Chapter 2
First Macroseismic Maps in Southern Poland in the Late 19th Century

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Abstract The principles of macroseismic earthquake observation and classification in pre-instrumental era are briefly outlined and commented, which—in the course of the 19th century—resulted in making macroseismic intensity maps, forerunners of present maps of seismicity. The achievements in macroseismic earthquake study found their reflections in Central Europe, namely in Poland: for the second half of the 19th century (1858–1901) a total of 19 macroseismic maps were found for three Sudetic events and two Polish border area earthquakes in Saxony and NW Slovakia. They are reproduced and discussed below.

Keywords Macroseismic earthquake treatment · Macroseismic maps · Macroseismic intensity scale · South Poland historical earthquakes

2.1 Geopolitical Note

In the 19th century, the term *Poland*, and its territorial content, was variable in shape and size due to complex geopolitical development of Polish state in the past centuries. Similarly, the area of Silesia (which was more-or-less stable in shape and size), has varied considerably as concerns its geopolitical status, its population's alienisms and ethnic profile.

Since the cogitations given below deal with the historical seismicity of the region in question, one could be confused by the above-mentioned diversity. To avoid it we—in the following text—shall understand Poland, with its southwestern part, Silesia, exclusively as it has been settled and confirmed in 1945.

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2.2 Macroseismic Cartography in Transalpine Europe in the Second Half of the 19th Century

2.2.1 Introductory Remarks

Since the early Modern Age, European naturalists and philosophers strengthened their effort to better understand the perplexing phenomenon of *earthquakes* initiated deep in the Earth during which, without any warning, enormous portion of mechanical energy was suddenly released, demolishing settlements and killing people. In the late 18th century it became obvious that without a deeper insight into the complex behavior of the inner Earth processes, geosciences could not proceed to reply the main question: when these enigmatic forces will strike again, i.e., to the forecast an earthquake approach (this aim—by the way—remains unsolved up to the present time for the great deal of seismically active zones).

The first serious studies on earthquakes were presented by Swiss and English savants at the second half of the 18th century, in the time when the 1755 Great Lisbon Earthquake was subjected to a detailed investigation by numerous intellectuals of that-time Europe; for details see, e.g., Davison (1978, 2nd ed.), Reid (1914), Kendrick (1956), Schmidt (1980) and others. Ch. Davison in his book describes the main ideas on an earthquake presented by John Bevis, who lived in 1693–1771, as well as Bertrand (1757) and Michell (1761). After that glorious period of the early seismology—after Ch. Davison—a long pause occurred, from the 1760s to ca 1847, characterized by a kind of retardation of the progress in earthquake studies.

Of course, the *pause* seen by Ch. Davison was not quite tangible as concerns achievements in seismology. It was especially the long series of strong Calabrian earthquakes from 1783 to 1791 which excited Europeans similarly as the previous Great Lisbon earthquake of 1755; in Calabria six consequent strong earthquakes caused medium or large damage to the buildings within the area of more than 100 000 miles^2, which corresponds to ca ¼ million km^2. The vast regions of Calabria and eastern Sicily, which were hit by these earthquakes, were carefully studied by Italian naturalists, who summarized macro-seismic observations in their reports and books, see, e.g., Vivenzio (1783 and 1788), Dolomieu (1785) and others; confer also Barbano et al. (1980) and Placanica (1985).

As for the state of geosciences in the mid-19th century, many a concrete achievement obtained earlier in the field of investigation of seismic energy awakening, propagation and interaction with the Earth surface was forgotten. On the other hand, the naturalists succeeded in learning more clearly *which way* they should follow in the next research in order to proceed in the earthquake study; it was found and affirmed at the break of the 18th century that especially the seismic data of macroseismic nature detected by human observers on the Earth surface—if properly treated and interpreted—may shed light upon the invisible underground processes of seismic energy release.

This new insight into the earthquake study in Europe appeared at the break of the 18th century as being accompanied by a new phenomenon: by the expansion of savants' interest in the field investigation of seismic events *from the Mediterranean zones towards the north*, to the transalpine regions. The first steps in this process were done for the western parts of the continent, later for Central Europe, up to Poland and Hungary. This *transalpine* progress, which became clearly evident since the first years of the 19th century, and which strengthened later in that century, did not occur by chance: in that time German population went on a mass-moving eastward from their traditional seats around Rhine, Danube and Elbe Rivers so that in the course of 18th–19th centuries a large part of Central Europe appeared under German influence, expressed in political and cultural Germanic supervision. As concerns the natural sciences development in this region, one has to admit that the strong German states, Prussian, Hapsburgs' and Bavarian, undoubtedly appeared in a positive light in numerous aspects. Let us look—first of all—at the situation in geosciences, namely in early macro-seismology, which gradually developed as an important new discipline of geophysics in transalpine Europe, in which also Poland was involved.

Local transalpine geo-savants, not yet having the desired *Erdbebenmesser* (=device to measure an earthquake) for collecting and treating the *objective* seismic data at their disposal, developed instead a practical system of *subjective* macroseismic data collection, selecting and valuing by (more-or-less instructed and trained) human observers. These observers recorded visible seismic damage and classified it by means of answering the questions given in advance prepared *earthquake questionnaires*; possible variations in classification of the same damage by individual observers were compensated by averaging a large number of observations. The data obtained in such a way enabled to be sized according to the level of seismic damage advised by pertinent macroseismic intensity scale(s).

Soon in the 19th century it became clear that the "strength" of the earthquake is reflected—besides the observed degree of seismic damage on the Earth's surface—also by the *size of the stricken territory*. This fact led directly towards constructing macroseismic maps, alias geographical maps, in which the observed macroseismic data were localized according to their geographical coordinates λ, φ.

Later in the 19th century it appeared reasonable to investigate earthquakes not as separate events and classify them according to arbitrary criteria, but to apply an unified approach to earthquake studies as to mutually dependent phenomena and to analyze them using the same methodical tools, such as, e.g., quantity of seismic damage (=macroseismic degrees of damage), using the unified scale of damage, etc. Such a general unification appeared as an important condition for comparative studies of individual seismic territorial, time and intensity situations.

Having in mind this general effort aimed on an earthquake study, which can be considered as a rational and integral whole, we may classify the 19th century as a period of macroseismic pre-instrumental seismology birth. This period was at its end crowned by the first macroseismic maps and maps of seismicity on one hand, and by the first seismometers by J. Ewing and D. Milne at the turn of the 1870s, on the other hand. Let us now characterize briefly the individual steps in this macroseismic study advancement during the 19th century.

2.2.2 *Quantity of Earthquake "Strength"; Earthquake Intensity and Intensity Scales*

The seismic effects occurring on the Earth's surface due to seismogenic displacements in the Earth interior, as seen by human observers, were expressed by degrees of macroseismic intensity I (symbol I_o being reserved for maximum I value in the earthquake epicenter zone). It follows that the I-values were derived by means of statistics of macroseismic observations of humans, on animals, and man-made structures and natural formations.

Quite naturally, due to diversity of the Earth surface and local seismic activity of a given region, and also due to space/time varying culture and traditions of the residing local population, also formulation of I-degrees and consequently of macroseismic intensity scales *varied considerably region to region*. This diversity, reflected by the variable content of individual I-degrees, and also by total number of damage degrees of a given scale, often hampered the desirable general comparison of individual world earthquakes.

In the first ancient and medieval reports on the earthquakes, the described events were, in most cases, named according to the principal town in the affected area; for strong earthquakes the whole region (province, county) was named. Later, in the 17th and 18th centuries, for some Italian earthquakes, the seismic damage to buildings was differentiated in the pertinent maps, e.g., 4 levels of damage for the 1627 Puglia event (Foglia 1627) or 3 levels of damage for the 1783 Calabria earthquakes (Vivenzio 1783). In the first half of the 19th century, new macroseismic scales were proposed (6-degree scale by P.N.C. Egen for the 1828 upper Rhine earthquake (Egen 1828) and by J.J. Noggerath for the 1846 mid-Rhine earthquake (Noggerath 1847)); sometimes, the names of the settlements damaged in given degree were underlined in the standard geographic maps by color corresponding to the degree of damage given in the map legend. The isoseismal lines were not drawn in most cases; however, in some earthquake maps of this period the line showing limit of (human) perception of the Earth shaking was drawn; actually, the first such map presenting this limit was prepared and presented by two Hungarian naturalists, A. Tomtsanyi and P. Kitaibel, in their report on the 1810 Mór earthquake, see below.

In the second half of the 19th century, macroseismic cartography advanced rapidly, especially due to conscientiously performed macroseismic analysis of the 1855 Visp earthquake (Wallis, Switzerland), which was presented by Volger (1856 and 1857–1858); 5 years after O. Volger's publishing of his voluminous monograph, R. Mallet presented his 3-volume work on the 1857 Great Neapolitan earthquake (Mallet 1863). Both monographs represented model examples of the high level macroseismic analysis of a strong earthquake, including cartographic expression of pertinent seismic effects.

O. Volger, German naturalist teaching mineralogy at the high school in Bern, Switzerland, studied phenomenon of an earthquake as his hobby. After the 1855 Visp earthquake he spent several years collecting macroseismic data in

Switzerland and in the adjacent parts of France, Italy and Germany, which were also affected by the Visp earthquake. Then he defined his 6-degree macroseismic scale of seismic damage (in degrees of intensity I) and plotted his data into standard geographical map of the studied region. By plotting envelope curves for individual intensity degrees he got a standard macroseismic intensity map with the isoseismal lines as we understand it at present. Additionally, he improved his map in three points.

First, he added into his isoseismal map also thre perception limits of three weaker aftershocks, which followed the main shock.

Second, he strictly kept the curvature of his isoseismal lines according to the collected seismic macrodata plotted in his map (in contrast to other naturalists, who smoothed out "by sight" the shape of isoseismal lines, which they transformed into nice ovals, see, e.g., Mallet (1863) or Mouchketow (1903). It seems that O. Volger understood that the medium in which seismic waves propagate is not homogeneous and that due to complex geometrical texture of the medium the geometry of propagation of seismic waves may be influenced.

Third, in the right bottom corner of O. Volger's map the epicentral zone's sketch blown up is inserted to show the details of the pleistoseismal zone complexity.

We could also appreciate that he tried to mount the 1855 event into the pattern of seismically active arc of the central and western Alps.

The only weak point in O. Volger's macroseismic map can be seen in the numerical order of individual intensity degrees: namely, he denoted the strongest ($I_o = I_{max}$) intensity of the Visp earthquake as the zone **zero**, the next (still strong) zone as the zone No. **one**, then zone No. **two**, etc. up to weakest zone No. **six**. This order of intensity degrees was perhaps acceptable for one earthquake (=Visp), but it did not allow an intensity comparison with other, stronger earthquakes (unless one could agree to describe stronger events by negative numbers: −1, −2, −3, …). However, even with this small reservation, O. Volger's macroseismic map must be highly appreciated and valued.

