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The 1561 Earthquake(s) in Southern Italy: New Insights into a Complex Seismic Sequence

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In the summer of 1561, a strong seismic sequence struck southern Italy, then the Spanish-ruled Kingdom of Naples. Both the Italian seismological tradition and the latest catalogues locate it in the Vallo di Diano (Diano Valley), a low-seismicity intermontane basin 100 km south-east of Naples. We explore the hypothesis that current perception of the 1561 earthquake is distorted by the nature of the historical dataset from which its parameters have been assessed, and which mostly derive from a single—albeit very detailed—primary source. We present and discuss several previously unconsidered original accounts. Our results cast doubts on the traditional interpretation of the earthquake, which could have been either one Vallo di Diano mainshock or several strong earthquakes within a time/space window compact enough for contemporary viewers to perceive them as one. Unquestionably, there is much more to the 1561 earthquake(s) than previously appeared. We hope that this groundbreaking effort will rekindle the interest of the seismological community in this seismic episode, our knowledge of which is still far from complete.

Keywords Historical Seismicity; 1561 Earthquakes; Active Faults; Seismotectonics; Vallo di Diano; Southern Italy

1. Introduction

Peninsular Italy is one of the most tectonically and seismically active regions of the central-western Mediterranean area. Almost all the strongest seismic events along the chain (7 > M > 6) are generated by NW-SE normal faults (Fig. 1), which accommodate, on the whole, a NE-SW extension. The 1561 earthquake was located by the CPTI04 parametric catalog [CPTI Working Group, 2004] in the Tyrrhenian side of the Apennine chain (Mw = 6.4), and more precisely, in the Vallo di Diano (“Diano valley”, from an ancient name of the chief local town), where severe damage was reported by historical evidence first collected by Bonito [1691], Mercalli [1891] and Baratta [1901]. This evidence was recently reassessed for the compilation of the CFTI [Boschi *et al.*, 1995; 1997, 2000] and the NT4.1 [Camassi and Stucchi, 1997] parametric catalogs, by two independent research teams. Both studies of the 1561 earthquake [Boschi *et al.*, 1995, 2000; Camassi *et al.*, 1997, unpublished] were based on a critical revision of extant bibliography, i.e., by and large, on the same set of sources; the CPTI04 catalog adopted the parameters proposed by the published studies [Boschi *et al.*, 1995, 2000].

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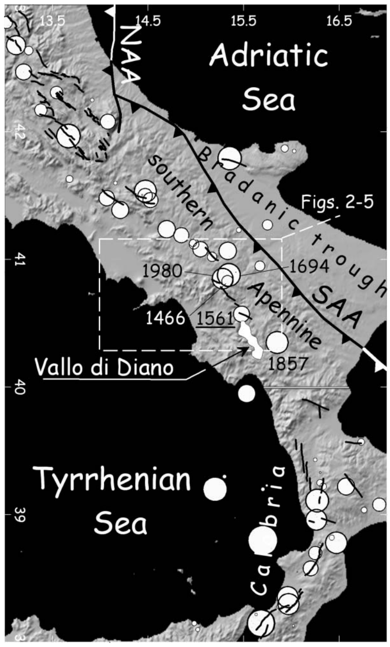

FIGURE 1 Distribution of major earthquakes (M $\geq$ 6; mod. after CPTI04) along southern Italy (black lines, primary seismogenic faults, mainly bounding intermontane Pleistocene basins; NAA, SAA, buried front of the northern and southern Apennine thrust and folds Arc, respectively). The main earthquakes in the investigated area are labeled.

The 1561 event is the only strong earthquake on record in the Diano valley, an otherwise low-seismicity area. The historical evidence responsible for its location in the Diano valley comes from a single, albeit very detailed primary source, whose depiction of the 1561 earthquake effects could be partial or biased. To test this hypothesis, independent historical evidence is required; accordingly we collected several primary historical documents which had never been previously used in investigations of the 1561 earthquake. Taking into account the seismotectonic framework of the region, we explore the hypothesis that the 1561 earthquake was actually a complex seismic sequence that involved different, although conterminous, seismogenetic structures.

2. Overview of the Seismotectonics in the Area of the 1561 Earthquake

The Apennines are a fold-and-thrust belt chain that developed as a consequence of Africa-Adria-Europe relative plate-motion. The southern sector of the Apennine chain is basically a buried duplex system of Mesozoic-Tertiary carbonate thrust sheets overlain by a thick pile of rootless nappes derived from platform and basin depositional realms [Patacca and Scandone, 1989; Cinque *et al.*, 1993]. From 0.7–0.5 My ago, the southern Apennines have been affected by a NE-SW extension [Ward, 1994], with the largest deformations, the strongest earthquakes and the greatest evidence of active normal faulting concentrated mainly along the axial belt [Pantosti and Valensise, 1990; Galli and Galadini, 2003].

Very little is known about most of the faults responsible for these earthquakes. Apart from the deep structural complexity of the inherited fold-and-thrust belt chain, the difficulties with the identification of active faults in the southern Apennines is mainly due to the high erodibility of the siliciclastic units that form the surface structure of the seismogenic belt, which does not allow the preservation of short-term, low-rate (<1 mm/yr) tectonic indicators (e.g., fault scarps). Thus, it is not by chance that the only paleoseismic investigations in this sector of the chain focus on the ~NW-SE faults that affect carbonate rocks. Among these, it is worth noting the Caggiano fault, a normal fault that partly faces the Diano valley and that was recently investigated by Galli *et al.* [2006] using three trenches, as discussed in the following paragraphs.

A number of M > 6 earthquakes have occurred in the southern Apennines over the last millennium, with the mesoseismic area of the 1561 earthquake falling between the earthquakes of 1466, 1694, 1857, and 1980 (all with Mw $\geq$ 6.5; Fig. 1). The damage areas of these earthquakes partly overlap that of the 1561 earthquake. Apart from the 1980 event, their seismogenic structures have not yet been convincingly associated with any surficial geological features.

Recent paleoseismological studies (D. Pantosti, pers. comm.) suggest that the 1466 earthquake (not reported by the CPTI04; Mw = 6.5, according to Galli *et al.*, 2006; see also Figliuolo and Marturano, 1996; Galli, 2003; Guidoboni and Comastri, 2005) could have been generated by segments of the Mount Marzano fault system, (MF in Fig. 2; Pantosti and Valensise, 1990; see Galli *et al.* 2006), which also produced the 1980 earthquake. The 1980 earthquake (Mw = 6.9; Fig. 3) occurred on a normal fault system [Westaway, 1996] comprising 3–5 N310° segments (mainshock and 20-s sub-event), and

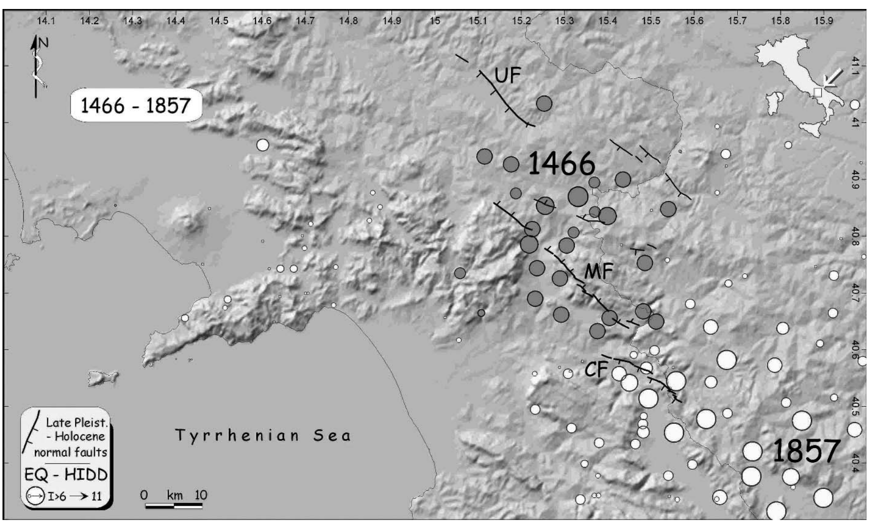

FIGURE 2 Highest intensity datapoint distribution for the 1466 (Is = 6–10 MCS; Galli *et al.*, 2006) and 1857 (Is = 6.5–11 MCS; Boschi *et al.*, 2000; partial view) earthquakes. Symbol size is proportional to site intensity (Is). Black lines are the known primary active faults (teeth on downthrown side. UF, Ufita fault; MF, Mt. Marzano fault system; CF, Caggiano fault). Galli *et al.* (2006) hypothesizes the partial rupture of the MF and CF in the 1466 and 1857 earthquakes, respectively.

