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Seismic Monitoring of Poland – Description and Results of Temporary Seismic Project with Mobile Seismic Network

Jacek TROJANOWSKI, Beata PLESIEWICZ,
and Jan WISZNIOWSKI

Institute of Geophysics, Polish Academy of Sciences, Warszawa, Poland
e-mail: jtroj@igf.edu.pl

Abstract

The paper describes a temporary seismic project aimed at developing the national database of natural seismic activity for seismic hazard assessment, officially called “Monitoring of Seismic Hazard of Territory of Poland” (MSHTP). Due to low seismicity of Poland, the project was focused on events of magnitude range 1-3 in selected regions in order to maximize the chance of recording any natural event. The project used mobile seismic stations and was divided into two stages.

Five-year measurements brought over one hundred natural seismic events of magnitudes M_L range 0.5-3.8. Most of them were located in the Podhale region in the Carpathians. Together with previously recorded events this made it possible to conduct a preliminary study on ground motion prediction equation for this region. Only one natural event, of magnitude $M_L = 3.8$, was recorded outside the Carpathians in a surprising location in central-west Poland.

Key words: seismic monitoring, mobile network, seismicity of Poland, GMPE.

Ownership: Institute of Geophysics, Polish Academy of Sciences;

1. INTRODUCTION

Although Poland is known as a region of very low natural seismicity, some earthquakes occur there from time to time. The historical catalogue (Guterch B. 2009) consists of less than one hundred earthquakes in the time span of almost one thousand years (Fig. 1).

There are two main regions of natural seismicity − mountains in south Poland and Teisseyre–Tornquist Zone (TTZ), which passes through Poland as about 100 km wide band from NW to SE.

The TTZ is a passive contact zone between two stable platforms − the Precambrian East European Craton (EEC) and the Paleozoic West European Platform (WEP). This complicated and very interesting structure is very difficult to study because it is covered by thick sediments. Most of our knowledge about it comes from three wide-angle experiments covering Poland and vicinity with many 2D profiles: POLONAISE'97 (Guterch A. *et al.*

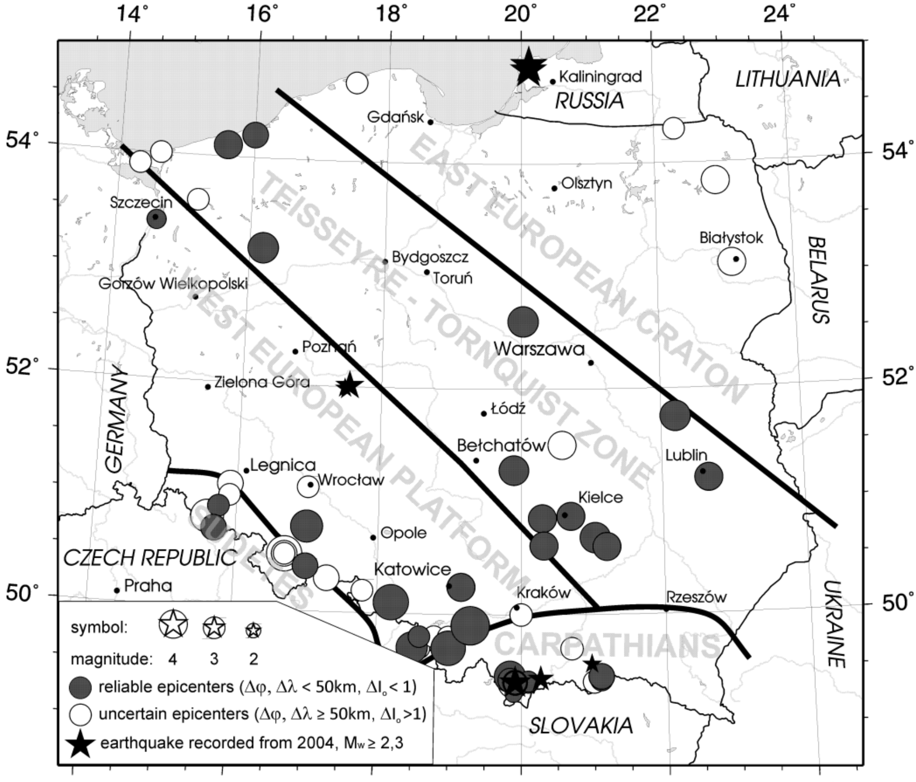

Fig. 1. Maps of the historical seismicity and strong recent earthquakes from 1400 to 2012 (data after Guterch B. (2009) and MSHTP).

1999), CELEBRATION 2000 (Guterch A. *et al.* 2003), and SUDETES 2003 (Grad *et al.* 2003).

A stable area of central and north Poland is pushed from the south by the Carpathians, which is manifested in mountains in south and south-east Poland. The Carpathians is young active orogen, contrary to older, Variscan Sudetes in south-west Poland.

Regardless of these significant genetic differences, south Poland in general is a site of the majority of earthquakes including the biggest ones, with maximum intensity of 7 in EMS-98 scale. The reason for using the EMS intensity scale, instead of magnitude, is that the biggest earthquakes occurred before any form of seismic measurement was set up in the area.

In other parts of Poland, there were much fewer earthquakes and they were smaller, hardly ever reaching intensity 6. But there is a spectacular exception of a recent well described earthquake – 5.2 magnitude earthquake on 21 September 2004 in Kaliningrad Oblast, about 50 km from the Polish-Russian border (Wiejacz 2006, Domański 2007). It was felt in the whole north Poland causing minor losses. It was also felt in Sweden and even Denmark. Together with another earthquake in southern Poland the same year, it was probably one of the important reasons for establishing the project focused on natural seismicity.

The project assumptions were based on historical seismicity (Guterch 2009) and seismic hazard study for Polish area (Schenk *et al.* 2000). Parameters of seismic hazard made it possible to assess that earthquake occurrence rate in the regions being considered is high enough to record at least a few events of magnitudes above $M_L = 1$. Because of too large area to monitor with 24 stations assigned to the project, it was decided to monitor only selected areas with the highest occurrence rate of earthquakes. Additionally, the project was divided into two 2.5-year stages. Some practical experience was gained during realization of PASSEQ experiment in the years 2006-2008 (Wilde-Piórko *et al.* 2008) which comprised almost 200 stations in temporary locations. On the contrary, though, in MSHTP the stress was put on mobility and immediate data transfer. In case of an exceptionally large event (above $M_L = 3$) it was assumed that some of the stations have to be able to be moved in two days from current positions to the epicentral area.

Although the project was focused on the natural seismicity only, there are regions of Poland with relatively high induced seismicity. The strongest earthquakes are induced by copper mines near Legnica and Głogów in south-west Poland and can exceed magnitude $M_L = 4$, which happens almost every year (*e.g.*, Lizurek and Wiejacz 2011, Orlecka-Sikora *et al.* 2012, Idziak and Dubiel 2011). Other regions highly influenced by induced seismicity is Upper Silesia in south Poland, where big coalfields have been intensively exploited for last centuries (Zuberek and Jochymczyk 2010) and Bełchatów brown coal open-cast mine region (Wiejacz and Rudziński 2010). Events in these regions were not analyzed. There exist local networks maintained by mines and controlled by appropriate authorities, which monitor regions of induced seismicity.

2. INSTRUMENTATION

Mobile seismic network requires transportable equipment which can be easily deployed without much effort to prepare the site. The Institute of Geophysics, Polish Academy of Sciences (IGF PAS) decided to use its long experience in the field of developing data loggers (*e.g.*, Aleksandrowicz 1982, Hościłowicz *et al.* 1990, Olszewski and Wiszniowski 1993) and launched a new Net Data Logger (NDL) in 2008. The NDL served in the project with a sampling rate of 100 sps and dynamics of 132 dB. Continuously recorded data were stored on Compact Flash in the internal data format and immediately transferred through the Internet provided by GSM operators. The NDL together with external devices form a mobile station.

