The 1991 eruption of Pinatubo and its muddy aftermath

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and PHIVOLCS-USGS team

**Now at Earth Observatory of Singapore*

The Saga Begins…

July 16, 1990 † M 7.8 Earthquake

… April 2, 1991 Phreatic explosions

… June 7, 1991 Lava dome appears

From Day 1, our challenge was to:

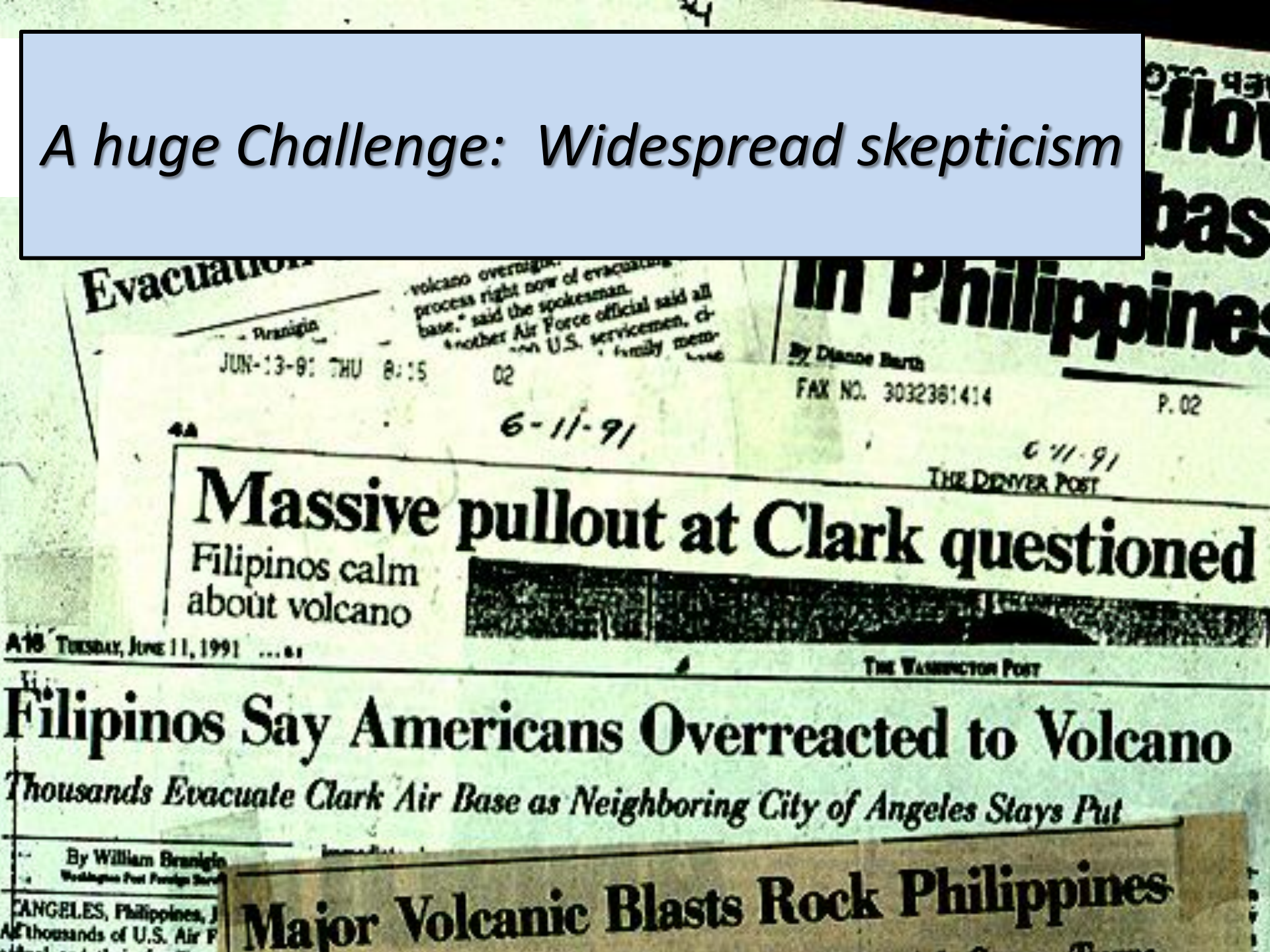
- Forecast what Pinatubo would do:
  - Would it erupt and, if so, when?
  - What type(s) of eruptions were likely?
  - How much warning would we be able to give?
  - How far would dangers reach?

- Educate hundreds of Philippine officials, ~20,000 indigenous Aetas, and ~1,000,000 lowland Filipinos, and ~40,000 US military about Pinatubo hazards, and, ultimately, convince them to do whatever would be needed to stay safe.

What was our strategy?

- Establish new monitoring, including seismic network and gas and deformation monitoring.
- Geologic reconnaissance, new 14C eruption dates
- Nightly science meetings.
- Network with everyone – Governors, Mayors, military at all levels, teachers, nuns, NPA, other scientists, news media. PHIVOLCS in front.
- Develop understandable tools – alert levels, hazard map, evacuation radii, and probability tree

A huge Challenge: Widespread skepticism



Evacuation

Branigin

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volcano overnight. process right now of evacuating base," said the spokesman. another Air Force official said all U.S. servicemen, ci- family mem-

6-11-91

In Philippines

By Dianne Barth

FAX NO. 3032361414 P. 02

6-11-91

THE DENVER POST

Massive pullout at Clark questioned

Filipinos calm about volcano

A18 TUESDAY, JUNE 11, 1991

THE WASHINGTON POST

Filipinos Say Americans Overreacted to Volcano

Thousands Evacuate Clark Air Base as Neighboring City of Angeles Stays Put

By William Branigin

ANGELES, Philippines, J
thousands of U.S. Air F

Major Volcanic Blasts Rock Philippines

Why so much Skepticism?

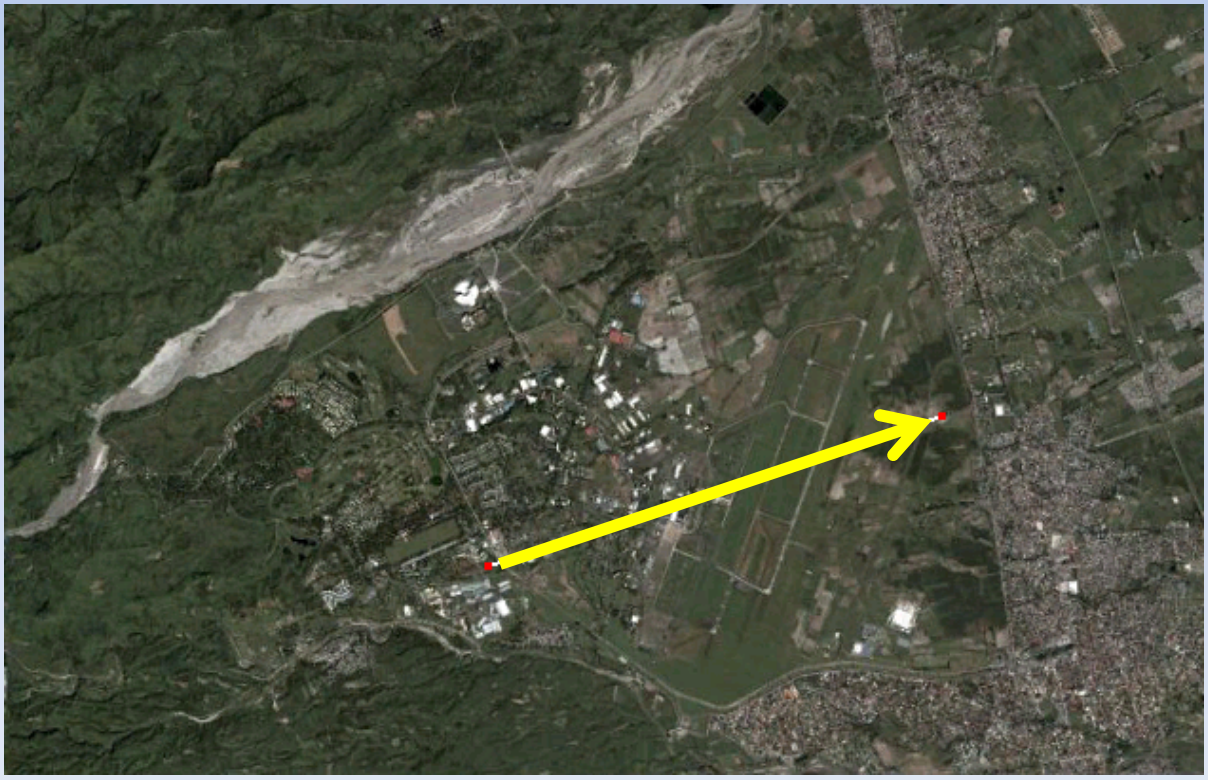
- No eruption in >500 yr; hard for most to envision any eruption, much less a huge one
- US-Philippine bases renegotiation
- USAID country director suspected a USGS research project
- Insurgency (NPA), local politics (Mayor of Angeles)
- Cultural distances – scientists, military, indigenous Aetas, lowland Filipinos

Other Challenges:

- PHIVOLCS was short on staff and equipment and Taal was also threatening; key players were overseas on study leave.
- No prior monitoring at Pinatubo, and no prior monitoring anywhere of an eruption as large as what was likely.
- We knew fuse was lit but could only guess how long it was

