

Aspectos Gerais

Aspectos sismológicos da crise de l'Aquila Abril 2009

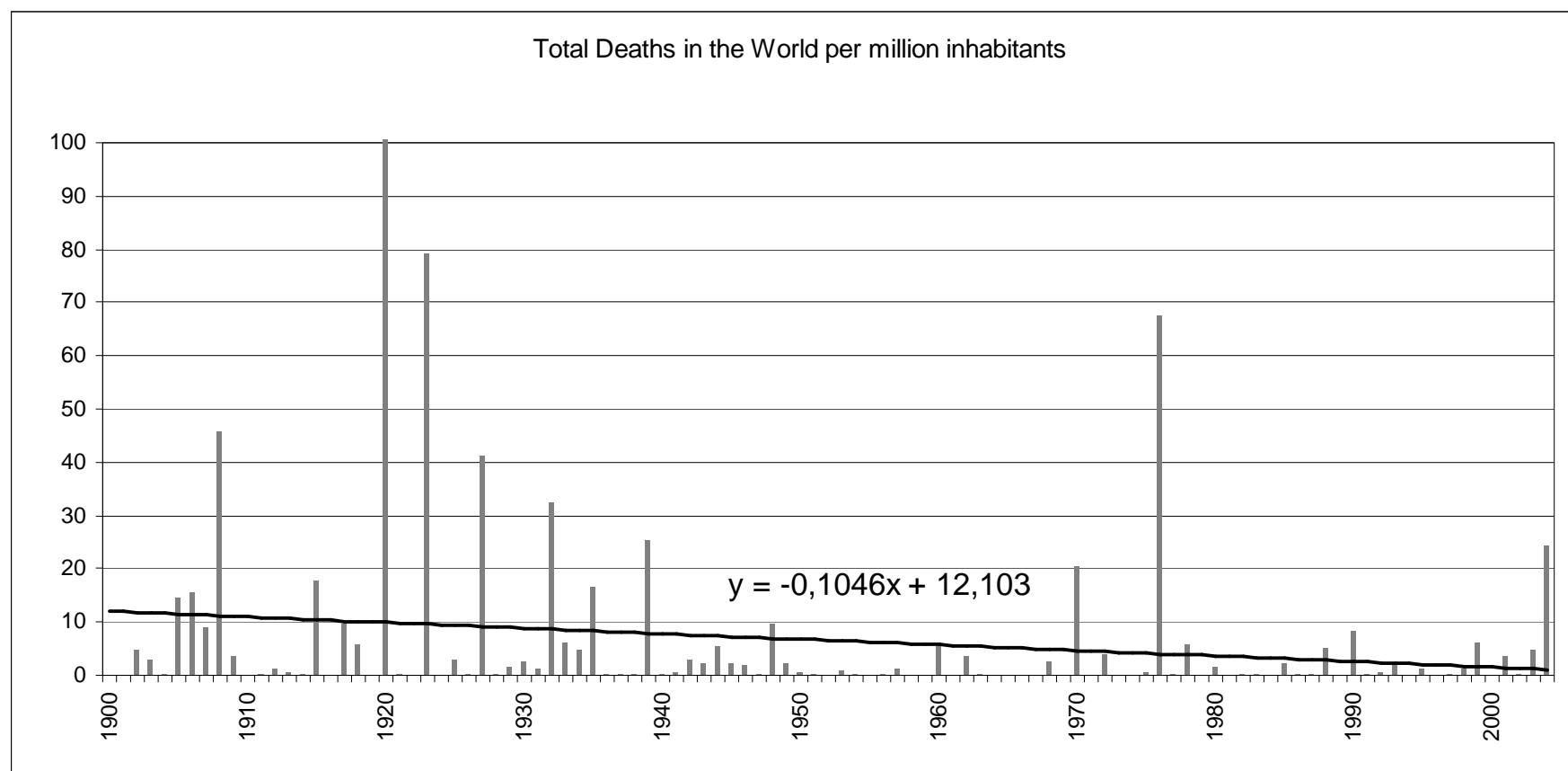


Carlos Sousa Oliveira

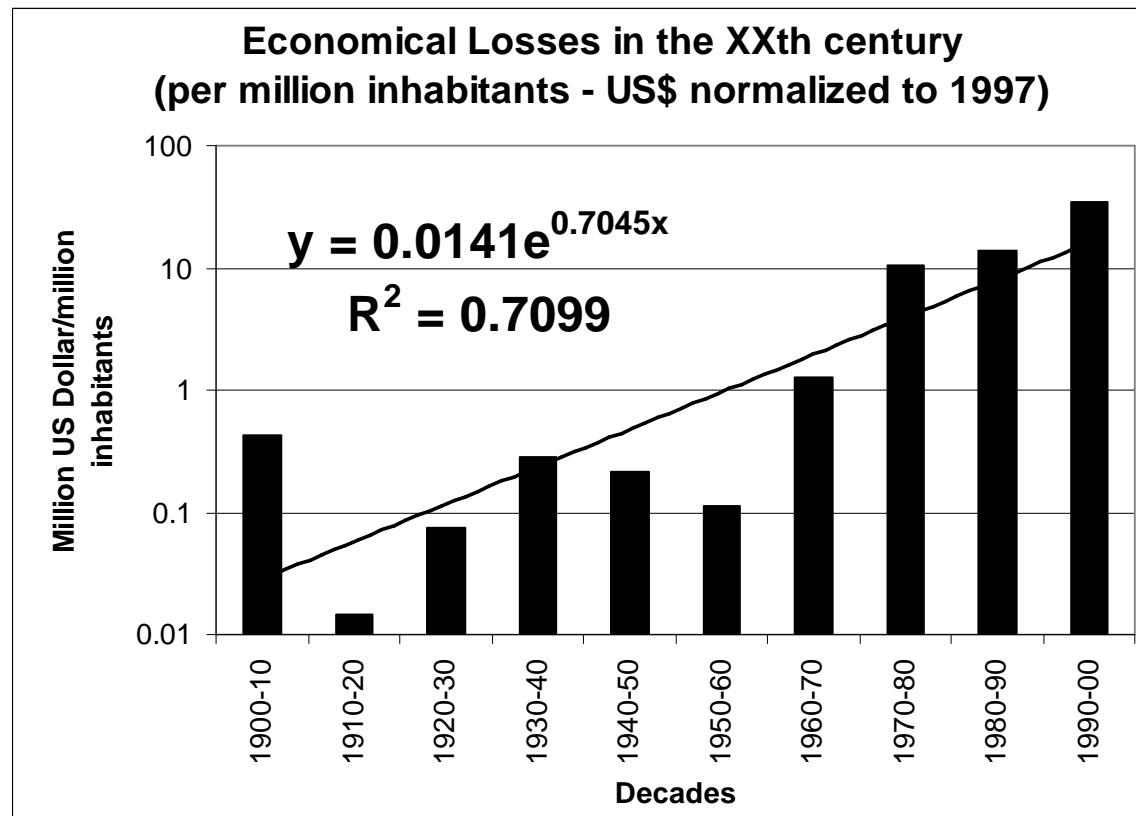
LNEC, 10 de Julho de 2009

0. Os grandes sismos desde 1900
1. O sismo da China em 2008
2. O contexto Geodinâmico de Abruzzo
3. Sismicidade Histórica e as crises mais recentes
4. Perigosidade e normativa (Regulamentos) em Itália
5. A Tectónica da região
6. Movimentos registados nas estações
Acelerométricas e Espectros de Resposta
7. Síntese das observações

Perdas humanas provocadas pelos sismos desde 1900
por milhão de habitantes (Total de 1.5 Milhões de pessoas)



Perdas económicas mundiais durante o séc XX





Sismo de Sichuan, China 12 Maio 2008

Dados mais importantes

- **69,200 dead (20,000 missing)**
- **374,200 injured**
- **5.4 million buildings collapsed**
- **21 million buildings damaged**
- **5 million homeless**
- **15 million evacuated**
- **46 million people affected**
- **10 million additional people living below poverty line**
- **Total loss 80 billion euro (Sichuan GDP 155 billion euro - 10% –40% of provincial GDP; 0.5 –1.5% of national GDP –China)**

ANTES

Bailu Middle School



DEPOIS





BEICHUAN





BEICHUAN



L'Aquila, Itália, 6 de Abril de 2009

Hora: 3:32 a.m.

Magnitude: $M_L=5.8$

Coordenadas epicentrais: 42.334°N, 13.334°E

Profundidade focal: 8.8 km

Área de percepção: 26 “comuni” (localidades)

Mortos: 306

Feridos: 1.500 (150 graves)

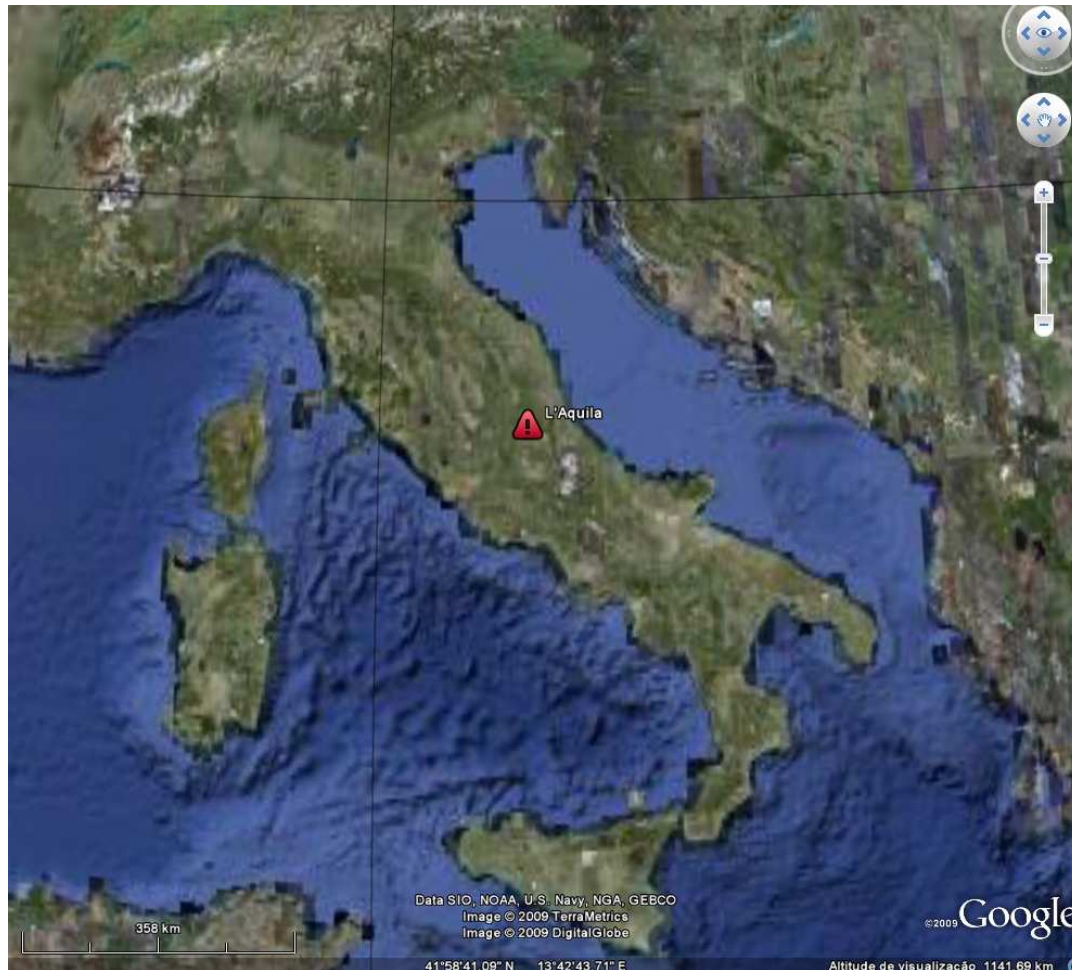
Desalojados no 1º mês: ~62.000 (população da zona afectada ~ 80.000)

Custo Estimado: (10-12) Bilhões Euro (€)

Alguns ensinamentos

- Parecença com potencial sismo no Baixo Tejo (i.e. Benavente)
- Dificuldade em prever os danos ocorridos (simuladores sísmicos com resultados muito aquém do observado)
- Um sismo com relativa pequena magnitude pode causar grandes estragos e impactos numa sociedade desenvolvida.
- Muitos ensinamentos na área da Tectónica, Sismologia, Engenharia Estrutural, Social, Económica, etc.
- O impacto deste sismo mostra a grande importância do pré e pós-sismo em toda a problemática da mitigação

O sismo de L'Aquila



Localização da região epicentral - Abruzzo



Sítios afastados onde o sismo foi sentido



**THE NEWSLETTER OF
THE EUROPEAN ASSOCIATION
FOR
EARTHQUAKE ENGINEERING**

May 2009

Volume 27, Number 1

L'Aquila earthquake viewed from World Wide Web: A Preliminary report - The first week

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Abstract

Just seven years ago, the so called Molise earthquake strikes San Giuliano di Puglia and 28 people died, including 27 children when their primary school collapsed. On April 6, 2009 another tragic event struck Italy, L'Aquila region more precisely, as residents slept, killing at least 294 people and leaving 30.000 homeless.

The World Wide Web is a powerful mean of information, promoting multiple searches at any time in any place around the world. After the Sichuan earthquake (May 12, 2008), it was possible to collect extensive information using online newspapers. Unfortunately, language barriers hampered non-chinese researchers in the collection of the extensive information existent on online newspapers, institutional sites, opinion articles, blogs, videos or online interviews, unlike the earthquake that struck Italy a week ago (April 6, 2009) permitting to collect a huge set of documents and images, using the Web, from different subjects like social, technical, political, religious, personal comments and others.

The present paper tries to describe the different post-earthquake phases using only online data, long before eyewitness and reflected reports are made available.

<http://www.eage.boun.edu.tr/newsletter/Newsletter8.pdf>

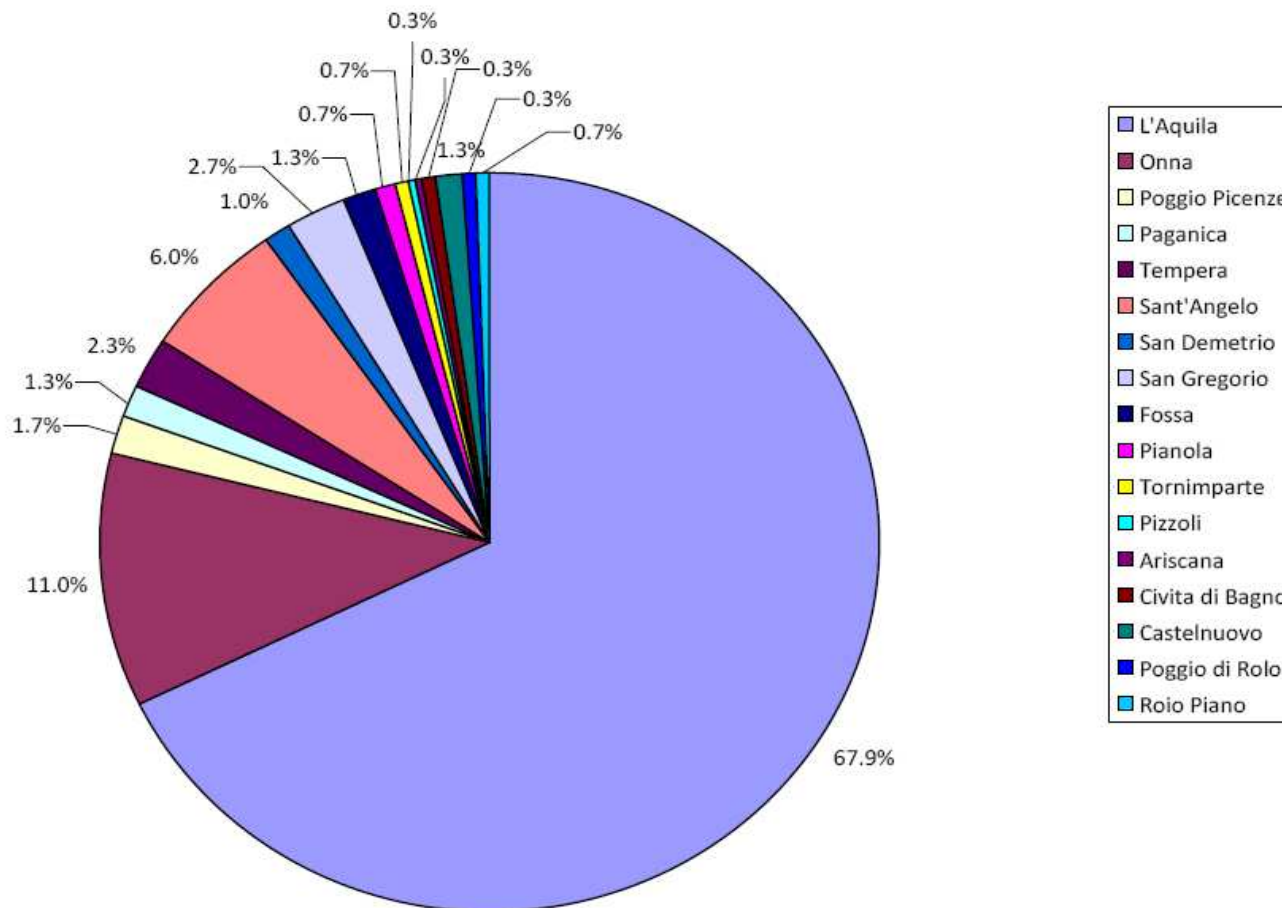
Localidade	Comune	Nº mortos total	Mortos após alguns dias
Bazzano	L'Aquila	1	
Castelnuovo	San Pio delle Camere	5	
Civita di Bagno	L'Aquila	2	
Fossa	Fossa	4	
Lucoli	Lucoli	1	
Onna	L'Aquila	40	
Paganica	L'Aquila	5	
Pianola	L'Aquila	2	1 (heart attack)
Poggio di Roio	L'Aquila	1	
Poggio Picenze	Poggio Picenze	5	
Rio Piano	L'Aquila	2	
San Demetrio	San Demetrio Ne' Vestini	2	
San Gregorio	L'Aquila	8	
Sant'Angelo di Bagno	L'Aquila	1	
Tempera	L'Aquila	7	
Tornimparte	Tornimparte	2	1
Villa Sant'Angelo	Villa Sant'Angelo	17	
L'Aquila	L'Aquila	199	9 (2 heart attack)
Unknow		2	
Total		306	
Comune L'Aquila		268	

(Ferreira, 2009)

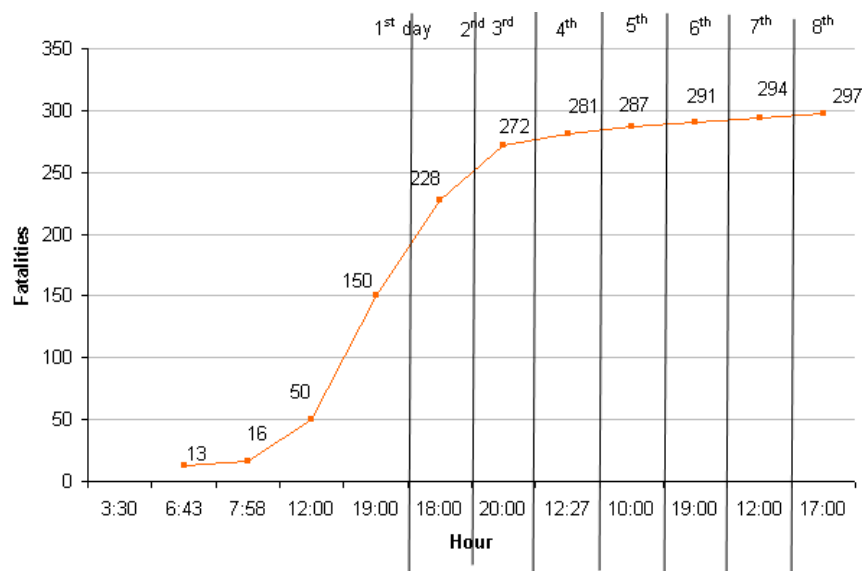
Town/Village	Population (from 2001 census)	Fatalities	% Fatalities in population	Dominant collapsed building type causing fatalities
L'Aquila	68,500	203	0.3%	1970s RC frame 7-8 storey buildings and 2-storey masonry houses
Onna	350	33	9.4%	1-2 storey stone masonry - little evidence of wall ties
Paganica	661	4	0.6%	1-2 storey stone masonry with weak mortar
Poggio Picenze	1,011	5	0.5%	1-2 storey stone masonry with weak mortar
Fossa	661	4	0.6%	1-2 storey stone masonry inner floor collapse.

(EEFIT, 2009 Dados de 1 de Maio)

Distribution of Fatalities in the Affected Area (by comuni)
 source: Il centro (Reporting 299 deaths, April, 2009)

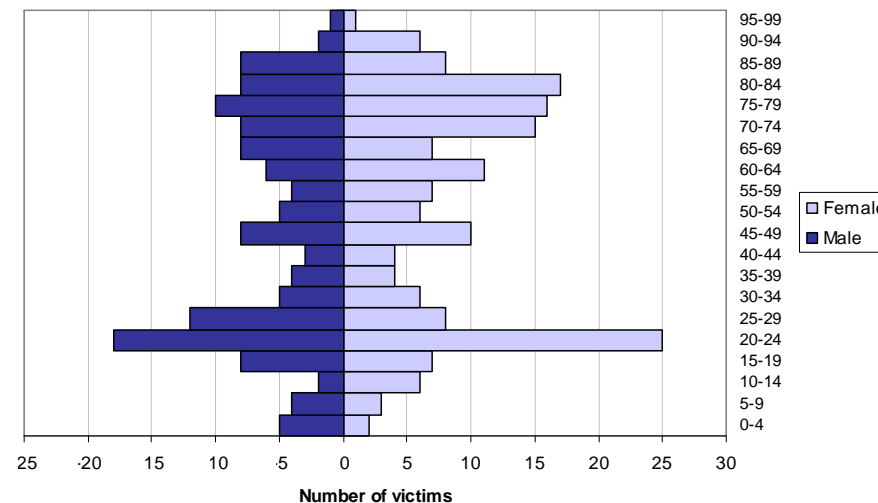


(source: Il Centro newspaper on 22nd April 2009)



Evolução do nº de vítimas ao longo dos primeiros 8 dias

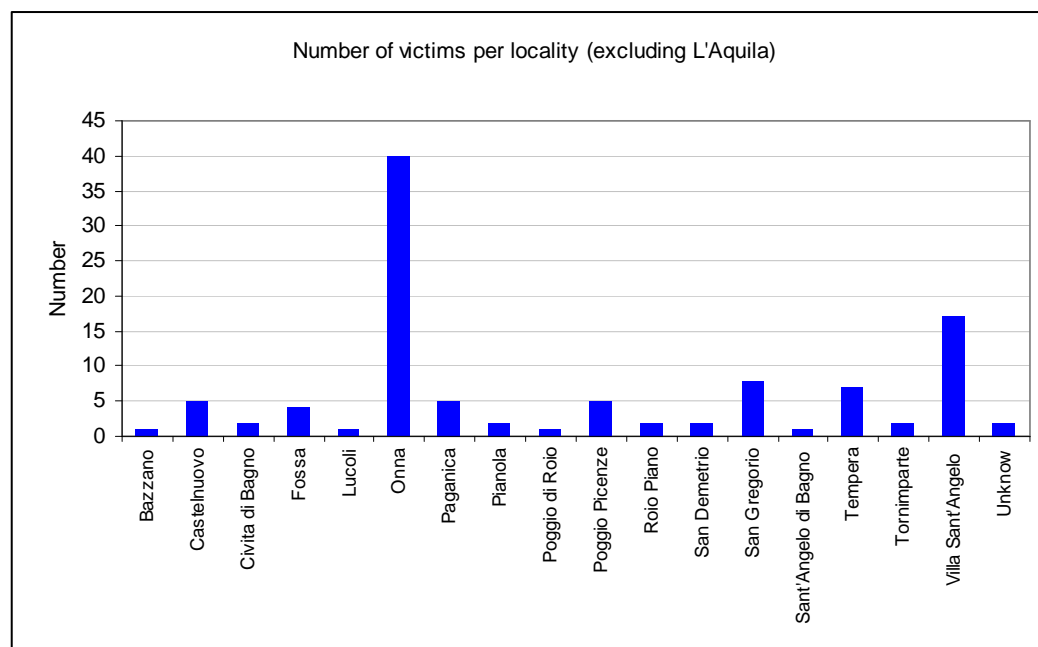
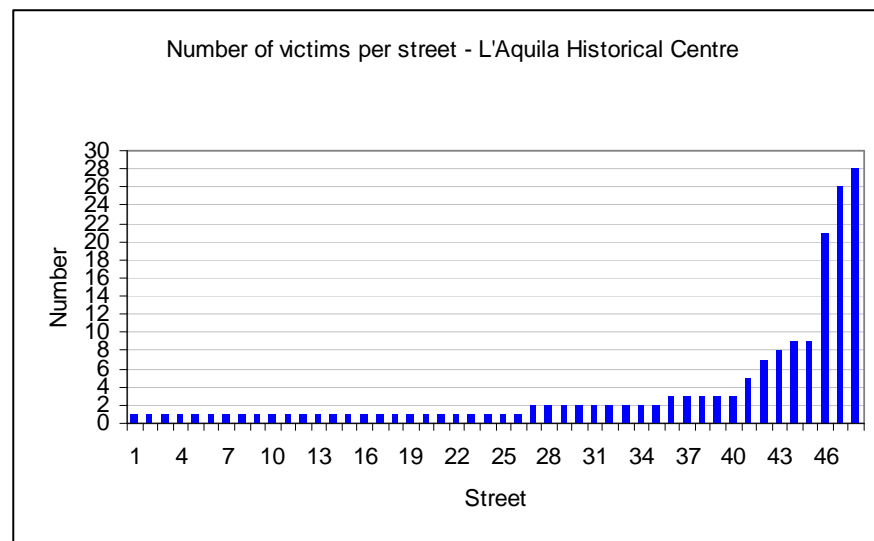
Estudo para 296 vítimas



“The highest mortality group corresponds to those aged 20; L'Aquila is a university city with many students, the dormitory collapse and other houses collapse/damage located in the center increased the number of fatalities in this specific age group.

The youngest victim is a boy with 4 months and the oldest a female with 96 years old.”