All stations were equipped with three-component short-period seismometers Lennartz LE-3DLite (1 Hz), which are appropriate to measure local and regional seismicity, as the main content of seismic waves comes in the range of a few Hz. Additionally, this type of seismometers is easy to handle and does not require time-consuming procedure as most long period seismometers (*e.g.*, STS-2), which is very important for projects requiring high mobility of stations.

Data downloaded from the stations are collected and archived by the SeisComp system (www.seiscomp3.org/wiki/doc). During the whole project, SeisComp has been extended and supplemented by our components which support handling a seismic network. It comprises a set of tools to control network status and check data quality.

For data processing there was chosen a Seismic Wave Interpretation Program (SWIP) developed by IGF PAS for the purpose of routine job in seismological observatories (private.igf.edu/~jwisz). It has a direct connection to MySQL data base of events and to all recorded data (via ArcLink protocol).

3. DETECTION METHODS

At first, only visual inspection of seismograms was done but it shortly appeared to be time consuming and not reliable. As the acquisition was based on SeisComp system, tools built in this system were tested − AutoPick and AutoLoc. Unfortunately, they are meant for other recording conditions. AutoPick is based on the ratio of Short Term Average to Long Term Average (STA/LTA), which makes it vulnerable to high amplitude disturbances and generates many false detections which makes these tools inapplicable for our data.

The problem was that most stations were deployed in temporary locations close to human neighborhoods, which causes a high level of noise and disturbances in recorded seismic signal. Therefore, detection of small events is associated with unacceptable number of false detections.

It was decided to apply Real Time Recurrent Neural Network (RTRN) to detect small natural seismic events. It had already been studied on regional events by Wiszniowski (2000) but it got accommodated for local events (Wiszniowski *et al.* 2014). This method is able to assess relations of seismic signal in frequency domains as well as in time of seismic phases.

4. MEASUREMENTS

The seismic network used in MSHTP is registered in IRIS with a name PD – Polish Seismic Monitoring Network, but as a mobile network; individual station names have not been reserved. The full list of all stations which worked in the project is listed in the Appendix 1 and shown on maps in Figs. 2 and 3 for the first and the second stage of the project, respectively.

According to the contract with the project founder, in case of appearance of a natural earthquake of significant scale, some stations should be moved to the epicenter area in 48 hours to monitor potential aftershocks. For this reason, stations are designed and deployed so as to make mobilization and demobilization easy, without expensive and time-consuming site preparation.

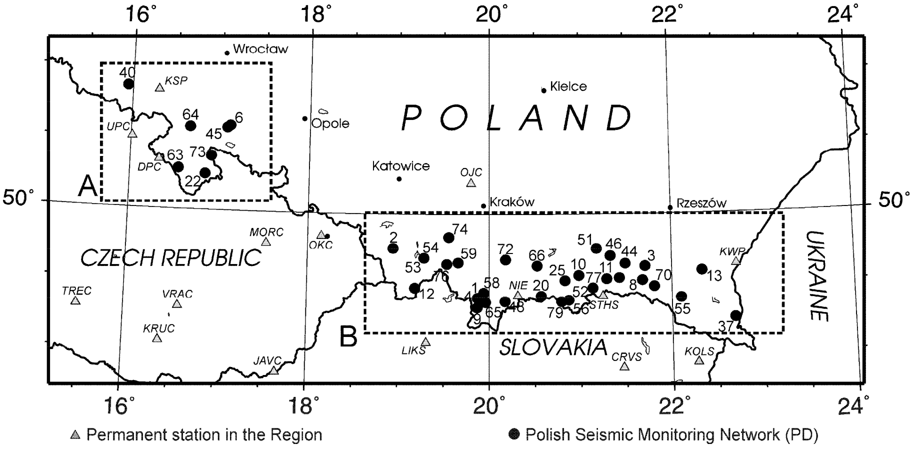

Fig. 2. Locations of stations in the Sudetes (region A) and Carpathians (region B) during the first stage of MSHTP in 2008-2010 (circles). Other stations in the region are marked by triangles.

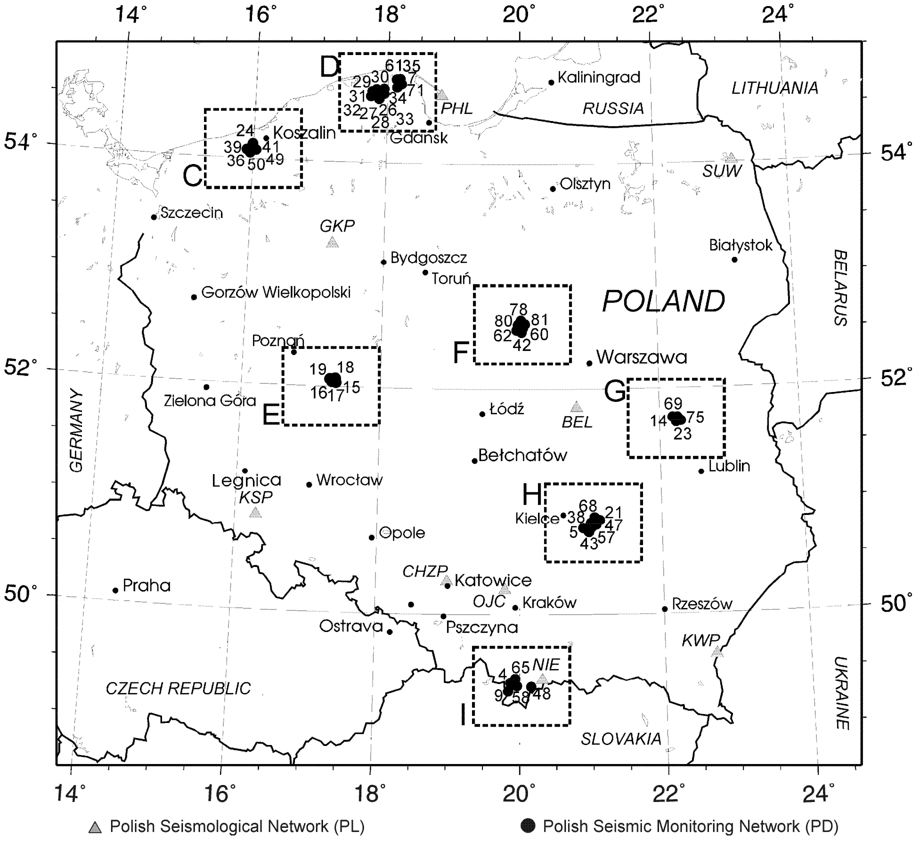

Fig. 3. All seismic stations maintained by IGF PAS during the second stage of MSHTP in the years 2010-2012 (circles). Other stations in the region are marked by triangles. Monitored regions: C – West Pomerania / near Koszalin, D – Pomerania / vicinity of Łebień and Żarnowiec, E – Wielkopolska / near Jarocin, F – Mazovia / near Płock, G – Mazovia / near Łuków, H – Holly Cross Mountains, I – Podhale / Tatra Mountains.

The project was focused on areas of known historical seismic activity. In the first stage, the monitoring covered mountain regions of the Sudetes and Carpathians in south Poland, where the majority of historical earthquakes occurred (Fig. 2). In the second stage, several regions of central and north Poland were selected (Fig. 3). It was assumed that in these places it is most probable to find seismic activity, although among these regions the region of Holy Cross Mountains has exceptionally high seismic hazard parameters (Schenk *et al.* 2000) which suggested very high chance of recording natural events. Additionally, three stations have remained during second stage in

Podhale/Carpathians, where continuous seismicity was discovered in the first stage.

Locations were selected in order to have good coverage of the monitored area and to avoid noisy areas. The second requirement means in general that stations should be put far from highly populated areas but it entails problems with infrastructure which is necessary to provide a station with power supply and internet access. Especially in mountains there was often a lack of GSM signal, which was necessary to transmit data. In most cases, stations were installed in private properties to assure protection and power supply. Although station locations were carefully selected, no tests were performed prior to station deployment. As a result, it was often necessary to move stations because of disturbances or high noise level which appeared after a station had been deployed. However, this was relatively easy due to simple installation procedure. Such a trial-error method led to 38 station locations during the first stage and 46 during the second stage.