Unintended help vs. skepticism

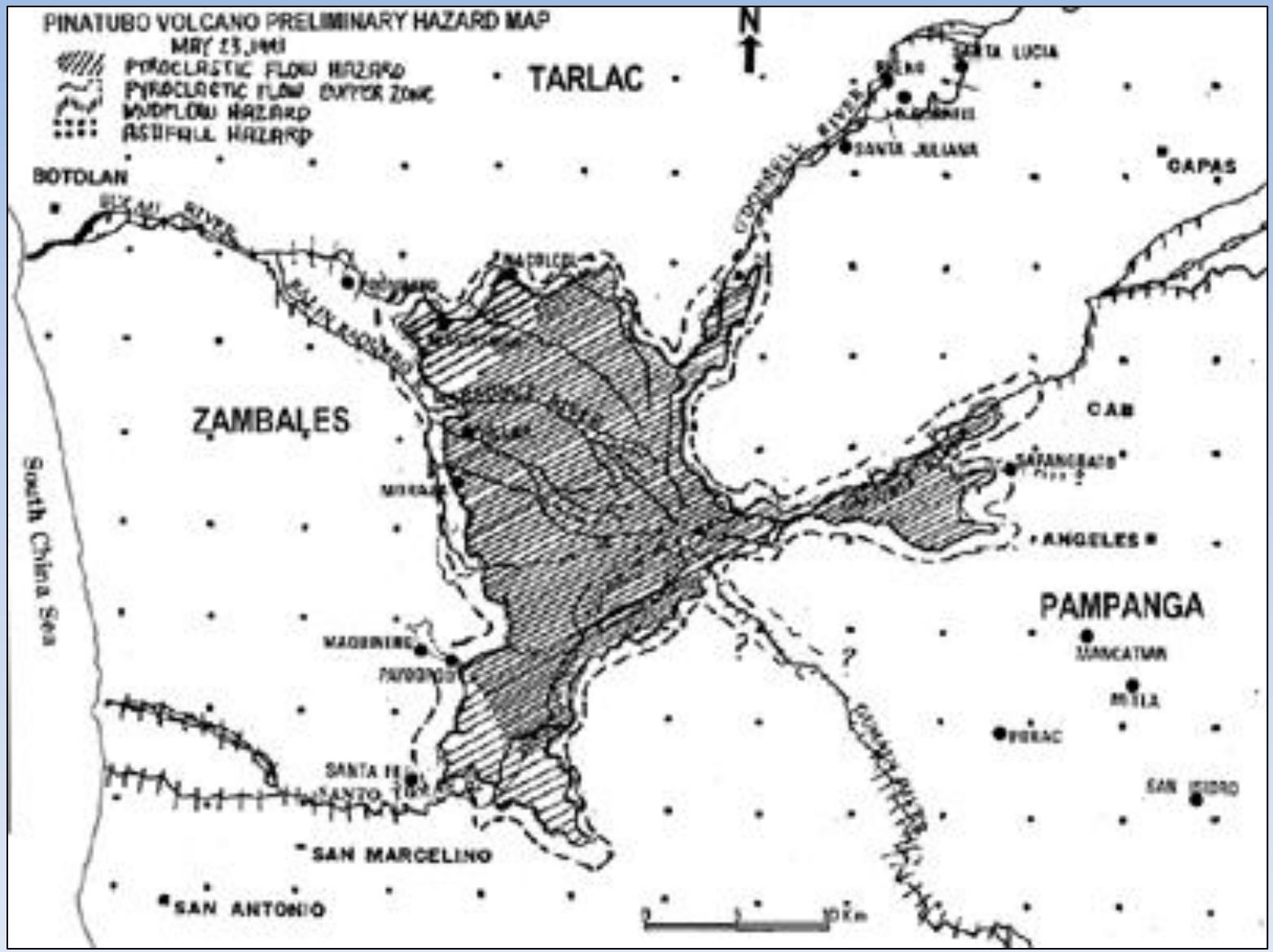
The 1st Pinatubo Volcano Observatory was near center of Clark Air Base. For safety, on June 10, the team decided to move 5 km farther away from the volcano – to the far edge of Clark AB. This had the unintended effect of convincing USAF officials that the hazard was serious!



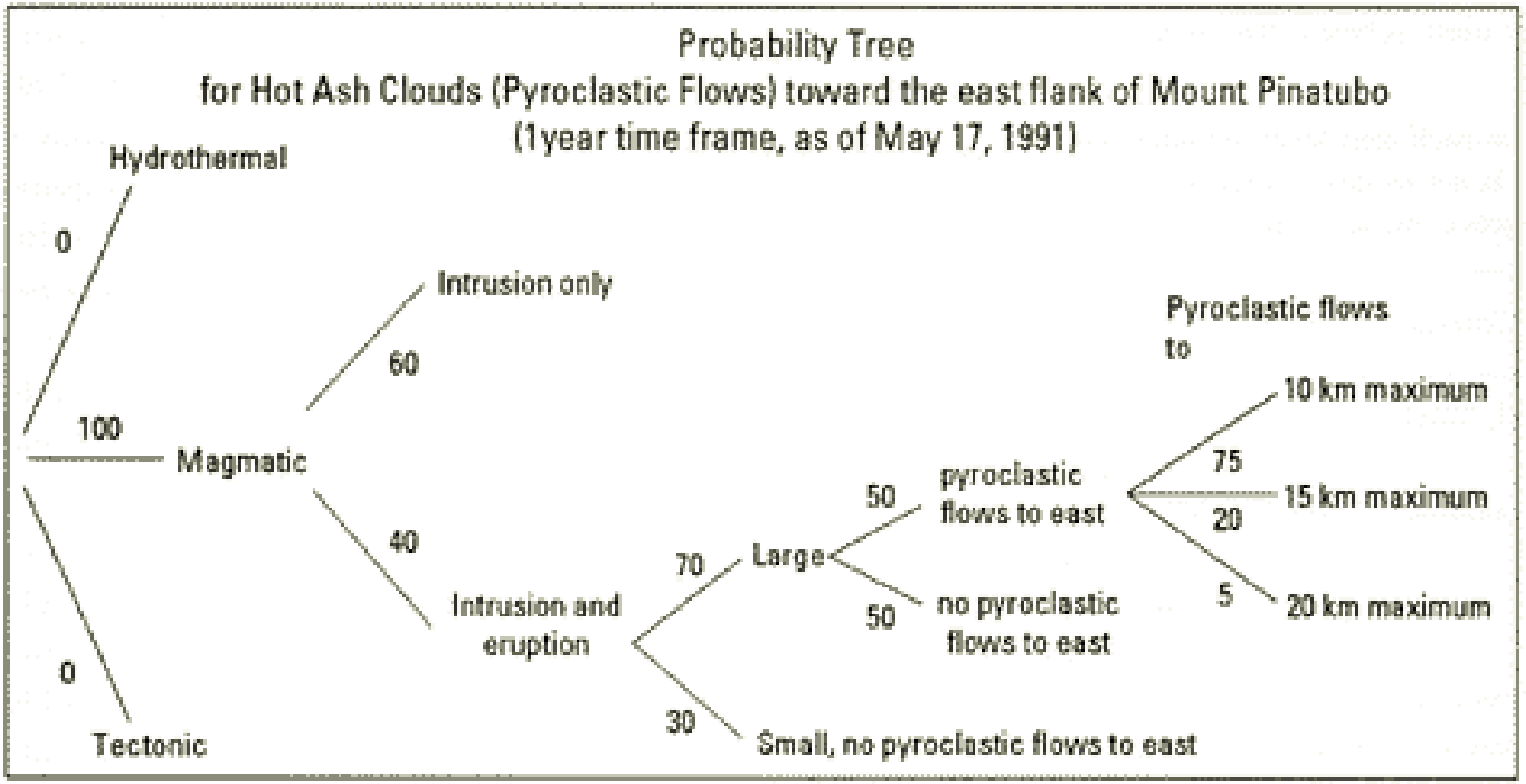
Alert levels and evacuations

Alert Levels	**Evacuations**
	April 7 – 10 km (temporary)
May 13 – Level 2, magmatic	
	May 13 – 10 km
June 5 – Level 3, eruption possible within 2 weeks	June 5 – 10 km
June 7 – Level 4, eruption possible within 24 h	June 7 – 20 km June 9 – 20 km
June 9 – Level 5, explosive eruption in progress (actually, premature, but helpful!)	June 14 – 30 km June 15 – 40 km

