Proceedings, 11th FIG Symposium on Deformation Measurements, Santorini, Greece, 2003.

NATURAL TECTONIC HAZARD FOR WATER DAMS SYSTEM IN THE SUDETES AND FORE-SUDETIC BLOCK*

Bernard Kontny, Stanisław Dyjor, Stefan Cacoń

Department of Geodesy and Photogrammetry
Agricultural University of Wroclaw

Abstract

Lower Silesia was broken into numerous tectonic blocks, graben and horsts during late Alpine orogeny. These movements were at its peak in the Neogene. Througout the Quaternary till present times this activity wakened, nevertheless their existence is still felt as local earthquakes. The area of SW Poland is characterised by dense settlement and development resulting from favourable climatic and soil conditions and abundant mineral resources. Numerous engineering objects: water dams, mines, city agglomerations have been built. Some of water dams have been located in tectonic zones, whose activity was confirmed by geological studies. This creates possible threat for people living there. Within successive projects a geodetic monitoring system, based on satellite GPS, geodetic, gravimetric and relative (feeler gauge) observations, in "geodynamic profiles" connected by means of GPS network, has been developed. Multiple measurements indicate differentiated crustal movements in the investigated area, particularly in young tectonic graben. Analysis of changes determined from geodetic observations will help selecting dams and water reservoirs with potentially greatest degree of hazard.

1. Introduction

The southern and central parts of Lower Silesia are potentially threatened by present-day surface movements and shocks connected with them. These arise from numerous tectonic zones of Neogene origin, whose activity has been observed till present times. Many regional faults break old crystalline structures of the Sudety Mts. and Fore-Sudetic Block into separate tectonic blocks and horst and graben zones associated with them. Development of these structures culminated in Miocene and Pliocene times with intensity diminishing in the Quaternary *(Dyjor, 1976; 1983; 1993; 1995)*.

Historical records reveal many descriptions of seismic events that were felt in Lower Silesia, region with the greatest number of registered earth tremors in Poland. These were compiled by Olczak *(1962),* Pagaczewski *(1972),* Guterch & Lewandowska *(2002),* Mortimer *(2002),* Schenk et al. *(2001)* and Zwolinski *(2002).*

The Fore-Sudetic Block and partially Sudetes have good climatic and soil conditions and are rich in mineral deposits favouring settlement development. As a result industrial, mining and civil infrastructure has been developed. Numerous water dams have been constructed, often in or close to active tectonic structures.

The issue of neotectonic and present-day crustal movements and the threats arising for infrastructure in Lower Silesia did not get much attention until the 70'ties of the 20th century. This was connected with the assumption that Poland and Lower Silesia lie in an aseismic zone.

Thus probable natural hazards were not taken into consideration during design and operation of water dams system and other engineering objects.
The first publications devoted to these problems in Lower Silesia were written by Dyjor *(1976, 1983, 1993),* Dyjor and Oberc *(1983),* Dyjor et al. *(1978),* Cacoń *(1986, 1994),* Cacoń and Dyjor *(1993, 1995, 2002)*. The subject was widely discussed during successive symposiums on "Present-day and neotectonic earth crust movements in Poland" that were held in Warsaw and Wrocław between 1975 and 1981. The topic was continued in the Cracow circles with conferences on "Neotectonics of Poland, Recent Advances" organised from 1993 to 2002.
Regular geodetic observations of present-day crustal movements in Lower Silesia have been started by S. Cacoń, from the Department of Geodesy and Photogrammetry at Agricultural University of Wrocław, in the 1980-ties *(Cacoń, 1986; 1994; Cacoń and Kontny, 1993; 1994, Cacoń et al., 1998)*. Investigations covered selected tectonic structures in the Fore-Sudetic Block and Sudetes. Cooperation with interested academic centres in Czech Republic has been established and joint research activities started. Results have been discussed in Czech-Polish Workshops "On recent geodynamics of the Sudety Mts. and adjacent areas" taking place regularly since 1998 *(Schenk et al., 1999, 2000, 2001, 2002)*. Geodynamic profiles have been designed and established across the most active tectonic faults zones within the frames of successive research projects *(Cacoń and Dyjor, 1999; 2000)*. GPS, geodetic, gravimetric and relative observations carried out on these profiles, since the early 1990-ties, provide grounds for assessment of tectonic hazards for engineering objects in the region *(Cacoń, Dyjor 1995).*

