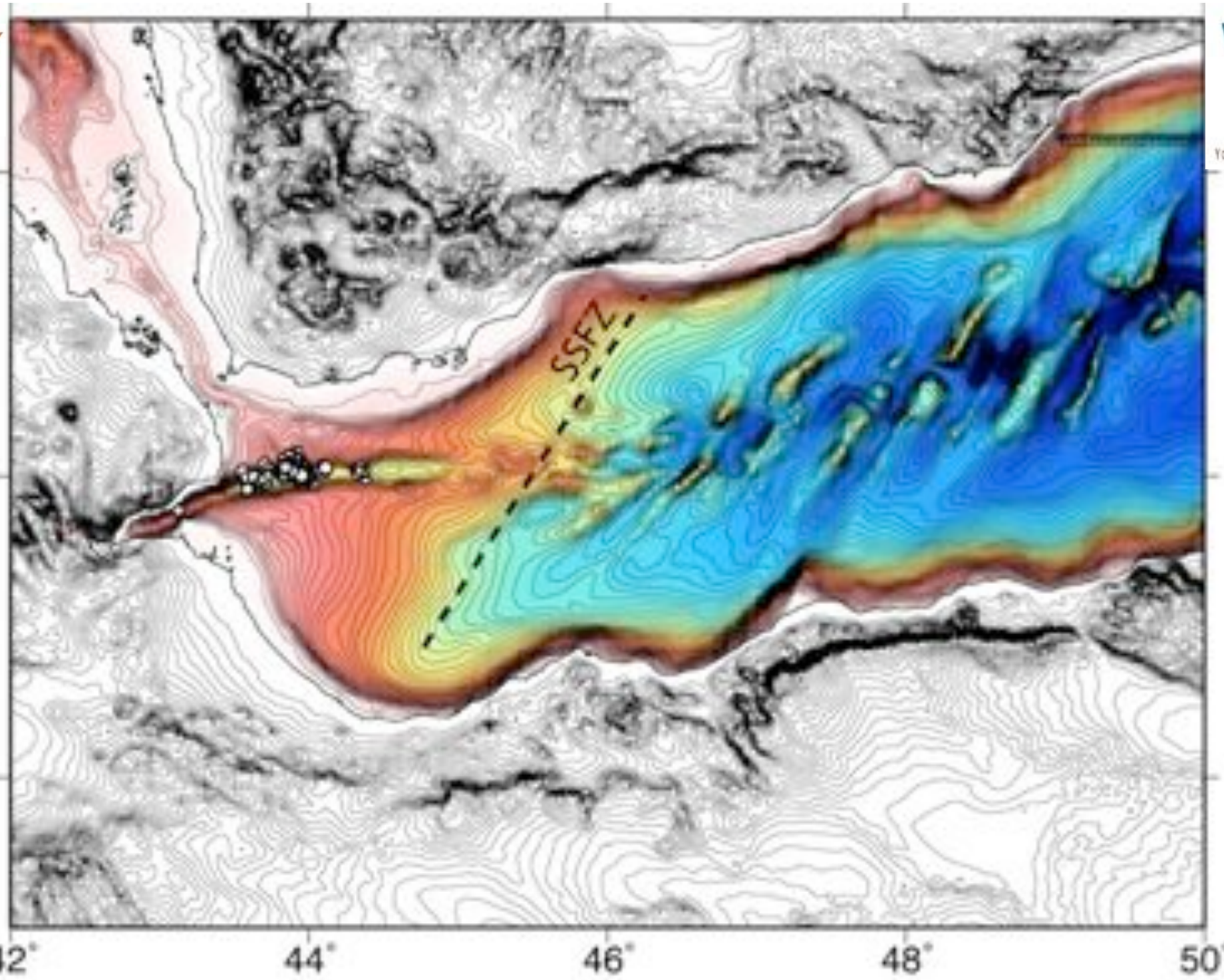
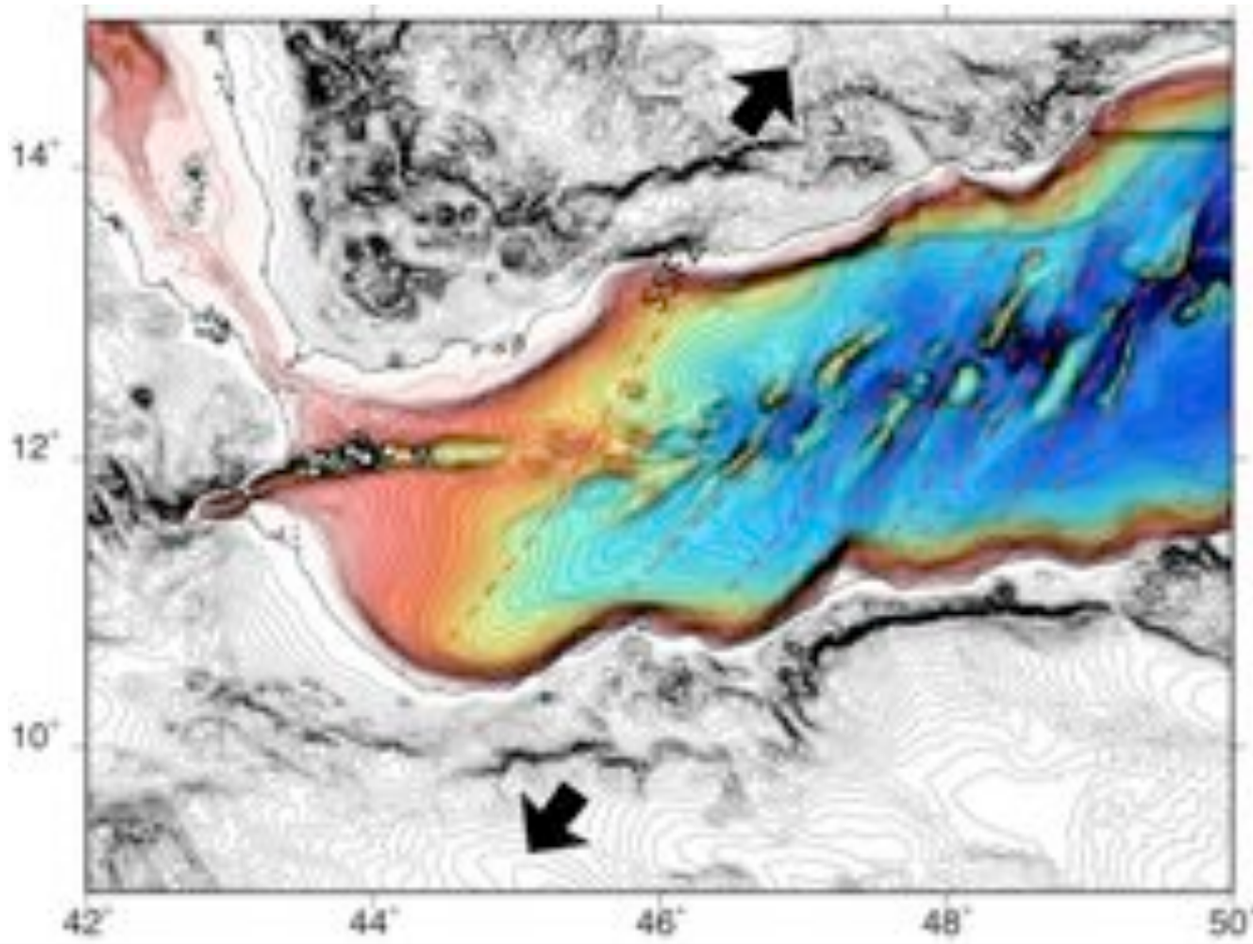
November 2010 Earthquake Swarm - Western Gulf of Aden

A. Ahmed (1,2), C. Doubre (3), S. Leroy (2), K. Mohamed (9) , J. Perrot (4), L. Audin (5), F. Rolandonne (2), D. Keir (6), I. Al-Ganad (7), K. Khanbari (8), J. Vergne (3), E. Jacques (10), A. Nercessian (10)



(1) Seismological and Volcanological Center, Yemen (2) iSTeP, UPMC, France (3) EOST, France (4) IUEM, France (5) IRD (6) National Oceanographic Center, UK
(7) Yemen Geological Survey (8) Ministry of Telecommunication (9) Geophysical Observatory of Arta, Djibouti (10) IPGP, France

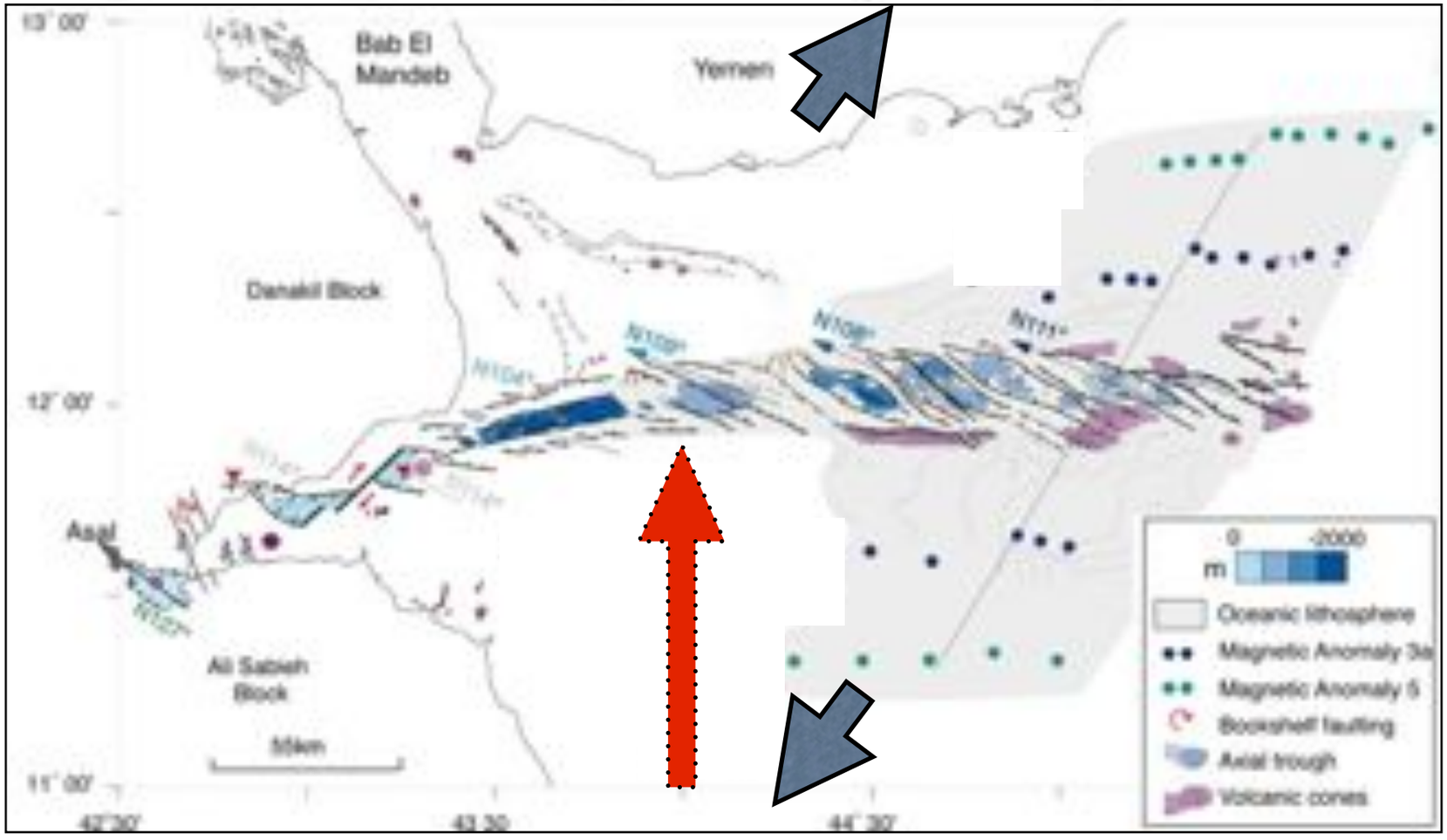
Western Gulf of Aden



* Large event :
  - numerous earthquakes with magnitude above 5.0

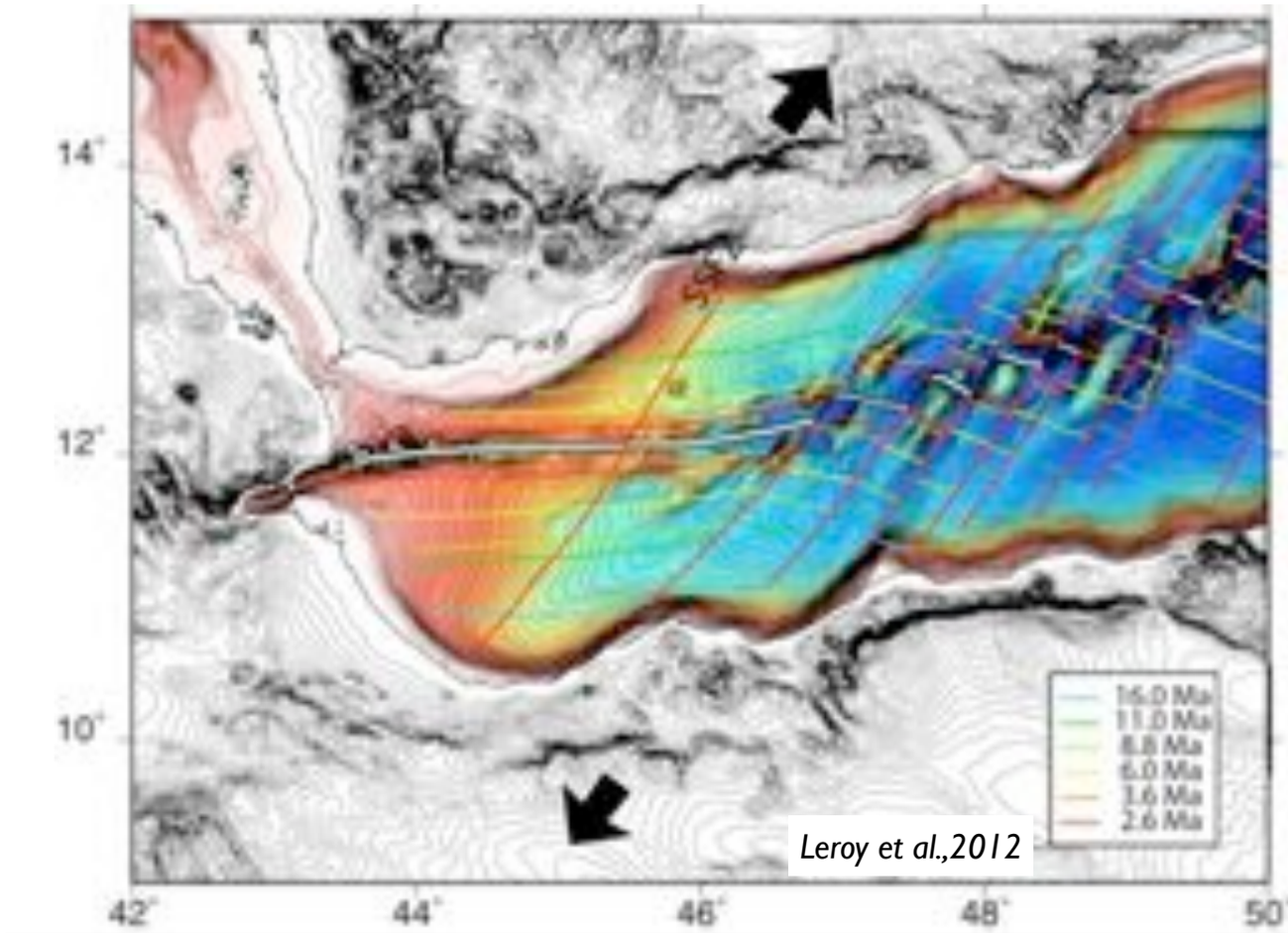
* West of Shukra El Sheik Transform Zone :
  - Large change of bathymetry
    - *shallow seafloor*
    - *elastic thickness*
    - *deep axial valley: faults, grabens*
  - Last magnetic anomaly

* Event location
  - Last magnetic anomaly
  - Change of the Aden Ridge direction



Audin, 1998

Western Gulf of Aden



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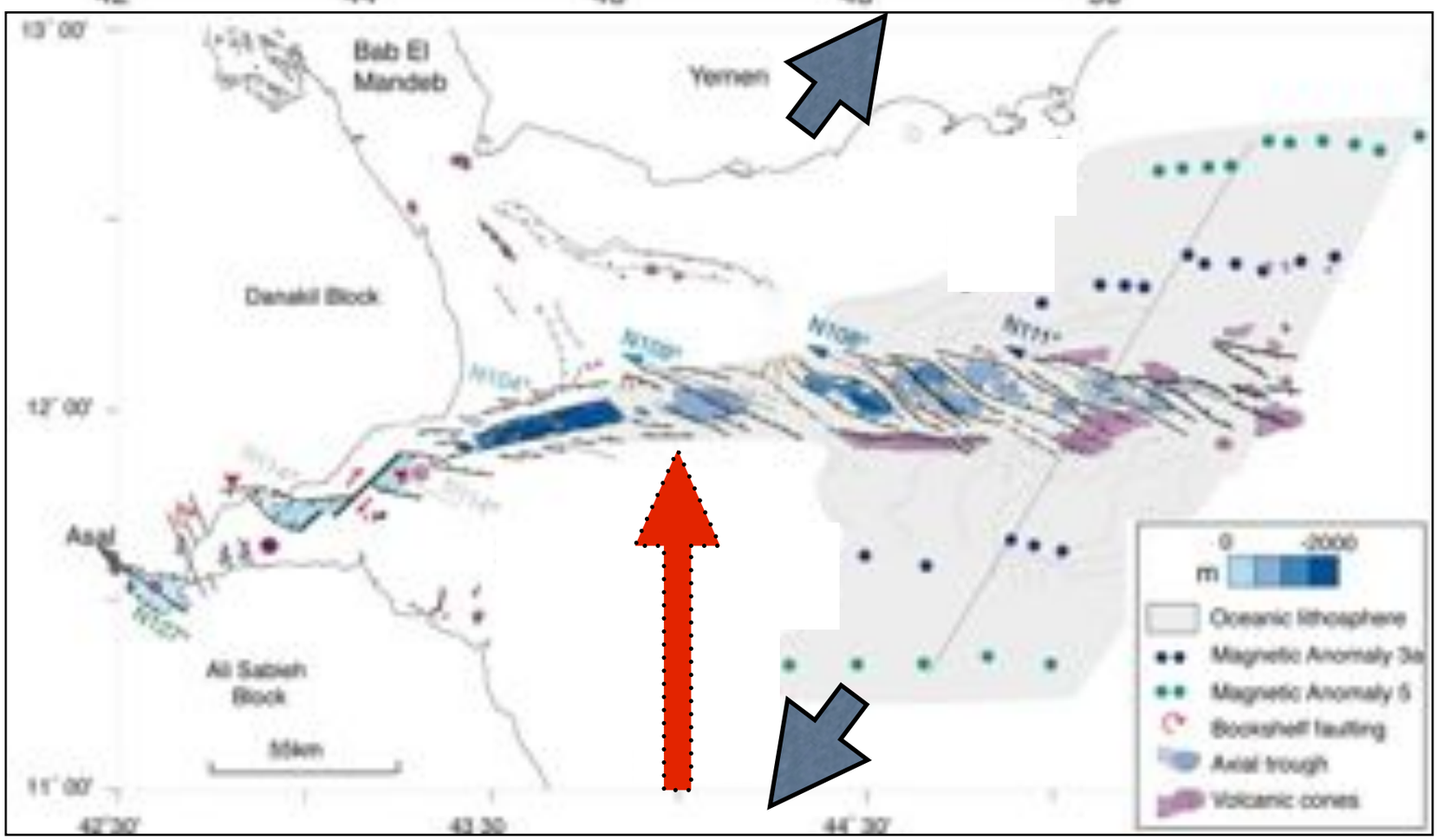
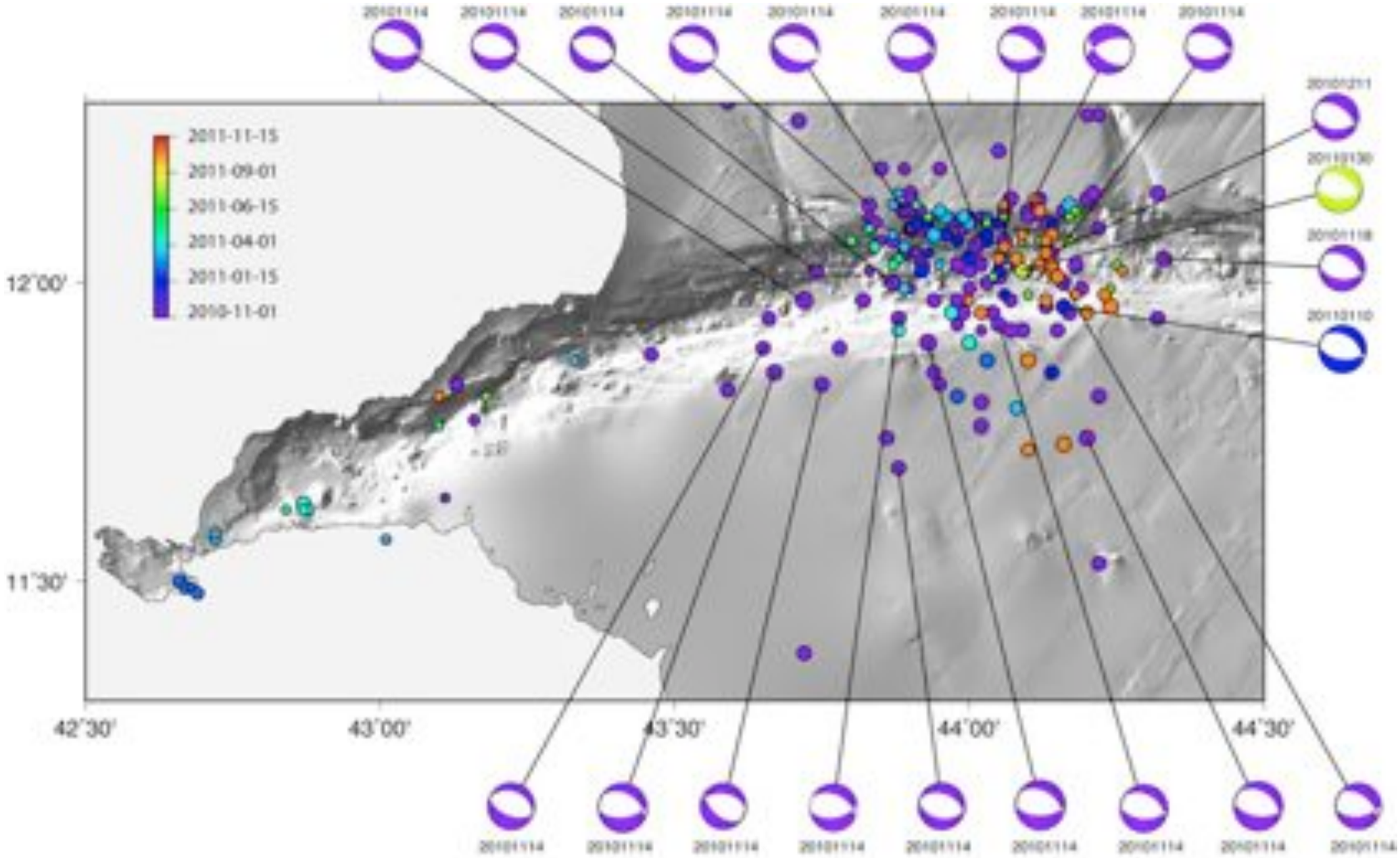