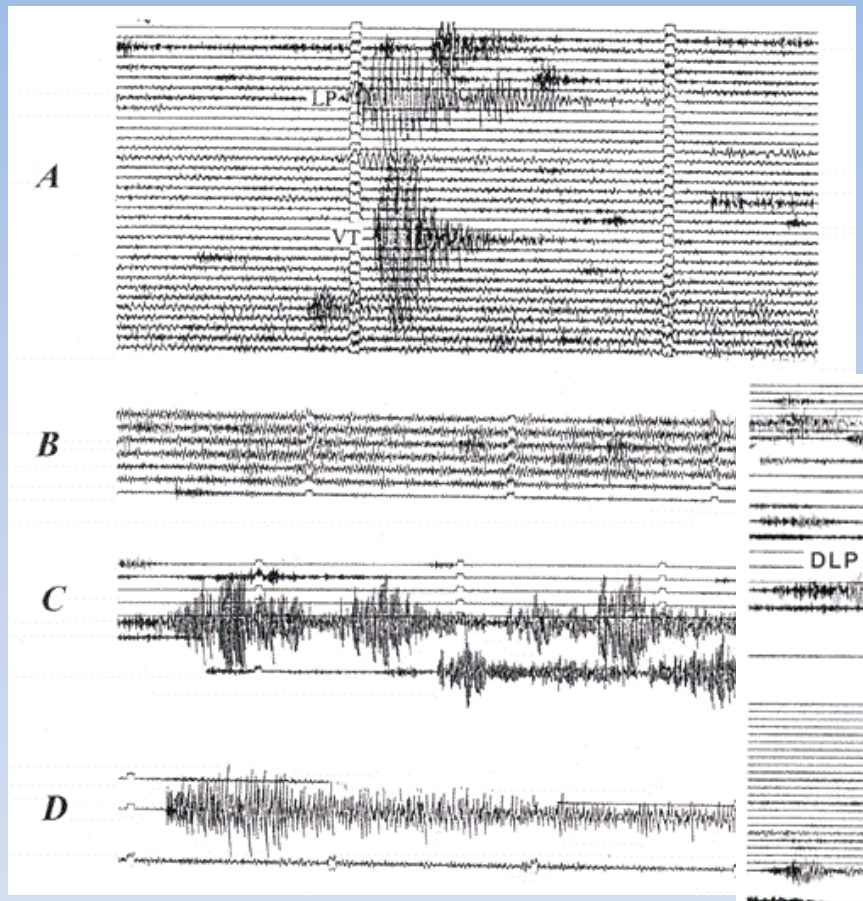
Hazard map released May 13



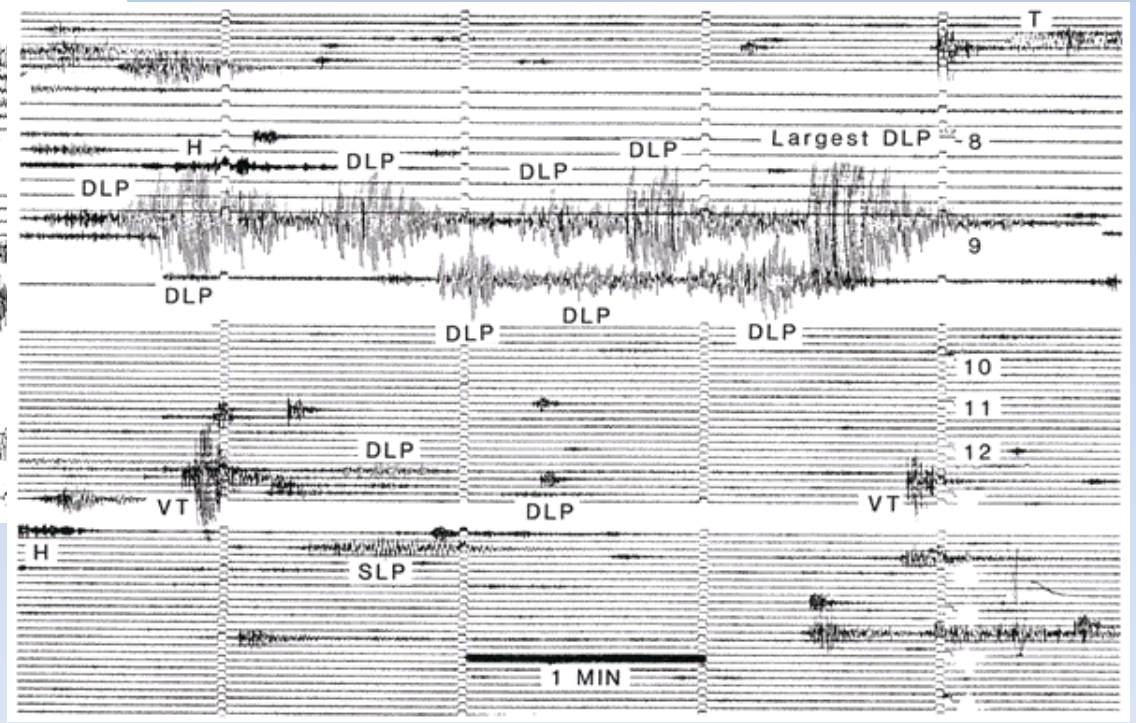
Probability tree for civil defense, military, May 17, 1991, an early stage of unrest



Pre-climactic seismicity, May-June 1991

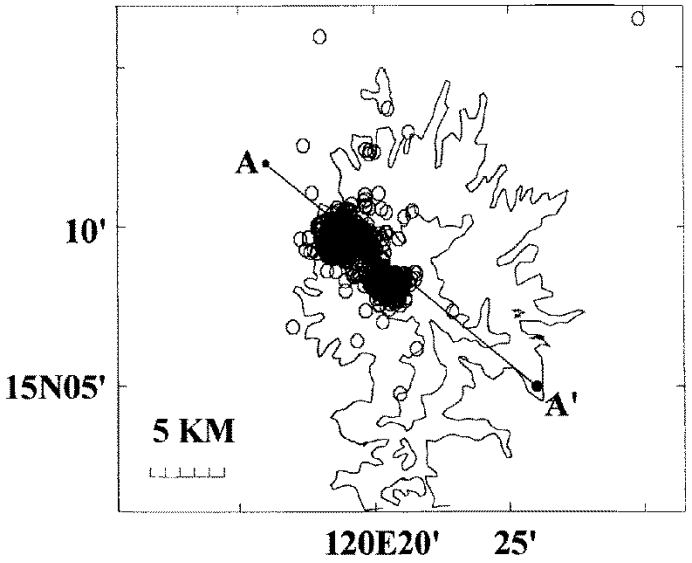


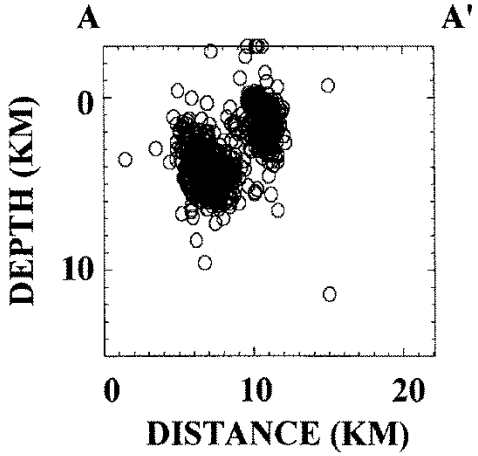
A: LP & VT; B: many sm LP's;
C: tremor; D: Explosion

