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The 6 May 1976 Friuli earthquake revisited: macroseismic intensities in Central and north-eastern Germany

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ABSTRACT The M_w 6.4 earthquake on 6 May 1976, was not only the most devastating one in its epicentral region for centuries, it was also felt in many parts of Europe from central Italy to the Baltic Sea and from France to Slovakia. In addition to its devastating consequences in northern Italy, the earthquake had a strong impact on the development of modern seismology in several countries of Europe. The fact that the Friuli quake was widely felt in Central and north-eastern Germany, even in Berlin, where many people in high-rise buildings were frightened and ran outdoors, contributed to the decision to establish seismology on a larger scale at the Potsdam Institute on the Telegrafenberg. This event also instituted the research field of engineering seismology with macroseismology. The macroseismic data collection for the Friuli event started after a long delay owing to the lack of a permit by the state authority to carry out inquiries. Nevertheless, the reaction to the inquiry was overwhelming, despite the delay. Altogether, we received positive reports from 205 localities. The intensity assignments were performed with the MSK-64 scale. The only region with a well-established intensity 4 was the area of Zittau in the south-easternmost edge of Saxony. The region that was shaken with intensity 3 extends to Berlin and the area NE of the city and continues further south covering Halle, Leipzig and Erfurt with the surrounding Thuringian basin. Unexpectedly, we received observation messages even from several towns at the Baltic Sea. The macroseismic data are also discussed according to contemporary cross border isoseismal maps of the 1976 Friuli earthquake. Similar macroseismic observations as those of the 1976 earthquake were made in Central and north-eastern Germany also for the 1690 Carinthia quake. The available macroseismic data points for this historical event are presented and compared with the observations of the 1976 Friuli quake.

Key words: 1976 Friuli earthquake, macroseismic investigation, Central Germany.

1. Introduction

On 6 May 1976, at 21:00 (CEST) the devastating Friuli earthquake struck north-eastern Italy, an event with a moment magnitude M_w = 6.4 (Slejko, 2018). The intensity in the region of the reported epicentre (46.241°N, 13.119°E) was assessed to be I_0 = 9-10 MCS (Rovida *et al.*, 2016). It caused about 1000 fatalities, with a further 1000 seriously injured. Over 100,000 people were left homeless from the 20,000 destroyed or badly damaged flats mainly in the Friuli-Venezia

Giulia region (Glauser *et al.*, 1976). The destruction to villages and towns in the epicentral region left a terrifying spectacle (Fig. 1).

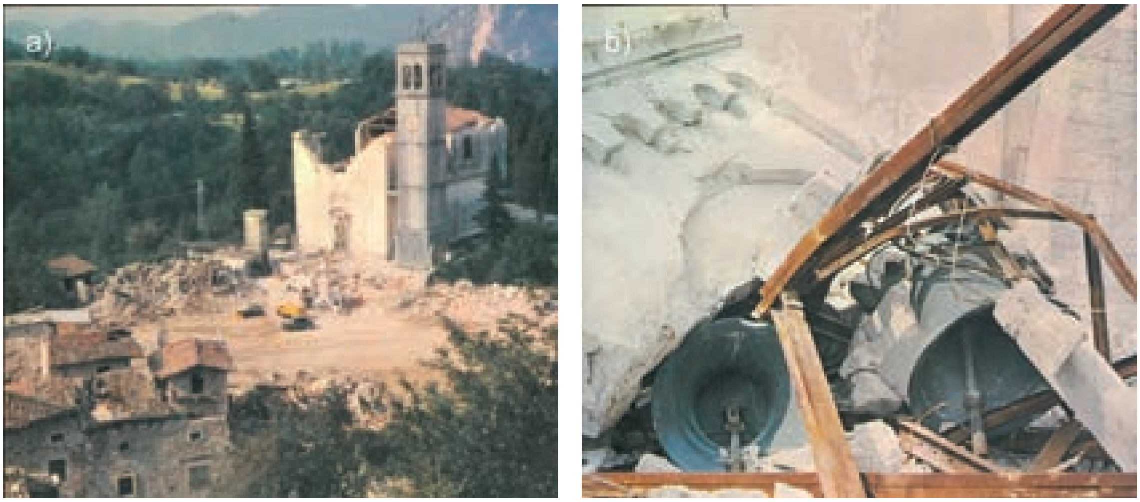

Fig. 1 - Typical damage observed in the epicentral region of the Friuli earthquakes [after CNEN-ENEL (1976): photos by Diego Molin]. The left photo shows a view over parts of Forgaria del Friuli [pers. communication by Dario Slejko].

The location of the event is shown on the epicentre map of western central Europe in a broader view (Fig. 2). It is clear from the map that the Friuli area and its immediate surroundings represent the seismically most active part of the depicted region, i.e. the western part of central Europe *sensu lato*.

The mainshock of the Friuli earthquake was felt across large parts of Europe; from France to Slovakia, from southern Italy to the German Baltic Sea coast. Even in Berlin, for example, it was widely felt, especially on the upper floors of high-rise apartment buildings. People were frightened and ran into the open. It is worth noting that the epicentral distance to Berlin amounts to about 700 km. Observers of that time still remember vividly what they felt, though often they cannot recall the exact year. Most people associated the observed effects immediately with an earthquake, but there was confusion surrounding the location of the causative quake, since the GDR[1] media were still a long way from the speedy information transfer we are accustomed to nowadays. For most, the confirmation of what was felt came the day after.

Also at some seismological stations, which were in most cases not linked with other stations in online mode at that time, there was some confusion. A foreshock, about one minute before the main shock with a magnitude of $M_W = 4.5$, was originally interpreted at a certain number of observatories as the arriving P-waves and the onset of the $M_w = 6.4$ main shock as the arriving S-waves (Fig. 3). The outcome was that all these stations initially reported the same erroneous distance to the epicenter. This preliminary location was, of course, later on corrected.

The disadvantages of a single station practice in combination with the exceptionally extended macroseismic effects prompted the institutional and state authorities to re-activate instrumental seismology in Potsdam at the Central Institute of Physics of the Earth (ZIPE). Permanent