After O. Volger's analysis published in 1857–58 it became commonly understandable how to create the macroseismic scale of intensity I, how to order its degrees corresponding to seismic damage, and how to express correctly the individual I-levels by $\boldsymbol{I_0 = I_{max}}, I_{max-\mathbf{1}}, I_{max-\mathbf{2}}, I_{max-\mathbf{3}}, \ldots\ I_1 = \boldsymbol{I_{min}}$. The first macroseismic intensity scale which was internationally accepted as a standard 10- (later12)-degrees of macroseismic intensity classification was the Forel (1881) scale, in which the value I_0 always corresponded to maximum (=epicenter) intensity, while I_{min} represented the lowest level of seismic damage observed, or, in some cases, the limit of Earth trembling perception felt by a man. Later on, the M. Rossi scale or M. Rossi and F. Forel macroseismic intensity scales were repeatedly changed, complemented, their degrees being refined and formulated more in detail (Rossi and Forel 1881). The last present variant of the macroseismic intensity scale represents simultaneously the widely used *European Intensity Scale-98* (EIS 1998), which was edited and composed by G. Grünthal and published just at the turn of the 20th century (Grünthal 1998). It should be noted that the scale EIS-98 is not used all over the world as the only mandatory macroseismic intensity degree scale; in many countries of Asia and America, older scales are used as well.

As for the territory of Poland, the name and life-work of the outstanding Polish geo-savant and geosciences promoter M.P. Rudzki, professor at the Jagielonian University, astronomer, geophysicist and seismologist, who organized foundation of the first seismological observatory at Kraków in 1903, must be recalled in this context. However, regardless of great M.P. Rudzki's merits as concerns Polish seismology, he did not engage himself in macroseismic cartography; also his main seismological activities fall into the 20th century,[1] which is not considered in the macroseismic studies presented here.

Today we know that the degree of seismic damage alone does not provide the proper degree of earthquake "strength" unless the geometry of the source and seismogenic displacement and especially the depth of seismic foci are considered. (As for the earthquake foci depth, in the early times geo-savants had no reliable tool in their hand to determine it. However, in some cases they spoke about a *shallow* earthquake in the situations in which seismic effects became detectable on the Earth's surface relief.)

2.2.3 Macroseismic Questionnaires and Seismic Historical Catalogues

Since the macroseismic analysis of an earthquake is based on treatment of observational information, its proper collection, recording, and delivery are of a crucial importance for obtaining undistorted results. In principle, these observational data are—first of all—used for two reasons. First, local or higher-level administrative institutions use them to organize the rescue and aid operations to mitigate the earthquake damage and, secondly, to study the observed data carrying new information on the seismic phenomenon itself; they helped to understand better the destructive seismic process and, in an optimum case, they were believed to be considered in the terms of the desired local seismic prognosis.

Seen from this viewpoint, the collected macroseismic data (which come from unequally trained and educated humans) should be still obtained in a form characterized by maximum objectivity and minimum of subjective and emotional viewpoints so that they would allow a correct determination of the given degree of macroseismic intensity for localities visited by the earthquake in question. It has appeared in the course of the last two or three centuries that (in the countries inhabited by literate population) for the above-mentioned requirements the *macroseismic questionnaires* serve as an important tool.

The questions asked for in these question-forms can be formulated according to the macroseismic scale used so that assignments of individual *I*-values

[1] His pioneering book "Physics of the Earth" was published in Polish in 1909 and then in German in 1911 (Rudzki 1909, 1911).

to individual situations described in the reports are quick and relatively unambiguous. The fact that the questionnaires can be submitted to a large number of respondents reduces the weight of possible extreme and/or incorrect data and figures.

A questionnaire after-earthquake circularization was reported, e.g., in the Iberian Peninsula in 1755/56, after the Great Lisbon earthquake occurrence, which devastated a large part of SW Europe on Nov 01, 1755. In the last two centuries, the seismic questionnaires represented an important source of macroseismic data: today modern seismographs supply directly and in an objective form a great portion of the required information, which earlier had to be assessed by making use of macroseismic observations. In some specific cases, however, both approaches, instrumental and macroseismic, have been successfully combined up to the present.

Other important tools for seismological research are represented by seismic historical catalogues.

For the first attempt to create a historical inventory of world earthquakes, which appeared in the seismically active regions, primordially in Italy, see, e.g., Münster (1544→1618) and Rasch (1582); however, their lists contain only a limited number of earthquakes, often wrongly dated and/or located and described. The earthquake information was often many-times taken over and distorted. On the other hand, the information about *old-time* seismic events has always been valuable, because the recurrence time of strong earthquakes could be much longer than that of a human lifespan. Therefore, each true point in the long-term diagram of given zone's seismic activity is much welcome. However, it does not change the fact that all the catalogues are in a sense incomplete, which must be always taken into account.

It can be concluded that the work on the "most complete version" of the catalogues is an endless work. First, nobody can get more-or-less complete catalogue but for the recent period only; beyond that, the new, modern seismic research brings new requirements to furnish the modern catalogue records by new parameters, which cannot be detected for the historic events. Finally, modern and newly collected catalogues may seem to be relatively perfect when they are completed; however, in a couple of years they appear out of date. Yet, regardless of these weak points of catalogues, geo researchers cannot but work with them since nothing better is at their disposal.

2.2.4 Seismic Catalogues of Polish Territory and Polish Border Countries

In the countries of low seismicity, such as Poland, the first catalogues of the whole country appeared much later than in seismically active countries, such as, e.g., Italy, because seismic risk and seismic endangerment of the population were low. The first catalogue of Polish territory was published by Láska (1902), where a brief verbal description of 70 earthquakes in the time interval 768–1900 is given. Seventy years later, a catalogue of Poland for the time span 1000–1970 was published by Pagaczewski (1972); his catalogue is accompanied by a modern map of seismicity of the regions in question; for the focal zones of Poland, e.g., for Lower and Upper Silesia, where the seismicity is relatively high, local historical catalogues appeared earlier.

Seismicity of Western Carpathians was investigated by Kárník (1960).

Historical earthquakes in the territory of Czechoslovakia can be, for the period 460–1956, found in the Erdbeben Katalog der Tschechoslowakei by Kárník et al. (1957).

The recent catalogue related to the Czech and Polish Sudetes zone was compiled by Schenk and Schenková (2007).

The newest catalogue of Germany partly covering also Silesia was composed by Leydecker (2011).

Obviously, there were other old local catalogues published in the last centuries for the territory of Silesia, Saxony, Bohemia, Moravia and West Carpathians, in which some earthquakes occurring in Polish border regions are listed, similarly as some events having epicenters out of Poland, which were perceptible and/or recorded in Polish territory as well. Since the earthquakes listed in these old, mostly local catalogues were altogether accounted for in modern catalogues mentioned above, they will not be further considered in this contribution.

2.2.5 Forming Seismic Research in a Global Dimension

Under activities named in the title of this section we understand the establishment of specific seismological institutions, seismic observatories and university divisions, organizing international seismological meetings, founding specific seismic journals, etc.

In the course of the 19th century a new approach towards earthquakes became apparent in a growing rate. It was based on the global character of strong phenomena of dynamical Earth's manifestation—including earthquakes—in contrast to the early period of seismic studies in the end of the Middle Ages up to late 19th century, in which seismic studies tried to explain the mysterious forces ruling the inside of the Earth as solitaire, mutually not related categories. This tendency was reflected in a number of relevant changes. First, seismic studies left off the status of a "poor relation" struck on the famous, already well-known disciplines of geology, geography, volcanic sciences or physics. On the contrary, seismology alone became new, independent geophysical branch of geo-research lectured in newly founded university seismological departments (=cathedras) and driven in newly established seismological institutions and observatories. The achievements reached in these institutions were presented and discussed in newly organized international meetings and published in newly founded geophysical journals.

For all of the new seismological institutions, we may give the names of sites where they were established in Transalpine Europe at the second half of the 19th century: Strasbourg, Goettingen, Berlin, Królewiec/Königsberg, Muenchen, Vienna, Leoben, Zagreb, Budapest, Kraków,[2] Lwów, Czerniowce, etc. Also some earlier founded institutions (e.g., the Bergakademies in Banská Štiavnica, in Freiberg/Sachsen, Clausthal-Zellerfeld, Kraków and Leoben and national Academies of Sciences in Berlin, Vienna…) expanded their research program to seismic studies.

In Germany, geophysics got an international recognition in 1898, when E. Wiechert was appointed at the University of Göttingen as the first Professor of Geophysics. In the same year he founded the first Institute of Geophysics at this University. In 1895 E. Wiechert also organized "The 1st International conference on seismology"; this meeting was held in Strasbourg on April 1–3, 1901 (Schröder 2000; Kozák 2001).

As for new seismological journals let us mention at least Garland's Beiträge zur Geophysik (Leipzig, since 1887, regularly since 1898), Mittheilungen der Erdbeben Kommission (Vienna, since 1897) or A. Belar's Erdbebenwarte (Zagreb, since 1902).

Today, with the benefit of hindsight we may proclaim the second half of 19th century as the period of birth of scientific seismology, which made the first steps in seismic wave recording and seismogram evaluation.

Now, let us turn our attention to the southern territory of Poland, i.e., Lower and Upper Silesia and Galicia (or Sudetes and West Carpathians) to examine up to which degree the advancement of the European macro-seismology, as outlined above, was reflected in that time of occurrence of macroseismic intensity maps of earthquakes prepared in southern Poland.

2.3 The First Macroseismic Maps (MSM) of the Polish Territory

Three macroseismic maps related to the earthquakes in the transalpine region in 1810–1846 ***preceding the Polish maps*** should be mentioned, namely the maps of the 1810 Mór earthquake (in Hungary), the 1828 event (in the Lower Rhine region) and the 1846 earthquake (in the Central Rhine region).

The earthquake of 1810, Jan 14, by Mór (ca 70 km west of Budapest), damaged buildings in several villages in the broad terrain-gap in the Bakónyi Hills ridge. Earthquake intensity reached $\mathbf{I_0} \approx$ 8–9 MSK, perception area was equal to ca 32 000 km^2. Special commission of geo-savants was appointed at the Buda University to examine the earthquake and delegated to visit the afflicted area. Two members of the commission, P. Kitaibel and A. Tomtsányi, accompanied their report on the earthquake by a simple macroseismic map, in which the seismically damaged settlements were marked and circumscribed by a dotted line in the

[2] The first in the world geophysical chair, named Chair of Mathematical Geophysics and Meteorology, was created for the previously mentioned M.P. Rudzki at the Jagielonian University in Kraków in 1896.

map, roughly equal to the damage limit line; no intensity scale was considered (Kitaibel and Tomtsanyi 1814). By present viewpoints, the Mór earthquake map cannot compete with the standard present macroseismic intensity maps. However, the effort of the Hungarian geo-savants to express the earthquake effects in a map of the affected region must be highly appreciated: they were the first ones who re-discovered the far forgotten ideas of Italian naturalists in the 17th century to present the earthquake effects in a map form. Detailed information on the Mór earthquake and Mór macroseismic map can be found in several younger studies, see Günther (1908–1909), Réthly (1960), Varga (2008) and Kozák and Prachař (2010); the Mór map is reproduced in Fig. 2.1.

