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# SEISMIC EVENTS IN THE ORAWA-NOWY TARG BASIN, WESTERN CARPATHIANS, NOVEMBER 30, 2004 - DECEMBER 2005

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**ABSTRACT**
An earthquake of magnitude M = 4.4, macroseismic intensity $I_o$ = 7 in the EMS scale, followed by a long series of aftershocks occurred on November 30, 2004 in southern margin of the Orawa–Nowy Targ Basin, Western Carpathians. Macroseismic epicentral data were determined for the main earthquake and the strongest aftershocks. The foci were shallow, less than 5 km i.e., originated in the Podhale Flysch. An array of seismic stations located in this seismically active area is necessary for better recognizing of the ongoing tectonic process.

**KEYWORDS:** Orawa-Nowy Targ Basin, Pieniny Klippen Belt, series of earthquakes, macroseismic data

## 1. INTRODUCTION

On November 30, 2004 an earthquake of magnitude about M = 4.4, intensity $I_o$ = 7 in the EMS-98 scale, occurred in the Western Carpathians within the intramontane Orawa-Nowy Targ (ONT) Basin. The earthquake caused considerable local concern mostly due to the unusual damage to buildings although, in this region, these are generally of high vulnerability in the EMS scale. The main earthquake was followed by a series of aftershocks, which were still observed in December 2005.

The ONT Basin is located at the most northern part of the Pieniny Klippen Belt (PKB), a nearly 600 km long tectonic structure dividing the Carpathians into their inner and outer parts. Seismic activity along the PKB is recognized in many areas (Procházková et.al., 1986). The intramontane ONT Basin covers parts of the Magura Nappe, Pieniny Klippen Belt and the Podhale Flysch. The tectonic position of the ONT Basin presented in Fig. 1 is after Żytko et al. (1988), simplified by Tokarski and Zuchiewicz (1998).

Earthquakes have been recorded in the ONT Basin since 1935 when an event of similar intensity occurred. The last seismic events to be macro-seismically recorded were in 1995 on September 11 of intensity $I_o$ = 5 EMS and on October 13 of $I_o$ = 4 EMS (Guterch et al., 2005). Older historical earthquakes are hardly recognized. However, it seems that poorly determined events in 1716 and 1717 could also originate in the ONT Basin (Guterch et al., 2002). Nyka (1962) quoted from the church archive (in difficult Polish) at Rabka:

In year 1716 the Earth shook beneath the Tatras in the church at Czarny Dunajec, and again on March 11, 1717 also the Earth shook beneath the Tatras, the Tatras shook so much that it seemed to people that buildings would collapse in the church at Czarny Dunajec and in Orawa.

These words are hard to interpret with accuracy pending further evidence. People dwellings were only wooden in XVIII century of high vulnerability class in the EMS scale and epicentral intensity might reach 7 EMS. Secondly, the Tatras used to be uninhabited in winter. Probably, for the anonymous Author at Rabka, „in the Tatras" would mean the villages near the Tatras. Therefore, this could be the first acknowledgment of the quakes at Czarny Dunajec and in the Orawa Basin, precisely where the earthquake on November 30, 2004 was mostly felt.

## 2. REVIEW OF INSTRUMENTAL DATA

The epicenter parameters of the main earthquake after NEIC are as follows:

$$H = 17^h18^m36.89^s,\ \varphi = 49.456N,\ \lambda = 19.854E,$$
$$h = 5km,\ mb = 4.8,\ MS = 4.4$$

The main earthquake was followed by a long series of aftershocks with decreasing frequency. The aftershocks were still being recorded there in December 2005. Any foreshocks immediately before the main earthquake were not recognized.

The shallow, normal mechanism was determined by the ETHZ Swiss Moment Tensor Solution for the main earthquake on November 30, 2004:
h = 4km, $M_o$ = 6.3E+22dyn cm, $M_W$ = 4.5,
Nodal Plane 1: strike = 246, rake = -80, dip = 66,
Nodal Plane 2: strike = 43, rake = -112, dip = 26,
(http://www.seismo.ethz.ch/moment_tensor/2004/041130_1718.ap.30_50s4k).

