Montefeltro seismicity: from Serpieri's seismograph to the RSNC seismograph station

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Abstract
In recent years, the recovery of some historical documents has permitted us to operate the seismographs used by Alessandro Serpieri (1823-1885) at the Observatory of the University of Urbino in the XIX century. The space-time concept of sensor network was already clear to Serpieri and he tried to apply this concept to the analysis of seismic phenomena in Italy. This paper reviews the history of the Urbino Observatory from Serpieri's age to present times. The historical region of Montefeltro, where Urbino is the main town, is affected by seismicity with typical magnitudes between 2.2 and 2.5. Most of these events occur in the upper 15 km of the crust. The seismicity of the neighbouring regions is mainly concentrated in three zones: Northern Rimini, the Apennine belt and the Sibillini Mountain area. From the overall data, it is possible to infer that there is a basin characterised by microseismicity and essentially dominated by a compressive tectonic regime in the Montefeltro area. Furthermore, seismological data seem to show a «quiet» segment, separating the extension area from the compression area, characterised by a low concentration of seismic events.

Key words *seismicity – Montefeltro – seismological data – Urbino Observatory*

1. Introduction

An overall seismic or geodynamic interpretation of the Central-Northern Apennines is difficult, the latter being characterised by complex structures which cannot be defined in the form of a simple, standard model. From the XIX century to the present day, many attempts have been made to explain the evolutionary stages behind the present tectonic structure. The most recent reconstructions interpret the Apennine belt according to the accretionary wedge model (Treves, 1994; Vai, 1994).

The present paper reviews the history of seismological observations in Urbino, from Serpieri's age to the present day. This study is oriented towards the definition of Montefeltro seismicity.

The amount of data and information increased notably over the years and, above all, with the development of better processing systems and techniques.

2. Seismology in the XIX century

The study of earthquakes in XIX century in Italy was not only aimed at the study of the seismic paroxysm, an exceptional and destructive event, but also at examining those movements, called microseismic, which could not be perceived by the human senses. This was a purely Italian field of study.

Many accurate observations on the movement of level bubbles were carried out by Mr.

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D'Abbadie from 1837 in Brazil, Abyssinia and in France, in which he noted that the Earth's surface is subject to slow small oscillations, and consequent variations of the vertical. Mr. Plantamour, 1878, repeated these experiments in Switzerland and obtained similar results (Serpieri, 1850).

In Italy, in 1855-1856, Canon Parnisetti from Alessandria carried out numerous experiments on the small spontaneous movements of pendulums. Nonetheless, those observations remained isolated and largely unknown until 1870 when Father Bertelli, after observing a simple pendulum seismometer, noted that there were many oscillations in the absence of any earthquake tremors. To be certain that those small movements of the pendulum were really of seismographic origin, he tried to eliminate any cause of error by isolating the pendulums in order to protect them from vibrations not inherent to seismic movement. Furthermore, in his observations of pendular movements he used a microscope with a metric scale in the eyepiece. Bertelli's first instrument invented for observing not only perceivable earthquakes but all the microscopic movements of the Earth, was called a «Tromosismometro» (fig. 1).

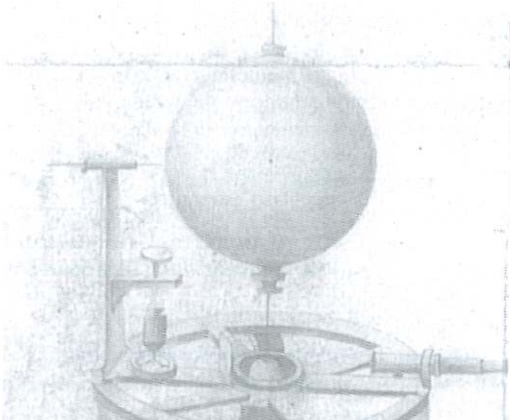

Fig. 1. Bertelli's tromometer, from his original drawing (Ferrari, 1991).

With the «Tromosismometro» Father Bertelli observed not only the minimum oscillation movements and the instantaneous jump of the pendulums, but also the slow upheaval and downheaval of the Earth's surface, shown in the movement of the vertical.

Figure 2 shows a few examples of recordings obtained by Bertelli's tromometer in 1872, and thus the first observations. The dominant period of the signals is in the order of hours and the episodes often follow one another with a more than daily occurrence. Maximum dimensions are of 100 μrad.

Following the first observations by Parnisetti, Bertelli, Monte, De Rossi, etc., many other Italian seismologists started microscopic observations. Bertelli and De Rossi together designed and built a Normal Tromometer that was adopted by all the observatories in the various microseismic stations, thus making the observations easier to compare. They suggested, for example, that the pendulum was to be 1.50 m in length and weigh 100 grams. Lastly, one must mention the observation made by many Italian seismologists who stated that perceivable earth tremors are usually preceded by extraordinary microseismic activity and specifically by vertical movements (Serpieri, 1854).

3. Serpieri's seismograph

The eldest son of a large family, Alessandro Serpieri was born in 1823 at San Giovanni in Marignano, a few kilometres from Rimini. He received the first rudiments of his education at home and later attended school in Rimini where he obtained excellent results. In view of this, his father took him to Urbino, where he studied under the religious order of the Piarists, whose school had been founded in 1699 by Pope

