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# GEOGRAPHIA POLONICA



**33** PART ONE

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# GEOGRAPHIA POLONICA

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ABSTRACT

Abstract: This paper discusses the role of the state in the development of the economy. It examines the impact of government intervention on the growth and development of the economy. The paper also discusses the role of the state in the provision of public goods and the regulation of the economy. The paper concludes that the state plays a crucial role in the development of the economy and that government intervention is necessary to ensure the growth and development of the economy.

## PLANATION SURFACES IN THE LIGHT OF THE 1:300,000 GEOMORPHOLOGICAL MAP OF POLAND

MARIA BAUMGART-KOTARBA, SYLWIA GILEWSKA, LESZEK STARKEL

### INTRODUCTION

Planation surfaces, being included into the contents of the 1:300,000 Geomorphological Map of Poland, are surfaces of subaerial destruction which resulted from the joint action of various factors in pre-Pleistocene *sensu stricto* times. These surfaces cut across rocks of different resistance and various structures forming the Sudetes Mts., together with the Sudetes Foreland, the Central Polish Uplands and the Carpathians. North of lat. 51°N the down-warped Central Polish Uplands merge gradually beneath the unbroken cover of glacial and glacio-fluvial deposits. In the Polish Lowland, therefore, old surfaces are now buried by Miocene, Pliocene and Pleistocene deposits (S. Biernat 1968; E. Ciuk 1961; F. Różycki 1956). Beyond the limit of the last Scandinavian glaciation, young destruction surfaces of exogenic origin also developed on the older glacial and glacio-fluvial deposits (J. Dylík 1953; K. Rotnicki 1966). A discussion of the fossil planation surfaces and Pleistocene surfaces of destruction, however, falls outside the scope of this paper. Its aim is to show the regional differentiation in the development and state of preservation of the pre-Pleistocene planation surfaces in southern Poland in relation to morpho-structure, its general neotectonic tendencies and trends of evolution.

Regional analysis is based upon the 1:300,000 Geomorphological Map of Poland which was prepared in the Cracow Branch of the Institute of Geography, Polish Academy of Sciences, during the period 1966 to 1973, acting in cooperation with specialists in regional geomorphology from Wrocław, Poznań, Warszawa, Lublin, Toruń and Gdańsk. The regional maps described in this paper were prepared by H. Piasecki (the Sudetes Mts. and Sudetes Foreland), S. Gilewska (the Uplands of Silesia and Małopolska), H. Maruszczak (the Lublin-Volhynian Upland), K. Klimek and L. Starkel (sub-Carpathian Basins) and L. Starkel (the Carpathians).

### SCOPE OF CONTENTS, DEFINITION OF TERMS

The 1:300,000 Geomorphological Map of Poland shows the main morpho-structures which differ by their general tendencies towards neotectonic and geomorphic development, namely:

(A) Crystalline massifs and planated mountains of old folding produced by uplift along fault-lines (the Sudetes, and the Świętokrzyskie Mts.).

(B) Crystalline massifs and young fold mountains produced by uplift along tectonic lines (the Tatra Mts.).

(C) Young fold (flysch) mountains — folded after the Paleogene (the Carpathians) (see Chart 2 at the end of the volume).

(D) Horizontal and subhorizontal structures composed of Mesozoic and Neogene sedimentary rocks (the Stołowe Mts. in the Sudetes, and the Central Polish Uplands) (see Chart 1 at the end of the volume).

Each of the morphostructures comprises erosional-denudational relief types which differ by relief energy and age, for instance, mountains of intermediate height (*Mittelgebirge*), low mountains, foothills of different heights, plateaux and upland ridges, upland divides and basin floors etc. Supplementary data include, for instance, primary fault- and flexed scarps, fault-line scarps, subsidence area, denudational scarps etc. (for more details see "Legend for the Geomorphological Map of Poland 1:300,000" — L. Starkel 1974).

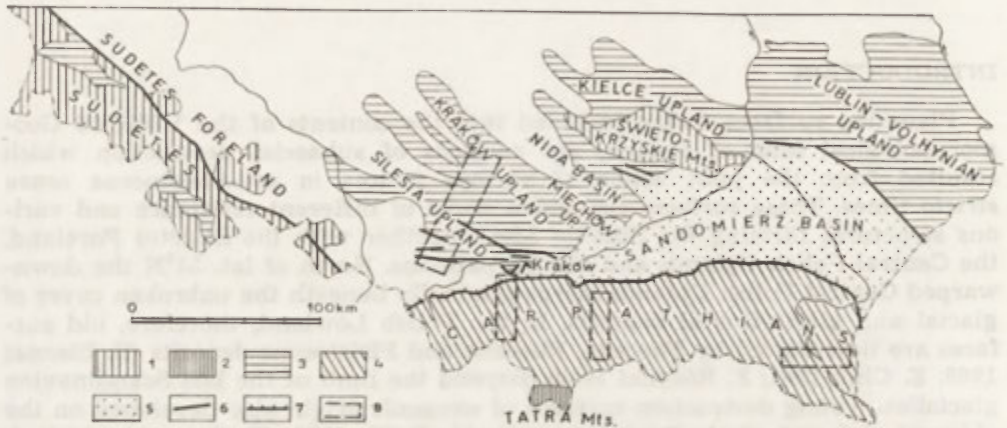


Fig. 1. Map showing the occurrence of the remaining fragments of different planation surfaces within:

- 1 — crystalline massifs and planated mountains of old folding, 2 — crystalline massifs and young fold mountains, 3 — young fold (flysch) mountains, 4 — horizontal and subhorizontal structures composed of Mesozoic and Neogene sedimentary rocks, 5 — depressed areas with prevailing accumulation, 6 — main fault and flexed scarps, 7 — front of the Carpathian overthrusting, 8 — localization of the 1:300,000 Geomorphological Map samples

The various erosional-denudational relief types include either traces or remnants of planation surfaces now preserved as more or less extensive (a) flat or undulant summit plains above which hard rock residuals (ridges and hills) may rise; (b) lower mountain steps usually slightly inclined; (c) flat or gently rolling surfaces of the foot-hills, upland plateaux and broad upland ridges above which uponliers, outliers or hard-rock residuals may rise; (d) assemblages of flat-topped or rounded ridges and hills of similar heights which indicate the former existence of a planation surface now heavily dissected; (e) flat or undulant divides of low relief (up to 40 m) occupying the interior of broad tectonic or denudational depressions.

The old surfaces differ by origin, age and degree of modification. On the map concerned, within the diverse relief types the following surfaces were distinguished:

(1) The Paleogene planation surface — it includes fragments of the true regolith — covered pre-Oligocene surface due to tropical weathering.

(2) Planation surfaces founded in the Paleogene — these levelled surfaces do not exactly correspond to the prior Paleogene planation surface since the re-



lith mantle has been removed from them. Their formation began as early as the Paleogene.

(3) Pre-Tortonian (= pre-Badenian) surfaces — these surfaces already existed before the transgression of the Opolian seas. They were either rising above the sea-level or in part drowned and subsequently exhumed without distinct modification.

(4) Surfaces founded in the Neogene — these surfaces formed during the various phases of the Miocene, Pliocene and the Lower Quaternary, and were subsequently modified by later processes.

The above chronologic data included in the map's content point either to the beginning of relief development or to the phases of relief planation.

The earlier 1:25,000 geomorphological mapping of selected areas revealed that the state of preservation of the old surfaces is not good since most of Poland was invaded by the Scandinavian inland-ice, while the ice-free areas were subjected to intense periglacial processes. As a consequence, the old relief features had to be reconstructed (L. Starkel 1965). It was impossible to represent true to scale the individual remnants of a planation surface which survived on the this map. Consequently, the map shows only the occurrence and extent of the various genetic relief types, together with the basic chronologic data. The different erosional-denudational relief types frequently surround, in a series of steps, the great tectonic elevations reflecting the vertical zonation of features and the successive stages of development. A complex analysis of the mutual relation of various genetic-chronologic relief types and of the associated smaller landforms (especially of tectonic and denudational scarps, stream-valley net etc.), together with supplementary data on the type of weathering residues and of different allogenic covers makes it possible to reconstruct the course of relief planation, dissection and subsequent destruction of the older surfaces of planation (viz. *Geomorfologia Polski*, 1972).

## REGIONAL ANALYSIS

### THE SUDETES MTS. AND THE SUDETES FORELAND

The 1:300,000 Geomorphological Map of Poland shows the twofold structural division of the area into the Variscan fundament of crystalline massifs and tightly folded Paleozoic rocks and the Mesozoic cap-rock of horizontal and subhorizontal bedding. The area was subjected to intense relief planation in pre-Oligocene times. During the Mid-Oligocene phase of uplift the Paleogene surface of planation was undulated and divided by the great border fault into the higher Sudetes Mts. and their foot-hills and the lower Sudetes Foreland, being separated by a distinct tectonic scarp from the Sudetes. The Sudetes in turn also broke into minor fault blocks of various heights (over 1000 m a.s.l., 500–1000 m, and under 500 m) which are divided by great tectonic basins and smaller grabens. Differential upheaval of the blocks and cyclic relief evolution in the Neogene produced three distinct "relief horizons" in the sense used by A. Jahn (1953).

On this map relief horizon I is expressed as mountains of intermediate heights with remnants of a planation surface founded in the Paleogene. In the highest inner blocks — watershed ranges, the flat or undulant summit plains with monadnocks (Śnieżka 1603 m in the Karkonosze) extend up to 1200–1480 m a.s.l. In the outer blocks this planation surface lies generally at 700–1000 m a.s.l. Everywhere the summit plains consist of fresh or slightly decomposed rocks on which only thin weathering products are found, whereas the

kaolin and laterite mantle has been removed from them. Thus it appears that the present flats are probably the stripped basal surface of weathering.

In the Sudetes Foreland which showed long lasting subsidence tendencies the rolling Paleogene planation surface survived at 350–400 m a.s.l. On the magmatic and metamorphic rocks it bears thick kaolin and laterite covers *in situ* and massive inselbergs (400–716 m a.s.l.) rising above it. This is the pre-basalt or sub-basalt surface. In the Sudetes Foot-hills and Foreland Oligocene basaltic flows buried the regolith covered surface thus terminating the Paleogene planation (H. Teisseyre 1960; L. Pernarowski 1963; W. Walczak 1970, 1972).

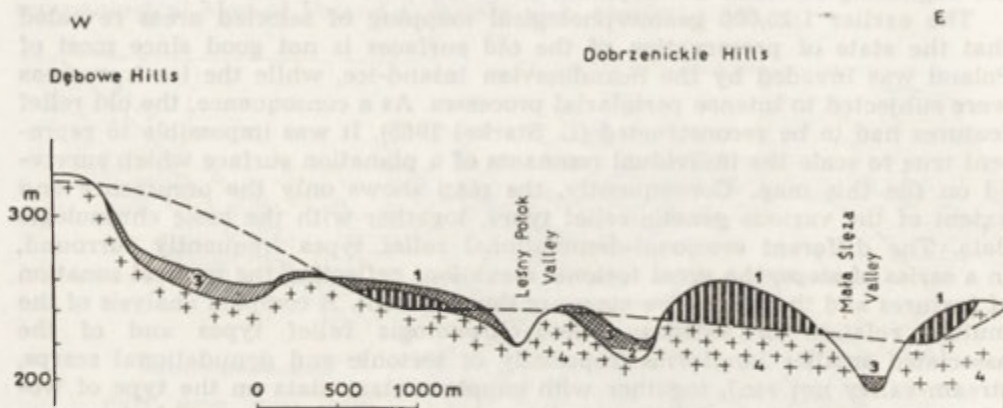


Fig. 2. Parallel section across the Wzgórza Dębowe and Dobrzeńskie showing the reconstructed pre-basalt surface (stippled) and the basaltic covers (after L. Pernarowski 1963)

1 — basalt, 2 — Upper Miocene, 3 — Pleistocene, 4 — crystalline bedrock

Relief horizon II includes mountains of intermediate height and foot-hills with planation surfaces founded in the Neogene. The surfaces which extend along the valleys formed by back-wearing of the valley slopes and by pediment development under periodically semi-arid conditions of the Upper Oligocene–Lower Miocene at 600–800 m a.s.l. in the Sudetes and at about 400 m a.s.l. in their Foreland (W. Walczak 1972). In front of the retreating scarps and slopes outliers were left. These surfaces are best preserved in the outer subdued ranges. Phases of uplift, dissection and renewed planation being associated with the removal of regolith are documented by sand and gravel, and clayey deposits with brown coal intercalations which filled in the valleys and depressions of the Sudetes Foreland (H. Teisseyre 1960; L. Pernarowski 1963; H. Piasecki 1964; W. Walczak 1970, 1972).

Relief horizon III contains low foot-hills with the lowest planation surfaces founded in the Neogene (Upper Miocene–Lower Pliocene). These sub-slope surfaces of pediment type including fossil bolsons developed on medium resistant and weak rocks at 300–360 m a.s.l. in the low foot-hills and rise upstream to 400–500 m, whereas numerous characteristic domical hills formed on the resistant rocks. The Mid- and Upper Pliocene oblique and differential uplift of the Sudetes was followed by deep valley incision into the rocky basin and valley floors. Selective erosion also gave rise to typical structural escarpments in the Central Sudetes (W. Walczak 1968, 1972).

## THE CENTRAL POLISH UPLAND BELT

The Central Polish Upland belt includes several units, namely the Uplands of Silesia-Cracow and Miechów, the Nida Basin, the Kielce Upland and the Lublin-Volhynian Upland.

