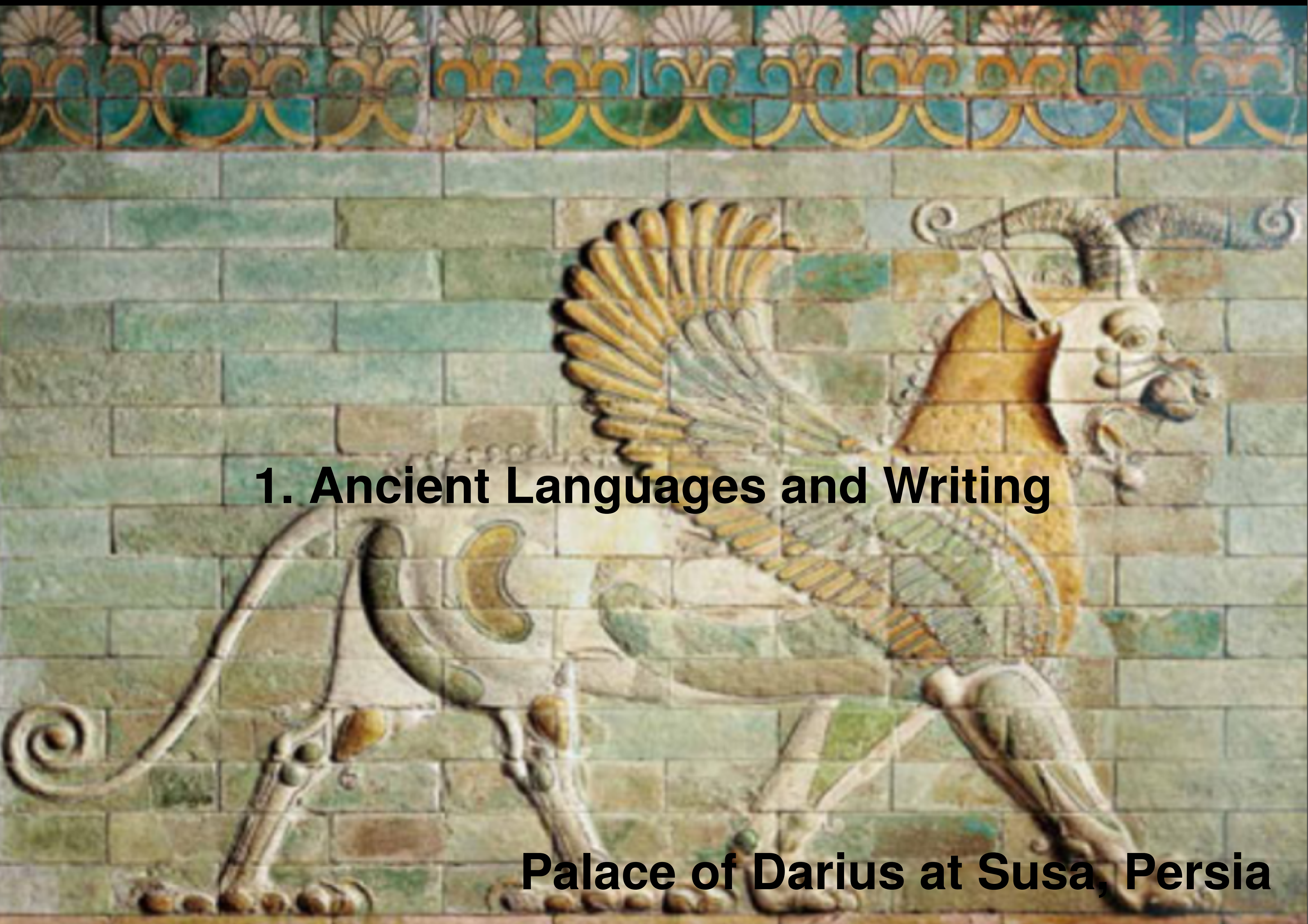
2017 GNU Hackers Meeting

The GNU Behistun Package

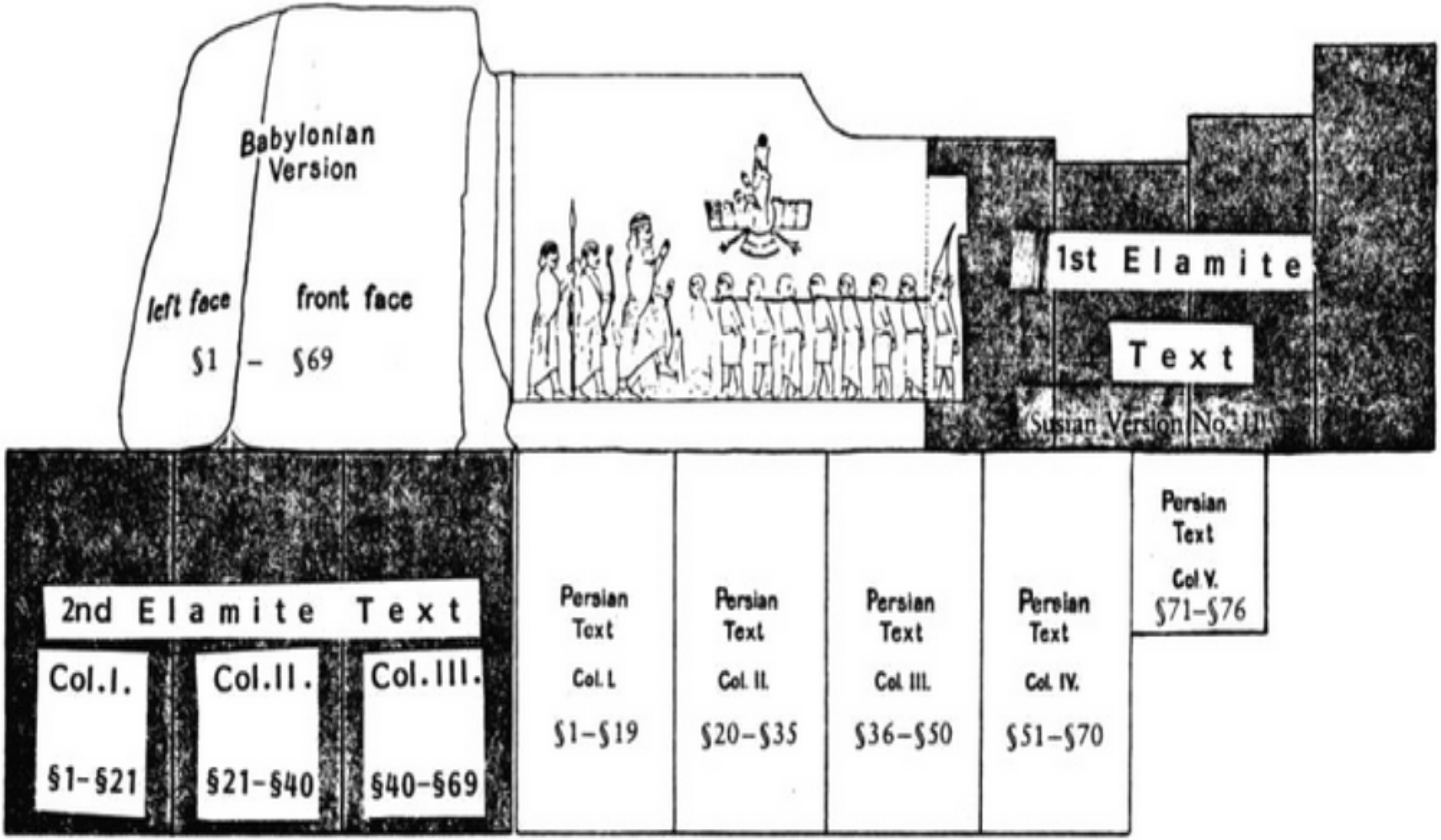
1. Ancient Languages and Writing
2. Disaster Preparedness and Mitigation
3. Seismic Subsurface Mapping