Tadjouraden Cruise (1995)
Audin, 1998

Locations EMSC



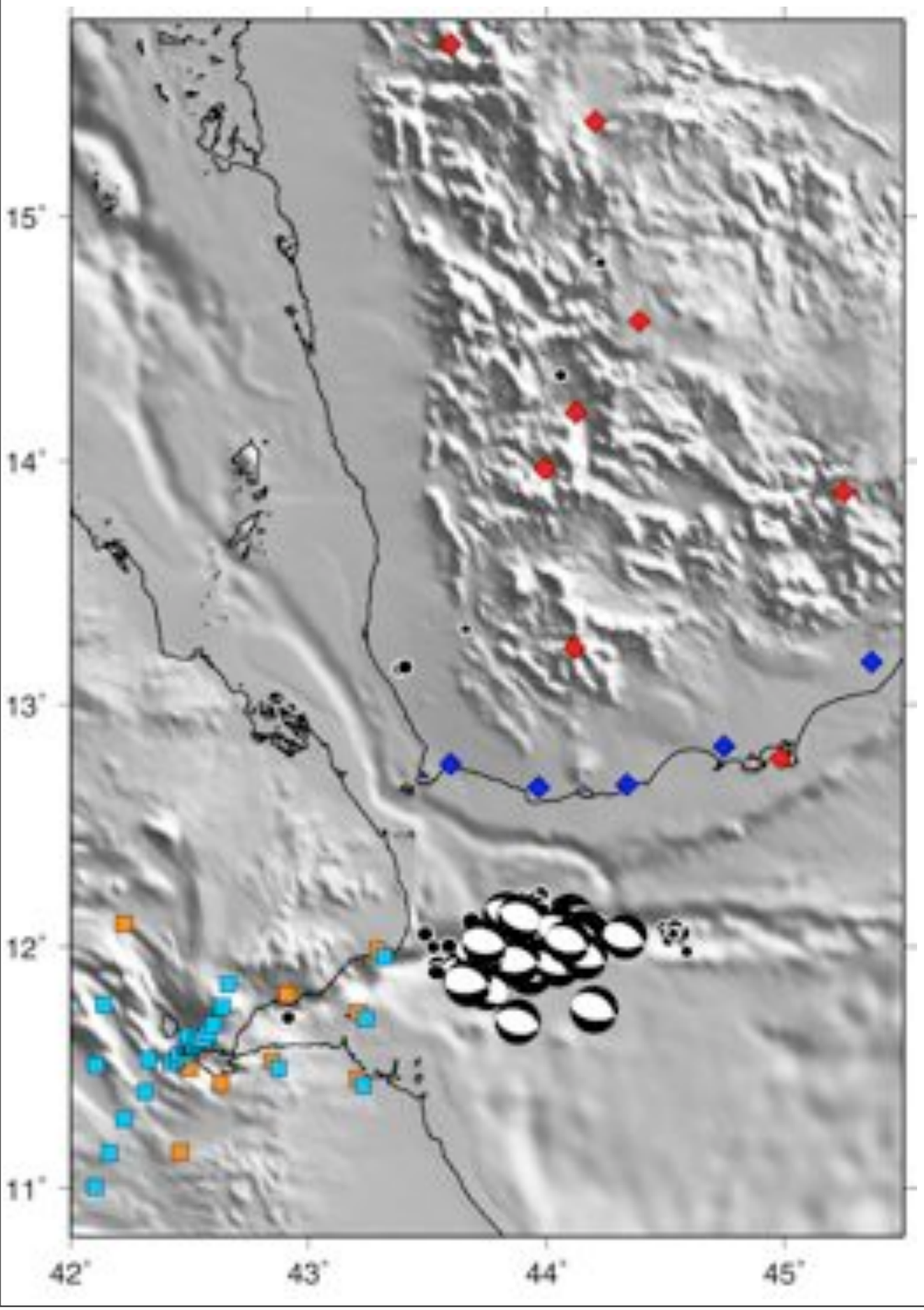
World seismic networks (USGS / EMSC):

200 events from Nov 2010 to Nov 2011 - large marjority at the period beginning

Focal Mechanisms

Normal Faulting

Combination of networks



Yemen:

- 8 permanent one-component short-period stations
- 5 temporary one-component short-period stations
  (deployed ~2010, Dec 15)

Djibouti

- 12 permanent one-component short-period stations
- 25 temporary one-component broad-band stations
  (4 deployed ~2010, Nov 20)

Crustal Model

Vp (km/s)	Depth (km)
4.00	02.00
6.10	10.00
6.80	13.00
7.90	19.50
8.10	00.00

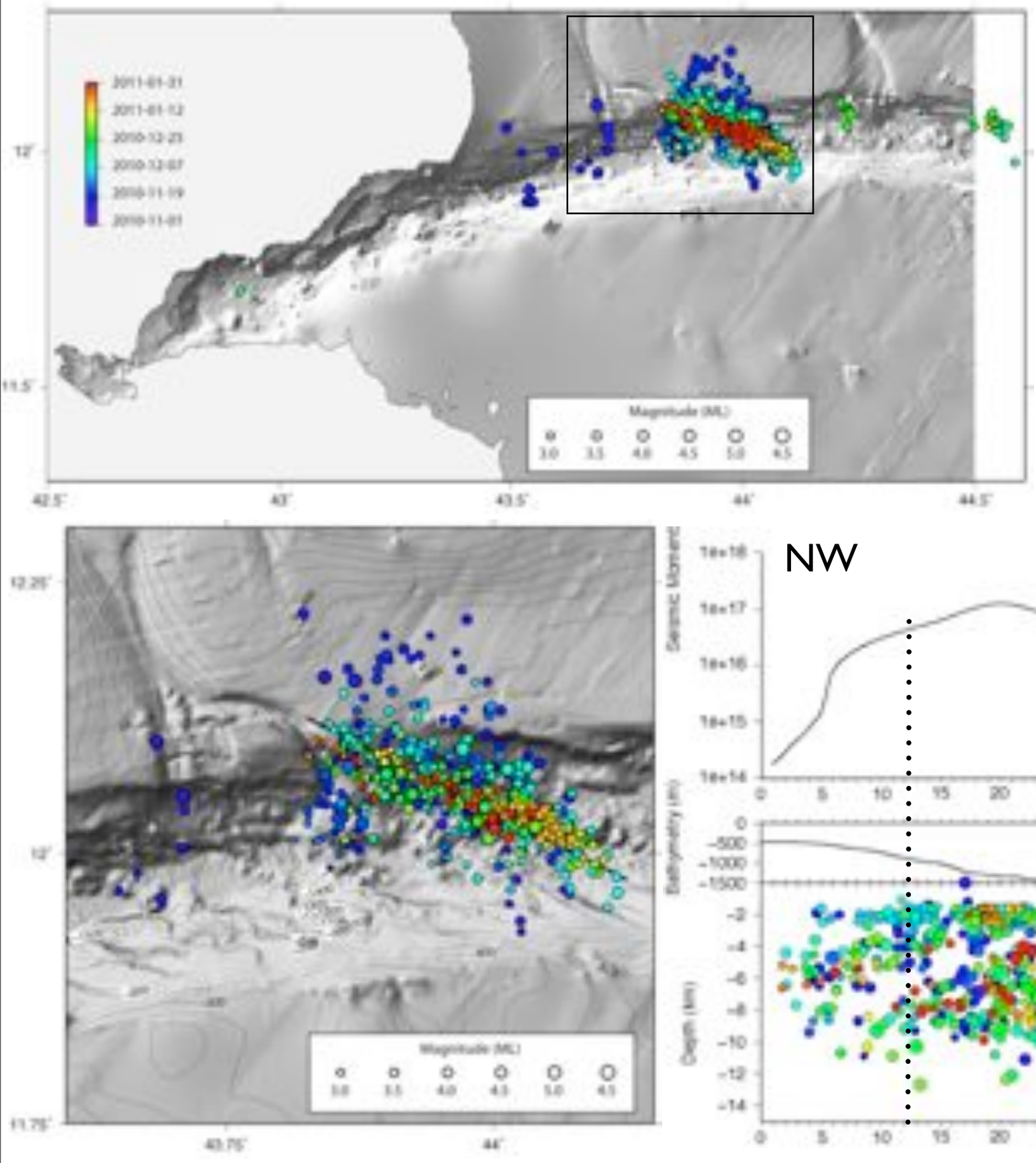
Djibouti

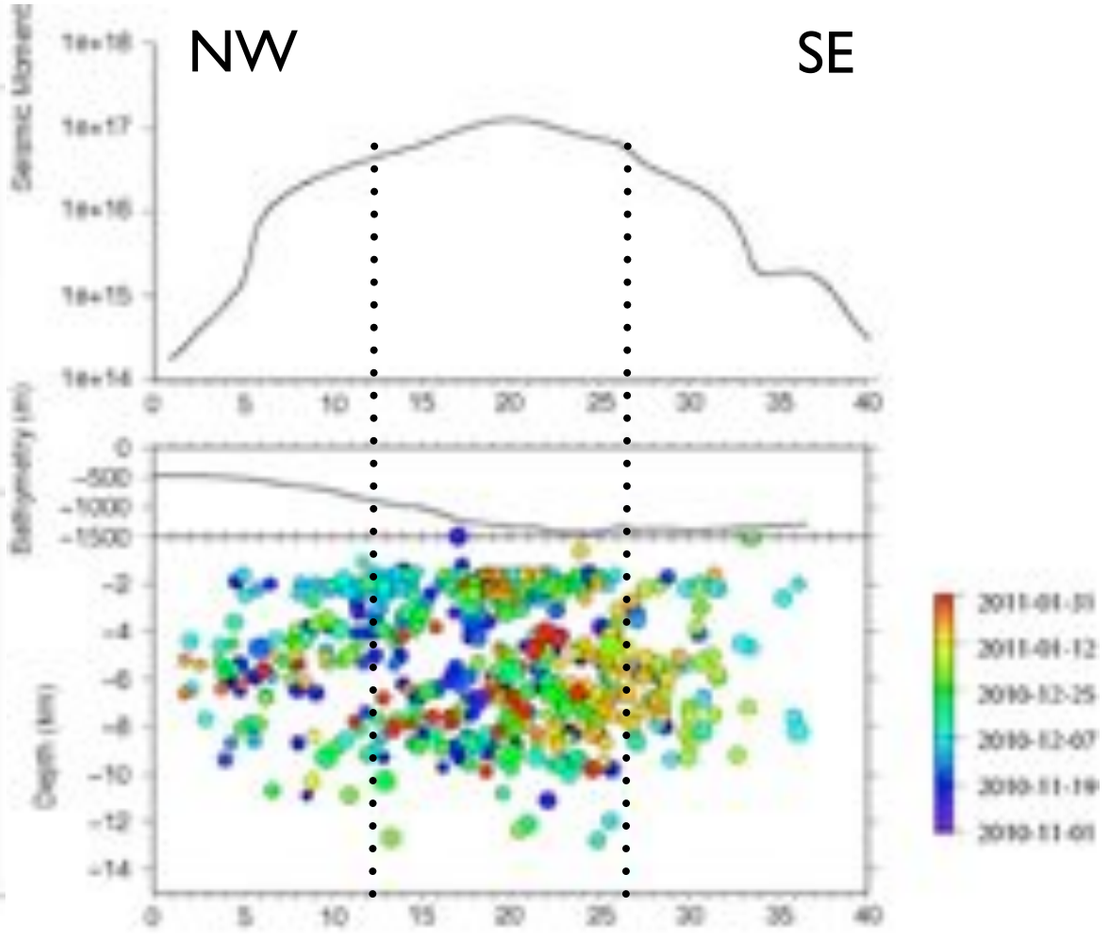
Vp (km/s)	Depth (km)
3.40	0.0
4.60	1.5
6.10	3.0
6.75	6.2
7.10	12.0
7.40	18.0

Yemen

Vp (km/s)	Depth (km)
3.40	-2.0
4.20	0.5
6.00	2.0
6.20	12.0
6.80	27.0
7.00	28.0
8.00	58.0

Activity during the 3 first months





* Period

3 first months :

Nov. 01, 2010 to Jan. 31, 2011

* Locations

600 located events with $M_L \geq 3.0$

Location precision dependent on the evolution of the network configuration

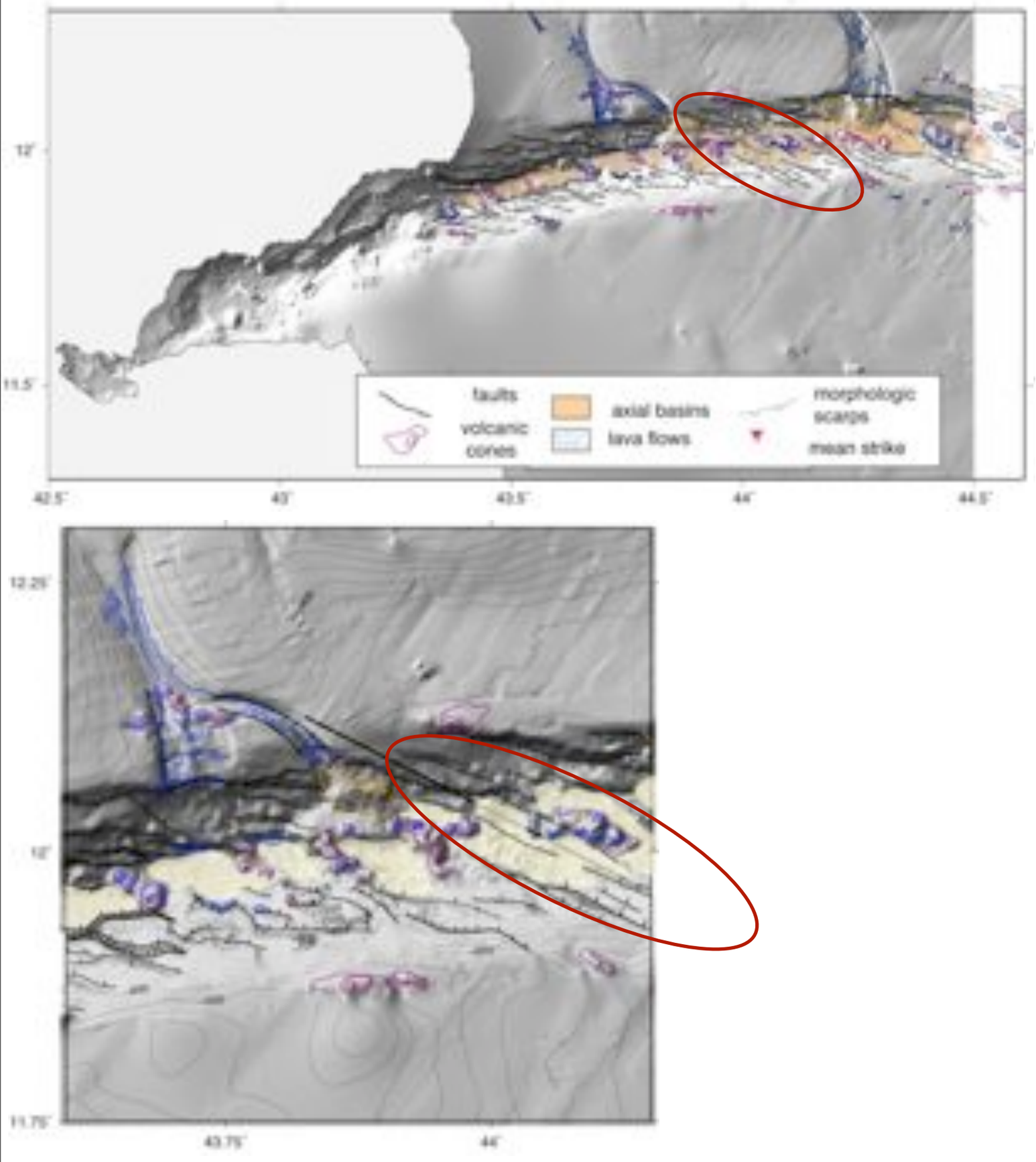
1 main swarm + 2 small ones

* N110°-trending alignment

Half of the events = central third of segment

20°-dipping seismic zone

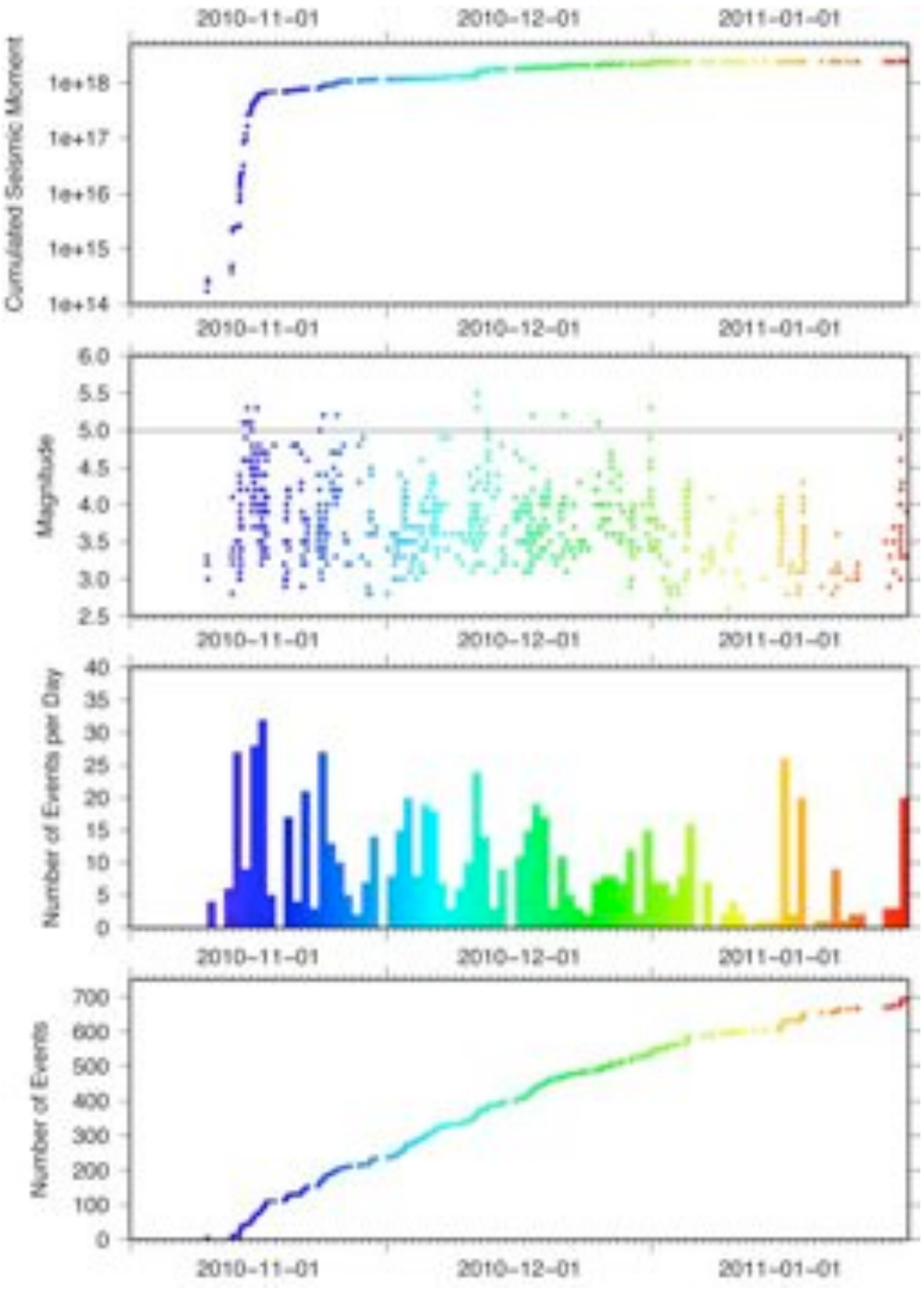
Activity during the 3 first months



* Activity of one segment
  - large bassin
  - central volcanic area

* Other structures:
  - canyons
  - fans

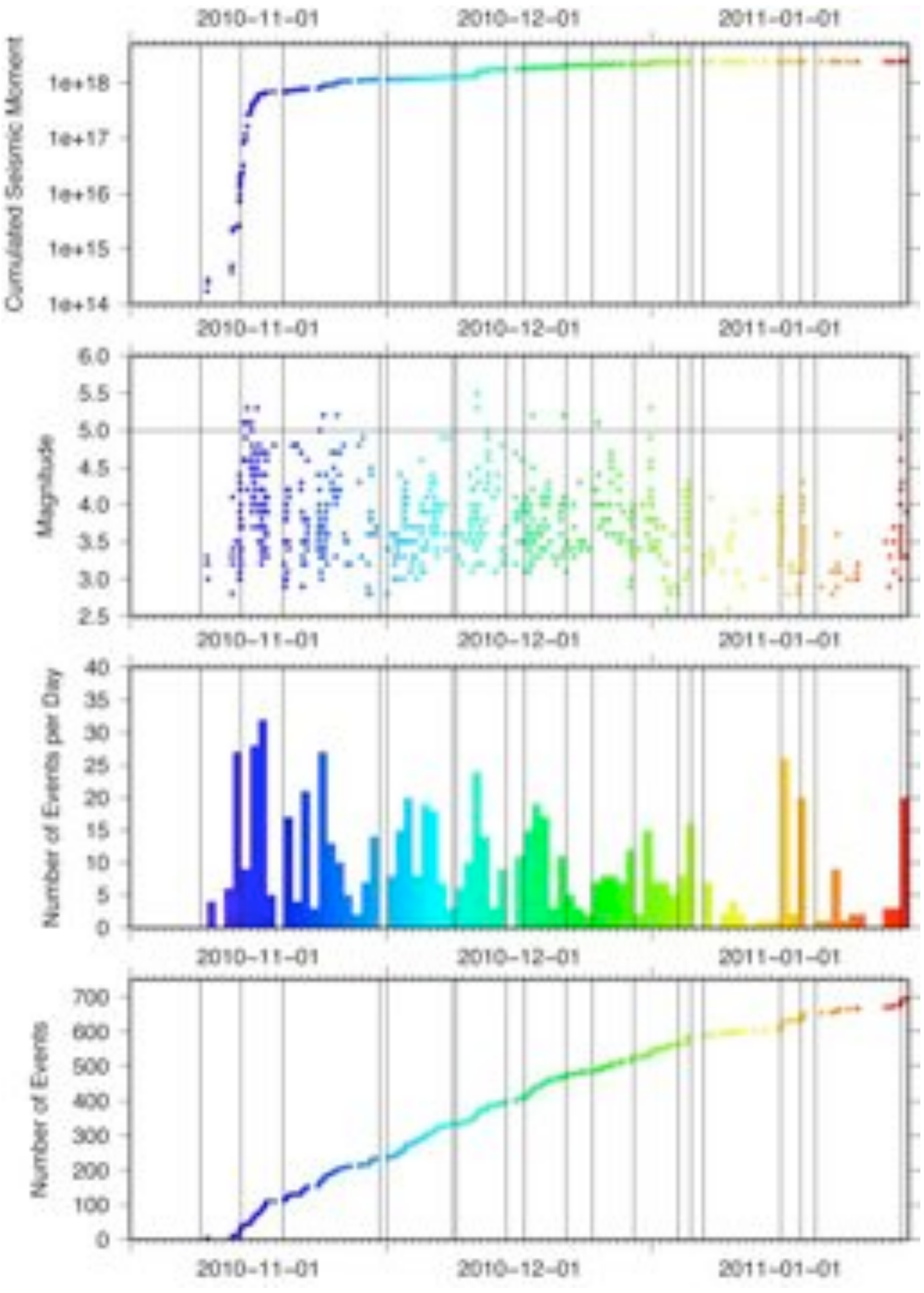
Time Evolution



* Beginning
  - small activity from Nov. 10, 2010
  - 5 large events on Nov. 14-16, 2010
    - (30% of seismic energy released over the 3 first months)

* Evolution
  - Picks of activity
  - High magnitude resume in December
  - Low activity in January 2011 (only one-day lasting burts of activity)