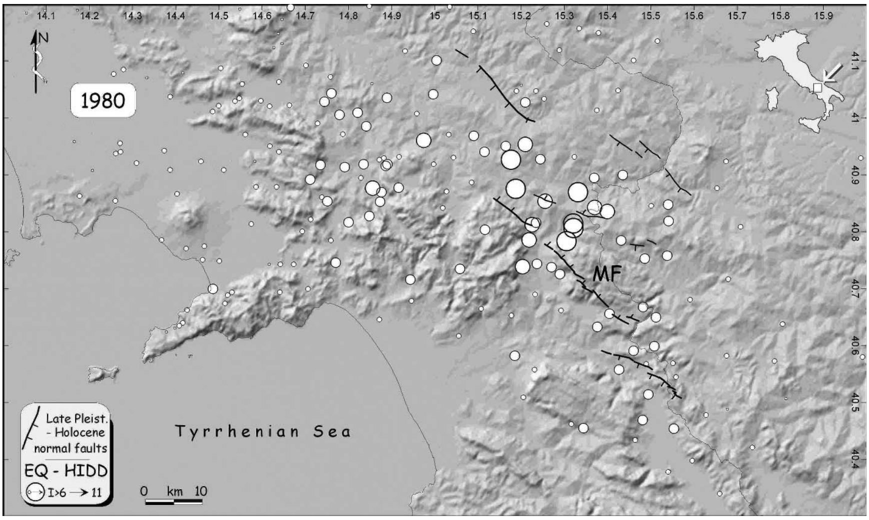

FIGURE 3 Highest intensity data points distribution for the 1980 earthquake (Is = 6.5–10.5 MCS; Monachesi and Stucchi, 1997). MF is the Mount Marzano fault system, which was responsible for the earthquake. It is worth noting that the earthquake had a NW directivity, as can be deduced by the intensity data points.

an antithetic SW-dipping fault (40-s sub-event; Bernard and Zollo, 1989). The rupture nucleated at ~10 km depth [Amato and Selvaggi, 1993], causing ~35 km of discontinuous surface faulting along the Mount Marzano Fault System [Cinque *et al.*, 1981; Westaway and Jackson, 1987; Pantosti and Valensise, 1990].

The causative fault of the 1694 Irpinian earthquake (Mw = 6.9; Fig. 4) is still not known, although the damage distribution is very similar to that of the 1980 earthquake. No surface rupture has been identified in any of the trenches dug across the Mount Marzano fault system.

A lively scientific debate is still open concerning the nature, location and trend of the structure responsible for the 1857 earthquake (Mw = 7; see Pantosti and Valensise, 1990; Benedetti *et al.*, 1998; Cello *et al.*, 2003). Two mainshocks apparently occurred within 3–4 min of each other [Baratta, 1901; Magri and Molin, 1979], causing heavy damage in the Diano and Agri valleys, with the first shock felt mainly in the northern part of this mesoseismic area [Branno *et al.*, 1983; Fig. 2].

Finally, as mentioned above, recent paleoseismological studies along the Caggiano fault structure, placed south-east of the Mount Marzano fault [Galli and Bosi, 2003; Galli *et al.*, 2006; Fig. 5], have revealed repeated surface faulting over the past 7 ky. The two most recent events are roughly datable to between the 1500s and the 1800s, AD [Fig. 5b]. The Caggiano fault was accordingly suggested as the possible causative fault for the 1561 earthquake and/or for the northernmost 1857 shock. Moreover, the existence of an active structure at depth in the Caggiano fault hanging wall was demonstrated by the January 25, 1893, earthquake. This earthquake was located between the villages of Auletta and Pertosa, both of which were seriously damaged [Fig. 5], and was felt across a vast area of southern Italy [Fig. 6]; the net NW-SE elongation of its mesoseismic area [Fig. 6] suggests fault orientation similar to that of the Caggiano fault.

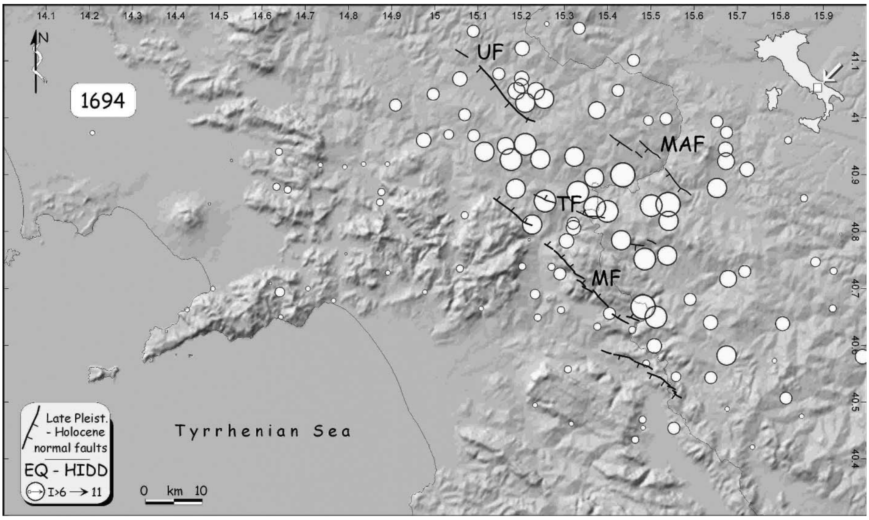

FIGURE 4 Highest intensity data points distribution for the 1694 earthquake (Is = 6.5–11; mod. after Boschi *et al.*, 2000). Black lines are the known primary active faults in the area (teeth on downthrown side. UF, Ufita fault; MF, Mount Marzano fault system; MAF, Mount Mattina-Atella fault; TF, Teora fault). The seismogenic structure of this catastrophic earthquake is still unknown. Galli *et al.* [2006] hypothesize that the rupture might have occurred along the Ufita, Teora, and Mount Mattina-Atella faults. Note that the 1694 intensity data points includes those of 1466 and 1980.

3. Why Does Pacca's Description of the 1561 Earthquake Puzzle Us?

The current view concerning the 1561 earthquake is that there were two primary shocks, on July 31 and August 19 (see Boschi *et al.*, 2000; the CPTI04 lists only the latter, being a de-clustered catalog). The July 31 event has a very poorly constrained macroseismic field, with heavy damage to the town of Buccino and no specific effects documented elsewhere, although it is said to have affected a large area. The macroseismic field of the August 19th event is better constrained: the highest intensity values occurred in the Diano valley, with severe damage reported in several sites of the Basilicata region and around (but not "in") Buccino (Fig. 7).

The August 19th dataset has been the basis for the assignment of the epicenter of this earthquake to the Diano valley (near Polla). This dataset, as with most of the 1561 historical dataset, was derived from a single source or rather from two different descriptions by a single author (Pacca, 1563; Pacca, 16th century). In this case "most" means 28 out of a total of 32 intensity data points (IDP) provided by the CFTI studies [Boschi *et al.*, 1995, 1997, 2000], and 28 out of a total of 30 IDP provided by Monachesi and Stucchi [1997; i.e., the macroseismic database for the NT4.1 catalog].