Speaker: Christopher Dimech

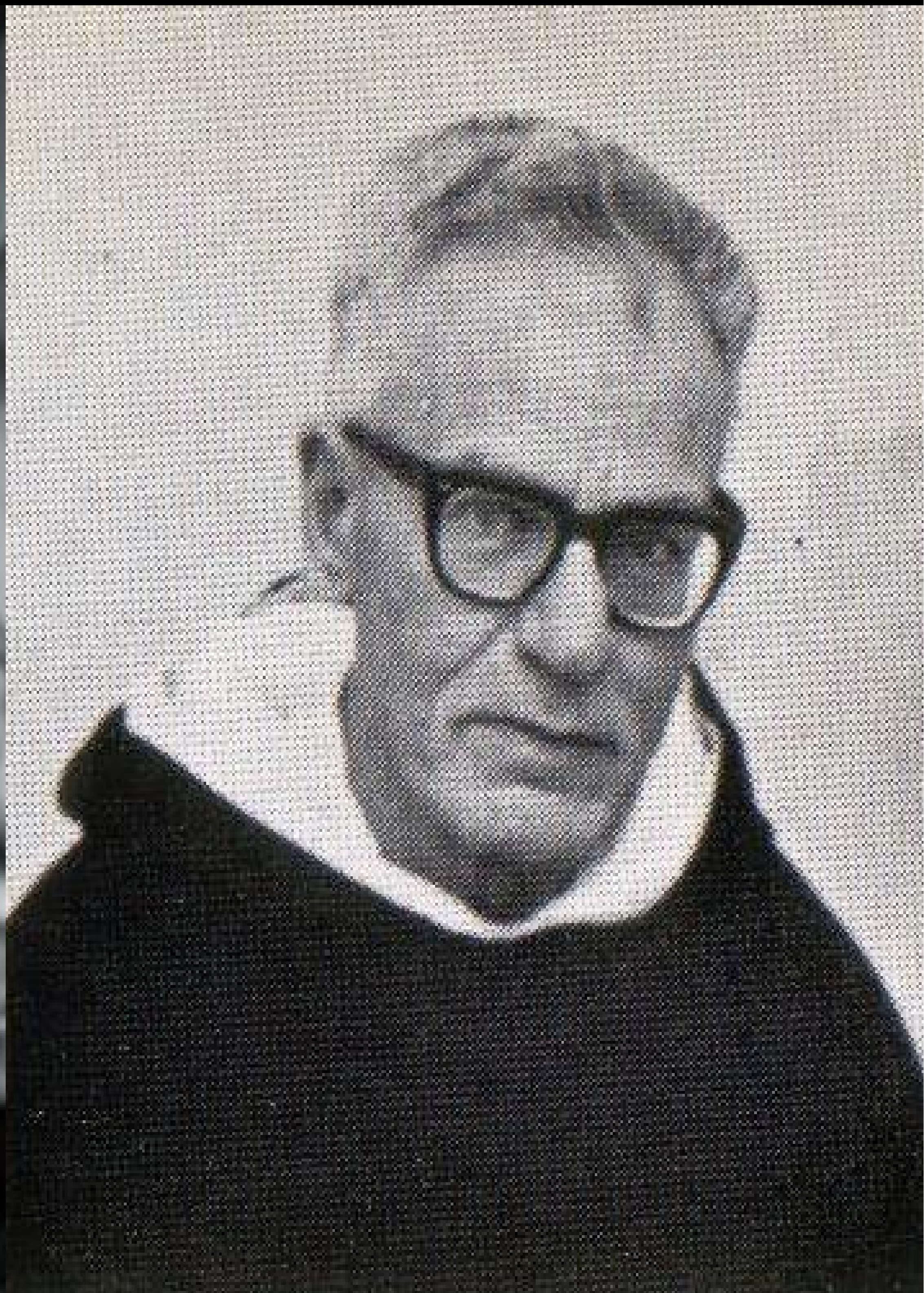
Palace of Darius at Susa, Persia



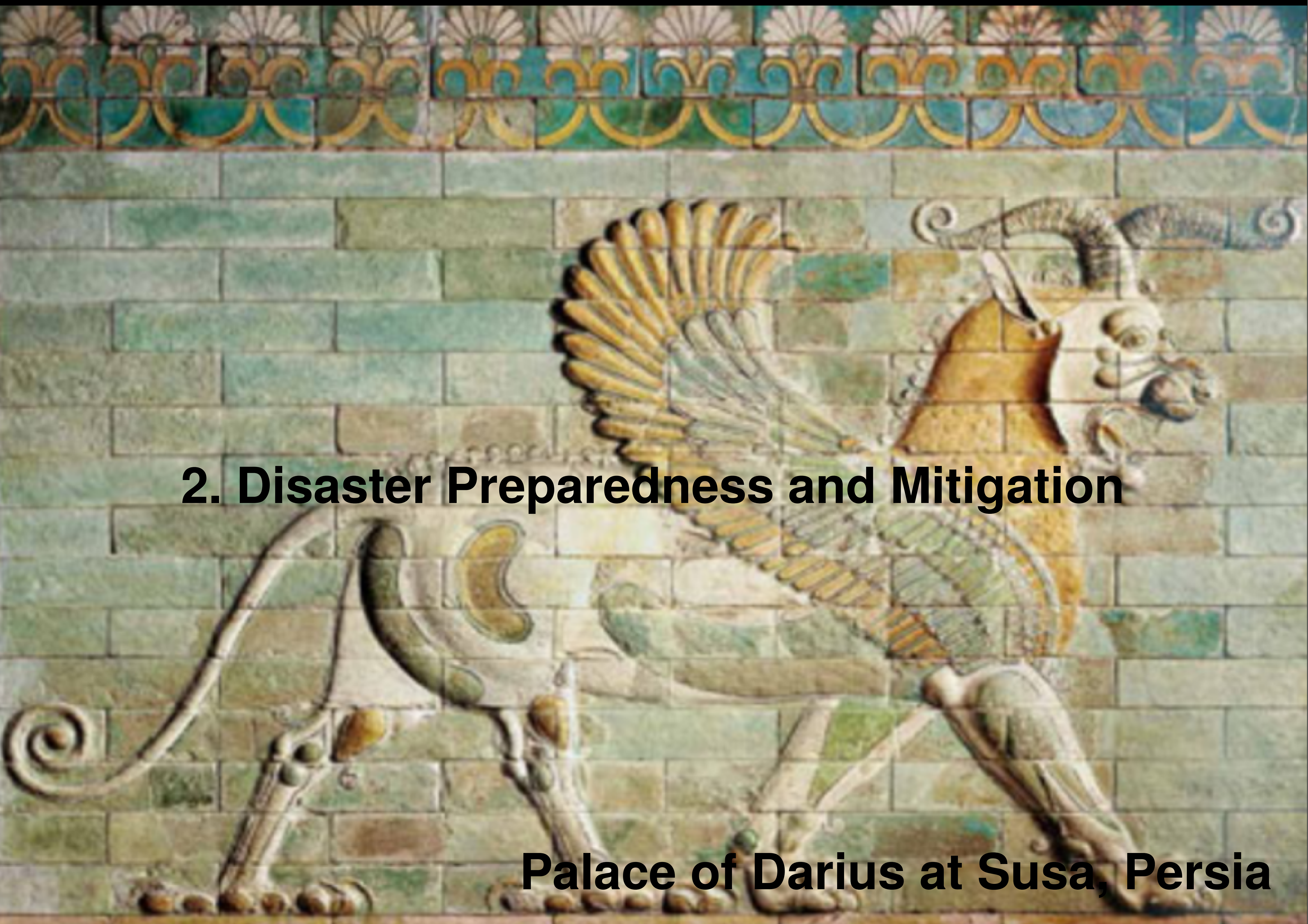
Palace of Darius at Susa, Persia



The positions of the Old Persian, Elamite, and Babylonian versions of the major trilingual inscription DB on the rock at Bīsotūn. Source: King and Thompson, pl. VI; corrected by Borger, fig. 2; adapted by R. Schmitt

2. Disaster Preparedness and Mitigation



Palace of Darius at Susa, Persia

2011. The Fukushima Daiichi Nuclear Disaster

2011. The Fukushima Daiichi Nuclear Disaster

2010, Deepwater Horizon Drilling Rig at Macondo Prospect

Inextinguishable Fire, Sinking two days later, leaving the well gushing at the seabed.

1986. Chernobyl Nuclear Disaster

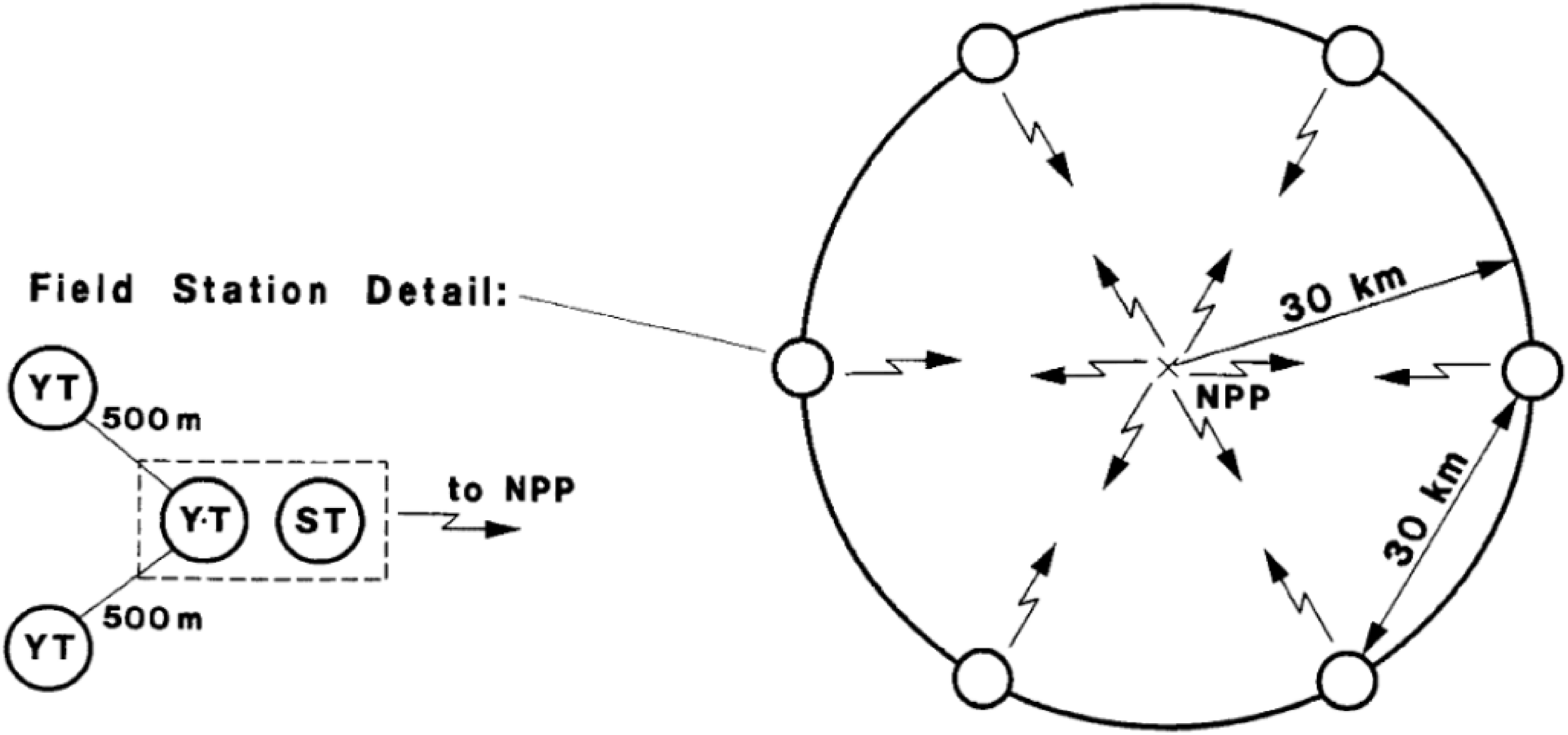
Ukrainian Soviet Socialist Republic, Soviet Union

Reactor Safety Flaws and Human Actions

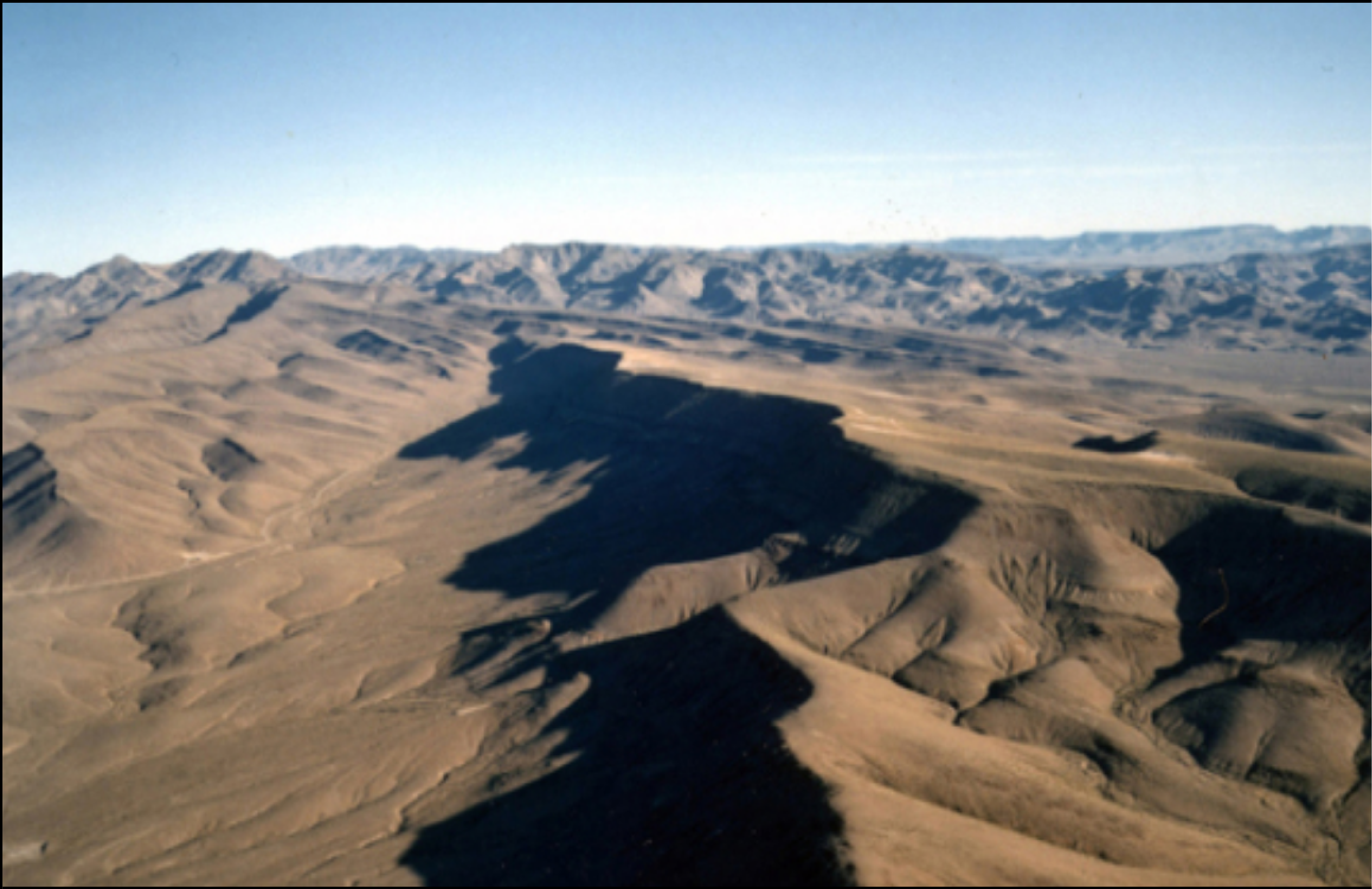
Ignalina Nuclear Power Plant

Similar to Chernobyl Nuclear Power Plant

2004, 2009 Closed two-unit RBMK-1500 Reactors



Ignalina Nuclear Station Earthquake Early Warning



The Yucca Mountain Nuclear Waste Repository

The Yucca Mountain Nuclear Waste Repository

Hanford Radioactive Containment Site

Hanford site represents two-thirds of the nation's high level radioactive waste by volume

