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Regular Article

Improving performance of seismic networks in the Montefeltro region: historical seismographs and current local network

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Abstract Seismology, which had previously relied on descriptive and observational methods, began incorporating appropriate instrumentation and effective techniques for the parametric and theoretical analysis of seismic data starting in the mid-nineteenth century. Alessandro Serpieri, rector of the Raffaello College in Urbino from 1857 to 1884, was a pioneering figure who first proposed the creation of a seismic network in Italy. A significant contribution also came from Luigi Guidi (1824–1883), director from 1861 to 1883 of the Valerio Observatory in Pesaro. Today, comprehensive coverage of study areas is essential for the high-resolution analysis of low-magnitude seismic events. To this end, a temporary seismic network was established in the Montefeltro region in December 2018 as part of a collaborative project between the University of Urbino and the National Institute of Geophysics and Volcanology. The aim was to acquire new seismic data to supplement those recorded by the National Seismic Network. The Montefeltro area, with Urbino as its provincial capital, has recently experienced seismic activity with magnitudes below 4. Data analysis indicates that the region is characterized by a seismically active basin with microseismicity, while the surrounding areas show more concentrated seismic activity in three zones: Rimini, Forlì, and along the Apennine belt. In this contribution, we review the evolution of seismological studies in the broad Montefeltro region since the seminal work of Serpieri up to present times.

1 Introduction

Seismology emerged as an empirical science through the earliest efforts to quantify ground motion caused by earthquakes. These initial attempts not only sought to measure seismic disturbances but also led to the development of instruments capable of recording and reporting data across an early network of observatories. These efforts laid the groundwork for modern seismic networks, which now enable detailed analyses of seismic activity from structural geology, geodynamic, and seismotectonic perspectives. The pivotal contributions of Alessandro Serpieri (1823–1885) played a key role in this evolution. His work at the University of Urbino Meteorological Observatory during the latter half of the nineteenth century provided groundbreaking methodological and theoretical insights. Recently unearthed documents have further illuminated the technical operation of his seismographs, enhancing our historical understanding of seismic monitoring practices during that era.

Serpieri identified a range of characteristic earthquake parameters worth to study, including the precise origin time and direction propagation of seismic waves. These observations, corroborated by international researchers, significantly advanced the methodological rigour of seismological studies. The integration of the telegraph system in the nineteenth century proved revolutionary. When grounded, telegraph cables revealed telluric currents associated with seismic activity, occasionally delivering electric shocks to operators (Serpieri 1873a; Boteler 2006; Cliver and Dietrich 2013)—a phenomenon that prompted Serpieri to collaborate with the Italian Telegraph Administration. The systematic monitoring of events, combined with the proposal to convert telegraph offices into temporary seismic stations (De Rossi 1879), received official approval in 1873. This initiative led to the foundation of Italy's first Seismic Correspondence Telegraph Service (Serpieri 1873b). Serpieri's meticulous analyses, including his 23-year study of over 100 earthquakes in Urbino, demonstrated recurring propagation patterns along perpendicular axes (NNW–SSE and WSW–ENE) (Serpieri 1878). His innovation of a cost-effective, easily reproducible seismograph model enabled further insights into the directionality of seismic waves (Serpieri 1873b; Santini 2000). Although

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these observations likely originated from surface waves caused by reflection and refraction following direct P- and S-wave arrivals, they allowed him to assess the damage potential of earthquakes on specific structures and formulate guidelines for earthquake-resilient construction (Serpieri 1878). The Meteorological Observatory operated throughout Serpieri's tenure in Urbino, until his departure in 1884 (TROMOS 1990), and there was a revival of seismological studies from 1901 to 1909 under the directorship of Tito Alippi (1870–1959) (Alippi 1904, 1911).

By the late nineteenth century, Italy had established a network of climatological and seismological observatories. However, due to administrative and financial disparities—often relying on municipal or volunteer support—this network remained fragmented (Alippi 1865; Guidi 1856). Luigi Guidi (1824–1883), founder and director of the Valerio Meteorological-Seismic Observatory in Pesaro, played a crucial role in standardizing measurement practices. He was also director of Pesaro's Technical Institute, and his dedication to sourcing precision instruments across Europe marked a turning point in data reliability and cross-border scientific collaboration (Cambrini and Ortolani 2025).

Seismic instrumentation at the observatory advanced incrementally: the standard tromometer was installed in 1876, and Guidi was one of the first and most assiduous collaborators of De Rossi in the experimentation and systematic use of this instrument (Ferrari 1991). Around 1875, the Galileo Factory in Florence built several copies of the Cecchi sliding-paper seismograph. One of these is now at the Ximeniano Observatory, another was in use at the Moncalieri Observatory, a third instrument was purchased in 1877 by Guidi, and a fourth was located in Foggia. The instrument at the Valerio Observatory in Pesaro, put into operation in January 1877, had a brief history: just a few years later, it was almost abandoned; currently, after the observatory was destroyed in 1944, only a few small parts remain. The De Rossi microseismograph was acquired in 1879 but never fully activated (Borchi et al. 2009).

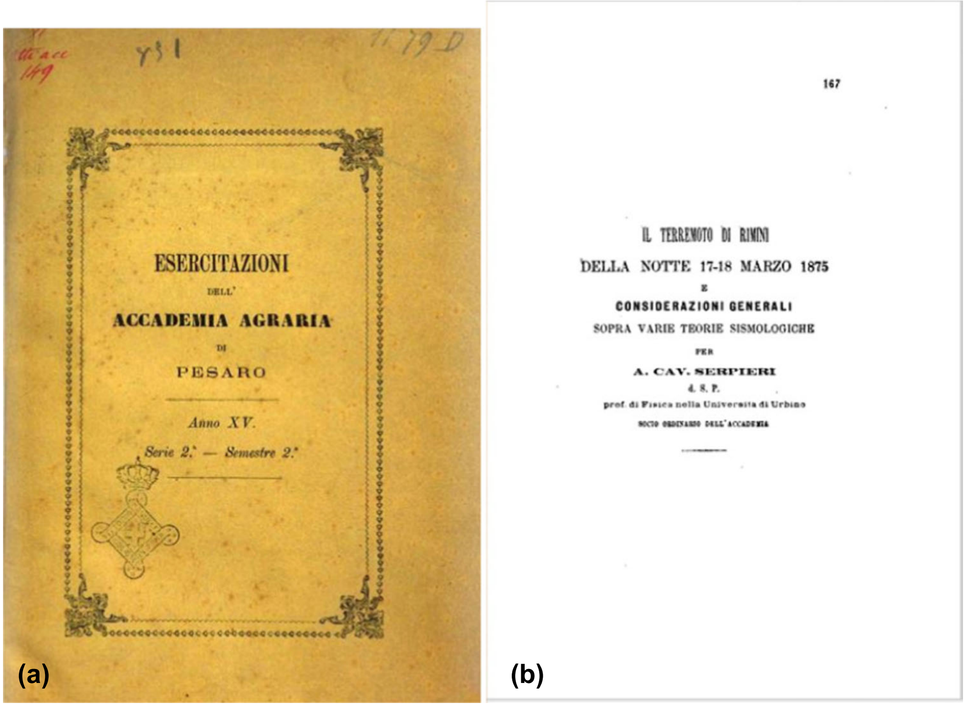
Scientific progress in understanding seismic wave propagation and earthquake genesis spurred the invention of more advanced instruments capable of recording ground motion in three dimensions. In recent decades, with the advent of electronic data collection and digital transmission, seismology transitioned from manual logging to real-time data processing. Modern information technologies now enable the deployment of advanced seismographs in even the most remote regions. This transformation has allowed for the integration of local and national seismic networks, enhancing both scientific research and public safety. In northern Marche, extensive monitoring initiatives began in the 1980s using analog instruments and progressed to fully digital networks by the early 2000s. Since 2012, the number of seismic stations has steadily increased, enabling high-resolution studies of microseismicity and improving event localization. To further improve monitoring in the northern Montefeltro region—characterized by minor seismic swarms and burst-type sequences—a temporary seismic network with international FDSN code "1S" was deployed to increase station coverage. The combination of data from this local network and the National Seismic Network has improved the resolution of earthquake event relocation. All collected data have been published and are freely available through the Zenodo repository (https://doi.org/10.5281/zenodo.8344614), organized by year and station in downloadable zip archives.

2 The seismographs of the Valerio Observatory of Pesaro Municipality in the first half of twentieth century

In 1856, Luigi Guidi established a meteorological observatory in Pesaro, naming it in honour of Lorenzo Valerio, the Extraordinary Commissioner for the Marche. Seeking to move beyond subjective meteorological interpretations or analyses limited to the immediate surroundings of his residence in Pesaro, Guidi forged ties with the Meteorological Telegraphic Correspondence of Rome and expanded infrastructure dedicated to atmospheric sciences. Collaborative efforts with the Urbino observatory, under the direction of Serpieri, were pivotal in fostering scientific exchange. Both Guidi and Serpieri contributed to the Esercitazioni, a journal published by the Accademia Agraria di Pesaro (Baldassini 1838; Guidi 1861; Serpieri 1879) (Fig. 1a). In fact, the observatory was installed near the Accademia location, at the Orti Giuli.

A landmark moment for the Esercitazioni occurred in 1875 when Serpieri, following to the Rimini earthquake, published a detailed account of observations obtained with his instrumentation, field surveys (Fig. 1b) as well as data from other Italian and international observatories. He also outlined his seismological theories, emphasizing the importance of determining the origin time and the "provenance" of the earthquake. Moreover, he stressed the need to study past seismic events from various perspectives in order to better understand the phenomenon and prepare for future earthquakes.

