Polish Geological Institute Special Papers, 24 (2008): 75–82
Proceedings of the Conference “The abiotic environment – evaluation of changes and hazards – case studies”

INVESTIGATIONS OF MASS MOVEMENTS HAZARD IN THE VISTULA RIVER VALLEY

Danuta ILCEWICZ-STEFANIUK[1], Michał STEFANIUK[1]

Abstract. Steep escarpments of the Vistula River valley and its ice-marginal valley promote the development of surface mass movements. An additional catalyzing factor for landslide processes is the river dynamics, particularly during violent flood rising. Taking into account those factors, the Vistula River valley could be regarded as more or less homogeneous area endangered by landslide processes. Five zones of landslide concentration were separated along the Vistula River valley. These are: the western boundary of the Nadwiślańska Lowland, loess escarpments close to the town of Sandomierz, escarpment in Warsaw City, the Włocławek artificial lake zone and regions of Kujawy and lower Vistula River.

Key words: mass movements, landslides, Vistula River valley, inventory.

Abstrakt. Strome skarpy doliny i pradoliny Wisły sprzyjają rozwojowi powierzchniowych ruchów masowych. Dodatkowym czynnikiem katalizującym procesy osuwiskowe jest dynamika rzeki, szczególnie w okresach gwałtownych wezbrań powodziowych. Te czynniki uzasadniają wyodrębnienie doliny Wisły jako względnie jednolitego obszaru zagrożonego procesami osuwiskowymi. W dolinie Wisły wydzielono 5 rejonów koncentracji aktywnych osuwisk. Są to: zachodnia część Niziny Nadwiślańskiej, wysoczyzna lessowa okolic Sandomierza, skarpa warszawska, rejon Zalewu Włocławskiego oraz rejon Kujaw i dolnej Wisły.

S³owa kluczowe: ruchy masowe, osuwiska, dolina Wisły, inwentaryzacja.

INTRODUCTION

The landslide processes in the Vistula River valley were studied as a part of vast geological surveys including recording and cataloguing of natural geological hazard over Poland’s territory (Lemberger ed., 2005). The studies aimed at recognizing all hazards at the studied area. Because the scale of the observed phenomena was greater than it was expected, it was necessary to concentrate the investigations in selected regions and zones, which were most endangered (Ilcewicz-Stefaniuk *et al*., 2004a, b).

Steep escarpments of Vistula River valley and ice-marginal valleys promote the development of surface mass movements. An additional factor catalising landslide processes is the river dynamics, particularly during violent flood rising (Dobrowolski, 2005). In the authors’ opinion, those factors give reasons that the Vistula River valley could be regarded as a more or less homogeneous area endangered by landslide processes (Fig. 1). Eighty four landslides and other surface mass movements were recognized and catalogued in “Inventory Cards” in the Vistula River valley. Numerous small-size or less hazardous sites were also observed. (Ilcewicz-Stefaniuk *et al*., 2004a, b). However, the scale of the geodynamical processes in that area is much greater.

Detailed geodetic measurements, resistivity tomography and shallow geological drillings were made at selected landslides, which endangered the environment. The aim of those studies was to obtain input data for generating digital models of landslides and recognize them prior to routine monitoring of landslides development (Ilcewicz-Stefaniuk *et al*., 2005a).

Some subjectivism could not be avoided while evaluating the recent activity and development rate of the landslides. The movements of soil masses change in time and are hard to foresee, and therefore criteria for evaluating their activity are not precise. The landslide “freshness”, the existence or lack of veg-

[1] AGH University of Science and Technology, Department of General Geology and Environmental Protection, al. A. Mickiewicza 30, 30-059 Kraków, Poland; e-mails: d.ilcewicz@gmail.com, stefan@geolog.geol.agh.edu.pl

Fig. 1. Study area

etation, its kind and age, as well as deformations were used to assess the landslide processes.

Analysing groups of landslides with similar origin and geological and geomorphological conditions and their concentration in the Vistula River valley, the following zones of intense landslide processes were isolated:

– the western boundary of the Nadwislańska Lowland;
– loess escarpment near Sandomierz;
– the Warsaw City escarpment;
– the Włocławek artificial lake zone;
– Kujawy and the lower Vistula valley.