Hanford Radioactive Containment Site

Waste Isolation Pilot Plant, New Mexico, United States

Radioactive Containment Casks arriving at WIPP

Waste Isolation Pilot Plant

Radioactive Waste is placed in Rooms Underground

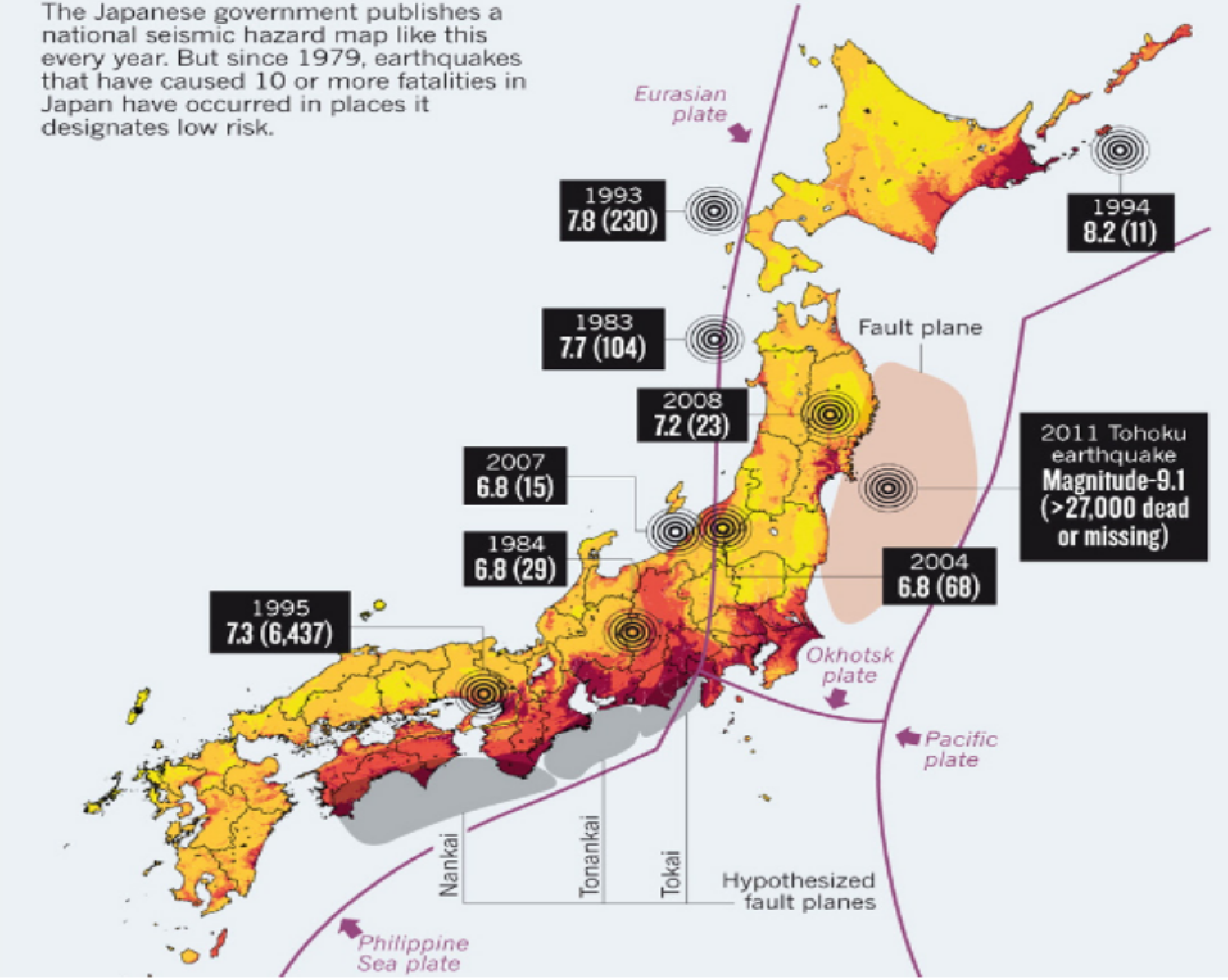
Waste Isolation Pilot Plant, New Mexico, United States

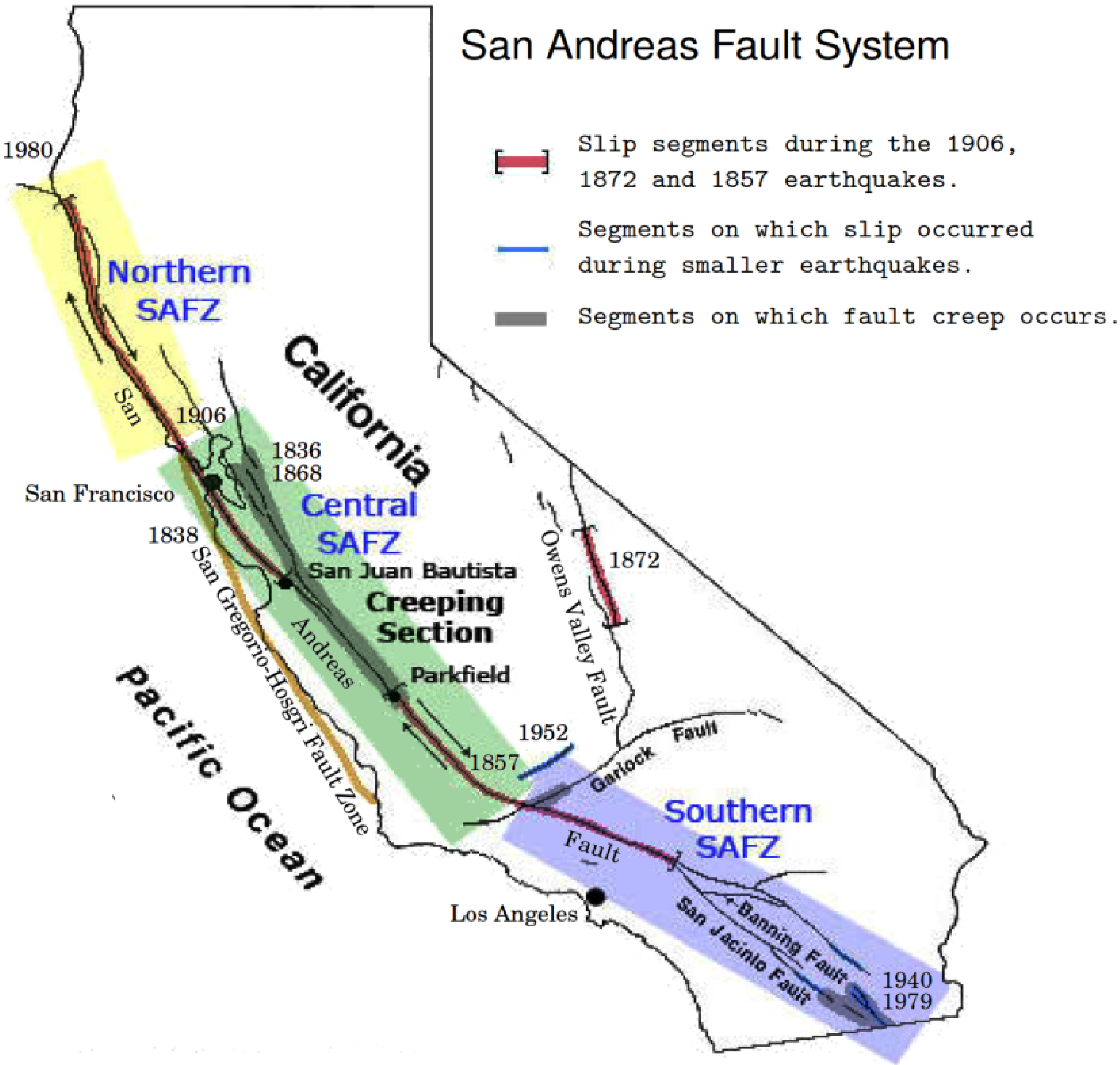
2014. Radioactive Leaks from Damaged Storage Drum

Waste Explosion, Airborne Release of Radiological Material

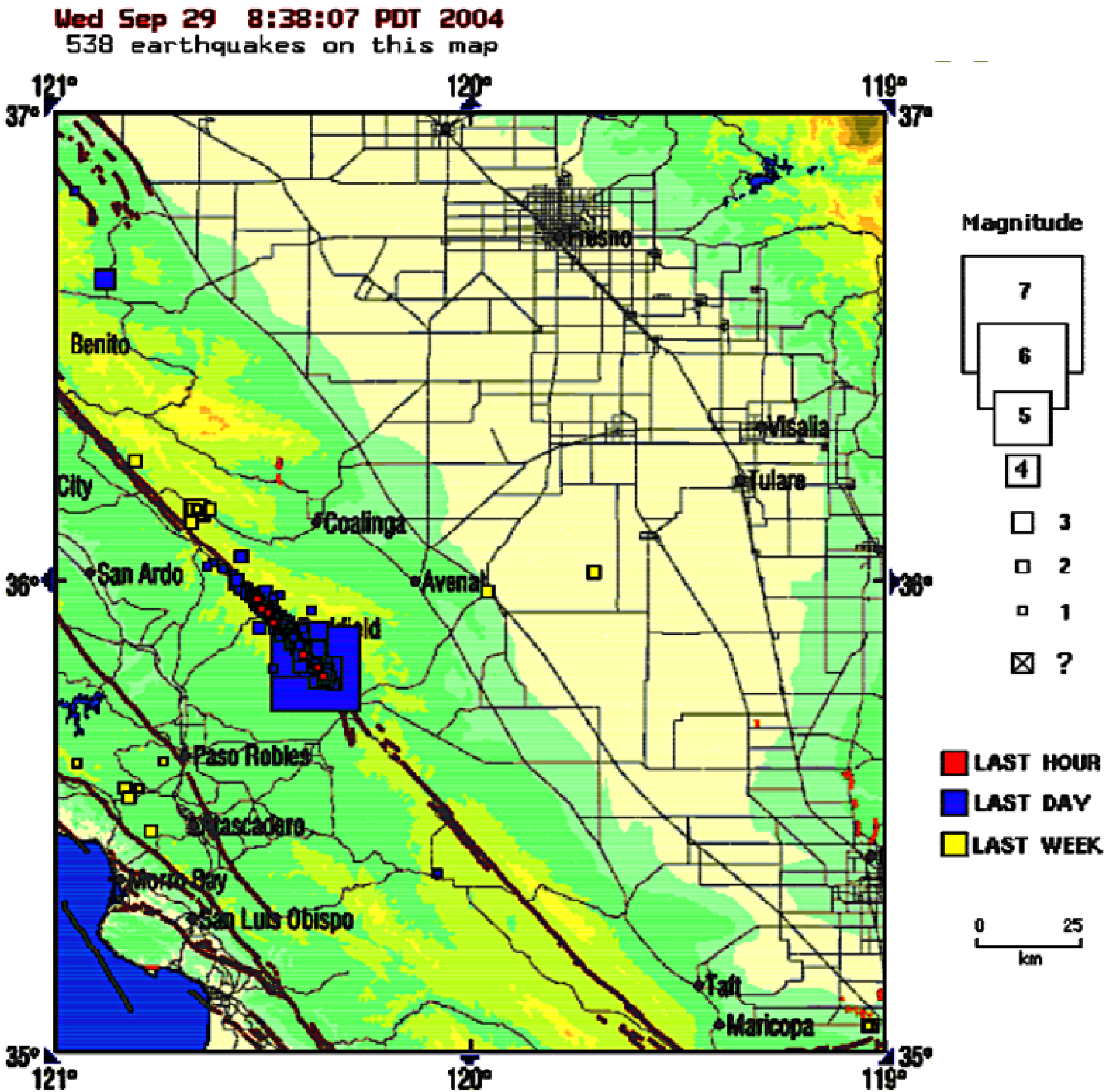
REALITY CHECK

The Japanese government publishes a national seismic hazard map like this every year. But since 1979, earthquakes that have caused 10 or more fatalities in Japan have occurred in places it designates low risk.