Signal quality in different regions of Poland

Recording conditions in Poland vary because of differences in population density, industrialization, and geology. In general, low noise level is in southern Poland – in mountains. In central and northern Poland there are thick sediment layers and soils without any outcrops which are associated with higher noise level. Site selection and verification was carried out for every potential seismic station. A very useful criterion for noise assessment was to analyze power spectrum density of the recorded ground velocity. Sometimes high amplitude noise is concentrated around particular frequencies or frequency bands, which makes it possible to filter it out. This is especially easy for most signals generated by machines. The worst possible kind of noise is that related to the whole band of seismic waves (a few Hz), which makes it impossible to filter it out without significant loss of the seismic signal. Useful information about human generated noise comes from a comparison of day and night spectra, as human activity is usually higher during a day.

A comparison of power spectrum density for different regions of Poland is presented in Fig. 4. Day and night spectra were calculated for all stations and then averaged to represent respective regions. All spectra are plotted in the same scale to make it possible to easily compare noise levels between regions.

The best signal is in mountain regions, for which velocity power spectra density stays below 10^{-16} (m/s)^2/Hz (regions A and B) or 10^{-15} (m/s)^2/Hz (region H). All other regions with sedimentary background have values varying between 10^{-15} (m/s)^2/Hz and 10^{-13} (m/s)^2/Hz.

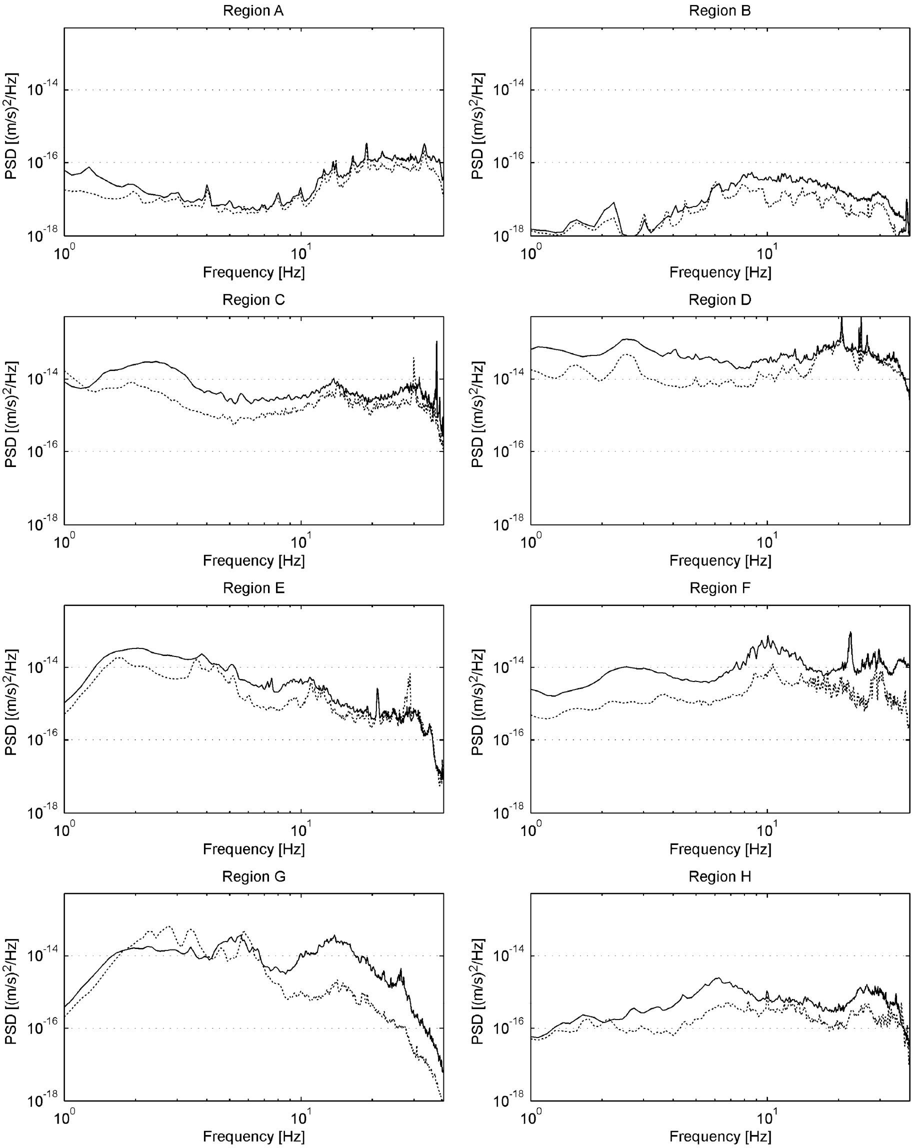

Fig. 4. Velocity power spectra density for stations in regions A-H shown in Figs. 2 and 3. Day spectra – solid line, night spectra – dashed line. Few days with small wind speed (average day wind speed below 3 m/s) were selected in each region. Day was defined as a time between 6 a.m. and 6 p.m. local time.

5. RESULTS

General description

The first stage of MSHTP covered southern Poland where the probability of earthquake occurrence is the highest. Indeed, it has been confirmed that Podhale is seismically active (over 100 events). There were also two micro-earthquakes recorded near Krynica in Beskid Sądecki. In other places monitored during the first stage of MSHTP, no natural event was recorded.

Places of previously recognized seismic activity in TTZ became the object of seismic monitoring in the second stage of MSHTP. Most of the stations were put in regions with thick sediment and soil layers which makes the noise level high. From this point of view, stations in Holy Cross Mountains had good recording conditions but a problem was with high activity of quarries in the region. To distinguish its records from natural events, source location and spectrograms of the recorded signal were analyzed. Finally, during the entire MSHTP no natural seismic event was found in the whole TTZ.

The last not described region of Poland is Wielkopolska in central-western Poland. It is a part of WEP and by January 2012 there was no single earthquake known there. Surprisingly, on 6 January 2012 at 15:38 UTC an earthquake of magnitude $M_L = 3.8$ frightened inhabitants of the area in a radius of 10 km from the epicenter. Later, macroseismic questionnaires were coming from distances over 60 km from the epicenter. Unfortunately, this region was not monitored and the nearest stations were about 100 km off. Immediately after the earthquake, five stations were moved there from other regions. The earthquake was described in detail by Lizurek *et al.* (2013).

Apart from seismic events, both natural and man-induced, there were also recorded non seismic events considered generally as disturbances but they are rarely recorded by more than one station. If so, it is necessary to verify a possible source to distinguish it from possibly natural seismic source. Events of this kind may be, for example, quarry blasts or jet sonic waves.

The next two sections describe in more details natural seismicity recorded in the project and an interesting example of non-seismic events recorded on an exceptionally large area. The last section concerns derivation of ground motion prediction equation (GMPE) for the Podhale region / Carpathians.