Time Evolution



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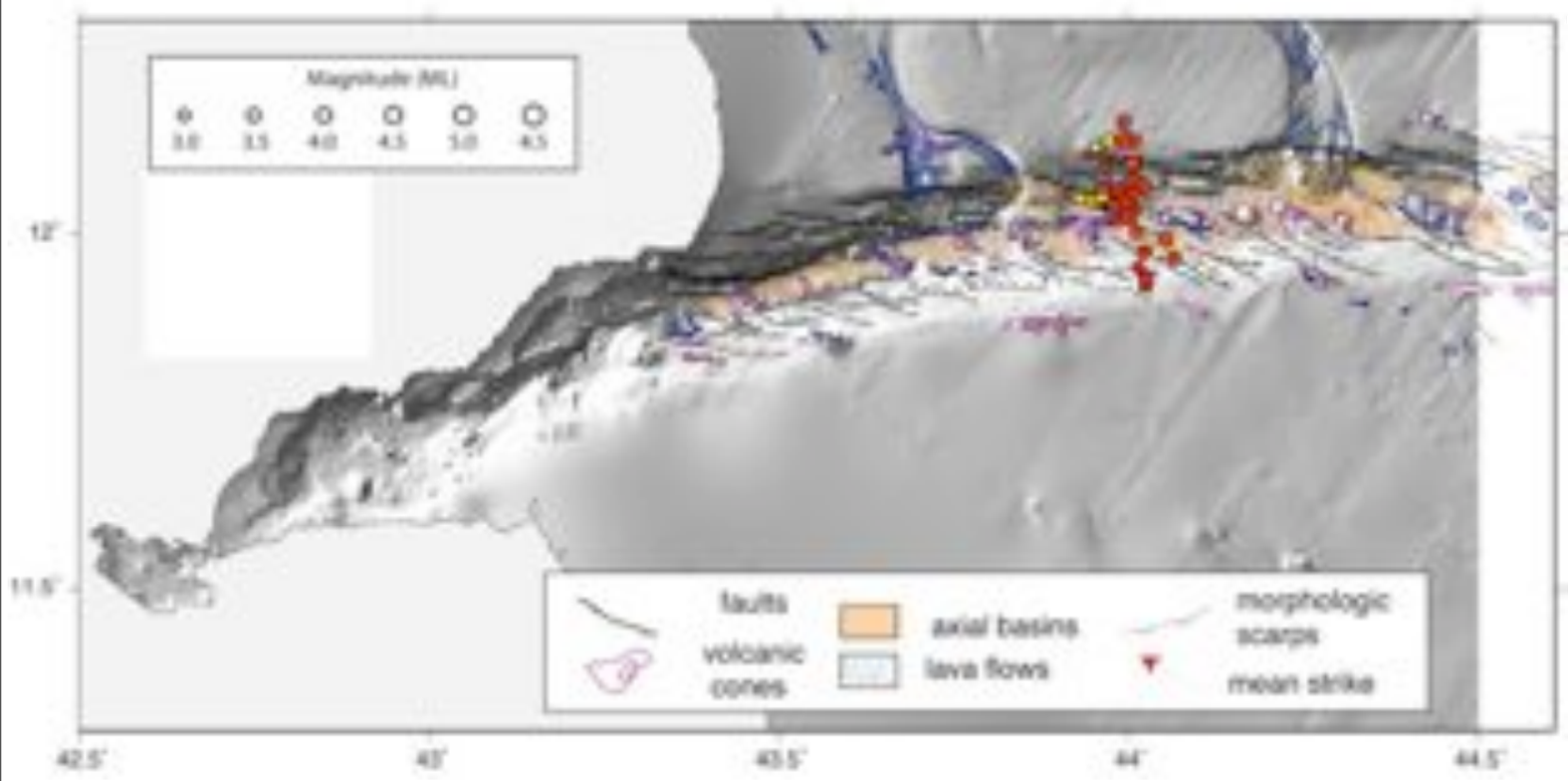
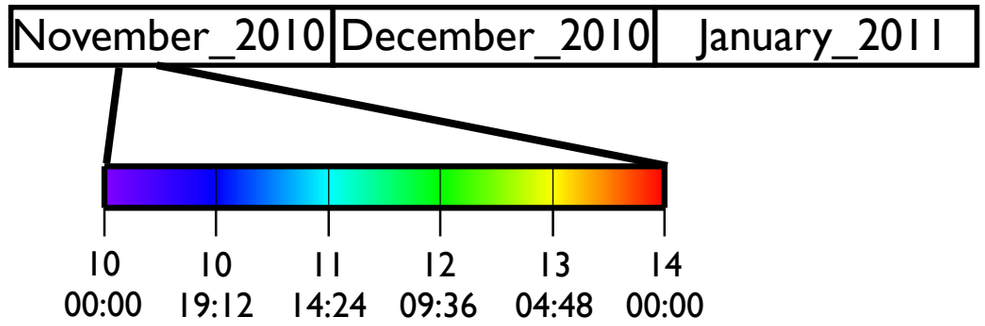
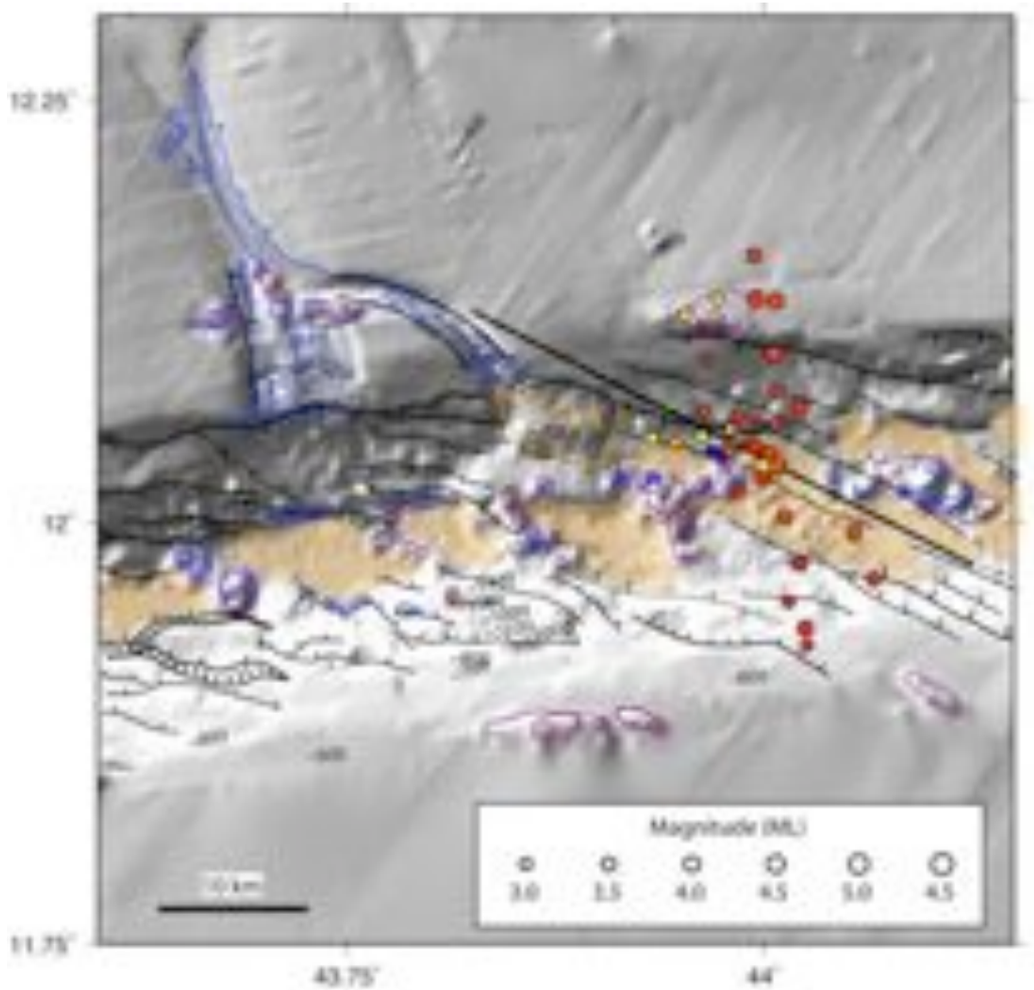
Time Evolution



10-13 November 2010 (*4 days*)

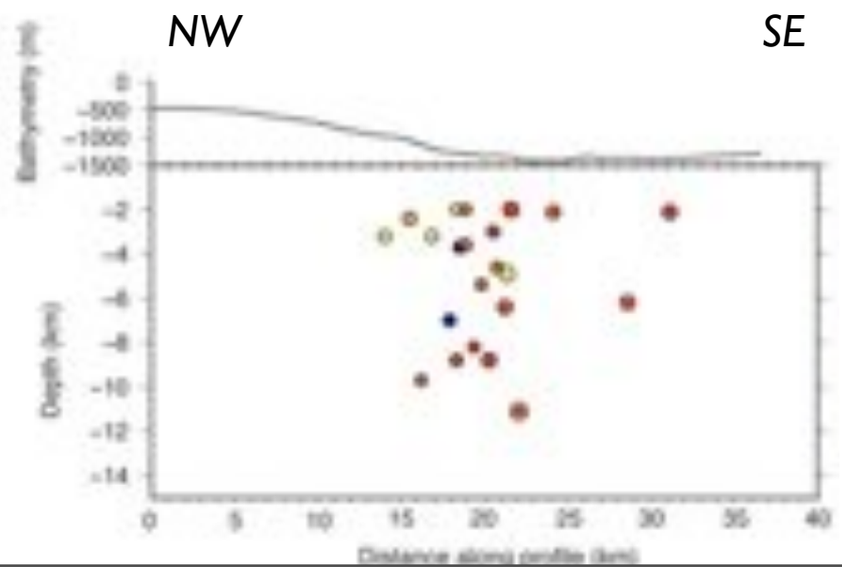




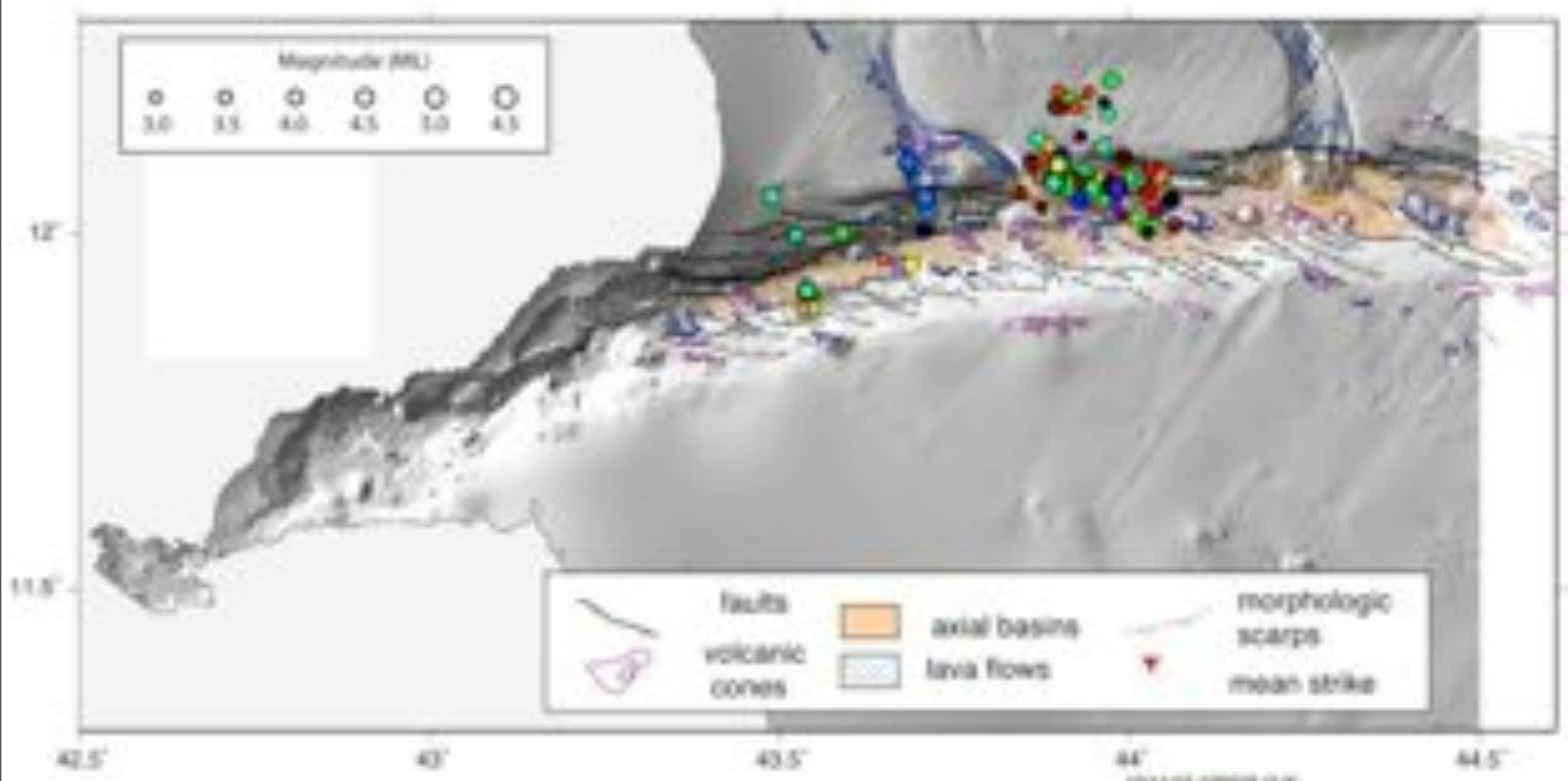
«Pre-activity»

NS alignment

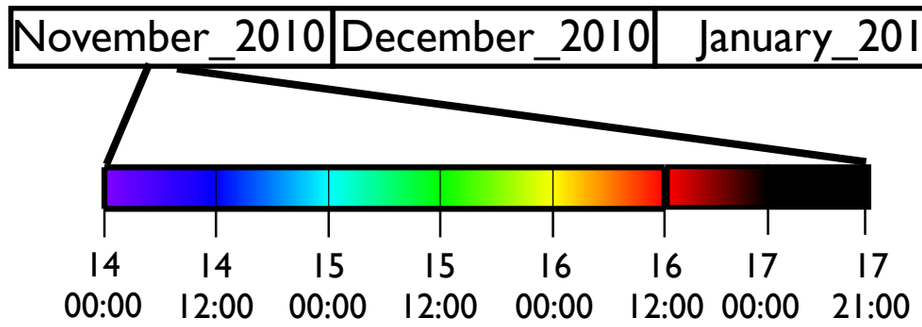
Large number of events at the bottom of the ridge wall

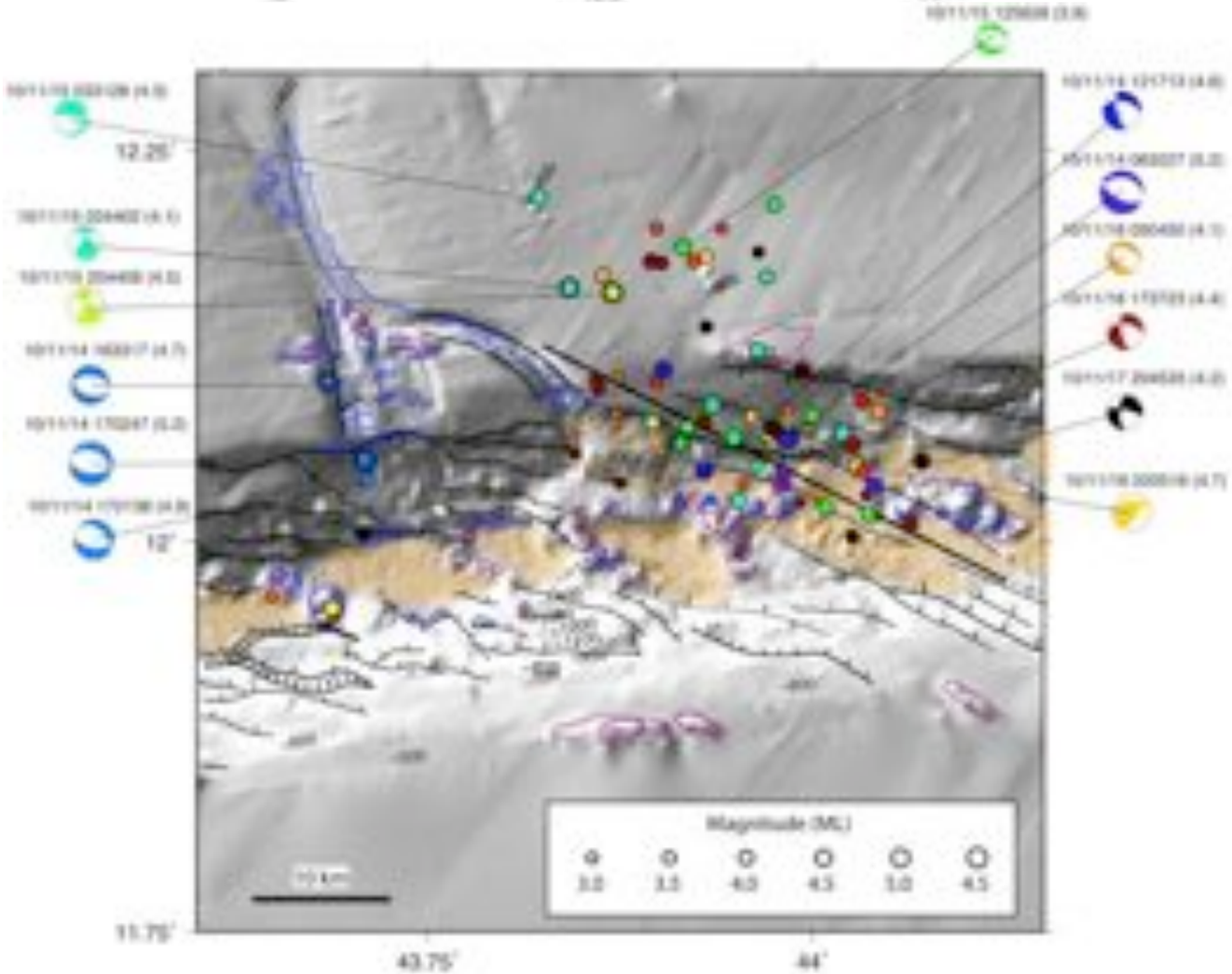


Time Evolution



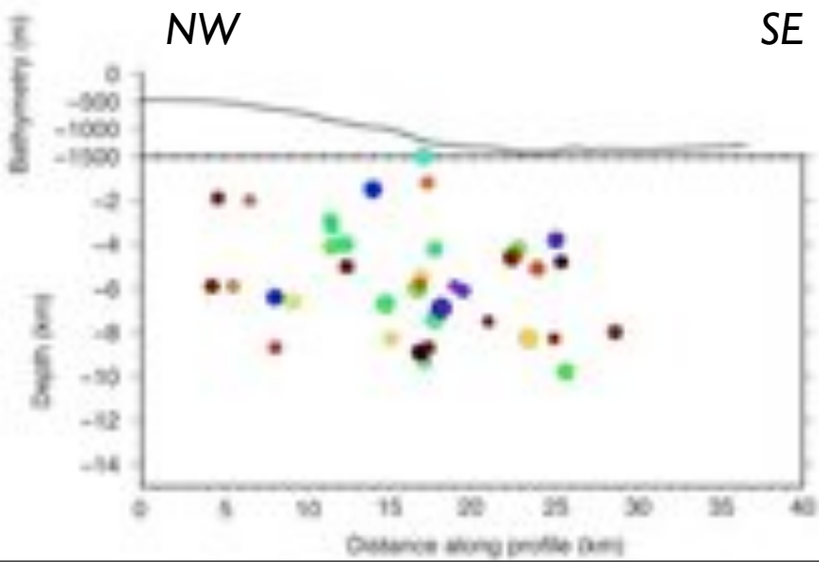
14-17 November 2010 (~*4 days*)



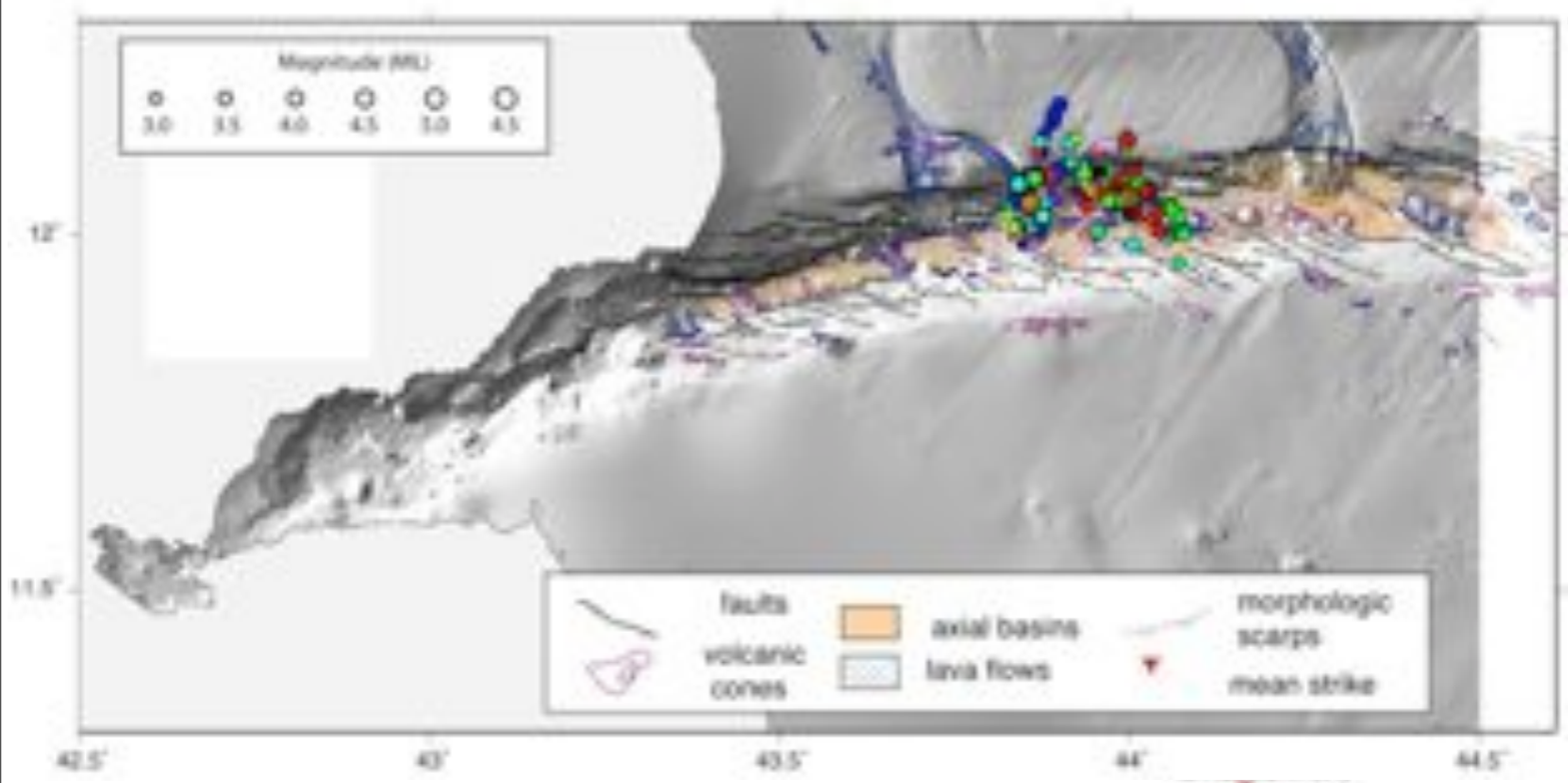


Main Swarm

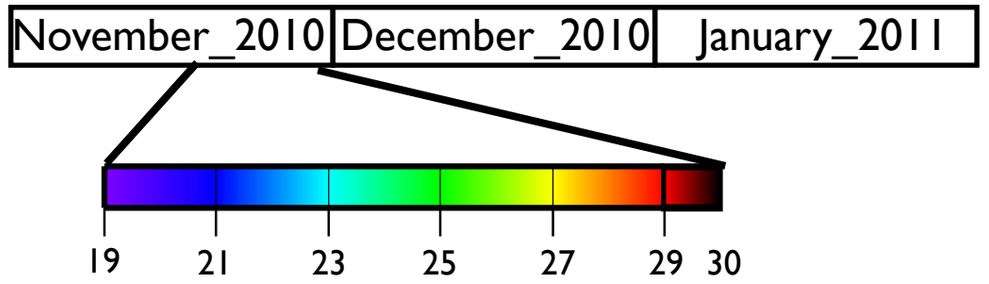
Most events along the segment axis
but below the main northern border of the rift valley
Main event: N110° normal faulting
Northern swarm (off axis): complex set of mechanisms
showing extension perpendicular to the ridge valley
Western swarm: large events along the canyon with normal faulting

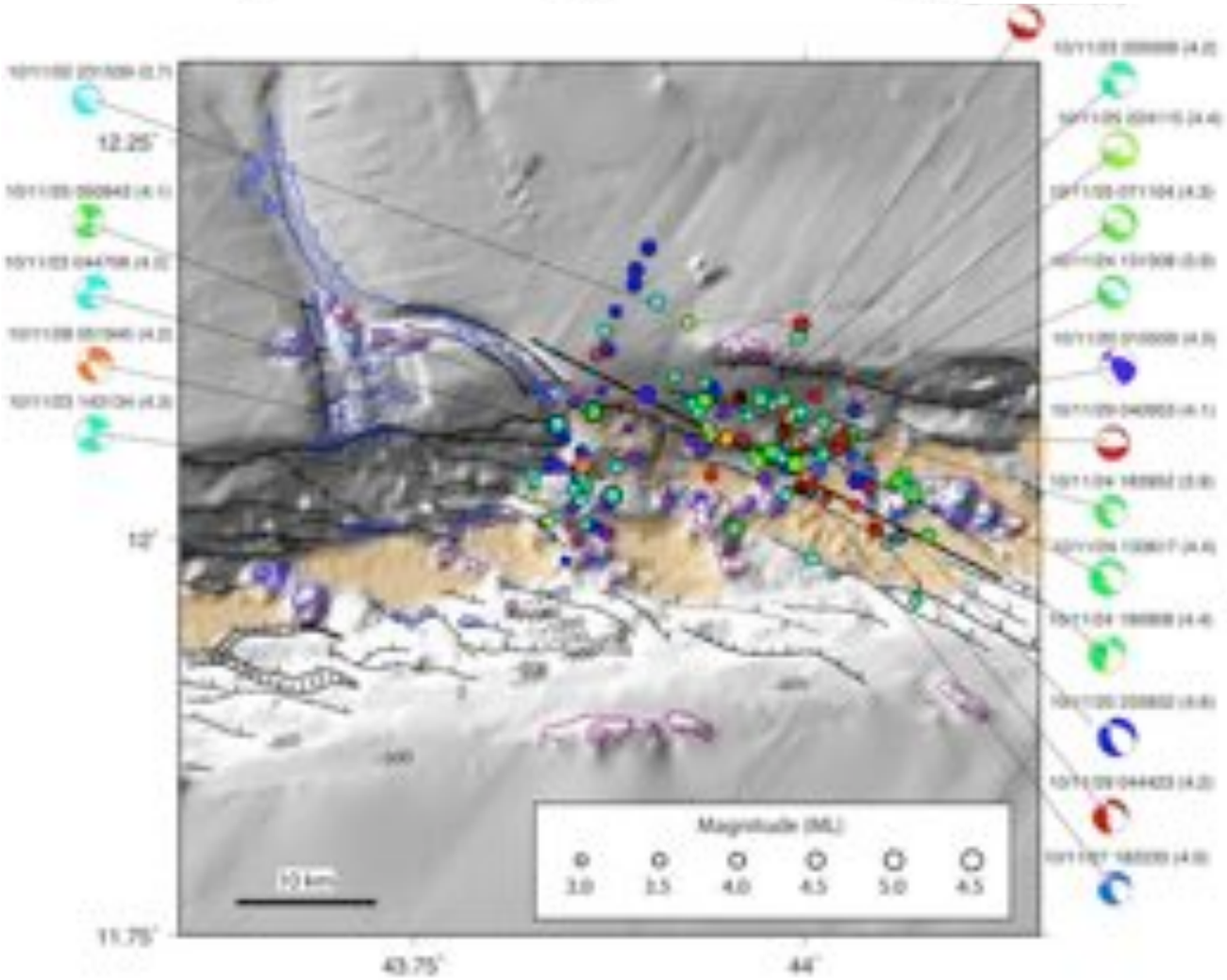


Time Evolution



19-29 November 2010 (*12 days*)