After 1800, the second earthquake map approaching later macroseismic maps was created by German mathematician P.N.C. Egen, who analyzed the Dutch earthquake of Feb 23, 1828 (Egen 1828).

Also the map by P. Egen is far behind the present macroseismic maps' standard. The author used an ordinary geographical map as a cartographic base, in which he underlined individual seismically afflicted settlements by different colors, corresponding to three couples of degrees of macroseismic intensity (he alone formulated his 6-degree macroseismic intensity scale): namely, the degrees 6 and 5 he underlined red, degrees 4 and 3 blue, and degrees 2 and 1 yellow. Isoseismal lines were not plotted in the map. However, in transalpine Europe P. Egen's map is the first in which an attempt is made to depict the earthquake intensity variations throughout the disturbed area (Davison 1978).

As the third example we mention the macroseismic intensity map presented by German naturalist, professor of mineralogy and mining in the University of Bonn, J.J. Nöggerath. His map showed the distribution of the macroseismic effects of the (Mid) Rhenish earthquake of 1846, Jul 29 (Noggerath 1847).

A quick look onto the map will confirm that the author utilized local reports on the earthquake for the construction of three isolines. The area of the largest damage reported was closed inside a small circle containing the towns Coblentz and St. Goar, inside of which also the highest intensity of the shock was felt. The next line of polygonal shape joins the outermost places at which the shock was actually felt. The third line, consisting of a dotted circle line, which surrounds the disturbed localities indicates the probable size of the disturbed area "So far I know the earthquake map contains the first attempt to draw isoseismal lines… leading to the first determination of the position of the epicenter by means of such lines" [cited from the text by Davison (1978)].

The presented examples bear witness how toilsome was the way towards the standard macro seismic intensity maps in the course of the first decades of the 19th century. In this gray area of slow progress all the more shines the remarkable advancement of O. Volger in the macroseismic mapping of the 1855 Visp event (Kozák and Vaněk 2006); his ideas gave a lead towards a meaningful and reasonable macroseismic earthquake analysis, as demonstrated in Sect. 2.2 of this text. Let us look in which degree these new achievements, including seismic cartography, were utilized in the analyses of South Poland earthquakes.

Fig. 2.1 The first MSM—by Tomtsanyi and Kitaibel—is related to the 1810, Jan 14, Mór (Hungary) earthquake

2.4 Selected Earthquakes in South Poland and Its Vicinity and the Respective Macroseismic Maps

By examining the second half of the 19th century, i.e., the time span in which the first macroseismic intensity maps appeared in South Poland, we learn that several earthquakes which occurred in this region played an important role in the all-European "earthquake mapping" effort of that time. In the region in question, three moderate earthquakes with the epicenter in Lower Silesia or in Czech/Polish border occurred in 1883, 1895 and in 1901, for which the macroseismic intensity maps were constructed (Réthly 1952; Kárník and Ruprechtová 1963; Kozák et al. 2002).

Additionally, these three moderate Sudetic events were preceded by two stronger seismic events, which occurred out of the territory of Poland, namely in NW Slovakia (1858) and in N. Saxony (1872), for which the macroseismic maps were also prepared. Since the seismic effects of these border-zone earthquakes were clearly felt deep in the Polish territory, they and their cartographic expression will also be mentioned in the following considerations. The whole set of five above-named earthquakes of the time interval 1858–1901 is shown in Table 2.1; for the geographical distribution of the treated events, see the map in Fig. 2.2.

At the end of the 19th century, in many European countries the 12-degree Rossi or Rossi-Forel macro-seismic intensity scales (RS, RFS) were used; see Forel (1881) and Rossi and Forel (1881). After 1964, in the retrospective studies on the 19th century Sudetic earthquakes, it was usually the Medvedev-Sponheuer-Kárník-64 scale (=MKS-64 scale) that served for intensity assessments of treated earthquakes (Medvedev et al. 1965); at present, the newest scale EMS-98 edited by G. Grünthal is recommended for macroseismic intensity assessments (Grünthal 1998).

The 1858 Žilina earthquake

On Jan 15, 1858, a strong earthquake with epicenter within the Váh River elbow near the present town Žilina (*Sillein* in German) occurred in NW Slovakia. The

Table 2.1 The earthquakes of the second half of the 19th century, which were felt and recorded in the Polish territory and processed in a form of a macroseismic intensity maps

Two earthquakes in Slovakia and Saxony preceding the Polish events
1858, Jan 15, 20^H 15^M, near Žilina, NW Slovakia, ca 40 km south of the Polish border
$I_o = 9$ (MCS), epic. 49° 10′N, 18° 47′°E, felt in the area of 66,000 km^2
1872, Mar 06, 15^H 55^M, at Posterstein, (Saxony), ca 135 km west of the Polish border
$I_o = 7.5$ (MCS), epic. 51.6°N, 12.3°E, h = 9.4 km, felt in: r = 150 km (circle radius)
Three earthquakes with epicenters in the Polish territory or in Polish border
1883, Jan 31, 14^H 43^M, at Trutnov, near to the Polish/Czech border
$I_o = 7$ (MSK), epic. 50.5°N, 15.9° E, felt in 4,500 km^2
1895, Jun 11, 09^H 27^M, at Strzelin in Mid-Silesia
$I_o = 7$ (MSK) and (MCS) and I_o = (6°–7° in R-F Scale), epic. 50.8°N, 17.0°E, felt in 25,000 km^2
1901, Jan 10, 02^H 30^M (GMT), at the Upper Úpa Valley, near to the Czech/Polish border
$I_o = 7$ (MSK), epic. 50.5°N, 16.1°E, felt in 50,000 km^2

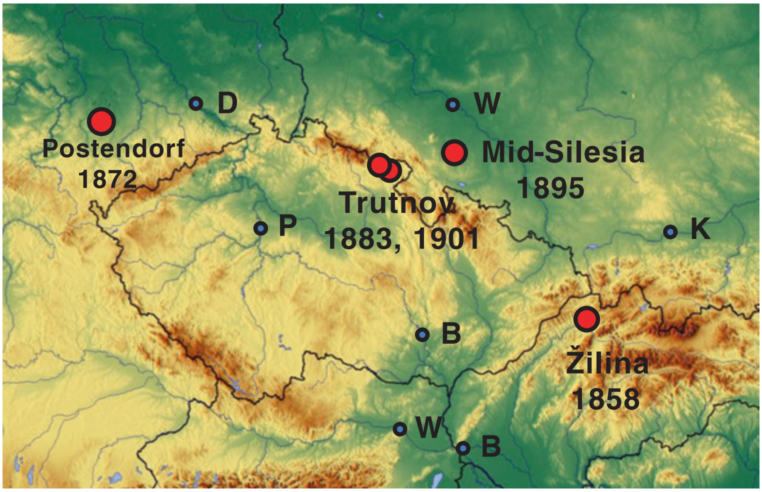

Fig. 2.2 Modern map showing the locations of the 19th century transalpineearthquakes discussed in this paper. B—Brno (CZ), B—Bratislava (SK), D—Dresden, K—Kraków, P—Praha, W—Wien (A), W—Wrocław (PL)

radiation pattern of the source displayed three maxima, towards S (up to Esztergom in Hungary), towards NW (up to Wrocław in Lower Silesia) and W (towards Moravia and Bohemia). The largest seismic damage was ascribed to the Žilina town where as many as 29 houses were damaged or ruined (classified as not safe for use). In the next 10 months of 1855, 16 aftershocks were recorded in the region.

This strong earthquake, the effects of which were clearly felt in the vast, densely inhabited adjacent regions, attracted large attention and interest of local naturalists and geo-savants, which resulted in numerous written reports; three of them were complemented by macroseismic maps. These maps carry some elements of novelty and therefore—as a whole—they also represent a kind of milestones in Central European macroseismic cartography. The two macroseismic maps in question, constructed by J.F.J. Schmidt, were attached to his 72-page report on the event (Schmidt 1858). In his first detailed map, reproduced in Fig. 2.3, the shape, orientation and size of the largest damage zone was outlined as an oval elongated in NW-SE direction, similarly as another outer oval which limits the region of weaker earthquake effects. The map is plotted in the network of geographical coordinates and, besides the river pattern, also main mountain ridges are given. The direction of seismic wave impact was recorded for some localities, see the 11 arrows in the inner zone, 13 ones in the outer zone. In the second, general map (see Fig. 2.4), a larger geographical segment of the affected region is given: the complementary macroseismic data enabled the author to construct the shape and orientation of three intensity zones between the Danube River and Lower Silesia and to distinguish them by different shades of red color. The map also gives three calculated circular isochrones: I, II, III.

Fig. 2.3 The MSM—by J.F.J. Schmidt—is related to the 1858, Jan 15, Žilina earthquake, a detailed map

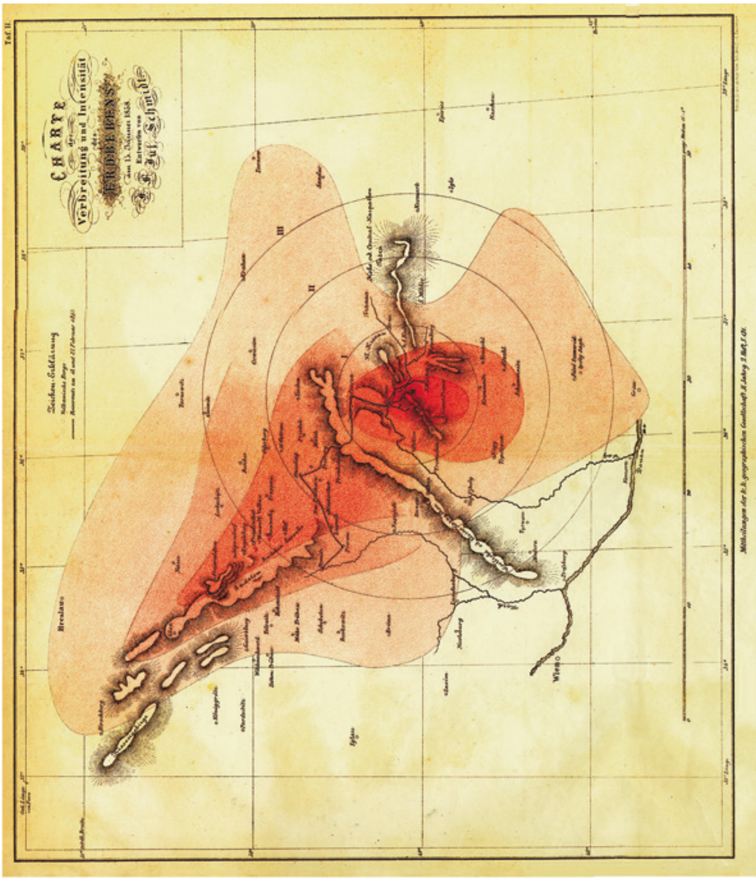

Fig. 2.4 The MSM—by J.F.J. Schmidt—is related to the 1858, Jan 15, Zilina earthquake, general map.