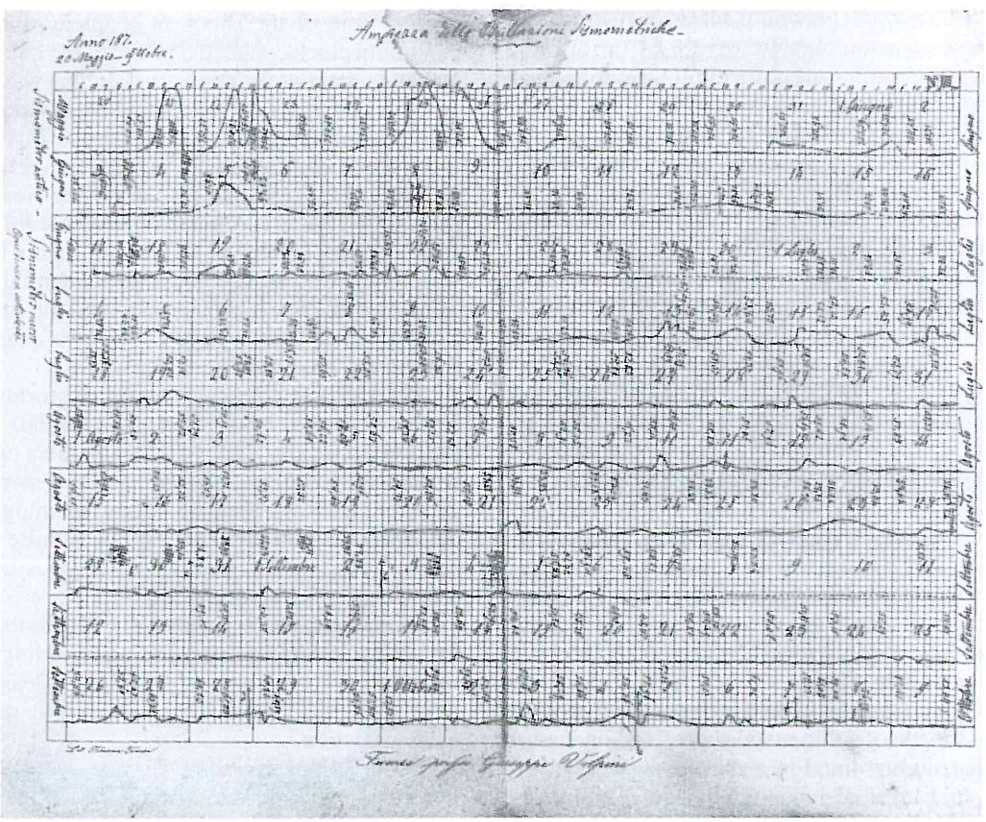

Fig. 2. Tromometric curves obtained by Bertelli (Dragoni, 1991).

Clement XI, also from Urbino. The school, originally assigned to the Piarists of the Province of Rome, came under the jurisdiction of the Province of Tuscany in 1831.

In 1838, at the age of 15, Serpieri left Urbino to continue his education in Florence, again at a Piarist school. The first period of training for young people following the Piarist educational system was carried out in quiet solitude in a house near Florence. On completing this training at the end of 1840, Serpieri went to the Specola Ximeniana, at St. Giovannino, where he immediately started his scientific studies, which were to continue for a period of three years.

Finally, in 1843 Serpieri began his teaching career. The chair of Mathematics and Philosophy at the Tolomei College in Siena, considered to be one of the foremost in Italy, became vacant and was assigned to Serpieri, despite the fact that he was only twenty years old at the time. In the meanwhile, in 1846, the chair of Physics and Philosophy had become vacant at Urbino and was temporarily assigned to Serpieri. Two months later, confirmation of the position arrived from Rome in the form of a decree dated 19th January 1847. Therefore, at only twenty-three years of age, Serpieri became University Professor of Physics, a position which he held until 1884.

Serpieri designed his seismograph on the basis of his experience. The pendulum consisted of a long wire 135 cm in length with a ball on the bottom which had a vertical point on the

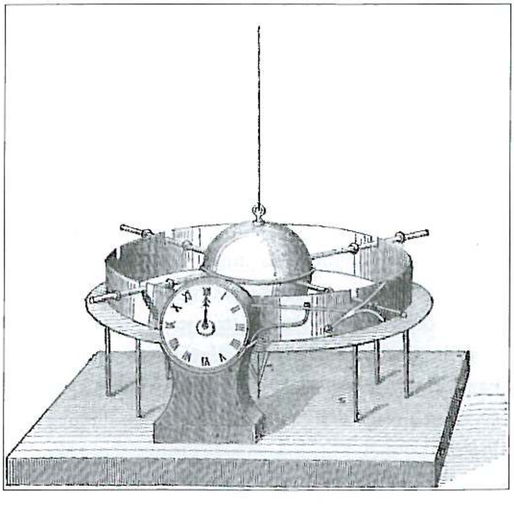

Fig. 3. Serpieri's seismograph, as described in a memory of 1873.

lower side, slightly touching a layer of lycopodium dust (fig. 3).

A horizontal circle is concentric to the ball. This is made of a thin metal sheet fixed on many small columns fixed in a marble surface, covered in a layer of lycopodium dust. The circle has a diameter of 32 cm and the ball 10 cm.

The upper rim of the circle is about 4 cm higher than the equator of the ball. There are small recesses on that circle, 15 mm deep, semicircular, in directions going from N-S, W-E and in the intermediate points. Around the equator of the ball there is a ring made of metal wire. Four or eight small metal bars rest their ends on this equatorial ring. Near the other ends they rest in the recesses in the circle around the ball, jutting out to a large degree from the same and remaining more or less horizontal.

Therefore if the Earth moves from W to E, the bar resting on the W recess falls out, pulling along and then rotating on the edge of that recess. In the same way the side bars of N and S fall inwards as the resting point on the equatorial ring of the ball has been removed. In this way, the bar which has fallen out, will indicate the direction of the first wave. Furthermore, it will be possible to read the tracks left by the point attached to the ball from the powder underneath.

The time of the shock is given by a small pendulum clock connected to one of the bars and placed in front of the apparatus. In this way, the clock indicates only the time that has passed since the first shock. It is necessary to subtract this time interval from the real time to obtain the correct time.

From the information supplied by Serpieri himself (Serpieri, 1879), we know that this instrument was located in a niche dug into a large wall, many metres high, built on the land of the «Collegio dei Nobili» in Urbino, and the instrument was protected by glass doors. To date this instrument has never been found.

Two other instruments were more fortunate. These were used by Serpieri at a later date than the one previously described. These are a protoseismograph designed in 1875 by the seismologist M.S. De Rossi and a recording seismograph designed and built around 1882 by Achille Scateni, assistant to the Cabinet of Physics at the University of Urbino (see fig. 4).

From what can be seen from various studies, including those by Serpieri on buildings or monuments in Urbino, earthquakes, at least the stronger ones, always shake the Earth in the same direction.

Observations covering 23 years show that, out of 100 earthquakes, 33 have directions covering the line NNW to SSE and the remaining 67 fall near the line WSW-ENE and what is more, the two lines are perpendicular one to the other, as set forth in the theory.