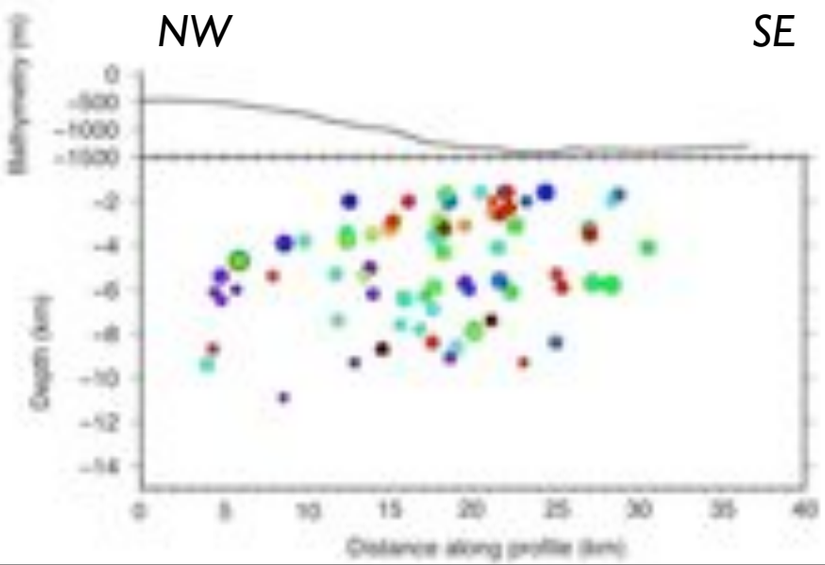


Main Swarm - part II

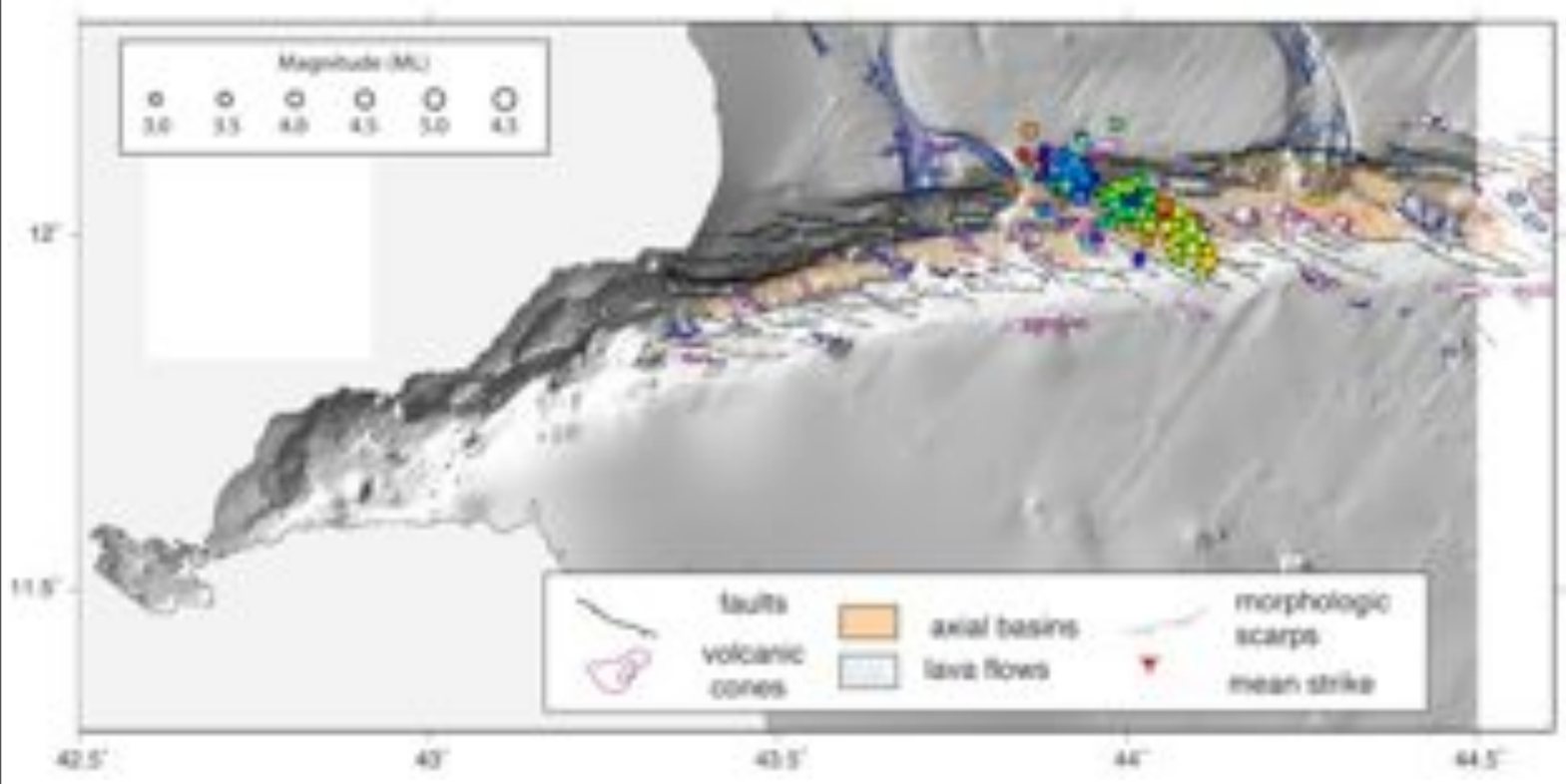
Same N110°-trending alignement

No clear temporal organisation

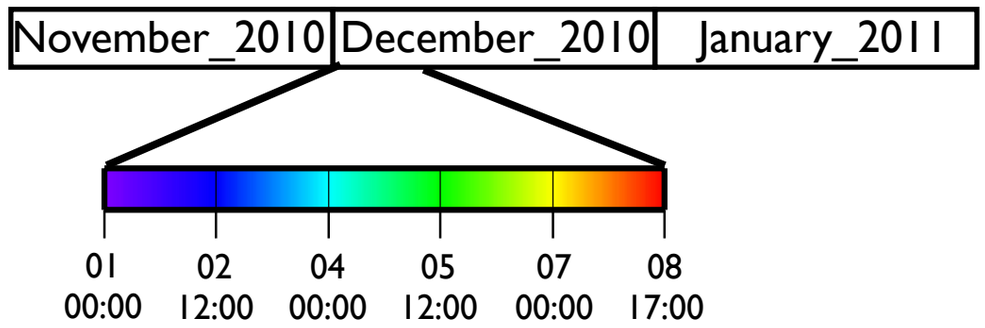
Eastern Swarm: strike slip events located at the base of the fan at the junction of the canyon and the ridge: landslides induced by the main shocks?

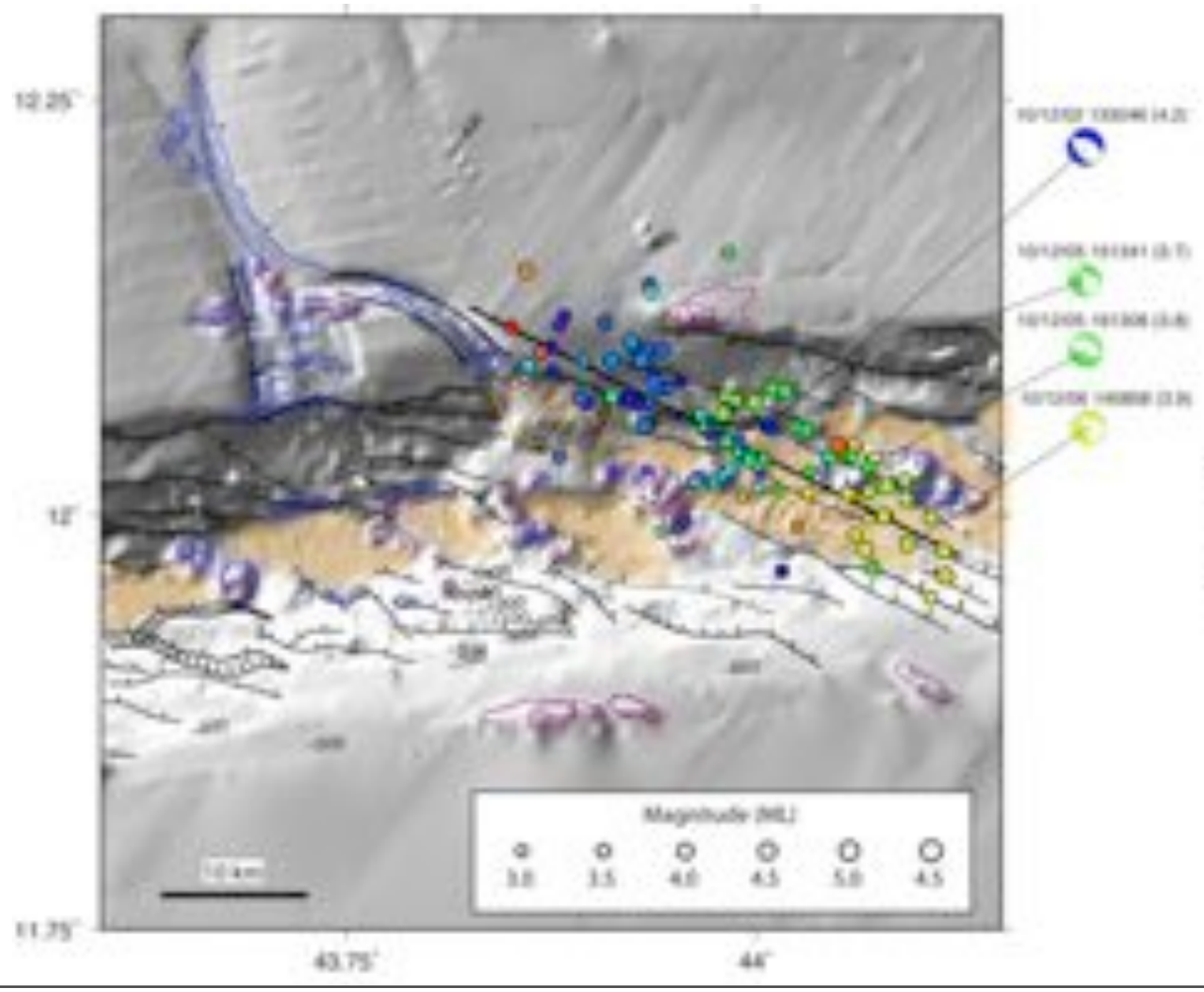


Time Evolution



01-08 December 2010 *(9 days)*



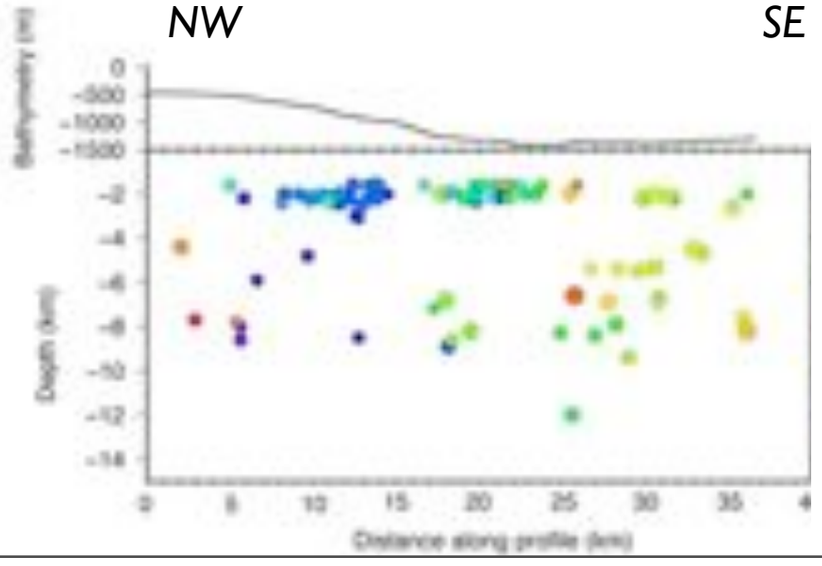


Main Swarm - part III

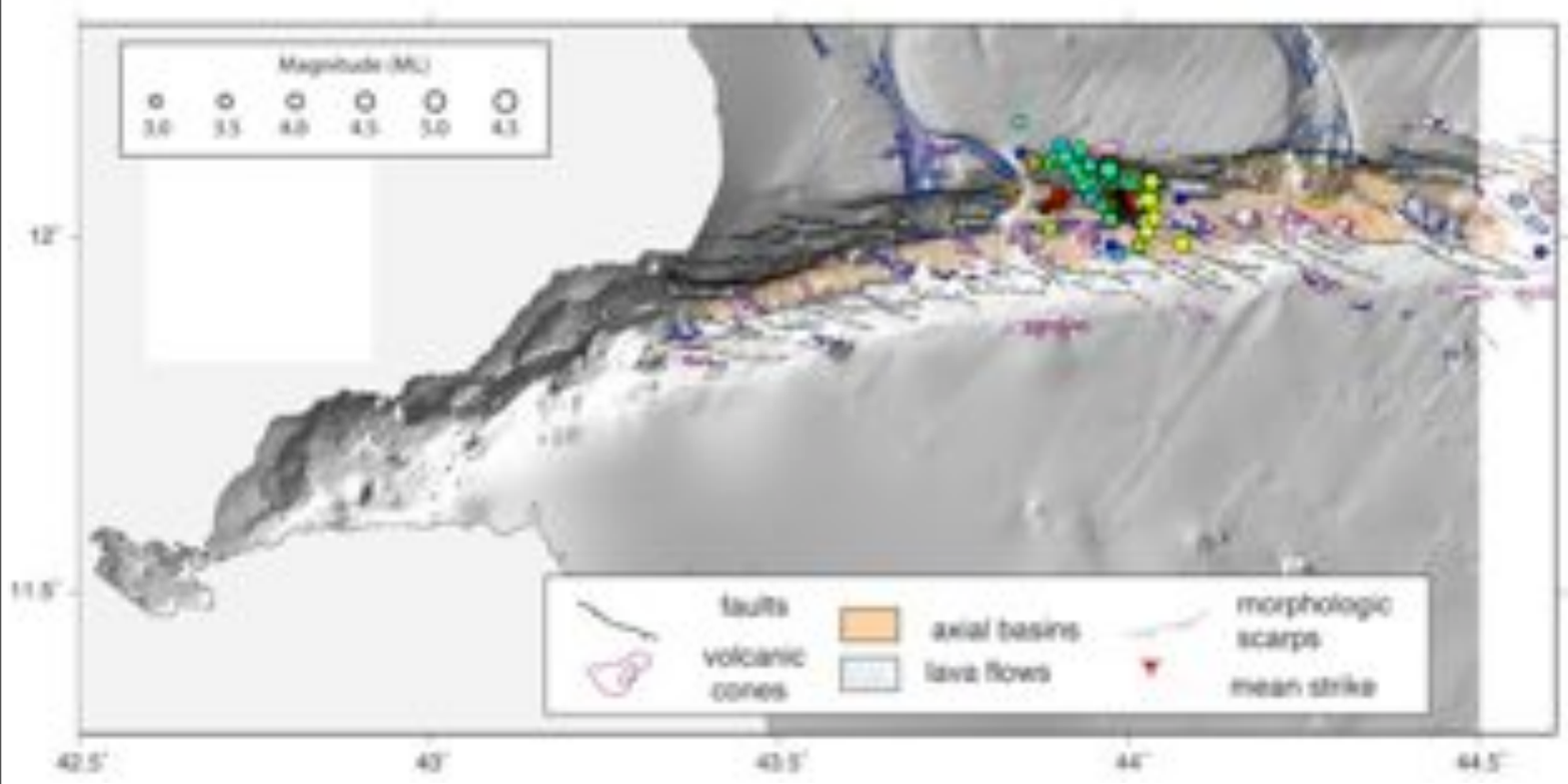
Same N110°-trending alignement

Very clear temporal organization: Southeastward propagation from the flank to the central volcanic area

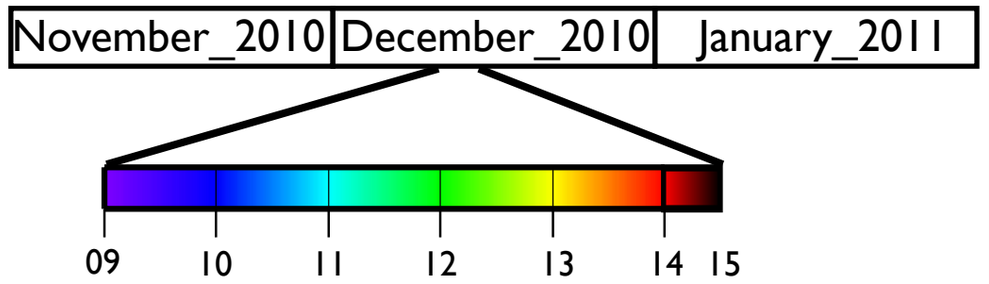
Very slow velocity: 0.2 km/h !!

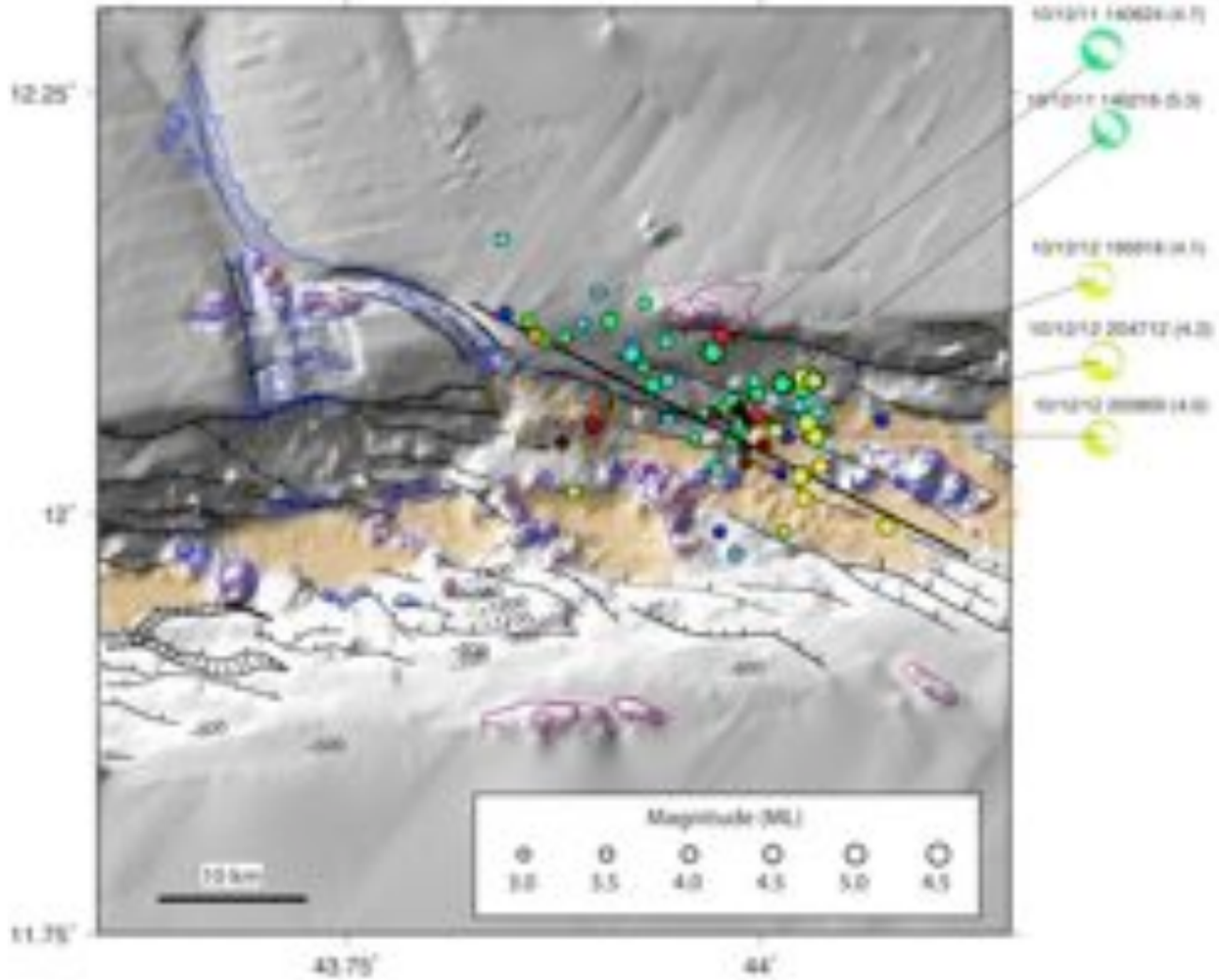


Time Evolution



09-14 December 2010 (*6 jours*)

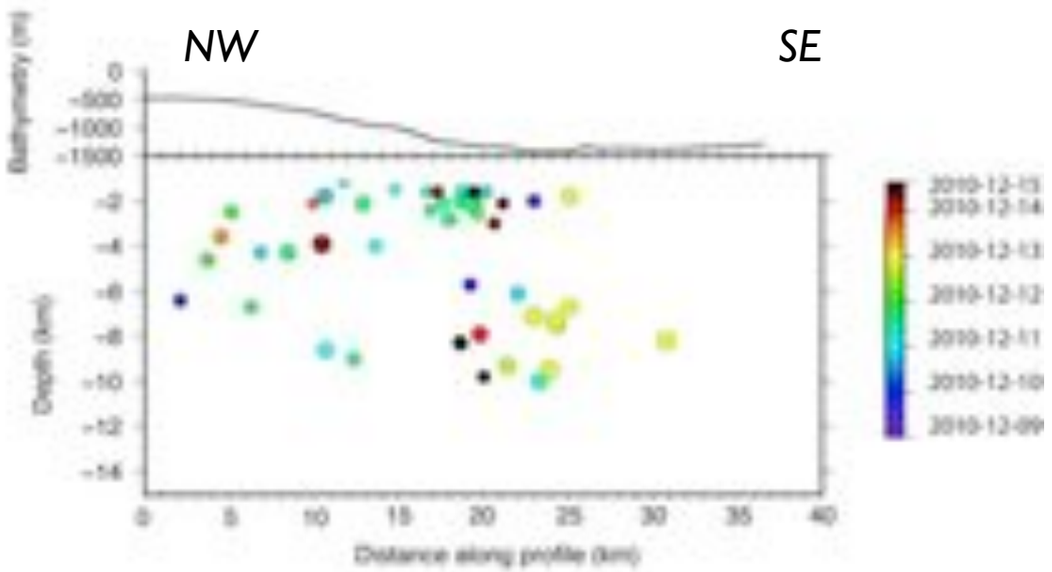




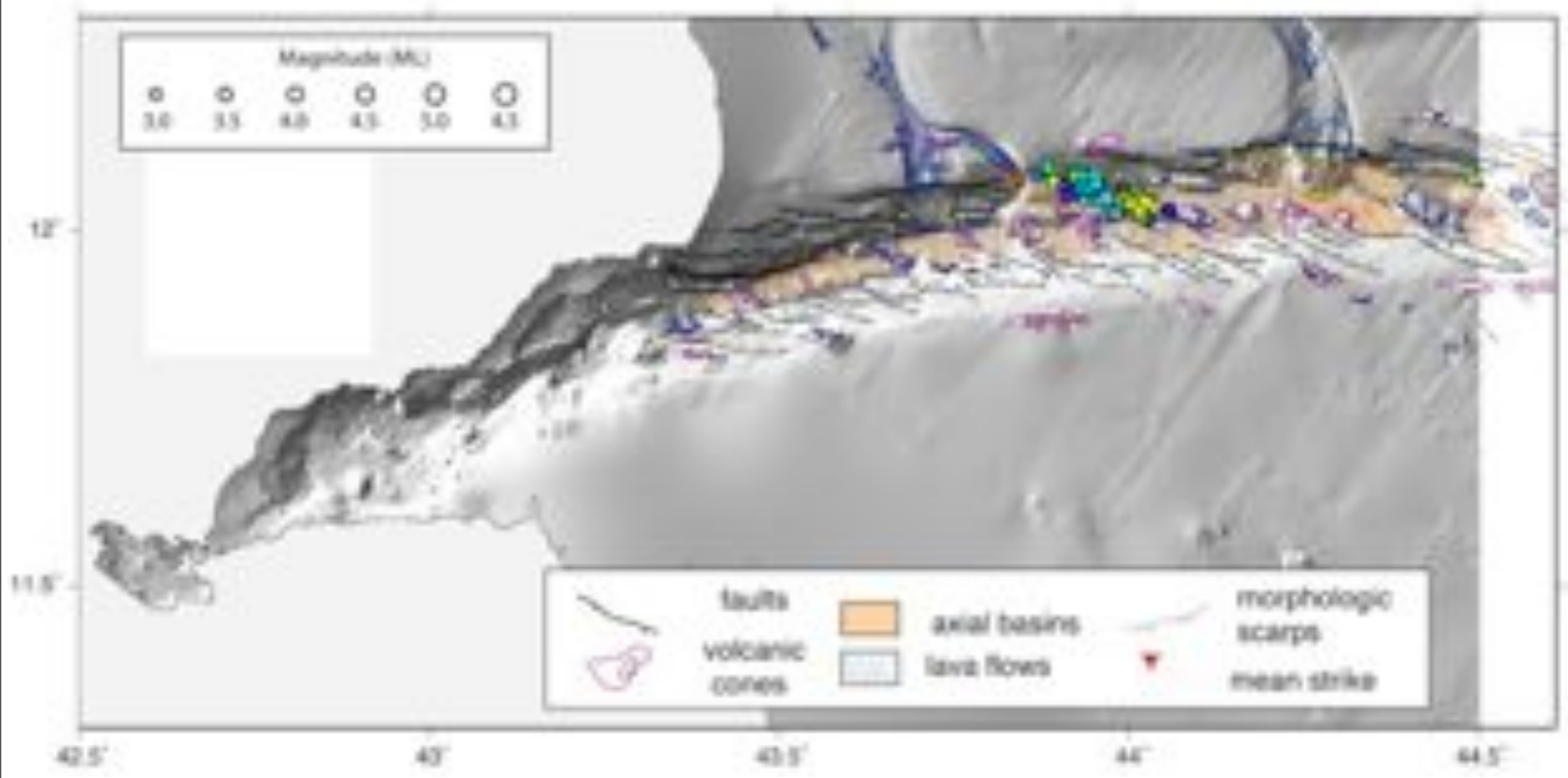
Main Swarm - part IV

Same N110°-trending alignement

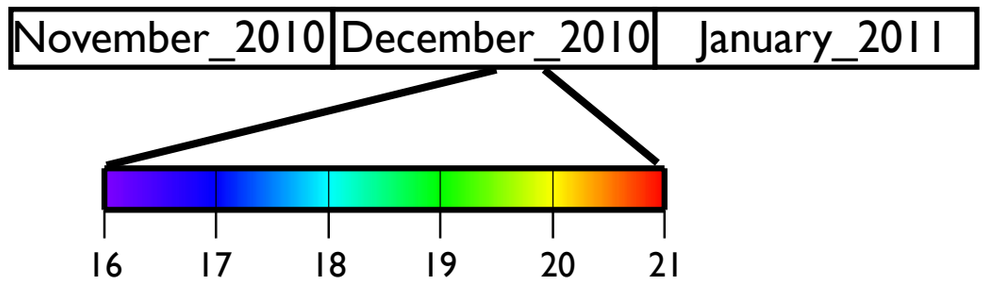
High concentration at the bottom of the ridge wall



