GEOLOGICAL SURVEY OF CANADA

OPEN FILE 1789

Report on field visit to damage from the magnitude 4.9, Sant'Agata Fossili, Italy, earthquake of 2003 April 11

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ABSTRACT

Damage from the Sant’Agata Fossili earthquake is described and illustrated.

RÉSUMÉ

Les dommages causés par le tremblement de terre de Sant'Agata Fossili sont décrits et illustrés.

Introduction

This earthquake happened while I was at a conference in Nice, France enroute to a seismic hazard consultation visit to Albania. On the morning following the earthquake I collected Italian newspaper reports, documenting the unusually wide area the earthquake was felt over and the unexpected amount of damage. On my return from Albania the flight schedule had already forced a 18-hour layover, so I took the opportunity to visit the epicentral region on April 16th in the hope of better understanding the final Italian reports on the earthquake and their relevance for Canada.

Logistics and Costs

The cost of the layover had been estimated at 110 Euro, for a standard Milan hotel, plus airport/hotel transfers. The field visit to Sant'Agata Fossili cost 135 Euro, 52 Euro for a cheap provincial hotel in Tortona and the remainder was the cost of the rental car, gas and road tolls for the 330 km return trip from Milan's Malpensa airport.

I picked up the rental car at 1600 on April 16th and by 1830 was in the epicentral village of Sant'Agata Fossili, with about 2 hours of light left for photography. My arrival would have been faster if I had had better maps of the region available and if the persons at gas bars had known more of their local geography (or indeed had decent local maps). Language was also a barrier as my Italian is rudimentary. Time and light precluded visiting any damage in neighbouring villages.

Regional Setting

The epicentre sits on the northern flank of the Apennine Mountains that run from the southern tip of Italy to the French border where they merge with the eastern Alps. To the north and east of the Apennines lies the Adriatic microplate, a rigid block being thrust north and east by the collision of Africa with Europe (Fig. 1). Faulting along the Apennines commonly involves normal (extensional) faulting. The earthquake occurred twenty kilometres to the east of the main road/rail corridor joining Milan to the port city of Genova port across the narrow low mountains in this part of the Apennines. Tha main Milan-Genova railway passes through Tortona and Villalvernia, the latter lying immediately to the west of the epicentral area (Fig. 2). It is almost certainly not an accident that the mountains take a sharp bend to the south (allowing the Milano-Genova transportation corridor) at this point. The Milan-Genova railway route follows the Servia River valley and marks the boundary between the flat lowland of the river valley and the hilly topography of the epicentral region to the east (Fig. 3).

Previous Earthquakes

The region around Tortona lies in one of the lowest seismic hazard zones in Italy. In historical times only four significant earthquakes are known (see Fig. 4):

- 1541 (magnitude 5.2)
- 1680 (magnitude 4.8)
- 1828 (magnitude 5.2, which caused damage to the Sant'Agata Fossili church)

- 1913 (magnitude 4.1).

Information is from the cited web page and the basis for the assigned magnitudes is not known. Microseismicity of the region is also low (Fig. 5).

The 11 April 2003 Earthquake

The earthquake occurred at 11:26 am (0926 UTC) with preliminary location at 44.78 N, 8.88 E from the Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti, Sorveglianza Sismica Roma. While the preliminary magnitude was 4.6, subsequent instrumental magnitudes of M_L= 4.7, M_L= 5.1 and Mw = 4.9 have been reported on web sites, the latter probably being the most reliable. The closest towns were: Cassano Spinola and Gavazzana at less than 3 km, and Carezzano, Castellania, Costa Vescovato, Paderna, Sant'Agata Fossili, Sardigliano, Stazzano, and Villalvernia at less than 6 km distance. The depth of the earthquake was variously reported as 3, 10, and 26 km, but eight aftershocks in following two and a half days (Table 1) had depths in the range 11-15 km, and this seems likely the correct depth. It does not seem that the mainshock was very shallow (<5 km), so this is not an explanation of the heavy damage in Sant'Agata Fossili described below. The focal mechanism indicates strike-slip on northeast or northwest trending plane (Fig. 6)

Effects of the earthquake

The earthquake was felt widely in northern Italy, from at least Turin in the west, Milan in the north, Piacenza in the east and Genoa in the south i.e. to distances exceeding 100 km. A prototype felt intensity map (Fig. 7) suggests a maximum intensity of VIII and a large area of intensity VII, as well as unwarranted intensity of VIII 100 km to the west. Actual values may be lower than these first reports. The strong shaking caused evacuation of a Tortona school, closure of Genova earthquake (distance = 45 km) for half an hour, and newspaper headlines the next day "Paura al Nord" or "fear in the north" (Fig. 8). It was certainly an unusually widely felt earthquake for the region (see above), but likely the reaction was conditioned by the November 2002 Molise earthquake of magnitude 5.4 which had recently caused collapse of a school and 27 deaths in southwestern Italy.

Emergency response

An emergency response centre had been set up near the Sant'Agata Fossili church, in an undamaged modern concrete frame structure that was due to be occupied by a clinic. Furniture and computers had been trucked in and several designated operations rooms set up (Fig. 9). A geophysicist was collecting building damage reports (Fig. 10), and at least eight uniformed Italian Army Red Cross workers were still on site.

Damage Observations in Sant'Agata Fossili

Church

Almost immediately on driving into the village I saw the church that had been figured in the newspaper articles. This church sustained light external cracking, with the heavy east frontal wall moving slightly away from the main body of the church (Fig. 11A,B). A damaged pillar or chimney visible in the immediate post-earthquake photographs (Fig. 11C) had been removed (see endnote 1). The heavy cross fell from the peak of the east wall (Fig. 12), and was still where it had fallen at the time of my visit. The tower at the rear of the church did not have visible external damage. The church was roped off and could not be visited. A web photograph suggested interior cracking and resultant damage to interior frescos (Fig. 13) (see endnote 2).

Damage to older houses

Minor damage was quite widespread, estimated at 50% of buildings. In almost all cases the visible damage represented cracked exterior plaster (Fig. 14), fallen tiles from walls (Fig. 15), and broken chimneys (Fig. 16). Most of the houses appear to be heavy stone or brick construction, perhaps with light concrete frame, but the level of plastering makes these speculations uncertain. Although some corners of some buildings were cordoned off with tape (Fig. 15) , there seemed to be little danger. Light cracking was evident from the plaster and included shear cracking related to window and door openings (Figs 17, 18), and wall separations near their joins (Fig. 19) (see endnote 3).