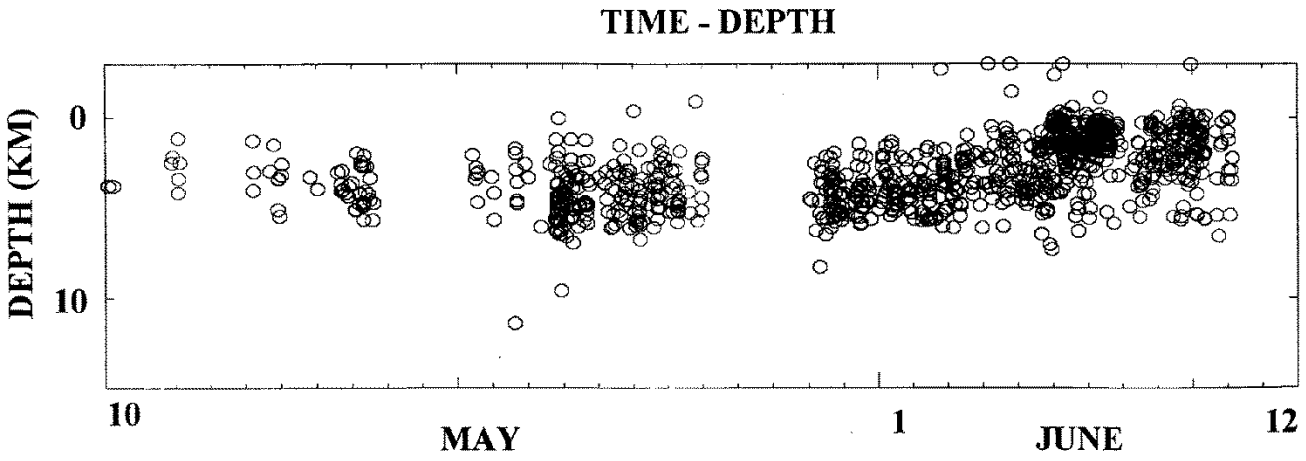


Deep LP events (30-35 km deep), late May early June

Shift of VT's from NW to summit

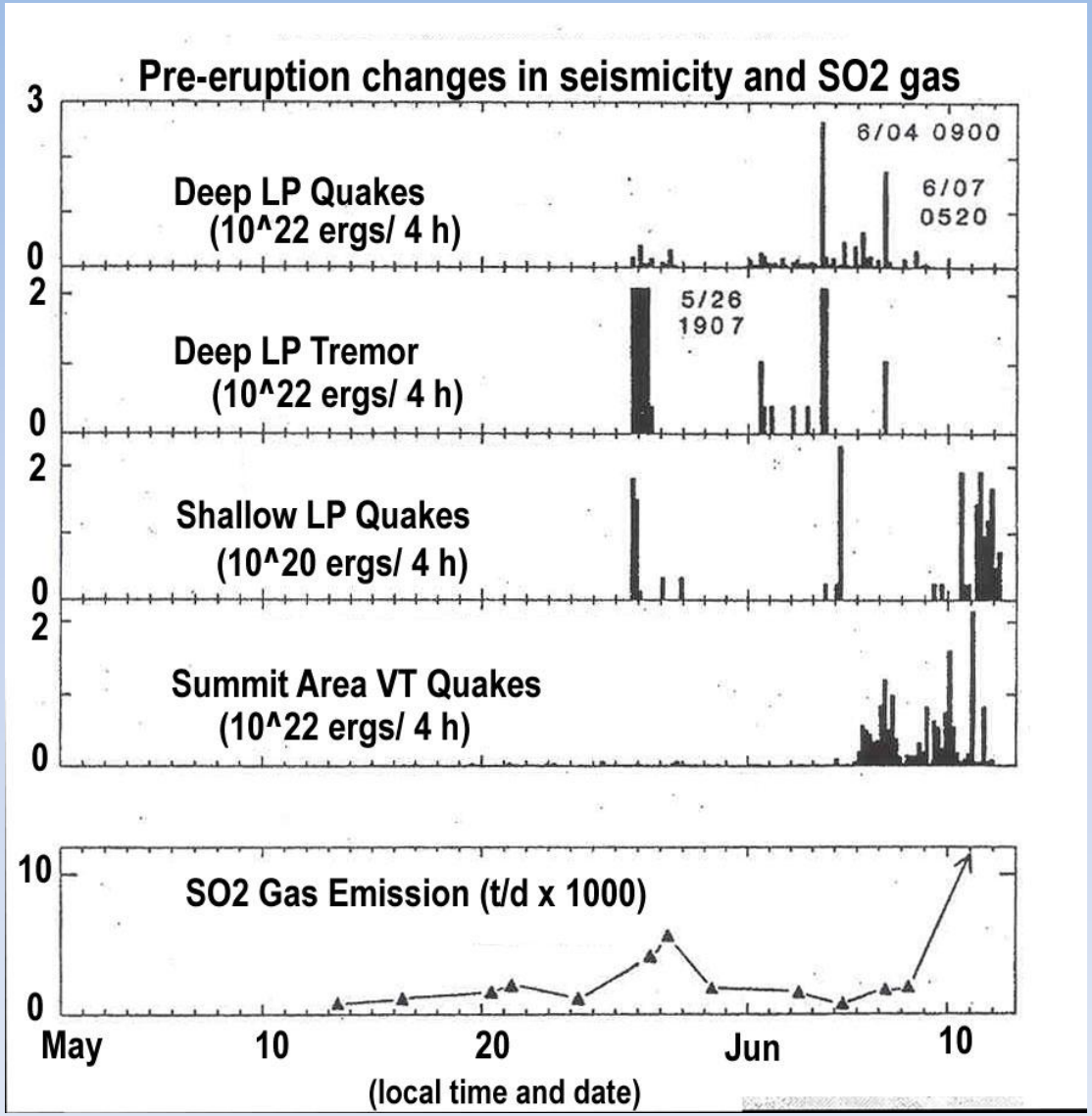






Pinatubo synthesis fig. 4

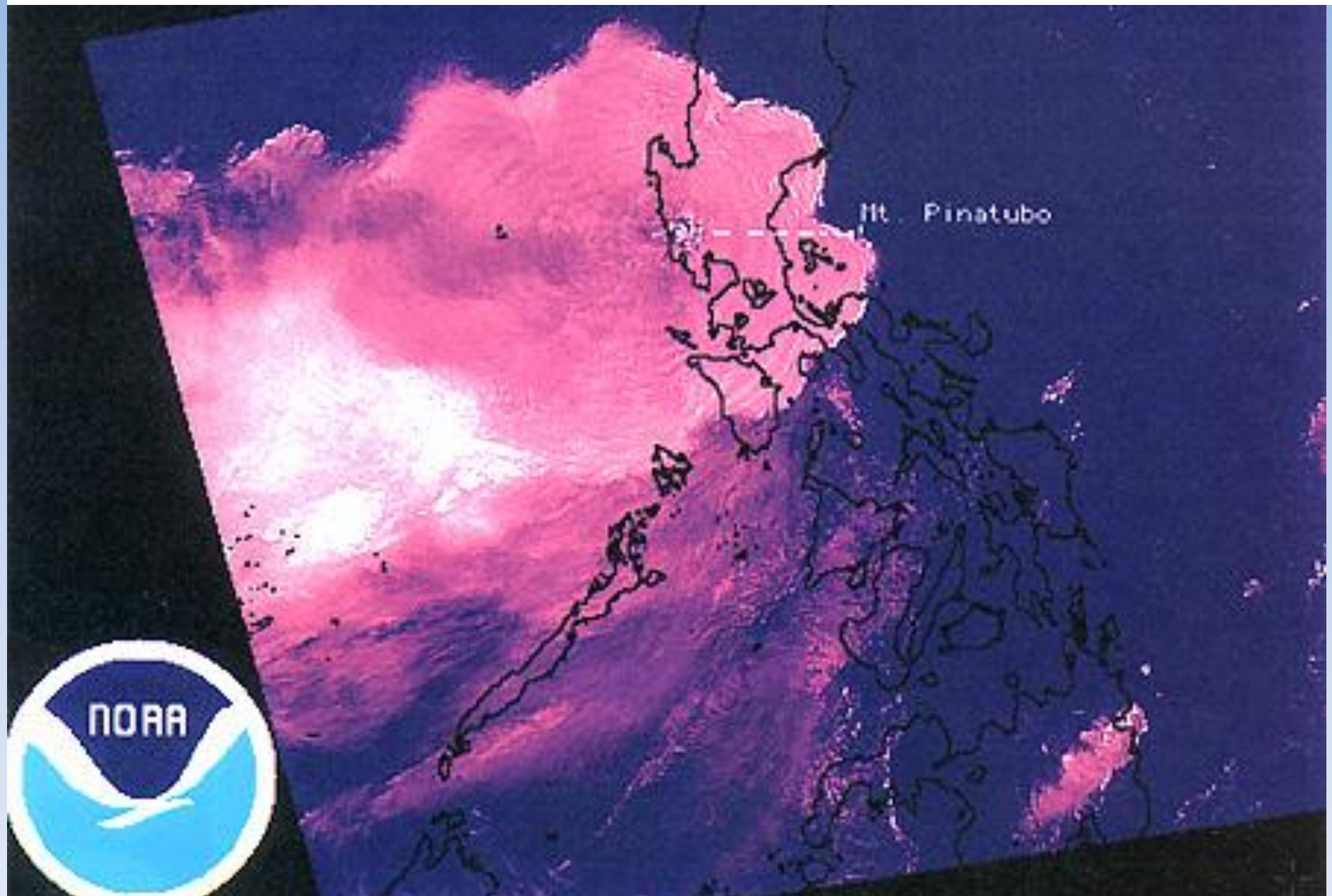
Magma tracked up to surface

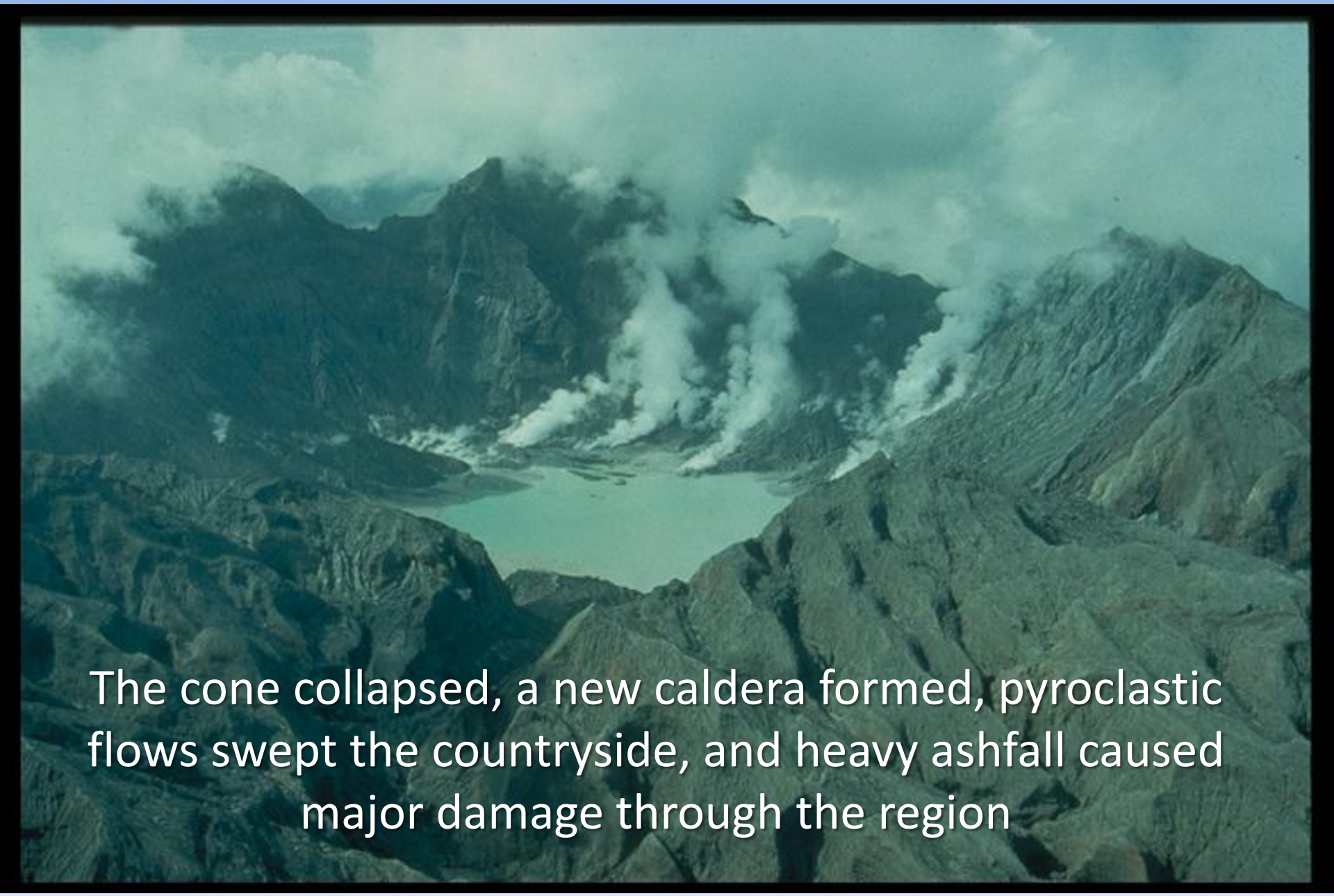


Magma reaches the surface – June 7

Then, “small scale” eruptions, June 12-14, 1991

June 15, 1991 : 2nd largest eruption of the 20th century, and the largest ever in a densely populated area

