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GULLY EROSION DATING BY MEANS OF ANATOMICAL CHANGES IN EXPOSED ROOTS (PROBOSZCZOWICKA PLATEAU, SOUTHERN POLAND)

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Abstract: Re-incision occurs in gullies in the undulating loess plateau in southern Poland. The gully hillslopes are mainly covered with beech trees. The beech roots are exposed in the gullies through erosion. The wood cells in the root tree rings divide into early wood and late wood, and after the roots are exposed, they start to make fewer cells. Dolomites and limestones lying under the loess cover are transported and wound the tree roots. As a result of this process on the border between exposed and unexposed tree rings in the tree roots, scars sometimes occur. These anatomical changes in root tree rings allow to date erosion episodes with one year accuracy.

Dating of the exposure of roots indicates that intensive gully erosion in the studied gully started in the 1970s. Since that time, numerous extreme rainfall events responsible for initiating erosion have also occurred. The bottom of the valley head eroded during extreme rainfall events in 1984 and 1991. Erosion here alternates with deposition, its rate being relatively small. Incisions in hillslopes retreated during the flood in 1997, but they originated during earlier rainfall episodes. Hillslope undercutting occurring in the lower part of the gully was formed during older erosion episodes in 1971 and 1984.

1. INTRODUCTION

Quantity and intensity of precipitation is one of the main factors conditioning gully erosion. Studies conducted in Canada prove that natural processes associated with climatic fluctuations are insufficient to cause gully initiation, but may contribute to ongoing gully expansion (Burkard and Kostaschuk, 1995). Gullies are formed during periods of extensive forest clearance, but the triggering mechanism of gully erosion is extreme rainfall events (Stankovianski, 2003). Therefore, deforestation and the introduction of cultivated plants in areas covered with eolian deposit with low cohesion are the only important factors causing gully erosion (Wells and Andriamihaja, 1993; Fanning, 1999). Erosion develops particularly fast in areas where conventional tillage practices are carried out (Casalí *et al.,* 1999). Increasing the amount of forested area and grassland by 50% at the expense of arable land may cause erosion to decrease by about 25 % (Fu *et al.*, 2000). The rate of erosion may increase significantly, even by 100%, under the influence of forest clearance (Gábris *et al.,* 2003). Another factor conditioning the initiation of gully erosion is relief. Local hillslopes and drainage basin area are the most important topographic parameters affecting gully erosion (Vandekerckhove *et al.,* 1998). Also lithological conditions as well as the thickness of eolian deposit with low cohesion and the underlying rock structure can be significant factors affecting the development of gully erosion (Beavis, 2000; Kirkby and Bull, 2000; Oostwoud Wijdenes *et al.*, 2000).

Studies of gully erosion rate are often based on the comparison of gully lengths on maps produced in different centuries or on aerial photos (Daba *et al.,* 2003; Dotterweich *et al.,* 2003; Martínez-Casasnovas, 2003; Ries and Marzolff, 2003; Vandekerckhove *et al.,* 2003). The accuracy of estimating erosion rate is increased when using stereoscopic photos with high resolution (Nachtergaele and Poesen, 1999). Another method of measuring the rate of gully erosion includes continuous monitoring of headcuts (Malde and Scott, 1976; Thomas *et al.,* 2004). Analyses of the content of the ^{137}Cs isotope and other isotopes in the boundaries between sediments deposited as a result of erosion allow one to estimate their age (Chappell, 1999; Belyaev *et al.,* 2004). Also a dendrochronological method has been used for estimating the rate of gully erosion, using in addition to root exposures, corrasion scars on exposed roots or on above-ground parts of fallen trees, exposed and dead root ends, root suckers, stems, branches and leading shoots of fallen trees and the age of trees within a gully (Vandekerckhove *et al.,* 2001).

A tree ring analysis reflects geomorphic processes in the past, but it is concentrated mostly on the stem, and only to a lesser extent on roots (Alestalo, 1971; Shroder, 1980; Ciszewski and Malik, 2004). There are few studies of erosion intensity conducted on the basis of exposed roots. They frequently only measure the length of an exposed part of the root and indicate its age, which allows one to estimate the erosion volume (Carrara and Carroll, 1979; Hupp, 1990). An exception are studies conducted in southern Spain where based on dendrochronological root analysis, the time of erosion episodes was indicated together with an estimation of the rate of gully erosion (Vandekerckhove *et al.*, 2001). In order to estimate precisely the gully erosion volume, samples should be collected from various places on the exposed root, depending on its position (Vandekerckhove *et al.*, 2001). Cross-dating of tree ring series from trees and roots allows one to identify the moment when an erosion episode occurred. Scars in roots as well as the corrasion effect during an erosion episode were both dated. However, not all wounds are the result of corrasion during erosion, some roots could have been damaged by animals (Vandekerckhove *et al.,* 2001).

For some time, research has been conducted on the possibility of determining an erosion episode based on anatomical changes occurring in root wood after exposure (Gärtner *et al.,* 2001). The research has shown that cells within tree rings become more numerous and smaller after exposure. One can clearly see the division into early wood and late wood within tree rings originating after exposure.

In the process of exposure roots are often wounded. Scars frequently occur on the boundary between exposed and unexposed tree rings. They document one erosion episode that has led to their exposure. These anatomical changes in root tree rings allow one to date erosion episodes.

The aim of this study is to demonstrate the possibility of dating gully erosion events by means of anatomical changes in tree rings in exposed roots in the gullies of the Proboszczowicka Plateau in southern Poland.

2. STUDY AREA

The study area is located on the Proboszczowicka Plateau, whose northern part belongs to the Silesian Upland and the southern part falls in the Silesian Lowland (**Fig. 1;** Kondracki, 1994). A dense network of gullies 10-15 meters deep dissects large areas of the summit surface at 270-300 above m.s.l. Gullies network has been formed in loess sediments. These sediments are underlain with Triassic dolomites and limestones, or in places with Quaternary fluvioglacial sands (Klimek, 1972).

The gullies are forested, as opposed to the areas of summit plateau used for agriculture. Arable land constitutes 88% of the surface area, whereas forests comprise only 11%. In the gullies, the predominant tree is mainly beech (*Fagus sylvatica*), sometimes spruce (*Picea abies*), lime (*Tilia platyphyllos*), oak (*Quercus robur*), elm (*Ulmus carpinifolia*) and hornbeam (*Carpinus betulus*). Sediments forming the bottom of the valleys and the slopes in the upper parts of the gullies are covered only in places with grass-like plants. The lower parts of the gully are much more densely covered with plants.

