Pageoph, Vol. 116 (1978), Birkhäuser Verlag, Basel

Map of Isoseismals of the Main Friuli Earthquake of 6 May 1976

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Summary – The isoseismal map of the North-Italian earthquake of 6 May 1976 was compiled using the contributions of the European countries lying within the shaken area. The characteristic feature of the macroseismic field is discussed.

Key words: Seismic intensity of Friuli earthquake; Friuli earthquake; Map of isoseismals.

The disastrous earthquake which originated in the Friuli province, Italy, 6 May 1976, caused damage in a large area; 44 villages were destroyed in Italy. It was strongly felt throughout Central Europe; slight tremors were reported even from the Baltic Coast and from the Netherlands in the North. The parameters of the shock given by Italian seismologists (GIORGETTI, 1976) are $\psi = 46° 17'$ N, $\lambda = 13° 07'$ E, H = 20h 00m 09s GMT, $I_0 = 10°$ (MSK-64), $M = 6.4$, $h = 7$–8 km. CSEM calculated the following parameters: 46.23° N 13.20° E, $M = 6.5$, $I_0 = 9$–10° (MSK-64). The main shock was followed by several hundreds of aftershocks and a new period of activity started on 11 September culminating on 15 September. Since an earthquake of such intensity is rare in the Eastern Alps the shock of 6 May was studied from various points of view. First, in each country shaken by the earthquake the isoseismals were drawn. The individually investigated

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parts of the macroseismic field were joined and compiled into a complete isoseismal map presented in this paper (Fig. 1). The data collected in Yugoslavia, Czechoslovakia, Austria, FRG, France, Poland and Switzerland have already been discussed in an earlier paper (KÁRNÍK *et al.* 1976). The information on the macroseismic field on the territory of the GDR was included later, as well as the more detailed additional data received from Italy (Giorgetti, 1976).

In the GDR the macroseismic field extends over the whole territory, some observations being reported even from the Baltic Sea coast. There were, however, no observations reported from a large area in the north-western part of the country. The strongest macroseismic effects were observed in the south-eastern part of the GDR.

Divergencies in the assignment of intensities cannot be avoided, they are caused by a different approach of individual authors to the treatment of macroseismic observations. It is impossible to avoid this type of inconsistency without a revision of all macroseismic questionnaires by a single person. Nevertheless, the combination of the individual portions of the macroseismic field can be expected to yield a good general survey of the macroseismic effects in Europe. In Austria, the isoseismals are more complicated and follow all local variations of intensity. For uniformity, generalized isolines are indicated in Fig. 1 by dotted lines.

The most conspicuous phenomenon is the irregular extension of the isoseismal 4° towards the North, including the Bohemian Massif. This is typical for all strong East-Alpine earthquakes. These irregularities of the radiation of seismic energy and their causes were the topic of many papers. The anomalous radiation of seismic energy to the North and Northwest, i.e. to the Bohemian Massif, was already studied by SUESS (1873, 1885) who introduced the concept of 'Stosslinien'. The connection of these lines with the horizontal and vertical geological discontinuities on the territory of Austria was studied by KOWATSCH (1911), HERITSCH (1918, 1920) and KOLÁČEK (1926). SIEBERG (1932) and SCHWINNER (1926, 1929) tried to explain the transmission of seismic energy to the North by the existence of wave-conduction along deep boundaries. The hypothesis of KAUTSKY (1924)—the Bohemian Massif reacting as a homogeneous block—on the transmission of seismic waves from the East-Alpine earthquakes was denied by ZÁTOPEK (1948) who showed that the irregular extension of the macroseismic effects is related to the block structure of the Bohemian Massif. This explanation was confirmed by the analysis of the macroseismic observations of the East-Alpine earthquakes from 1963–64 by BABUŠKA *et al.* (1965, 1966).

