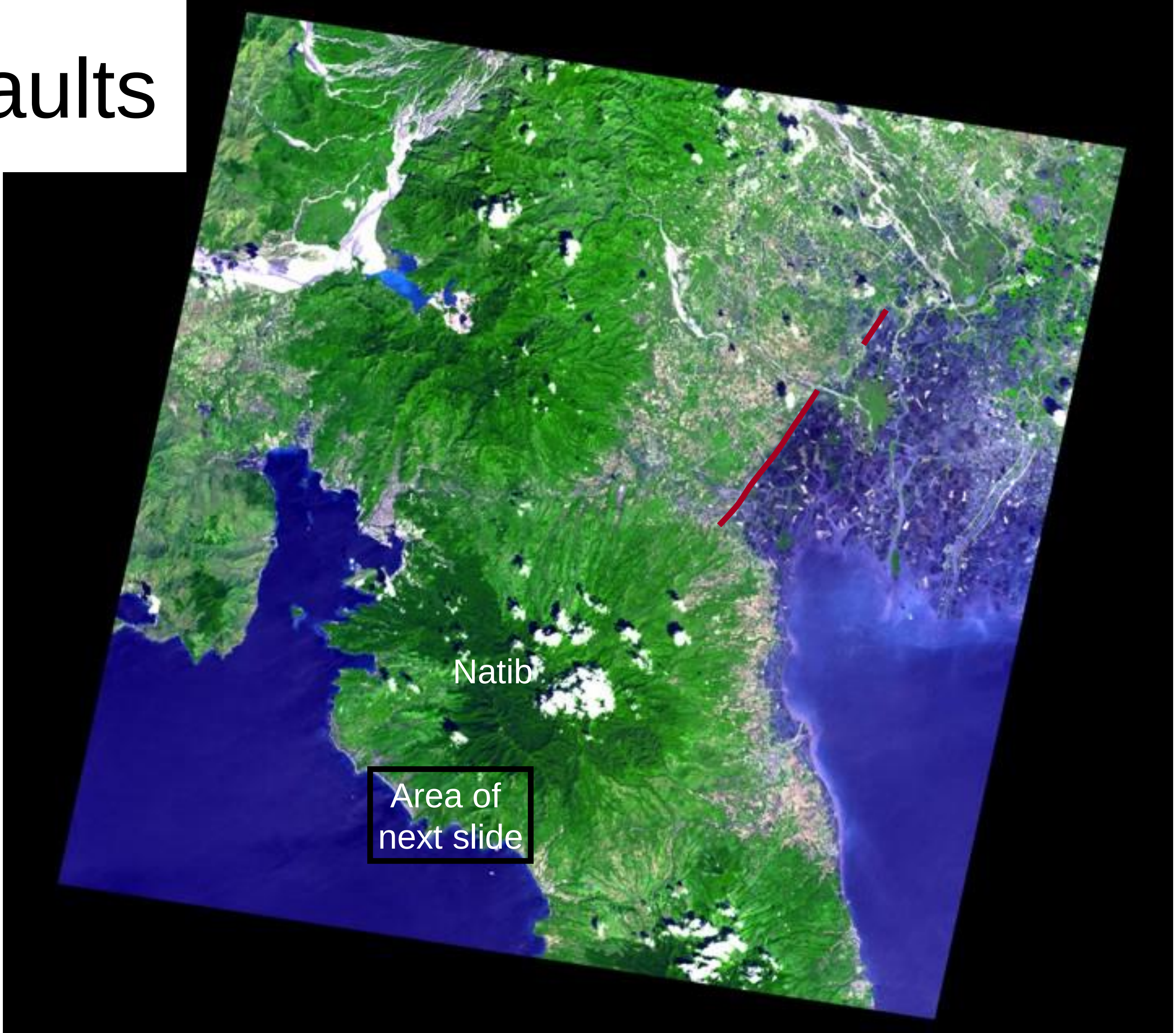
- We have the expertise in Geothermal
- We are rich in geothermal resources
- Disaster risk is very low
- Clean and renewable energy
- Energy source from all parts of the Philippines (Luzon, Visayas, Mindanao)
- Potential of up to 1000+ MW
- Base load