The second naturalist who plotted a macroseismic map of the effects caused by the 1858 Žilina earthquake was L.H. Jeitteles (born in Prague), professor of biology, botany and geography; in 1858 he was professor at the grammar school in the Moravian Opava town. Shortly after the earthquake he visited Žilina and its broad vicinity, collected personally and in detail macroseismic effects and published them in a brilliant paper complemented by a color-lithographic macroseismic map reproduced in Fig. 2.5 (Jeitteles 1859, 1860), showing three zones corresponding to three levels of seismic damage, namely *small*, *middle*, and *maximum.* However, in contrast to the J.F.J. Schmidt's map in Fig. 2.4, the map by L.H. Jeitteles (also drawn

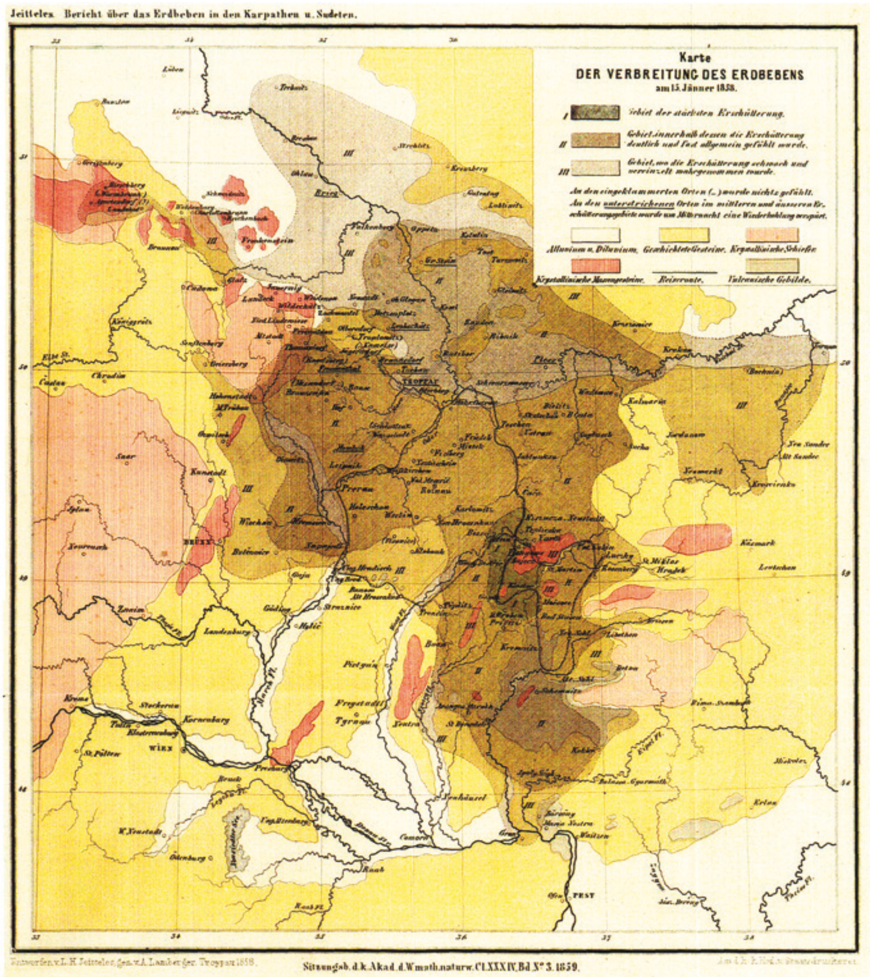

Fig. 2.5 The MSM—by L.H. Jeitteles—is related to the 1858, Jan 15, Žilina earthquake; seismic data are laid on geological backround.

with geographic coordinates and also prepared for the large region, from 47°N up to 51½°N) gives a much more detailed pattern of the three zones of macroseismic intensity. He was the first map maker who superimposed macroseismic data over the geological background. Thus, according to our knowledge, his map was the first in the world where seismic and geological fields were plotted together and their mutual relation discussed. In this sense the map by L.H. Jeitteles—no doubt—belongs to the milestones of world macroseismic cartography. The map was reproduced and discussed in detail by Vaněk and Kozák (2007).

Two further maps of the 1858 Žilina earthquake were prepared by M. Sadebeck, professor in Technical School in Opava. In his first macroseismic map-sketch, see Fig. 2.6, he gave the names of localities where the earthquake was felt, and also localized the epicenter zone. He demonstrated that the seismic effects were felt far in the Polish territory, from Nowy Sącz, Tarnów and Kraków in the northeast up to Wrocław, Kłodzko and Jelenia Góra in the northwest. Sadebeck, similarly as Schmidt and Jeitteles, confirmed that the general shape of the seismically loaded field was prolonged in the NW-SE direction (Sadebeck 1858).

In his second map (Fig. 2.7) he plotted a detailed map of the Žilina Valley (with 34 localities where seismic effects were reported) together with a remarkable city map of the Žilina town center, where the 29 damaged houses were marked, which was a novelty in macroseismic cartography.

The 1872 Mid-German Earthquake

The next strong earthquake occurred in the eastern part of Germany, in Saxony, on Mar 6, 1872, near to Posterstein by Gera, usually named *Leipzig earthquake* or *Middle German earthquake*. The principal investigation of this seismic event has been carried out by K.A.L. von Seebach, professor of geology at the university of Göttingen, inventor and promoter of the terms *isoseist*, *homoseist* and *pleistoseist zone* (Seebach 1873). Appreciating the map constructed by K. Seebach, reproduced in Fig. 2.8, we may state that he plotted the actually observed macroseismic intensity values as isolines which have the E ↔ W prolonged, far not circular shape (Seebach 1873; Sponheuer 1952).

Another map showing the shaken area of the earthquake was composed and presented in 1872 by L. Grebe, *Oberlehrer* (=deputy head teacher) in a grammar school in Cassel. In his presentation he summarized some of the earthquake effects and illustrated them in his map of German territories and adjacent parts of Bohemia, Bavaria and Poland, namely in Budziszyn, Lwówek Śl., Lubin, Wałbrzych, Głogów and Wrocław. However, Grebe in his map did not distinguish seismically affected localities according to degree of seismic damage so that he could not draw any isoseismal lines; that is why his map cannot be considered as a macroseismic map (for Grebe 1872 see Grünthal 1992).

The 1883 Trutnov earthquake

Cartographic portrayal of the extension of the 1883, Jan 31, Trutnov (*Trautenau* in German) earthquake in the northeast Bohemia was presented by two naturalists, G.C. Laube of the Austro-Hungarian monarchy and H. Kunisch of Prussian Silesia's Wrocław (*Breslau* in German). Laube (1883) in his map reproduced in Fig. 2.9

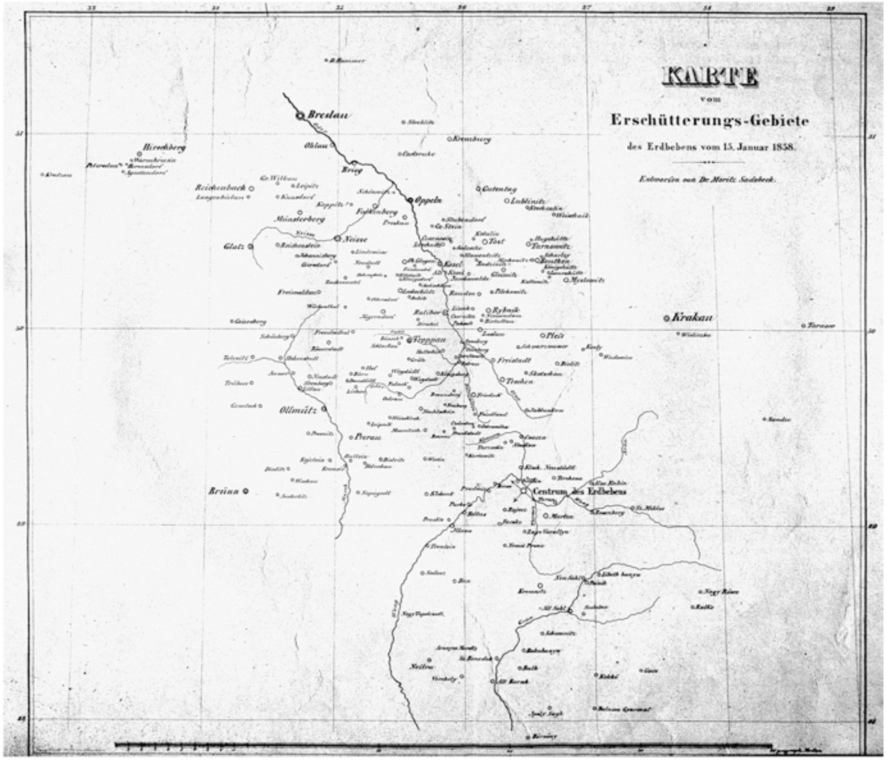

Fig. 2.6 The MSM—by M. Sadebeck—is related to the 1858, Jan 15, Žilina earthquake. Affected zone and localities are plotted.

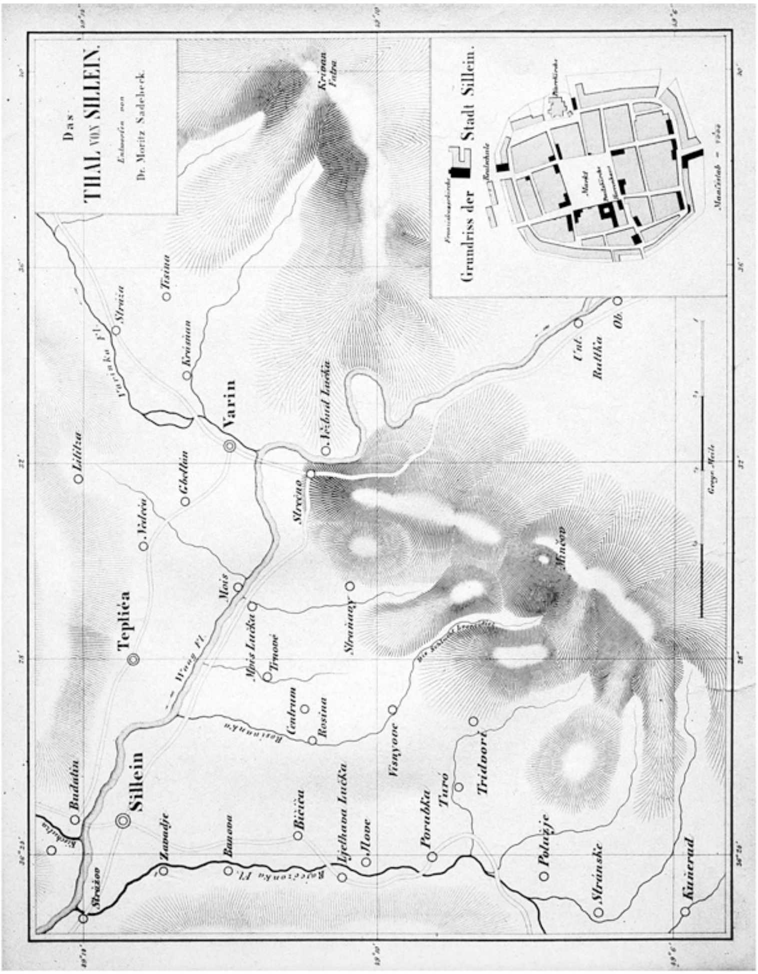

Fig. 2.7 The MSM „Das Thal von Silein" was made by M. Sadebeck. The map is related to the earthquake of Jan 15, 1858. Small marginal city map shows the edifices damaged by the earthquake.