The comparison of isoseismals of the Friuli earthquake (Fig. 1) with the geological structure shows that the shape of isolines corresponds to some Alpine structural units. The observations may, however, be influenced by the density of population in the Alpine valleys. Two about 40 km wide zones of intensive shaking are evident in the direction approximately North-Northeast. The eastern zone begins near Sankt Pölten and Mariazell and continues towards Brno, the western one runs from

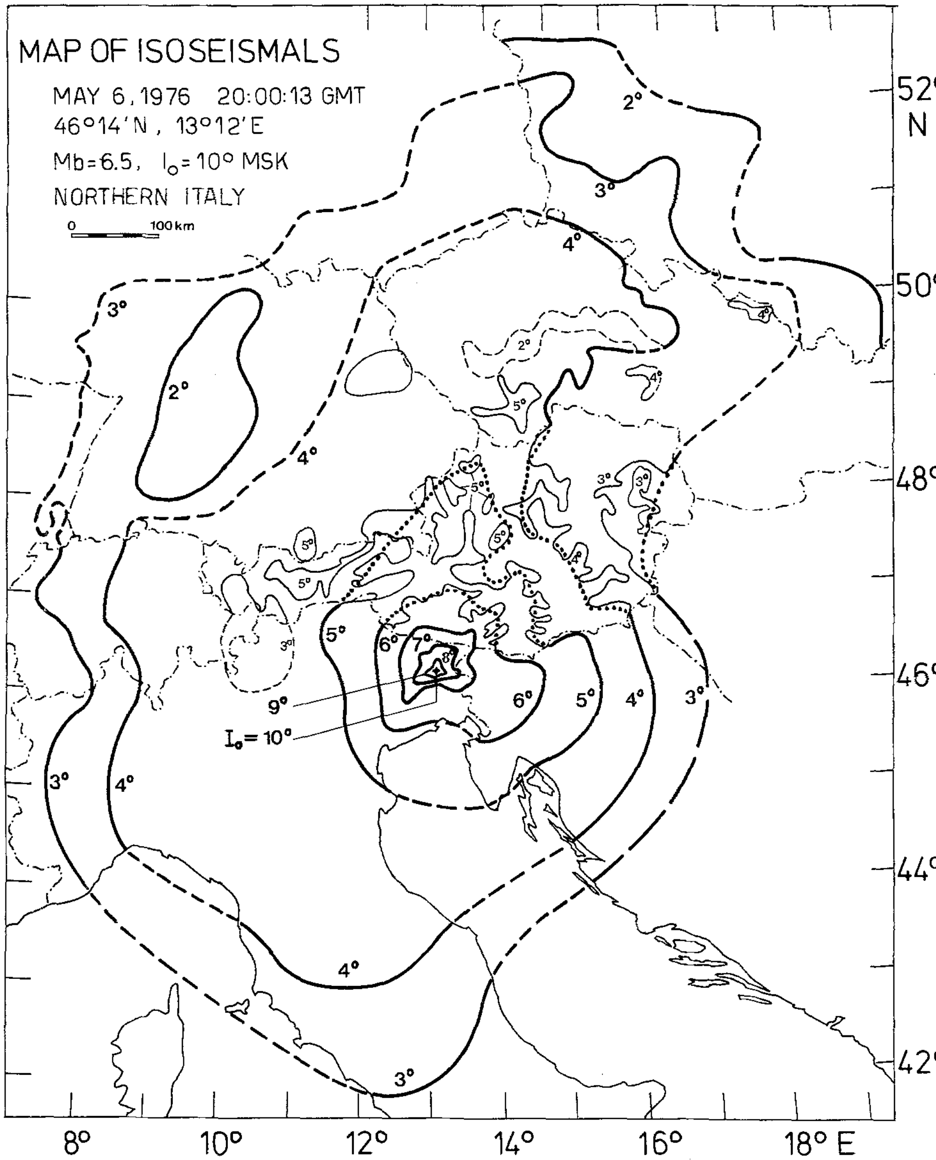


Figure 1
Map of isoseismals of the main shock in Friuli, 6 May 1976. The original map for Austria was slightly generalized for reproduction. Contributors to this map are: Czechoslovakia: D. Procházková, Z. Schenková, V. Kárník, L. Ruprechtová. Poland: B. Guterch, H. Lewandowska. Austria: J. Drimmel. Switzerland: D. Mayer-Rosa. Yugoslavia: D. Cvijanović. Fed. Rep. Germany: C. Schmedes, G. Leydecker. France: J. P. Rothé. Italy: F. Giorgetti. German Dem. Rep.: G. Grünthal, E. Hurtig.