The average annual precipitation in the studied area amounts to about 680 mm. St. Anna Mountain with an altitude of 400 m is situated 3 km to the northeast of the gully under study and constitutes a local barrier forcing incoming air to rise. It causes frequent storms, which are especially intense in the summer period. Maximum frequency of occurrence of storms in the area under study occurs at the beginning of June as well as at the end of June and early July (Bielec-Bąkowska, 2002). The highest monthly

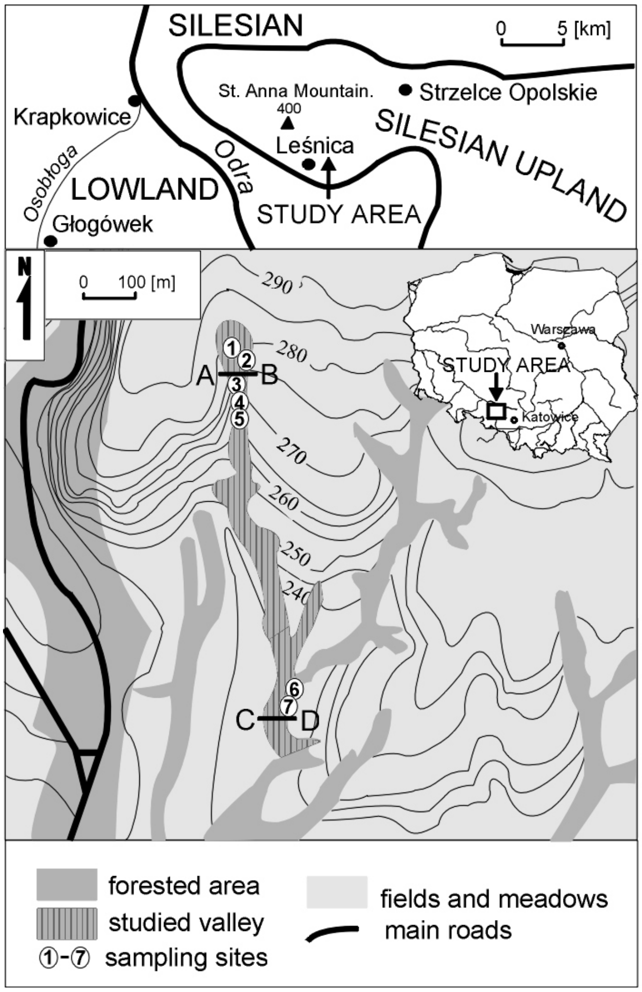

Fig.1. Location of study area and sampling sites.

precipitation reported in Leśnica is considerable and amounts to 200-260 mm (the precipitation gauge in Leśnica is situated about 1.5 km away from the studied gully). Daily precipitation exceeds 30 mm several times per decade; in the years 1970-2000 daily precipitation exceeded 60 mm as many as four times (**Fig. 7**).

During heavy downpours the run-off intensifies, which leads to the occurrence of new incisions in gullies. Erosion not only initiates dusty sediments, but also causes transportation and deposition of the limestones and dolomites underneath them. Sometimes building material stored by people in the higher part of the gullies is redeposited.

The Commune of Leśnica, which covers the area of research, already had the character of an agricultural settlement similar to nowadays at the beginning of 13th century (Panic, 1992). On the basis of studies conducted in adjacent loess areas, one may assume that the change to agriculture occurred much earlier, since the land was already used in Neolithic times and deforestation relating to this was already occurring (Śnieszko, 1995; Klimek, 2002; Zygmunt, 2004). Based on results from the analysis of the course of gullies on maps dating from the mid 19th century and on contemporary maps, the valley under consideration and adjacent valleys are of the same size, and also the tree cover indicated on maps coming from different centuries is the same. Thus, one may say that the gullies have not been rapidly eroded during the past 150 years. The presence of a 200 year old trees growing in the hillslopes of the valley indicates that the existing gully is much older then the recent erosional activity that is investigated in this study.

The research was conducted in a 900 m long gully whose upper part is narrow and V-shaped (**Fig. 2a**). The valley is wide, flat-bottomed and possesses terraces in the lower part (**Figs 1** and **2b**). Samples were collected at 7 sites. Three sites were located in the bottom of the upper part of the valley, two on each slope and two at its mouth (**Fig. 1**).

3. MATERIAL AND METHODS

In the incisions the height, width and length were measured by means of a rod and a measuring tape, while in the upper course and at the mouth cross-sections were made of the whole valley. Ten-cm pieces of exposed beech tree roots were collected using a handsaw. In 7 sites, 53 samples were collected from 28 roots. Samples were collected in April 2003 and 2004. Between 1 and 3 samples were collected from each root. In most cases, two samples were collected in places were the root connects with the soil and a third one from the middle of the exposed part of the root. In addition, samples were collected in places were roots were wounded. In order to date the initiation of incision, and not its deepening or extension, samples were collected from halfway through the length of exposed roots located in the surface parts of incised gully at sites number 1-5. In addition, the height of the root outcrop above the gully bottom and the distance from the beginning of the incision were also measured.

Samples were cut with knives. The exposure moment was identified by means of a binocular microscope on the assumption that it is indicated by an obvious decrease in cell size and increase in their number, as well as a division of cells into early wood and late wood within each tree ring occurring after exposure (**Fig. 3**). The exposure time was calculated by counting the number of tree rings with anatomical changes. In addition, scars occurring on the boundary between anatomical differences in root wood were noted. They confirmed the year in which exposure of the roots occurred (Schweingruber, 1996). In the case of 22 root samples, the number of tree rings after exposure was difficult to calculate by means of a binocular microscope. Microscopic sections were prepared from these samples in order to better show the wood structure of the roots. Slices of wood 15-20 μm thick were cut by means of a microtome and the number of tree rings occurring after exposure was then calculated under the microscope.