1 GDR: the former German Democratic Republic

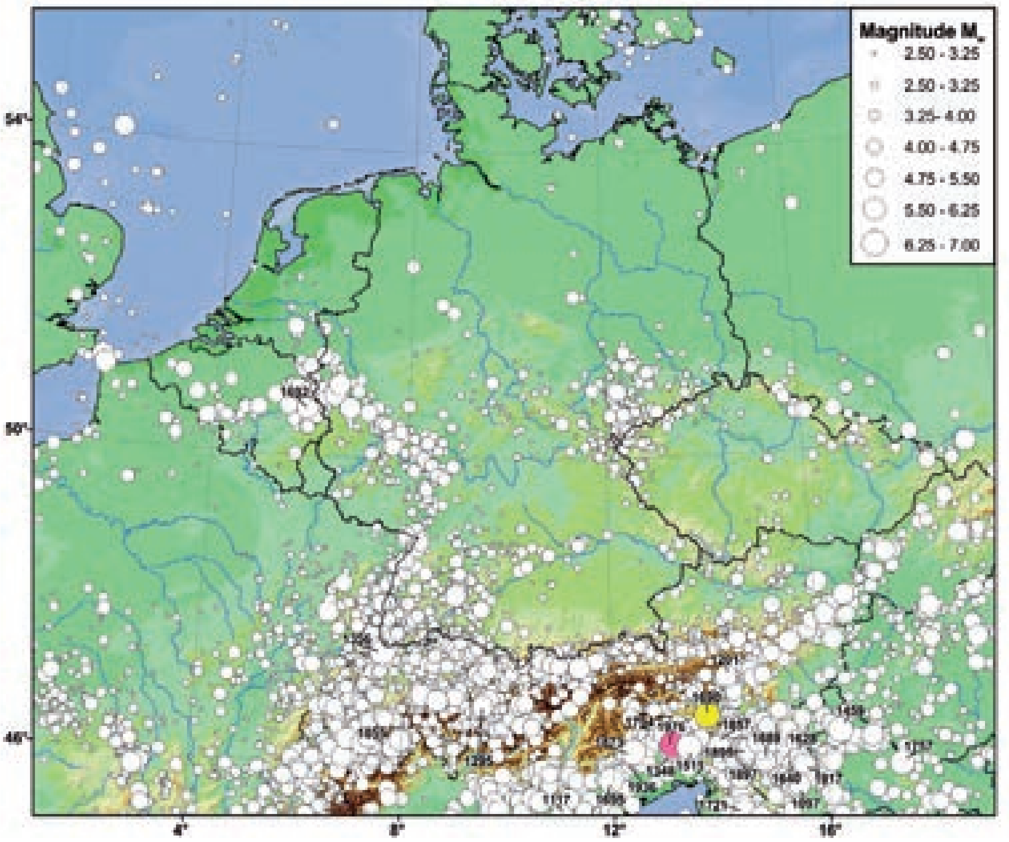

Fig. 2 - Areal distribution of seismicity in western central Europe in a broader view after the extended database of the European Mediterranean Earthquake Catalogue EMEC (Grünthal and Wahlström, 2012). The map section has been chosen to illustrate the location of the Friuli earthquake with respect to the study area; i.e. Central and north-eastern Germany. To improve the readability of the map, only main shocks are shown. Epicentres of earthquakes with $M_w \geq 6.0$ show their year of occurrence. The epicentre of the 1976 Friuli earthquake is highlighted in pink, while the similar event of 4 December 1690, which will be dealt with below, is shown in yellow.

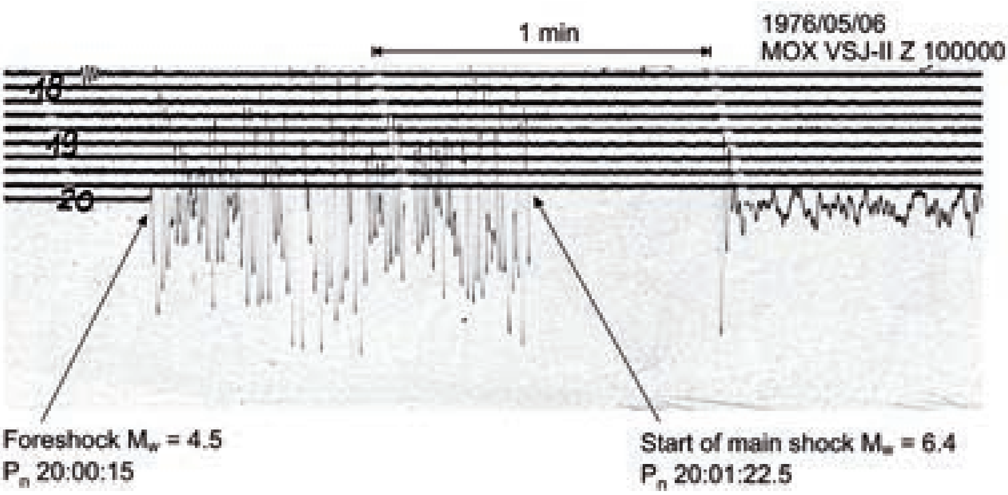

Fig. 3 - The record of the M_w 4.5 foreshock about 1 minute before the 1976 M_w 6.4 main shock according to the analogue photographic record at the seismological station Moxa (Thuringia) with a short period seismograph VSJ-II. The amplitudes of the main shock are for about 15 minutes out of scale for this high amplification recording.

seismological recordings were initially started in Potsdam on the Telegrafenberg in 1896 by the Geodetic Institute in its main building (today the building A17, Fig. 4a). In 1902, the so-called "Earthquake House" (Fig. 4b) as part of the Geodetic Institute was completed and the recordings were continued there. The increasing seismic noise on the Telegrafenberg was one of the reasons to cease the recordings in 1954. The underground conditions in the area were found unfavourable for sensitive seismic recordings.

Fig. 4 - Buildings at the campus area of the Telegrafenberg where seismographs were formerly operating: a) the house A17, b) the "Earthquake House".

Immediately after 6 May 1976, a 24/7 permanent seismological service was established, the Seismic Information Service (<u>S</u>eismischer <u>I</u>nformations<u>D</u>ienst, SID), initially with analogue telemetry lines to Potsdam POT from the seismological observatories Collmberg CLL, Moxa MOX and Berggießhübel BRG. Several more stations were added over the years during its operation (Hurtig *et al.*, 1980; Bormann *et al.*, 1992).

Besides the SID, there was also the need to establish the research field of engineering seismology at the Potsdam branch of the ZIPE after the 1976 Friuli earthquake, which encompassed the disciplines of macroseismology, earthquake cataloguing, strong ground motion and site effects, seismic hazard assessment, and seismotectonics. The author of the present paper was given the task of building up these research fields in Potsdam, following the long and great tradition of such works at the Jena branch of ZIPE with Wilhelm Sponheuer (1905-1981) and its famous predecessor August Sieberg (1875-1945). Although the author specialized in deep seismic sounding at that time, he gained a solid background in global seismological aspects after extensive volunteer work as a trainee at the seismological observatory Collmberg CLL of the University Leipzig, which led to cepstral investigations to determine the focal depths of underground nuclear explosions (Grünthal, 1974). Following the new task entrusted to the author, he made intensive use of the opportunity to work closely together with Wilhelm Sponheuer in Jena up to 1981.

The main subject of this paper is the presentation of the as yet unpublished macroseismic data of the 1976 Friuli main shock within the former GDR; today the Central German[2] and north-

2 Mitteldeutschland (Central Germany) is the official name for the three German federal states Saxony, Thuringia, and Saxony-Anhalt.

eastern federal states of Germany. The obtained and archived macroseismic data are discussed in comparison with the macroseismic data points according to a 17th century SE Alpine earthquake, and, in connection with studies on soil amplification, as one aspect to explain the far north reaching macroseismic effects in the region.