That division includes the most important – in the authors' opinion – factors that decide on the development of surface mass movements (i.e. occurrence of escarpments of uplands and ice-marginal valleys, river erosion *etc.*) as well as the concentration of the observed processes.

OUTLINE OF GEOMORPHOLOGY AND GEOLOGY

The springs of the Vistula River are at the foot of the Barania Góra Mt. in the Beskid Śląski Mountains. In its upper course, the Vistula River flows north between the hills of the Beskid Śląski Mountains and the Pogórze Cieszyńskie Hills. Having left the Carpathians, the river twists in front of the Carpathian overthrust, in the foreland that developed as a tectonic trough filled with Miocene sediments. The northern edge of the depression is built of Paleozoic rocks, mainly Carboniferous of the Upper Silesian Trough, and Mesozoic deposits that overly them in the eastern part (Stupnicka, 1988). Near Kraków, the Vistula breaks a distinct morphological threshold formed by outcrops of firm Jurassic rocks. A system of local tectonic trenches and horsts reach diagonally the front of the Carpathian overthrust. Near Tyniec, the Vistula River valley narrows and locally takes the form of river bluffs (e.g. so called Kraków Gate). East of Kraków, the river flows northeast along the tectonic frameworks of eastern part of the Carpathian Foredeep. The SE edge of the valley is low and flat, while the NW edge forms a distinct boundary, which separates the Nadwiślańska Lowland and the Małopolska Upland. Generally, in that region the Vistula River valley separates the Miocene Carpathian Foredeep from the Miechów Trough.

Between the towns of Sandomierz and Puławy, the Vistula crosses a distinct morphological threshold (meta-Carpathian bank), which was formed by the Holy Cross Mts. and the Roztocze range of hills. There, the river forms a narrow gorge with steep slopes covered with loess. The basement is built of Paleozoic (Holy Cross Mts.) and Mesozoic and Cenozoic rocks (the Roztocze hills and the Lublin Upland, and the Holy Cross Mts. surroundings). Down the gorge, the valley was formed in a thick cover of postglacial, moraine and fluvial sediments, which are younger and younger with the river course. From the Dęblin region, the river flows in wide ice-marginal valleys, e.g. in a part of the Toruń–Eberswald valley. North of Bydgoszcz, the Vistula breaks through a belt of young glacial uplands which altitude reach 300 m above seal level, and forms a deep valley with steep slopes (Gniew and Tczew regions).

CONDITIONS AND CHARACTERISTICS OF LANDSLIDE PROCESSES

THE NADWIŚLAŃSKA LOWLAND

The Nadwiślańska Lowland is a westernmost part of the Sandomierska Valley. It includes the wide Vistula River valley, from Kraków to Zawichost, which width ranges from 8 to 12 km. The river meanders there. The valley is filled with Quaternary fluvial deposits with several metres thickness. There are flood terrace, upper sand terrace (partly with dunes) and loess-covered terrace there. From south, ostiaries and fluviatile fans of Carpathians' rivers: Raba, Dunajec, and Wisłoka, join the Nadwiślańska Lowland. Beneath sands and muds depos-