## The Upland of Silesia-Cracow

In the Tertiary monocline, alternations of soft Mesozoic rocks form a typical scarpland region separated from the southern fault blocks and grabens by a distinct flexed-fault scarp (K. Bogacz 1967; S. Doktorowicz-Hrebniński 1935; S. Dżużyński 1953). The faulted upland in turn dips beneath the Miocene marine deposits of the Carpathian foredeep. On the central watershed of the Cracow Upland composed of hard Upper Jurassic limestones and showing long lasting uplift tendencies the highest planation is expressed as a flat or gently rolling summit surface containing numerous buried karst hollows of different sizes. It carries massive residual hills of biohermal limestone (e.g., at Ogrodzieniec 504 m a.s.l.). The surface lies highest in the Myszków-Kraków anticline and slopes gradually northwards from 480 to 390 m a.s.l. The surface discussed is believed to represent a humid-tropical karst-plain with mogotes of Paleogene foundation (M. Klimaszewski 1958a, 1958b; J. Polichtówna 1962). The actual surface, however, may well be younger, for illite-montmorillonite weathering clays and a cave breccia with Upper Pliocene bats preserved in the Podlesice residual (K. Kowalski 1951) indicate advanced lowering of the limestone surface by that date. The lack of through-flowing caves and the occurrence of numerous vertical karst pits indicates early isolation of the highest upland surface by the incision of deep strike valleys in the Neogene. The surface described overlooks its northern footslope, the Silesian scarpland in the west, the faulted upland in the south and the Miechów upland in the east. These areas contain either tectonically deformed pre-Badenian surfaces or Pliocene surfaces of varying appearance.

The extensive northern footslope (200–300 m a.s.l.) mostly masked by Pleistocene allogenic sediments carries massive residuals — outliers. It probably developed by pedimentation on the southern shores of the great Pliocene freshwater lake or swamps which occupied North Poland.

In the south, the lower step of the summit surface is a gently rolling plain at 450–460 m a.s.l. containing small hard-rock residuals (J. Pokorný 1963), karst depressions with infills of unknown ages and smooth slopes of the upper valleys into which deep karst canyons were incised at the close of Tertiary and in Quaternary times (S. Dżużyński et al. 1966). The distribution of residuals suggests that these resulted in part from later selective denudation and not wholly from prior karst planation, and that this surface may well be post-Badenian, karst planation reaching the former level of the waterproof Opolian marine clays.

The Silesian cuervas (Map 1) formed on outcrops on Mid-Jurassic sandstones and conglomerates (230–330 m a.s.l.), Upper Triassic limestones and breccias (240–359 m a.s.l.) and Mid-Triassic limestones and dolomites (300–398 m a.s.l.). The cuervas are divided by flat-floored strike valleys on the soft rocks capped with Pleistocene deposits. The present master valleys are consequent upon the general northward and southward descent of the earlier summit surface, and the rivers pass in water gaps through the cuervas. Because of varying resistance of the cuesta-formers the northern scarps are so thoroughly dissected that they contain mostly rounded ridges and hills with accordant tops. On the contrary, the limestone and dolomite escarpment includes synclinal plateaux



and broad bevelled ridges with remnants of a pre-Badenian planation cut through Mesozoic and Paleozoic rocks. Its unevenness results from later deformation by broad warping, faulting and flexing, and from post-Opolian selective destruction. Formation of Pliocene pediments carrying outliers was controlled by the level of the downthrow side or foreland of the tectonic scarp. The successively lower *glacis d'érosion* is early Quaternary on evidence of incised pre-glacial valleys (S. Gilewska 1963, 1972).

The development cycle of the faulted upland which in the Badenian formed the northern border of the Carpathian foredeep (S. Alexandrowicz 1960; K. Bogacz 1967; S. Dżułyński 1953), shows either two (the Cracow Upland) or three (the Silesian Upland) fill- and exhumation stages. The upheaved fault blocks and grabens were exhumed from beneath the thin Opolian cap-rock, and the Cracovian/Elster and Middle Polish/Saale glacial and glacio-fluvial deposits as well. The successive stages of exhumation associated with epigenesis were controlled by base-level changes in the sub-Carpathian basins (S. Doktorowicz-Hrebniński 1935; S. Gilewska 1963, 1967, 1972; S. Dżułyński et al. 1966). Buried karst hollows, facets, marine cliffs and breccias which survived in the exhumed fault blocks (S. Alexandrowicz et al. 1960) suggest that the old landforms tended to be conserved here.

In the Miechów Upland, the upland plateaux and broad ridges consist of nearly flat lying Cretaceous rocks (mostly marl), and Badenian cap-rock. Two distinct planation surfaces are here preserved. The older one is of pre-Badenian foundation and slopes eastward from 380 m to 270 m a.s.l. It contains residuals with traces of decalcified Cretaceous gaises and *opoki*<sup>1</sup> (J. Rutkowski 1965), *padolę* or structure controlled elongated and flat-floored depressions, and valleys (A. Michalski 1884, et al.). The younger surface which cuts across the Opolian marine cap-rock and Cretaceous bedrock is post-Badenian (H. Ruszczyńska 1958). The successive stages of valley deepening are documented by rock-cut pre-glacial terraces (J. Flis 1956; C. Radłowska 1966; J. Łyczewska 1969). The old relief is in part conserved by allogenic deposits of the Cracovian glaciation and by loess up to 10 m thick.

#### The Nida Basin

In the north, a monotonous plain of 230–250 m a.s.l. originated throughout the Tertiary on the horizontal Cretaceous marls of the Miechów syncline axis. A lower pre-glacial step 220 m a.s.l. is dissected by deep also pre-glacial valleys (J. Czarnik 1966; W. Nowak 1970). In the highly mobile southern part of the area, distinct variations in lithology and resistance of Cretaceous and Miocene deposits, and selective erosion complicated by Badenian and post-Sarmatian minor folding, faulting and downwarping (the latter continuing into present times) are responsible for the present types and amplitudes of relief (J. Czarnocki 1948; J. Flis 1954; T. Osmólski 1963; S. Pawłowski 1965; A. Radwański 1969). The Sarmatian sedimentary surface survived as low table-land (240–280 m a.s.l.) on the resistant horizontal detritic deposits only at the foot of the Świętokrzyskie Mts. (M. Baranowska-Janota 1965). In the remaining area, Pliocene planation surfaces cut across the diverse rock types and structures and range in altitude from 180–220 m a.s.l. on soft clays in the divides and on the depressed cuesta of folded gypsum to 260–330 m a.s.l. in the high standing faulted Pińczów ridge (C. Radłowska 1966) which carries inversional uponliers of Miocene limestone. The 80 m thick <sup>1</sup>Witów gravel and sand series laid down in an erosional channel in the south-west part of this area (compare also

<sup>1</sup> Marls and marly limestone having a siliceous skeleton.



p. 15) indicated further downwarping at the break of the Pliocene and Lower Quaternary (S. Dzułyński et al. 1968). The successively lower flattenings preserved in the divides are Pleistocene.

### The Kielce Upland

The heart of the area lying within the Świętokrzyskie anticlinorium are the folded and uplifted Świętokrzyskie Mts. This Variscan orogen, buried during the Mesozoic was stripped in post-Cretaceous times and re-exposed as low mountains of typical Appalachian relief. The parallel mountain ranges form three steps. The highest central range (611 m a.s.l.) consists of the hardest Cambrian rocks, the lower ranges (ca 350–430 m a.s.l.) are formed of Cambrian and Upper Paleozoic rocks, the lowest step (ca 300–350 m a.s.l.) includes the outer ranges composed of Mesozoic rocks. Steep-sided ranges and ridges rise above the low foot-hills with a distinct Pliocene planation surface of pediment type at 280–300 m being capped with Pleistocene allogenic deposits. It passes eastward into the levelled surface of the downthrown Opatów Upland. The question is do the above steps reflect lithologic control or the successive stages of evolution? The existence of a prior surface either of structural or destructional origin (S. Lencewicz 1934 b) is suggested by the inherited radial arrangement of stream-valleys which break the ranges in a series of gaps. It is difficult to reconstruct the relief evolution because the age of the last folding of the Świętokrzyskie Mts. is not known exactly. Furthermore, detailed geomorphological maps of the mountains are lacking. Fossil marine cliffs, breccias and other sediments left by the Opolian sea in the southernmost isoclinal valleys indicate that the ridge-and-valley topography did already exist in pre-Badenian times (A. Radwański 1969).

The development stages of the Kielce Upland may be reconstructed by analyzing the landform complex of the mountain foreland formed of weaker Cambrian and Paleozoic rocks and tilted Mesozoic strata of varying resistance. The foreland ascends in three steps towards the mountains. The dating of steps is controversial. The lowest step contains divides with fragments of a Pliocene planation surface at 160–180 m a.s.l. bearing Pleistocene allogenic deposits. It truncated Cretaceous marl and patches of Oligocene marine deposits under which relics of the Eocene decalcified surface (123–155 m a.s.l.) are buried (W. Pożaryski 1951; C. Radłowska 1963, 1968). Outliers rise above the Pliocene surface in front of the middle step (200–240 m a.s.l.) which includes

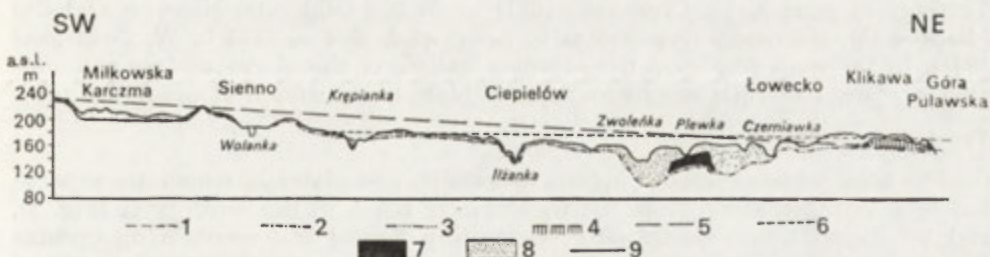


Fig. 3. Scissor-like arrangement of planation surfaces in the NE foreland of the Świętokrzyskie Mts. (after C. Radłowska 1962)

1 — top of Jurassic rocks, 2 — top of Cretaceous rocks, 3 — top of Cretaceous rocks (Danian), 4 — Oligocene rocks, 5 — line connecting relics of the Paleogene planation surface, 6 — line connecting relics of the Pliocene planation surface, 7 — pre-glacial deposits, 8 — glacial deposits, 9 — presumed top of bedrock

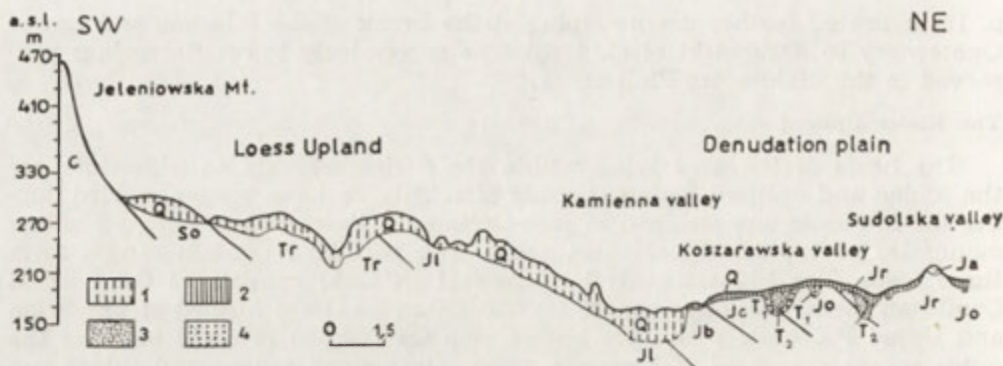


Fig. 4. Section across the NE foreland of the Świętokrzyskie Mts. (after D. Kosmowska-Suffczyńska 1966)

C — Cambrian, So — Silurian, Tr — Triassic, Jl — Liassic, Jb — Bajocian, Jc — Callovian, Jo — Oxfordian, Jr — Rauracian, Ja — Astartian, T<sub>1</sub> — Paleogene, T<sub>2</sub> — Neogene, Q — Quaternary; 1 — boulder clay, sand and gravel under loess cover, 2 — remains of boulder clay, sand and gravel, 3 — sand with admixture of debris, clay and silt, 4 — debris with admixture of silt and clay

low monoclinical ridges of Jurassic limestone and hard Cretaceous marl with remnants of the "Paleogene planation surface B" (D. Kosmowska-Suffczyńska 1966, 1968). The intervening strike valleys contain Miocene valleys and karst depressions now conserved by diverse weathering residues and allogenic deposits which range in age from Eocene to late Pliocene (S. Z. Różycki 1967). The highest step (260–300 m a.s.l.) is on the coarse-grained Mesozoic, Paleozoic and Cambrian rocks which form the levelled Opatów upland surface being considered as the "Paleogene planation surface A" (D. Kosmowska-Suffczyńska 1966, 1968). It is mantled with glacial and glacio-fluvial sediments and loess up to 30 m thick. Explanations of this vertical differentiation of the "Paleogene planation surface" include a scissor-like arrangement of diverse planations (C. Radłowska 1963) (Figs. 3, 4) and the lithologic control of planation dynamics (D. Kosmowska-Suffczyńska 1966). The other view is that the middle surface was founded at the furthest in the Miocene since it postdates the Oligocene inundation, whereas the foundation of the highest surface may be Miocene-Oligocene or older (S. Gilewska 1972). This surface, however, has been modified by processes moulding the Świętokrzyskie Mts. in times that followed the mountain uplift along the revived transverse fault-lines either in the Lower Tertiary in general (J. Czarnocki 1931) or in the Oligocene-Miocene and the Miocene (M. Klimaszewski 1958 a; S. Lenciewicz 1934 a, 1934 b; W. Pożaryski 1951). In the map discussed the complex nature of the above surface is indicated as "low foot-hills with remnants of planation surfaces of unknown age".