Seismicity of the Carpathians (Polish part)

Earthquakes felt in the Polish Carpathians were known for many years. Some of them are only mentioned in chronicles but more recent ones are better described (Guterch B. *et al.* 2005, Guterch B. 2006, 2007, 2009, Wiejacz and Dębski 2009). Seismicity concentrates in the west part of the region – in the Podhale but some events occur also in the east part, mainly in Beskid Sądecki (Fig. 5). Before 2008, seismic events were rarely recorded but the MSHTP project has shown a continuous activity. Figure 6 shows an increasing capability to detect seismic events in this region with the majority of events recorded during the MSHTP project. In the Podhale region, where

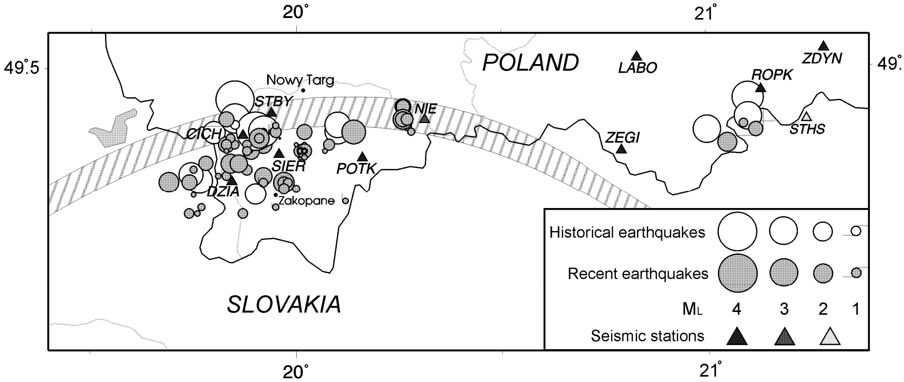

Fig. 5. Seismic events in Podhale. The most important geological structure is PKB – Pieniny Klippen Belt (hatched area). Seismic stations are marked with triangles.

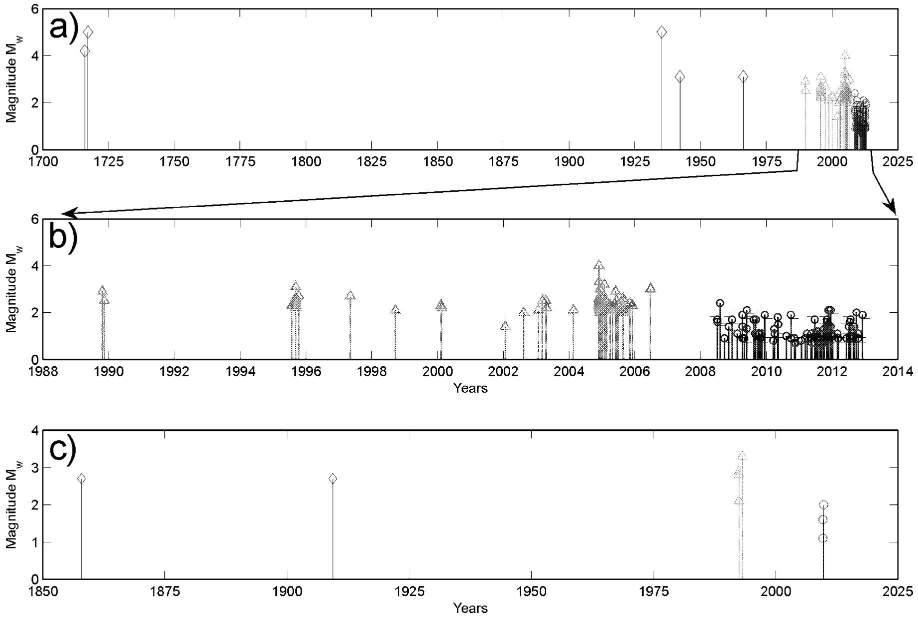

Fig. 6. Time sequence of all earthquakes in the Polish Carpathians separated into the Podhale region – panels (a) and (b), and Beskid Sądecki – panel (c). Diamonds – historical earthquakes, triangles – recorded instrumentally, and circles – recorded during MSHTP.

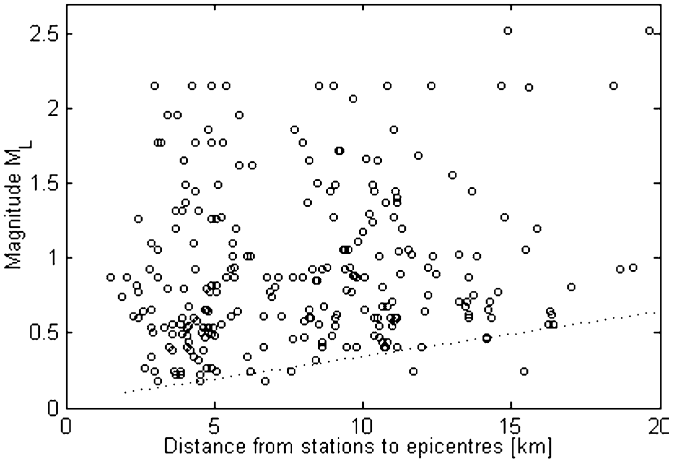

Fig. 7. The dashed line on the diagram shows a sensitivity of the network in the Podhale region. Each circle represents a magnitude calculated for an individual station.

several seismic events were recorded, a sensitivity of the seismic network, in terms of a minimum magnitude possible to be detected at a given distance, is shown on a diagram in Fig. 7. Generally, events below a dashed cut-off line are not detectable by this network, although in very good recording conditions it happens.

Over one hundred microearthquakes have been detected and 81 of them, of magnitude (M_L) range from 0.5 to 2.2, located (Appendix 2). Some of them are part of a swarm which took place in November–December 2011. All of the swarm events are located in the Pieniny Klippen Belt (PKB) formation and may be related to a nearby Czorsztyńskie Lake – an artificial reservoir on the Dunajec River, whereas the majority of other events are located to the south of PKB and are not related to the lake. In general, active regions fit well with regions where stronger events were recorded previously (Fig. 5).

Although the number of records was not sufficient to conduct full moment tensor analysis, it was possible to derive basic spectral parameters. The values of Ω_0 and f_0 of Brune's (1970) model were calculated separately for three components using the method of Andrews (1986). The spectrum of the signal was computed by the multitaper method of Park *et al.* (1987) with scaling of the spectra based on the Parseval equality. The seismic moment was calculated from three components (Wiejacz and Wiszniowski 2006).

There were selected three events of magnitude $M_L = 1$ and three of $M_L = 2$. A corner frequency (f_0) calculated for different stations was for $M_L \sim 1$, in the range of 5.9-11.9 Hz for *P* waves and 3.6-7.2 Hz for *S* waves. For stronger events, of magnitude $M_L \sim 2$, the calculated f_0 was in the range of 4.1-11.7 Hz for *P* waves and 3.3-7.3 Hz for *S* waves. Spectral parameters for events of $M_L = 1$ are less reliable because, as a result of inelastic dumping, high frequency signal is below the noise level.

Ground Motion Prediction Equation (GMPE) for Podhale

Relatively high number of seismic events recorded in Podhale / West Polish Carpathians allowed us to derive GMPE for this region. The only equation used before was a very general equation used by Shenk *et al.* (2000) to jointly describe Czech, Polish, and Slovak region.

At first, a standard regression model of GMPE was used, which assumes geometric damping

$$\log Y = a_1 + a_2 m + a_3 \log\sqrt{d^2 + h^2} \ , \tag{1}$$

where Y is the Peak Horizontal Acceleration (PHA) [m/s^2], m the magnitude, and d the distance [km]. Coefficients a_1, a_2, a_3, and h were estimated using three methods (Joyner and Boore 1993): single stage regression (SSR), two stage regression (TSR), and least squares. The results are presented in Table 1.

Table 1

Coefficients of Eq. 1 computed using different regression methods

Regression method	a_1	a_2	a_3	h	σ
SSR	–1.6957	1.1251	–2.7167	7.0646	0.255 ($\gamma = 0.009$)
TSR	–2.1658	1.1105	–2.4095	4.8663	0.25 ($\sigma_e = 0.096$)
Least squares	–2.0945	1.0985	–2.4438	5.2665	0.25

All three methods gave similar results within 30% confidence interval. Then, stability of the solution was tested for different distances to the epicenter (Table 2). Small variation of the parameters at every distance indicates good fit to the data, which can also be visually inspected in Fig. 8.

Apart from the standard form of the GMPE of Eq. 1, a GMPE with assumed anelastic damping was also tested. It is given by the general equation

$$\log Y = a_1 + a_2 m - \log\sqrt{d^2 + h^2} + a_3 d \tag{2}$$

and gave very similar results, in terms of σ value, to previous GMPE model for all source-receiver distances, although data extended by older events does not fit as well as previously, having higher σ-value (Table 3). This means that the previous GMPE model with elastic damping is better for the region of Podhale.