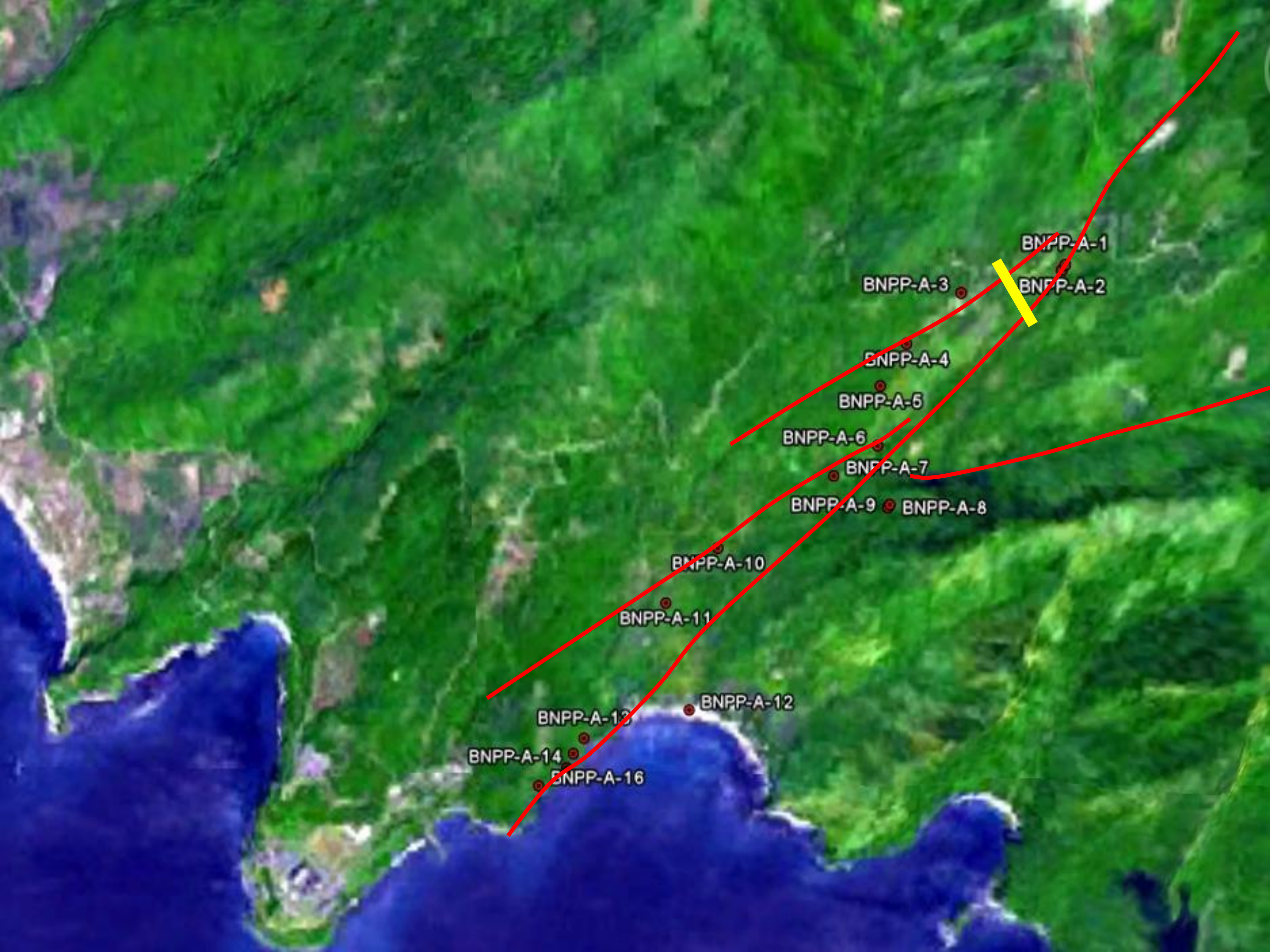
Thank you for listening



Twenty-one time-series images from 19 March 2003 to 8 March 2006

Faults




BNPP-A-1
BNPP-A-2
BNPP-A-3
BNPP-A-4
BNPP-A-5
BNPP-A-6
BNPP-A-7