Industrial building

At the south end of Sant'Agata Fossili a circa 1960 industrial building used for wine production was seen. This building, approximately 40 x 15 m (estimated after the visit) consisted of precast concrete frames with concrete block infill walls (Fig. 20). No significant damage was seen, though the infill appeared to have moved slightly against the precast frame (Fig. 21).

Damage to newer house

At the operations centre (see below) I met Mrs Judith Calvi, a British expatriate who had lived in the village for 21 years. She wanted to show me her house, said to be one of the most damaged in the village. The house lay on an upper road, parallel to the main road but facing across the valley to the east - a glorious view (Fig. 22). The Calvis had had the house built in 1977/8 as a retirement home while they were in Kenya, so Mrs Calvi could not provide details of the construction. The builder has died. The house was a 2-storey structure (Fig. 23) built on a sloping lot and with a partial basement open at the rear (Fig. 24), and consisted of two living units (one of which was unoccupied at the time of the earthquake and was being remodelled). From a cursory examination the house was a brick structure with poured concrete floors and stairs. The walls were plastered and painted. The building had been "flagged" by the authorities, but I briefly entered the building with Mrs Calvi to examine the damage.

The ground floor had sustained heavy in-plane damage on the south (side) wall, evident in both exterior (Fig. 24) and interior shots (Fig. 25 and 26). Shear cracking focused on the door and window openings was evident. By contrast the east wall was less damaged (Fig. 27), and the north end of the house had the least visible cracking. Only light cracking occurred on the upper floor.

My initial assessment was that the damage was severe enough that the house would require demolition. But email discussions with Mrs Calvi indicated that repair was considered. Given the lack of displacement of the upper floor relative to the ground floor, and the lack of damage (as would have been revealed by plaster cracking, had it begun) of the upper walls, it might have been practicable to support the first floor and replace the brick walls of the ground floor. However subsequent discussions indicate that the house will be demolished (see endnote 4).

Contributors to damage

Damage from the earthquake in SAF seemed unexpectedly heavy to this Canadian seismologist, though less so to an Italian seismologist who remarked "Damage of this size (and even higher) is common in Italy for such a magnitude, unfortunately..." (M. Stucchi, stucchi@mi.ingv.it, pers comm.) (see endnote 5). The damage can not be attributed to:-

- earthquake depth - the event was not abnormally shallow.
- stronger shaking on the hanging wall of a thrust fault - the event was a strike-slip event.
- soil amplification - from the village's position on a hill, it seems likely that the average foundation conditions were probably good (i.e. "firm ground"). This does not preclude pockets of poorer material, or indeed uncompacted fill used to level sloping sites, perhaps including the Calvi house.
- dilapidated structures - both well-maintained and modern houses were damaged.

However the fact that much of the construction was of brittle masonry certainly contributed. A possible additional contributor was the long time since the last damaging earthquake, meaning firstly that poorer structures had not failed and been replaced with better ones, secondly that there was little community memory of earthquakes to drive earthquake improvements, and thirdly that the region was placed in a low seismic hazard zone and hence incurred low seismic design requirements. Speculative additional contributors were: topographic amplification of the seismic waves due to the hilltop site and amplified seismic waves caused by directivity in the rupture propagation.

Lessons for Canada

Four recent earthquakes felt in southeastern Canada can be compared to the Sant'Agata Fossili earthquake (in order of increasing moment magnitude, Mw):

Date	Earthquake	Mw	depth (km)
1999 03 16	Cote-Nord, Quebec	4.5	19
1997 11 06	Cap-Rouge, Quebec	4.5	22
2000 01 01	Kipawa, Quebec	4.7	12
2003 04 10	Sant'Agata Fossili, Italy	4.9	14?
2003 04 20	Au Sable Forks, N.Y.	5.0	11

Of the four earthquakes, the Au Sable Forks earthquake was of similar size to Sant'Agata Fossili and the other three were smaller. Damage from Au Sable Forks included failure of road embankments and cracks in masonry buildings amounting to perhaps $US 10M, with most of the damage occuring to in alluvial valleys (Seeber et al., 2002). Damage from the three Canadian earthquakes was trivial, certainly by comparison with Sant'Agata Fossili. The low damage from the Cap-Rouge earthquake (under a suburb of Quebec City) may be partly the result of its somewhat greater depth. The two main things that have contributed to the lower damage are (i) sparse population, reducing the risk that facilities are close to the epicentre and exposed to damage and (ii) less brittle construction, i.e. wood frame rather than masonry.

Acknowledgments and Endnotes

I thank Mrs Judith Calvi for showing me around her damaged home answering questions about the village and the damage by email. The following endnotes have been compiled from that correspondence (jcalvi@tiscalinet.it).

1. The pillar (called timpano in Italian) is a sort of sustaining block to the wall.

2. The church was originally built circa 1100-1200. There have been various alterations to the original building over the centuries, and after the 1828 earthquake and the roof of the nave had to be rebuilt. The current facade dates from 1930. Firemen worked from 8am-8pm one day putting a sort of harness of steel ropes round the bell tower, which is from circa 1400. Vaults in the graveyard behind the church were damaged. Some of the wall vaults' marble plaques fell off and others were buckled and damaged. The inside is very badly damaged especially the frescoes. If the earthquake had come at the same time on a Sunday there would certainly have been some deaths and injuries. It will take 600 000 euro to repair.

3. Although from the outside none of the houses look too bad about 20 houses have been rendered uninhabitable for the moment but many can be rebuilt. I am not sure how many houses will be demolished but in the place where we are living there are 10 families.

4. The west wall (front) which had light cracks has definitely worsened over the weeks. They still

say it must be demolished. We are now waiting patiently and hoping that before the autumn we may be given little wooden prefabricated houses to live in, but it is all very uncertain.

5. The amount of compensation being asked for by the village is 15 000 000 euro. If the earthquake had come at the same time on a Sunday there would certainly have been some deaths and injuries. If there are no deaths they do not seem to consider it very bad and this is probably the reason for Sig.Stucchi's comment.

Reference

Seeber, L., Kim, W-Y., Armbruster, J. Du, W-X., and Lerner-Lam, A., 2002. The 20 April 2002 Mw 5.0 earthquake near Au Sable Forks, Adirondacks, New York: A first glance at a new sequence. Seismological Research Letters 73, 480-489.

