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REVIEWING THE INTENSITY DISTRIBUTION OF THE 1933 EARTHQUAKE (MAIELLA, CENTRAL ITALY). CLUES ON THE SEISMOGENIC FAULT

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ABSTRACT: Here we deal with the study of a strong earthquake occurred in 1933 in the mountainous area of the Maiella massif (Abruzzi, central Italian Apennines). We carried out original archive researches that allowed to evaluate a novel macroseismic field, and new parameters for this earthquake (Io=Imax 9 MCS; Mw 6.01±0.07; epicentral coordinate: N42.050°, E14.191°). Then we compared its highest intensity distribution of this event with the known, active normal fault of the region, finding any possible matching with none of these. Therefore, considering the subsurface tectonic interpretation provided by the recent scientific literature, we hypothesize that a possible seismogenic structure for both the 1933, and the catastrophic 1706 event (Mw 6.9; roughly same 1933 epicenter) is the blind backthrust that developed during Early-Middle Pleistocene in the footwall of the Maiella anticline.

Keywords: 1933 earthquake; macroseismology; compressive tectonics; Maiella massif.

1. INTRODUCTION

At dawn of September 26 1933 (4:33 local time, 3:33 GMT) a strong earthquake struck the southeastern area of the Maiella massif (Abruzzo, central Italian Apennines), damaging heavily several villages, and causing extensive destruction in few localities, as in Lama dei Peligni, Taranta Peligna, and Civitella Messer Raimondo. The mainshock was closely preceded by two foreshocks that - alarming the inhabitants of the region - prompted most of them to escape from their houses, and to pass the night outsides their fragile, old stone-masonry houses. Therefore, in spite of the large amount of collapses and destructions (Fig. 1), this yielded a relatively little death toll (12 casualties), and less than two hundred injured.

Two centuries before, in 1706, the same region was hit by one of the strongest and deathful earthquake in the Italian history (Io 10.5; Mw=6.8. More than 2200 victims). Interestingly, the two events share a similar mesoseismic area, the older presenting much higher site intensities. Although the seismogenic sources of both earthquakes have remained unknown so far, giving the similarity of the respective Highest Intensity Datapoints Distribution (HIDD), it is possible that they could share segments of the same fault system.

In order to enhance the knowledge concerning the highest intensity distribution (Is$\geq$7 MCS) of the 1933 earthquake, and thus indirectly enlighten the rough location of its causative fault (and hopefully the 1706 one), here we carried out a reappraisal of all the data quoted or reported in the Italian seismic databases (e.g., DBMI15, 2016; CFTI5Med, 2018; ASMI, 2019). As the previous studies were mainly based upon the information listed in few newspapers and on the works of Cavasino (1935a; 1935b) and Margottini et al. (1992), we also performed farther archive and library researches that allowed us to collect new, original and reliable data.

2. MATERIALS AND METHODS

With the aim of completing the information concerning the damage within each municipality, firstly we carried out an extensive reading of contemporary periodical publications at the Central National Library of Rome, where we collected useful information reported inside 15 Italian newspapers (i.e., Il Mattino; Il Giornale d'Italia; La Nazione; Il Popolo d'Italia; Il Popolo di Roma; Il Regime Fascista; il Corriere della Sera; La Tribuna; l'Osservatore Romano; la Gazzetta del Popolo; Roma; L'Avvenire d'Italia; il Lavoro Fascista; il Tevere; il Messaggero), for a total of 58 articles specifically dealing with the earthquake. We also found generic information on French papers at the National Library of France (Paris), as in Le Journal, Le Populaire and L'Ouest-Éclair.

Although newspapers contain first-hand news and accounts, we have found that the information were often qualitative, reporting just the number of victims in each village, the number of injured people, and a rough