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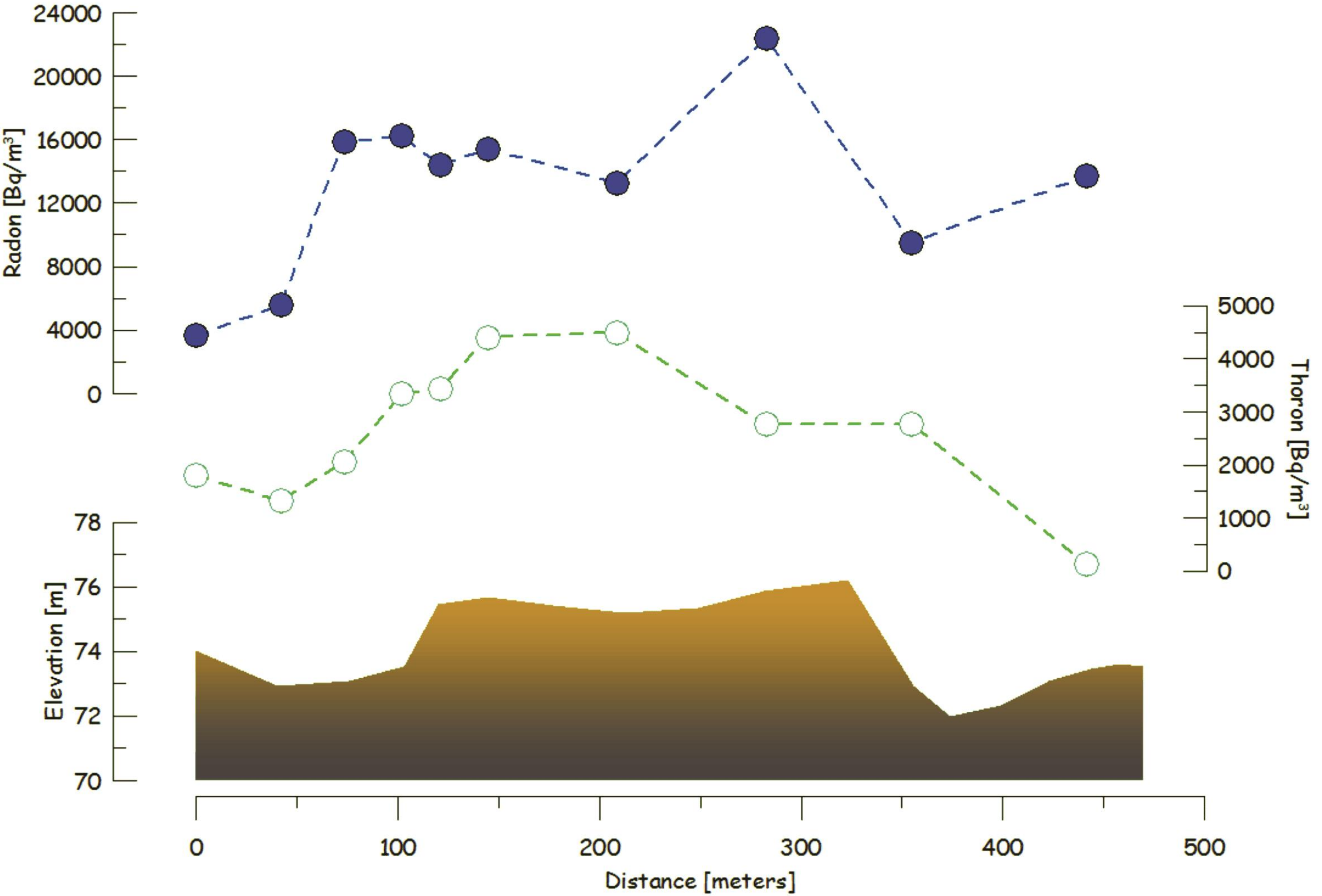
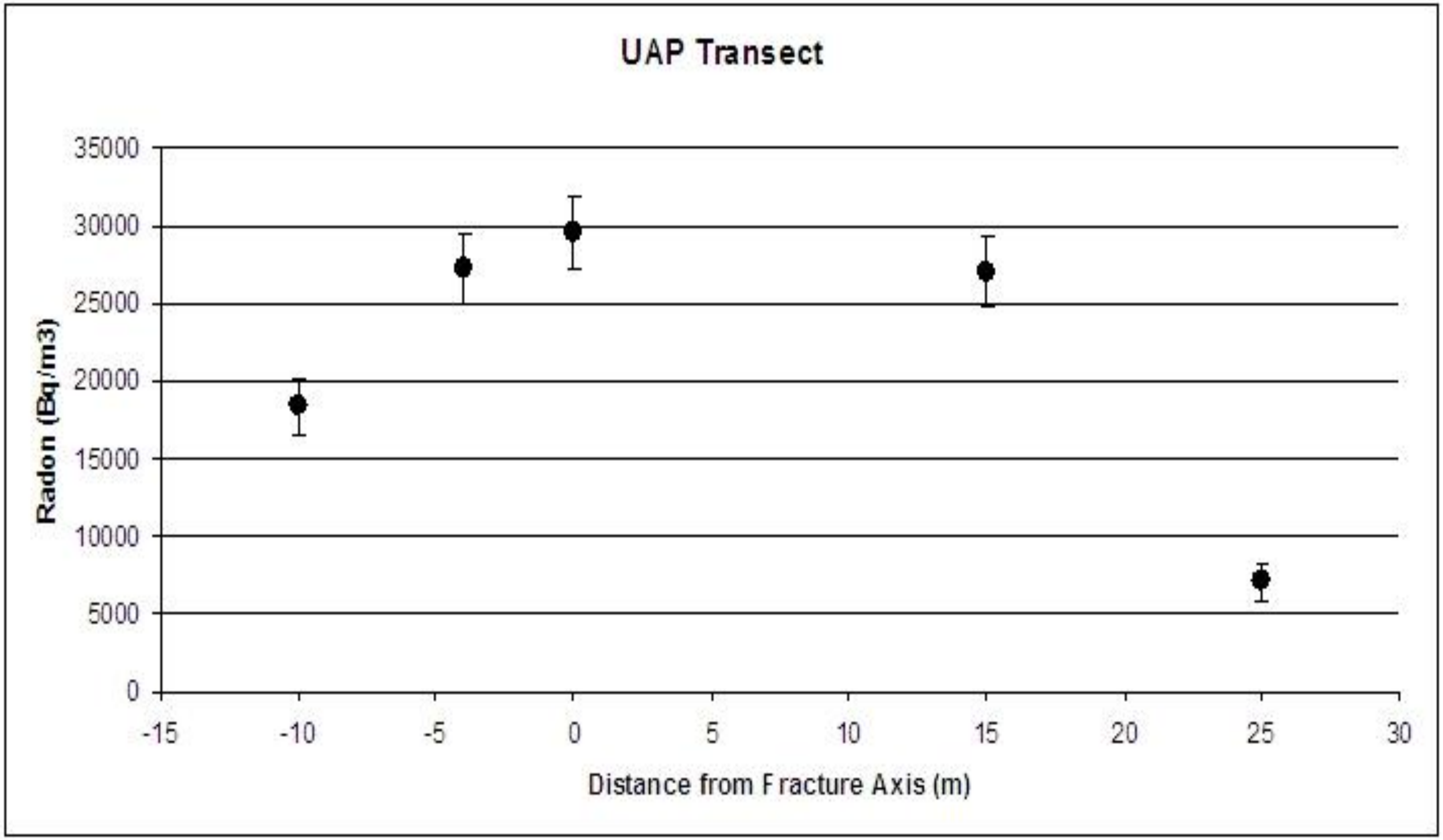
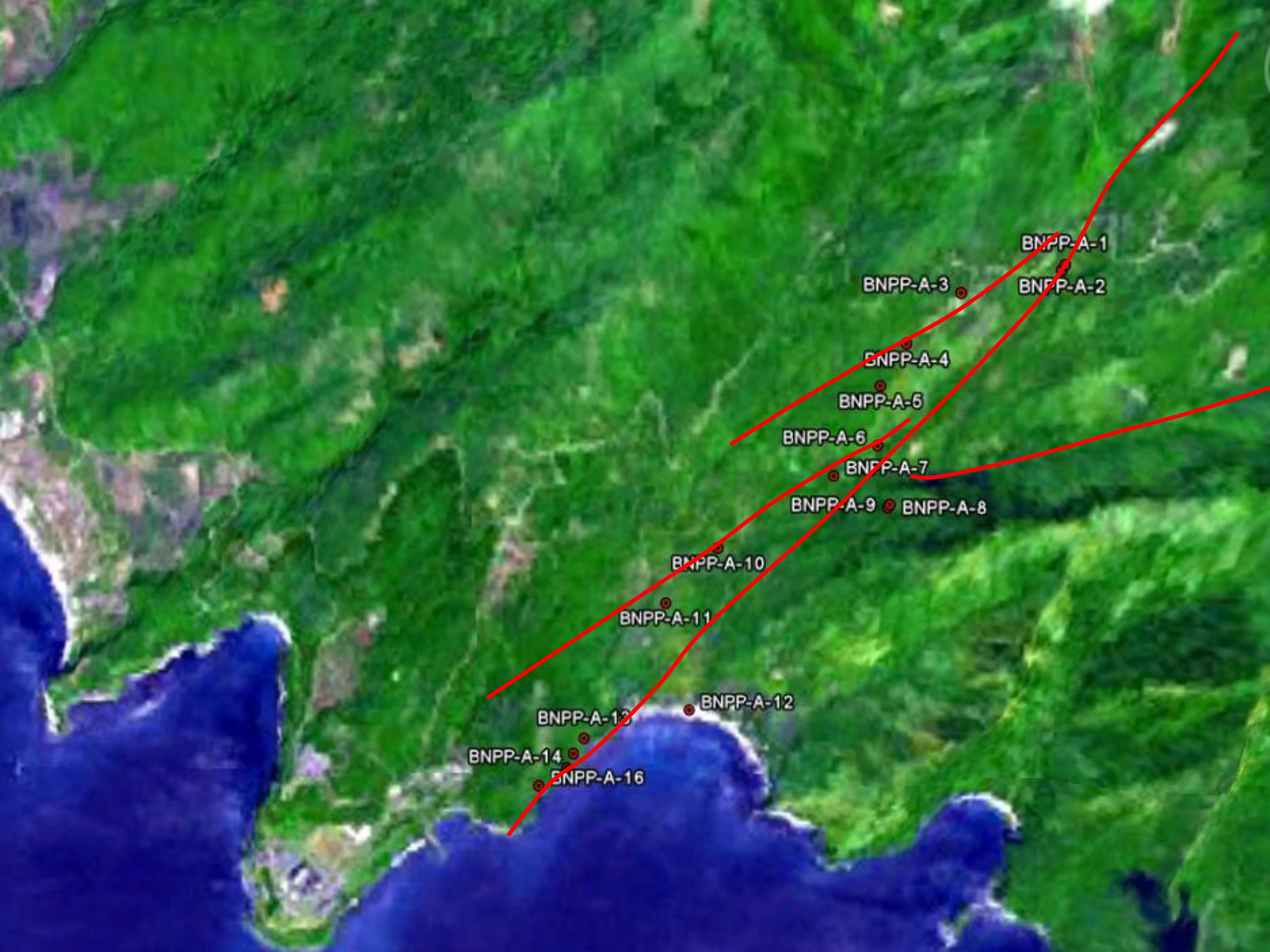
BNPP-A-13
BNPP-A-14
BNPP-A-16



