Imaging of internal density structure of volcanoes: past and recent works

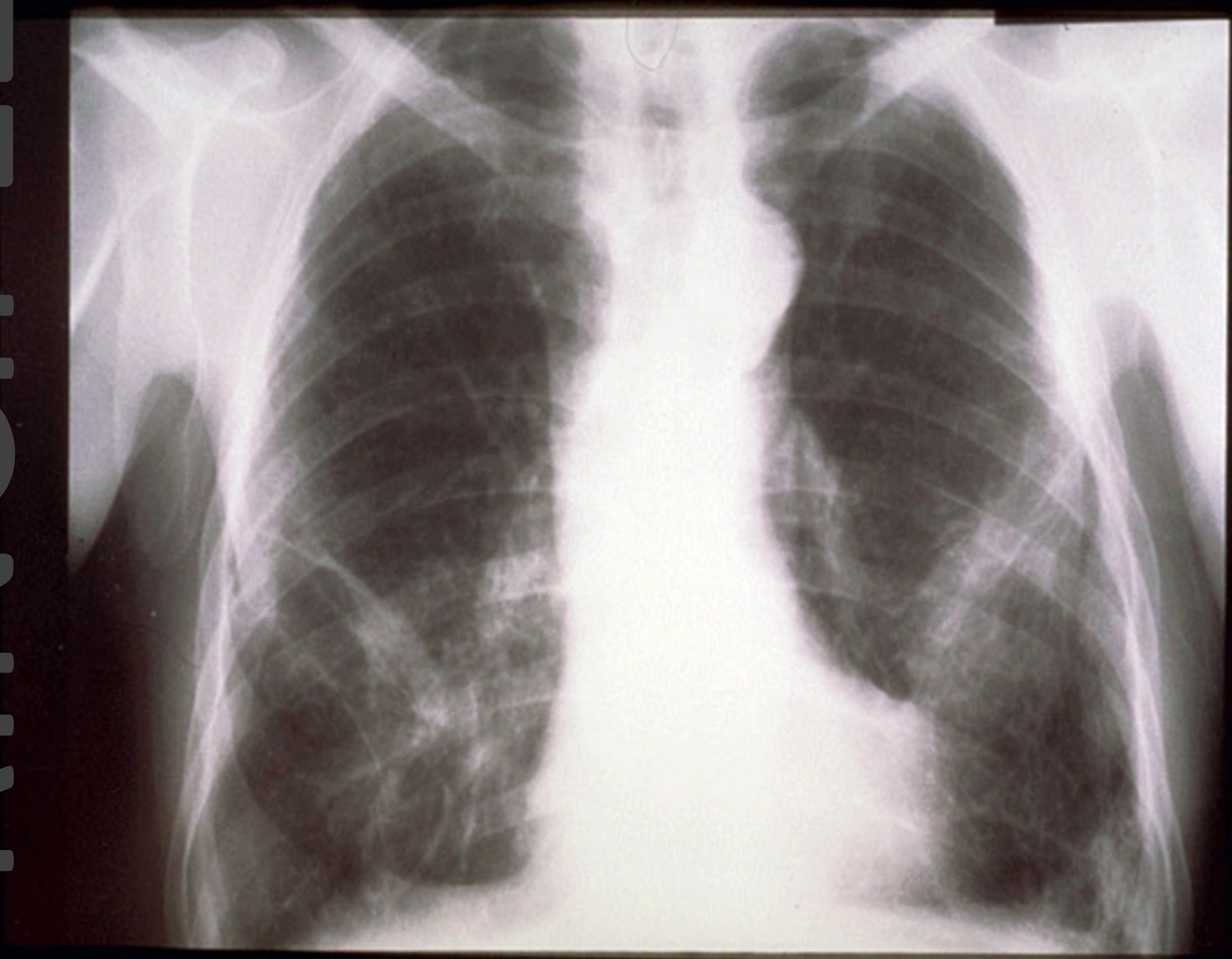
Seigo Miyamoto
Earthquake research institute
The University of Tokyo

NuFACT 2012 24th Jul. Williamsburg

OVERVIEW

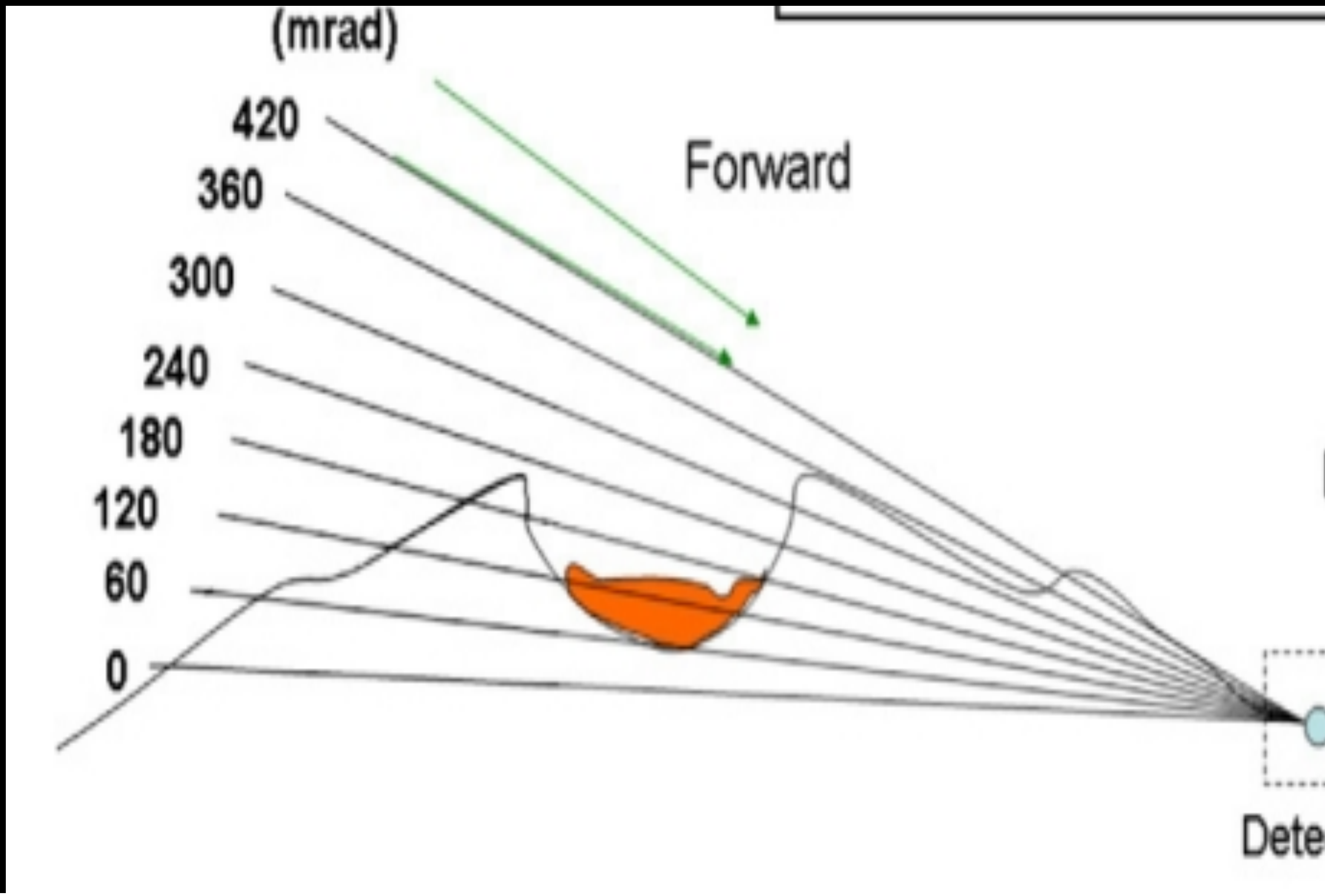
- The basic principle of muon-radiography
- Muon detectors
- Past and recent works
- Going-on projects
- Summary

PRINCIPLE

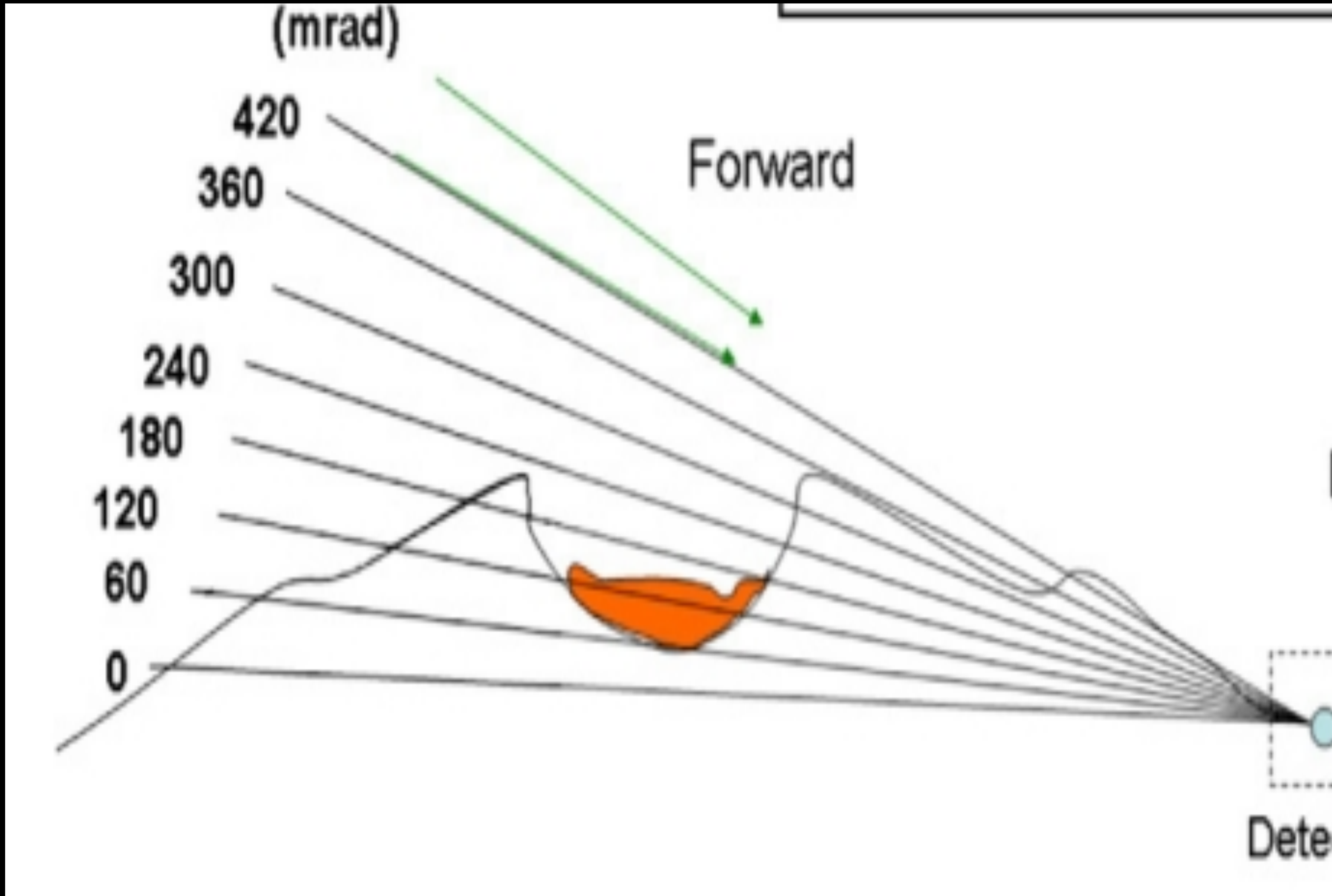


PRINCIPLE

- Beam source : X-ray ⇔ cosmic-ray muon
- Detector : X-ray film ⇔ muon detector
- Target : Human body ⇔ Volcano
- Dense Part: Our borne ⇔ Magma Rock