2. Location of water dams relative to active tectonic structures

In the middle and western part of Lower Silesia a lot of water dams characterized by varying degree of hazard from tectonic faults were constructed (Fig. 1). Some of them, such as those in Leśna and Gryfów on Kwisa River and Plichowice on Bóbr River, were built in zones of massive Izera gneisses. No threats by present-day tectonic movements were detected for these dams. However, water dams on Strzegomka River in Dobromierz, Nysa Szalona River in Słup and Piława River in Bielawa are located in the immediate neighbourhood of the Sudetic Marginal Fault. It is an active zone where tectonic graben of Variscan origin, filled by Rotliegendes deposits, is cut up by numerous fault zones attributed to the Sudetic Marginal Fault Zone. The Słup dam has been placed over extension of the Roztoka-Mokrzeszów tectonic graben in a zone of major fault limiting it in the North. Geotechnical conditions create additional hazard. Weathered basaltic tuffs, metamorphosed into bentonite type minerals were used for construction of the dam crest. In Bielawa, the dam is located directly on the downthrown wing of Sudetic Marginal Fault. In the eastern part of Fore-Sudetic Block, between Bardo and Nysa, next to Sudety Mts., a young zone of Paczków-Kędzierzyn graben is located (Fig. 1). Two water dams: Otmuchów and Nysa, were constructed there and two more, Topola and Kozielno, are under construction. The fifth one in Kamieniec Ząbkowicki is planned. The collected geodetic, GPS and gravimetric data indicate present-day activity of this zone. The greatest vertical displacements were detected in the Nysa dam surroundings (*Cacoń et al., 1991; Cacoń and Dyjor, 1993; Wyrzykowski, 1985*). Horizontal movements were also identified *(Cacoń et al., 1998)*.