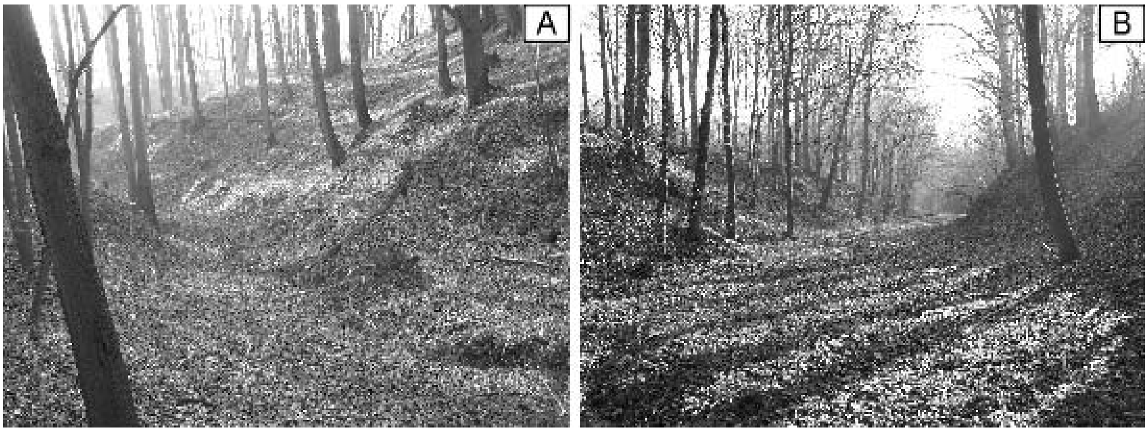

Fig. 2. *Shape of the valley studied.*
a) V-shaped upper part of the valley studied. b) Flat-bottomed lower part of the valley studied.

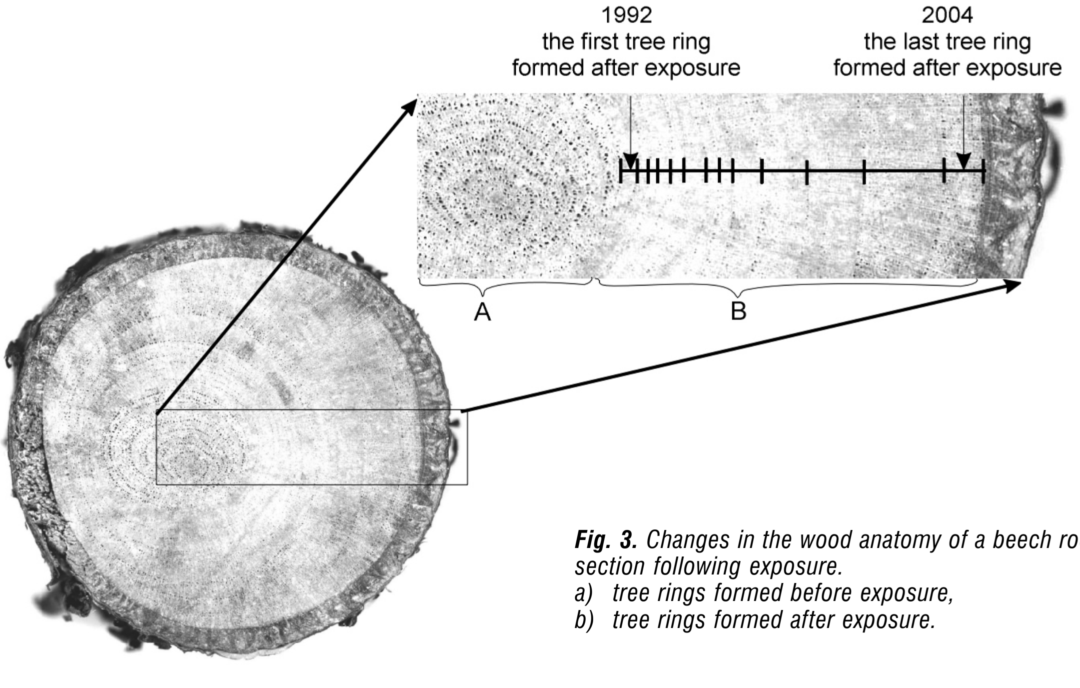

Fig. 3. Changes in the wood anatomy of a beech root cross-section following exposure.
a) tree rings formed before exposure,
b) tree rings formed after exposure.

4. RESULTS AND DISCUSSION

Erosion dating based on the time of root exposure in the sites studied

Site number 1 is a valley bottom incision located at the point where the valley head changes into a V-shaped valley. The bottom incision, which has a length of about 12 m, is initiated behind a log and is about 1.2 m wide and 0.6 m deep at this point. It narrows and deepens slightly in its middle section. The slope gradient in the area of the incision is 18%. In total, eight roots collected from various places in the upper half of the area of incision were sampled. The earliest exposure of roots was reported in the upper part of the incision. Roots were exposed here from 1981 to 1984, whereas 1.5 m lower down the exposure of roots occurred in the years 1992-1997. Halfway through the incision it becomes older again: the exposure of root number 9 was dated to 1984 (**Fig. 4**). At the moment of collection of the samples, roots nos. 2 and 7 were dead and other roots were alive. Roots nos. 3 and 4 had erosion wounds.

Site number 2 is an incision running down the hillslope between espaliers of trees and along its gradient. It lies about 30 m below the incision at site 1. It starts at the top of the left hand hillslope but is not very clear here. Halfway down, the incision deepens and extends and from this point the hillslope becomes steeper. It is about 0.4-0.7 m wide and up to 0.5 m deep, the gradient of the slope here being 48%. In total, 4 roots were sampled originating from different places in this incision. The exposure of roots in the lower part of the incision occurred in the years 1981 and 1984, whereas the exposure of roots in the upper parts of the incision occurred in the years 1998 and 2000 (**Fig. 5**). All of the roots examined were alive. Roots nos. 10 and 12 had wounds.

At site 3, halfway along the left hillslope of the valley, about 20 m below site 2 there is an oval niche which is 0.5 m deep and has a diameter of 3.5 m. The niche originated as the result of a tree falling, which raised up a considerable amount of sediment. One of the arms of the niche is prolonged by the erosion incision reaching 3 m up the hillslope. It is 0.5 m wide and about 0.3 m deep. The slope gradient in the area of the incision is 43%. In total, two roots were dated here: one of them situated within the niche was exposed in 1991. The other one, situated 2 m above the niche, was exposed in the years 1999-2000 (**Fig. 5**). The roots were alive and did not have any wounds.

