Barshchevskyi M. E. **Development of relief of the southern part of Ukraine in the early Pliocene.** This article presents characteristic of development of Black Sea monocline's relief evolution in the early Pliocene. One has distinguished three types of geomorphogenesis with prevalence of marine (subaqueous) type and which subjugated to the existence of Humid and Arid types. One has described the characteristic of several genetic forms of early Pliocene paleorelief.

Keywords: type of geomorphogenesis, early Pliocene, Black Sea monocline, paleorelief.

Барщевский Н.Е. **Развитие рельефа юга Украины в раннем плиоцене.** В статье дана характеристика развития рельефа Причерноморской моноклинали в раннем плиоцене. Выделены три типа геоморфогенеза с преобладанием морского (субаквального) и починенным положением гумидного и аридного типов. Дана характеристика некоторых генетических форм раннеплиоценового палеорельефа.

Ключевые слова: тип геоморфогенеза, ранний плиоцен, Причерноморская моноклиналь, палеорельеф.

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CHANGES IN THE COURSE OF THE VISTULA RIVERBED VS. THE RISK OF FLOOD ON THE TERRITORY OF SANDOMIERZ

Keywords: flood, Vistula, river regulation

Introduction. At the beginning of the 19th century, a large-scale river regulation works were started and continued in the 20th century. Those works were carried out in order to prepare rivers as waterways and their scope involved shortening the course as well as narrowing riverbeds [10]. One of the elementary functions of each river is to drain excess water from a river basin. Valley formation is based, among others, on variable analysis of water volume in a river during annual and multiannual periods. The formation of a valley has to be adapted to the amount of water and rock material rendered by a river basin, as well as the size of a water catchment area. Seasonal variability of water and rock material causes fluctuations of water in rivers. Due to increasing its amounts, water comes out of a riverbed and flows through an entire valley or some part of it. Such phenomenon is defined as flood [4].

The terms of overflow and flood are often confused. An overflow means a raised level of water (e.g. in a river) that is caused by meteorological, hydrological as well as physical and geographical factors. It is a natural phenomenon that is very useful as it has a positive influence on natural environment. Flood, in turn, is such a raised level of water that causes not only threats to life, but also natural, economic and social losses. If a floodplain is used, e.g. as pasture lands, periodic flooding may increase grass crops. If such area is inhabited by people, it often causes damage and death. The main reason for floods is an overflow of water. [16].

The basic criteria for classifying floods in Poland are: origin, range and size [12].

Tab. 1 – **Classification of Floods in Poland**

Classification of Floods				
Factor	rainfall – related to heavy and expansive rainstorms	thaw – caused by sudden ice melting	storm – occur at reservoirs and sea coasts as a result of strong winds	wintry – resulted in exceptional intensity of some ice phenomena
Range	local –small water catchment area that is related to heavy rainstorms, often known as a "cloudburst"	regional – usually one hydrographic al region	national – covering several hydrographical regions	
Size	common	large	catastrophic	

Floods are caused not only by natural factors. There are also anthropogenic factors that have an impact on occurrence and formation of such phenomenon. Man causes floods due to improper management of water that is stored in reservoirs, breakdowns of hydraulic structures (random and intentional) and controlled inundation. [2]. The main cause of floods in Poland is rainfall of various intensity and duration, which results in overflows during Spring and Summer. The second most common cause of floods is ice melting in Spring.

Aim. The aim of this paper is to present reasons for the risk of flood in the Town of Sandomierz, that are related to changes in the course and character of the Vistula riverbed.

Research Site. Sandomierz is situated in the eastern part of the Swietokrzyskie Province. Two different physical and geographic units can be distinguished within the administrative boundaries of the Town.First of them is an elevation covered with loess soils and located in the Sandomierska Upland. The second one is the Vistula Valley covered with river diluvial soils and located in the Sandomierska Hollow [8]. The territory of the Town is drained by the Vistula. The river flows through the embanked riverbed. However, there are wetness and oxbow lakes in the inter-embankment zone. It can be also noticed that there are alluvial forms, i.e. sand bars covered with green vegetation. The length of the Vistula within the administrative boundaries of the Town is 3,8 km, what constitutes 0,34% of the total river course (1047 km). The width reaches about 200 m.