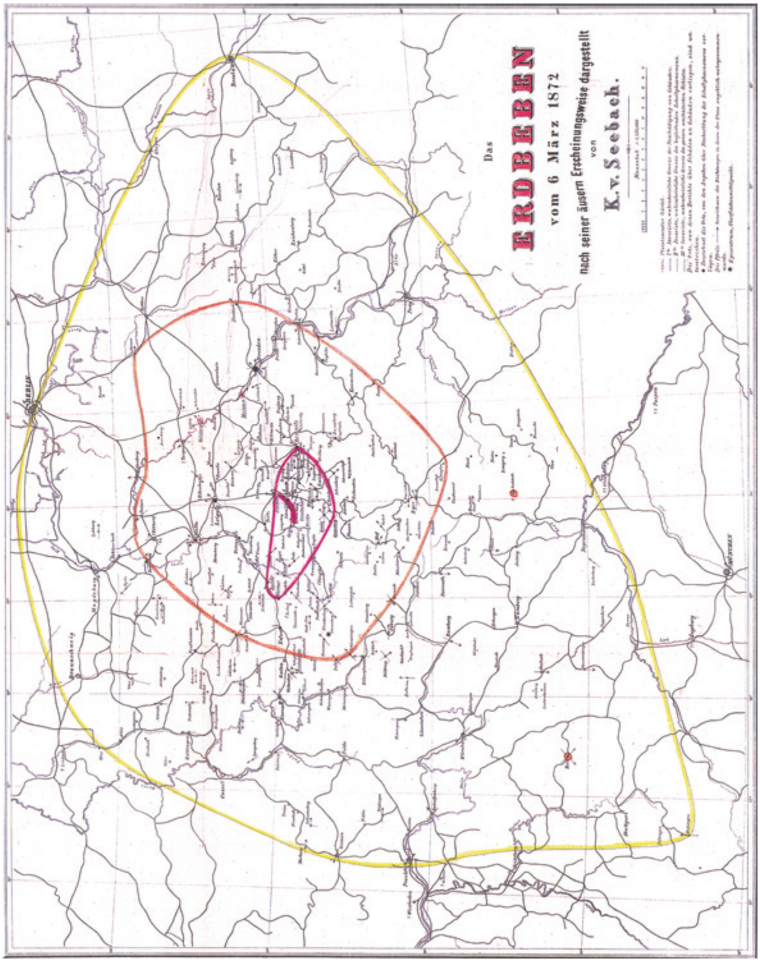

Fig. 2.8 The MSM—by K. von Seebach—is related to the 1872, Mar 12, *Mid-Deutsche-Erdbeben*. Note four *isoseismal lines*

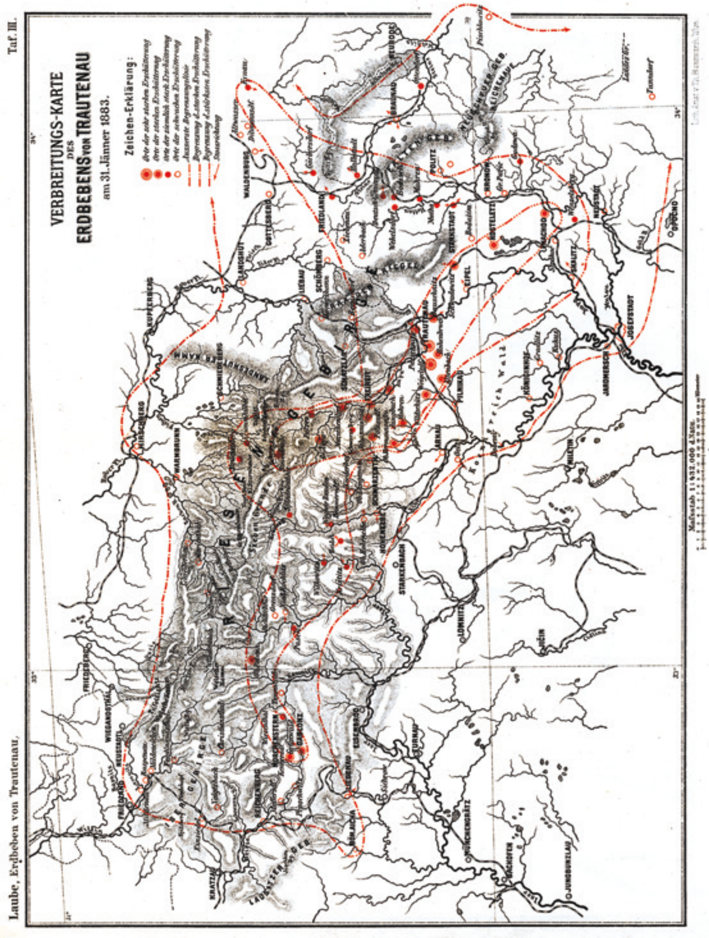

Fig. 2.9 The MSM—by G. Laube—is related to the 1883, Jan 31, Trutnov earthquake. Note the unusual shape of pleistoseismal zone; 3 *isoseismal lines* are plotted in the map

classified the affected localities in four levels of seismic intensity (very strong, strong, rather strong and low); for some localities he marked directions of seismic impact. He utilized local reports for constructing three isoseismal lines. As for the first zone (which may represent the pleistoseist zone), its extraordinarily curious shape should be pointed out: it has a S-shaped form of a narrow strip of a length of 50–52 km and width of 5–6 km, see the map in Fig. 2.9. It should be noticed that the zone of the highest macroseismic intensity, between the Sněžka Mt. towards the Náchod town, lies entirely on the territory of Bohemia. The whole prolonged macroseismic field is predominantly oriented as parallel with the Krkonoše main mountain ridge, i.e., in the NW-SE direction.

In the map shown in Fig. 2.10, which was created by Silesian seismologist H. Kunisch, on the other hand, only two zones are plotted. The inner zone, non-regularly lobed, extending from SE to NW, about 100 km in length and 20–30 km in width, is erroneously denoted as *pleistoseismal* zone. The second dashed line gives "approximate limits of the earthquake", the limit line of the earthquake effects' perception. Localities with negative (or no) reports are also marked. In contrast to the orientation of the pleistoseismal zone laid in the NW-SE direction, the line denoting the limit of ground shaking has its axis of prolongation considerably inclined to the north, *due to a single point in the map sketch*, *namely due to positive reports from the Żagań town.* Evidently, without this single „Żagań" point (surrounded by localities reporting negative observations) the perception zone would be radically reduced in size and re-oriented similarly as the pleistoseismal zone (Kunisch 1883). We may conclude that the map by H. Kunisch was struck by several errors.

The 1895 Mid-Silesia earthquake

At the turn of the spring of 1895, a strong earthquake occurred in Lower Silesia on Jun 11th. Three authors portrayed the event cartographically. First, R. Leonhard and W. Volz, presented two specially drawn maps (see Figs. 2.11 and 2.12) of this earthquake and published them in Wrocław in 1895 (first version) and in Berlin in 1896 (second, complemented version). In these maps, the isoseismal lines separating the zones of macroseismic intensities corresponding to the 3rd, 4th, …, 7th degrees of the Rossi-Forel intensity scale were plotted, together with the isochrones and seismic impact directions (*Stossrichtungen* in German). Both their *Übersichts-Karten* must be appreciated as good-standard macroseismic maps of the 1890s. In Fig. 2.12 the second, supplemented map version is shown; the isoseismal lines are plotted over geological background, similarly as in the map by L.H. Jeitteles (see Fig. 2.5), related to the 1858 Žilina earthquake. In small left bottom corner-map a comparison is given of the extension of the 1895 earthquake (wrongly dated as of June 15th instead of June 11th), with two significant seismic events, which were felt in Lower Silesia, namely the 1883 Trutnov and 1858 Žilina earthquakes. The detailed and very carefully prepared map enables to identify two separate zones of maximum intensities, namely Strzelin-Münsterberg and Pieszyce-Diersdorf, between which the seismogenic fault can be traced by means of the seismic impact directions given between both the regions by arrows (Leonhard and Volz 1895, 1896).

The third map, shown in Fig. 2.13, also related to the 1895 Middle Silesian earthquake, was prepared by E. Dathe; for his map he used large, standard

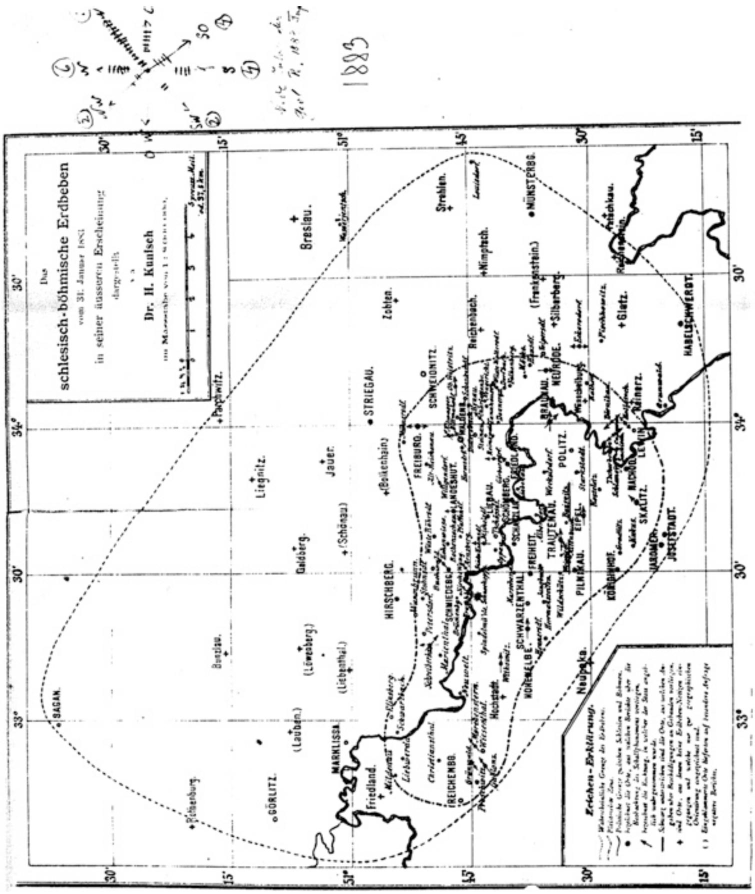

Fig. 2.10 The MSM—by H. Kunish—is related to the 1883, Jan 31, Trutnov earthquake. Note the unusual size and shape of the last *isoseismal line* going far to north due to single locality "Sagan" lying inside the field of negative reports