(Ferreira, 2009)



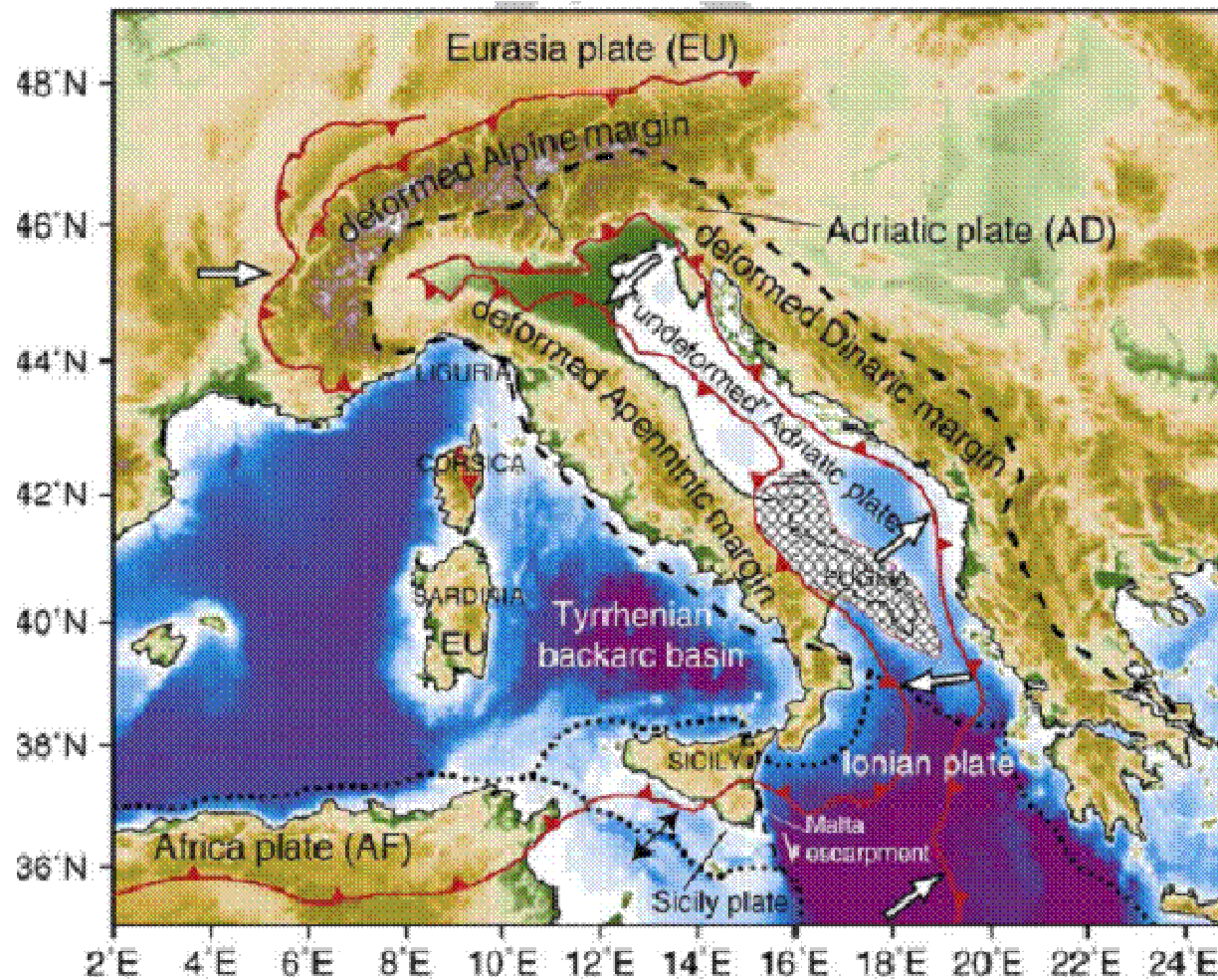
O sismo de L'Aquila



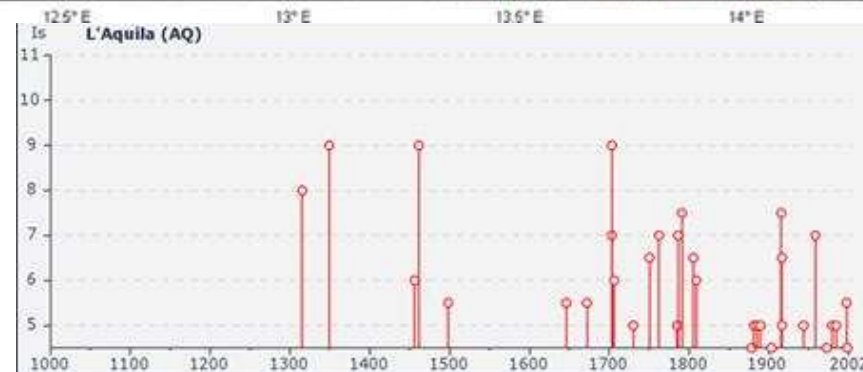
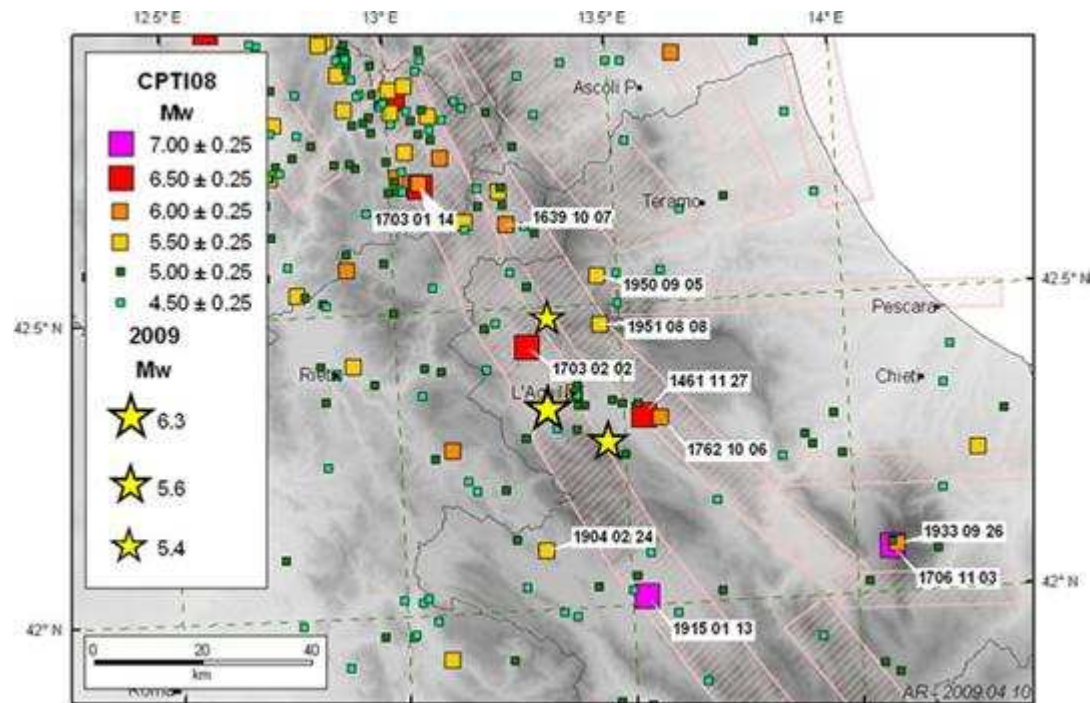
 Campos desalojados

 Colapsos

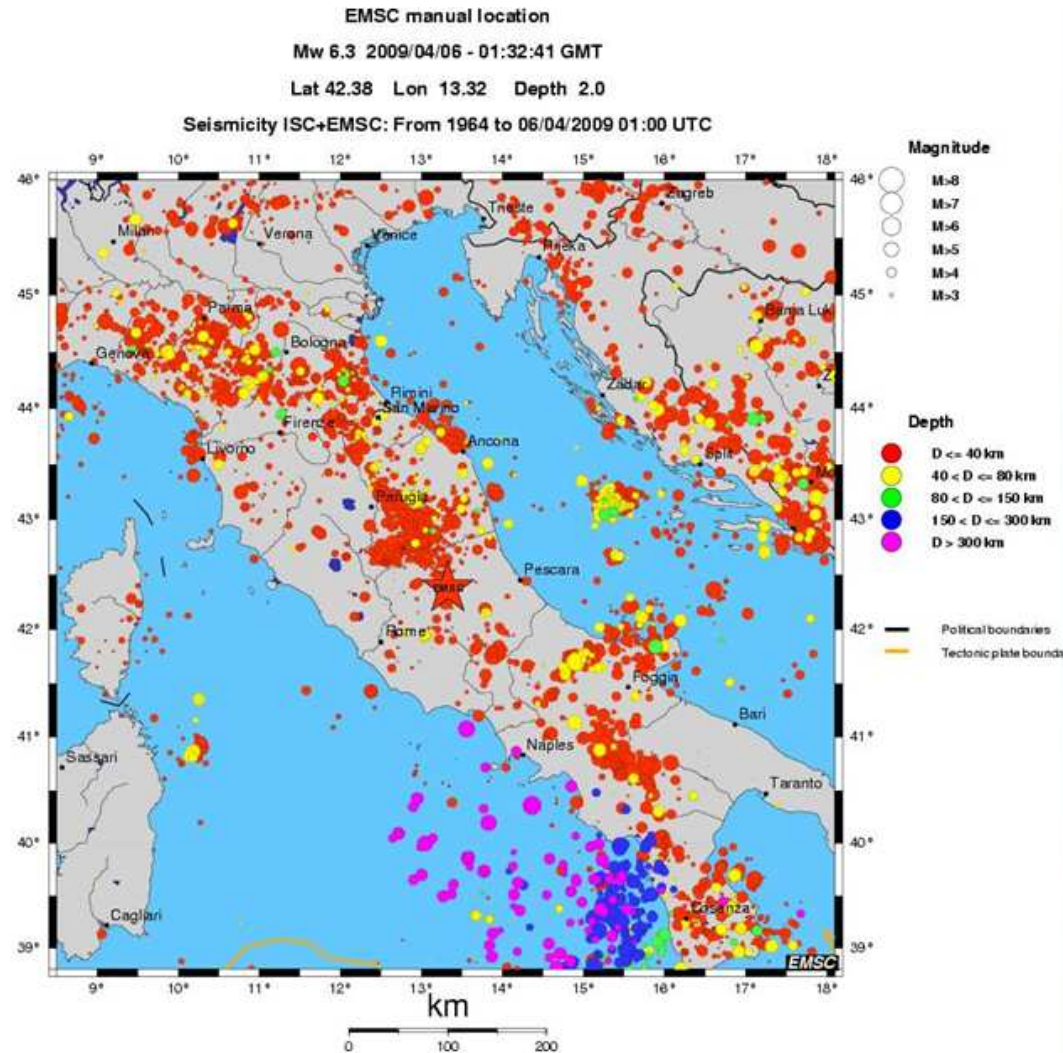
- MODELO GEODINÂMICO DO MEDITERRANICO CENTRAL (Devoti et al., 2008)



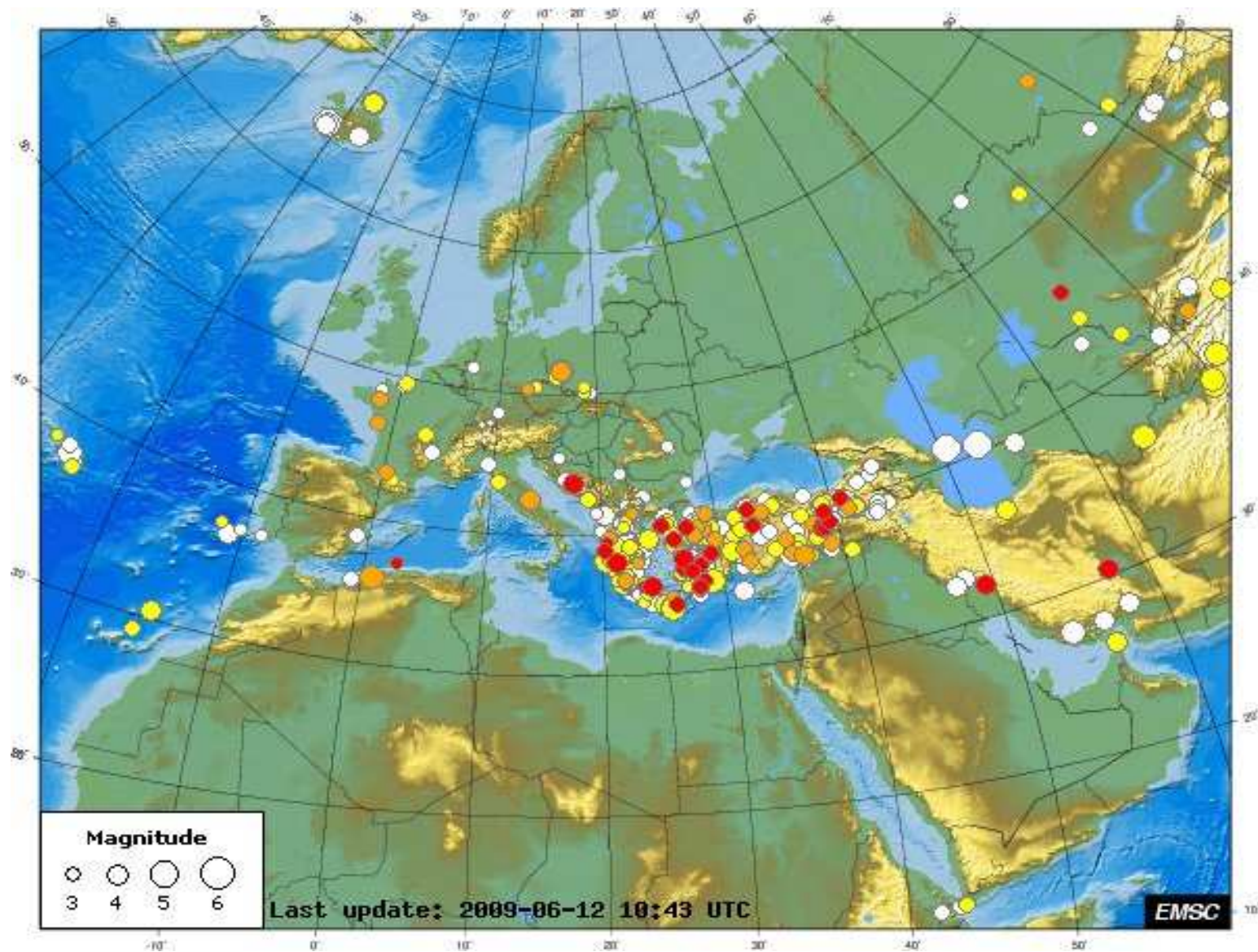
- SISMICIDADE HISTÓRICA NOS APENINOS



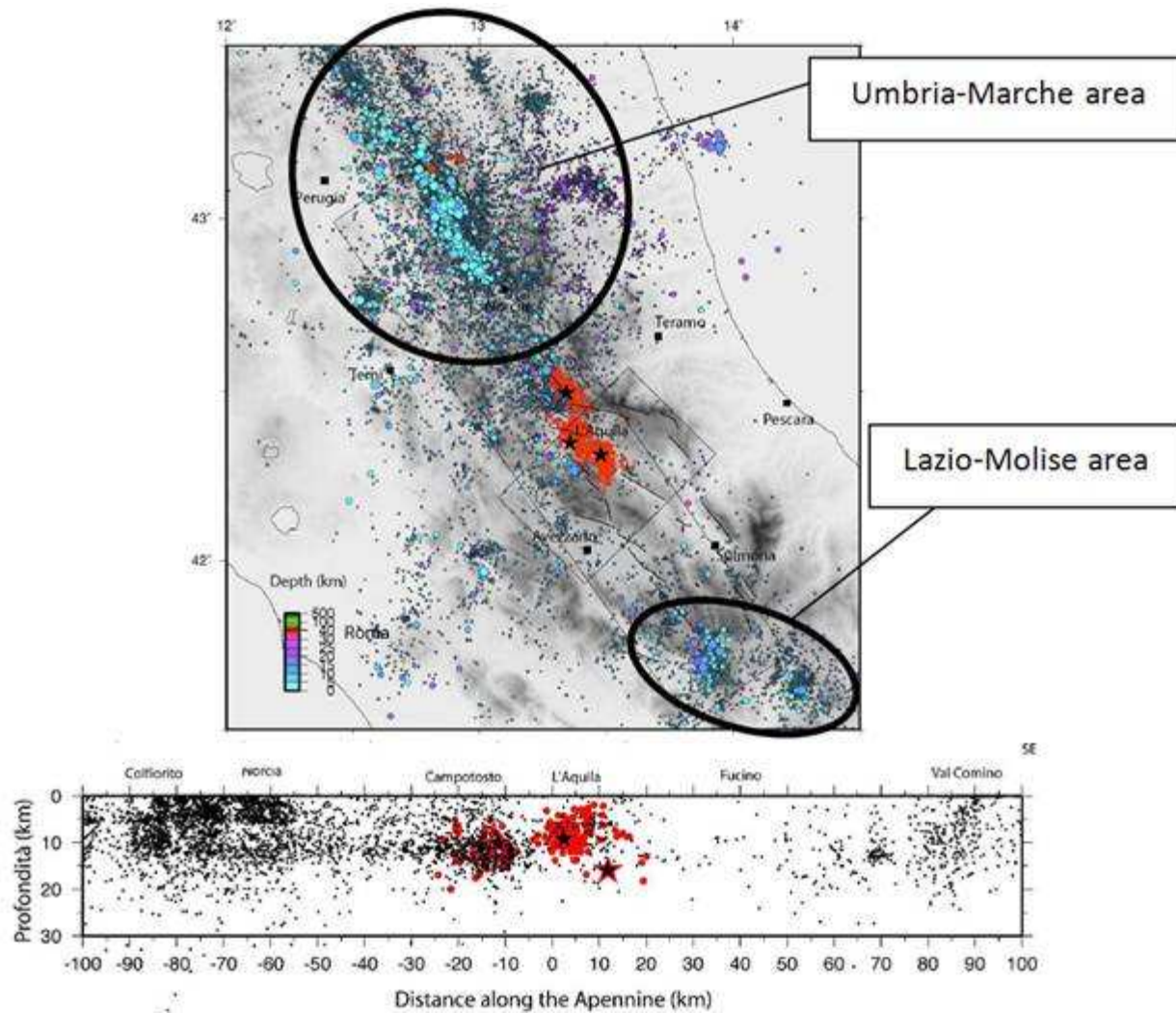
Sismicidade em Itália (1964-2009)



O sismo de L'Aquila



- CRISES SÍSMICAS DE UMBRIA-MARCHE DE 1997 E DE MOLISE DE 2002

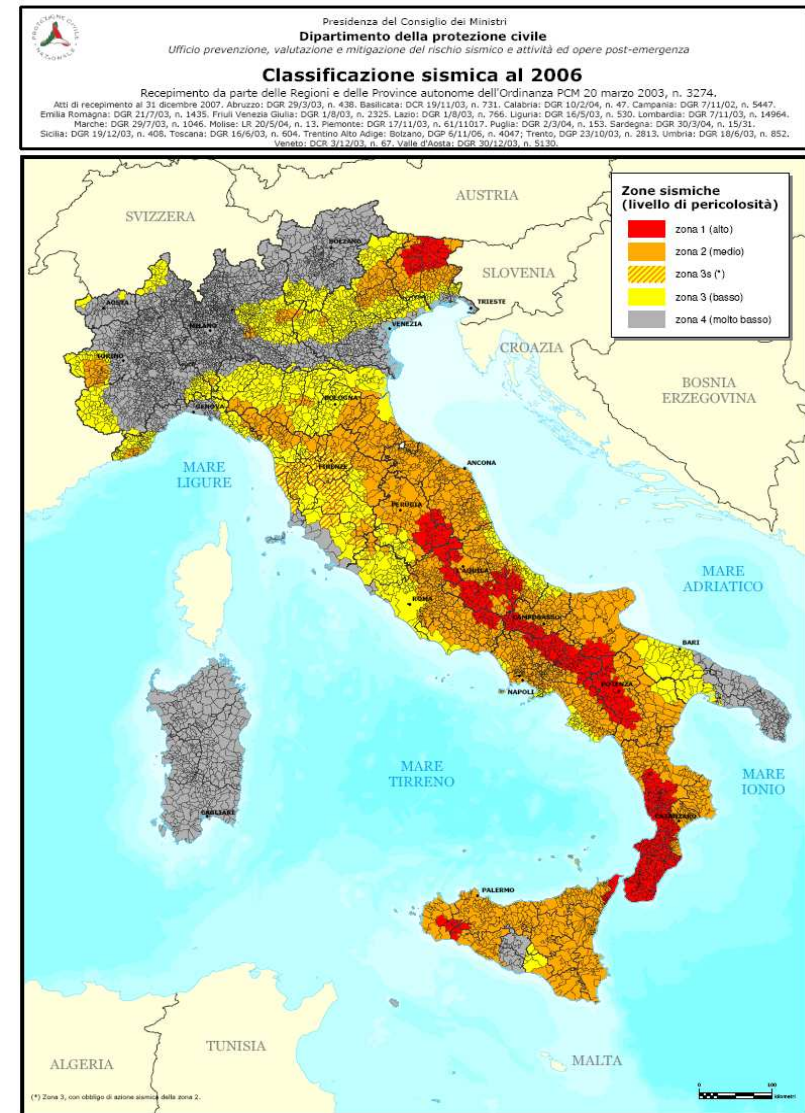
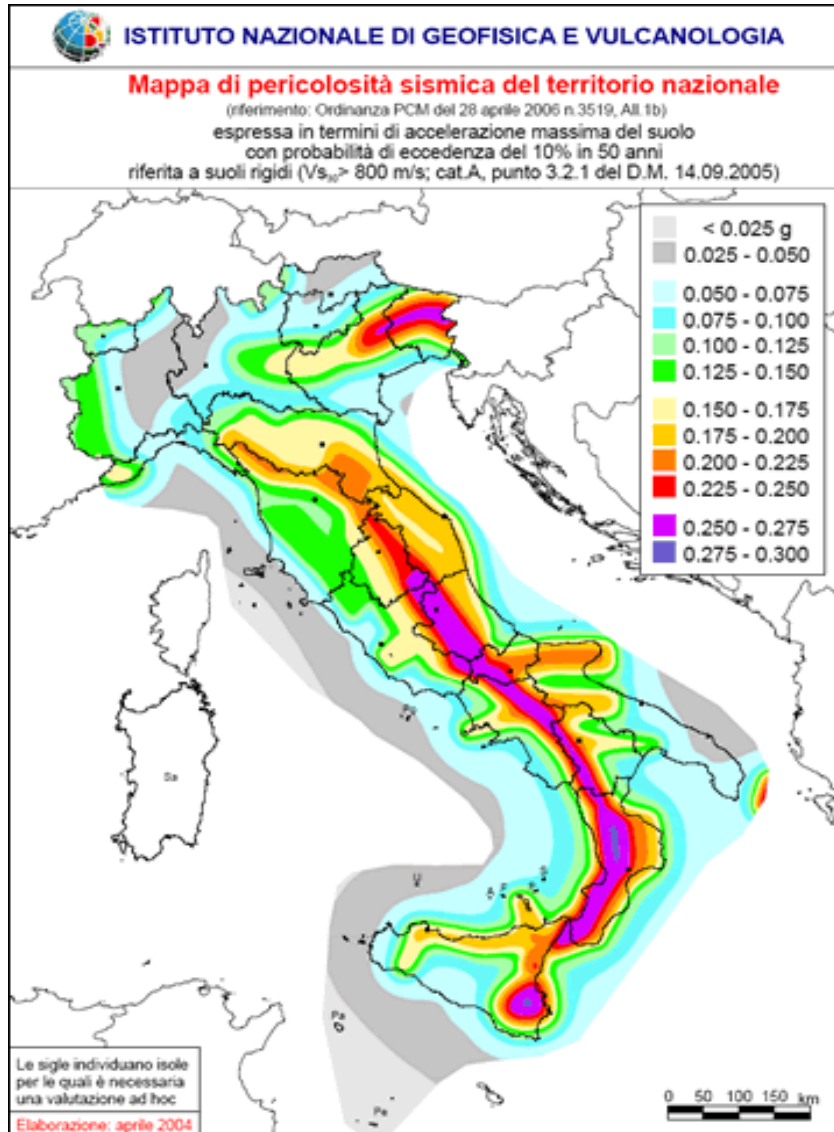




ICIST

O sismo de L'Aquila

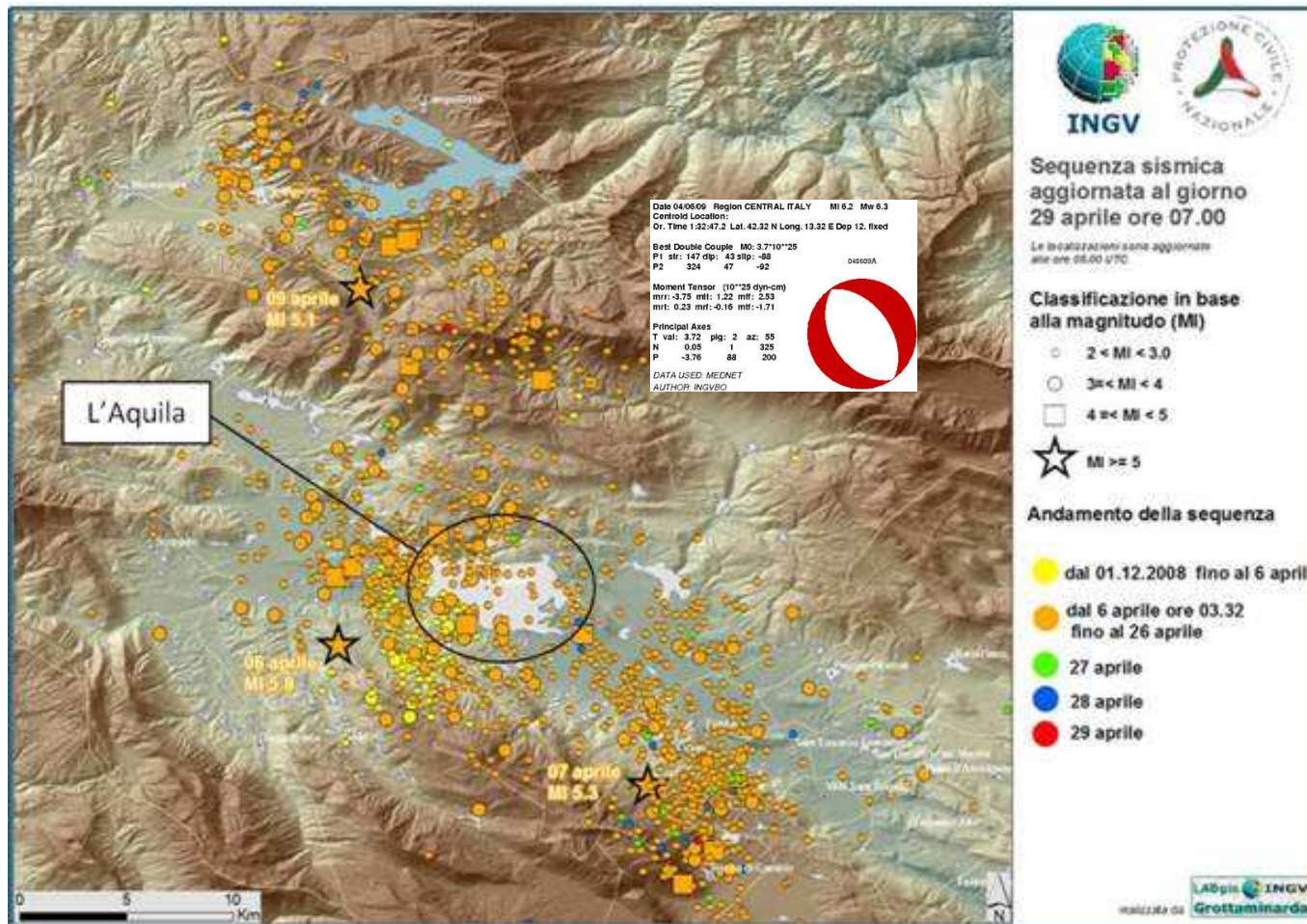
MAPA DE PERIGOSIDADE E REGULAMENTO ITALIANO