Examining all the small and large earthquakes recorded from 1850 to 1873 Serpieri obtained the data shown in table I.

As a result, certain walls in buildings in Urbino are cracked and others perpendicular to those are intact, and vaulted ceilings become disconnected due to undulations perpendicular to their axes.

4. The 12th March 1873 earthquake

An important seismological analysis was made by Serpieri with a study of the 12th March 1873 earthquake, whose epicentral zone was the Southern Marche area and the epicentral intensity was between VIII and IX degrees on the Mercalli scale.

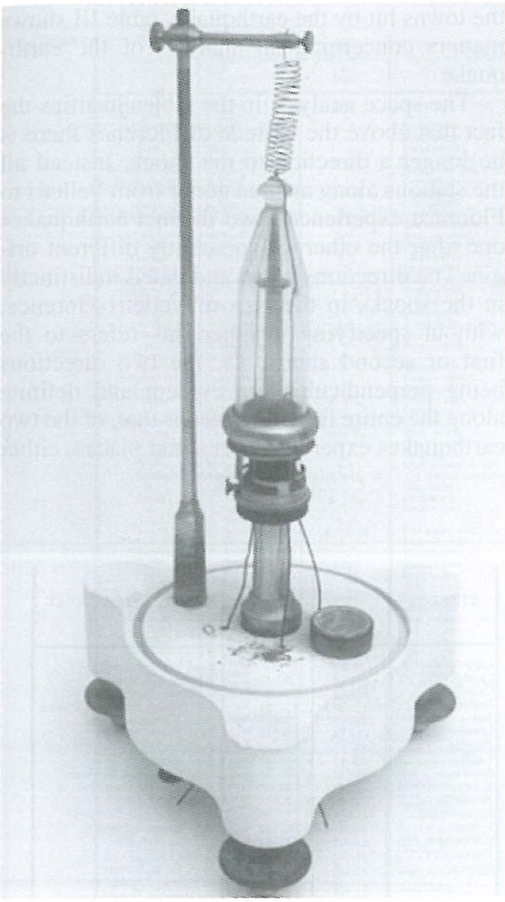

Fig. 4. Scateni's seismograph, for horizontal oscillations (photo by R. Persi).

Serpieri wrote the following (Serpieri, 1873a): «*Il giorno 13 Marzo, quando ancora l'impressione lasciata dallo strepitoso fatto era vivissima in tutti e le sue particolarità erano argomento dei comuni discorsi, mandai una circolare ai primari nostri Osservatorii e a molti distinti professori, pregandoli di precise risposte a una breve serie di quesiti che credetti più opportuni per giungere a fissare gli elementi principali del fenomeno. Ben presto, favorito dalla gentilezza di tutti, mi trovai in possesso di molte ben fatte relazioni. Queste prime relazioni mi suggerirono nuove ricerche, e mi fecero conoscere che alcuni dati, massime quello dei tempi, erano ben difficili a stabilirsi con certezza, e richiedevano nuove pazienti indagini. D'altro canto io vedeva bene che senza avere giustamente stabilito in che ora e a che minuto preciso il terremoto traversava le varie stazioni, non si sarebbe mai giunti a formarsi un esatto criterio sull'andamento del fenomeno.*» («On 13th March, when the thunderous event was still fresh in everyone's minds and every detail was being discussed by all, I sent a circular to our leading Observatories and to many distinguished professors, asking for exact replies to a short series of questions which I thought most opportune to establish the principal features of the phenomenon. Favoured by the kindness of all concerned, I was soon in possession of many well-written reports. These first reports gave me ideas for new research and informed me that some data, especially those on the times, were difficult to establish with certainty and required patient new

Table I. Earthquakes recorded from 1850 to 1873 by Serpieri (Gambuti, 1990).

Legenda	*P*-wave direction			Number of events		
Shocks from	S	to	N	8	out of	100
Shocks from	SSW	to	NNE	0	out of	100
Shocks from	SW	to	NE	38	out of	100
Shocks from	WSW	to	ENE	4	out of	100
Shocks from	W	to	E	25	out of	100
Shocks from	WNW	to	ESE	0	out of	100
Shocks from	NW	to	SE	25	out of	100
Shocks from	NNW	to	SSE	0	out of	100

studies. On the other hand, I could well see that without having rightly established at what hour and what exact minute the earthquake had struck the various stations, we would never have been able to formulate an exact criterion as to the trend of the phenomenon.»).

Having stated this fundamental fact, Serpieri once again invited observers to clarify the hour and minute in which the earthquake was noticed, in order to know for certain whether the time given referred to real time, average time of the area or average time in Rome (Serpieri, 1873b).

A general outline analysis of the earthquake is shown below, consisting of two tables: table II is an organisational chart of the latitudes of the towns hit by the earthquake, table III shows matters concerning an analysis of the earthquake.

The space analysis in the tables justifies the fact that above the latitude of Florence there is no longer a direction to the shock. Instead all the stations along an area going from Velletri to Florence experienced two distinct earthquakes one after the other, of apparently different origin. The directions noted and dated indistinctly in the shocks in the area of Velletri-Florence, without specifying whether this refers to the first or second shock, *i.e.* the two directions being perpendicular, are evident and definite along the entire line. This means that, of the two earthquakes experienced in some places, either