By 1888, under Pio Calvori's leadership (1883–1928), the Valerio Observatory became part of a nascent national network of seismic stations, managed by the Central Office of Meteorology and Geodynamics. Through systematic postcard reports, the institution contributed to macroseismic data collection. In his 1904 Monograph, Calvori remarked that initially, only a single Cavalleri pendulum was available. These early instruments were designed not to detect major seismic events but rather slow, small ground movements. Despite technological limitations, the



ESERCITAZIONI
DELL'
ACCADEMIA AGRARIA
DI
PESARO

Anno XV.
Serie 2.ª — Semestre 2.ª

167

IL TERREMOTO DI RIMINI
DELLA NOTTE 17-18 MARZO 1875
E
CONSIDERAZIONI GENERALI
SOPRA VARIE TEORIE SISMOLOGICHE
PER
A. CAV. SERPIERI
d. S. P.
prof. di Fisica nella Università di Urbino
SOCIO ORDINARIO DELL'ACCADEMIA

Fig. 1 **a** "Esercitazioni", XV year volume, 1879. **b** Serpieri's article cover published in the volume

observatory maintained systematic tromometric records from 1888 to 1938. Notably, this included basic notes on seismic activity, although the equipment's sensitivity permitted only rudimentary analysis of seismic events.

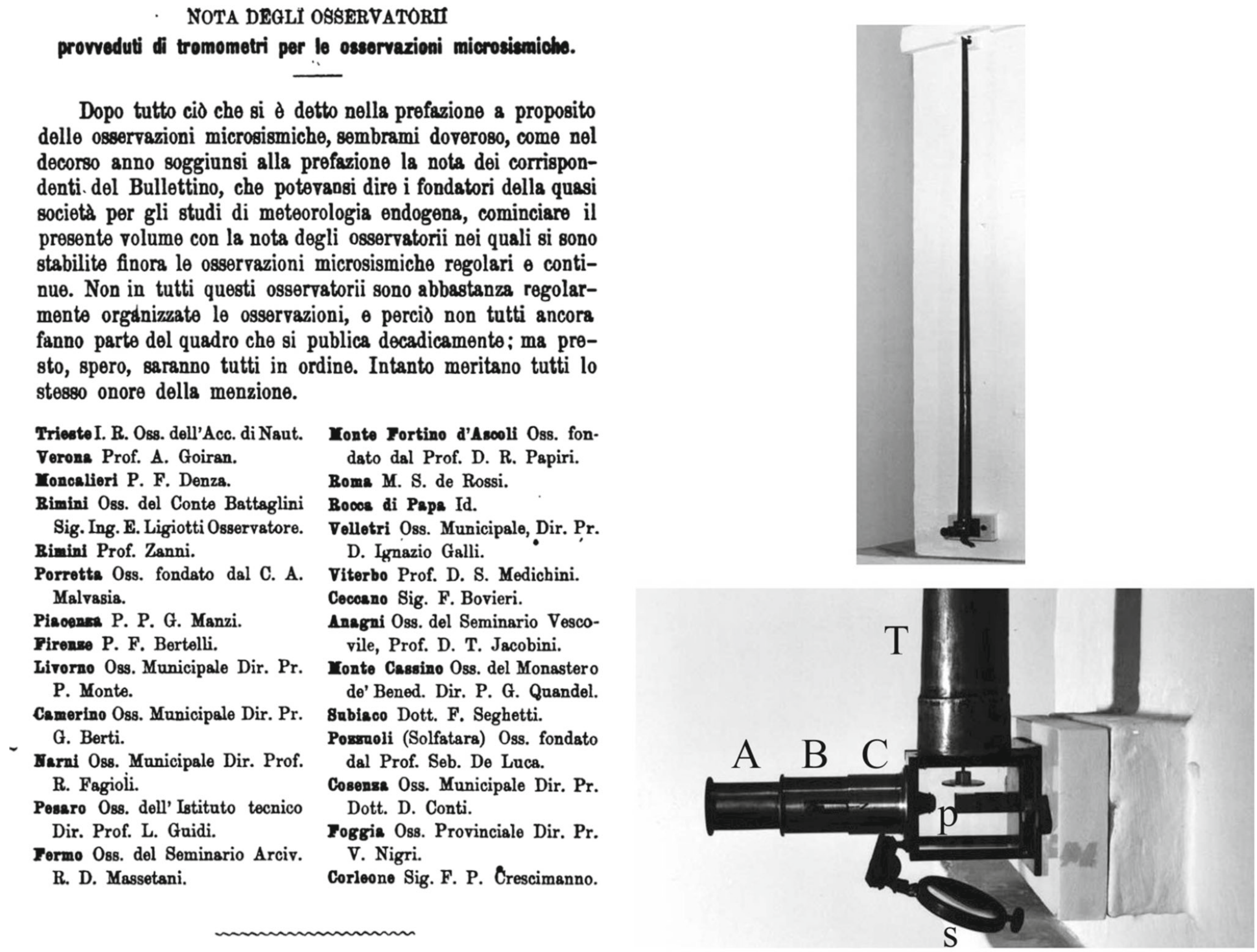
These preliminary observations, alongside reports gathered from numerous observatories distributed throughout Italy, including Pesaro as reported by (Guidi 1875), were meticulously compiled and systematically categorized by the seismologist Michele Stefano De Rossi. He constructed comprehensive tables with the explicit objective of elucidating the evolution and propagation of seismic phenomena, making a clear distinction between events perceptible to the population and those detectable solely by seismic instruments, without any human perception.

De Rossi further introduced a significant differentiation between two types of readings obtained using the "Bertelli–De Rossi normal tromometer." On one side were instruments installed independently of any structural framework (i.e. "isolated" tromometers); on the other, devices affixed directly to the walls or floors of buildings, which inevitably registered both ground motion and structural vibrations. The tromometer located at the Valerio Observatory in Pesaro fell into the former category of isolated instruments (Fig. 2). Luigi Guidi, the observatory's founder, had deliberately designated a ground-floor room whose floor was in direct contact with bedrock, thereby allowing seismic activity to be recorded with minimal interference from structural movement. This arrangement substantially enhanced the precision and credibility of the collected data.

Beyond documenting ground shaking and seismic episodes, De Rossi's tables also incorporated observations of volcanic phenomena, including eruptions and related manifestations such as gas emissions or ground deformation in the vicinity of craters. The aim of compiling such an extensive dataset was to facilitate an integrated study of natural phenomena, seeking to identify potential correlations between seismic and volcanic activity, even over extensive geographical areas. As an illustrative case, Fig. 3a displays the table detailing microseismic data from the event that occurred in the Marche region on 27 February 1888, as recorded by the tromometer at the Valerio Observatory. Complementarily, Fig. 3b shows a handwritten summary of microseismic data from the same event, based on observations conducted using the Bertelli–De Rossi tromometer at various locations across Italy, including Pesaro. Through this rigorous and detailed approach, researchers of the time endeavoured to discern broader patterns and governing principles underlying Earth's dynamic processes, with the ultimate aspiration of gleaning insights that might aid in the anticipation of future seismic or volcanic events.

Following the death of Luigi Guidi in 1883, the directorship of the Observatory was entrusted to Pio Calvori. The new head immediately found himself facing a precarious situation, both economically and structurally. Despite these challenges, Calvori worked tirelessly to prevent the closure of the institution.

The first formal recognition came shortly afterwards: in 1888, the Valerio Observatory was incorporated into the national network of seismic observatories, coordinated by the Central Office of Meteorology and Geodynamics. From that point on, the observations carried out in Pesaro became an integral part of the national data collection, contributing to the construction of the seismic memory of central Italy. Calvori ensured continuity in seismological monitoring, meticulously maintaining records between 1888 and 1938—documents that remain a valuable resource



NOTA DEGLI OSSERVATORII
provveduti di tromometri per le osservazioni microsismiche.

Dopo tutto ciò che si è detto nella prefazione a proposito delle osservazioni microsismiche, sembrami doveroso, come nel decorso anno soggiunsi alla prefazione la nota dei corrispondenti del Bullettino, che potevansi dire i fondatori della quasi società per gli studi di meteorologia endogena, cominciare il presente volume con la nota degli osservatorii nei quali si sono stabilite finora le osservazioni microsismiche regolari e continue. Non in tutti questi osservatorii sono abbastanza regolarmente organizzate le osservazioni, e perciò non tutti ancora fanno parte del quadro che si publica decadicamente; ma presto, spero, saranno tutti in ordine. Intanto meritano tutti lo stesso onore della menzione.

Trieste I. R. Oss. dell'Acc. di Naut.
Verona Prof. A. Goiran.
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Monte Cassino Oss. del Monastero de' Bened. Dir. P. G. Quandel.
Subiaco Dott. F. Seghetti.
Pozzuoli (Solfatara) Oss. fondato dal Prof. Seb. De Luca.
Cosenza Oss. Municipale Dir. Pr. Dott. D. Conti.
Foggia Oss. Provinciale Dir. Pr. V. Nigri.
Corleone Sig. F. P. Crescimanno.

(a) (b)

Fig. 2 **a** Italian observatories list equipped with tromometers in 1877 (De Rossi 1878). **b** The tromometer installed at the Valerio Observatory with a close-up of the measurement reading system including telescope (A,B,C), prism (p), mirror (s), and tube (T) (modified from (Cambrini and Ortolani 2025) and labelled as by (De Rossi 1877))

for historical seismology to this day. Unfortunately, records predating 1888 were lost, likely handed over by Calvori to De Rossi.

The observatory was equipped with a number of seismic instruments—including a Cavalleri pendulum, a Brassart seismoscope, a De Rossi microseismograph, and seismographs by Cecchi and Scateni—but their scientific utility proved limited. Many devices were never activated or were found to be unreliable; others, such as the De Rossi microseismograph, were almost entirely lost. Nevertheless, the consistent use of the tromometer and the regular transmission of data to the Central Observatory in Rome reflect a determined effort to keep the observatory active within the national scientific network, despite the difficulties.

Calvori published two collections of meteorological data and compiled a handwritten monograph on the Valerio Observatory, for which he was awarded a silver medal at the Romagna Regional Exhibition in Ravenna in 1904 (Vasapollo 1993). Calvori remained in charge until 1928, when he was joined by his nephew Alessandro Procacci due to his progressive blindness. Procacci assisted him until his death in 1931. A discreet yet constant presence, Procacci worked alongside several directors over the decades, and his dedication became a unifying thread in the evolution of the observatory.