Pacca (b. 1534, d. 1587) was a Neapolitan writer and academician [Morelli, 1993; Castelli, 2003]. His first, succinct description of the 1561 earthquake is included in a narrative of occurrences in the Kingdom of Naples over the years 1557–1562, first published in 1563 as an addition to a multi-authored Istoria del Regno di Napoli (Pacca, 1563). The Istoria's original author was Pandolfo Collenuccio (d. 1504), but the work was later extended to 1586 through successive additions by Mambrino Roseo (d. 1584), Pacca himself, and Tommaso Costo (d. 1613). Owing to the vagaries of printers, Pacca's name does not appear in the main frontispiece of any of the several extant printings

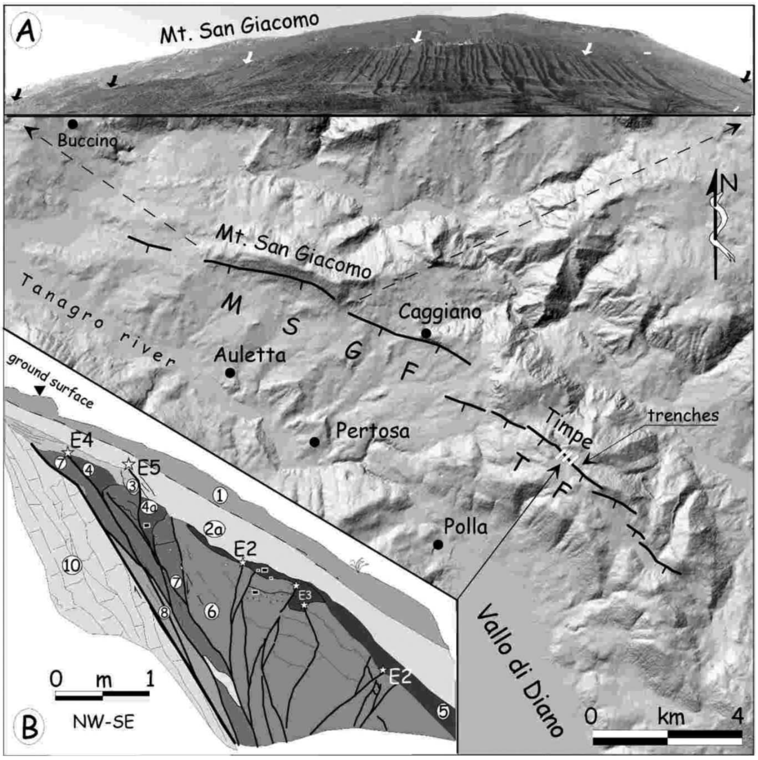

FIGURE 5 Shaded relief image of the northern Maddalena mountains, facing the Vallo di Diano. MSGF is the post-last-glacial-maximum Mount San Giacomo fault (arrows indicate bedrock fault scarp in inset A), which continues SW with the Timpe fault (TF). According to paleoseismological analyses (i.e., inset B; from Galli *et al.*, 2006), the last ruptures of this fault system (E4 and E5) occurred during/ after the Little Ice Age (1200–1800 AD), being consistent with both the 1561 and 1857 fault ruptures.

of the Istoria, but only in an easy-to-miss internal "sub-frontispiece." However, Pacca's part-authorship of the Istoria is reliably attested by later bibliographers [Soria, 1781; Minieri Riccio, 1844]. Pacca also left a longer description of the 1561 earthquake in his *Discorso del terremoto* (Pacca, 16th century), an unpublished treatise on which he worked probably to the end of his life. Giuseppe Mercalli brought it to light in 1891 when he published a selection of its descriptions of 16th century earthquakes [Mercalli, 1891].

Pacca's "short" description of the 1561 earthquake was written no later than 1563 (the year it was published), and possibly earlier, perhaps as early as late 1561. The "long" description is more detailed than the "short" one; this could mean that it relied on more extensive research and/or that it was written later, but no more precise dating is possible. What really matters, however, is that the "short" and "long" descriptions give rather different versions of the July 31 and August 19 events (Fig. 8), and we cannot know why Pacca altered his first version, and whether or not the latter should be considered more reliable than the former. The above-mentioned previous studies, which were both of a preliminary nature and part of a large-scale reviewing project, exploited as best they could the richest source readily available; considering these circumstances, a reasonable approach. Here, however, we focus on an in-depth investigation of the 1561

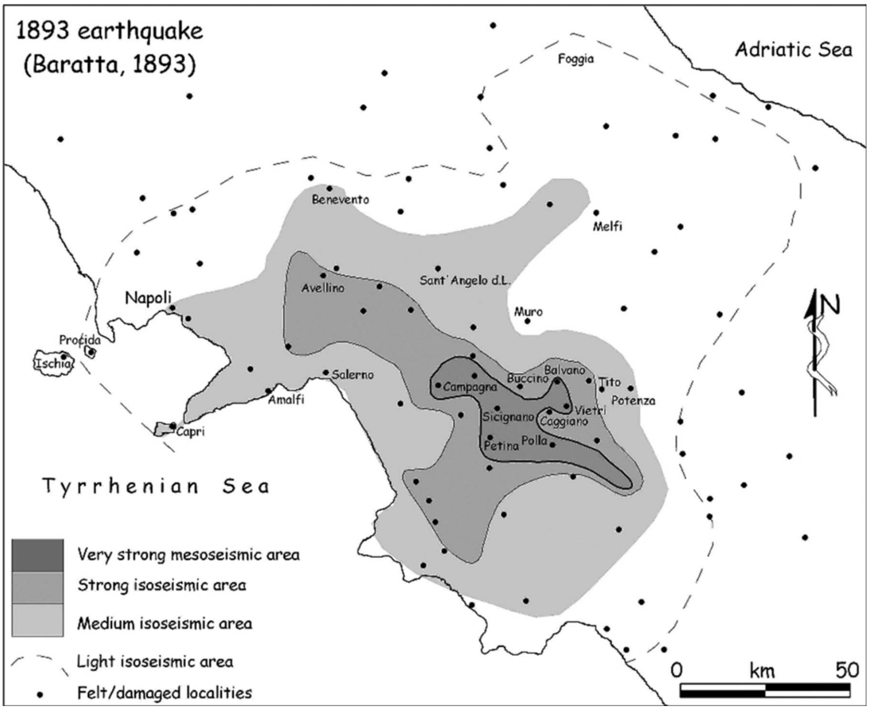

FIGURE 6 "Snap-shot" of the 1893 earthquake according to Baratta (1893, modified). The net NW-SE elongation of the "*area isosismica forte*" (strong isoseismic area, in legend) should account for the trend in the seismogenic structure. Baratta himself though that this earthquake was "probably a repetition of the one that in 1561" damaged the Basilicata region, and which was caused by the same "seismic center."

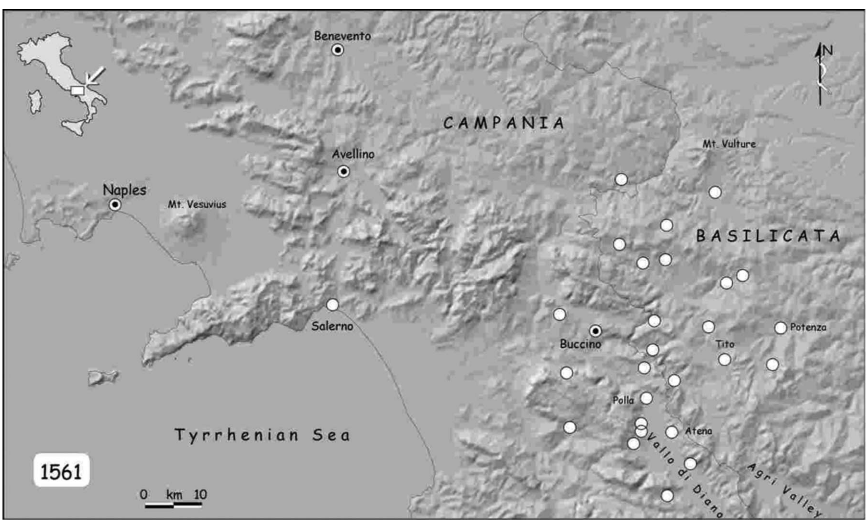

FIGURE 7 Geographic distribution of the sites affected by the 1561 earthquake (according to Boschi *et al.*, 2000): the information on most affected sites was supplied by Pacca (16th century) only. Black symbols are those reported as hit by the July 31 shock.