Table 2

Coefficients of the GMPE equation
calculated for events within different distances to the epicenter

Distance limit	Data points	a_1	a_2	a_3	h	σ
5	88	–2.4716	1.1782	–2.2901	5.2500	0.2055
10	165	–2.6556	1.165	–2.0001	6.9019	0.2262
15	230	–2.5984	1.1191	–2.0217	4.99	0.2262
20	244	–2.5411	1.1133	–2.084	5.6697	0.2239
30	256	–2.6027	1.1155	–2.0144	4.195	0.2208
50	269	–2.3774	1.0868	–2.2392	6.6336	0.2336
100	280	–2.3652	1.0818	–2.2476	5.7368	0.2399
100	288*	–2.3601	1.0741	–2.2457	5.2665	0.2529

*)including stronger events recorded prior to MSHTP project

Table 3

Coefficients of the GMPE Eq. 2
calculated for events within different distances to the epicenter

Distance limit	Data points	a_1	a_2	a_4	h	σ
5	88	–3.0214	1.1784	–0.0846	5.5441	0.2056
10	165	–2.8465	1.165	–0.0779	9.225	0.2256
15	230	–3.217	1.1192	–0.0429	3.7152	0.2262
20	244	–3.1949	1.1155	–0.0445	3.9287	0.2229
30	256	–3.3544	1.1161	–0.0301	2.2112	0.223
50	269	–3.3029	1.108	–0.034	2.7008	0.2254
100	280	–3.4162	1.0913	–0.0235	1.182	0.2456
100	288*	–3.4941	0.9547	–0.0062	0	0.3342

*)including stronger events recorded prior to MSHTP project

Finally, a model of the form of Eq. 1 obtained with TSR regression method ($a_1 = -2.17$, $a_2 = 1.1$, $a_3 = -2.4$, $h = 4.87$) was compared with other GMPE's. There was chosen an equation of Schenk *et al.* (2000) which was dedicated for the whole area of Czech, Poland, and Slovakia and five other equations used in the project SHARE (Delavaud *et al.* 2012) to describe central European region. An example plot for an event of magnitude $M_w = 4$ is shown in Fig. 9. For small distances, our solution gives higher values than other models except the one by Campbell (2003), but for distances over 10 km from the epicenter it gives the highest values. The most probable rea-

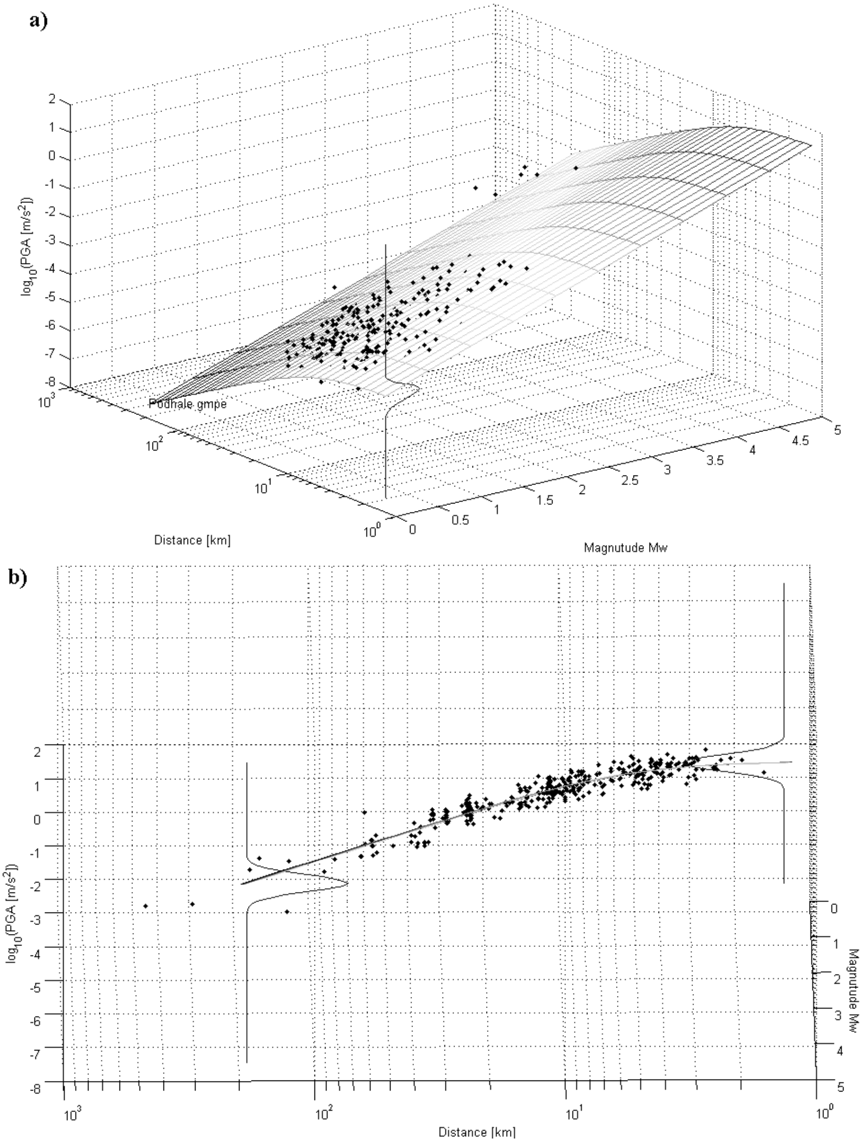

Fig. 8. TSR regression model as a surface in 3D plotted in two projections, (a) and (b), together with recorded peak horizontal acceleration – black dots. Uncertainty of the model is given by the probability distribution plotted in a vertical axis.

son for this difference from other models is that the majority of events in Podhale were of small magnitude and at small distance, which makes a weak fit for strong and distant events. To obtain a better GMPE for Podhale it is necessary to record stronger events with a wide spectrum of distances.

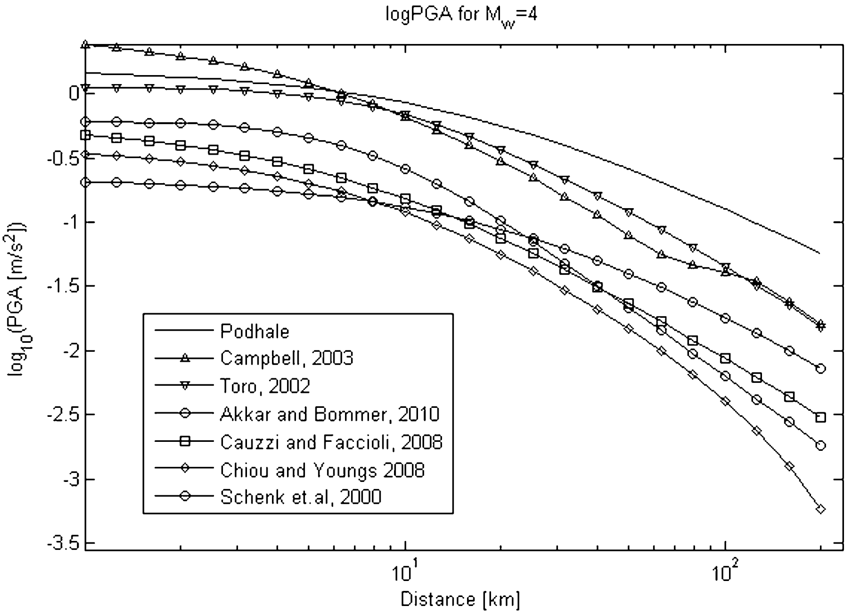

Fig. 9. Comparison of different GMPE's for an event with magnitude $M_w = 4$.

Non-seismic events

When continuous measurements are carried out, there are many non-seismic events recorded by seismic stations. Usually they are local and are recorded only by one station, so they are not even detected by algorithms. Sometimes, such signals are recorded by more stations but still in one region. It can be, for example, a sonic wave caused by an explosion or a shock wave of a supersonic jet. It is easy to distinguish such an event from seismic one because it has much smaller propagation velocity.