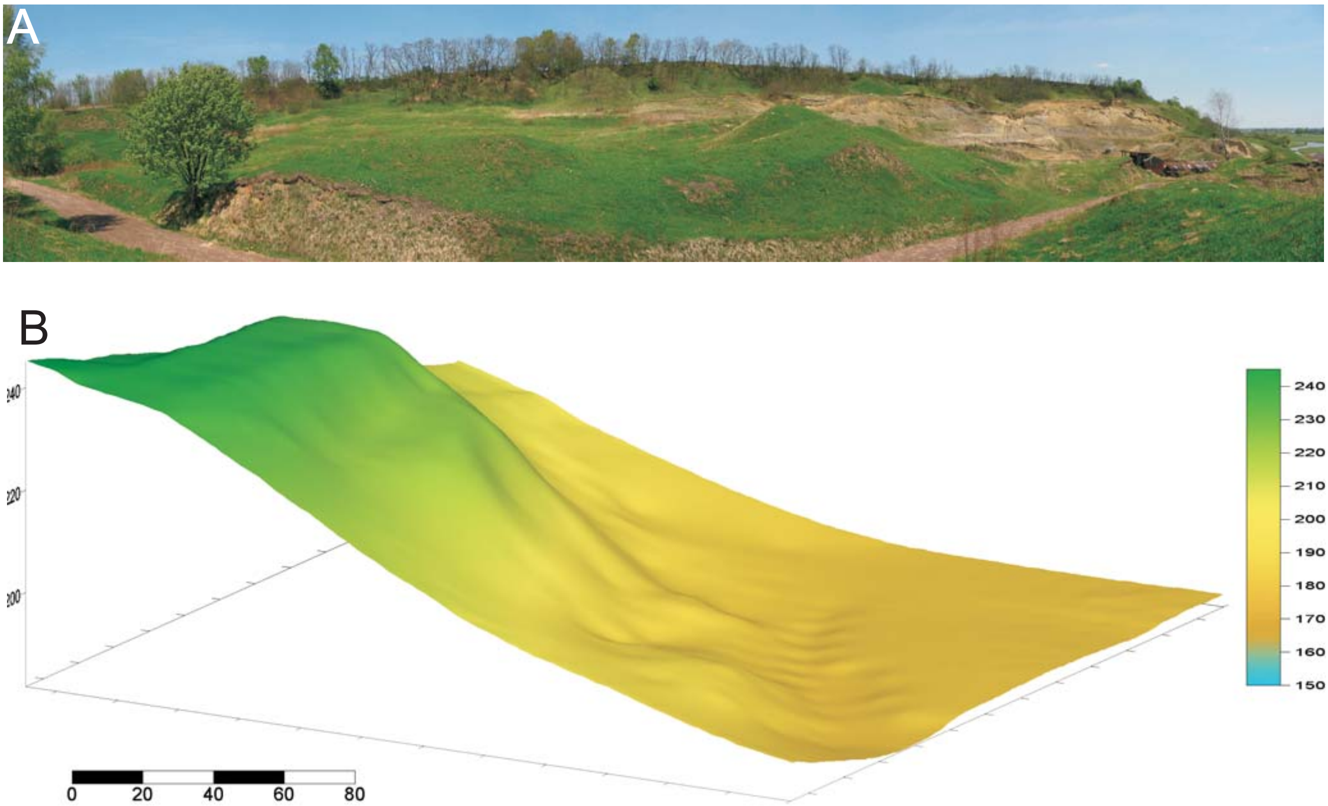

Fig. 2. Hebdów area – example of landslide in the north-west boundary the Nadwiślańska Lowland

A – general view (photo. M. Stefaniuk); **B** – model of landslide surface based on detailed topographic measurements

ited by rivers rest marine Miocene sediments. From west, the Nadwiślańska Lowland is limited by a few-dozen-meter-high erosional edge of Miocene- and loess-covered Małopolska Upland (Starkel ed., 1995).

Landslides develop at the edge of the Małopolska Upland due to favourable geological conditions there. Those include loesses resting at Miocene clays and fluvial deposits as well as meandering and undercutting escarpment the Vistula River, which is pushed aside by fluviatile fans of the Carpathians rivers (Starkel ed., 1995). In that region, near the town of Nowe Brzesko, there is a vast landslide zone extending at the left river bank, from Kraków through Hebdów to Śmiłowice and Witów. The landslides there are stable over a long-term cycle; however their activity depends on the amount of rainfalls and the water level in the Vistula River. Two big landslides were documented and catalogued there: one in Nowa Huta and the other in Hebdów (Fig. 2A, B).

THE SANDOMIERZ REGION

The landslides of the Sandomierz region were found at the Sandomierz–Opatów Highland, which is a loess upland cut by numerous erosional valleys and loess glens with high vertical or almost vertical walls. The upland is built of Quaternary loesses of *ca.* 20 m thickness, which rest at fluvioglacial and fluvial sands and clays. Abrupt landslides and soil creep dominate there as surface mass movements (Fig. 3). The activation of those processes is usually observed during thaws or long-lasting and intense rainfalls. The activity of landslides of the Sandomierz region is rather poor and small-activity landslides prevail there (Borecka, Kaczmarczyk, 2005). However, since the region is densely populated and developed, even poor and small-active mass movements make a big hazard to dwelling houses and farm buildings and infrastructure, especially roads. Plough lands and meadows are also endangered.