After Calvori, the directorship passed to Gino Pampana, former assistant professor of Geodesy at the University of Pisa. Under his leadership (1931–1935), the observatory became more open to the scientific community, although its publications remained limited. Pampana promoted the systematization of meteorological data and, together with Procacci, contributed to formalizing data collection procedures. However, his attention soon shifted towards his teaching career, and he left the post in 1935.

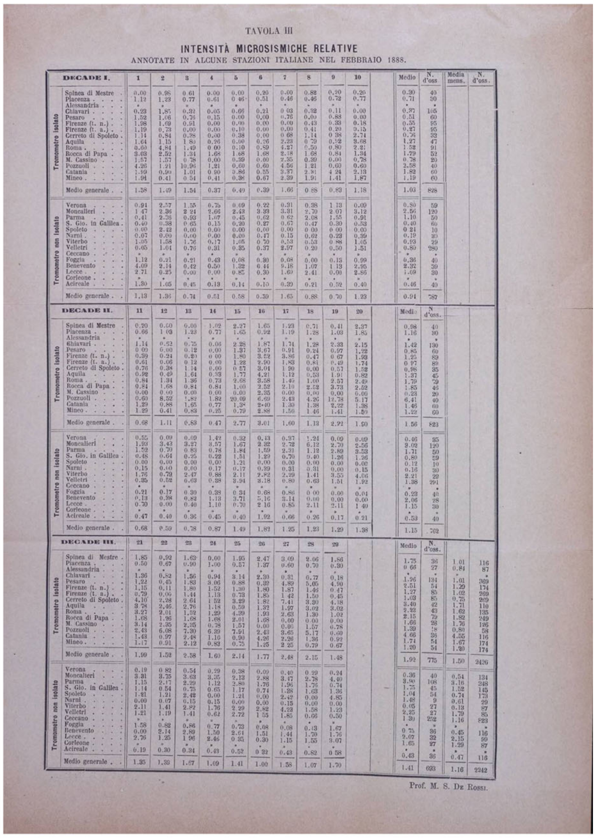


TAVOLA III

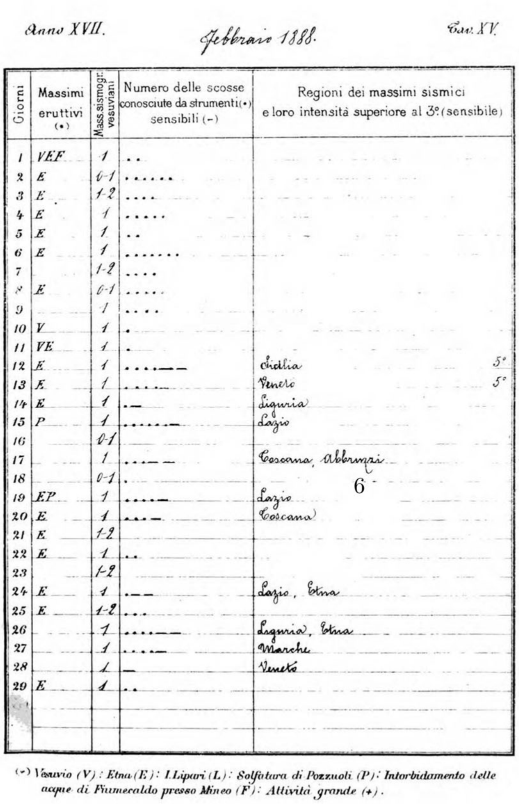
INTENSITÀ MICROSISMICHE RELATIVE

ANNOTATE IN ALCUNE STAZIONI ITALIANE NEL FEBBRAIO 1888.

	DECADE I.	1	2	3	4	5	6	7	8	9	10		Medio	N. d'oss.	Media mens.	N. d'oss.
Tromometro isolato	Spinea di Mestre	0.00	0.96	0.61	0.00	0.00	0.20	0.00	0.82	0.20	0.20		0.30	40		
	Piacenza	1.12	1.23	0.77	0.61	0.46	0.51	0.46	0.46	0.72	0.77		0.71	30		
	Alessandria	•	•	•	•	•	•	•	•	•	•		•	•		
	Chiavari	0.23	1.85	0.32	0.05	0.66	0.21	0.03	0.32	0.11	0.00		0.37	105		
	Pesaro	1.52	1.06	0.76	0.15	0.00	0.00	0.76	0.00	0.83	0.00		0.51	60		
	Firenze (t. n.)	1.98	1.69	0.91	0.00	0.00	0.00	0.00	0.43	0.33	0.18		0.55	95		
	Firenze (t. a.)	1.19	0.73	0.00	0.00	0.10	0.00	0.00	0.41	0.20	0.15		0.27	95		
	Cerreto di Spoleto	1.14	0.84	0.38	0.00	0.38	0.00	0.68	1.14	0.38	2.74		0.76	33		
	Aquila	1.64	1.15	1.80	0.26	0.00	0.26	2.23	0.79	0.92	3.68		1.27	47		
	Roma	0.60	4.84	1.49	0.00	0.10	0.89	4.27	0.50	0.80	2.21		1.52	91		
	Rocca di Papa	3.03	2.52	1.34	1.68	1.68	1.68	2.18	1.68	0.84	1.34		1.79	52		
	M. Cassino	1.57	1.57	0.78	0.00	0.39	0.00	2.35	0.39	0.00	0.78		0.78	20		
	Pozzuoli	4.26	1.21	10.96	1.21	0.60	0.60	4.56	1.21	0.60	0.60		2.58	40		
	Catania	1.99	0.90	1.01	0.90	0.86	0.55	3.37	2.31	4.24	2.13		1.82	60		
	Mineo	1.94	0.41	0.54	0.41	0.38	0.67	2.39	1.91	1.41	1.87		1.19	60		
	Medio generale	1.58	1.49	1.54	0.37	0.49	0.39	1.66	0.88	0.83	1.18		1.03	828		
Tromometro non isolato	Verona	0.91	2.57	1.55	0.75	0.09	0.22	0.31	0.38	1.13	0.09		0.80	59		
	Moncalieri	1.47	2.36	2.24	2.66	2.43	3.33	3.31	2.70	2.07	3.12		2.56	120		
	Parma	0.41	2.38	0.93	1.07	0.45	0.62	0.62	2.08	1.55	0.91		1.10	50		
	S. Gio. in Galilea	0.40	0.38	0.65	0.15	0.20	0.27	0.67	0.47	0.30	0.53		0.40	60		
	Spoleto	0.00	2.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.24	10		
	Narni	0.07	0.00	0.00	0.00	0.00	0.47	0.15	0.62	0.23	0.39		0.19	30		
	Viterbo	1.05	1.58	1.76	0.17	1.05	0.70	0.53	0.53	0.88	1.05		0.93	29		
	Velletri	0.05	1.04	0.76	0.31	0.35	0.37	2.97	0.20	0.50	1.51		0.80	280		
	Ceccano	•	•	•	•	•	•	•	•	•	•		•	•		
	Foggia	1.12	0.21	0.21	0.43	0.08	0.30	0.08	0.00	0.13	0.99		0.36	40		
	Benevento	4.09	2.14	0.42	0.50	1.32	0.44	9.18	1.07	1.13	2.95		2.32	39		
	Lecce	2.71	0.25	0.00	0.00	0.85	0.30	1.60	2.41	0.00	2.86		1.09	30		
	Corleone	•	•	•	•	•	•	•	•	•	•		•	•		
	Acireale	1.30	1.05	0.45	0.13	0.14	0.10	0.39	0.21	0.52	0.40		0.46	40		
	Medio generale	1.13	1.36	0.74	0.51	0.58	0.39	1.65	0.88	0.70	1.23		0.94	787		
	DECADE II.	11	12	13	14	15	16	17	18	19	20		Medio	N. d'oss.		
Tromometro isolato	Spinea di Mestre	0.20	0.60	0.00	1.02	2.27	1.65	1.23	0.71	0.41	2.37		0.98	40		
	Piacenza	0.66	1.03	1.23	0.77	1.65	0.92	1.19	1.28	1.03	1.85		1.16	30		
	Alessandria	•	•	•	•	•	•	•	•	•	•		•	•		
	Chiavari	1.14	0.52	0.75	0.06	2.28	1.87	1.74	1.28	2.33	2.15		1.42	130		
	Pesaro	0.00	0.00	0.12	0.00	1.37	3.67	0.91	0.24	0.97	1.22		0.85	60		
	Firenze (t. n.)	0.39	0.24	0.20	0.00	1.80	3.52	3.86	0.47	0.67	1.93		1.25	89		
	Firenze (t. a.)	0.61	0.06	0.12	0.00	1.22	2.90	1.83	0.81	0.49	1.74		0.97	89		
	Cerreto di Spoleto	0.76	0.38	1.14	0.00	0.57	3.01	1.90	0.00	0.57	1.52		0.98	35		
	Aquila	0.92	0.49	1.64	0.33	1.77	4.21	1.12	0.53	1.91	0.82		1.37	45		
	Roma	0.84	1.34	1.36	0.73	2.68	3.58	1.40	1.00	2.57	2.49		1.79	79		
	Rocca di Papa	0.84	1.68	0.84	0.84	1.00	2.52	2.10	2.52	3.73	2.52		1.85	46		
	M. Cassino	0.00	0.00	0.00	0.00	0.00	2.35	0.00	0.00	0.00	0.00		0.23	20		
	Pozzuoli	0.60	8.52	1.82	1.82	20.09	6.69	2.43	4.26	12.78	5.17		6.41	40		
	Catania	1.29	0.88	1.65	0.77	1.38	2.40	1.30	1.38	2.22	1.38		1.46	60		
	Mineo	1.29	0.41	0.83	0.25	0.79	2.88	1.50	1.46	1.41	1.59		1.22	60		
	Medio generale	0.68	1.11	0.83	0.47	2.77	3.01	1.60	1.13	2.22	1.90		1.56	823		
Tromometro non isolato	Verona	0.55	0.09	0.09	1.42	0.32	0.43	0.37	1.24	0.09	0.09		0.46	35		
	Moncalieri	1.93	3.43	3.27	3.57	1.67	2.32	2.72	6.12	2.70	2.56		2.02	120		
	Parma	1.52	0.70	0.83	0.78	1.84	1.59	2.31	1.12	2.89	3.53		1.71	50		
	S. Gio. in Galilea	0.48	0.64	0.25	0.22	1.51	1.29	0.70	0.40	1.26	1.26		0.80	59		
	Spoleto	0.00	0.00	0.00	0.00	1.21	0.00	0.00	0.00	0.00	0.00		0.12	10		
	Narni	0.15	0.00	0.00	0.17	0.17	0.39	0.31	0.31	0.00	0.15		0.16	30		
	Viterbo	1.76	0.79	2.47	0.88	2.11	2.82	2.29	1.41	3.55	4.06		2.21	29		
	Velletri	0.35	0.52	0.63	0.38	3.94	3.18	0.80	0.63	1.51	1.92		1.38	291		
	Ceccano	•	•	•	•	•	•	•	•	•	•		•	•		
	Foggia	0.21	0.17	0.30	0.38	0.34	0.68	0.86	0.00	0.00	0.04		0.23	40		
	Benevento	0.13	0.38	0.82	1.13	3.71	5.16	3.14	0.00	0.00	0.00		2.06	28		
	Lecce	0.70	0.00	0.40	1.10	0.70	2.16	0.85	2.11	2.11	1.40		1.15	30		
	Corleone	•	•	•	•	•	•	•	•	•	•		•	•		
	Acireale	0.47	0.40	0.36	0.45	0.40	1.92	0.66	0.26	0.17	0.21		0.53	40		
	Medio generale	0.68	0.59	0.78	0.87	1.49	1.82	1.25	1.23	1.29	1.38		1.15	762		
	DECADE III.	21	22	23	24	25	26	27	28	29			Medio	N. d'oss.		
Tromometro isolato	Spinea di Mestre	1.85	0.92	1.63	0.00	1.95	2.47	3.09	2.06	1.86			1.75	36	1.01	116
	Piacenza	0.50	0.67	0.90	1.00	0.57	1.37	0.60	0.70	0.30			0.66	27	0.84	87
	Alessandria	•	•	•	•	•	•	•	•	•			•	•	•	•
	Chiavari	1.36	0.82	1.56	0.94	3.14	2.30	0.31	0.77	0.18			1.26	134	1.01	369
	Pesaro	1.22	0.45	1.83	3.06	0.88	0.32	4.89	5.05	4.90			2.51	54	1.29	174
	Firenze (t. n.)	1.15	0.11	1.80	1.52	1.30	1.80	1.87	1.46	0.47			1.27	85	1.02	269
	Firenze (t. a.)	0.79	0.06	1.44	1.13	0.73	1.85	1.42	1.50	0.45			1.03	85	0.75	269
	Cerreto di Spoleto	4.10	2.28	2.64	1.52	3.29	1.82	7.41	3.30	4.18			3.40	42	1.71	110
	Aquila	3.78	2.46	2.76	1.18	0.59	1.32	1.97	3.02	3.02			2.23	43	1.62	135
	Roma	3.27	2.01	1.52	1.29	4.39	1.93	2.63	1.30	1.02			2.15	79	1.82	249
	Rocca di Papa	1.68	1.26	1.68	1.68	2.01	1.68	0.00	0.00	0.00			1.66	28	1.76	126
	M. Cassino	3.14	2.35	2.35	0.78	1.57	0.00	0.00	1.57	0.78			1.39	18	0.80	58
	Pozzuoli	2.43	6.08	7.30	6.39	7.91	2.43	3.65	5.17	0.60			4.66	36	4.55	116
	Catania	1.43	0.97	2.48	1.10	0.90	4.26	2.26	1.36	0.92			1.71	54	1.67	174
	Mineo	1.17	0.91	2.12	0.83	0.75	1.25	2.25	0.79	0.67			1.20	54	1.20	174
	Medio generale	1.99	1.52	2.58	1.60	2.14	1.77	2.48	2.15	1.48			1.92	775	1.50	2426
Tromometro non isolato	Verona	0.19	0.82	0.54	0.29	0.38	0.09	0.40	0.29	0.24			0.36	40	0.54	134
	Moncalieri	3.31	3.75	3.63	3.35	2.13	2.88	3.47	2.78	4.40			3.90	108	3.16	348
	Parma	1.15	2.17	2.29	1.12	2.80	1.76	1.96	1.76	0.74			1.75	45	1.52	145
	S. Gio. in Galilea	1.14	0.54	0.75	0.65	1.17	0.74	1.38	1.63	1.36			1.04	54	0.74	173
	Spoleto	1.21	1.21	2.42	0.00	1.21	0.00	2.42	0.00	4.85			1.48	9	0.61	29
	Narni	0.00	0.07	0.15	0.15	0.00	0.00	0.15	0.00	0.00			0.05	27	0.13	87
	Viterbo	2.11	1.41	2.82	1.76	2.29	2.82	4.23	1.58	1.23			2.25	27	1.79	85
	Velletri	1.21	1.19	1.41	0.62	2.72	1.55	1.85	0.66	0.50			1.30	252	1.16	823
	Ceccano	•	•	•	•	•	•	•	•	•			•	•	•	•
	Foggia	1.58	0.82	0.86	0.77	0.73	0.08	0.08	0.13	1.67			0.75	36	0.45	116
	Benevento	0.00	2.14	2.89	1.50	2.61	1.51	1.44	1.70	1.76			2.07	32	2.15	99
	Lecce	2.76	1.25	1.96	2.46	0.35	0.30	1.15	1.55	3.07			1.65	27	1.29	87
	Corleone	•	•	•	•	•	•	•	•	•			•	•	•	•
	Acireale	0.19	0.30	0.34	0.43	0.52	0.32	0.43	0.82	0.58			0.43	36	0.47	116
	Medio generale	1.35	1.39	1.67	1.09	1.41	1.00	1.58	1.07	1.70			1.41	693	1.16	2242