2. Investigation of macroseismic effects of the 1976 Friuli main shock in Central and NE Germany

One of the first tasks in the newly established research field of engineering seismology at ZIPE after the 1976 Friuli earthquake was the collection of macroseismic data. It became immediately clear that the event was felt widely at least as far north as Berlin. Spontaneously submitted letters or postcards, where people described their observed effects, were sent to both branches of the ZIPE, to Potsdam and to Jena, but mainly to the Meteorological Service, which operated offices or branches in different districts. People were concerned that neither calls to submit observations appeared in newspapers nor was any questionnaire campaign started, since they were used to responding to such calls in the past. For the first time, such a campaign was forbidden since it became a standard action during the last quarter of the 19th century (Heim, 1879; Rudolph, 1895; Belar, 1902; Gerland 1902). The restraint, as the author was informed, was imposed by the director of ZIPE, but it seemed that the restriction came from higher levels of the Socialist Unity Party of Germany (SED). This must be seen as one of the countless examples of how the research practice of the East German state was controlled by a tight security regime. The explanation given for the prohibition was "not to trouble the population with such an activity". This was probably not the only or true reason. Presumably, an essential aspect might have been the concern of the SED not to have full control over inquiries. However, the effect of the veto was the opposite as the population became troubled that no inquiry was performed in time. It is widely recognised that the overall and ubiquitous regulations led to a general inefficiency and frustration among the population. The persistence of the author to take action resulted in two measures. The first was to contact the District Offices for Geology and offices of the State Building Agency (Staatliche Bauaufsicht) to collect internally macroseismic observations in their commuting areas. The second was to apply for a permit from the State Central Administration for Statistics (Zentralverwaltung für Statistik) to perform macroseismic inquiries.

The delay in performing our investigation, owing to the waiting time to get a green light for an inquiry, was used to assign the intensities of the spontaneously submitted letters with often detailed descriptions of observed macroseismic effects. There were even inquiries organized privately by the public. For example, among the staff of the branch of the Meteorological Service in Dresden/Radebeul 40 responses were gathered. Also the first reports by the District Offices for Geology and by the State Building Agency were achieved and arrived with the collected data.

The waiting time for the permit to start the inquiry was also used to prepare a new macroseismic questionnaire. The questionnaire applied up until that time originated in a version that was drafted by Sieberg. The new questionnaire was designed as a DIN A5 reply postcard. For sending to people to fill in the form, it can be folded so that their address is on the outside (Fig. 5a). To send the completed form back, the inner part is reversed so the address of the institute is on the outside (Fig. 5b). The part with the questionnaire itself is shown in Fig. 6.

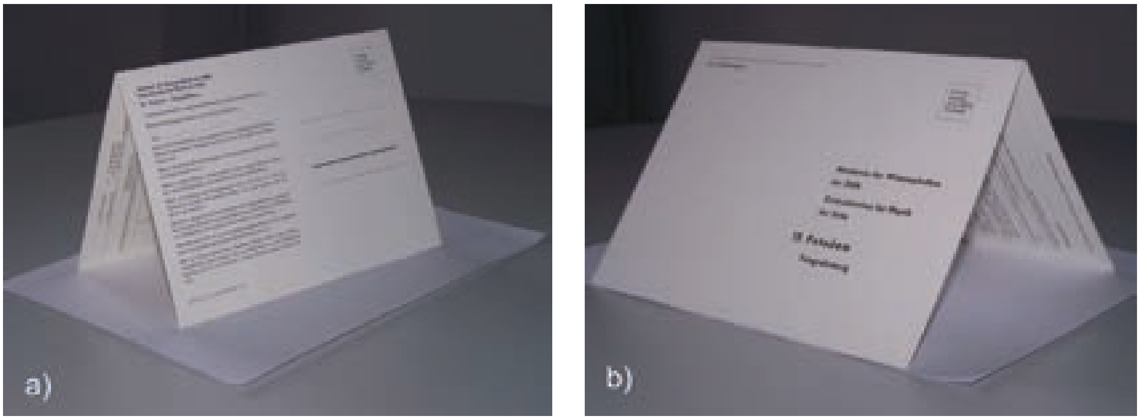

Fig. 5 - The macroseismic questionnaire with the page for sending out (a, page 1) and for sending back to Potsdam (b, page 4). The question part (pages 2 and 3) is shown on Fig. 6 (photo: Uwe Lemgo).


AKADEMIE DER WISSENSCHAFTEN DER DDR
Zentralinstitut für Physik der Erde
15 Potsdam, Telegrafenberg

Fig. 6 - The question part of the macroseismic questionnaire (pages 2 and 3).

Finally, on 12 December 1976, permission was granted by the central administration for statistics, more than seven months after the quake. The permit came with certain conditions. These included the need to apply for an inquiry after each related earthquake[3], and, if authorized, to print on each questionnaire the note of the permit of the central administration with the respective number of permission and the period of time within which the permitted inquiry was allowed. The

3 It should be noted that the permits for future inquiries were provided in due time after respective earthquakes.

necessary modification of the questionnaire, produced by offset-litho in a printing house, caused an additional delay of quite a number of weeks. Those were the days to live with excessive and widespread bureaucracy.

The authorisation also permitted issuing press releases, where readers were asked to submit their descriptions of observations. The severely delayed calls, particularly in newspapers, were limited to verifying the preliminary assignment of intensity 4 in the area of Zittau. It would have been too embarrassing to release countrywide calls as press releases with nine months delay.

Despite the difficulties and huge delay, it was possible to collect a large amount of macroseismic data. Altogether, we received positive replies from 205 towns or villages. There was no indication that people had problems recalling what they had felt about nine months ago. The intensities were originally determined according to the MSK-64 scale by Medvedev, Sponheuer and Kárník (e.g., in Medvedev *et al.*, 1967). Later, and in particular for this study, the EMS-98 (Grünthal *et al.*, 1998) has been applied.

The main difference between the original and the new intensity assignment is that previously several intensities of 3-4 had been determined according to macroseismic effects that are somewhat higher than those which are typical for intensity 3, but without reaching intensity 4. It became obvious during the current re-investigation that such observations seem to be maximal effects which are not representative for respective locations; i.e. the frequency of such observations fit rather with intensity 3, but hardly with intensity 4. Following the Guidelines for applying the EMS-98, such evidences have to be assigned as intensity 3 [cf. sub-chapters of the EMS guidelines 1.4 and 4.5 on pages 27-28 and 56-58 in Grünthal *et al.* (1998)]. Only cases where the intensity can be assessed equally well as 3 or 4 are given as 3-4. The difference in intensity determinations between the original and the new ones is in no case larger than half a degree, which is indeed minor and within the range of uncertainty of such assignments. The list of macroseismic data points (MDPs) is given in Table 1 with the numbering of the MD from north to south. The respective map of MDPs is shown in Fig. 7 with intensities of 2-3 in locations at or near to the Baltic Sea coast, up to intensity 4 in the south-easternmost part of the study area. The intensity symbols used in the map are those by the KAPG, the former Commission of the Academics of Sciences of Socialist Countries for Planetary Geophysical Research, except of the symbol for intensity 2 [cf. Musson (2002) concerning advantages of these symbols], which basically originate in a proposal by Sieberg (1904). The area affected by intensity 3 is delimited from NE to SW by Seelow/Mark (east of Berlin with MDP 32), the region of Berlin itself, Wittenberg, Halle/S., and Erfurt. The only area where an agglomeration of intensity 4 occurs is the region of Zittau (cf. enlarged inserted map of Fig. 7).