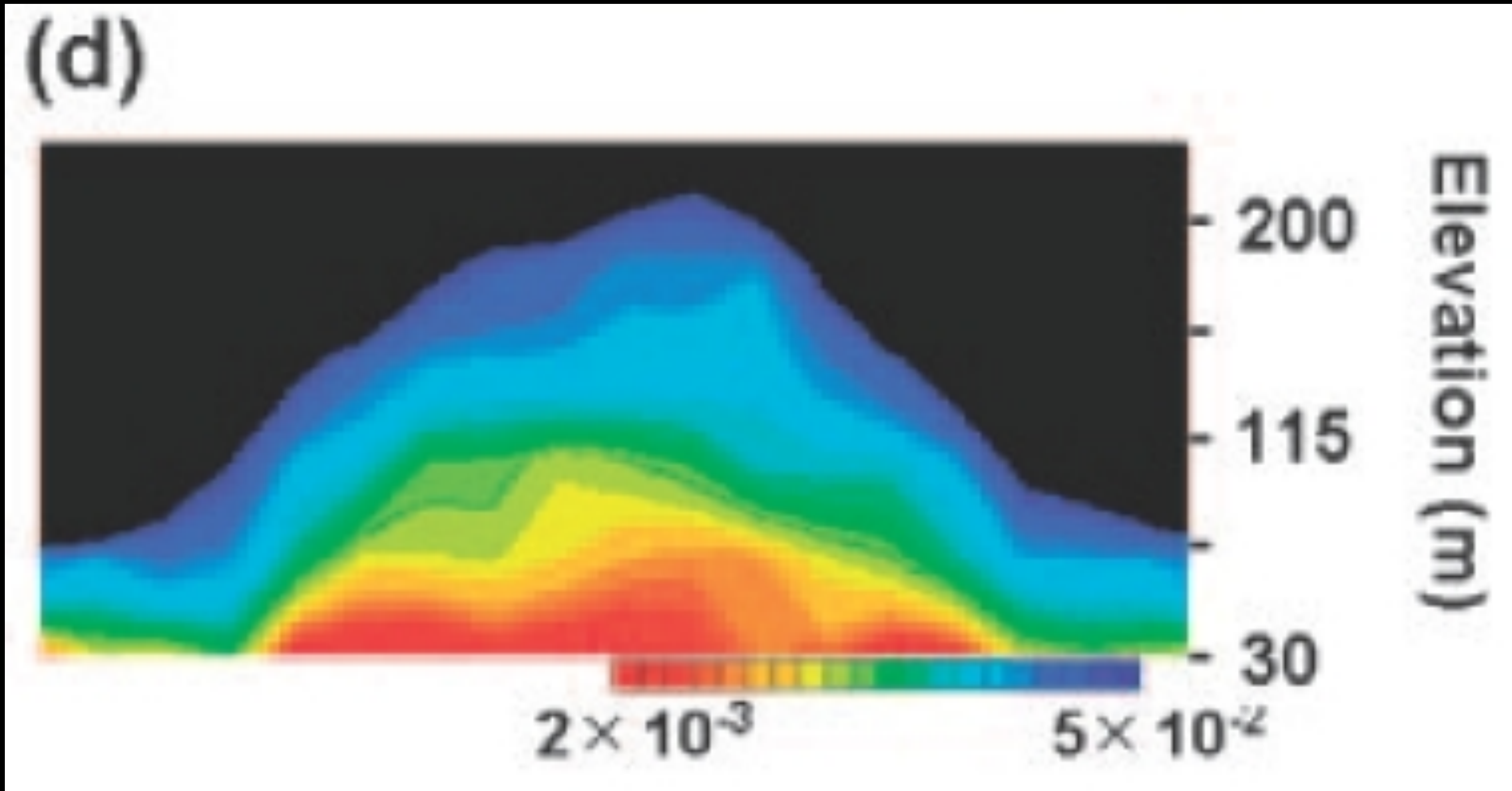


PRINCIPLE



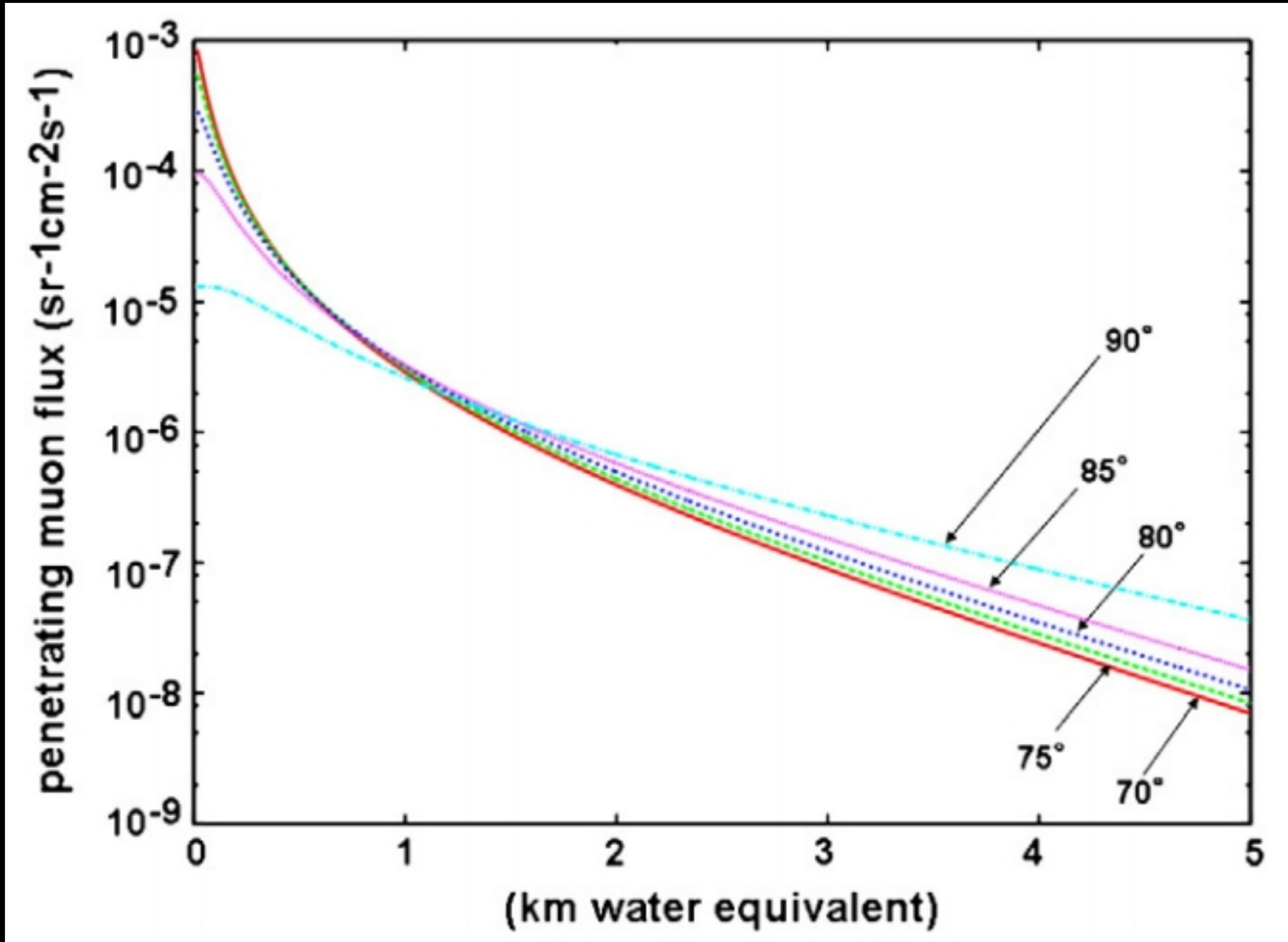
- Calculate the thickness of rock from observation point by using topographic Digital Elevation Map(DEM) data.

PRINCIPLE



- Measure the muon attenuation ratio for each zenith angles and phi angles.

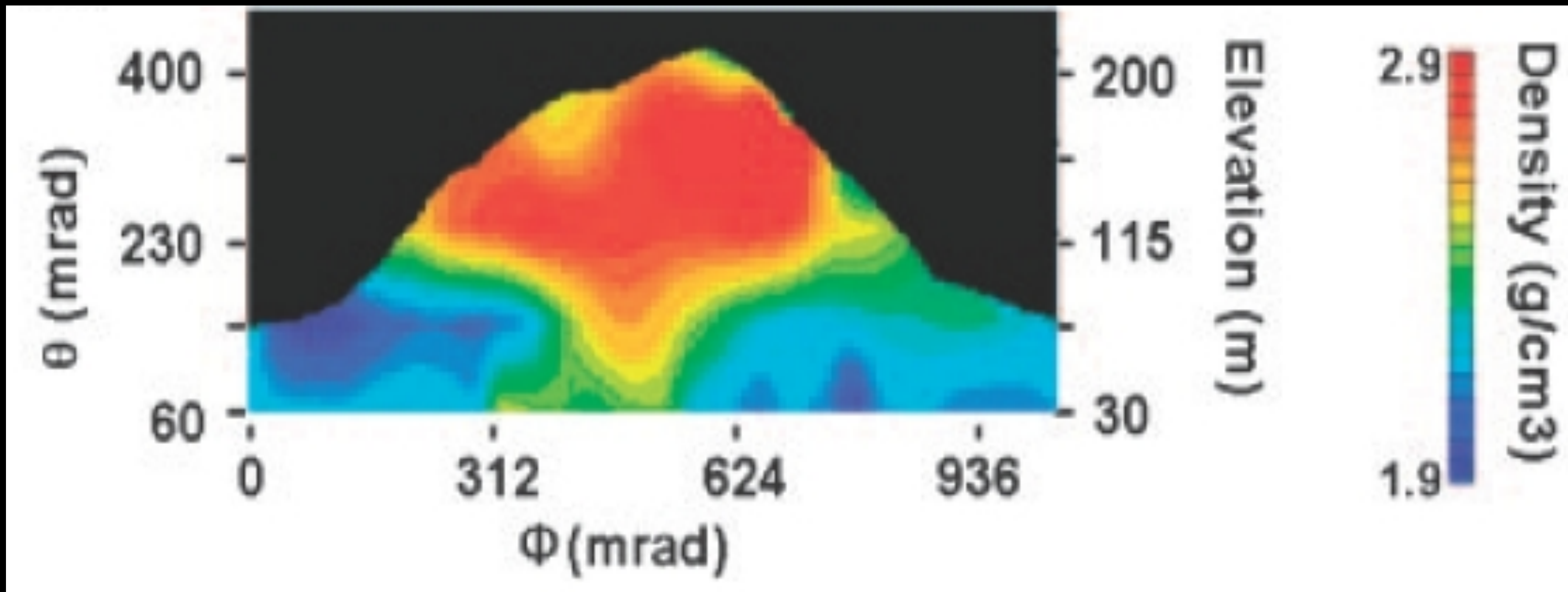
PRINCIPLE



- The “Density x length” is determined.

PRINCIPLE

- Average density
= (“Density x Length”) / Rock Length.