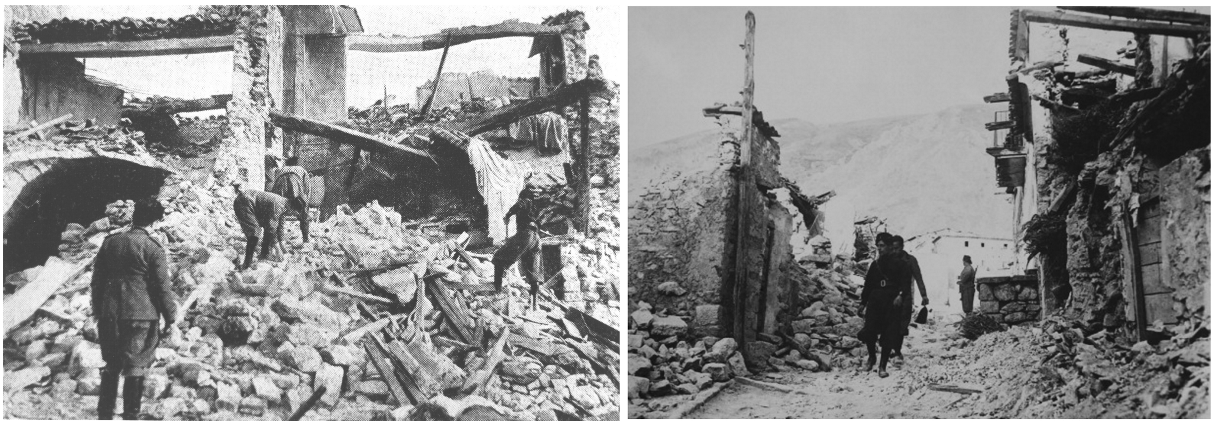


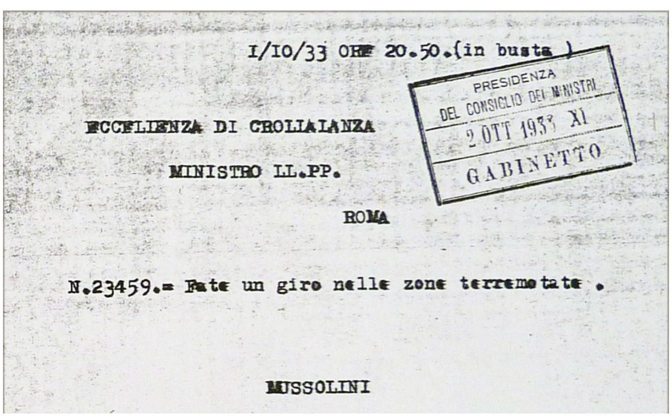
Fig. 1 - View of the collapse of some poor stone-masonry houses in a village east of the Maiella Massif (left; L'Illustrazione Italiana, 1933) and in Lama dei Peligni (right; photo Keystone-France/Abruzzes/gettyimages).

framework of the destroyed houses and of those still inhabitable. It is worth noting that, similarly to what happened three years before after the so-called Vulture earthquake (July 23, 1930; Mw 6.7, southern Italian Apennines. See Castenetto & Sebastiano, 2002), Italian press-reporters widely emphasized the prompt rescue and assistance provided to the inhabitants by the Fascist government and by the local authorities. And then, as in 1930, in spite of the severe damage scenario, the whole national press suddenly minimized the event, which soon disappeared from all the newspapers pages. The spirit of the times is well condensed in a telegram, sent on October 1 by the Italian Prime Minister to the Minister of the Public Works, which just says: "Go for a ride in the earthquake zone - Mussolini", clearly implying to minimize anything (Fig. 2).

We also made researches inside the former archive of the Civil Protection Department where - besides a large amount of telegrams sent by the Prefects to the Interior Ministry, mostly containing the early news on the earthquake effects - we have found an enormous quantity of documents attesting the requests of economical support sent by each single citizens, their associated technical expertise, and, sometime, the answers provided by the authorities in the following months or years. Most of this information supported the evaluation of the level of damage existing in each locality, providing also complementary data in places not fully covered by other sources.

Nevertheless, one of the most important and novel data in our study derives from the huge mass of information collected by Ridolfi (2005), who was previously ignored in any seismic compilation. Her work is entirely devoted to the effects that the 1933 earthquake had on the region surrounding the Maiella massif (Abruzzo side). Data were mainly collected in archives and libraries, such as: Central State Archive; State Archive of Chieti; State Archive of Pescara; historical archive of Banco di Napoli; historical Archive of the municipality of Avezzano; archive of the Superintendency of Public Works; Library of the Chamber of Deputies; Library of the Ministry of Agriculture; Library of the Bank of Italy; archive of the Chamber of Commerce, Industry, Agriculture and Crafts of Chieti.

By ordering and systematizing all of these huge amount of valuable information, it was possible to precisely estimate the number of building affected by each specific damage level (e.g., light, moderate and severe damage, destruction, collapse), and thus evaluate the intensity degree according to the Mercalli-Cancani-Sieberg (MCS) scale, published just three years before by Sieberg (1930). As explained in the following, to do



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PRESIDENZA
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2 OTT 1933 XI
GABINETTO

ECCELLENZA DI CROLLALANZA

MINISTRO LL.PP.

ROMA

N.23459.= Fate un giro nelle zone terremotate .

MUSSOLINI

Fig. 2 - The telegram sent by Benito Mussolini to Araldo di Crollalanza, Minister of the Public Works: "Go for a ride in the earthquake zone". It is quite clear the intent to minimize the effects of the earthquake. (Civil Protection Department Archive).