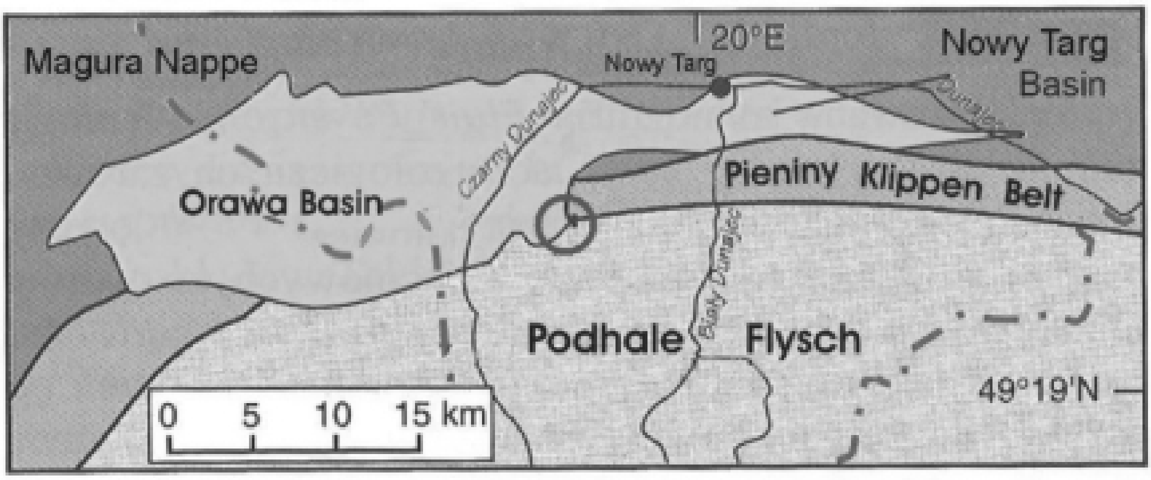


**Fig. 1** Tectonic position of the Orawa–Nowy Targ Basin after Żytko et al. (1988), simplified by Tokarski and Zuchiewicz (1998). The area where seismic events occurred is marked by a circle.

Source parameters for the main earthquake determined after digital records of station Ojców (OJC) are as follows: spectral magnitude M = 4.3, seismic moment Mo = 4.0E+22dyn cm, source radius r = 700m, stress drop $\Delta\sigma$ = 5.1MPA, average displacement ũ = 86mm.

The cummulative number of seismic events recorded by station NIE the nearest one to the epicenter, between November 30, 2004 and February 15, 2005 is presented in Fig. 2. The estimated relation lgN = 4.00–1.09ML is valid only for ML > 1.4. Weaker events were poorly recorded. The station is too distant, 30 km from the epicenter, to record seismic events of ML < 1.3 and microevents cannot be recognized.

The time distribution of seismic events recorded by NIE during one year after the main earthquake is presented in Fig. 3. Out of 270 events, 44% occurred within 24 hours after the strongest one. Every aftershock of magnitude ML > 2.5 were followed by increased seismic activity and were recorded by a sufficient number of stations to determine the epicenter data. Seismic events of M < 2.0 were recorded only by station NIE.

Epicenters of seismic events determined after records of the nearest stations in the Czech Republic, Poland and Slovakia, are presented in Fig. 4. A dispersion of epicenters seems to be caused by location errors that reach up to 10 km for weakest events. Errors of epicentral location for the main event reach ± 7 km in latitude and ± 5 km in longitude. Only two events, on February 18 of M = 2.7 and M = 2.5, originated from another source about 7 km west from the epicenter of the main November 30, 2004 earthquake. Single seismic events of M < 2.0, recorded only by NIE station with time differences $\Delta t$(Sg-Pg) > 5s, might originate in the same area.

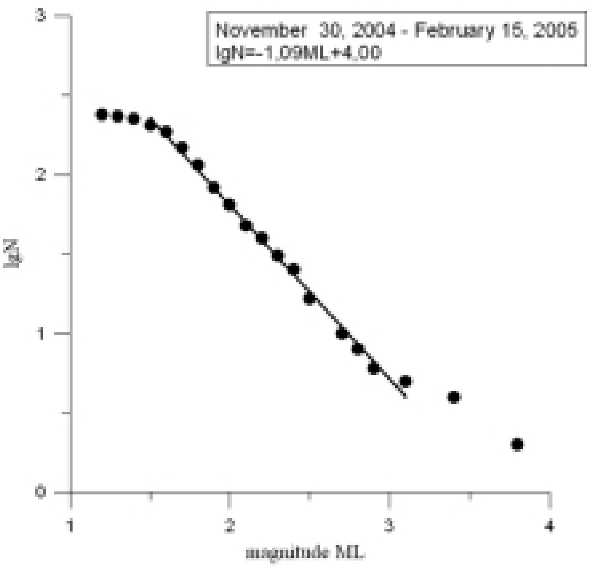


**Fig. 2** Cummulative number of earthquakes recorded between November 30, 2004 and February 15, 2005 by station Niedzica (NIE). ML – local magnitude after station NIE.

Arrival time differences $\Delta t$ (Sg-Pg) recorded by NIE for all local events from November 2004 to December 2005 are given in Fig. 5.

### 3. MACROSEISMIC STUDIES

Macroseismic data were collected by visiting the area and interviewing people immediately after the main earthquake, and later after the strongest aftershocks. Village administrators were interviewed and they made general remarks on how the events were felt. Macroseismic questionnaires were put in