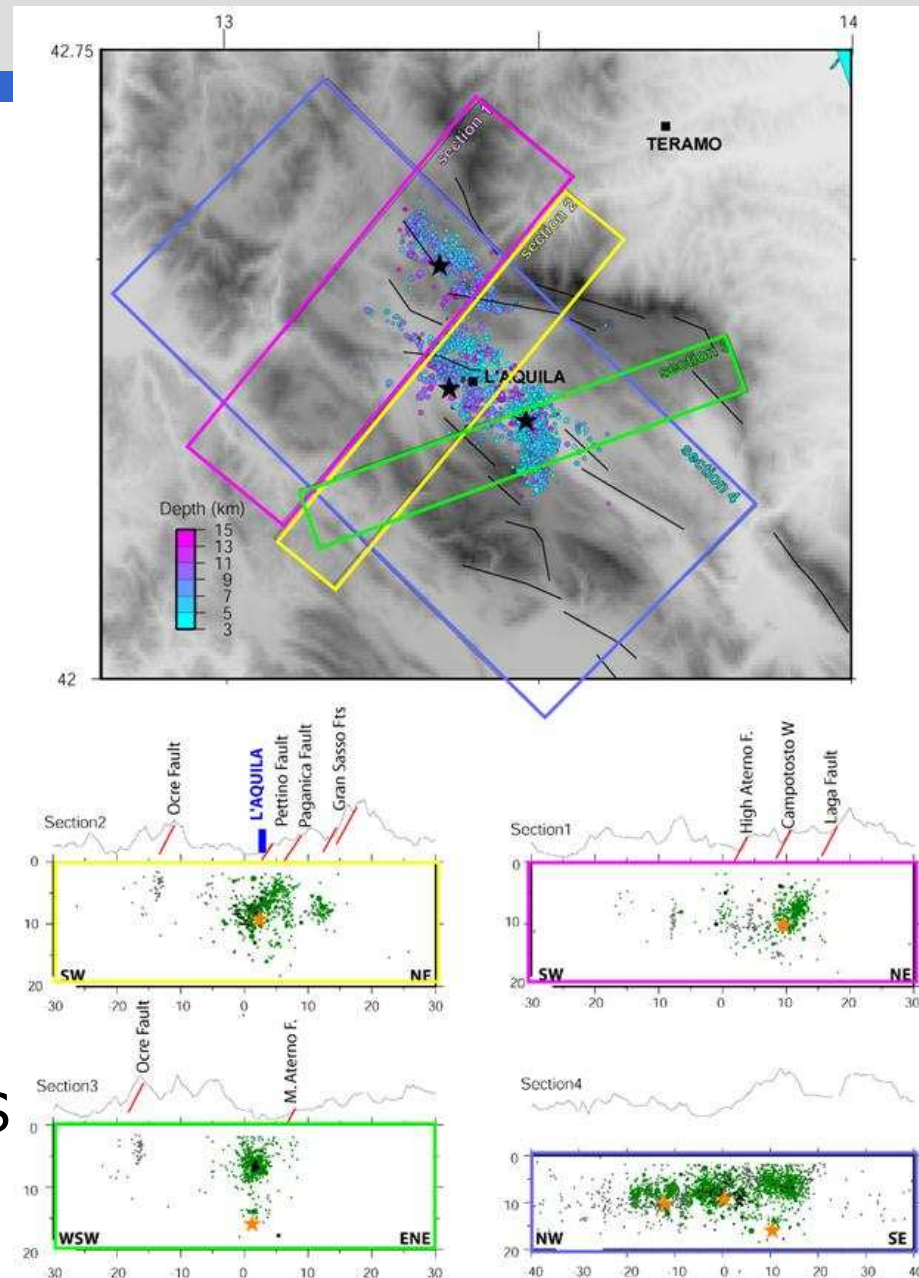


Mecanismo focal



- SEQUÊNCIA SÍSMICA E MECANISMO DO SISMO PRINCIPAL (INGV)

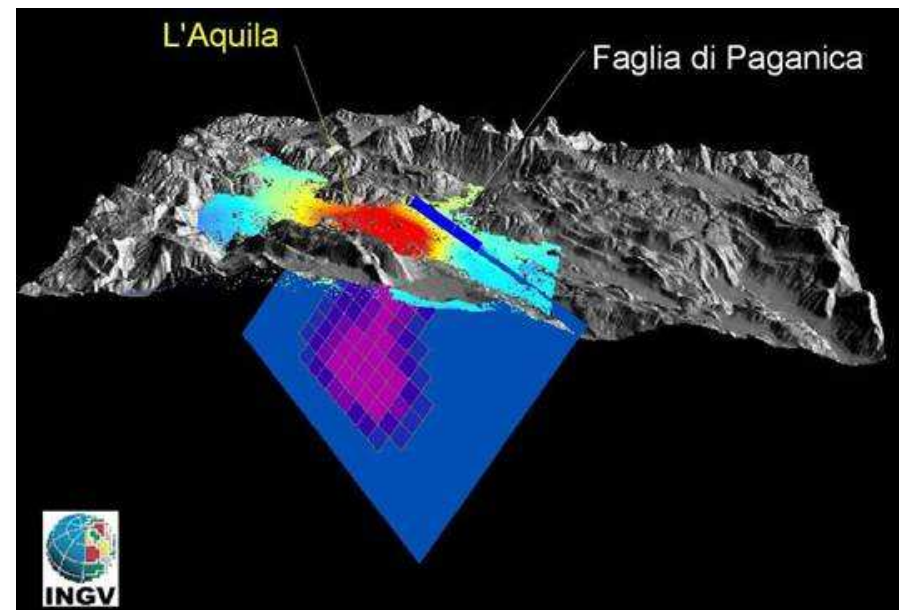
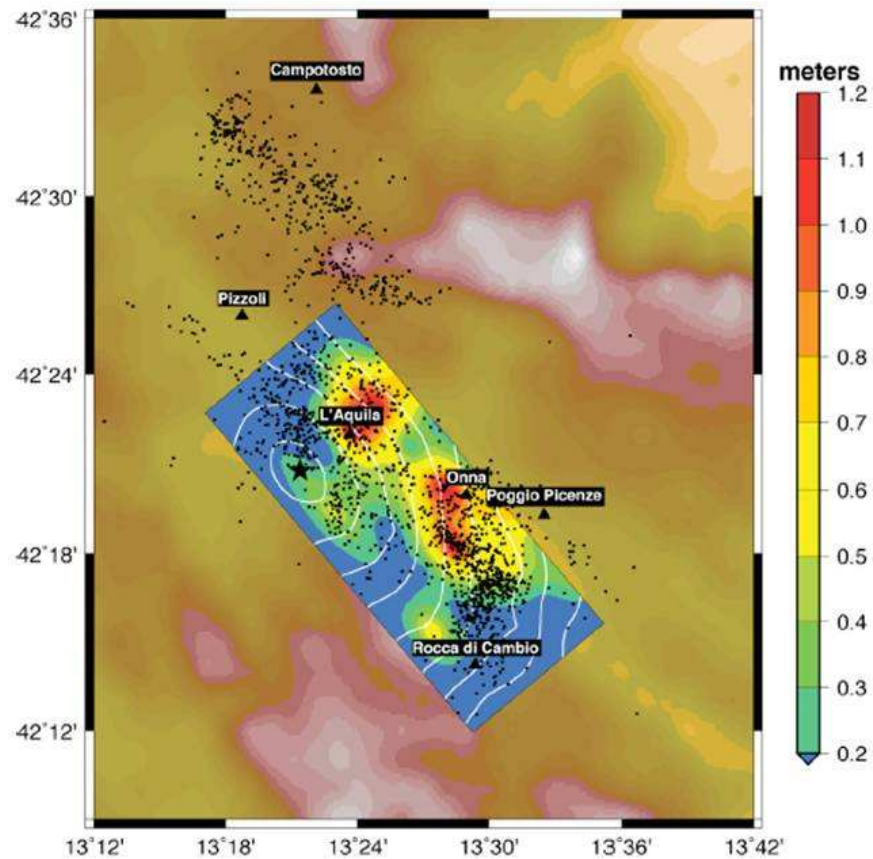




SECÇÃO VERTICAL COM RÉPLICAS

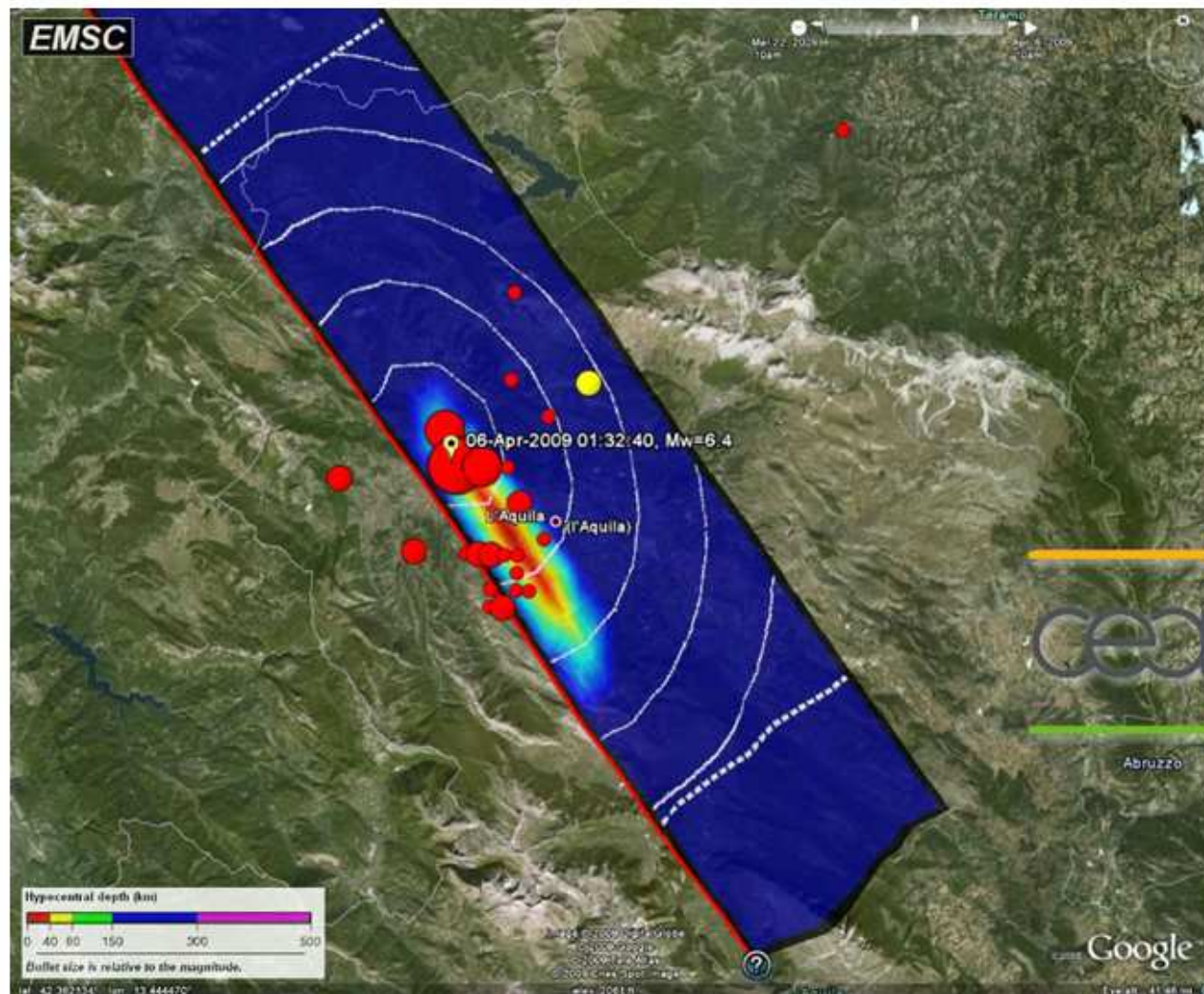
INGV

- DISTRIBUIÇÃO DA ROTURA NO PLANO DE FALHA DO ABALO PRINCIPAL

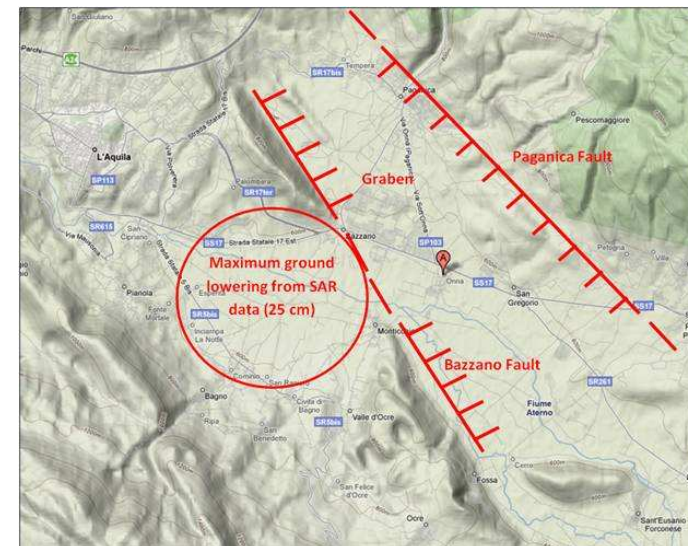
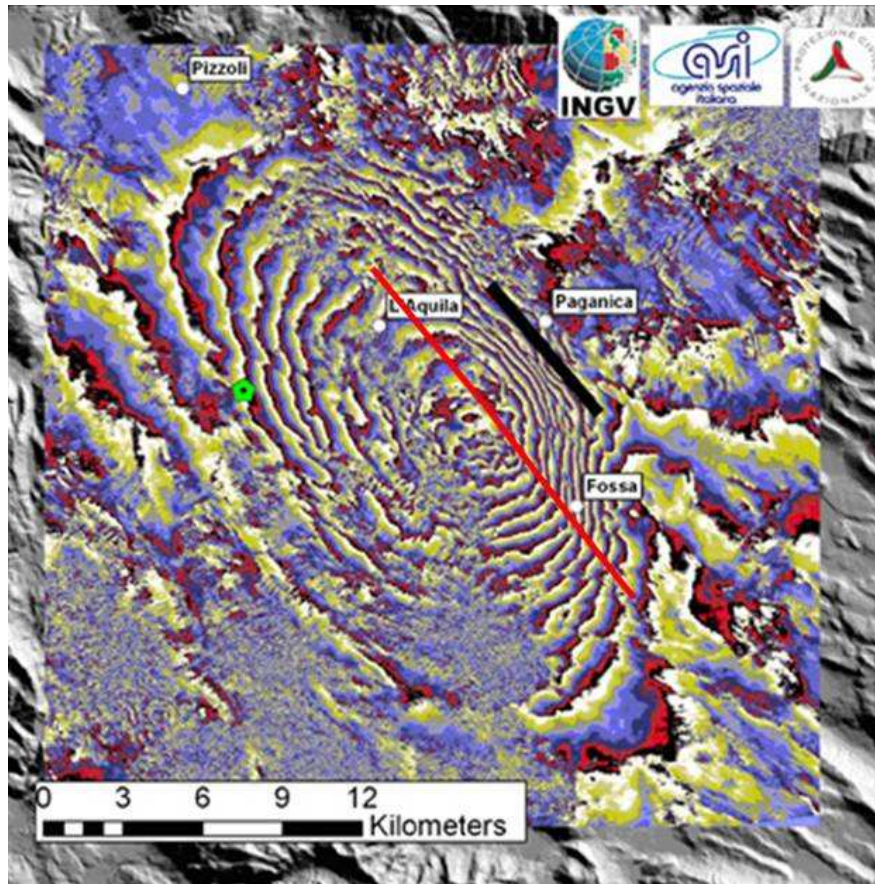


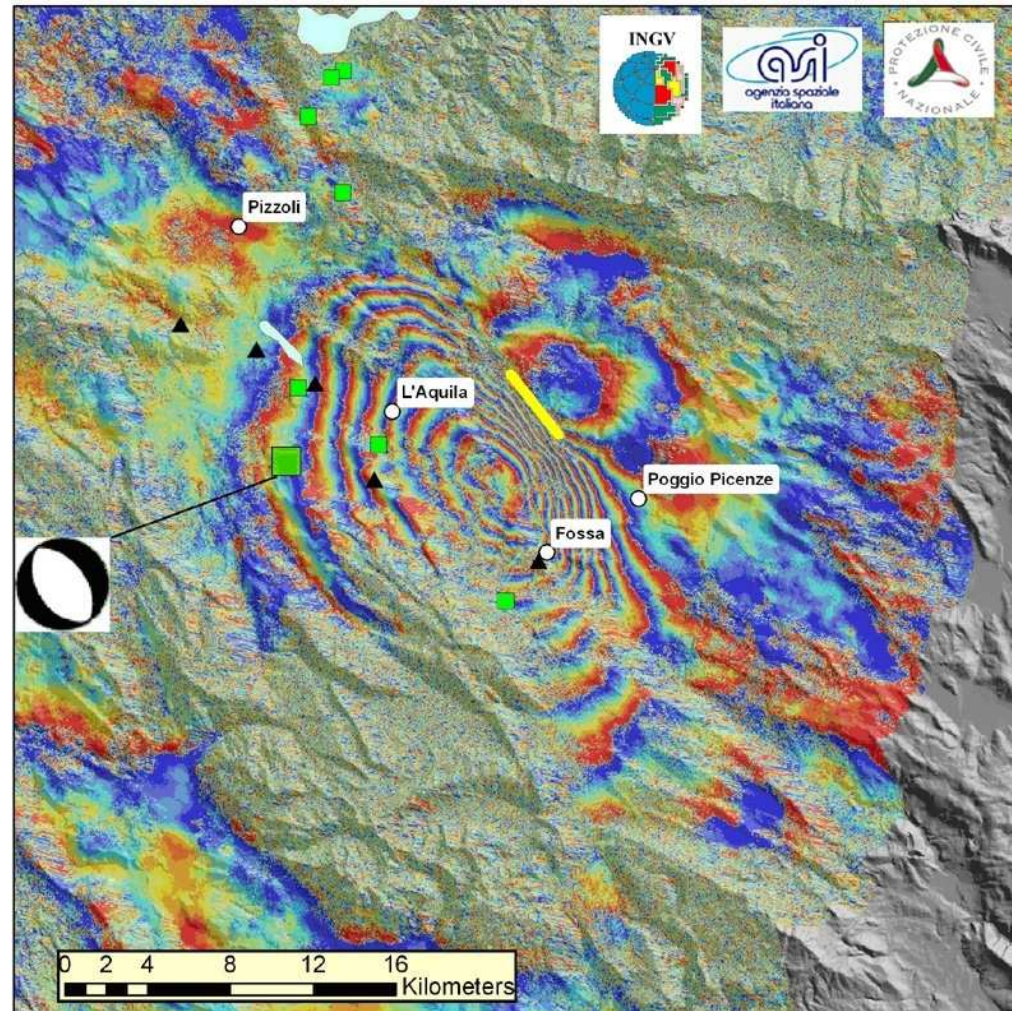
INGV

Modelo de ruptura ao longo da falha



- CAMPO DE DESLOCAMENTOS OBTIDOS POR INTERFEROMETRIA RADAR (SAR)

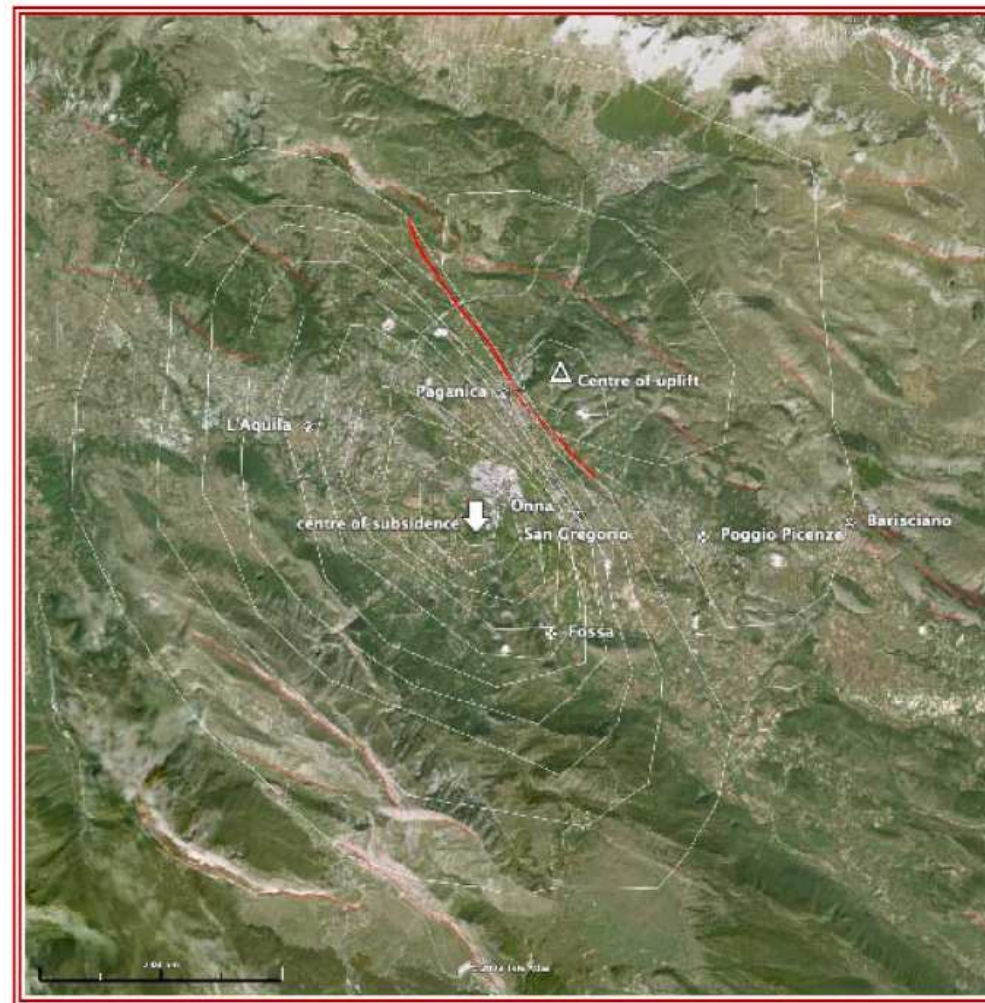




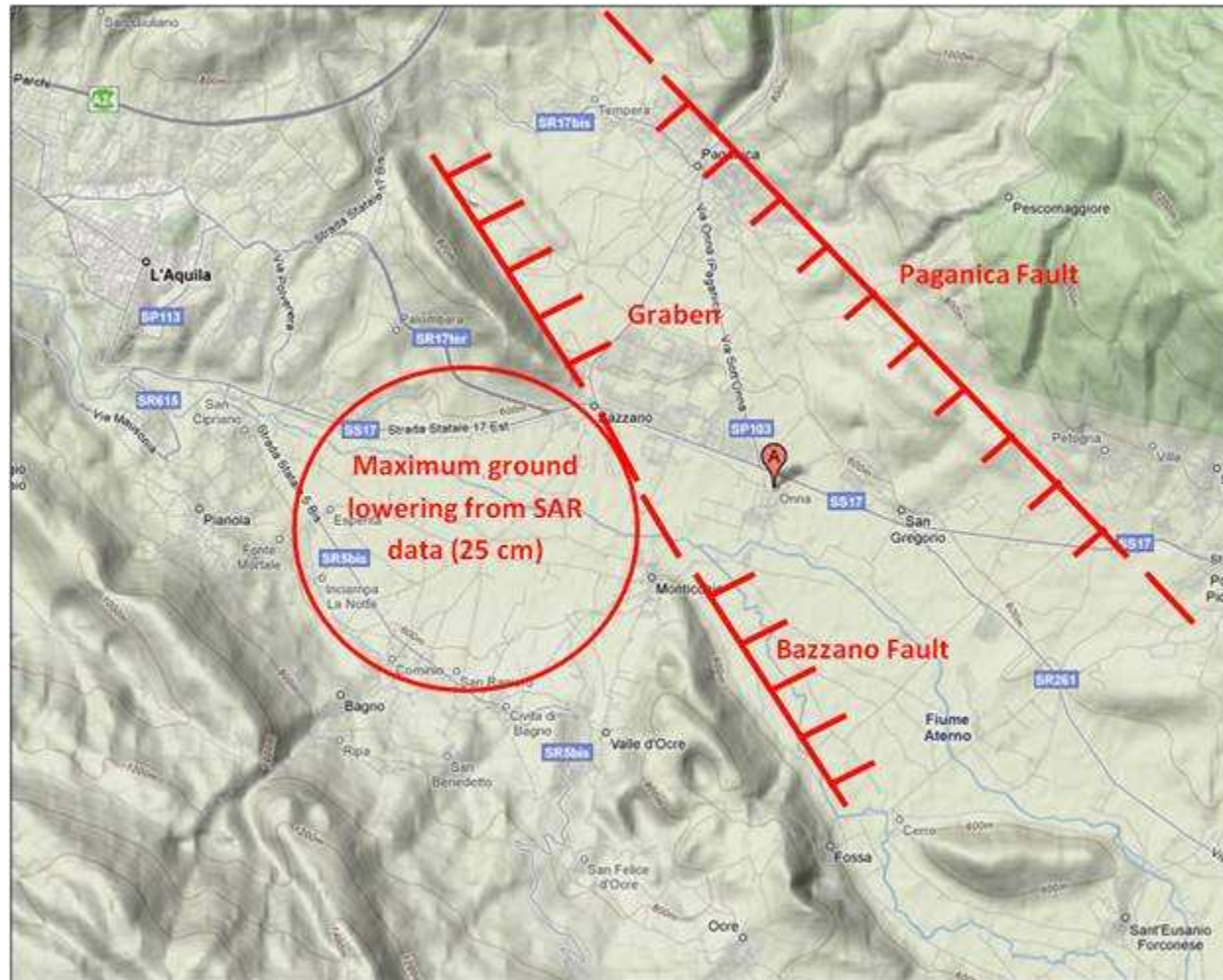
Interferometric fringes of co-seismic displacements (Salvi et al., 2009). The black line indicates the alignment of ground failures associated to the Paganica Fault. The discontinuity marked by the red line corresponds to the antithetic Bazzano Fault.