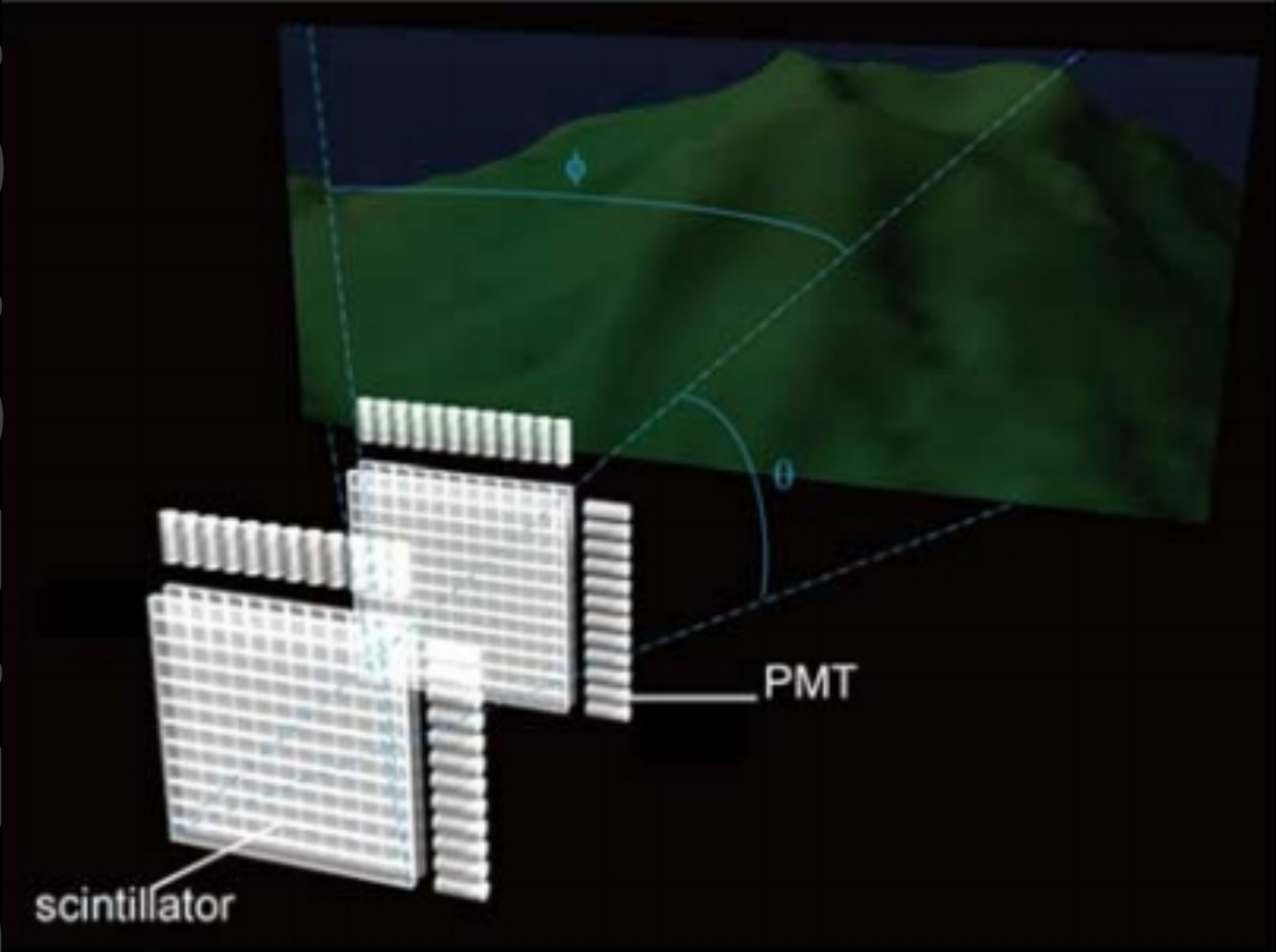


DETECTORS

- Nuclear Emulsion film
- Scintillator bar array and PMT

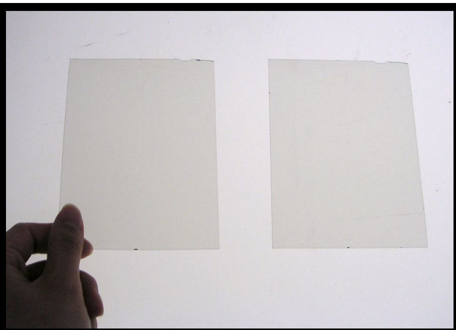
DETECTORS

Scintillator bar array + PMT

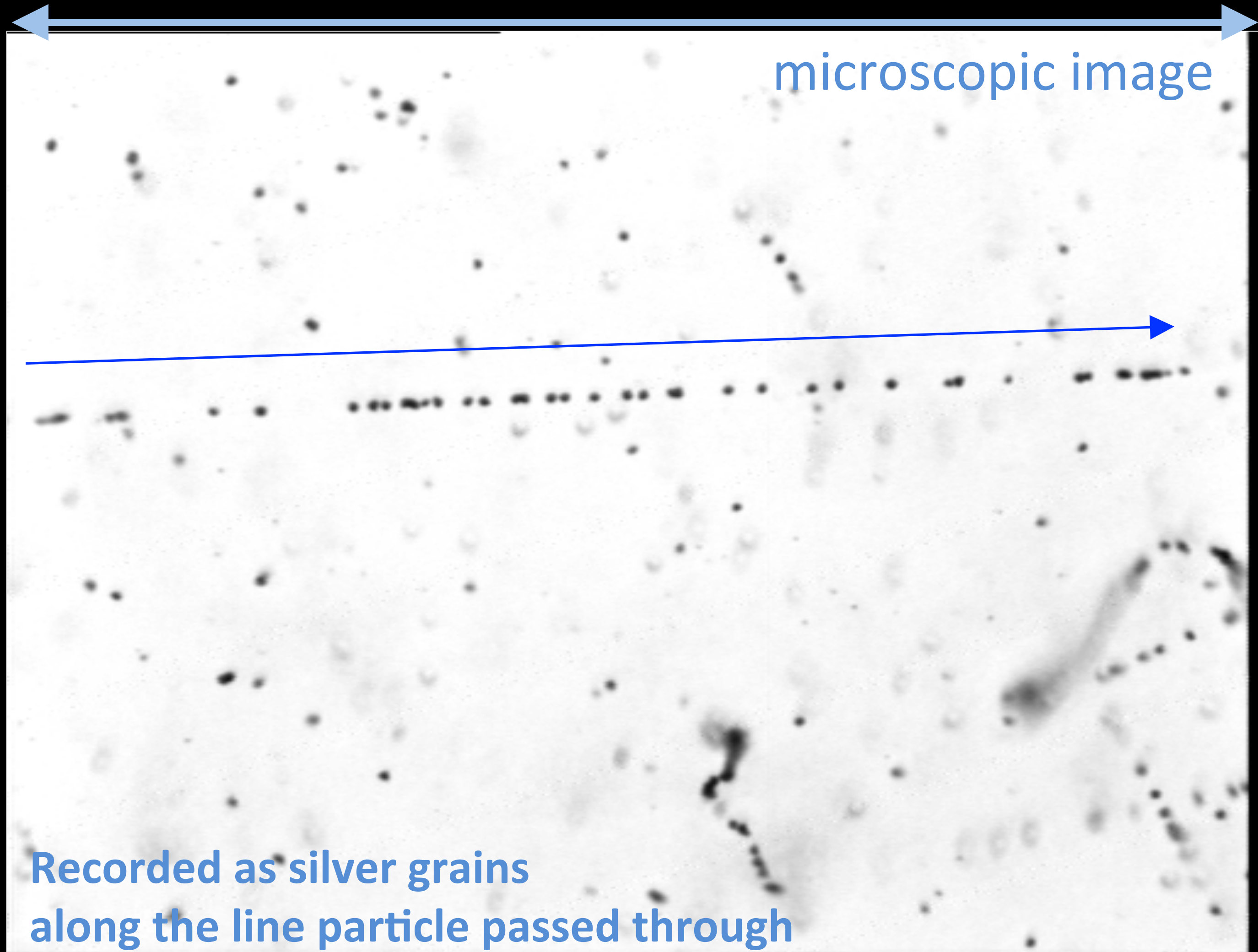


DETECTORS

Nuclear emulsion film



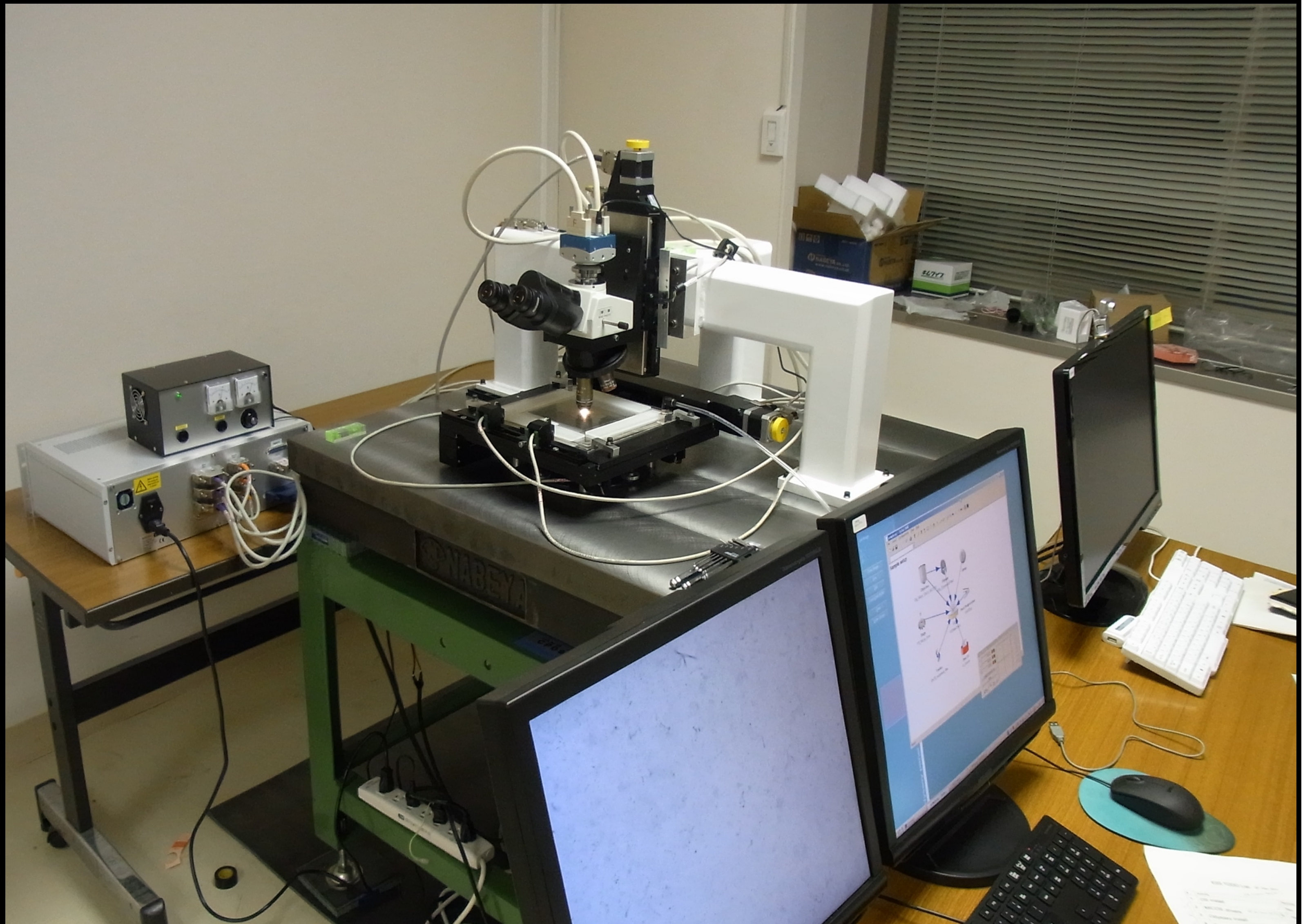
150 micron



DETECTORS

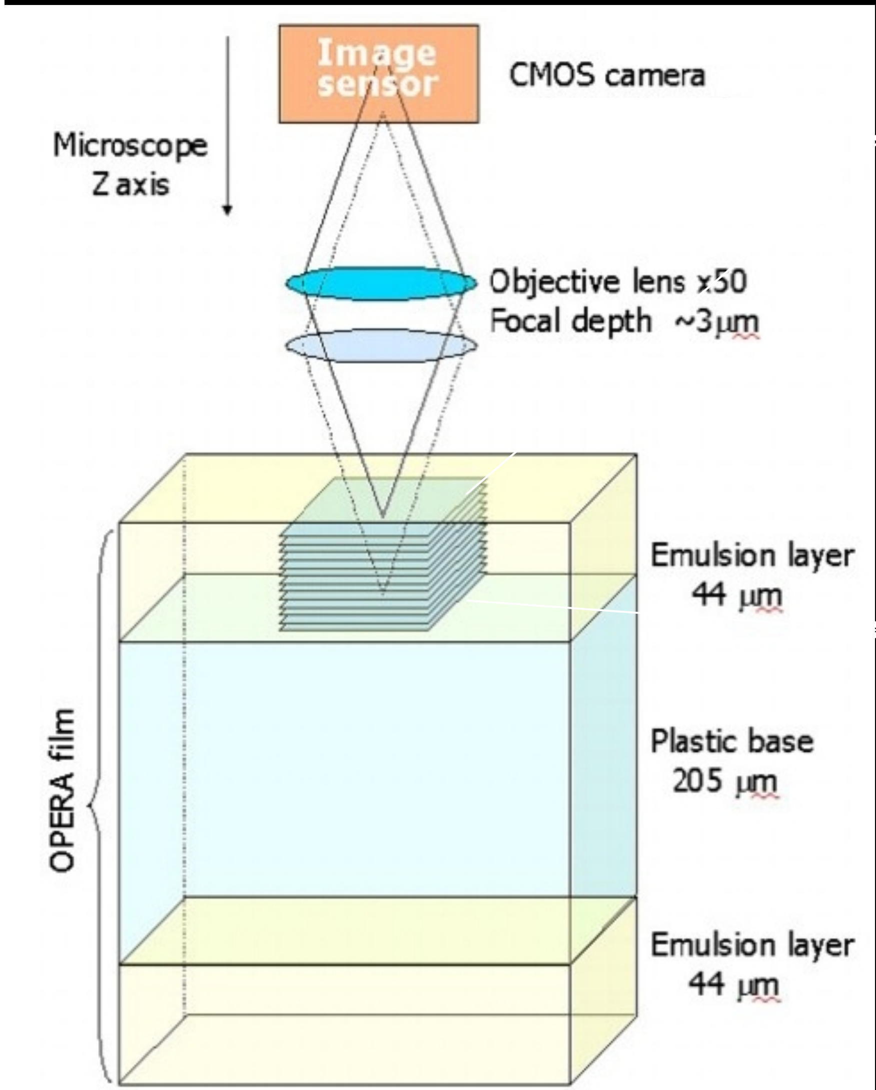
	Emulsion film	Scintillator + PMT
Power supply	Do not need	Need power supply
portability	Light and compact	Need large space
Stability for the environment	Very stable for the shock, water, dust and cold temperature, but temperature must be less than ~25 deg. Celsius	Need protection for the water and shock.
DAQ	Need Development & Additional analysis by automated readout system is need	Real-time monitoring is available
Spread of the technology	Miner	Major

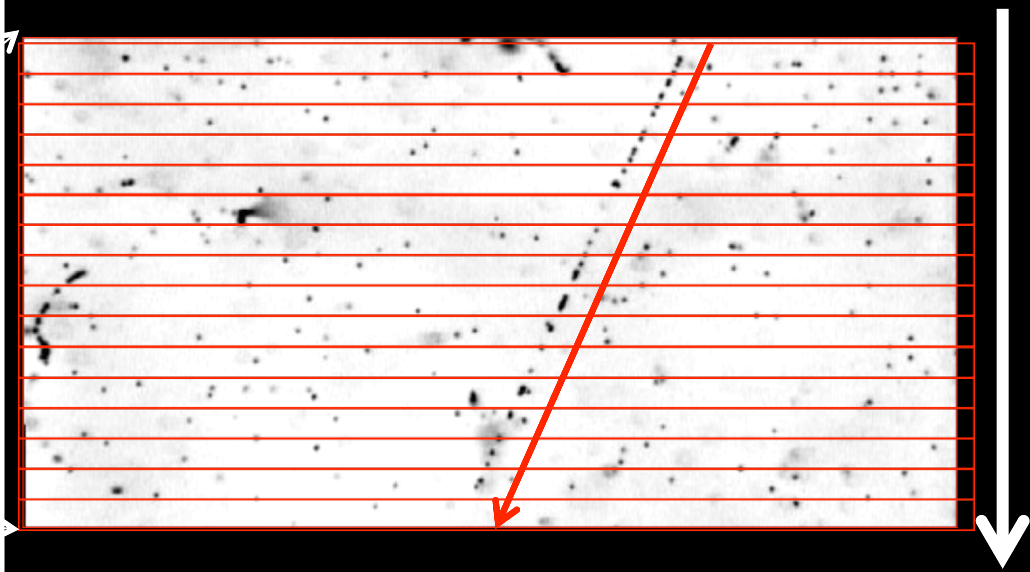
DETECTORS



- Scanning speed : 0.27 m^2 /month/system. Two is working.
- Next year scanning speed will be updated to 1.3m^2/

The flow of image acquisition





Synchronization of Z axis movement and camera shutter and acquisition of 16 tomographic images

-> Recognition of track by Linear fitting

PAST WORKS

- The original idea is very old :

e.c.) L. W. Alvarez tried to find hidden room in Pyramid in 1969 .

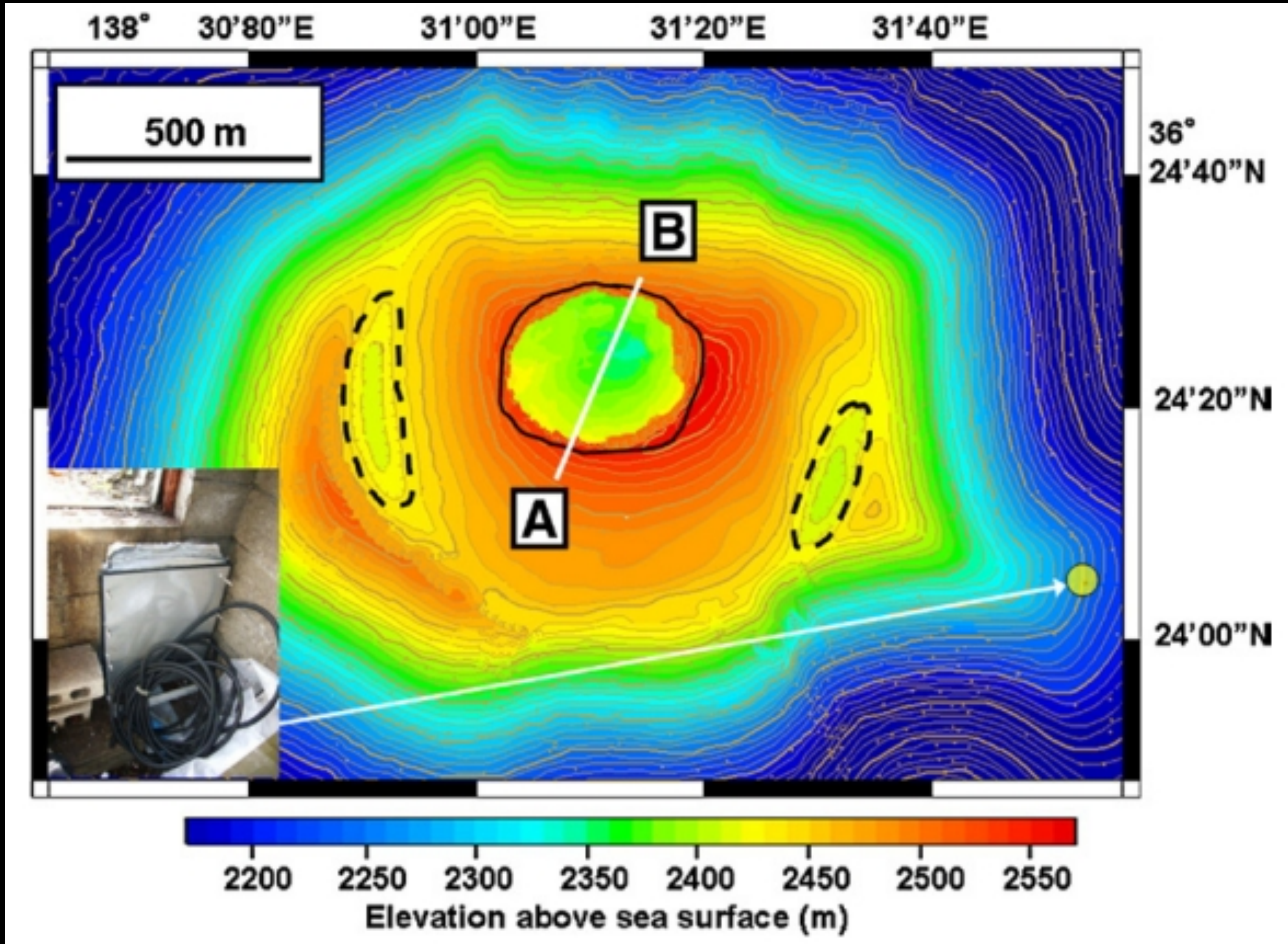
- Unfortunately his team couldn't find any new rooms.
- Any other people continue to find anything ,
  but no significant results until in 2006.