Table 1

Preliminary locations of the mainshock and aftershocks

Date ymmdd	Time hh	mm	ss	Lat	Long	Depth Km					Magnitude Ml			
3 411	9	26	58.25	44N47.50	8E53.55	3	41	0.4	2.	2.	5.1	1.8	km	S of CAREZZANO MAGGI (ALESSANDRIA)-PIEMONTE
3 411	10	28	10.61	44N44.16	8E52.94	15	34	0.3	1.	2.	2.6	1.4	km	NE of STAZZANO (ALESSANDRIA)-PIEMONTE
3 411	10	53	3.39	44N42.87	8E52.71	13	20	0.3	2.	2.	2.5	1.1	km	NW of VIGNOLE BORBERA (ALESSANDRIA)-PIEMONTE
3 411	12	2	15.63	44N44.39	8E53.14	12	27	0.3	1.	2.	2.6	1.7	km	SW of SARDIGLIANO (ALESSANDRIA)-PIEMONTE
3 412	0	13	11.45	44N45.73	8E52.48	11	44	0.5	2.	1.	3.0	1.0	km	SE of CASSANO SPINOLA (ALESSANDRIA)-PIEMONTE
3 412	0	27	29.84	44N45.88	8E53.90	15	40	0.2	1.	1.	2.5	1.3	km	N of SARDIGLIANO (ALESSANDRIA)-PIEMONTE
3 412	2	28	41.40	44N45.11	8E54.66	14	34	0.2	1.	1.	2.4	1.2	km	E of SARDIGLIANO (ALESSANDRIA)-PIEMONTE
3 412	23	28	16.68	44N46.53	8E54.42	13	25	0.2	1.	1.	2.3	1.5	km	SW of SANT'AGATA FOSS (ALESSANDRIA)-PIEMONTE
3 413	23	55	48.16	44N45.44	8E54.19	13	42	0.2	1.	1.	2.8	0.7	km	NE of SARDIGLIANO (ALESSANDRIA)-PIEMONTE

Source: Downloaded from http://www.dister.unige.it/geofisica/ on 20030418

FIGURES

Figure 1. Shaded relief map of Italy showing in cartoon fashion the approximate boundaries of the Adriatic plate, its northward movement (yellow arrow), the extension in the Apennines and compression along the northern coast of the Adriatic Sea. Location of the Sant'Agata Fossili earthquake shown by dot. Source: Alitalia flight magazine, April 2003, with annotations by the author.

Figure 2. Map of epicentral region showing Servia River at extreme left, Milan-Genoa railway passing through Villalvernia and the damaged villages near Sant'Agata Fossili (Sant'Agata Fossili is indicated by the arrow). Tortona lies just to the north of the map. Source: www.espressonline.it/ESW_articolo/ 0,2393,27361,00.html accessed 20030418

Figure 3. Top: Village of Sant'Agata Fossili viewed from the northwest. Note spire at rear of church shown in Figures 11 and 12. Bottom: village viewed from the south. Note cross pictured in Fig. 12 fell off the right-hand end of the church.

Figure 4. Seismicity of the Tortona-Genoa region. Source: web page http://www.mi.ingv.it/eq/030411/novi_sism_stor.html accessed 20030418

Figure 5. Seismicity of the Genoa region 1982-1997 from the IGG network, showing low seismicity of the Sant'Agata Fossili region (star). Source: web page http://www.dister.unige.it/geofisica/summary.html accessed 20030418.

Figure 6. The focal mechanism of the earthquake indicating strike-slip faulting on either a northeast or northwest trending plane. Source: web page http://mednet.ingv.it/events/QRCMT/030411_092656/qrcmt.html accessed 20030418

Figure 7. Experimental rapid intensity map. The high intensity to the west of the epicentre (star) is unlikely to be correct. Source: web page http://www.mi.ingv.it/eq/030411/novi_sism_stor.html accessed 20030418

Figure 8. Newspaper report from Corriere della Sera, Cronache, Sabato 12 Aprile 2003, page 19.

Figure 9. Temporary emergency response centre in Sant'Agata Fossili staffed by uniformed Italian Army Red Cross workers.

Figure 10. Geophysicist collecting building damage reports in the temporary office set up for the Servizio Sismico.

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701.htm

Figure 12. Cross fallen off top of Sant'Agata Fossili Church; compare to photograph with fireman (top right) taken soon after the earthquake. Source for newspaper photograph: web page linked from http://www.mi.ingv.it/eq/030411/info.html on 20030418.

Figure 13. Interior cracking Sant'Agata Fossili Church. Source: web page linked from http://www.mi.ingv.it/eq/030411/info.html on 20030418.

Figure 14. Cracked exterior plaster on house.

Figure 15. Tile cladding fallen off house.

Figure 16. Broken chimney covered with plastic.

Figure 17. Shear cracking related to window and door openings.

Figure 18. Shear cracking related to window openings

Figure 19. Wall separations near their join.

Figure 20 Older industrial building consisting of precast concrete frames with concrete block infill. See detail on Fig. 21.

Figure 21. Detail of near corner of Fig. 20 showing slight movement of concrete block infill against the precast frame.

Figure 22. View south from Sant'Agata Fossili, showing the hilly topography of the region.