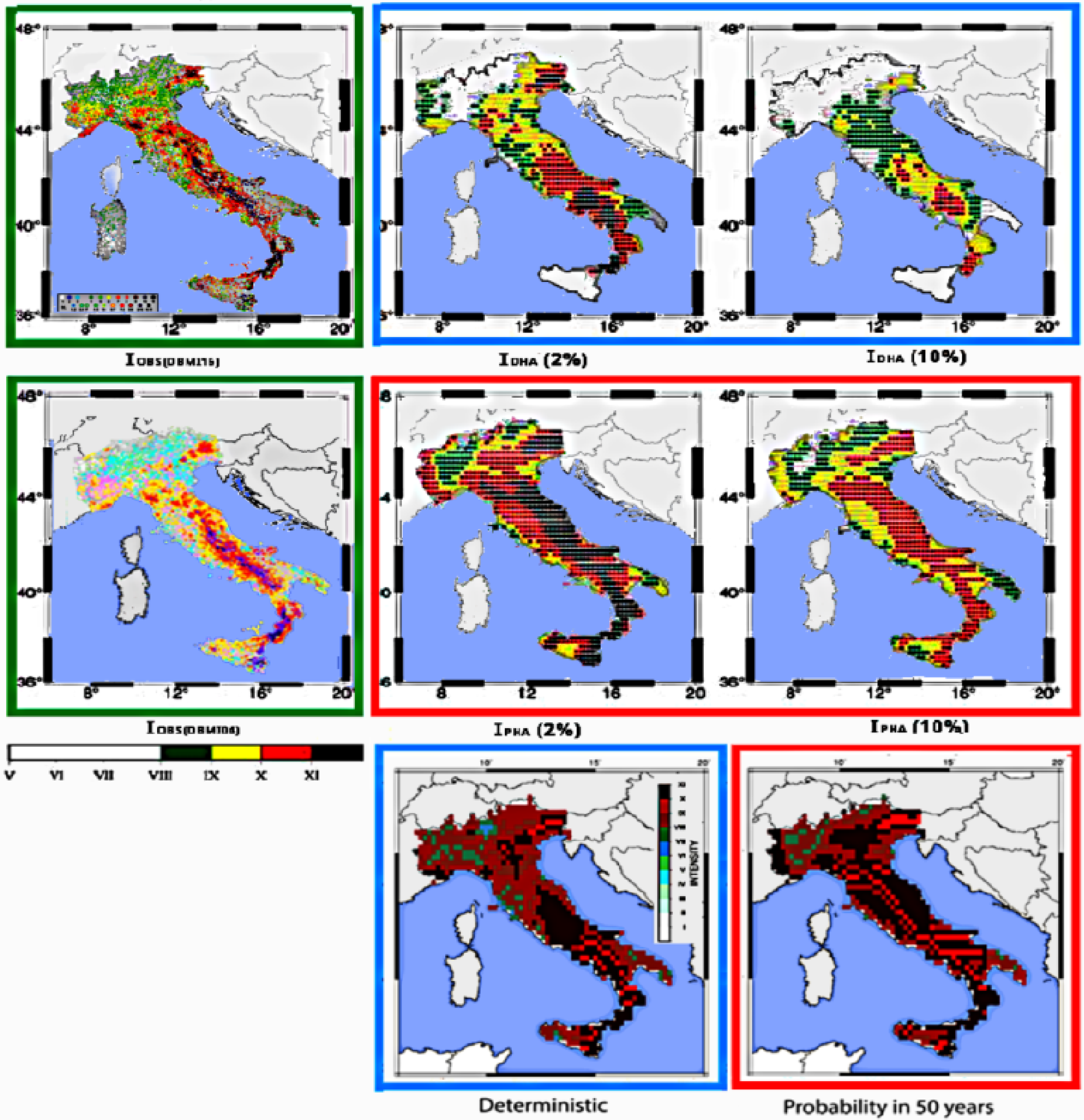


San Andreas Fault System
Slip segments during the 1906, 1872 and 1857 earthquakes.
Segments on which slip occurred during smaller earthquakes.
Segments on which fault creep occurs.
1980
Northern SAFZ
San
1906
1836
1868
California
San Francisco
Central SAFZ
1838
San Juan Bautista
Creeping Section
San Gregorio-Hosgri Fault Zone
Andreas
Parkfield
Owens Valley Fault
1872
Pacific Ocean
1952
1857
Garlock Fault
Southern SAFZ
Fault
Los Angeles
Banning Fault
San Jacinto Fault
1940
1979

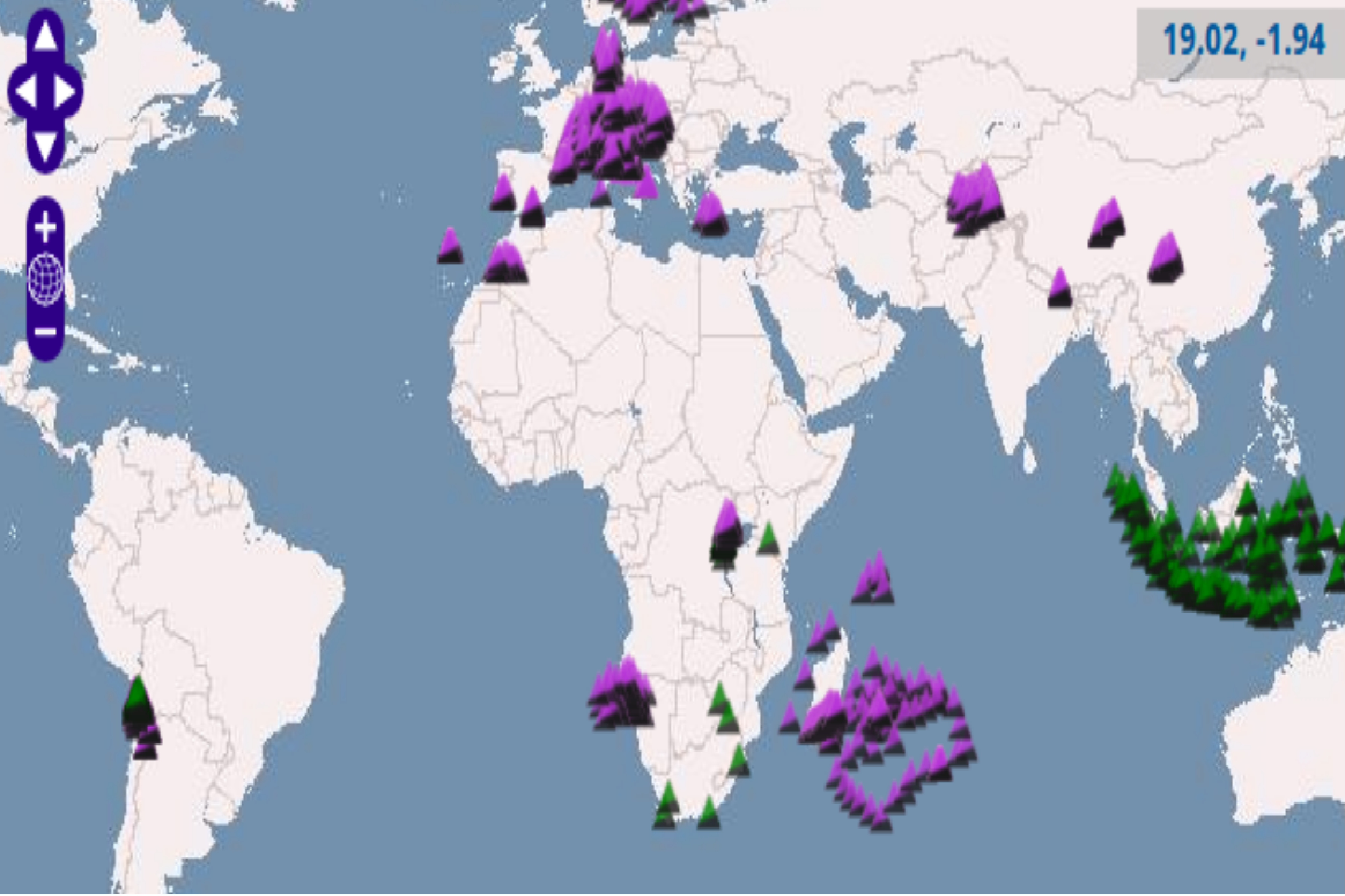


Wed Sep 29 8:38:07 PDT 2004
538 earthquakes on this map
121°
120°
119°
37°
36°
35°
Fresno
Benito
Visalia
Tulare
City
Coalinga
San Ardo
Avenal
Paso Robles
Atascadero
Morro Bay
San Luis Obispo
Taft
Maricopa
Magnitude
7
6
5
4
3
2
1
?
LAST HOUR
LAST DAY
LAST WEEK
0
25
km

Italian Seismicity



Overprediction of hazard risk levels



Legend for Map icons **Stations** ▲ Restricted and permanent ▲ Restricted and temporary

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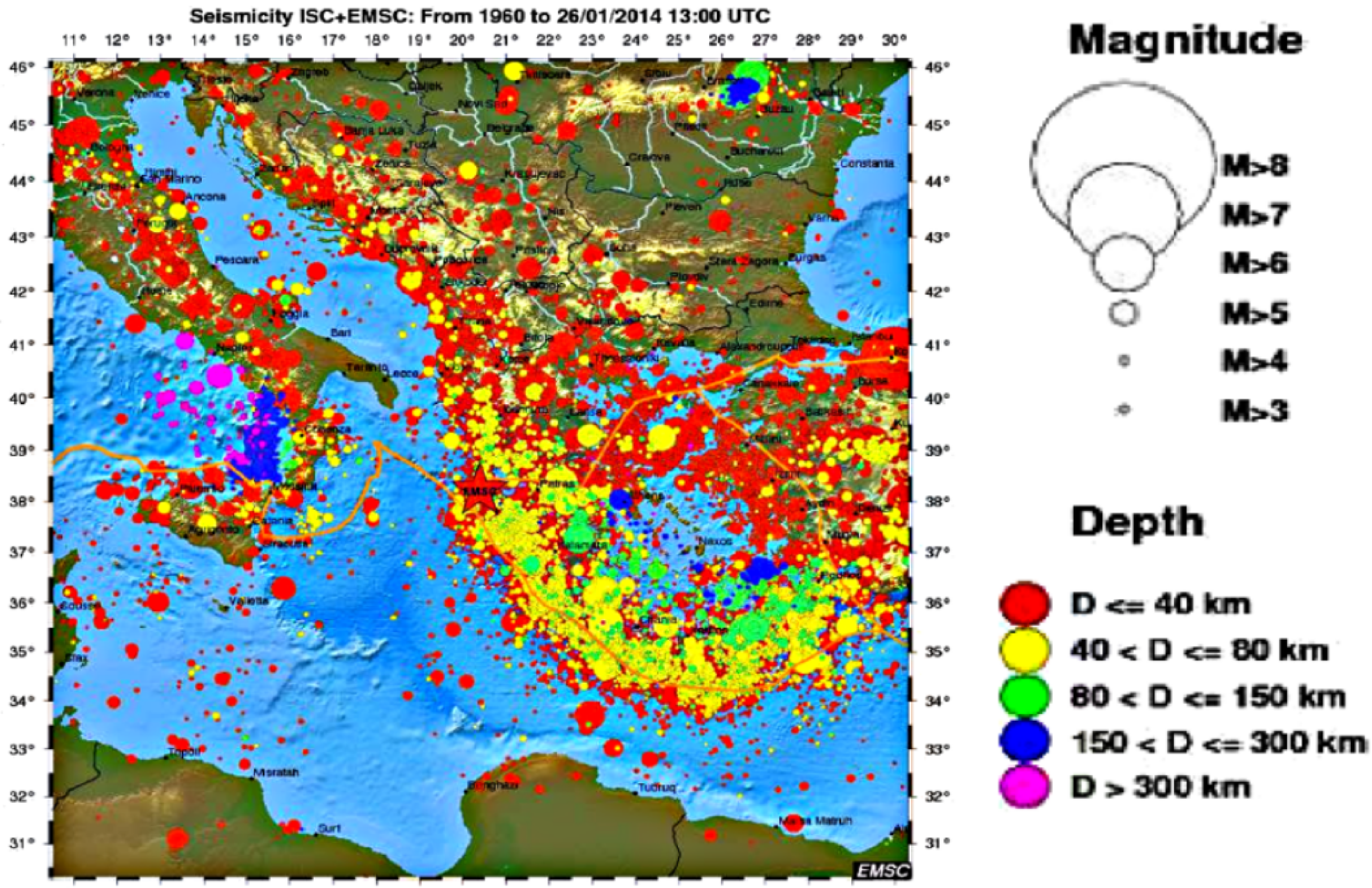
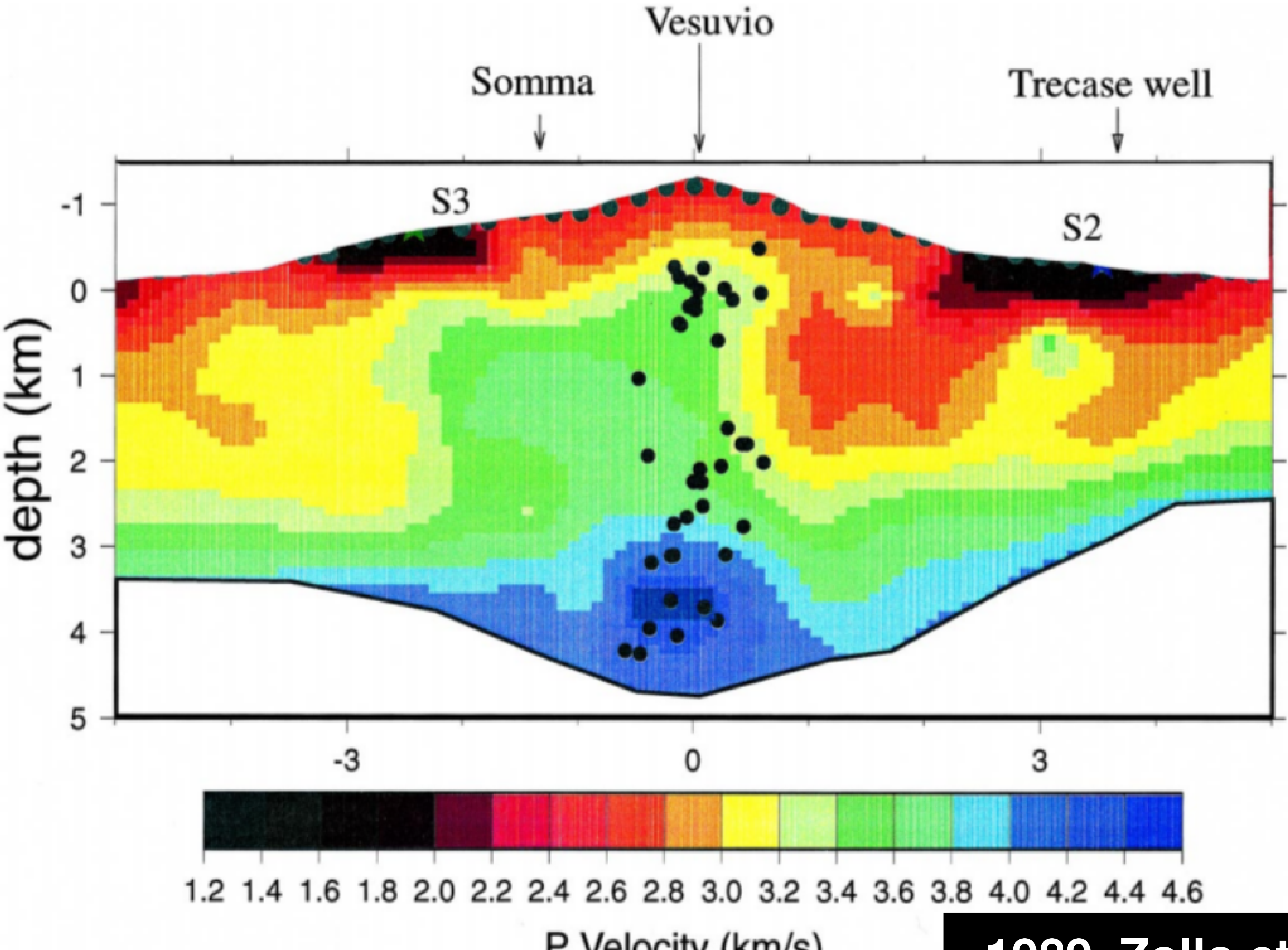
3. Seismic Subsurface Mapping