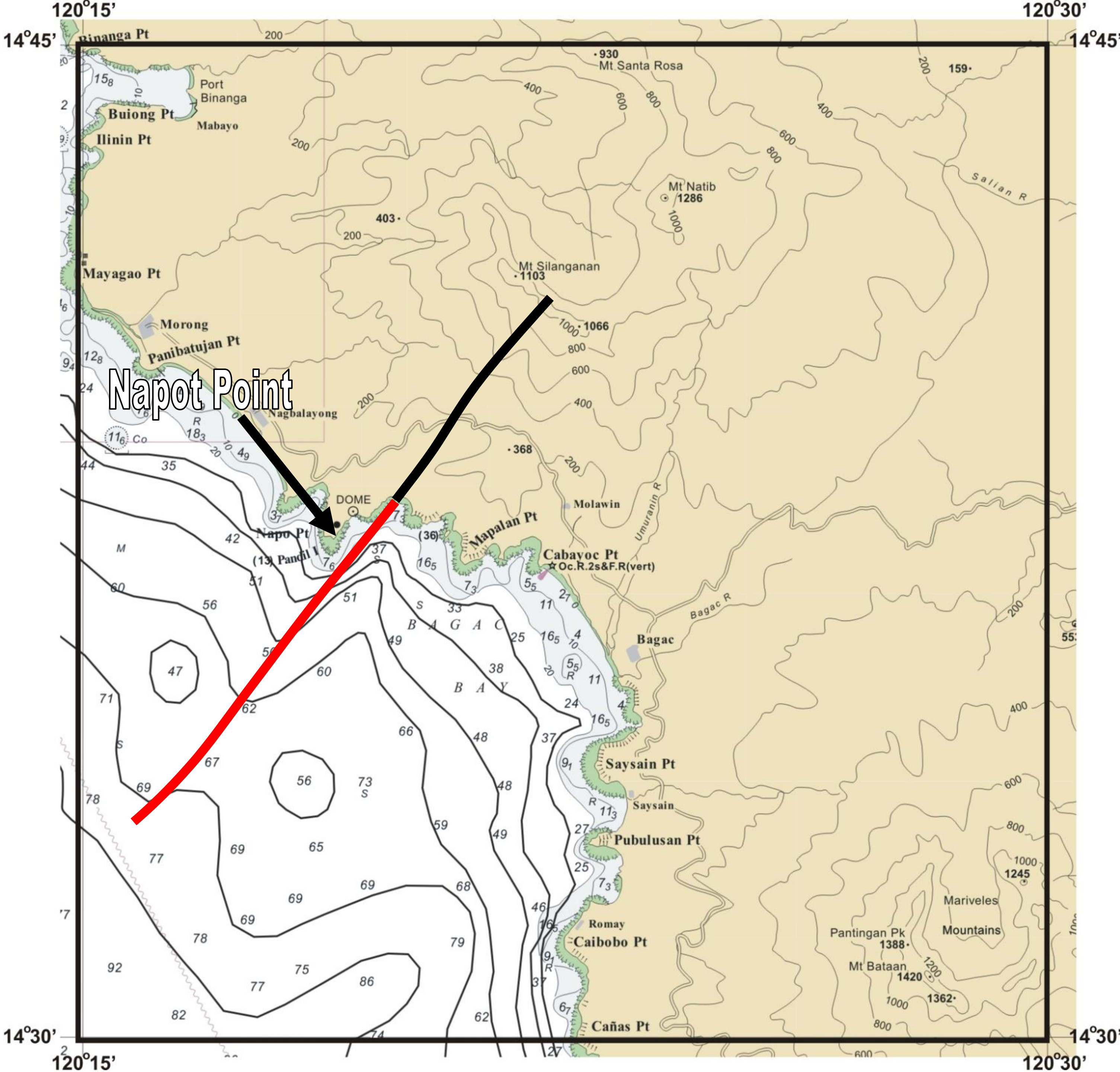
Radon [Bq/m3]
24000
20000
16000
12000
8000
4000
0
Thoron [Bq/m3]
5000
4000
3000
2000
1000
0
Elevation [m]
78
76
74
72
70
0
100
200
300
400
500
Distance [meters]