On analyzing the macroseismic data, we found cases where questionnaires were received with the information that the event was not felt in a particular town, although spontaneous letters describe respective macroseismic observations. Therefore, we refrained from including negative information in general. However, the map of MDPs (Fig. 8) includes the negative information (not felt) for locations of the Erzgebirge (Ore Mountains). These not-felt-data are the result of personal inquiries on the spot and according to preliminary information on the non-perceptibility of the event there (cf. Table 2 with 21 respective locations). The buildings within such locations are mostly founded on hard rock underground conditions. The rationale for this specific activity was that intensities of up to 5 were reported from almost neighboring locations in Czechoslovakia just beyond the summit line of the Erzgebirge, which corresponds roughly to the border. Many of the MDP south of the Erzgebirge with fairly high intensities are located in the Cenozoic Eger

Table 1 - List of MDPs of the 1976 Friuli main shock in central and NE Germany arranged from north to south.

ID of MDP	Location	Latitude	Longitude	Intensity
1	Spiekersdorf	54.20	12.75	2.00
2	Warnemünde	54.17	12.08	2.00
3	Heringsdorf (Ostseebad)	53.95	14.16	2.50
4	Neubrandenburg	53.56	13.26	2.00
5	Schmölln	53.29	14.10	3.00
6	Pinnow (bei Guben)	53.21	13.79	3.00
7	Stendell	53.14	14.16	2.50
8	Schwedt (Oder)	53.05	14.28	2.50
9	Angermünde	53.02	14.00	2.50
10	Molchow	52.97	12.83	2.50
11	Joachimsthal	52.97	13.74	2.50
12	Lindow (Mark)	52.97	12.98	2.50
13	Liebenwalde	52.87	13.39	2.50
14	Hohenwutzen	52.85	14.11	3.00
15	Eberswalde-Finow	52.84	13.78	3.00
16	Altglietzen	52.83	14.09	3.00
17	Spechthausen	52.81	13.77	2.50
18	Saalfeld/Sachsen-Anhalt (Salzwedeler Land)	52.76	11.18	2.00
19	Wriezen	52.71	14.13	2.50
20	Steinbeck (bei Bad Freienwalde)	52.70	13.92	2.50
21	Haselberg	52.70	14.03	2.50
22	Hennigsdorf	52.63	13.21	3.00
23	Bernau bei Berlin	52.62	13.58	3.00
24	Malchow	52.58	13.49	3.00
25	Strausberg	52.58	13.88	3.00
26	Pankow	52.57	13.40	3.00
27	Altlandsberg	52.56	13.72	3.00
28	Falkensee	52.56	13.09	3.00
29	Manschnow	52.55	14.55	3.00
30	Prenzlauer Berg	52.55	13.42	3.00
31	Waldsieversdorf	52.54	14.07	3.00
32	Seelow/Mark	52.53	14.38	3.00
33	Rüdersdorf bei Berlin	52.47	13.78	3.00
34	Tempelberg	52.45	14.16	3.00
35	Hasenfelde	52.43	14.20	3.00
36	Kleinmachnow	52.41	13.23	3.00
37	Brandenburg an der Havel	52.41	12.54	3.00
38	Potsdam	52.40	13.04	3.00
39	Teltow	52.40	13.27	3.00
40	Neu Zittau	52.39	13.74	3.00
41	Alt Madlitz	52.38	14.28	3.00
42	Schulzendorf	52.36	13.57	3.00
43	Frankfurt a. d. Oder	52.34	14.54	3.00
44	Rauen	52.33	14.02	3.00
45	Lehnin	52.31	12.74	3.00
46	Petersdorf bei Saarow-Pieskow	52.31	14.06	3.00
47	Ludwigsfelde	52.30	13.26	3.00
48	Königs Wusterhausen	52.29	13.63	3.00
49	Zeesen	52.27	13.63	3.50
50	Brieskow-Finkenheerd	52.25	14.57	3.00
51	Müllrose	52.24	14.41	3.00
52	Herzberg	52.21	14.12	3.00
53	Zossen	52.21	13.45	3.00
54	Brück	52.19	12.76	3.00
55	Rießen	52.19	14.53	3.00
56	Pohlitz	52.18	14.57	3.00
57	Beeskow	52.17	14.24	3.00
58	Eisenhüttenstadt	52.14	14.64	3.00
59	Bremsdorf	52.14	14.49	3.00
60	Märkisch Buchholz	52.11	13.76	3.00
61	Möbiskruge	52.10	14.59	3.00
62	Niemegk	52.07	12.69	3.00
63	Henzendorf	52.04	14.51	3.00
64	Lieberose	51.98	14.30	3.00
65	Schönwald (bei Herzberg)	51.97	13.76	3.00

Table 1 - continued.

ID of MDP	Location	Latitude	Longitude	Intensity
66	Guben	51.95	14.71	3.00
67	Lübben (Spreewald)	51.94	13.89	3.00
68	Seyda	51.88	12.90	3.00
69	Wittenberg (Lutherstadt)	51.87	12.64	3.00
70	Rathmannsdorf	51.82	11.62	3.00
71	Vetschau (Spreewald)	51.78	14.07	3.00
72	Kemberg	51.77	12.63	3.00
73	Cottbus	51.75	14.33	3.00
74	Calau	51.74	13.95	3.00
75	Forst (Lausitz)	51.74	14.64	3.00
76	Schlieben	51.72	13.38	3.00
77	Sonnewalde/Niederlausitz	51.69	13.64	3.00
78	Bad Schmiedeberg	51.68	12.73	3.00
79	Prettin	51.66	12.92	3.00
80	Drebkau	51.65	14.22	3.00
81	Finsterwalde	51.63	13.71	3.00
82	Bitterfeld	51.62	12.32	3.00
83	Spremberg	51.57	14.37	3.00
84	Torgau	51.56	13.00	3.00
85	Bad Muskau	51.54	14.72	3.00
86	Senftenberg	51.52	14.00	3.00
87	Bad Liebenwerda	51.51	13.39	3.00
88	Weißwasser/Oberlausitz	51.50	14.64	3.00
89	Lauchhammer	51.49	13.76	3.00
90	Neustadt/Sa.	51.49	14.45	3.50
91	Halle-Neustadt	51.48	11.97	3.00
92	Eilenburg	51.46	12.63	3.00
93	Schildau	51.45	12.93	3.50
94	Hoyerswerda	51.44	14.24	3.50
95	Schkeuditz	51.39	12.22	3.00
96	Rietschen/Oberlausitz	51.39	14.78	3.00
97	Wittichenau	51.38	14.24	3.00
98	Ortrand	51.37	13.75	3.00
99	Sondershausen	51.37	10.86	3.00
100	Dahlen	51.36	12.99	3.00
101	Merseburg	51.35	11.99	3.00
102	Bad Frankenhausen/Kyffhäuser	51.35	11.10	2.50
103	Leipzig	51.34	12.37	3.00
104	Borna	51.31	13.18	3.00
105	Riesa	51.31	13.28	3.00
106	Markranstädt	51.30	12.22	3.00
107	Nünchritz	51.30	13.38	3.00
108	Niesky	51.29	14.82	3.00
109	Königsbrück	51.26	13.90	3.00
110	Baruth	51.22	14.59	3.00
111	Jessen (bei Meißen)	51.20	13.53	3.00
112	Rötha	51.19	12.41	3.00
113	Hainichen	51.19	12.56	3.00
114	Pegau	51.16	12.25	3.00
115	Meißen	51.16	13.47	3.00
116	Leisnig	51.16	12.92	3.00
117	Görlitz	51.15	14.99	3.00
118	Treffurt	51.13	10.23	3.00
119	Löbau	51.09	14.66	3.00
120	Pretzsch (bei Wittenberg)	51.09	11.94	3.00
121	Hermsdorf (bei Rochlitz)	51.07	12.87	3.00
122	Mergenthal	51.06	13.36	3.00
123	Oppach/Löbau	51.06	14.50	3.00
124	Creuzburg	51.05	10.24	3.00
125	Dresden	51.05	13.75	3.00
126	Stolpen/Sa.	51.04	14.08	3.00
127	Neusalza-Spremberg	51.03	14.53	3.00
128	Grumbach	51.02	13.55	3.00
129	Herrnhut	51.01	14.74	3.50
130	Ostritz	51.01	14.93	3.00