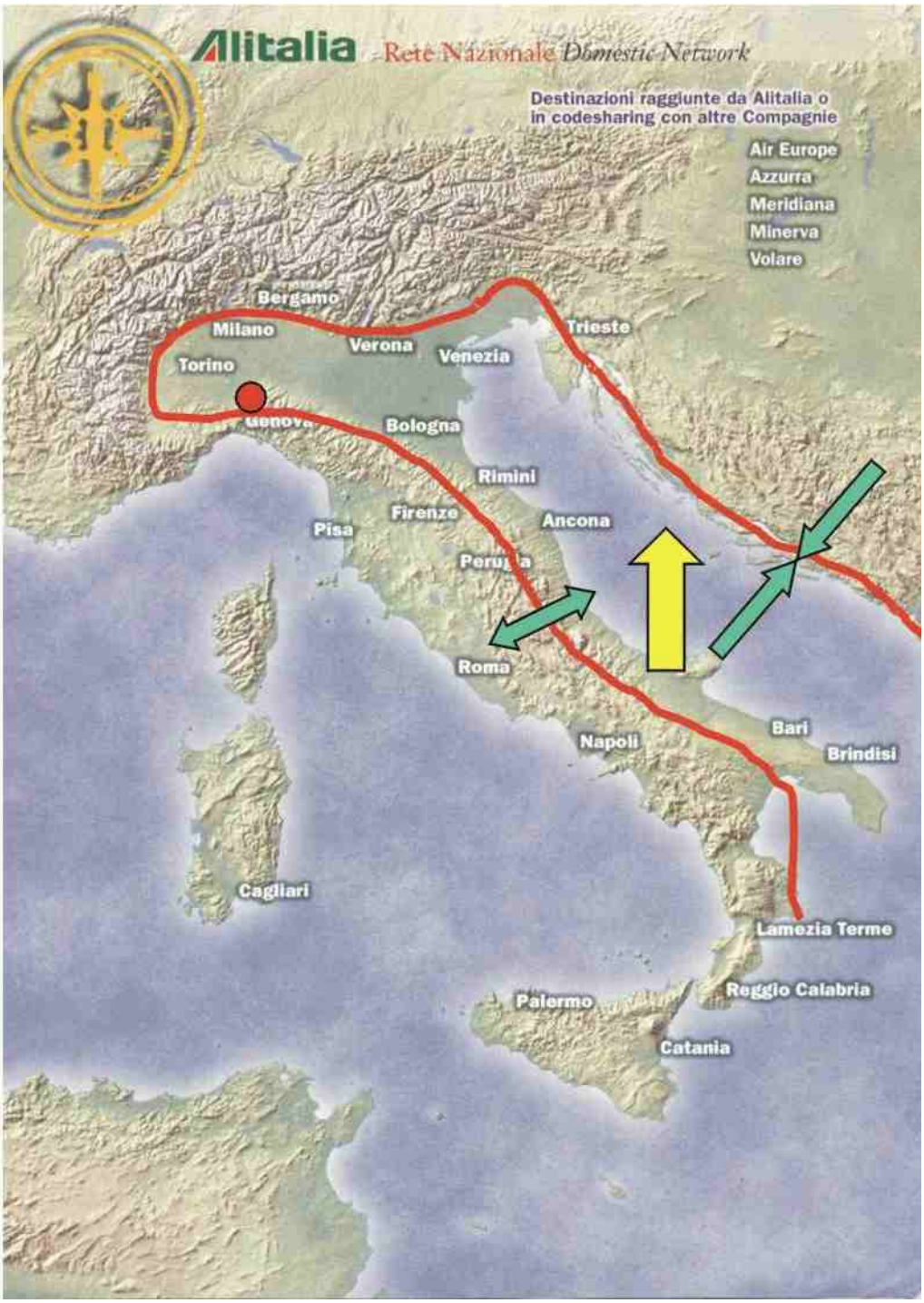
Figure 23. Front view of south side of the Calvi house. Mrs Calvi is in the foreground.

Figure 24. Exterior shot of the side of Calvi house showing partial basement and heavy in-plane damage on the south wall.

Figure 25. Heavy in-plane damage on the south wall of the Calvi house, interior view. Cracks around the window can be matched to those on left-centre of Fig 24.

Figure 26. Heavy in-plane damage on the south wall of the Calvi house, interior view. Cracks adjacent to the French door can be matched to those on right side of Fig 24.

Figure 27. Exterior and interior views of east wall of the Calvi house, showing relatively light cracking.



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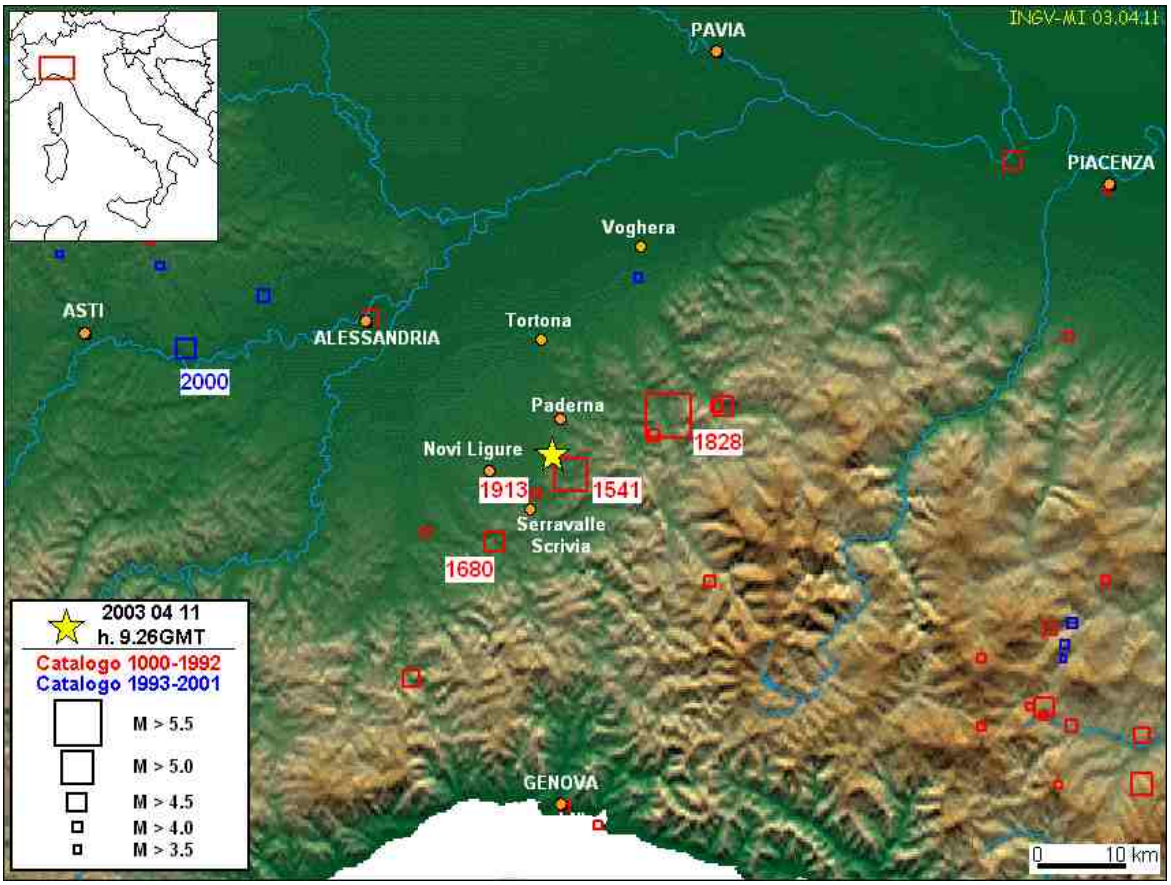


Figure 4. Seismicity of the Tortona-Genoa region. Source: web page http://www.mi.ingv.it/eq/030411/novi_sism_stor.html accessed 20030418