Prof. M. S. De Rossi.

(a)



Anno XVII. Febbraio 1888. Tav. XV.

Giorni	Massimi eruttivi (•)	Mass. sismogr. vesuviani	Numero delle scosse conosciute da strumenti (•) sensibili (–)	Regioni dei massimi sismici e loro intensità superiore al 3° (sensibile)	
1	VEF	1	••		
2	E	0-1	••••••		
3	E	1-2	••••		
4	E	1	•••••		
5	E	1	••		
6	E	1	•••••••		
7		1-2	••••		
8	E	0-1	•••••		
9		1	••••		
10	V	1	•		
11	VE	1	•		
12	E	1	•••——	Sicilia	5°
13	E	1	•••••—	Veneto	5°
14	E	1	•—	Liguria	
15	P	1	••••••—	Lazio	
16		0-1			
17		1	•••——	Toscana, Abbruzzi	
18		0-1	•		
19	EP	1	••••—	Lazio	
20	E	1	•••—	Toscana	
21	E	1-2			
22	E	1	••		
23		1-2			
24	E	1	•——	Lazio, Etna	
25	E	1-2	•••		
26		1	••••——	Liguria, Etna	
27		1	••••—	Marche	
28		1	—	Veneto	
29	E	1	••		

6

(•) Vesuvio (V): Etna (E): I. Lipari (L): Solfatara di Pozzuoli (P): Intorbidamento delle acque di Fiumecaldo presso Mineo (F): Attività grande (+).

(b)

Fig. 3 **a** The table detailing microseismic data recorded at the Valerio Observatory and **b** a handwritten summary of the same microseismic data (De Rossi 1890)

He was succeeded by Tito Alippi, a physics teacher, headmaster of the Classical High School in Pesaro, and chief geophysicist at the Military Air Force's Forecasting Office. Alippi had previously served as director of the Meteorological-Geodynamic Observatory of Urbino (1901–1909). Under his guidance, the observatory began to upgrade its equipment once more, acquiring in 1935 a Vicentini microseismograph from the Ximeniano Observatory in Florence as well as new meteorological devices. The Vicentini instrument saw active use, as in over 30 national and international observatories, including locations such as Genoa, Pavia, Pisa, and Naples (Ferrari 2014). Despite its widespread adoption, technical flaws of Vicentini seismograph (e.g. timing inaccuracies and susceptibility to traffic-induced vibrations) significantly limited its scientific validity (TROMOS 1990).

During the '40 years, Alessandro Procacci played a crucial role because he took steps to safeguard the observatory instruments. He managed to transport and disassemble most of the instruments by transferring them to the countryside and thus avoiding the II World War bombings, which destroyed 5 rooms and the dome of the Observatory, and damaged all the equipment. Reconstruction of the damaged sections began only in 1947, but the revival of scientific activities was hampered by a lack of funding for essential materials, such as lacquered paper and glass pens.

Upon Alippi's death, the directorship was formally passed to Alessandro Procacci in 1962, although he had already been actively involved for long time. Under his leadership, the observatory consolidated the regular publication of its meteorological bulletin and began systematizing long-term climate data. Of particular importance was his Contribution to the Chronicle of Earthquakes on the Marche-Romagna Coast, one of the first systematic syntheses of historical accounts on seismic activity in the Adriatic region (Procacci 1963).

In 1971, the directorship passed to Brunello Bedosti, graduated in natural sciences and pharmacy and the observatory last director (1971–1991). The Agamennone seismograph was acquired from the Fano Seminary in this year and the Vicentini seismograph reactivated in the following year. The Agamennone horizontal pendulum was never fully operational and the scientific output became more sporadic, partly due to the director's growing interest in other fields.

In conclusion, the seismic division of the Valerio Observatory played a more historical than scientific role throughout much of the twentieth century. While recordings were continuous until 1977, serious research contributions diminished. A brief resurgence occurred in 1976 with the acquisition of Geotech S-13 short-period seismometers (Fig. 4a), locally installed, recording only vertical component, and the resumption of the Seismic Bulletin. However, during the 80's years, both activity levels and long-term planning experienced a noticeable decline.

2.1 The Vicentini seismograph at Valerio Observatory

In 1895, Giuseppe Vicentini, together with his assistant Giulio Pacher, developed a microseismograph designed to detect the horizontal seismic components using a mechanical recording system. A few years later, they introduced a complementary instrument for recording the vertical components (Vicentini and Pacher 1897, 1899). At the time, their microseismograph was regarded as the most sensitive device of its kind (Fig. 4a).