Geological structure determines diversity of landforms ofthe Sandomierska Upland and the Vistula Valley. The area of the elevation belonged in the past to the Swietokrzyskie Mountains. The eastern part of the Sandomierska Upland, on which lies the Town, is covered with younger Tertiary and Pleistocene formations (with a thick layer of loess soils). Erosion removed younger sediments from the Sandomierska Upland and left there Palaeozoic rocks which are exposed only in ravines and valleys. The Pieprzowe Mountains are the examples of such exposure [13].

The bottom of the Vistula Valley is covered with diluvial soils. They are rendered nowadays by rainfall waters and melting ice that come from the slopes of the upper parts of the valley. The most frequent are silts deriving from scouring loess soils. Alluvial soils occur in the bottom of the Vistula Valley and its tributaries. In the cross-section they indicate a number of recurring sandy, silty and loamy series. River sands are under alluvial soils [7].

The Upland rises to 205 m a.s.l. from the north-western side, then falls gently towards the Vistula Valley, and ends in a form of steep slope near its brink. The bottom of the valley reaches a height of 140 m a.s.l. The height difference between the elevation and the valley is 65 m [7]. The characteristic feature of a loess upland is a large number of valleys and ravines. Herein two essential types can be distinguished: wide and flat valleys with gentle slopes, as well as deep and narrow ravines.The surface of the elevation between valleys and ravines is characterised by an average decrease of 5%. Decreases in the zone lying near the brinks are larger, i.e. 5-8%. Thanks to these differences in heights and flat surfaces, numerous terraces that have been used for housing development are observed. From the Vistula side there is a high slope where historical monuments were built on its various levels [7]. The Vistula Valley is a flat area that constitutes the floodplain for the Vistula. The floodplain, in turn, is protected by embankments.

Results. Hydrological conditions of the Town are related to its geological structure, morphology and landform. The Vistula, when flowing up to Krakowskie Przedmiescie, forms a gentle arc related to close proximity to the elevation. At the foot of the upland, it flows to the northeast. Its direction is initially parallel to the brink; however, after about 400 m it goes away from the slope and leaves over riverbed forms. Remains of former riverbeds are usually wet, covered with trees, wicker, meadows, or filled with water just like at the foot of the Pieprzowe Mountains [7]. On the one side, they are clung to the river; on the other one, there is the Sandomierska Hollow bearing traces of the former river course. Nowadays, this area has been significantly drained as a result of regulation and hydraulic engineering activities [9].

The Vistula has changed its course duringthe past few centuries. Historical records indicate that in the 14th century the river flowed in the close proximity to Sokolniki, i.e. from 1,5 to 2,5 km from the present course, and already in 15thcentury it flowed nearby Wielowies, i.e. about 2 km east of the present riverbed. In the 17th century, in turn, the Vistula flowed under the castle and the cathedral [1]. The largest changes in the Vistula riverbed on the territory of the Town were made at the turn of the 19th and 20th centuries, what is illustrated by the plans from 1815, 1865 and 1914 included in the book by Kwiatkowski (1919) (Fig. 1). After the first regulation, that had taken place in 1815, the river was reaching Kocmierzow and creating a large number of confluences and clumps covered with wicker. Later on, the meandering river moved westward and increased the number of confluences and clumps. Large scale regulation works were started not until 1873 due to the flood that occurred one year before. The present Vistula course results from regulation works that were carried out in 1914.

The San estuary changed its location as well. Nowadays, it is situated within 11 km from the Town; however, in 18th century it flowed into the Vistula about 5 km from Sandomierz [7].