THE WARSAW CITY ESCARPMENT REGION

The Warsaw City escarpment is situated in the Mid-Polish glaciation recession zone during which the fundamentals of recent landscape were formed. Land forms developed mainly as a result of fluvial, glacifluvial, denudation and eolic processes. The Warsaw escarpment is a boundary between the Warsaw Plain and the Vistula River valley. The Warsaw Plain is a denuded upland of glacial accumulation of the Mid-Polish glaciation, with an altitude exceeding 100 metres above sea level, which slopes down to the Vistula River valley as a 20–30 m escarpment.

The Warsaw escarpment region has favourable conditions to mass movement development, which are caused by soaking-prone Pliocene clays. The arrangement of the Pliocene top in the escarpment affects also the character of surface mass movements there. Where the top of Pliocene clays is above the average Vistula River level and slopes towards the river, one can observe that Quaternary deposits slide down the Pliocene top surface (Wysokiński *et al.*, 1980). Intensive traffic, dam-

Fig. 3. Kamieñ Plebañski (near Sandomierz) – an example of the landslide in loess escarpment (photo: A. Kaczmarczyk)

Fig. 4. The landslide in the Warsaw escarpment (photo: A. Koryczan)

A – Żoliborz section; **B** – Mokotów section; **C** – Śródmieście section

Fig. 5. Rumunki Zachodnie – the landslide in the bank of the W³oc³awek Artificial Lake (photo: A. Koryczan)

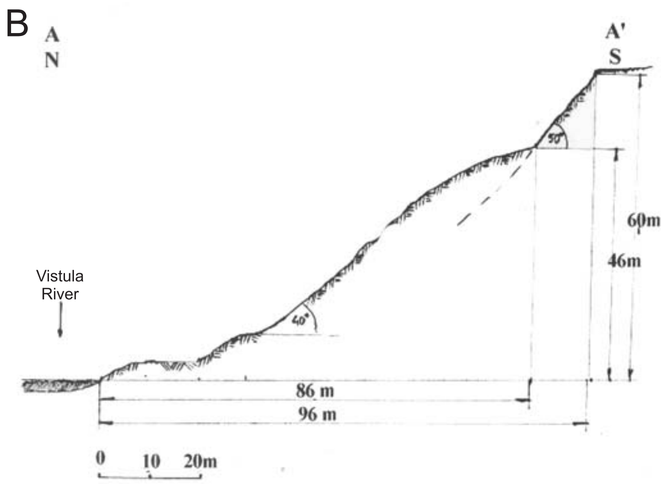

Fig. 6. Morsk – the landslide in the Kujawy region

A – general view (photo: A. Koryczan); B – schematic cross-section

ages of water-mains and other urbanization factors also endanger the stability of the Warsaw escarpment. There are landslides there, which seriously endanger the buildings and infrastructure of the city of Warsaw (Fig. 4A, B, C; Wysokiński, 1980, 1984; Koryczan, Mżyk, 2003).

THE WŁOCŁAWEK ARTIFICIAL LAKE REGION

The Włocławek artificial lake, and especially its right bank, is part of the biggest landslide zone of the Polish Lowlands, which extends between the towns of Włocławek and Płock at the Płock valley. The left slope of the Płock valley is gentle while its right edge, undercut by the Vistula River, is very steep. The difference of the altitudes of the valley bottom and the neighbouring moraine upland exceeds 50 m. The Płock valley includes a vast sandy terrace with postglacial forms and dunes at the left bank of the Vistula River, and a flood terrace, which at the late 1960s was converted into an impounding reservoir called the Włocławek artificial lake. The creation of the reservoir significantly altered the natural environment there (Banach 1977). As a result of damming up the river, about 22 km^2 of river-side area was flooded. Abrasion processes developed at the right under-washed side of the valley and gave rise to landslides (Fig. 5).