O sismo de L'Aquila

Interferogram fringes showing ground motion following the 6th April 2009 Earthquake (<ftp://ftp.earth.ox.ac.uk/pub/richardw/>). Each fringe represents 28mm of ground movement in the line of site of the satellite. Preliminary results show the strike and dip of the fault plane to be 143 and 60 degrees respectively and at depth there was 0.7m of slip.



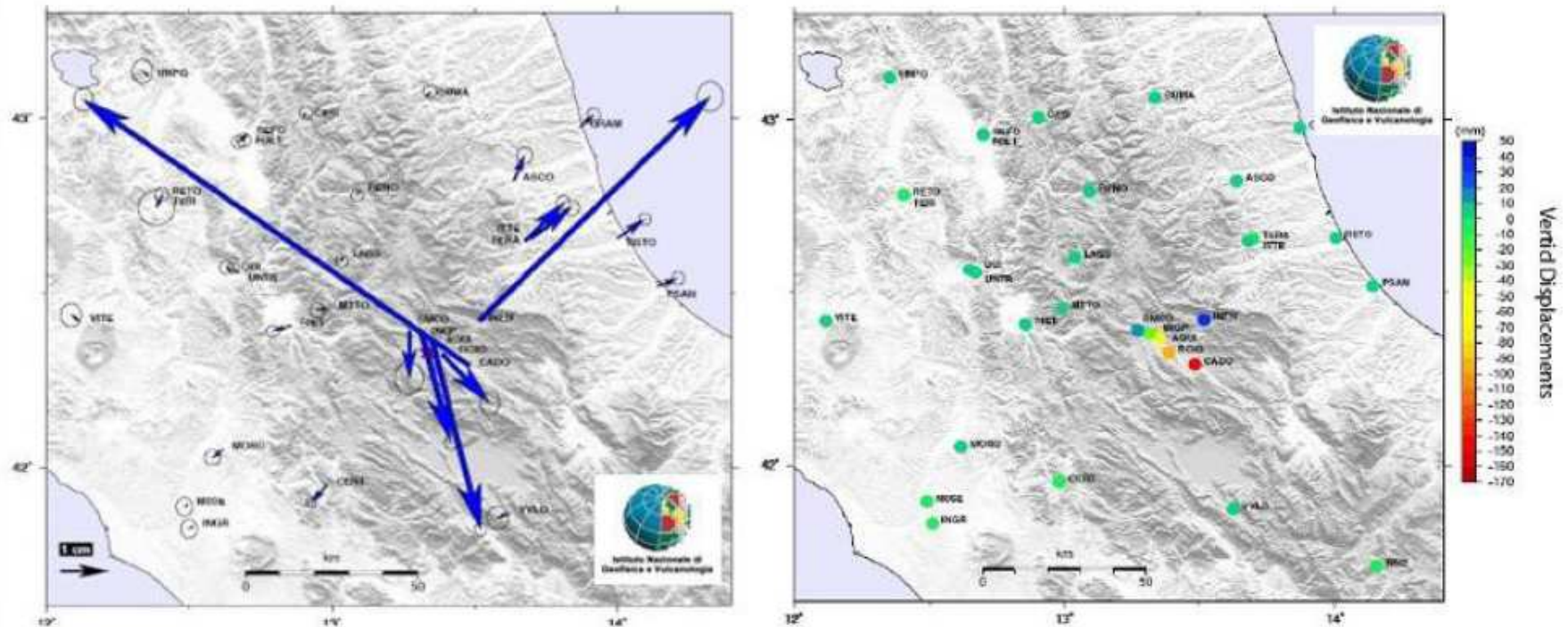
O sismo de L'Aquila



Relationship between Paganica and Bazzano active faults and topography.

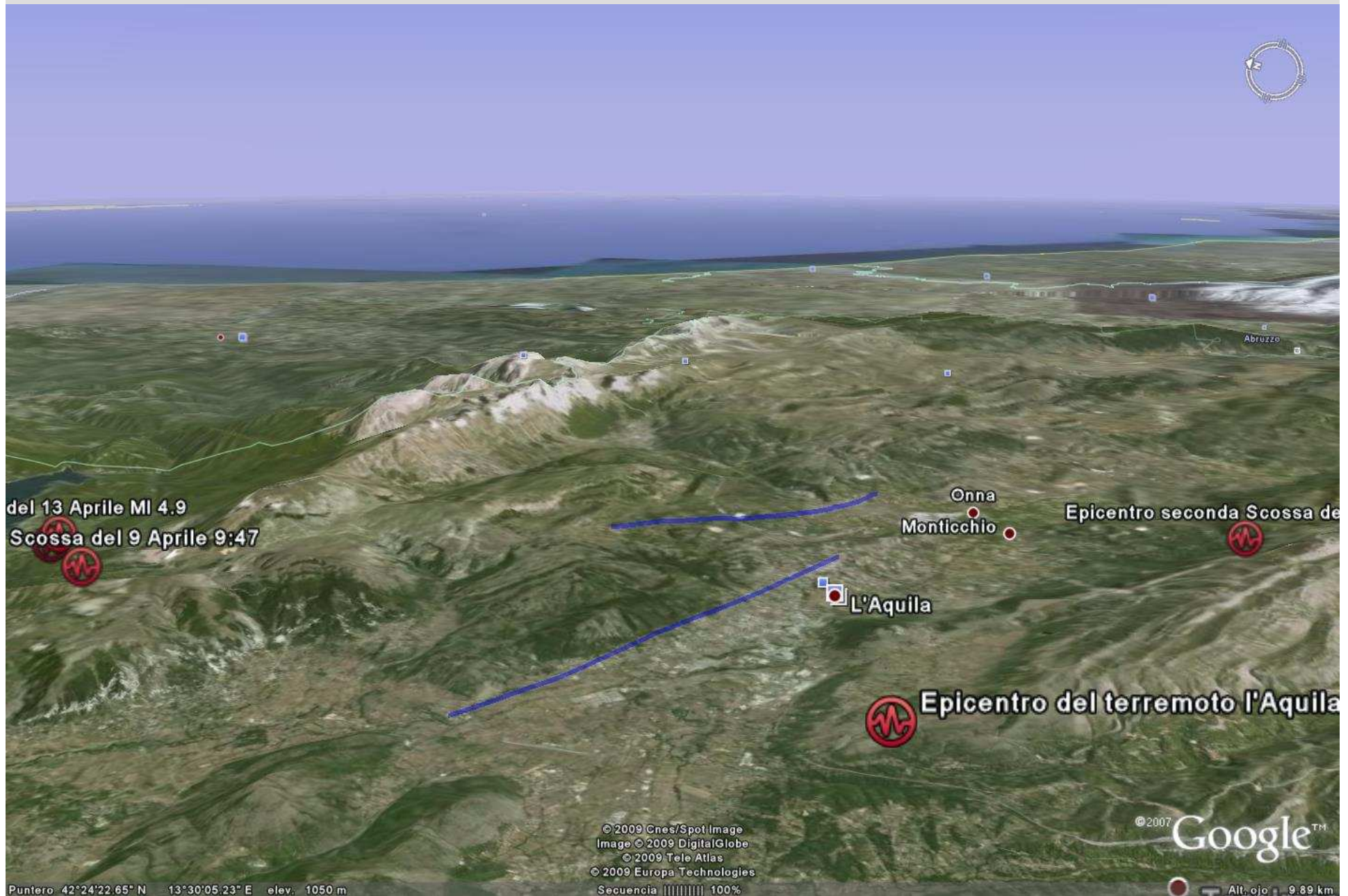
Data GPS

- ✓ The computed displacements suggest a permanent movement directed SE and downwards, in agreement with preliminary results from GPS



da: <http://portale.ingv.it/primo-piano/archivio-primo-piano/notizie-2009/terremoto-6-aprile/dati-gps>

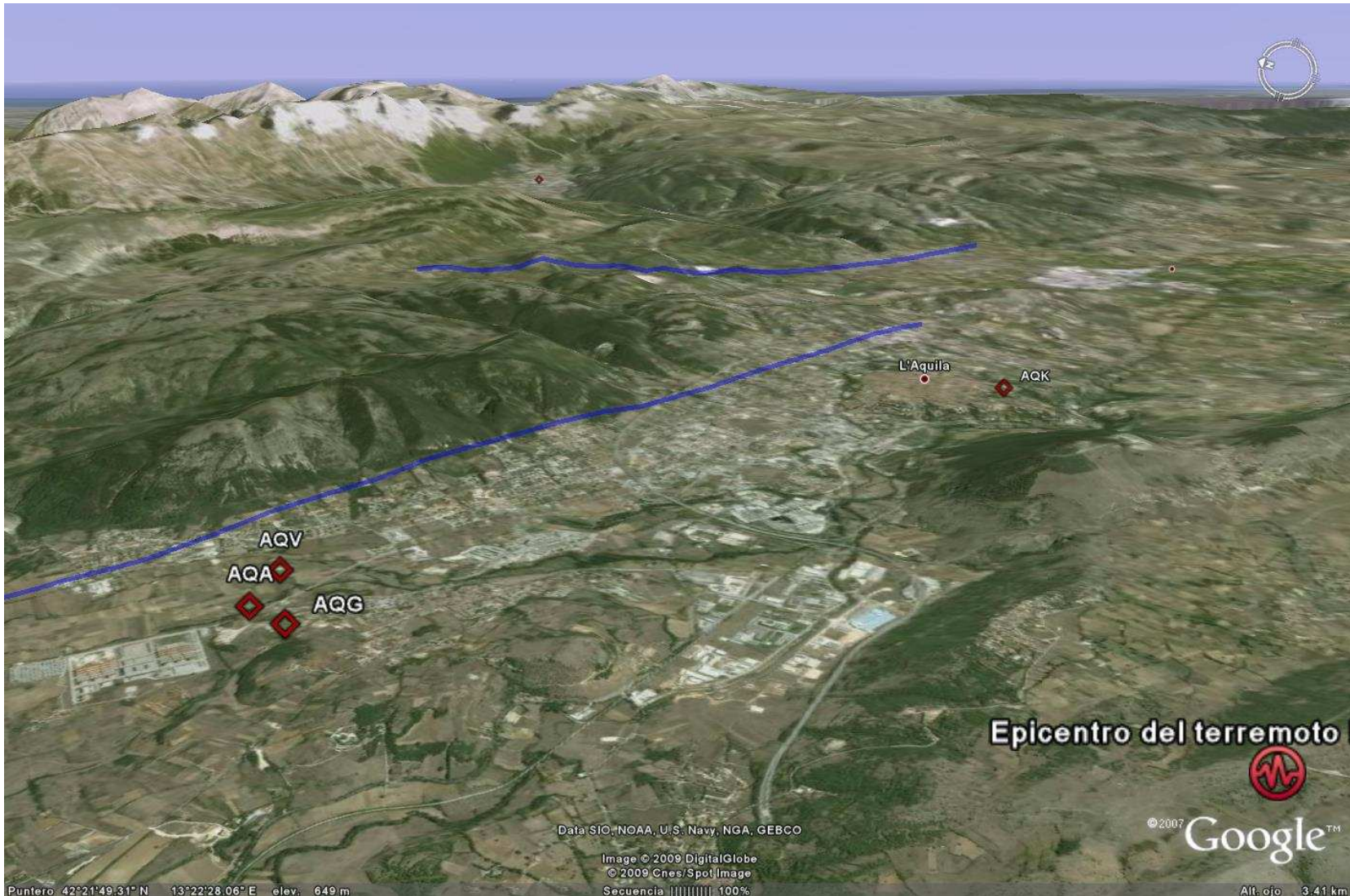
O sismo de L'Aquila





ICIST

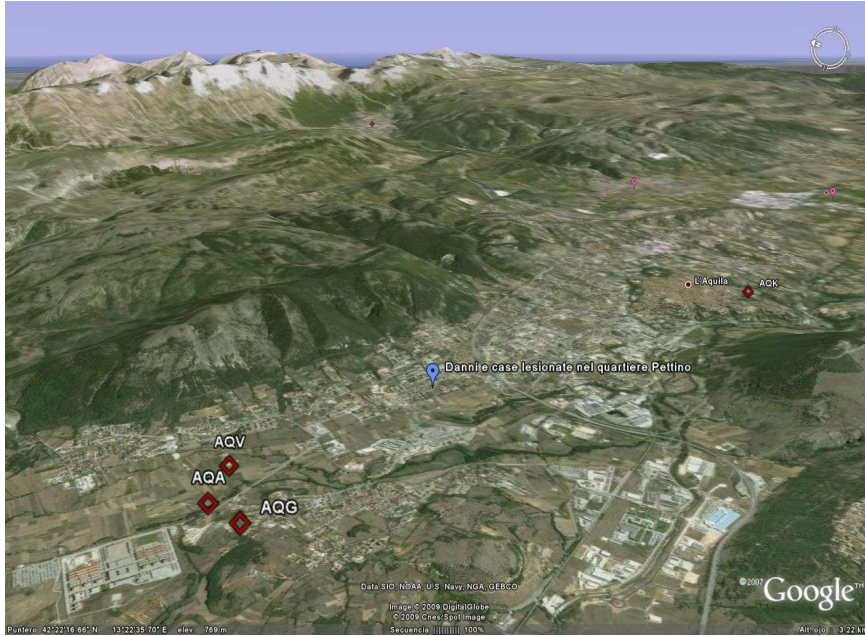
O sismo de L'Aquila



- ROTURAS EM PAGÂNICA



O sismo de L'Aquila



- Lago Sissino

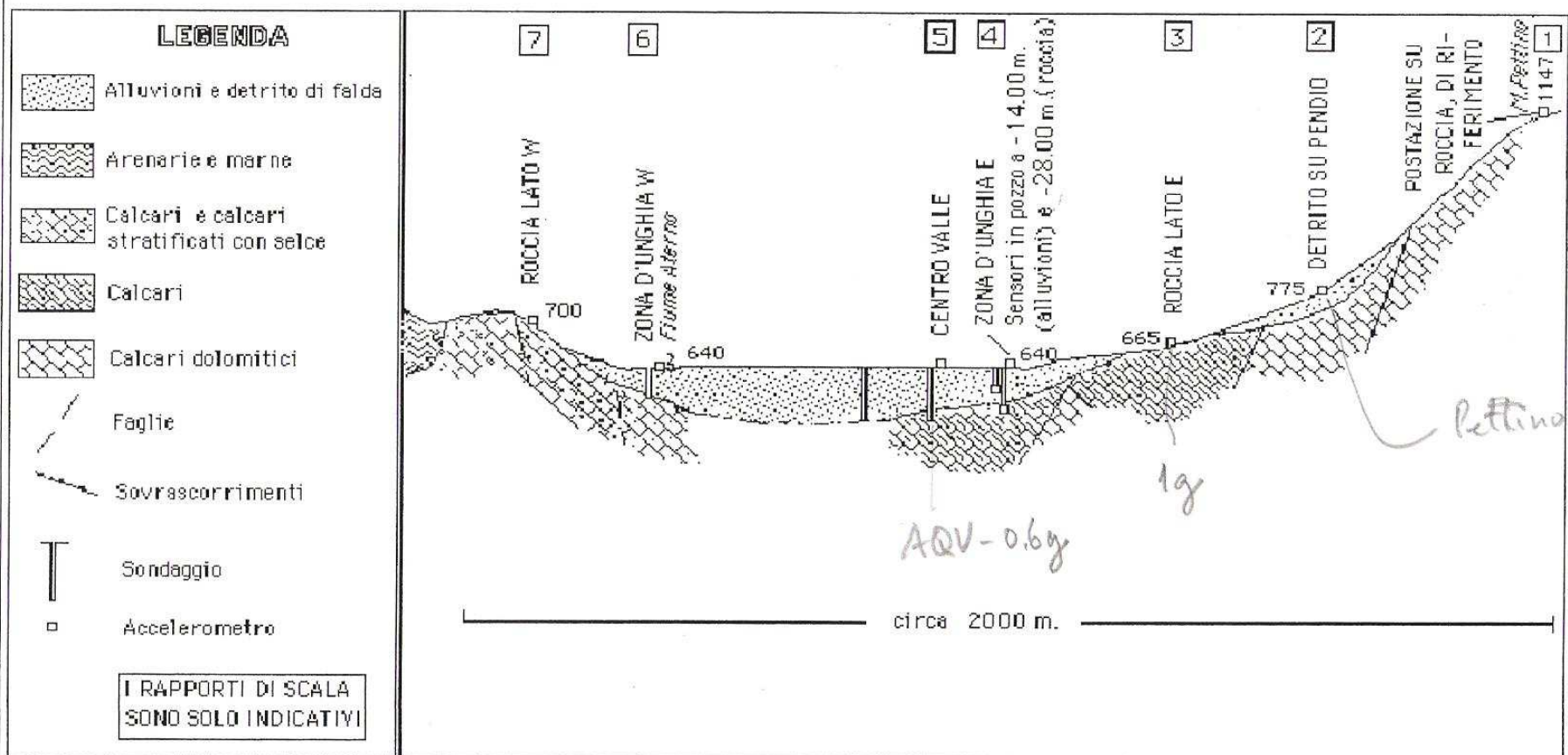
- GEOLOGIA DO VALE DO RIO ATERNO

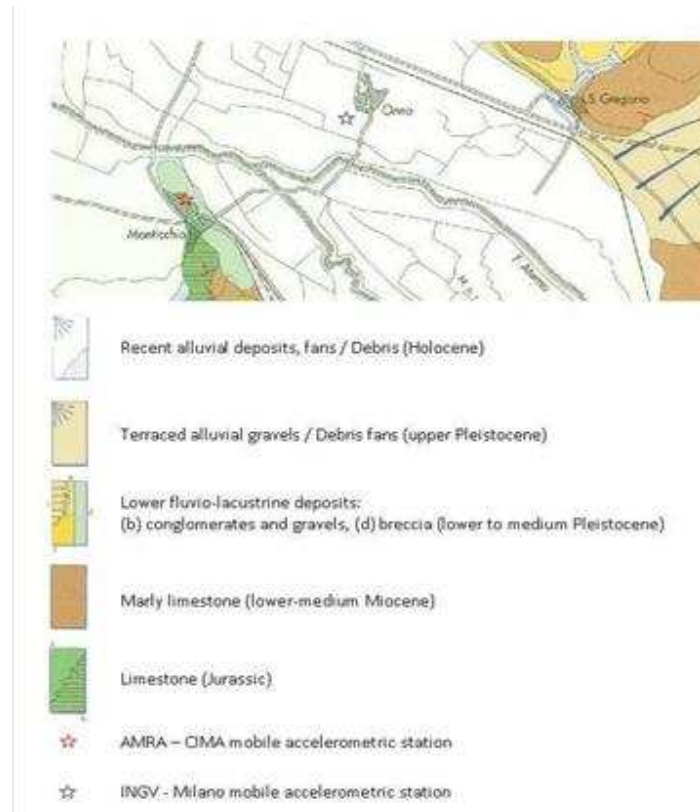


http://research.erc.berkeley.edu/projects/GEER/Post_EQ_Reports.html

Corte geológico junto das estações de SM

Sezione geologica interpretativa lungo l'array lineare.

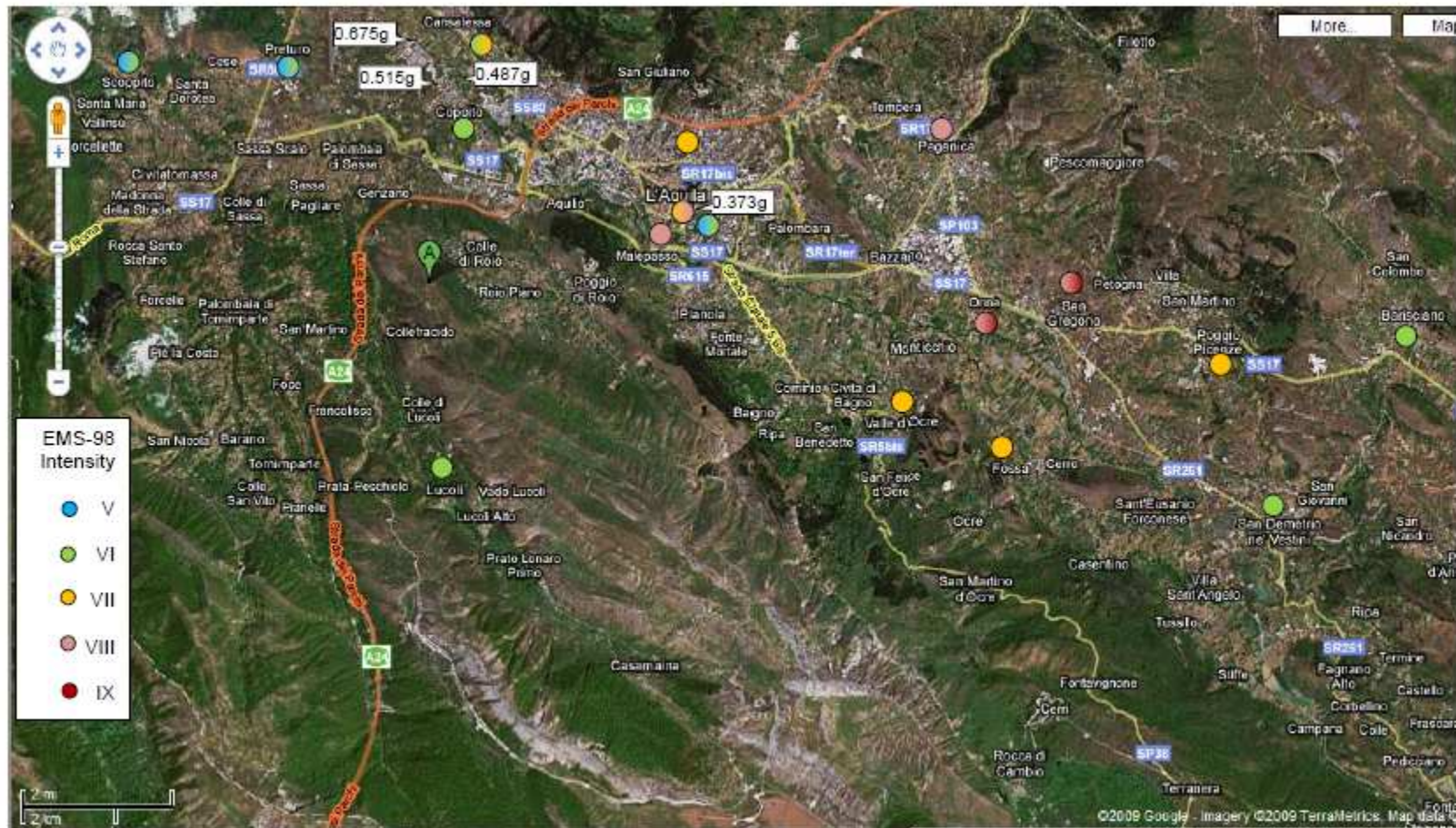




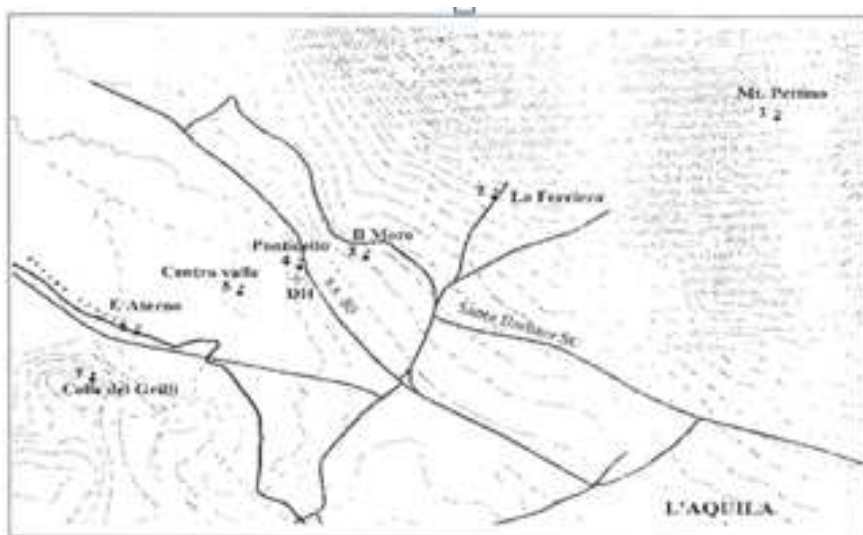
L'Aquila geologic map close-up of Onna, San Gregorio, and Monticchio.

Onna is built on Quaternary alluvium and suffered mostly D4-D5 damage in the masonry structures. Monticchio is built on Mesozoic limestone, and Quaternary breccia and suffered mostly D0-D1 damage. San Gregorio is built on Miocene limestone, Pleistocene Fluvial and lacustrine deposits, and Holocene alluvium. Damage was high in the historic center of town (mostly D4-D5). Damage was considerably lower on the limestone deposits (D0-D2).