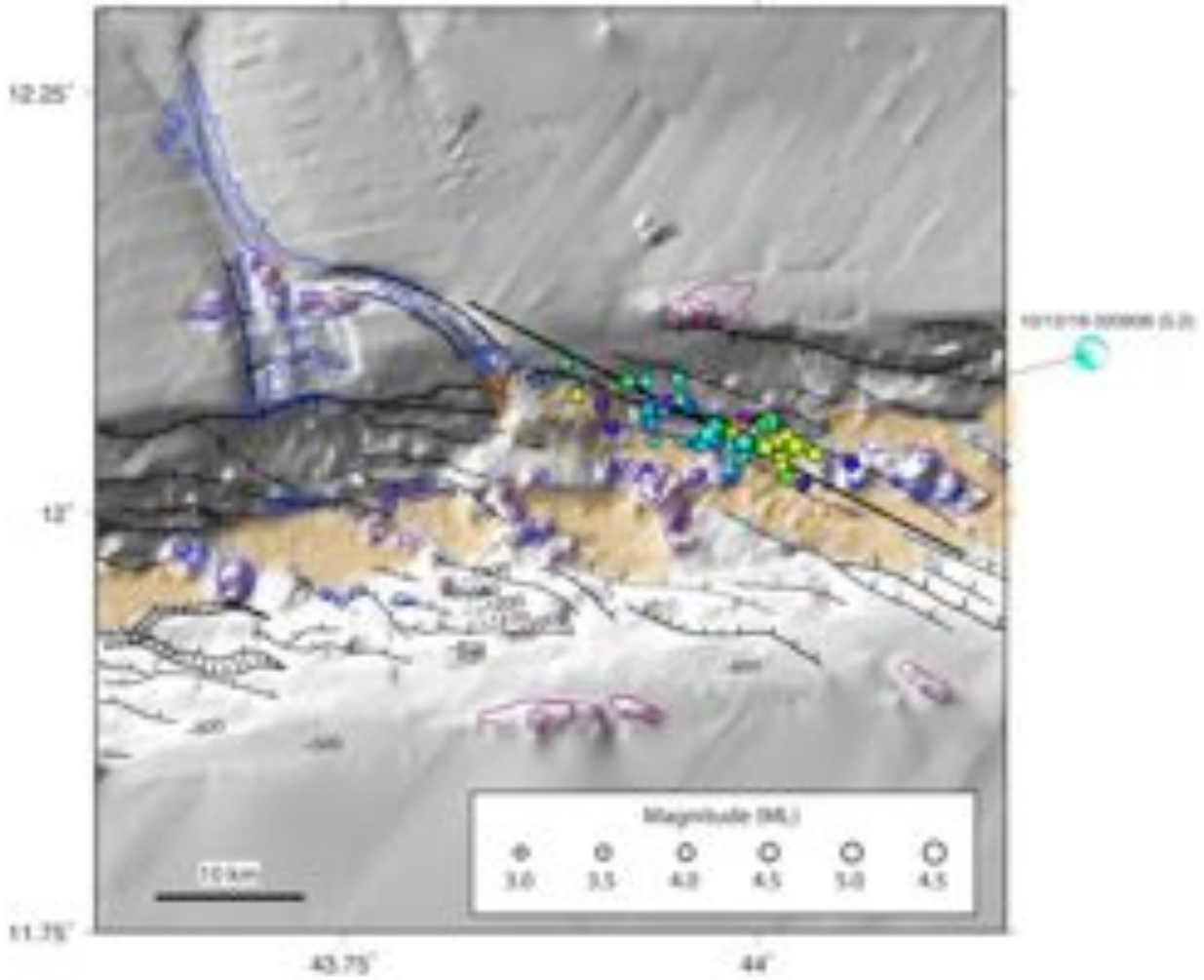
Time Evolution



16-20 December 2010 (*5 jours*)

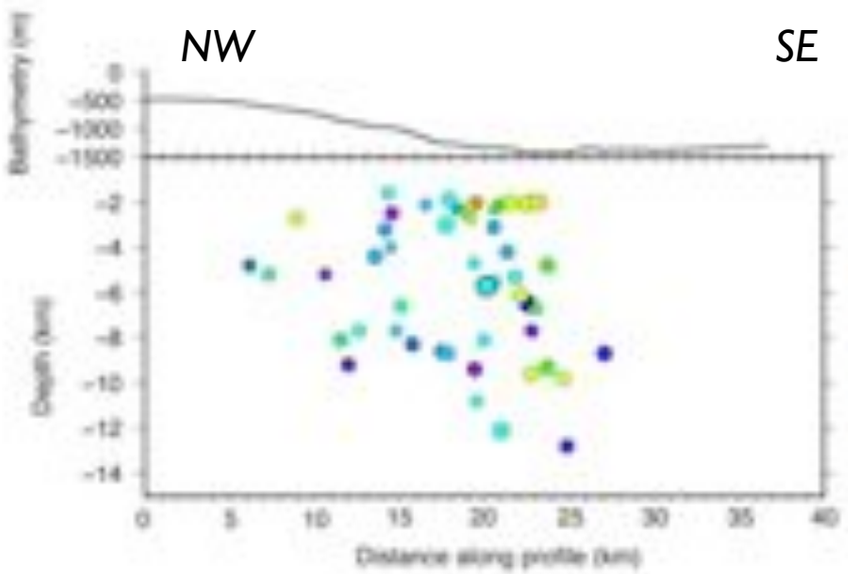


All temporary stations installed in Yemen and Djibouti

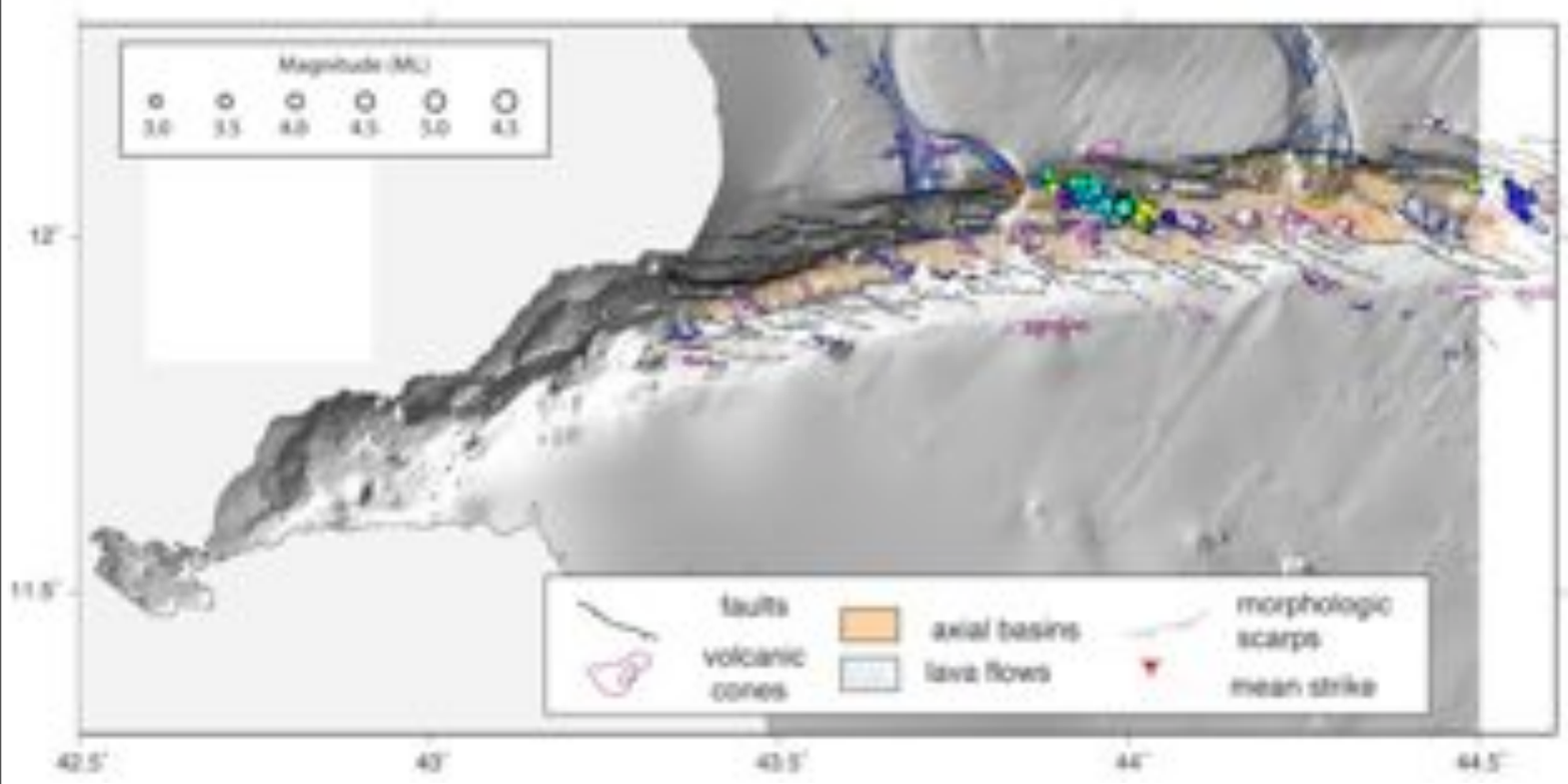


Main Swarm - part V

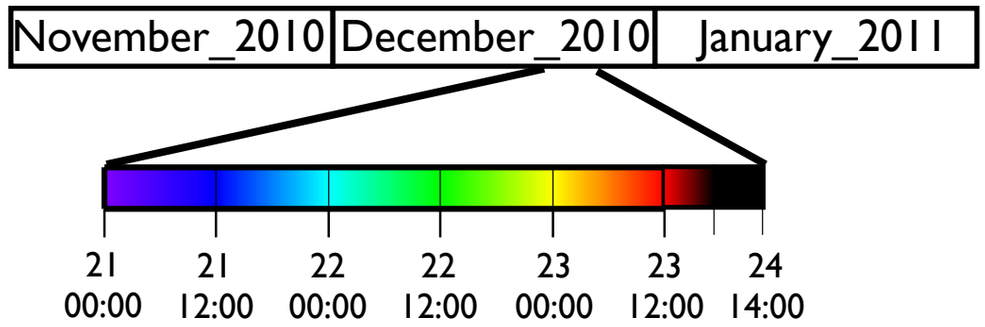
Same N110°-trending alignement
High concentration at the bottom of the ridge valley
Propagation to the SE : 0.15 km/h !!

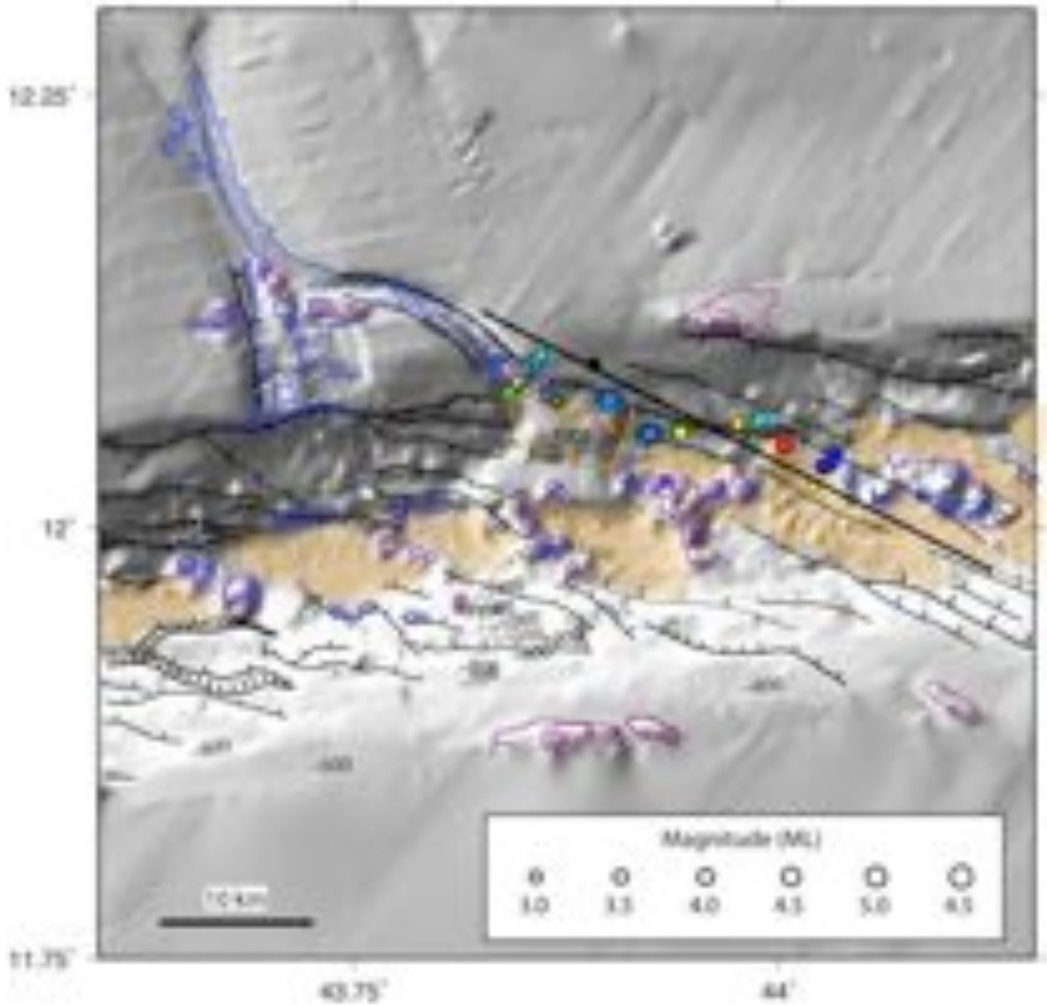


Time Evolution



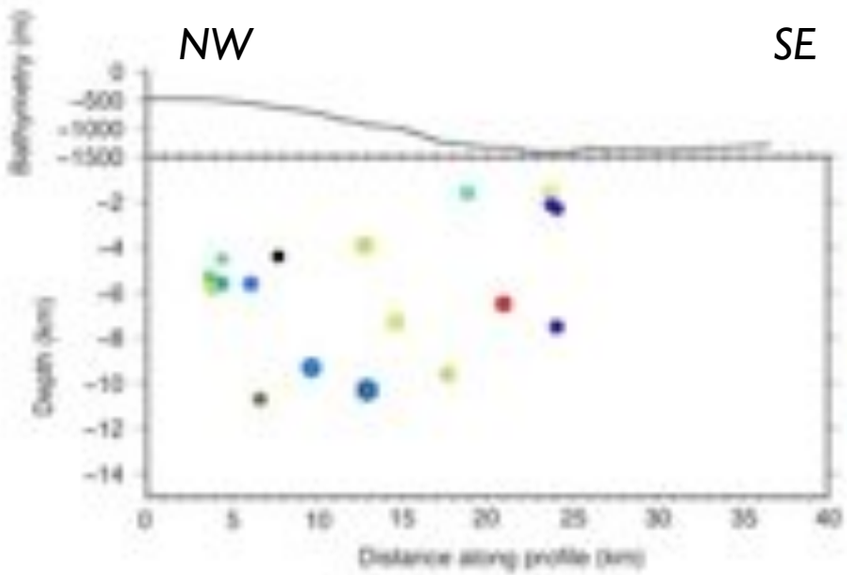
21-24 December 2010 (*6,5 days*)



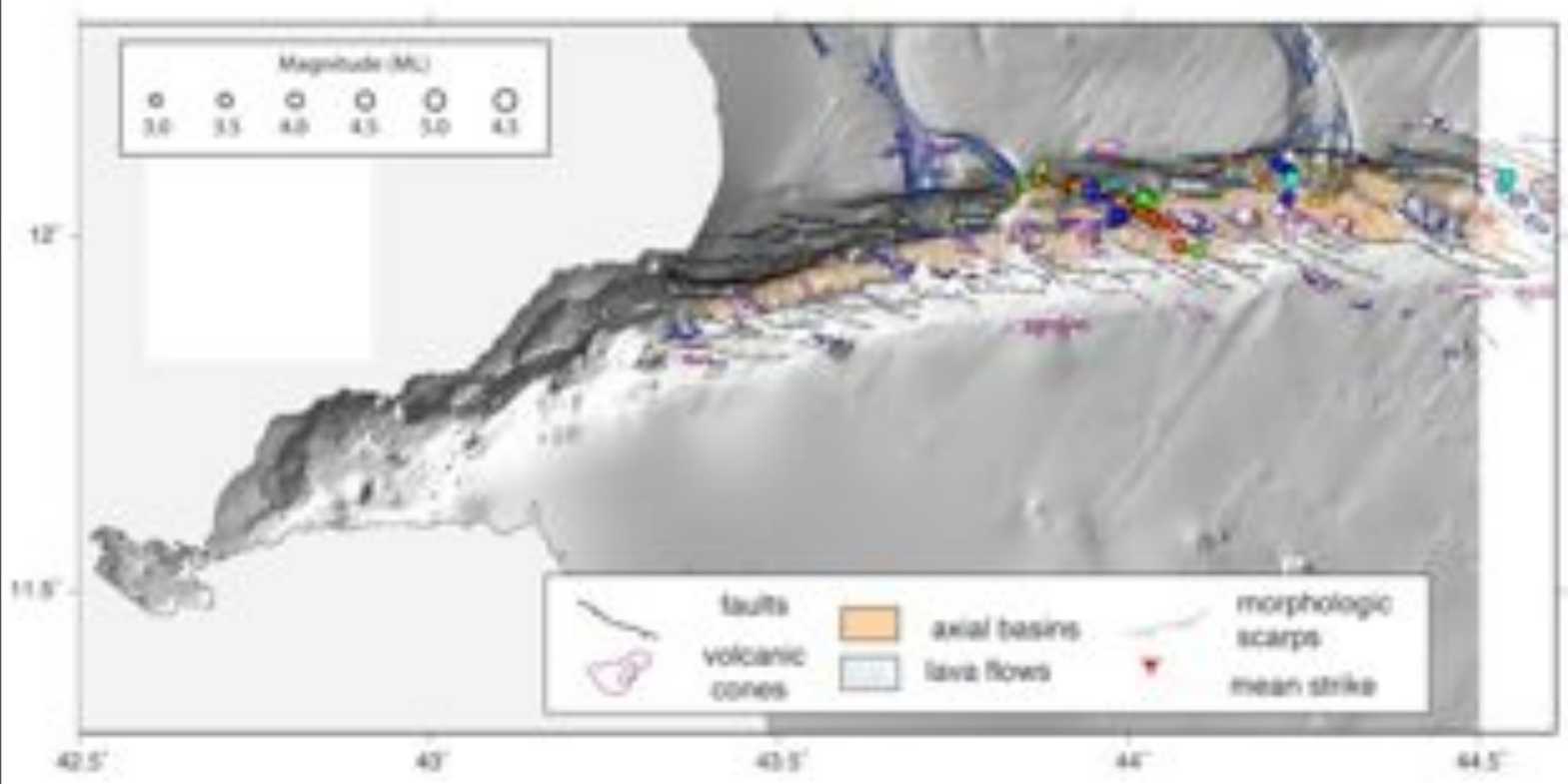


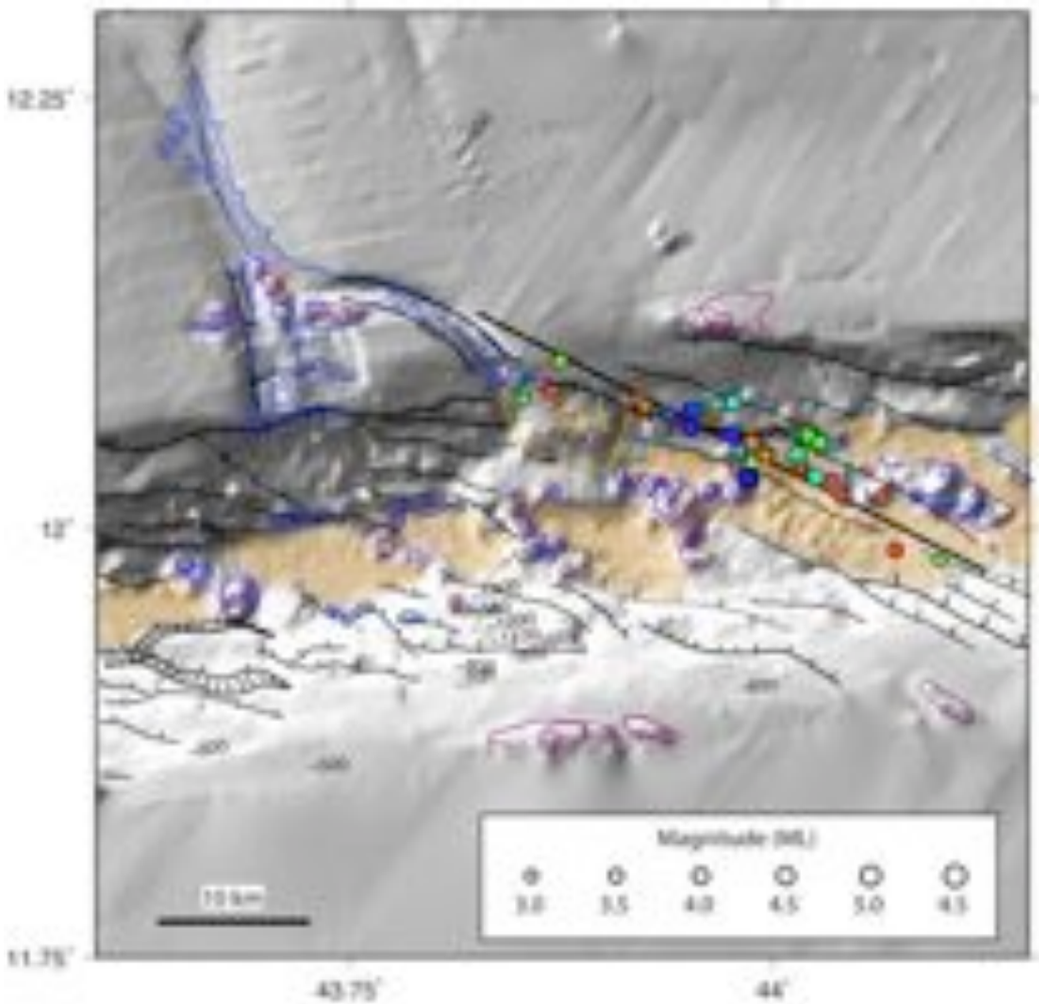
Decrease of activity

Same N110°-trending alignement
Large event at the bottom of the ridge valley
Small events near the canyon