A 150-year old beech tree grows at site number 4, on the left hillslope and 2 m above the bottom of the valley, located 110 m from the beginning of the incision at site 1. Its location at the edge of the valley bottom and the presence of a highly developed root system penetrating sediments has caused it to create a bastion. This protrudes from the axis of the valley and water flows round during freshets, eroding the opposite valley slope. The bastion is oval, has a diameter of about 2.5 m and is 2 m high. The gradient of the slope of the bottom, below the bastion, is equal to 15%. Roots are exposed at soil level within the bastion. They grow back into the soil below the place where they are partially exposed. At this site three roots were dated, all of them were partially exposed in the years 1994-1995 (**Fig. 4**). They were alive and did not have any wounds.

The incision at site 5 is situated in the bottom of the valley, about 10 m below the bastion, from site 3. It is up to 2 m deep, 17 m long and up to 1 m wide. Material that had slid down from the hillslopes is eroded there, thus the incision is deep. There is also an incision 1.3 m deep in the bedrock. The gradient of the slope in the area of the incision is equal to 16%. In total, four roots exposed in the middle part of the incision were dated from this site. They were exposed at different times in the years 1982-1994 (**Fig. 4**). Roots 15 and 16 were dead, but root no. 17 was alive. The roots had no wounds.

A beech tree growing on a hillslope about 200 m from the valley mouth was undercut at site 6. At the point where the valley narrows, a niche was created on the left hand side of the valley, below the beech tree. The bottom of the valley is 9 m wide at this point and 20 m further down the valley is almost twice as wide. The niche is located 2.5 m above the bottom of the valley; it is 1.2 m deep, 2.5 m high and about 4 m long. Below the niche there are 2 terrace levels: 0.5-0.8 m and 1.2-1.7 m. In the niche 3, roots were dated which were exposed in the years 1984-1989 (**Fig. 6**). They were alive, and root B4I had wounds.

At site number 7, situated on the left hillslope 120 m away from the mouth of the valley, there is an incision in the shape of a longitudinal niche, which is 20 m long and 3 m high above the bottom of the valley. Below the niche there is a 1-1.5 m terrace. In the incision five roots were dated, the oldest of them, exposed in the years 1974-1978, are located in the middle part of the exposure. Roots on the sides of the exposure are younger, uncovered from sediments in the years 1988, 1990 and 1994 (**Fig. 6**). Apart from roots B6 and B10, all of the roots examined are alive and have no wounds.

Precision of dating of erosion episodes by means of exposed roots

In order to verify the accuracy of dating erosion events by determining the year of exposure of roots, a figure has been developed to present the highest daily precipitation in the years 1946-2000 as recorded at the precipitation recording station in Leśnica. Subsequently, the timing of those events responsible for transforming the valley profile was documented dendrochronologically and added to the figure (**Fig. 7**). Daily precipitation does not precisely control erosion events investigated by root samples, because we there is no information about the intensity of precipitation per hour/minute. Long term rainfalls are very well recorded in daily precipitation data, but extreme rainfalls with short duration can be not clear from daily precipitation data. In spite of this limitation, the author decided to compare root investigation results and daily precipitation.