Table 1 - continued.

ID of MDP	Location	Latitude	Longitude	Intensity
131	Ruppersdorf/Oberlausitz	51.00	14.72	4.00
132	Mittweida	50.98	12.97	3.00
133	Eibau	50.98	14.66	4.00
134	Weimar	50.98	11.32	3.00
135	Erfurt	50.97	11.03	3.00
136	Heidenau	50.97	13.87	4.00
137	Sebnitz	50.97	14.27	3.00
138	Oberoderwitz	50.97	14.71	4.00
139	Pirna	50.96	13.94	3.50
140	Leutersdorf (bei Zittau)	50.96	14.65	3.00
141	Rathen	50.95	14.08	3.50
142	Dittelsdorf	50.95	14.87	4.00
143	Niederoderwitz	50.95	14.73	3.00
144	Hirschfelde (bei Zittau)	50.94	14.89	3.00
145	Oberseifersdorf	50.94	14.80	4.00
146	Wittgendorf (bei Zittau)	50.94	14.83	4.00
147	Spitzkunnersdorf	50.93	14.68	3.50
148	Seifhennersdorf	50.93	14.61	4.00
149	Jena	50.93	11.59	3.00
150	Eckartsberg	50.92	14.80	3.00
151	Draußendorf	50.92	14.87	3.00
152	Radgendorf	50.92	14.83	4.00
153	Bad Schandau	50.91	14.15	4.00
154	Burgstädt	50.91	12.80	3.00
155	Mittelherwigsdorf	50.91	14.76	3.50
156	Freiberg	50.91	13.34	3.00
157	Pethau	50.90	14.77	3.50
158	Hörnitz	50.90	14.75	3.50
159	Waltershausen	50.89	10.55	3.00
160	Zittau	50.89	14.80	4.00
161	Großschönau	50.89	14.66	4.00
162	Jena-Lobeda	50.89	11.60	3.00
163	Zug (bei Freiberg)	50.89	13.34	3.00
164	Bertsdorf-Hörnitz	50.88	14.73	3.50
165	Gera	50.87	12.08	3.00
166	Olbersdorf	50.87	14.77	3.00
167	Waltersdorf (bei Zittau)	50.87	14.65	3.50
168	Eichgraben	50.87	14.80	3.50
169	Ronneburg	50.86	12.18	3.00
170	Flöha	50.85	13.07	3.00
171	Hartau	50.85	14.81	3.00
172	Jonsdorf, Kurort	50.85	14.70	3.00
173	Meerane	50.85	12.46	3.00
174	Chemnitz	50.83	12.92	3.00
175	Arnstadt	50.83	10.94	3.00
176	Lückendorf	50.83	14.76	4.00
177	Grüna / Sa.	50.81	12.79	3.00
178	Hohenstein-Ernstthal	50.80	12.71	3.00
179	Hermsdorf (bei Hohenstein-Ernstthal)	50.78	12.67	3.50
180	Seelingstädt (bei Gera)	50.77	12.24	3.00
181	Erlbach-Kirchberg	50.76	12.73	3.00
182	Uhlstädt	50.74	11.47	3.00
183	Weißen/Rudolstein	50.73	11.45	3.00
184	Neustadt an der Orla	50.73	11.74	3.00
185	Etzelbach	50.73	11.43	3.00
186	Neuhausen/Erzgebirge	50.67	13.46	3.00
187	Seiffen	50.64	13.45	3.00
188	Deutscheinsiedel	50.63	13.49	3.00
189	Zwönitz	50.63	12.81	3.00
190	Reichenbach/Vogtland	50.62	12.30	3.50
191	Kaulsdorf	50.61	11.43	3.00
192	Schneeberg	50.59	12.64	3.00
193	Annaberg-Buchholz	50.58	13.00	3.00
194	Schleiz	50.57	11.81	3.00
195	Jöhstadt	50.51	13.09	3.00

Table 1 - continued.

ID of MDP	Location	Latitude	Longitude	Intensity
196	Crottendorf	50.51	12.94	3.50
197	Plauen/Vogtl.	50.49	12.13	3.00
198	Bad Lobenstein	50.44	11.64	3.00
199	Gefell	50.43	11.86	3.50
200	Johanngeorgenstadt	50.43	12.72	3.00
201	Hildburghausen	50.42	10.73	3.00
202	Blankenstein	50.40	11.69	3.00
203	Venzka	50.40	11.83	3.00
204	Mühlhausen / Thür.	50.29	12.26	3.00
205	Heldburg	50.28	10.72	3.00