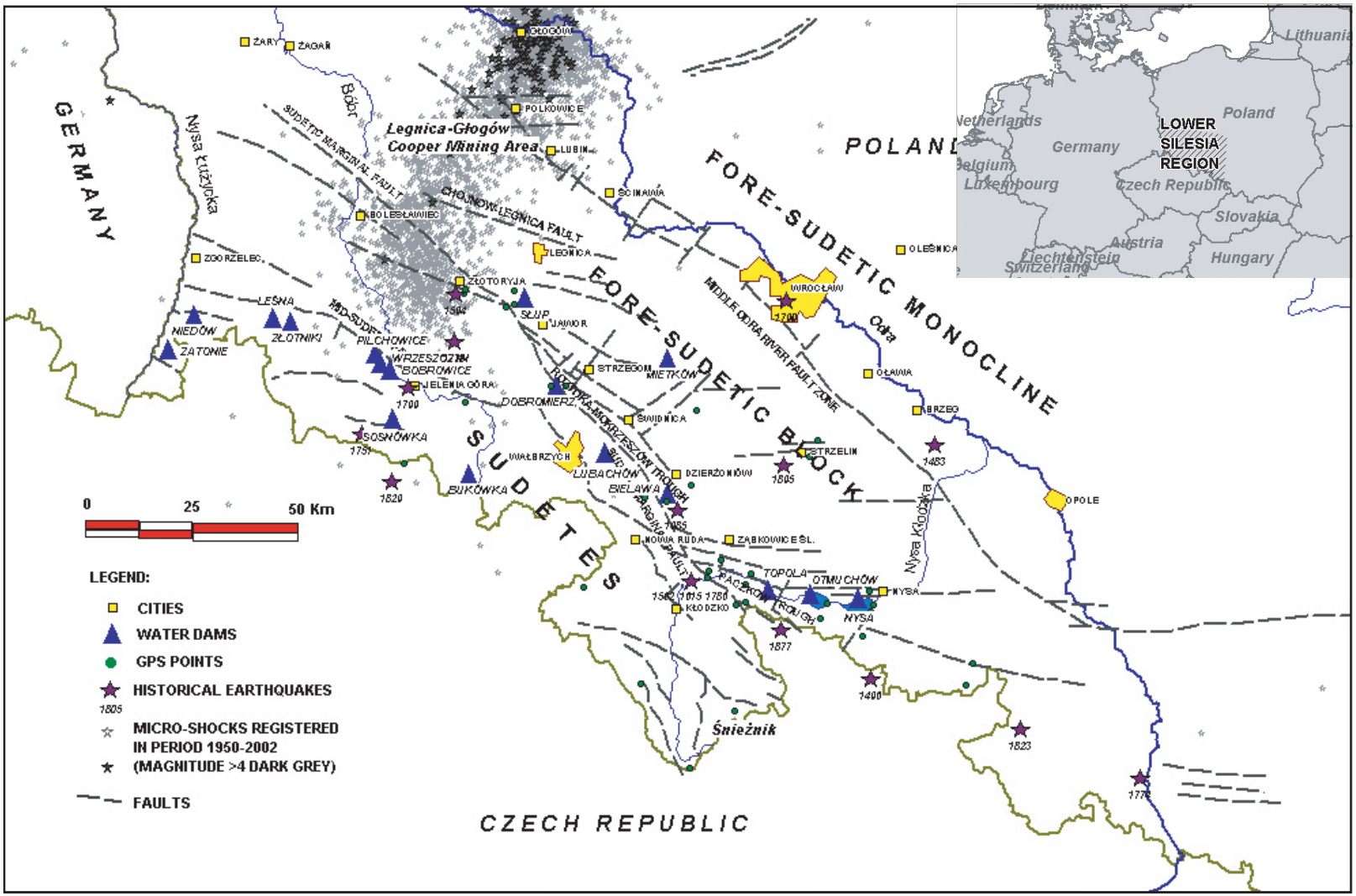

Fig. 1 The major water dams location in Lower Silesia region against a neotectonic background

3. Results of satellite GPS measurements

Local GPS research networks in Lower Silesia cover mainly its SE part, where measurements started earliest (Śnieżnik Massif – 1992, Stołowe Mountains, Paczków Graben – 1993). In the Sudetic Marginal Fault zone, GPS observations began in 1996 (S_up reservoir area) and became intensified in 2000 within GEOSUD II Project (*Cacoń and Dyjor, 2000*). Observations in the Western Sudetes (Karkonosze - *Kontny et al., 2002*) also started in 2000. GPS observations using precise dual-frequency geodetic receivers were performed in annual measurement campaigns (September). Duration of sessions ranged from several hours (local micro-networks) to 48 hours (frame network). Detailed description of measurement networks, organization of observations and data processing techniques were presented in publications by (*Cacoń et al., 1998, Bosy and Kontny, 1998 and Schenk et al. 1999; 2000; 2002*).
Basing on measurement data for selected GEOSUD network points, velocities of horizontal movement of these points relative to reference velocities defined from the closest IGS stations were calculated using BERNESE 4.2 package with ADDNEQ module and own MATLAB applications. Velocities for the 1996-2002 period are shown on Fig. 2.