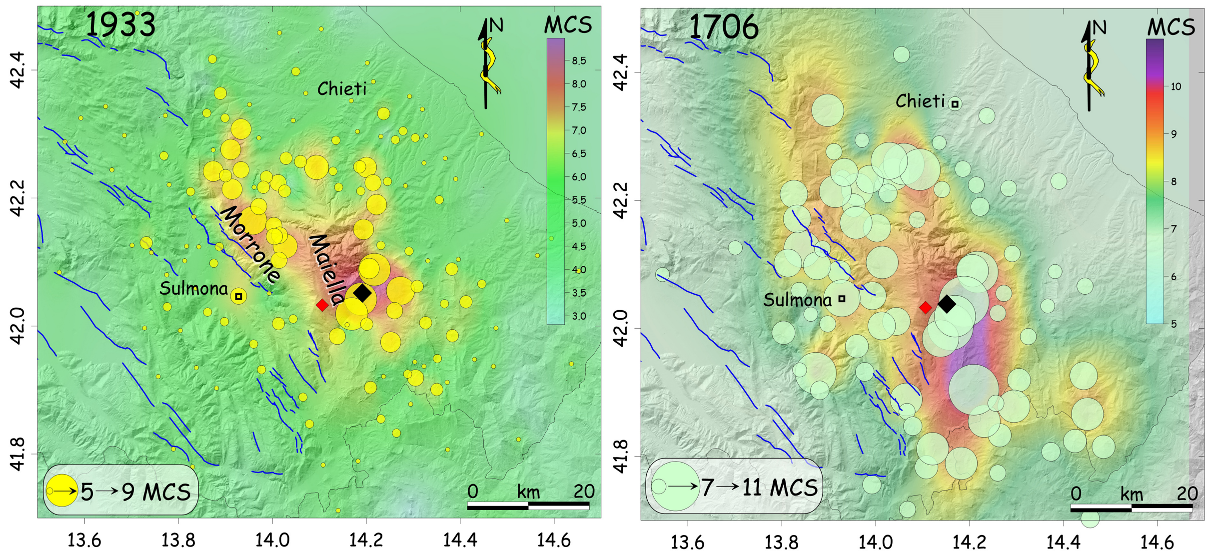

Fig. 3 - Left, distribution of the highest intensities distribution re-evaluated here for the 1933 earthquake (yellow circles proportional to Is 5-9 MCS). Background colors suggest the areal distribution of the intensities (see MCS scale; kriging interpolation); black rhomb is the macroseismic epicenter calculated through Boxer4 algorithm (Gasperini et al., 1999); red rhomb is the instrumental epicenter (Palombo, 2010). Right, same image for the 1706 earthquake (unpublished data of the authors); black rhomb is the 1706 macroseismic epicenter (Boxer4 algorithm); red rhomb is again the 1933 instrumental epicenter. Blue lines in both panels are the normal active faults of the region, all SW dipping (mod. From Galli & Peronace, 2014). Note that intensities span between 7-11 MCS in the 1706 panel vs 5-9 MCS in the 1933 panel.

this, we analytically applied the method suggested by Molin (2009), that considers the percentage of each damage level (1-5) as representative of every MCS degree (from 5 to 11 MCS).

3. RESULTS

First of all, for each singe locality, we obtained the percentage of buildings affected by the different levels of damage that we mainly deduced from the analytical data contained in the Ridolfi's (2005) work, filling the gaps with information collected from newspapers, telegrams and other primary sources found in the archive of the Civil Protection Department. Then we transformed these percentages in MCS degree, considering damage levels 2-3 (i.e., from moderate to severe damage, not distinguishable singularly in most of the documentary materials), 4 (destruction, and/or irreparable damage), and 5 (collapse) in the percentage progression proposed by Molin (2009). This allowed us to obtain robust intensities estimates (see Tab. 1) that generally move away from those reported in DBMI15 (2016) and CFTI5Med (2018) by just 0.5-1 degrees or, exceptionally, 1.5 degree.

It is worth noting that in the previous studies many intensity datapoints were derived uncritically from a crude list published by Cavasino (1935b), who likely estimated the MCS intensities on the basis of the fresh information gathered brevi manu from the local authorities of the time, leaving any written description of the effects felt by these localities. Therefore, in order to complete the dataset of our datapoints - that mainly lacks the lowermost intensities - we also decided to consider those published by Cavasino (1935b). However, before including tout court these intensities, we compared analytically our intensities with those in Cavasino (1935b), calculating thus a linear regression between the two datasets. Then, by applying the resulting equation, we obtained a Is value for the lacking intensities consistent with our macroseismic evaluation (Tab. 1).

The new areal distribution of the highest intensity datapoints (Fig. 3, left) provides a slightly different image of the mesoseismic area then before, although it remains strongly focused on the Maiella massif, with a macroseismic epicenter (black rhomb in Fig. 3) falling close to Lama dei Peligni. This epicenter falls ~7 km away from that calculated by Palombo (2010) by using the time arrivals of P and S-wave phases reported in the ISS bulletins, and coupled with the NonLinLoc code (Lomax et al., 2000), with this point assumed as the maximum likelihood instrumental location for the 1933 earthquake.

The epicentral intensity can be evaluated around Io 9 MCS, as in CPTI15 (2016) and CFT5Med (2018), with coordinates of N42.050°, E14.191°. In turn, the equivalent magnitude that we have calculated by applying BOXER4 algorithm (Gasperini et al., 1999) is Mw 6.01±0.07 (5.9±0.07 in CPTI15; 6.05±0.1 in CFT5Med; 6.4±0.3 in Palombo, 2010), with a source length of 13 km striking N30°±13°, that is perpendicular and external to all the main extensional, NW-SE active fault of central Apennines (Fig. 3).