An interesting event happened on 25 February 2011, but there were more very similar ones. A set of regularly spaced (2 min interval) impulses was recorded by some stations in very distant regions (over 300 km). The best records for vertical components are presented in Fig. 10 and associated station locations in Fig. 11.

Joint epicenter location and velocity inversion derived a velocity of ~350 m/s which fits sonic wave speed very well. The locations obtained for the first impulse and the last impulse are almost the same and are very close to $\varphi = 54.50$N, $\lambda = 20.83$E (Fig. 11). This suggests that the source was immobile and was on the territory of Kaliningrad Oblast / Russia. It is still not clear what kind of source could generate such a signal.

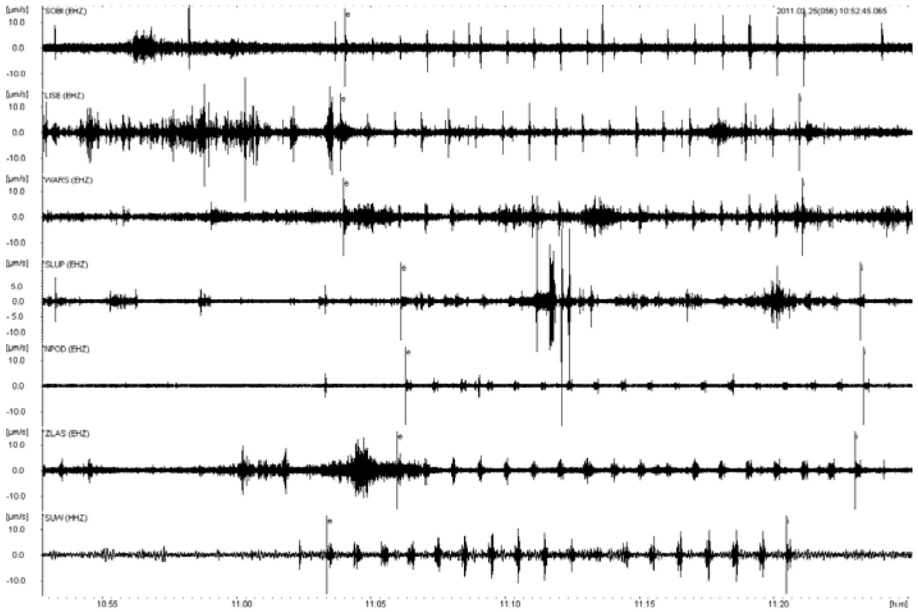

Fig. 10. Vertical components of stations: SOBI, LISE, WARS, SLUP, NPOD, ZLAS, SUW, which recorded the pulses in regular intervals in different regions of Poland. Delays between stations indicate much slower propagation than for seismic waves. First pulse on each seismogram is marked with "e" and the last one with "i".

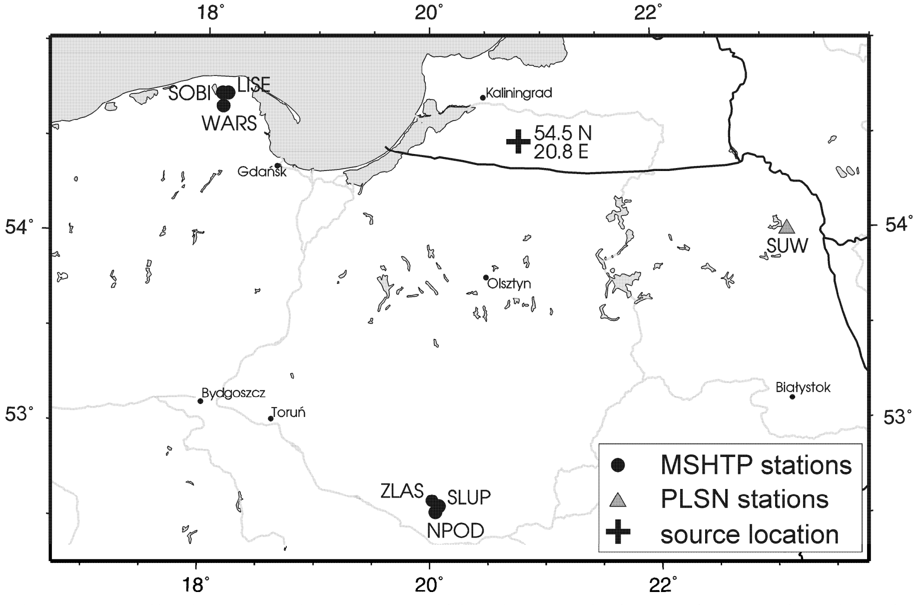

Fig. 11. Distribution of stations presented in Fig. 10 (circles) and source location obtained jointly with velocity inversion (cross).

6. CONCLUSIONS

“Monitoring of Seismic Hazard of Territory of Poland” was the first project of this scale in Poland that focused on local natural seismicity. The existing seismological network (9 stations) is meant for global and regional scale monitoring measurements. It is not capable to detect and locate events smaller than magnitude 3. A new seismic network composed of 24 mobile seismic stations significantly improved this sensitivity. Together with new seismic stations a new acquisition system was set up and new tools for maintaining a network and for data processing were developed, which makes a room for a further network growth.

Monitored regions were selected on the basis of analysis of historical seismicity and were scattered over the area of Poland. A five-year project confirmed seismic activity of the Carpathians (Stage 1, Region A, and Stage 2, Region I, Figs. 2 and 3), mainly in the Podhale region, where over 100 events have been recorded, and near Krynica / Beskid Sądecki / Carpathians (three events). At the beginning of the project both places have been already known for historical earthquakes and recent seismic activity. Second region with a surprisingly large earthquake is near Jarocin / Wielkopolska / western Poland (Stage 2, Region E, Fig. 3). This region was not considered as a potential source of such earthquake and was not covered by monitoring before the earthquake occurrence.

In other mountain regions, Sudetes (Stage 1, Region A, Fig. 2) and Holy Cross Mountains (Stage 2, Region H, Fig. 3), there has not been recorded any natural seismic event, which suggests that return period of detectable events is too long comparing to the monitoring period. This argument is valid for other regions as well, but bad recording conditions additionally reduce the detection possibility. The best recording conditions, in terms of noise level, are in mountains in the south, where sediments are very thin and it is often possible to put a seismometer directly on a rock. Much greater noise, by about two orders of the PSD magnitude, is in regions of sedimentary background (Stage 2, Regions C-G, Fig. 3).

The number of events in the Podhale region made it possible to conduct a preliminary study on ground motion prediction equation for this region, which is a key for future seismic hazard assessments. The obtained equation fits the data well but there is a lack of strong motion records, which makes the solution less adequate for higher magnitudes.

The project confirmed that some regions of Poland are seismically active, which makes them interesting objects of future studies. It was also proved that applied mobile monitoring network is a reliable and adequate tool for measurements of this type.