STAZIONI	LATITUD.	LONGITUD. in t. m. da Roma	NOMI DEGLI OSSERVAT.
Cosenza	39°. 19'	14'. 58'' E.	Prof. Domenico Conti.
Napoli	40. 52	7. 11 E.	Prof. Luigi Palmieri.
Velletri	41. 41	1. 18 E.	D. Ign. Galli e Ing. P. Dituccі.
Sora	41. 43	4. 59 E.	Prof. Nicolucci.
Anagni	41. 45	2. 49 E.	Dottor Zappasodi.
Castel Gandolfo	41. 45	0. 47 E.	Luigi Marazzi.
Rocca di Papa	41. 46	1. 2 E.	Salvatore Fondi ed altri.
Frascati	41. 48	0. 54 E.	P. Lavaggi.
Monte Porzio	41. 49	1. 3 E.	T. Ricci.
Piglio	41. 50	2. 46 E.	Ing. Ed. Lupi.
Roma	41. 54	0. 6 E.	P. Angelo Secchi.
»	41. 54	0. 0	Prof. Michele Stefano De Rossi.
Ciciliano	41. 57	1. 57 E.	R. Riccardi.
Tivoli	41. 58	2. 22 E.	Canon. Coccanari.
Avezzano	42. 2	3. 54 E.	Ing. Ludovici.
Monte Rotondo	42. 3	0. 39 E.	Giuseppe Gatti.
Civitavecchia	42. 6	1. 58 E.	Ing. Giuseppe De Andreis.
Aquila	42. 21	3. 31? E.	Ing. Partini e B. Bonanni.
Chieti	42. 21	6. 50 E.	Prof. Enrico Cristini.
Rieti	42. 24	1. 37 E.	Dottor Riccardo Gamba.
Viterbo	42. 25	1. 24 W.	Prof. G. Barbieri, e D. S. Medi-
Pescara	42. 26	7. 13 E.	Dott. Girolamo Orsi. (chini.
Orte	42. 27	0. 17 W.	Agostino Ralli.
Ragusa	42. 37	22. 40 E.	Prof. G. Podielm.
Bagnorea	42. 38	1. 26 W.	Carlo Raffaele Gualterio.
Teramo	42. 40	4. 49 E.	Prof. Carlo Fracassa.
Acquasparta	42. 41	0. 22 E.	E. Achillini.
Orvieto	42. 43	1. 22 W.	Prof. Luigi Chatel.
Spoleto	42. 44	1. 8 E.	Prof. Arpago Ricci.
Grosseto	42. 46	5. 21 W.	Prof. Andrea Bongini.
Todi	42. 47	0. 12 W.	Prof. Enrico Ippoliti.
Norcia	42. 47	2. 33 E.	Prof. Santoni e Prof. Colantoni.
Ascoli	42. 51	3. 51 E.	Prof. G. Tranquilli e A. Saladini.
Trevi	42. 53	1. 10 E.	Prof. Arpago Ricci.
Monte Fortino	42. 56	5. 33 E.	Luigi Antonini.
Foligno	42. 57	1. 0 E.	Prof. Giovanni Salvatori.
Amandola	42. 59	3. 38 E.	L. Antonini e V. Astorri.
Spello	42. 59	0. 52 E.	Prof. Luigi Gaspari.
Penna S. Giov.	43. 3	3. 52 E.	Vincenzo Astorri.
Sanginesio	43. 6	3. 27 E.	Signor Sindaco.
Perugia	43. 7	0. 16 W.	Prof. Dal Pozzo e Prof. Bellucci.
Camerino	43. 8	2. 27 E.	Prof. Luigi Berti.
Fermo	43. 10	5. 2 E.	Prof. Giulio Agolini Ugolini.
Matelica	43. 15	2. 13 E.	Prof. Filippo De Sanctis.
Macerata	43. 18	3. 59 E.	Prof. Piero Giuliani.
Civitanova	43. 18	5. 6 E.	Prof. F. Mici e Prof. G. Cecca-
Fiena	43. 19	4. 28 W.	Prof. Cesare Toscani. relli.
Sigillo	43. 20	1. 9 E.	Ubaldo Colini.
Sabriano	43. 20	1. 48 E.	Prof. C. Morbelli e Prof. A. Zon-
Cingoli	43. 22	3. 2 E.	Gaetano Castiglioni. ghi.
Volterra	43. 24	6. 22 W.	P. Prospero Lotti.

STAZIONI	LATITUD.	LONGITUD. in t. m. da Roma	NOMI DEGLI OSSERVAT.
Città di Castello	43°. 27'	0.' 52'' W.	Prof. Saverio Santini.
Cantiano	43. 28	0. 42 E.	Antonio Giordani.
Castelplanio	43. 29	2. 30 E.	Giacomo Angeli.
Spalatro	43. 30	15. 54 E.	I. R. Istituto Meteor. di Vienna.
Jesi	43. 31	3. 8 E.	Prof. V. Mattioni.
Livorno	43. 32	8. 37 W.	Prof. Pietro Monte.
Pergola	43. 33	3. 30 E.	P. Raffaele Piccinini.
Cagli	43. 33	0. 47 E.	Prof. Gregorio Mei.
Ancona	43. 37	4. 11 E.	Prof. Francesco De Bosis.
S. Angelo in Vado	43. 39	0. 12 W.	Prof. Ernesto Antonini.
Mondavio	43. 40	2. 1 E.	Giuseppe Monti.
Fossombrone	43. 41	1. 22 E.	Prof. Giuseppe Ceccarelli.
Urbino	43. 43	0. 44 E.	P. Alessandro Serpieri.
Cartoceto	43. 46	1. 12 E.	Camillo Marcolini.
Pontassieve	43. 46	4. 1 W.	Guido Libri.
Firenze	43. 46	4. 49 W.	Prof. G. B. Donati.
»	43. 46	4. 47 W.	P. Filippo Cecchi.
»	43. 47	4. 42 W.	P. Timoteo Bertelli.
Sebenico	43. 48	13. 56 E.	I. R. Istituto Meteor. di Vienna.
Pennabilli	43. 49	0. 44 W.	Prof. Dario Mattei.
Fano	43. 51	2. 14 E.	Prof. Avoni.
S. Marino	43. 56	0. 1 W.	Palamede Malpeli.
Rimini	44. 3	0. 33 E.	Osservatorio e P. T. Bertelli.
Savignano	44. 6	0. 14 W.	Ing. Lucio Fellini.
Zara	44. 7	11. 4 E.	I. R. Istituto Meteor. di Vienna.
Porretta	44. 9	5. 53 W.	P. Timoteo Bertelli.
Forlì	44. 13	1. 39 W.	Antonio Merlini.
Genova	44. 26	14. 4 W.	Prof. G. M. Garibaldi.
Bologna	44. 30	4. 24 W.	Prof. Alessandro Palagi.
Modena	44. 39	6. 6 W.	Prof. Domenico Ragona.
Pola	44. 52	5. 32 E.	I. R. Istituto Idrografico.
Alessandria	44. 54	15. 21 W.	Can. Pietro Parnisetti.
Moncalieri	45. 0	18. 55 W.	P. Francesco Denza.
Mantova	45. 10	6. 57 W.	Prof. Agostini.
Pisino	45. 13	5. 48 E.	I. R. Istituto Meteor. di Vienna.
Lodi	45. 19	11. 47 W.	Prof. Stanislao Belli.
Fiume	45. 20	7. 56 E.	Prof. Stahlberger dell'I. R. Acc.
Padova	45. 24	2. 20 W.	R. Osservatorio. (Milit.
Umago	45. 25	4. 17 E.	I. R. Istituto Meteor. di Vienna.
Venezia	45. 26	0. 27 W.	Prof. Giuseppe Meneguzzi.
Milano	45. 28	13. 0 W.	Prof. G. V. Schiaparelli.
Trieste	45. 39	5. 16 E.	I. R. Istituto Meteor. di Vienna.
Aosta	45. 44	20. 25 W.	Prof. P. G. Volante.
Varallo	45. 48	16. 44 W.	Prof. Pietro Calderini.
Lugano	46. 0	14. 0 W.	Osservatorio.
Udine	46. 4	3. 7 E.	Prof. Gio. Clodig.
Belluno	46. 8	0. 57 W.	A. De Fulcis.
Grubhof (nel Salisburgh.)	47. 35	0. 55 E.	Contessa Von Almasy.