Last but not least, we have found a novel and interesting information concerning surface effects produced by the earthquake. This regards the damage suffered by a tunnel of the Sulmona-Roccaraso line, that caused the stop of the trains between the stations of Campo di Giove and Palena (green circle in Fig. 4)

Località	Lon	Lat	Is MCS	Località	Lon	Lat	Is MCS	Località	Lon	Lat	Is MCS	Località	Lon	Lat	Is MCS
Lama dei Peligni	14.188	42.042	9.0	Giuliano Teatino	14.278	42.305	6.0	Pizzoli	13.303	42.435	5.0	Castiglione Messer Raimondo	13.882	42.531	4.0
Taranta Peligna	14.169	42.019	9.0	Pratola Peligna	13.875	42.098	6.0	Ofena	13.759	42.326	5.0	Castignano	13.622	42.937	4.0
Civitella Messer Raimondo	14.217	42.088	9.0	Quadri	14.288	41.925	6.0	Ascoli Piceno	13.576	42.855	5.0	Ceccano	13.334	41.568	4.0
Gessopalena	14.273	42.055	8.5	Roccacasale	13.887	42.124	6.0	Casalbordino	14.584	42.150	5.0	Civitanova Marche	13.730	43.307	4.0
Salle Vecchia	13.958	42.165	8.5	Castel di Sangro	14.108	41.783	5.5	Cellino Attanasio	13.859	42.586	5.0	Civitella del Tronto	13.668	42.772	4.0
Sant'Eufemia a Maiella	14.027	42.125	8.0	Chieti	14.168	42.352	5.5	Fagnano Alto (Vallecupa)	13.575	42.254	5.0	Controguerra	13.818	42.855	4.0
Serramonacesca	14.094	42.248	8.0	Lettopalena	14.159	42.002	5.5	Farindola	13.824	42.441	5.0	Corridonia	13.510	43.248	4.0
Cugnoli	13.933	42.308	7.5	Orsogna	14.283	42.219	5.5	Loreto Aprutino	13.988	42.433	5.0	Crognaleto	13.490	42.587	4.0
Montenerodomo	14.252	41.975	7.5	Perano	14.396	42.104	5.5	Moscufo	14.055	42.428	5.0	Falerone	13.472	43.107	4.0
Pietranico	13.911	42.276	7.5	San Pietro Avellana	14.182	41.789	5.5	Picciano	13.991	42.474	5.0	Fonte Arcione	14.032	42.219	4.0
Fara San Martino	14.206	42.090	7.5	Alanno	13.971	42.294	5.5	Santa Maria Imbaro	14.450	42.217	5.0	Frascati	12.681	41.808	4.0
Pennapiedimonte	14.194	42.151	7.5	Altino	14.331	42.102	5.5	Sant'Egidio alla Vibrata	13.716	42.825	5.0	Giulianova	13.958	42.751	4.0
Casacanditella	14.200	42.248	7.5	Bolognano	13.961	42.217	5.5	Trasacco	13.537	41.958	5.0	Grottammare	13.872	42.980	4.0
Guardiagrele	14.222	42.190	7.5	Bominaco	13.658	42.244	5.5	Tufillo	14.627	41.915	5.0	Isola del Liri	13.579	41.680	4.0
Pescosansonesco Vecchio	13.874	42.242	7.5	Campli	13.686	42.726	5.5	Vasto	14.708	42.117	5.0	L'Aquila	13.399	42.351	4.0
Tocco da Casauria	13.914	42.214	7.5	Carapelle Calvisio	13.685	42.298	5.5	Capistrello	13.391	41.966	5.0	Larino	14.911	41.800	4.0
Sulmona	13.928	42.047	7.0	Carrufo	13.772	42.329	5.5	Civitella Roveto	13.425	41.914	5.0	Macerata	13.453	43.300	4.0
Palena	14.138	41.984	7.0	Collepietro	13.780	42.221	5.5	Frosinone	13.353	41.640	5.0	Magliano de' Marsi	13.363	42.092	4.0
Abbateggio	14.012	42.224	7.0	Corfinio	13.843	42.124	5.5	Sante Marie	13.204	42.102	5.0	Matelica	13.009	43.256	4.0
Borrello	14.305	41.919	7.0	Pacentro	13.993	42.051	5.5	Tagliacozzo	13.251	42.068	5.0	Mogliano	13.479	43.185	4.0
Caramanico Terme [Caramanico]	14.003	42.157	7.0	Pescasseroli	13.789	41.808	5.5	Torino di Sangro	14.541	42.187	4.5	Villa Mondragone	12.696	41.809	4.0
La Canale	14.015	42.142	7.0	Popoli	13.833	42.171	5.5	Torricella Sicura	13.656	42.658	4.5	Monte San Pietrangeli	13.578	43.192	4.0
Roccacaramanico	14.014	42.103	7.0	Prezza	13.837	42.059	5.5	Trivento	14.551	41.781	4.5	Montecassiano	13.436	43.363	4.0