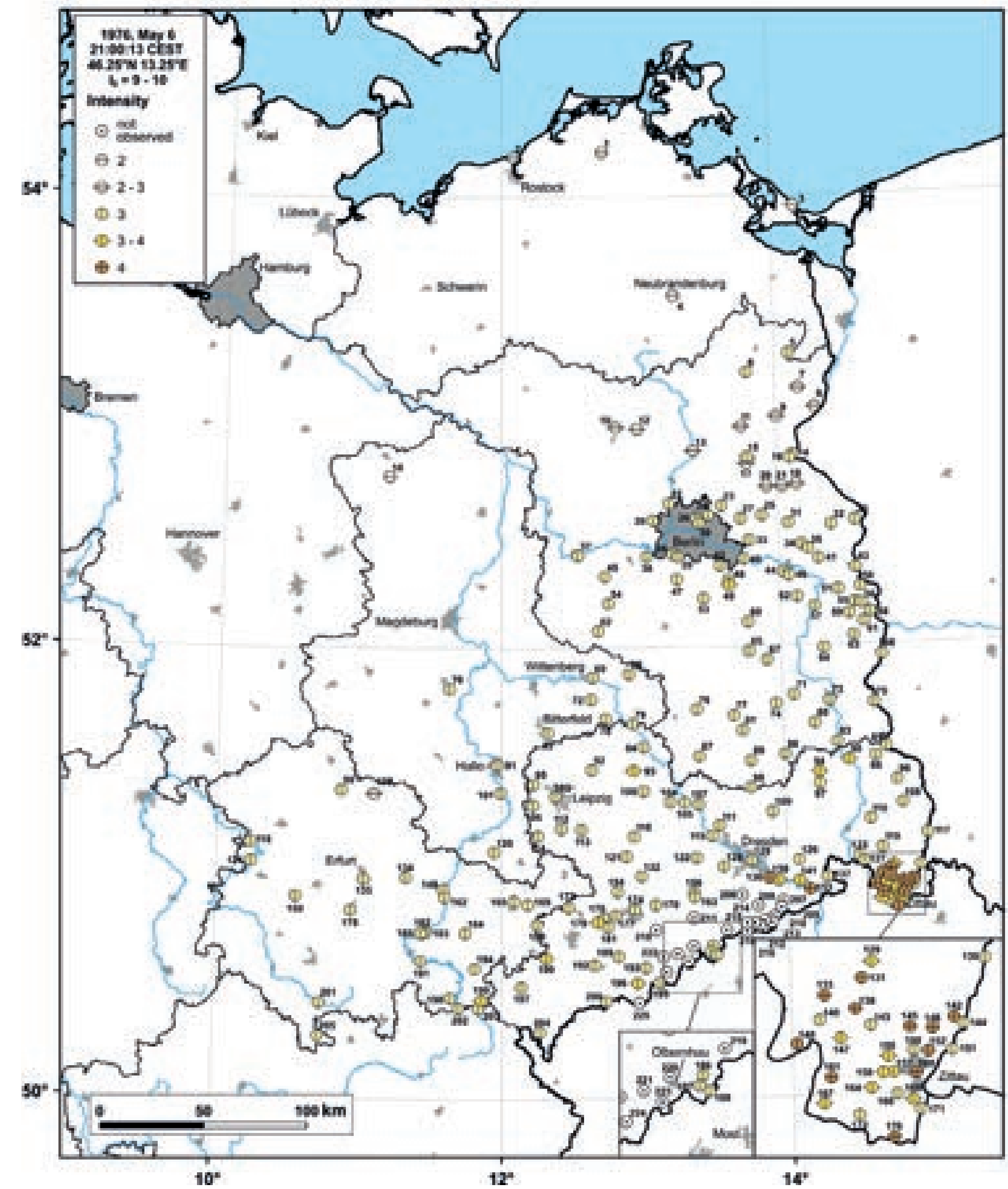

Fig. 7 - Observed macroseismic intensities of the 6 May 1976, Friuli earthquake in Central and north-eastern Germany. The areal extent of the federal state of Germany is shown as well.

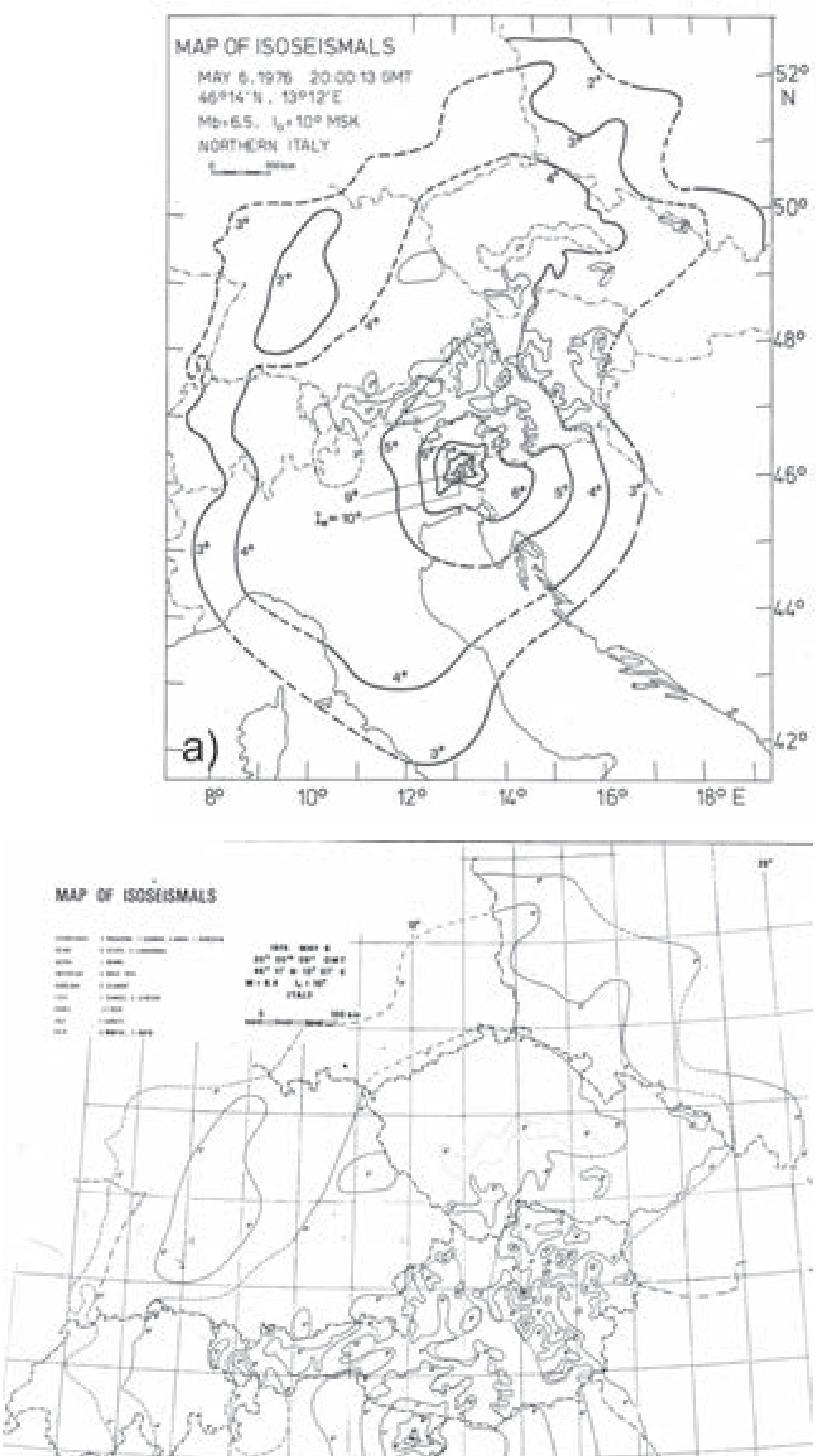

Fig. 8 - Joint macroseismic maps of the 1976 Friuli main shock after Kárník *et al.* (1978, left) and after Procházková and Kárník (1978). In Fig. 8b (right), the southern part is omitted. Both maps refer to the same basic map, but have a slightly different layout.

graben with often quite different subsoil conditions than in the Erzgebirge as a tilted fault-block formation with steep slopes towards the Eger graben.

A certain portion of macroseismic observations were made in high rise apartment buildings, in particular in 9 to 27 storey buildings in Berlin, Frankfurt/O., Halle/S., Leipzig, Erfurt and Chemnitz. If one would, contrary to the Guidelines of the EMS-98, assign intensities from observations in their upper floors, one would end up with intensities towards 5. Such intensity assignments were disregarded, as it was recommended later in the EMS-98 (p. 29).