#### The Lublin-Volhynian Upland

The area contains smooth upland elevations and plateaux which are separated by a complex scarp from the Sandomierz Basin in the south-west (Fig. 5), and by denudational northfacing scarps (dip-slopes) and southfacing cuestas from the strike valleys, the broad upland depressions and the Polish Lowland in the north. Some of the scarps show active uplift, e.g., the dip-slope of the major watershed plateau Roztocze (T. Wyrzykowski 1959) (H. Maruszczak 1972). The directions of the main morphostructural elements and their amplitudes are clearly controlled by lithology, rock resistance and cleavage. The highest elevations and greatest amplitudes are on the hardest Upper Cretaceous

ous gaizes and *opoki*, whereas the flat or rolling basin floors of low relief developed on the soft marly limestones and chalk (H. Maruszczak 1966, 1972).

The upland comprises two summit surfaces, the highest of which is preserved at 320–360 m a.s.l. in the Roztocze, at 280–300 m a.s.l. in the central Lublin upland plateaux and elevations and it descends northward to 200 m a.s.l., and at ca 280–290 m a.s.l. in the broad Volhynian upland ridges. This surface is overlooked by dome-shaped residuals of the oldest relief, some of which have duricrusted caps of Sarmatian deposits. Such residuals occur above the tectonic scarp of the Roztocze and Lublin Upland and in the Chelm Hills divided by wide karst basins on soft chalk. Under the Upper Eocene/Oligocene hill cappings there survived relics of the true Eocene surface form-

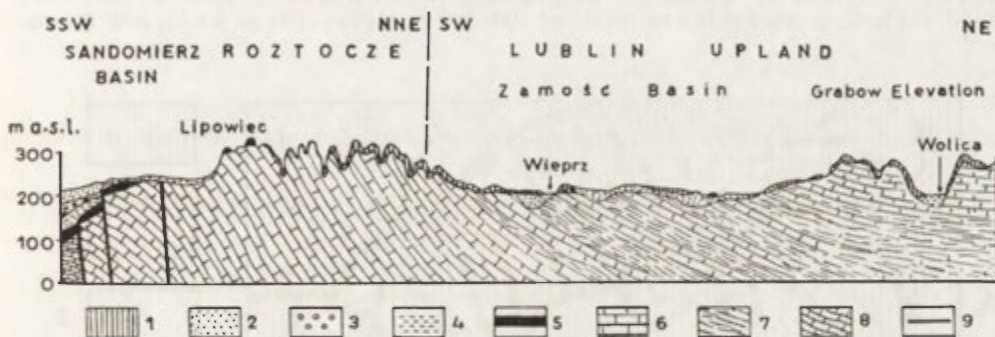


Fig. 5. Section across the Roztocze and eastern part of the Lublin Upland (after H. Maruszczak 1972)

1 — loess, 2 — alluvial, limnic and slope deposits (Holocene and Pleistocene), 3 — glacial and glacio-fluvial sediments, 4 — clayey and sandy deposits (Miocene), 5 — limestones (Miocene), 6 — *opoki* and gaizes (Upper Cretaceous), 7 — marl, in part marly *opoki* and gaizes (Upper Cretaceous), 8 — marl, dolomite, limestone (Jurassic), 9 — faults

ed of pumice-like decalcified *opoki* (Ł. Górecka 1958; M. Harasimiuk 1963, 1975; H. Maruszczak 1966, 1972). The subsequently younger surface being ca 20 m lower is by far the most extensive. It developed on typical marl in the upland elevations and plateaux and carries massive residuals. Both surfaces are locally conserved by thick loess covers which occupy some 30% of the whole upland. The ages of the summit surfaces are controversial. According to A. Jahn (1956), both surfaces of pediplain type developed under semi-arid conditions of the Upper Miocene and Upper Pliocene. H. Maruszczak (1972) dates them as Lower Pliocene and Upper Pliocene on the evidence of Upper Sarmatian duricrusts and desert rinds (M. Turnau-Morawska 1950) contained in the highest residuals of oldest relief. Following the Walachian movements of uplift was valley incision at the close of the Tertiary. Several incision phases are marked by rock-cut terraces. The formation of the lowest degradational surface of glacia type is due to periglacial processes.

#### THE CARPATHIANS

Amongst the mountains and uplands of South Poland, the Carpathians have the youngest erosional-denudational relief. The Carpathians which belong to the Alpine system were folded at the close of the Cretaceous in their inner part (the Tatra Mts.) but after the Paleogene in their outer part (the Flysch Carpathians). Rounded gravels of older flysch rock found in the Upper Krosno beds indicate syngenetic folding and denudation of the Carpathians (B. Świ-



derski 1932; S. Alexandrowicz et al. 1963) and consequently the initiation of relief development on the truncated anticlinal structures. In the Flysch Carpathians, the pattern of mountain ridges and depressions clearly reflects the low angle monoclinal thrusts in the west and the steep folds and scales in the east (L. Starkel 1965, 1972). Recent geological research shows that the Lower Miocene phase of folding was followed by thrust movements which continued into the Sarmatian (M. Książkiewicz 1972; R. Ney 1968). Displacements were on a wide scale, probably of the order of 60–80 km (S. Połtowicz et al. 1974; R. Ney et al. 1974). The above facts throw light on the ages of levels occurring in the Carpathians.

The 1:300,000 Geomorphological Map of Poland shows the stepwise arrangement of relief in the Flysch Carpathians which include mountains of intermediate height with relative relief of 400–800 m (1000–1700 m a.s.l.), low moun-



Fig. 6. Mountain ridges and their relation to resistance of bedrock (after M. Baumgart-Kotarba 1973)

1 — very resistant rock (mostly sandstones), 2 — rocks of medium resistance (sandstone-shales), 3 — little resistant rock (shale-sandstones), 4 — rocks of very little resistance (mostly shales), 5 — ridges and hummocks within the valley-level, 6 — ridges and hummocks from the dissection of the foot-hill level, 7 — ridges from the dissection of the intermontane level and ridges projecting above the foot-hill level, 8 — ridges from dismembering of the Beskidian surface; A — The Jaworzyna Krynicka Range in the Beskid Sądecki Mts. B — the Slonne Mts. and the Bieszczady Foreland

tains and high foot-hills, foot-hills of intermediate height, low foot-hills and valley floors (Chart 2). There is a rule that the higher the step, the harder is the rock on which it is preserved, and the lower the step, the smaller is its extent and the softer the bedrock — with a few exceptions (L. Starkel 1965). Each of the relief steps contains flattenings of planation type which cut across rocks of different resistance. These fragments of flattenings, the mountain ridges and hilly watersheds of levelled profiles form the basis for relief reconstruction within each of the steps. Both the destructional nature of planated surfaces and the polycyclic relief evolution is indicated by lower levels in the transverse valleys and by breaks in the long profiles of strike ridges that follow the outcrops of resistant rocks (L. Starkel 1965; M. Baumgart-Kotarba 1973, 1974) (Fig. 6).

Traces of the oldest level to which the name Beskidy level is applied (*poziom beskidzki* of L. Sawicki, 1909) are represented by summit flattenings and mountain ridges with levelled long profiles and denivelations of 200–500 m. This level survived on thick series of resistant sandstones mostly in the western part of the Polish Flysch Carpathians. The present occurrences of this level at different heights in the various mountain groups indicate later tectonic deformation.

The second level termed the intermontane level (*poziom srodgórski* of M. Klimaszewski, 1934) occurs in the low mountains and high foot-hills. It is best developed on the fringe of high ranges and reaches from 450–500 m a.s.l. in the Carpathian Foot-Hills, in the marginal part of the Carpathians up to 700–1000 m a.s.l. in the elevation axis where it is preserved on the levelled ridges. The dissection of this level rises from 250 m to 400 m.

The foot-hill level (*poziom pogórski* of M. Klimaszewski, 1934) survived on summits of the foot-hills of intermediate height with relative relief of 150–200 m. The level rises from 360–420 m a.s.l. in the Carpathian Foot-Hills to 800 m a.s.l. in the interior of mountains. It is of the pediment type and both residual and hard rock ridges stand above it. This level truncates rocks of varying resistance although being softer than those forming the intermontane level.

The lowest or riverside level (L. Starkel 1957, 1965) which corresponds to the *porieczna* or *podhorska roveń* of E. Mazúr (1963) includes flattenings within the low foot-hills which consist of soft rocks. Its height above the valley floors increases eastward from 40–50 m to 80–100 m.

The ages of levels are inferred from the relation of planations to the dated phases of tectonic movements and to correlation deposits. The thrust that has overridden the Lower Sarmatian deposits in the east where the Beskidy level does not occur indicates that the three successively younger levels extending along the valleys are post-Sarmatian. L. Starkel (1969, 1972) dates them as Lower Pliocene, Upper Pliocene and Lower Quaternary. With the formation of the lowest or riverside level of glacial type, the Witów gravel and sand series in the Sandomierz Basin is correlated (S. Dzułyński et al. 1968). The level is also dated by its relation to Pleistocene terraces being separated by only one intermediate bench from the Cracovian terrace. New data (S. Połtowicz 1974; S. Połtowicz et al. 1974) indicate that west of the Dunajec river at the Carpathian margin there occur deep folds containing disturbed Badenian and Lower Sarmatian deposits which were thrust on the Lower Sarmatian sediments (Fig. 7). However, in the Flysch Carpathians relief was initiated prior to the Attic phase of movements. This is documented by the Beskidy level preserved on the nappe structures in the west of the area and subjected to differential



uplift along faults in the Attic phase (for comparison see O. Stehlik 1965). In the marginal zone of the Flysch Carpathians, thrust movements affected not only the flysch but also the Grabovian (Upper Badenian) sediments that were laid down on the flysch. Correlation deposits responding to the destruction of the Carpathians are now found under the Carpathians (S. Połtowicz 1974).

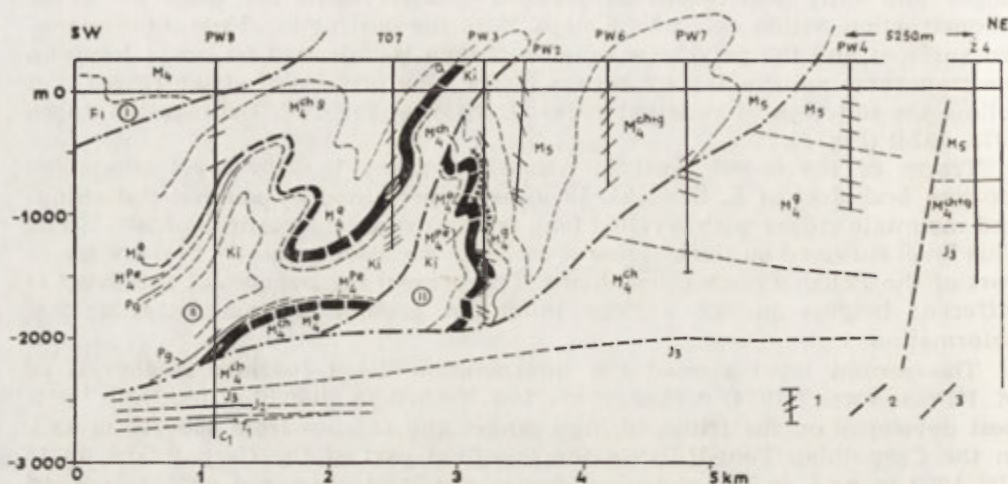


Fig. 7. Geological section across the marginal thrust between the Dunajec and Wiśłoka valleys (after S. Połtowicz 1974)

1 — bore-hole and dip of beds, 2 — overthrust, 3 — fault, I — Silesian unit, II — Skole unit, C<sub>1</sub> — Lower Carboniferous (Kohlenkalk), T<sub>1</sub> — Bunter, J<sub>2</sub> — Dogger, J<sub>3</sub> — Malm, K<sub>2</sub> — Upper Cretaceous, K<sub>1</sub> — Inoceranian beds (Upper Cretaceous), Pg — Paleogene, Fl — flysch rocks undivided, M<sub>4</sub> — Badenian (M<sub>4</sub><sup>pe</sup> — sub-evaporite "series", M — evaporite "series", M<sub>4</sub><sup>ch</sup> — Chodenice beds, M<sub>4</sub><sup>g</sup> — Grabowiec beds), M<sub>5</sub> — Lower Sarmatian, Q — Quaternary; crosses indicate tuffite intercalations

The Sarmatian deposits of the Carpathian foredeep cannot give information about the sequence of tectonic and climatic changes in the Flysch Carpathians because they have been transported from the northern shore of the Sarmatian sea (S. Połtowicz et al. 1974).

As a result of the multi-phase selective denudation the present relief of the Carpathians is adjusted to both lithology and tectonic style of the flysch (Fig. 6). Consequently in the western part of the Carpathians there occur mostly massive monoclinial and inversional mountain ridges frequently bounded by denudational scarps, whereas monoclinial and resequent ridges predominate in the east (Map 2).

