

# Complexity of inverse and direct cascading of earthquakes

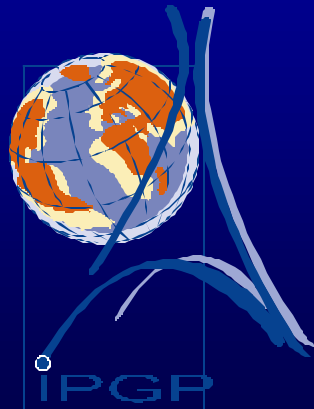
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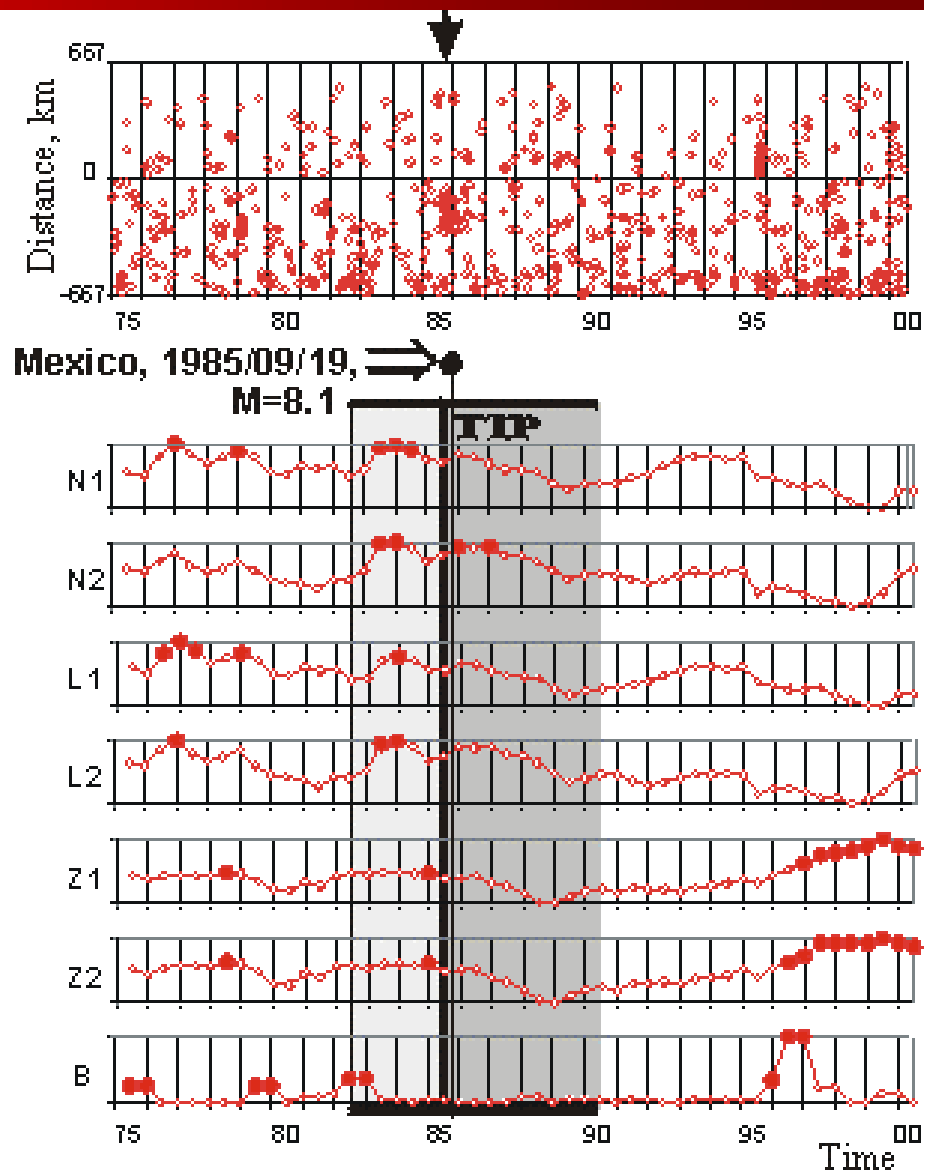
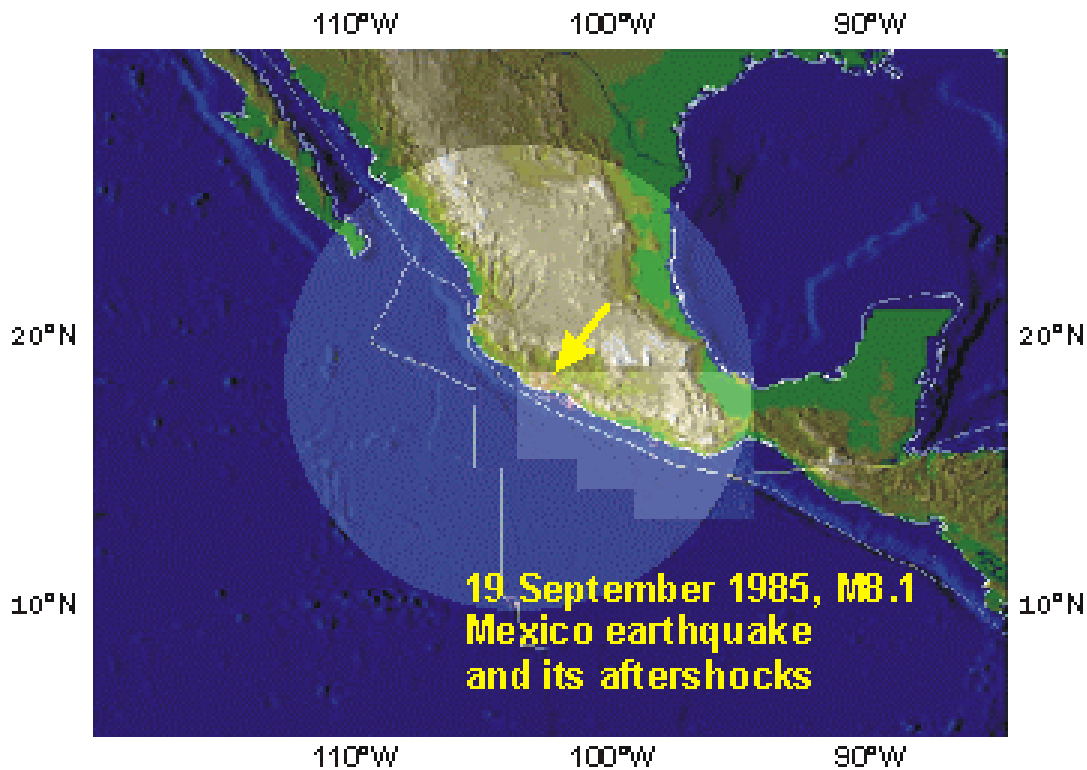
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"Complexity in Geophysical  
Systems"

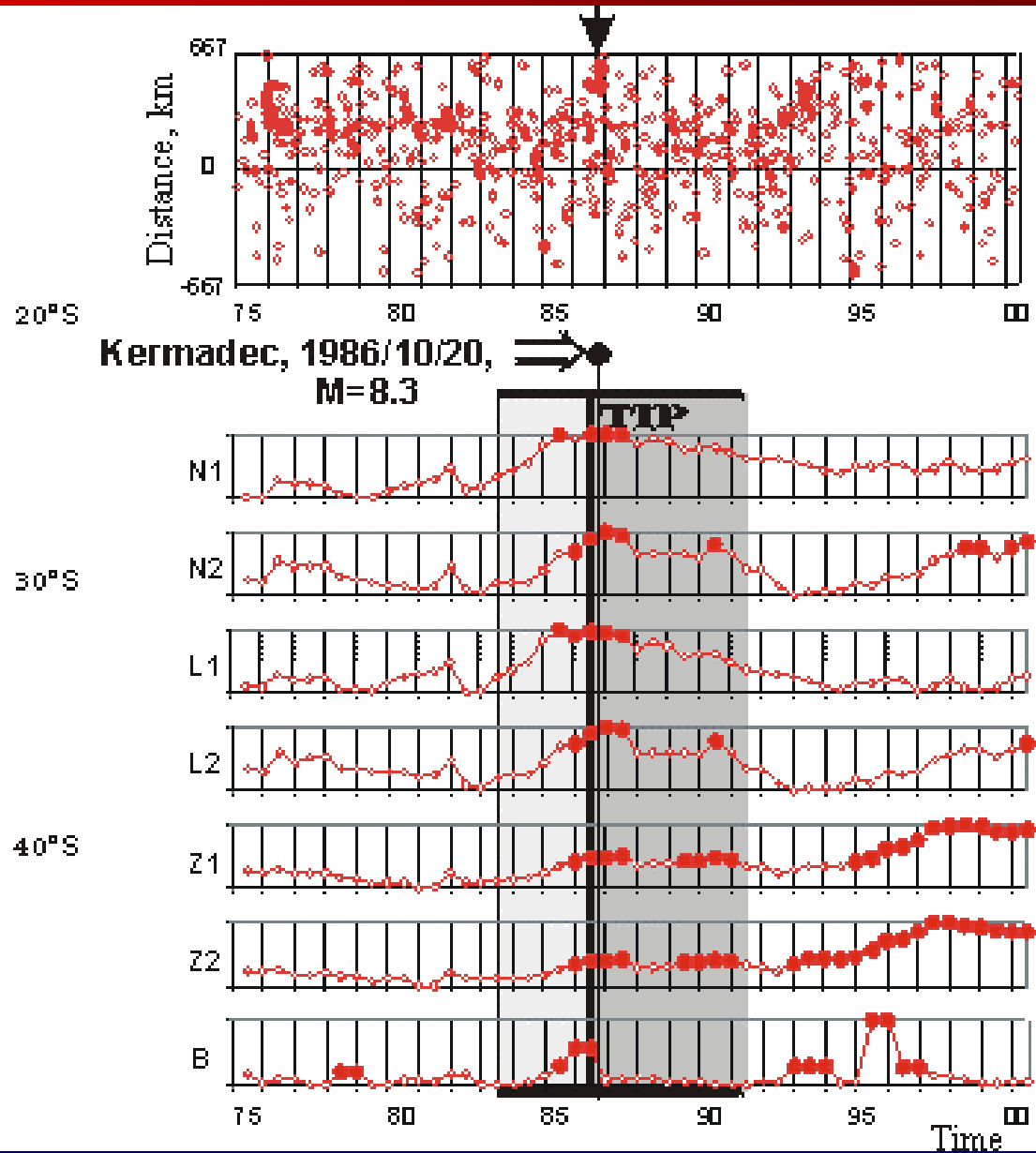
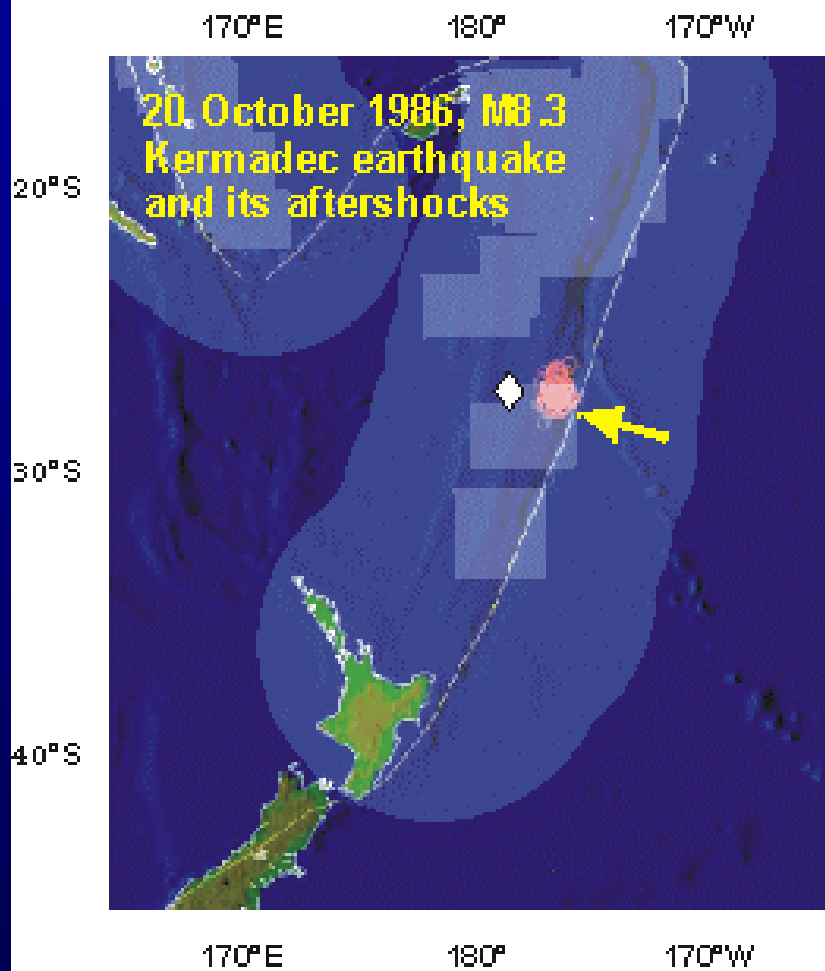
# Outline