San Martino sulla Marrucina	14.214	42.224	7.0	Raiano	13.813	42.102	5.5	Veroli	13.419	41.692	4.5	Montegranaro	13.633	43.233	4.0
San Tommaso	13.971	42.187	7.0	Rionero Sannitico	14.140	41.712	5.5	Villavallelonga	13.622	41.869	4.5	Montelupone	13.568	43.343	4.0
San Vittorino	14.004	42.140	7.0	Tossicia	13.648	42.545	5.5	Villetta Barrea	13.935	41.776	4.5	Monterubbiano	13.716	43.085	4.0
Torre de' Passeri	13.933	42.244	7.0	Vittorito	13.817	42.125	5.5	Abbazia di Montecassino	13.814	41.491	4.5	Montesilvano Colle	14.141	42.491	4.0
Torricella Peligna	14.260	42.024	7.0	Agnone	14.373	41.807	5.5	Amatrice	13.290	42.628	4.5	Mosciano Sant'Angelo	13.888	42.748	4.0
Archi	14.382	42.089	6.5	Anversa degli Abruzzi	13.804	41.993	5.5	Antrodoco	13.076	42.415	4.5	Nereto	13.817	42.819	4.0
Castelvecchio Subequo	13.731	42.130	6.5	Barisciano	13.592	42.325	5.5	Arpino	13.610	41.647	4.5	Ortezzano	13.609	43.031	4.0
Castiglione a Casauria	13.900	42.235	6.5	Bisegna	13.757	41.921	5.5	Arquata del Tronto	13.296	42.772	4.5	Penne	13.928	42.457	4.0
Civitella Casanova	13.889	42.364	6.5	Bisenti	13.802	42.528	5.5	Arsita	13.784	42.502	4.5	Petritoli	13.656	43.067	4.0
Colledimacine	14.201	42.003	6.5	Bucchianico	14.181	42.304	5.5	Atina	13.800	41.619	4.5	Poggio Mirteto	12.686	42.265	4.0
Colledimezzo	14.383	41.985	6.5	Cappelle sul Tavo	14.104	42.464	5.5	Atri	13.978	42.580	4.5	Porto di Vasto	14.714	42.171	4.0
Fara Filiorum Petri	14.186	42.249	6.5	Castel di Ieri	13.742	42.115	5.5	Balsorano (Nuovo)	13.560	41.808	4.5	Recanati	13.550	43.403	4.0
Manoppello	14.060	42.257	6.5	Castelguidone	14.524	41.823	5.5	Basciano	13.740	42.595	4.5	Ripatransone	13.762	42.999	4.0
Roccamorice	14.026	42.211	6.5	Castelli	13.712	42.489	5.5	Canistro (Inferiore)	13.411	41.940	4.5	San Benedetto del Tronto	13.880	42.955	4.0
Roccascalegna	14.308	42.062	6.5	Catignano	13.951	42.346	5.5	Cappadocia	13.282	42.006	4.5	San Ginesio	12.962	43.530	4.0
Rosello	14.350	41.901	6.5	Celano	13.546	42.084	5.5	Carpineto Sinello	14.504	42.009	4.5	San Giovanni Lipioni	14.562	41.843	4.0
S. Valentino in Abruzzo Cit.	13.987	42.233	6.5	Cepagatti	14.071	42.364	5.5	Castellafiume	13.333	41.988	4.5	Sant'Omero	13.803	42.786	4.0
Tornareccio	14.412	42.038	6.5	Città Sant'Angelo	14.060	42.518	5.5	Castellalto	13.818	42.677	4.5	Scurcola Marsicana	13.342	42.064	4.0
Troviglianо	13.981	42.217	6.5	Civitaluparella	14.303	41.944	5.5	Castilenti	13.918	42.533	4.5	Silvi	14.123	42.546	4.0
Turrivalignani	14.029	42.262	6.5	Collecorvino	14.015	42.458	5.5	Celenza sul Trigno	14.581	41.872	4.5	Teramo	13.703	42.659	4.0
Villamagna	14.237	42.332	6.5	Corvara	13.874	42.275	5.5	Ceprano	13.517	41.545	4.5	Termoli	14.993	42.000	4.0
Cansano	14.013	42.004	6.5	Crecchio	14.327	42.297	5.5	Colledara	13.681	42.540	4.5	Torrebruna	14.543	41.866	4.0
Gamberale	14.209	41.904	6.5	Dogliola	14.637	41.941	5.5	Corropoli	13.833	42.828	4.5	Torremaggiore	15.292	41.689	4.0
Pennadomo	14.326	42.005	6.5	Fallo	14.323	41.937	5.5	Elice	13.968	42.518	4.5	Tortoreto	13.914	42.803	4.0
Atessa	14.446	42.066	6.0	Fano Adriano	13.538	42.552	5.5	Furci	14.589	42.007	4.5	Velletri	12.778	41.688	4.0
Campo di Giove	14.044	42.011	6.0	Frisa	14.368	42.262	5.5	Gioia dei Marsi	13.692	41.953	4.5	Venafro	14.044	41.485	4.0