The high tilted block of the Tatra Mts. contains a late mature relief which survived on the resistant limestones, dolomites and granito-gneisses in the broad summit areas. Fragments of flattenings at 1500 m a.s.l. pass into the unrejuvenated valley floors at the valley heads and into a wide piedmont pediment which descends from 1200 m to 800 m a.s.l. in the Tatra foreland. Planations have been dated as Sarmatian and Lower Pliocene on the evidence that the above surface truncates the Lower Badenian-Sarmatian of the Domajski Wierch (M. Klimaszewski 1958, 1972). However, results of recent palynologic research by J. Oszaś (1973) show that the gravel and clay series of the Domajski Wierch fan is Upper Pliocene. Consequently the ages of planations in the Tatra foreland should be revised.

## CONCLUSIONS

A brief regional review based upon the 1:300,000 Geomorphological Map of Poland revealed the manifold aspects of planation surfaces.

(1) The general geotectonical regimen of Poland did not favour the formation of new and the survival of the oldest regolith-covered planation surfaces, except in some parts of the Sudetes and the Sudetes Foreland where subaerial planation occurred in Cretaceous and Paleogene times (H. Teisseyre et al. 1960). In the remaining area it is difficult to reconstruct the so-called "Paleogene surface of planation" on the evidence of remaining single landforms, weathering products and small relics of dated surfaces that originated during the short Eocene period of relative tectonic stability within a great anticlinal zone termed "the meta-Carpathian elevation" (J. Nowak 1927).

(2) Since the Oligocene/Miocene, tectonic movements of varying type and rate and the corresponding exogenetic processes have been favourable for the formation of stepwise arranged epicyclic planation surfaces which reflect the successive stages of uplift and relief evolution.

(3) The neotectonic tendencies were responsible for the general type of modification of the planation surfaces. In the high standing areas that showed uplift tendencies there has been a general lowering of the prior land surface with the removal of the original regolith mantle or thin cap-rock (e.g., the major Sudetes ranges, the major upland watershed of Silesia-Cracow and Roztocze, and even the Pinczów ridge in the Nida Basin). On the contrary in the areas that showed subsidence tendencies there has been a general levelling of prior relief by multiple deposition of allogenic materials upon which new levels of planation developed. The resulting polycyclic surface includes relics of older now buried surfaces (e.g., forelands of the Sudetes and the Świętokrzyskie Mts., faulted upland, and the northern slope of the Lublin Upland).

(4) The resistance of predominant rock complexes determines the state of preservation and modification of planation surfaces. The harder the rocks the better preserved are the highest surfaces of oldest foundation. Most of the successively lower surfaces truncate softer rocks. On soft bedrock the lowest surfaces are well developed although limited in extent and subjected to easy modification and destruction (e.g., the broad floors of upland basins).

(5) Lithology and tectonic style control the general relief pattern expressed: as domical hills rising above levelled surfaces in the crystalline massifs (the Sudetes):

- as ridge and valley topography on the narrow and steep folds and scales formed by rock complexes of different resistances (the Świętokrzyskie Mts., and the Bieszczady Mts. in the Eastern Carpathians),

- as mesas and table-land on horizontal structures of uniform hardness (the Table Mts. in the Sudetes, and the table-land at the foot of the Świętokrzyskie Mts.),

- as monotonous plains on horizontal structures formed of softer rocks (e.g., in the northern part of the Nida Basin),

- as structural escarpments and strike valleys on subhorizontal structures including alternations of hard and soft rocks (the Central Sudetes, the Silesian Upland, the NE foreland of the Świętokrzyskie Mts., the Lublin Upland) and on low angle thrusts in the Western Carpathians.

(6) Pleistocene allogenic cap-rock is responsible for the present conservation of planation surfaces. These are best conserved in the depressed areas where exhumation from beneath the Pleistocene cap-rock is less expressed (e.g., on the northern downwarped slope of the Central Polish uplands including the

transition belt where the lowland relief interdigitates with typical upland features). Exhumation is more advanced in areas uplifted by neotectonic movements e.g., the Mid Traissic escarpment (S. Gilewska et al. 1971).

(7) Periodically changing paleoclimates determined the nature of planation surfaces. The oldest planation surface developed under tropical conditions with heavy seasonal rainfall, on the evidence of kaolin and laterite lying *in situ* on massive crystalline rocks (pre-Oligocene etchplain?). Scattered occurrences of pre-Oligocene karst depressions, residual kaolinite clays and the decalcification of gaizes and *opoki* cannot be regarded as equivalents of karst planation and laterite formation for they indicate only intense chemical weathering of calcareous bedrock.

The Neogene levelled surfaces are partial planation surfaces of regional significance due to epicyclic relief evolution. Planations proceeding from the margin of mountains and uplands into their interior are mostly of pediment or *glacis d'érosion* type and developed under periodically semi-arid conditions. These intervened with phases of humid conditions under which karst development took place. More or less advanced modifications of the inherited planation surfaces are due to the changing climates of the Pleistocene. The resulting surfaces are polygenetic features.

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#### SELECTED REFERENCES

- Alexandrowicz, S., Odrzywolska-Bieńkowska, R., 1960, Morskie osady dolnego tertonu w Łędzinach (Zagłębie Górnośląskie) (Sum.: Marine deposits of the Lower Tortonian at Łędziny — the Upper Silesian Basin), *Biul. Inst. Geol.* 155, 71–106.
- Alexandrowicz, S., Jasionowicz, J., Szymakowska, F., 1963, Profil i mikrofauna najwyższej części warstw krośnieńskich w Kluczowej koło Jasła (Sum.: Profile and microfauna of the uppermost part of the Krosno beds at Kluczowa near Jasło), *Przeł. Geol.*, 6, 258–260.
- Baumgart-Kotarba, M., 1973, Polycyclic Mountain Ridges in the Flysch Carpathians, *Studia Geomorph. Carpatho-Balcan.*, 7, 41–51.
- Baumgart-Kotarba, M., 1974, *Rozwój grzbietów górskich w Karpatach fliszowych* (Sum.: Development of Mountain Ridges in the Flysch Carpathians), *Prace Geogr. IG PAN*, 106.
- Baranowska-Janota, M., 1965, *Rozwój geomorfologiczny Pogórza Szydlowskiego* (Relief evolution of the Szydłów Foothills), Master thesis, manuscript — Kraków.
- Biernat, S., 1968, Problemy tektoniki i morfologii stropu mezozoiku między Bełchatowem a Działoszynem (Sum.: Tectonical and morphological problems of the Mesozoic top between Bełchatów and Działoszyn), *Kwart. Geol.*, 2, 296–298.
- Bogacz, K., 1967, *Budowa geologiczna północnego obrzeżenia rowu Krzeszowickiego* (Sum.: The geological Structure of the Northern Border of the Krzeszowice Graben), *Prace Geol. Kom. Nauk Geol.*, 41.
- Ciuk, E., 1961, Charakterystyka chemiczna węgla brunatnego ze złoża w Rogoźnie na północ od Łodzi i możliwość jego użytkowania (Chemical propriety of the coalbeds at Rogoźno, northwards of Łódź and possibility of their exploitation), *Kwart. Geol.*, 4, 956–957.



- Czarnik, J., 1966, Stratygrafia Czwartorzędu północnych okolic Koniecpola nad Pilicą (Sum.: Quaternary stratigraphy of the country north of Koniecpol on the Pilica), *Acta Geol. Pol.*, 16, 3, 379–400.
- Czarnocki, J., 1931, Sposkrzeżenia w zakresie tektoniki południowowschodniego zbocza Gór Świętokrzyskich (Sur la tectonique du versant sud-est du Massif de S-te Croix), *Pos. Nauk. PI Geol.*, 29, 15–16.
- Czarnocki, J., 1948, *Przewodnik XX Zjazdu Polskiego Towarzystwa Geologicznego w Górach Świętokrzyskich w roku 1947* (Guide pour XX Reunion de la Société Géologique de Pologne dans les Montagnes de St. Croix en aout 1947), 237–295.
- Doktorowicz-Hrebnicki, S., 1935, *Arkusz mapy geologicznej Polski — Grodziec. Objaśnienia* (Sheet of the geological map of Poland: Grodziec), PI Geol., Warszawa.
- Dylik, J., 1953, *O perylacjalnym charakterze rzeźby środkowej Polski* (Rés.: Du caractère periglaciaire de la Pologne Centrale), *Acta Geogr. Univ. Lodz.* 4.
- Dżułyński, S., 1953, Tektonika południowej części Wyżyny Krakowskiej (Sum.: Tectonics of the southern part of the Cracovian Upland), *Acta Geol. Pol.*, 3.
- Dżułyński, S., Henkiel, A., Klimek, K., Pokorny, J., 1966, Rozwój rzeźby dolinnej południowej części Wyżyny Krakowskiej (Sum.: The Development of the Valleys in the Southern Part of the Cracov Upland), *Rocznik PT Geol.*, 36, 4.
- Dżułyński, S., Kryszowska-Iwaszkiewicz, M., Oszaś, J., Starkel, L., 1968, O staroczwartorządowych żwirach w Kotlinie Sandomierskiej (Sum.: On Lower Quaternary gravels in the Sandomierz Basin), *Studia Geomorph. Carpatho-Balcan.*, 2, 63–76.
- Flis, J., 1954, *Kras gipsowy Niecki Nidziańskiej* (Sum.: Gypsum Karst of the Nida Trough), *Prace Geogr. IG PAN*, 1.
- Gilewska, S., 1963, *Rzeźba Progu Środkowotriasowego w okolicy Będzina* (Sum.: Relief of the Mid-Triassic Escarpment in the Vicinity of Będzin), *Prace Geogr. IG PAN*, 44.
- Gilewska, S., 1972, Wyżyny Śląsko-Małopolskie (Silesian-Małopolska Uplands), in: *Geomorfologia Polski* 1, 232–339.
- Gilewska, S., Klimek, K., 1967, Czwartorzęd Wyżyny Śląskiej (Quaternary of the Silesian Upland), in: *Czwartorzęd Polski*, 498–527.
- Gilewska, S., Starkel, L., 1971, *On the representation of the Upland Lowland Transition Area on medium and small scale Geomorphological Maps*. Submitted to the 5th meeting of the IGU Commission on Geomorphological Survey and Mapping, Budapest, Hungary, August 1971, 1–7.
- Górecka, Ł., 1958, Budowa geologiczna złoża trzeciorządowych piasków kwarcowych w Czuczycach koło Chełma Lubelskiego (Geological structure of the Tertiary quartz sand deposit in Czuczycze near Chełm Lubelski (Eastern Poland)), *Przegl. Geol.*, 6, 483–486.
- Harasimiuk, M., 1963, Opoka odwapniona w Lechówce koło Rejowca (Sum.: Decalcified “Opoka” in Lechówka near Rejowiec), *Ann. UMCS, Sec. B*, 18, 9, 169–177.
- Harasimiuk, M., 1975, *Zarys rzeźby południowej części Pogórów Chełmskich* (Sum.: Relief evolution of the Chełm Hills in the Tertiary and Quaternary), *Prace Geogr. IG PAN* 115.
- Jahn, A., 1953, Morfologiczna problematyka Sudetów Zachodnich (Sum.: Morphological Problems of Western Sudeten), *Przegl. Geogr.*, 25, 3, 51–59.
- Jahn, A., 1956, *Wyżyna Lubelska. Rzeźba i czwartorzęd* (Sum.: Geomorphology and Quaternary history of Lublin Plateau), *Prace Geogr. IG PAN*, 7.
- Klimaszewski, M., 1934, Z morfogenezy Polskich Karpat Zachodnich (Rés.: Sur la morphogenèse des Carpates Polonaises Occidentales), *Wiad. Geogr.*, 12.
- Klimaszewski, M., 1958a, Rozwój geomorfologiczny terytorium Polski w okresie przedczwartorządowym (Sum.: The Geomorphological development of Poland's Territory in the pre-Quaternary Period), *Przegl. Geogr.*, 30, 1, 3–43.