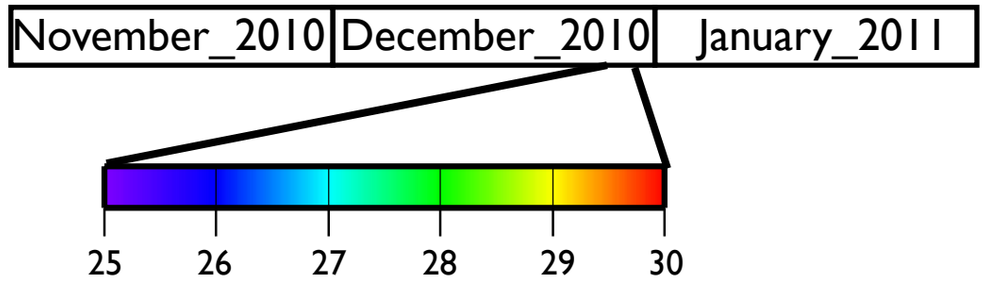


Time Evolution



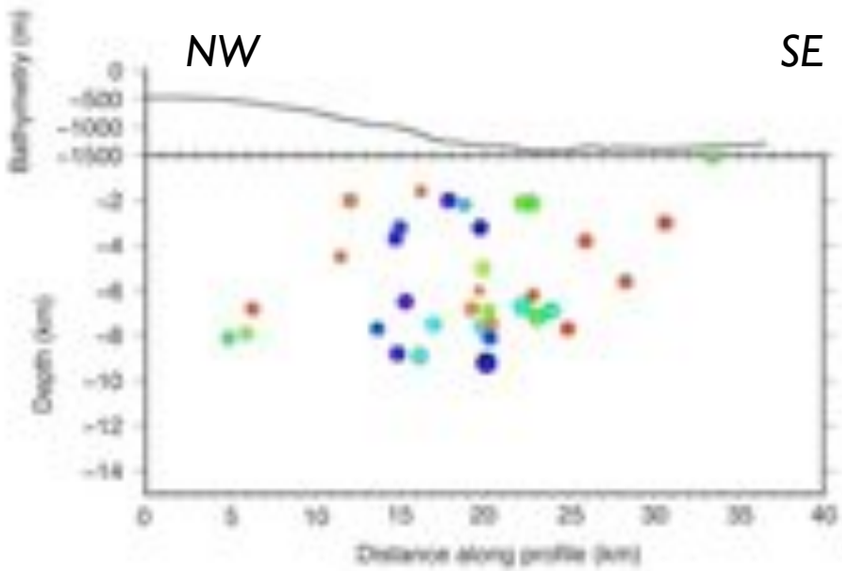


24-29 December 2010 (*5 days*)

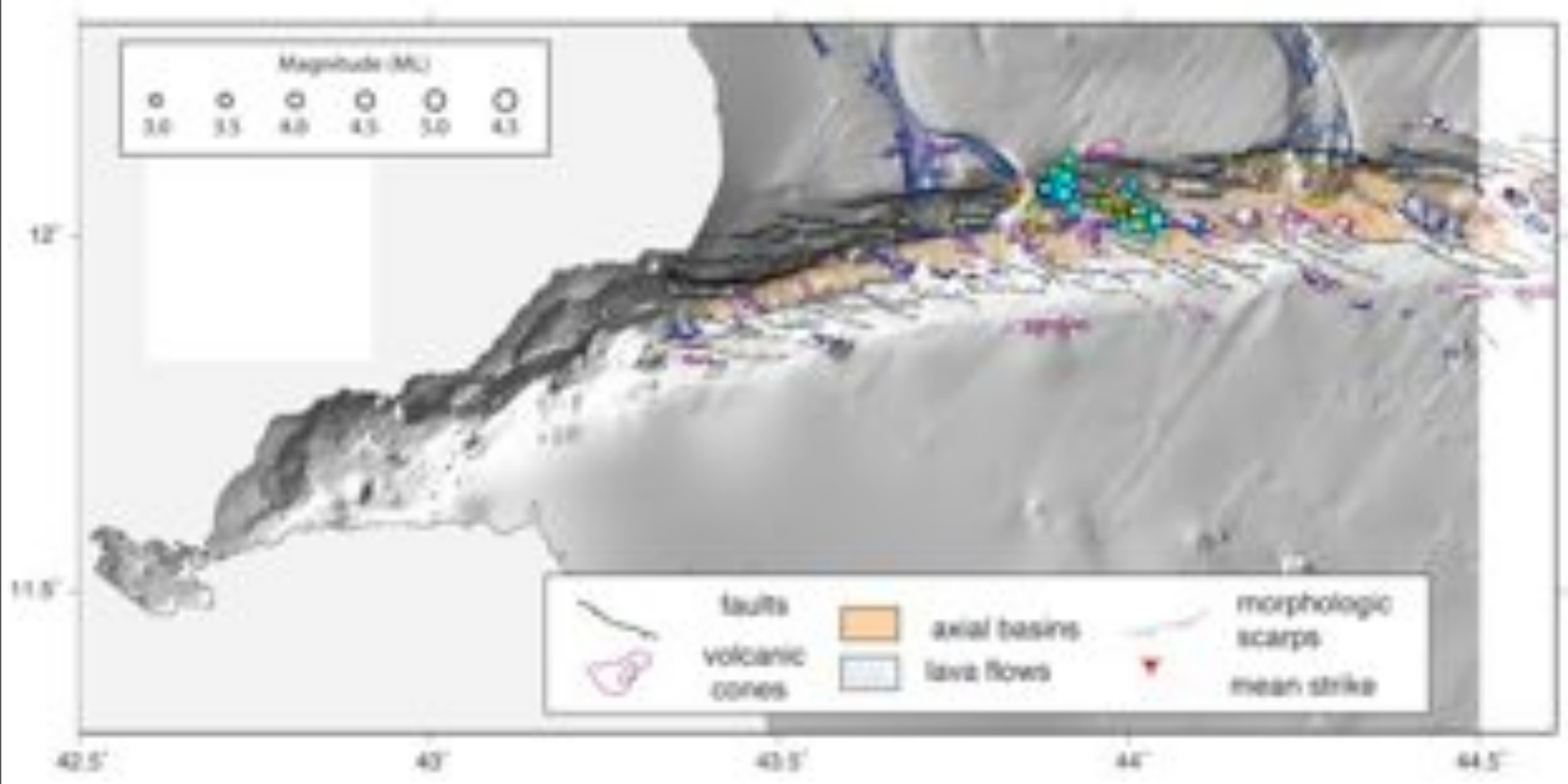


Decrease of activity

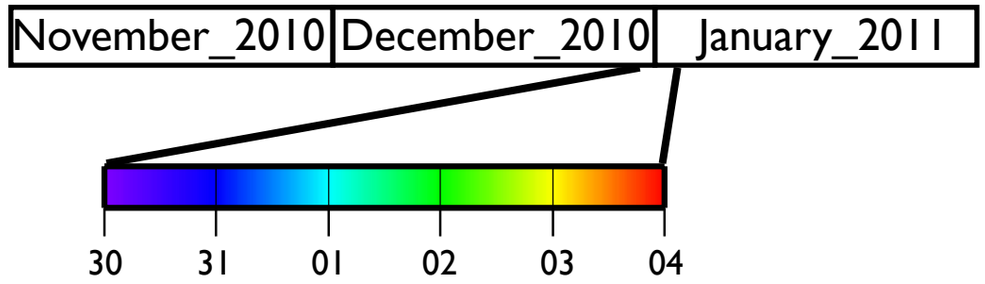
Same N110°-trending alignement
Moderate events at the bottome of the ridge valley
Small events near the canyon

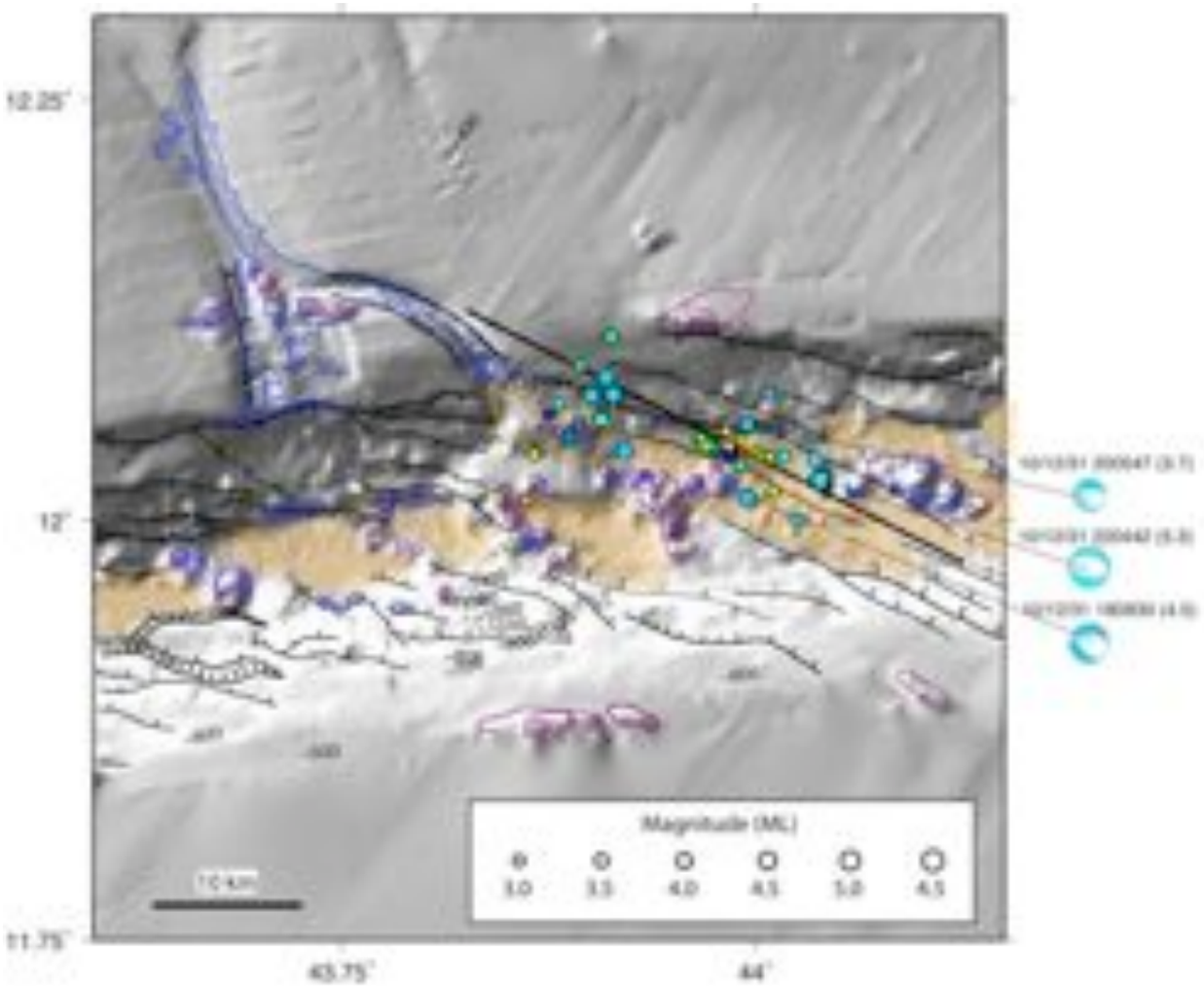


Time Evolution



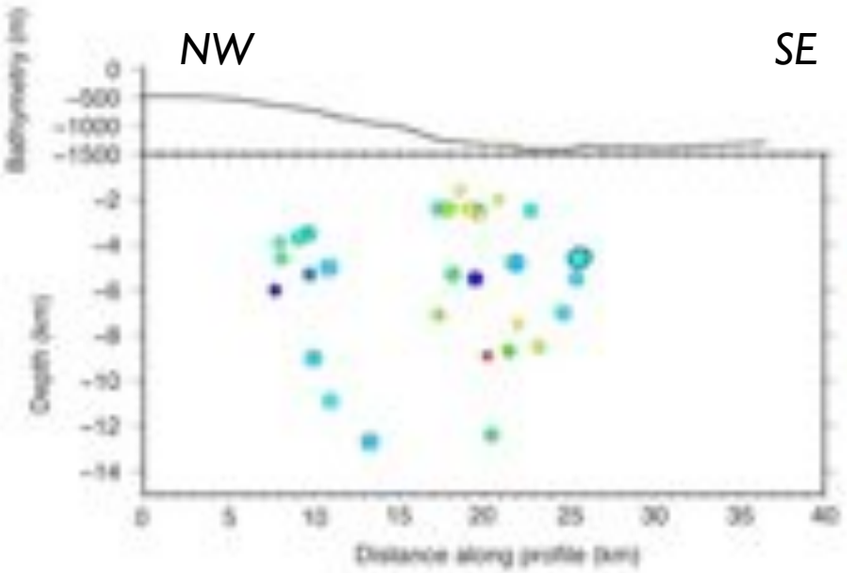
30 Dec. 2010 - 03 Jan 2011 (*5 days*)





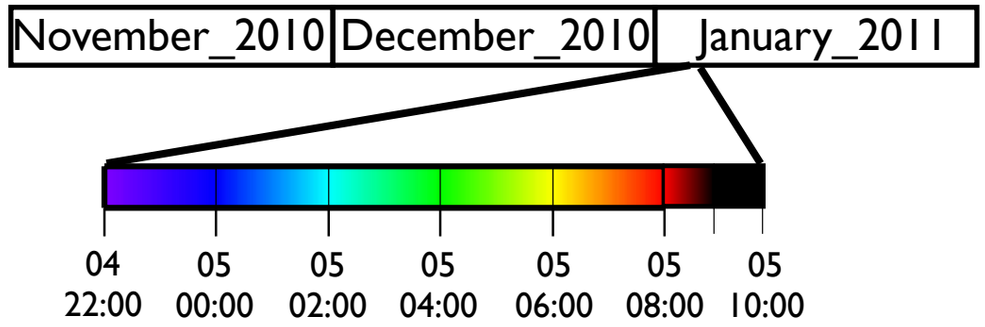
Decrease of activity

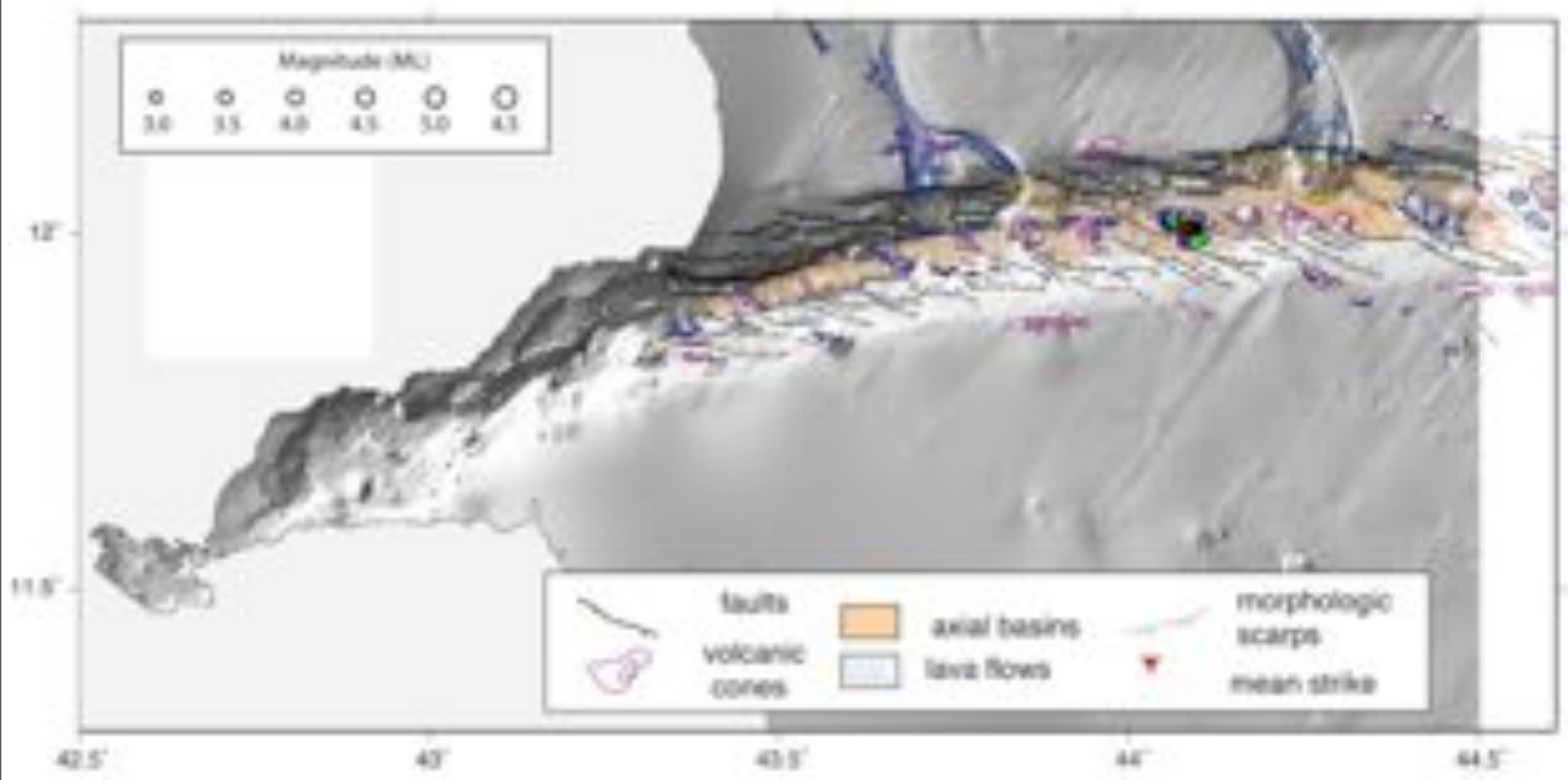
Same N110°-trending alignement
Large number of small, shallow events + Large events
Events located on the fan

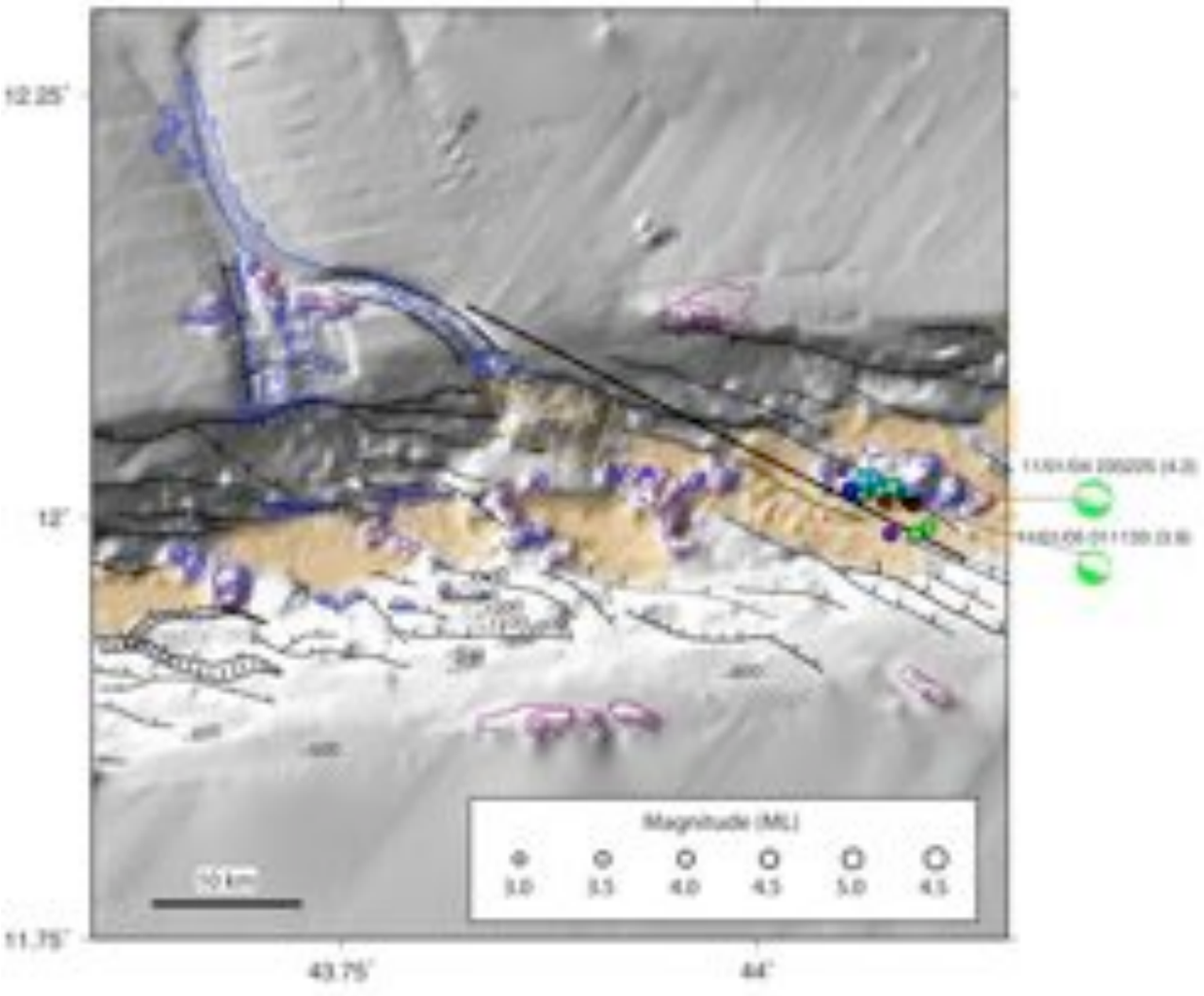


Time Evolution

04-05 January 2011 (*12 hours*)

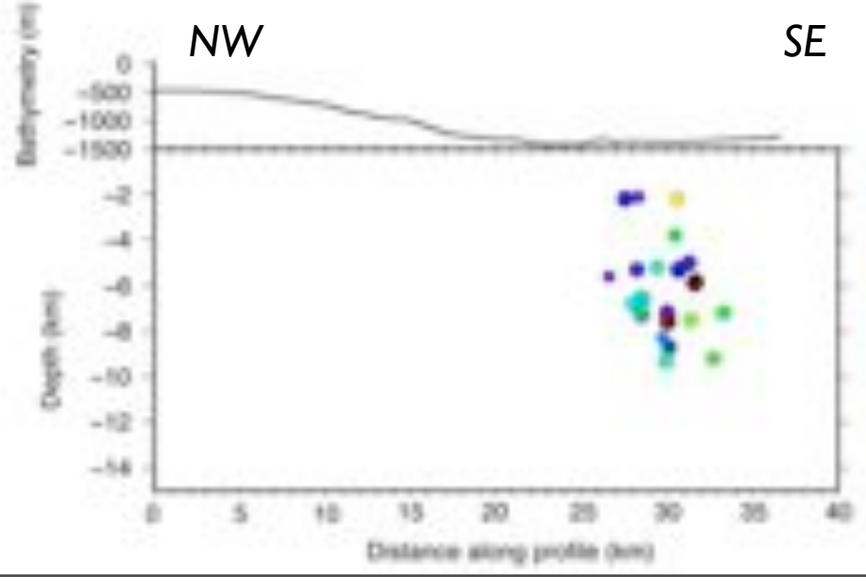




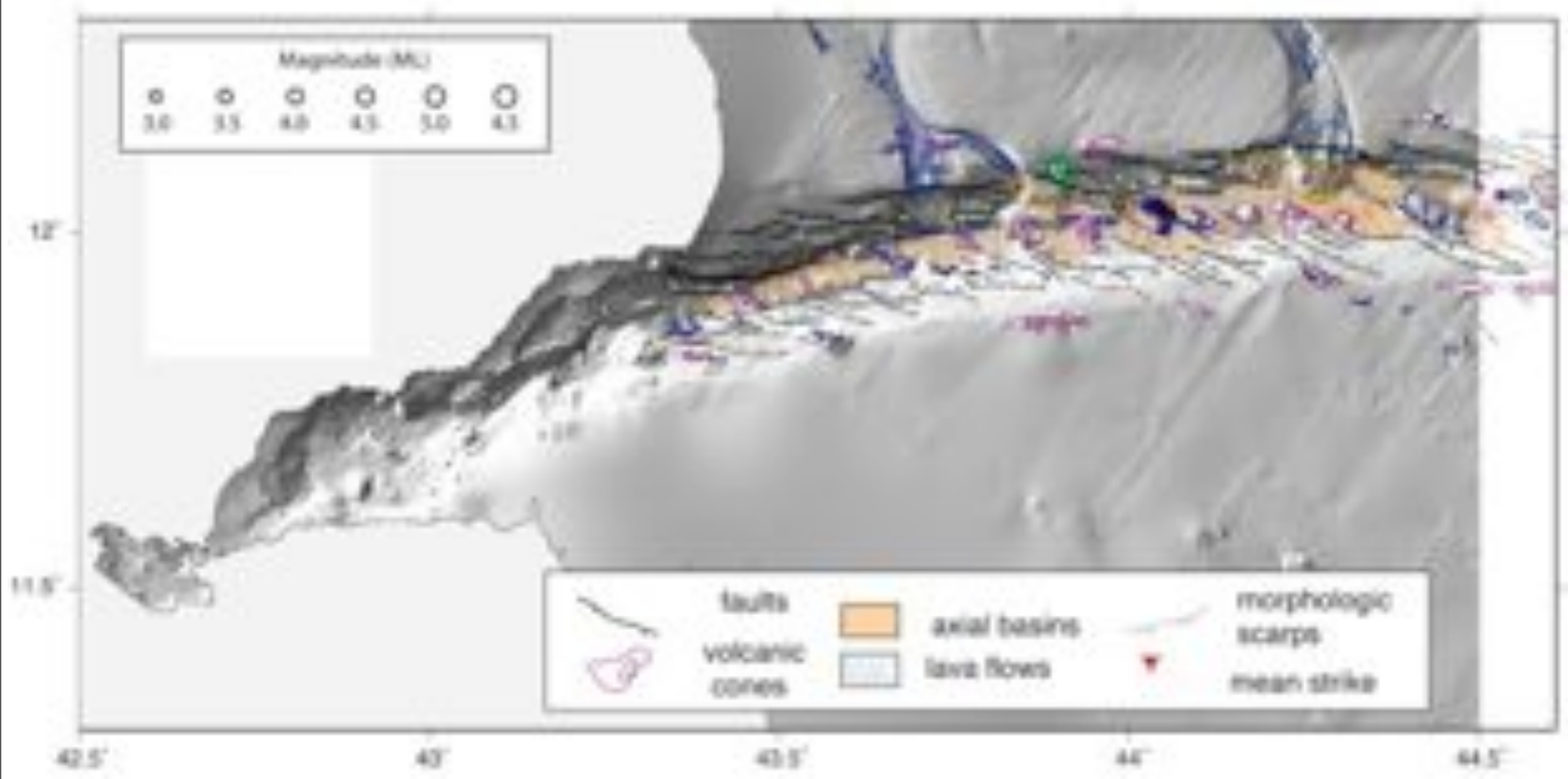


Burst of activity near the volcanic center

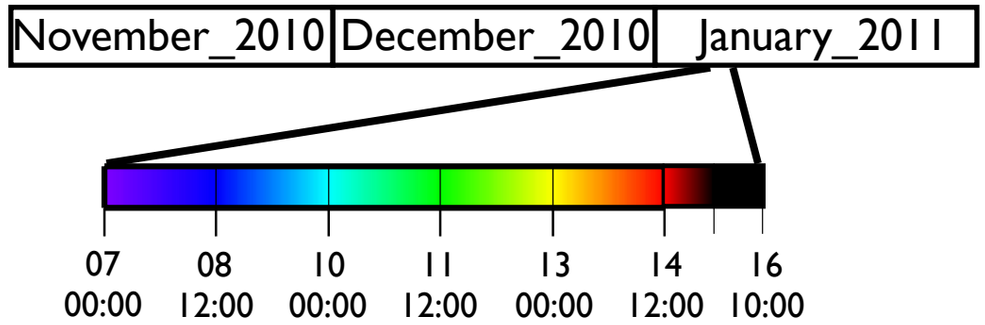
Concentration of 21 events at the SE of the active area in 12 hours