Plans for further regulation were interrupted by the outbreak of the second world war. By then, it was managed to build embankments along the entire length of the Town. The river, that was regulated in such a way, had to reach a depth of 1,5 m. However, due to low water levels, shallows started to emerge on both its sides. Because of large amounts of carried sediments, the depth varies from 1,5 to 4 m. In the years of 1903–1909, it was managed to build two river ports. One of them covered the area of 25 000 m^2, and the second one was located at the foot of the castle.Regulations of the Vistula were continued in the interwar period, and the result of those works were transversal dams, known in the region as "traverses" or "caps" (Phot. 1) [14].

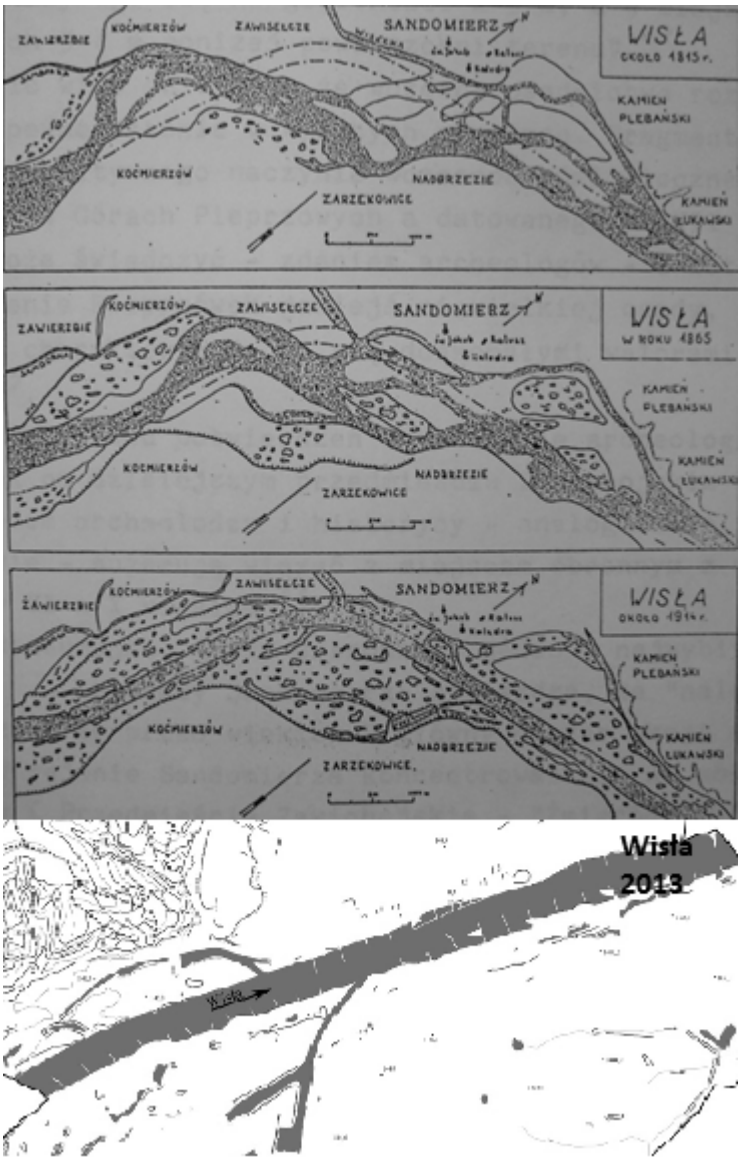

Fig. 1 – **The Vistula Course in Sandomierz from 1815, 1865, 1914, 2013**
Source: Kwiatkowski J. 1914. Vitula near Sandomierz, the Polish Tourist and Sightseeing Society.

Phot. 1 – **A Transversal Dam on the Vistula in Sandomierz and the Inter-Embankment Zone within the Town's Territory Covered with Wicker, Bushes and Trees**
Source: From the author's private archives.