PAST WORKS

Спасск-Дальний
Арсеньев
Уссурийск
Владивосток
Находка
长春
吉林
North Korea
日本
대한민국
서울
대전
대구
부산
광주
札幌
盛岡
秋田
仙台
新潟
福島
金沢
水戸
福井
前橋
松江
鳥取
東京
名古屋
岡山
大阪
広島
山口
津
福岡
大分
和歌山
松山
長崎
熊本
宮崎
鹿児島
East

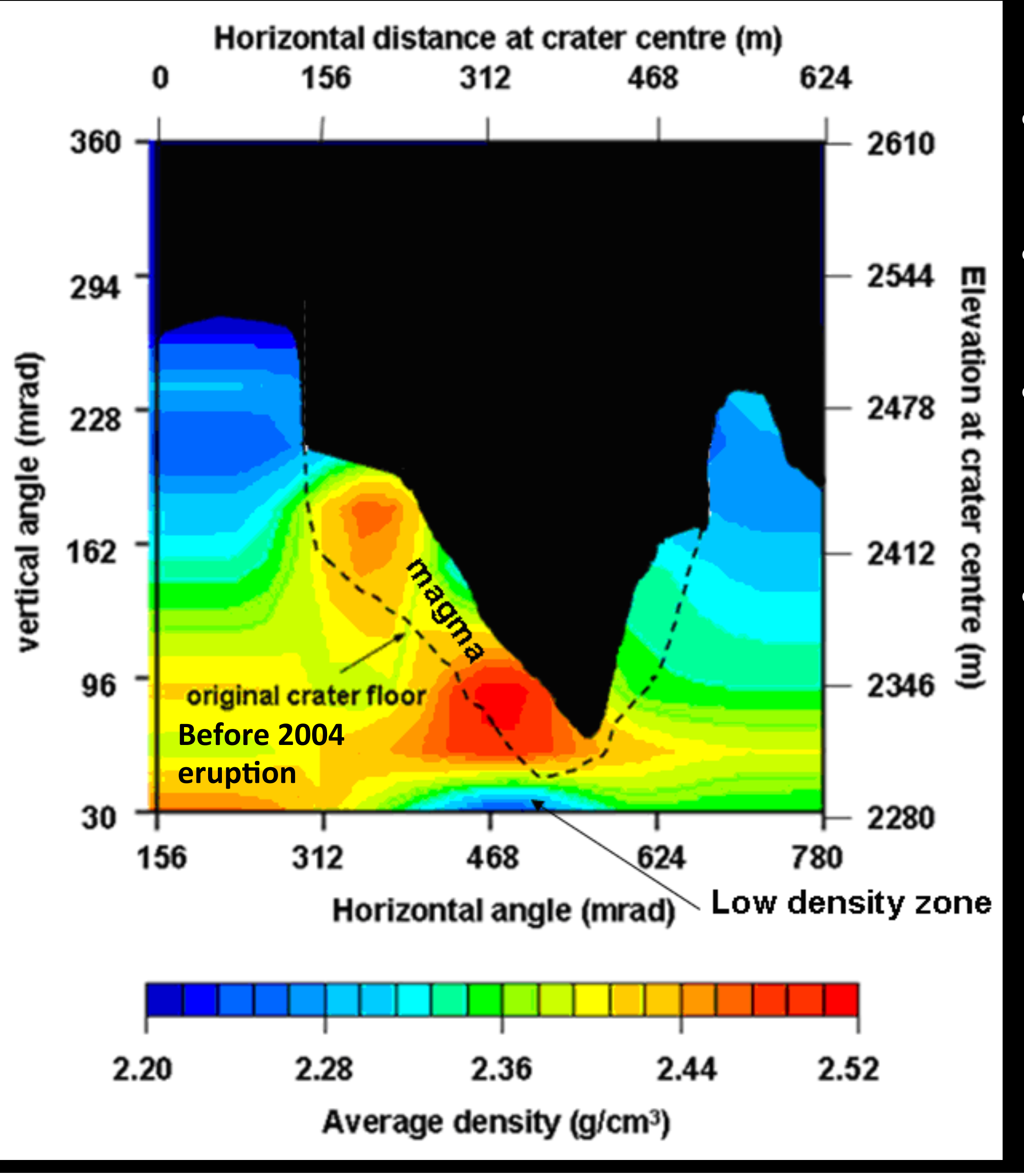
PAST WORKS

- Mt. Asama 2006-



PAST WORKS

- Mt. Asama 2006 , detector: emulsion film



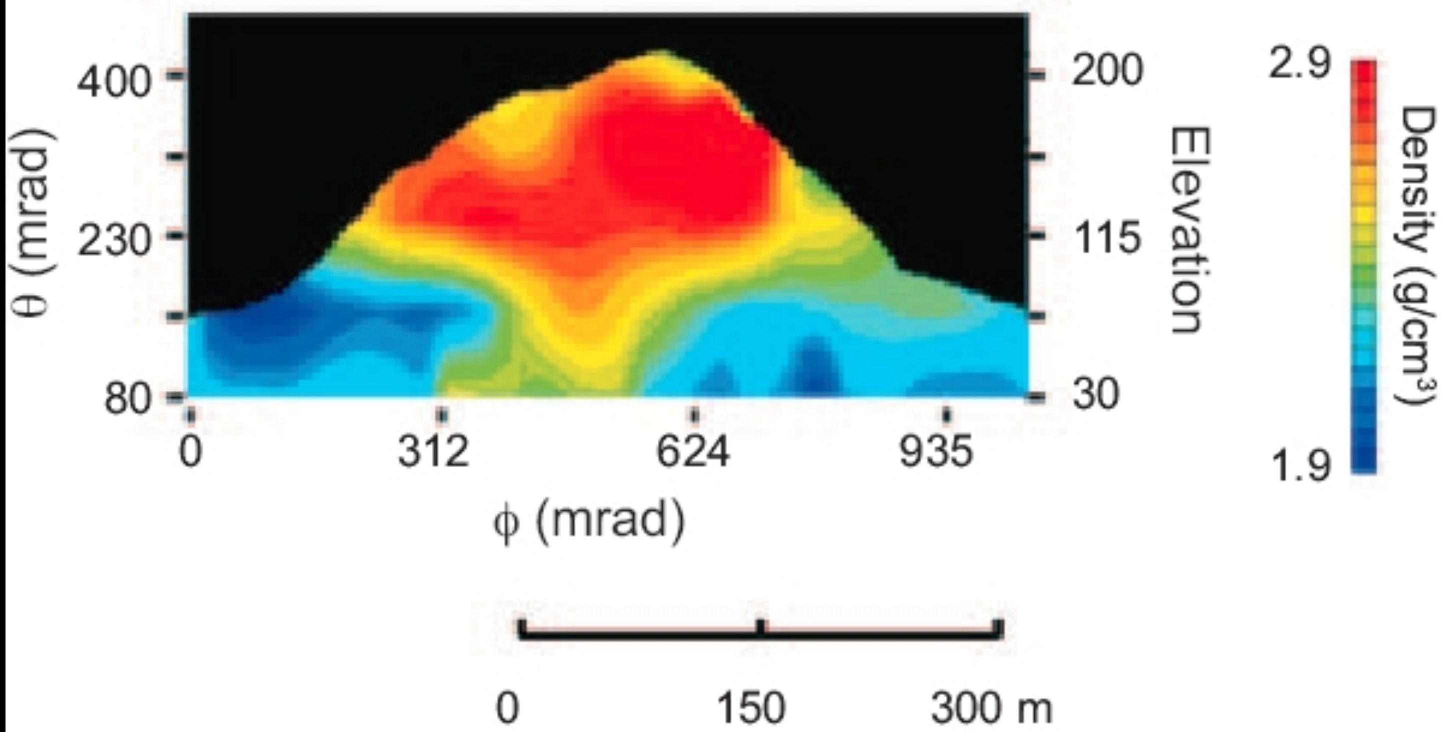
- 0.2 m^2
- 2 months
- 120m x 60m resolution
- +-0.07 g/cc error

PAST WORKS

Showa-Shinzan

0.12m² emulsion 3month Exposure

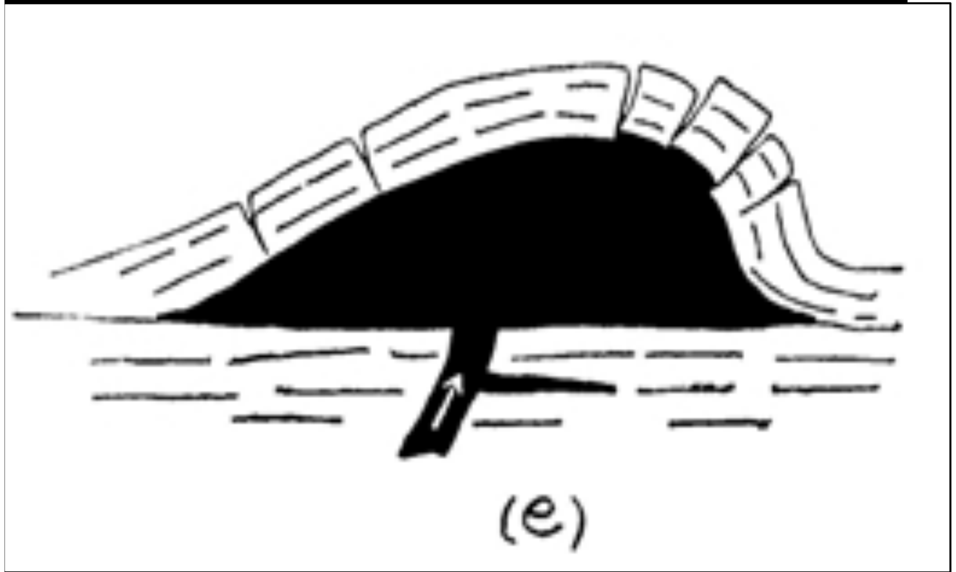
30m x 30m resolution

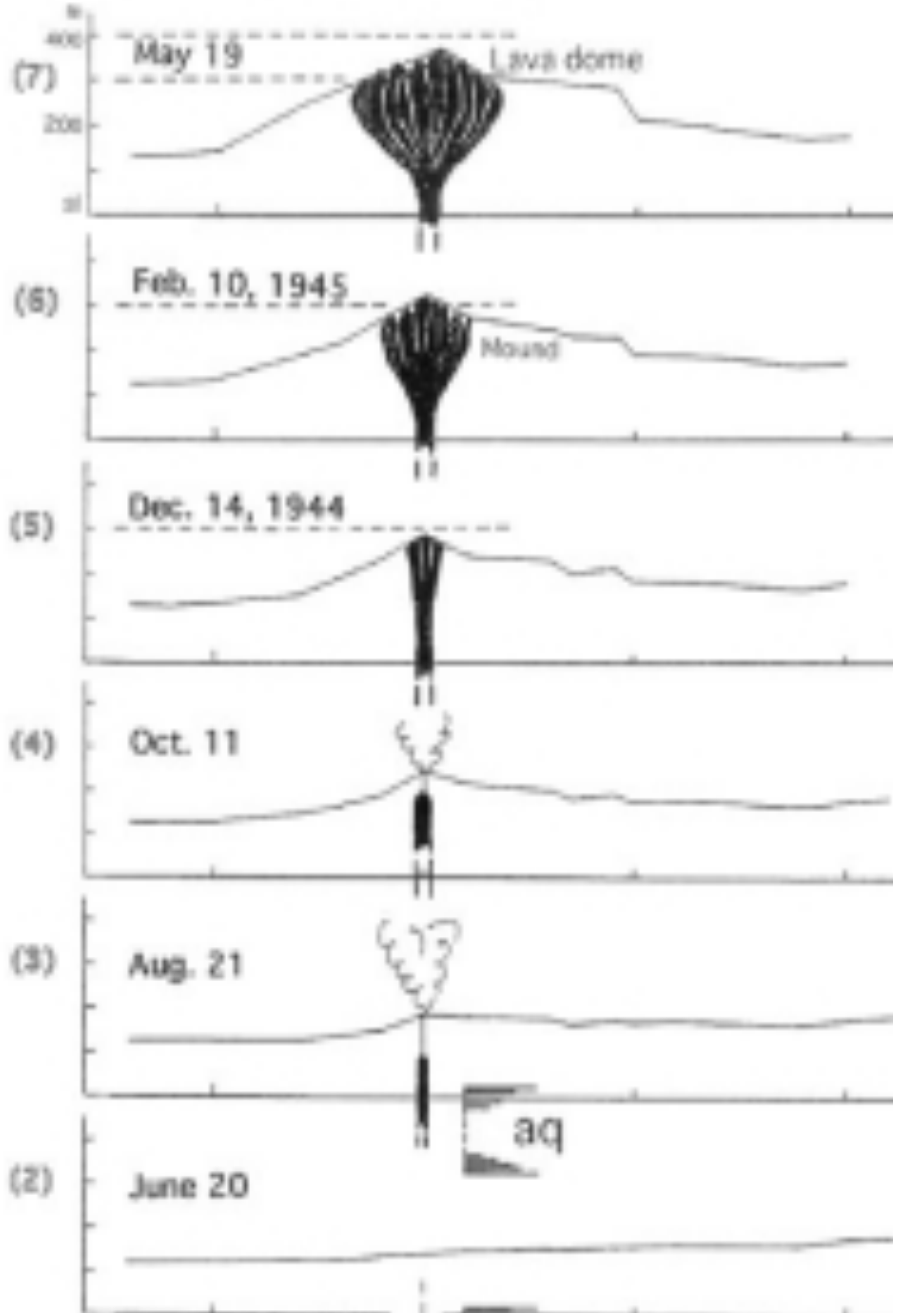


H.K.M.Tanaka, T.Nakano et. al.,

American Journal of Science, Vol. 308, Sep, 2007, P. 843–850.