Radon – Marikina Fault





BNPP-A-1
BNPP-A-2
BNPP-A-3
BNPP-A-4
BNPP-A-5
BNPP-A-6
BNPP-A-7
BNPP-A-8
BNPP-A-9
BNPP-A-10
BNPP-A-11
BNPP-A-12
BNPP-A-14
BNPP-A-16


120°15'
120°30'
14°45'
14°30'
Napot Point
Binanga Pt
Port Binanga
Buiong Pt
Mabayo
Ilinin Pt
Mayagao Pt
Morong
Panibatujan Pt
Nagbalayong
DOME
Napo Pt
Pandil I
Mapalan Pt
Cabayoc Pt
Oc.R.2s&F.R(vert)
Molawin
Umuranin R
Bagac R
Bagac
B A G A C
B A Y
Saysain Pt
Saysain
Pubulusan Pt
Romay
Caibobo Pt
Cañas Pt
Mt Santa Rosa
Mt Natib
Mt Silanganan
Salian R
Mariveles
Mountains
Pantingan Pk
Mt Bataan


Lahar
N25-30E
Surge


TIMEX
EXPEDITION
DIGITAL COMPASS
THU 10-29
3:12.09
INDIGLO
N
NE
E
SE
S
SW
NW

Capable volcano:

(1) may experience volcanic
activity during the performance period of the nuclear installation;

(2) such an event has the potential to produce phenomena that may affect
the site of the nuclear installation (IAEA 2009).

Capability

- Age dates
  - 27,000 yrs. based on carbon age dating (Newhall, personal communication – from Volentik, 2009)
  - 11,000 yrs
  - 4,060 years Mariveles Volcano (Siebert and Simkin, 2007)
- Geothermal activity
  - 13 hot springs
  - Indication of an active hydrothermal in sampled hot springs (Volentik citing Ruaya, 1991)

Annual probabilities of an eruption of Natib

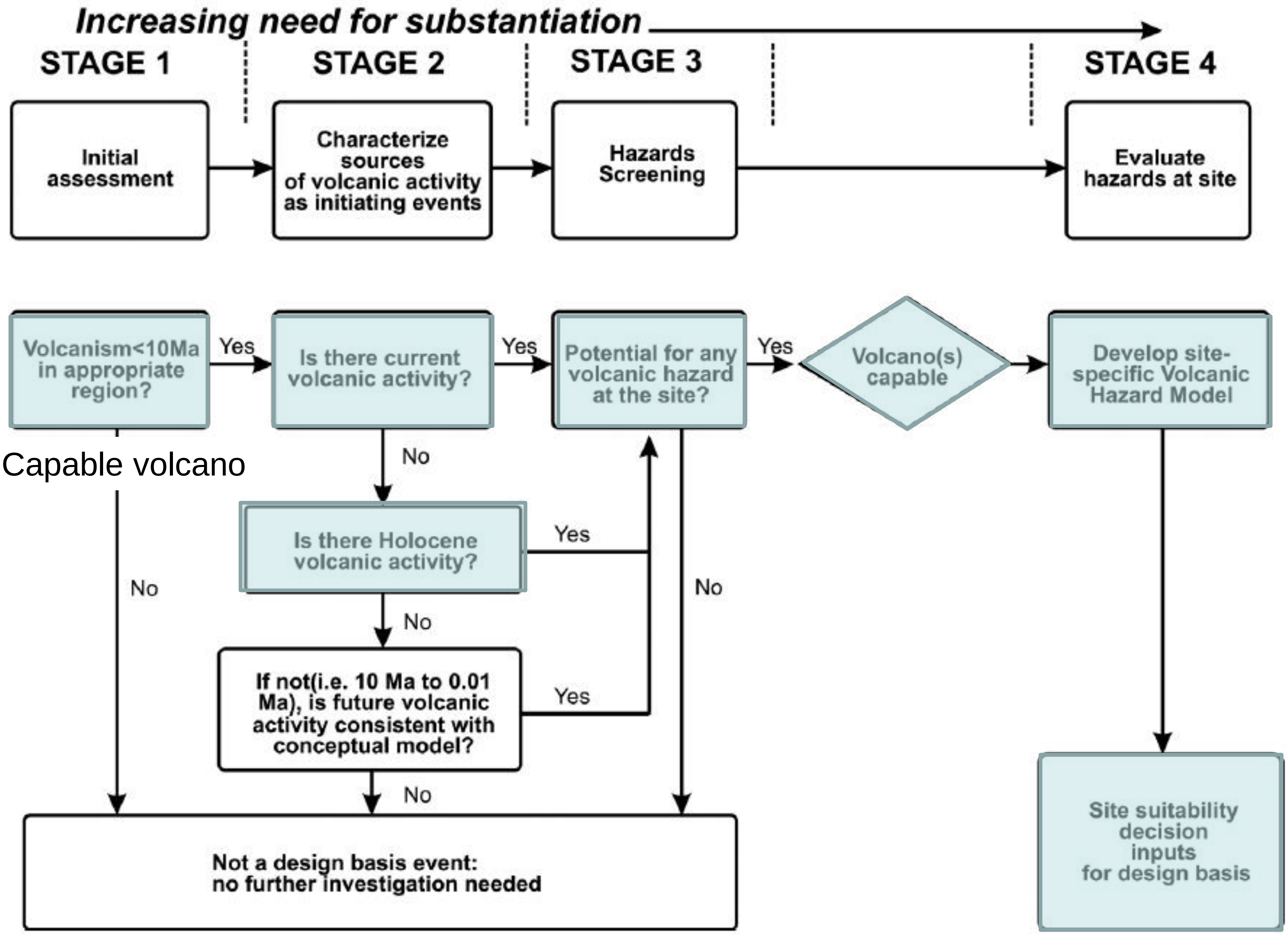
- Ebasco (1977) at 3×10^{-5} $year^{-1}$