Table II. Locations hit by the 12th March 1873 earthquake (Serpieri, 1873a).

Stazioni	Osservatori	Ora in tempo medio di Roma	Genere del movimento	Diminuzione o tregua	Durata in secondi	Direzione (Donde venivano o dove andavano le ondulazioni) prima	seconda	terza	unica	Forza
Cosenza	D. Conti	9. 0	Sussultorio — ondulat.		12				NW	debole
Napoli	F. Brioschi									debolissimo
Velletri	I. Galli	9. 5	Ondulatorio	dimin.	30		SW			forte
id.	P. Dinucci		Ondulatorio	tregua		WNW				forte
Sora	Nicolucci		Ondulatorio						W	mediocre
Anagni	Zapparodi	9. 7	Due scosse ond.		15				NW	forte
Castel Gandolfo	L. Marazzi		Due scosse ond.	lunga tregua	10				NW	mediocre
Rocca di Papa	S. Fondi		Ondulatorio		5				SW	
Frascati	P. Lavaggi	9. 2?	Ondulatorio		10				NW	
Piglio	E. Lupi		Ondulatorio		10				N	mediocre
Monte Porzio	T. Ricci	9. 3	Ondulatorio		16				WSW	debole
Roma	A. Secchi	9. 5	Tre moti ondosi							mediocre
id.	M. De Rossi	9. 6	Suss. — ondul.	tregua	18	NW	SW			forte
Tivoli	Coccanari		Ondulatorio		16	N?	W?			fortissimo
Ciciliano	R. Riccardi	9. 5	Ondulatorio						NW	fortissimo
Avezzano	Ludovici		Ondulatorio		4				N	forte
Monte Rotondo	G. Gatti		Ond. — sussul. — ond.	no	60					forte
Civitavecchia	De Andreis		Ond. — suss.			NW				forte
Aquila		9. 7?	Ondulatorio						W	debole
Chieti	E. Cristini		Ondulatorio	no	3				NW	debole
Rieti	R. Gamba	9. 6	3 ond. legg., 3 forti		11	NW	SW			mediocre
Viterbo	G. Barbieri	9. 0 — 9. 10	Suss. — ond.		6					mediocre
id.	S. Medichini		Suss. — ond.	tregua	9	SW	NW			forte
Pescara	G. Orsi	9. 5								debole
Orte	A. Ralli		Ondulatorio						SW	forte
Bagnorea	R. Gualterio		Suss. — ond.	tregua	15				SSW	forte
Ragusa	G. Podfelm	8. 55	Ondulatorio	no					NW	mediocre
Teramo	C. Fracassa	9. 4 1/6	Suss. — ond.	dimin.	8					mediocre
id.	B. Bonanni		Ondulatorio						SSW	leggiero
Acquasparta	Achillini		Ondulatorio		25	W	NW			fortissimo
Orvieto	L. Chatel	9. 4 1/3	Suss. — ond.		25				NW	forte
Spoleto	A. Ricci	9. 2	Suss. — ond.	dimin.	14				SSW	fortissimo
Grosseto	A. Bongini		Ondulatorio						N	debolissimo
Todi	E. Ippolni	9. 0	Ond. — suss. — ond.		30				N	fortissimo
Norcia	Santoni	9. 2 1/2	Tre serie di ondulazioni	due tregue	17				W	forte
id.	Colantoni		Suss. — ond.		23	W	NW			forte
Ascoli	G. Tranquilli	9. 3 1/2	Ondulatorio		16				N	forte
id.	A. Saladini		Suss. — ond.		14				NW	fortissimo
Trevi	A. Ricci	9. 4								
Foligno	G. Salvatori	9. 0 circa	Due scosse ond.	dimin.	7				WSW	forte
Monte Fortino	L. Antonini	9. 5	Suss. — ond.	no	18				NNW	forte
Amandola	V. Astorri		Ondulatorio						NNW	fortissimo
Spello	L. Gaspari	9. 3?	Suss. — ond.		6	NW?	SW?			mediocre
Penna	V. Astorri		Suss. — ond.				SW	W		fortissimo
San Ginesio	Sindaco		Suss. — ond.	dimin.	18				NW	fortissimo
Perugia	G. Bellucci	9. 2	Suss. — ond.	no	20	N. 30° W	S. 25° W	S. 5° W		fortissimo
id.	E. Dal Pozzo	9. 0	Misto: suss. - vort. - ond.		25		SW	NW		fortissimo
Camerino	L. Berti	9. 5 1/2	Suss. — ond. — suss.	dimin.	13				NNW	fortissimo
Fermo	A. Ugolini	8. 59	Suss. — ond.		38		SSW			forte
Matelica	F. De Sanctis	9. 5 1/2	Suss. — ond.		20				NW	forte
Macerata	P. Giuliani	9. 3	Suss. — ond.		15		WSW			forte
Siena	C. Toscani	9. 7 1/2	Ondulatorio		9	N	W			mediocre
Sigillo	U. Colini		Ondulatorio		7				SW	forte
Fabriano	C. Morbelli	9. 5	Ond. — suss. — ond.		25		SW			fortissimo
Fabriano	A. Zonghi		Scossa a 3 riprese		20	WNW				fortissimo
Cingoli	G. Castiglioni	9. 7 1/2	Ond. — suss. — ond.		12				NW	fortissimo
Volterra	P. Lotti	9. 7 1/2	Ondulatorio	no	14				SW	debolissimo
Città di Castello	S. Santini		Suss. — ond.		25		WSW			forte
Cantiano	A. Giordani		Ondulatorio		12				SW	forte
Castelplanio	Staz. ferrovia	9. 4								
Spalatro		9. 2 1/2			1 1/2				NW	forte
Jesi	V. Mattioni	9. 6	Ond. con sussulti		4				W	forte
Livorno	P. Monte	9. 8 1/2 - 9. 18 1/2	Ondulatorio			WSW	NNW?			debolissimo
Pergola	R. Piccinini	9. 5							SSW	fortissimo
Cagli	G. Mei	9. 4	Suss. — ond. — suss.		35		SSW			fortissimo
Ancona	F. De Bosis G. Orsi	9. 5	Ondulatorio	dimin.	9	SW	NW			mediocre
S. Angelo in Vado	E. Antonini		Ondulatorio	tregua	4				N	mediocre
Mondavio	G. Monti		Ond. — suss. — ond.		28				WSW	forte
Urbino	A. Serpieri	9. 4 1/4	Ondulatorio	tregua	35	NNW	WSW			fortissimo
Pontassieve	G. Libri		Due o tre scosse	tregua		NW				forte
Firenze	G. B. Donati	9. 5 4/6			4	NW				mediocre
id.	F. Cecchi	9. 3 4/6	Misto: ond. - rotat. - suss.		5 1/2		SSW			mediocre
id.	T. Bertelli	9. 2 5/6	Suss. — ond. — rotat.		5	NW	SW	N?		mediocre
id.	Uff. Telegr.	9. 4								
Sebenico		9. 2 1/2			4 1/2				NW	forte
Pennabilli	D. Mattei				60				W	forte
Fano	Avoni	9. 3 circa							SW	forte
S. Marino	P. Malpeli	9. 5	Sussult. — ondulatorio	tregua	6				N	debole
Rimini	Oss. e Bertelli	9. 5	Due scosse ondulatorie	tregua					W	mediocre
Savignano	L. Fellini	9. 4 1/2					W			mediocre
Zara		9. 0			3					forte
id.	Prof. del Sem.		Due scosse ondulatorie	tregua					NW	forte
Porretta	T. Bertelli	9. 5								debole
Forlì	A. Merlini		Ondulatorio	tregua	8				WNW	debole
Genova	P. M. Garibaldi	9. 15	Due scosse						SW	debolissimo
Bologna	A. Palagi	9. 6 1/2	Misto: ondul. — sussult.		3				W	debole
Modena	D. Ragona	9. 7	Due scosse ondulatorie	tregua					NW	debolissimo
Pola	I. R. Ist. Idrogr.	9. 4 1/2	Ondulatorio		3 1/2				NW	debole
Alessandria	P. Parnisetti								N	debolissimo
Moncalieri	F. Denza	9. 9							SSW	debole
Mantova	G. Agostini	9. 4	Ondulatorio						N	debole
Pisino		9. 4 3/4								forte
Lodi	S. Belli	9. 3?							NNW	forte
Fiume	E. Stahlberger	9. 4	Ondulatorio		7				W	mediocre
Padova	Osservatorio	9. 6 1/3	Sussult. — ondulatorio		4					debole
Umago		9. 5 1/2								forte
Venezia	G. Meneguzzi	9. 7 1/2	Sussult. — ondulatorio		25	NW	N			mediocre
Milano	G. V. Schiaparelli								NW	debole
Trieste		9. 4 1/2								forte
Aosta	G. Volante	9. 5 1/2 - 9. 10 1/2	Ondulatorio						NW?	debolissimo
Varallo	P. Calderini	9. 5 circa								debolissimo
Lugano	Osservatorio	9. 5 circa	1.a Scossa							debole
id.	idem	9. 10 circa	2.a Scossa							più debole
Udine	idem	9. 5								
Belluno	A. De Falcis	9. 8	Scossa ondulatoria							debole lungo
Grubhof (nel Salisburghese)	C.te Von Almasy	9. 22 1/2	Ondulatoria		3					mediocre