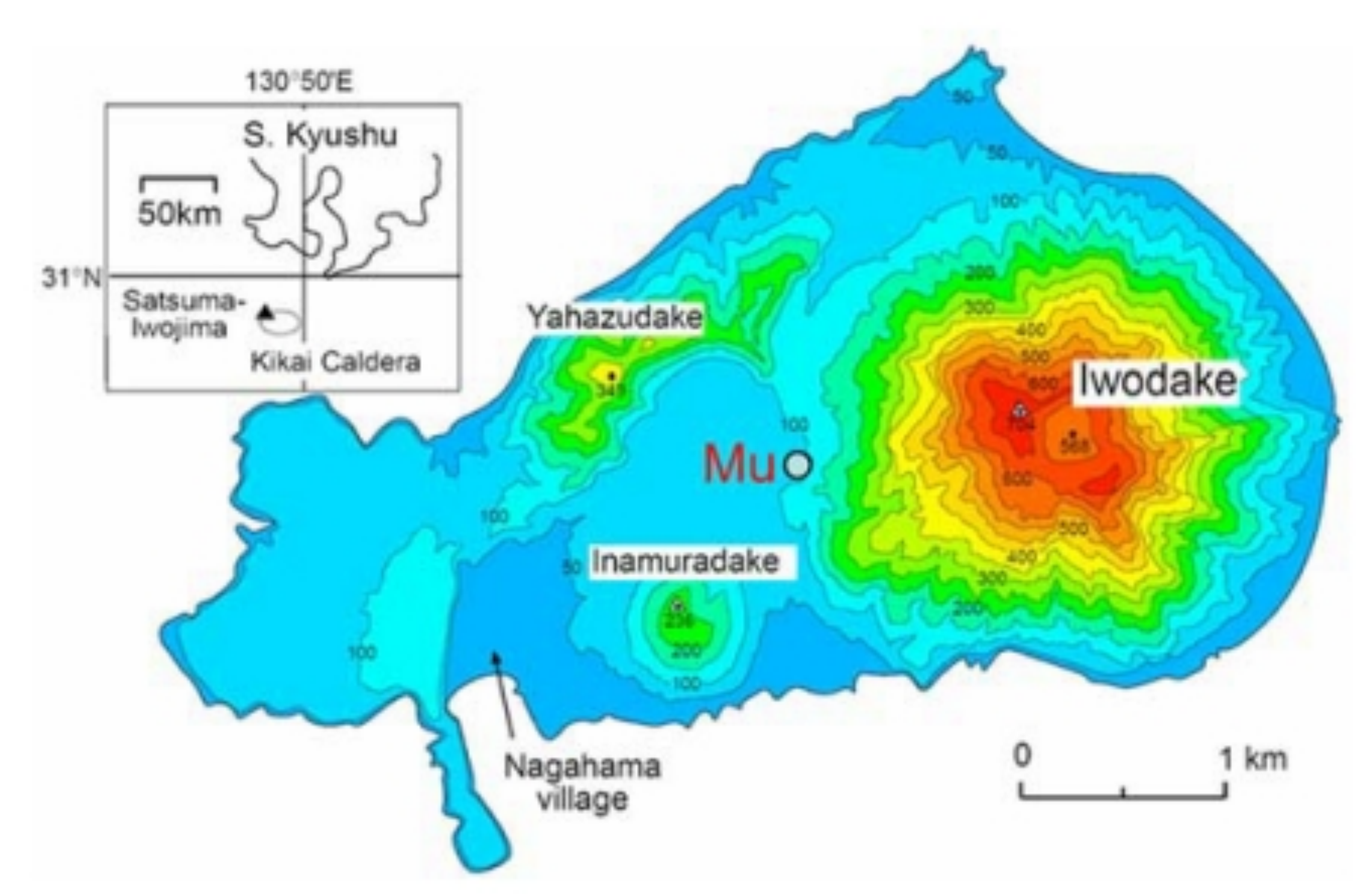
Showa-shinzan lava dome growth models before this work





RECENT WORKS

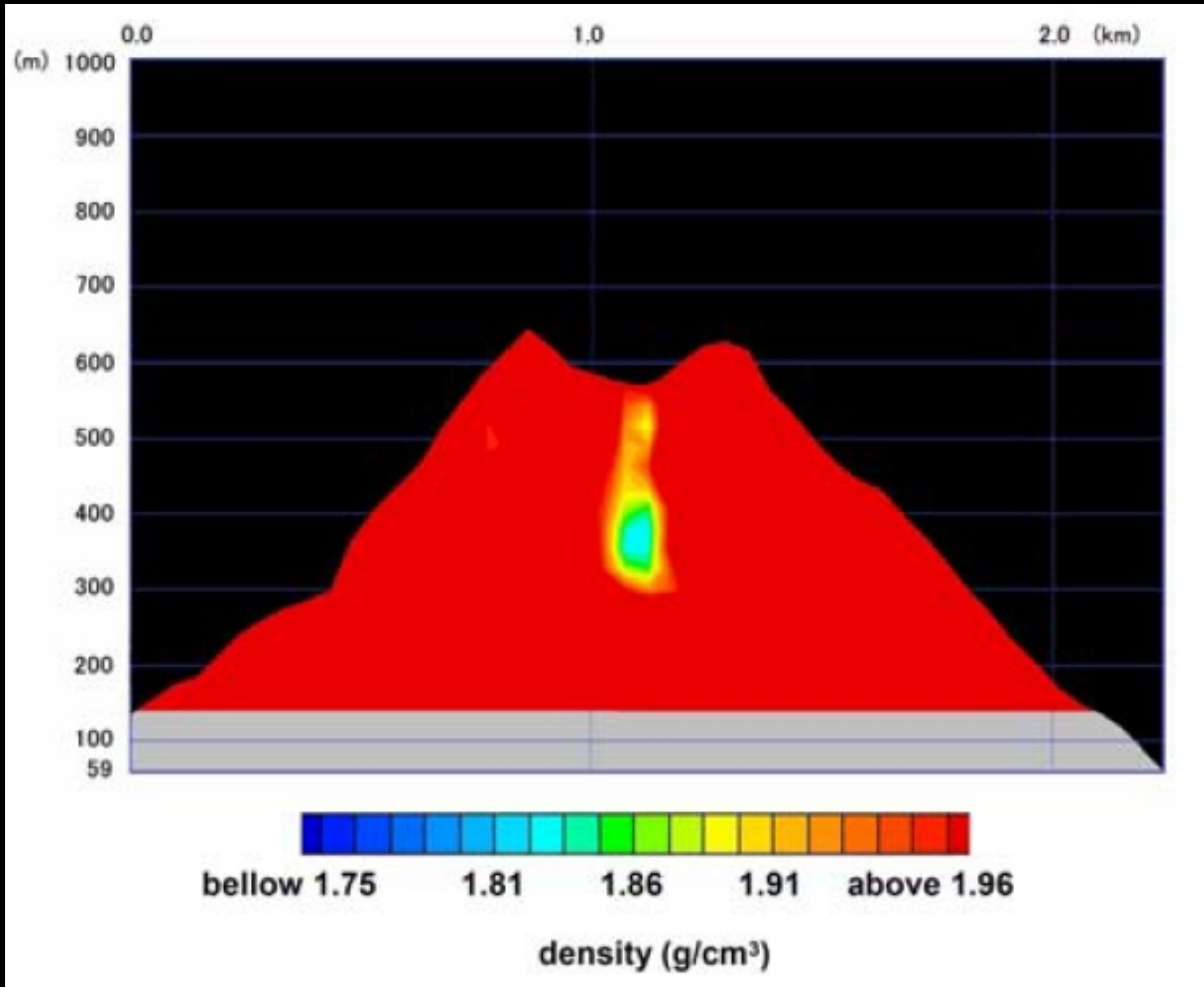
- Satsuma-Iwojima (2008)



- Continuous emission of volcanic gas for about 1,000 years.

RECENT WORKS

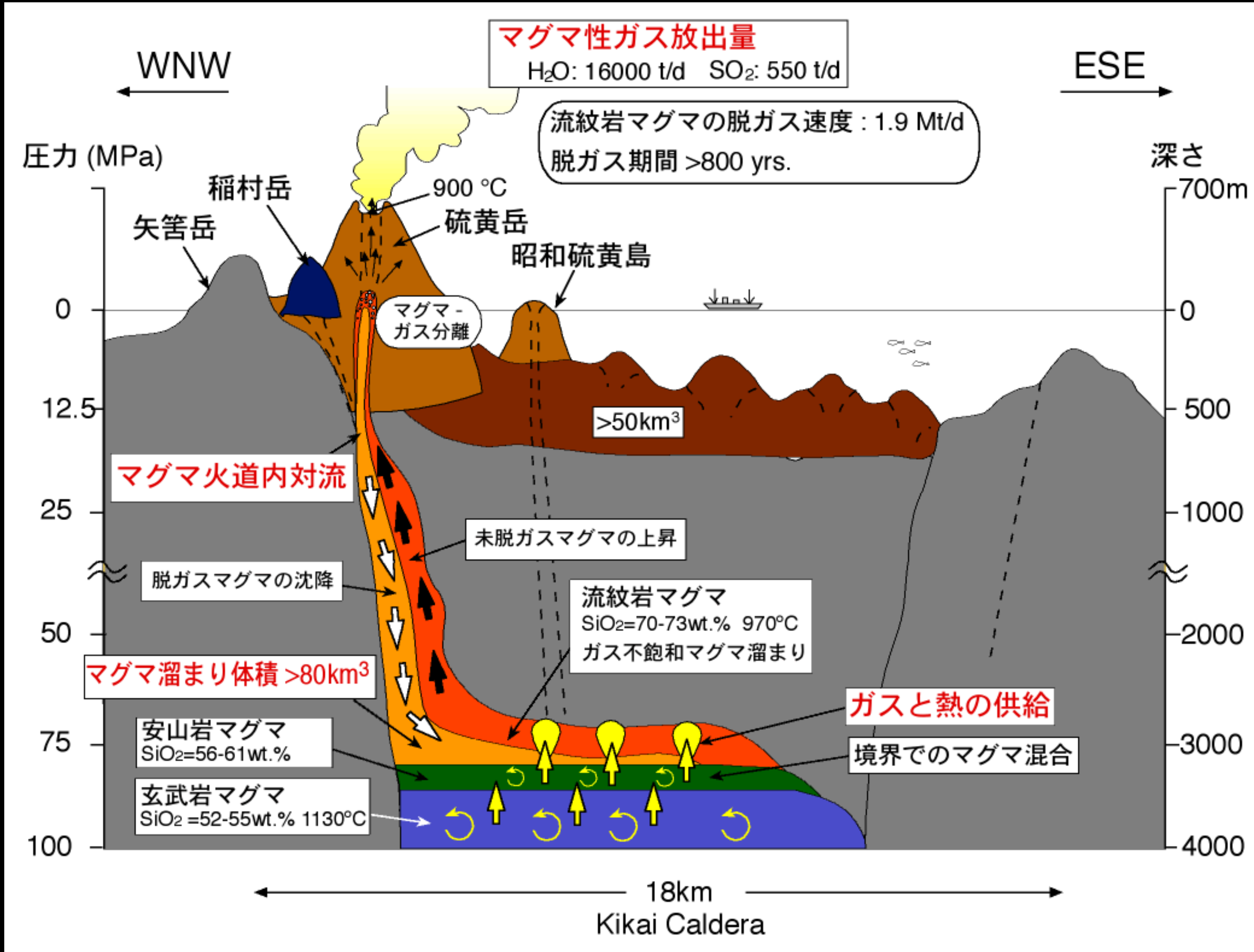
- Satsuma-Iwojima (2008)
- detector: Scintillator array



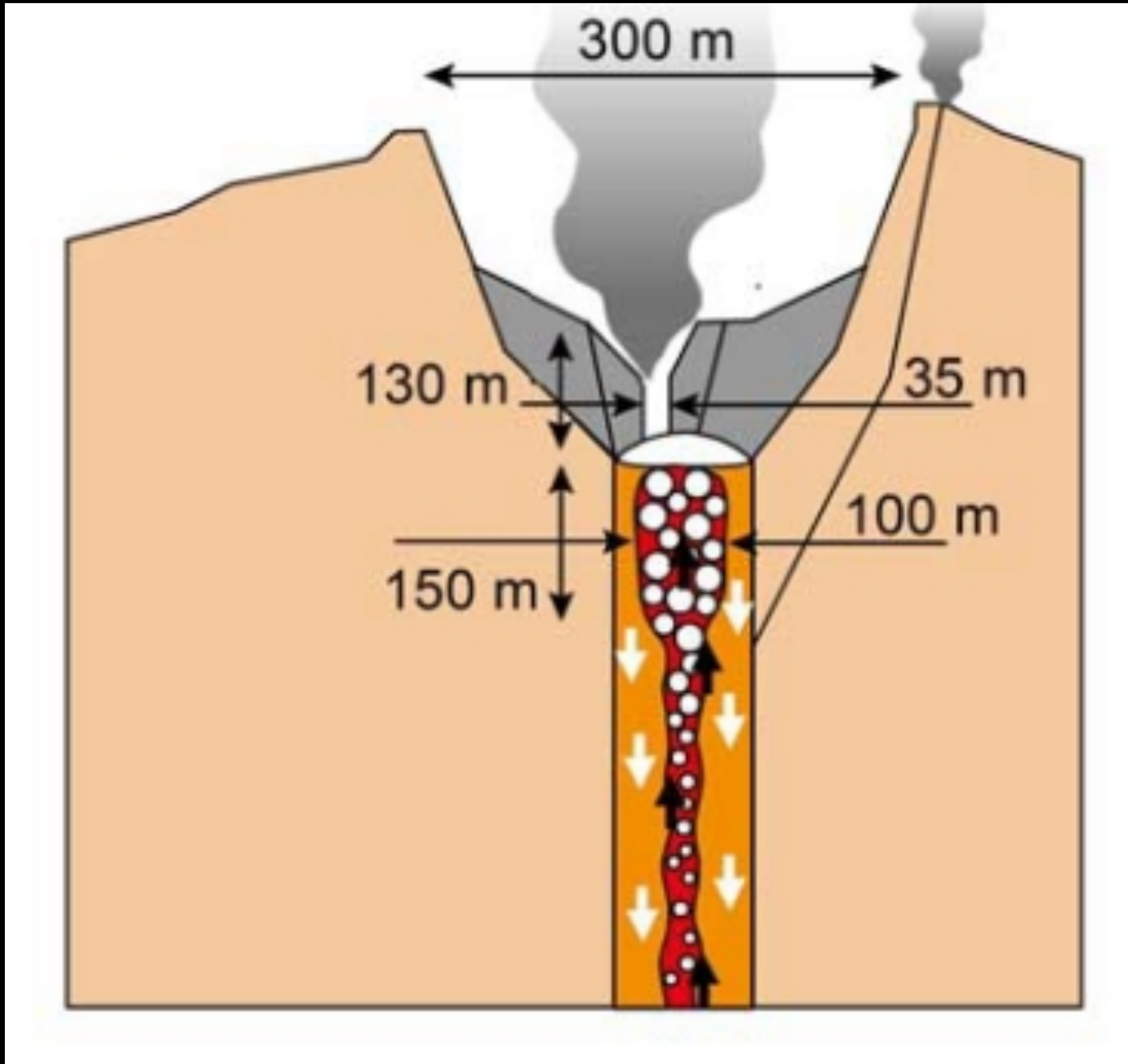
- 1.0 m^2
- 1 months
- 50m x 50m resolution
- +-0.06 g/cc error