- Klimaszewski, M., 1958b, Nowe poglądy na rozwój rzeźby krasowej (Sum.: Modern views on the development of the Karstic Relief, *Przegl. Geogr.*, 30, 3, 421–438.
- Klimaszewski, M., 1965, Views on the geomorphological development of the Polish West Carpathians in Tertiary times, *Geomorphological Problems of Carpathians* 1, Bratislava, 91–126.
- Klimaszewski, M., 1972, Karpaty Wewnętrzne (Central Carpathians), in: *Geomorfologia Polski* 1, 21–51.
- Kirchner, Zb., Połtowicz, St., 1974, Budowa geologiczna obszaru między Brzeskiem a Wojniczem (Sum.: Geological Structure of the area between Brzesko and Wojnicz (Southern Poland)), *Rocznik PTGeol.*, 44, 2–3, 293–320.
- Kosmowska-Suffczyńska, D., 1966, *Rozwój rzeźby w trzeciorzędzie okolic Ostrowca Świętokrzyskiego i Ćmielowa* (Sum.: Tertiary relief evolution of the region of Ostrowiec Świętokrzyski and Ćmielów), *Prace Geogr. IG PAN*, 54.
- Kosmowska-Suffczyńska, 1968, Development of subaerial relief during the Tertiary Period in the area to the North of the Holy Cross Mountains, *Geogr. Pol.*, 13, 31–48.
- Kowalski, K., 1951, Brekcja nietoperzowa w Podlesicach koło Kroczy w powiecie olkuskim (Résumé: La brèche à ossements de chauves-souris), *Zabytki przyrody nieożywionej*, 38–40.
- Książkiewicz, M., 1972, *Karpaty* (Carpathians), Budowa geologiczna Polski IV, Tektonika 3.
- Lencewicz, S., 1934 a, Surface d'aplanissement tertiaire dans les monts Łysogóry, *Comptes rendus du Congr. Intern. de Géogr., Varsovie 1934*, 70–71.
- Lencewicz, S., 1934 b, Le massif hercynien des Łysogóry (S-te Croix) et ses enveloppes, *Congrès Intern. de Géogr., Varsovie 1934*, 12–21.
- Łyczewska, J., 1969, Sediments et processus Quaternaires du versant crétacé de la Vallée de la Basse Nida, *Biul. Perygl.*, 18, 195–208.
- Maruszczak, H., 1966, Zjawiska krasowe w skałach międzyczecza Wisły i Bugu (Sum.: Karst phenomena in rocks of the Wisła-Bug interfluve), *Przegl. Geogr.*, 38, 339–370.
- Maruszczak, H., 1972, Wyżyny Lubelsko-Wołyńskie (Lublin-Volhynian Upland), in: *Geomorfologia Polski* 1, 340–384.
- Mazúr, E., 1963, *Zilinská Kotlina a prilahlé pohoria* (Sum.: The Žilina Basin and the Adjacent Mountains), SAV, Bratislava.
- Michalski, A., 1884, Zarys geologiczny strony południowo-zachodniej Gubernii Kieleckiej (Outline of geology of the south-western part of the Kielce District), *Pam. Fizjogr.*, 4, Warszawa.
- Ney, R., 1968, *Rola rygla Krakowskiego w geologii zapadliska przedkarpackiego i rozmieszczenie złóż ropy i gazu* (Sum.: The Role of the "Cracow belt" in the Geological History of the Carpathian Fore-deep and in the distribution of oil and gas deposits), *Prace Geol. Oddz. PAN w Krakowie*, 45.
- Ney, R., Burzewski, W., Bachleda, T., Górecki, W., Jakubczak, K., Słupczyński K., 1974, *Zarys paleogeografii i rozwoju litologiczno-facjalnego utworów miocenu zapadliska przedkarpackiego* (Sum.: Outline of Paleogeography and evolution of lithology and facies of Miocene layers in the Carpathian Fore-deep), *Prace Geol. Oddz. PAN w Krakowie*, 82.
- Nowak, J., 1927, *Zarys tektoniki Polski* (Outline of tectonic of Poland).
- Nowak, W., 1970, Rzeźba podczwartorzędowa i ewolucja układu sieci dolinnej w północno-środkowej części Wyżyny Małopolskiej (Sum.: The Sub-Quaternary relief and the evolution of the Valley system in the North-Central part of the Małopolska Upland), *Prace Geogr. IG PAN*, 80, 89–124.
- Osmólski, T., 1963, Miocen w widłach rzek Wisły i Nidy oraz jego siarkonośność (Sum.: Miocene deposits within the fork of the Nida and the Vistula rivers and their sulphur contents), *Kwart. Geol.*, 7, 337–352.



- Oszast, J., 1973, The Pliocene profile of Domajski Wierch near Czarny Dunajec in the light of palynological investigations (Western Carpathians, Poland), *Acta Palaeobotanica*, 14, 1.
- Pawłowski, S., 1965, Zarys budowy geologicznej okolic Chmielnika-Tarnobrzega (Sum.: Outline of geological structure in vicinities of Chmielnik-Tarnobrzeg), *Przegl. Geol.*, 6, 238-245.
- Pernarowski, L., 1963, Morfogeneza północnej krawędzi Wzgórz Niemczańskich (Sum.: Morphogenesis of the Northern Edge of the Niemcza Hills), *Acta Univ. Wratisl.*, 10, *Studia Geogr.*, 2.
- Piasecki, H., 1964, *Rozwój geomorfologiczny Pogórza Kaczawskiego* (Geomorphological evolution of the Kaczawskie Foothills), Doctor dissertation, manuscript, Wrocław.
- Pokorny, J., 1963, The development of Mogotes in the Southern Part of the Cracow Upland, *Bull. Acad. Pol. Sci. Ser. Sci. geol. geogr.*, 11, 3, 169-175.
- Polichtówna, J., 1962, Ostańce Wyżyny Krakowsko-Częstochowskiej, ich geneza i znaczenie w krajobrazie (Sum.: The Monadnocks of the Cracow-Częstochowa Upland, their origin and importance in the landscape), *Ochr. Przyr.*, 28, 255-284.
- Połtowicz, S., 1962, Możliwość czwartorzędowych ruchów Przedgórza w widłach Wisły i Raby (Possible quaternary uplift of the Carpathian Foreland at the confluence of Wisła and Raba rivers), *Spraw. Pos. Kom. Oddz. PAN Kraków*, VII-XII, 509-511.
- Połtowicz, S., 1974, Wgłębna tektonika brzegu Karpat w okolicy Tarnowa i Pilzna (Sum.: Tectonic Structures of the Carpathian border in the Tarnów and Pilzno area (Polish Middle Carpathians)), *Rocznik PTGeol.*, 44, 4, 491-514.
- Połtowicz, S., Starczewska-Popow, A., 1974, Rozwój zapadliska przedkarpackiego między Tarnowem a Przemyślem (Sum.: The Development of the Carpathian Foredeep between Tarnów and Przemyśl, Polish Eastern Carpathians), *Rocznik PTGeol.*, 53, 4, 495-518.
- Pożaryski, W., 1951, *Odwapnione utwory kredowe na północno-wschodnim przedpolu Gór Świętokrzyskich* (Decalcified Cretaceous Formations in the NE Peripheries of the Holy Cross Mts.), *Biul. PIGeol.*, 75.
- Radłowska, C., 1963, *Rzeźba północno-wschodniego obrzeżenia Gór Świętokrzyskich* (Res.: Relief de la bordure Nord-Est des Montagnes de S-te Croix), *Prace Geogr. IG PAN*, 38.
- Radłowska, C., 1966, Z geomorfologii okolic Pińczowa (Sum. in: *Studia Geograficzne w pow. Pińczowskim*), *Prace Geogr. IG PAN*, 47, 17-37.
- Radłowska, C., 1968, On the morphogenesis of European Highlands based on the field studies in the Holy Cross Mountains, *Geogr. Pol.*, 14, 67-76.
- Radwański, A., 1969, Transgresja dolnego tortonu na południowych stokach Gór Świętokrzyskich (strefa zatok i ich przedpola) (Sum.: Lower Tortonian transgression into the southern slopes of the Holy Cross Mts.), *Acta Geol. Pol.*, 9, 1.
- Rotnicki, K., 1966, *Rzeźba wzgórz Ostrzeszowskich jako rezultat rozwoju stoku podczas Würmu* (Sum.: The relief of the Ostrzeszów Hills as result of slope development during the Würm), *Pozn. Tow. Nauk.*, *Prace Kom. Mat.-Przyr.*, 2.
- Różycki, F., 1956, *Trzeciorzęd Łodzi i okolic* (Sum.: Tertiary deposits in the country around Łódź), *Acta Geogr. Nniv. Lodz.*, 6.
- Różycki, S. Z., 1967, *Plejstocen Polski środkowej na tle przeszłości w górnym trzeciorzędzie* (Pleistocene of Central Poland with upper Tertiary as a background), Warszawa.
- Ruszczyńska, H., 1958, Przedplejstocenijskie powierzchnie i czwartorzędowy rozwój rzeźby w okolicach Białej Góry (Sum.: Pre-pleistocene surfaces and the Quaternary development of relief in the vicinity of Biała Góra (Central Poland)), *Przegl. Geol.*, 11, 487-488.

- Rutkowski, J., 1965, Senon okolicy Miechowa (Sum.: Senonian in the area of Miechów, Southern Poland), *Rocznik PTGeol.*, 35, 1.
- Sawicki, L., 1909, *Z fizjografii Karpat Zachodnich* (On the physiography of the Western Carpathians), Arch. Nauk., Lwów.
- Starkel, L., 1957, *Rozwój morfologiczny progu Pogórza Karpackiego między Dębicą a Trzycianą* (Sum.: Morphological development of the Escarpment of the Pogórze Karpackie between Dębica and Trzyciana), *Prace Geogr. IG PAN*, 11.
- Starkel, L., 1965, *Rozwój rzeźby polskiej części Karpat Wschodnich* (Sum.: Development of Relief of the Polish East Carpathians — on the Example of the Upper San Basin), *Prace Geogr. IG PAN*, 50.
- Starkel, L., 1969 a, Odbicie struktury geologicznej w rzeźbie Polskich Karpat fliszowych (Sum.: Reflection of the Geological Structure in the Relief of the Polish Flysh Carpathians), *Studia Geomorph. Carpatho-Balcan.*, 3, 61–71.
- Starkel L., 1969 b, The Age of the Stages of development of the relief of the Polish Carpathians in the light of the most recent geological investigations, *Studia Geomorph. Carpatho-Balcan.*, 3, 33–44.
- Starkel, L., 1972, Karpaty Zewnętrzne (Outer Carpathians), in: *Geomorfologia Polski* 1, 52–115.
- Starkel, L., 1971, Phases of Erosion and Accumulation in the Quaternary Evolution of Valleys of the Polish Flysh Carpathians and their Foreland, *Studia Geomorph. Carpatho-Balcan.*, 5, 183–187.
- Starkel, L., 1974, Legend for the geomorphological map of Poland 1 : 300,000, *Studia Geographica*, 41, Brno, 159–168.
- Stehlik, O., 1965, The Beskidy Mts. arch (in: Tertiary elements in the relief of the Outer Carpathians in Moravia), *Geomorphological Problems of Carpathians* 1, Bratislava, 71–80.
- Świdorski, B., 1932, O młodych ruchach tektonicznych, erozji i denudacji (Sur l'évolution tectonique et morphologique des Karpates polonaises au Tertiaire et au Quaternaire), *Rocznik PTGeol.*, 8, 1, 239–265.
- Teisseyre, H., Smulikowski, K., Jahn, A., 1960, Utwory trzeciorzędowe i czwartorzędowe oraz pogląd na rozwój budowy geologicznej Sudetów (Tertiary and Quaternary deposits and view on the geological evolution of the Sudetes), in: *Regionalna Geologia Polski*, 3, 2, 300–438.
- Turnau-Morawska, M., 1950, Spostrzeżenia dotyczące sedimentacji i diagenety sarmatu Wyżyny Lubelskiej (Sum.: Remarks concerning sedimentation of Sarmatian deposits on the Lublin Upland), *Ann. UMCS*, sec. 4, 135–194.
- Walczak, W., 1956, *Czwartorzęd i morfologia południowej części Jury Krakowskiej* (Sum.: Quaternary Deposits and Morphology of the Southern Part of the Cracow Jura in the Będkowska and Kobylanka Basin), *Biul. IGeol*, 100, 419–453.
- Walczak, W., 1968, *Sudety* (Sudetes Mts.), Warszawa.
- Walczak, W., 1970, *Obszar Przedsudecki* (Sudetes Foreland), Warszawa.
- Walczak, W., 1972, Sudety i Przedgórze Sudeckie (Sudetes Mts. and Sudetes Foreland), in: *Geomorfologia Polski* 1, 167–231.
- Wyrzykowski, T., 1959, Zagadnienia współczesnych ruchów pionowych skorupy ziemskiej na obszarze Polski i ich badania metodą powtarzalnej niwelacji precyzyjnej (Problems of the contemporary vertical earth crust movements on the Poland's territory and methods of their studying using repeated precise nivelation), *Przegl. Geodez.*, 15(31), 125–128.

## ON GLACIAL ORIGIN OF GRUDZIĄDZ BASIN, LOWER VISTULA RIVER VALLEY

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### INTRODUCTION

The characteristic features of the lower Vistula River valley are numerous widenings known from the literature as basins. Their geologic structure and relief differ considerably from the adjacent valley reaches as a result of differential action of both glacial and fluvial processes. This is particularly true for the largest widening of the lower Vistula River valley — the Grudziądz Basin.

The origin of this basin have been discussed for a long time. So far, two hypotheses have prevailed: the first, put forward by A. Jentzsch (1911), relates the formation of the Grudziądz Basin to a large proglacial lake at the mouth of the Maława River outwash, the second, advanced by R. Galon (1934), regards lateral erosion of the meandering Vistula River as the main process responsible for its origin.

The present paper is a new attempt at solving the problem based on geologic and geomorphologic research (E. Drozdowski 1974, 1975), including results of pollen analysis and radiocarbon dating. It emphasizes the hitherto unrecognized glacial landforms and deposits associated with the melting of dead-ice blocks which — as it turned out during the field examination — occur in that area together with distinctive fluvial features. This fact justifies the conclusion that the fluvial processes operating in the valley in the Late Glacial period were intimately associated with glacial processes. Consequently, the former existence of the Scandinavian ice sheet and its geomorphologic activity are regarded here as a substantial factor which affected the formation of the discussed widening of the Vistula River valley.

### GENERAL GEOMORPHOLOGIC FEATURES

Three distinctive valley widenings occur along the lowest course of the Vistula River from the gap near Fordon to the river mouth delta, namely Unisław Basin, Chełmno (or Świecie) Basin and Grudziądz Basin. The width of the valley, being normally 3 to 4 km, extends in these basins for more than 10 km. The investigated Grudziądz Basin (Fig. 1) is the largest one. It is 18 km wide, 20 km long, and covers a roughly circular area of 240 sq.km.