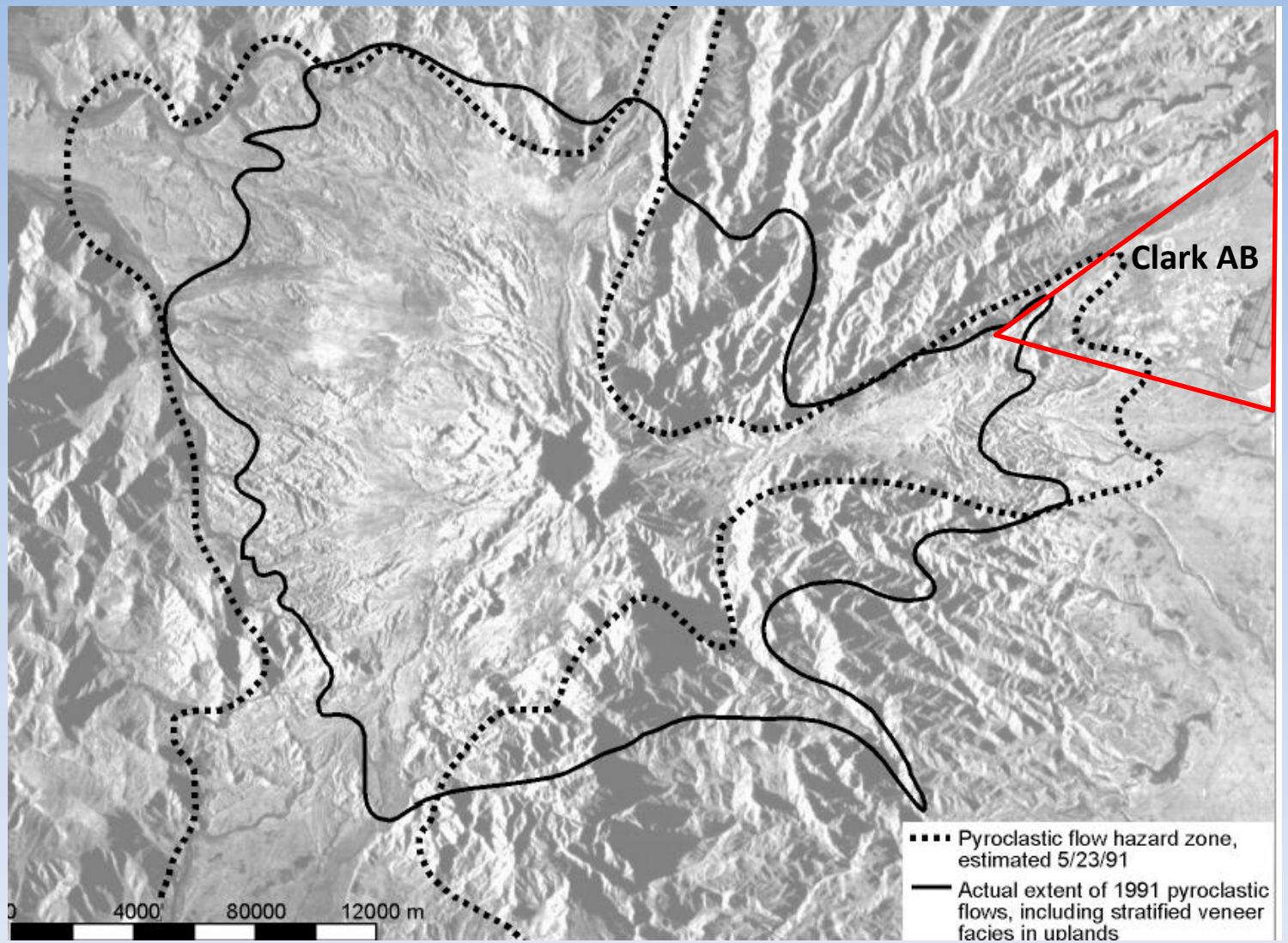



The cone collapsed, a new caldera formed, pyroclastic flows swept the countryside, and heavy ashfall caused major damage through the region

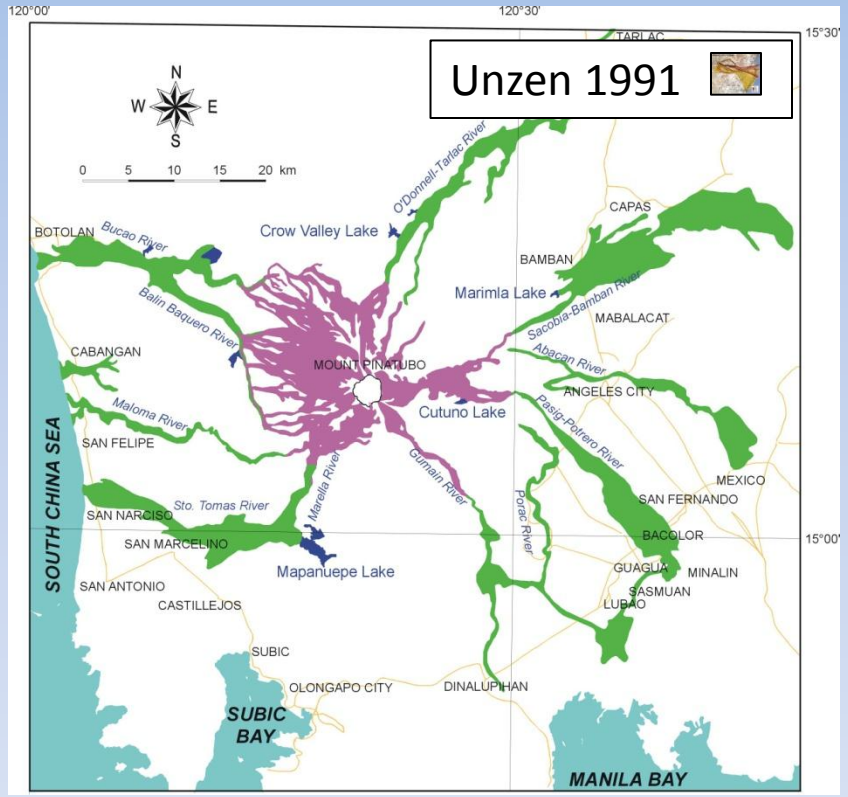
Everything near the volcano was devastated!

Only those who had evacuated survived.

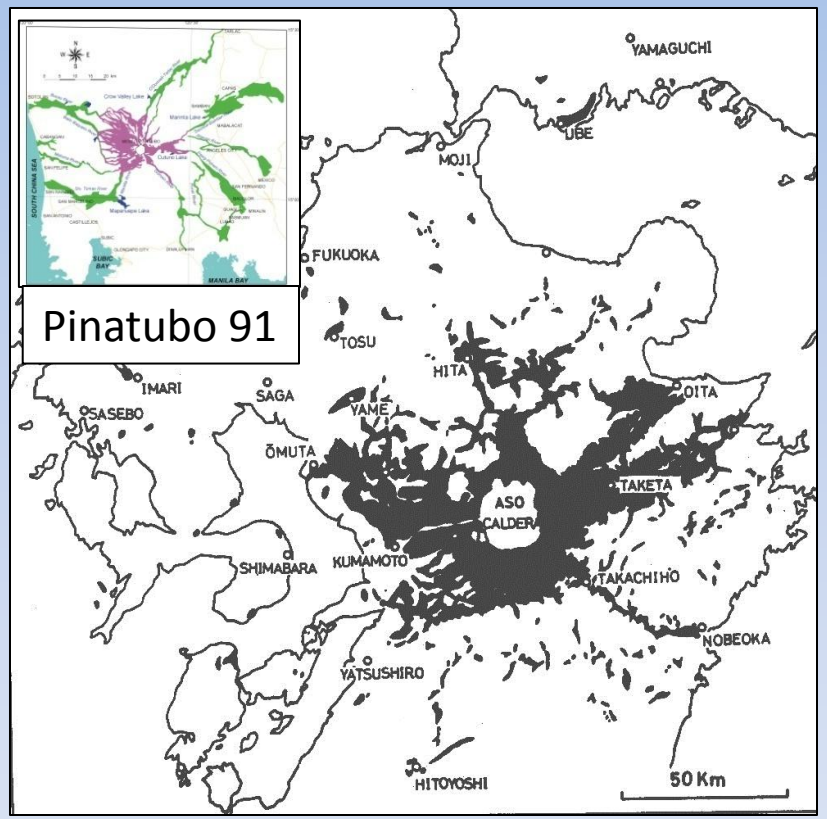
How well did hazard map predict actual pyroclastic flows?