These dams, also called "spurs", start with the bank and cut perpendicularly through the river current. They are mostly used in order to move the current away from the banks, and form calm water areas in the brink zone of spurs. These spurs, on the territory of the Town, are made of gravel and stone material [3].

The shape of the Vistula within the territory of Sandomierz has been completely changed during the past few centuries. From the meandering and overflowing river to the regulated and embanked one. The main cause for river regulation not only within Town's boundaries, but also throughout its length, was to create a convenient transit route and gain new investment areas.

The lowest level of water in the Town as well as throughout the Vistula's entire length occurs in October. A raised water level, related to thawing snow, falls at the end of February and the beginning of March. A low water level is noted again at the turn of May and the second half of June (however, it is not as low as it is in October). There may occur overflows during this period, that are caused by the largest amounts of rain at this time.

The area that is the most at risk of flood is the territory of the Town situated in the Sandomierska Hollow. It is one of its parts that was built after completing the river regulation works in the early 20th century.

The study by W. Wiacek [14] indicates that the wicker, causing problems in the inter-embankment zone today, was planted there intentionally. There were created vast wicker plantations that provided valuable material for building fascine dams (Phot. 2) [6]. It also played the role in protecting and preserving the banks.

The flood that occurred in 2010 led to inundation of the right-hand part of the Town. Due to exceeding the alarm level on 17th May, the Vistula threatened the right-bank part of Sandomierz. The weakest point was in Kocmierzow where embankments, were being additionally strengthened,from 18th to 19th May, with the construction of a temporary clamp. The Vistula broke the temporary clamp on the 50-metre-long embankment. The 2,5-metre-high wave culmination reached the Town on 19th May at 10 p.m. The huge mass of water (240 m/s) overflowing the breach led to evacuation of that part of the Town and the Tarnobrzeg suburbs inhabited by 4500 people. At that time, the Vistula exceeded the alarm level by 7 m. The entire right-bank part of the Town was flooded (Fig. 2).

Phot. 2 – **The Example of Stone and Fascine Dam on the Vistula Bank** Source: From the author's private archives.

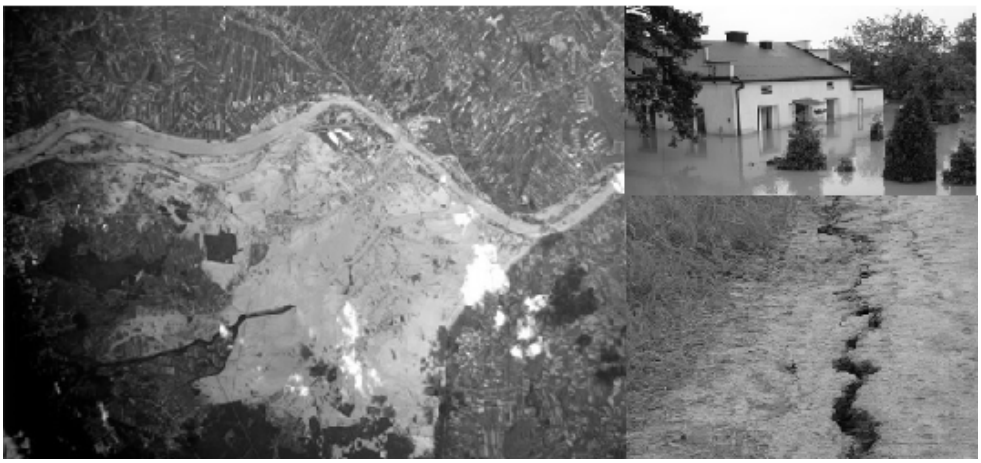

Fig. 2– **The Territory of Sandomierz and its Surrounding Areas Flooded as a Result of Breaking the Embankment in Kocmierzow**
(Source: http://www.gadu-gadu.pl/satelitarne-zdjecie-zalanego-sandomierza)

The ford on the Vistula was closed due to inundation of the route between Sandomierz and Tarnobrzeg. During the day of coming wave culmination the Vistula was 830 cm deep. It was the largest flood in the history of the Town as far as flooded areas and damage are concerned. The level of water was raising at such a rate that not all inhabitants managed to evacuate. The embankments along the entire length were soaked not only with rain water, but also with water from the river. Because of many passing cars that took part in the rescue operation, the embankments underwent cracking. It could lead to emerging of further breaches and sudden inrushing of another mass of water.