Capestrano	13.769	42.266	6.0	Gagliano Aterno	13.701	42.126	5.5	Gissi	14.546	42.020	4.5	Venarotta	13.493	42.881	4.0
Carpineto della Nora	13.860	42.333	6.0	Goriano Sicoli	13.775	42.080	5.5	Isernia	14.228	41.592	4.5	Villa Celiera	13.859	42.381	4.0
Casoli	14.291	42.117	6.0	Guilmi	14.476	41.997	5.5	Lentella	14.677	41.996	4.5	Fermo	13.718	43.162	3.5
Castel del Giudice	14.231	41.855	6.0	Lanciano	14.390	42.230	5.5	Liscia	14.557	41.954	4.5	Ancona	13.513	43.619	3.0
Castel Frentano	14.355	42.197	6.0	Miglianico	14.292	42.359	5.5	Luco dei Marsi	13.471	41.959	4.5	Apiro	13.132	43.391	3.0
Filetto	14.245	42.226	6.0	Montazzoli	14.430	41.948	5.5	Massa d'Albe	13.393	42.107	4.5	Benevento	14.778	41.131	3.0
Palombaro	14.231	42.126	6.0	Monteodorisio	14.652	42.086	5.5	Mozzagrogna	14.445	42.212	4.5	Campagnano	12.445	43.190	3.0
Ari	14.262	42.291	6.0	Montorio al Vomano	13.629	42.582	5.5	Notaresco	13.894	42.657	4.5	Carovilli	14.295	41.713	3.0
Bugnara	13.862	42.022	6.0	Opi	13.830	41.780	5.5	Offida	13.691	42.935	4.5	Cingoli	13.216	43.375	3.0
Canosa Sannita	14.304	42.294	6.0	Ortona dei Marsi	13.728	41.997	5.5	Oricola	13.040	42.049	4.5	Colonnella	13.867	42.872	3.0
Casalincontrada	14.135	42.290	6.0	Paglieta	14.499	42.165	5.5	Ortucchio	13.644	41.954	4.5	Cupra Marittima	13.860	43.024	3.0
Cocullo	13.776	42.030	6.0	Pescopennataro	14.294	41.878	5.5	Ovindoli	13.516	42.136	4.5	Foggia	15.545	41.462	3.0
Introdacqua	13.898	42.007	6.0	Pizzoferrato	14.237	41.921	5.5	Pescara	14.213	42.461	4.5	Foligno	12.704	42.955	3.0
Montebello di Bertona	13.872	42.417	6.0	Poggiofiorito	14.323	42.255	5.5	San Buono	14.571	41.980	4.5	Gambatesa	14.913	41.509	3.0
Pescocostanzo	14.065	41.889	6.0	Pollutri	14.594	42.137	5.5	San Salvo	14.731	42.046	4.5	Labro	12.800	42.525	3.0
Pettorano sul Gizio	13.960	41.972	6.0	Roccaspinalveti	14.471	41.937	5.5	Schiavi di Abruzzo	14.485	41.815	4.5	Loro Piceno	13.416	43.166	3.0
Pianella	14.050	42.398	6.0	Roio del Sangro	14.372	41.912	5.5	Aielli	13.591	42.081	4.5	Montecarotto	13.063	43.526	3.0
Pretoro	14.141	42.217	6.0	Rosciano	14.044	42.321	5.5	Capitignano	13.301	42.520	4.5	Montefano	13.438	43.411	3.0
Rapino	14.188	42.211	6.0	San Demetrio ne' Vestini	13.558	42.288	5.5	Montefino	13.885	42.543	4.5	Montegiorgio	13.537	43.130	3.0
Rocca Pia	13.977	41.932	6.0	San Giovanni Teatino	14.202	42.411	5.5	Acquasanta	14.240	42.299	4.0	Montereale	13.246	42.522	3.0
Roccamontepiano (San Rocco)	14.129	42.242	6.0	San Vito Chietino	14.445	42.300	5.5	Anagni	13.156	41.742	4.0	Morro d'Oro	13.920	42.663	3.0
Roccaraso	14.079	41.847	6.0	Santo Stefano di Sessanio	13.645	42.343	5.5	Avezzano	13.426	42.032	4.0	Pollenza	13.348	43.267	3.0
Villa Santa Maria	14.351	41.949	6.0	Scanno	13.881	41.903	5.5	Baranello	14.554	41.527	4.0	Rocca di Papa	12.710	41.760	3.0
Bomba	14.366	42.035	6.0	Scerni	14.564	42.110	5.5	Caldarola	13.226	43.137	4.0	Roma	12.477	41.899	3.0
Bussi sul Tirino	13.826	42.210	6.0	Tollo	14.319	42.339	5.5	Camerino	13.068	43.135	4.0	Treia	13.312	43.311	3.0
Capracotta	14.264	41.833	6.0	Torrevecchia Teatina	14.215	42.382	5.5	Capranica Prenestina	12.952	41.862	4.0				
Casale	14.476	41.668	6.0	Vacri	14.231	42.296	5.5	Carsoli	13.084	42.098	4.0				
Civitaquana	13.899	42.325	6.0	Villalago	13.838	41.935	5.5	Carunchio	14.525	41.918	4.0				