The outstanding features of the Grudziądz Basin are three "islands" of moraine plateau, so-called *kępy*, elevated as much as 60 m above the flood-plain and isolated from the surrounding moraine plateau by deeply incised curves of the former Vistula River bed. Immediately east of the channel rise Kępa Forteczna, with its summit at 86.1 m a.s.l. and Kępa Strzemięcińska,





Fig. 1. Geomorphologic sketch of the Grudziądz Basin

1 — moraine plateau 2 — outwash, 3 — erosive surfaces of meltwater flow, 4 — subglacial channels, 5 — kame terraces, 6 — dead-ice slope topography, 7 — alluvial fans, 8 — flood areas with peat and gyttia, 9 — landslide pseudoterraces, 10 — rim of moraine plateau with aggradation zone, 11 — river terraces with rim; number indices after R. Galon's (1968) system, F, G, S — moraine plateau islands, so-called *kępy*: F — Kępa Forteczna, G — Kępa of Górna Grupa, S — Kępa Strzemięcińska

79.3 m a.s.l.; on the west side of the river, separated from the channel by the flood-plain 4 km wide, projects Kępa of Górna Grupa, with its summit at 77.3 m a.s.l.

The river terraces in the Grudziądz Basin occur in a set of nine steps corresponding, in R. Galon's classification (1968), to from IX to I. The most extended levels are terraces III and II, elevated 27-28 m and 24-25 m a.s.l., i.e. 9-10 m and 6-7 m above the flood-plain respectively. They form the surface of the incised curves, separating the *kępy*-hills from the surrounding moraine plateau. The thickness of alluvial deposits increases generally from the older to younger levels, ranging from 1 to 2 m within terraces IX to IV, and from 6 to 7 m for the most part of terraces III and II.

The flood-plain is a lowland stretch varying in width from 2 to 4.5 km and bordered by steep valley sides which rise often over 50 m above its surface. The surface of the flood-plain within the examined area gradually slopes down valley from approximately 20 to 17 m a.s.l. Data from many logs of borings and a few test borings show that beneath the surface of the flood-plain occurs a mass of alluvial silty-sandy deposits up to 18 m thick; hence the buried erosive floor of the valley here lies near the altitude of present-day sea level.

Noteworthy from the morphogenetic point of view are lakes which cover approximately 1.30 per cent of the whole area under consideration. Abandoned channel-lakes are very common, occurring on the flood-plain close to the present-day channel, although the most interesting ones exist on the higher altitudes, on terraces II and III. Among these the largest ones are: Rudnickie Wielkie Lake, Tarpno Lake, and Fletnowskie Lake (Fig. 1). The elongated shape and irregularities in the depth of the two latter lakes suggest that their depressions might be subglacial channels (S. Kopczyński 1963).

It should be added, moreover, that the area under consideration is situated within the limits of the Last (Würm) Glaciation as expressed in the present-day relief.

#### TYPES OF GLACIAL LANDFORMS AND DEPOSITS

The glacial landforms which are found in the Grudziądz Basin and which have a significance in the elucidation of the problem of the origin of this large depression create a distinct interrelated group or assemblage. It comprises kame terraces, dead-ice slope topography, and kettle-holes occurring on the river terraces and alluvial fans. All these landforms are unified and simultaneously separated from other genetic types of landforms occurring in the Grudziądz Basin by melting of dead-ice blocks as a dominant morphogenetic process. Beside the landforms associated with the melting of dead-ice there are also deposits linked with them, but not pronounced in the present-day topography. They are spread over the entire investigated area within other genetic types of landforms, especially on the river terraces and alluvial fans.

In this paper the glacial landforms will be described and discussed in more detail, and the glacial deposits occurring within the river terraces will be briefly summarized by using the example of one site only.

#### KAME TERRACES

The kame terraces are found in the western part of the Grudziądz Basin, in the vicinity of Święte, Nowe Marzy and Rulewo. Kame-like terrace was encountered also in the eastern part of the basin, on the gentle slope of Kępa Forteczna (Fig. 1). Their surfaces lie at various altitudes, starting with 75 down to 27 m a.s.l., i.e. from a level higher than the uppermost river terrace IX down to the level of river terrace III. The main features which distinguish the kame terraces are their geologic structure (examined against the background of the general geologic pattern of the slope) and texture of the material building them.

Well-developed kame terraces occur on both valley-slopes of the "basin" reach of Mątawa River, between the Kępa of Górna Grupa and the moraine plateau marked on the map by outwash plain (Fig. 1). This valley reach is characterized by numerous kettle-holes, among them the largest and deepest one is the depression of Święte Lake, through which Mątawa River flows.

The kame terrace which occurs on the western valley-slope near Święte village was investigated in detail. Its surface is elevated 57-58 m a.s.l., thus



Fig. 2. Kame terrace on the western side of the Maława River valley



it lies slightly lower than the uppermost river terrace IX. The morphologic characteristics of this kame terrace are shown on the photograph (Fig. 2), and the geologic structure of the terrace in relation to the adjacent slope is indicated on the cross-section based on accurate levelling measurements and field examination (Fig. 3).

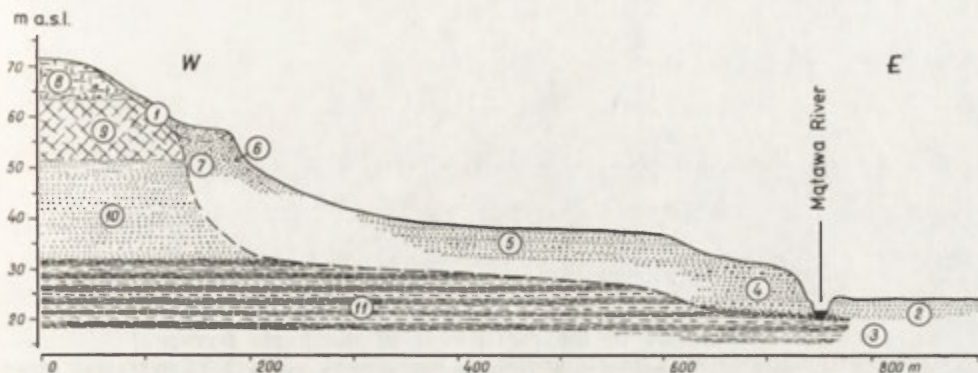


Fig. 3. Geologic cross-section through the western slope of the Maława River valley near Święte

1 — slope wash, 2 — fine-grained sands, 3 — cover on the erosive surface of grey varved clays, 4 — fine- and medium-grained sands with gravels, 5 — fine-grained sands with intercalations of silty sands and medium-grained sands, 6 — collapsed sand-gravel deposits (Fig. 3 — 2 to 11), 7 — unstratified fine- and medium-grained sands with gravel grains, 8 — till (first glacial-drift horizon), 9 — yellow-brown varved clays underlain by till (second glacial-drift horizon), 10 — fine-grained sands, 11 — grey varved clays

The kame terrace has ledge shape, 200 m long, up to 15 m high and up to 45 m wide. Its surface is flat or slightly inclined ( $2-3^\circ$ ) toward the valley. The inclination of the river-facing slope of the terrace ranges prevalingly from  $15$  to  $20^\circ$ .

The terrace has a simple structure. An exposure made near the valley-slope at a distance of approximately 30 m from the edge of the terrace, shows two different kinds of deposits. On the unstratified medium- and fine-grained sands of the glaci-fluvial type rest loamy sands with gravels and boulders of the slope-wash type connected with the till occurring higher within the adjacent valley-slope. The diameters of boulders within the slope-wash deposits are usually less than 0.5 m, but on the surface of the terrace boulders were found exceeding 1.0 m in diameter. Gravel grains and small boulders are often disintegrated as a result of frost action.

Close by the edge of the kame terrace, devoid of the slope-wash deposits, the structure of the glaci-fluvial deposits changes. The medium- and fine-grained sands (Fig. 4 — 2-11) prove horizontal stratification, and simultaneously they are *en masse* inclined towards the valley at an angle of  $38-40^\circ$ , thus more than the angle of repose of these deposits. The beds are also disturbed by small faults, whose amplitudes of replacement are of the order of 3-5 cm.

As is shown on the geologic cross-section (Fig. 3), the deposits which build up the terrace differ from those within the moraine plateau at the same level. This fact precludes an eventually alternative genetic interpretation of the terrace — that it is a trath river terrace, and that the disturbances of the deposits are due to the pressure of the active ice prior to the formation of the terrace. The presence of deep kettle-holes occurring lower, in the bottom of the

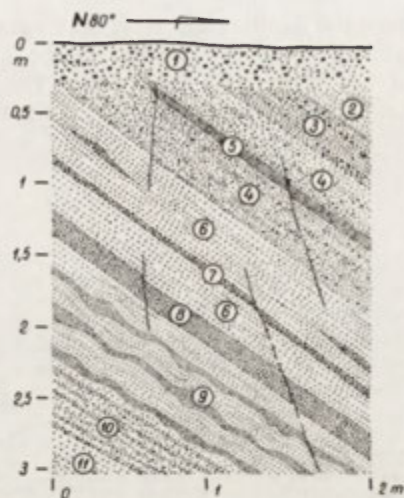


Fig. 4. Exposure in the escarpment of the kame terrace

1 — medium-grained sands with gravel grains, 2 — fine-grained sands, 3 — fine-grained sands and gravels, 4 — fine-grained sands with admixture of medium-grained sands and gravels, 5 — fine-grained sands with calcium carbonate concentrations, 6 — fine- and medium-grained sands, 7 — sands with gravels, 8 — medium-grained sands, 9 — fine-grained sands with intercalations of silty sands, 10 — medium-grained sands with gravels, 11 — medium-grained sands

valley, as well as the disturbed sedimentary structure of the deposits in the terrace pointed out that it may be closely related in origin to the kame terrace formed between the slope from one side and the ice-wall from the other. When the river level lowered and the progressive melting of the ice masses proceeded, then the deposits, supported by ice, collapsed. The presence of faults in the collapsed deposits indicated that the collapsing process took place when the deposits were still in a frozen state.

#### DEAD-ICE SLOPE TOPOGRAPHY

The other conspicuous landforms associated with the melting of large dead-ice blocks occupying the former Vistula River curves in the Grudziądz Basin represent specific topography named tentatively kame and kettle slope topography of the ablative type (E. Drozdowski 1974) or more generally: dead-ice slope topography.

The prominent landforms of this type occur along the eastern slope of the investigated area between the villages of Turznica and Marusza (Fig. 1). The moraine plateau grades here from about 95 to 30 m a.s.l. into the broad "slope zone", 2 to 3 km wide. Its topography is characterized by a moderate local relief with numerous irregularly distributed hills and small depressions (Fig. 5), so that the cross-profiles of the slope zone appear as very ragged lines (Fig. 6). In contrast to the steep erosive segments of the valley slopes, well-developed stream-valleys and gullies are absent or fragmental. The existing valley-like depressions have sinuous courses and irregular floors with thresholds. On some reaches of these valleys there occur larger basin-shaped widenings with several depressions of lower order. There are often sloughy or filled by water. The slopes of hills between individual depressions are generally more inclined towards the higher situated depressions than to the lower ones.



Fig. 5. Dead-ice slope topography on the eastern side of the Grudziądz Basin



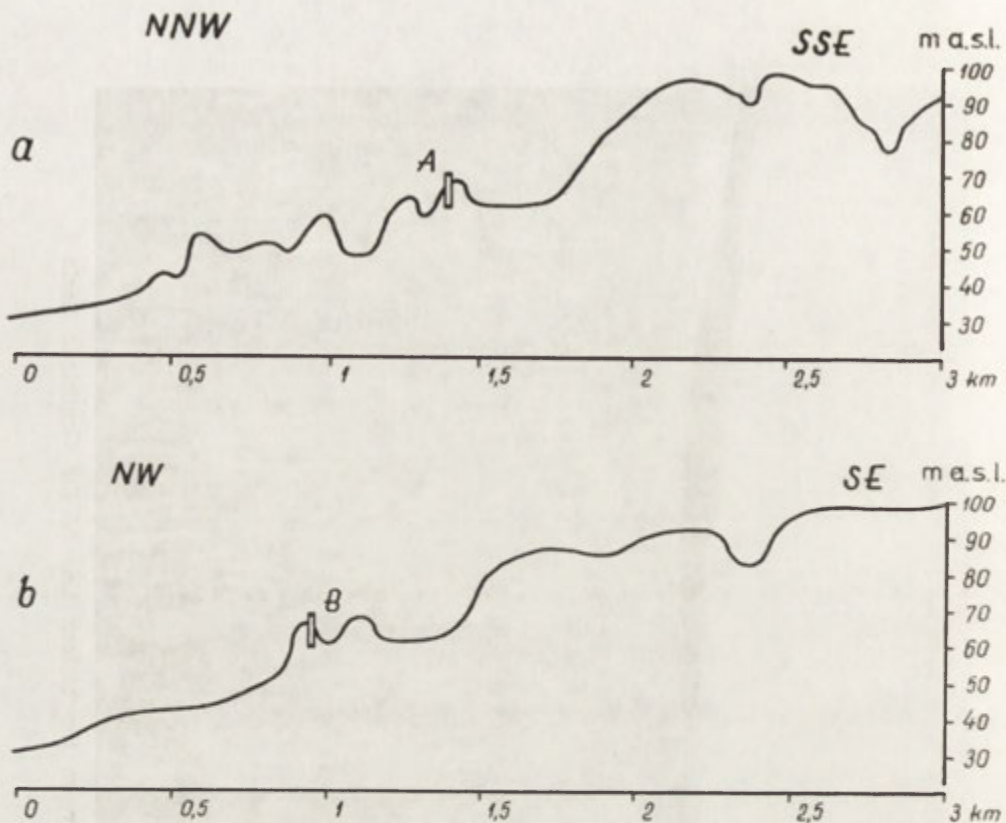


Fig. 6. Morphologic profiles of the Grudziądz Basin slope north of Turznicie  
A, B — location of exposures

The “slope zone” is composed mainly of till and sandy-gravel deposits. In the upper part, near the edge of the moraine plateau it is covered by a more-or-less continuous blanket of till averaging a few meters thick, while in the lower part, starting from about 60 m a.s.l. sands and gravels more often appear on the surface. Two exposures A and B (Fig. 6) show the geological structure of the hills.