After the flood, there was a discussion on cleaning the area among the embankments. It was concluded that the main reason for flooding the Town's territory was the riverbed covered with wicker, bushes and trees. It was believed that they prevented the water outflow during the period of raised water level. Their clearance was started in February. The territory subjected to clearance covers 19-hectare area on both sides of the Vistula and is extended above as well as below the Town. It was also decided to deepen the riverbed (known as desilting) and build new and higher embankments. According to local authorities, this vegetation was one of the major causes of flooding the Town.

Changes in the Vistula Valley on the territory of the Town were related to its drainage and development, increasing inland waterways as well as providing flood protection. In order to do so, it was decided to straighten and concentrate the river course, cut off the meanders, deepen the river, and build the new embankments. All these actions resulted in a negative impact on the ecosystem of the river and its valley, what led to increased flood losses. The main causes of the flood in the Town of Sandomierz in recent years are: a poor condition of embankments (lack of maintenance and money for their modernisation caused negligence of this infrastructure) and narrowing the floodplain (the inter-embankment zone). The industrial and housing district that was builton the floodplain – the Sandomierska Shallow – is still at the risk of flood although existing embankments. All works whose aim is to clean the inter-embankment zone from bushes and trees, repair damaged embankments and raise existing ones seem to be only temporary flood protection. The existence of bushes and trees in river valleys and in inter-embankment zones is highly controversial. On the one hand, this type of vegetation usually stores a large amount of water and lowers the speed of its flow. It reduces the pressure of water on embankments as well. On the other hand, when the area of inter-embankment zone is not wide enough, the trees growing there dam up the flowing water [5]. There are several methods that are used in order to strengthen existing embankments. First of them is strengthening embankments with organic vegetation that has well-developed root system. The next one involves using stones, known as gabions. They are boxes made of metal mesh filled with stones. The third method concerns concrete embankments [11].

Conclusion. Hydrological conditions of Sandomierz played and still plays a vital role for the Town. The Vistula was one of the major factors contributing to localisation and development of the settlement. The river is not just a convenience and merit, but also a threat of flood. Floods in Sandomierz are natural phenomena that will always be a threat to its inhabitants. Complete flood prevention is not possible; however, such phenomenon can be successfully limited. Foundations for effective flood protection lie in legal provisions. Built-up areas, even if they are protected with embankments, are subjected to damage caused by flood waters.

One of the reasons for this state of affairs, not only in Sandomierz, but also in the whole Poland are embankments that are too low and made of low-strength soils, deprived of proper stuffing and slope protection. Also regulation works, that have been carried out since the 19th century, results in shortening the river course, reshaping the riverbed, and creating relatively narrow area of the inter-embankment zone. All these activities led to considerable acceleration of flood waters flow – the river course has been shortened.

The Town is situated in specific geological conditions. On the one hand the Sandomierska Upland is covered with loess soils, that are subjected to erosion from water;on the other hand the Sandomierska Hallow covered with diluvial soils is at the risk of flood.

Poor flood protection causes great damage not only to river valley ecosystems, but also to entire infrastructure of a town. Local authorities should focus on temporary solutions, such as raising and repairing embankments;

however they also ought to designate non-buildable areas on floodplains as well as improve ground retention. In Poland, a system of polders and reservoirs should be created in order to minimise effects of flood. Only a coherent system may reduce the risk of flood. The success in flood protection will be achieved at the time of undertaking interdisciplinary activities, that include: spatial planning, insurance system, education, effective evacuation planning, hydraulic engineering, river retention, melioration, river regulation.