Tab. 1 - MCS intensities (Is) related to the 26 September 1933 mainshock. Lon and Lat are WGS84 geographic coordinate of centroid of locality.

4. DISCUSSION AND CONCLUSIONS

Observing the left panel of Fig. 3, we notice that the highest site intensities of the 1933 earthquake fall at the base of the eastern edge of the Maiella massif (i.e., Taranta dei Peligni, Lama dei Peligni, and Civitella Messer Raimondo, all with Is 9 MCS; see Tab. 1), decreasing then progressively eastward and northward. Intensities 7-8 MCS also characterize the eastern flank of the Morrone ridge, with a peak of Is 8.5 MCS in Salle Vecchia, where diffuse landsliding, more than shaking, contributed to the severe damage framework. Obviously, the lack of localities in the mountainous zones of the Maiella massif alters the perception of the real shaking distribution, although it is clear that the strongest ground acceleration is confined in the Adriatic side of the Morrone-Maiella ridge.

Definitively, this means that none of the ~west dipping active normal faults of the region (i.e., all the blue lines in Fig. 3 - 4) can be the source of this earthquake. Indeed, the 1933 HIDD is fully concentrated in the footwall of these structures, in contrast to all the earthquakes of the Italian Apennines, the HIDD of which fall always in the hangingwall of their causative faults (e.g. in Galli & Galadini, 1999; Galli et al., 2009; 2017).

As far as the possible 1933 and 1706 sources are

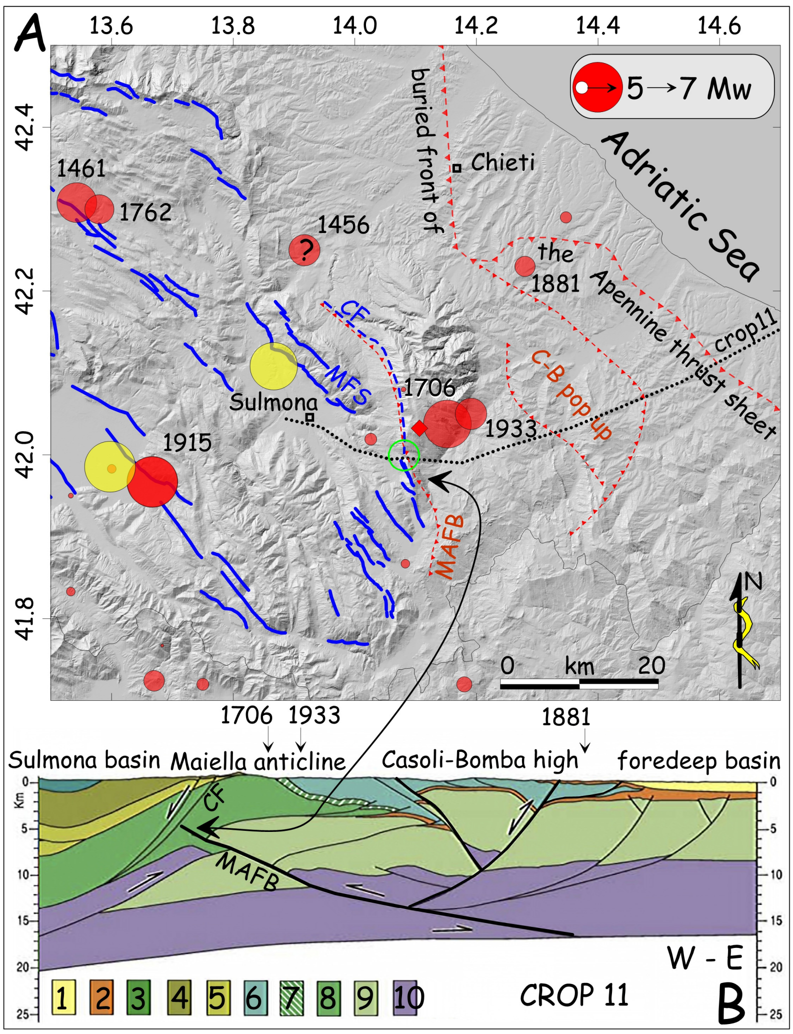

Fig. 4 - A, shaded relief map of central Apennines with the major historical seismicity (red circles, Mw>5.0; yellow circles, well-dated Mw>6.5 paleoseismological events; Galli et al., 2015; 2016) and the main, active normal faults (blue lines; mod. from Galli and Peronace, 2014). MFS, Mount Morrone fault system; CF, Caramanico fault. Red rhomb is the 1933 instrumental epicenter (Palombo, 2010). Red triangles-dashed lines suggest the bounding thrust of the Casoli-Bomba (C-B) pop-up and of the buried backthrust below the Maiella anticline footwall (MAFB; inferred northward mimicking the Caramanico fault path; Ghisetti and Vezzani, 2002; Calamita et al., 2009). Dotted line is the segment of CROP-11 line shown in panel B; green circle indicates the area where the railway tunnel was damaged by the 1933 earthquake. B, part of CROP-11 line interpreted by Patacca et al. (2008). 1, Pleistocene marine deposits of the foredeep basin; 2, Pliocene marine deposits conformably overlying the Apulia carbonates; 3, Mount Genzana unit; 4, Mount Morrone-Porrara unit; 5, Upper Cretaceous -Pliocene Mount Queglia unit; 6, Molise units; 7, Lower Pliocene flysch of Maiella unit; 8, Mesozoic-Tertiary carbonates of Maiella unit; 9, Mesozoic-Tertiary carbonates of Apulia Platform; 10, Paleozoic-Triassic deposits.