RECENT WORKS

- Magma Convection model in Mt. Satsuma-Iwojima

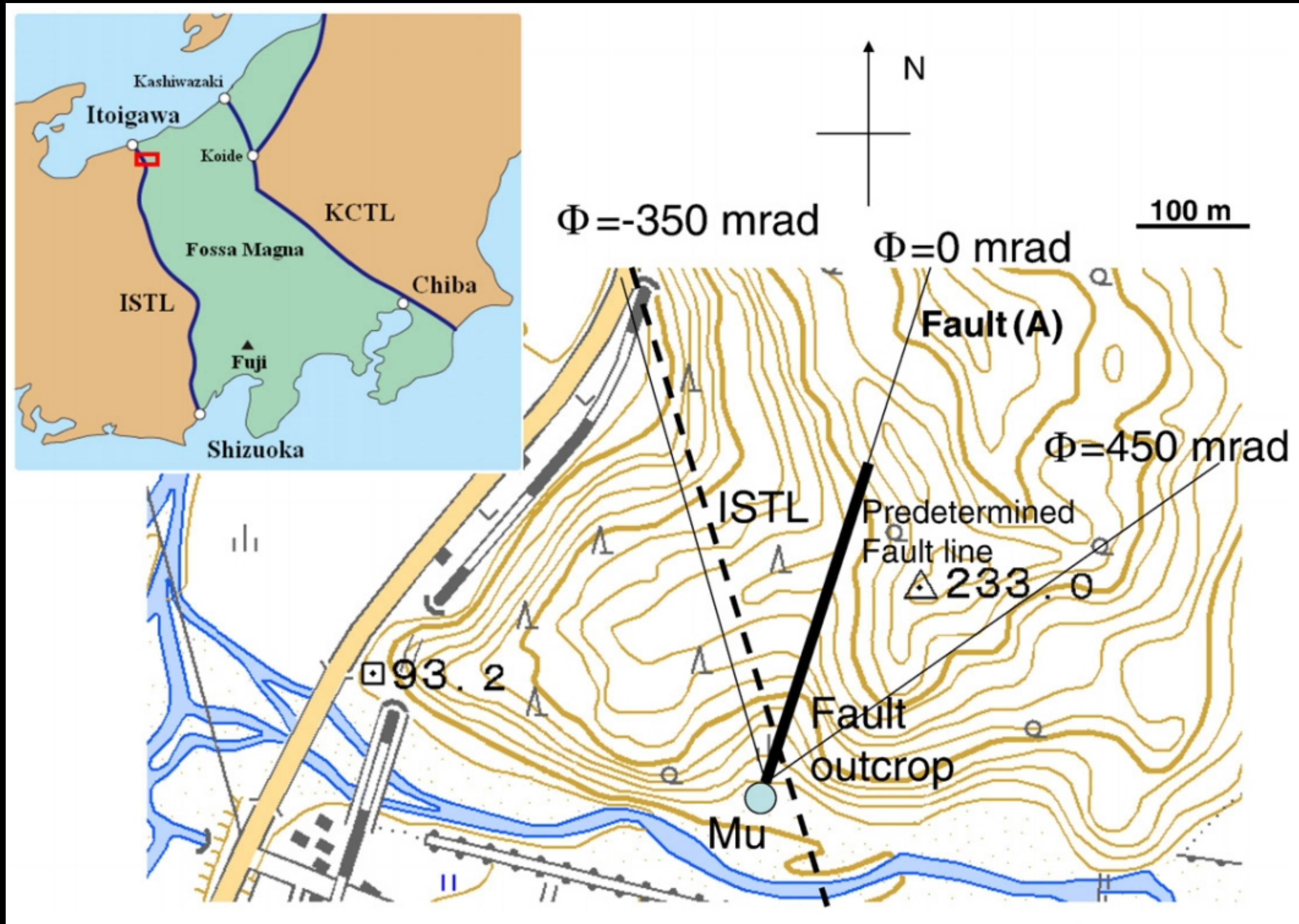


RECENT WORKS



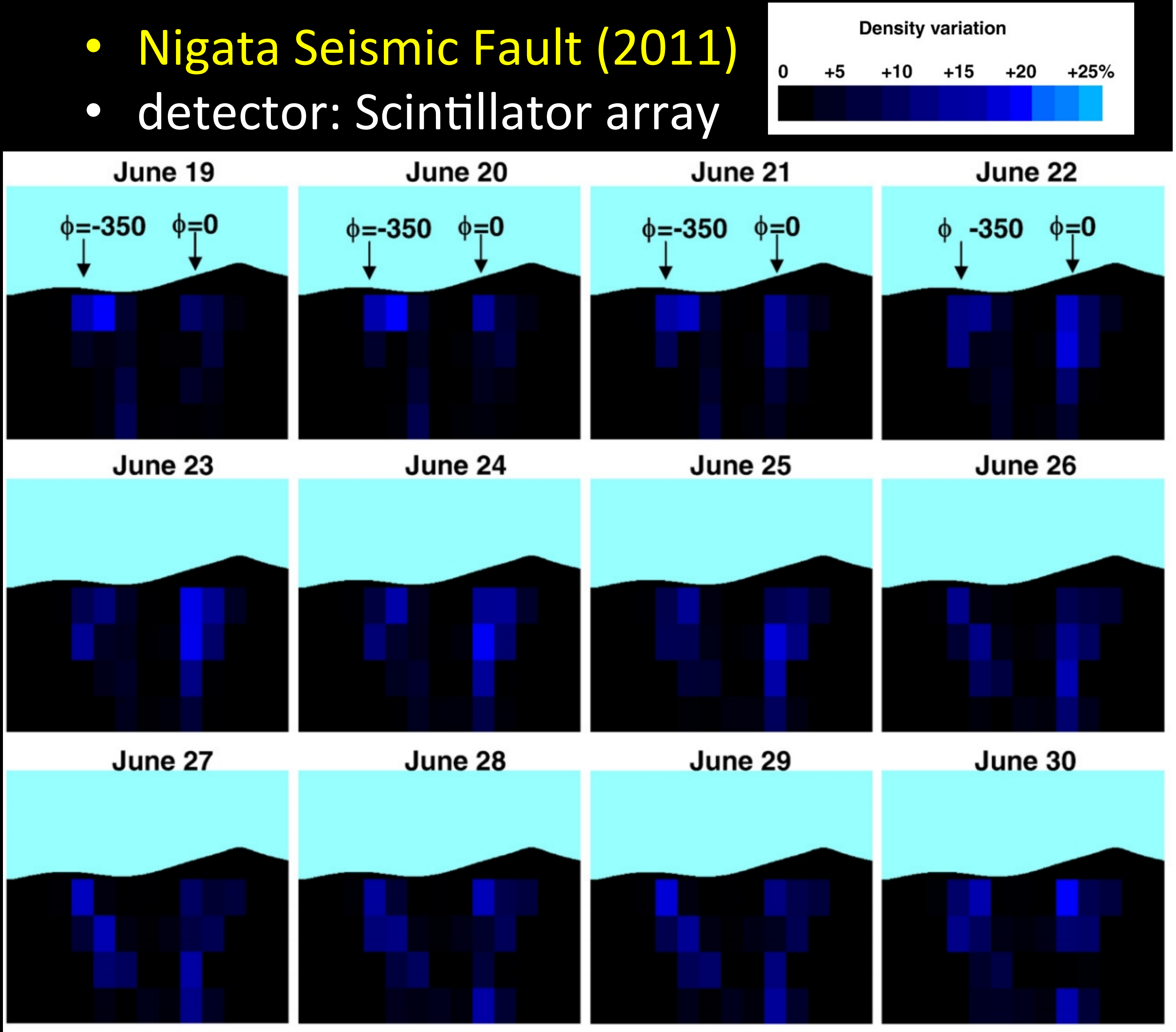
RECENT WORKS

- Nigata Seismic Fault (2011)
- detector: Scintillator array, 0.4m2

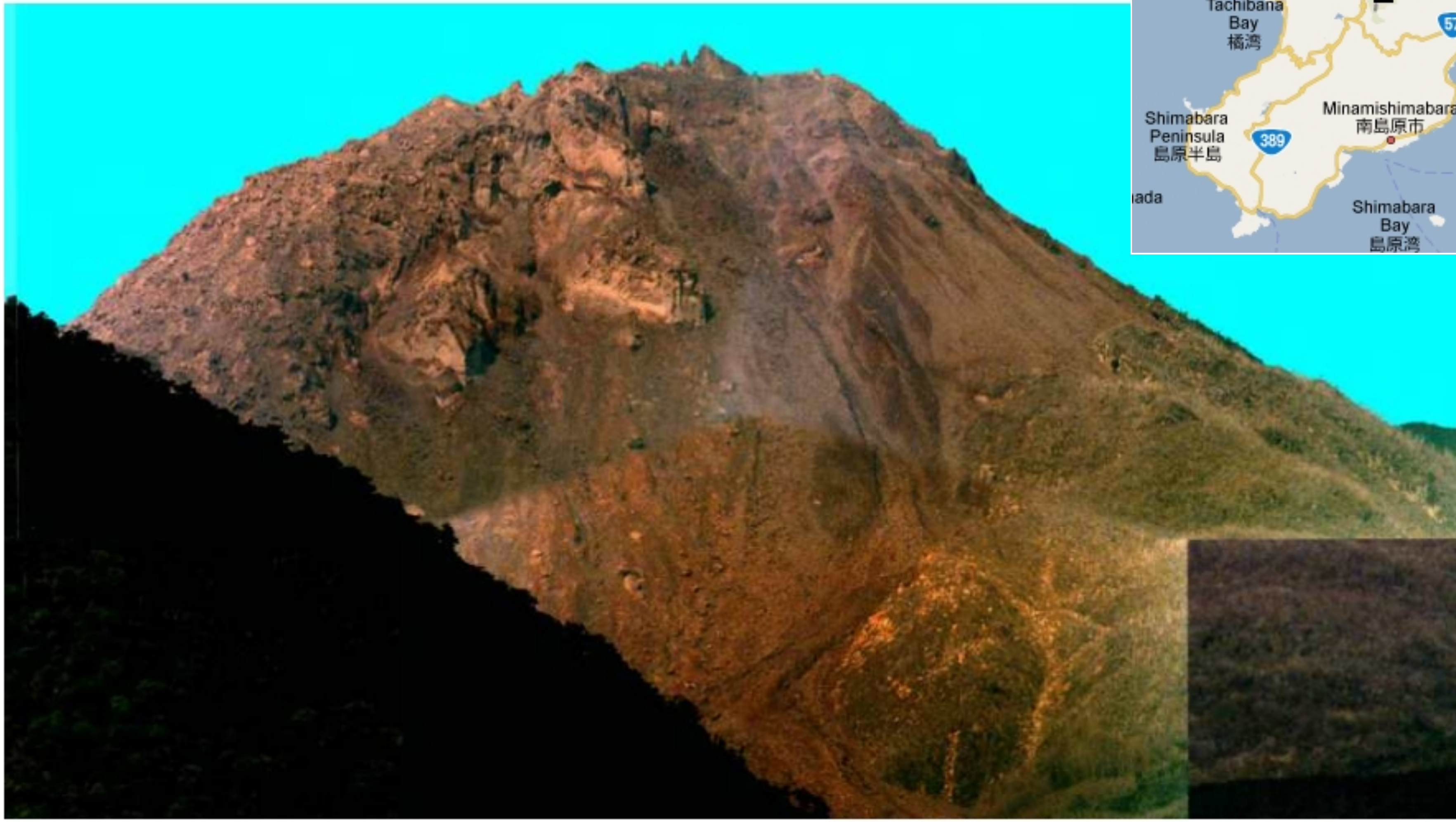


RECENT WORKS

- Nigata Seismic Fault (2011)
- detector: Scintillator array

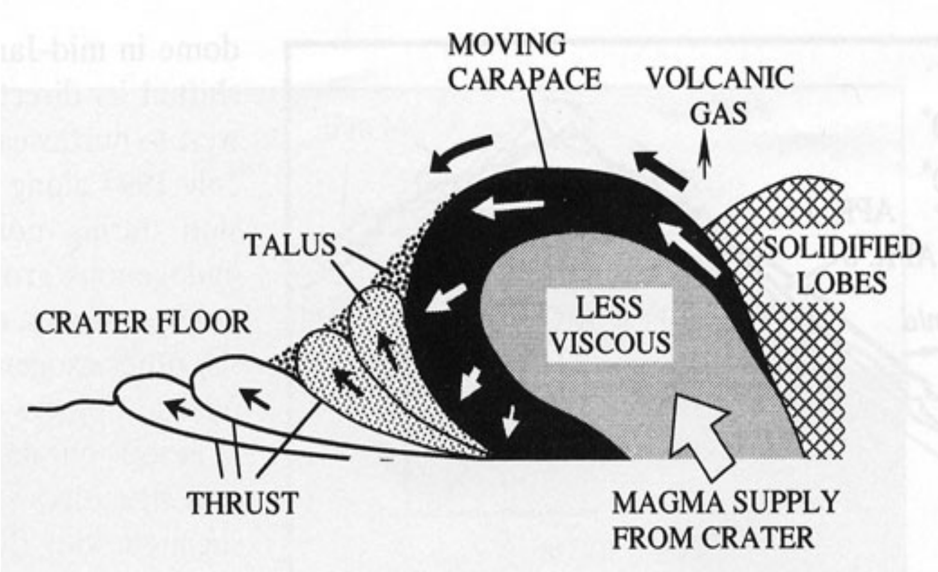


Unzen eruption in 1991

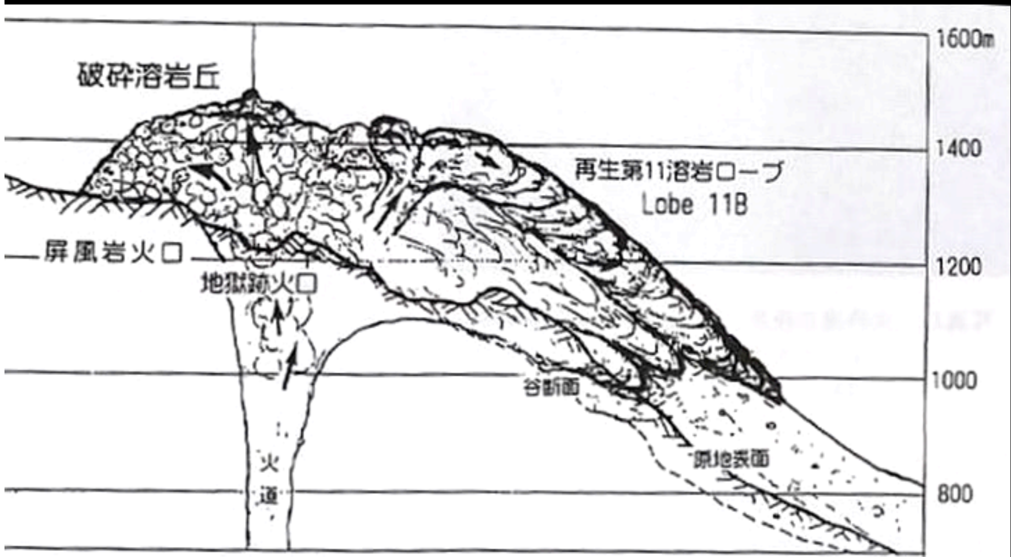


950701SiHi

By Terai, Nakada



S. Nakada et al. (1995) Geology 23, 157-160

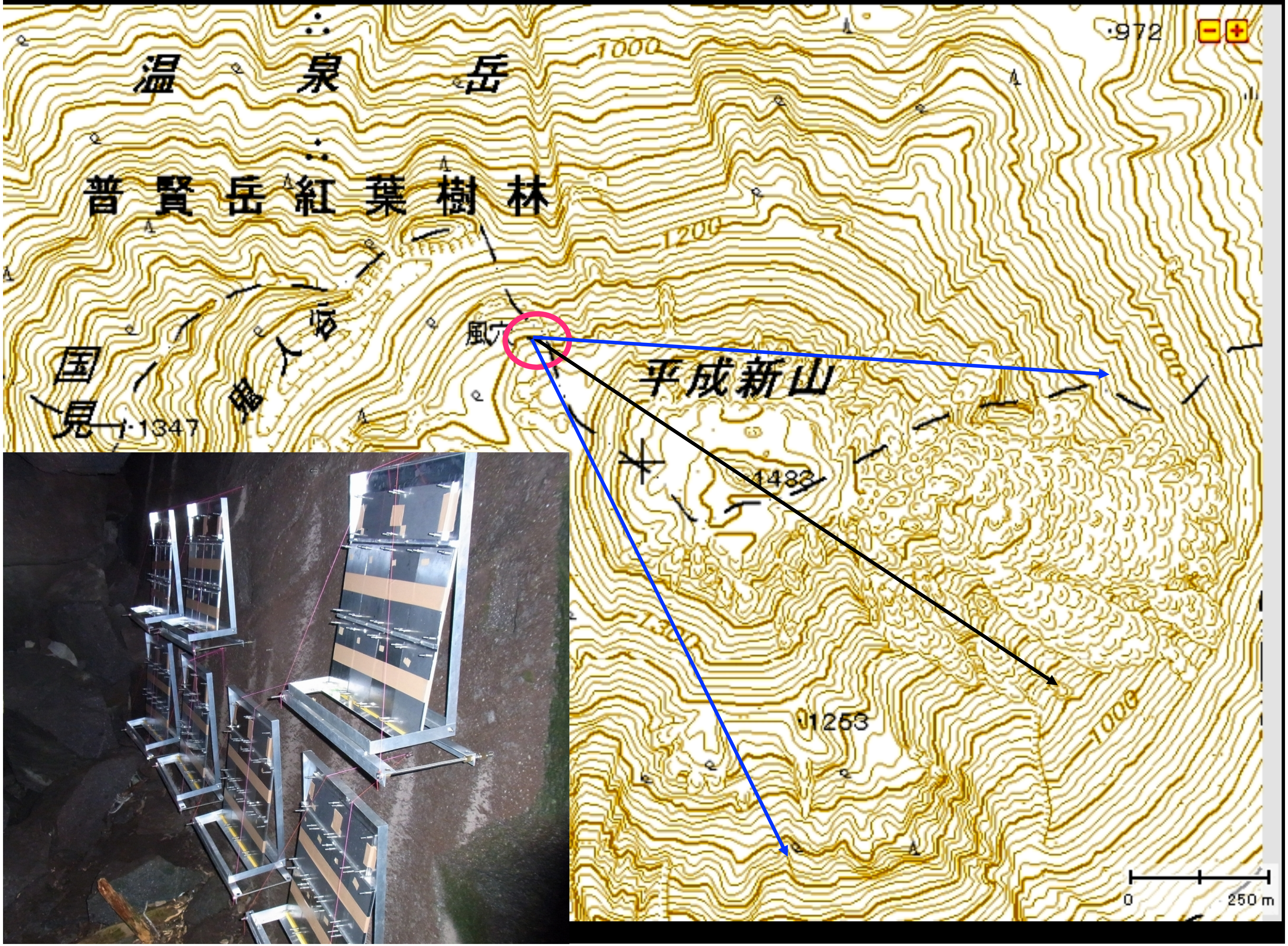


K. Ohta 地熱 vol.33 No.4 1996

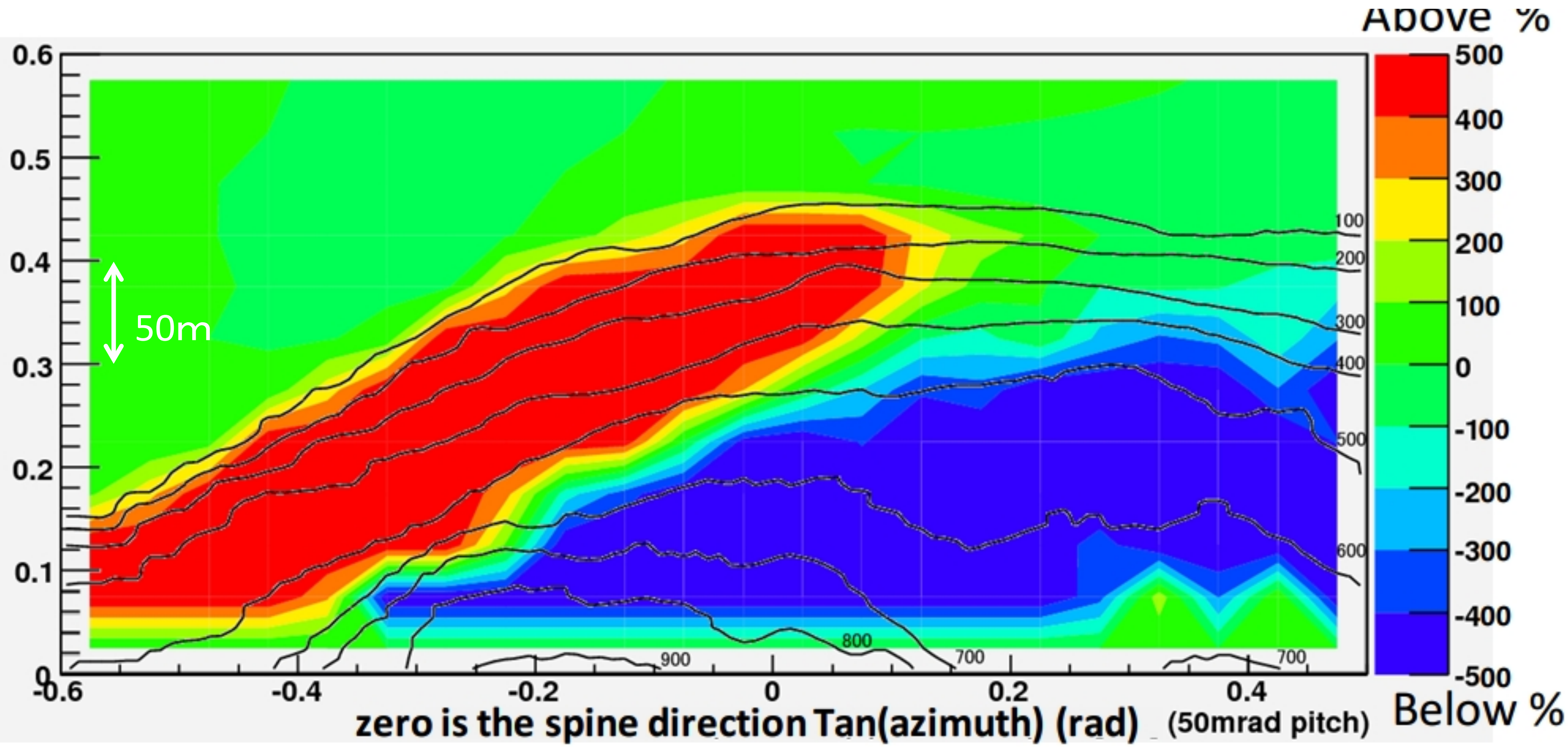
- Feb, 1991 : Lava dome started to grow. Huge pyroclastic flow killed 43 people.
- The Unzen lava dome density map will clear :

(i) Mechanism of lava dome growth model .

(ii) where part is easy to happen mudslides.


温泉岳
普賢岳紅葉樹林
国見
1347
風穴
平成新山
1483
1253
972
1000
1200
0
250 m

Preliminary results ($0.16m^2$)



- (observed # of muons－expected muons)÷(expecetd muons) when we assume montain density 2.5g/cm^3
  Red : More muons than expected Blue : Less muons than expected
- Not enough statistics where the rock thickness is more than 400m .
  → we'll add the other emulsion data.
- Systematic error -> under studying : Free sky region is about 15%。

Stromboli
Italy

The imaging of conduit is critical for the eruption dynamics model

The exposure was already finished. Under scanning.

SUMMARY