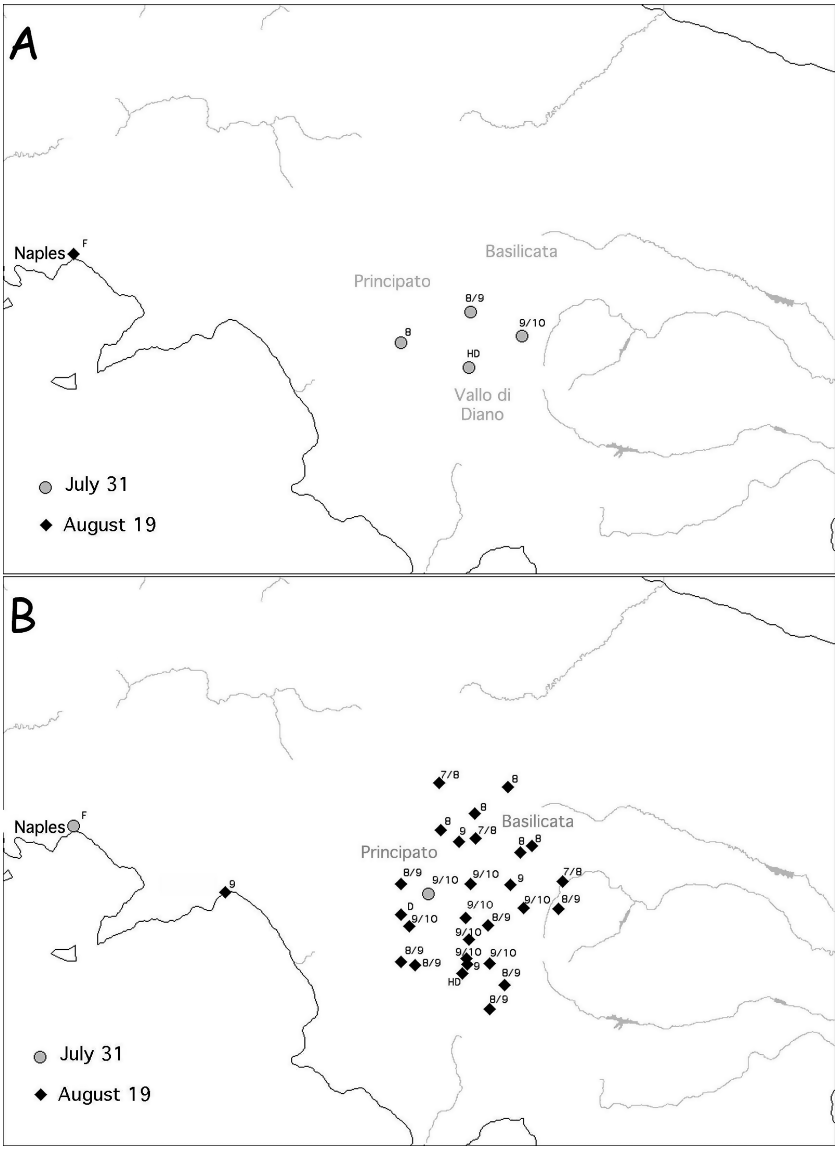

FIGURE 8 Pacca's "changing opinions." Panel A summarizes the first report of Pacca (1563; F = felt, D = damage, H = heavily), that is: (1561.07.31) Neapolitan Kingdom (F), Principato province and Basilicata province (HF/D?), Balvano, Tito, Piperno, San Licandro, Polla, Vallo di Diano area (HD). (1561.08.19): Naples (F), Principato province and Basilicata province (HD); in the above: 584 dead, 551 ruined buildings. Panel B summarize the second report of Pacca (16th century), that is: (1561.07.31) Neapolitan Kingdom (F), Principato province, Basilicata province and Terra di Lavoro province (HF/D?), Buccino (HD). (1561.08.19): Naples (F), Atella, Atena, Avigliano, Balvano, Bella, Caggiano, Calitri, Muro, Ottati, Palo, Pantoliano, Picerno, Pignola, Polla, Potenza, Sant'Angelo, Sant'Arsenio, San Fele, San Giacomo, San Licandro, San Pietro, San Ruffo, Sala, Sicignano, Tito, Vietri (D/HD).

earthquake, including consideration of several original accounts that had never been taken into account before this study.

4. Looking for New Evidence about the 1561 Earthquake

Our search for original accounts of the 1561 earthquake was a "no-budget," expeditious one. Accordingly, we pooled together the findings of a few previous studies [Galli, 2003; Castelli 2003] and those by an ongoing study of 16th century newsletters (details in Camassi and Castelli, 2004; Castelli and Camassi, 2005). The resulting set of sources includes newsletters, notarial records, private memoirs, epigraphic sources, and historiographical materials, the earliest of which were written no later than August 9, 1561, and the latest in the second half of the 17th century (Table 1). It must be stressed that—given the preliminary nature of the study—we purposely did not attempt to assay either of the main documentary complexes available for the history of southern Italy in the 16th century, namely the Archivio di Stato of Naples and the Archivo General of Simancas (Spain). Obviously, no study of the 1561 earthquake could aspire to call itself complete while these two tremendous record depositories remain unexplored. We hope that our present attempt will rekindle interest in the 1561 earthquake, and that an adequately funded concerted effort can be set in motion.

4.1. Newsletters

Records 2, 3, and 6 of Table 1 are from newsletters (*Avvisi*), a typical 16th century source. They were produced in many European towns by professional "intelligencers" who collected the latest news from a mix of official and occasional sources and sent it to subscribing customers. *Avvisi* writers relied heavily on hearsay and their work needs to be carefully scrutinized to weed out mistakes, misspellings, and outright lies. On the whole, however, *Avvisi* are a valuable source of information and well worth the effort needed.

Newsletters 2 (BAV, 1561a) and 3 (ASMo, 1561) of Table 1 are especially interesting because they shed new light on the July 31 event. Newsletter 2 (written in Rome on August 9, 1561, based on "news from Naples") describes an undated shock (which must be that of July 31) as causing damage to "houses and palaces." The buildings named are the Duomo (Cathedral), the St Lorenzo, and St Agostino churches, and the nunnery of St Maria Regina Coeli, whose inmates had to seek shelter elsewhere (a detail which appears confirmed by Ceva Grimaldi, 1857, for the nunnery). According to the previously available dataset, the 1561 earthquake shocks did not cause any damage in Naples.

Newsletter 3 (written in Naples on August 9, 1561) gives a list of localities outside Naples that were damaged by the July 31 event. Some are individually named and easily identifiable, and there is reference to "four 'castles' (i.e., walled urban settlements) belonging to Signor Bernabò Caracciolo." The Neapolitan nobleman bearing this name in 1561 was the Lord of four villages/small towns: Balvano, Sicignano, Ricigliano, and Pietramala [Shamà and Dominici Battelli, 2003]. It thus appears reasonable to identify them as the "*quattro castelli*" (four castles) of the *Avviso*. Balvano, Sicignano, and Ricigliano are among the sites cited by Pacca (16th century) as damaged by the event of August 19. If our identification is acceptable, this would backdate the earliest instance of damage in Balvano, Sicignano, and Ricigliano to July 31. Unfortunately, we have been unable to identify "Pietramala." There is a Pietramala in Tuscany and a former Pietramala, now Cleto, in Calabria, but neither appear likely to have been affected by the 1561 earthquake.