EMS 98 Intensities



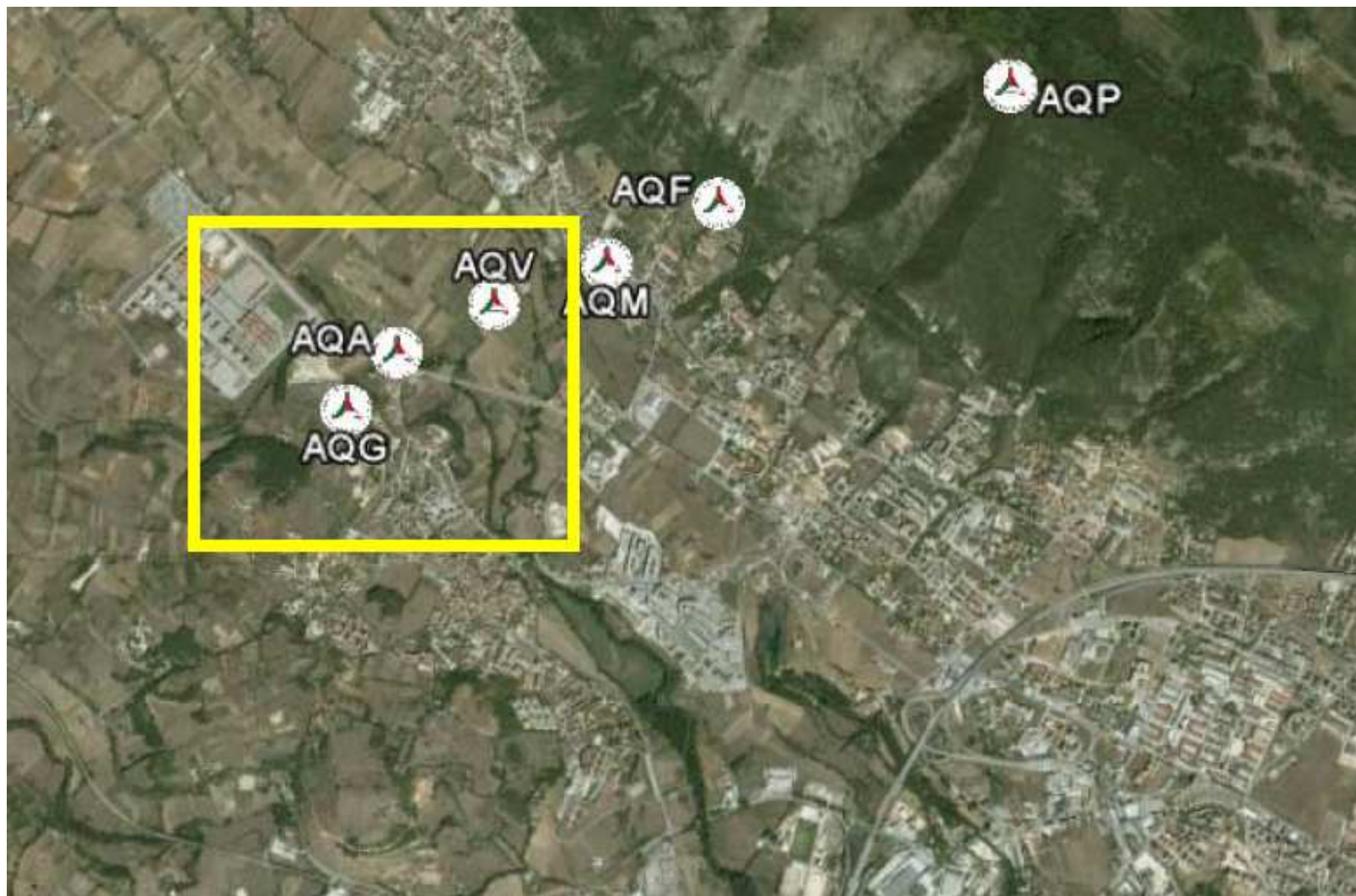
Estações SM (acelerométricas)



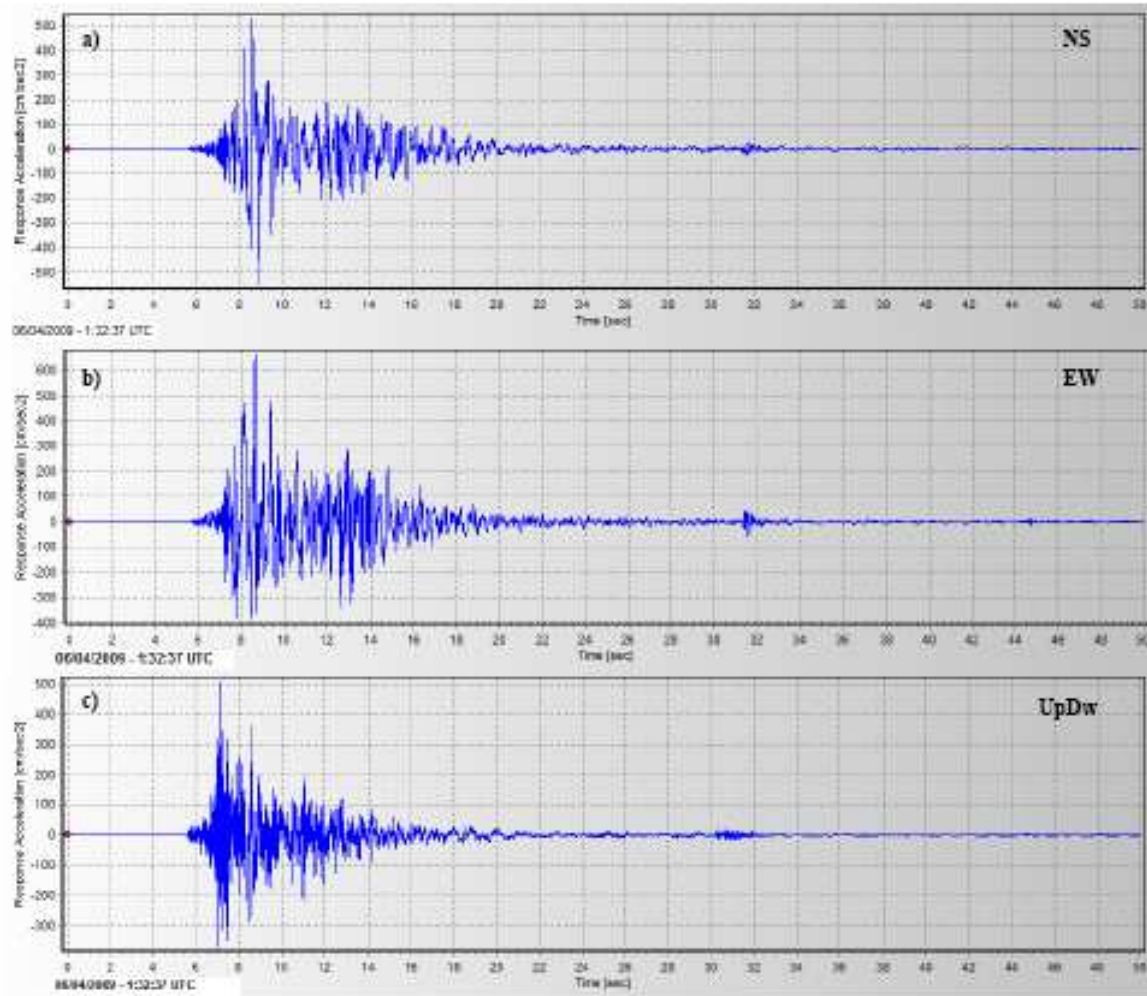
Localização Strong-Motion



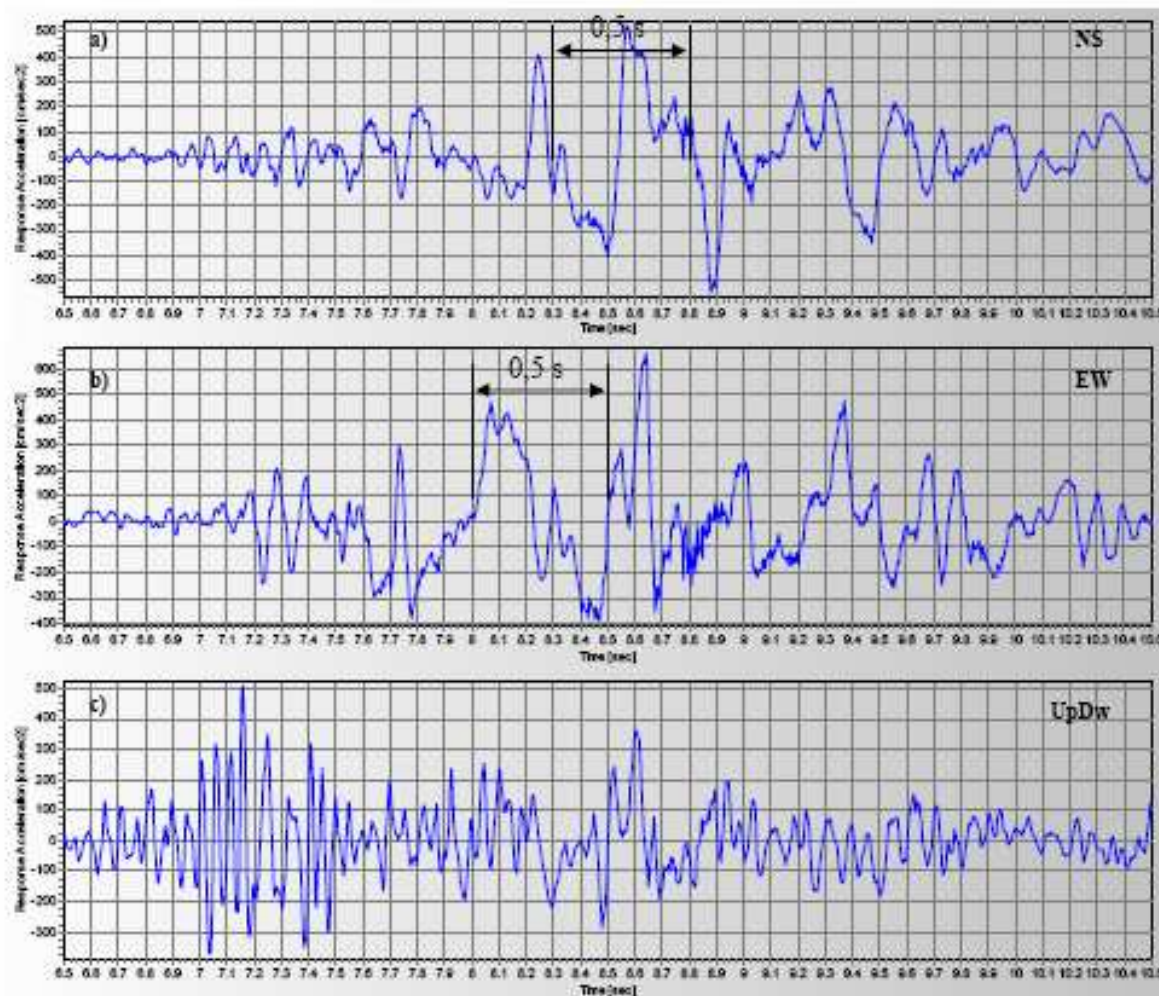
Detalhe



STAZIONE AQV

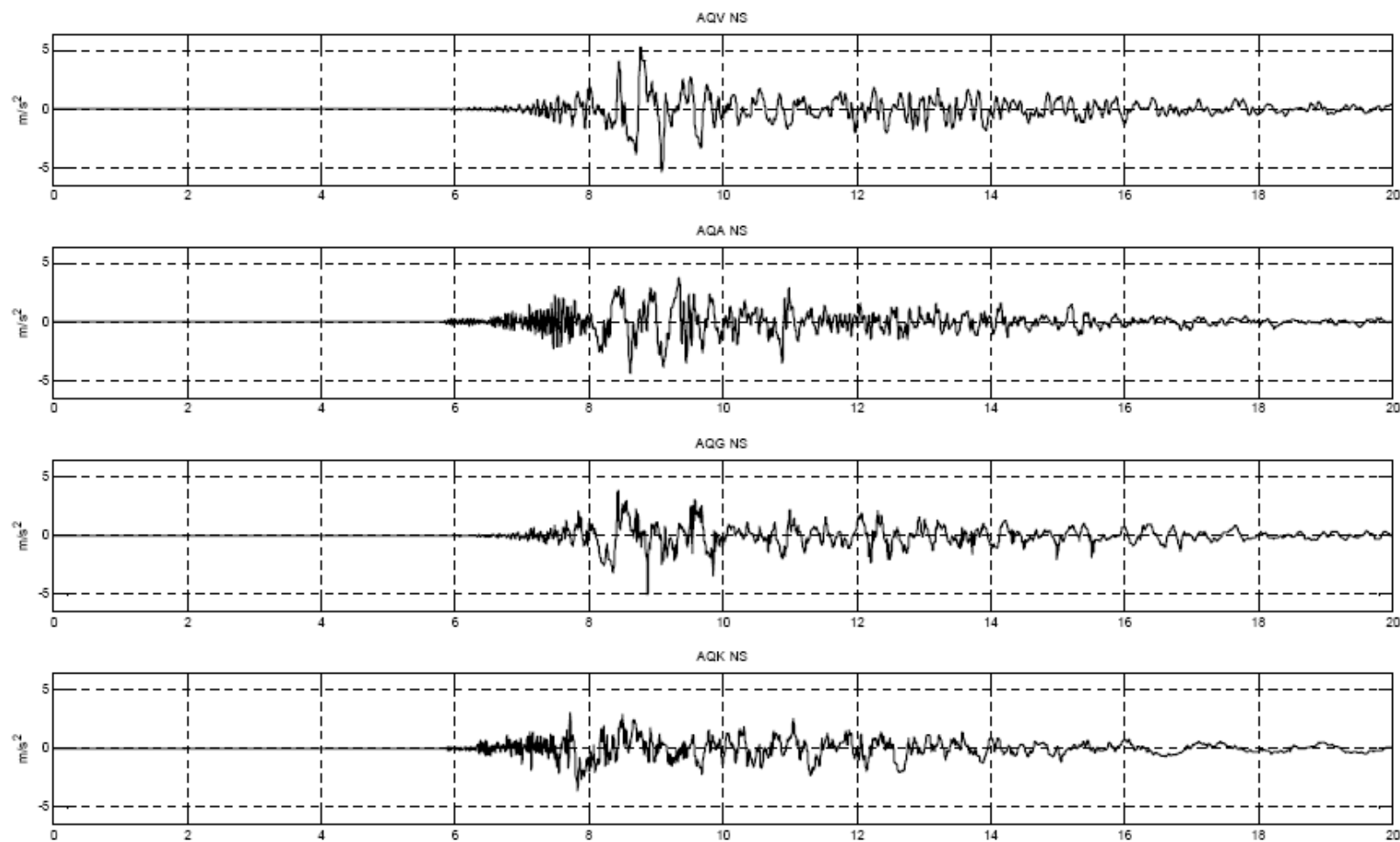


O sismo de L'Aquila

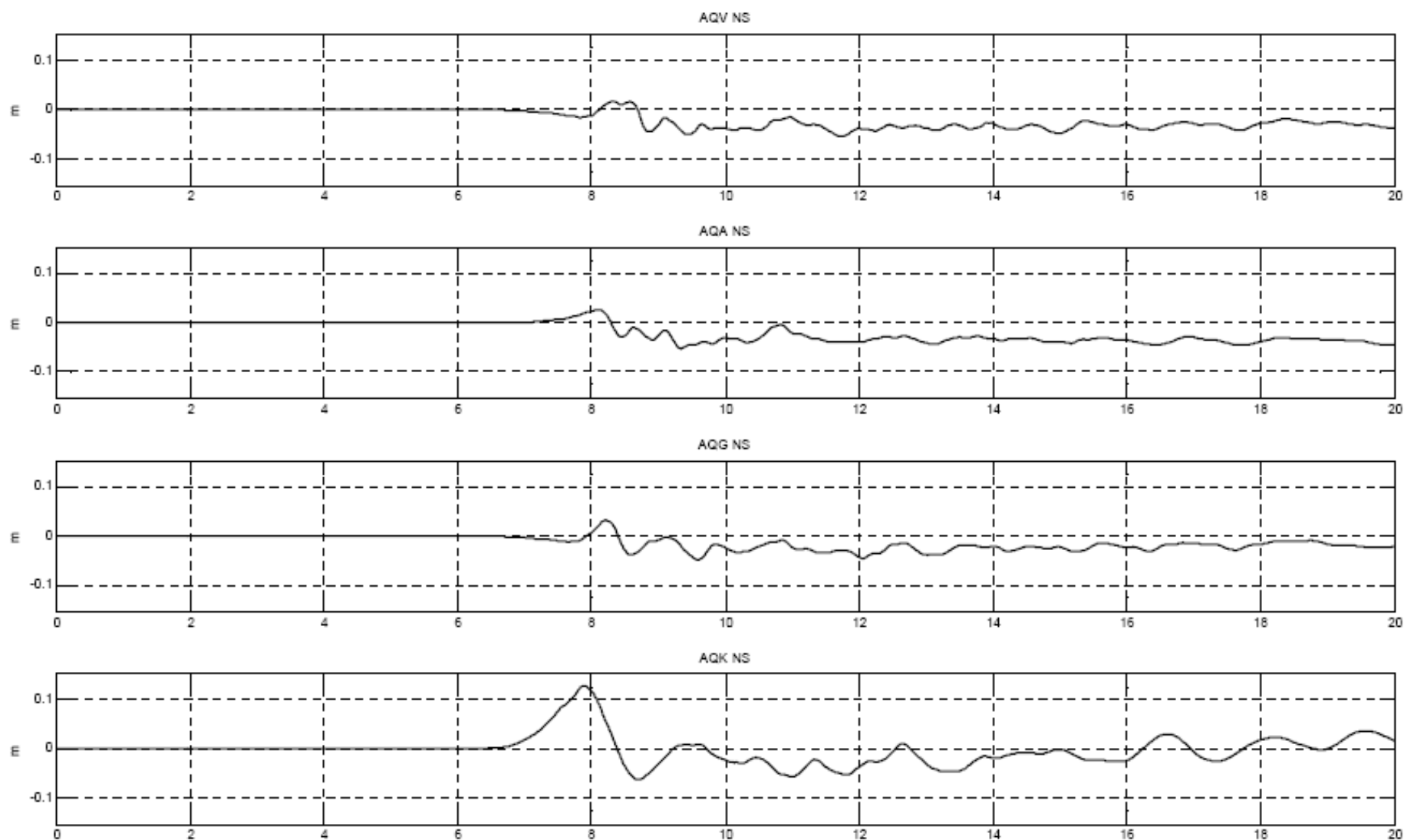


NS – Component (PGA)