Salzburg and Zell am See to the South Bohemian Basin. Both zones traverse the boundary between the Bohemian Massif and the Alps. In the North they are connected with the Boskovice and Blanice Furrows which are parallel to the Rhinegraben. In the South they slightly deviate from this direction. The northern part of the eastern zone which follows the course of the Carpathian Molasse might be partly explained by the influence of the accumulated sedimentary complexes, but the southern part of the zone leaves the Molasse and continues into the Northern Calcareous Alps. Similarly, the western zone is partly connected with the sedimentary deposits in the South Bohemian Basins and in the Bavarian Molasse, the continuation to the southwest runs again into the Northern Calcareous Alps. It is impossible to account for both zones only by the existence and influence of the sedimentary cover in the depressions. Their cause might be in the deep structure of the earth's crust. According to the present knowledge these zones do not coincide with the areas which were tectonically most active in the neotectonic era.

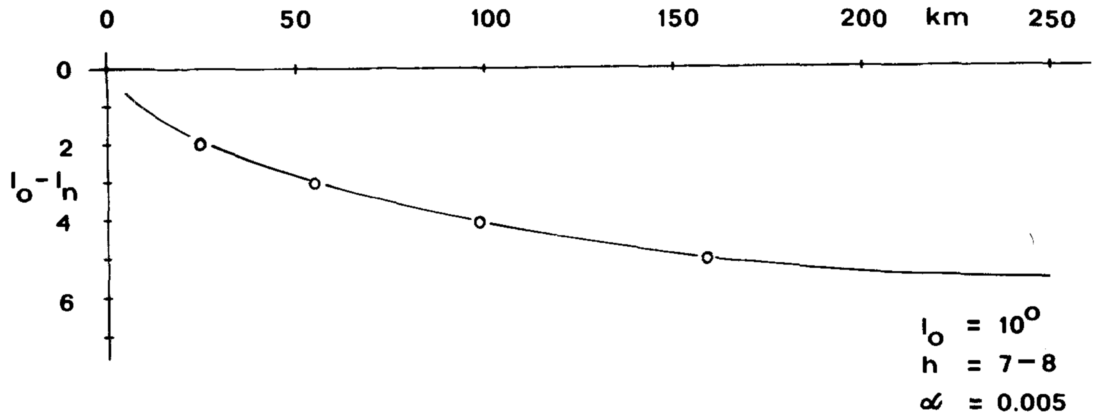
Although the isoseismal map of the Friuli earthquake is based on dense observations, the comparison of geological conditions and macroseismic data does not lead to a satisfactory interpretation of large macroseismic anomalies.

The mean radii of isoseismals were calculated using both the surfaces encircled by the isoseismals and the measurements in eight azimuths. The decrease of intensity with distance fits well the simple model defined by the Kövesligethy formula usually applied to the calculation of the focal depth and the absorption coefficient. The radii and the calculated values of depth h and absorption coefficient α are given in Table I; for comparison, the same parameters were determined using the version of the isoseismal map compiled by CONSOLE (1976). The depth varies from 7 to 14 km, α from 0.001 to 0.005, however, Console's data yield $h = 13$ km and $\alpha = 0.01$,

Table 1

Radii of isoseismals in different directions (km)

Isoseismal	Mean	N	S	E	W	NE	SE	NW	SW	Console (1976)
10°	4	2	2	5.5	4	2	2	3	3	7.5
9°	9	13	10	10	10	8	9	4	10	22
8°	26	30	12	28	22	35	18	25	21	41
7°	44	50	16	43	42	57	50	50	53	83
6°	84	86	58	123	68	90	86	68	86	
5°	167	196	156	184	114	155	135	165	132	
4°	350	498	308	240	344	214	368	300	377	
3°	500	648	469	308	404	577	458	545	481	
2°	680					616				
h	7	7	4	5	5	5	5	7	7	13
α	0.005	0.001	0.001	0.001	0.005	0.001	0.001	0.005	0.005	0.010