TABLE 1 Original records for the 1561 earthquake available to date. 1–24: written from August 1561 to ~100 years after; 25–27: written more than 100 years after 1561; A-B: records possibly dealing with earthquake effects without explicitly mentioning them

No	Type	Date written	Place written	Source	Quoted localities	Availability
1	Notarized deposition	August 1561?	Atripalda	Eyewitness account (Notary De Masi)	Atripalda	Original MS
2	Newsletter	Aug 9, 1561	Rome	News from Naples	Naples	Original MS
3	Newsletter	Aug 9, 1561	Naples	News from the provinces	Naples, Nocera, Cava, Polla, Torella, Buccino, Sicignano and *"four castles belonging to Bernabò Caracciolo"*	Original MS
4	Notarial deed	Aug 12, 1561	Buccino	Notary Anguillara	Buccino	Original MS
5	Private journal	Aug 22, 1561	Trento	News from Salerno	Salerno	Original MS
6	Newsletter	Sept 6, 1561	Rome	News from Naples	Basilicata, Salerno	Original MS
7	Notarial deed	Sept 1561	Buccino	Notary De Tisbia	Buccino	Original MS
8	Notarial deed	October 7, 1561	Buccino	Notary De Tisbia	Buccino	Original MS
9	Memorandum	end 1561	Atena Lucana	Notary Sabuto	Atena Lucana, Auletta, Buccino, Caggiano, ettina, Polla, Sant'Arsenio, San Pietro, Tito, Vietri (Vietri di Potenza)	Original MS
10	Chronicle	1561?	Naples?	Notary Castaldo	Naples ?	Printed (Castaldo, 16th c.)
11	Memorandum	1561? (transcr. 1635)	*Benevento*	Anonymous	Benevento	Printed (Vipera, 1635)
12	Memorandum	1561? (transcr. 1656)	*Avellino*	Notary Paulella	Avellino	Printed (Bella Bona, 1656)
13	Memorandum	1561?	*Naples?*	Eyewitness account?	Buccino	Printed (Raimo and Raimo, 16th c.)
A	*Epigraph*	*1561?*	Viggiano	*Anonymous*	*None (earthquake not mentioned)*	*Original inscription*

(*Continued*)

TABLE 1 (*Continued*)

No	Type	Date written	Place written	Source	Quoted localities	Availability
14	Chronicle	before 1563	Naples	Pacca	Balvano, Picerno, Polla, San Licandro, Tito	Printed (Pacca, 1563)
15	Treatise	before 1564	Solofra	Maffei	Solofra	Printed (Maffei, 1564)
16	Treatise	before 1574	Naples	Pacca	Atella, Atena Lucana, Avigliano, Balvano, Bella, Caggiano,Calitri, Muro, Naples, Ottati, Palo, Pantoliano, Picerno, Pignola, Polla, Potenza, Sant'Angelo de la Fratta, Sant'Arsenio, San Fele, San Giacomo, San Licandro, San Pietro, San Ruffo, Sala,Sicignano, Tito, Vietri (Vietri sul Mare)	Original MS Pacca (16th cent.)
17	Epigraph	1568	Tito	Anonymous	Tito	Original
18	Epigraph (fragm.)	before 1580	Sant'Angelo dei Lombardi	Anonymous	*Sant'Angelo dei Lombardi*	Original
19	Chronicle	~1586	Atena Lucana	Anonymous	Atena Lucana	Original MS
20	*Chronicle*	~1586	Auletta	Anonymous	Auletta	Original MS
21	Chronicle	~1586	Buccino	Bardario	Buccino	Original MS
22	Chronicle	~1586	Polla	Anonymous	Polla	Original MS
23	Epigraph	1590	Polla	Anonymous	Polla	Original
B	*Epigraph*	*before 1599*	*Torrella dei Lombardi*	*Anonymous*	None (earthquake not mentioned)	*Original*
24	Epigraph	before 1601	Sant'Angelo dei Lombardi	Anonymous	*Sant'Angelo dei Lombardi*	Original
25	Chronicle	before 1691	Conza	Castellano	Buccino, Santomenna	Original MS
26	Epigraph	1779	Sant'Angelo dei Lombardi	Anonymous	*Sant'Angelo dei Lombardi*	Original
27	Epigraph	1867	Buccino	Anonymous	*Buccino*	Original

Newsletter 6 (BAV, 1561b) was written in Rome on September 9, 1561, and was based on "news from Naples." This account simply states that "the earthquake does not cease to cause ruins in Basilicata" (a probable reference to the August 19 event, that according to Pacca (16th century) damaged several localities in Basilicata) and that "many houses collapsed in Salerno," which is midway between Naples and the Diano valley. Judging from the private journal of the Bishop of Salerno, who in 1561 was away from his Diocese but did keep in regular touch, this last piece of news could be exaggerated. The Bishop's journal is discussed at more length below.

4.2. Notarial Records

Italian notaries are officers who are authorized to perform legal formalities, such as drawing up contracts and deeds, and certifying their correctness and conformity to law. There are many situations in which notarial records can double up as accounts of earthquakes: for instance, if a notary was called to prepare a contract concerning business related to an earthquake, such as the restoration of a damaged building, or if the notary used an earthquake as a chronological reference. Notaries also sometimes chose to fill a blank space in their notebook with the account of an earthquake they had personally witnessed or heard about. Table 1 includes examples of all of these instances. Record 1 of Table 1 is an eyewitness notarized deposition that gave a description of the July 31 event as it was felt by a group of people in the village square in Atripalda (ASAv, 1561); records 4, 7, and 8 mention single damaged buildings in Buccino (ASSa, 1561a-b); record 9 (ASSa, 1561c) is a memorandum that was probably written towards the end of 1561, by a notary of Atena Lucana (Diano valley) who described the earthquake sequence from its start on July 31, 1561, continuing to August 19, 1561 and on to the end of that year; this notary listed the localities damaged by the July 31 event, adding that the August 19 event increased the damage to all of the previously mentioned sites.

4.3. Private Memoirs and Historical Chronicles

The earliest available private account of the 1561 earthquake is an entry in the journal of the Archbishop of Salerno (Seripando, 16th century). The Prelate was then in Trento (northern Italy), attending the ongoing ecumenical Council, but he kept in regular touch with the Salerno Diocese by post. On August 22, 1561, Archbishop Seripando recorded having just received news of an earthquake that had been felt recently in Salerno (on an unspecified day) and the collapse of a palace that occurred eight days later. The inland distance between Trento and Salerno is about 1,000 km; so assuming a daily cover of ~100 km for a fast courier on horseback, it would have taken at least a dozen days for this news to reach Trento. Therefore, the earthquake recorded in Seripando's journal must be either the July 31 event or another shock that occurred before August 19. A couple of shocks were recorded as felt in Avellino at the beginning of August 1561 by Bella Bona (1656), a local historian that extracted this detail from a notarial memorandum for which the original is now lost. A few more felt accounts of the 1561 earthquake were almost certainly written down by direct witnesses in Naples, Solofra, Benevento, and Avellino, although their precise dates of compilation cannot be ascertained; these accounts were included in books that were printed from a few years to a century after 1561 (Castaldo, 16th century, Maffei, 1564; Vipera, 1635).

4.4. Epigraphic Records

Galli [2003] gives detailed information on epigraphic and archaeological evidence connected/likely to be connected with the 1561 earthquake. Here we give a brief summary of it (Fig. 9).