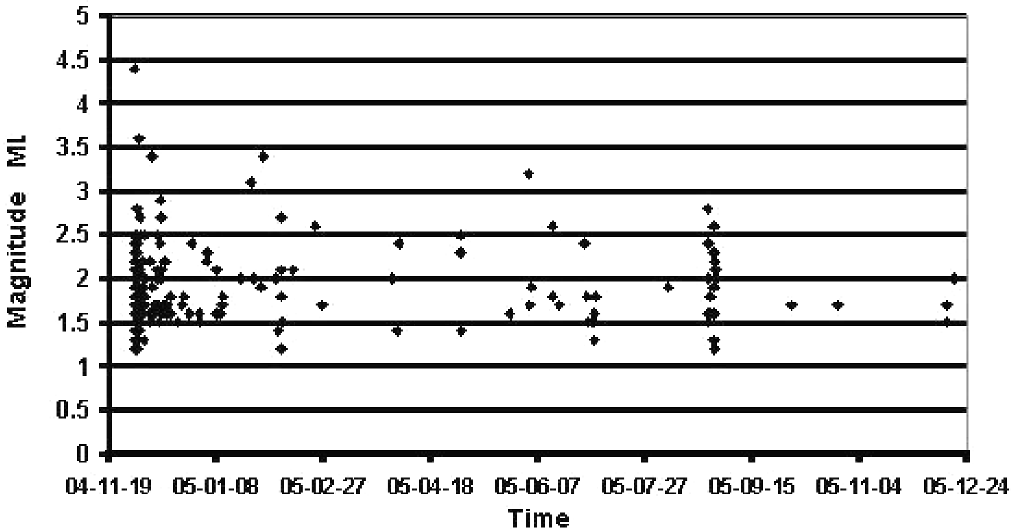


**Fig. 3** Time distribution of seismic events after the main earthquake of November 30, 2004 recorded by station Niedzica during one year.

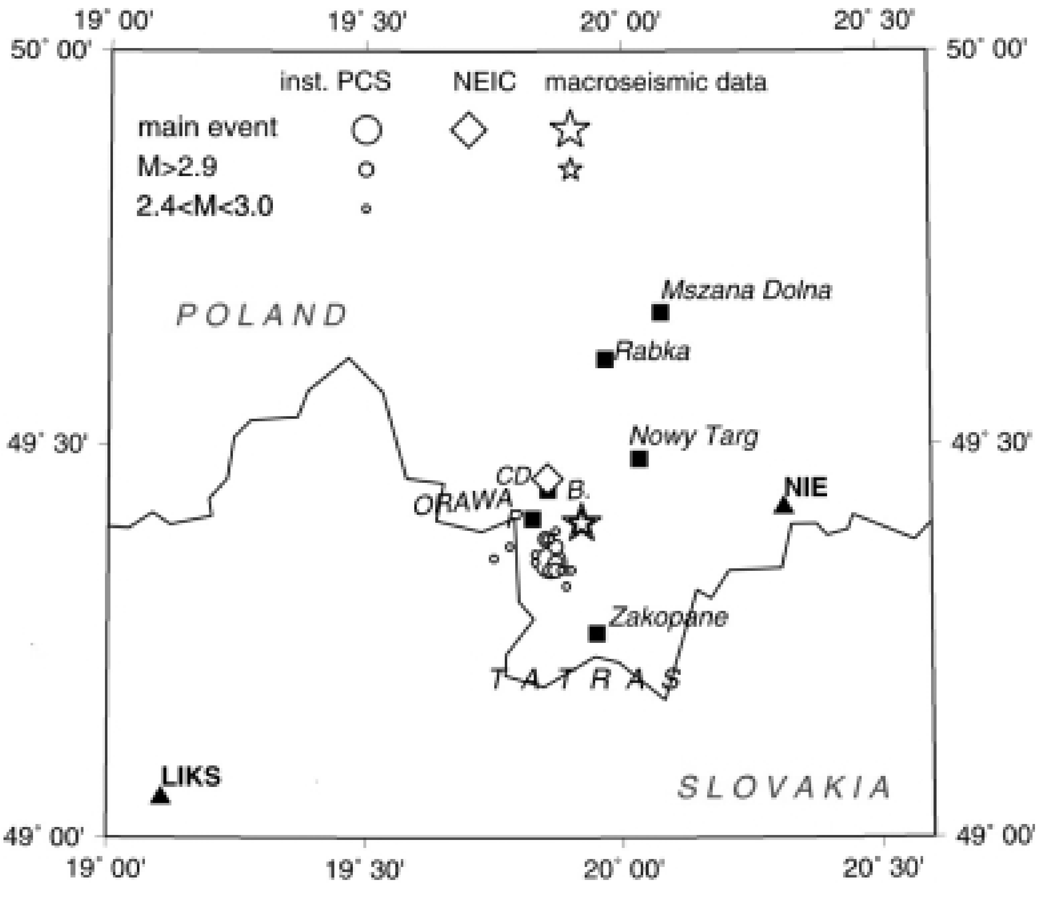


**Fig. 4** Location of seismic events with magnitude M > 2.4 after records of Polish, Czech, and Slovakian stations (Inst. PCS). NEIC and macroseismic epicenters are also given. NIE, LIKS - seismic stations, CD – Czarny Dunajec, P – Podczerwone, ORAWA B. – Orawa Basin.