- **Uniform presentation of seismic dynamics prior to and after all the recent earthquakes of magnitude 8.0 or larger, 1985-2000**
- **What is in common and different?**
- **Witness to “transient phase changes” in system of blocks-and-faults?**

# 19/09/1985 Mexico Earthquake



# 20/10/1986 Kermadec Earthquake

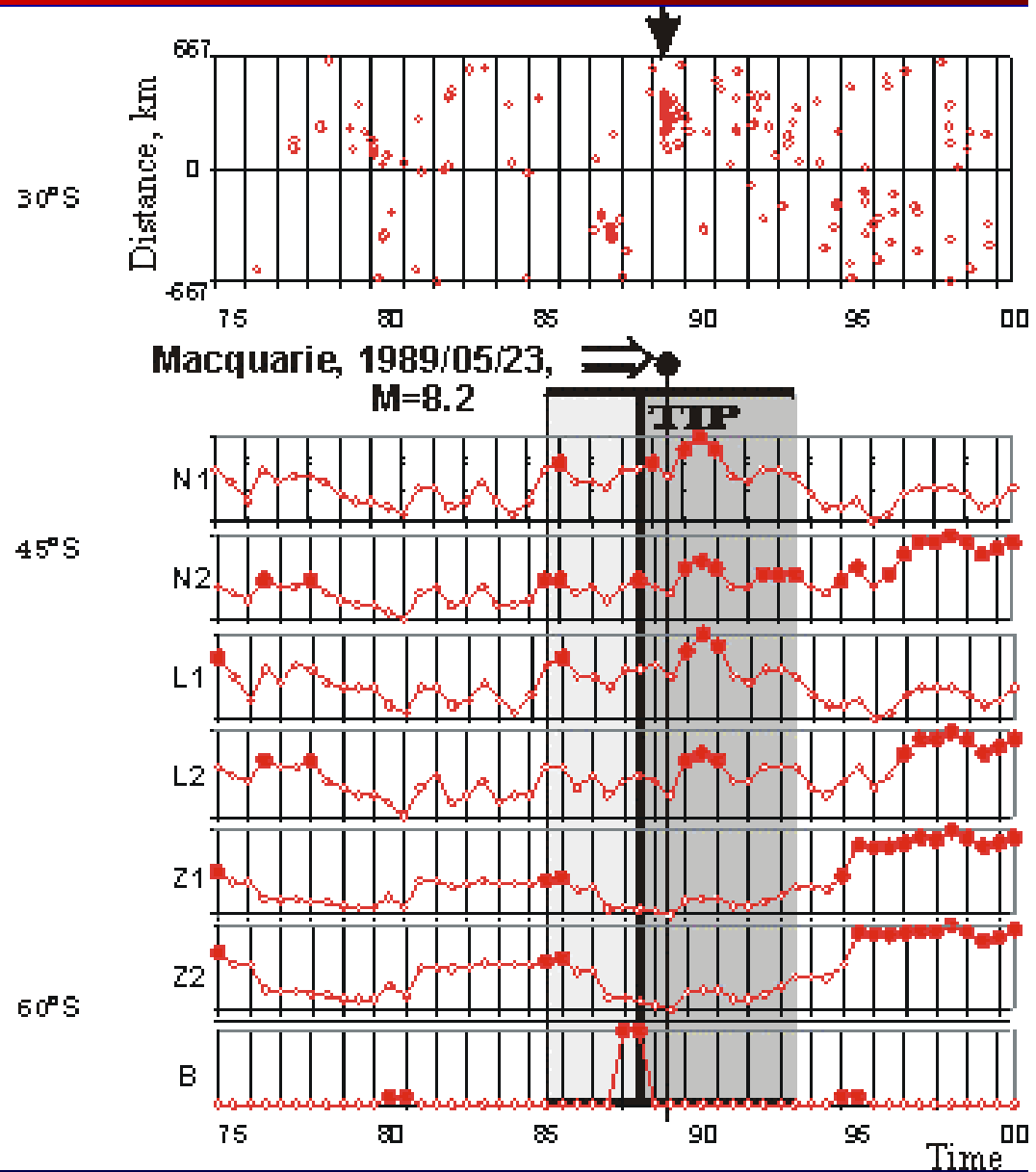
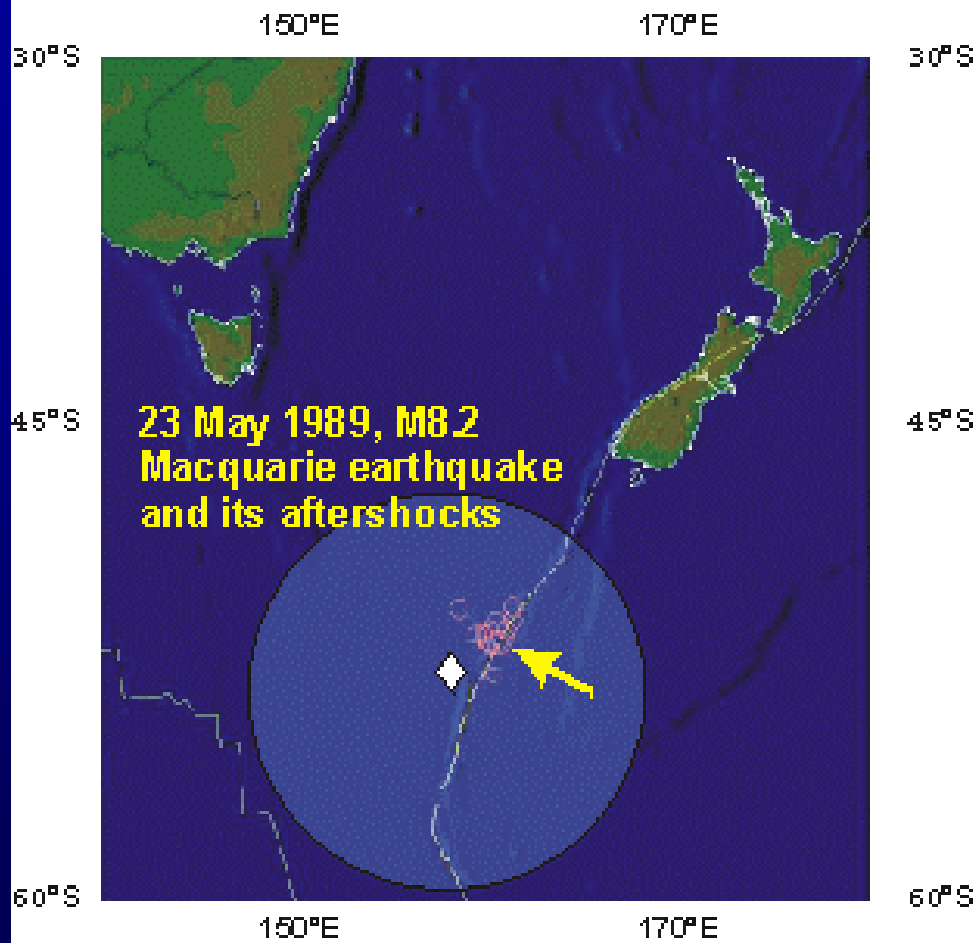


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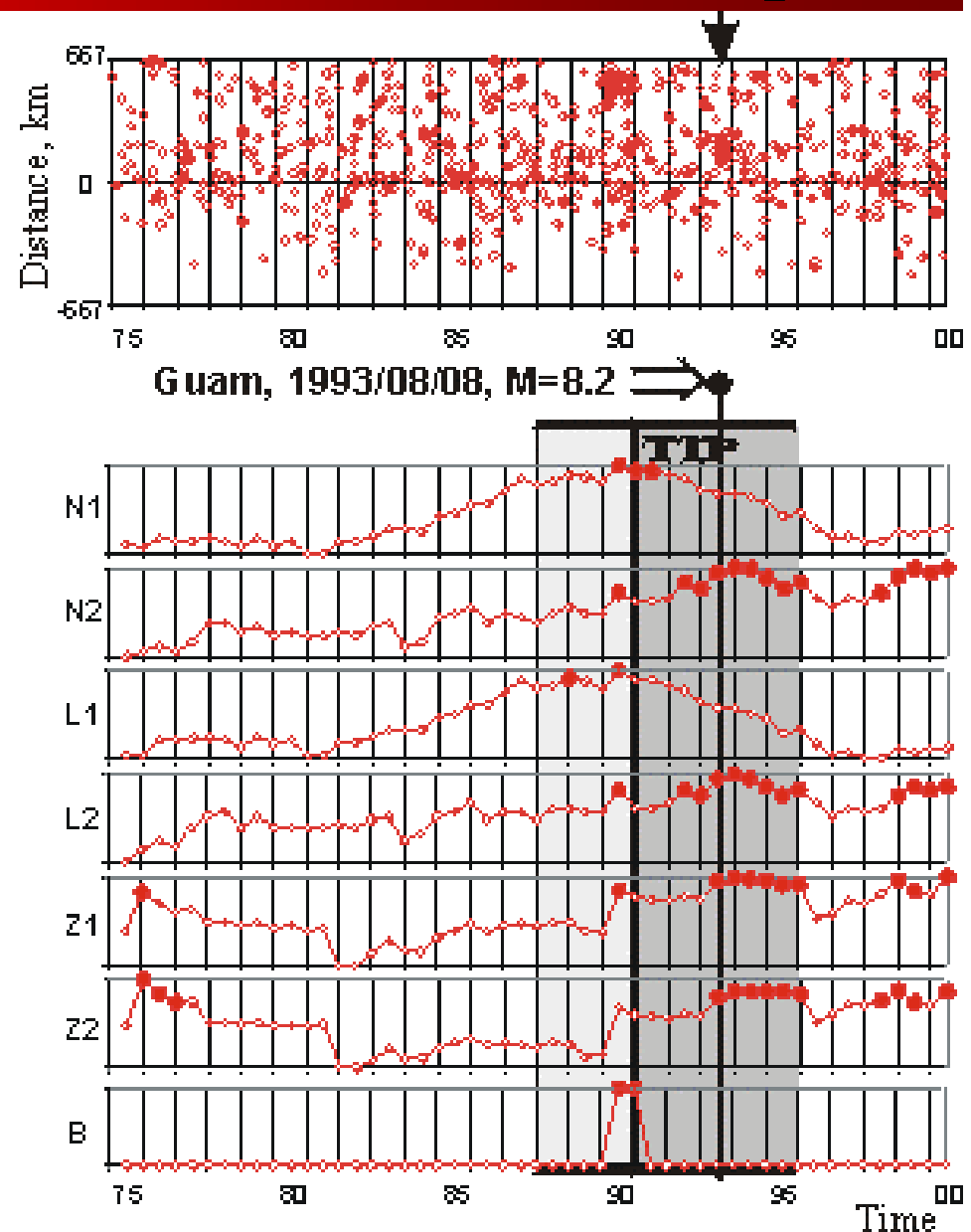
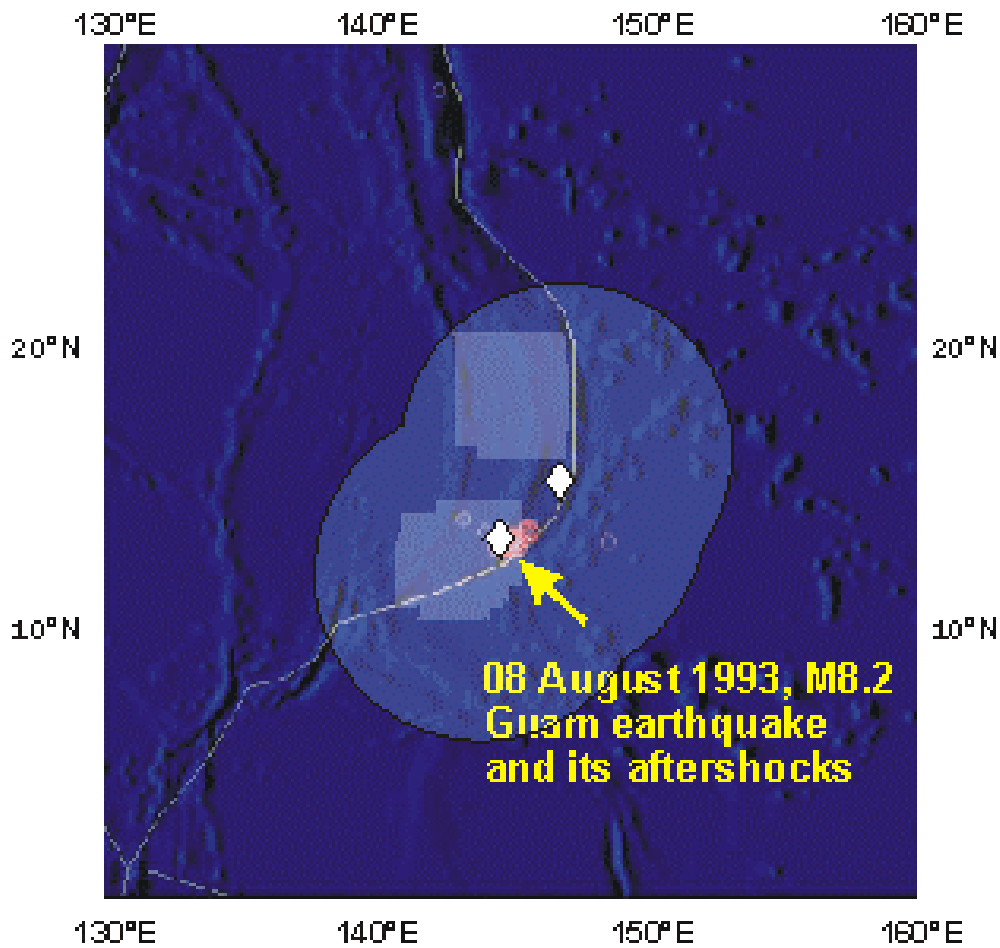
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# 23/05/1989 Macquarie Earthquake