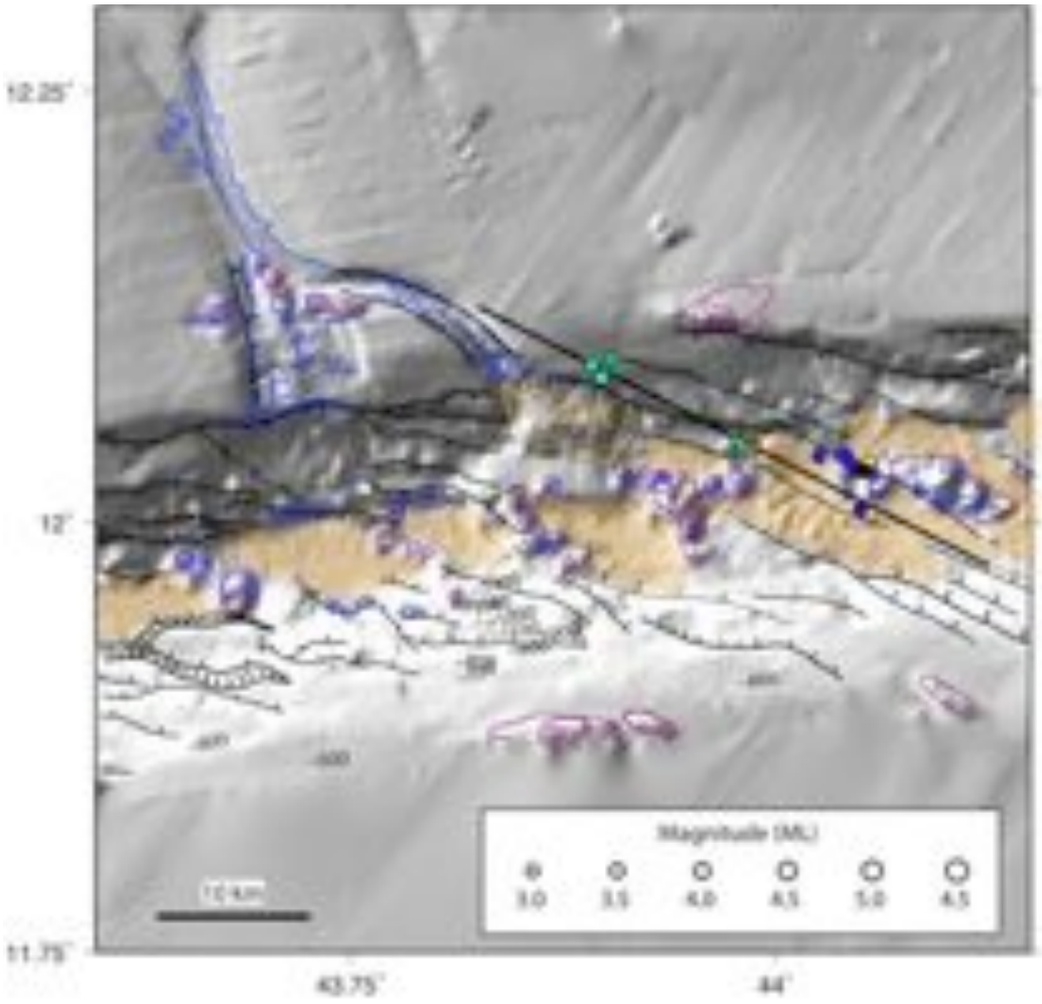


Time Evolution



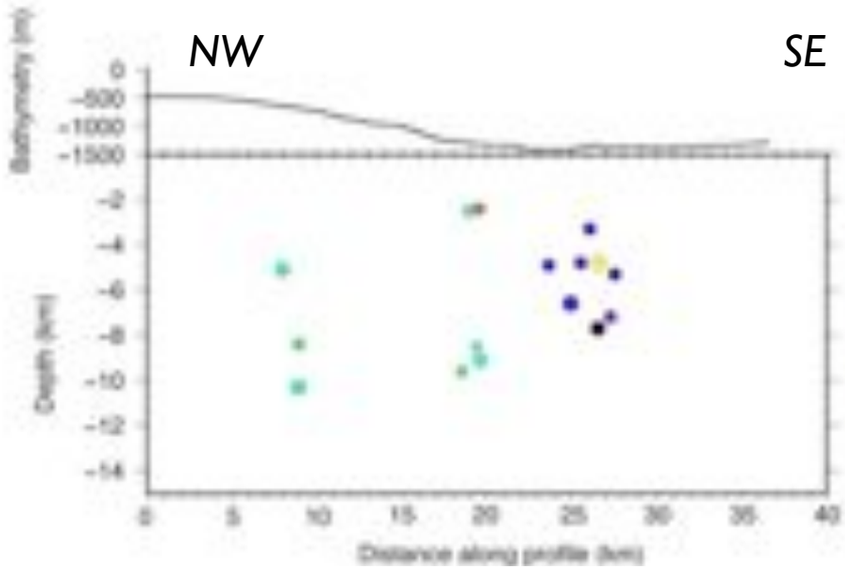
07-15 January 2011 (~1.5 days)



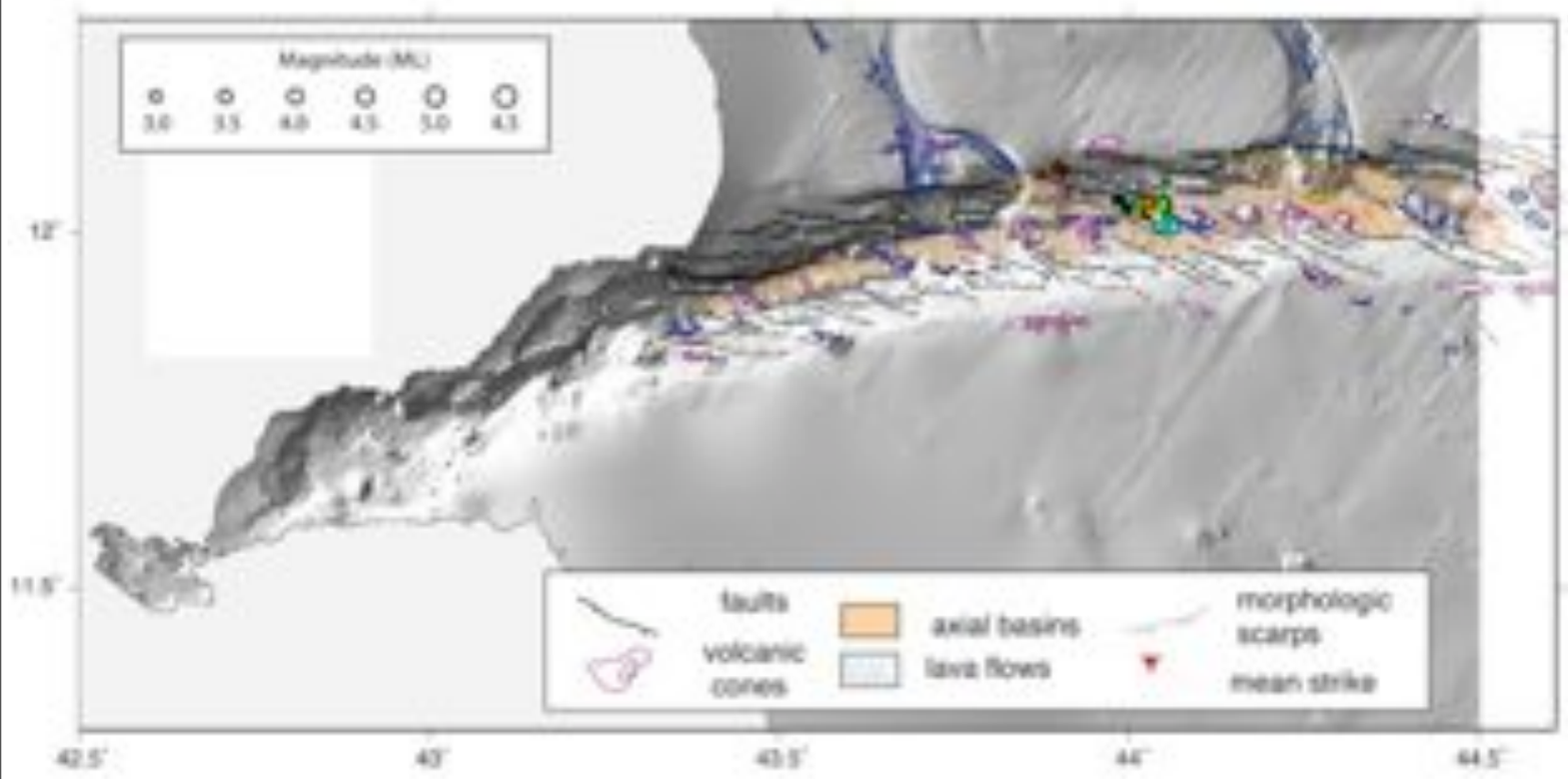


Decrease of seismicity

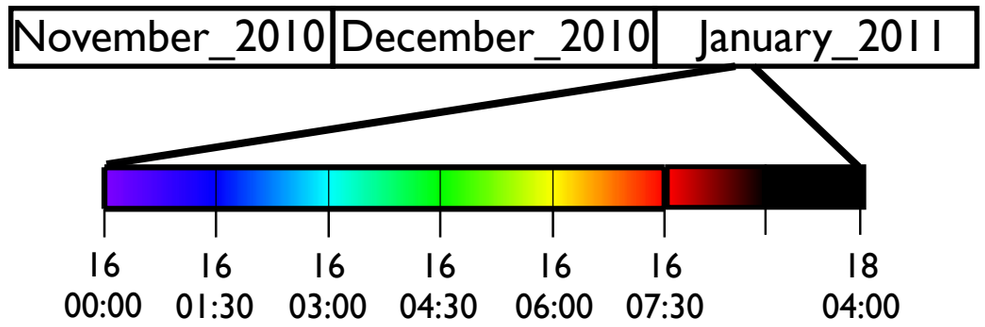
Few swarms along the segment

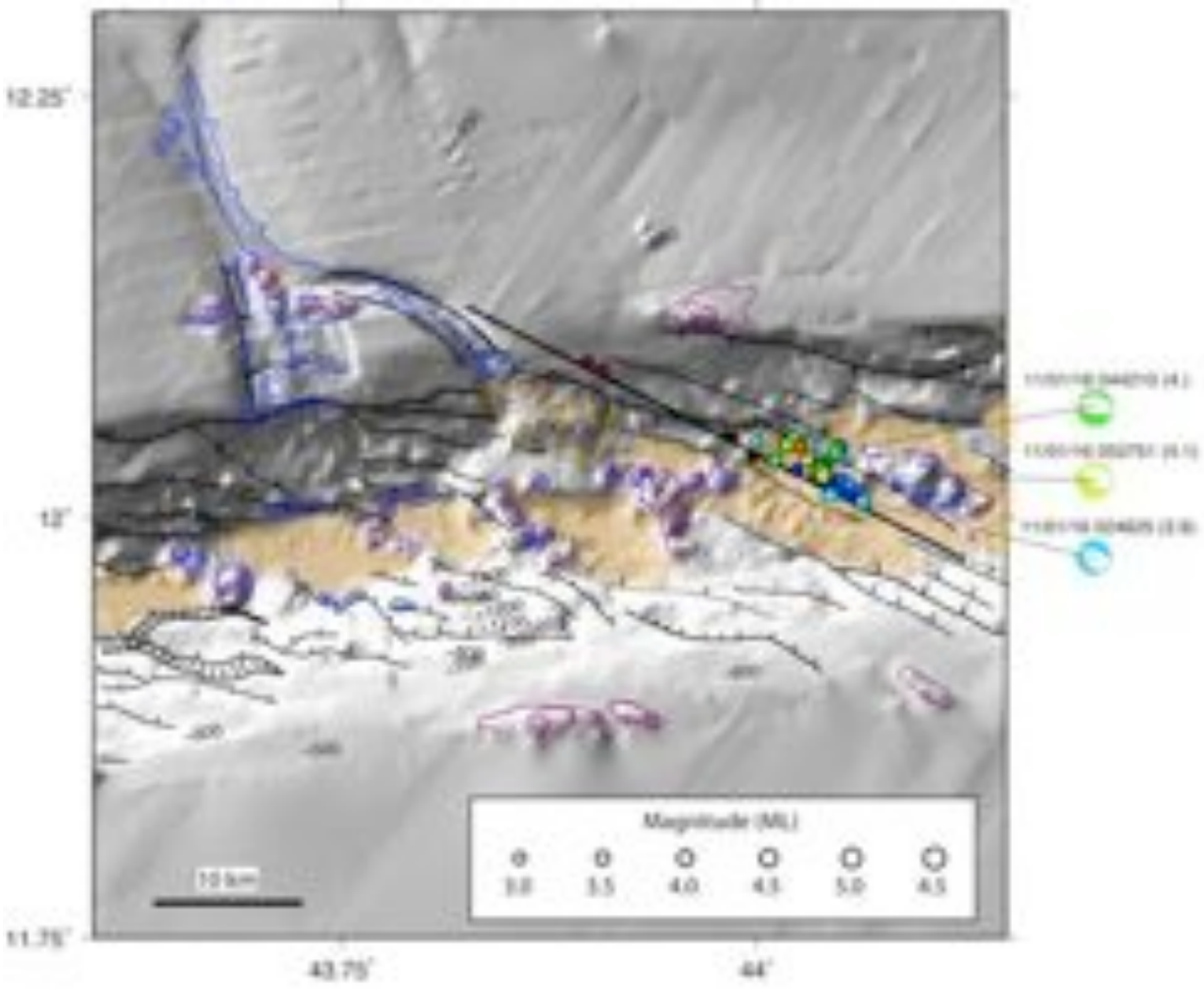


Time Evolution



16 (-18) January 2011 (*7,5 hours +2 days*)

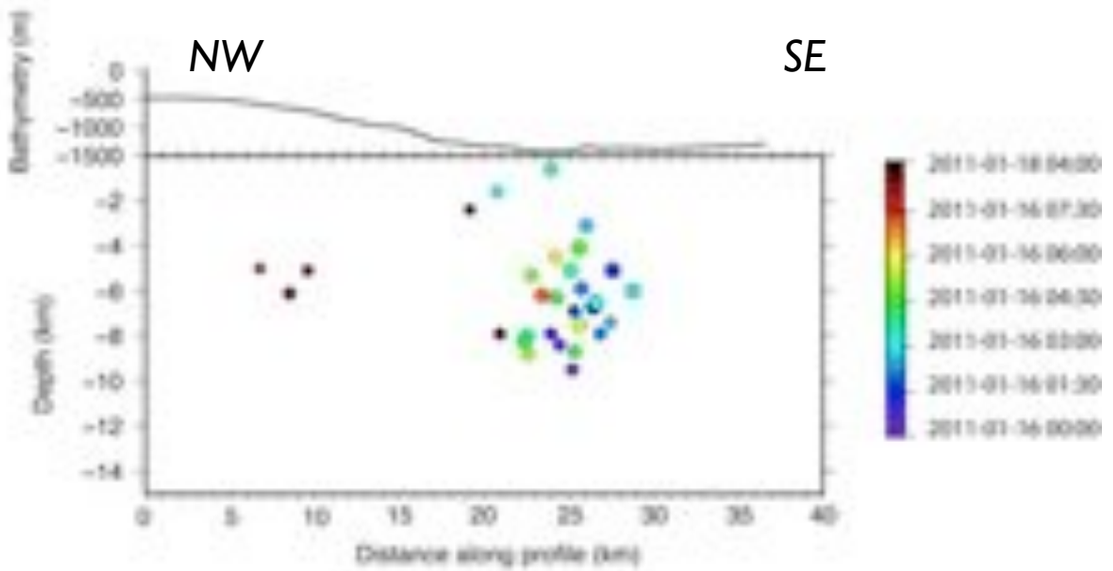




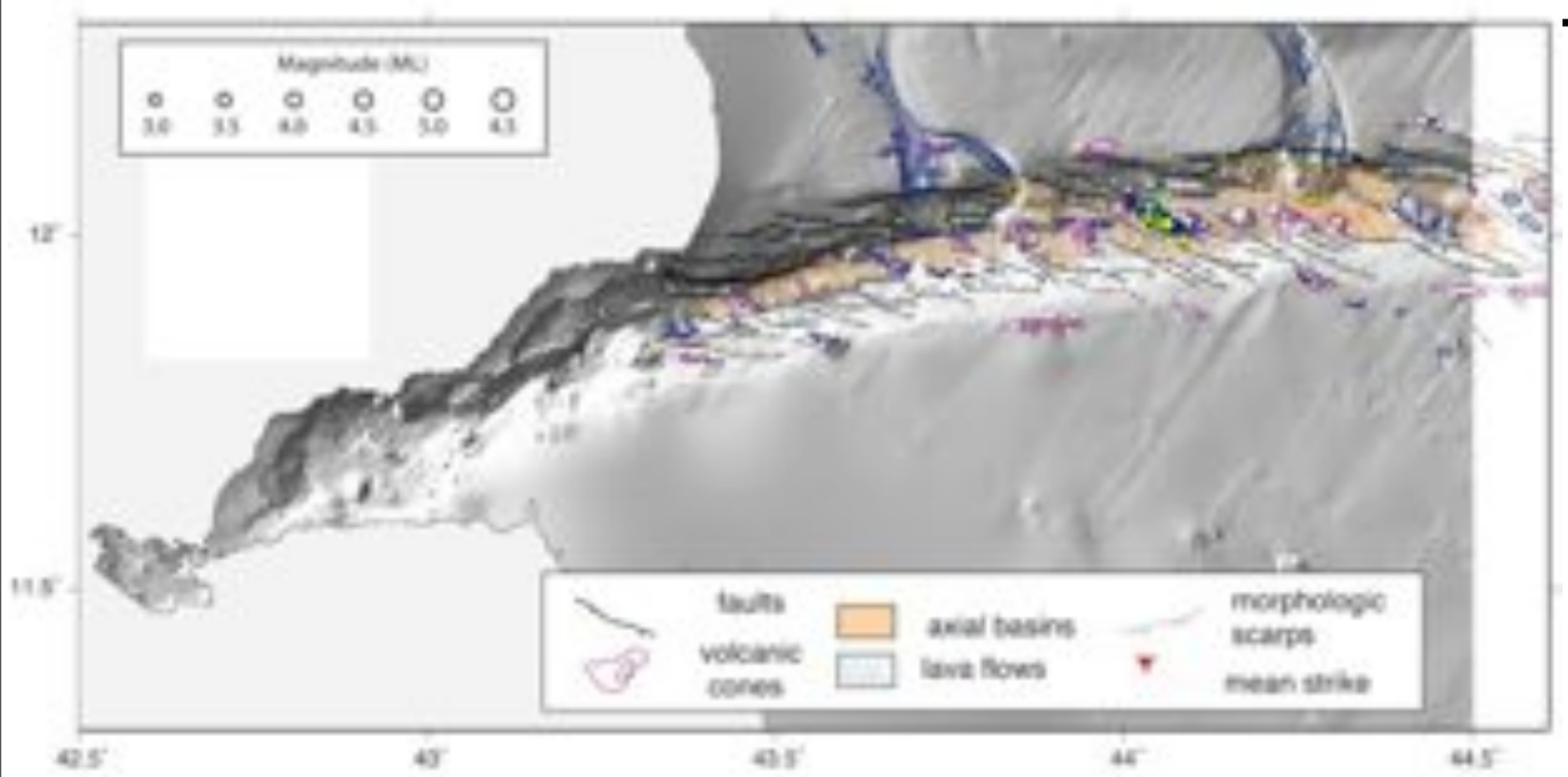
Burst of activity near the volcanic center