Giuseppe Vicentini (1860—1944), an Italian physicist and seismologist, served as a professor at the University of Padua from 1894 to 1931. His research encompassed the electrical conductivity of metals and gases, as well as seismological phenomena. He is particularly noted for the development of this microseismograph, which was primarily constructed from iron, steel, and brass, and measured 200 × 40 × 300 cm (Alfani 1912).

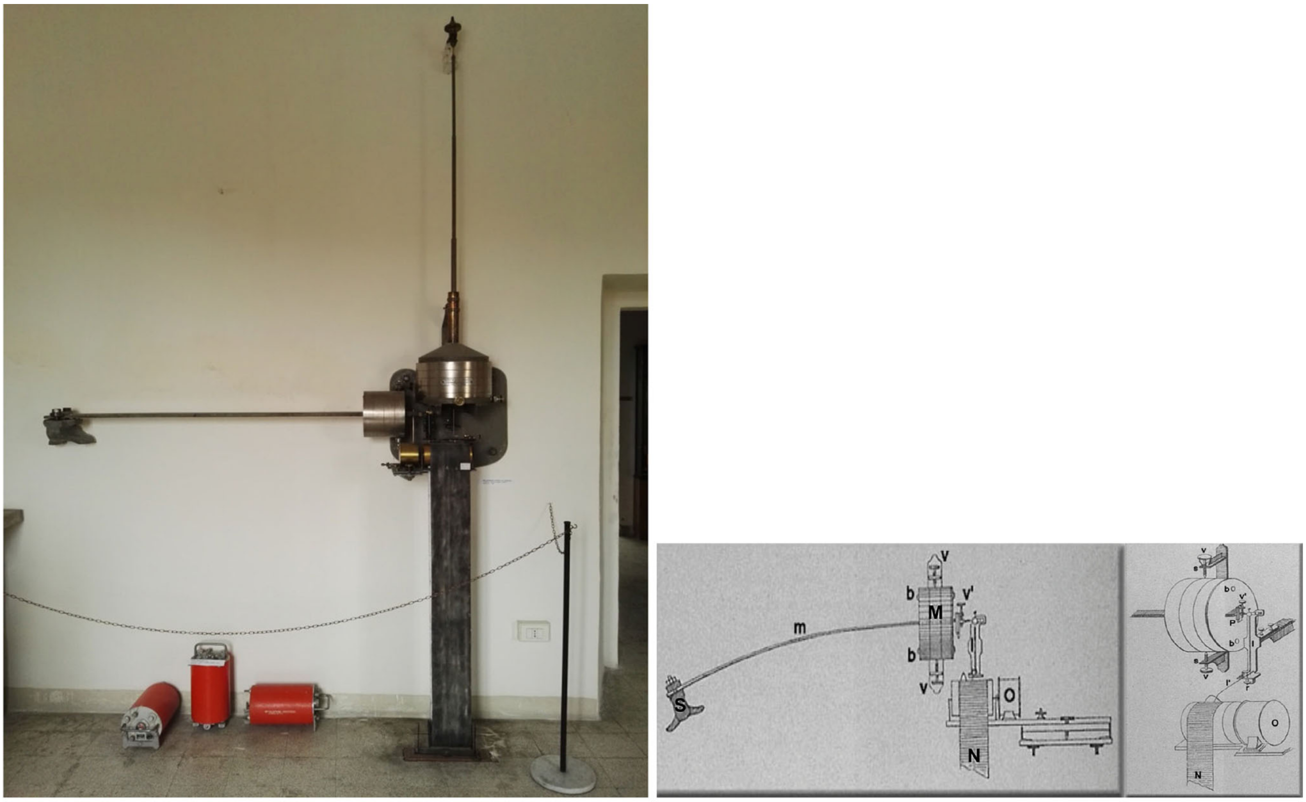
2.1.1 Horizontal microseismograph

The horizontal component is a pendulum composed by a 100-kg mass suspended from a 1.5-m vertical rod. Its relative horizontal motion was amplified by a vertical lever and then resolved into two orthogonal directions—parallel and perpendicular to the supporting wall—using an additional lever system. This configuration achieved approximately 80-fold amplification. Two fine glass strips served as nibs to inscribe movements onto smoked paper.

The smoked paper formed a continuous loop stretched between two small cylinders: the upper cylinder rotated consistently via a clockwork mechanism, while the lower cylinder maintained paper tension. A third nib, activated by an electric circuit, marked minutes and hours to synchronize recordings.

Vicentini also integrated a damping mechanism originally designed by E. Wiechert and B.B. Galitzin. This innovation minimized residual oscillations of the pendulum mass. When subjected to an artificial shock, the mass completed only one oscillation, unlike undamped systems which continued to oscillate.

The Vicentini seismograph installed at the Valerio Observatory include this damping system (the conical top of the horizontal pendulum contains the damping device). Instead, the technical tools to improve performance of the vertical component were not installed.



(a) **(b)**

Fig. 4 **a** The Vicentini seismograph installed at the Pesaro Observatory, manufactured by Antonio Cagnato (Padua), with Geotech S-13 short-period seismometers positioned beneath the seismograph. **b** Labelled sketch of the instrument, illustrating the front view (Ferrari 2014) and a detailed technical drawing of the clockwork mechanism

2.1.2 Vertical microseismograph

To achieve a longer free period, instead to use a simple spring, Vicentini utilized a 1.5-m leaf spring derived from a railway carriage. One end of the spring (Fig. 4b) was fixed to a cast iron bracket embedded at an angle in the wall, allowing the loaded spring to rest horizontally under its own weight (Fig. 4a). The mass—composed of stacked lead discs weighting between 100 and 150 kg—was secured with two bolts (b). The substantial weight not only stabilized the system but also increased the free period, enhancing sensitivity to long-period seismic waves.

The movement range of the mass was limited by screws (v) mounted on horizontal crosspieces (s), themselves attached to a vertical iron bar anchored to the wall. Amplification and recording were managed through two aluminium levers: the first (l), angled to convert vertical into horizontal motion, and the second (l'), equipped with a glass strip to inscribe movements onto smoked paper. A steel needle was mounted on a support (P), fixed to the spring free end via screws. A fine adjustment screw (v') allowed precise positioning of the nib relative to the paper ribbon. This ribbon (N) was again powered by a clockwork mechanism (O), placed on a shelf beneath the device (Fig. 4b).

In the first decades of twentieth century, Vicentini introduced technical enhancements to improve instrument performance. However, these improvements were not incorporated into the seismograph installed in Pesaro. The device exceptional sensitivity was evident from the outset, as demonstrated by a 1940 seismogram recorded in Pesaro (Fig. 5a): it captured the Mount Amiata earthquake on October 16, with an intensity of the III degree on the Mercalli scale (Fig. 5b).

2.2 Agamennone seismograph with horizontal pendulums

The seismograph was designed by Giovanni Agamennone and constructed by the Fascianelli Company in Rome in the early years of the twentieth century (Fig. 6a). Giovanni Agamennone was born in Rieti on 24 June 1858 to Alessandro and Barbara Palmeggiani and passed away in Rome on 3 October 1949. In 1884, he earned a degree in

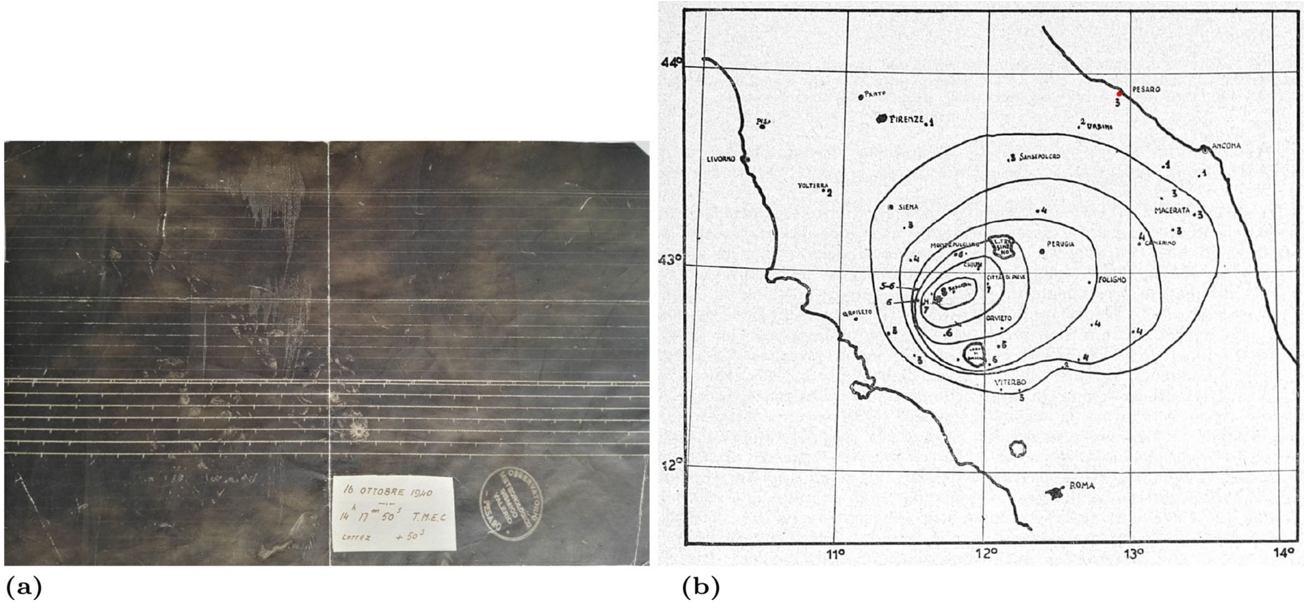


Fig. 5 **a** A fragment of the recording of the Vicentini seismograph installed at the Valerio Observatory during the Mount Amiata earthquake on October 16, 1940. **b** Earthquake macroseismic isolines by (Giorgi 1941); the red point is the Observatory location

physics from the University of Rome and began his career as a seismology assistant at the Geodynamic Observatory of Ischia, later moving to the Central Office of Meteorology and Geodynamics in Rome.