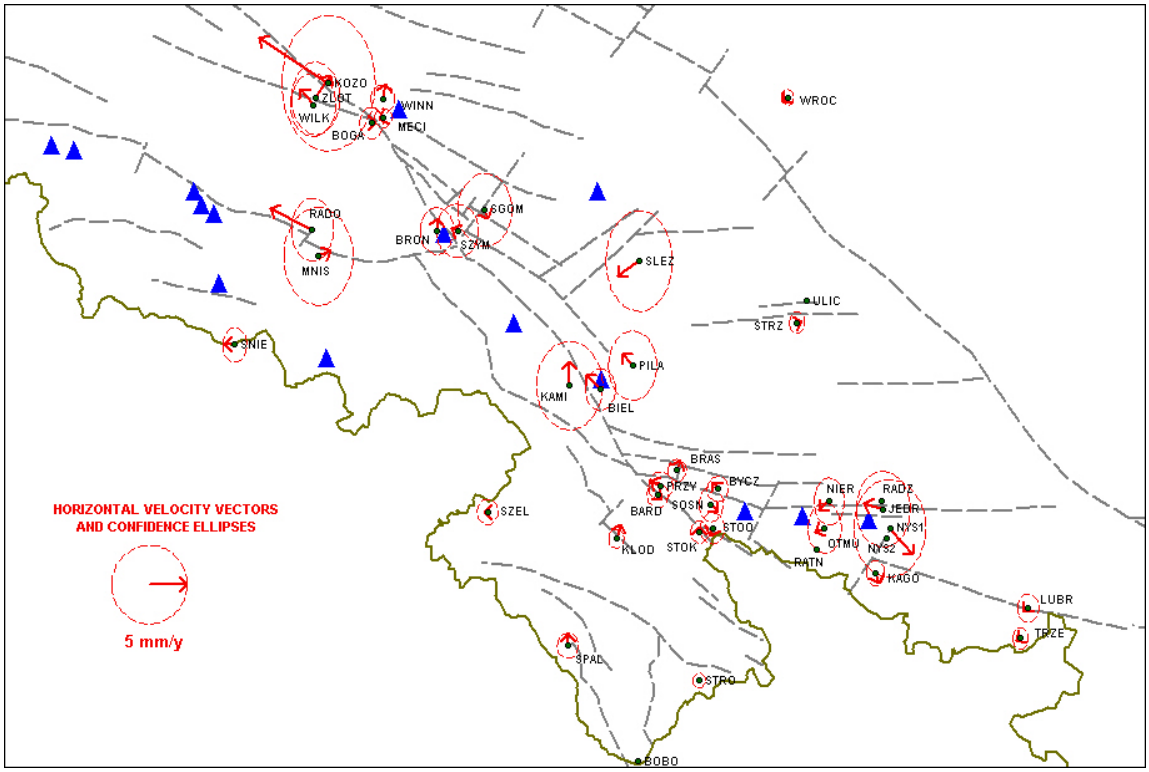

Fig. 2 Horizontal velocity vectors of GPS points for 1996-2002 period

Maximum velocities of horizontal movements, exceeding values of 5 mm/year, were estimated for points located in the north-west part of the Sudetes (KOZO, RADO) but only three years of observations (2000-2002) seems to be to short period for reliable interpretation. However, these values must be verified for possible systematic effects due to different antennas used on GPS points. Significant velocity values were also calculated for points BIEL and WINN, located near the water reservoirs and for point KLOD. The remaining points show movements within 1-2 mm/year limits, which not exceed their confidence ellipses. Considering relatively short period of observations and considerably lower accuracy of height estimation in comparison with the accuracy for horizontal coordinates, velocity of vertical movement was not calculated at this time.

4. Results of gravimetric measurements

Gravimetric measurements are carried out in accordance with principles of the control and measurement system *(Cacoń and Kontny, 1993; 1994)*. Frequency of measurements depends on periodic satellite GPS observations performed on the same research stations. Observations of gravitational acceleration with La Coste & Romberg (G model) and Scintrex CG-3M Autograv gravimeters have been carried out since 1992 (*Barlik and Cacoń, 2001*).