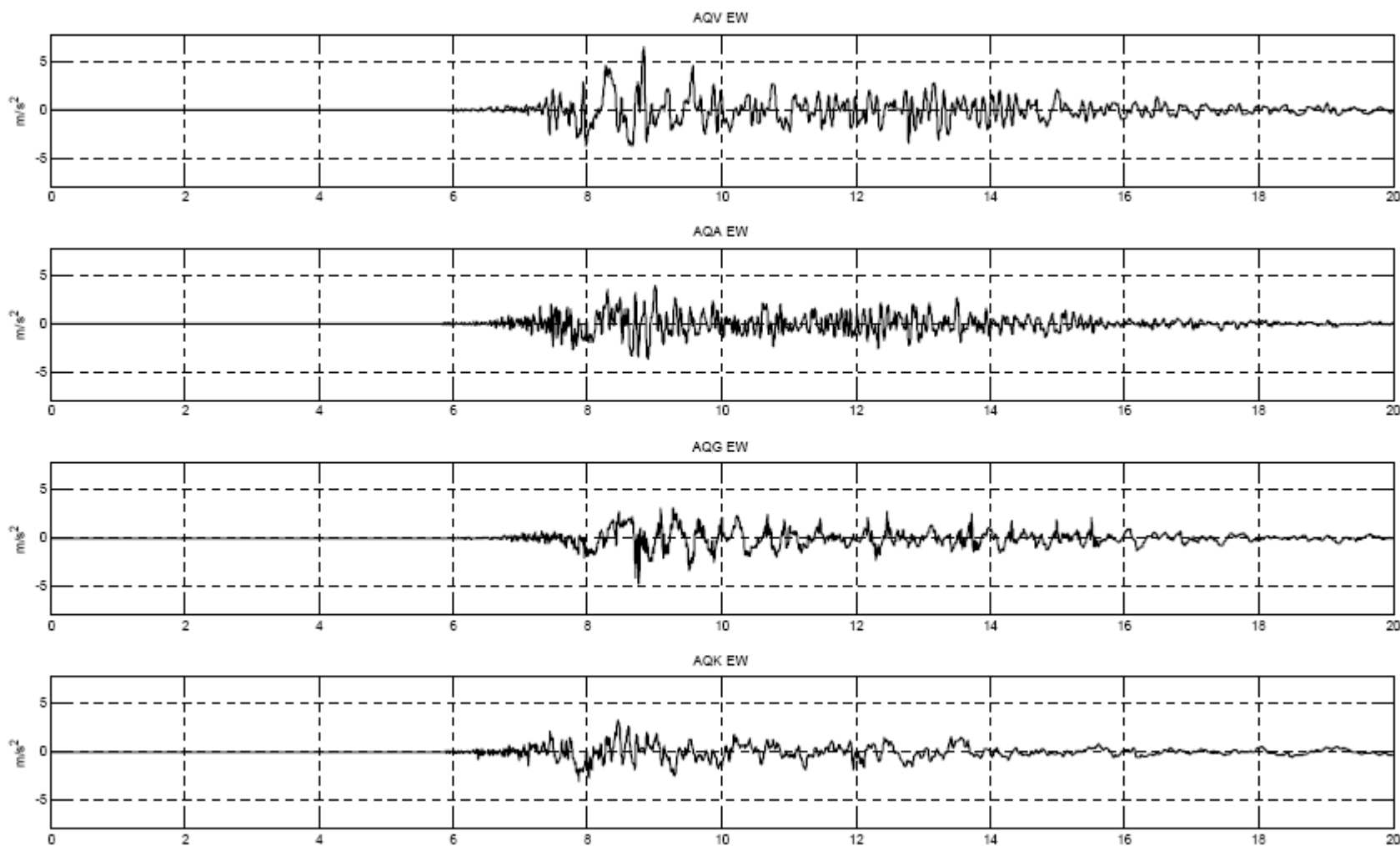
Roberto Paolucci



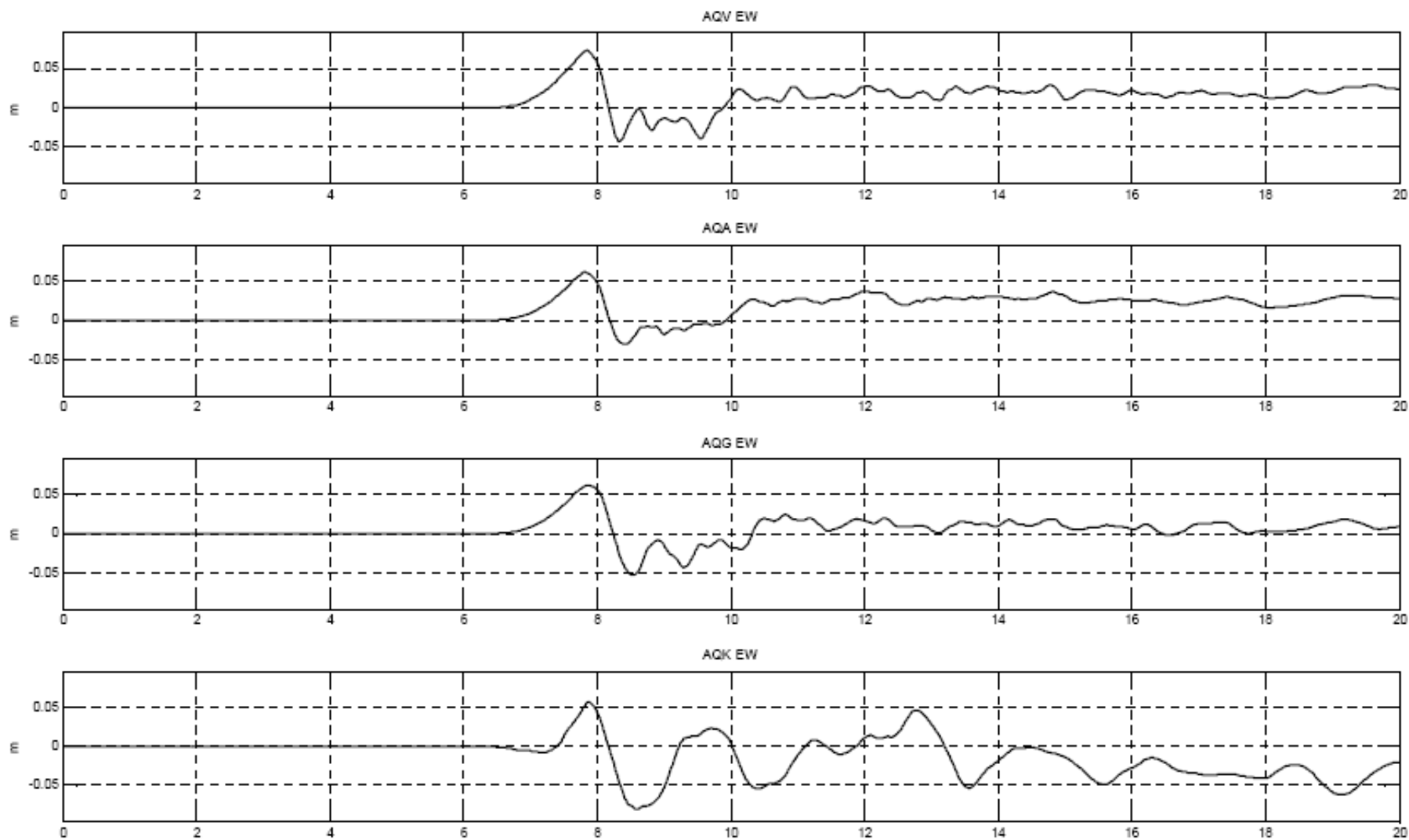
NS - Displacements



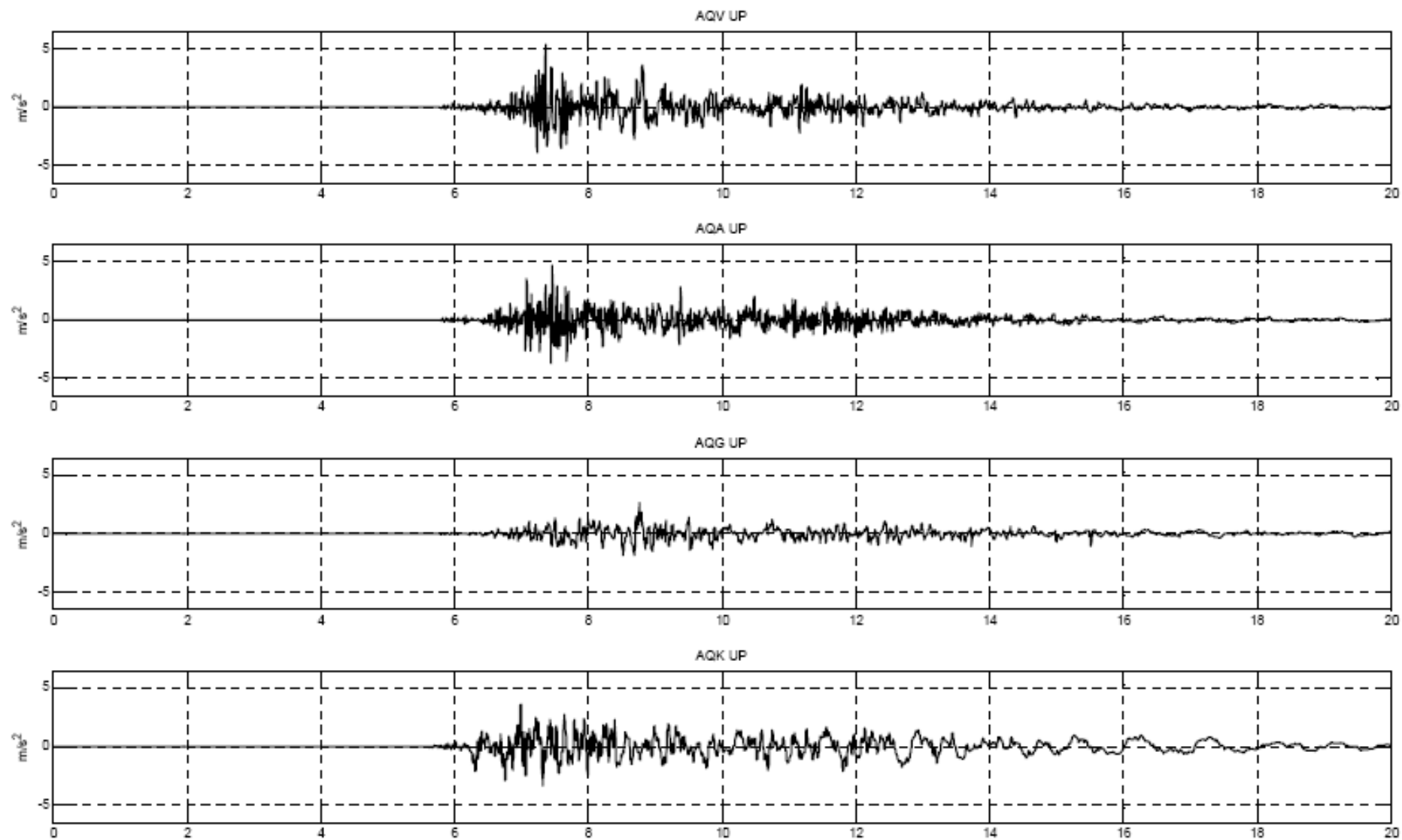
EW- Acceleration



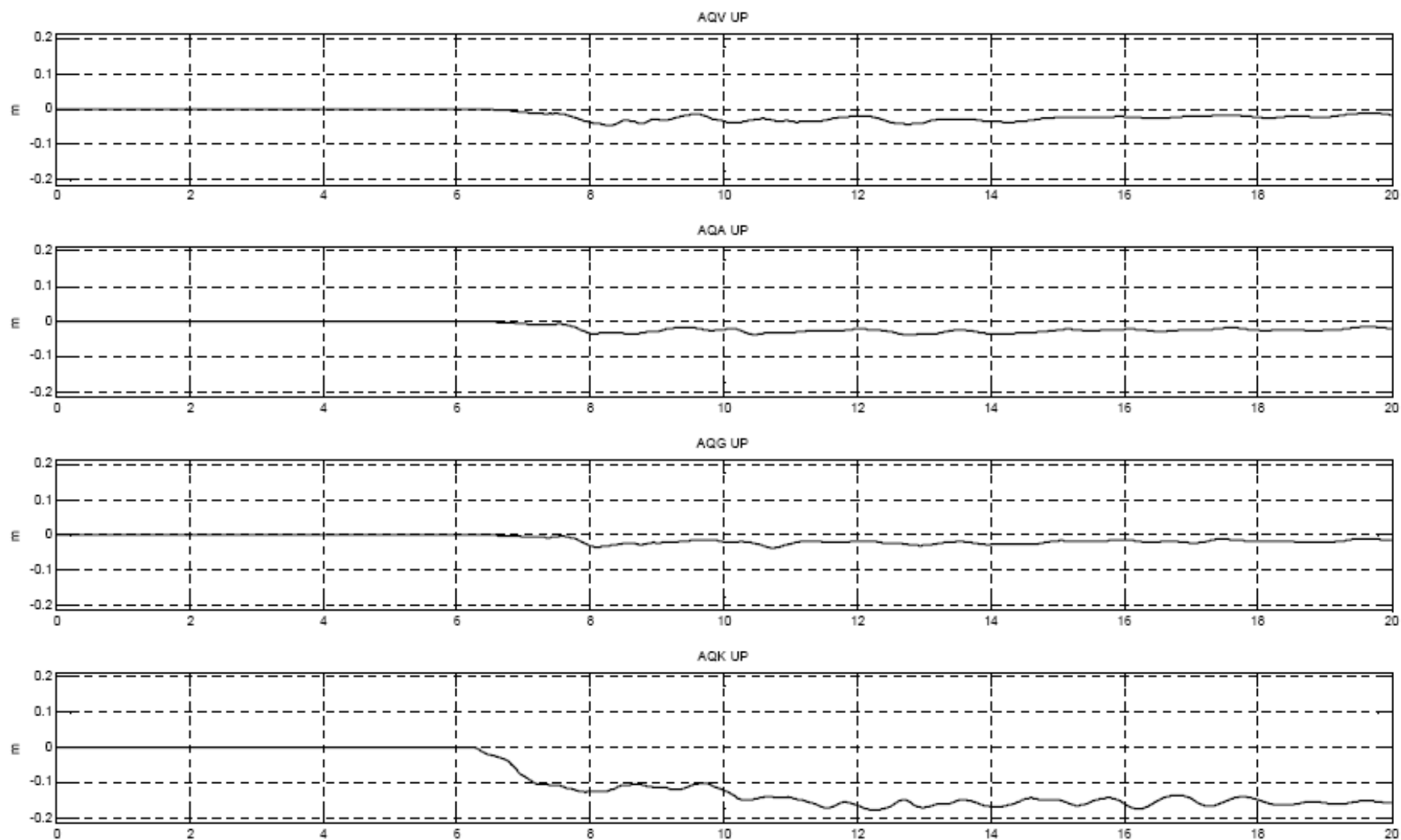
EW - Displacements



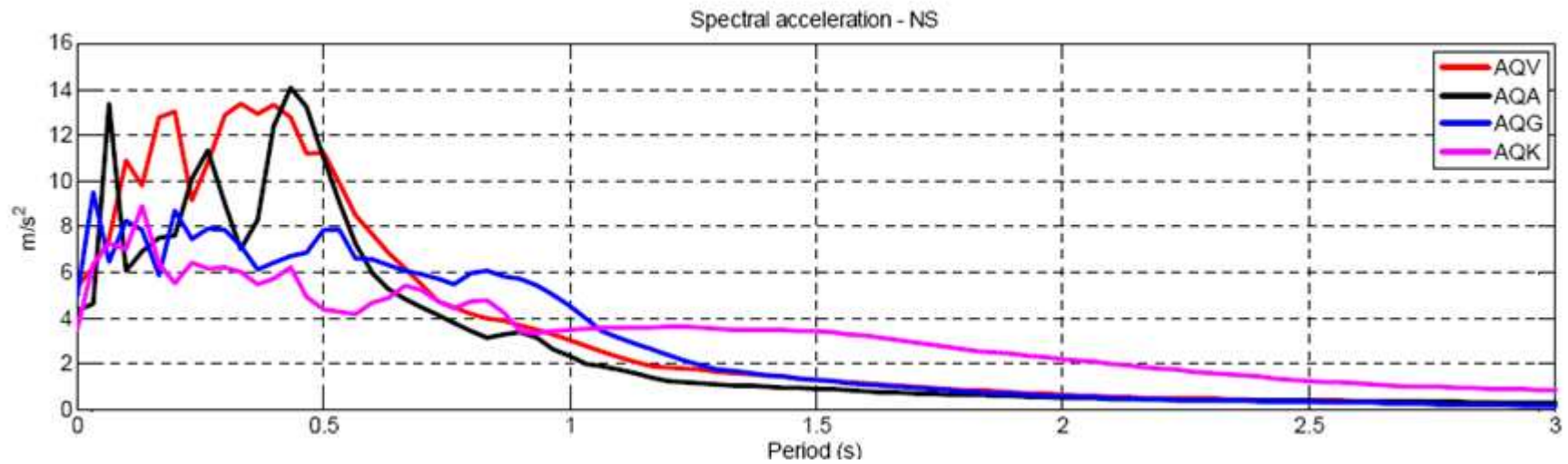
Vertical Accelerations



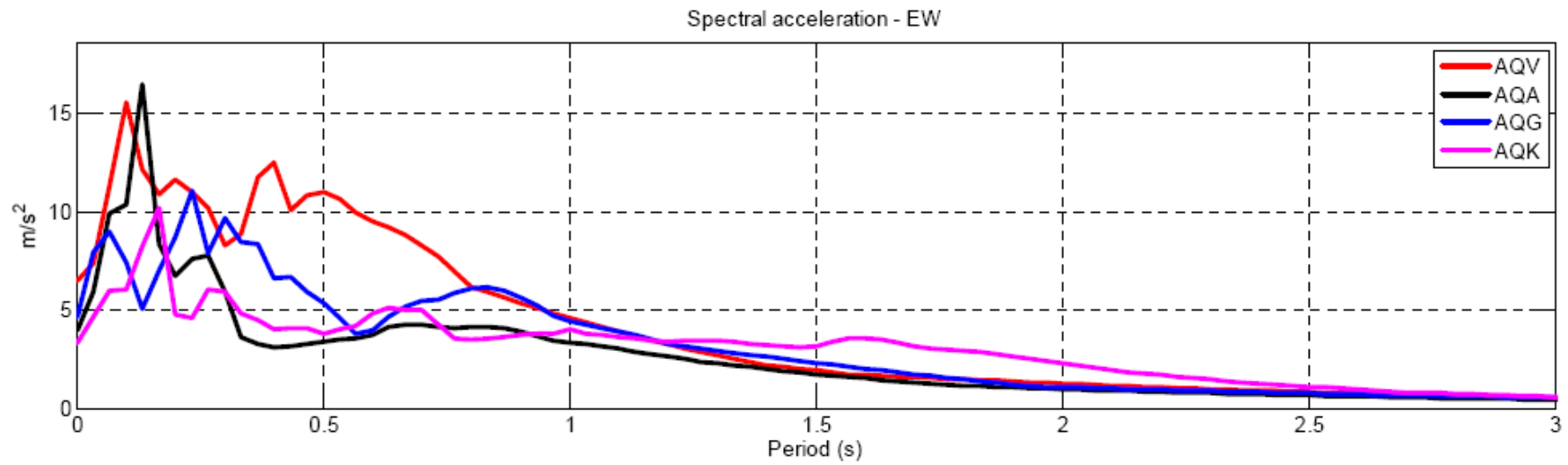
Vertical Displacements



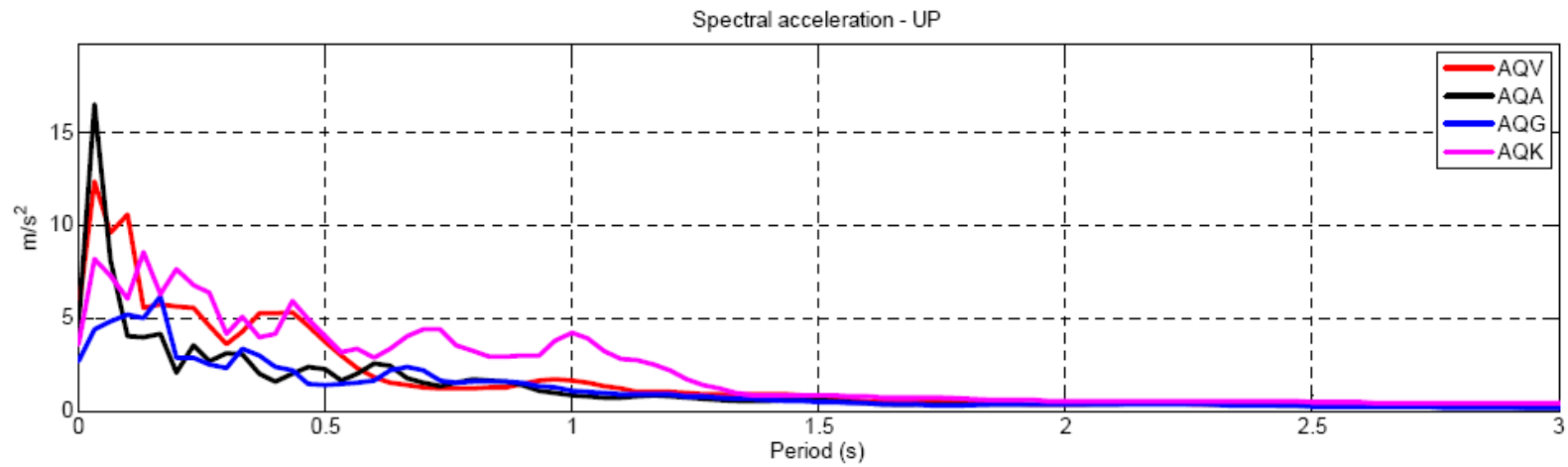
NS Spectra



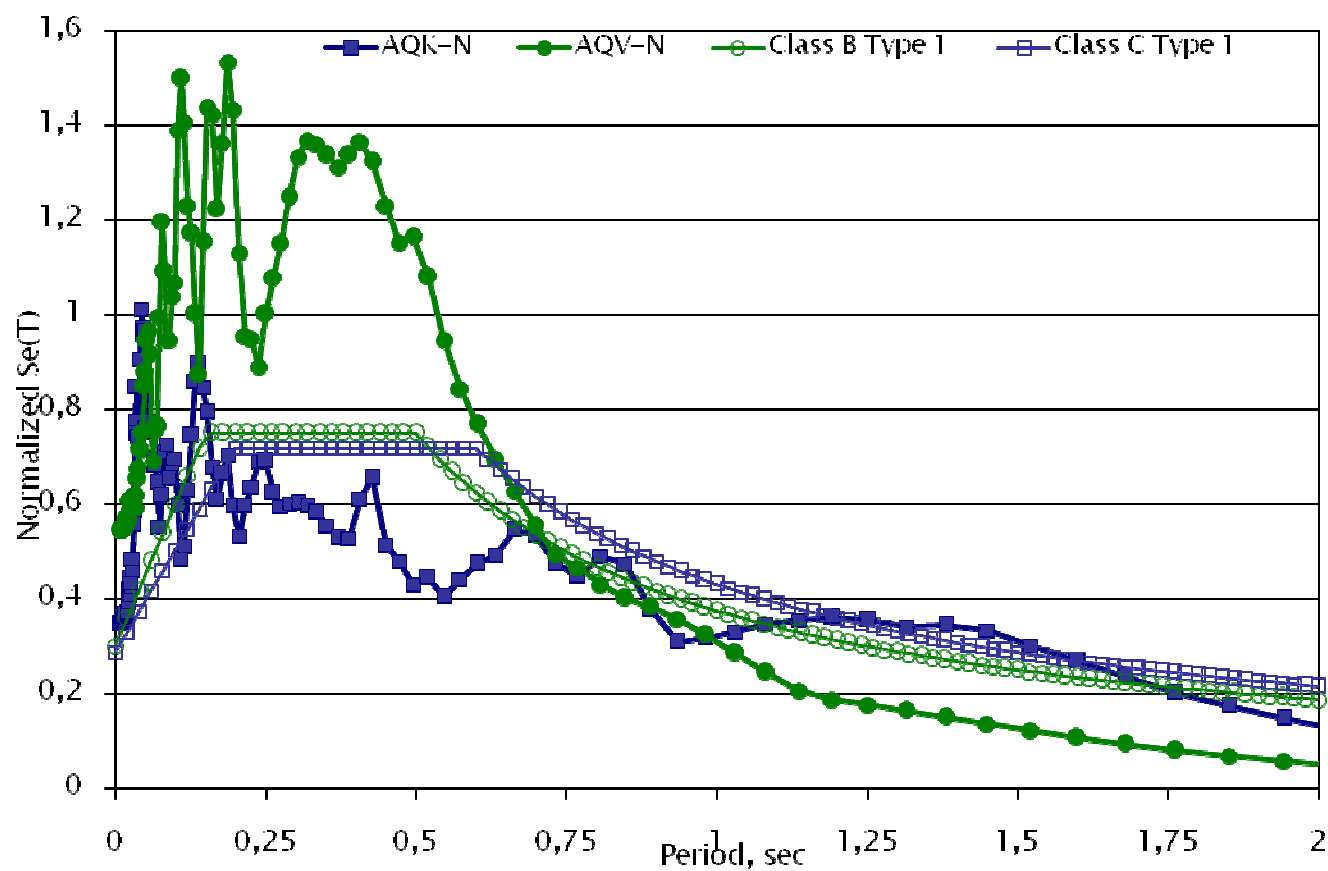
EW Spectra



Vertical Spectra

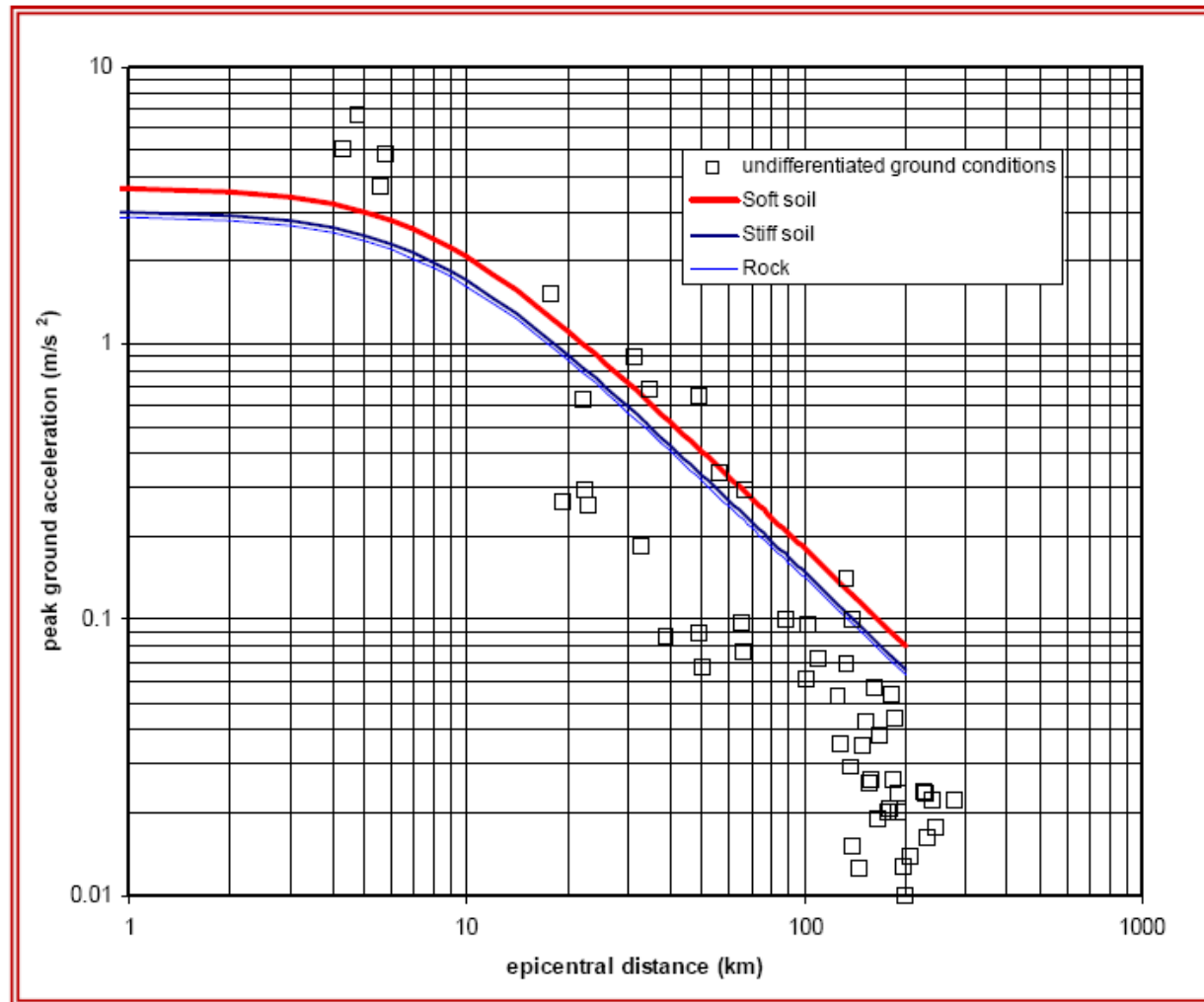


COMPONENTES HORIZONTAIS COMPARAÇÃO COM O EC8, PARA CLASSES DE SOLOS B e C

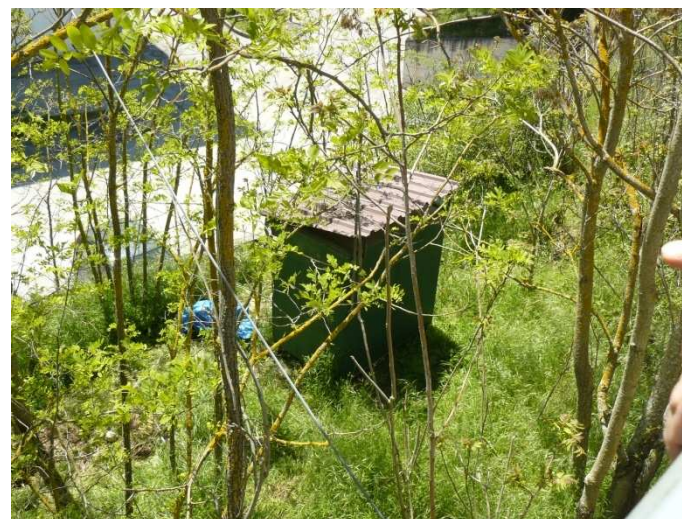


Station Code	Province	Lat N	Log E	PGA (m/s ²)	PGA (g)	Epicentral distance (km)
AQV	L' Aquila	42.377	13.344	6.626	0.675	4.85
AQG	L' Aquila	42.373	13.337	5.049	0.515	4.34
AQA	L' Aquila	42.376	13.339	4.780	0.487	4.69
AQK	L' Aquila	42.345	13.401	3.663	0.373	5.64
GSA	L' Aquila	42.421	13.519	1.489	0.152	18.01
CLN	L' Aquila	42.085	13.521	0.894	0.091	31.68
AVZ	L' Aquila	42.027	13.426	0.677	0.069	34.97
ORC	L' Aquila	41.954	13.642	0.644	0.066	49.30
MTR	L' Aquila	42.524	13.245	0.622	0.063	22.35
GSG	L' Aquila	42.460	13.550	0.292	0.030	22.60
FMG	Rieti	42.268	13.117	0.264	0.027	19.30
ANT	Rieti	42.418	13.079	0.259	0.026	22.93
CSO1	L' Aquila	42.101	13.088	0.183	0.019	32.89
LSS	Rieti	42.558	12.969	0.086	0.009	38.95
MMP1	Rieti	42.249	12.748	0.089	0.009	49.12

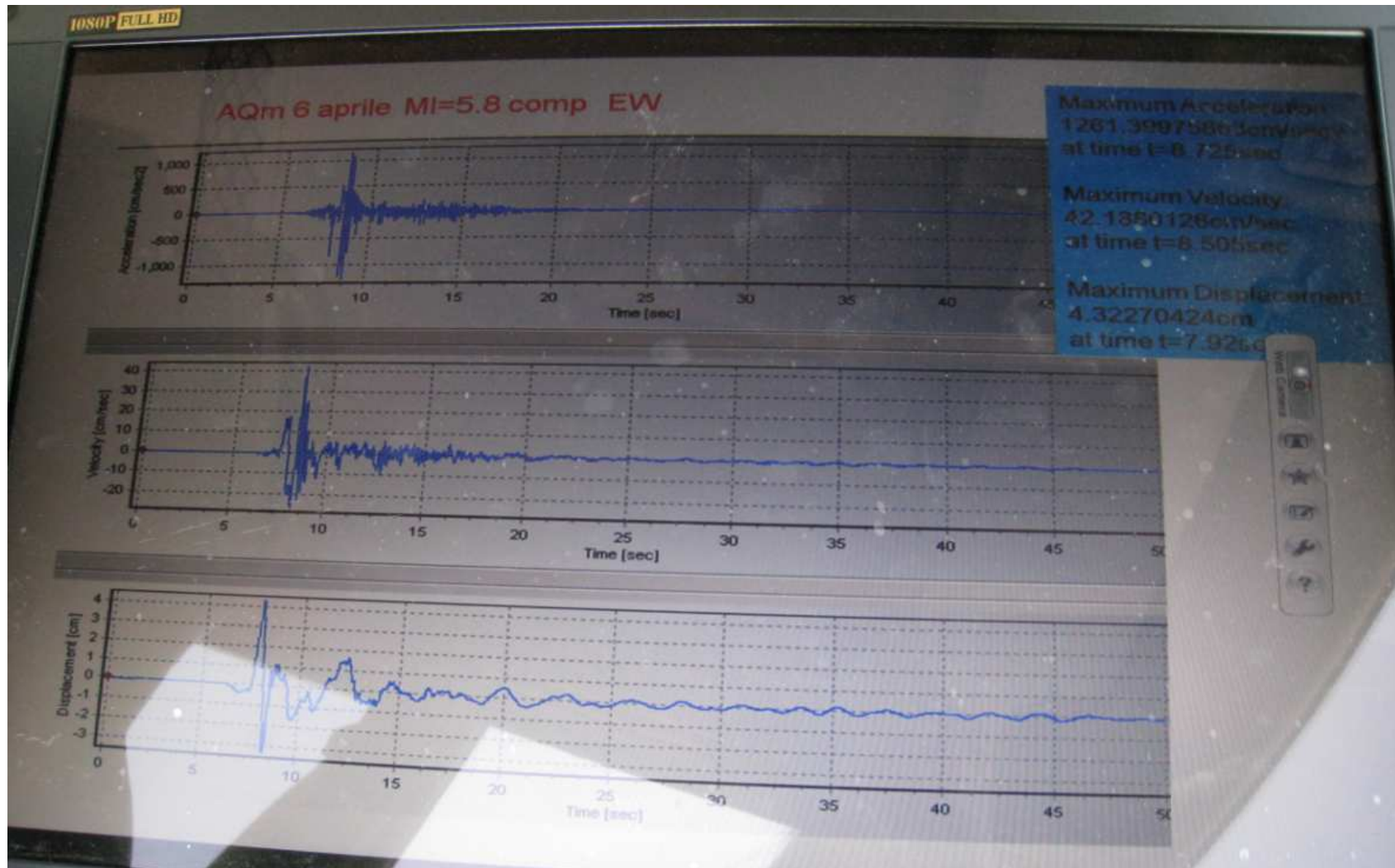
Attenuation (Akkar & Bommer 2007)