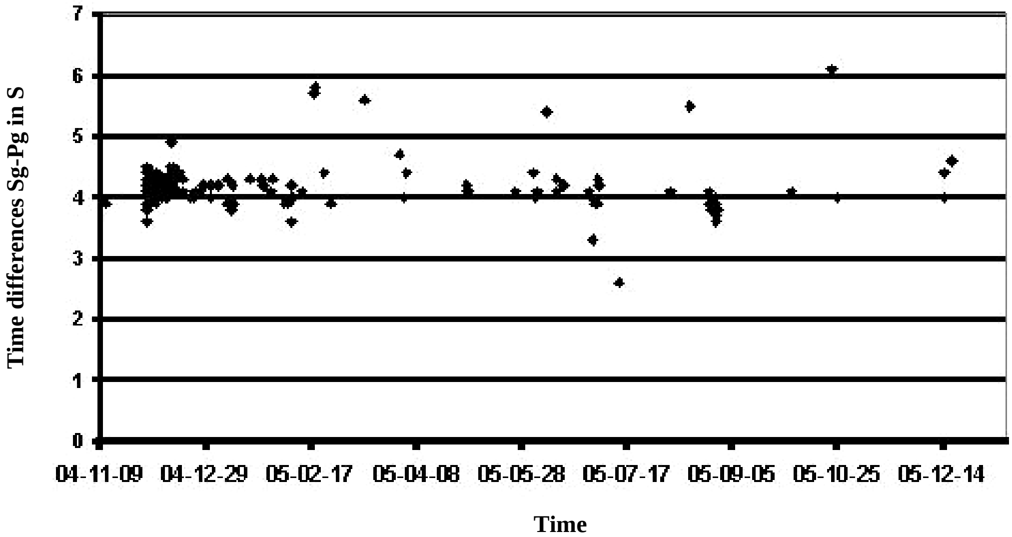


**Fig. 5** Time differences Sg-Pg for all local events recorded by station Niedzica since November, 2004 to December, 2005.

local newspapers and on internet but the feedback was poor. Additionally, questionnaires were sent to local authorities over a wide region in southern Poland where felt intensities of about 3 might be expected. Responses, mostly negative, arrived from 55 localities. Thus, negative responses delineated the perceptibility area of the earthquake.

Assessment of macroseismic intensities have been made in the MSK-64 (MSK) scale and EMS-98 (EMS) scale to enable data comparisons for historical earthquakes published during last 40 years in the MSK scale, for example by Procházková (1990) for Europe; by Pagaczewski (1972), and Guterch and Lewandowska-Marciniak (2002) for Poland. Damage to houses was most unusual although buildings in this region are generally of vulnerability class B-D in the EMS scale. Formerly, mainly one-storied wooden buildings were the norm in this region. The earthquake resistance of such timber buildings is high and the vulnerability class D in the EMS scale is most likely. Earthquakes of intensities I < 8 should not damage such buildings. Since 1950-60's two or even three stories houses have been built from unreinforced bricks and air bricks with reinforced concrete floors. The vulnerability class of such masonry buildings is most likely B-C (Grünthal, 1998).

### *3.1. NOVEMBER 30, 2004, MAIN EARTHQUAKE*

The main earthquake on November 30, 2004 occurred two hours after sunset, at 18:18 local time, when most people were indoors. Macroseismic intensities of the earthquake were the highest in the SE area of Czarny Dunajec bounded by villages: Bystre Stare Górne, Czerwienne, Ratułów, Sierockie, Skrzypne Dolne, Skrzypne Górne, Ciche Dolne, and Ciche Górne. Geographical coordinates of these villages are given in Table I. People indoors were frightened. Many panicked and ran outdoors. Nearly all the inhabitants at least went outside to find out what had happened. Electricity went off in many places. Everyone outdoors felt the earthquake. Some people even saw the ground moving and kept balance with difficulty. Strong shaking of whole buildings was felt. Wooden houses rocked and creaked. People were frightened that their dwellings would collapse. Others noticed that wooden houses slightly creaked the whole night after the earthquake. A man felt the earthquake when driving a car at approximately 60 km/hour in Bystre Stare Górne. Stopping the car he noticed sparks from electricity cables and that electric pylons were rocking. Sparks around electricity cables were reported also at Ciche. Water disappeared in many wells and surface sources mainly at Czerwienne and Skrzypne even if there were 5 meters of water before the earthquake. Although water slowly returned over 3 months, many people had to drill another well.

Most houses in the aftermentioned villages sustained damage of grade 1 and many of grades 2 in the EMS scale. Slight thin cracks in plaster inside and outside the houses commonly occurred. Chimneys were partly damaged in many houses i.e., twisted and/or cracked above or below the roof, top pieces fell down. Exceptionally, a whole chimney came down. A few buildings sustained moderate structural damage of grade 2-3. Such damage occurred to the church at Miętustwo and to two nearby buildings both of vulnerability class A. Playing music and singing in the church were forbidden for safety reasons. At a school of vulnerability class B-C at Skrzypne, two inside structural walls and a corner of the building had to be immediately pulled down and rebuilt. Examples of damage are presented in Figs. 6, 7, 8.