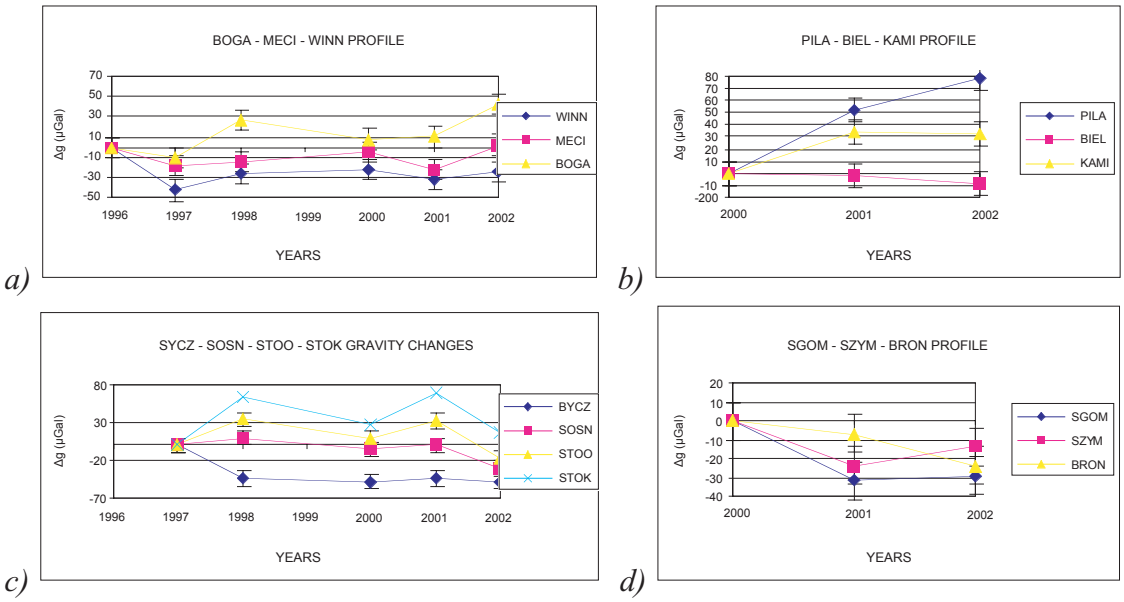

Fig. 3 Gravity changes of selected GEOSUD profiles, located near the dams:
a)Słup Dam, b) Bielawa Dam, c) Kamieniec Dam (designed), d) Dobromierz Dam

Mean error of acceleration of gravity determination (mΔg) on research points has not exceeded ± 12 μGal. Fig. 3 presents significant changes of gravity (Δg ≥ ±30 μGal) registered on research network points in the Sudetes and Fore-Sudetic Block from 1996 to 2002. These changes relate to points in the "GEOSUD II" network (*Cacoń and Dyjor 2000*) and selected, characteristic points in the "Paczków Graben" geodynamic area. Location of points, with vectors representing their horizontal velocities, is shown on the Fig. 2. Significant changes of gravity (Δg) registered between 1997 and 1998, in the "Paczków Graben" network, are connected with the catastrophic flood in Nysa Kłodzka river valley (July 1997). Significant changes of acceleration of gravity (Δg ≥ ±30 μGal) were identified for points in the Eastern and Central Sudetes. These relate to stations on both sides of the Sudetic Marginal Fault with increasing (+) and decreasing (-) trends of gravitational acceleration. The changes are accompanied by probable vertical displacements of research points. Values of these displacements, as has been mentioned in section 3, cannot be determined by GPS technique. It should be noted that significant changes of gravity do not correspond with the greatest horizontal movements of research points. Analyses of past records from repeated measurements of national levelling lines across main faults in the Sudetes and Fore-Sudetic Block are planned.

5. Summary

Natural hazards for engineering objects known in the world arise, primarily, from present-day tectonic movements and the resulting earthquakes. In Poland these hazards are not significant but nevertheless they still exist. Preliminary results of present-day crustal movements in Lower Silesia (Sudetes and Sudetic Foreland), using epoch GPS observations, indicate heterogenous, local movements with mean velocities of 1 to 2 mm/year. The Sudetic Marginal Fault zone near

Bielawa and Złotoryja end the estern part of Paczków Graben, appear to be the most tectonically active, in view of GPS, gravimetric and levelling measurements. Water dams and reservoirs located in active tectonic zones are the most threatened, and should be controlled not only for engineering purposes (obligatory deformation measurements) but also from the point of view of long term dynamics of geological and tectonic conditions.