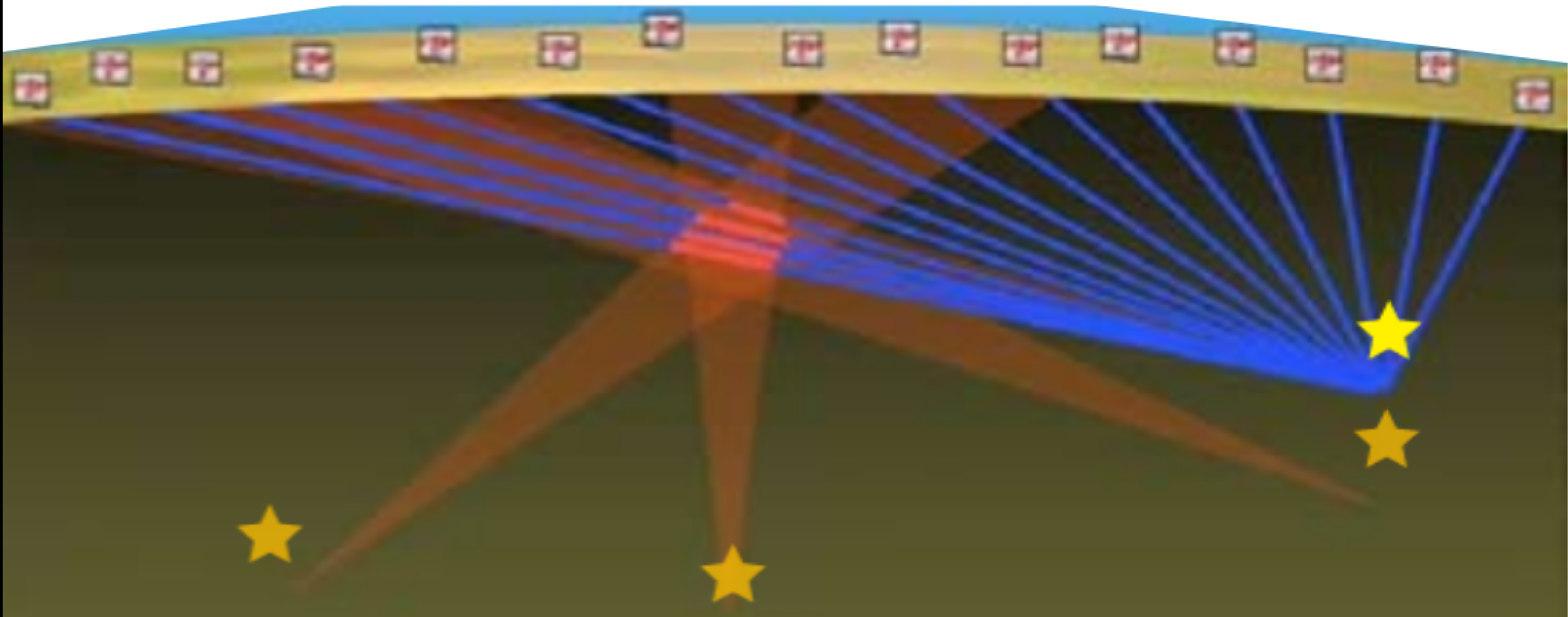


European Mediterranean Seismological Centre

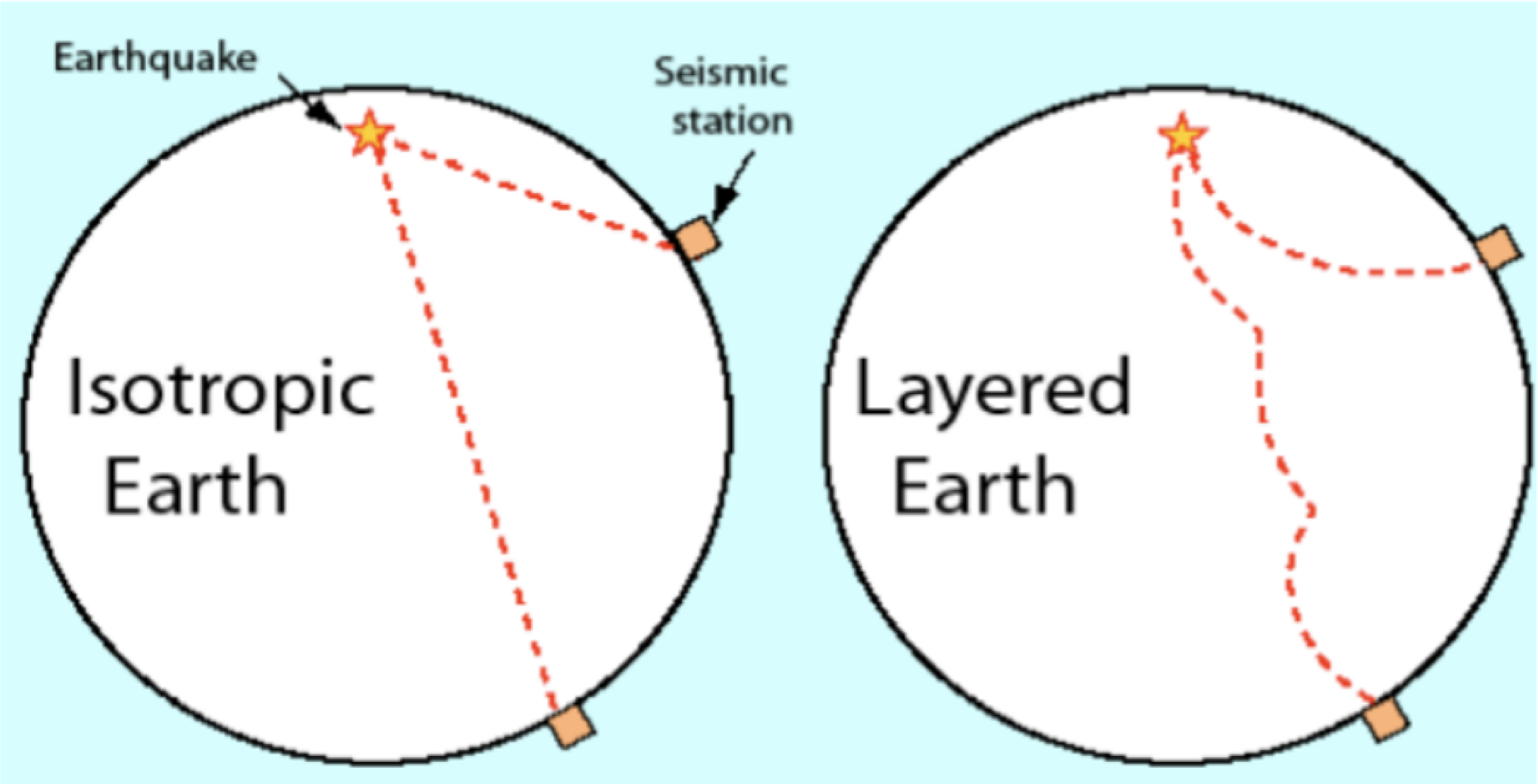
İnduced Seismicity Consortium



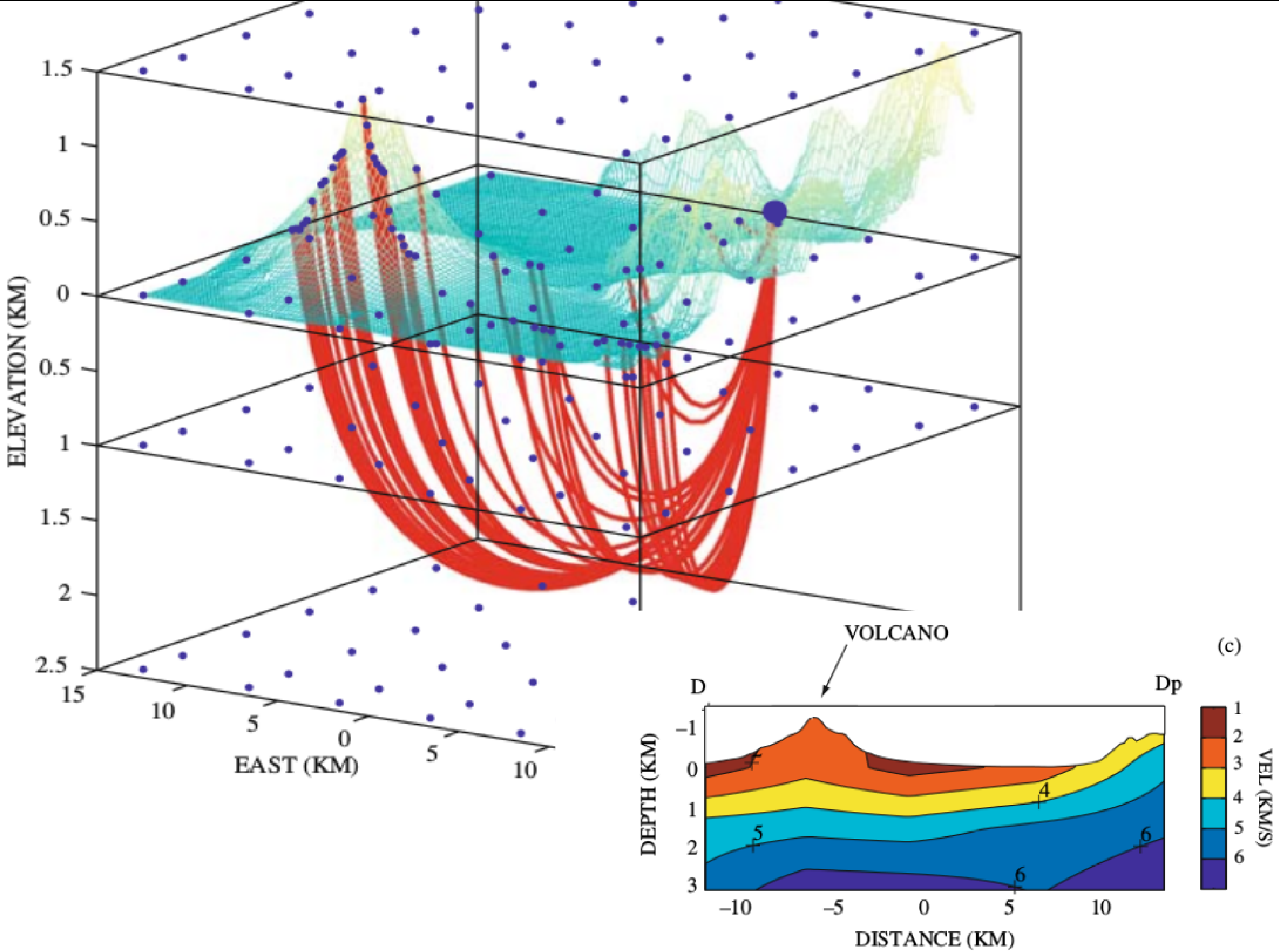
1989. Zollo et al.