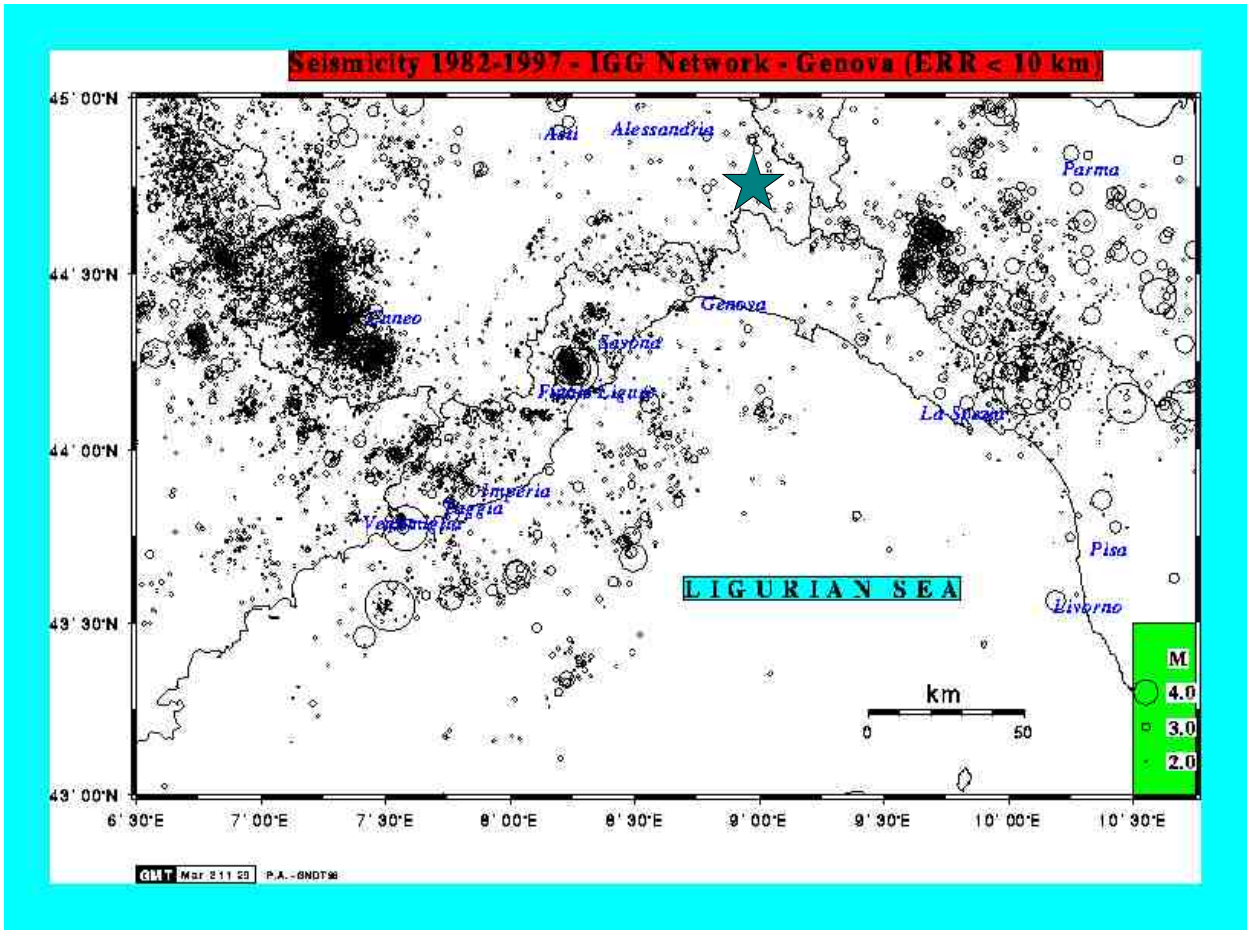


Figure 5. Seismicity of the Genoa region 1982-1997 from the IGG network, showing low seismicity of the Sant'Agata Fossili region (star). Source: web page http://www.dister.unige.it/geofisica/summary.html accessed 20030418.

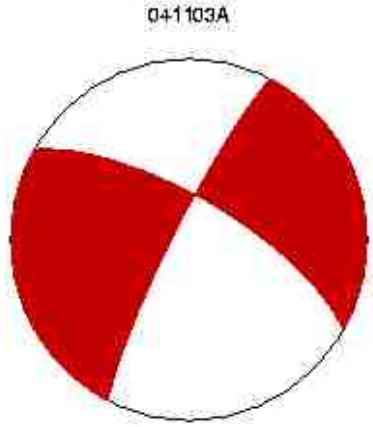
Date 04/11/03 Region NORTHERN ITALY Ml 4.7 Mw 4.9
Centroid Location:
Or. Time 9:27: 1.8 Lat. 44.68 N Long. 8.82 E Dep 26.

Best Double Couple M0: 3.0*10**23
P1 str: 300 dip: 71 slip: -172
P2 207 83 -19

Moment Tensor (10**23 dyn-cm)
mrr: -0.63 mtt: -2.12 mff: 2.75
mrt: 0.54 mrf: 0.69 mtf: -1.55

Principal Axes
T val: 3.27 plg: 8 az: 255
N -0.46 70 6
P -2.81 18 162

MEDNET & VEBSN ORFEUS DATA USED



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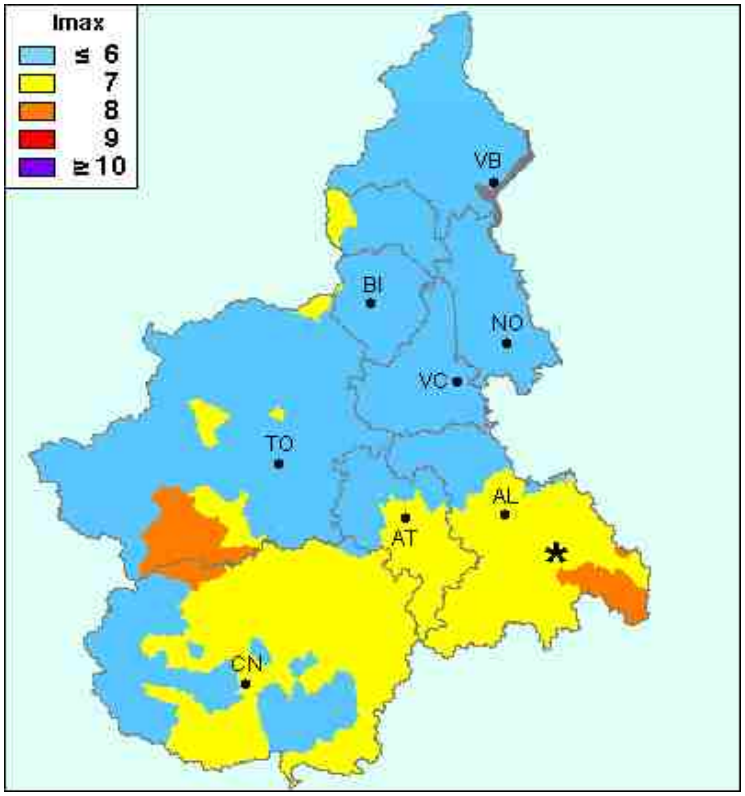