- Volentik et al. (2009) at 1×10^{-4}–2×10^{-4} $year^{-1}$, with a confidence level of 95%

+ Active hydrothermal system means it has credible potential for a future eruption

What probability constitutes serious radiological consequences

In some States a value for the annual probability of 10^{-7} is used in the hazard assessment for external events as a reasonable basis to evaluate whether a volcano in the region could produce any type of activity in the future that could lead to serious radiological consequences(IAEA 2009).


Increasing need for substantiation
STAGE 1
STAGE 2
STAGE 3
STAGE 4
Initial assessment
Characterize sources of volcanic activity as initiating events
Hazards Screening
Evaluate hazards at site
Volcanism<10Ma in appropriate region?
Yes
Is there current volcanic activity?
Yes
Potential for any volcanic hazard at the site?
Yes
Volcano(s) capable
Develop site-specific Volcanic Hazard Model
Capable volcano
No
No
Is there Holocene volcanic activity?
Yes
No
No
If not(i.e. 10 Ma to 0.01 Ma), is future volcanic activity consistent with conceptual model?
Yes
No
Not a design basis event: no further investigation needed
Site suitability decision inputs for design basis

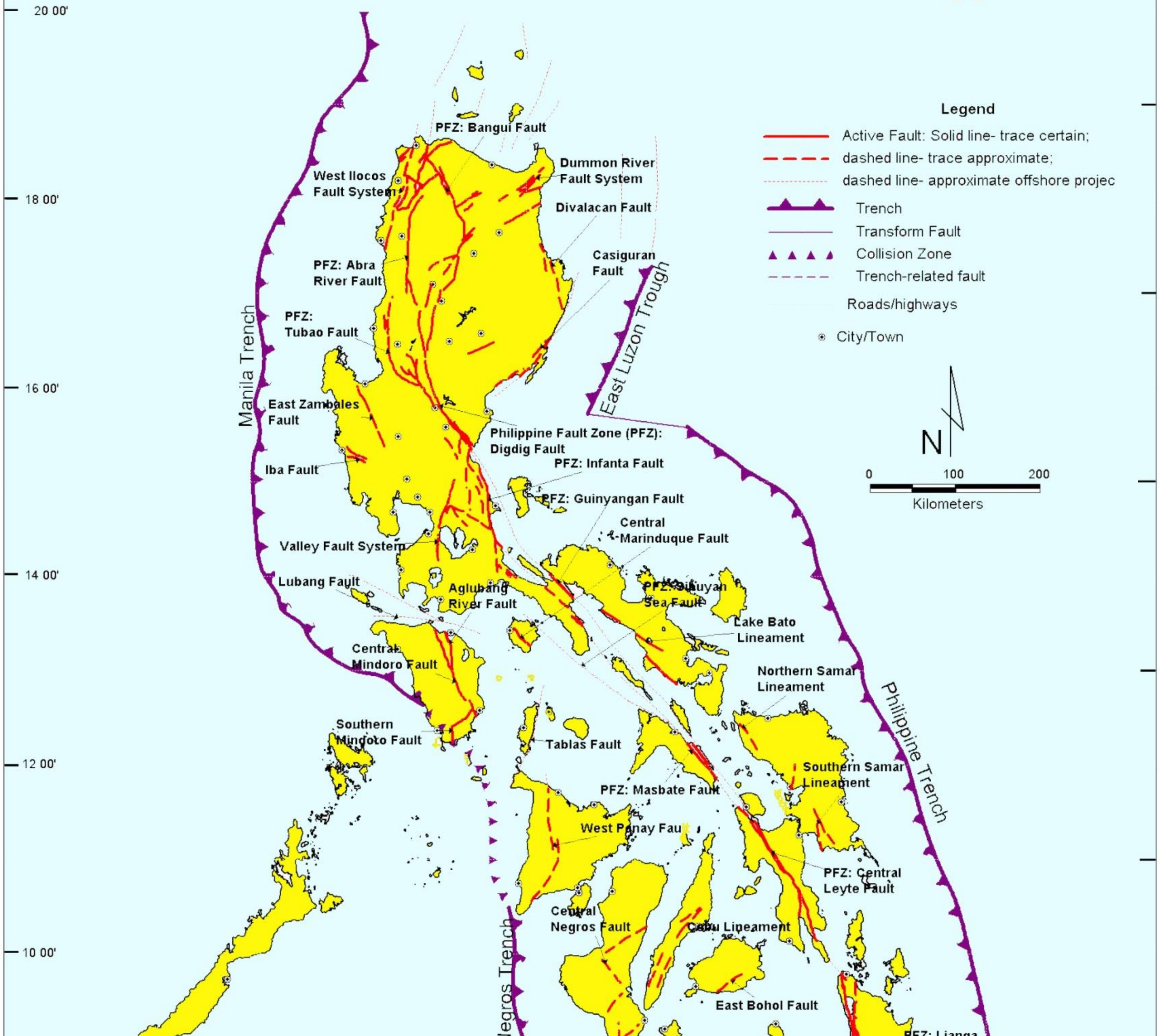
Screening distance values

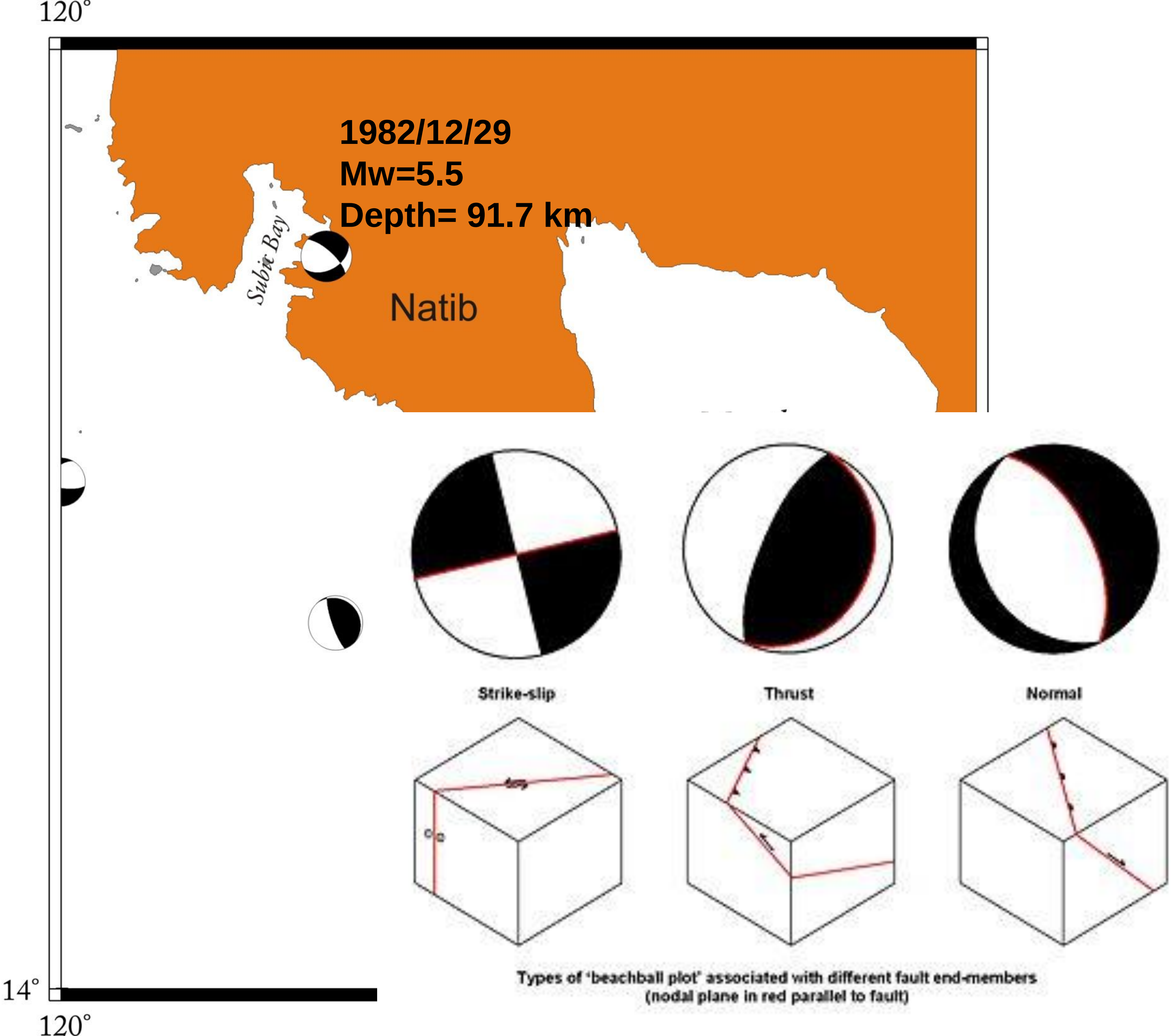
the maximum distance from the source to the site at which each phenomenon could be a hazard

- Pyroclastic flow hazard – within SDV
- Pyroclastic surge hazard – within SDV
- Lahar hazard – within SDV
- Lava flow hazard – within SDV (nearest eruptive center 5 km away from the Nuclear reactor)