- We can see the internal density structure of volcano by using cosmic muons .
- The muon detection technologies have been developed in the experiment of particle physics .
- We will continue to apply this method to various target and also improve the muon detection technology.

Thank you for listening

Backup slides

Density determination errors

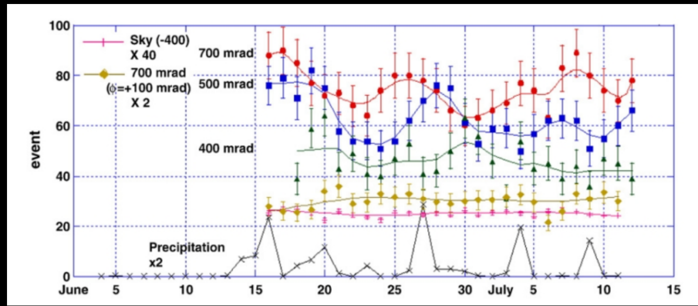
- Systematic : the resolution of topographic map
- Statistical : the number of muon, for each angular bin.
- Systematic : Muon detection efficiency estimation
- Systematic and statistical : Back ground noise estimation
- Systematic : the uncertainty of CR flux
- Systematic : the uncertainty of dE/dX of muon,
- especially > several hundred GeV

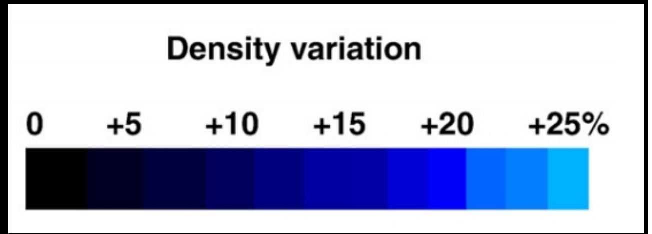
How to reconstruct the density image ?

- Calculation the rock length from topographic map
- The measurement of the number of penetrating muon for each angular bin.
- Attenuation of cosmic ray flux
- → Energy cut off
- → typical range of muon
- → water equivalent
- Water equivalent(θ,ϕ) = rock length(θ,ϕ) * density(θ,ϕ)

RECENT WORKS

- Nigata Seismic Fault (2011)
- detector: Scintillator array





HOW TO CALC

$$dE/dX = a + bE$$

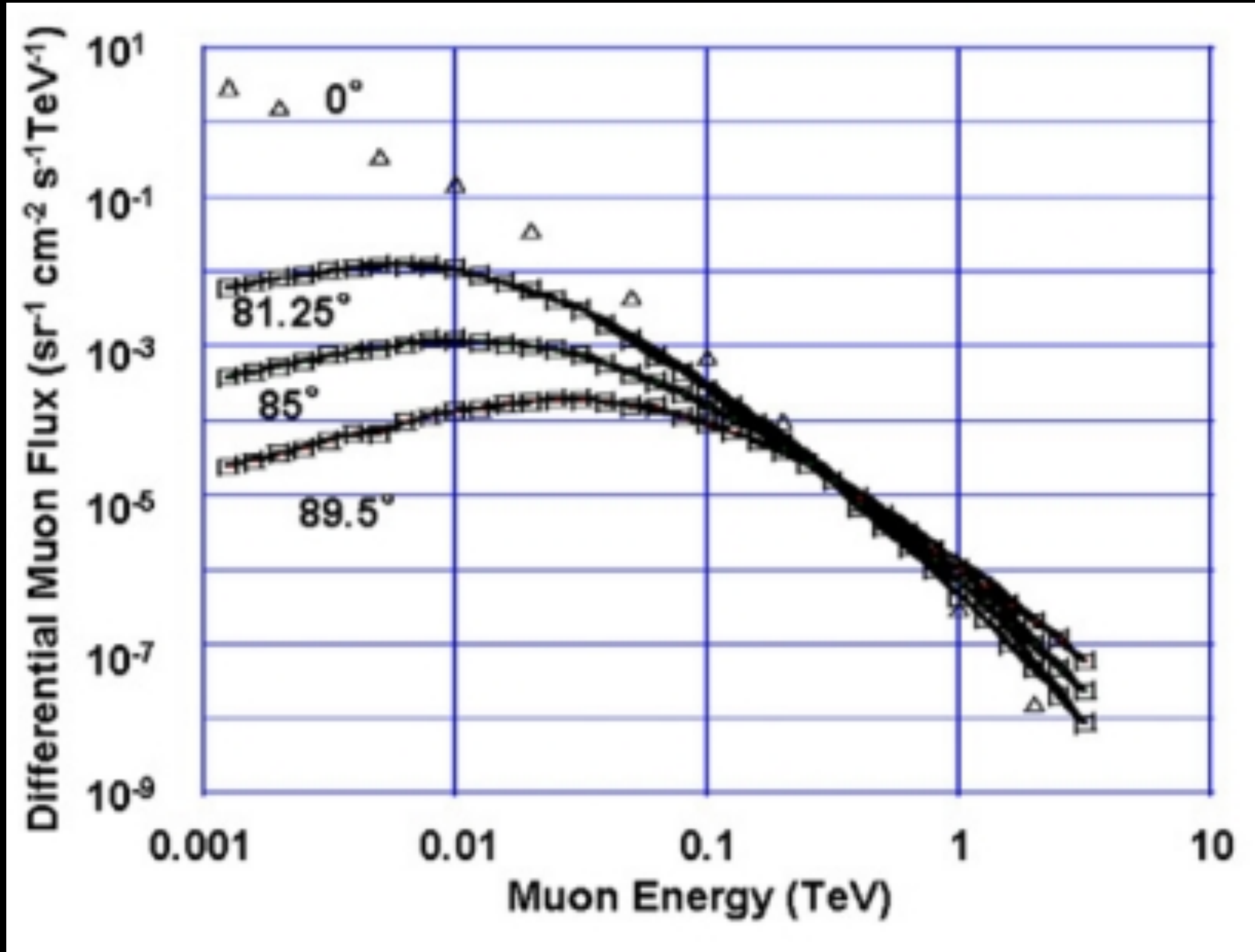
Table 1
Muon range R and energy loss parameters calculated for standard rock

E_{μ} (GeV)	R (km.w.e)	a (MeV g^{-1} cm^2)	b (MeV g^{-1} cm^2)
10	0.05	2.15	1.91
100	0.41	2.40	3.12
1000	2.42	2.58	4.01
10,000	6.30	2.76	4.40

Range is given in km-water-equivalent.