A note on scales



Pinatubo 1991

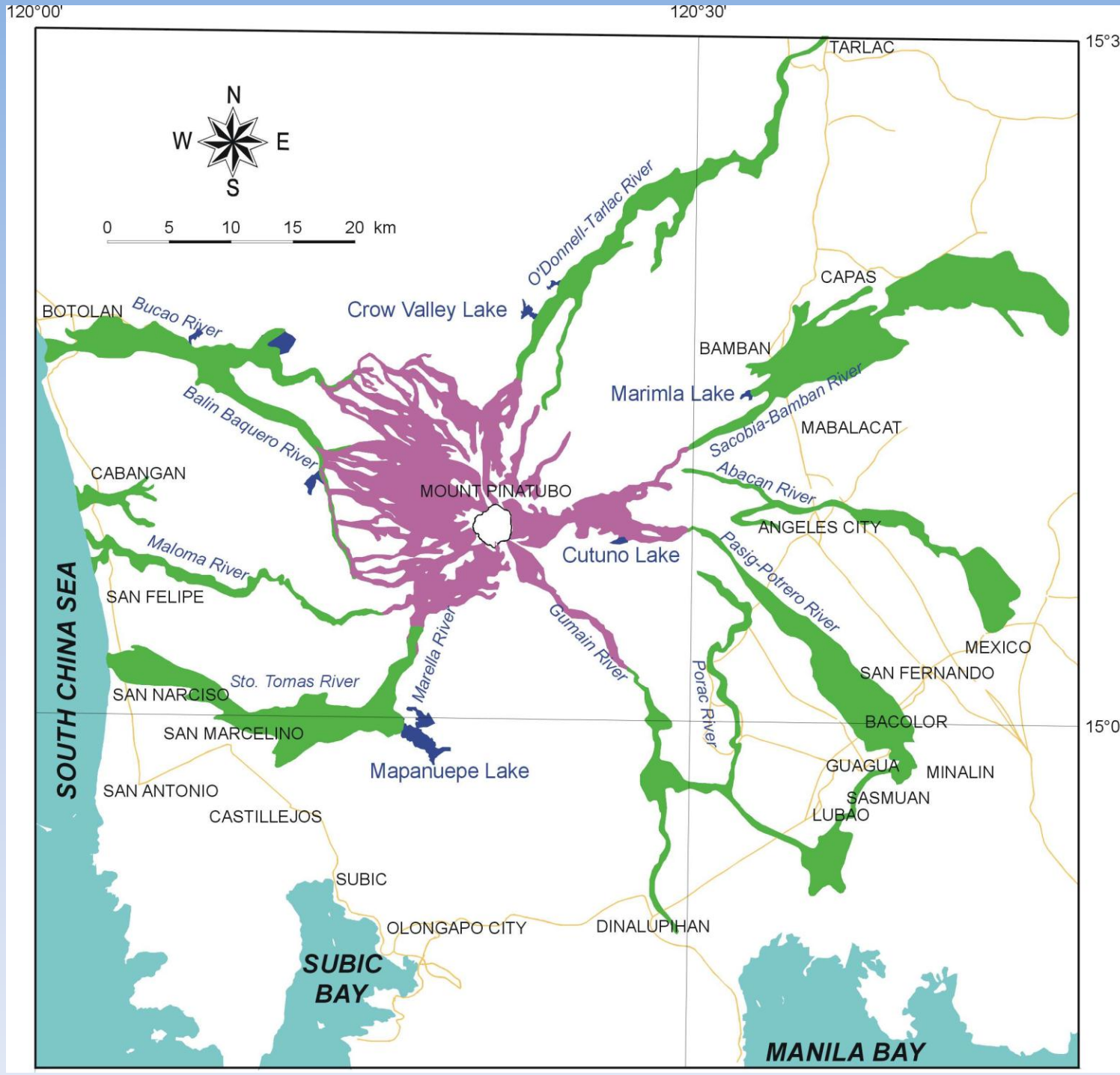


Aso-4 pyro flow, ~ 70 ka,

Ono et al. 1981 after Matumoto

But the eruption was just the beginning of problems!

Soon, lahars (in green) became the big problem

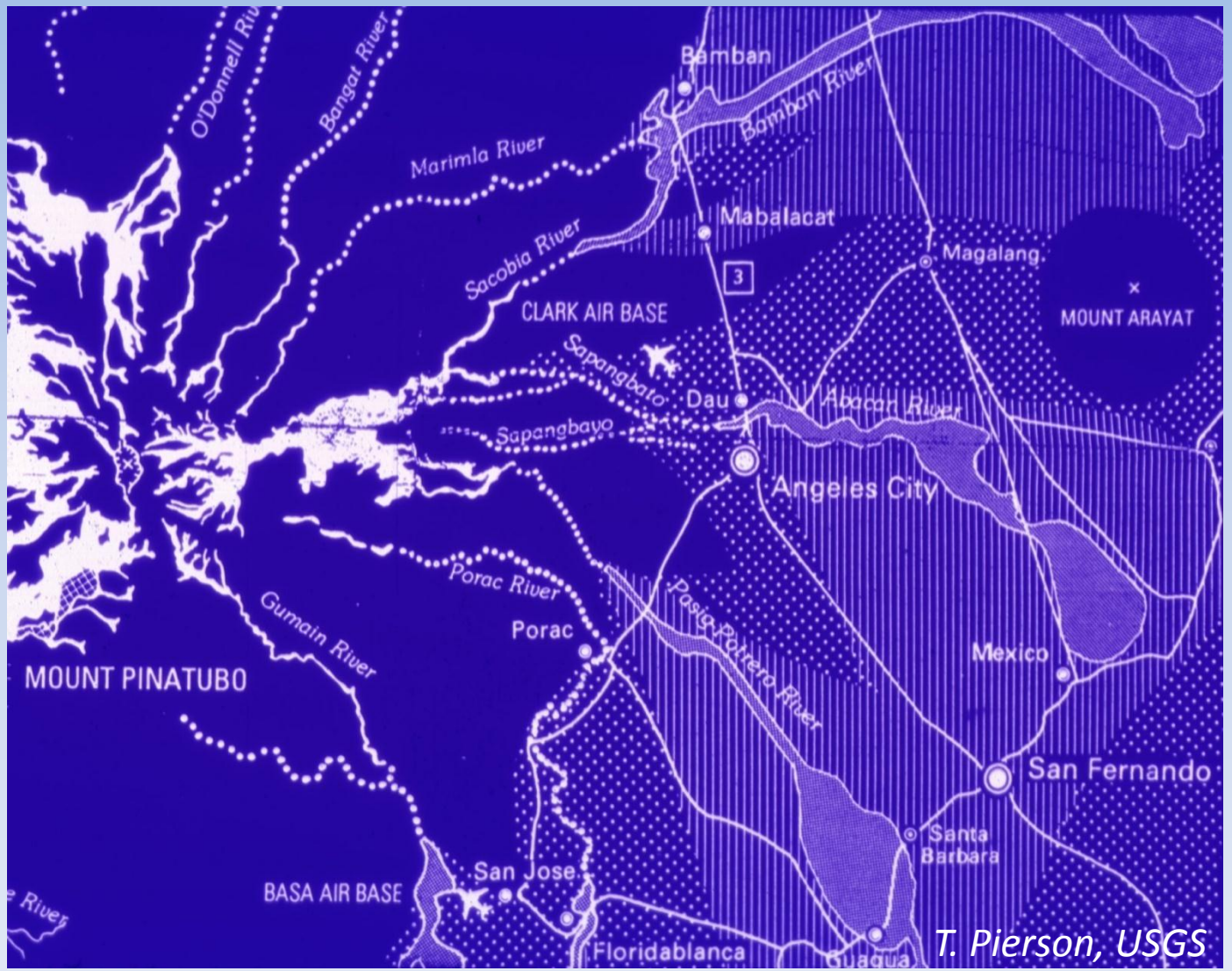


New challenges – re: lahars…

- How could scientists best contribute to lahar warnings? (Instruments high in the watersheds)
- What % of the fresh debris would be remobilized as lahars?
- How widely would it spread – i.e., how thick, how many km2?
- What made more sense – to relocate towns at risk or to build sediment control structures?
- If the latter, where could the sediment be trapped / contained?
- Secondary explosions … Possible to forecast when they would occur? How big? And how long would they last?

For warnings, Raingages, Acoustic Flow Monitors, Tripwires, and Manned Posts

For a lahar hazard map, rough approximations



Lahars

upper slopes

lower slopes

Rains carried loose ash and pumice from the mountain into the lowlands.

>200 m of erosion in Marella Valley, 1991-1994

By 2001, ~60% of the 5-6 billion m^3 of pumice and ash on Pinatubo slopes was already eroded away, mostly by lahars.

Effects of lahars on more distant alluvial fan, town of Bamban, Tarlac, ~30 km from summit:

Initial scouring, then all deposition thereafter

Bacolor, distal alluvial fan, 35 km from summit

Early 1994, Bacolor was recovering from 1991-92 lahars

By late 1994, overwhelmed again by huge new lahars after Pasig-Potrero River "captured" headwaters of the Sacobia River

Bacolor, a valiant but futile effort to save a business

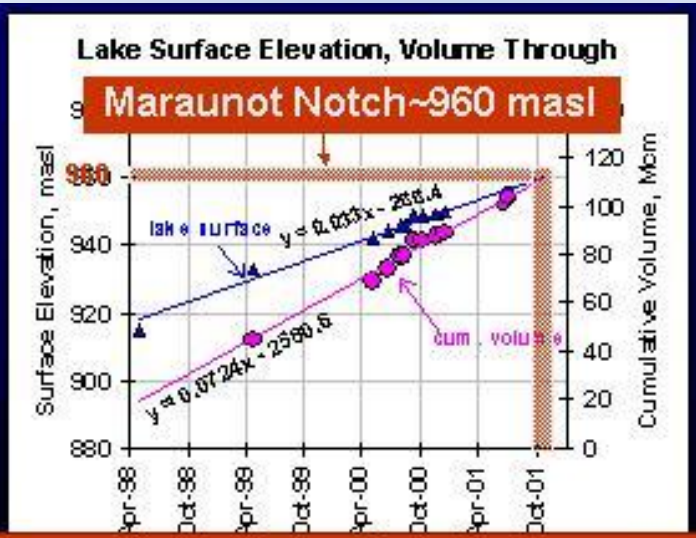
A homegrown solution: jack up your house!
(Small wooden houses jacked up on new stilts; larger concrete homes doomed to burial)

The “last” big lahar issue at Pinatubo, 2001-02

What to do about a large impounded lake in Pinatubo’s new caldera?