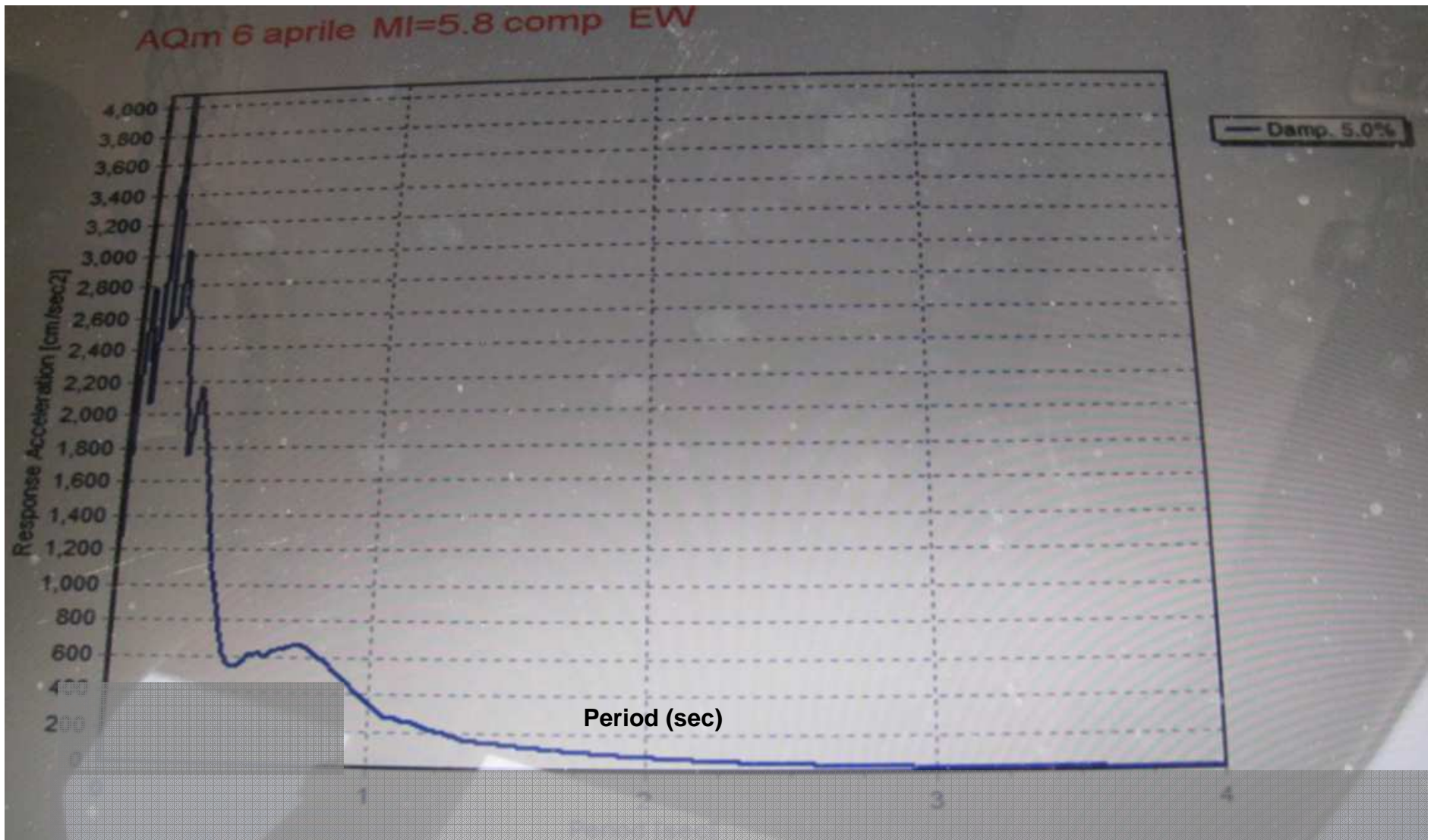
Local de registro de SM



O sismo de L'Aquila



O sismo de L'Aquila



O sismo de L'Aquila



Edifício a menos de 50 m.





Satellite photo from Google Earth of the L'Aquila with a general view of the building damage survey.

Onna



Onna - detalhe





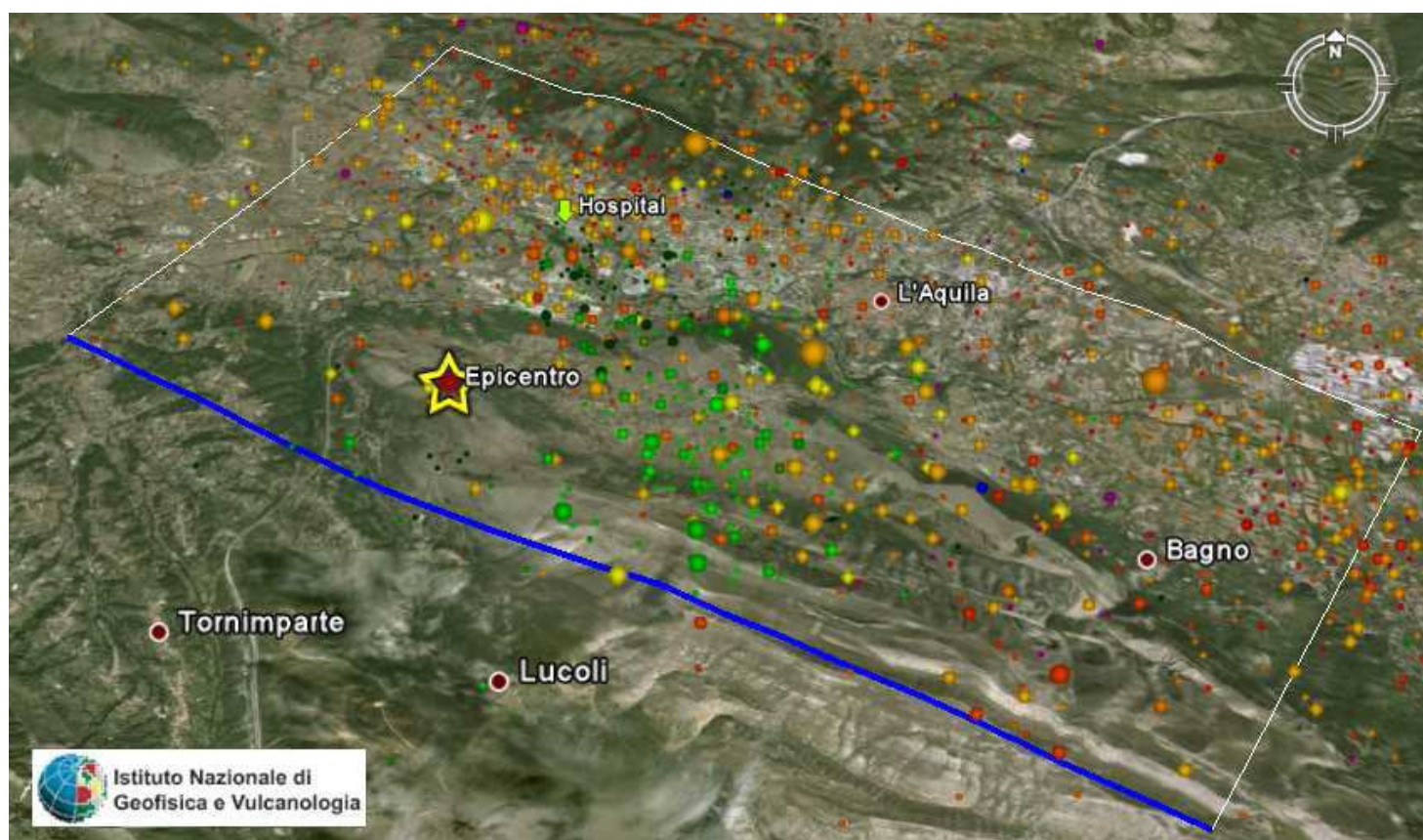
Onna – pós sismo

Surveyed distribution of building damage in Onna (EEFIT, 2009)

Town	Total number buildings surveyed	D0	D1	D2	D3	D4	D5
Masonry	44	0	2	7	2	16	17
R.C.	2	1	1	0	0	0	0
Total	46	1	3	7	2	16	17

The preliminary death toll after the main-shock is reported to have been 33, i.e. 9.4% of the total population.

Simulações com o SIMULSIS – L'AQUILA 2009
Falha normal (13.8x11.6 km) e MW=6.3 (Simulação João Estêvão, 2009)

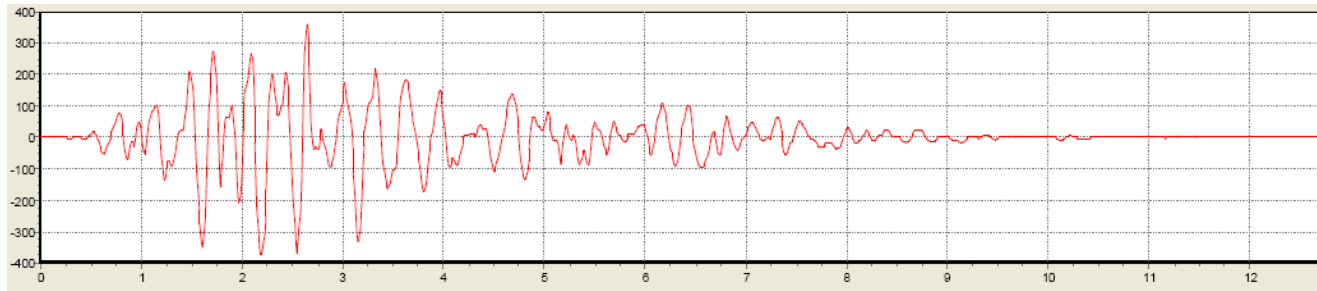


Hospital de San Salvatore

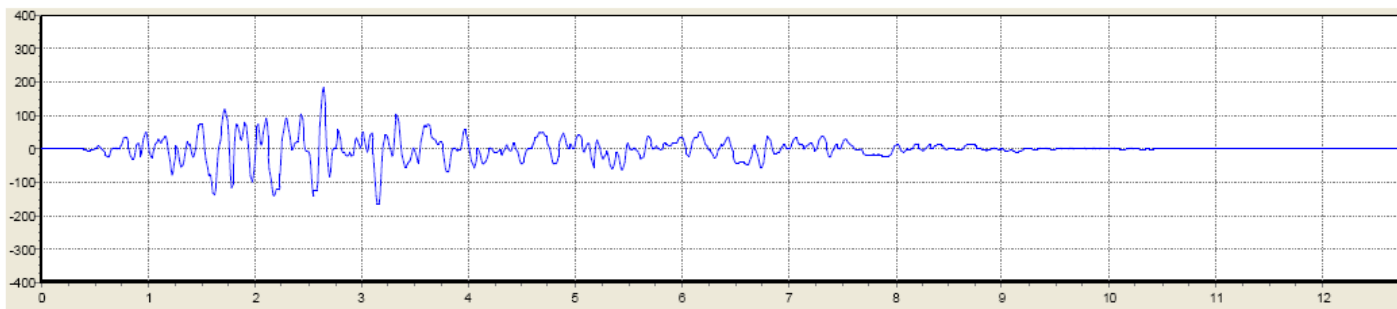


O sismo de L'Aquila

Aterro: pico médio de 406 cm/s²



Afloramento rochoso: pico médio de 183 cm/s²



Espectro de Resposta (período, s)

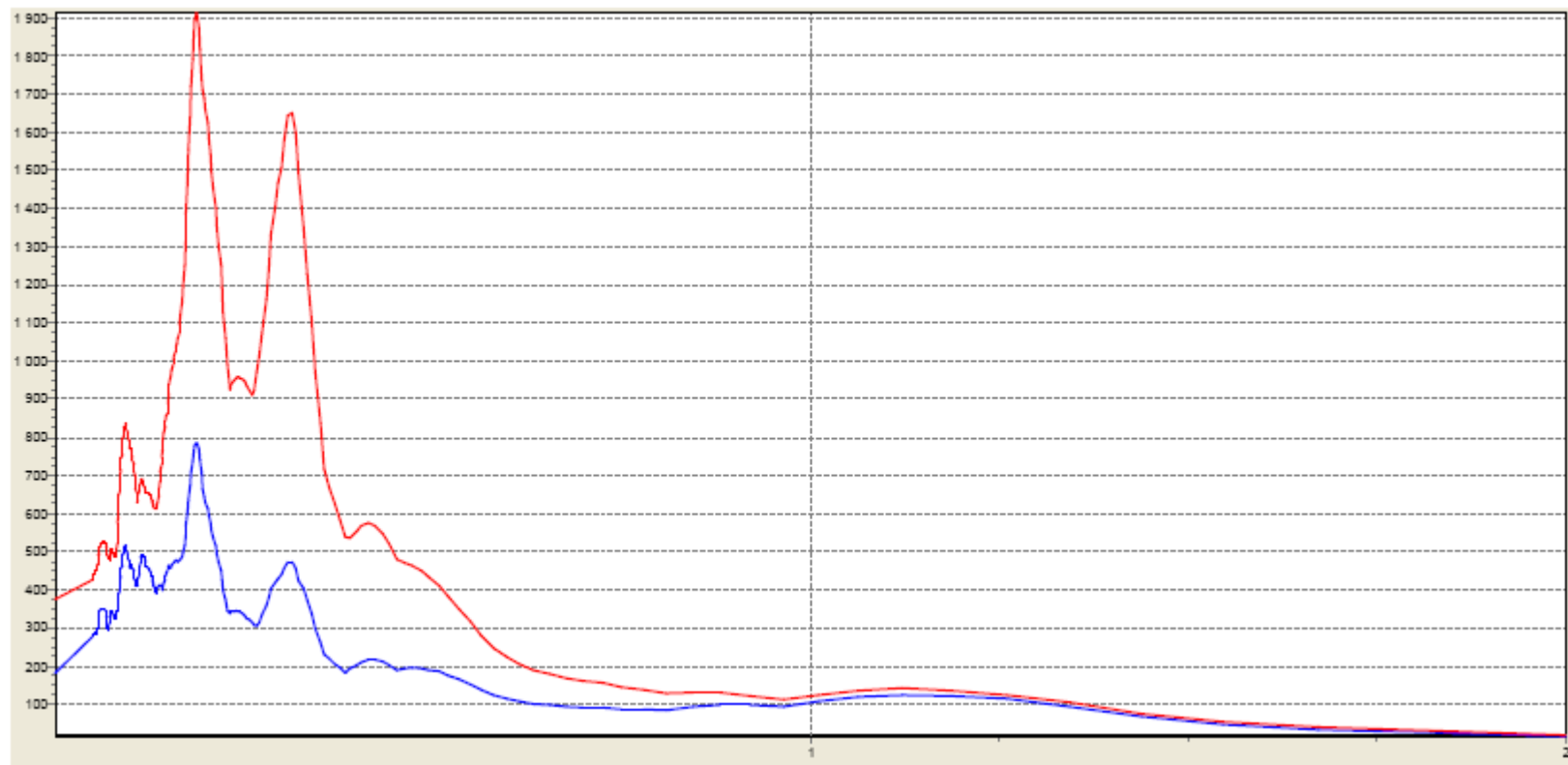


Figura 12

Corte vertical do Farol da Ribeirinha e modelo analítico ("elementos discretos", Oliveira et al., 2002).

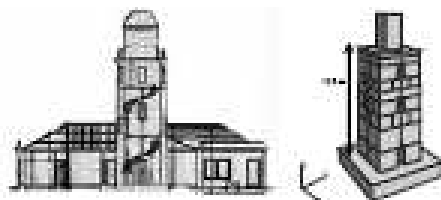


Figura 13

A estátua de Manuel Amiega na Horta (com o parte superior rodado) e o modelo analítico.

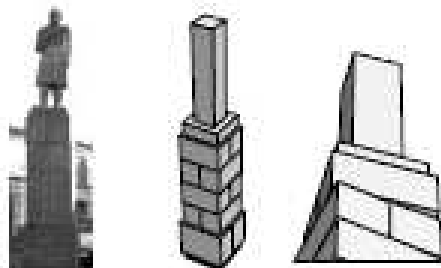
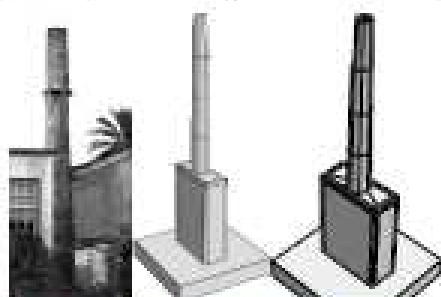


Figura 14

Chaminé na Horta: a) estrutura identificada; b) modelo analítico; c) estrutura deformada.



7. Estudo detalhado de estruturas simples

Foram vários os casos de estudo desenvolvidos no sentido de tentar recuperar o movimento sísmico a partir do conhecimento do comportamento de estru-

turas simples (Figura 11). Foram eles: o Farol da Ribeirinha, uma chaminé, a estátua de Manuel de Amiega, a Torre do Relógio na Horta, e Pia Baptista da Igreja de Espalhafatos. Para tal desenvolveram-se modelos matemáticos de comportamento não-linear (Oliveira et al., 2003) onde se reproduzem as características mecânicas das estruturas em estudo, aplicando na base a ação sísmica registada no Observatório.

A análise do registo analógico obtido a 15 km do epicentro permitiu verificar que a órbita do movimento da partícula no plano horizontal, em termos de deslocamento, apresenta um primeiro movimento na direcção NNW-ESE que está de acordo com as observações feitas em diferentes objectos e estruturas, conforme se mostrou nas descrições anteriores, ou seja, na direcção aproximada N-S. Contudo, nem todas as estruturas apresentam esse movimento. Por exemplo, a Torre do Relógio na cidade da Horta, uma estrutura ex-líbris da cidade com cerca de 30 m de altura e frequência de 1.4 Hz sofreu movimento mais importante na direcção E-W, com sentido predominantemente para Oeste.

- A amplificação observada no Observatório Príncipe de Mónaco dá-se nas frequências de 1.7 e 2.7 Hz, aparentemente desacopladas do mecanismo da falha, enquanto que os três grandes impulsos na componente N-S ou os dois impulsos na componente E-W se deverão atribuir à rotura da falha.
- O farol da Ribeirinha (Figura 12) é uma estrutura em alvenaria de pedra de muito boa qualidade, construída em 1918 no alto de uma falésia de proclasto. Localiza-se a cerca de 5 km do epicentro. A estrutura, muito mais alta do faroleiro, sofreu danos muito importantes, tendo o topo rodado no sentido levógiro (visto de cima), com alargamento da secção por movimento de abertura das pedras a mais altura. Há sinais de movimento preferencial na direcção NNE-SSW, tanto agora como já no caso do sismo de 1926, que, embora não tenha



ICIST

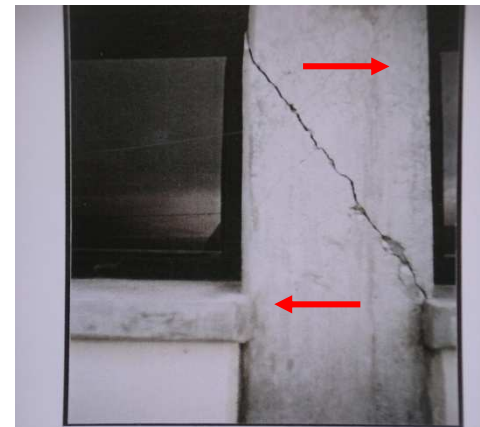
Building walls and RC Columns

O SISMO DE L'Aquila

Out of plane



In-plane



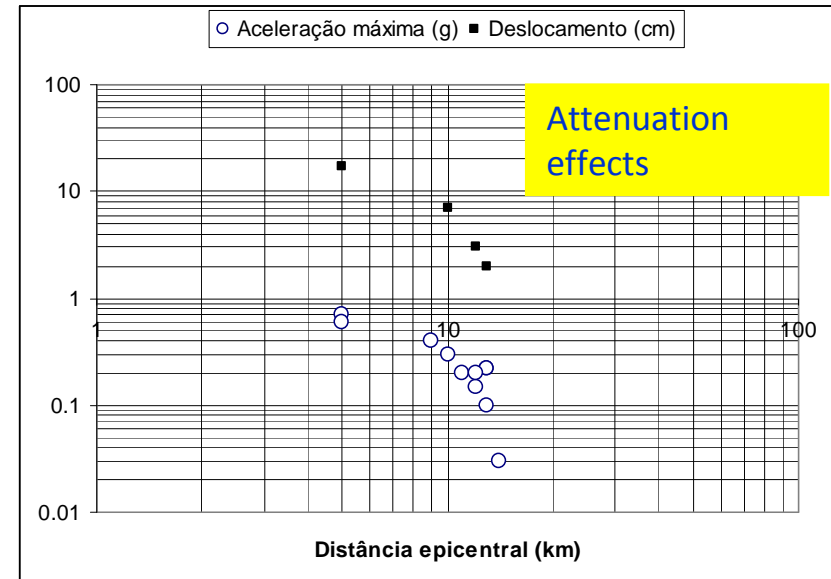
Pilar P9 entre janelas. Fissura na zona das janelas acompanhada por microfissuração e ligeiro esmagamento do betão



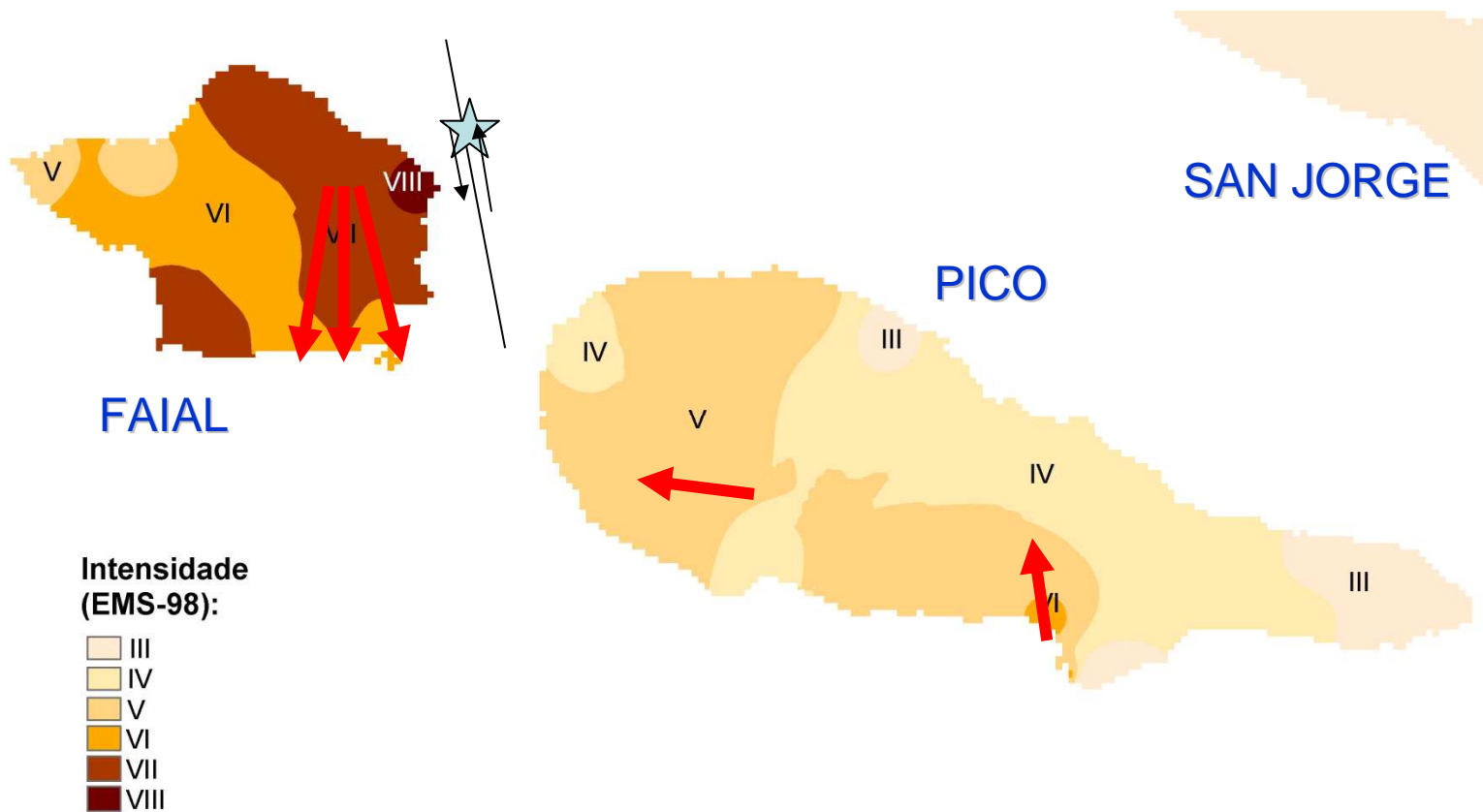
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Sliding and rotating objects

O SISMO de L'Aquila



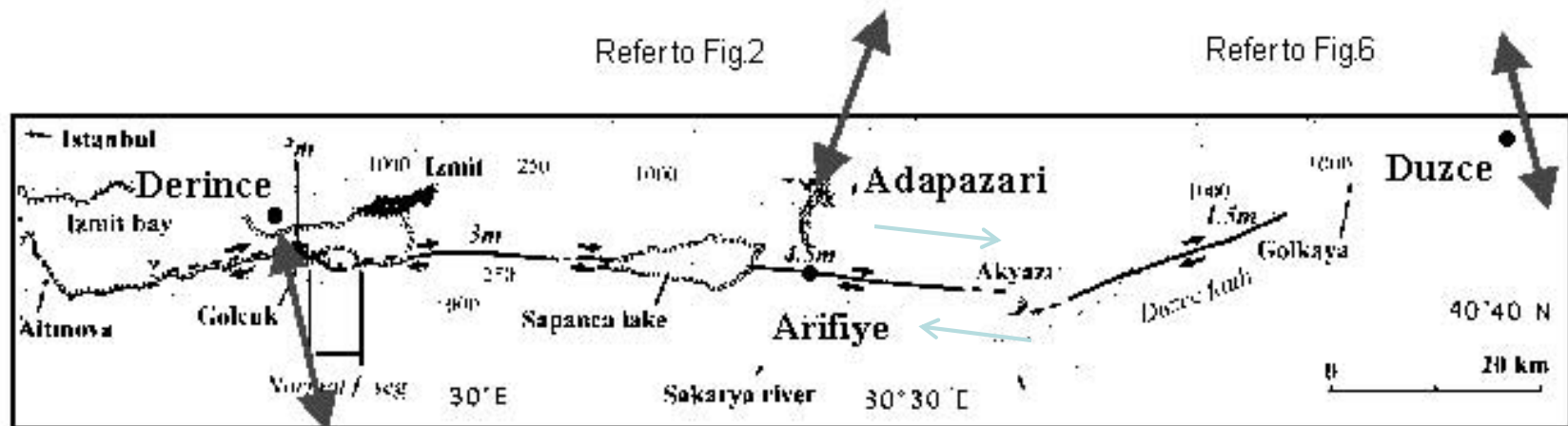
Predominant direction of collapse Inconsistency with fault rupture?