# 08/08/1993 Guam Earthquake



11/10/2001

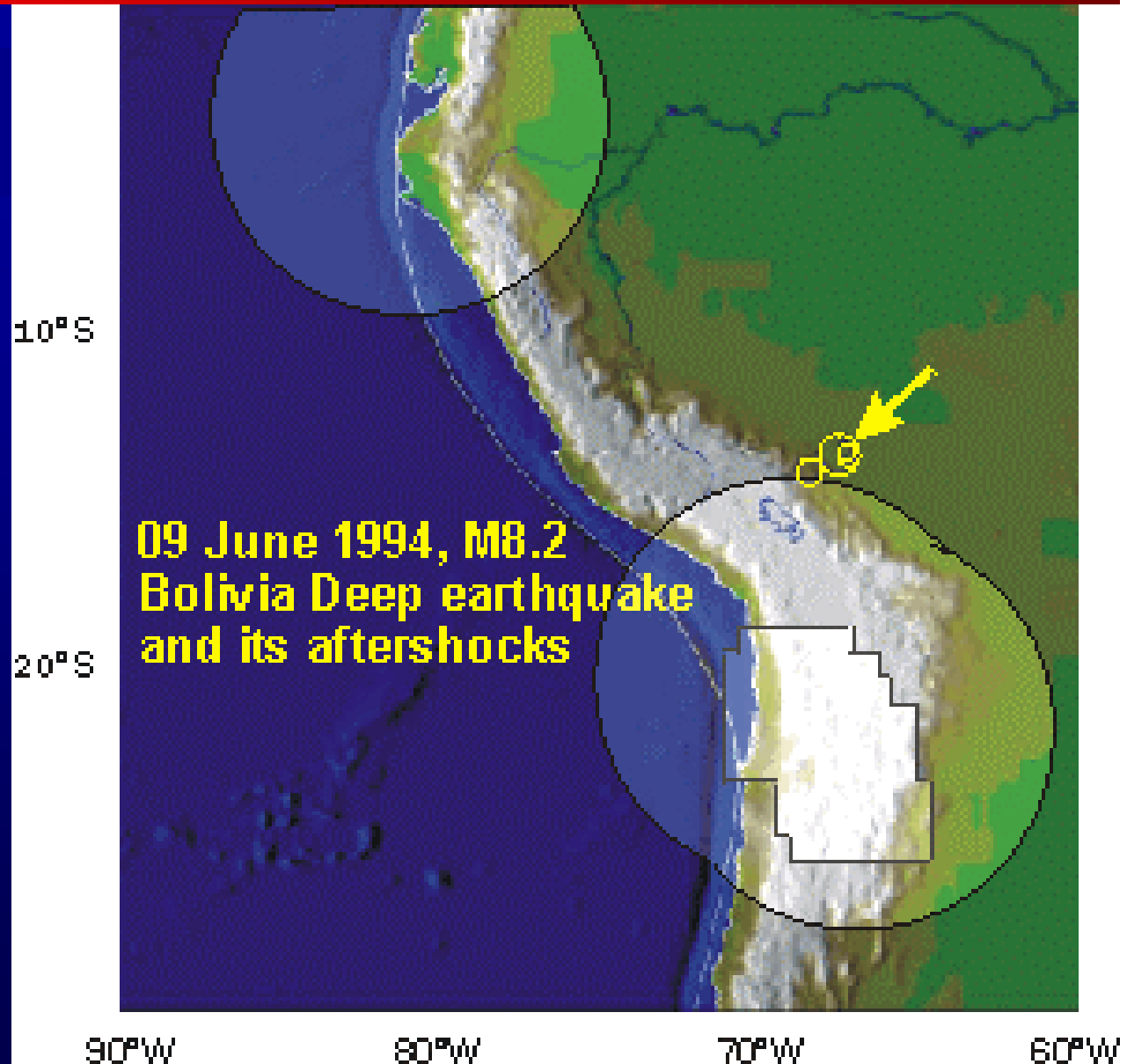
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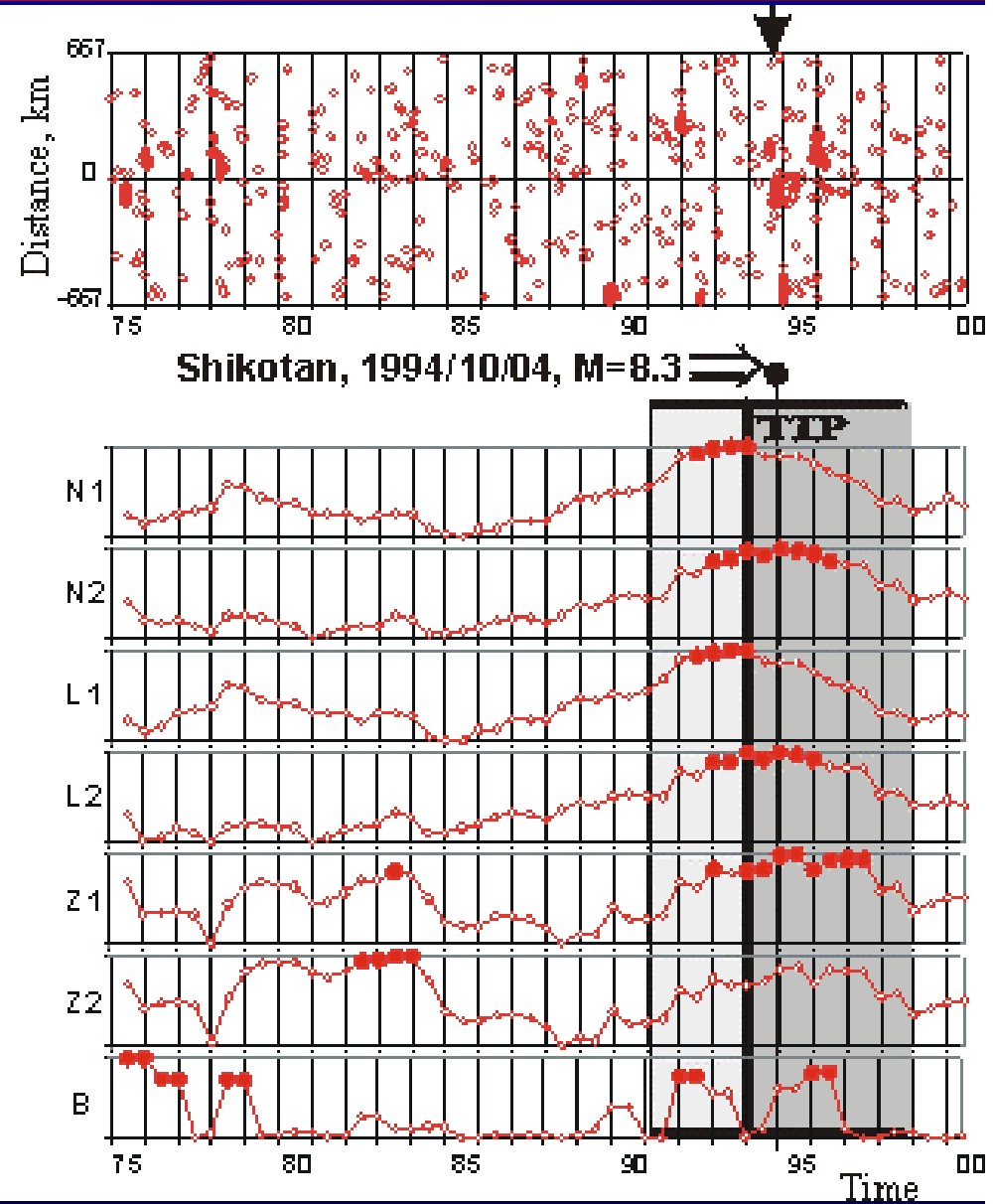
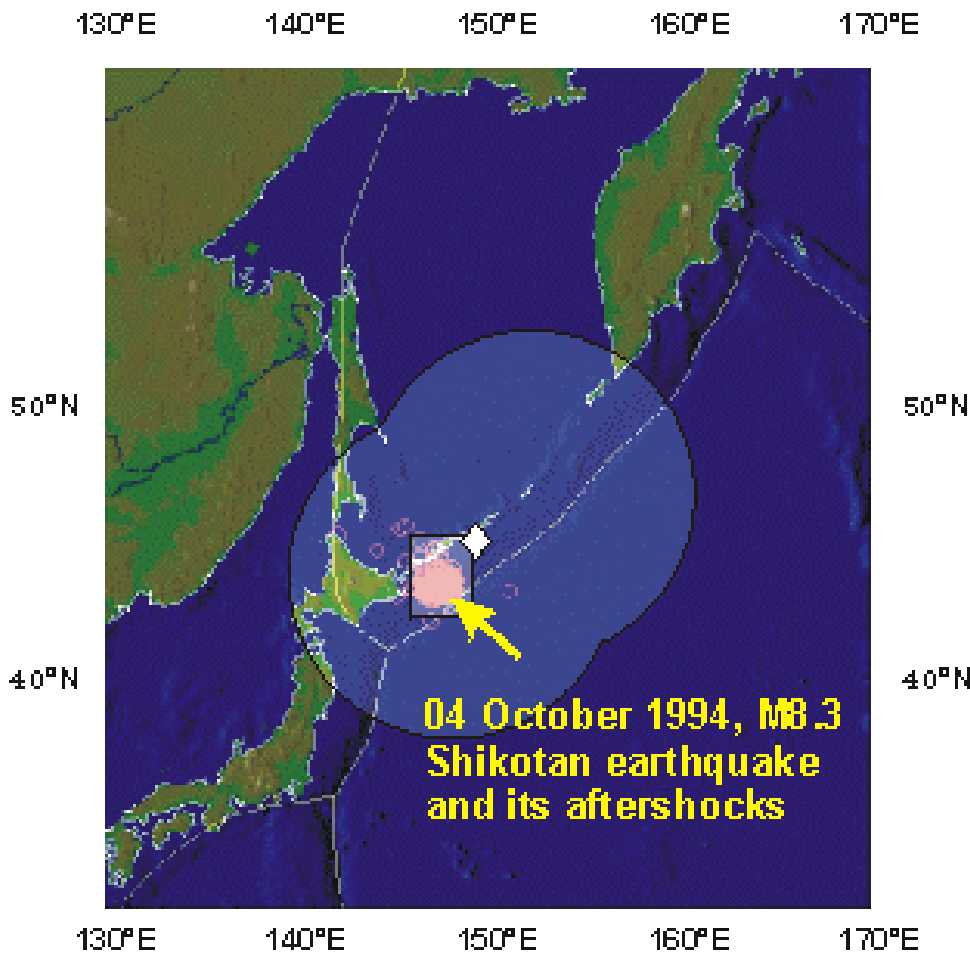
# 09/06/1994 Bolivia Deep Earthquake

- The Great Deep Bolivia earthquake did occur after the January 10, 1994, magnitude 6.9, depth 595 km earthquake at distance of about 250 km.