concerned, some authors associated these earthquakes to two consecutive ruptures of patches of a so-called, SW-dipping Abruzzo Citeriore Basal Thrust (Lavecchia & de Nardis, 2010). However, the existence of this Basal Thrust is denied by the interpretation provided by Patacca et al. (2008) of the CROP 11 deep reflection seismic profile, where the entire Pliocene Maiella ramp-anticline overlies a popup structure in the Mesozoic-Tertiary carbonates of the Apulia Platform. This popup is instead related to an important E-dipping backthrust (MAFB in Fig. 4; Patacca et al., 2008), which likely controlled also the growth of the neighboring Casoli-Bomba high (C-B pop-up in Fig. 4).

According to Patacca et al. (2008), the existence, timing and importance of this blind structure, which developed in the footwall of the Maiella anticline, is testified also by the impressive uplift of the Maiella anticline just over the backthrust hanging-wall. The uplift started in the Early Pleistocene, rising the top of the Maiella carbonate massif at a rate of some centimeters per year (i.e., vertical component of the active-thrust slip vector), from few hundred meters a.s.l. to the present elevation (~2800 m), or more. Another evidence for this is the > 3500 m vertical throw accommodated by the Caramanico normal fault (CF in Fig. 4B; see also Ghisetti & Vezzani, 2002), which could represent a gravity collapse feature developed in the roof of the passively growing Maiella tectonic edifice (Patacca et al., 2008).

If this interpretation is correct, as the HIDD of the 1706 and 1933 earthquakes mainly fall in the broad hanging-wall of this backthrust, one could hypothesize that both events were sourced by a residual activity of this Quaternary structure that, tentatively, could also trigger the passive motion of the Caramanico fault. Likewise, also other earthquakes occurred in the farther, backthrust hanging-wall, as the 1881 one (Mw 5.4; Fig. 4A), could have been sourced by structures rooted at depth to the sole thrust, for instance those bounding the Casoli-Bomba high (Fig. 4B).

Nevertheless, whereas the largest slip of the backthrust occurred during the late Emilian-early Sicilian (Patacca et al., 2008), today we have not geological evidence for such a persisting activity in its hanging-wall, with the exception of some morphotectonic indication suggesting post-Middle Pleistocene anticline growing (Pomposo & Pizzi, 2009). Even the geodetic data published so far (D'Agostino et al., 2011; D'Agostino, 2014; Angelica et al. 2013; Devoti et al., 2011; Galvani et al., 2012) show that the outer Morrone-Maiella region is not experiencing NE-SW compression, as GPS vectors located westward and eastward of these massifs roughly show the same NE velocity. Moreover, there are neither focal mechanisms, nor borehole breakouts in the whole region supporting or ruling out ongoing compression (e.g. in Mariucci & Montone, 2018).

Actually, Palombo (2010) tried to calculate the 1933 focal mechanism from eighteen retrieved paper-seismograms, although only eight had useful P wave first motion. Amongst the possible solutions, Palombo (2010) evidenced two groups with different kinematics; one with average NW-SE trend associate to a NE-SW tensional axis (i.e., transtensive NE-SW faults), and the other compatible with a NE-SW compressive field (NNE-SSW, transpressive, right strike-slip fault, i.e., similar to the strike of the source resulting from the Boxer4 algorithm).

Honestly, at the moment, we can conclude that the seismogenic sources of these two frightful earthquake are still uncertain. We can surely exclude that they were generated by any of the known, active normal faults mapped in Fig. 4, and least of all by the Mount Morrone fault system which bounds the eastern side of the Sulmona basin (MFS in Fig. 4A). As aforementioned, the HIDD of the 1706 and 1933 events fall in the footwall of all these faults, while the Mount Morrone fault, although very close to both epicenters, and partly running inside the 1706 HIDD, sourced its last earthquake in the far 2nd century AD, as definitely demonstrated by recent paleoseismic studied (Galli et al., 2015).

Concluding, our working hypothesis - which makes no claims to being conclusive - is that the source of both 1706 and 1933 events might be the blind backthrust in the footwall of the Maiella anticline, the geometry of which matches the HIDD of both events. In this case, it is also possible that the Caramanico fault might move passively, inducing some surface rupture, as suggested by the damage in the railway tunnel in 1933. All this implies the existence of active, NE-SW compression just east to the extensional belt highlighted by the active faults shown in Fig. 4B, which is not (yet?) adequately supported by either geological or instrumental data.

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