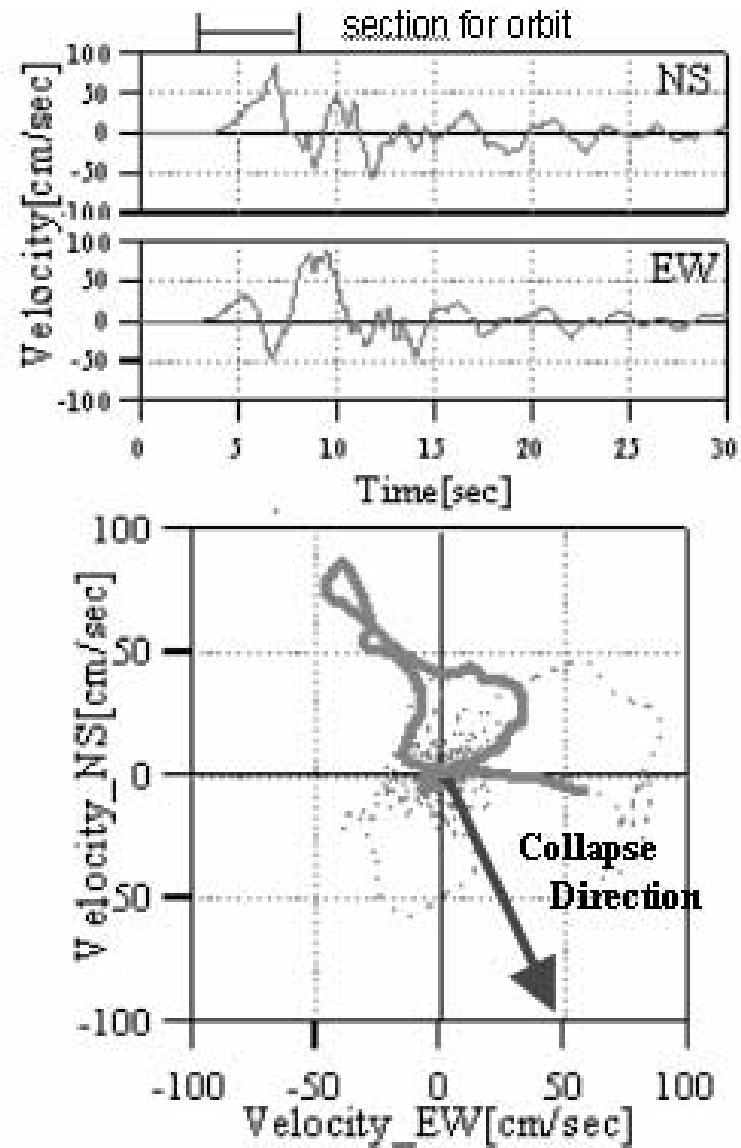
Fall of minarets

Minarets are a good target to investigate the ground motion directionality, because they are simple cantilever structure without structural directionality.

During the two 1999 earthquakes in Turkey, from a damage Survey indicating the direction of fallen minarets, it is found that the fault normal direction (FN) was dominant with a certain distance from the fault, say, less than 1km; while, at the region with shorter distances, the damage direction was not FN but about 40° from the fault strike.



Fall of minarets



Fall of minarets



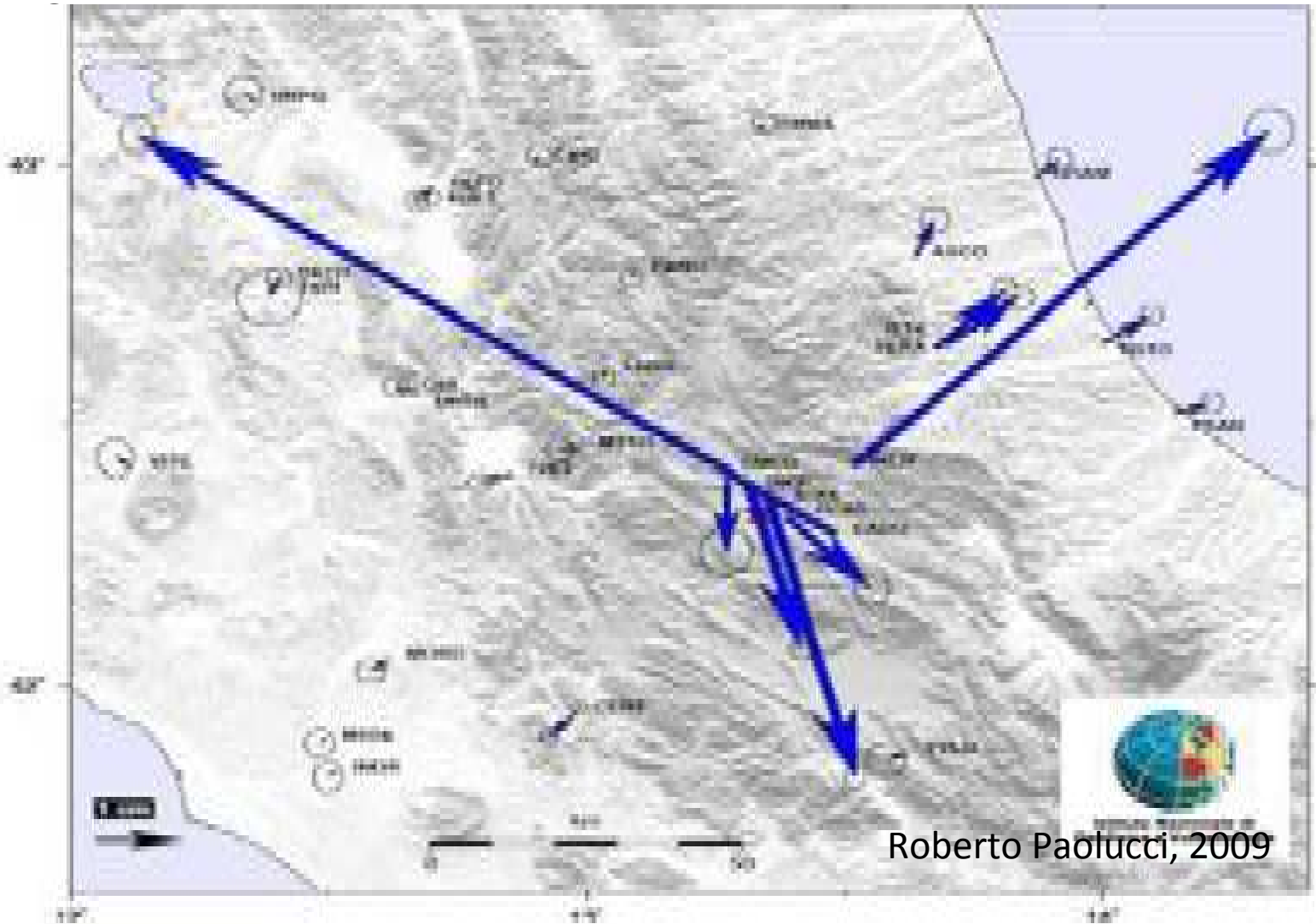


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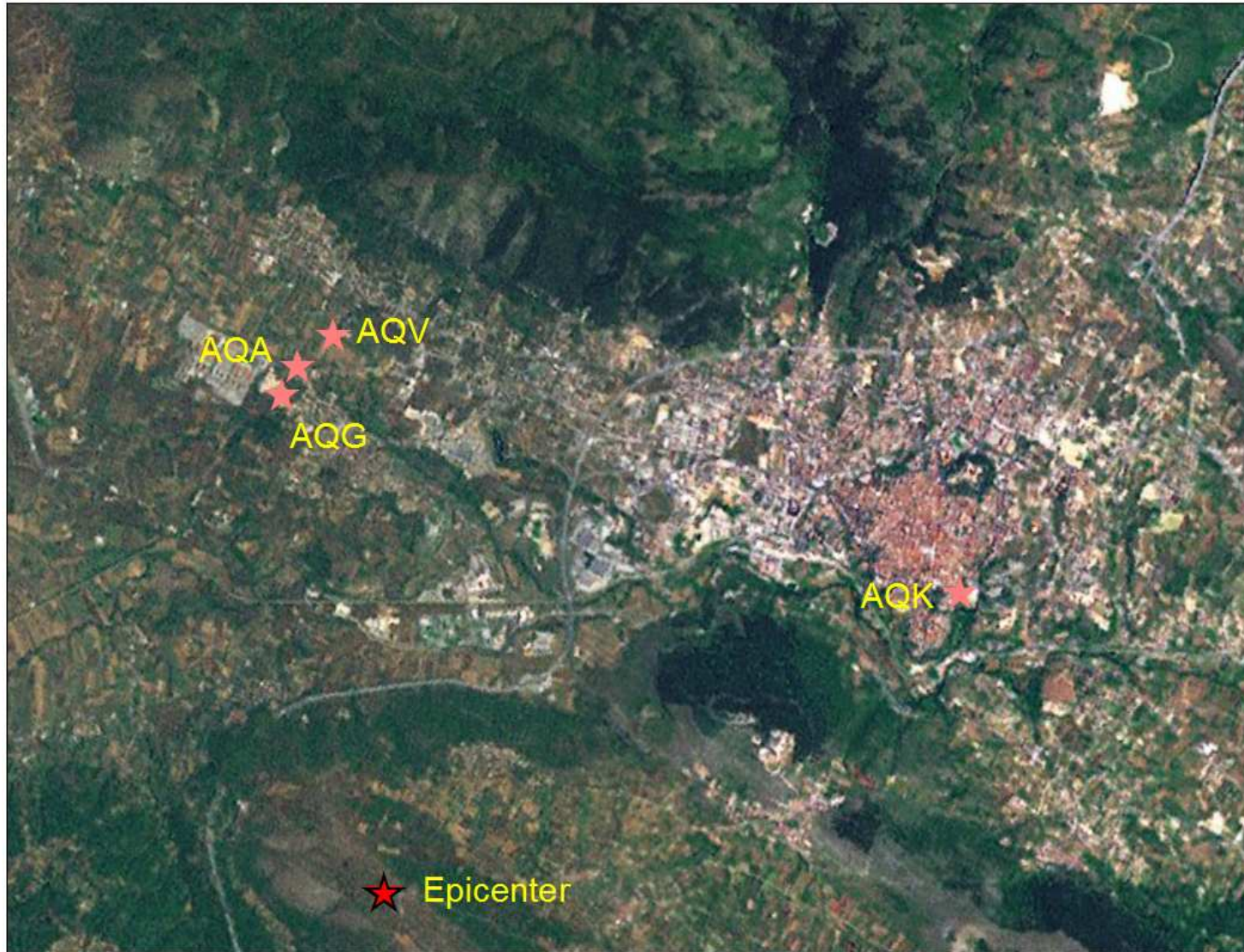
Other examples: L`Aquila 2009

Computed displacements suggest a permanent movement directed

SE and downwards, in agreement with preliminary results from

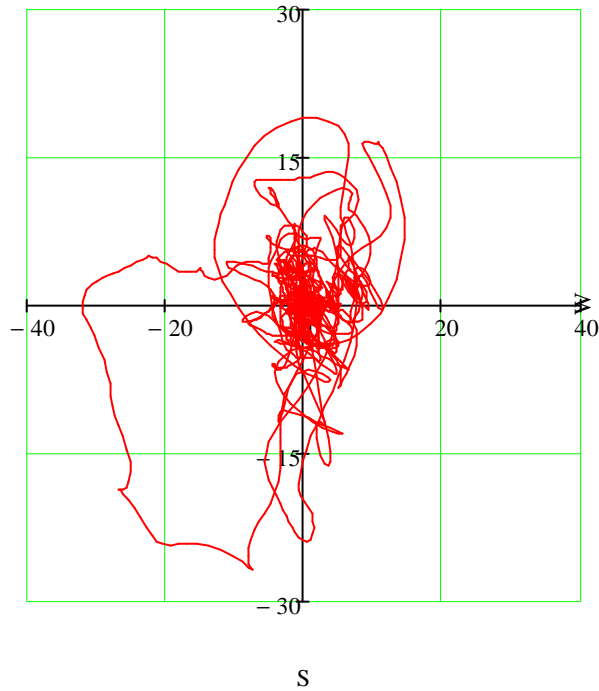


O sismo de L'Aquila



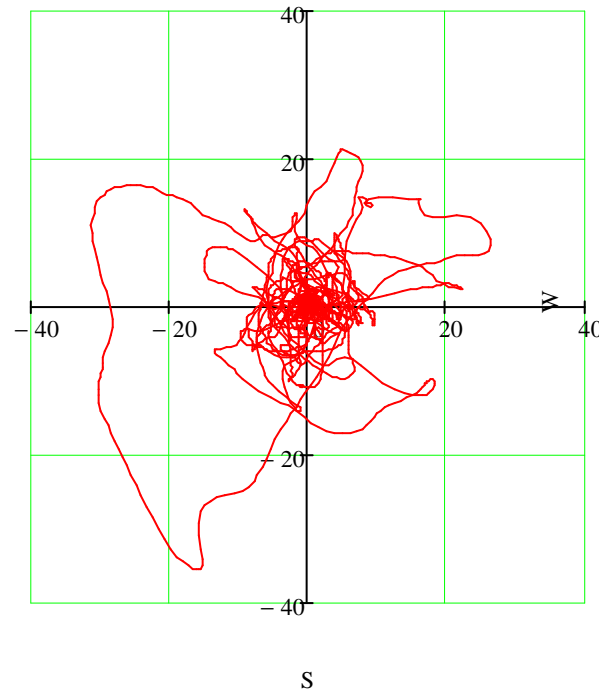
Órbitas no plano horizontal: Em velocidade

6 Abril 2009 - Aquila AQA



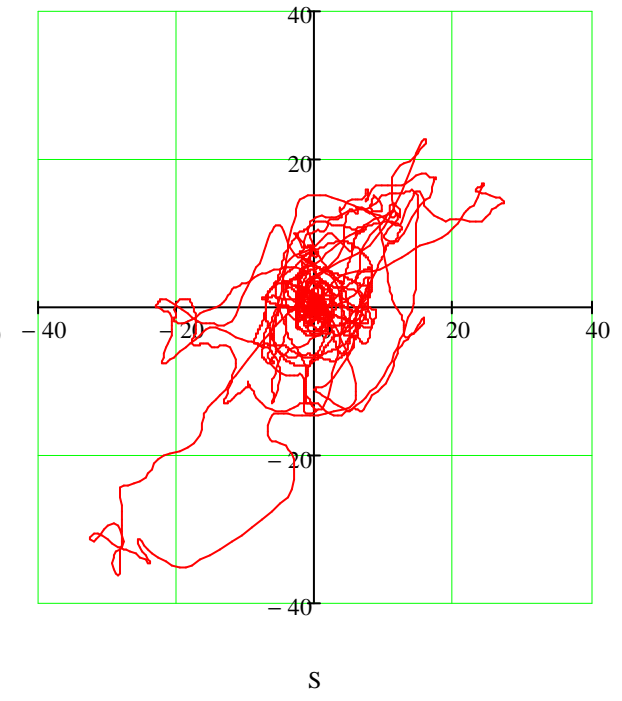
— Particle Orbits

6 Abril 2009 - Aquila AQG



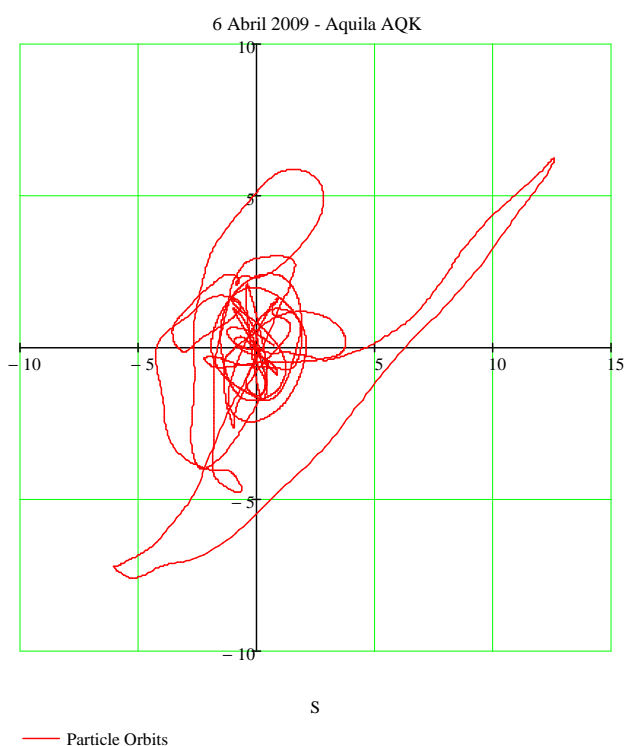
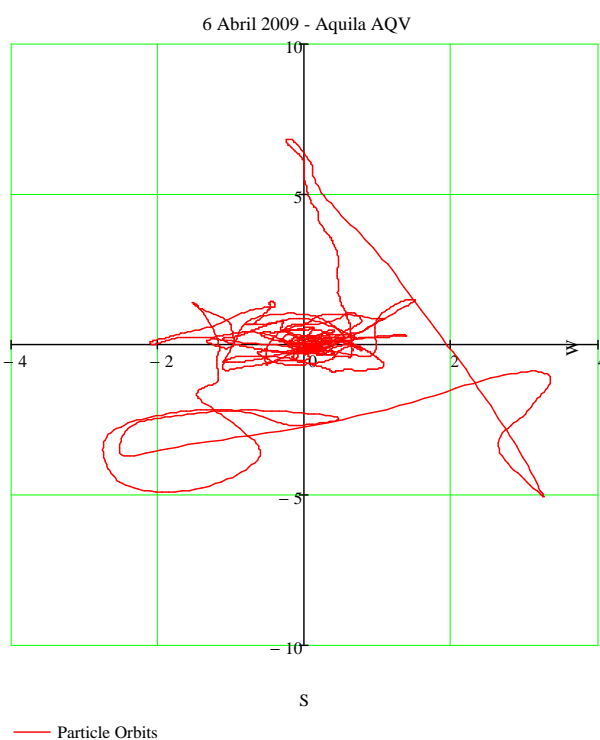
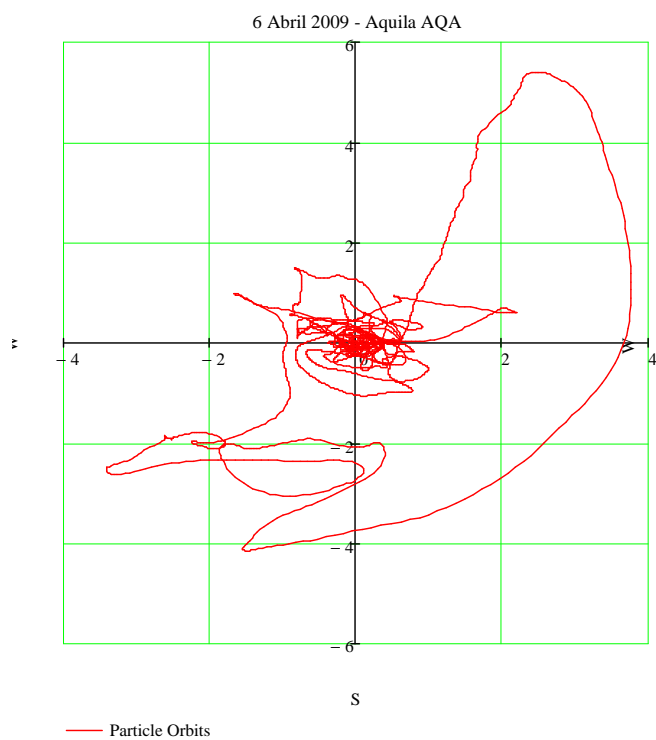
— Particle Orbits

6 Abril 2009 - Aquila AQK

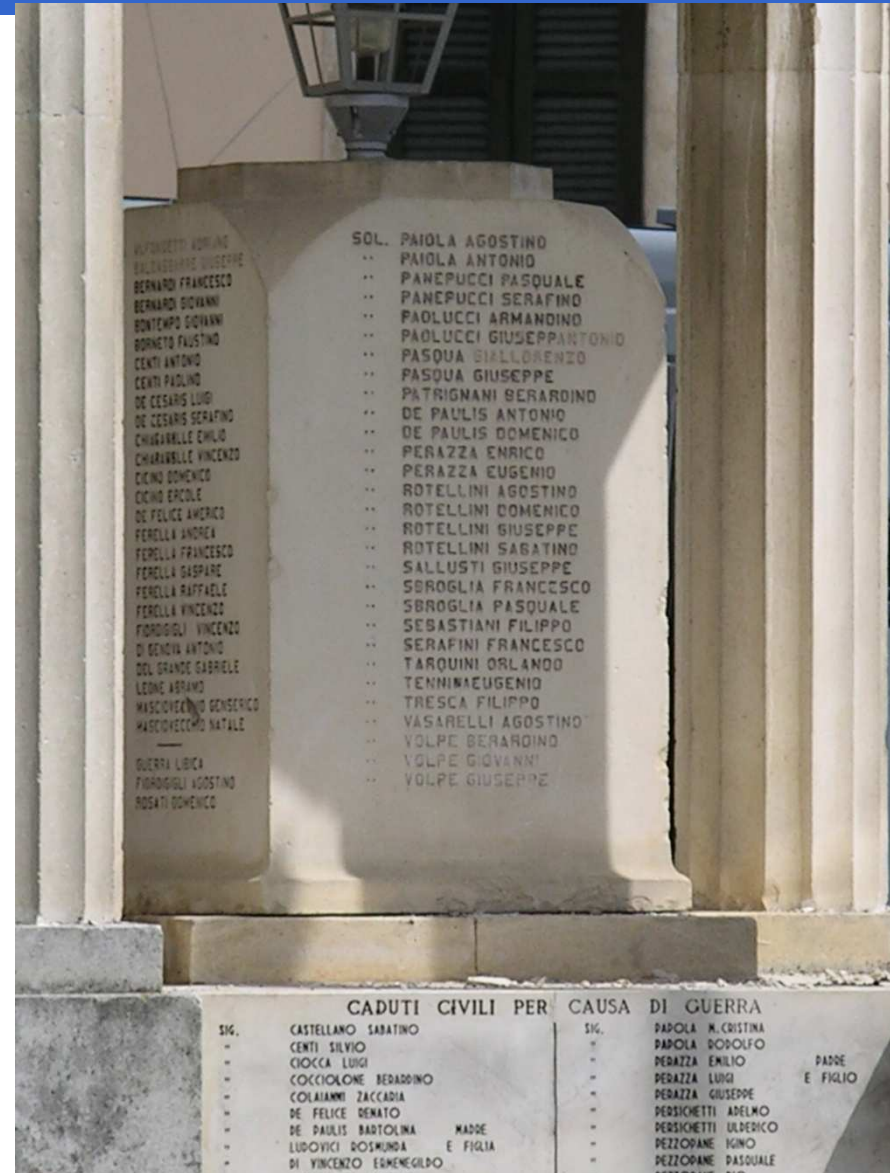


— Particle Orbits

Em deslocamento



Os Movements in given direction



- SÍNTESE DAS OBSERVAÇÕES MAIS IMPORTANTES

FONTE SÍSMICA

- Pré-Monitórios desde Novembro 2008
- Magnitude do sismo principal: $M_L=5.8$; $M_w=6.3$
- Réplicas ocorridas em sistema de falhas paralelas
- Reduzida expressão superficial da rotura
- Distribuição da rotura complexa.

FENÓMENOS ASSOCIADOS

- Roturas de pequena dimensão relacionadas com falhas associadas à falha principal

MOVIMENTO DO SOLO

- Acelerações muito fortes medidas a pequenas distâncias da falha. Domínio das altas frequências.
- Possíveis efeitos de sítio, com grandes amplificações em zonas localizadas (Onna)
- Efeitos de radiação com predominância de movimentos na direcção NNE-SSW
- Danos ao longo da falha principal

Obrigado pela atenção.