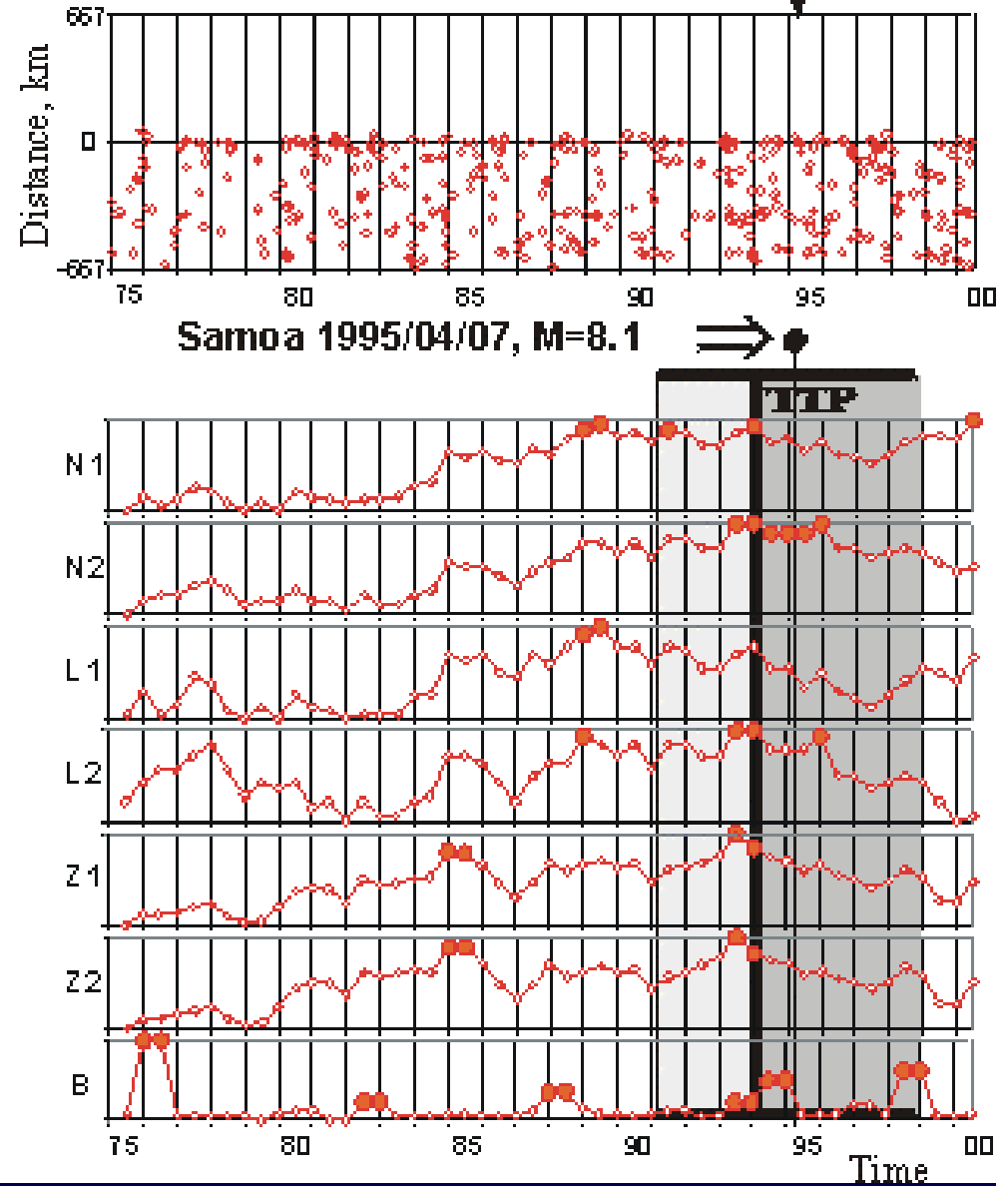
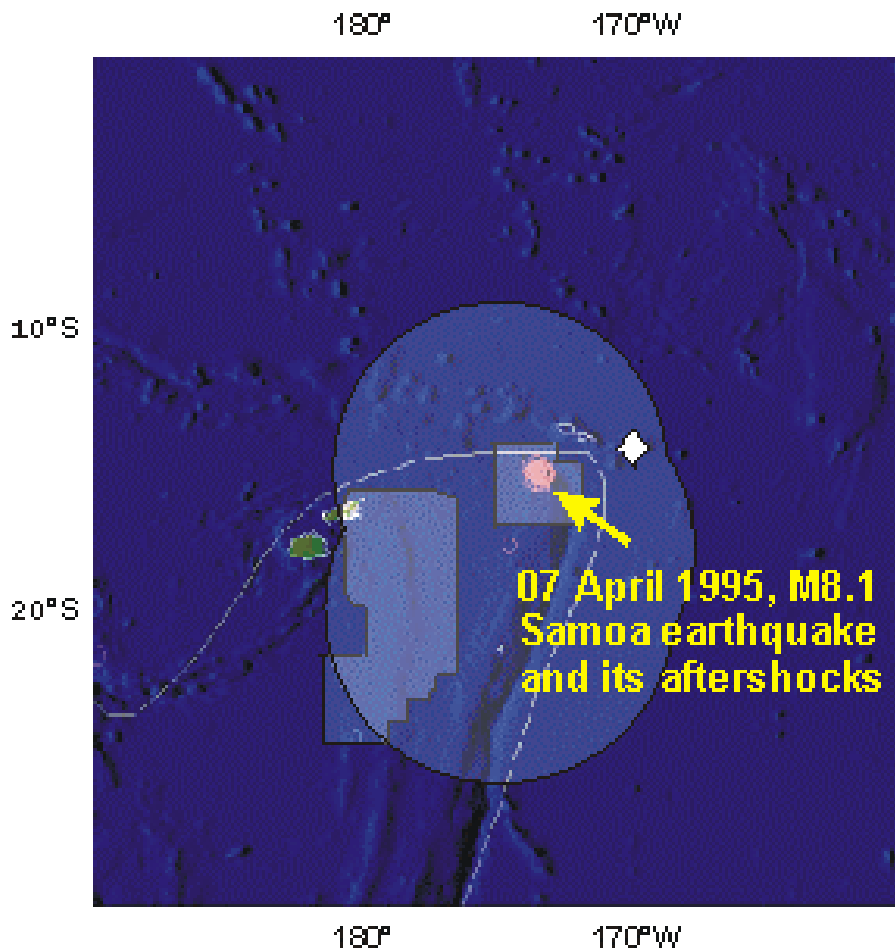
The previous earthquake that deep happened here in 1963.



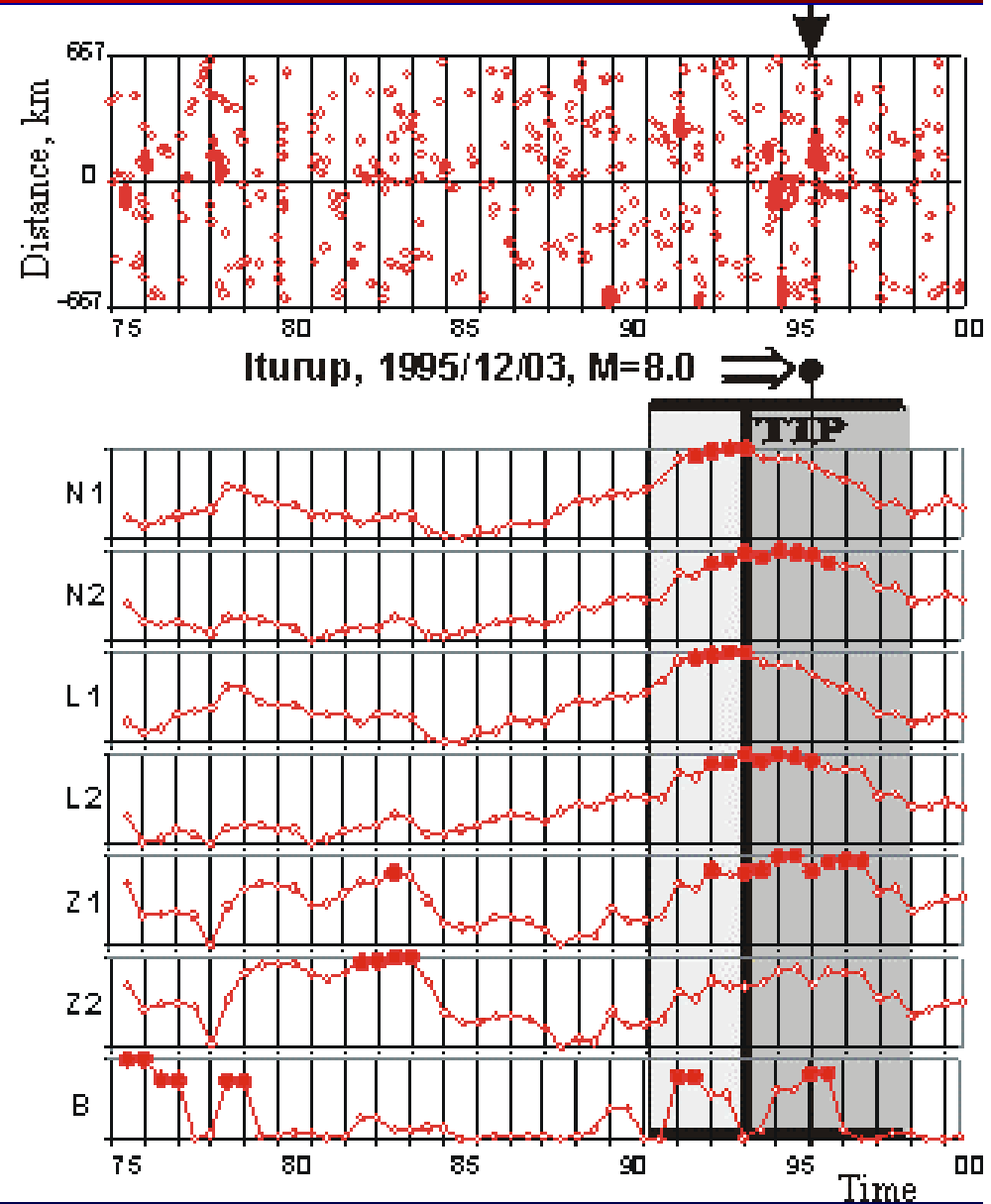
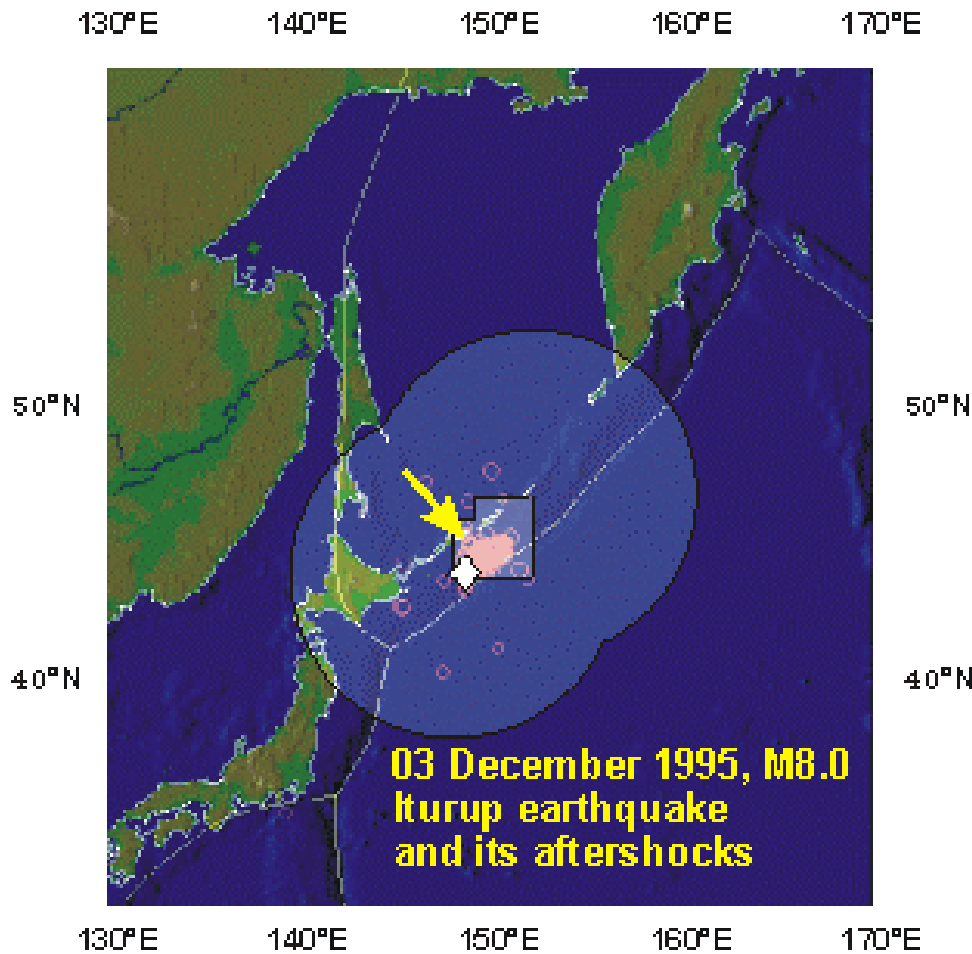
# 04/10/1994 Shikotan Earthquake