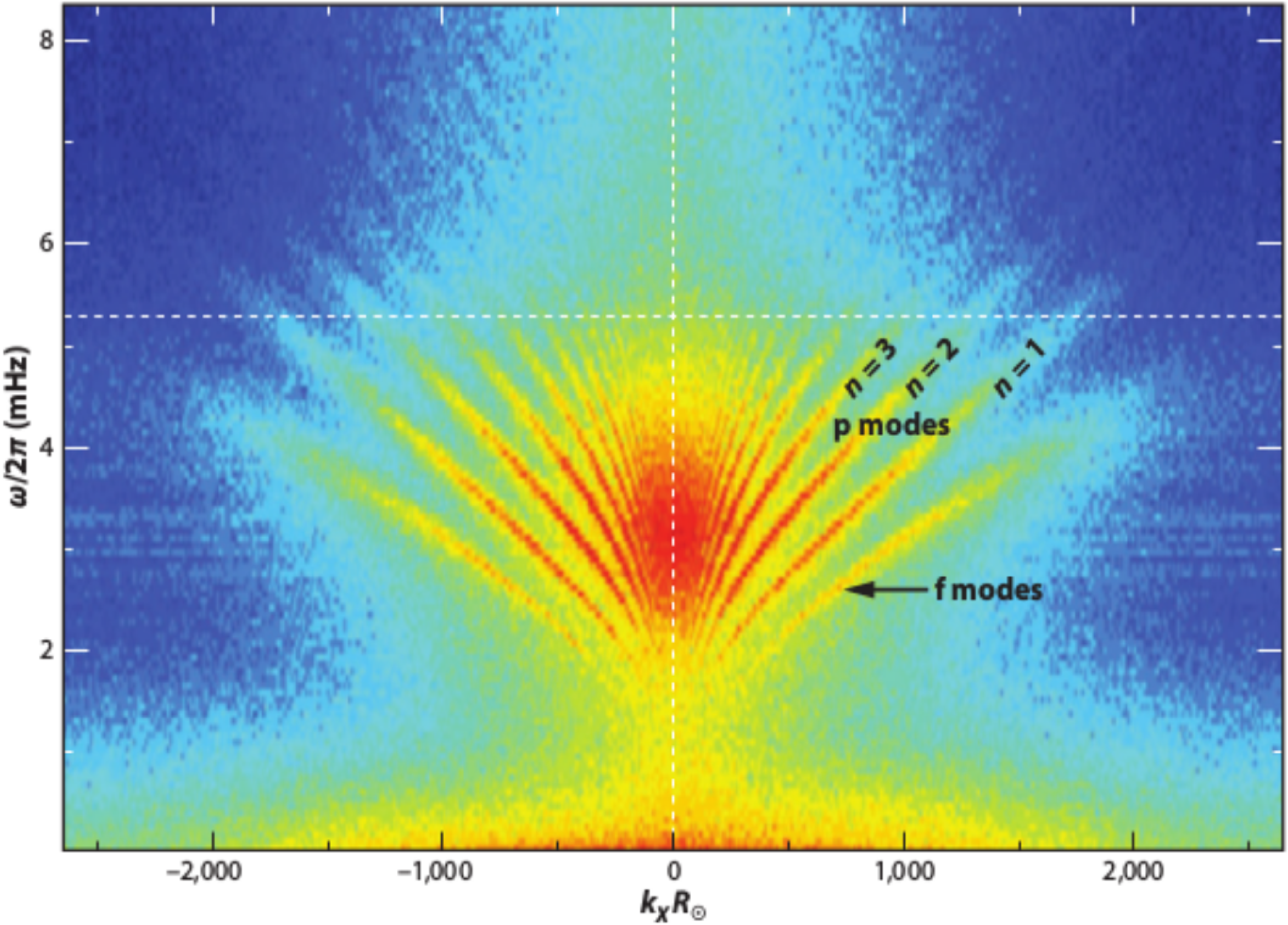
Slower region indicates different material than the surroundings, and is often termed "an anomaly."



Earthquake
Seismic station
Isotropic Earth
Layered Earth



ELEVATION (KM)
1.5
1
0.5
0
0.5
1
1.5
2
2.5
15
10
5
0
5
10
EAST (KM)
VOLCANO
(c)
D
Dp
DEPTH (KM)
−1
0
1
2
3
4
5
6
6
−10
−5
0
5
10
DISTANCE (KM)
1
2
3
4
5
6
VEL (KM/S)

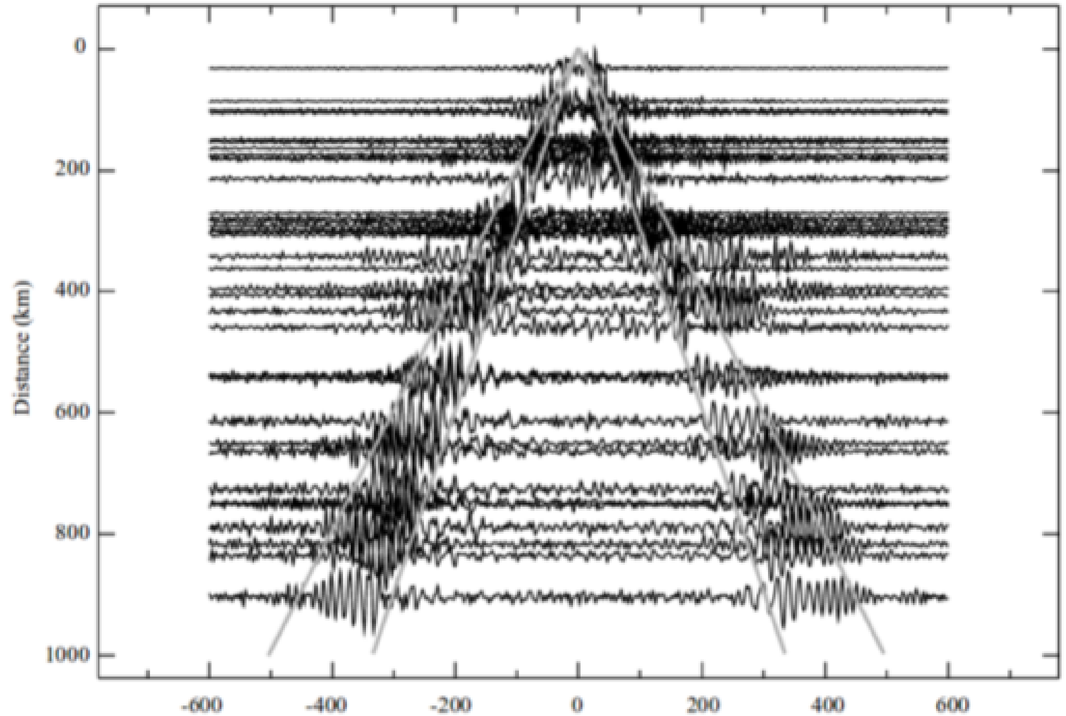

8
6
4
2
ω/2π (mHz)
−2,000
−1,000
0
1,000
2,000
kₓR⊙
n = 3
n = 2
n = 1
p modes
f modes

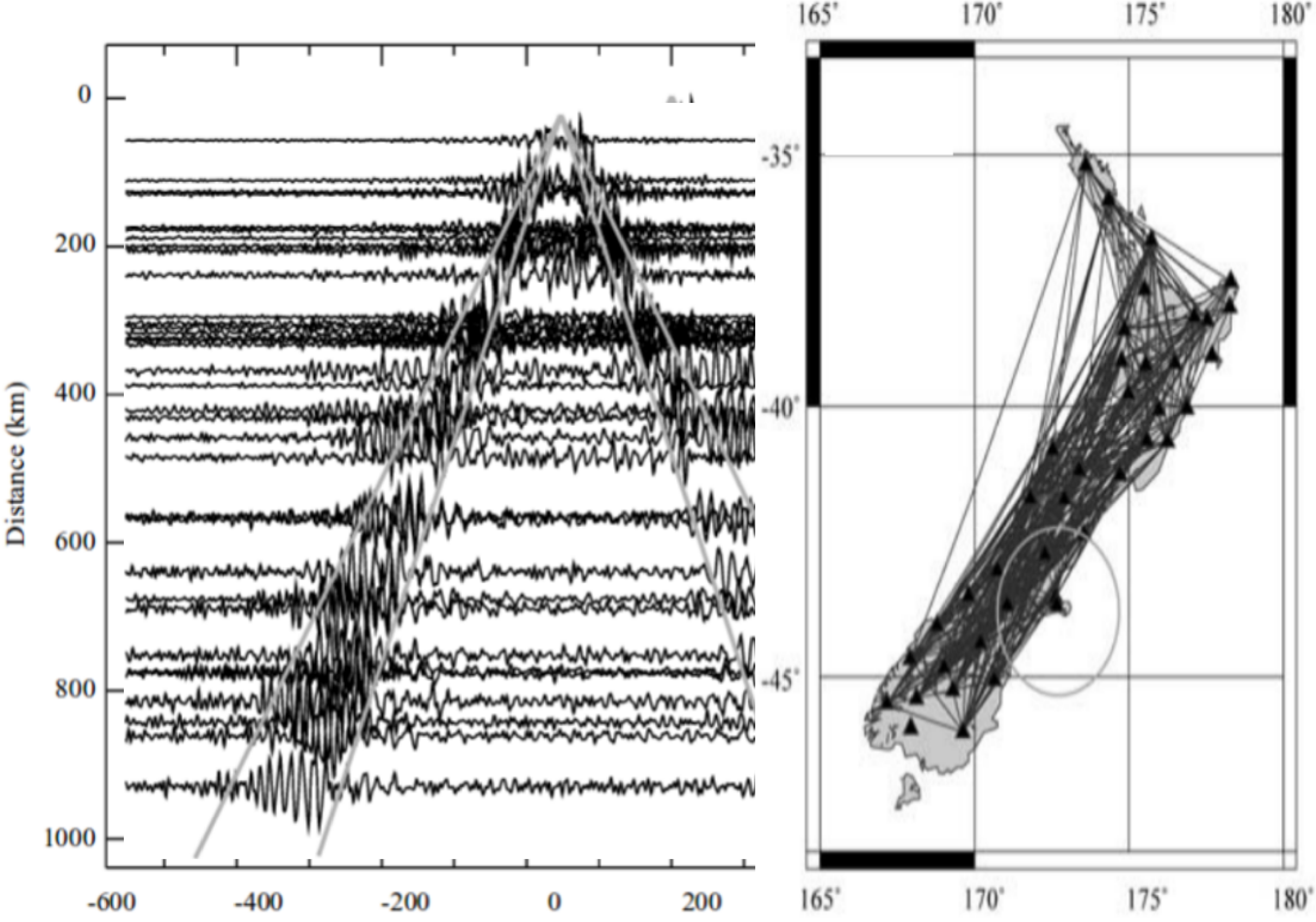
3.2. The Cross-Covariance Function

Time-distance helioseismology is based on the measurement of the cross-covariance between the Doppler signals at two points $\mathbf{r}_1$ and $\mathbf{r}_2$ on the solar surface,

$$C(\mathbf{r}_1, \mathbf{r}_2, t) = \int_0^T \mathrm{d}t' \, \phi(\mathbf{r}_1, t')\phi(\mathbf{r}_2, t' + t), \tag{5}$$

where t is the correlation time lag. **Figure 6*a*** shows a cross-covariance function measured from 144 days of MDI medium-degree data. The cross-covariance has been averaged over many pairs of points $(\mathbf{r}_2, \mathbf{r}_1)$ and is presented as a function of the heliocentric angle between these two points. This diagram is known as the time-distance diagram. The cross-covariance is essentially a phase coherent average of the random oscillations (Bogdan 1997, and **Supplemental Video 2**). It is a solar seismogram: it provides a way to measure wave travel times between two surface locations.