3. Cross-bordering contemporary macroseismic maps of the Friuli main shock

The cross-bordering study of the macroseismic effects of the Friuli main shock was initiated by Vít Kárník and Dana Procházková in 1976. The resulting cross-bordering macroseismic map for the earthquake was designed in terms of isoseismal lines. It was published by Kárník *et al.* (1978) and by Procházková and Kárník (1978), as shown in Figs. 8a and 8b. Both maps represent a slightly different layout of one and the same basic map. These maps highlight the different macroseismic practices in the different affected countries and the "jumps" of intensities along state boundaries, as seen between the former Yugoslavia and Austria. In the SE part of Central Germany, i.e. in the Erzgebirge near the border to Czechoslovakia, the course of the 4-degree isoseismal line unfortunately crosses the area, where the quake was in fact not felt. The fairly large northerly extension of the area, which was shaken with intensity 3, in the eastern part of the GDR up to the latitude of Berlin, corresponds very well with the observations in Poland as is shown in both maps of Fig. 8.

Table 2 - List of localities in the Erzgebirge, where the 1976 Friuli was not felt according to inquiries on the spot.

ID of MDP	Location	Latitude	Longitude
206	Dippoldiswalde	50.90	13.68
207	Berggießhübel	50.86	13.96
208	Glashütte	50.84	13.78
209	Bad Gottleuba	50.84	13.94
210	Breitenau	50.79	13.89
211	Großhartmannsdorf	50.79	13.34
212	Lauenstein	50.79	13.82
213	Liebenau	50.77	13.88
214	Altenberg	50.77	13.76
215	Schellerhau	50.77	13.71
216	Geising	50.75	13.80
217	Zschopau	50.75	13.07
218	Rehfeld-Zaunhaus	50.74	13.71
219	Rechenberg-Bienenmühle	50.74	13.56
220	Niederneuschönberg	50.66	13.32
221	Pobershau	50.63	13.22
222	Großrückerswalde	50.63	13.11
223	Rübenau	50.61	13.30
224	Oberschaar	50.56	13.14
225	Oberwiesenthal, Fichtelberg	50.43	12.94

4. Comparison of macroseismic data with the 4 December 1690, Carinthia earthquake as historical precedent

The macroseismic findings concerning the 1976 Friuli main shock can be compared with observations of historical earthquakes of similar strength in the focal region of Friuli-Venezia Giulia and adjacent northern Carinthia. A striking example in this respect is the 4 December 1690, Carinthian earthquake at 3:45 p.m. There are contemporary reports describing observations of this earthquake from 26 locations in Central Germany and surroundings, shown in Fig. 9. Table 3 provides all these MDPs. Concerning most of these MDPs reference is made to Eisinger and Gutdeutsch (1994). Their findings are enriched here by several more sources from additional locations. Details of the study on the observations of the 1690 earthquake in Central Germany remain reserved for a specific paper dedicated to this earthquake, which is in preparation.

It was formerly seen with doubt that the relatively rich sources for this earthquake in the region would really belong to the Carinthian earthquake, since there occurred a local earthquake on 23 November 1690. However, this event occurred at about 9 a.m., which might have led to confusion

Table 3 - List of MDPs of the 4 December 1690 3:45 p.m. Carinthian earthquake in Central Germany and surroundings. The numbering is from north to south.

ID of MDP	Location	Latitude	Longitude
1	Guben	51,95	14,72
2	Calbe (Saale)	51,90	11,78
3	Wittenberg (Lutherstadt)	51,87	12,65
4	Düben	51,59	12,59
5	Melpitz	51,53	12,94
6	Halle a. d. Saale	51,48	11,97
7	Gröditz	51,42	13,45
8	Nemsdorf	51,36	11,66
9	Leipzig	51,34	12,38
10	Borna	51,32	13,19
11	Zebrzydowa (Siegersdorf am Queis)	51,23	15,39
12	Lützen	51,25	12,13
13	Oberlichtenau	51,22	13,99
14	Weißenfels	51,20	11,97
15	Görlitz	51,15	14,99
16	Meißen	51,16	13,48
17	Pegau	51,17	12,25
18	Lubań (Lauban)	51,12	15,30
19	Bischofswerda	51,13	14,18
20	Naumburg	51,15	11,81
21	Buttstädt	51,12	11,42
22	Lubomierz (Liebenthal)	51,01	15,51
23	Dresden	51,05	13,74
24	Altenburg	50,99	12,43
25	Weimar	50,98	11,33
26	Erfurt	50,98	11,03
27	Varnsdorf	50,91	14,62
28	Jena	50,93	11,59
29	Zittau	50,90	14,81
30	Litoměřice	50,54	14,13
31	Rakovnik	50,10	13,73
32	Kulmbach	50,11	11,46
33	Bayreuth	49,95	11,58

in reporting since the difference between both quakes in days is similar to the difference between the Julian and Gregorian calendars. The new study has shown that sources concerning the local event exist only from 4 locations within a relatively small area within the Thuringian basin. Only in two of them both events are described. The MDPs of the local event eleven days before the Carinthian earthquake are shown in the map of Fig. 9 as well. The MDPs of this Thuringian earthquake are given in Table 4.