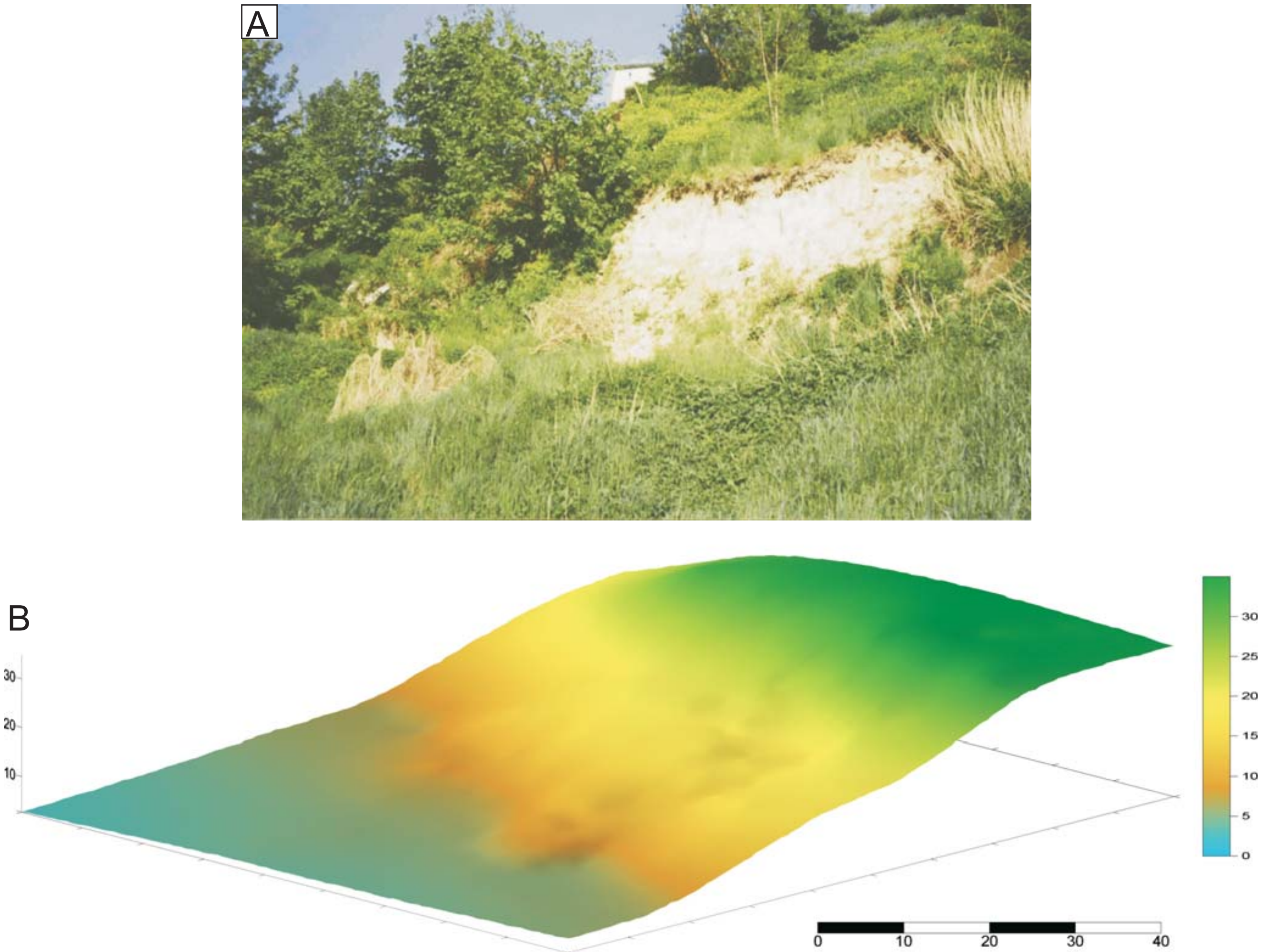

Fig. 7. Malbork – the landslide in lower Vistula region

A – landslide scarp; **B** – model of landslide surface

At the level of the lake's water-table there occur easily soaking Pliocene clays. Their top slopes towards the water table. Those factors make favorable conditions to developing dangerous and intensive landslides, whereas the lake's shore is damaged mainly by abrasion caused by strong waving (Banach, 1977). Due to specific geology, geodynamic conditions and influence of the artificial lake, that zone is considered Poland's region most endangered by surface mass movements.