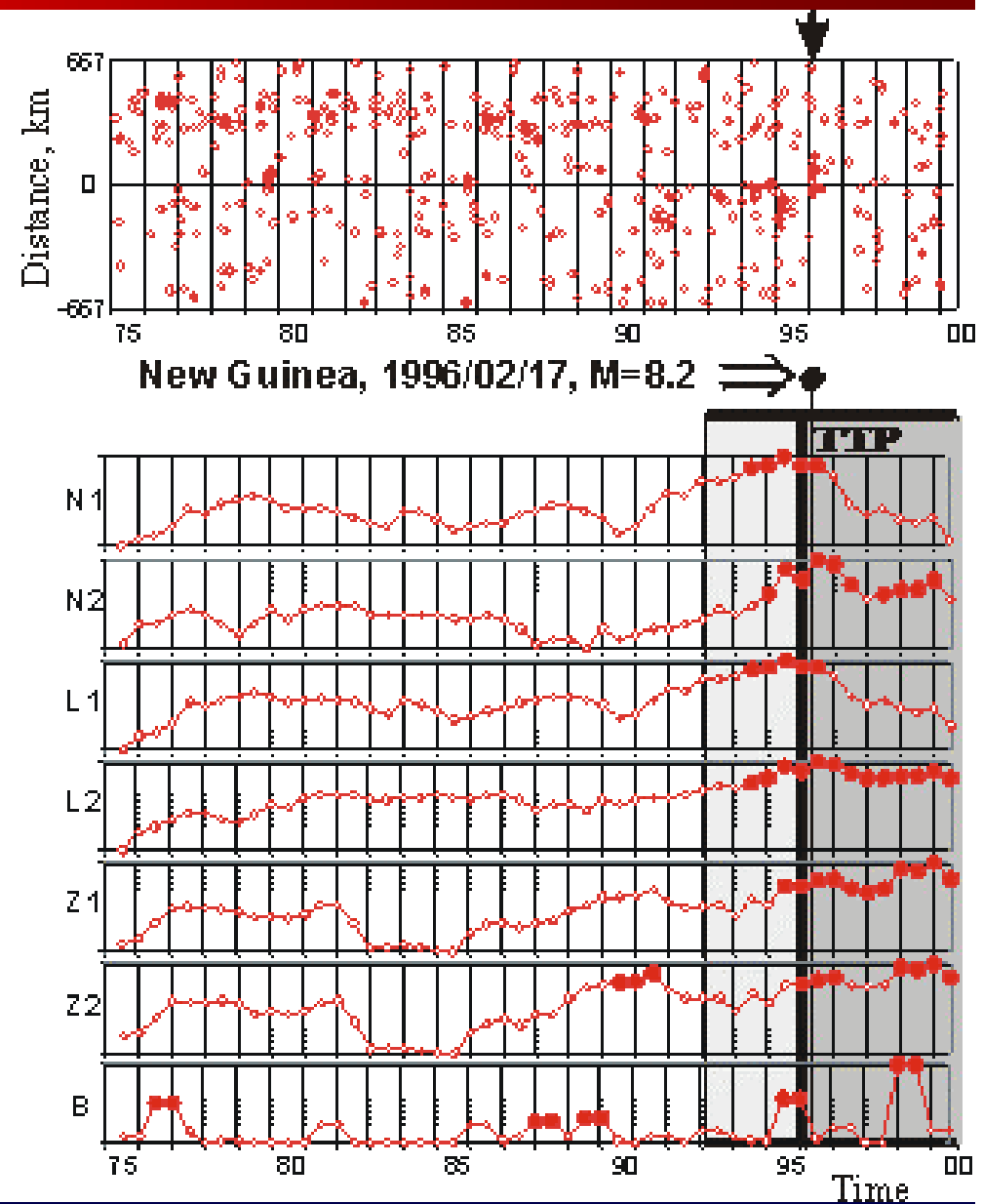
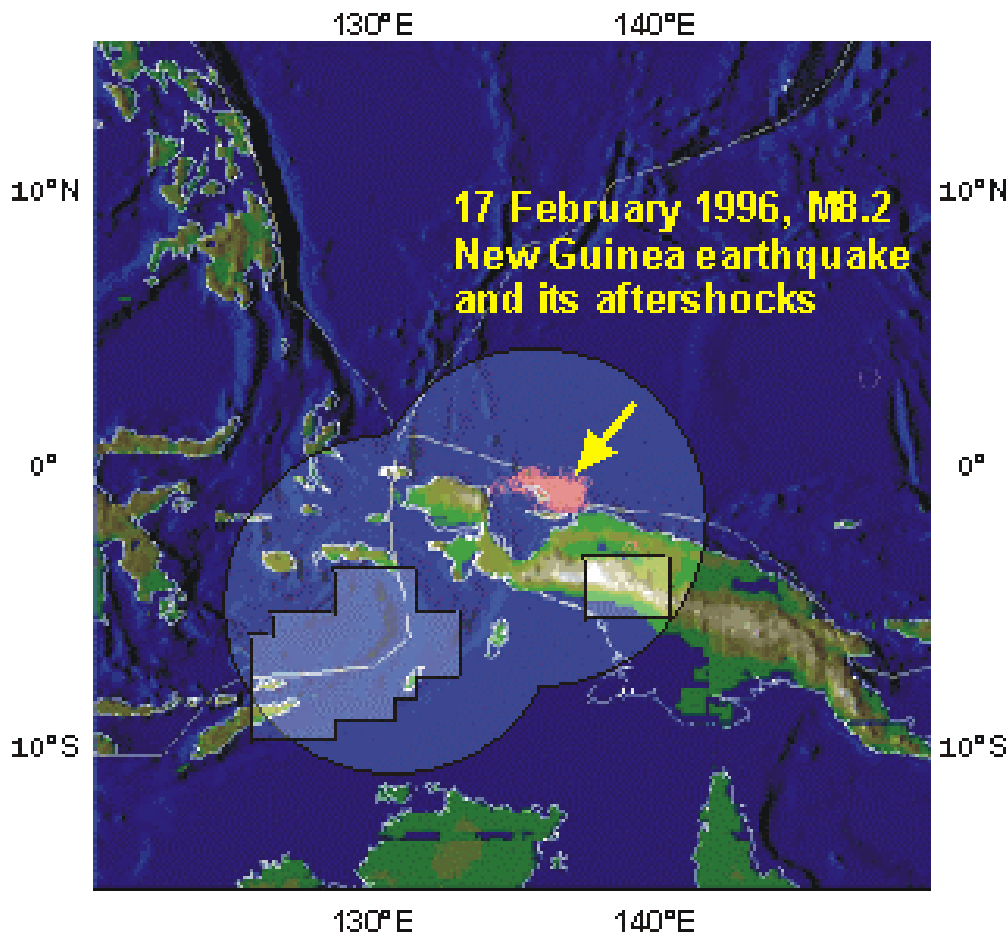
# 07/04/1995 Samoa Earthquake