In 1895, Agamennone co-founded the Italian Seismological Society and, in the same year, was invited by the Ottoman government to Constantinople, where he organized the national seismic service and established a seismic station equipped with instruments of his own design. By 1899, he was appointed director of the Geodynamic Observatory of Rocca di Papa. Over his lifetime, he developed several seismographic instruments and authored nearly 300 scientific works on seismology. In 1929, he was named director of the Seismic Service at the Central Office of Meteorology and Geodynamics in Rome, and he was a member of various national and international scientific societies and an honorary professor at the University of Athens (Zanon 1926).

2.2.1 Description of the instrument

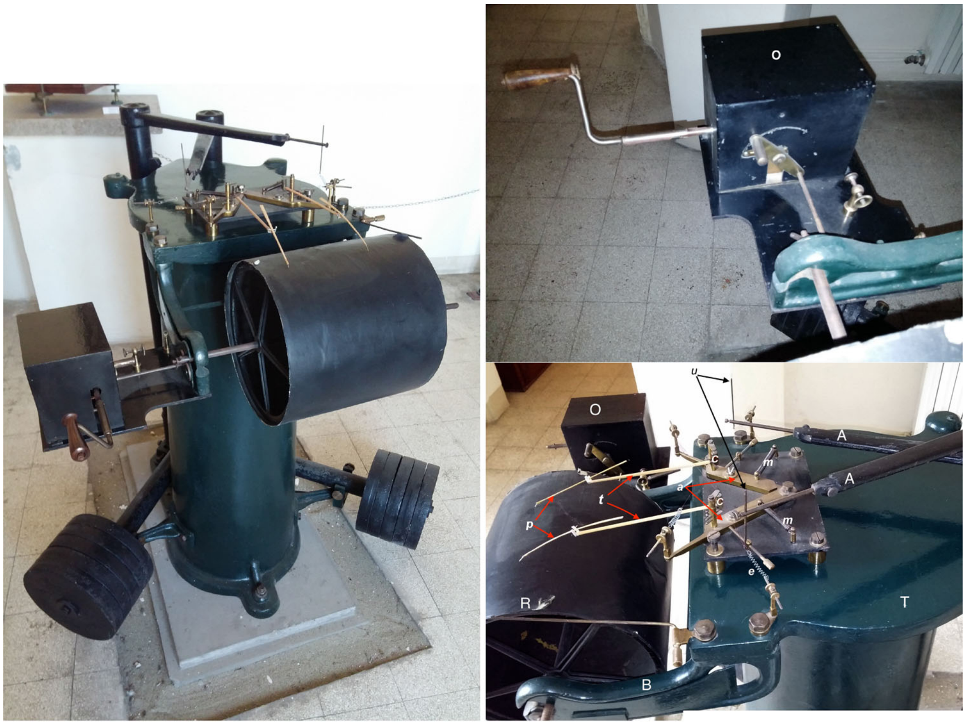
The Agamennone seismograph was a two-component instrument designed to record ground motion in two perpendicular horizontal directions (Zanon 1926). The apparatus consists of a cast iron column approximately 105 cm in height and weighing about 450 kg. This column is mounted on a 4-cm-thick cast iron base plate, securely fixed to a stone foundation anchored to the ground. At the top of the column lies a thick cast iron table (T), 20 mm thick, serving as the instrument's main support Fig. 6(b). Two front-facing arms (B) support the recording drum (R), while two rear extensions provide mounts for the twin horizontal pendulums, which oscillate at right angles to each other to detect seismic wave motion.

Each pendulum is composed of a vertical iron tube with a perpendicular tube attached at its base, holding five cast iron discs (10 kg each), summing to a 50-kg mass. The suspension system features a steel cap with an oblique conical cavity resting on the conical tip of a steel screw set obliquely through the rear extension. A bottom bracket with adjustable screws ensures vertical alignment of the tubes. Notably, the pendulum's sensitivity is directly influenced by the inclination of its axis, which should not be perfectly vertical for optimal function (Zanon 1926).

Two horizontal rods (A) extend from the top of the pendulum tubes towards the recording drum and are linked to the writing levers. To avoid excessive oscillations that could damage the recording mechanism, amplitude limiters are installed. These limiters, composed of two robust screws, also serve to measure the instrument's magnification. The brass recording drum (R), measuring 25 cm in width and 26 cm in diameter, rotates on a central steel shaft supported by four steel wheels for minimal friction. The axis is housed in iron plates on both sides, stabilized with adjustable pins and connected at the end of a vertical metal rod (u). Rotation is driven by a clockwork device (O) located on the left side, while time markings are managed by an iron anchor and an electromagnet on the right. The electromagnet receives electric signals from a chronometer every minute and hour, causing a lateral shift in the drum. A return spring resets it, allowing time to be marked by the same nibs used for seismic data.

The core of the system is its amplification and recording mechanism. An iron sheet affixed to the table (T) holds two movable alidades (a) rotating around a shared pin. Their separation is controlled by spiral springs (m) and

Fig. 6 **a** Agamennone seismograph of the Pesaro Observatory. Builder: Fascianelli Company (Rome). **b** The plate T of the Agamennone seismograph with white labels for a detailed description and the clockwork device zoom placed above



(a) **(b)**

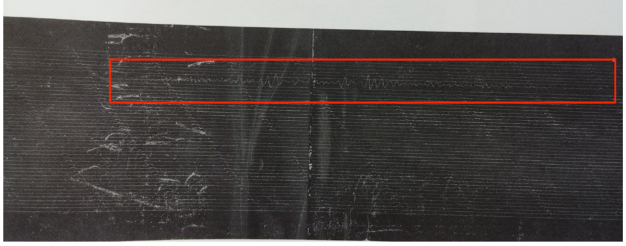


Fig. 7 Detail of the seismogram of an earthquake occurred in Northern Croatia coast on 10 September 1925 (Rovida et al. 2022), recorded at the Alberoni College Observatory of Piacenza by an Agamennone seismograph

micrometric screws (v). Each alidade supports a lightweight vertical cylinder (c) that pivots on a fine needle for low-friction movement. The pen holder (t), made from wheat straw, is fixed perpendicularly to these cylinders. The nib (p)—a thin wheat straw segment with a steel tip—is balanced on a horizontal needle and linked to the pendulum via a system of cotton threads. These threads are tensioned using elastic spirals (e) and can be finely adjusted with micrometric screws to optimize sensitivity. Movement of the pendulums causes tension changes that rotate the pen-holding cylinders, enabling precise trace recording.

Both Agamennone and Vicentini seismographs used the same recording medium: a rotating drum wrapped with glossy paper coated in carbon black. This smoked paper was prepared in a dedicated room using a special burning mixture. The nibs, lightly scratching the surface, left continuous traces of the seismic activity Fig. 7. As the drum rotated along a threaded rod, it gradually shifted sideways to expose a clean surface beneath the nibs. Every 48 h, the paper was carefully removed and preserved by immersing it in shellac to fix the carbon black, ensuring durability and handling ease.

3 Montefeltro local seismic network

The idea of establishing a meteorological observation network in Italy was first proposed in a letter to Count Paoli by Alessandro Serpieri in 1850 (Serpieri 1850). This initiative included the use of the telegraph for data transmission, a concept that soon became a reality. In 1859, Italy saw the creation of its first local seismic network, led by Francesco Denza, director of the Observatory of the Real Collegio Carlo Alberto in Moncalieri, with the

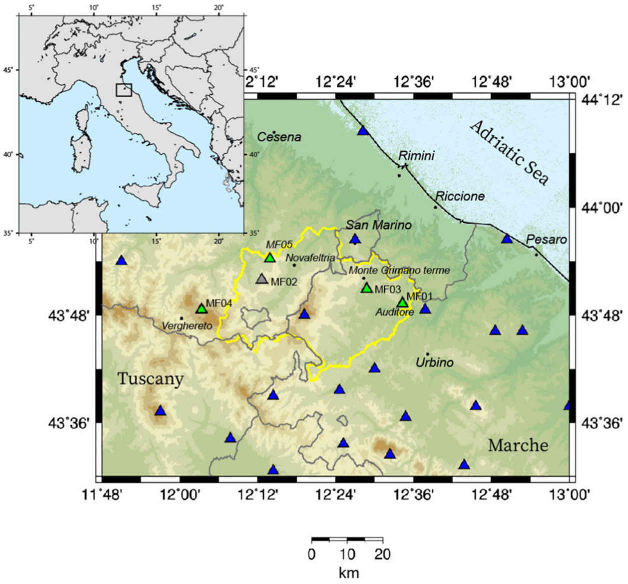


Fig. 8 Map of the eastern area of the central-northern Apennines of Italy. The yellow line represents the Montefeltro area, the blue triangles are the stations of the RSN seismic network in the Montefeltro area and surrounding zones. MF01, MF03, MF04 and MF05 (green triangles) are the four currently operative stations of the Montefeltro seismic network (1S). The grey triangle represents the closed station MF02

support of Serpieri. Denza's wide network of correspondents facilitated early geodynamic observations, especially in locations where meteorological and astronomical data were already being collected. These observatories would form the foundation of Italy's first instrumental earthquake observation network.

In 1873, Serpieri took a further step by developing the first national network capable of associating electrical signals with seismic activity via telegraphic lines. Galvanometric anomalies detected at telegraph stations served as early indicators of seismic events. Station operators, upon recognizing anomalies, could alert nearby stations and take precautionary measures, as documented by Luigi Gatta (Gatta 1875). The establishment of the "Servizio Geodinamico" within the Royal Central Office of Meteorology and Geodynamics in 1906 marked the first organized national seismic monitoring effort. Modern seismic stations were gradually introduced in cities like Rome, Florence, and Naples. The catastrophic Messina-Reggio Calabria earthquake of 1908 prompted a substantial advancement in seismic instrumentation and monitoring.