THE KUJAWY AND LOWER VISTULA RIVER REGION

High slopes of the valley in the lower course of the Vistula River make favorable conditions to landslide development. The geology of the region was formed mainly by glacial and postglacial processes. The Toruń valley and the Grudziądz valley, which occupy the northern part of the region, were formed in the zones where the direction of the primary flow of the Pra-Vistula River changed from west to northwest and northeast, respectively.

Landslides develop there at 22–25 m high slopes of the Vistula ice-marginal valley and in ravines, which cut its edges (Ilcewicz-Stefaniuk *et al.*, 2005a, b, c; Koryczan, Mżyk, 2004). Their causes include lateral erosion of the Vistula River, seepage of underground water (Morsk – Fig. 6A,B) and improper draining of thaw- and rain-water from cultivated lands of the upland (Malbork – Fig. 7A, B). The landslides will further develop during intensive precipitation and high river water level.

CONCLUSIONS

All landslides in the Vistula River valley are of earth slide type and develop in Quaternary deposits (boulder-clay, sand, gravel, clay, mud). In some regions, e.g. Hebdów and Dobrzyń on the Vistula, Tertiary rocks were observed. The most frequent rocks in landslides include sands, moraine clays and gravels, and loesses in the Małopolska Upland. Almost all landslides are active, and have mostly a one-year or two-year cycle, rarely a few-year-cycle. Their activity manifests as small soil displacements, mainly during intense rainfalls and high flood rising of the Vistula River and its tributaries. The majority of the landslides there are typical landslips and falls, rarely screes. In most cases the landslides cause danger to forests, in some cases to meadows. The main reason of landslides in the mentioned regions is lateral erosion of the Vistula and its tributaries. In the Włocławek artificial lake zone, bank abrasion due to strong waves of water is also a cause.

The biggest landslide hazard in the Vistula River valley is observed at the banks of the Włocławek artificial lake, near Dobrzyń on the Vistula. There is a fast rate of the withdrawal the escarpment and the shore line undergoes frequent changes.

Landslide inventory works in the Vistula River valley included only part of landslides and therefore should be continued. Since landslide processes develop very fast, systematic observations should be carried out in addition to single recognition of the process, particularly in zones with stronger landslide activity. In zones where buildings, roads and other infrastructure objects are endangered, landslide processes should be routinely monitored by means of methods and measures that are adequately chosen to the scale and intensity of processes as well as the degree of hazard.

The paper was based on results of the project "Identifying and cataloguing natural geological hazards (especially landslides and other geodynamic phenomena) over Poland's territory", ordered by the Ministry of the Environment, and financed by the National Fund for Environmental Protection and Water Management. Results of investigations made as part of the statutory research of the Department of Basic Geology and Environmental Protection, AGH University of Science and Technology, Kraków, were also used. (project No: 11.11.140.447).

REFERENCES

BANACH M., 1977 — Rozwój osuwisk na prawym zboczu doliny Wisły między Dobrzyniem a Włocławkiem. *Pr. Geogr. IGiPZ PAN*, **124**.

BORECKA A., KACZMARCZYK R., 2005 — Powierzchniowe ruchy masowe w utworach lessowych Lubelszczyzny i w rejonie Sandomierza. *In*: Mat. Seminarium „Rejestracja i inwentaryzacja naturalnych zagrożeń geologicznych (ze szczególnym uwzględnieniem osuwisk oraz innych zjawisk geodynamicznych) na terenie całego kraju", Kraków, 23.11.2005 (ed. M. Stefaniuk): 35–36. AGH.

DOBROWOLSKI A., GŁOWACKA B., MIERKIEWICZ M., SASIM M., 2005 – Zagrożenia powodziami i podtopieniami. *In*: Mat. Seminarium „Rejestracja i inwentaryzacja naturalnych zagrożeń geologicznych (ze szczególnym uwzględnieniem osuwisk oraz innych zjawisk geodynamicznych) na terenie całego kraju", Kraków, 23.11.2005, (ed. M. Stefaniuk): 22–23. AGH.