- Calculation the Average “Density x Length” from muon attenuation.

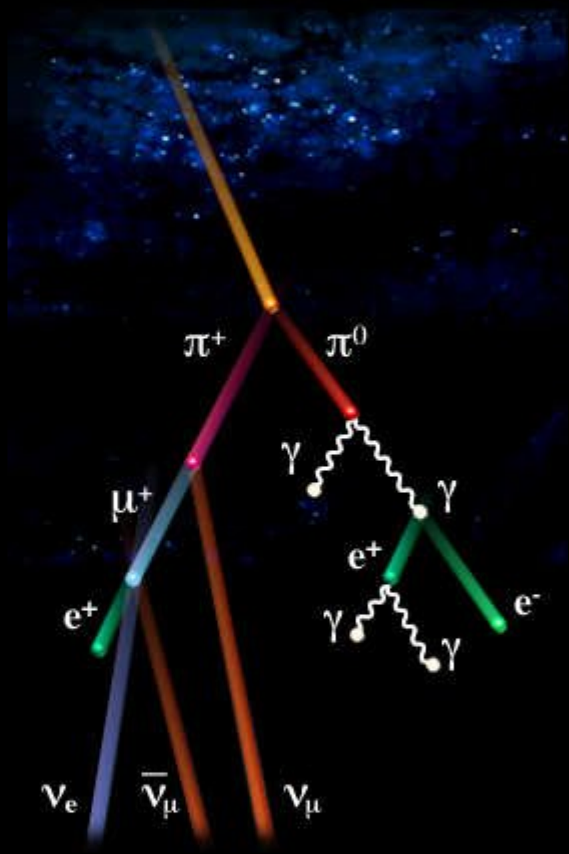
SOURCE



- Cosmic muon flux on the various altitude is well measured.

PRINCIPLE

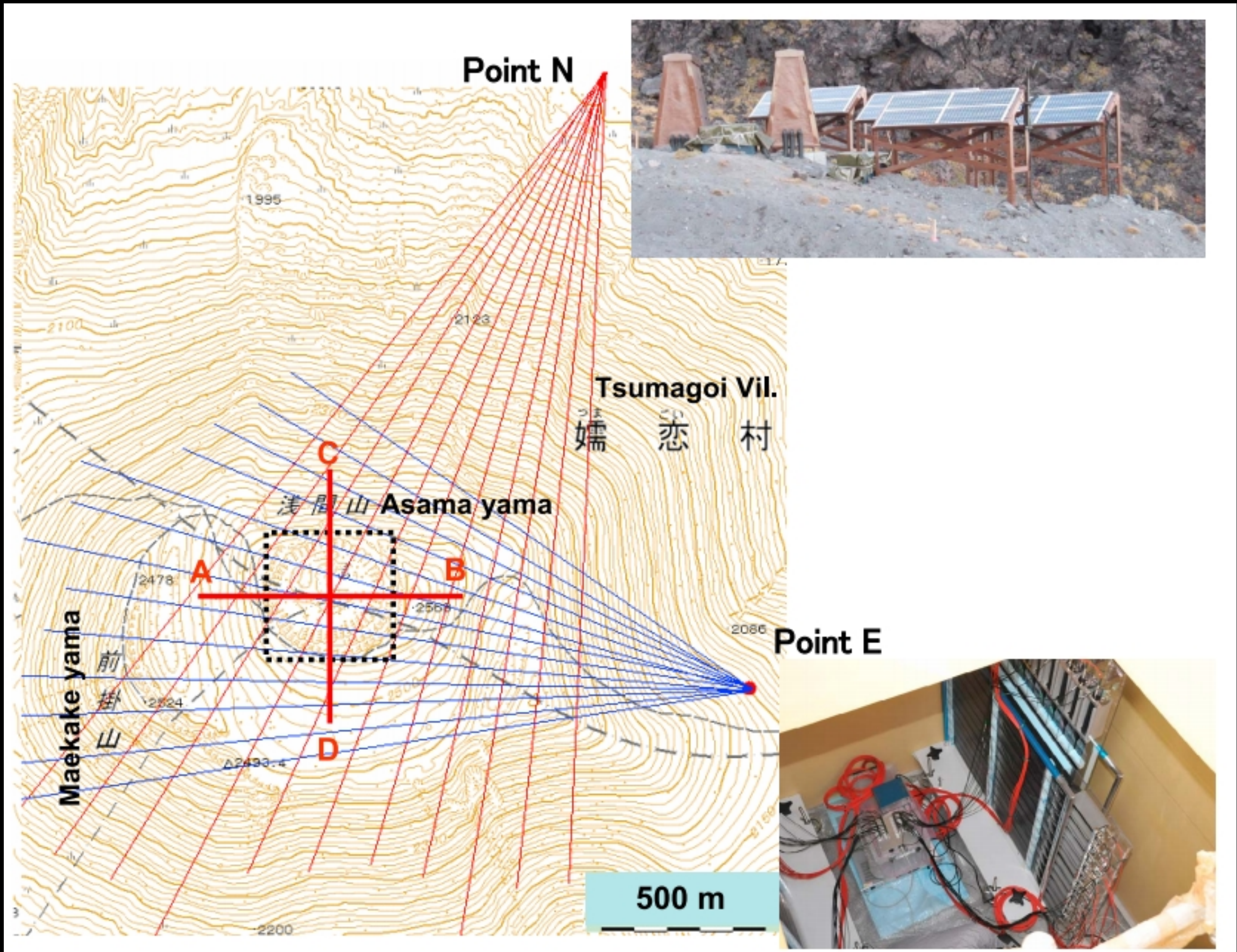
SOURCE



- High energy proton or Helium from outer space
- Interaction with atoms in atmosphere
- Creation of pions ($E=mc^2$)
- Pion decay into muon
- About 1 muon / sec hand
- Muons have very high energy -> it can penetrate several km Rock !

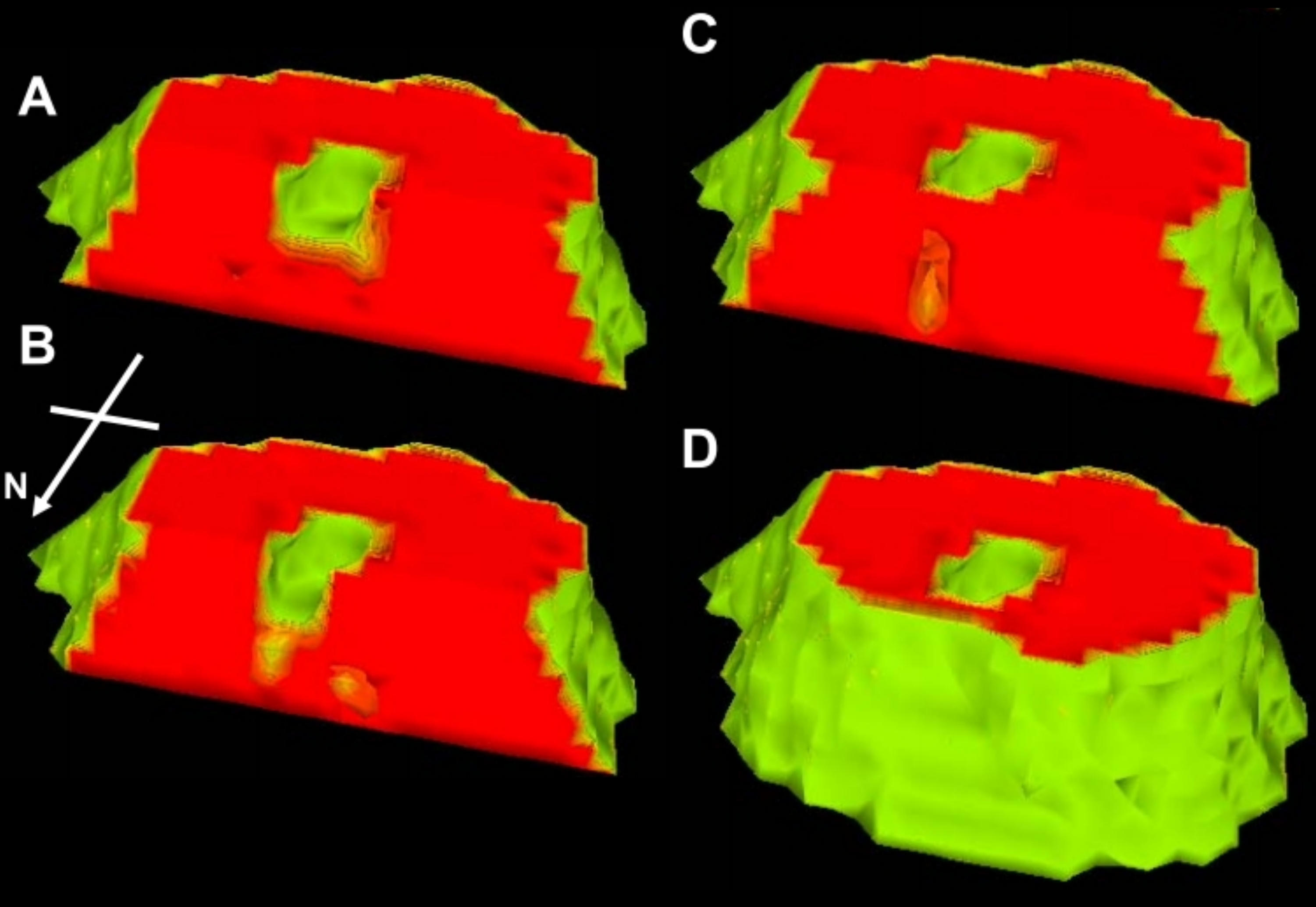
RECENT WORKS

- Mt. Asama Stereo (2010)
- detector: Scintillator array



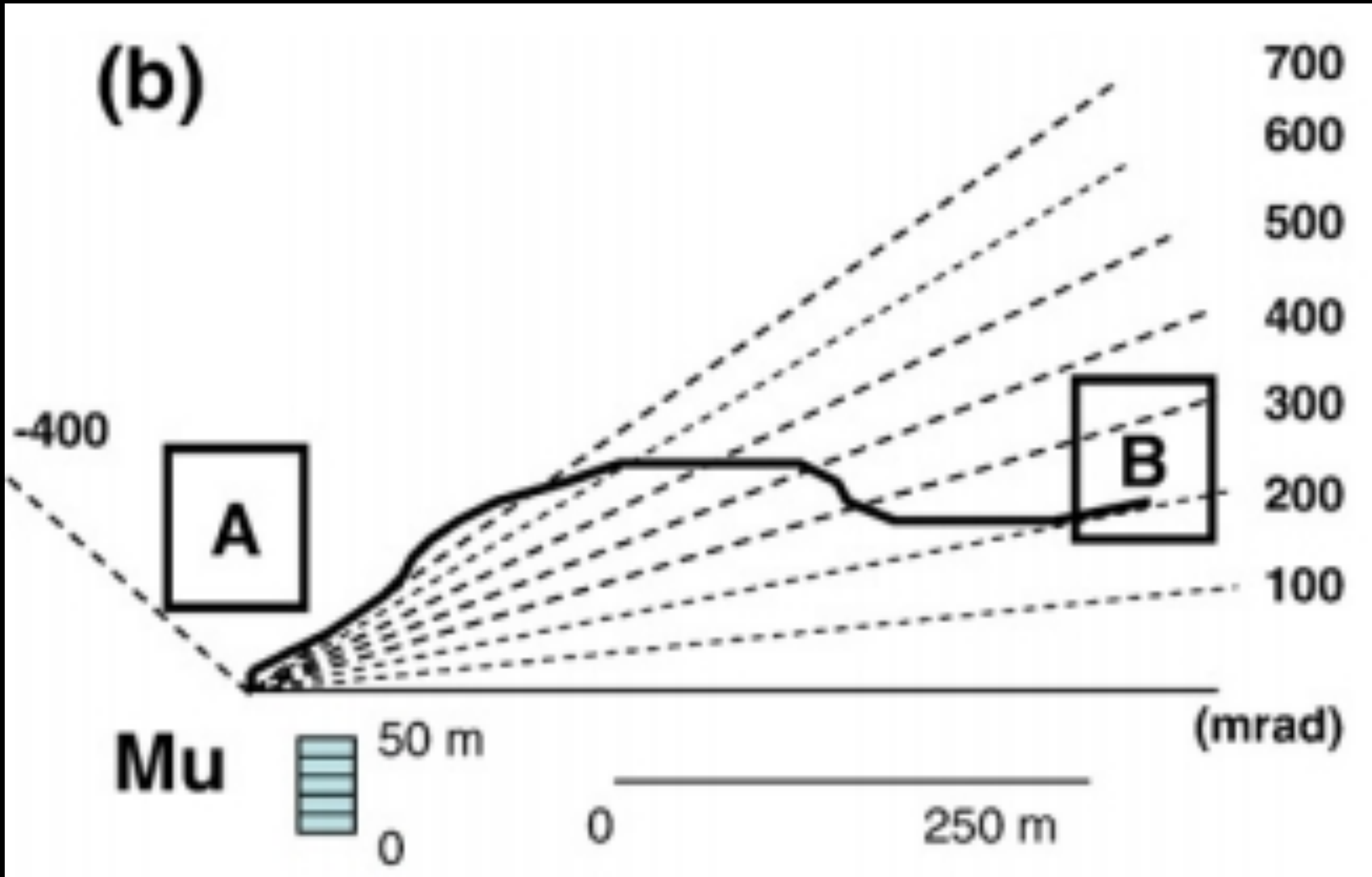
RECENT WORKS

- Mt. Asama Stereo (2010)
- detector: Scintillator array



RECENT WORKS

- Nigata Seismic Fault (2011)
- detector: Scintillator array , 0.4m2,



- Fault Width = ~ 20m

- Nigata Seismic Fault (2011)
- detector: Scintillator array , 0.4m2,