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Appendix 1

List of stations in the project

Station name	Stage	Site name	Recording period	Lat. [°]N	Long. [°]E	Elev. [m]	Region
AWRA	1	Ciche	17 Jun 2008 – 10 Aug 2008	49.40	19.87	670	B
BLAT	1	Błatnia	6 May 2009 – 2 Oct 2009	49.75	18.94	887	B
BOBR	1	Bóbrka	9 Sep 2008 – 19 May 2010	49.62	21.71	334	B
CICH	1+2	Ciche	11 Aug 2008 – 31 Dec 2012	49.39	19.87	670	B, I
CISO	2	Cisów	13 Jul 2010 – 31 Dec 2012	50.77	20.90	331	H
DEBO	1	Dębowiec	23 Sep 2008 – 1 Dec 2008	50.59	17.11	278	A
DOMA	2	Domatowo	28 Jul 2010 – 31 Dec 2012	54.71	18.21	103	D
DUKL	1	Dukla	19 Jun 2008 – 6 Aug 2008	49.52	21.68	502	B
DZIA	2	Dzianisz	27 Oct 2010 – 31 Dec 2012	49.32	19.84	921	I
FLOR	1	Florynka	18 Jun 2008 – 4 Sep 2008	49.55	20.98	403	B
GLAD	1	Gładyszów	26 Oct 2009 – 9 Jan 2010	49.53	21.29	521	B
GLIN	1	Glinka	17 Sep 2009 – 14 Apr 2010	49.46	19.18	673	B
HOLU	1	Hołuczków	17 Jul 2008 – 8 Jun 2010	49.58	22.33	381	B

to be continued

continuation

Station name	Stage	Site name	Recording period	Lat. [°]N	Long. [°]E	Elev. [m]	Region
HORD	2	Hordzieszka	7 Jul 2010 – 21 Oct 2010	51.74	22.18	175	G
JAR1	2	Mniszew	8 Jan 2010 – 31 Dec 2012	52.04	17.69	81	E
JAR2	2	Stęgosz	8 Jan 2010 – 31 Dec 2012	52.04	17.52	97	E
JAR3	2	Ludwinów	8 Jan 2010 – 31 Dec 2012	52.05	17.62	82	E
JAR4	2	Pogorzelica	9 Jan 2010 – 31 Dec 2012	52.14	17.59	71	E
JAR6	2	Lgów	9 Jan 2010 – 31 Dec 2012	52.10	17.53	72	E
JAWO	1	Jaworki – Biała Woda	18 Jun 2008 – 20 Jul 2008	49.41	20.57	616	B
JELE	2	Jeleniów	27 Oct 2010 – 31 Dec 2012	50.83	21.13	347	H
KLET	1	Kletno	2 Dec 2008 – 15 Dec 2008	50.25	16.84	878	A
KONO	2	Konorzatka	7 Jul 2010 – 31 Dec 2012	51.71	22.24	158	G
KRAS	2	Kraśnik Koszaliński	23 Aug 2010 – 31 Dec 2012	54.13	15.99	30	C
LABO	1	Łabowa	10 Sep 2008 – 19 May 2010	49.52	20.83	509	B
LE01	2	Karlikowo Leborskie	12 Jul 2011 – 4 Oct 2011	54.64	17.78	73	D
LE02	2	Rekowo Leborskie	13 Jul 2011 – 4 Oct 2012	54.63	17.79	66	D
LE03	2	Obliwice	14 Jul 2011 – 7 Oct 2013	54.62	17.74	56	D
LE04	2	Lebien	14 Jul 2011 – 4 Oct 2014	54.64	17.72	50	D
LE05	2	Basewice	20 Jul 2011 – 25 Sep 2015	54.67	17.79	69	D
LE06	2	Krepa Kaszubska	21 Jul 2011 – 7 Oct 2016	54.63	17.66	73	D

to be continued

continuation

Station name	Stage	Site name	Recording period	Lat. [°]N	Long. [°]E	Elev. [m]	Region
LE07	2	Niebedzino	21 Jul 2011 – 7 Oct 2017	54.57	17.62	55	D
LE08	2	Lubowidz	21 Jul 2011 – 7 Oct 2017	54.54	17.81	29	D
LE09	2	Leczyn Dolny	22 Jul 2011 – 6 Oct 2019	54.64	17.95	125	D
LISE	2	Lisewo	28 Jul 2010 – 31 Dec 2012	54.75	18.18	25	D
LULE	2	Lulewice	14 Jul 2010 – 31 Dec 2012	54.05	15.95	24	C
LUTW	1	Lutowiska	18 Jul 2008 – 31 May 2010	49.24	22.69	650	B
MAKO	2	Lechów	13 Jul 2010 – 31 Dec 2012	50.81	21.00	334	H
MERZ	2	Mierzynek	13 Jul 2010 – 31 Dec 2012	54.10	15.90	32	C
MNIS	1	Mniszków	9 Aug 2008 – 31 May 2010	50.86	15.94	626	A
NOSO	2	Nosówko	13 Jul 2010 – 23 Aug 2010	54.10	16.00	29	C
NPOD	2	Nowy Podleck	23 Aug 2010 – 6 Jan 2012	52.55	20.05	127	F
OCIE	2	Ociesęki	13 Jul 2010 – 31 Dec 2012	50.73	20.97	312	H
OSIE	1	Osiek Jasielski	19 Jun 2008 – 3 Sep 2008	49.64	21.49	226	B
OSIN	1	Osina Wielka	8 Aug 2008 – 4 Sep 2008	50.58	17.07	229	B
PAGO	1	Pagorzyna	9 Sep 2008 – 27 May 2010	49.69	21.33	360	B
PLUC	2	Płucki	25 Oct 2010 – 31 Dec 2012	50.80	21.07	315	H
POTK	2	Potok	26 Oct 2010 – 31 Dec 2012	49.36	20.16	886	I
PUS2	2	Pustkowo	23 Aug 2010 – 31 Dec 2012	54.08	16.04	20	C

to be continued

continuation

Station name	Stage	Site name	Recording period	Lat. [°]N	Long. [°]E	Elev. [m]	Region
PUST	2	Pustkowo	27 Jul 2010 – 23 Aug 2010	54.06	16.03	19	C
RACL	1	Racławice	7 Aug 2008 – 30 Aug 2008	49.75	21.18	342	B
ROPK	1	Ropki	9 Aug 2008 – 1 Jun 2010	49.46	21.13	563	B
RYC2	1	Rychwałdek	5 May 2009 – 17 May 2010	49.68	19.28	464	B
RYCH	1	Rychwałdek	1 Nov 2008 – 5 May 2009	49.68	19.28	493	B
RZEP	1	Rzepedź	19 Jul 2008 – 31 May 2010	49.39	22.10	458	B
SCWK	1	Szczawnik	9 Aug 2008 – 29 Oct 2008	49.38	20.87	523	B
SEDK	2	Sędek	13 Jul 2010 – 31 Dec 2012	50.77	21.01	396	H
SIER	1+2	Sierockie	11 Aug 2008 – 31 Dec 2012	49.36	19.96	1007	B, I
SKAW	1	Skawica	20 Jul 2008 – 12 May 2010	49.65	19.66	686	B
SLUP	2	Słupca	1 Jul 2010 – 6 Jan 2012	52.58	20.08	139	F
SOBI	2	Sobieńczyce	28 Jul 2010 – 31 Dec 2012	54.75	18.13	102	D
SOCH	2	Sochocino-Praga	1 Jul 2010 – 6 Jan 2012	52.57	19.98	129	F
SPAL	1	Spalona	17 Dec 2008 – 1 Jun 2010	50.28	16.54	760	A
SRGO	1	Srebrna Góra	8 Aug 2008 – 1 Jun 2010	50.58	16.66	483	A
STBY	1+2	Stare Bystre	20 Jul 2008 – 31 Dec 2012	49.43	19.94	682	B, I
STRO	1	Stronie	13 Sep 2008 – 1 Jun 2010	49.62	20.53	578	B
SWIA	1	Świątkowa Wielka	8 Aug 2008 – 4 Sep 2008	49.54	21.42	444	B

to be continued

continuation

Station name	Stage	Site name	Recording period	Lat. [°]N	Long. [°]E	Elev. [m]	Region
SWKR	2	Święty Krzyż	25 Oct 2010 – 31 Dec 2012	50.86	21.05	556	H
SZCZ	2	Szczałb	7 Jul 2010 – 21 Oct 2010	51.77	22.24	159	G
SZKL	1	Szklary	7 Aug 2008 – 31 May 2010	49.47	21.81	559	A
WARS	2	Warszkowo	28 Jul 2010 – 31 Dec 2012	54.68	18.14	43	D
WILC	1	Wilczyce	11 Aug 2008 – 31 May 2010	49.67	20.18	615	B
WRZO	1	Wrzosówka	7 Aug 2008 – 1 Jun 2010	50.38	16.90	722	A
ZAGR	1	Zagórze	21 Jul 2008 – 16 Jun 2010	49.83	19.55	337	B
ZAKE	2	Zakępie	7 Jul 2010 – 21 Oct 2010	51.73	22.30	158	G
ZAWO	1	Zawoja	17 Jun 2008 – 20 Jul 2008	49.64	19.53	613	B
ZDYN	1	Zdynia	30 Sep 2009 – 26 Oct 2009	49.49	21.27	521	B
ZDZW	2	Zdziar Wielki	2 Jul 2010 – 23 Aug 2010	52.63	20.05	134	F
ZEGI	1	Żegiestów	29 Oct 2008 – 31 May 2010	49.37	20.79	466	B
ZLAS	2	Zdziar Las	23 Aug 2010 – 6 Jan 2012	52.61	20.02	146	F
ZOCH	2	Żochocino	1 Jul 2010 – 23 Aug 2010	52.63	20.12	127	F