Table III. Observations of the 12th March 1873 earthquake (Serpieri, 1873a).

Fig. 5. Seismographic chart of the 12th March 1873 earthquake, from Serpieri's studies (photo by R. Persi).

one or the other was also noted in the intermediate areas. Furthermore it can be stated that the shock occurred around the axis of the peninsula and was concentrated along the axis itself.

The time analysis of the tables clearly shows that the clocks in the central area shook, on average, 3 min before those in the lateral areas and it is as if the earthquake in the central axis of the peninsula branched out to the sides.

This space/time analysis which Serpieri recorded of the earthquake on 12th March 1873 was a superb demonstration of the De Rossi theory, as shown by the graphic representation of the seismographic chart in fig. 5.

5. Instrumental recent developments in the Montefeltro area

The FB9 seismographic station installed at Cesane near Urbino in 1995, initially with the vertical component only, was the result of collaboration between the University of Urbino, Institute of Physics and the National Institute of Geophysics (ING) at Rome. This station is part of a network scattered throughout the national territory operated by ING with the purpose of monitoring and recording seismic phenomena in the interests of research and civil defence.

To ascertain that the system undertook a speedy acquisition and an accurate reproduction of seismic waves, particular attention was paid to the collection of data, used, not only in the formulation of statistics, but above all in the interpretation of tectonic phenomena underway and the study of the structure of the Earth's crust.

This necessity has led to the adoption of an A/D data collection system which is fast, with a high resolution (80000 readings/s and 12 bit resolution) and able to store a large quantity of data on the main memory of a PC as well as being able to view all seismic events transmitted by the station in real time.

An automatic method of continual monitoring over the twenty-four hours has been set up to detect seismic events, determine the magnitude and record on file. The data is stored in the form of files which can be copied onto floppy disks, ready for processing by the user.