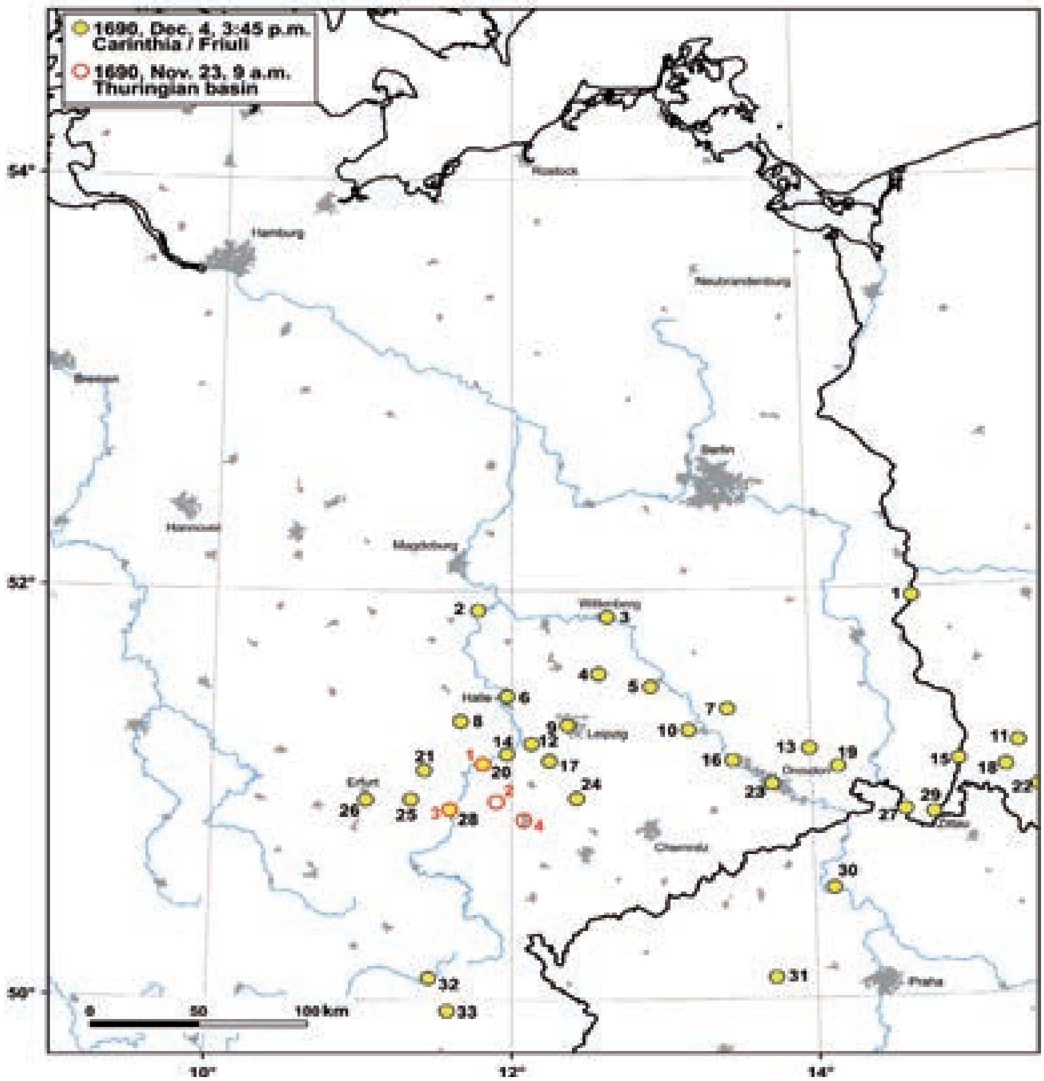

Fig. 9 - Map of MDPs of the 4 December 1690, 3:45 p.m., Carinthian/Friuli earthquake (in yellow) within Central Germany and surroundings and the MDPs of the 23 November 1690, 9 a.m., earthquake in the Thuringian basin (red circles).

Table 4 - List of MDPs for the 23 November 1690, 9 a.m. earthquake in the Thuringian basin with numbering from north to south.

ID of MDP	Location	Latitude	Longitude
1	Naumburg	51,15	11,81
2	Eisenberg	50,97	11,90
3	Jena	50,93	11,59
4	Gera	50,88	12,08

5. Soil amplification as one explanation for the relatively strong macroseismic seismic effects in the studied far field

The distinct macroseismic observations of the Friuli earthquake at great distance in NE and Central Germany raised the question of their origin. Therefore, the incoming recorded seismic waves on hard rock at the seismological station Collmberg, roughly midway between Leipzig and Dresden, were used for numerical modelling of the amplification of seismic waves according to detailed depth profiles of shear wave velocity v_S for sites with soft underground conditions. This modelling considered the frequency dependent attenuation of v_S. The calculated amplification effects for those borehole data sets were published by Grünthal (1978) for one borehole near Berlin, and another one for a location in the Lausitz brown coal region. Fig. 10 shows, as an example, the amplification according to the data of the borehole east of Berlin with the v_S profile (left), the Fourier spectrum of the amplification in a broad frequency range (with and without attenuation) in the middle part. On the right, there is the amplification in the time domain for the record of a 1976 Friuli earthquake of smaller magnitude on hard rock at the seismological station Collmberg. The largest amplification occurs in the period range of 1–2 s. The amplification at shorter periods is largely omitted due to the attenuation characteristics. The incoming S waves of the rather distant Friuli earthquakes only have fairly large amplitudes within the highly amplified period range. This might be, at least, one of the reasons for the pronounced macroseismic observability of Friuli quakes in the region. Modern studies with improvements in understanding the peculiar macroseismic field in the eastern part of the study area as well as in the adjacent part of Poland are not known to the author.

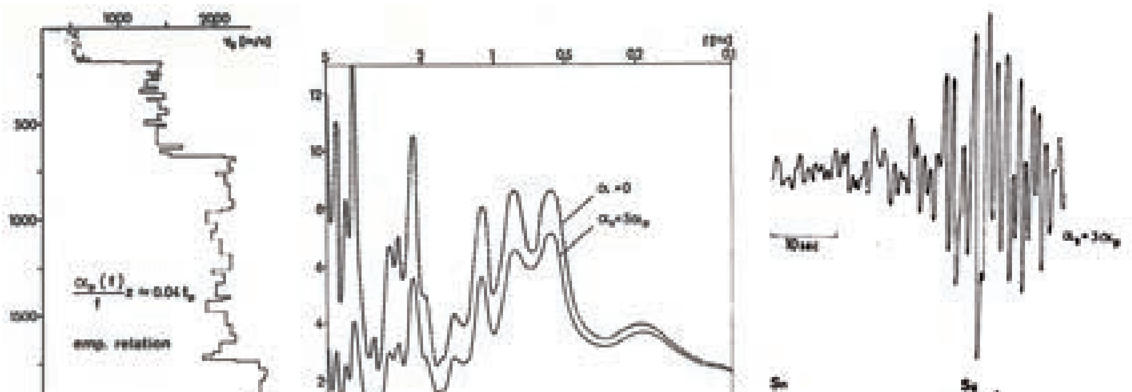

Fig. 10 - Illustration of soil amplification according to the shear wave velocity depth profile of a borehole near Berlin (left), the corresponding Fourier amplification spectrum with and without frequency dependent attenuation α (middle) and the amplification in the time domain (right) according to a record on hard rock at the seismological station Collmberg (after Grünthal, 1978).

6. Summary

The 1976 Friuli mainshock was widely felt in eastern parts of NE and Central Germany, as far north as the Baltic Sea coast. The long delay of about nine months in obtaining the permit to perform a macroseismic investigation did not affect the successful data collection. Additional macroseismic data was acquired by spontaneously submitted letters or postcards by observers and by non-public inquiries within state authorities. Altogether, positive reports from 205 locations were collected. Most observations were assigned with intensities 3 and 2-3 in the very north. Only in the area of Zittau, in the most south-eastern part of Saxony, is an agglomeration of intensity 4 manifested. The fairly strong macroseismic effects in high-rise apartment buildings were not used for intensity assignments[4]. By contrast, the earthquake was not felt in large parts of the Erzgebirge in towns with mostly hard rock foundations of buildings.

The rich macroseismic material of the 1976 earthquakes confirms the extensive contemporary and independent observations of the 1690 Carinthian earthquake in Central Germany. Formerly, these comprehensive historical data were viewed with some doubt, or as a result of a mix-up with a very local earthquake in the region eleven days earlier but at a very different local time.

The far-reaching macroseismic observations can, at least partly, be explained by soil amplification effects. Detailed profiles of shear velocities with depth and corresponding well-determined frequency dependent attenuation of shear waves were used to calculate respective transfer functions. The convolution with records of the 1976 earthquake on a hard rock site within the area clearly shows the frequency dependent amplification effects.

The presented detailed macroseismic data on the 1976 Friuli main shock in the study area became part of the re-assessment of such data for the entirely felt area of this quake. These new findings on this European key earthquake are published in the paper by Tertulliani *et al.* (2018).

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4 A recent example of far reaching strong macroseismic effects in high rise buildings is the observation of the M_w 6.2 2016 Amatrice earthquake in central Italy as far as in Kirchberg, Luxembourg (Margarita Megally Cassar; personal communication).

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