Acknowledgments

The work has been supported by the Polish State Committee for Scientific Research (KBN): project No 9T12E02918 *"The mobility of the main tectonic zones in the Polish Sudetes and the Fore-Sudetic Block – GEOSUD II Project*

References

Barlik, M, Cacoń, S. (2001), Gravity variations monitoring in the Polish part of Eastern Sudety Mts. and Sudetian foreland in period 1992-2000; *Reports on Geodesy* No. 2(57), 2001, Warsaw University of Technology, Institute of Geodesy and Geodetic Astronomy, pp. 115-124;

Bosy J., Kontny B. (1998) Strategy of GPS data processing in local geodynamical networks, *Reports on Geodesy* No. 9(39), 1998. Warsaw University of Technology, Institute of Geodesy and Geodetic Astronomy, pp. 105-114;

Cacoń S., (1986), Analysis of geodetic dam deformation measurements in the safety evaluation accuracy aspect, *Proceeds. of 3rd Dam Monitoring Conference*, Warsaw, (in Polish);

Cacoń S., (1994), Geodynamic investigations in Sudety Mts. and Sudetic Foreland*, Sci. Papers of Agricult. Univ. of Wrocław*, 255, Conf. VII, Wrocław, pp. 151-160, (in Polish);

Cacoń S., Dyjor S. (1993), General evaluation of threats for water dams in young tectonic graben of Paczków on Eastern Sudety Mts. Foreland*, Sci. Papers of Agricult. Univ. of Wrocław*, Engineering Environment Series, V, 234, pp. 19-31, (in Polish);

Cacoń S., S. Dyjor (1995), Neotectonic And Recent Crustal movements As Potential Hazard To Water Dams In Lower Silesia, SW Poland. *Folia Quaternaria* 66, Kraków s. 59-72;

Cacoń, S., Dyjor, S. (1999). "Neotectonic and recent movements of the earth crust in Polish Part of the Sudeten and the Fore–Sudetic Block*". International Journal of Exploration Geophysics, Remote Sensing and Environment*, Vol. VI, No. 2, pp. 11–16;

Cacoń S., S. Dyjor (2000), Project Of Geodynamic Investigations Development In The Sudeten And Adjacent Areas. *Reports On Geodesy* No. 7 (53). Warsaw pp. 132-140

Cacoń S., S. Dyjor (2002), Recent Crustal Movements in Late Tertiary Tectonic Zones of the Sudetes and Northern Sudetic Foreland, SW Poland. *Folia Quaternaria* 73, Kraków, pp. 31-46;

Cacoń S., Kontny B., (1993) System of survey, analysis and interpretation of rocky block deformations in the mountain, *IAG Symposia 188 "Applications of Geodesy to Engineering*", Stuttgart, 1991, Springer-Verlag, Berlin, Heidelberg, New York, 1993 pp. 157-165;

Cacoń S., Kontny B. (1994), Measurement and monitoring system for deformation investigation of lithosphere of natural and engineering objects in Sudety Mountains, Proceed. of. *1st Turkish Int. Symp. on Deformations*, Istanbul, September 5-9, 1994, pp. 97-104;

Cacoń S., Kontny B., Bosy J. (1998), Recent geodynamics of Eastern Sudety Mountains and Foreland, *Reports on Geodesy* No. 9(39), Warsaw University of Technology, Institute of Geodesy and Geodetic Astronomy, pp. 115-124.

Cacoń S., Musioł P., Szuster M., (1991), The role of geodetic research in estimation of threat for hydro-engineering objects as a result of recent tectonic movements in Sudety Mts. and Fore-Sudetic Block, *Scientific Papers of Agricult. Univ. of Wrocław*, Wrocław, 210, Geodesy and Agricultural Engineering X, pp. 9-19;

Dyjor S., Oberc J., (1983), Recent earth crust movements in Poland and resulting risks for mining and engineering objects*, Proceeds. of III Nat. Symp. on Recent and neotectonic earth crust movements in Poland,* IV, Ossolineum, Wrocław, pp. 7-23, (in Polish);