Intensities in this area exceeded 6 EMS, but intensity 7 EMS could not be evaluated for the whole village. Therefore, intensity 6-7 in EMS scale, but 7 in MSK scale, was assessed at Skrzypne, and similarly at

**Table 1** Evaluated macroseismic intensities in the epicentral area for the main earthquake on November 30, 2004 and the strongest aftershocks.

| Locality | Latitude | Longitude | Main event, Nov 30,2004 | | Aftershocks | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Year 2004 | | Year 2005 | | |
| | | | | | Dec 02 | Dec 09 | Jan 23 | Jan 29 | Jun 02 |
| | | | I (MSK) | I (EMS) | I (EMS) | I (EMS) | I (EMS) | I (EMS) | I (EMS) |
| Bańska Niżna | 49º24.7' | 20º00.7' | 6 | 6 | | | 3-4 | 4 | |
| Bustryk | 49º21.5' | 19º58.2' | 6 | 6 | 4 | 5 | | | 4-5 |
| Bystre Stare Dln | 49º26.0' | 19º55.2' | 6 | 6 | | 5 | 4-5 | 4-5 | |
| Bystre Stare Grn | 49º25.0' | 19º54.8' | 6.5 | 6-7 | 5 | 4-5 | | | 4 |
| Ciche Dolne (II) | 49º23.5' | 19º52.2' | 7 | 6-7 | 5 | | | | |
| Ciche Dolne (I) | 49º24.2' | 19º52.2' | 6.5 | 6 | 5 | 4 | 3-4 | 4 | 4-5 |
| Ciche Górne (I) | 49º23.0' | 19º51.2' | 6.5 | 6 | 5 | | | 4 | |
| Ciche Górne (II) | 49º21.8' | 19º51.4' | 6 | 6 | | 4 | | | 3-4 |
| Czarny Dunajec | 49º26.5' | 19º51.3' | 6 | 6 | 4 | 3-4 | 4-5 | | |
| Czerwienne | 49º23.0' | 19º55.0' | 6.5 | 6-7 | | | | 4-5 | 4-5 |
| Czerwienne II | 49º21.4' | 19º56.5' | 6 | 6 | 5 | | 3 | 4 | |
| Koniówka | 49º23.8' | 19º49.7' | 6 | 6 | 4-5 | | 4 | 4 | |
| Maruszyna Dln | 49º25.1' | 19º57.5' | 6 | 6 | | | 4 | 5 | |
| Maruszyna Grn | 49º25.3' | 9º59.5' | 6 | 6 | | | 4 | 5 | 4 |
| Miętustwo | 49º23.9' | 19º52.8' | 6.5 | 6 | 4 | | | | |
| Ratułów (I) | 49º22.8' | 19º53.5' | 6.5 | 6-7 | 5 | | | | |
| Ratułów (II) | 49º21.6' | 19º54.2' | 6.5 | 6-7 | 5 | | 4 | 5 | |
| Sierockie | 49º22.6' | 19º57.7' | 6.5 | 6-7 | 4 | | 4-5 | 5 | 4 |
| Skrzypne Dln | 49º24.0' | 19º57.0' | 7 | 6-7 | | 4-5 | 3-4 | 4 | 4-5 |
| Skrzypne Grn | 49º24.0' | 19º57.7' | 7 | 6-7 | | | | 4-5 | 4-5 |

Ciche. Evaluated intensities in both scales for localities where the earthquake was felt with I ≥ 6, are given in Table 1.

Intensities were strongly attenuated with distance and the earthquake was usually not felt 50 km from the epicenter. Only in cities such as Kraków, Zabrze, and Racibórz the earthquake was felt by individuals on high floors, especially strongly if the building was located on poorly consolidated grounds or there was a high level of underground water. The macroseismic map in EMS scale of the main earthquake is presented in Fig. 9. Data from Slovakia are not yet available.

### *3.2. AFTERSHOCKS*

It was more difficult to collect macroseismic data for aftershocks even for the strongest ones. People had in mind what they experienced during the main earthquake and discounted their observations. Any new damage to houses was not confirmed. Many cracks in plaster and even slight cracks in walls or foundations were found much later and it was impossible to establish when damage happened.

The strongest aftershock, on December 02, 2005, occurred at 19:25 local time when individuals were outdoors. There are few reports that it was felt outside. Some people were frightened. Others felt slight shaking of a whole house or wanted to run outside. Some noticed small objects moving. The shaking was comparable to that on September 11, 1995 (Guterch et al., 2005). In epicentral area intensity exceeded 5 and was assessed I = 5.5 MSK, but I = 5 EMS.

Other aftershocks of ML > 3.0 were felt with maximum intensity I = 5. The area where the aftershocks were most strongly felt is the same as for the main earthquake. Assessed intensities in the EMS scale for events of ML > 3 are given in Table II. An example of macroseismic map for the aftershock on December 02, 2004 is presented in Fig. 10. Two night events of magnitude ML = 2.8 on December 01, 2004 at 23:25 and 23:50 GMT were felt by people resting. Those who slept were not wakened. The highest assessed intensities were I = 4 EMS.

### *3.3. MACROSEISMIC PARAMETERS*

Macroseismic epicenters have been determined in the centre of maximum felt intensities. Macroseismic epicenters are the same

$$\varphi = 49°24'N, \lambda = 19°55'E$$

for the main earthquake and aftershocks. Errors of macroseismic location reach ± 2 km. The epicenter intensities $I_o$ were accepted as maximum felt intensities. They have been assessed in both MSK and EMS scales.

Focal depths were determined using the Kövesligethy formula for the main earthquake and the strongest aftershock on December 2, 2004.