Throughout the 1920s and 1930s, Italy's seismic network expanded significantly. Universities and observatories began installing their own stations, utilizing advanced instruments such as the Galitzin seismograph. In 1936, the National Institute of Geophysics (Istituto Nazionale di Geofisica—ING) was established, taking on a coordinating role for seismic monitoring across the country. Although World War II slowed these efforts, the post-war years saw renewed expansion, and by the late 1940s, the Italian seismic network comprised several dozen of ING station and a handful of private observatories.

Up until 1980, the network consisted of approximately 24 stations using mainly analog mechanical seismographs that recorded on smoked or photographic paper. However, following the significant earthquakes in Friuli (1976), Valnerina (1979), and Irpinia (1980), the government launched a modern National Seismic Network under the management of the National Institute of Geophysics (ING).

In the following years, in addition to the expansion of the seismic network with new sites, the instrumentation was progressively replaced by short-period electronic sensors, with signals telemetered to the ING headquarters. Within this framework, the FB9 seismographic station was installed in 1995 at Cesane, near Urbino (Santini 2000). It was the first station in the Pesaro-Urbino province installed by a collaboration between the National Institute of Geophysics and the University of Urbino, as part of the broader network distributed across the national territory (https://ingv.maps.arcgis.com/home/item.html?id=83e6aaf952d54a66b3de953871fb37fd).

From the mid-1990s, the network integrated three-component broadband sensors with high dynamics. Data transmission methods also evolved, incorporating satellite, UMTS, and Wi-Fi technologies. Today, the national seismic network comprises around 500 stations.

Within this context, and to enhance seismic, tectonophysical, and geodynamic analysis in the Montefeltro region (yellow contour line in Fig. 8), a high-resolution local network was established. The northern sector of the Montefeltro area lacked sufficient coverage, with the closest national network station over 60 km away. The temporary local network aimed to monitor microseismic swarms and examine their spatial and temporal evolution.

Table 1 List of the 1S network stations for years 2021 and 2022 with their coordinates and characteristics of the used 3-component sensors/recorders

Code station name	Location			Instruments	
	Lat (N)	Lon (E)	Ele (m)	Sensor	Recorder
MF01 Auditore (PU)	43.82150	12.57190	368	Lennartz 3D/5s	Sara SL06
MF03 Monte Grimano	43.84860	12.47990	541	Guralp CMG/30s	Reftek 130
MF04 Verghereto (FC)	43.81030	12.05620	1043	Sara SS20/0.5s	Sara SL06
MF05 Perticara (RN)	43.90497	12.22708	554	Lennartz 3D/5s	Gaia2

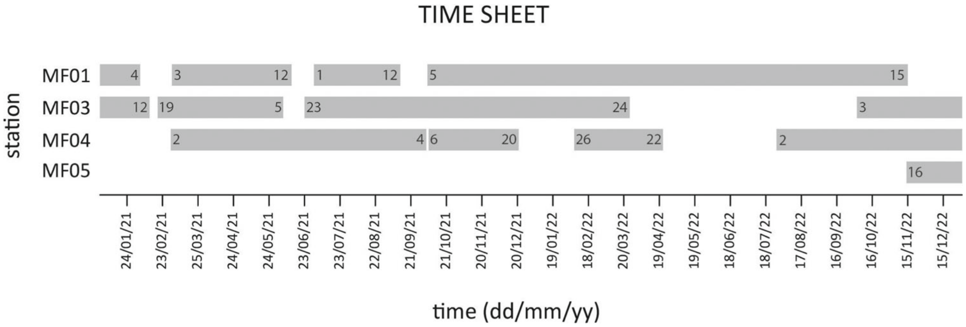


Fig. 9 Data availability for the stations of the 1S network. Availability of the recordings for each station as a function of time (grey boxes). The numbers into the boxes indicate the start and end days of the recorded data

The first local station (MF01, in Auditore Municipality) was installed in December 2018. Two additional stations (MF02 in Sant'Agata Feltria and MF03 in Monte Grimano Terme) were added in 2019, followed by MF04 (in Balze di Verghereto) in 2020.

The network operated continuously from December 2018 to December 2022, with data from two periods (2018–2020 and 2021–2022) already available online in (Santini et al. 2022, 2023), and the description of the 2018–2020 network can be found in (Megna et al. 2019, 2022). In 2021, the network was slightly reconfigured to improve signal-to-noise ratios. Station MF02 (grey triangle in Fig. 8) was replaced by MF05 in Perticara di Novafeltria, with a better signal/noise ratio in the northern area. Despite the aim to increase the stations number, logistical challenges, including the COVID-19 pandemic and the difficulty of finding suitable sites, limited the network to four stations during 2021 and 2022.

The network faced several data acquisition issues. Access to local discs was limited, causing data gaps, and power supply interruptions affected continuous recording. Nonetheless, approximately 75% of the total monitoring period was successfully recorded by stations MF01, MF03, and MF04 (Table 1).

Figure 9 shows data acquisition periods for 2021 and 2022, with each station's activity represented by grey boxes and labelled start and end dates. For most of the observation period, at least three stations were operational, except between 23 April and 1 August 2022, when only one station functioned, and from 13 to 18 February 2021, when no data were recorded. During the progressive deployment of the Montefeltro seismic network, different types of recording systems were utilized, including RefTek RT130, Sara SL06, and Gaia2 (Rao et al. 2010), all equipped with three 24-bit channels (https://www.reftek.com, www.sara.pg.it, www.ingv.it).

3.1 Recent events in the Montefeltro region

In the 2021 and 2022 years, the events that occur within the Montefeltro area are very few with respect to the events that occur in the sector between the three regions where the 1S mobile network is located, whereas the most of seismicity is concentrated towards the Apennine arc (Fig. 10).

It is possible to highlight the occurrence of two small seismic sequences, one near Verghereto on 4–6 February 2021, with a maximum magnitude of 2.3, and the other near Casteldelci on 8 and 9 February 2021, with a maximum magnitude of 2.2. The events generally have very small magnitudes, greater than 2.5 for few events, and the maximum magnitude recorded is 3.0 (M_L) (Fig. 11a). From the depth point of view, two ranges can be seen in which the hypocenters are concentrated (Fig. 11b), one between 10 and 12 km in which most of the Apennine arc events often occur, while a non-negligible number of events concentrate in the interval between the 38 and 48 km when occur between the Apennine arc and the coast (Fig. 10).

Figure 12 shows the waveforms of an event that occurred in the Montefeltro area, in the Municipality of Belforte all'Isauro (PU), recorded by three of the four seismic stations of the 1S temporary network, the MF01 station being temporarily turned off in the Municipality of Auditore. The event shown in Fig. 10 occurred on the southern limit of Montefeltro on 30 December 2022 at 18:54 with magnitude $M_L = 1.9$ at a depth of approximately 10 km. Fig. 12a) shows the three components (E–W, N–S and vertical) of the event recorded by station MF03 (Municipality

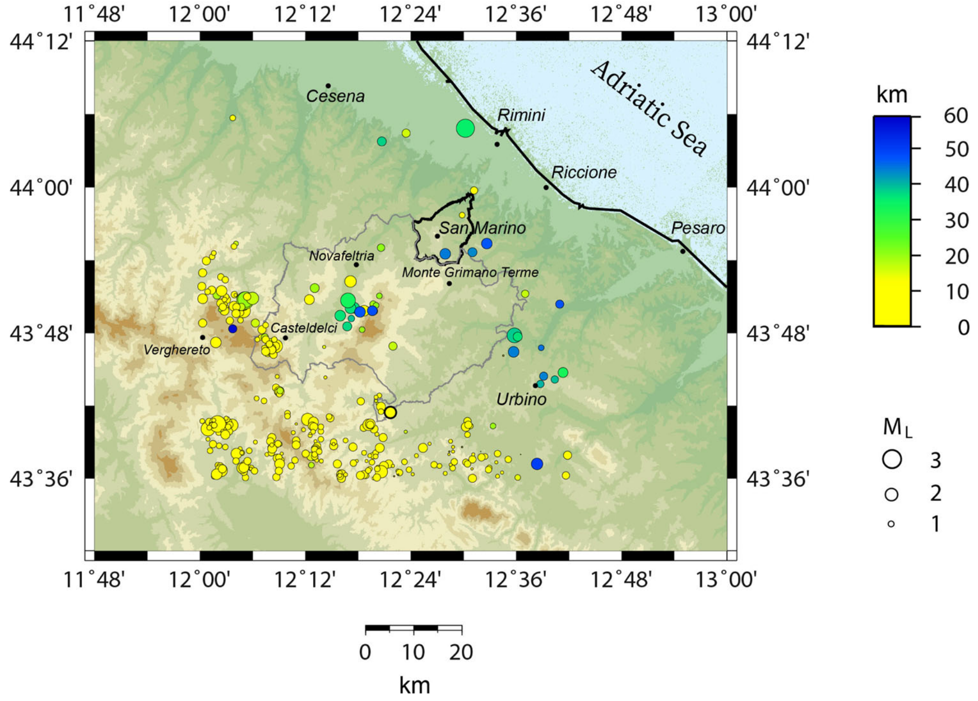


Fig. 10 Events map for the years 2021 and 2022 into the studied area (from (ISIDe 2007)). The circle size is proportional to the magnitude M_L and the colour tone is in function of the depth. The circle with the thicker contour represents the event on 30 December 2022, and the light grey line is the boundary of the Montefeltro area