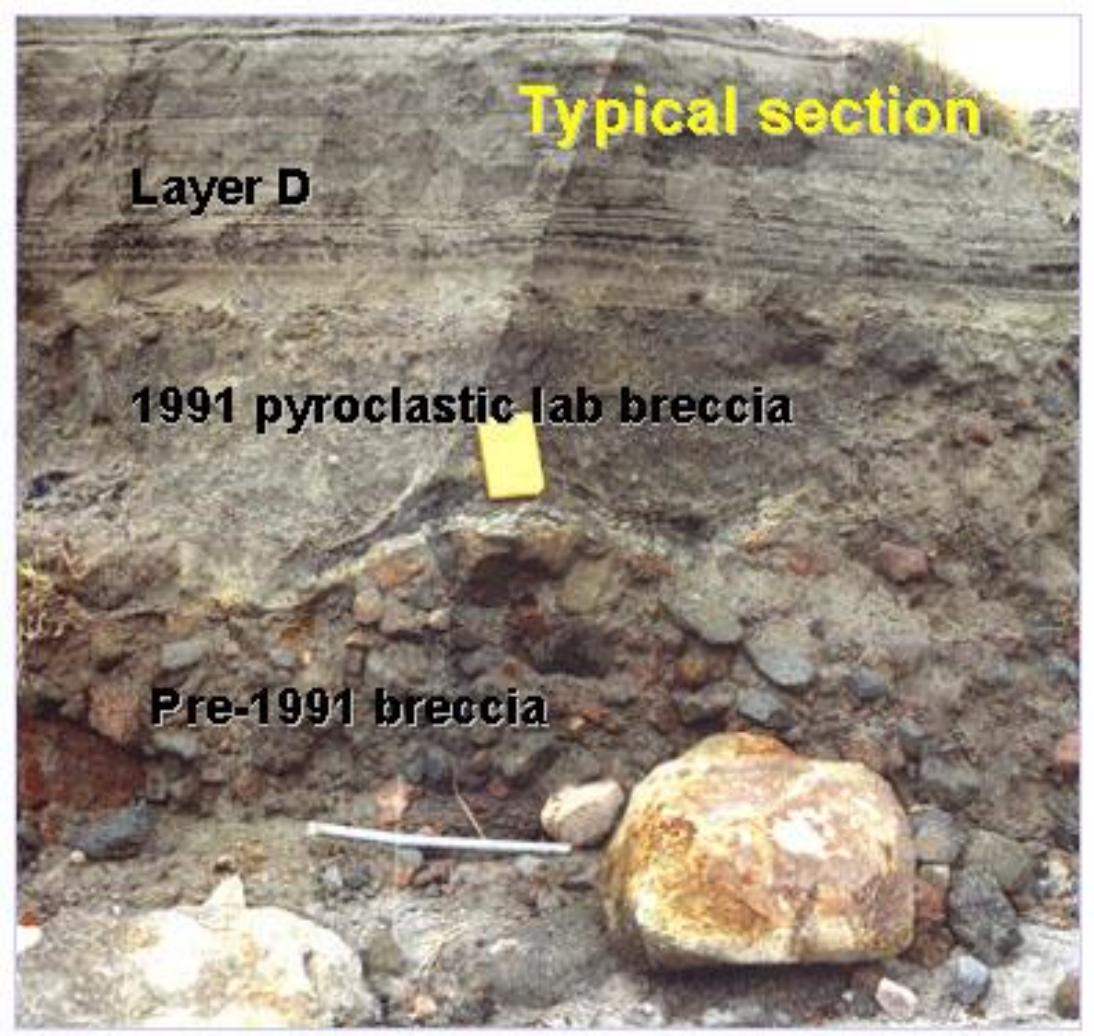
Progressive, rain-fed rise of Pinatubo caldera lake

~2-4 m/y of monsoon and typhoon rains raised the lake level ~ 10 m/y. Projected overtopping, Maraunot Notch (NW side), late 2001. Total vol lake 2.7 M m3; volume behind erodible top 20 m of "dam" = 30-50 M m3



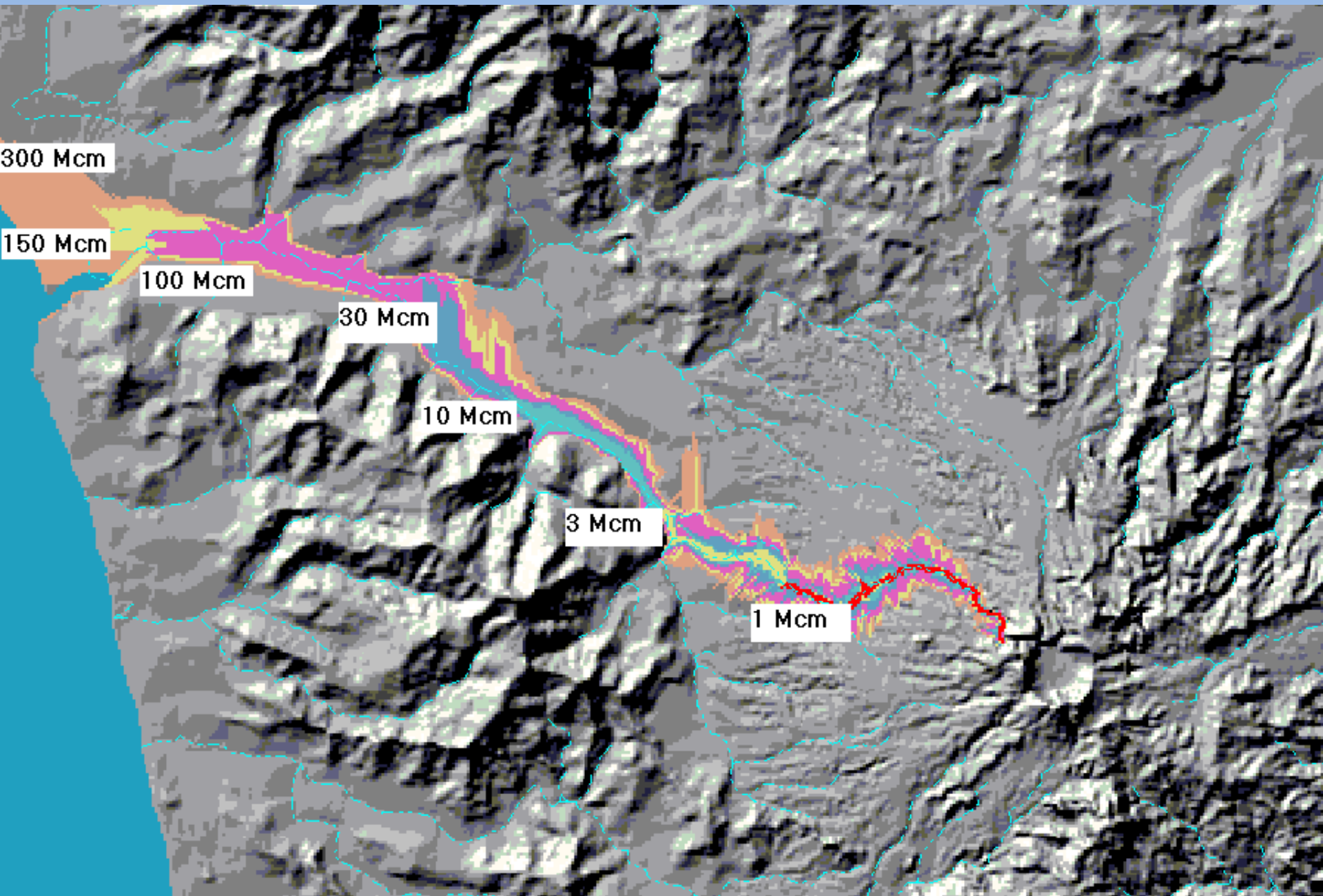
Overtopping last quarter 2001

Would material at the Maraunot Notch erode quickly, as in a dambreak?