**Fig. 6** Chimney debris at Ciche.

**Fig. 7** Displaced voult above the church door at Miętustwo.

**Fig. 8** Structural damage to a house at Ratułów.

$$I_o - I_n = 3\log(D_n/h) + 3\lambda(D_n - h)\log e\,,\ D_n^2 = h^2 + r_n^2$$

where $I_o$ – maximum intensity, $I_n$ - intensity of degree n, λ - attenuation coefficient, $r_n$ - radius of intensity $I_n$.

The best agreement of data was found assuming attenuation coefficient λ = 0.025. Determined focal depth is h = 3±1km for both events. Similar general pattern of all macroseismic maps allow to accept h = 3-5km for other felt aftershocks.

Macroseismic magnitudes were calculated using the Karnik´s formula for the Western Carpathians: $M = 0.55I_o + 0.93\log h + 0.14$. There is good agreement of instrumental magnitudes recorded by station NIE and macroseismic magnitudes calculated using the Karnik´s formula-confirming values of determined focal depths. Macroseismic parameters and magnitudes ML(NIE), ML(OJC) are given in Table 2.

## 4. DISCUSSION AND RESULTS

The series of earthquakes that began on November 30, 2004 occurred in the southern margin of the ONT Basin, a few kilometers east from the area, where the PKB is expected to be crossed by the Ružemberok-Mszana Dolna fault. This deep fault of NE-SW direction, known from geological data, at the section Podczerwone-Mszana Dolna was confirmed by magnetotelluric studies as the western border of the crystalline basement depression Nowy Targ–Krynica (Żytko, 1999). This fault is supposed to be the western