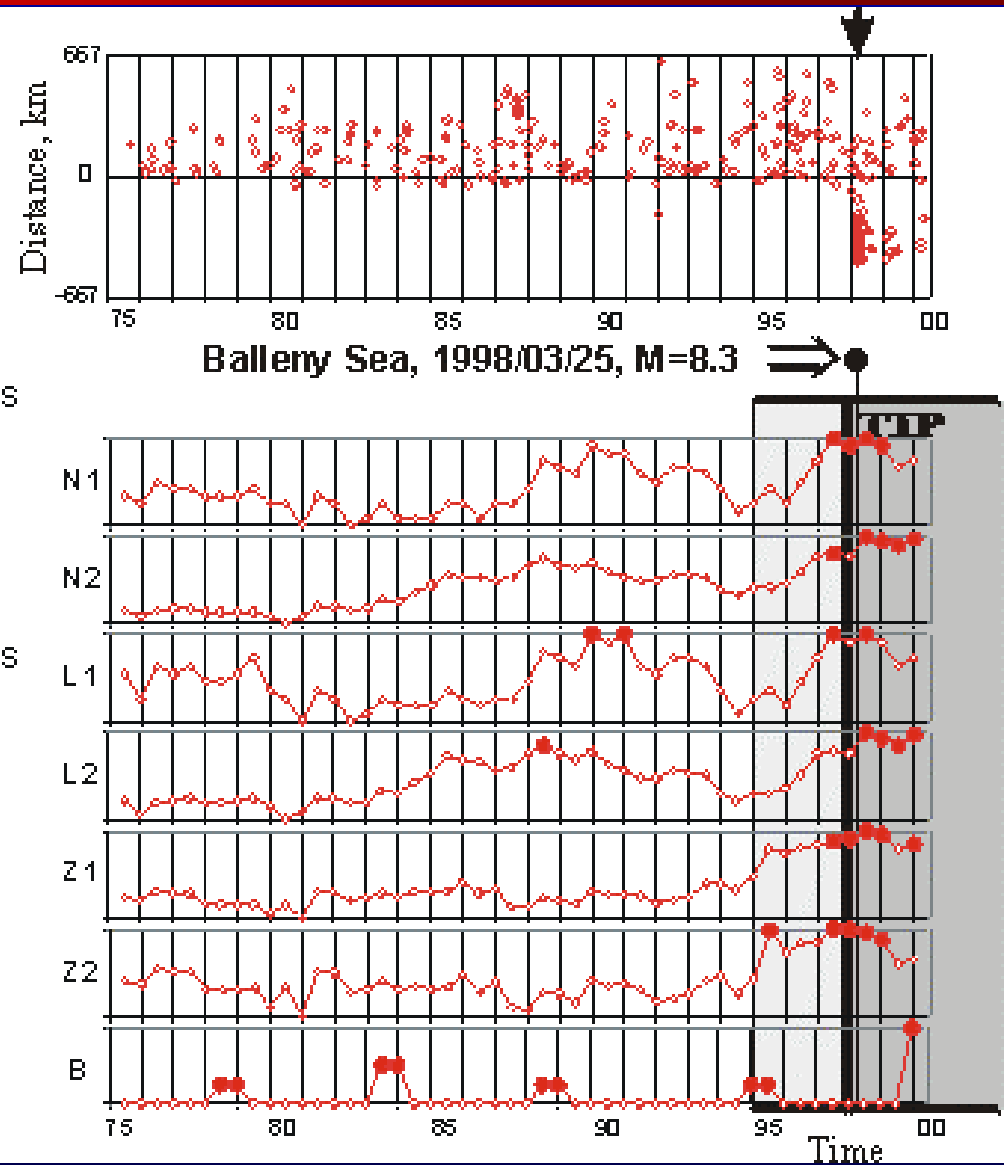
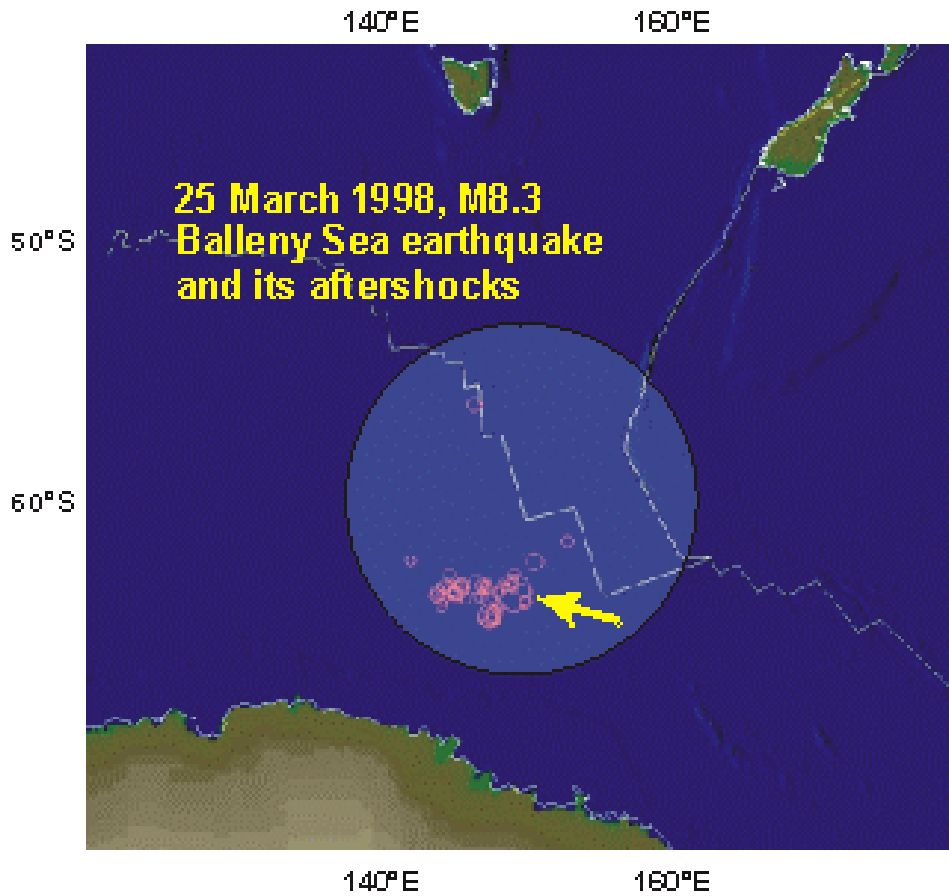
# 03/12/1995 Iturup Earthquake



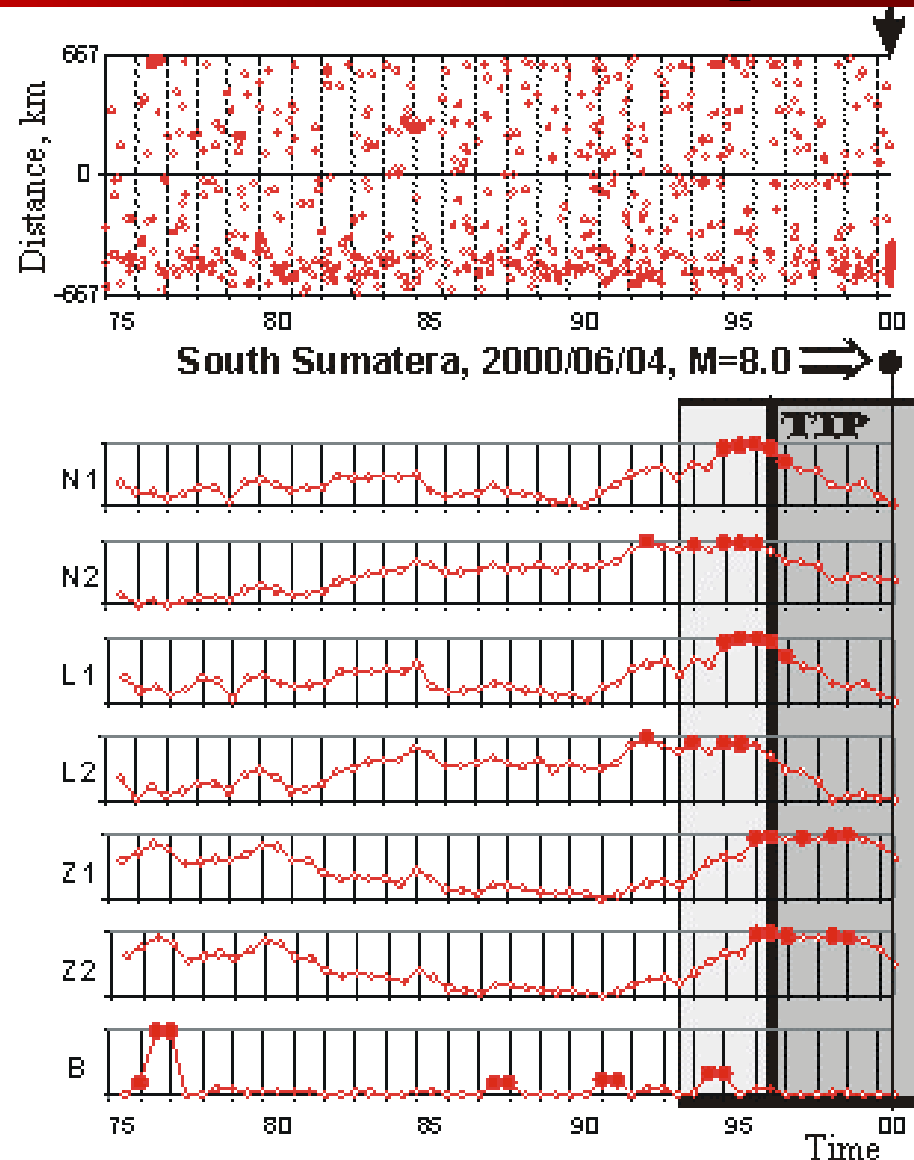
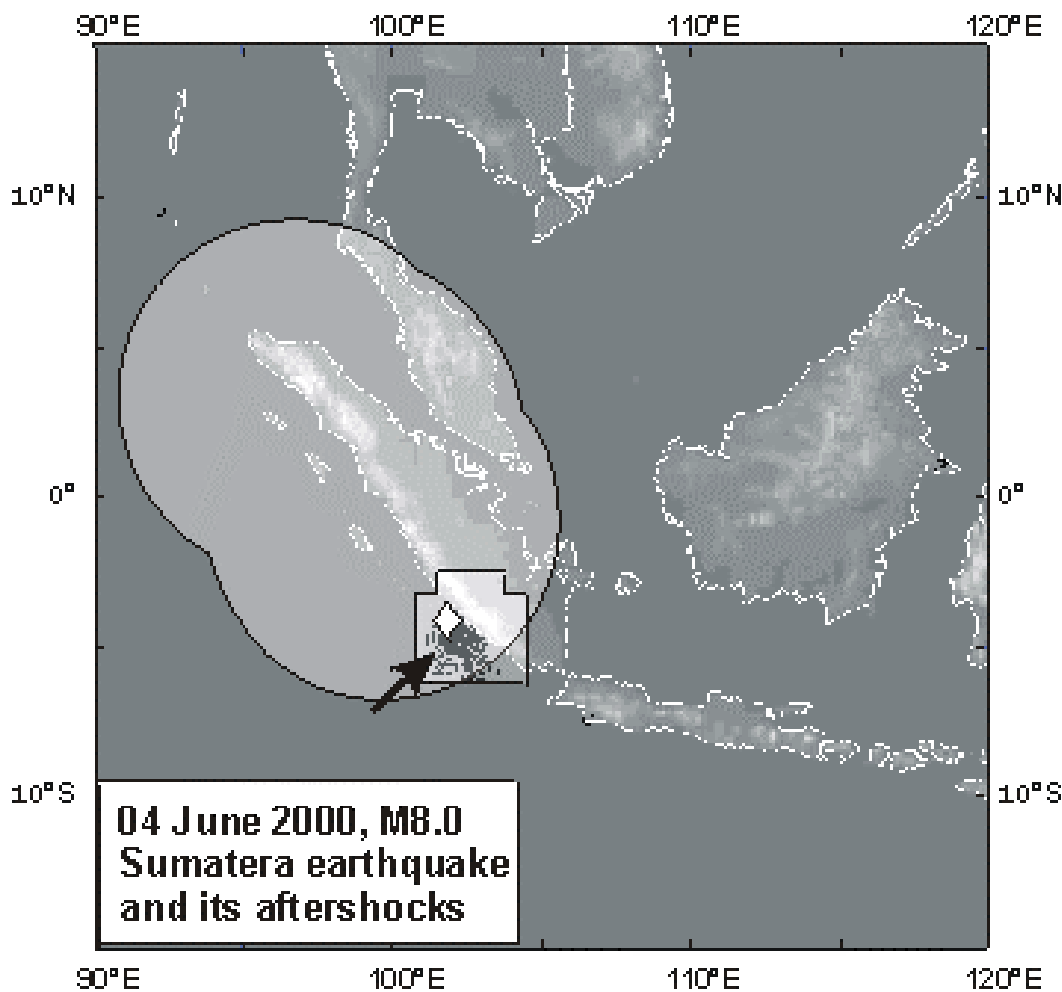
# 17/02/1996 New Guinea Earthquake



# 25/03/1998 Balleny Sea Earthquake



# 04/06/2000 South Sumatra Earthquake



# Cascading of earthquakes

**... detectable by reproducible  
*earthquake prediction methods***

- **Case histories of the recent earthquakes of magnitude 8 or above prove it and evidence consecutive stages of inverse cascading of seismic activity to the main shock.**

# Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: Magnitude 8.0 or more.