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Corriere della Sera — CRONACHE

La mappa delle scosse

Alle 11.26 di ieri una scossa del 7° grado della scala Mercalli è stata avvertita in tutto il Nord-Ovest. Epicentro a Sant'Agata Fossili

1806 — **NEL REGGIANO**
L'epicentro del sisma di ieri ricade in un'area dove nel 1806 fu avvertito un altro terremoto, del 5-6° grado della scala Mercalli, con epicentro nella provincia di Reggio Emilia

1951 — **NEL PIACENTINO**
Era il 15 maggio: un terremoto del sesto grado della scala Mercalli, con epicentro nel Piacentino e nel Cremonese, si avvertì in Piemonte, Lombardia ed Emilia Romagna

2000 — **NELL'ASTIGIANO**
Il 21 agosto una scossa d scala Mercalli provoca pa ma pochi danni, nell'Astig La scossa, come è avvenu stata avvertita in quattro r

La terra trema al Nord, paura

Epicentro in provincia di Alessandria. La scossa avvertita in Lombardia e Liguria. Chiuse

CROLLI Un vigile del fuoco osserva la croce caduta dalla chiesa di Sant'Agata Fossili, in provincia di Alessandria, durante la scossa di terremoto. Il sisma si è avvertito in tutto il Nord-Ovest

Terremoto e panico, ancora una volta, ieri mattina alle 11.26. Numerosi i feriti (di cui

LA PAURA — Forte allarme a Torino, ma anche a Milano, dove alcuni presidi hanno mandato

Un ferito grave. Centinaia di case danneggiate, pronta

ca e Vulcanologia, guidati da Enzo Boschi. Gravi le condizioni di Ivano Rossi, 40 anni,

protezione civile. «Non ci sono probabilità che l'evento si ripeta nella prossima settima-

«Ho visto
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MILANO — G
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le auto ferme an
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sa percepita so
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fossero situazio
genza. E il presi
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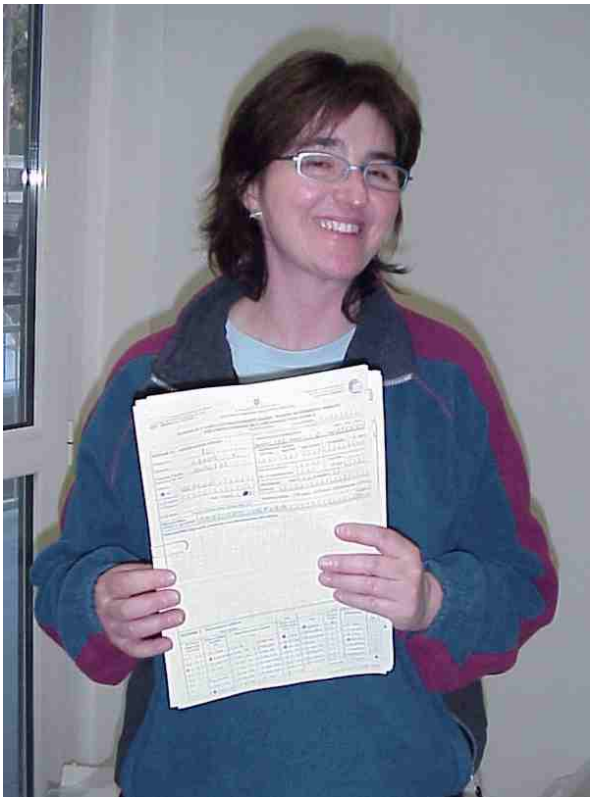

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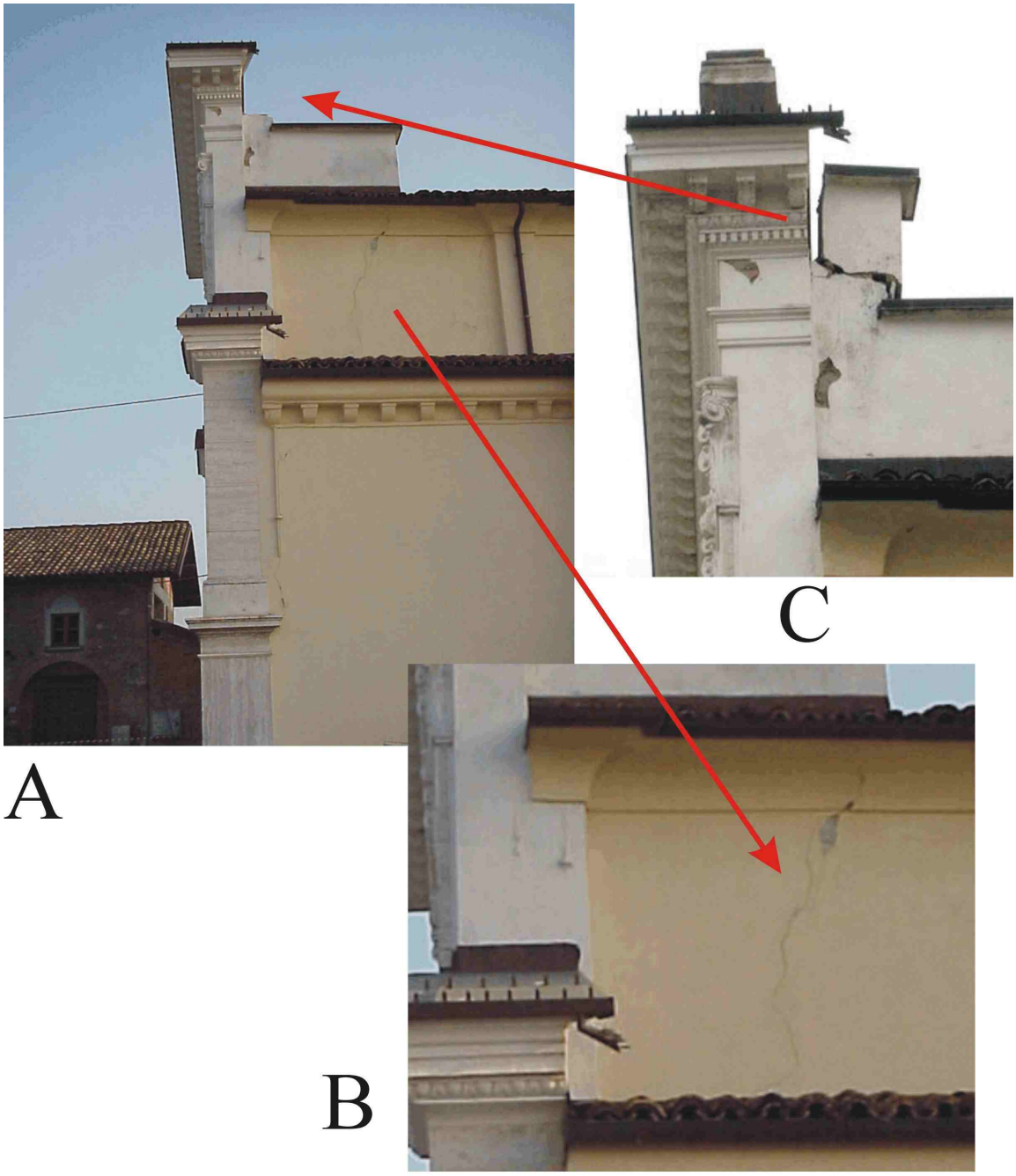