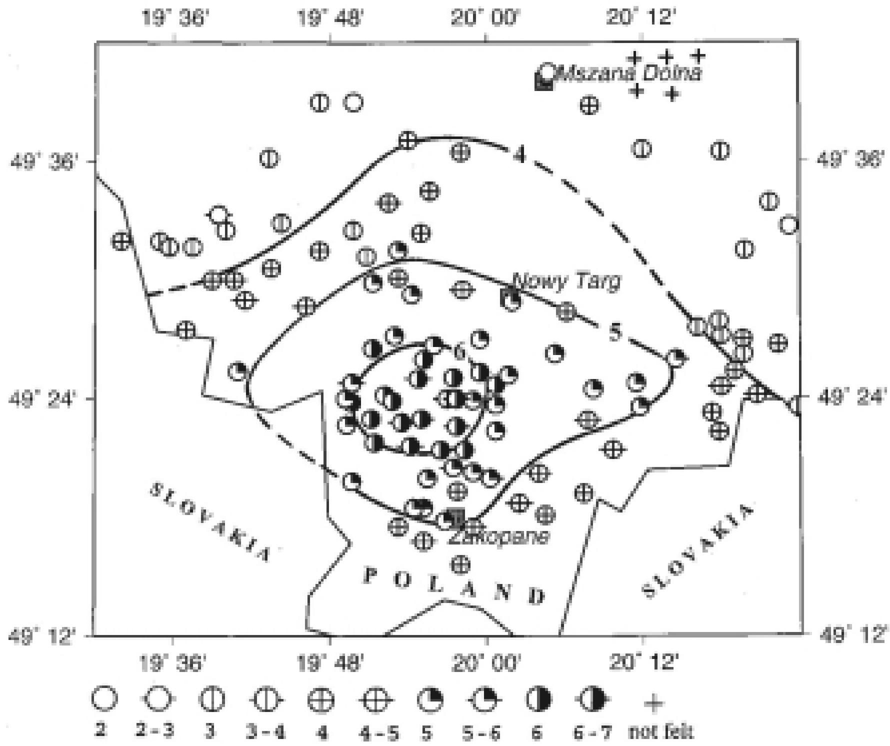


**Fig. 9** Macroseismic map in the EMS scale of the main earthquake on November 30, 2004.

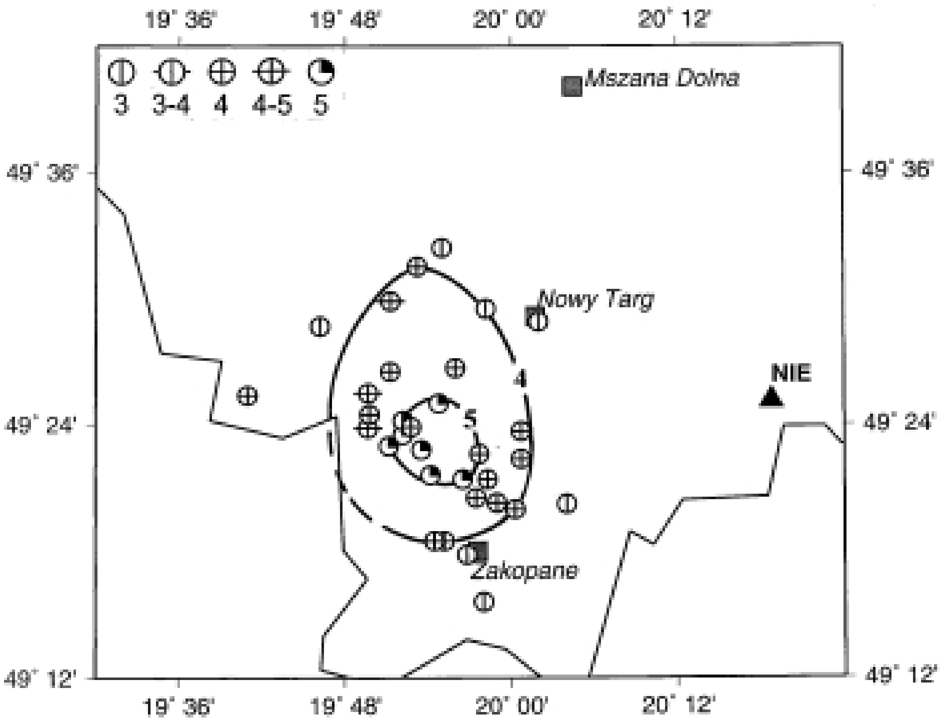


**Fig. 10** Macroseismic map in the EMS scale of the aftershock on December 02, 2004, at 18:25.

**Table 2** Macroseismic parameters of the earthquakes in the Orawa-Nowy Targ Basin, (φ = 49°24'N, λ = 19°55'E), MM – macroseismic magnitude.

| Date | Time | Epicentral Intensity $I_o$ | | Focal depth | Magnitude | | |
|---|---|---|---|---|---|---|---|
| | | MSK | EMS | (km) | MM | ML (NIE) | ML (OJC) |
| 2004 11 30 | 17: 18: 37 | 7 | 7 | 3 ± 1 | 4.4 | | 4.3 |
| 12 01 | 23: 25: 14 | 4 | 4 | 3-5 | 2.9 | 2.8 | 2.7 |
| 12 01 | 23: 50: 14 | 4 | 4 | 3-5 | 2.9 | 2.8 | 2.6 |
| 12 02 | 18: 25: 38 | 5.5 | 5 | 3 ± 1 | 3.6 | 3.6 | 3.5 |
| 12 09 | 01: 09: 04 | 5 | 5 | 3-5 | 3.4 | 3.4 | 3.2 |
| 2005 01 23 | 23: 33: 19 | 4.5 | 4-5 | 3-5 | 3.2 | 3.1 | 2.9 |
| 01 29 | 17: 16: 54 | 5 | 5 | 3-5 | 3.4 | 3.4 | 3.4 |
| 02 07 | 06: 08: 40 | 3.5 | 3 | 3-5 | 2.6 | 2.7 | 2.6 |
| 06 02 | 07: 43: 27 | 5 | 5 | 3-5 | 3.4 | 3.2 | 3.1 |

boundary of the High Tatra Massif (IBID). Crossing areas of tectonic faults are usually supposed to be seismogenic and, even if earthquakes are unrecognized, the possibility of their occurrence should be considered in the seismic hazard assessment.

Pomianowski (1997, 2003), studying the tectonics of the area, confirmed the ONT Basin is cut into blocks by faults further distinguishing two major fault systems: normal faults parallel or sub parallel to the PKB; and strike-slip faults mainly of NNW-SSE direction and some of NE-SW direction cutting and displacing normal faults.

A series of seismic events on September 11, 1995 originated in the same area of the southern margin of the ONT Basin, a few kilometers west of the one on November 30, 2004 (Guterch et al., 2005). Isoseismals and areas of maximum felt intensities corresponding to macroseismic epicenters for the main earthquakes recorded in year 1995 and 2004 are presented in Fig. 11.

Macroseismic as well as instrumental data confirm that the main set of seismic events in years 2004-2005 occurred in the same epicentral area. The foci of earthquakes are shallow, less than 5 km. It means that the events originated in the Podhale Flysch basement of the ONT Basin. However, possible movement of the focus cannot be established since location errors are too high. Errors of instrumentally determined epicenter reach ± 7 km in latitude and ± 5 km in longitude for the main event but they are higher for all other weaker events. Macroseismic epicenter seems the best as it was made by locally collected data but its error also can reach ± 2 km. At least two other events, on February 18, 2005 of M = 2.7 and M = 2.5, originated in another area about 7 km west of the November 30, 2004 main earthquake. Without an array of seismic stations located in the ONT Basin better locations cannot be expected, especially that event are weak mostly of M << 3.0 (see Fig. 2).

Tectonic activity since Middle Miocene to Quaternary at the southern margin of the Orawa Depression, just in the epicentral area of the November 30, 2004 earthquake, was confirmed by studies of fractured clasts initiated by Tokarski and Zuchiewicz (1998). Vertical or subvertical fractures, strike mainly NNE-SSW to NE-SW are evidence of the strike-slip faults expected in this area, were formed due to the maximum principal stress ($\sigma_1$) horizontaly oriented, approximately NNE to NE (Tokarski and Zuchiewicz, 1998). Of special interest, it would be the clasts with fractures striking subparallel to normal faults bordering the ONT Basin (Tokarski and Zuchiewicz, 1998). Normal faults imply that the tensional stress field regime lasted there untill Quaternary and was at least locally replaced by a single compression episode (Zuchiewicz et al., 2002).