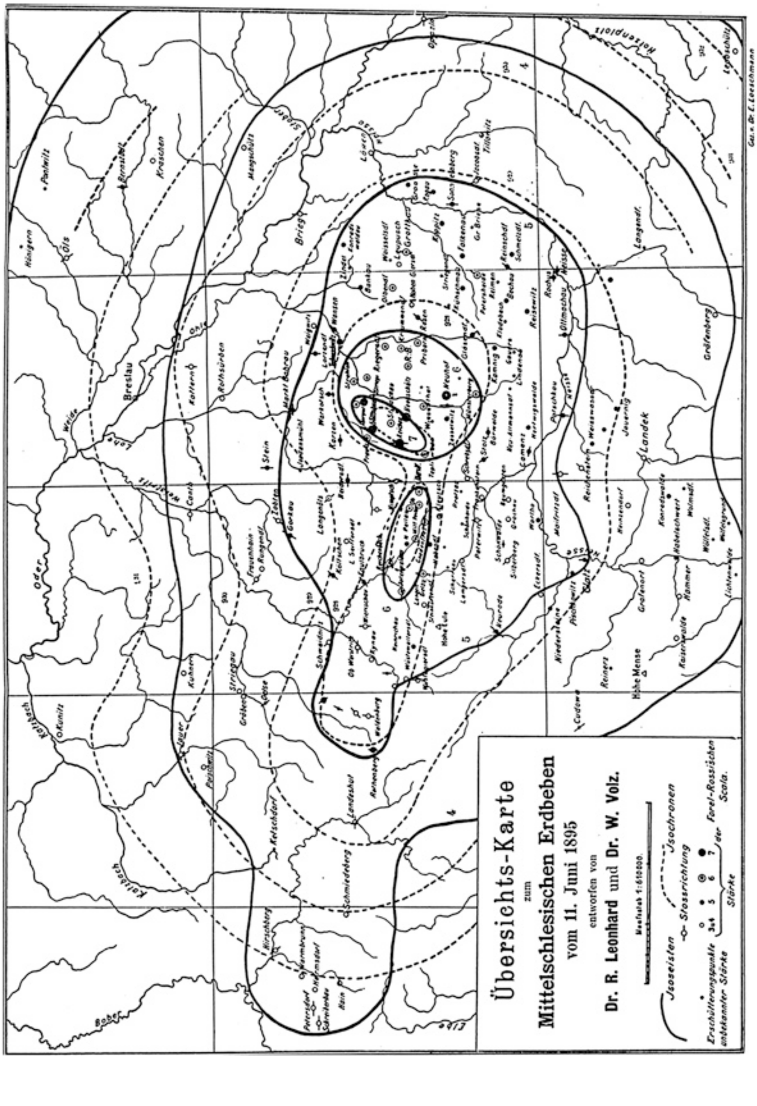

Fig. 2.11 Preliminary MSM—by R.V. Leonard and W. Volz—is related to the Mid-Silesian 1895, Jun 11, earthquake. Both *isoseismal lines* and *isochrones* are plotted.

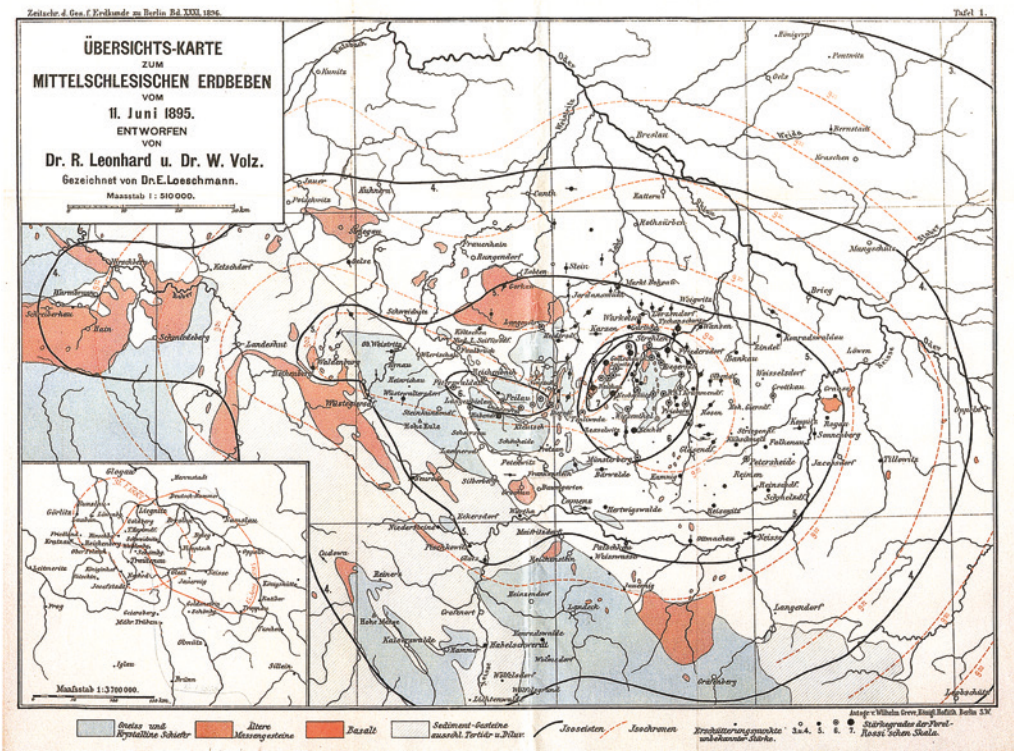

Fig. 2.12 Complete MSM—by R.V. Leonard and W. Volz—is related to the 1895, Jun 15, Mid-Silesian earthquake. Simple geology, intensity classification after Rossi and marginal map of two other earthquakes are given.

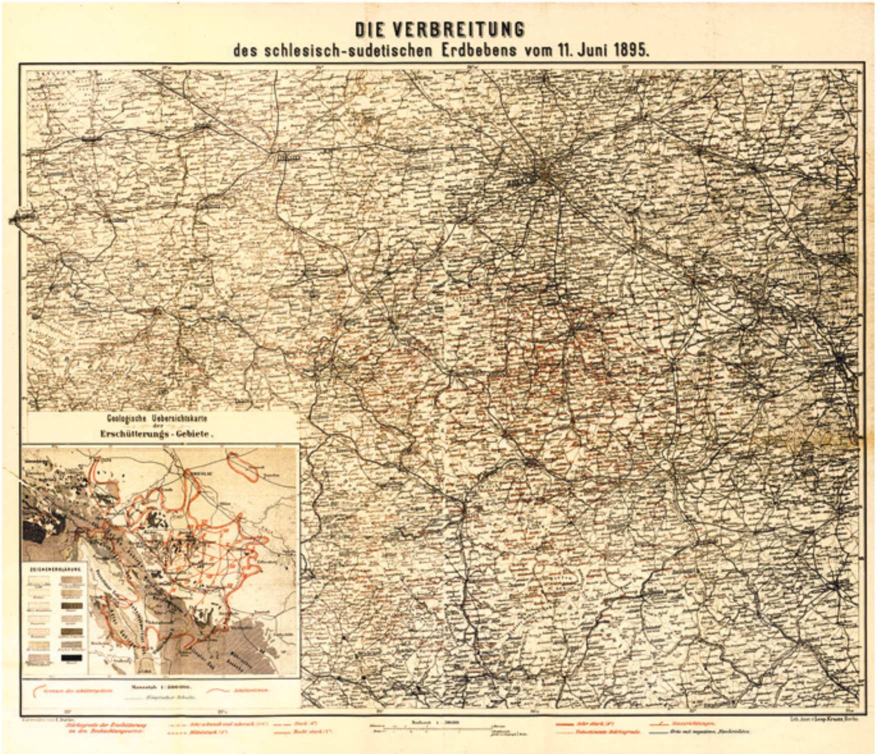

Fig. 2.13 The MSM—by F. Dathe—is related to the 1895, Jun 15, Mid–Silesian–Erdbeben. The marginal map given in the *left bottom corner* shows local geology and limits of perception zone

geographical map of Lower Silesia, into which he plotted various red-color marks, underlined the locality names and inserted other symbols for classification of the affected localities in 5 levels of earthquake intensity degrees, 3°–7°, of not specified intensity scale (namely very weak and weak, mid strong, strong, very strong, extremely strong). The large main map—already filled densely with standard cartographic information—after addition of numerous macroseismic symbols—became practically unreadable, especially when the map is reduced in size. The main map, however, is complemented with a small additional map of the region, where, on the background of the local geology (12 geological structures), geographical limits of earlier earthquakes and positions of principal faults are given. In general, E. Dathe's map carries a great amount of valuable macroseismic data; however, a magnifying glass is necessary (Dathe 1897).

In the last years of the 19th century, most papers analyzing individual weak and middle size earthquakes which occurred in the Central European region, were complemented with larger or smaller macroseismic maps. Not all of them, however, reached the high standard and quality of the maps by L.H. Jeitteles (Fig. 2.5), G. Laube (Fig. 2.9) and C. Leonhard and W. Volz (Fig. 2.12) discussed above. On the contrary, many of them appeared as simple map sketches, especially those preparet for weak seismic events.

The 1901 Sudetic earthquake

The Czech naturalist N.J. Woldřich, one of the authors of the 1901 event evaluation, named systematically this earthquake as "*The 1901 North-East Bohemian Earthquake*", since most of its pleistoseismal area occurred in Bohemia (=Czech Republic at present), similarly as the previous 1883 Trutnov event. However, the German speaking naturalists named this earthquake as „*The 1901 Sudetic earthquake*". Having in mind that the „Sudetic" area lies in Polish as well as in Czech foothills of Krkonoše Mts., the German name seems to be correct as well.

J.N. Woldřich published two papers on the 1901 event, first in Czech and repeatedly also in German academic journals; both were complemented by two macroseismic maps; they are reproduced here as Figs. 2.14 and 2.15. In the map in Fig. 2.14 he denoted all the towns, villages and other settlements afflicted by the earthquakes, according to the Rossi scale (degrees: 7°, 5°–6°, 4° and 3°); he even distinguished the localities in which the displacement was accompanied by underground sounds. In the map, also principal parallel fault zones were drawn. The isoseismal lines were not plotted, except of the shape and size of the epicenter zone. In the second map (Fig. 2.15), also originally published in the Czech paper (Woldřich 1901a, b), the general situation illustrating the afflicted area was given: seismic intensities are classified in three levels according to the Rossi scale and mutually contrasted by the three tunes of blue color. It is apparent from the map that the seismic field in Lower Silesia, Upper and Lower Lusatia and in eastern Saxony is clearly prolonged towards NW, from Frývaldov in the Moravian part of Silesia up to Leipzig in Saxony. The paper published in the Austrian academic journal (Woldřich 1901b) carries the same pair of macroseismic maps as the Czech paper and therefore it will not be discussed here.