Bibliography

1. *Bulinski M.* 1879. Monograph on the Town of Sandomierz, Warsaw. **2.** *Ciepielowski A., Dabkowski Sz. L.* 1995. Problems of Small Retention in Forests, Sylwan 11. **3.** *Debski K.* 1970. Hydrology, Arcades, Warsaw. **4.** *Falkowski E.,* 1982. The Nature of a River, [w:] Piskozuba A. (red.) Vistula. Monographof the River, Transport and Communication Publishers, Warsaw. **5.** *Jankowski W.,* 1997. Is it Possible to Reconcile Environmental Protection with Flood Protection. [w:] Ecological Methods of Flood Prevention, The Olawa and Nysa Klodzka Rivers Foundation, Wroclaw. **6.** *Jedryka E.,* 2007. Hydraulic Structures Made of Natural Materials,[w:] Water – Environment – Rural Areas, the Institute for Land Reclamation and Grassland Farming in Falenty, v: 7 no. 2b (21). **7**. *Karaszewska U.,* 1967. Natural Conditions for Development of Sandomierz, [w:] Pazdur J. (ed.) Sandomierz Studies, People's Publishing Cooperative, Warsaw. **8.** *Kondracki J.*, 2000. Regional Geography of Poland, Polish Scientific Publishers PWN, Warsaw. **9.** *Kwiatkowski J.*, 1914. Vitula near Sandomierz, the Polish Tourist and Sightseeing Society. **10.** *Lajczak A.* 2006. River Training vs. Flood Exposure. The Example of The River Vistula Between Skoczow and Pulawy, [w:] Infrastructure and Ecology of Rural Areas, the Krakow Branch of the Polish Academy of Sciences, No. 4/1/2006. **11.** *Mamak W.* 1958. Regulation of rivers and streams, Arcades, Warsaw. **12.** *Radczuk L., Zyszkowska W.* 2001. Ways of Using High-Risk Flood Zones, the World Bank Project Coordination Office, Wroclaw. **13.** *Wasowicz T.* 1967. Sandomierz Studies. Materials on the History of the Town and Region of Sandomierz, Sandomierz. **14.** *Wiacek W.* 1931. What Has Been Done for the Vistula at the time of Independent Poland in the County of Sandomierz, Machow. **15.** *Woloszyn J., Czamara W., Eliasiewicz R., Krezel J.* 1994. Regulations of Rivers and Streams, the Agricultural University, Wroclaw. **16.** *Zelazinski J.* 2000. General Information about Overflows and Floods in Poland, [w:] Environmentally-Friendly Strategy on Flood Protection, The Society for Earth, Oswiecim. **17.** *Bednarczyk S., Jarzebinska T., Mackiewicz S., Woloszyn E.* 2006. Vademecum for Flood Protection, the National Council of Water Management, Gdansk. **18.** *Tomialojc L.* 1993. Nature and Environmental Conservation in Polish Lowland River Valleys, The Institute of Nature Conservation, Krakow, – p.234.

Noga B. **Changes in the course of the Vistula riverbed vs. the risk of flood on the territory of Sandomierz.** Vistuladiffers, throughout its length, in progress of regulation works that have been started in the 19th century. Around 3,8 km of its length lies within the territory of Sandomierz. The Town has specific geological and morphological location. On the northern side, there is the Sandomierska Upland covered with loess soils(that are subjected to erosion from water); on the other one, there is the Sandomierska Valley covered with diluvial soils (a high-risk flood area). The results of carrying out regulation works have led not only to shortening the river course and reshaping the riverbed, but also building the new embankments as well as creating relatively narrow area of the inter-embankment zone. In recent years, there were some floods one the territory of Sandomierz and they were caused, in large part, by the poor condition of embankments (lack of maintenance and money for their modernisation resulted in negligence of this infrastructure), and developing as well as narrowing high-risk flood areas.

Keywords: flood, Vistula, river regulation.

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