The choice of a system most suited to our requirements was made on the basis of careful documentary research, with particular attention to software available and the hardware necessary for the development of the various applications. The objective was to have flexible, simple software available which could also be used by people with no programming experience.

Since December 1997 the Cesane seismographic station has been equipped with two further sensors (two horizontal components) having a frequency band from 0.1 Hz to 1.1 Hz. As a result it is now possible to collect a quantity of data that, when properly processed, will be of considerable help in achieving a better understanding and a more in-depth analysis of seismic phenomena.

6. Instrumental data analysis

Historical and instrumental data on seismicity in the Montefeltro area are considered. It is well known that the use of historical data involves considerable problems, largely connect-

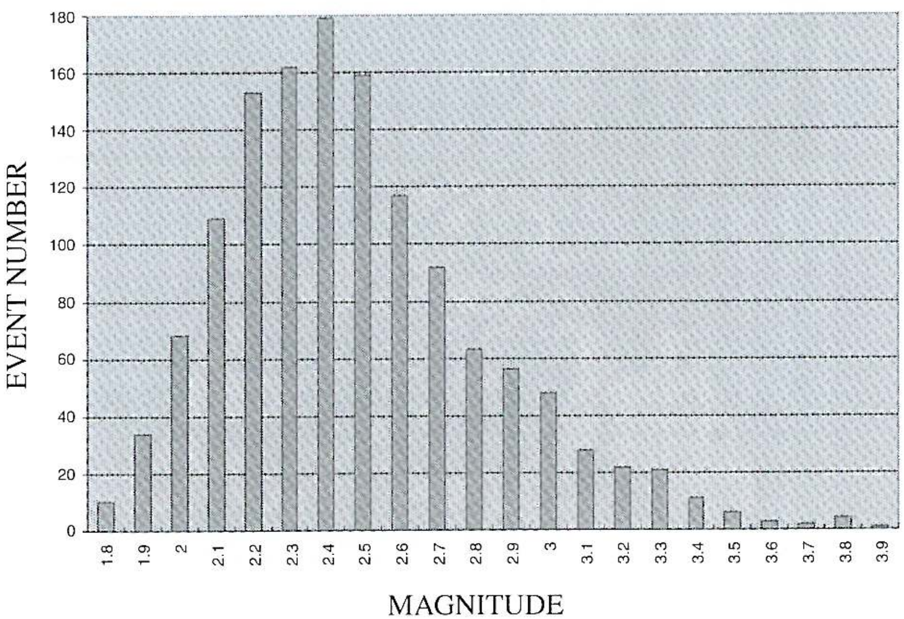

Fig. 6. Bar chart of the number of events in the period January 1990 - April 1996 in the considered area; the abscissa axis shows the duration magnitude, while the ordinate axis shows the event number.

ed to their strongly subjective nature, the difficulty in locating and differentiating real and apparent epicentres, or the assessment of effects and damage caused by an earthquake.

Instrumental data (from 1990 to 1996) were extracted from the Italian Seismic Data Bank which stores data of events recorded from 1986 by the National Centralised Seismic Network (RSNC), in which «FB9» is the Urbino station of approximately 85 stations distributed nation-wide.

The statistical analysis of instrumental data foresees dividing the events distributed in classes of magnitude. The analysis indicates that the North-East Apennine area is marked by frequent microseismicity.

Relative to the bar chart of division in accordance with class of magnitude with variation of 0.1 (fig. 6), the events occur in an interval of magnitude between 2.2 and 2.5. The events are cut off below a value of 1.8 (the minimum magnitude recorded by the ING network and below which the signal is considered to be background noise).

From the diagram of epicentre distribution (fig. 7), it is possible to observe that the region being studied is characterised by widespread activity and also that it has no aseismic areas. The areas with the highest concentrations of activities, as shown by red ellipses, are:

– The Romagna sector, around the provincial town of Forlì.

– The Apennine Tusco-Umbro-Marchian sector, which extends from NW-SE following the general direction of the mountain range.

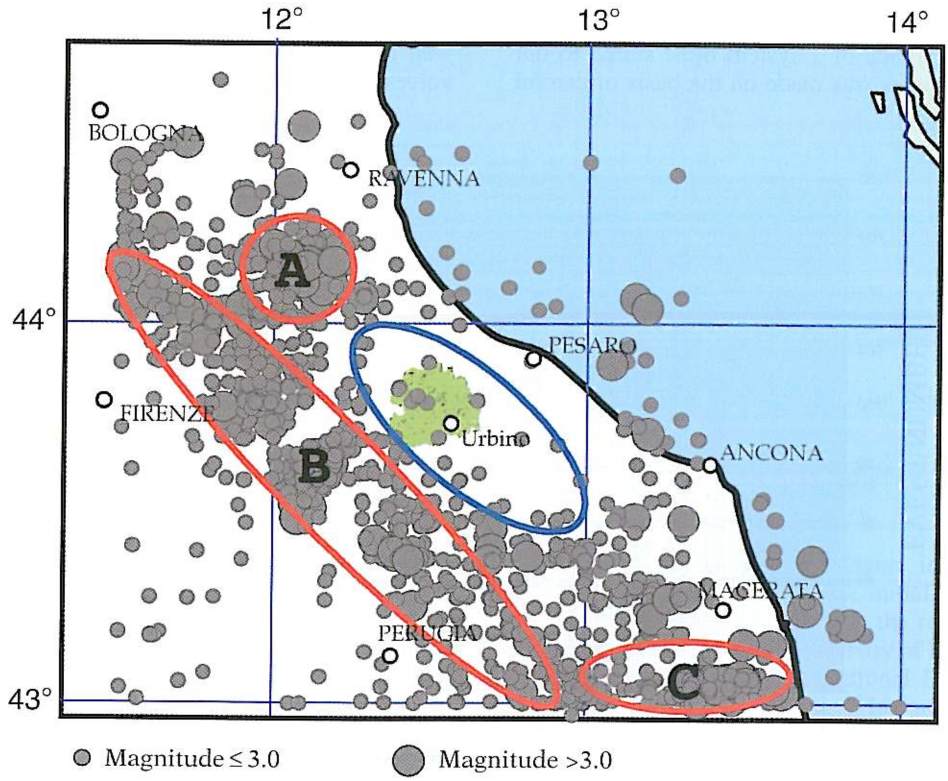

Fig. 7. Epicentre distribution of the events recorded by the Centralised National Seismic Network (RSNC) in the period January 1990 - April 1996.