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Figure 13. Interior cracking Sant'Agata Fossili Church. Source: web page linked from http://www.mi.ingv.it/eq/030411/info.html on 20030418.

Figure 14. Cracked exterior plaster on house.

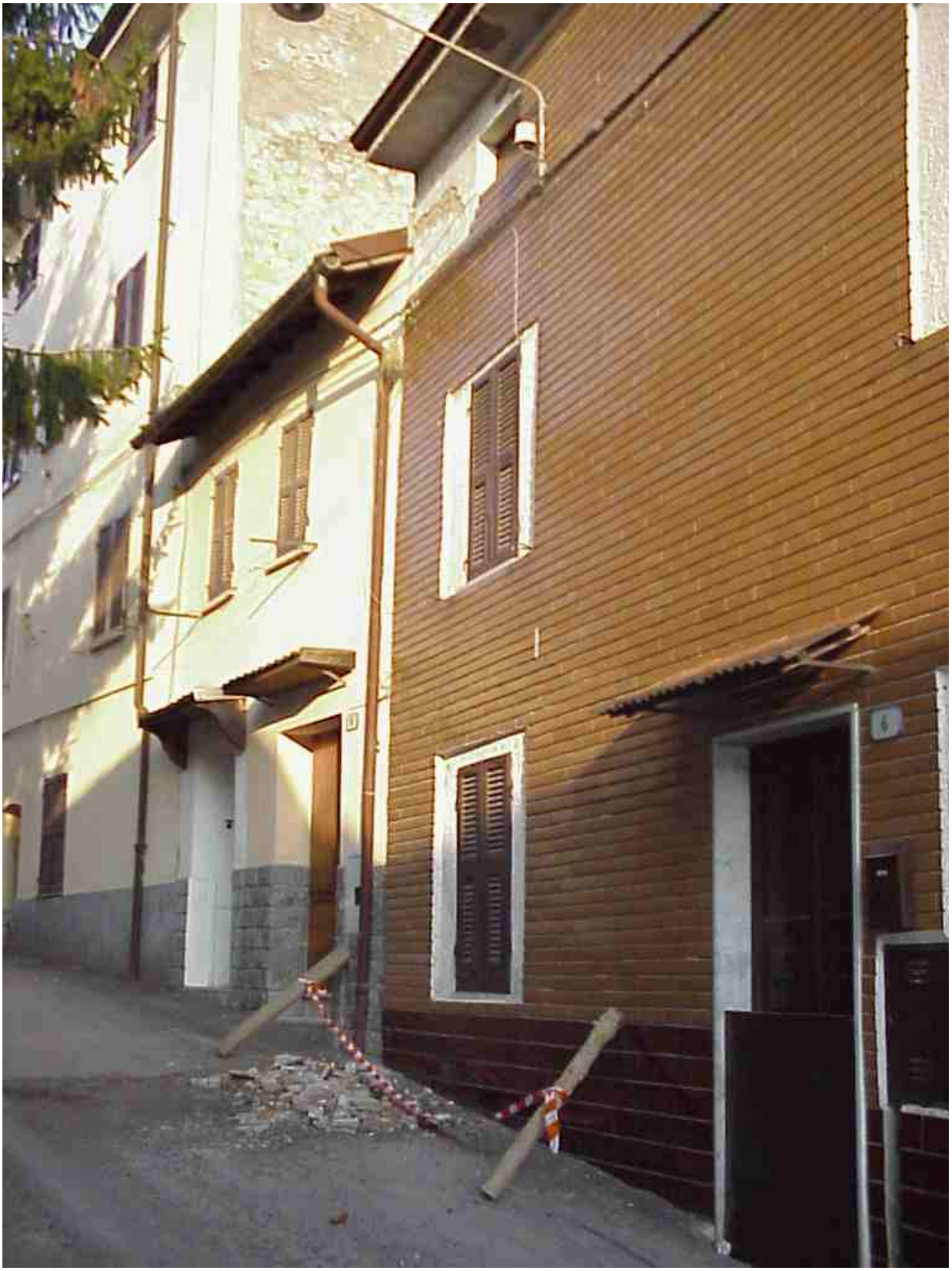

Figure 15. Tile cladding fallen off house.

Figure 16. Broken chimney covered with plastic.

Figure 17. Shear cracking related to window and door openings.