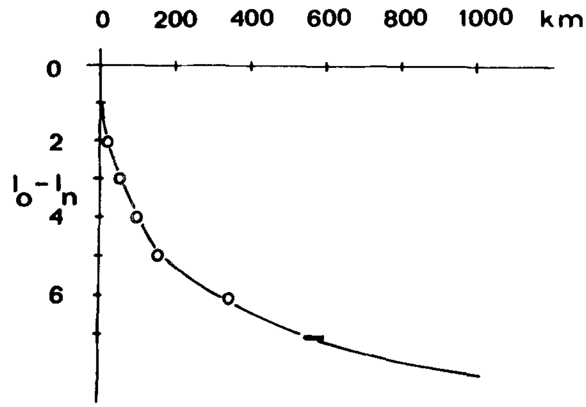


Figure 2
Intensity attenuation with epicentral distance.

respectively. From macroseismic data which correspond to an azimuth WNW, a focal depth of 8 km in conjunction with $\alpha = 0.001$ was found by other investigators (MAYER-ROSA *et al.* 1976), using a similar procedure as described in this paper.

The focal depth can be also calculated by the Blake formula, which is a simplified version of the Kövesligethy formula, namely

$$I_0 - I_n = k \log \frac{D_n}{h},$$

where I_0 is the epicentral intensity, $D_n = \sqrt{r_n^2 + h^2}$, r_n being the radius of the isoseismal I_n and h is the depth of the focus. The constant k ranges from 3 to 6, the mean value for Europe was found to be $k = 4.5$ (KÁRNÍK, 1968). The values of the focal depth obtained by the application of the Blake formula are listed in Table 2.

Table 2

Depth of focus calculated using the Blake formula

Isoseismal	h [km]
8°	10.3
7°	10.1
6°	11.5
5°	13.8
4°	17.5
3°	15.1
2°	12.5
$h = 13$ km	

The mean value of $h = 13$ km is larger than the values calculated according to the Kövesligethy formula, indicating that k should probably be smaller for the investigated area, approximately $k = 3.7$.

The variation of the mean radii in different azimuths (Table 1) reflects the anomalies in the propagation of seismic energy. Except for the isoseismals 6°, 9° and 10° all other isolines are extended to the North and shortened in the southern direction. The dispersion of the values of mean radii increases for the isoseismal $I \leq 5°$.

The magnitude of the main shock can be calculated from the empirical formula by KÁRNÍK (1968) relating magnitude, epicentral intensity I_0 and focal depth h

$$M = \tfrac{2}{3}I_0 + 1.4 \log h - 1.25$$

and according to the relation by FRANKE-GUTDEUTSCH (1974), derived for the East-Alpine earthquakes

$$M = 0.542I_0 + 0.495 \log h + 0.673$$

(both formulae are valid for $I_0 \geq 6°$). The values of $M = f(I_0, h) = 6.6$ and 6.5, respectively, were obtained; both being close to the magnitude determined from the instrumental data (6.4–6.8).

The macroseismic field of the main shock in Friuli (6 May 1976) shows an exceptionally good propagation of seismic energy to large epicentral distances towards the North, and a rapid damping to the macroseismic effects towards the East. The regional deviations connected with the geological conditions appear throughout the area under investigation. A relative increase of intensity was observed in the young sedimentary basins. Increasing intensities are also related to the faults and to their crossings reactivated in the neotectonic era. Also densely fractured blocks characterized by recent differential movements seem to be more sensitive to shaking.

The strong shocks of 11 and 15 September 1976 were also widely felt in Central Europe; the distribution of intensities confirms in general the conclusions made on the basis of the isoseismal map of the main shock of May 1976.

The details of the distribution of the macroseismic effects will be studied in each country, the presented map gives only a general information on the macroseismic field as a whole. There are only a few complete isoseismal maps of East-Alpine events; usually maps covering only a certain national territory are published. The presented example should be followed in the future using a standard procedure for analysis and compilation of all available macroseismic data.

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(Received 14th July 1977)