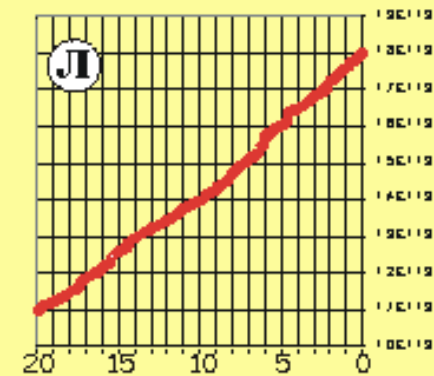
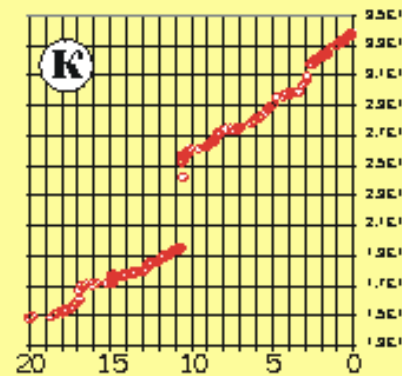
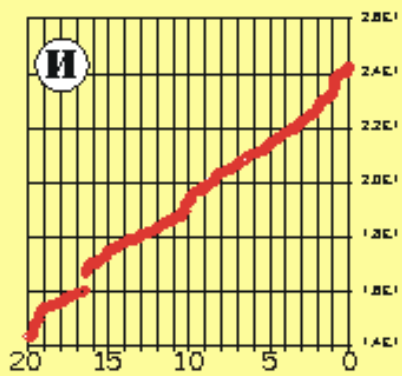
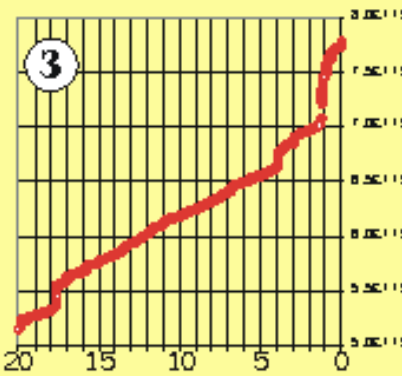
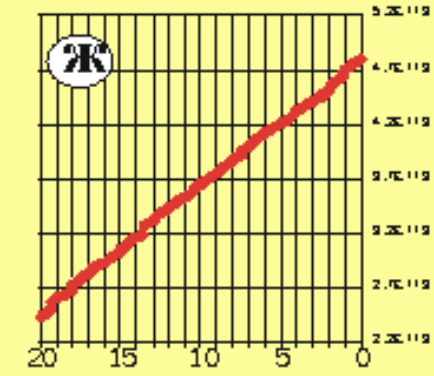
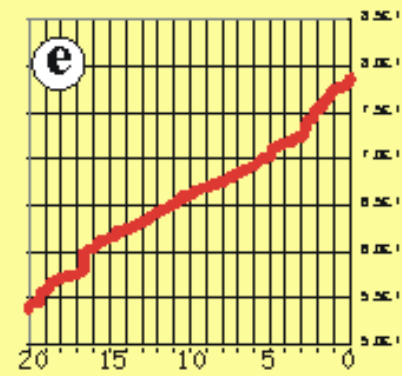
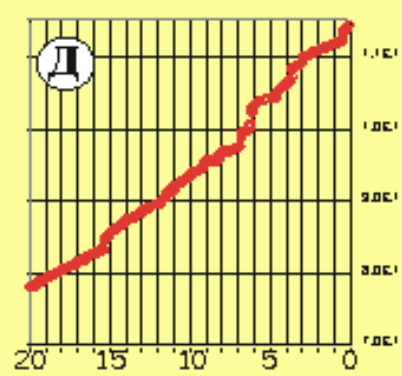
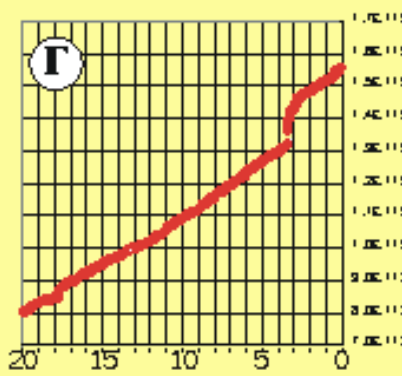
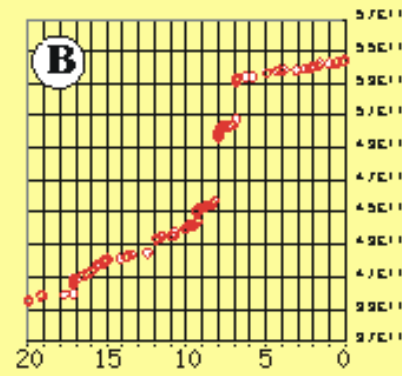
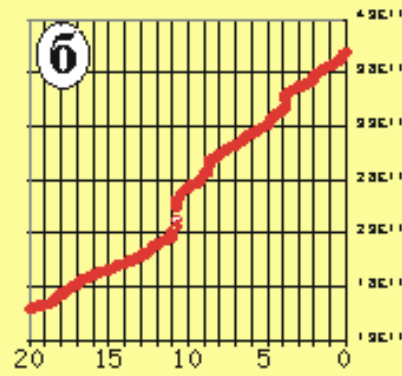
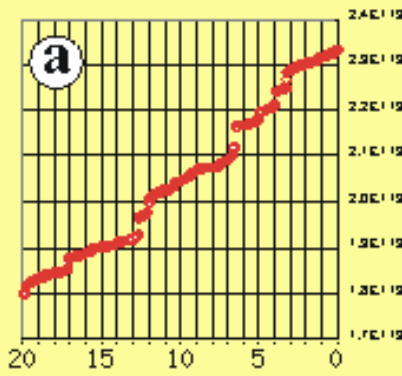
Test period	Large earthquakes			Percentage of alarms		Significance, %	
	Total	Predicted by		M8	M8-MSc	M8	M8-MSc
		M8	M8-MSc				
1985-2001	9	8	7	34.9	18.0	99.86	99.98
1992-2001	7	6	5	30.2	15.3	99.61	99.87

The significance level estimates use the most conservative measure of the alarm volume accounting for empirical distribution of epicenters.

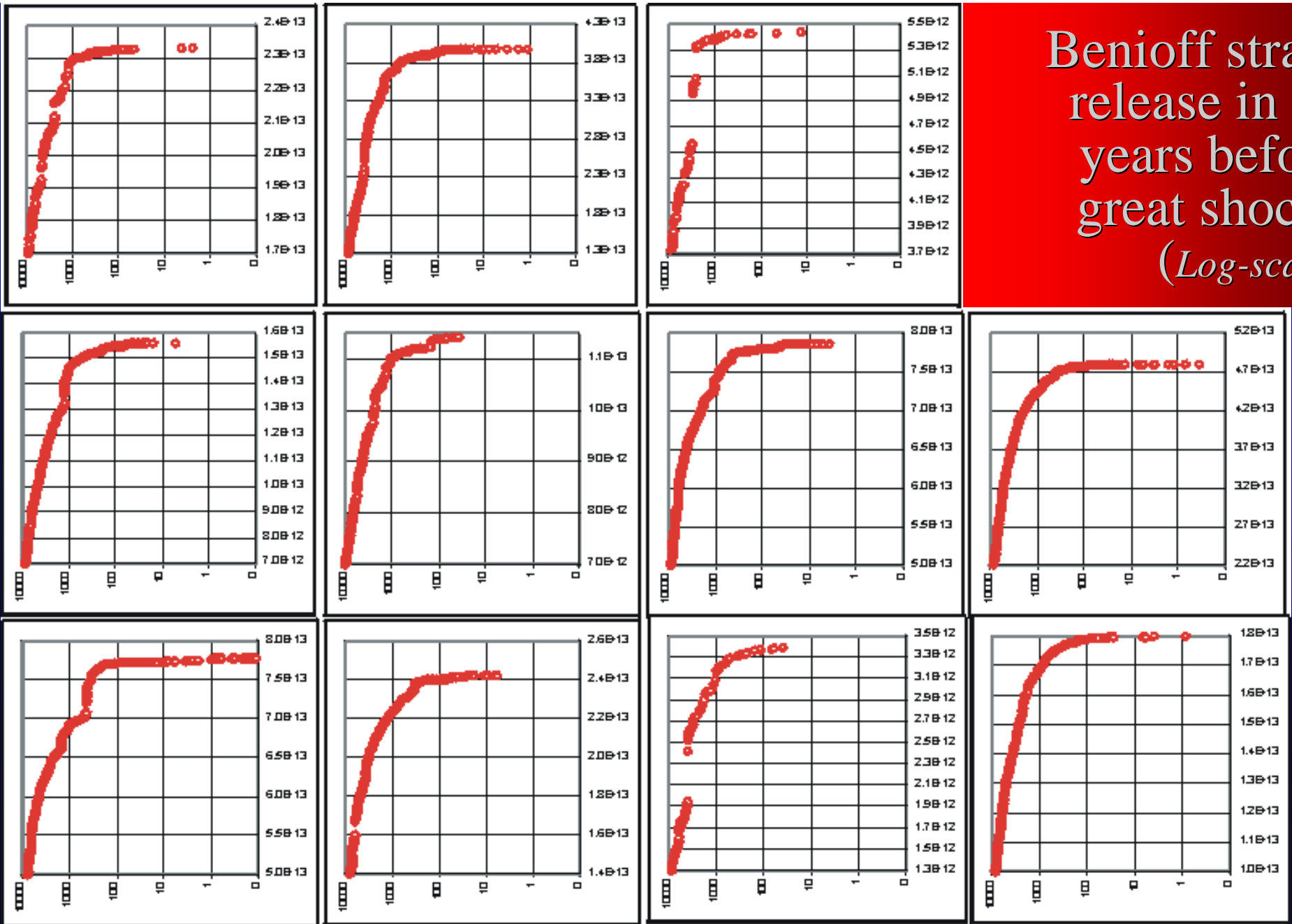
# Cascading of earthquakes

**Apparently more complicated than so far suggested power-laws...**

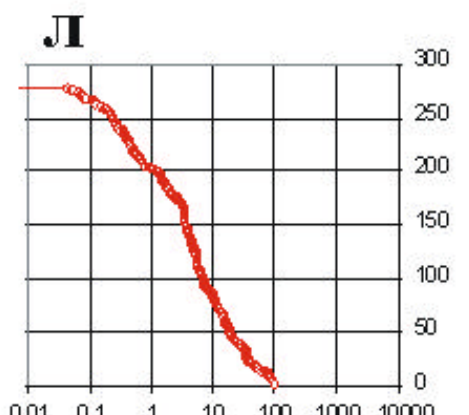
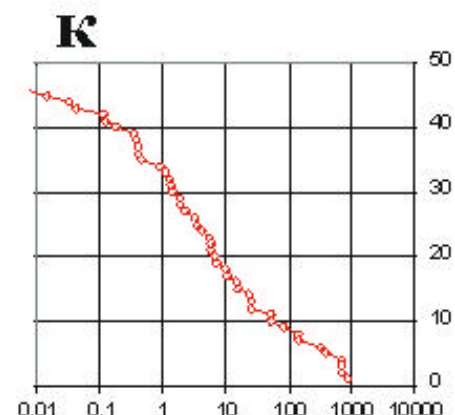
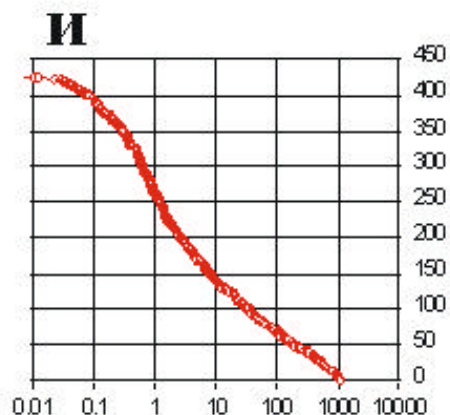
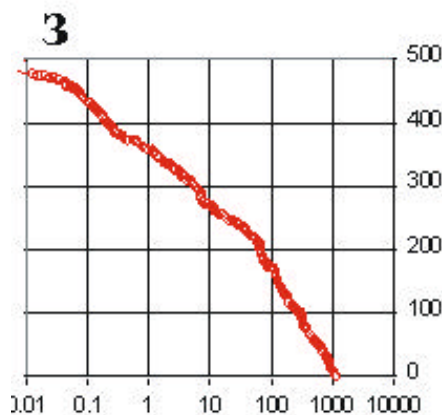
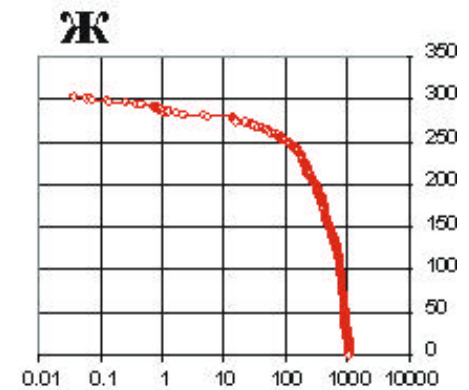
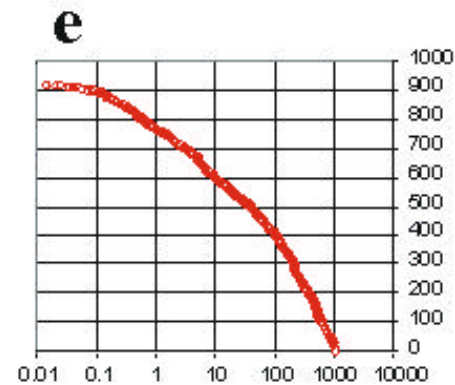
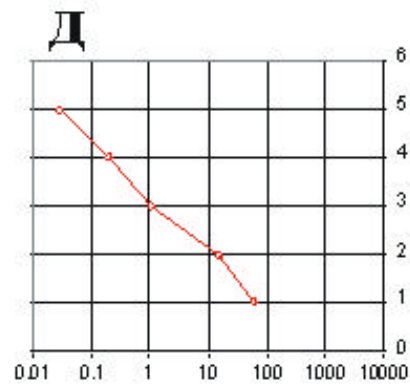
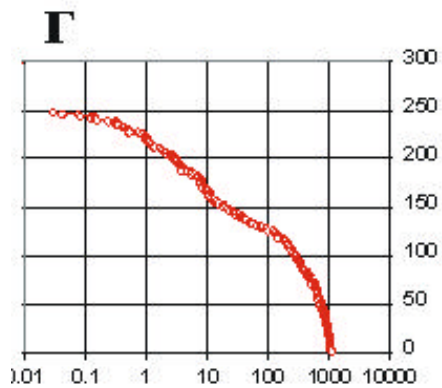
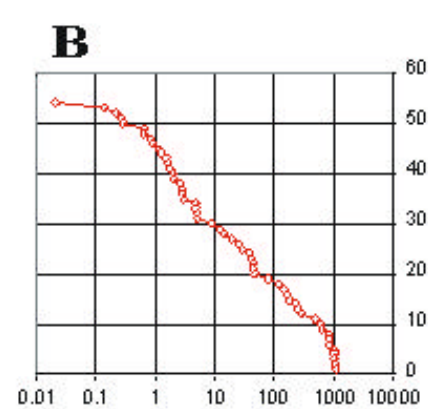
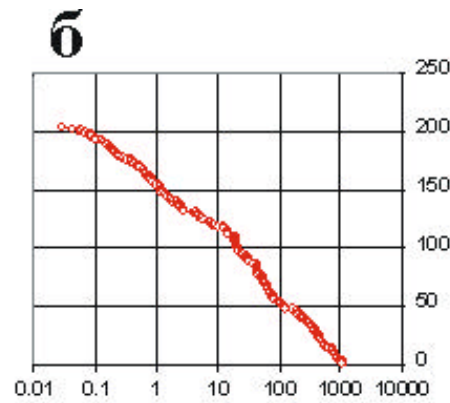
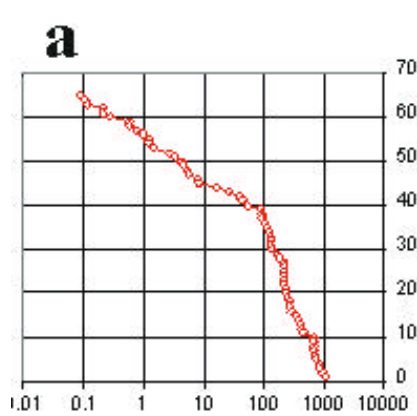
# Benioff strain release in 20 years before the great shocks