Exposure A (Fig. 7) is located in the upper part of the hill, 68 m a.s.l., on its slope which is inclined  $2-3^\circ$  towards the lower depression. The summit of this hill is elevated as much as 10 m above the lower depression and about 6 m above the higher one.

Beneath a layer of till 1 m thick (Fig. 7—2) deposits occur of a typical fluidal structure, composed of all gradations from silt to sand with gravel grains and pebbles (Fig. 7—3-8). Individual sedimentary units are developed in the form of irregular layers, lenses, and streaks dipping towards the lower depression, but at an angle much greater than the inclination of the slope surface of the hill. Both the lithology and structure of these deposits indicate that they are typical mudflows which may have resulted from the flow of the semi-plastic, waterlogged material on the slopes of dead-ice blocks. Such material is known from modern glaciers as ablation deposits (J. Szupryczyński 1963; S. Kozarski, J. Szupryczyński 1973).

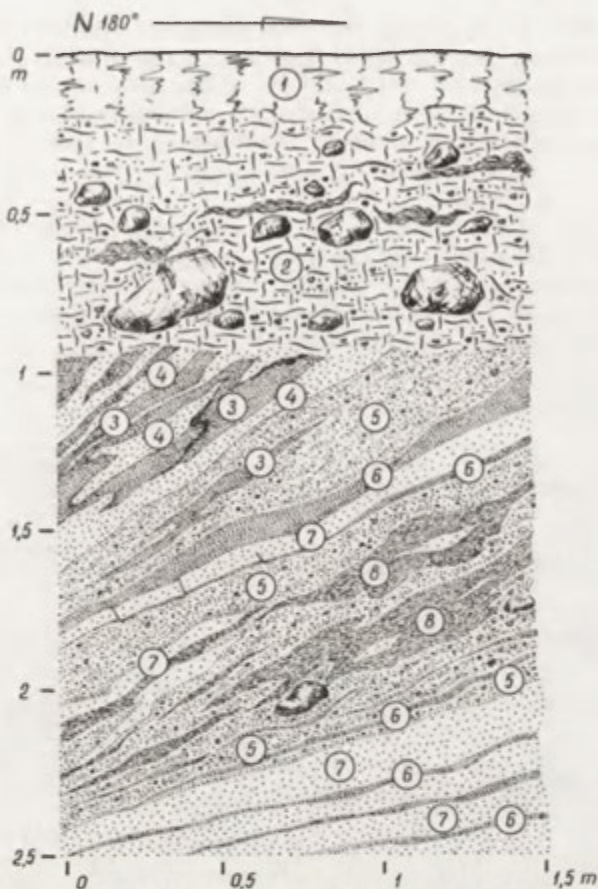


Fig. 7. Exposure A

1 — humus, 2 — ablation till with large quantities of boulders and pebbles as well as streaks of dark-brown silt, 3 — silty sands, 4 — medium- and fine-grained sands, 5 — various-grained sands with silt admixture, sporadic gravel grains and pebbles, 6 — silty sands, 7 — medium-grained sands, 8 — clayey silts with gravel grains

The significant properties that can be used to explain the origin of the hill are the thickness and dipping relationships between individual units of the mudflow. The measurements show that the dip angles of layers, lenses and streaks increase gradually upwards from 20 to 58°, and simultaneously marked layers tend to grow in thickness. The differences in grades between bedding planes of individual layers reach 5°. These facts point to the flowing of the waterlogged material in the direction inverse to the actual slope-surface of the hill. Consequently, the presented evidence makes it possible to draw the conclusion that the exposure proves an overturning of the material resulted from the disappearance of the dead-ice wall by which the material was supported. The existence of the dead-ice block indicates the lower situated kettle-hole.

The till cover is similar in origin to the underlying deposits. It contains great quantities of sand, gravel, pebbles and cobbles, and sporadically loops of silty clays and precipitations of calcium carbonate in the form of thin veins. Some of the pebbles and cobbles underwent completely frost disintegration.

Near the base the till is fissile, and the planes of fissility dip at an angle  $56-62^\circ$  in the direction concordant to the dips of the underlying deposits. This evidence in association with the lithologic properties of the till allowed the interpretation of its origin as an ablation till redeposited from the top surface of dead-ice blocks into spaces between these blocks. It was subsequently overturned together with the underlying silty-sandy mudflows when an inversion of the topography proceeded.

Exposure B (Fig. 8) is located in the upper part of a lower lying hill, 58 m a.s.l. In contrast to the previously described hill it is devoid of till cover on the top and on the slope inclined toward the basin. Till cover occurs only on the opposite, inward slope. The exposure wall show the inner structure of deposits in a plane directly parallel to the slope inclination.

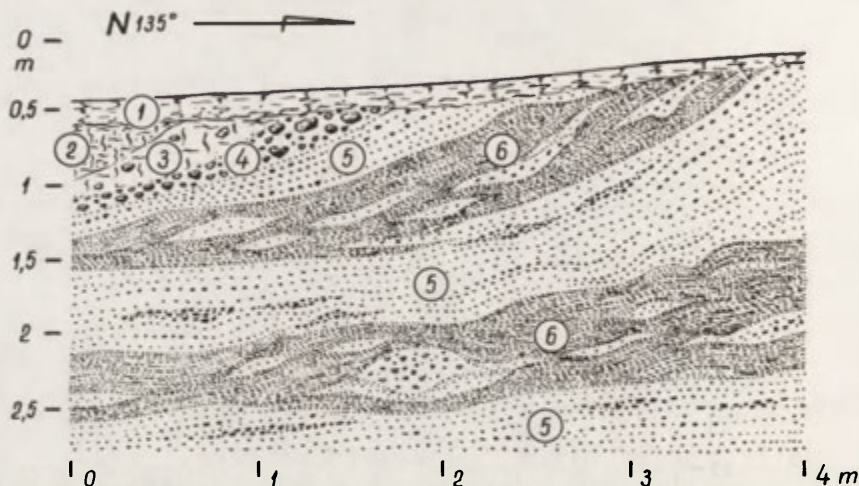


Fig. 8. Exposure B

1 — humus, 2 — ablation till, 3 — ablation till with calcium carbonate concentrations, 4 — gravels and boulders, 5 — medium- and coarse-grained sands with sand-gravel lenses, 6 — sandy silts with gravel lenses

Similarities in the structure and sequence of deposits are striking. The mudflows, developed as fine-grained sands intermixed with silts and medium-grained sands (Fig. 8—5–6), dip at an angle greater than the angle of slope inclination. As in the exposure A they show a distinct fluidal structure and an increase of thickness upwards. An innovation is the layer of gravels and boulders, situated between the silty-sandy mudflows and the till cover (Fig. 8—4). The growing thickness of this layer together with a gradually increasing size of boulders indicate that it is a typical debris cone overturned *en masse* when the ice melted away.

#### TYPES OF DEPRESSIONS ASSOCIATED WITH THE MELTING OF BURIED ICE ON THE RIVER TERRACES AND ALLUVIAL FANS

There are at least two different types of depressions closely related to the melting of buried ice within the river terraces and alluvial fans, depending upon the origin of the ice and the conditions of its burying. These are:



(1) Typical kettle-holes resulted from the melting away of dead-ice blocks, buried by deposits of various origins (glacial, glacifluvial, fluvial, slope wash). Within the investigated area they are represented by roughly circular and considerable deep depressions, usually sloughy or filled by water.

(2) Landforms originated from the melting away of authigenic ice (winter ice) filling previously eroded subglacial depressions and buried by deposits of various origins. Subglacial channels are an example of this type of landforms, though some of their reaches can be filled in by dead-ice (cf. P. Woldstedt 1954; W. Niewiarowski 1968).

The presence of such depressions on the river terraces III and II, whose surfaces lie approximately 60 m below the surface of the bordering moraine plateau, suggest erosion and melting away of upper parts of the dead-ice blocks during the beginning stages of the valley development. Ultimate melting away of these dead-ice remainders took place after the formation of river terraces III and II, and hence with the river flow at lower levels.

### KETTLE-HOLES

Prominent landforms of this type are represented by depressions of Rudnickie Wielkie Lake, Rudnickie Małe Lake within the eastern incised curve of the Grudziądz Basin and the depression of Święte Lake within its western curve (Fig. 1).

The Rudnickie Wielkie Lake, which lies on river terrace II is the largest one in the area under discussion. It covers, according to S. Kopczyński (1963), 177.7 ha and its depth is as much as 11.5 m. As the water-level is 22.6 m a.s.l., the maximum depth of the depression lies approximately 11.0 m a.s.l., that means nearly 6 m below the present-day surface of the flood-plain. Taking into account a few meters of alluvium cover that was probably accumulated on the top of the dead-ice block and subsequently submerged during melting of the ice and also some meters of the lake sediments later accumulated, it can be concluded that the original glacial bottom of the depression lies at least 5 m a.s.l., thus about 75–80 m below the surface of the adjacent moraine plateau.

Similar properties reveals the depression of the adjacent Rudnickie Małe Lake, which is actually in the final phase of overgrowing. It is oval in plane, about 800 m long and 400 m wide. The water-level lies 20.0 m a.s.l., and the maximum depth of its mineral bottom, determined by means of a hand auger, is approximately 10 m. In relation to the surface of the flood-plain it gives a difference of about 9 m. Adding also the thickness of the submerged alluvial deposits, it seems reasonable to assume that the original glacial bottom lies near the level of the valley-floor (about 3 m a.s.l.), thus similarly 75–80 m below the surface of the bordering moraine plateau.

Pollen analysis of the organogenic deposits (peat and gyttia) which fill the depression of Rudnickie Małe Lake, carried out by B. Noryśkiewicz, has been proved that the bottom peat was accumulated in the pine phase of Allerød (pollen diagram in: E. Drozdowski 1974). This result has been recently confirmed by radiocarbon analysis carried out by S. Hakansson in Lund. The dating of the sample taken from the sandy peat layer at the bottom, 6.74–6.80 m below the surface, has shown the following age:

Rudnik (I) ..... Lu-984       $11.630 \pm 265$  B.P.

These dating points out both the minimum age of the terrace and the beginning of the melting of dead-ice.

## SUBGLACIAL CHANNELS

Two large channels that were bound up with the activity of subglacial meltwater are present in the Grudziądz Basin. These are: channel of Fletnowskie Lake in the western part of the Grudziądz Basin and channel of Tarpno Lake in its eastern part.

The channel of Fletnowskie Lake runs in a meridian direction for a distance of nearly 10 km. It is incised both into the moraine plateau and river terraces together with the superimposed alluvial fan within the area of Grudziądz Basin (Fig. 1). The bottom of the channel lies at various depths ranging from approximately 10–20 m on the moraine plateau up to more than 70 m within the Grudziądz Basin in relation to the surface of moraine plateau that can be treated as a bed level of the last ice sheet in the area investigated (approximately because the till lying on the surface is usually 5–7 thick).

In the case of the channel of Tarpno Lake, the difference in altitude between the moraine plateau surface and the bottom of the channel is about 60 m.

## DEPOSITS ASSOCIATED WITH MELTING OF DEAD-ICE BLOCKS

This type of deposits obviously forms the described glacial landforms, in addition to them, however, they are scattered all over the Grudziądz Basin. Within the over-flood terraces II and III they constitute usually channel lag deposits which occur at the base of the alluvial sediments, although locally, predominantly on the convex side of the incised curves and in the vicinity of the kettle-holes, they may occur as deposits unaltered by the river activity just beneath the surface of the terrace.

A characteristic example reveals the river terrace II which for its most part is constructed only from alluvial sandy deposits up to 6–7 m from the surface. Nevertheless, nearby the western end of the Rudnickie Wielkie Lake, where a gentle depression exists in the topography, lying 1.0–1.5 m lower than the surrounding surface of the terrace, the geologic structure of the terrace changes considerably. An extensive trenching (for building purpose) shows two different kinds of deposits. First the thin cover of loose, fine-grained sands and silty sands (Fig. 9—1), averaging 0.5 m in thickness, then in a descending sequence: sandy gravels with boulders (Fig. 9—2), pocket of poorly sorted fine- and medium-grained stratified sands, warped into a syncline (Fig. 9—3), brown calcium carbonate concentrations (Fig. 9—4), grey-green loamy sands (Fig. 9—5), and grey clayey till (Fig. 9—6).

The topmost layer (Fig. 9—1) apparently represents sediments of river accumulation, while all lower resting material-deposits resulted from the melting of dead-ice and subsequent downslope movement under gravity in a waterlogged condition. Such interpretation is justified by the occurrence of typical flowtill with its characteristic structural properties (cf. G.S. Boulton 1972; E. Drozdowski 1974; R. J. Price 1973), big boulders which seem to have rolled down an ice slope, as well as the pocket of fine- and medium-grained sands which most likely had been redeposited from ice surface as frozen block, and later on, as a result of thawing, subsided and warped into a syncline.

The topographic depression mentioned, jointly with the lithology and structure of deposits suggest that the site was still occupied by remnants of





Fig. 9. Deposits associated with the melting of dead-ice block within the river terrace II  
 1—fine-grained sands and silty sands, 2—sandy gravels with boulders, 3—fine- and medium-grained  
 sands, 4—loamy sands intermixed with gravels, cobbles and numerous calcium carbonate  
 concentrations, 5—loamy sands, 6—clayey till

dead-ice after the formation of the terrace. Thus, the 0.5 m alluvial cover postdating the final melting of dead-ice was accumulated during overbank floods, when the river flowed at lower levels.