ILCEWICZ-STEFANIUK D., LEMBERGER M., MAGIERA J., RYBICKI S., SŁOMKA T., STEFANIUK M., 2004a — Cataloguing natural geological hazards over Poland's territory. Proceedings of the conference "Risks caused by the geodynamic phenomena in Europe'', May 20–22, 2004, Wysowa, Poland. *Pol. Geol. Inst. Sp. Papers*, **20**: 53–60.

ILCEWICZ-STEFANIUK D., LEMBERGER M., MAGIERA J., RYBICKI S., SŁOMKA T., STEFANIUK M., 2004b — Landslide hazard in Poland: review and database. *In*: ITALIA 2004: 32nd International Geological Congress: Florence, Italy, August 20–28, 2004 abstracts. Pt. 1 / Poster: 146-23.

ILCEWICZ-STEFANIUK D., CZERWIŃSKI T., KORYCZAN A., TARGOSZ P., STEFANIUK M., 2005a – Landslides survey in the northeastern Poland. Proceedings of the conference "Mass movement hazard in various environments'', October 20–21, 2005, Kraków, Poland. *Pol. Geol. Inst. Sp. Papers*, **20**: 67–73.

ILCEWICZ-STEFANIUK D., KACZMARCZYK R., KORYCZAN A., STEFANIUK M., 2005b — Powierzchniowe ruchy masowe w dolinie Wisły. *In*: Mat. Seminarium „Rejestracja i inwentaryzacja naturalnych zagrożeń geologicznych (ze szczególnym uwzględnieniem osuwisk oraz innych zjawisk geodynamicznych) na terenie całego kraju"; Kraków, 23.11.2005 (ed. M. Stefaniuk): 33–34. AGH.

ILCEWICZ-STEFANIUK D., RYBICKI S., SŁOMKA T., STEFANIUK M., 2005c — Inwentaryzacja powierzchniowych ruchów masowych w Polsce – przegląd. *In*: Mat. Seminarium „Rejestracja i inwentaryzacja naturalnych zagrożeń geologicznych (ze szczególnym uwzględnieniem osuwisk oraz innych zjawisk geodynamicznych) na terenie całego kraju"; Kraków, 23.11.2005 (ed. M. Stefaniuk): 16–17. AGH.

KORYCZAN A., MŻYK S., 2003 — Sprawozdanie z inwentaryzacji osuwisk lub innych przejawów powierzchniowych ruchów masowych na obszarze Mazowsza, Pojezierza Mazurskiego i Pojezierza Wschodniopomorskiego. PBG Archives. Warszawa.

KORYCZAN A., MŻYK S., 2004 — Sprawozdanie z inwentaryzacji osuwisk lub innych przejawów powierzchniowych ruchów masowych na obszarze Mazowsza, Pojezierza Mazurskiego i Pojezierza Wschodniopomorskiego. PBG Archives. Warszawa.

LEMBERGER M. (red.), 2005 — Rejestracja i inwentaryzacja naturalnych zagrożeń geologicznych (ze szczególnym uwzględnieniem osuwisk oraz innych zjawisk geodynamicznych) na terenie całego kraju. Sprawozdanie końcowe. PGI Archives. Warszawa.

STARKEL L., (ed.) 1995 — Ewolution of the Vistula river valley during the last 15 000 years. Part V. *Geogr. Stud. PAN. Sp. Iss*., **8**.

STUPNICKA E., 1989 — Geologia regionalna Polski. Wyd. Geol. Warszawa.

WYSOKIŃSKI L., 1980 — Problem zabezpieczenia wysokich brzegów i miast zabytkowych wzdłuż doliny Wisły. *Prz. Geol*., **28** (6): 354–357.

WYSOKIŃSKI L., 1984 — Analiza warunków geologicznych i prognoza stateczności Skarpy Warszawskiej dla celów zagospodarowania przestrzennego, zabezpieczeń i ochrony środowiska w dzielnicy Śródmieście i Żoliborz. Dept. of Geology UW, Archives. Warszawa.