Phenomena	Potentially adverse characteristics for nuclear installations	Site selection	Design/ operation
Tephra fall	Static physical loads, abrasive and corrosive particles in air and water	No	Yes
Pyroclastic density currents: Pyroclastic flows, surges and blasts	*Dynamic physical loads, atmospheric overpressures, projectile impacts, temperatures >300 °C, abrasive particles, toxic gases*	*Yes*	*No*
Lava flows and lava domes	*Dynamic physical loads, water impoundments and floods, temperatures >700 °C*	*Yes*	*No*
Debris avalanches, landslides and slope failures	Dynamic physical loads, atmospheric overpressures, projectile impacts, water impoundments and floods	Yes	No
Debris flows and lahars, floods	Dynamic physical loads, water impoundments and floods, suspended particulates in water	Yes	Yes
Opening of new vents	Dynamic physical loads, ground deformation, volcanic earthquakes	Yes	No
Ballistic projectiles	Projectile impacts, static physical loads, abrasive particles in water	No	Yes
Volcanic gases and aerosols	Toxic and corrosive gases, water contamination, gas-charged lakes	No	Yes
Tsunamis, seiches, crater lake failure, glacial burst	Water inundation	Yes	Yes
Atmospheric phenomena	Dynamic overpressures, lightning strikes, downburst winds	No	Yes
Ground deformation	Ground displacements >1 m, landslides	Yes	No
Volcanic earthquakes and seismic events	Continuous tremor, multiple shocks usually $<M\,5$	No	Yes
Hydrothermal systems and groundwater anomalies	Thermal water >50 °C, corrosive water, water contamination, water inundation or upwelling, alteration, landslides	Yes	No