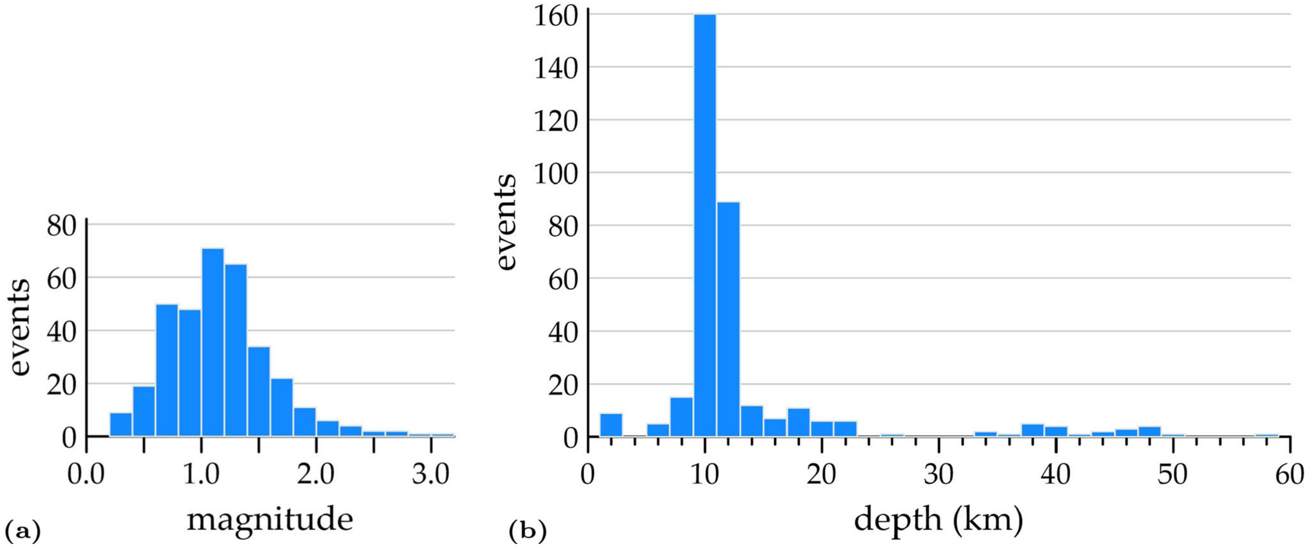


Fig. 11 Histograms of the events for the years 2021 and 2022 into the studied area [from (ISIDe 2007)) vs. magnitude (**a**) and depth (**b**)]

of Monte Grimano Terme) about 25 km NE from the epicentre, Fig. 12b shows the three recorded by station MF04 (Municipality of Verghereto) about 30 km NW from the epicentre and Fig. 12c the three of station MF05 (Municipality of Novafeltria) about 30 km N from the epicentre.

4 Conclusion

Historic seismic observatories represent the earliest forms of earthquake monitoring stations and have played a pivotal role in documenting seismic activity over time. Often affiliated with academic institutions or governmental bodies, these observatories established the foundation for the study of regional seismicity. Within this historical framework, the contributions of Alessandro Serpieri in Urbino and the establishment of the Valerio Observatory in

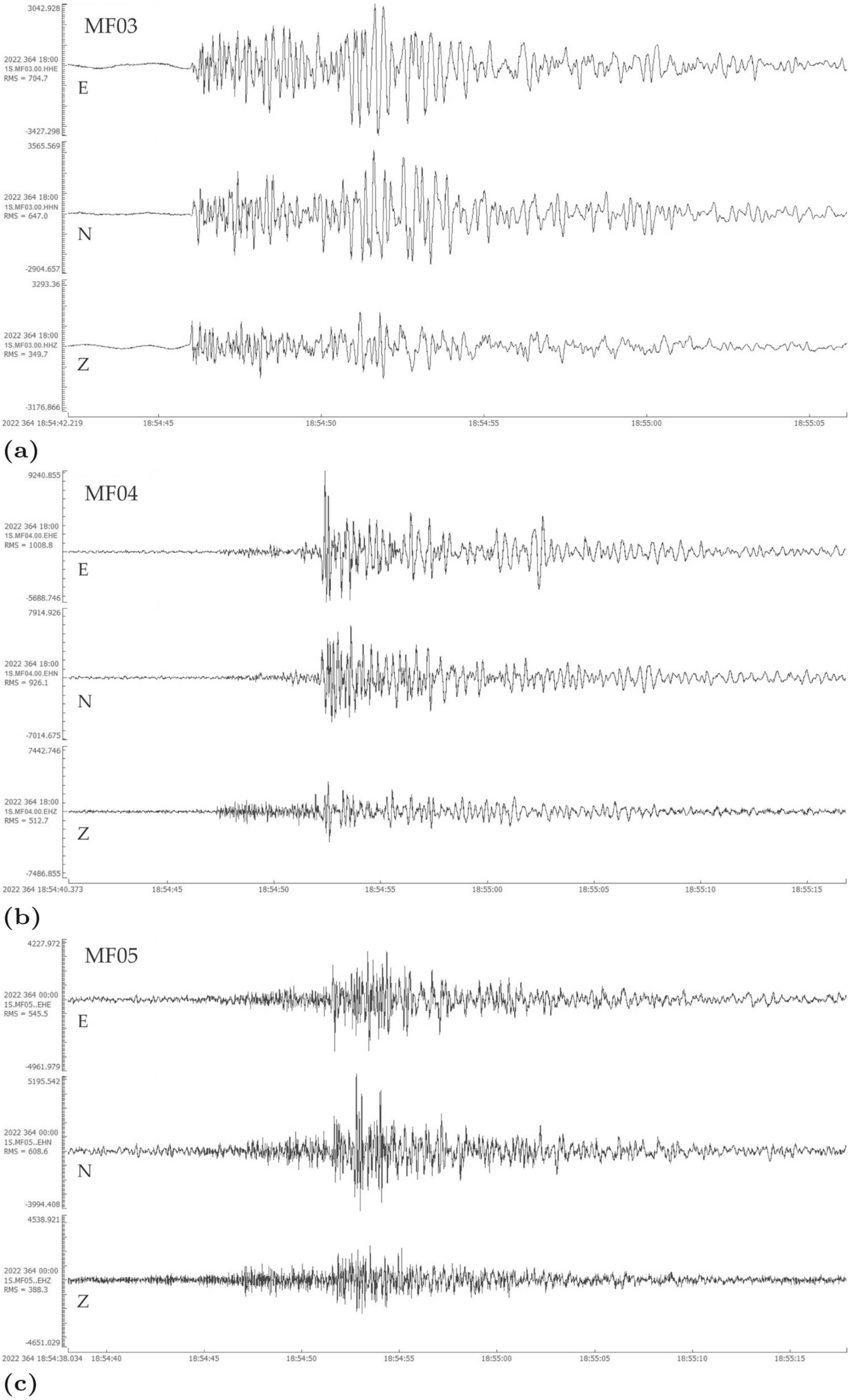


Fig. 12 Waveforms by Passcal Quick Look software (PQL) showing the **a** MF03, **b** MF04 and **c** MF05 three-component recordings for the event that occurred in the Municipality of Belforte all'Isauro on 30 December 2022 (Julian day 364). A high pass filter with 2 poles and a cutoff frequency of 0.5 Hz was applied for this event

Pesaro stand out as particularly significant milestones in the development of seismology in Italy. Serpieri pioneered a rigorous, instrument-based approach to studying earthquakes, anticipating the potential of the telegraph system not only as a means of communication but also as an indirect method for detecting seismic events. Concurrently, Luigi Guidi, in founding the Valerio Observatory in 1856, advocated for the standardization of both meteorological and seismic measurements. He equipped the observatory with precision instruments sourced from across Italy and Europe. Since its founding, the Valerio Observatory has played an important role in historical seismic monitoring thanks to the distribution of observed data and its inclusion in the national seismic network in 1888.

Alongside the Pesaro Observatory, several other monitoring stations across the country became integral components of the national network, contributing regular seismic bulletins. From the mid-twentieth century through the 1980s, the number of observatories grew, and the adoption of advanced instrumentation—such as continuously recording seismographs—improved the quality of seismic data collection. The subsequent expansion of the national seismic network, coupled with technological advancements in data transmission and centralized monitoring, enabled near-continuous surveillance of the Italian territory. This development allowed researchers to better identify and characterize different seismic patterns and risk zones throughout the country.

Until the mid-twentieth century, the Northern Marche region was considered to have relatively low seismicity compared to the Apennine range, which limited interest in strengthening the seismic monitoring network. However, following the implementation of anti-seismic regulations and seismic microzonation, Northern Marche was included in the seismogenic zone of the Adriatic coast and offshore. Active and passive seismic surveys, along with detailed geological studies, revealed significant tectonic structures beneath the coastal and hilly areas, underlining the importance of reinforcing the seismic network in Marche for more effective instrumental coverage. The expansion of the seismic network has also made it possible to detect transversal alignments of great geodynamic significance. In this context, the role of local seismic networks becomes fundamental, allowing for more precise and in-depth analysis of regional tectonic structures.

The introduction of seismographs enabled a quantitative assessment of the energy released by seismic events, whereas subjective evaluations remain relevant only for historical earthquakes. With the development of electronics, seismic instruments became more compact and lightweight compared to older models, such as those by Vicentini and Agamennone. These new instruments are easier to transport and deploy, and the ability to record across different frequency bands enables the analysis of both seismic sources and wave propagation. Digitalization has further enhanced data acquisition, making it possible to collect and analyse large volumes of data efficiently. Today, high-dynamic digital seismic data acquisition systems can be designed using commercially available components at relatively low costs. Digital lines now allow seismic stations to transmit not only digital signals but also extensive information that analogue systems could not carry. Each transmitted data packet includes the sampled seismic signal, the GPS-based sampling time, a station ID code, and all relevant parameters describing the station, the seismic sensor, and the installed electronics.

This system ensures that each data packet is self-contained, with all necessary information for data interpretation included within. Consequently, accurate data analysis no longer depends on managing separate parametric archives manually. Furthermore, seismic stations equipped with computing capabilities can report on the operational status of the installed instruments. Digital transmission allows verification, testing, and calibration remotely from a central control room, without needing to send technicians to the site.

The National Institute of Geophysics and Volcanology (INGV) operates a network of more than 500 seismic stations across Italy and nearby regions, forming the National Seismic Network (RSN). Additional regional and local networks, such as the Montefeltro Seismic Network managed by institutions like the University of Urbino in collaboration with INGV, also contribute to national seismic monitoring. These local networks are particularly useful for detecting low-magnitude earthquakes, even those below M = 1.0. In the near future, efforts will focus on achieving more accurate hypocentral relocations to better outline the seismogenic structures in the Montefeltro area. A new software tool is also expected to be used for calculating focal mechanisms, enabling solutions even for small-magnitude events.

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