4.4.1. Epigraphs explicitly mentioning an "earthquake" (dated in/ around "1561" or undated). **Tito**. A door lintel salvaged from a church destroyed in the 1980 earthquake bears an inscription attesting that the church had already collapsed in the earthquake of July 31 "1560" (Fig. 9a; Laurenzana, 1989). This is certainly a mistake of the carver, as Pacca (16th century) lists Tito among the sites damaged by the August 19, 1561 event. This record allows to backdate the start of damage in Tito to July 31, as confirmed by ASSa (1561c) too.

Polla. On the façade of the Villano palace, a 1590 inscription records the completed restoration of the town, previously destroyed by an undated earthquake (Fig. 9b). This is likely to be the 1561 earthquake, as Pacca (1563; 16th century) list Polla among the affected localities.

Sant'Angelo dei Lombardi. In the Franciscan convent, a 1779 inscription records its destruction by an undated earthquake and subsequent reconstruction by Felice Peretti, the local *Regens studiorum* (Head of Studies) and later Pope Sixtus V (1585–1590). Peretti,

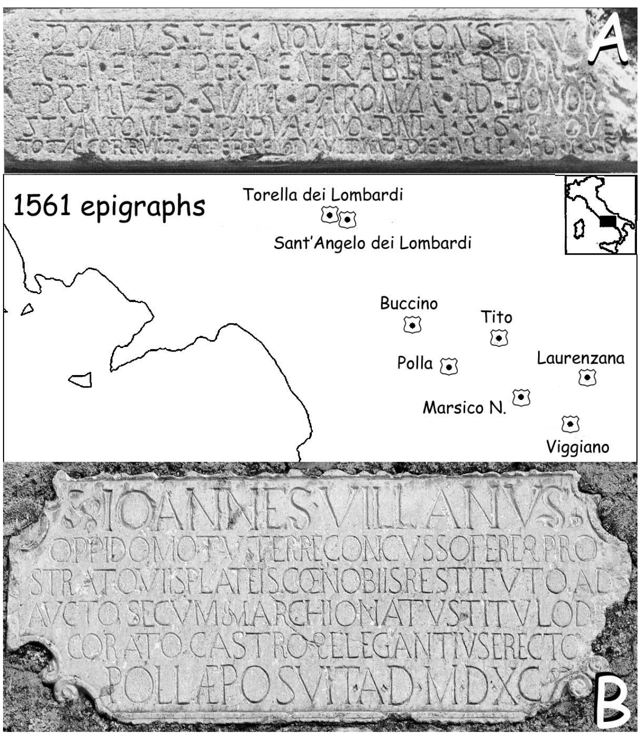

FIGURE 9 Location of epigraphic evidence certainly or possibly connected to the 1561 earthquake (Galli, 2003). A, Tito, (formerly in the local Congrega). Note in the last row: "tota corruit a terremotu ultimo die 1560" (i.e., mistake for 1561). B, Polla; front of Palazzo Villani. Note in the 2nd row: "oppido motu terre concusso …," and in the last: "… AD MDXC" (i.e., 1590, meaning that they took 30 years to restore the castle!).

who was never actually *Regens studiorum* in Sant'Angelo dei Lombardi, was nonetheless the General Superior of the Franciscan Order in 1566–1568. In that capacity, he personally inspected several Franciscan houses of the Kingdom of Naples and could have ordered the restoration (I.L. Gatti, personal communication). If things went really so, the earthquake involved could have been that of 1561.

Buccino. On the façade of St. Maria Soldicta (a church destroyed in the 1980 earthquake), a 19th century inscription mentions the 1561 and 1857 earthquakes as responsible for previous collapses of the building. Recent archaeological findings in the mediaeval castle [Galli, 2003] reveal a collapse of the drawbridge machinery room, dated *circa* mid-16th century (from shards of pottery found sealed under the rubble, A. Lagi, pers. comm.) and possibly related to the 1561 earthquake.

4.4.2. Epigraphs not explicitly mentioning an earthquake. **Viggiano**. In the church of St Benedetto, the date "1561" is carved on a door lintel. None of the available sources mention Viggiano as involved in the 1561 earthquake.

Laurenzana. On the façade of the St. Maria church, an inscription records the 1583 restoration of the building, then near collapse for unspecified causes.

Marsico Nuovo. On the façade of the St. Gianuario church, an inscription records the 1591 restoration of the building.

Torella dei Lombardi. An inscription on a bell in the St. Maria del Perillo church records that it was recast in 1599 after having crashed to the ground on an unspecified date between 1553 and 1599. This episode hints at a collapse of the bell-tower, for which the 1561 earthquake could have been responsible; ASMo (1561) lists Torella dei L. among the places affected by the July 31, 1561, event.

5. Using the New Dataset to Piece Together the 1561 Seismic Sequence

The new dataset includes several original sources that can be used to piece out the extension of the macroseismic fields of the July 31 and August 19 events, and a few intermediate shocks. According to the new dataset, the July 31 macroseismic field looks like the one described by Pacca (1563), rather than the one by Pacca (16th century). The resulting image is consistent with the hypothesis of an "Irpinian" earthquake that was strong enough to cause some damage in Naples, and severe damage in Basilicata and as far as the Diano valley. As for the August 19 event, the only available detailed description of its effects remains that of Pacca (16th century). Other sources either simply note that the July 31 event was followed by further shocks (undated), or at most that on August 19 *"further damage"* occurred in the same area that had already affected by the July 31 event (ASSa, 1561a; Pacca, 1563). However, the description by Pacca (16th century) is too detailed for the August 19 event to be dismissed as a mere aftershock of an "Irpinian" earthquake. All the more so as there is unquestionably some evidence of seismic activity in the Diano valley in 1561; ASSa (1561c): a memorandum by a local notary, mentions tremors that were felt, possibly in Atena Lucana and its surroundings, until the end of 1561; Pacca (16th century) records minor seismic events in the Diano Valley in 1562 and 1563. The shock of August 19, 1561, could thus have triggered a local seismic sequence in the Diano Valley, in an area already afflicted by the non local earthquake of July 31. The combined effect could have appeared to be a major catastrophe to the *"trustworthy witnesses"* mentioned by Pacca (16th century).

Examining the 1561 damage distribution from a strictly geographical point of view (i.e., without consideration of the timing of events that caused damage), one notes a concentration of high intensities around Vietri sul Mare[1] (Is = IX MCS). Pacca (16th century) listed a "Vietri" among the localities affected by the August 19, 1561 event, explicitly explaining that it was "a castle positioned between Amalfi and Salerno" (i.e., Vietri sul Mare). However, all other localities which Pacca mentioned side by side with "Vietri" are placed well within the Apennines, some even quite close to present-day Vietri di Potenza. Remarking on this point, all past studies of the 1561 earthquake—from Mercalli [1891], to Boschi *et al.* [2000], to Castelli [2003]—assumed that Pacca must have made a mistake and that he really meant to cite "Vietri di Potenza", rather than "Vietri sul Mare." This was a justifiable assumption, on the basis of the then available evidence but the availability of a wider set of original accounts leads us to a new assessment of the "Vietri vs Vietri" question. On one hand, the involvement of Vietri di Potenza in the 1561 earthquake is unequivocally attested by ASSa (1561c), a notarial memorandum that includes "Vietri" in a group of Apenninic localities affected by the July 31 event. On the other, ASMo (1561), BAV (1561b), and Seripando (16th century) name no less than three localities positioned in close proximity to Vietri sul Mare (Cava dei Tirreni, Nocera, and Salerno), as affected by earthquakes from July 31 to late August 1561. This leads us to believe that when Pacca (16th century) named Vietri "between Amalfi and Salerno" as an earthquake-affected locality, he was not completely wrong after all but rather that he was conflating the two Vietris into one. It is quite likely that Vietri sul Mare experienced the same shocks that affected nearby Cava dei Tirreni, Nocera, and Salerno. On the other hand, it is much less likely is one and the same earthquake could have affected both Vietri di Potenza and Vietri sul Mare to the extent described by the sources.