Distance (km)
0
200
400
600
800
1000
-600
-400
-200
0
200
165°
170°
175°
180°
-35°
-40°
-45°
165°
170°
175°
180°

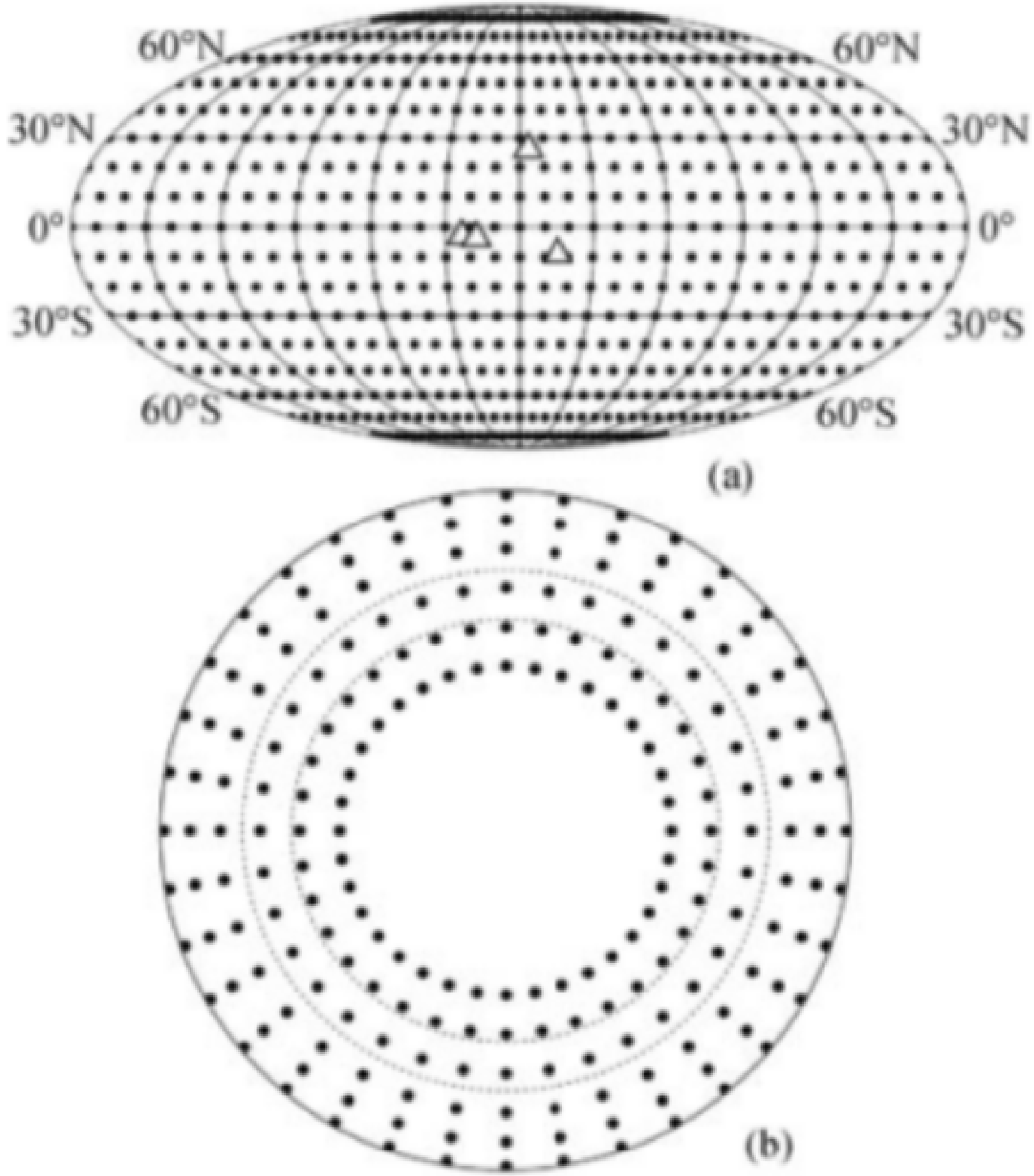
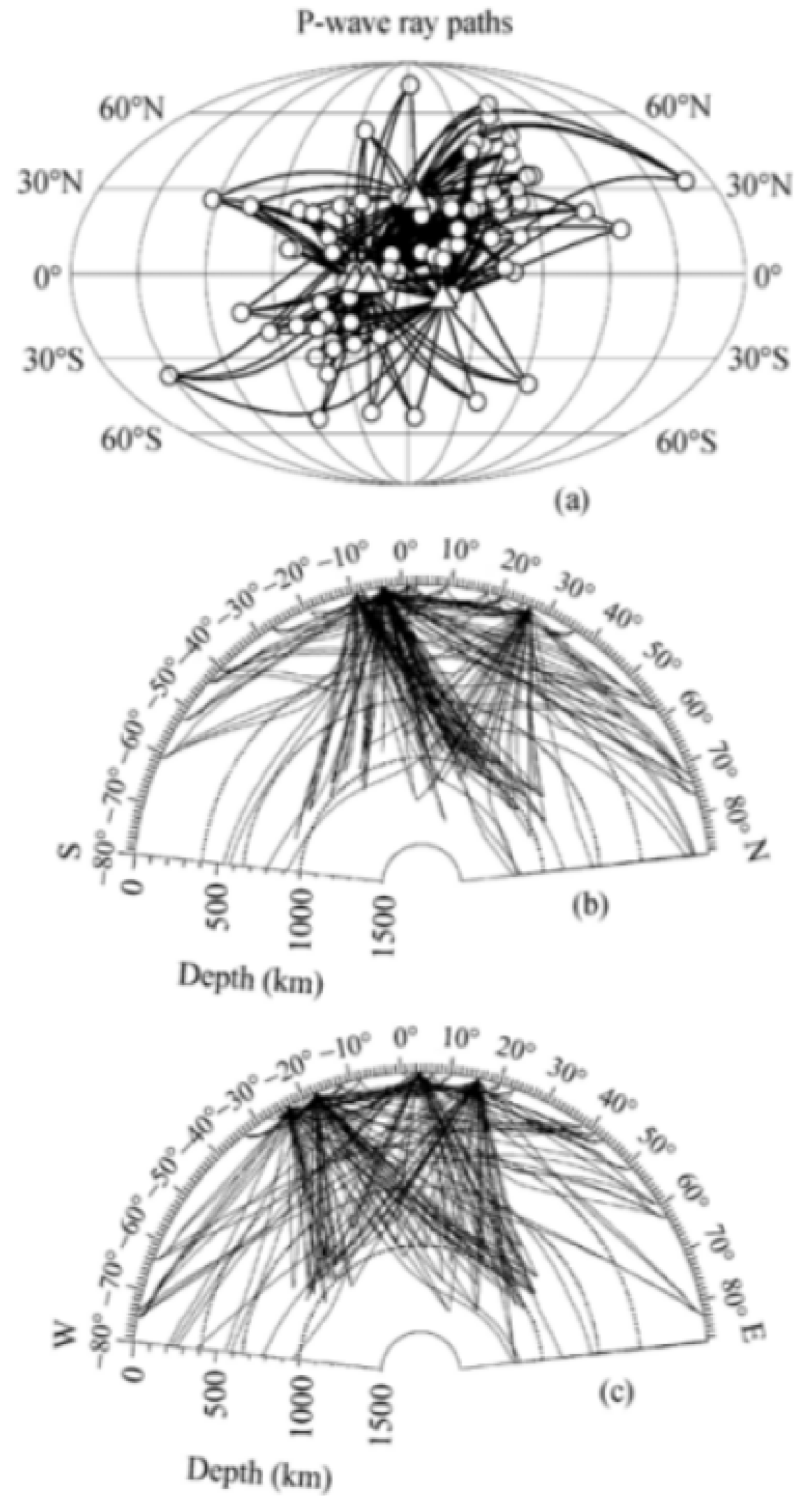


Figure 4 Distribution of the grid nodes adopted for the tomogra
inversion in plan view (a) and vertical cross section (b). The open tr
gles in (a) denote the four Apollo seismic stations.



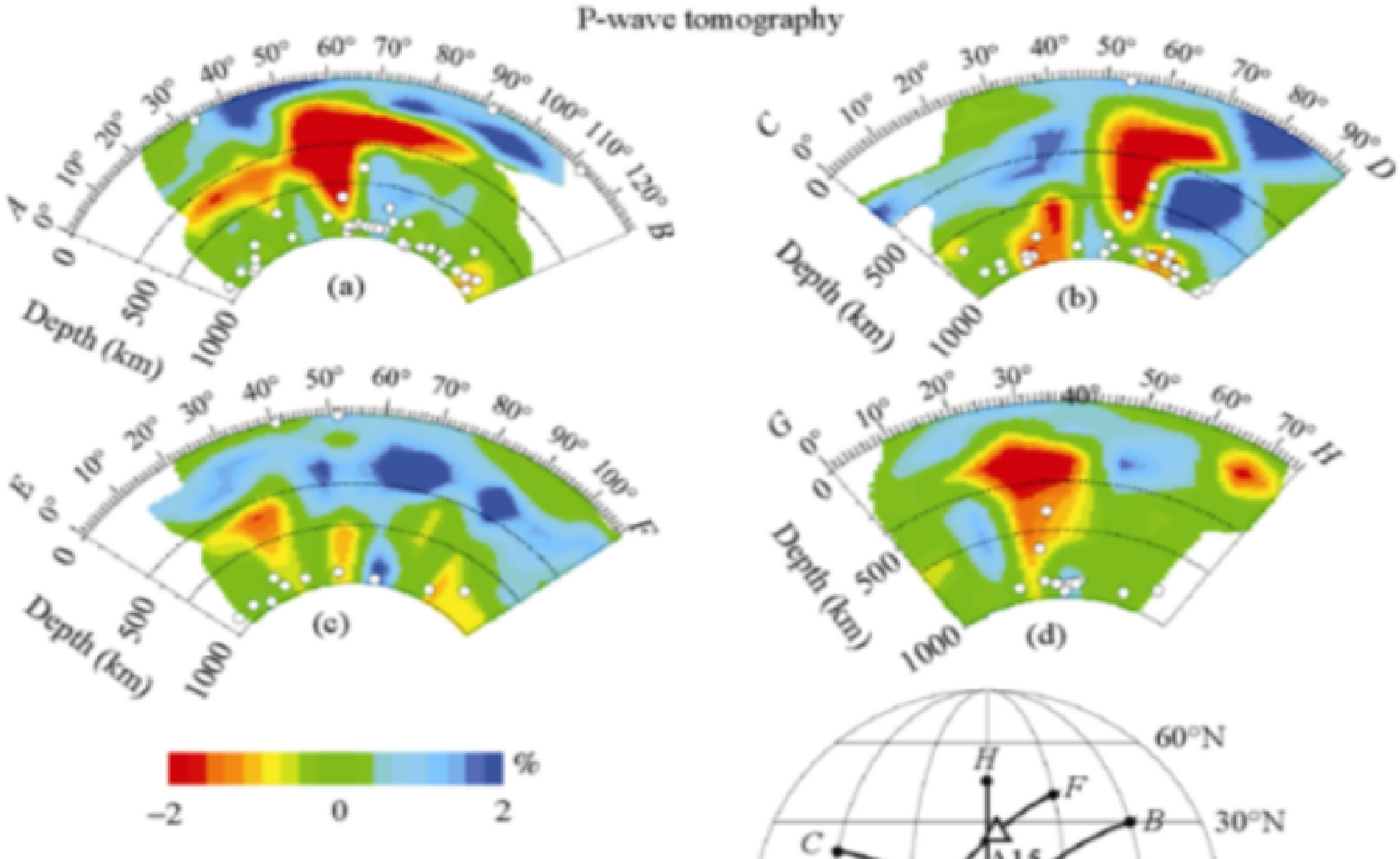
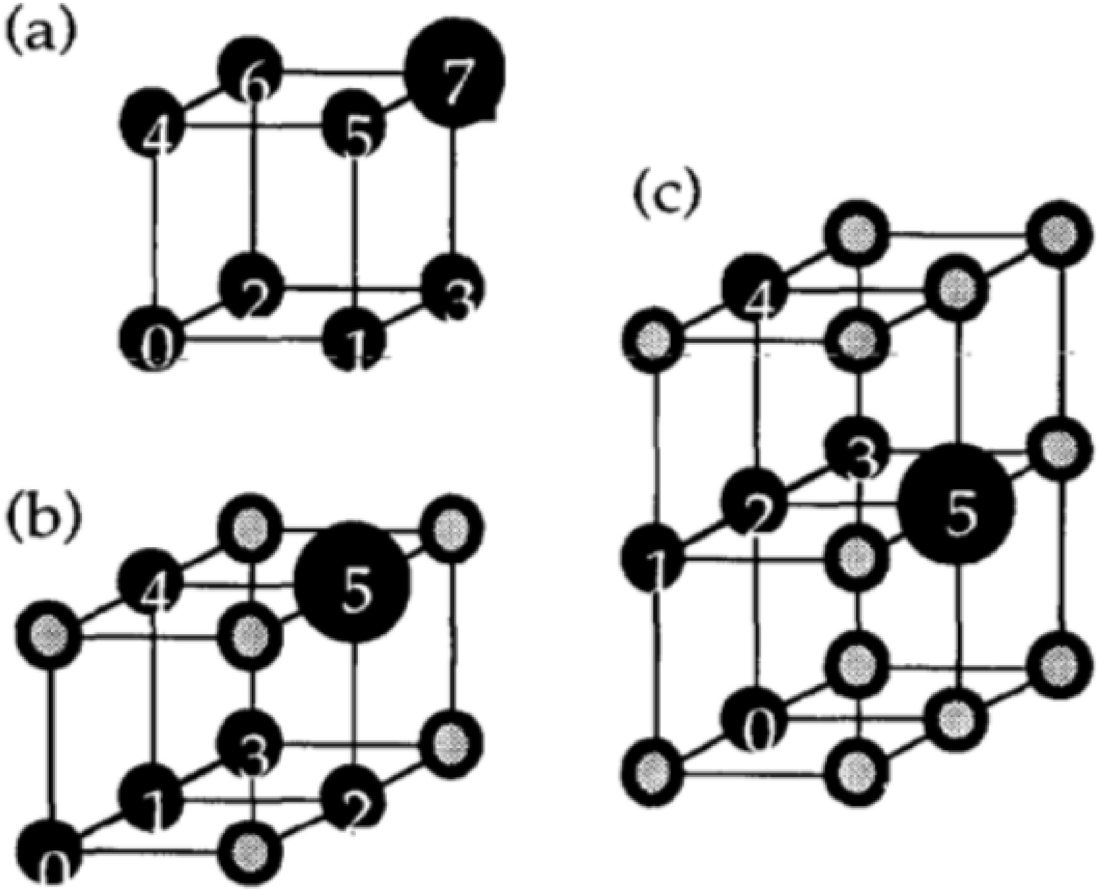