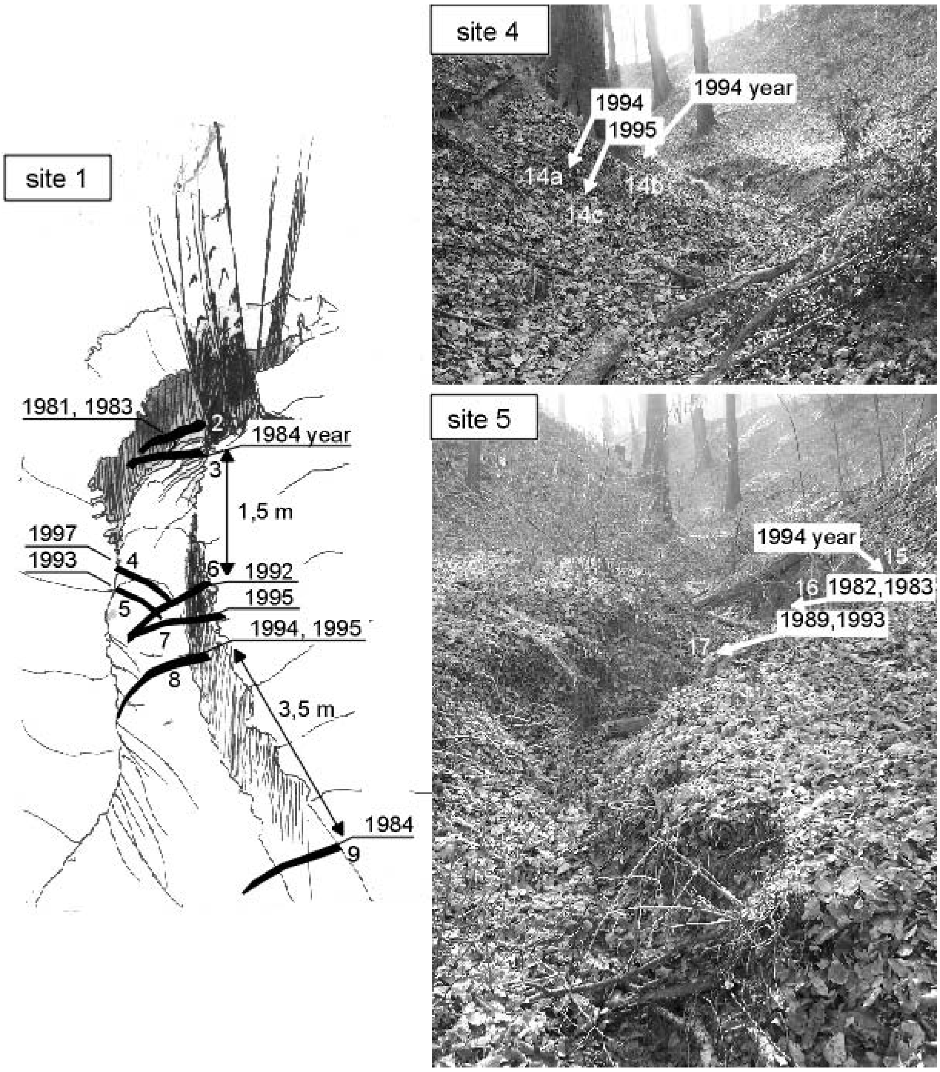

Fig. 4. *The years of root exposure at sites 1, 4 and 5.*

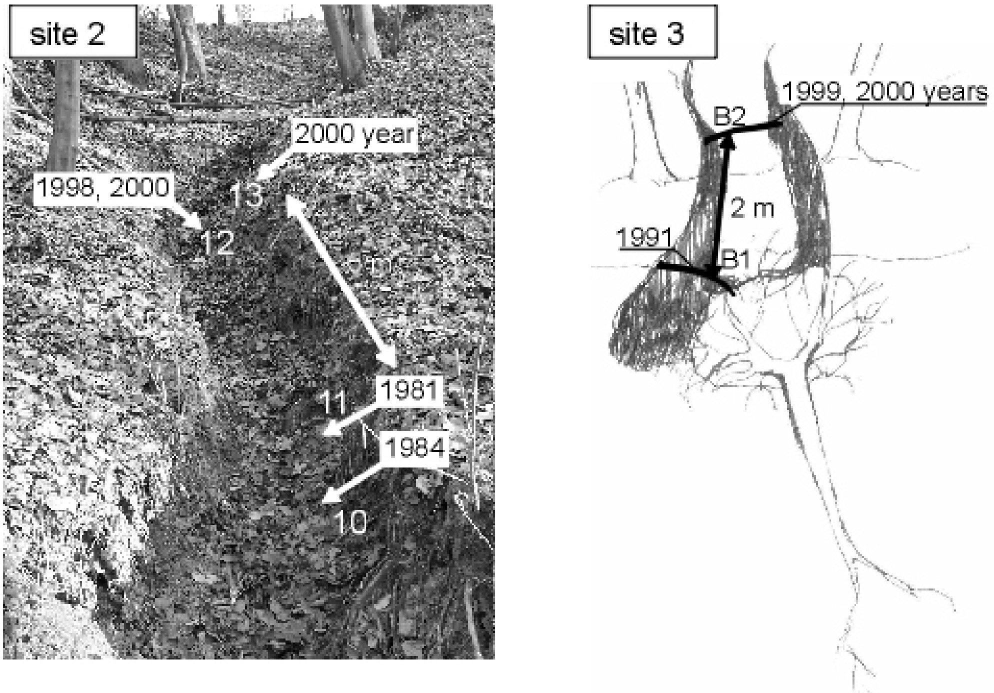

Fig. 5. *The years of root exposure at sites 2 and 3.*

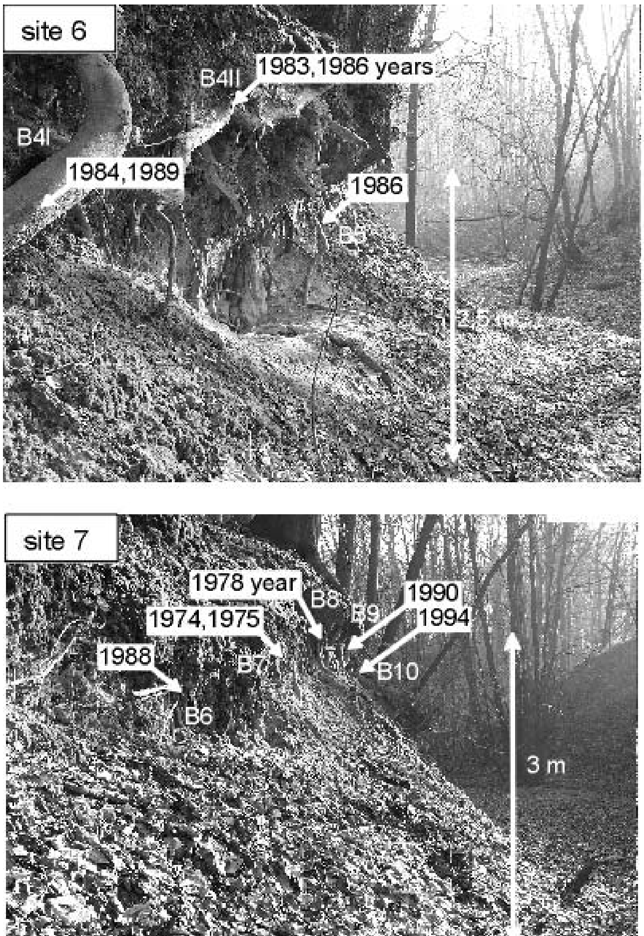

Fig. 6. *The years of root exposure at sites 6 and 7.*

The years in which extreme rainfall events were reported are frequently not the same as the years in which markers of root exposure were reported. One of the reasons may be the fact that the data from the precipitation gauge describes daily precipitation of varying intensity. Some of the extreme precipitation episodes represent heavy local downpours of short duration, e.g. a rainstorm in 1991, whereas others are continuous rainfalls affecting extensive areas over long periods of time, e.g. a rainfall in 1997. The course of a precipitation event has a significant effect on gully erosion; that is why daily precipitation with a similar daily size does not necessarily have a similar impact on gully form (Starkel, 2002).

The time of root exposure as identified from the analysis of anatomical changes within its tree rings is not always the same as the actual year of the exposure of that root. Tree rings are shaped in a moderate climate in the period from May to August (Zielski and Krąpiec, 2004). When a root is exposed at this time, anatomical changes are visible in the area of a tree ring. If the root exposure occurred from January to August, the tree ring may be changed in the same year as the exposure occurred. If the exposure occurred between September and December, the tree ring with anatomical changes will appear the following year. A marker of exposure may be thus recorded in roots one year after an erosion episode.

In the area under study, roots frequently include signs of exposure over one year after an extreme rainfall event (**Fig. 7**). These result from the fact that subsequent rainfall episodes may not be sufficiently intense for the erosion to continue as the one that initiated the incision. This is why numerous signs of erosion appear in several years following major rainfall episodes in spite of the fact that at that time no precipitation with high intensity was reported. Such a situation can be clearly seen in the case of a downpour in 1991, after which, in the years 1992-1995, as many as 12 roots were exposed (**Fig. 7**).

The moment of exposure can be precisely dated, provided that a root is damaged by the material transported during a downpour. Such situations were observed in the case of roots 3 and 4 at site 1, root no. 10 at site 2 and root B4I at site 6. All of the damaged roots indicated the year 1984 or 1997 as the moment of exposure.