ASMo (1561), BAV (1561b), and Seripando (16th century) mention damage in Vietri sul Mare, Cava dei Tirreni, Nocera, and Salerno that cannot be attributed to an earthquake generated by the Mount Marzano-Caggiano structures, or by any of the neighbouring seismogenic structures (i.e. those of the Ofanto and Agri valleys). For one thing, there is no evidence that in 1561 there were any effects in dozens of localities midway between these structures and Vietri sul Mare, and where an earthquake generated by the above-mentioned structures would have caused heavier damage than in Vietri sul Mare itself. Moreover, the intensity that was reached in this Vietri by the 1561 earthquake (IX MCS) was much higher than the VI MCS intensity due to the 1694, 1857, and 1980 earthquakes, which wereall stronger than the 1561 earthquake. One can thus not attribute the high intensity in 1561 to local site amplifications. We suggest it is most reasonable to attribute the strong effects along the Tyrrhenian coast in 1561 to a local earthquake occurred some time between July 31 and August 19.

The effects felt in Naples could be related to a contemporary eruption—presumably accompanied by earthquakes—of Vesuvius (that "burnt Pozzuoli"; ASMo, 1561), which would have added to the damage following the Vietri sul Mare and Apennines shocks. It is worth noting that according to Nostro *et al.* [1998], Apennine earthquakes can promote eruptions of Vesuvius by compressing the magma body at depth.

The present dataset (Table 2) allows the traditional view of the earthquake to be revised, with emphasis on addressing two specific questions: were the events of July 31 and August 19, 1561 really part of the same seismic sequence? And, if they were not, exactly how many earthquakes did occur in southern Italy in the summer of 1561?

[1]In southern Italy there are two towns named Vietri. Along the Tyrrhenian coastline, between Amalfi and Salerno (Vietri sul Mare), and 100 km inland (Vietri di Potenza). The suffixes "sul Mare" (on the Sea) and "di Potenza" are fairly recent additions to their name, made after the unification of Italy (late 19th century) for the sake of administrative clarity. In older times, confusion between the two Vietri must have been common.

TABLE 2 Apparent chronological sequence of the now-available 1561 earthquake data. Although fairly confusing from a seismogenetic point of view, it includes information that derives from news that reached the sources with different days of delay

m	d	h	m	PLACENAME	LAT	LONG
7	31	18	50	Avellino	14.791	40.914
7	31	19	45	Atena Lucana	15.553	40.454
7	31	19	45	Auletta	15.426	40.558
7	31	19	45	Buccino	15.376	40.633
7	31	19	45	Caggiano	15.489	40.568
7	31	19	45	Petina	15.375	40.533
7	31	19	45	Picerno	15.638	40.640
7	31	19	45	Polla	15.494	40.514
7	31	19	45	San Licandro	15.284	40.588
7	31	19	45	San Pietro al Tanagro	15.482	40.455
7	31	19	45	Sant'Arsenio	15.481	40.469
7	31	19	45	Solofra	14.848	40.828
7	31	19	45	Tito	15.675	40.582
7	31	19	45	Vallo di Diano area	–	–
7	31	19	45	Vietri di Potenza	15.508	40.599
7	31	20	10	Balvano	15.512	40.650
7	31	20	10	Cava dei Tirreni	14.706	40.700
7	31	20	10	Napoli	14.260	40.855
7	31	20	10	Nocera	14.642	40.743
7	31	20	10	Pietramala (unidentif.)	0.000	0.000
7	31	20	10	Ricigliano	15.482	40.668
7	31	20	10	Sicignano degli Alburni	15.308	40.558
7	31	20	10	Torella dei Lombardi	15.115	40.941
7	31	23	45	Avellino	14.791	40.914
7	31			Atripalda	14.835	40.919
7	31			Benevento	14.777	41.129
7	31			Salerno	14.765	40.679
7	31			Santomenna	15.321	40.807
8	2	12	0	Avellino	14.791	40.914
8	19	15	50	Atella	15.653	40.877
8	19	15	50	Atena Lucana	15.553	40.454
8	19	15	50	Balvano	15.512	40.650
8	19	15	50	Bella	15.538	40.758
8	19	15	50	Caggiano	15.489	40.568
8	19	15	50	Calitri	15.435	40.900
8	19	15	50	Castelgrande	15.431	40.785
8	19	15	50	Monte S Giacomo	15.542	40.342
8	19	15	50	Muro Lucano	15.486	40.753
8	19	15	50	Napoli	14.260	40.855
8	19	15	50	Ottati	15.316	40.462
8	19	15	50	Palomonte	15.292	40.662
8	19	15	50	Pantoliano	15.273	40.472
8	19	15	50	Picerno	15.638	40.640

(*Continued*)

TABLE 2 (*Continued*)

m	d	h	m	PLACENAME	LAT	LONG
8	19	15	50	Pignola	15.786	40.573
8	19	15	50	Polla	15.494	40.514
8	19	15	50	Potenza	15.805	40.638
8	19	15	50	Ruoti	15.679	40.717
8	19	15	50	Sala Consilina	15.596	40.398
8	19	15	50	San Fele	15.541	40.819
8	19	15	50	San Licandro	15.284	40.588
8	19	15	50	San Pietro al Tanagro	15.482	40.455
8	19	15	50	San Rufo	15.464	40.434
8	19	15	50	Sant'Angelo Le Fratte	15.558	40.545
8	19	15	50	Sant'Arsenio	15.481	40.469
8	19	15	50	Sicignano degli Alburni	15.308	40.558
8	19	15	50	Tito	15.675	40.582
8	19	15	50	Vietri sul Mare	14.729	40.670
8	19			Auletta	15.426	40.558
8	19			Buccino	15.376	40.633
8	19			Petina	15.375	40.533
8	19			Vietri di Potenza	15.508	40.599

6. Seismotectonic Hypothesis and Conclusions

If we accept that the anomalous far-field accounts of the 1561 earthquakes were caused by independent events, we can focus on interpreting the remaining intensity values to better understand the mainshocks of July 31 and August 19, 1561.

The combined damage distribution in 1561 is consistent with expectations for a rupture of the Caggiano fault, with a rupture length of approximately 17 km and an Mw of approximately 6.3 (Fig. 10.) The earliest Modern Age rupture on this fault identified through paleoseismological studies by Galli *et al.* [2006; E4 in Fig. 5b] would correspond to this event.

Rupture on the Caggiano fault would not, however, easily explain the heavy damage observed at relatively large distances on the footwall (i.e., the Ofanto valley; see Torella dei Lombardi, Sant'Angelo dei Lombardi, Santomenna) and in Muro Lucano and Atella (Fig. 10). Conversely, although characterized by lower and sparse intensities, the coverage of effects in the Ofanto-Basilicata area roughly matches the mesoseismic region of the 1466, 1694, and 1980 earthquakes (Figs. 2–4; northern ellipse in Fig. 10). Strong damage in this area suggests a local mainshock, the seismogenic source of which would be between the Marzano and Ufita faults. Indeed, the Irpinian seismogenic structures are characterized by complex, still not completely understood fault systems, segments of which may rupture either simultaneously or individually. For example, the 1980 sequence included distinct sub-events occurring 20 and 40 s after the initial mainshock [Bernard and Zollo, 1989; Galli *et al.*, 2006].