Distribution of Active Faults and Trenches in the Philippines





Types of 'beachball plot' associated with different fault end-members
(nodal plane in red parallel to fault)

Capable faults are structures that are most relevant when evaluating the geological features of the site. They are faults that have a significant potential for relative displacement at or near the ground surface

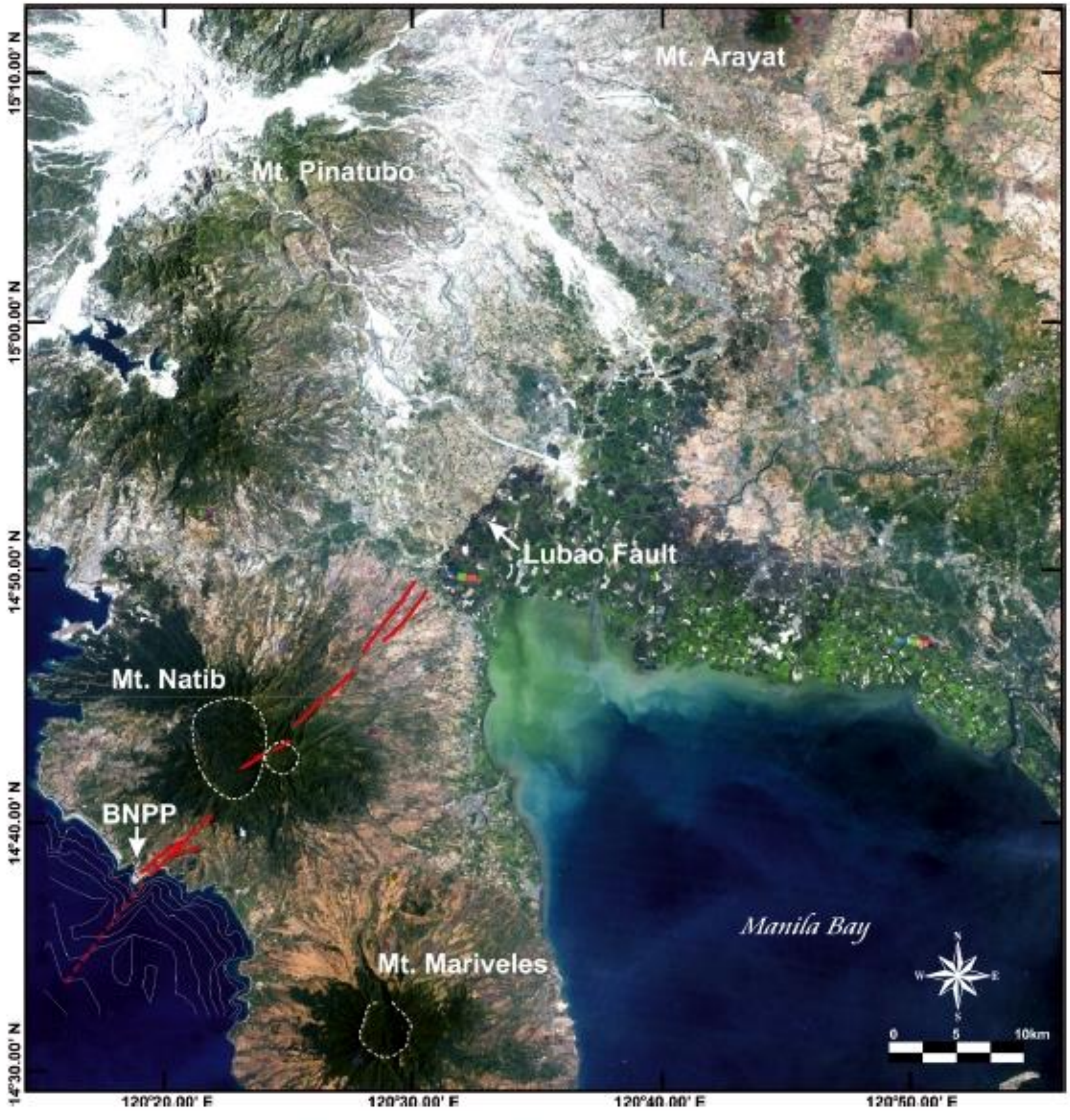
Criteria

1. Shows evidence of past movement of a recurring nature within a period that it is reasonable to conclude that further movements at or near the surface may occur. In tectonically active areas, where both earthquake data and geological data consistently reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years may be appropriate.

Capable faults are structures that are most relevant when evaluating the geological features of the site. They are faults that have a significant potential for relative displacement at or near the ground surface

Criteria:

2.A structural relationship with another known capable fault has been demonstrated, such that movement at one may cause
movement of the other at or near the surface.


Mt. Arayat
Mt. Pinatubo
Lubao Fault
Mt. Natib
BNPP
Mt. Mariveles
Manila Bay
N
W
E
S
0
5
10km
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

Conclusions – site not suitable

- Pyroclastic flow hazard – within SDV
- Pyroclastic surge hazard – within SDV
- Lahar hazard – within SDV
- Lava flow hazard – within SDV (nearest eruptive center 5 km away from the Nuclear reactor)
- Seismic hazard – seismically active area with the nearest identified fault 400 m away from the Nuclear reactor