Propagation on a short distance (5 km) from the volcanic area

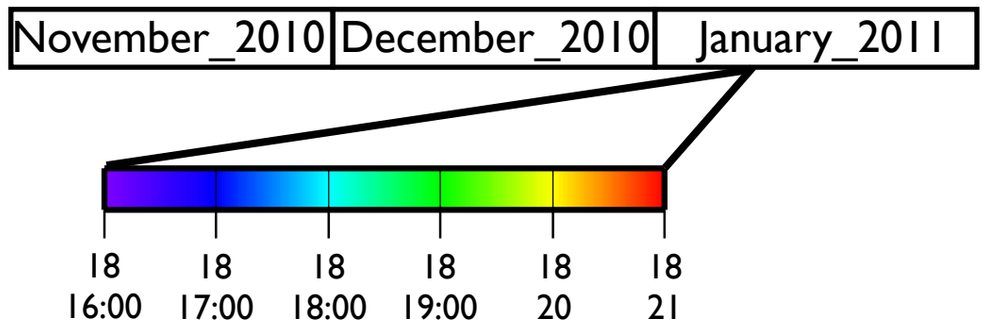
Velocity: 1 km/h

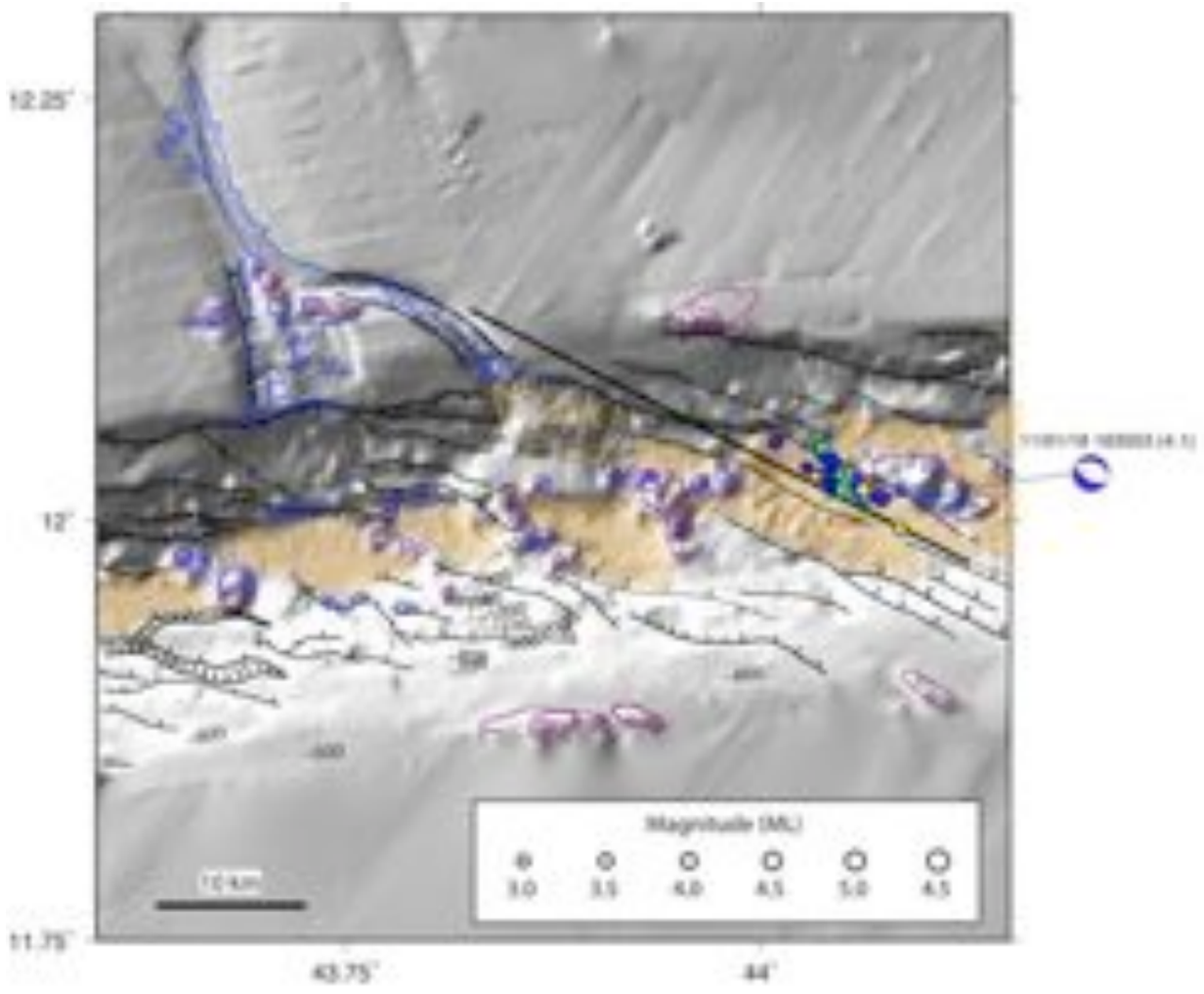


Time Evolution



18 January 2011 (*5 hours*)

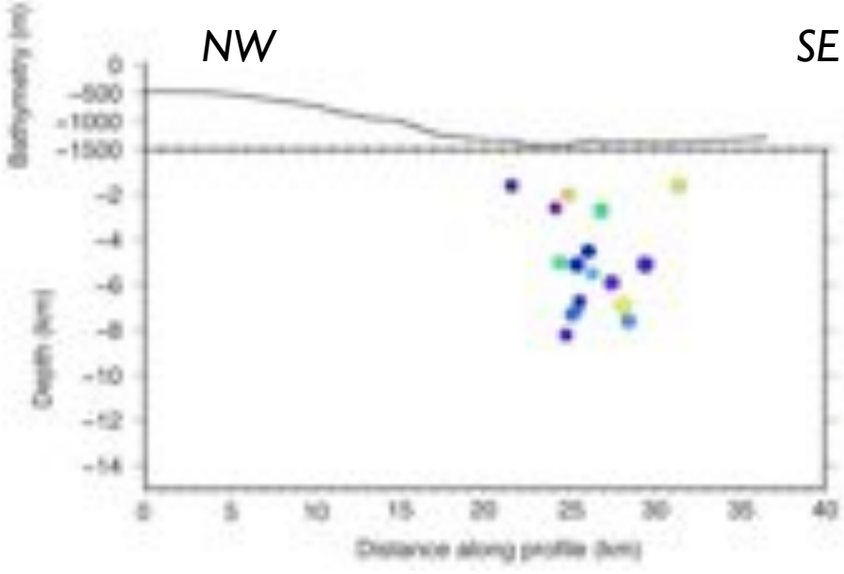




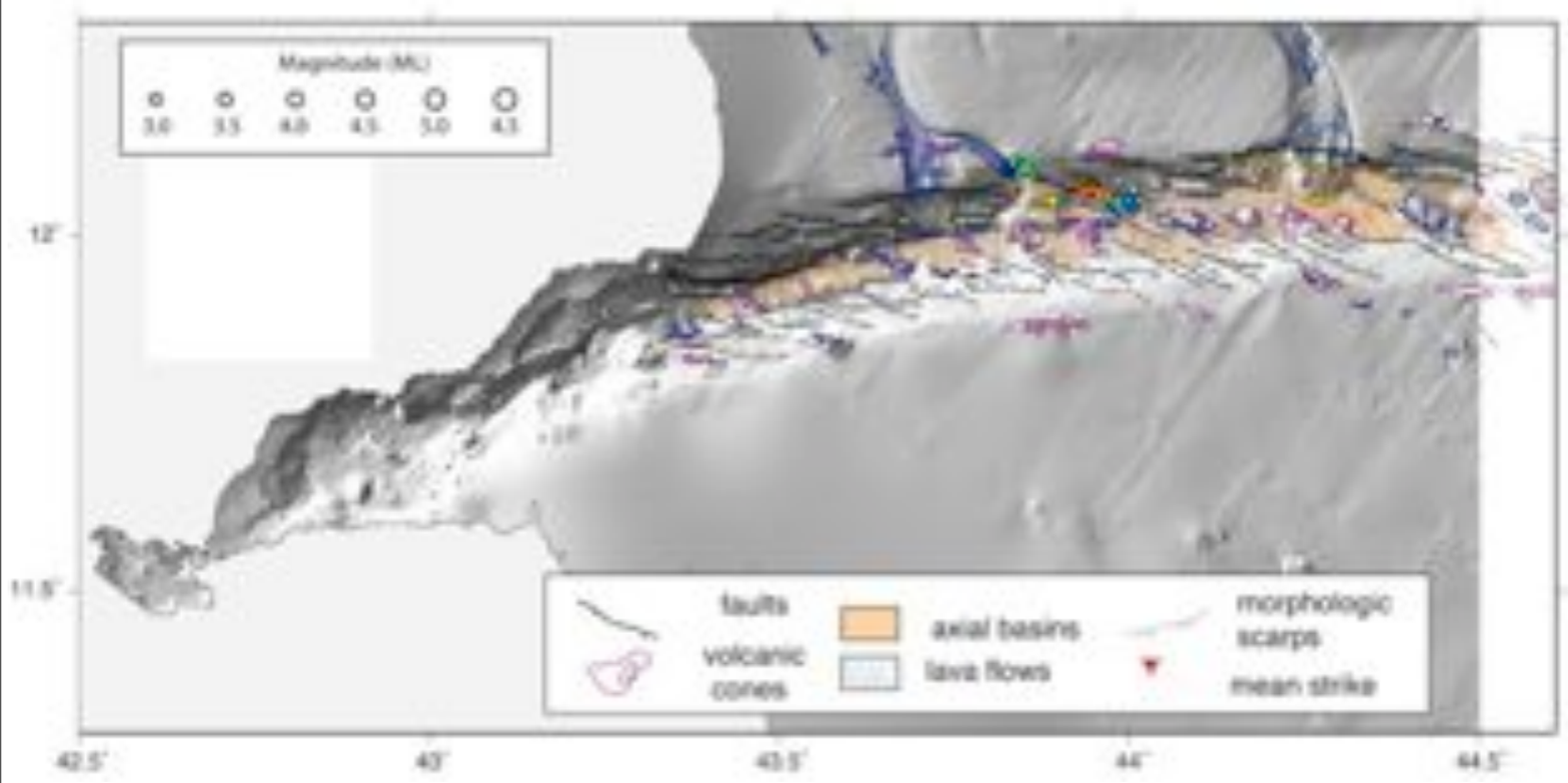
Burst of activity near the volcanic center

16 small events in 3 hours

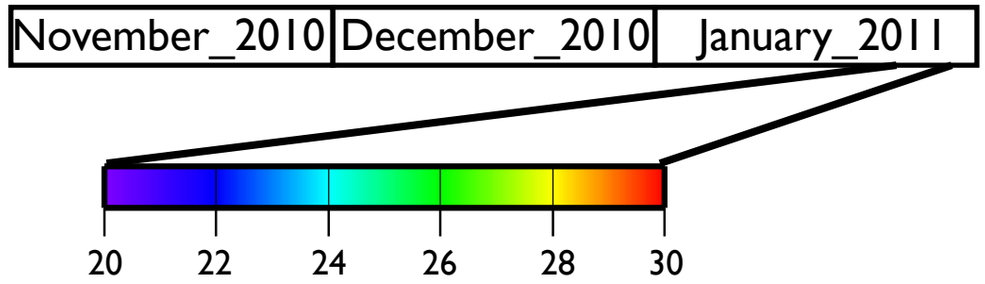
No temporal organization

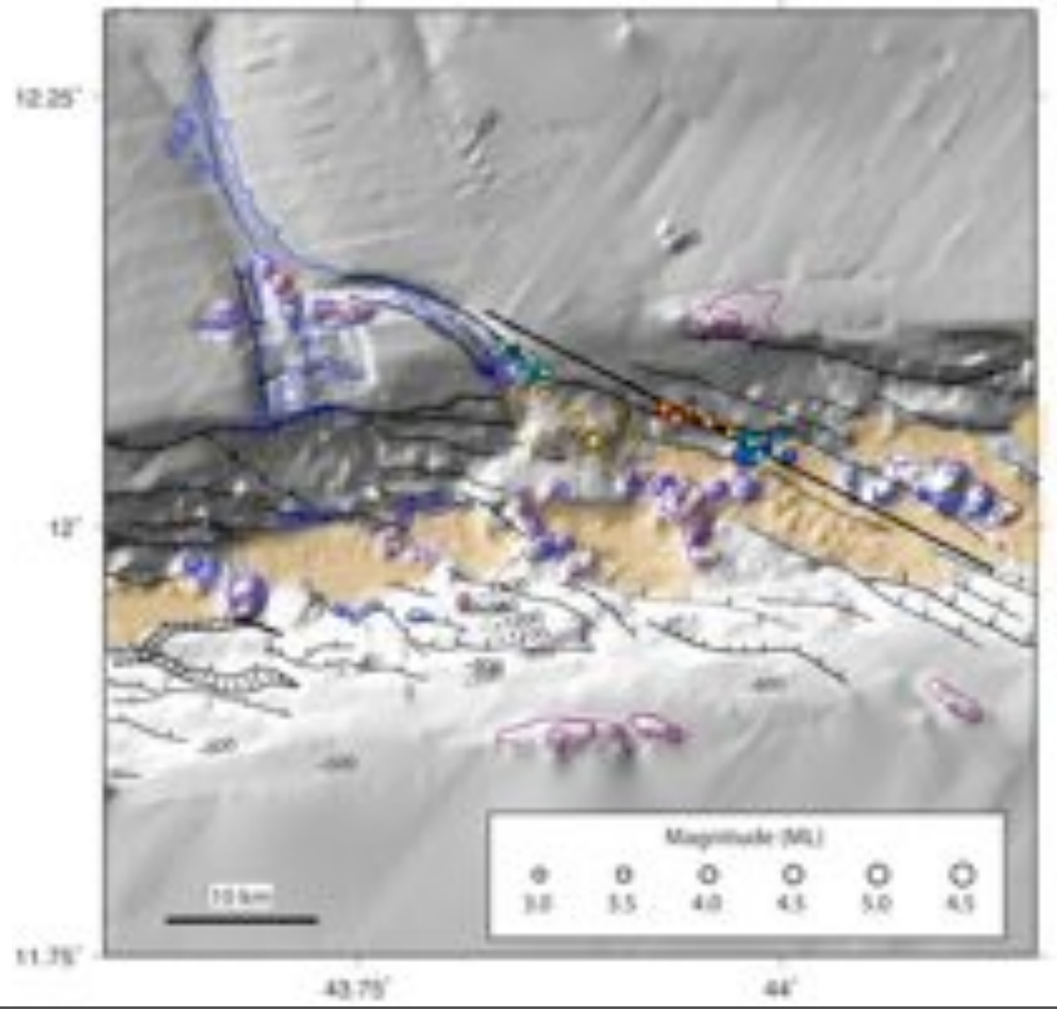


Time Evolution



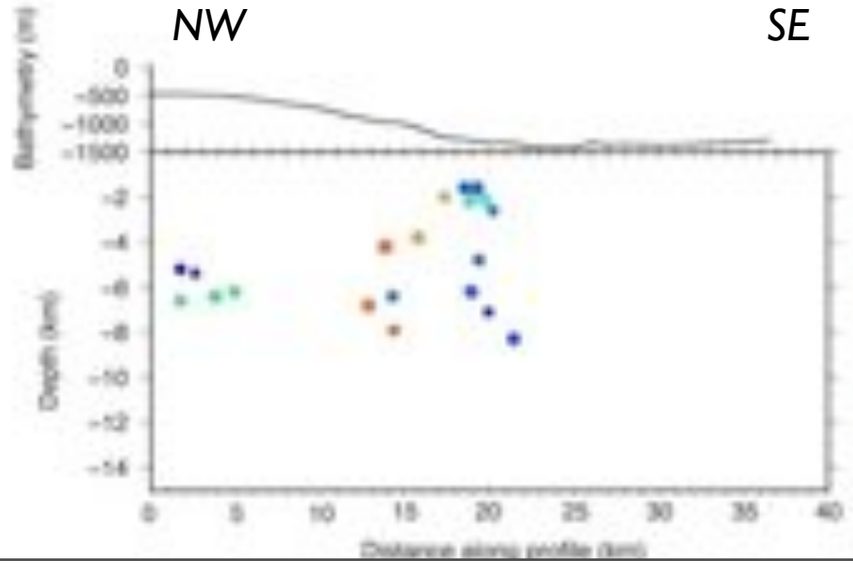
20-29 January 2011



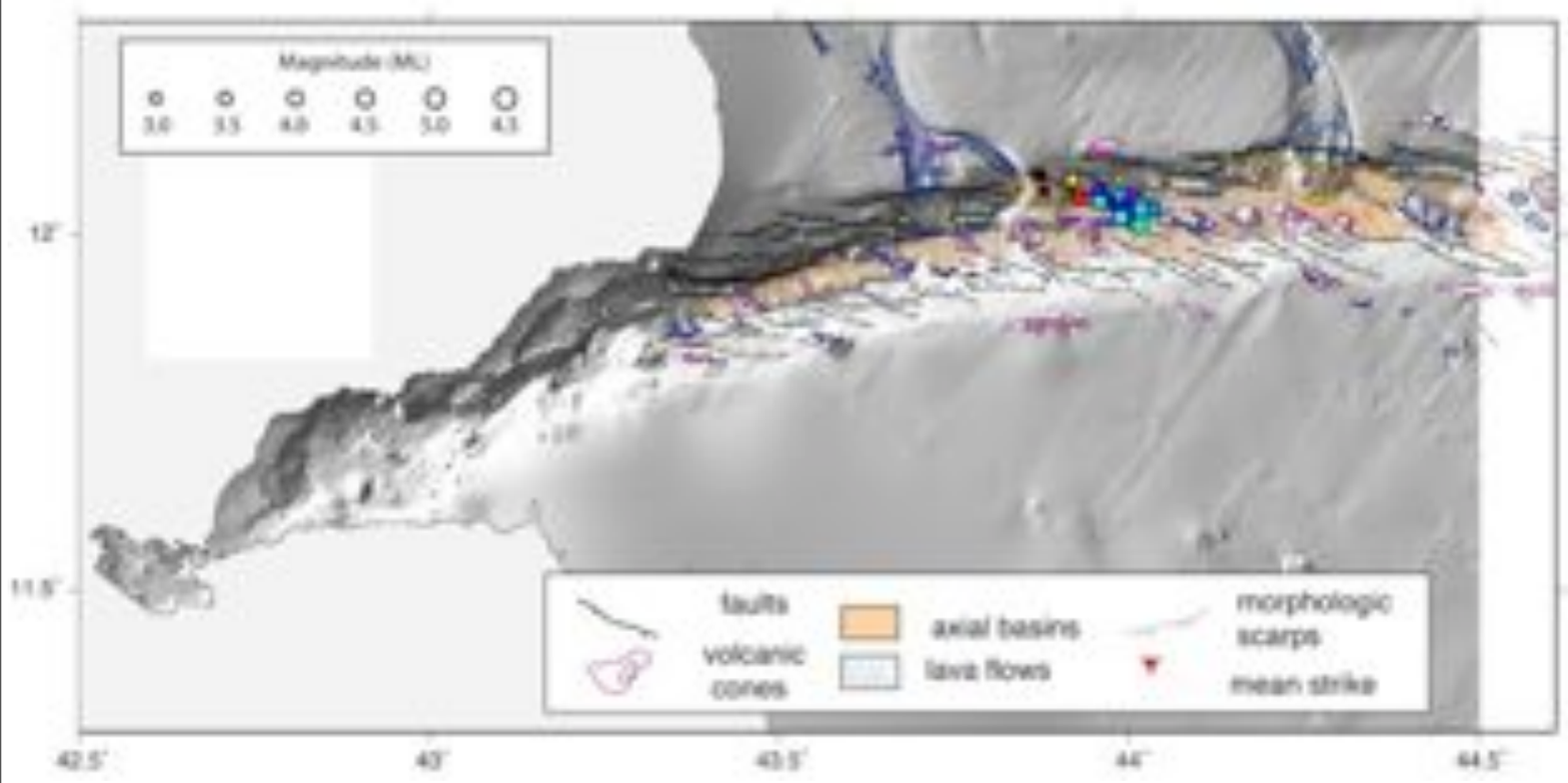


Decrease of activity

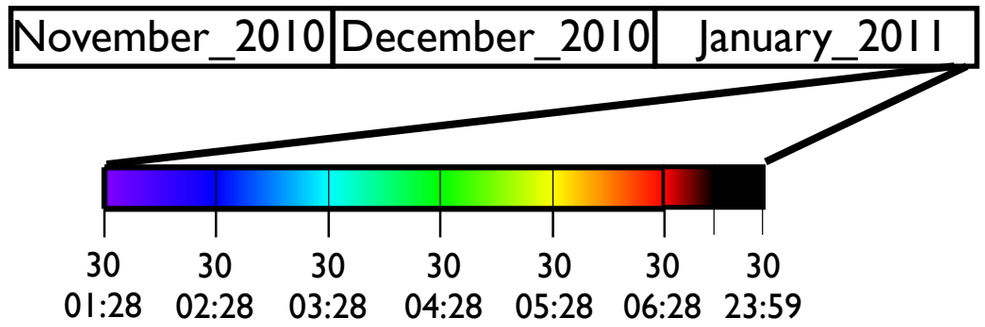
Small events at the bottom of the ridge valley
Small events in the canyon

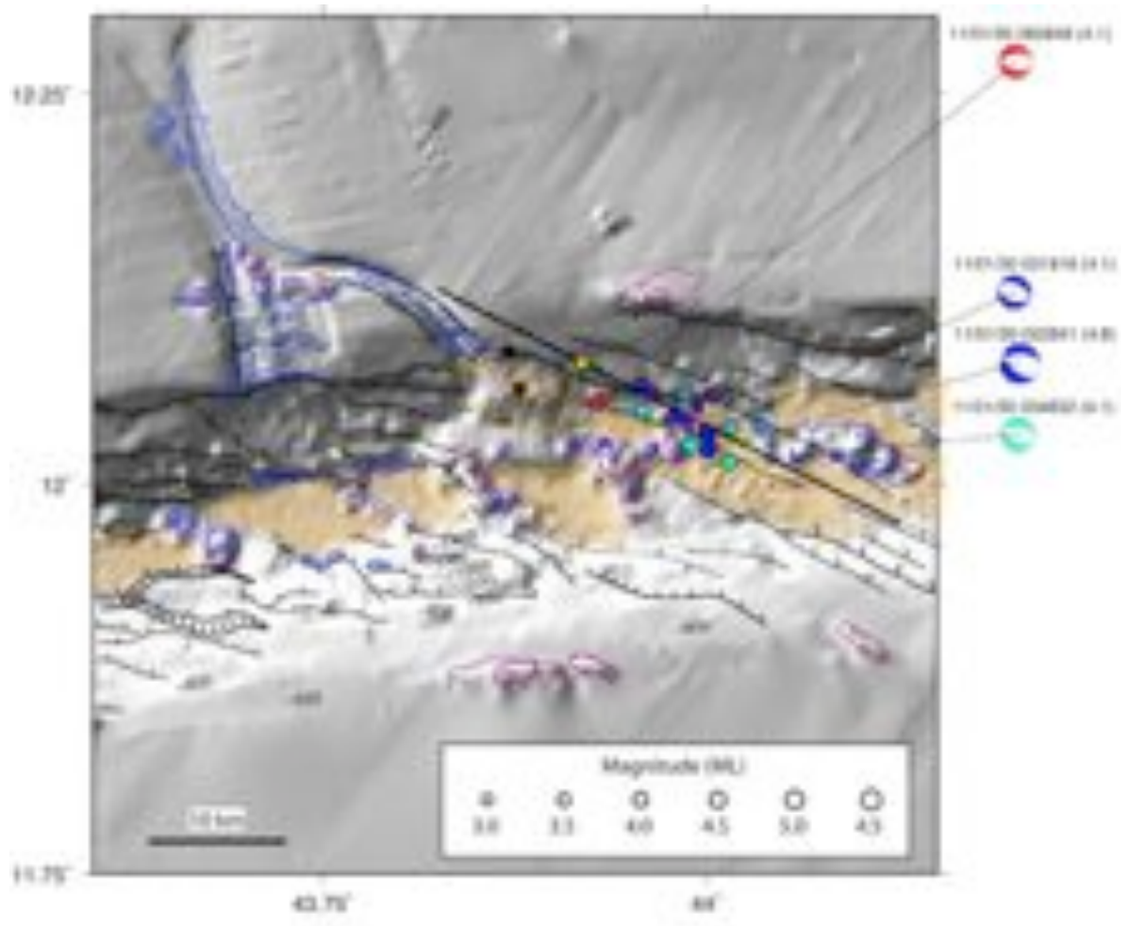


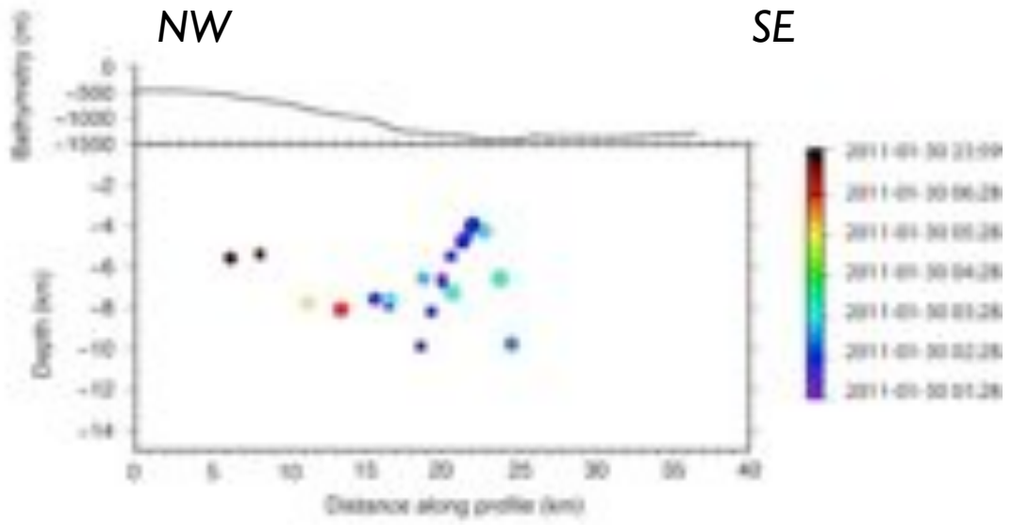
Time Evolution



30 January 2011 (*23 hours*)







Conclusions

- Very large seismic episode
  Total seismic moment 2.4 10^{18} Nm (Dabbahu : 3.4 10^{18} Nm)

- Spatial distribution of seismicity (alignement)
- Temporal evolution of seismicity (propagations)

} Several small dyking events

However migration towards the central volcanic area !

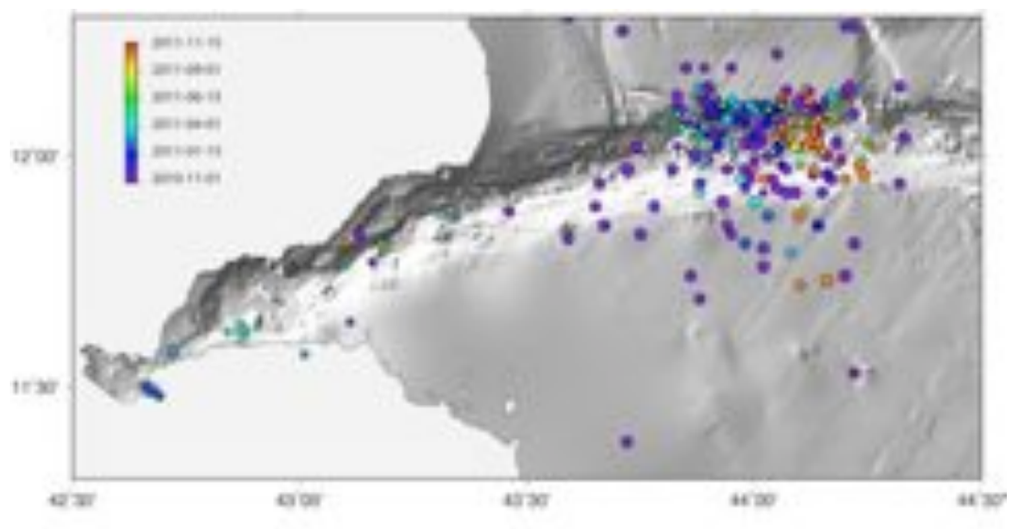
Very slow earthquake propagation (~0.2 km/h << ~0.5 to 3 km/h seen in Dabbahu or Krafla or MOR)

Belashew *et al.*, 2011; Grandin *et al.*, 2011, Keir *et al.*, 2009; Brandsdottir & Einarsson, 1979, Dziak *et al.*, 2007)

Beginning: only the NW section is activated
(Nov 2005 Dabbahu-Manda Harraro Event)

Then: activity migrated to the SE

Later: Dyking into the SE section (Nov 2010?)



- Oceanic Context

- By analogy with the onland rifting episodes -Dabbahu_MH (2005-2010?) - Tanzania (2007) - Arabia Saoudia (2009) : Geodetic moment / Seismic Moment
  Opening along a short distance (40 km max) higher than 10 m

- Future work: following months, waveform analysis...