Incisions are dated more precisely by roots that are alive at the moment of sample collection. When an exposed root is dead, the number of years indicated since its exposure constitutes the minimal time that has elapsed since the erosion episode exposing the root (Shroder, 1980). Dead roots are very useful for erosion dating when we cross-date them with living part of roots or stem (Vandekerckhove *et al.,* 2001).

False rings, missing rings or discontinuous rings occur in stems in a similar manner as in roots (Schweingruber, 1988). They may distort the number of years that have elapsed since the erosion episode. However, the error relating to that limitation is not large, since, as opposed to cores collected from trees, the whole cross-section is examined in the case of roots. This makes identification of double, missing or discontinuous rings easier.

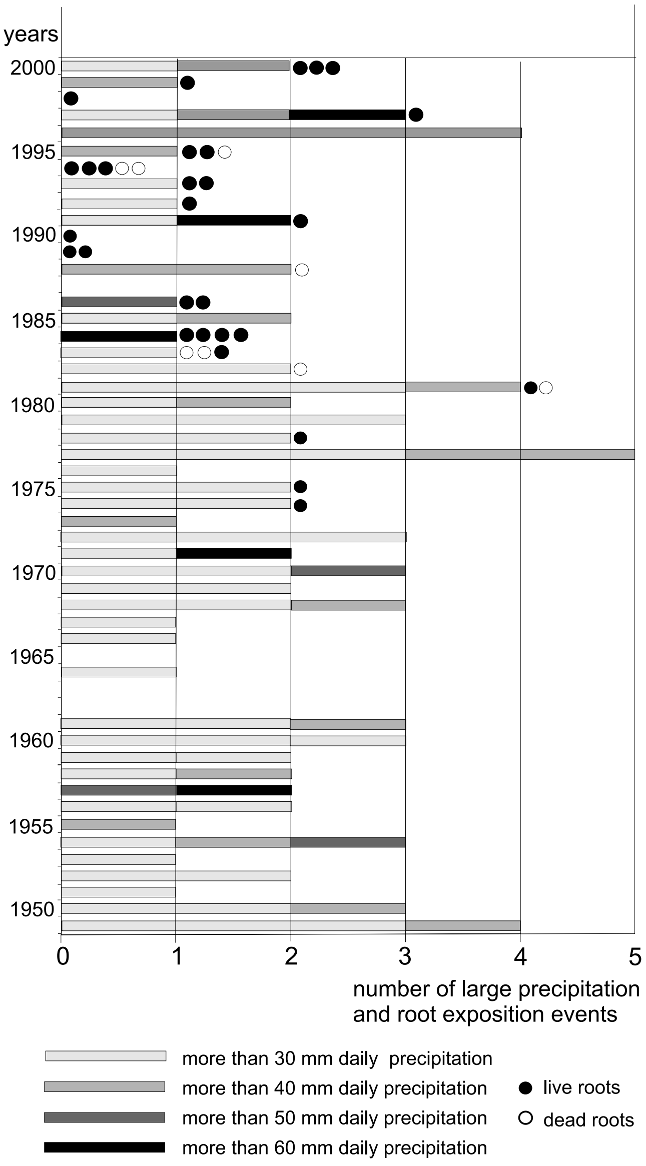

Fig. 7. Comparison of root exposure dating and big daily rainfall events recorded at the Leśnica gauge in 1949-2000.

The place from which a given root is collected is important when inferring the course of erosion based on the exposure of roots. To determine the moment of origin of the incision, roots should be collected as high as possible above its bottom. Dating roots occurring near the bottom of the exposure may indicate the moment of its deepening and not of its origin.

The course of erosion may also be determined by comparing markers regarding exposure from the middle part of the exposed part of the root and the part adjacent to the soil. If the marker is identical, then the exposure occurred as a result of one episode. If the time of exposure recorded in the part of the root adjacent to the soil is younger, then the exposure occurred as a result of at least two erosion episodes. It appears from the research conducted that roots could have been exposed as a result of several erosion episodes, as in case of roots B4I and B4II at site 6 exposed in the years 1984, 1989 and 1983, 1986, respectively.

Reasons for erosion in the gully

The results obtained prove that intense erosion occurred at the beginning of 1970s in the gully under study. At the same time, the number of precipitation episodes has decreased since the 1970s, but they have become much more intense with time. This explains the revival of erosion processes in that gully.

The markers obtained by means of dating roots point to at least several erosion and deposition episodes shaping the valley under consideration. The markers can be divided into 4 main groups. In the first group, there are 9 markers coming from years 1974-1983. Probably, the erosion documented by the roots took place in 1971. As many as half of the roots are dead, all of them document exposure in the years 1981-1983, and thus it was a relatively long time after a major precipitation episode in 1971 (**Fig. 7**). Therefore, they may be roots documenting erosion relating to a rainfall in 1971 or demonstrating an even older major precipitation episode. The second group of markers covers 10 roots exposed in the years 1984-1990. They are the effect of erosion relating to an intense rainfall in 1984. The third and the largest group of roots, including 12 markers, represents years 1991-1996. They document a major rainfall episode in 1991. The last group constitutes 6 markers and documents the intense rainfall of July 1997.

It seems from root dating that the incision in the valley studied was shaped mainly during the extreme rainfall events in 1971, 1984, 1991 and 1997. A secondary role in shaping the valley studied was played by other precipitation episodes during which the total precipitation was 50% smaller than in the years with extreme rainfall events e.g. 1973, 1977, 1980, 1981, 1985, 1986, 1995, 1996 and 2000. It is surprising that there are no markers regarding erosion older than 1970, for the years 1950-1960 had many large precipitation events, although there were not as many of them as within the last 35 years. Perhaps the relatively small number of sites resulted in no roots documenting erosion in that period being found. It is also possible that roots were exposed in the 1950's, but died since that time.