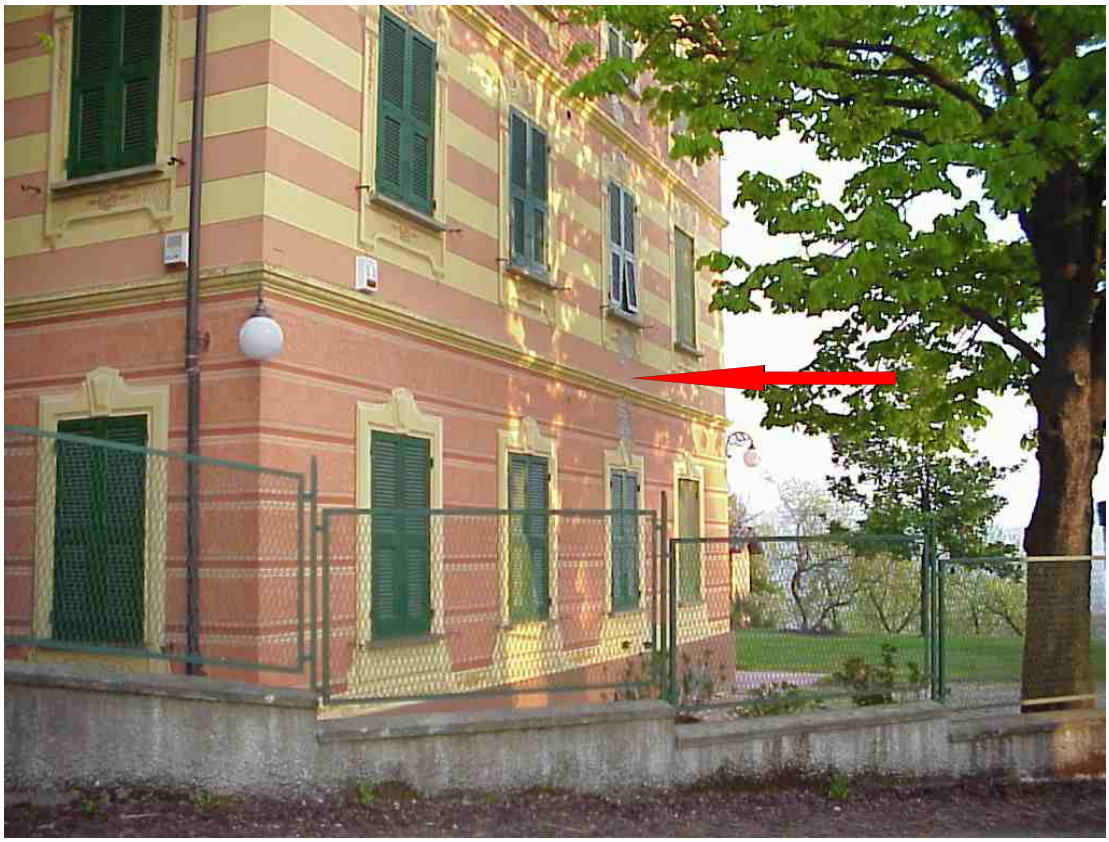

Figure 18. Shear cracking related to window openings

Figure 19. Wall separations near their join.

Figure 20 Older industrial building consisting of precast concrete frames with concrete block infill. See detail on Fig. 21.

Figure 21. Detail of near corner of Fig. 20 showing slight movement of concrete block infill against the precast frame.

Figure 22. View south from Sant'Agata Fossili, showing the hilly topography of the region.

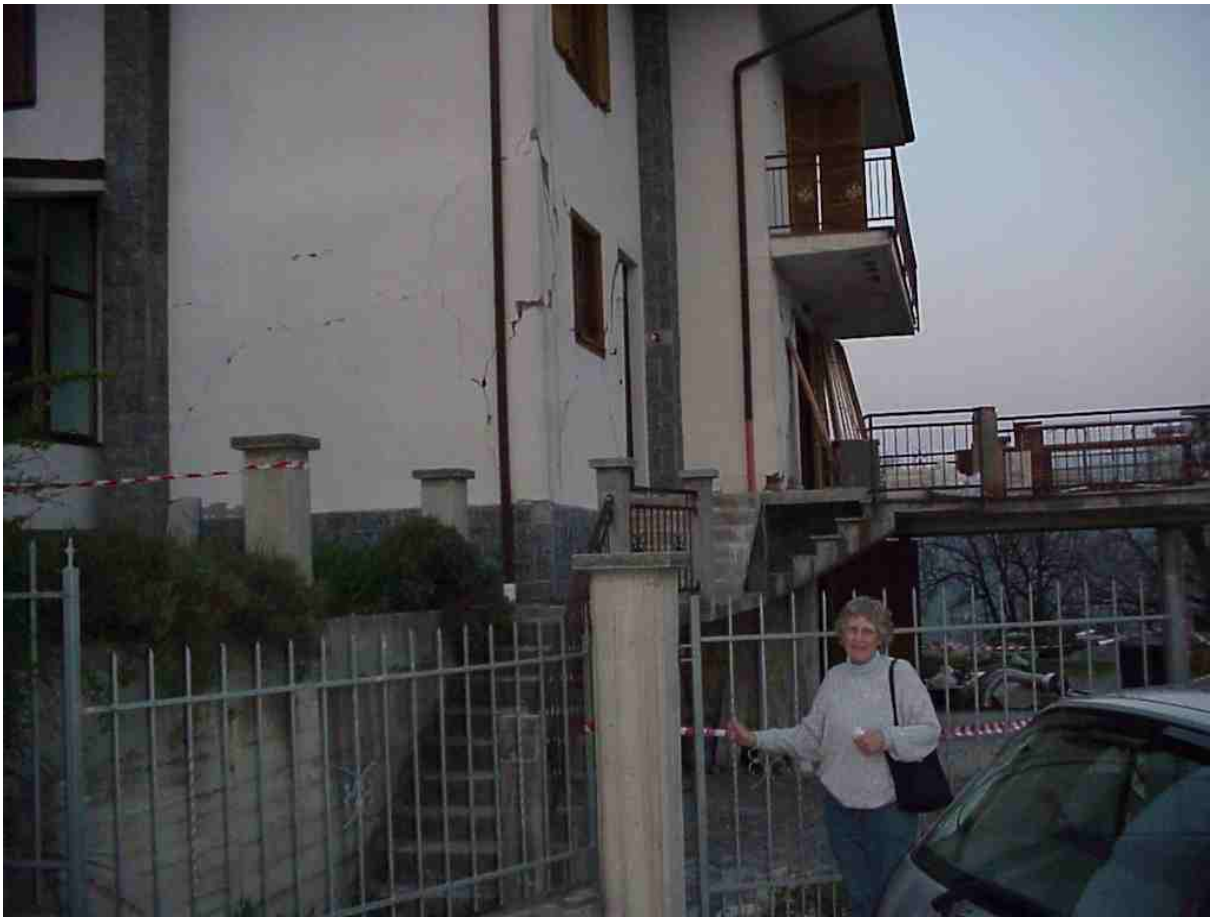

Figure 23. Front view of south side of the Calvi house. Mrs Calvi is in the foreground.

Figure 24. Exterior shot of the side of Calvi house showing partial basement and heavy in-plane damage on the south wall.

Figure 25. Heavy in-plane damage on the south wall of the Calvi house, interior view. Cracks around the window can be matched to those on left-centre of Fig 24.

Figure 26. Heavy in-plane damage on the south wall of the Calvi house, interior view. Cracks adjacent to the French door can be matched to those on right side of Fig 24.

Figure 27. Exterior and interior views of east wall of the Calvi house, showing relatively light cracking.