Dyjor S., (1976), Late Tertiary Roztoki-Mokrzeszów tectonic graben*, Proceeds. of I Nat. Symp. on Recent and neotectonic earth crust movements in Poland,* Publ. House Wydawnictwo Geologiczne, Warsaw, pp. 135-138, (in Polish);

Dyjor S., (1983), Evolution of Tertiary graben in Central and Eastern Sudety Mts., *Proceeds. of I Nat. Symp. on Recent and neotectonic earth crust movements in Poland*, IV, Ossolineum, Wrocław, pp. 155-181, (in Polish);

Dyjor S., (1993), Stages of Neogene and Early Quaternary faulting in the Sudetes and their foreland, *Folia Quaternaria* 64, Kraków, pp. 25-41;

Dyjor S., (1995), Young Quaternary and recent crustal movements in Lower Silesia, SW Poland, *Folia Quaternaria*, 66, Kraków, pp. 51-58;

Dyjor S., (1997), Neotectonics – Map 1:100000, in: *Atlas of Lower and Opole Silesia*, ed. W. Pawlak, University of Wrocław, Lower Silesia Atlas Research Centre;

Dyjor S., Dendewicz A., Grodzicki A., Sadowska A., (1978), The Neogene and old-Pleistocene sedimentation in the Paczkow and Kedzierzyn graben zones, Southern Poland*, Geologia Sudetica* 13 (1), pp. 31-65;

Guterch B., Lewandowska-Marciniak H., (2002), Seismicity and seismic hazard in Poland, *Folia Quaternaria* 73, Kraków, 85-99;

Kontny B., J. Bosy, S. Cacoń (2000), Geodynamic GPS Network "GEOSUD" - Preliminary Results of the campaigns 1997-1999. *Reports On Geodesy* No. 7 (53). Warsaw s.43-49

Kontny B., J. Bosy, K. Mąkolski, (2002) Geodynamic GPS Network Karkonosze – Preliminary results of the campaign 2001, *Acta Montana, Ser. A, Geodynamics*, No 20, Prague, pp. 25-29;

Mortimer Z. M., (2002) Seismicity of Poland, *Folia Quaternaria*, 73, Kraków, pp. 79-84;

Olczak T., (1962), Seismic phenomena on the territory of Poland during the period 1901-1950, Acta Geophys. Polon., 10, pp. 1-9, (in Polish);

Pagaczewski J., (1972), Catalogue of earthquakes in Poland in 1000-1970 years*, Publs. Inst. Geoph. Pol. Acad*. Sc. 51, Warsaw, pp. 3-36;

Schenk V., Cacoń S., Schenkowa Z., Kontny B., Bosy B., Kottnauer P. (1999) GPS Regional Geodynamic Network SUDETEN, EGRS - *The International Journal of Exploration Geophysics, Remote Sensing and Environment of the Central Europe*, VI.2/99, pp. 28-30;

Schenk V., Cacoń S., Bosy B., Kontny B., Kottnauer P., Schenkowa Z., (2000) GPS Network SUDETEN, - preliminary results of the campaigs 1997-1999, *Reports on Geodesy*, No 7(53), 2000, pp. 25-33;

Schenk V., Schenkova Z., Kottnauer P., Guterch B., Labak P., (2001), Earthquake Hazard Maps for the Czech Republic, Poland and Slovakia, *Acta Geophysica Polonica*, Vol. XLIX, No 3, pp. 287-302;

Schenk V., Cacoń S., Bosy J., Kontny B., Kottnauer P., Schenkowa Z., (2002), The GPS Geodynamic Network East Sudeten - Five annual campaigns (1997-2000). Data processing and results, *Acta Montana, Ser. A, Geodynamics*, No 20, Prague, pp. 13-23;

Wyrzykowski T., 1985, Map of recent vertical velocities of earth crust movements in Poland 1:2 500 000, *Geological and Cartographical Institute Publishing Office*, Warsaw, (in Polish);

Zwoliński Z., (2002), *Earthquakes in Poland*, (http://main.amu.edu.pl/sgp/gw/tzpl/gwtzpl.html), (in Polish);