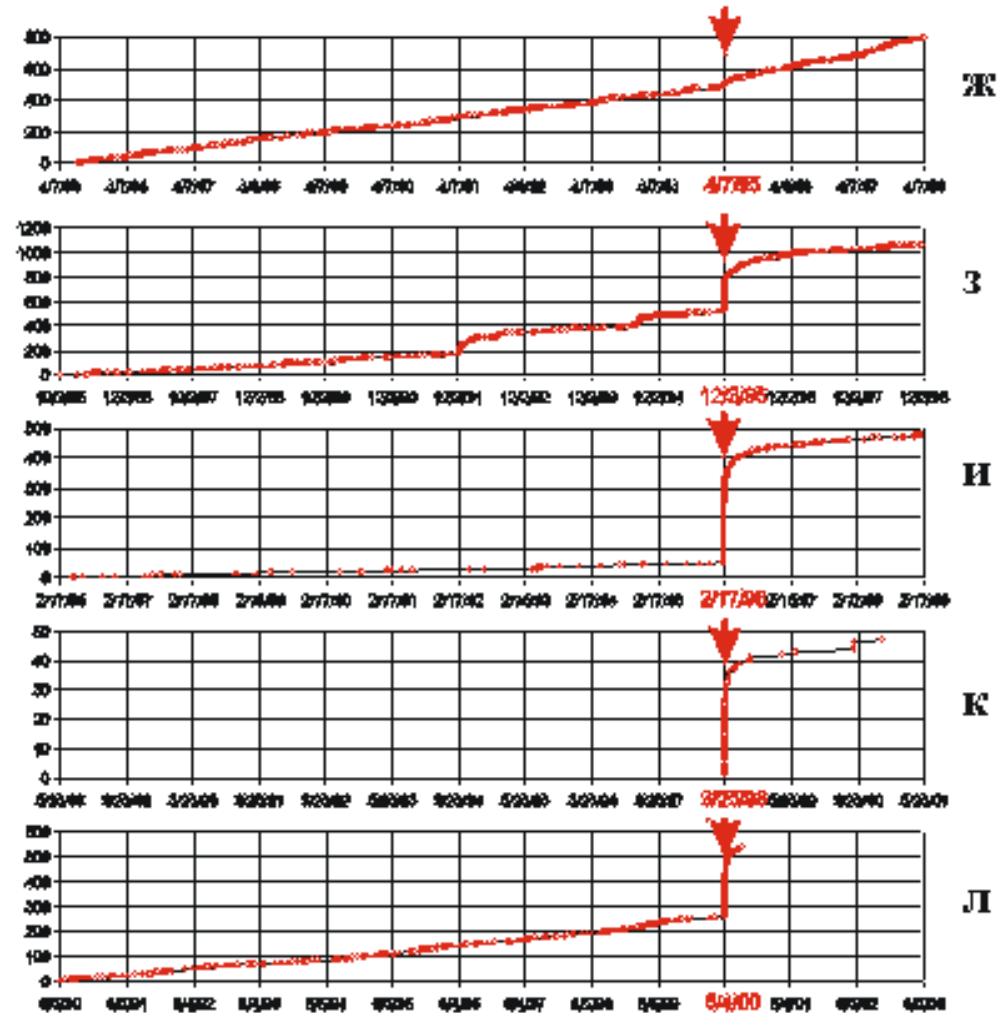
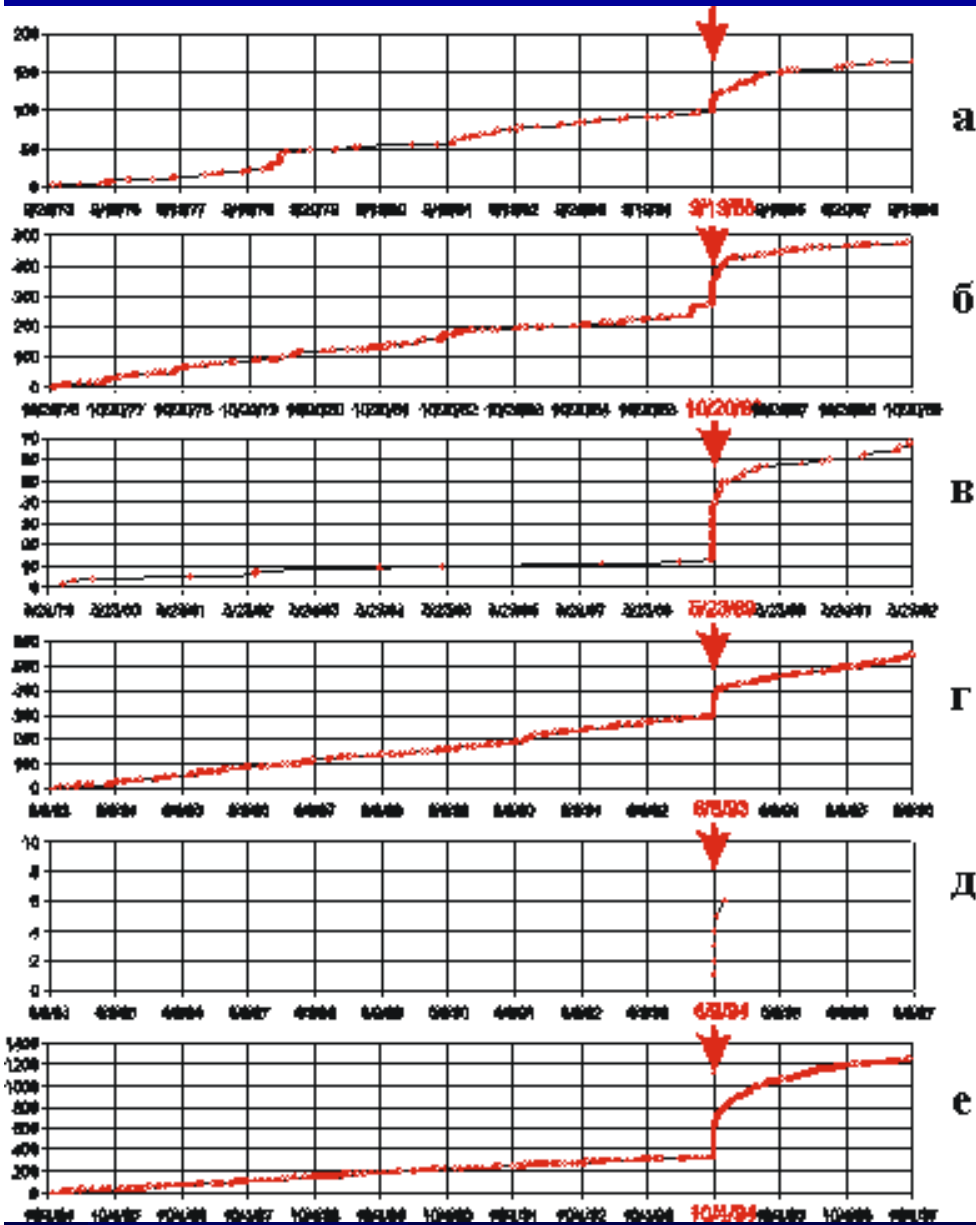
# Benioff strain release in 20 years before great shocks (Log-scale)



# Aftershock sequences of the great shocks



# Activity in 10 years before + 3 years after the great shocks



## Aftershock sequences of the great shocks (summary)

Date	Number 100 days	Number 3 years	Aftershocks decay 100 d	Aftershocks decay 3 y	Relaxation time, years
1985/09/19	29	65	Omori Law	Modified OL 3	284 days
1986/10/20	151	205	Modified OL 3	Modified OL 3	100 days, =1.5
1989/05/23	36	54	Omori Law	Modified OL 2	1.3 years, >3
1993/08/08	121	247	Modified OL 2	Modified OL 3	65 days, >1.5
1994/06/09	5	5	Modified OL 2	-	-
1994/10/04	515	919	Modified OL 2	Modified OL 3	2 years, >2.5
1995/04/07	52	302	Modified OL 2	Modified OL 2	14 days, >2
1995/12/03	311	483	Modified OL 2	Modified OL 3	1 year
1996/02/17	357	427	Modified OL 2	Modified OL 2	2 years, >2.5
1998/03/25	38	46*	Omori Law	Modified OL 2	140 days
2000/06/04	278	278*	Modified OL 2	*	*

# Conclusions

- Earthquakes evidence consecutive stages of inverse cascading of seismic activity to main shock and direct cascading of aftershocks.
- The first may reflect coalescence of instabilities at the approach, while the second may indicate readjustment of a complex system of blocks-and-faults in a new state after a catastrophe.
- The cascades observed in seismic dynamics are by far more diverse than a power-law family.

- *Global Hypocenters Data Base CD-ROM, version III, 1994. NEIC/USGS, Denver, CO. and its PDE and QED updates)*
- *Keilis-Borok and Kossobokov. Phys. Earth Planet. Inter. 61:73-83, 1990*
- *Kossobokov, Keilis-Borok, Romashkova, and Healy. Phys. Earth and Planet. Inter., 111, 3-4: 187-196, 1999.*
- *Kossobokov, Keilis-Borok, and Smith. J. Geophys. Res., 95: 19763-19772, 1990.*
- *Romashkova and Kossobokov, Comput. Seismol., 32: 162-189, 2001.*

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