Course and rate of erosion

Erosion in the bottom of the upper part of the valley (sites 1, 4, 5) was most intense in the years 1981-1989 and 1992-1995 (**Fig. 4**). The precipitation episodes of 1971, 1984 and 1991 account mainly for the origin of incisions. The incision in the upper part of site 1 is older and is likely to have occurred during an intense rainfall in 1971. In the middle part, the incision is younger and was initiated in 1991. Further down, halfway through the incision, it becomes older again and root no. 7 indicates erosion in 1984. Parts of roots nos. 3 and 4 which were collected from below sediments had wounds covered with earth dating from 1984 and 1997 respectively. This proves that those parts of the roots were initially exposed and later covered with earth again. Site 1 is located at a point where there is a significant increase in the slope gradient below the boundary between a head valley and the beginning of a V-shaped gully. There is therefore a higher likelihood of erosion on this boundary between the two forms of the valley. From dating evidence, it seems that this occurs alternately with the deposition of material coming from the deforested summits. This alternate occurrence of erosion and deposition in the incision does not permit one to estimate the rate of erosion. However, we may state that this takes place slowly taking into account the small gradient of the bottom of the gully examined, so that the material can be transported for small distances. Roots at site number 5, included markers regarding exposure in the years 1982-1989 and 1993-1995. This site was composed of incised rocks in the bottom of the gully lying under dust-like material. This means that the incision was formed during precipitation episodes in 1971 and 1991, similar to the incision at site 1. Those episodes are responsible for the incision of the rocky foundation at this site. At site no. 4 roots were exposed during rainfall in 1991. Their location about 2 m above the bottom of the gully indicates high flow dynamics during the precipitation in 1991.

The incisions are relatively young at sites nos. 2 and 3 located on the valley hillslope. The vast majority of roots have given markers dating from 1998-2000 (**Fig. 5**). The incision at site number 2 was initiated in the lower part of the site and afterwards retreated. The lower part of the incision originated in 1984, whereas the upper part developed after rainfall in 1997. It is likely that the incision could also have been initiated during a precipitation episode in 1971 since the exposure of one of the roots in the lower part of the incision was dated to 1981. At a distance of about 5 m, the maximum age difference identified between roots is 19 years. This means that the incision retreats at least 2.6 m yr^{-1}. At site no. 3, the exposure of roots in the niche took place as a result of a precipitation episode in 1991. Roots in the incision above it were exposed after extensive rainfall in 1997. This implies that the niche occurred as a result of a tree falling, which, at a later date, caused the erosion above the site. Erosion at site no. 4 amounted to 3 m yr^{-1}. The results obtained enable one to conclude that the rate of erosion is much faster in the area of very steep hillslopes than in the bottom of the upper part of the valley.

At sites 6 and 7 situated at the mouth of the valley erosion markers are generally older than in the upper part of the valley (**Fig. 6**). The undercutting at site no. 6 was formed during a precipitation episode in 1984. The undercutting at site no. 7 is the oldest one in the middle part of the valley and a precipitation episode in 1971 was responsible for its origin or deepening. Its form was also further developed during freshets in 1984 and 1991. The distribution of areas of undercutting at a height of even 3 m above the valley bottom proves the existence of a water level at least this high during the precipitation episodes which modelled those incisions. Such a high water level in the valley results from catching significant amounts of water from the higher parts of the gully. A very small number of markers of erosion of areas of undercutting from the most recent precipitation episodes and terrace levels in the bottom of the valley prove that it was deepened during older erosion episodes, e.g. 1971 and 1984.

5. CONCLUSIONS

The analysis of changes to anatomical properties in root tree rings allows one to date the erosion episode which led to its exposure. The age of the erosion episode exposing a root cannot always be dated very precisely, since:

- a marker of exposure may be delayed one year after the erosion episode which led to the exposure of the root. If such erosion exposed a root in the period from January to August, the marker appears in the same year, and if it appeared in the period from September to December, then it appears the following year;
- erosion often occurs within several years after extensive precipitation episodes initiating incision. This results from the fact that subsequent rainfall episodes may not be as intense to continue erosion as the one that initiated the incision;
- the moment of erosion can be dated more precisely where there are roots with wounds in the zone of the first tree ring in which the anatomical properties of the wood change;
- dating dead roots only allows one to determine a minimum time that has lapsed from a given erosion episode, which is why live roots date erosion more precisely;
- in roots, the number of tree rings may be distorted by false rings, missing rings or discontinuous rings, however, the analysis of complete cross-sections of roots minimises errors resulting from this factor;
- the moment of origin of the incision is dated by roots exposed on the surface, as high above the bottom of the incision as possible. Roots exposed low above the bottom may only provide information about the deepening of such an incision and those that have been

exposed near sediments provide evidence of a widening of the incision.

Erosion started in the valley studied as a result from the occurrence of extensive precipitation within the last 35 years. The observed erosion contributes to the deepening and headcut retreat of the valley, as well as to the origin of new incisions on hillslopes.

The bottom of the upper part of the valley was mainly transformed during extensive precipitation episodes in 1984 and 1991. Sediments are being eroded there and the incisions thus formed may be filled with sediments again. The bottom erosion in the upper parts of the valley is relatively slow. The hillslopes of the examined valley were intensely incised during an extraordinary precipitation event in 1997, but erosion was initiated during earlier precipitation events. The estimated rate of the hillslope incisions is at least 2.5-3 m yr^{-1}. Erosion occurred at the mouth of the gully during an extreme rainfall events in 1971, 1984 and 1991. The valley has deepened as a result of the incision of the bottom of the valley within the last 35 years. This has resulted in areas of undercutting becoming inactive.

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REFERENCES

Alestalo J., 1971: Dendrochronological interpretation of geomorphic processes. *Fennia* 105: 1-140.

Beavis S.G., 2000: Structural controls on the orientation of erosion gullies in mid-western New South Wales, Australia. *Geomorphology* 33: 59-72.

Belyaev V.R, Wallbrink P.J., Golosov V.N., Murray A.S. and Sidorchuk A.Yu., 2004: Reconstructing the development of a gully in the Upper Kalaus basin, Stavropol region (southern Russia). *Earth Surface Processes and Landforms* 29: 323-341.

Bielec-Bąkowska Z., 2002: Zróżnicowanie przestrzenne i zmienność wieloletnia występowania burz w Polsce (1949-1998) (Long-term thunderstorm occurrence variability in Poland during 1949-1998). *Prace Naukowe Uniwersytetu Śląskiego w Katowicach* 2059, Katowice (in Polish).

Burkard M. B. and Kostaschuk R. A., 1995: Initiation and evolution of gullies along the shoreline of Lake Huron. *Geomorphology* 14: 211-219.

Casalí J., López J.J. and Giráldez J.V., 1999: Ephemeral gully erosion in southern Navarra (Spain). *Catena* 36: 65-84.