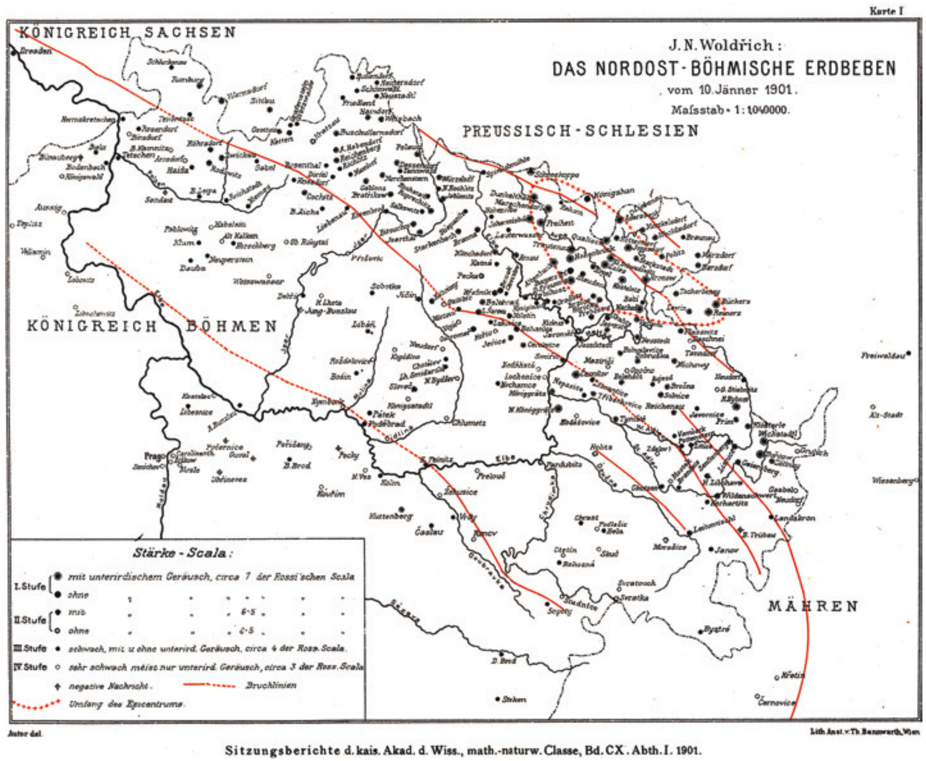

Fig. 2.14 The MSM—by J.N. Woldřich—is related to the 1901, Jan 10, northeast Bohemia earthquake. Pleistoseismal zone and 3 main faults (in SE–NW direction) are given by the *red lines*.

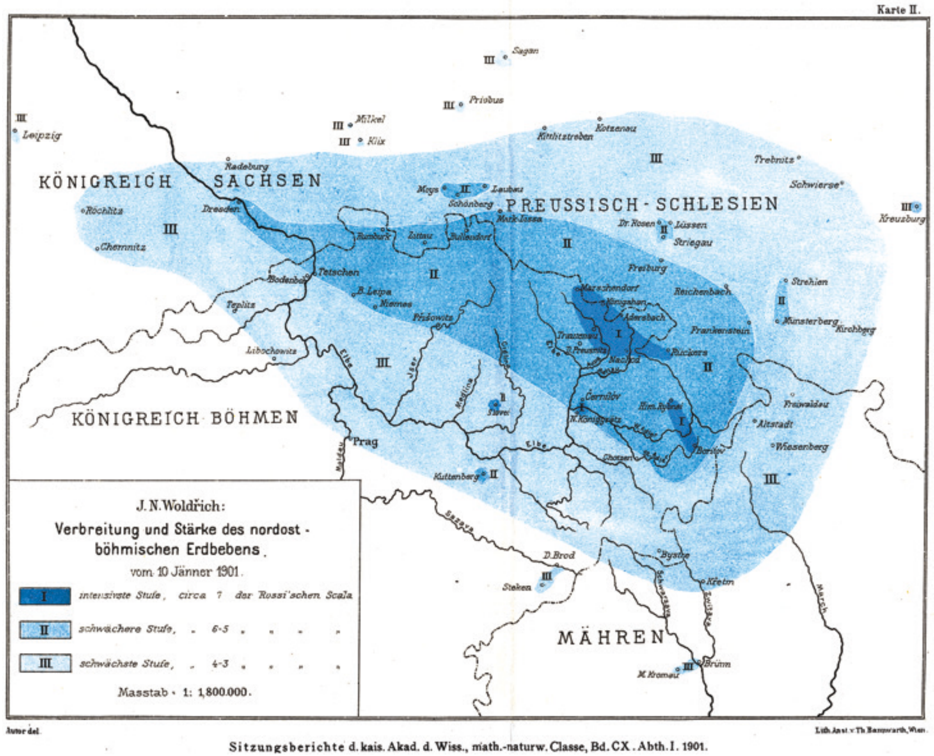

Fig. 2.15 The MSM—by J.N. Woldřich—is related to the 1901, Jan 10, in northeast Bohemia. Three intensity levels are differentiated by three tunes of *blue*.

The map by H. Credner, see Fig. 2.16, represents one-color (blue) macroseismic map, which neither cartographically nor seismically surpasses the common standard of the time. Two tunes correspond to the degrees of Rossi intensity scale, (5°–6°)—darker blue and (4°–5°)—lighter blue. By a red line, the Great Lusatia Dislocation runs in the central part of the seismically afflicted field from SE to NW. In the map margin there are also distant localities shown, from which positive reports also arrived. The map is not easily readable due to intensive blue tune shading, especially the zone of strong seismic effects (Credner 1901).

The map by J. Gränzer, see Fig. 2.17, who has seen the earthquake effects from the Czech part of the *Sudetes*, resembles the map by J.N. Woldřich given in Fig. 2.14. The author classified the intensity degrees in four levels on macroseismic effects while the fifth level was reserved for the localities declaring negative reports. The Great Lusatia Dislocation is given in the map, as a straight line broken in the Velká Úpa town lying on the Úpa River in NE Bohemia. By four variable tunes of grey color, four geological structures are denoted: Primary and Silurian, Bitumen, Permian, Cretaceous. The map carries author's seismic sketch of a cross-section of the Earth (Gränzer 1901).

The last couple of maps related to the 1901 Sudetic earthquake was prepared and published by F. Sturm, who was active in the Geological Institute of the Wrocław University. His first (general) map, see Fig. 2.18, shows the seismically loaded field plotted for the 1901 earthquake prolonged between Magdeburg and Moravská Třebová. Except of several details, the Sturm map is practically identical with the map by J.N. Woldřich, see Fig. 2.14 The seismic intensity is classified in three degrees of the Rossi intensity scale (7°, 6°–4° and 3°–4°). Quite evident is the NW-SE orientation of the seismic field, which is stretched up to distant Magdeburg in the map. The second Sturm's map, reproduced in Fig. 2.19, brings an interesting comparison of four earthquakes (Sturm 1903). In 1858 and 1901, Lower Silesia was vexed by two strong earthquakes and in 1883 and 1895 by two moderate seismic events. It is noteworthy that the three „Sudetic" earthquakes of 1883, 1895 and 1901 display nearly the same pleistoseismal zone of maximum intensity, between Jelenia Gora, Świdnica and Legnica. Can this area be understood as a zone of Lower Silesia earthquake foci concentration? In contrast to it the 1858 Žilina earthquake, the perceptivity limits of which reached the JelGóra-Świd-Leg zone, displayed a specific behavior: the seismic effects of this distant earthquake seemed to avoid the entrance into this „Sudetic earthquake foci center".

2.5 Poland: Maps of Seismicity?

Seismic events, which always meant a danger for population in seismically active regions, represented, on the other hand, a strong engine drafting local naturalists to search for the measures of the dreaded seismic effects' mitigation.

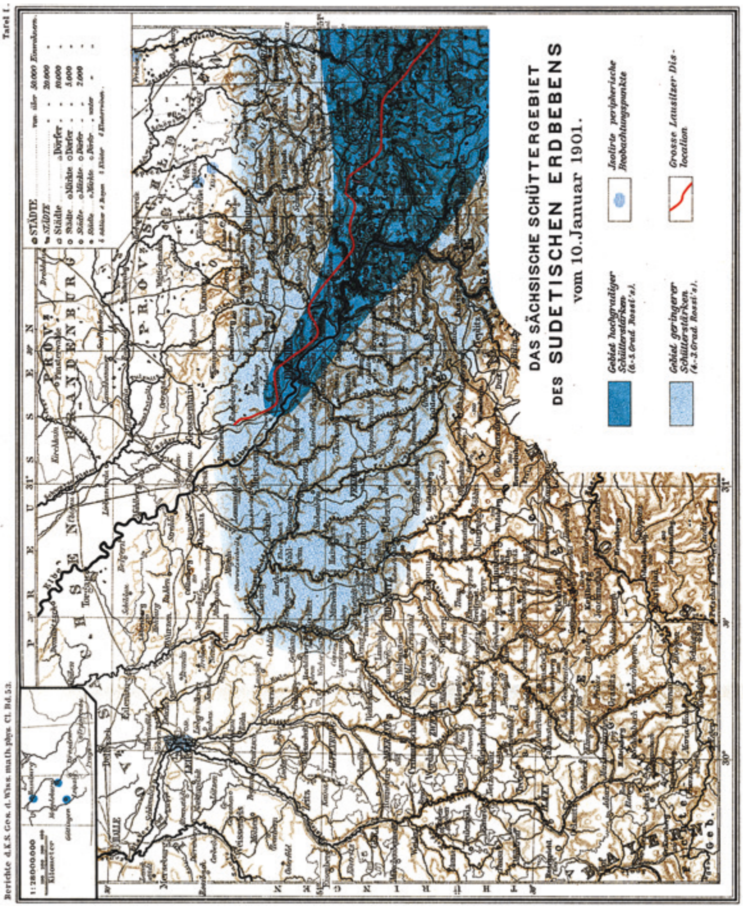

Fig. 2.16 The MSM—by H. Credner—is related to the 1901, Jan 10, northeast Bohemia earthquake. Three degrees of seismic intensity are expressed by three tunes of *blue* colour