Appendix 2

List of events localized in Podhale/Carpathians during MSHTP project

No.	Date	Time	Latitude [°N]	Longitude [°E]	Depth [km]	M_L
1	5 Jul 2008	20:11:10.7	49.320	19.742	5	1.6
2	6 Jul 2008	11:58:11.5	49.354	19.780	7	1.5
3	5 Aug 2008	12:28:54.5	49.405	20.142	4	2.5
4	21 Sep 2008	16:05:23.8	49.356	20.013	3	0.4
5	10 Nov 2008	07:55:45.1	49.385	20.084	3	1.1
6	16 Dec 2008	23:31:54.9	49.373	20.012	4	1.6
7	12 Feb 2009	15:20:25.5	49.321	19.916	5	0.9
8	10 Apr 2009	17:45:39.1	49.379	19.917	3	2.0
9	10 Apr 2009	19:00:51.6	49.391	19.904	4	1.3
10	12 Apr 2009	00:27:31.2	49.391	19.910	6	0.5
11	30 Apr 2009	05:44:31.2	49.388	19.916	4	0.5
12	29 May 2009	14:57:24.4	49.317	19.690	3	2.1
13	29 May 2009	20:33:28.3	49.344	19.878	1	1.0
14	13 Aug 2009	19:47:23.9	49.384	19.834	3	1.7
15	29 Aug 2009	23:20:19.9	49.384	19.846	3	0.9
16	3 Sep 2009	20:40:52.7	49.392	19.835	3	0.9
17	7 Sep 2009	16:52:39.7	49.401	20.015	3	1.6
18	1 Oct 2009	07:06:41.7	49.393	19.903	3	0.8
19	4 Oct 2009	00:32:59.4	49.393	19.904	4	0.8
20	4 Oct 2009	23:50:21.9	49.308	19.975	3	0.8
21	16 Oct 2009	04:22:33.4	49.368	19.884	3	0.9
22	28 Oct 2009	22:00:28.2	49.331	19.924	8	0.6
23	12 Nov 2009	14:38:18.3	49.320	19.976	3	0.9
24	15 Dec 2009	11:46:51.3	49.332	19.916	7	1.9
25	19 Mar 2010	07:18:54.9	49.380	19.904	4	0.3
26	31 Mar 2010	04:09:01.9	49.384	19.907	4	1.1
27	3 Apr 2010	20:28:21.1	49.312	19.970	5	1.0
28	4 Apr 2010	07:18:33.6	49.406	19.851	4	0.7
29	7 May 2010	20:50:00.4	49.367	19.885	4	1.8
30	13 May 2010	19:02:02.7	49.396	19.921	5	1.3
31	11 Aug 2010	05:05:49.6	49.392	19.910	4	0.7

to be continued

continuation

No.	Date	Time	Latitude [°N]	Longitude [°E]	Depth [km]	M_L
32	1 Oct 2010	06:31:53.3	49.389	19.912	3	1.8
33	2 Oct 2010	23:17:54.9	49.391	19.910	4	0.5
34	7 Nov 2010	09:52:42.9	49.387	19.923	4	0.5
35	8 Nov 2010	23:16:41.2	49.376	19.884	5	0.6
36	10 Nov 2010	00:32:52.9	49.392	19.963	4	0.2
37	19 Nov 2010	02:56:19.3	49.398	19.924	5	0.2
38	25 Jan 2011	02:26:28.5	49.381	20.000	3	0.4
39	8 Mar 2011	01:50:32.1	49.331	19.813	4	0.6
40	28 Mar 2011	01:53:40.3	49.332	19.828	5	0.9
41	12 May 2011	01:38:58.2	49.291	20.119	3	0.7
42	17 May 2011	20:21:50.8	49.306	19.993	3	0.7
43	21 May 2011	01:33:01.2	49.397	19.956	3	0.2
44	21 Jun 2011	14:54:25.9	49.418	19.829	4	1.4
45	11 Jul 2011	21:14:07.8	49.398	19.943	4	0.6
46	11 Jul 2011	22:06:24.2	49.280	19.774	5	0.8
47	12 Jul 2011	02:41:53.8	49.272	19.735	5	0.9
48	12 Jul 2011	02:54:13.3	49.267	19.762	5	0.6
49	24 Jul 2011	03:28:57.3	49.270	19.869	5	1.0
50	26 Jul 2011	00:53:33.8	49.296	19.746	5	0.5
51	29 Jul 2011	20:28:58.8	49.391	19.907	5	0.3
52	22 Aug 2011	22:20:52.9	49.374	20.072	2	0.4
53	3 Sep 2011	19:20:09.7	49.370	19.889	2	0.2
54	26 Sep 2011	03:48:16.9	49.374	20.018	4	0.3
55	26 Sep 2011	16:30:54.8	49.401	19.925	5	0.8
56	26 Sep 2011	22:23:07.9	49.392	19.934	4	0.4
57	6 Oct 2011	23:05:21.8	49.385	19.831	6	1.1
58	6 Nov 2011	11:35:07.1	49.366	19.834	5	0.5
59	6 Nov 2011	13:19:37.6	49.368	19.833	5	1.5
60	26 Nov 2011	16:31:42.6	49.386	19.910	3	2.1
61	26 Nov 2011	18:13:37.1	49.385	19.907	3	0.9
62	15 Dec 2011	03:05:42.9	49.320	19.968	2	2.1
63	15 Dec 2011	04:56:33.7	49.318	19.968	2	1.3
64	23 Dec 2011	17:07:03.8	49.339	19.750	3	0.8
65	8 Jan 2012	21:45:55.5	49.283	19.946	3	0.6
66	1 Mar 2012	19:34:38.3	49.377	19.882	3	0.9

to be continued

continuation

No.	Date	Time	Latitude [°N]	Longitude [°E]	Depth [km]	M_L
67	5 Mar 2012	14:24:45.6	49.372	20.011	3	0.6
68	8 Mar 2012	21:33:30.3	49.379	20.019	3	0.5
69	9 Jun 2012	03:11:50.2	49.366	20.018	4	0.6
70	6 Jul 2012	06:18:25.3	49.397	19.950	4	1.2
71	16 Jul 2012	09:15:28.6	49.368	20.018	3	1.4
72	17 Jul 2012	00:47:16.8	49.369	20.015	4	0.7
73	17 Jul 2012	05:27:13.0	49.365	20.016	3	0.6
74	17 Jul 2012	23:15:12.7	49.369	20.014	4	0.4
75	21 Jul 2012	22:36:52.9	49.370	20.015	4	0.4
76	25 Aug 2012	23:27:40.4	49.407	19.948	4	0.6
77	28 Sep 2012	17:09:34.2	49.351	19.845	3	1.9
78	16 Oct 2012	14:35:31.5	49.365	20.015	3	0.8
79	16 Oct 2012	14:48:30.0	49.374	20.020	4	0.4
80	4 Dec 2012	03:57:55.2	49.392	19.924	4	0.6
81	4 Dec 2012	13:09:30.9	49.351	19.855	3	1.9

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