The normal fault mechanism of the main November 30, 2004 earthquake implies NNW oriented maximum extension. Taking into account the most probable strike and dip angles of the ONT faults, nodal plane 1 after ETHZ data would be suggested as the fault plane i.e.: strike = 246°, rake = -80°, dip = 66°. Suspected subsidence being the result of tensional forces, that caused the main earthquake of November 30, 2004 in southern margin of the ONT Basin, could be confirmed by gravimetric and geodetic studies in process in this region by Łój et al. (2006). The tectonic stress pattern of the Outer Carpathians resulting from north-northeast advance of the ALCAPA units against the European Plate would suggest NNW oriented compression in the Carpathians autochthonous basement and NNE oriented thin-skinned compression (Jarosiński, 1997).

The ongoing tectonic process in the ONT Basin along the PKB cannot be well recognized without an array of seismic stations located in and around this seismically active area. Such an array would record microshocks of M << 1 and provide, not only data for accurate earthquake locations, but the style and orientation of deformation in foci and seismic hazard assessment of the region.

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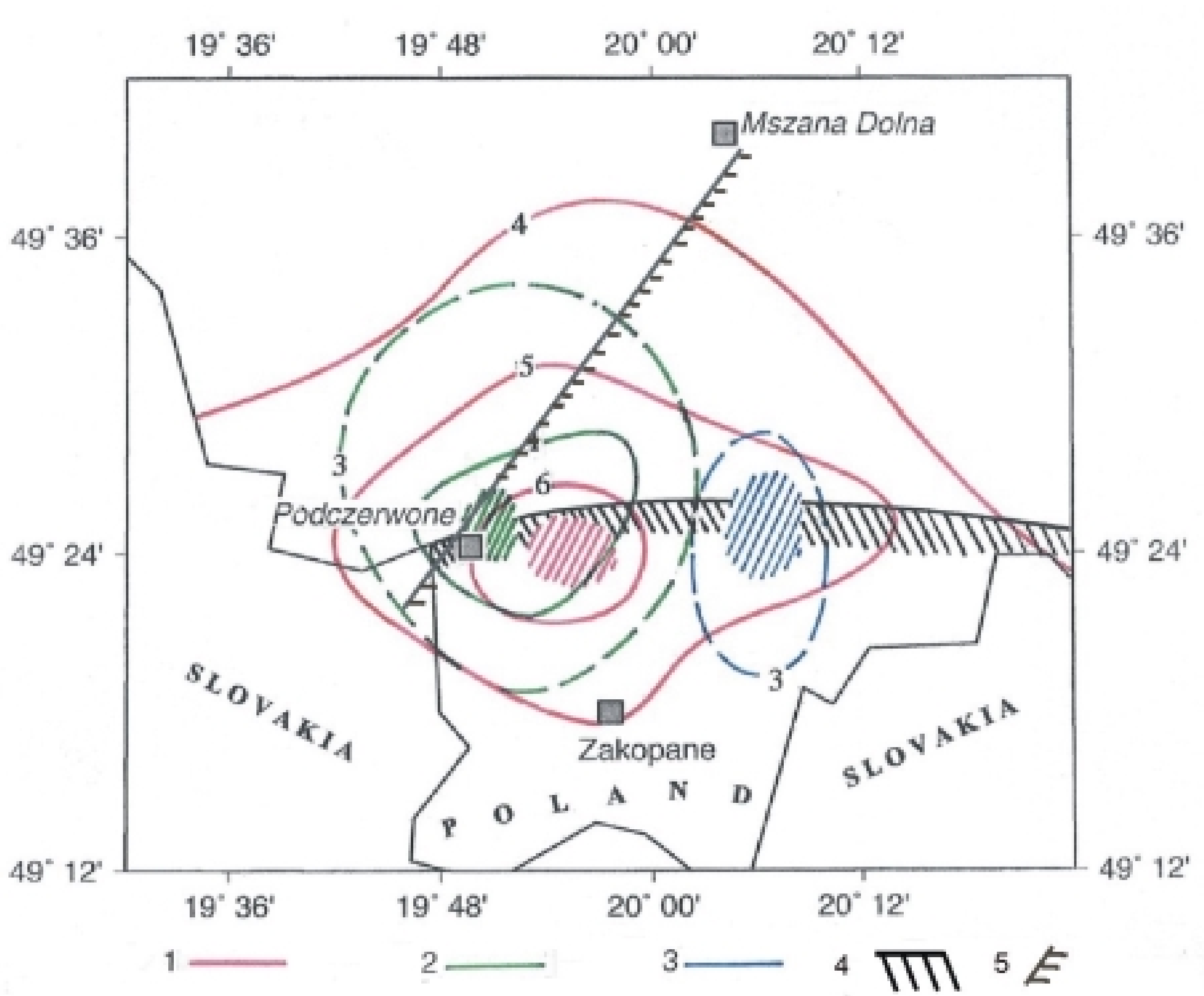


**Fig. 11** Isoseismals and areas of maximum felt intensities for the main earthquakes recorded in year 2004 and 1995.

1 - November 30, 2004, Imax ≥ 6
2 - September 11, 1995, Imax = 5
3 - October 13, 1995, Imax = 4
4 - Pieniny Klippen Belt
5 - Ružemberok-Mszana Dolna fault marked after Żytko (1999)