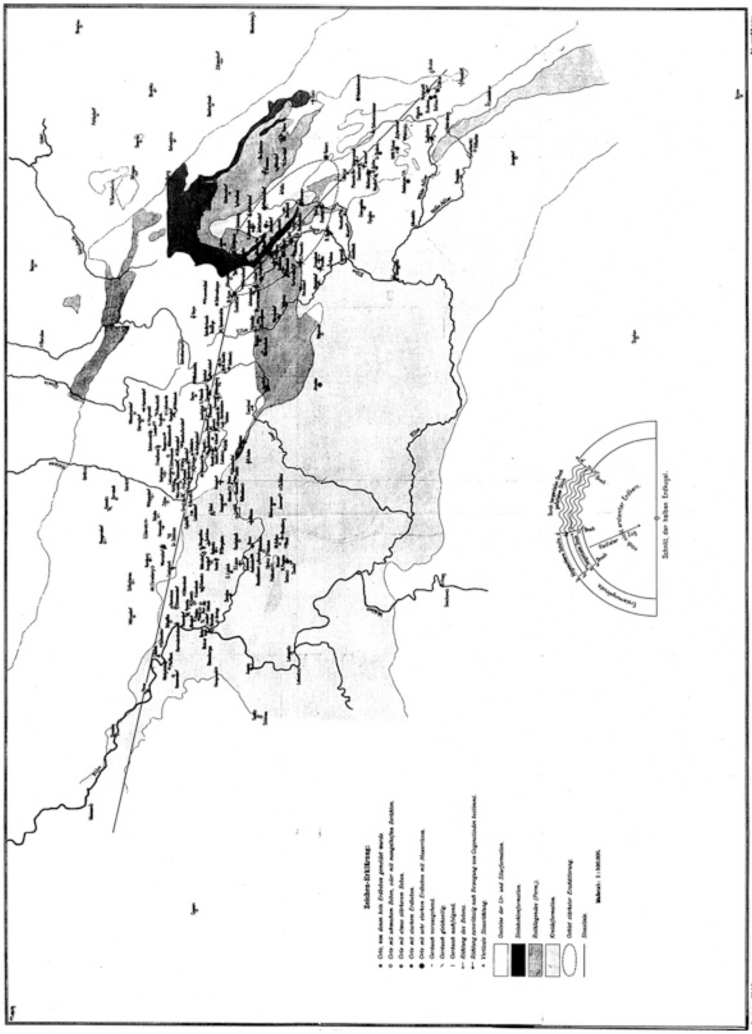

Fig. 2.17 The MSM—by J. Gränzer—is related to the 1901, Jan 10, northeast Bohemia earthquake. Seismic observations and geological structures together with geological faults, are plotted in the map

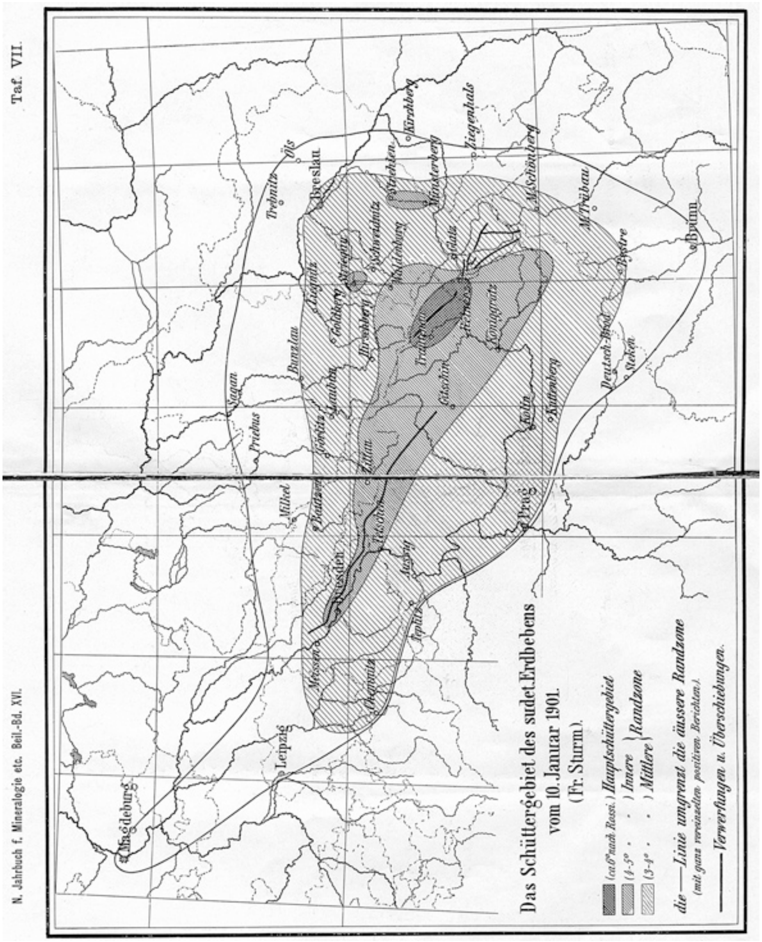

Fig. 2.18 The MSM—by F. Sturm—is related to the 1901, Jan 10, northeast Bohemia earthquake. *Isoseismal lines* separate 4 zones (levels of seismic intensity). The map resembles the map by Woldrich in Fig. 2.14.

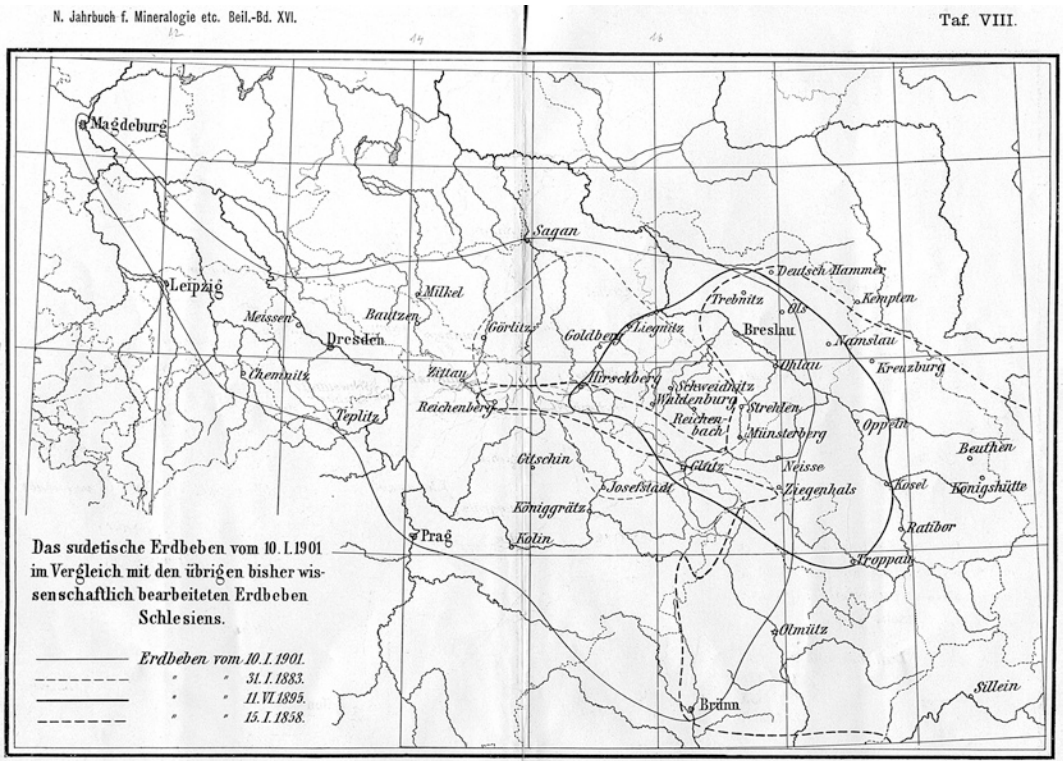

Fig. 2.19 Map of south Poland, north Bohemia and east Saxony: Limits of perception of 4 strong earthquakes, which were felt in the region in the years 1858, 1883, 1885 and 1901, are plotted and pertinent earthquakes mutually compared

And the macroseismic intensity maps seemed to be a kind of building blocks for such an effort.

However, even though nobody would query or oppose such a conclusion, the correct assessment of seismic danger has always been loaded by numerous circumstances and conditions, namely:

- by the length of the observational period, which should be long enough to enable collection of statistically sufficient number of seismic recordings. Evidently, the longer the observational period is the higher the degree of reliability may be attributed to the resulting pattern of seismic danger.
- by the occurrence of strong earthquakes, the epicenter and isoseismal lines of which would be more easy to determine.

Coming back to the assessment of the seismic danger in the area loaded by moderate seismic impact we have to agree that the above-discussed five seismic events felt and recorded in South Poland (for which macroseismic maps were prepared in 1858–1901) are not sufficient for the desired assessments. We may conclude that for these seismically relatively quiet regions (only 4 earthquakes occurred Poland having the intensities $\mathbf{I_o} \geq 7°$ of Mercali-Cancani-Sieberg scale in the time span 1011–1970) the *macroseismic treatment* of the weaker seismic event does not seem to be an effective tool for the required achievement of the seismic danger assessment; see, e.g., the unequal classification of the "boundary" earthquakes—the 1783 Trutnov and the 1901 NE Bohemia ones, presented by the that time Czech, Polish, Silesian and German naturalists (Schweitzer, undated).

As concerns the seismically (moderately) active zone running approximately parallel along to the Czech-Polish border (sometimes called the Sudetic-West Carpathian zone), for making a reliable seismic danger assessment the seismologists would need the outcome of sensitive instrumental seismic monitoring performed in the country in the course of the 20th century, associated with seismic mapping of Poland.

2.6 Conclusions

As concerns the early macroseismic intensity maps of earthquakes constructed in the second half of the 19th century for Polish territory, and for Polish border regions we collected altogether 17 maps, related to 5 earthquakes.[3] It appeared that the largest obstacle in constructing these maps has laid in the lack of strong earthquakes occurrence; weak earthquakes and weak ground shaking during seismic swarms, which make the majority of seismic activities there, did not provide enough data necessary for constructing standard and reliable macroseismic maps.

[3] Six maps, namely those presented in Figs. 2.5, 2.6, 2.7, 2.14, 2.15 and 2.18, are deposited in private collection "New Kozak Collection" (*NKC*) and are protected by copyright Jan Kozák ©.

Regardless of this limitation, five medium-size earthquakes, VI $\leq$ I_o $\leq$ IX (MSK-64), which occurred in the regions of Žilina 1858, Gera 1862, Trutnov 1883, Mid-Silesia 1895, and the 1901 Sudetic event, were processed and the results were expressed in 17 excellent macroseismic maps. It is demonstrated in the text of the previous section that some of these 17 maps, mainly those prepared by J. Schmidt, L. Jeitteles, K. Seebach, G. Laube, C. Leonhard, W. Volz and J. Woldřich, may be considered as remarkable macroseismic maps of the period.

We may conclude that in the 19th century Central Europe became one of important world centers of earthquake macroseismic research, in which geo-savants active in Poland played an important role: In the last decades of the 19th century, numerous institutions for studying Earth sciences—including seismic manifestations—were established in Central Europe; Kraków, Ojców, Wrocław, Lwów and Królewiec/Kaliningrad definitely belong to them.

The proper methodology and technology of macroseismic mapping appeared as a necessary step towards constructing the long desired *maps of seismicity*, which today represent the essential manuals regulating construction of large, seismically endangered edifices in seismically active regions. This, however, is already the story of the 20th century.

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