– The Southern Marche sector, including the Sibillini Mountains and thereby the highest elevations of the area under examination.

The Montefeltro area (coloured in green in fig. 7) lies between areas marked by notable seismic activity and is characterised by limited values in terms of intensity and frequency (Console *et al.*, 1992). Until a short time ago, this area was considered to be totally aseismic. The Umbria-Marche area is affected by dual seismic activity which makes it possible to identify areas with distinctive tectonic styles. The areas of the Apennine ridge are, in fact, affected by a distensive tectonic phase, as is also shown by the focal mechanisms of the earthquakes in the Val Nerina (1979) and in Perugia (1984), both of which are characterised by a normal fault mechanism with a distension axis in an anti-Apennine direction and a vertical axis of maximum compression. On the contrary, the areas of Forlì and Ancona are characterised by seismicity that is essentially associated with transpressive and compressive type deformation (Lavecchia and Pialli, 1981; Gasparini and Praturlon, 1981; Frepoli and Amato, 1997), in spite of the fact that focal mechanisms relative to the event of Ancona (1972) and the sequence of Porto San Giorgio (1987) are still not yet clear (due to the scarce number of stations installed and of the fact that the epicentres were located in the sea).

It is important to note that the microseismicity of the portion of the Central-Northern Apennines studied is characterised by repeated event

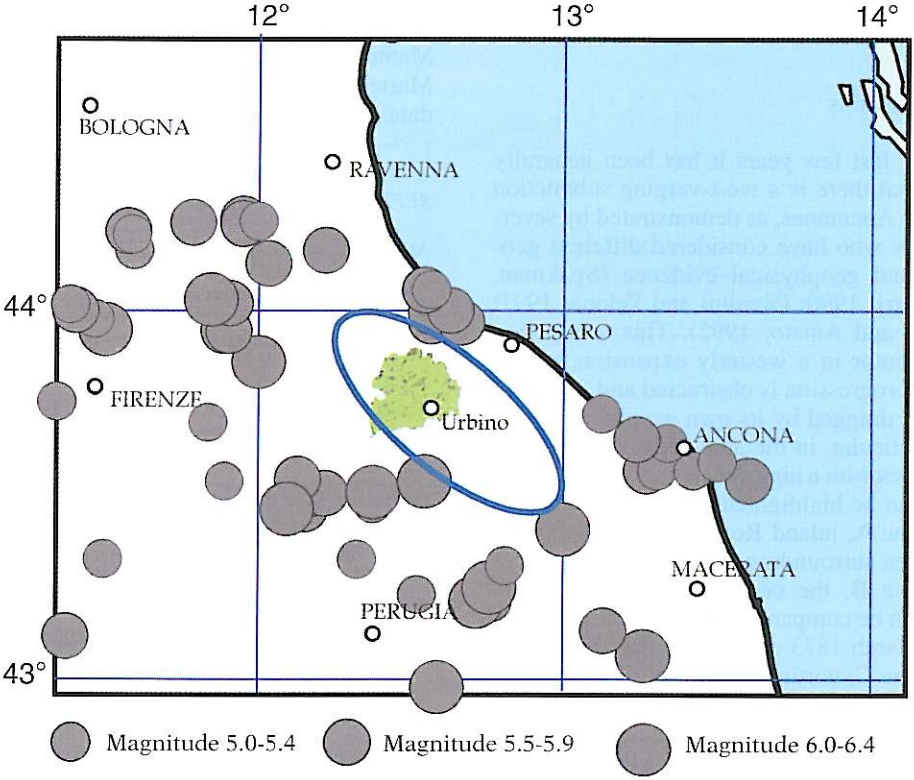

Fig. 8. Historical seismicity of the examined zone, with a magnitude $M \geq 5$.

sequences (swarms) which occur in the same zone and are separated by extremely reduced time intervals. This response to stresses can be attributed to a particular crustal structure at more superficial levels, since the events occur for the most part in the first 15 km. This is in agreement with the hypothesis that the presence of sub-crustal earthquakes, distributed along a plane dipping from the Adriatic towards the Tyrrhenian with a slope of approximately 40°-45°, is related to the subduction process of the Adriatic lithosphere under the Apennine arc (Amato and Selvaggi, 1991). A hypothesis of this nature is confirmed by further seismological evidence such as the anomalous propagation of surface waves as well as tomographic studies. In spite of this particularity, it is easy to observe a seismogenetic level between 0 and 15 km, inside which practically all earthquakes are concentrated. Activity, therefore, results as being mostly due to surface sources.

7. Conclusions

In the last few years it has been generally agreed that there is a west-verging subduction under the Apennines, as demonstrated by several authors who have considered different geological and geophysical evidence (Spakman, 1989; Serri, 1990; Giardini and Velonà, 1991; Selvaggi and Amato, 1992). This subduction has its motor in a westerly expansion, whose easterly progression is obstructed and the deeper part is dragged by its own weight.

In particular, in the area considered (fig. 7) three zones with a high concentration of seismic events can be highlighted as follows:

– Zone A, inland Romagna, corresponding to the area surrounding the town of Faenza;

– Zone B, the central pedeapennine belt, which can be compared to the epicentral area of the 12 March 1873 earthquake (fig. 5);

– Zone C, north of the Sibillini Mountains, defined by the neotectonics of the Southern Marche.

The absence of macroseismic events in the Montefeltro area, is confirmed by the absence in the examined zone of historical events, with magnitude $M \geq 5$ (Boschi *et al.*, 1997), as shown by the blue ellipse (fig. 8).

Further, from the overall data, it is possible to infer the presence of a microseismic basin in the Montefeltro area. This basin is essentially dominated by compressive tectonic structures. Furthermore, the seismological data seem to define a «quiet» segment, separating the extensive and compressive zones, with a low concentration of seismic events.

In conclusion, the considered area is characterised by low values of the magnitude and frequency of seismic events; but it is placed between areas with an appreciable seismic magnitude and then it can be affected by events with epicentres in the border zones.

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