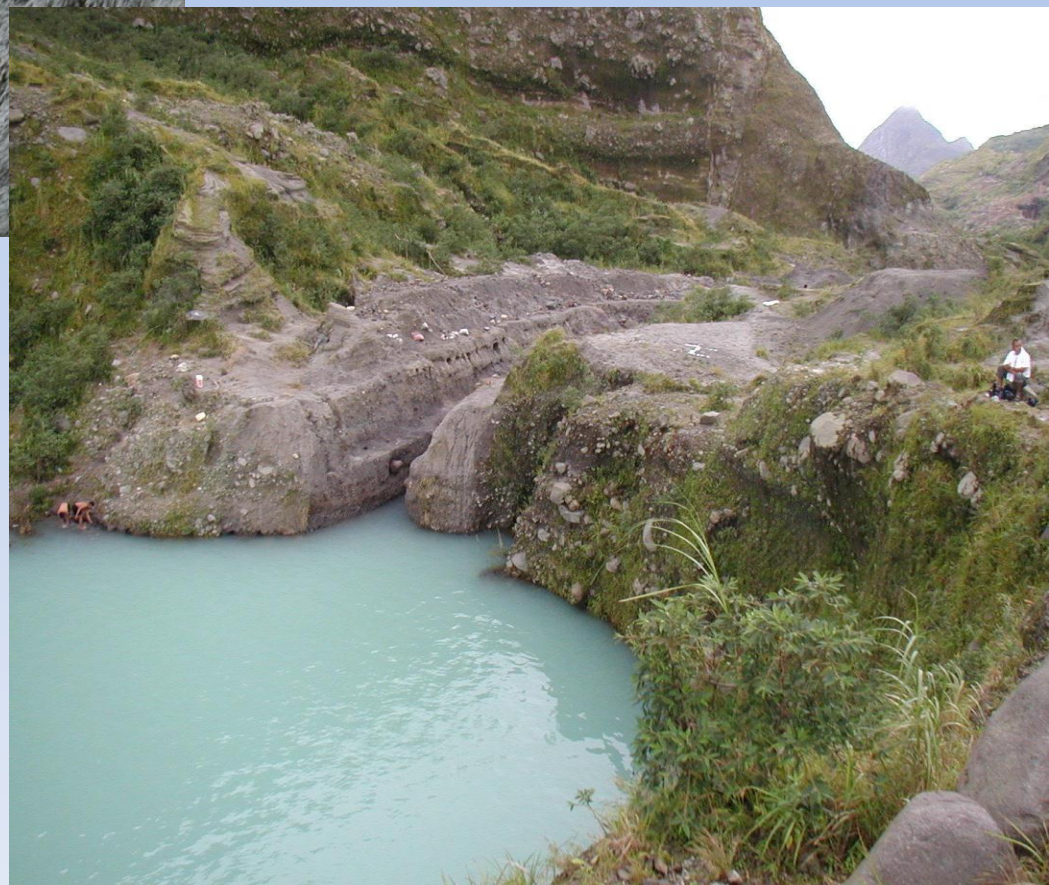


MAV Bornas

Modeled impacts of lake breakout lahars (of various volumes)



5.5 m deep spillway dug by hand, late August- early September, 2001



Botolan town evacuated for 2 days when spillway completed; unfortunately, no scouring occurred. Engineers were too conservative!

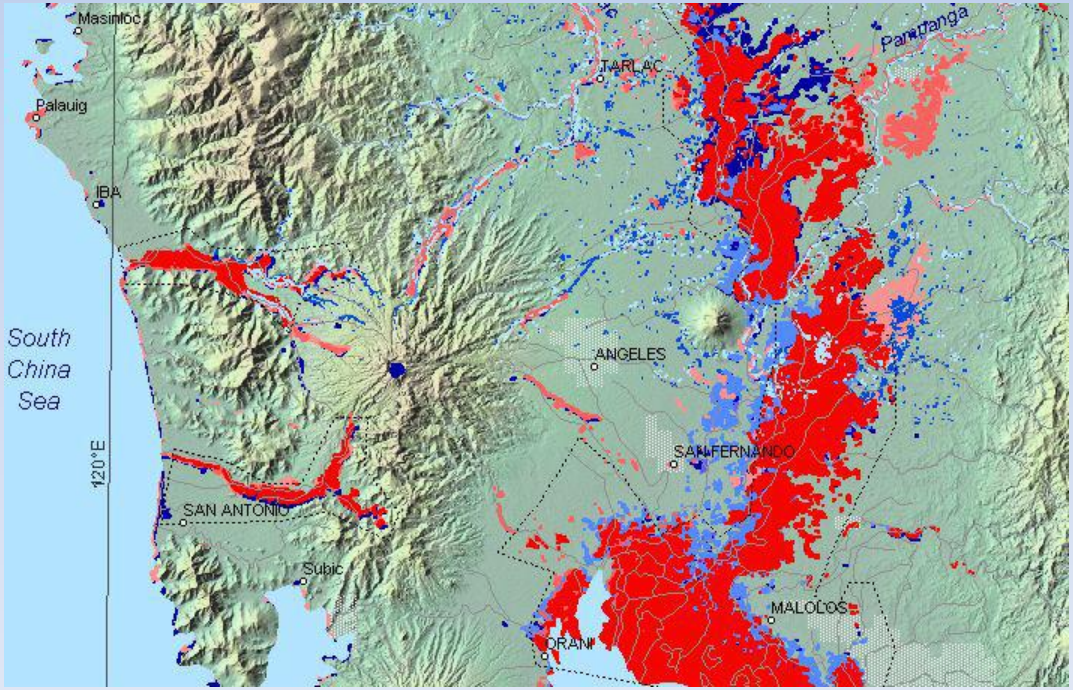
Huge loss of face …

But, 1st typhoon of 2002 breached the dam and released a massive flood that became lahar.

Lake level dropped 23 m!

Botolan survived – BARELY!

The saga still continues, with flooding outside sediment-choked channels



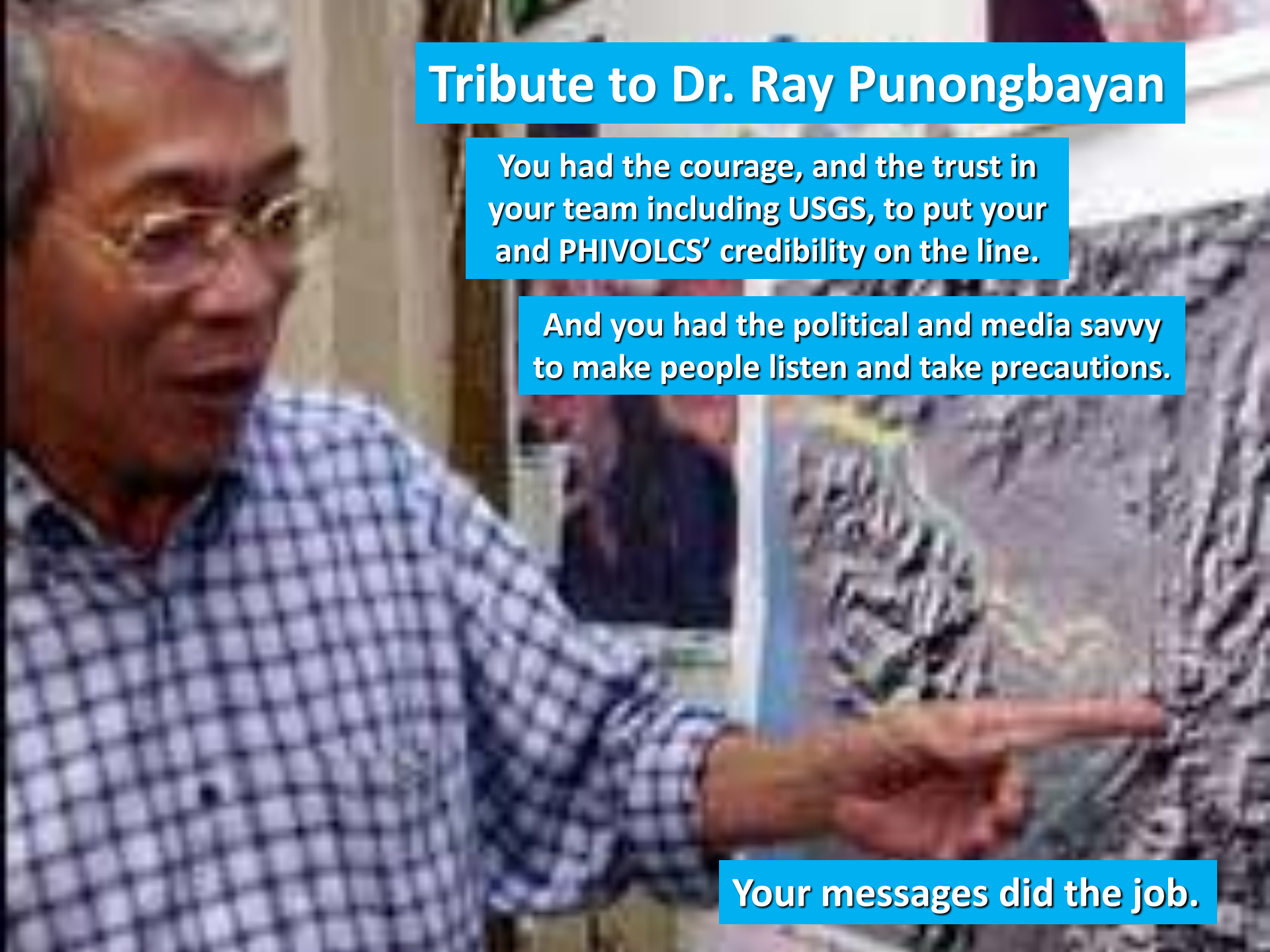
Dec '04 floods,
Bob Brakenridge, Dartmouth

At risk, killed, and saved

- ~ 1,000,000 at risk, incl. 20,000 in area devastated by eruption and >100,000 in areas devastated by mudflows ("lahars")
- Up to 250,000 evacuees
- ~400 died in eruption; ~500 in evacuation camp (from measles!); ~400-500 more from lahars
- Thousands of lives, and billions of pesos, saved by good scientific advice.

A research team of 1000!

- Count is from GEOREF, 10 yrs after eruption
- Includes:
  - Philippines-based researchers
  - Researchers in at least 21 other countries
  - Graduate students in at least 10 countries
  - Undergraduate students from several universities in the Philippines and abroad
- This is a great model – open volcano!


Tribute to Dr. Ray Punongbayan
You had the courage, and the trust in your team including USGS, to put your and PHIVOLCS' credibility on the line.
And you had the political and media savvy to make people listen and take precautions.
Your messages did the job.