Carrara P.E. and Carroll T.R., 1979: The determination of erosion rates from exposed tree roots in the Piceance basin. Colorado. *Earth Surface Processes and Landforms* 4: 307-317.

Chappell A., 1999: The limitations of using ^{137}Cs for estimating soil redistribution in semi-arid environments. *Geomorphology* 29: 135-152.

Ciszewski D. and Malik I., 2004: The use of heavy metal concentrations and dendrochronology in the reconstruction of sediment accumulation, Mała Panew River Valley, southern Poland. *Geomorphology* 58: 161-174.

Daba S., Rieger W. and Strauss P., 2003: Assessment of gully erosion in eastern Ethiopia using photogrammetric techniques. *Catena* 50: 273-291.

Dotterweich M., Schmitt A., Schmidtchen G. and Bork H.R., 2003: Quantifying historical gully erosion in northern Bavaria. *Catena* 50: 135-150.

Fanning P. C., 1999: Recent landscape history in arid western New South Wales, Australia: a model for regional change. *Geomorphology* 29: 191-209.

Fu B., Chen L., Ma K., Zhou H. and Wang J., 2000: The relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shaanxi, China. *Catena* 39: 69-78.

Gábris G., Kertész Á. and Zámbó L., 2003: Land use change and gully formation over the last 200 years in a hilly catchment. *Catena* 50: 151-164.

Gärtner H., Schweingruber F.H. and Dikau R., 2001: Determination of erosion rates by analysing structural changes in the growth pattern of exposed roots. *Dendrochronologia* 19: 81-91.

Hupp C.R., 1990: A dendrogeomorphic approach to estimating slope retreat, Maxey Flats, Kentucky. *Geology* 18: 658-661.

Kirkby M.J. and Bull L.J., 2000: Some factors controlling gully growth in fine-grained sediments: a model applied in southeast Spain. *Catena* 40: 127-146.

Klimek K., 1972: Wyżyny Śląsko–Małopolskie (Śląsko-Małopolskie Uplands). In: Klimaszewski M., ed., *Geomorfologia Polski, tom 1 (Geomorphology of Poland).* PWN, Warszawa, pp. 326 (in Polish).

Klimek K., 2002: Human-induced overbank sedimentation in the foreland of the eastern Sudety Mountains. *Earth Surface Processes and Landforms* 27: 391-402.

Kondracki J., 1994: *Geografia Polski. Mezoregiony fizyczno-geograficzne*(Geography of Poland. Physical Geography Mezoregions). PWN, Warszawa, pp. 340 (in Polish).

Malde H.E. and Scott A.G., 1976: Observations of contemporary arroyo cutting near Santa Fe, New Mexico, USA. *Earth Surface Processes and Landforms* 2: 39-54.

Martínez-Casasnovas J.A., 2003: A spatial information technology approach for the mapping and quantification of gully erosion. *Catena* 50: 293-308.

Nachtergaele J. and Poesen J., 1999: Assessment of soil losses by ephemeral gully erosion using high-altitude (stereo) aerial photographs. *Earth Surface Processes and Landforms* 24: 693-706.

Oostwoud Wijdenes D.J., Poesen J., Vandekerckhove L. and Ghesquiere M., 2000: Spatial distribution of gully head activity and sediment supply along an ephemeral channel in a Mediterranean environment. *Catena* 39: 147-167.

Panic I., 1992: *Historia osadnictwa w Księstwie Opolskim we wczesnym średniowieczu (The history of the settlement in the Księstwo Opolskie in early Middle Ages)***.** Muzeum Śląskie, Katowice, pp. 196 (in Polish).

Ries J.B. and Marzolff I., 2003: Monitoring of gully erosion in the Central Ebro Basin by large-scale aerial photography taken from a remotely controlled blimp. *Catena* 50: 329-352.

Schweingruber F.M., 1988: *Tree rings. Basis and applications of dendrochronology*. Reidel, Dodrecht, pp. 276.

Schweingruber F.M., 1996: *Tree rings and Environment. Dendroecology*. Birminsdorf, Swiss Federal Institute for Forest, Snow and Landscape Research. Berne, Stuttgart, Vienna, Haupt: 222-226.

Shroder jr. J.F., 1980: Dendrogeomorphology: review and new techniques of tree-ring dating. *Progress in Physical Geography* 4: 161-188.

Stankovianski M., 2003: Historical evolution of permanent gullies in the Myjava Hill Land, Slovakia. *Catena* 51: 223-240.

Starkel L., 2002: Change in the frequency of extreme events as the indicator of climatic change in the Holocene (in fluvial system). *Quaternary International* 91: 25-32.

Śnieszko Z., 1995: Ewolucja obszarów lessowych Wyżyn Polskich w czasie ostatnich 15000 lat (The loess cover evolution during last 15000 years in Polish Uplands). *Prace Naukowe Uniwersytetu Śląskiego w Katowicach* 1496, Katowice, pp. 124.

Thomas J.T., Iverson N.R., Burkart M.R. and Kramer L.A., 2004: Long-term growth of a valley-bottom gully, western Iowa. *Earth Surface Processes and Landforms* 29: 995-1009.

Vandekerckhove L., Poesen J., Oostwoud Wijdenes D.J. and de Figueiredo T., 1998: Topographical thresholds for ephemeral gully initiation in intensively cultivated areas of the Mediterranean. *Geomorphology* 33: 271-292.

Vandekerckhove L., Muys B., Poesen J., De Weerdt B. and Coppé N., 2001: A method for dendrochronological assessment of medium-term gully erosion rates. *Catena* 45: 123-161.

Vandekerckhove L., Poesen J. and Govers G., 2003: Medium-term gully headcut retreat rates in Southeast Spain determined from aerial photographs and ground measurements. *Catena* 50: 309-328.

Wells N.A. and Andriamihaja B., 1993: The initiation and growth of gullies in Madagascar: are humans to blame? *Geomorphology* 8: 1-46.

Zielski A. and Krąpiec M., 2004: *Dendrochronologia.* (Dendrochronology) PWN, Warszawa, pp. 328 (in Polish).

Zygmunt E., 2004: Archaeological and radiocarbon dating of alluvial fans as an indicator of prehistoric colonization of the Glubczyce Plateau (Southwestern Poland). *Geochronometria* 23: 101-107