Considering that for normal faults the Coulomb stress rises lateral to the fault tips (see Nostro *et al.*, 1997), and that dynamic shaking effects can also potentially cause triggering (e.g., Gomberg and Bodin, 1994) the fault rupture on July 31 could have "loaded one of the nearby Ofanto structures, producing a complex sequence of events on

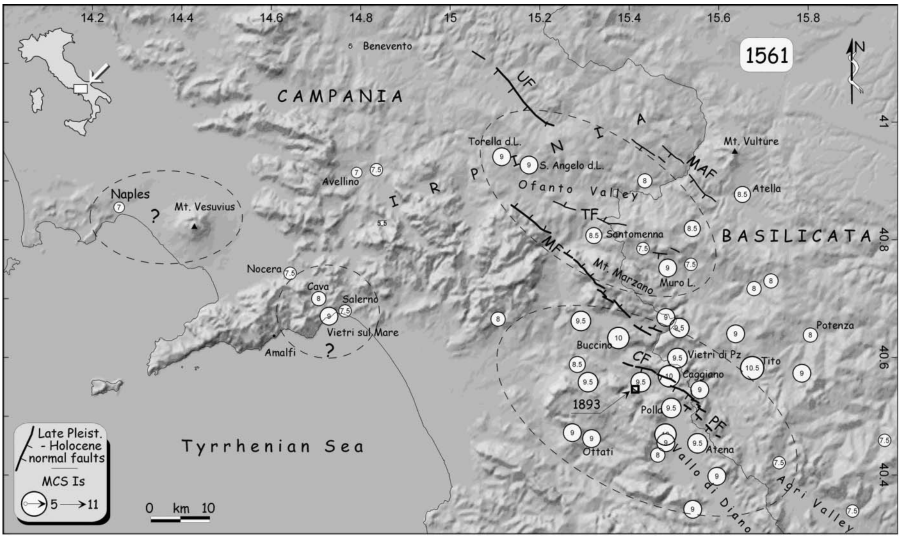

FIGURE 10 Intensity datapoint distribution of the July–August 1561 sequence according to the present study (see Table 3). The dashed ellipses include the possible mesoseismic areas of the different shocks. The one around Naples could be related to an eruption (and local earthquake) of Vesuvius (BAV, 1561a), the effects of which were cumulative with those of the other earthquakes of the sequence. The earthquake around Vietri sul Mare should be connected to a local (or offshore) epicentre, and not to the Apennine faults, since no other localities between the coast and the chain were damaged. The two ellipses between Campania and Basilicata hypothetically show the mesoseismic areas of the two mainshocks generated by the Caggiano fault (south) and by a subset of the Ofanto Valley seismogenic structures (fault names: see previous figure legends. PF, Polla fault). Note that the epicenter of the 1893 earthquake matches the Caggiano fault plane.

adjacent fault structures.'' Many such sequences have occurred in the Apennines, from Calabria to the Umbria-Marches, including the 1703, central Italy sequence [Galli *et al.*, 2005] and the 1783 Calabrian sequence [Jacques *et al.*, 2001; Galli and Bosi, 2002].

The Caggiano fault is itself complex, with two main segments separated by a right step accommodated by the Mount San Giacomo and Timpe faults, each approximately 10 km in length (Fig 5.; Galli *et al.*, 2006). A third segment, the Polla fault overlaps the latter, bordering the northern Vallo di Diano slopes (PF in Fig. 10). Macroseismic observations suggest that the July 31 occurred on this fault system, but given the imprecision of the data one cannot determine whether this earthquake was a single event or a complex rupture involving events separated by seconds or even hours.

If the July 31 and August 19 earthquakes occurred on the Caggiano fault and in the Ofanto valley, respectively, the sites placed between the two source zones would have experienced strong shaking twice, or even oftener, within 20 days. This is indeed what appears to have happened: Buccino was explicitly quoted by Pacca (16^{th} century) and De Raimo (15^{th}–16^{th} century) as being ''struck twice by the earthquake within one month,'' while Tito, Polla, Sicignano, and nearby places appear to have been severely damaged by the July 31 event before being destroyed or nearly destroyed in the August 19 event (ASMo, 1561).

TABLE 3 Intensities evaluated for the proposed 1561 shocks. The intensities of the Vietri sul Mare sub-event are given separately, because they are considered as due to a local earthquake (same for the Vesuvius earthquake/eruption). For the Irpinia-Diano Valley area there are great difficulties in discriminating the effects caused on the Apennine villages by the different events that occurred between July 31 and August 19. Therefore, we propose both a cumulated intensity value, and, tentatively, a separated assessment for the mainshocks of July 31 and August 19. Grey-shaded localities were not reported in Boschi *et al.* [2000]. (MCS, Mercalli-Cancani-Sieberg scale)

lon	lat	Intensity MCS			Locality
		Vietri sul Mare area (July 31)			
14.729	40.670	9			Vietri sul Mare
14.706	40.700	8			Cava
14.642	40.743	7–8			Nocera
14.765	40.679	7–8			Salerno
14.260	40.855	7			Napoli
		Vesuvius eruption (July 31 ?)			
14.260	40.855	7			Napoli
		Irpinia-Diano Valley areas			
		July 31	**Aug. 19**	**Cumul.**	
15.675	40.582	8–9	10–11	11	Tito
15.376	40.633	9–10	10	10	Buccino
15.489	40.568	8–9	10	10	Caggiano
15.481	40.469	8–9	10	10	Sant'Arsenio
15.553	40.454	8–9	8–9	8–9	Atena Lucana
15.426	40.558	8–9	9–10	9–10	Auletta
15.512	40.650	9	9–10	9–10	Balvano
15.292	40.662		9–10	9–10	Palomonte [Palo]
15.494	40.514	8–9	9–10	9–10	Polla
15.308	40.558	9	9–10	9–10	Sicignano degli Alburni
15.508	40.599	8–9	9–10	9–10	Vietri di Potenza
15.486	40.752		9	9	Muro Lucano
15.316	40.462		9	9	Ottati
15.273	40.472		9	9	Pantoliano
15.380	40.530	8–9	9	9	Petina
15.638	40.640	7	9	9	Picerno
?	?	9		9	Pietramala
15.786	40.573		9	9	Pignola
15.482	40.668	9		9	Ricigliano
15.596	40.398		9	9	Sala Consilina
15.542	40.342		9	9	Monte San Giacomo [San Giacomo]
15.482	40.455	8–9	9	9	San Pietro al Tanagro
15.176	40.927			9	Sant'Angelo dei Lombardi
15.558	40.545		9	9	Sant'Angelo le Fratte

(*Continued*)

TABLE 3 (*Continued*)

lon	lat	Intensity MCS			Locality
15.115	40.941	9		9	Torella dei Lombardi
15.653	40.877		8–9	8–9	Atella
15.541	40.819		8–9	8–9	San Fele
15.284	40.588	7–8	8–9	8–9	San Licandro
15.321	40.807	8–9		8–9	Santomenna
15.717	40.730		8	8	Avigliano
15.435	40.900		8	8	Calitri
15.107	40.665			8	Campagna
15.805	40.638		8	8	Potenza
15.679	40.717		8	8	Ruoti
15.464	40.434		8	8	San Rufo
14.835	40.919	7–8		7–8	Atripalda
15.538	40.758		7–8	7–8	Bella
15.431	40.785		7–8	7–8	Castelgrande
15.971	40.459			7–8	Laurenzana
15.735	40.421			7–8	Marsico Nuovo
15.899	40.339			7–8	Viggiano
14.791	40.914	7		7	Avellino
14.260	40.855		5	5	Napoli
14.848	40.828	5–6		5–6	Solofra
14.777	41.129	5		5	Benevento

Considering all the remaining questions regarding this complex sequence, and with the exception of a local triggered Vietri sul Mare event, one cannot identify detailed source zones for all of the principal events of the 1561 sequence, or even be sure how many distinct ruptures occurred. The newly considered historical sources do, however, further elucidate the seismotectonics and earthquake history of this part of the Apennines. The combined synthesis of archival and field data is, we suggests, the most powerful tool to understand past and potential future earthquake sources.

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