Figure 9 Vertical cross sections of P-wave tomography along the four profiles shown on the map. Red and blue colors denote low and high velocities, respectively. The scale of velocity perturbations relative to the 1-D velocity model (Figure 3) is shown below (c). White dots denote moonquakes occurring within 150 km width of each profile. Open triangles on the map denote the four Apollo seismic stations.



$$\left(\frac{\partial t}{\partial x}\right)^2 + \left(\frac{\partial t}{\partial y}\right)^2 + \left(\frac{\partial t}{\partial z}\right)^2 = s^2(x, y, z)$$

$$t_7 = t_0 + \frac{1}{\sqrt{2}}\sqrt{6h^2s^2 - (t_1 - t_2)^2 - (t_2 - t_4)^2 - (t_4 - t_1)^2 - (t_3 - t_5)^2 - (t_5 - t_6)^2 - (t_6 - t_3)^2}, \quad (2)$$

$$t_5 = t_1 + \sqrt{2h^2s^2 - 0.5(t_0 - t_3)^2 - (t_2 - t_4)^2}. \quad (3)$$

$$t_5 = t_2 + \sqrt{h^2s^2 - 0.25[(t_1 - t_3)^2 + (t_0 - t_4)^2]}.$$

1990. Vidale

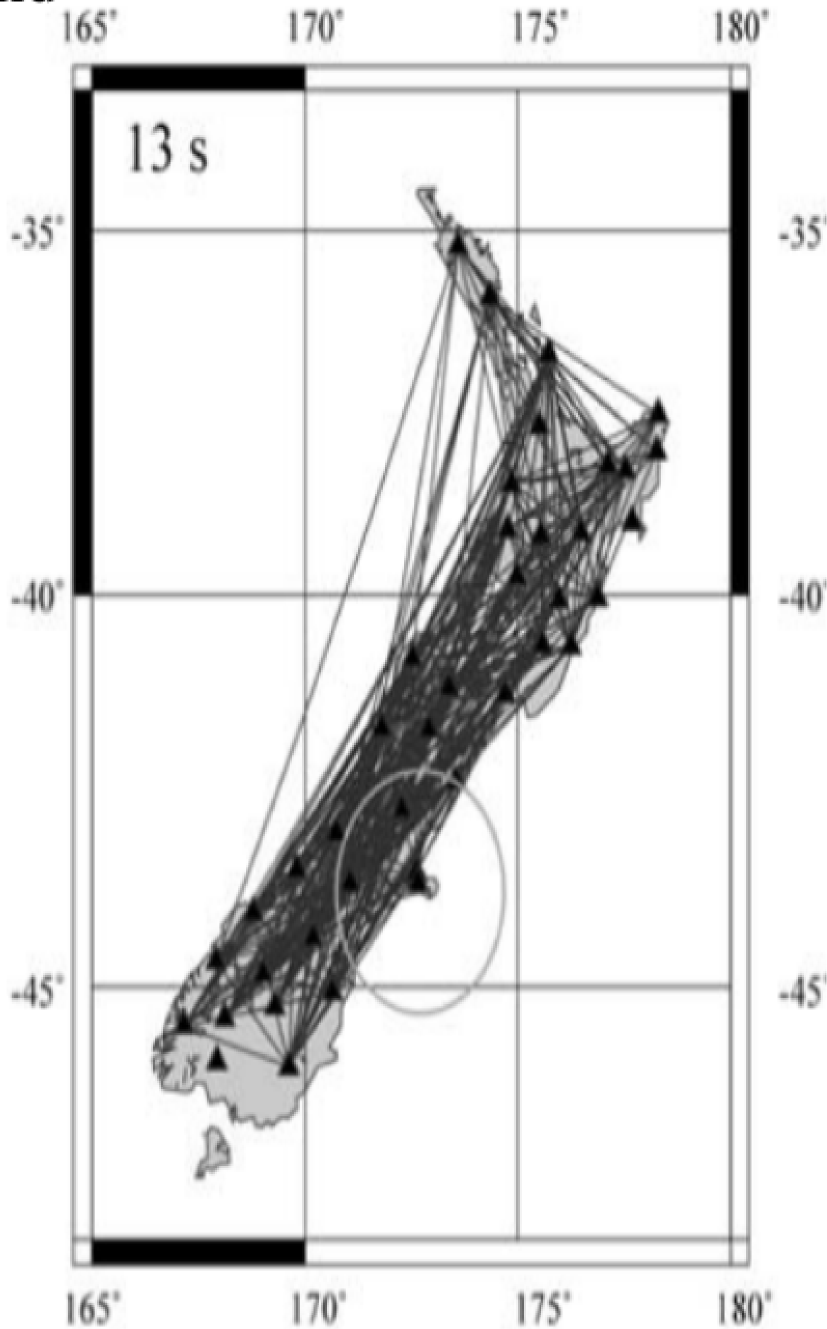
Seismic Data: Earthquakes, Anthropogenic, Background

The current velocity distribution is updated according to the vector computed, and the process is repeated until the Subsurface Map stabilizes.

The ray path from a source to the station is defined by following the steepest gradient in the time grid from the source. From the ray geometry of all source-receiver pairs the matrix describing the forward tomographic problem can be computed:

$$\mathbf{r} = \mathbf{G}\Delta u, \quad (1)$$

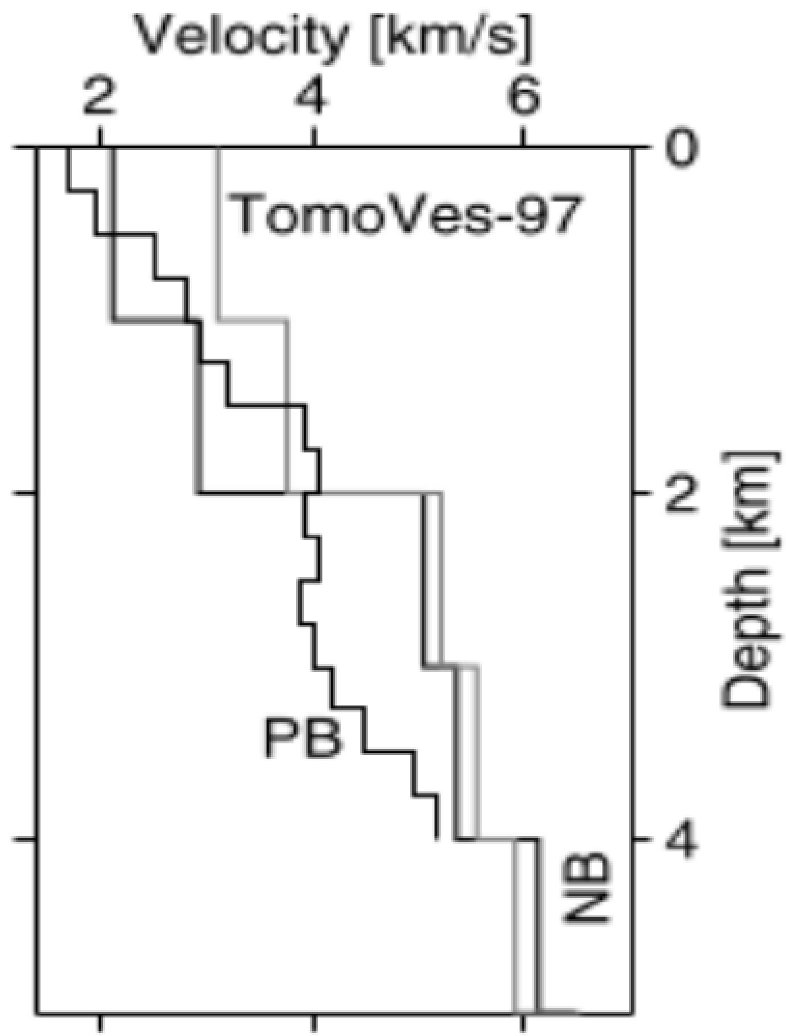
where $\mathbf{r}$ is the travel time residual vector, i.e., the difference between the observed travel times and the travel times computed in the current velocity distribution. Δu is the slowness (1/velocity) perturbation vector. Each G_{pj} coefficient is the length of the ray p sampling cell j.



$$d_i = G_i(x_j)$$

Initial 3-D Velocity Distribution:
Starting Model designed using a subsurface simulation grid (nx, ny, nz)

To image a region we use an estimation grid of cubic cells describing the scale we want to resolve (mx, my, mz)



The current velocity distribution is updated according to the vector computed, and the process is repeated until the velocity model stabilizes.

We give a quick overview of the theory of systems of linear, algebraic equations. This is not intended to serve as a text on linear algebra, merely a review of some important concepts. Detailed discussions of various aspect of this material can be found in [43] or [78].

Consider a system of m equations for n unknowns, $(x_1, \ldots, x_n)$:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \quad & \cdots + a_{1n}x_n &= y_1 \\ a_{21}x_1 + a_{22}x_2 + \quad & \cdots + a_{2n}x_n &= y_2 \\ \vdots \qquad\qquad & \qquad \vdots & \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \quad & \cdots + a_{mn}x_n &= y_m. \end{aligned} \tag{1.16}$$

There are four questions which require answers:

4.2.1 Inverse problem

The inverse problem corresponding to the forward problem given by 2 is nonlinear. We define the *a posteriori* probability density function (PDF) as

$$\begin{aligned} \sigma_M(m) = & \\ \exp\Bigg(-\frac{1}{2}\Bigg(&\sum_{i=0}^{I-1}\left(\frac{g(m)_i - d_i^{\text{obs}}}{\sigma_i}\right)^2 + \sum_{j=0}^{N-1}\frac{S_j}{S}\left(\frac{c_j - c_j^{\text{prior}}}{\sigma_c}\right)^2 \\ &+ \sum_{j=0}^{N-1}\frac{S_j}{S}\left(\frac{l_j - l_j^{\text{prior}}}{\sigma_l}\right)^2 + \sum_{k=0}^{M-1}\left(\frac{A_k - A_k^{\text{prior}}}{\sigma_A}\right)^2\Bigg)\Bigg) \end{aligned} \tag{7}$$

Existence:

For a given m-vector $(y_1, \ldots, y_m)$ does there exist an n-vector $(x_1, \ldots, x_n)$ which satisfies the equations in (1.16)?

Uniqueness:

When a solution exists is it unique? More generally, describe the space of solutions.

Solve in practice:

Give an algorithm to find approximations for the solutions of (1.16) and criteria to select a solution when there is more than one.

Stability:

How sensitive is the solution to small variations in the coefficients (a_{ij}) or the right hand side (y_j)?

It is a somewhat unexpected, but very important fact that these issues are in practice, rather independent of one another.

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