#### PROBLEM OF THE ORIGIN AND MORPHOLOGIC DEVELOPMENT OF THE GRUDZIĄDZ BASIN

The occurrence of landforms and deposits associated with the melting of dead-ice blocks within both incised curves of the ancient Vistula River bed in the Grudziądz Basin suggests that a basic cause of the origin of this part of the river valley may be closely related to the recovering of the fossil ice-filled glacial hole-forms by the mechanical and thermic action of the river. The fact that the glacial landforms and deposits step down from the basin slopes to the bottom of the kettles as much as 80 m in relation to the surface of the surrounding moraine plateau gives an indication of both the large dimensions of the fossil hollow landforms and the inclination of their beds towards the thalweg of the ancient river curves. The time of formation of these fossil landforms, as well as their filling up by dead-ice have particular significance for the solving of the problem of origin and development of the discussed valley widening. This question elucidates the following facts:

(1) big differences in altitude (up to 80 m) between the moraine plateau surface and the bottom of the kettle-holes occurring on the river terraces;

(2) lack of direct morphologic correlation between the course of subglacial channels (resulting from the activity of subglacial waters of the last ice sheet in the area investigated) and the distribution of glacial landforms and deposits associated with melting of dead-ice blocks;

(3) maximum depth of incision of the subglacial channel of the Fletnowskie Lake within the area of the Grudziądz Basin (up to 70 m), corresponding to that reach of the channel, in which dead-ice rested, more susceptible to the thermic action of the glacial meltwater than mineral bedrock.

On the basis of these morphologic evidences and also on geologic evidences which complement and support them (E. Drozdowski 1974), the most reasonable conclusion seems to be that the fossil hollow landforms originated and were filled in by dead-ice in the period prior to the last advance of the Scandinavian ice sheet, i.e. during the large-scale stagnation and gradual melting of the penultimate ice sheet in the investigated area. These deglaciation processes — as it was earlier pointed out (E. Drozdowski 1974, 1975) — took place during the lengthy Middle Würm Interstadial (Interstadial Complex).

The hollow fossil landforms, on which the river curves were developed, cannot be reconstructed in detail because of their subsequent destruction and modification by fluvial and denudation processes. However, taking into account the presence of typical erosive slopes on some segments of the basin sides (for instance between Marusza and Tarpno), as well as their variabilities in geologic structure, it should be inferred that the fossil hollow landforms were not similar in shape and dimensions to the actual incised curves of the Grudziądz Basin. Most likely they created several minor more-or-less connected hollow landforms of various shapes and depth. The deepest ones are indicated today by the depressions of the lakes: Rudnickie Wielkie, Rudnickie Małe and Święte. This assumption seems to be confirmed by glacial slope landforms, stepping down to river terrace II in the surroundings of just these lakes (Fig. 1).

As a result of the large-scale stagnation of the penultimate ice sheet the investigated area was covered by a thick blanket of supraglacial deposits. For a long time their insulating effect caused the maintenance of dead-ice which filled the hollow glacial landforms. As the last Scandinavian ice sheet advanced, it covered smoothed over topography, together with the underground dead-ice blocks. The subglacial meltwater carved into the mineral and ice bedrock of the ice sheet, i.e., into material unequally susceptible to thermoerosion, channels of differential depth. A pronounced example is the channel of Fletnowskie Lake. Its maximum depth (about 70 m) falls on that reach, where dead-ice rested, what is recorded by kame terraces on the bordering basin slope (Fig. 1).

After the retreat of the last ice sheet, the area of the Grudziądz Basin, together with its buried dead-ice and subglacial channels, was included initially in a system of proglacial outflow and later on it became a part of the developing valley of the lower Vistula River (R. Galon 1934, 1968). The formation of river terraces from IX to II was done in the Late Glacial period prior to the pine phase of Allerød. It proceeded in close connection with intensive melting of the buried dead-ice and short-term changes of the level of the Baltic Ice Lake (B. Rosa 1967; V. Gudelis 1973) as a base level for the Vistula River. Further detailed field studies are necessary to evaluate particular factors and their complex interrelations in the development of the valley at this time. The investigations carried out, however, allow some general remarks and conclusions with reference to the circumstances by which the described glacial landforms originated on the slopes of the river valley.

The formation of landforms produced by melting of dead-ice blocks in the river valley depended on several factors, chiefly on the river pattern, rate of changes in the course of the channels (especially meander swings, and waxing and waning of the arms of braided channels), rate of changes in sea level, and also the shape of fossil hollow landforms filled by dead-ice.

The kame terraces were formed between the dead-ice wall and the side of the valley in a manner described by R. F. Flint (1957). They are not as frequent in the Grudziądz Basin as the other type of glacial slope landforms called herein "dead-ice slope topography". In contrast to the kame terraces they are not ice-contact features but the result of local dissipation and melting away of buried dead-ice (Fig. 10). Therefore, in mode of formation they may be more related to features termed "dead-ice moraine" (G. Hoppe 1952; W. Niewiarowski 1959), though from the latter they ought to be distinguished by their morphologic location and present-day topography.

Of particular significance in the formation of dead-ice slope topography is the shape of fossil hollow landforms filled by dead-ice and the rate of changes in sea level as a base level of the river. They occur on these segments of the basin sides, where the configuration of the bed of buried dead-ice was irregular or gently inclined towards the thalweg of the channel. In such situations the river could reach the bed of the dead-ice block before melting away of its upper part. By contemporaneous rapid lowering of the base level prior to the pine phase of Allerød, which is recorded in shore-line features on the Baltic Sea coast (V. Gudelis 1973), this protected part of buried ice could melt more slowly than that beneath the river because of the insulating effect of the deposits cover (cf. W. G. Brown 1963; J. R. Mackay 1972; A. Jahn 1970; T. Czupek and J. Demek 1970).

It should be stressed, however, that one of the basic conditions which led to the formation of the glacial landforms described, were the considerable



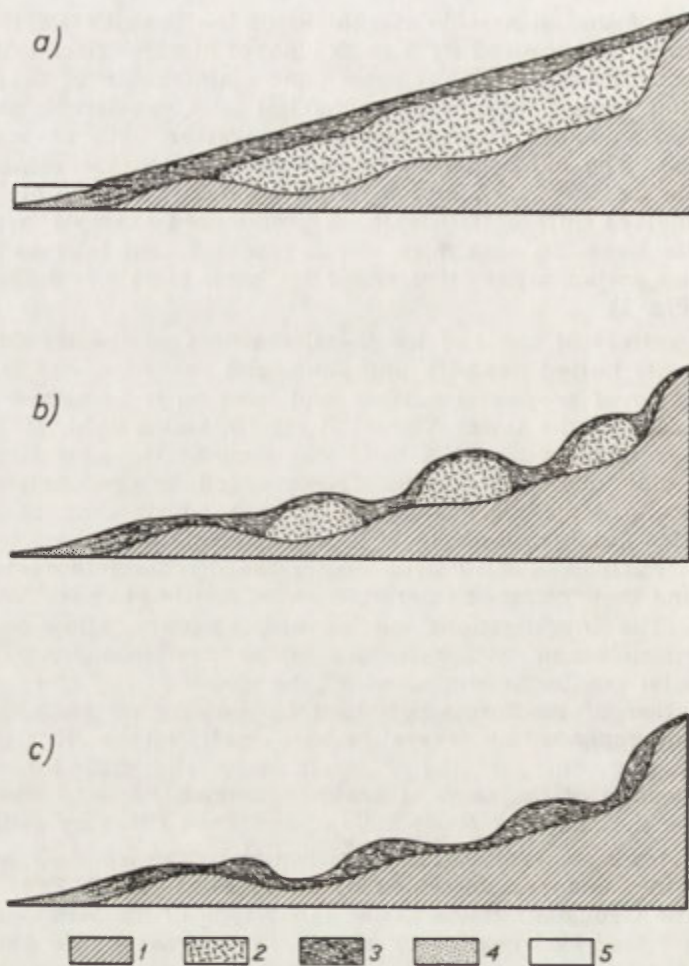


Fig. 10 Idealized scheme of developing phases of the dead-ice slope topography  
 1 — bedrock, 2 — dead-ice, 3 — deposits released from dead-ice and redeposited on the slope,  
 4 — water

dimensions of the dead-ice blocks resting beneath the river along and transverse to its valley. Minor blocks produced small holes which — as observations show at the margin of modern glaciers (K. Klimek 1972) — are quickly buried completely.

#### GENERAL CONCLUSION

The above discussed facts do not support either of the earlier hypotheses regarding genesis of the Grudziądz Basin. This largest widening of the lower Vistula River, with its incised meander curves, should be considered as a result of particular response of the river to the influence of buried glacial relief rather than a pure fluvial feature produced by changes in climatic conditions and connected with them hydraulic variables of the river (cf. G. H. Dury 1964; K. J. Gregory and D. E. Walling 1973; L. B. Leopold and M. G. Wolman 1960; S. A. Schumm 1972). This conclusion supports the former

meander dimensions which do not appear to agree with any theories involving the size and geometry of meander curves. The main hollow landforms in the present-day relief, i.e. the two forced curves of the ancient Vistula River bed developed on the foundation of the fossil hollow landforms that arose and were "stopped" with dead-ice during the penultimate period of deglaciation in the area investigated (probably in the Middle Würm), and were subsequently recovered in Late Glacial times as a part of the developing lower Vistula River valley, greatly due to the thermic action of the water.

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#### REFERENCES

- Boulton, G. S., 1972, Modern Arctic glaciers as depositional models for former ice sheets, *J. Geol. Soc. London*, 128, 361–393.
- Brown, W. G., 1963, *Graphical determination of temperature under heated or cooled areas on the ground surface*, Technical Paper of the Division of Building Research NRC, 163.
- Czudek, T. and Demek, J., 1970, Thermokarst in Sibiria and its influence on the development of lowland relief, *Quater. Res.* 1, 1, 103–120.
- Dury, G. H., 1964, *Principles of underfit streams*, U.S. Geol. Survey Prof. Paper, 452 A.
- Drozdowski, E., 1974, *Geneza Basenu Grudziądzkiego w świetle osadów i form glacialnych* (Sum.: Genesis of the Grudziądz Basin in the light of its glacial landforms and deposits), *Prace Geogr. IG PAN*, 104.
- Drozdowski, E., 1975, Penultimate period of deglaciation in the Grudziądz Basin, lower Vistula River valley: an interstadial-like interval of the Middle Würm, *Geogr. Pol.*, 31, 213–235.
- Flint, R. F., 1957, *Glacial and Pleistocene geology*. New York.
- Galon, R., 1934, Dolina dolnej Wisły, jej kształt i rozwój na tle budowy dolnego Powiśla (Zsf.: Die Gestalt und Entwicklung des unteren Weichseltales in Beziehung zum geologischen Aufbau des unteren Weichselgebietes), *Bad. Geogr. Pol. Pn.-Zach.*, 12–13.
- Galon, R., 1968, New facts and problems pertaining to the origin of the Noteć-Warta Pradolina and the valleys linked with it, *Przeegl. Geogr.*, 40, 2, 307–315.
- Gudelis, V., 1973, *Relyev i chetvertichniye otlozheniya Pribaltiki* (Relief and Quaternary of the East Baltic Region). Vilnius.
- Gregory, K. J. and Walling, D. E., 1973, *Drainage basin form and process*, London.
- Hoppe, G., 1952, Hummocky moraine regions, with special reference to the interior of Norrbotten, *Geogr. Ann.*, 34, 1–71.
- Jahn, A., 1970, *Zagadnienia strefy peryglacialnej* (Problems of the Periglacial zone), Warszawa.
- Jentzsch, A., 1911, *Erläuterungen zur geologischen Karte, Blatt Sartowitz*, Berlin.
- Klimek, K., 1972, *Współczesne procesy fluwialne i rzeźba równiny Skeidararsandur (Islandia)* (Sum.: Present-day fluvial processes and relief of the Skeidararsandur Plain (Iceland)), *Prace Geogr. IG PAN*, 94.
- Kopczyński, S., 1963, O niektórych jeziorach Basenu Grudziądzkiego (On some lakes of the Grudziądz Basin), *Roczn. Grudz.*, 3, 195–217.
- Kozarski, S. and Szupryczyński, J., 1973, Glacial forms and deposits in the Sidujökull deglaciation area, *Geogr. Pol.*, 26, 255–311.

- Leopold, L. B. and Wolman, M. G., 1960, River meanders, *Geol. Soc. America Bull.*, 71, 769–794.
- Mackay, J. R., 1972, The world of underground ice, *Ann. Ass. Amer. Geogr.*, 62, 1, 1–22.
- Niewiarowski, W., 1959, *Formy polodowcowe i typy deglacjacji na Wysoczyźnie Chełmińskiej* (Glacial forms and types of deglaciation on the moraine plateau of Chełmno), *Studia Soc. Sci. Torun.*, Sec. C, 4, 1.
- Niewiarowski, W., 1968, *Morfologia i rozwój pradoliny i doliny dolnej Drwęcy* (Sum.: Morphology and evolution of Pradolina and valley of the Drwęca River), *Studia Soc. Sci. Torun.*, Sec. C, 6, 6.
- Price, R. J., 1973, *Glacial and fluvioglacial landforms*, Edinburgh.
- Rosa, B., 1967, *Analiza morfologiczna dna południowego Bałtyku* (Morphologic analyses of the southern Baltic sea bottom), Toruń.
- Roszkó, L., 1968, Z historii rozwoju doliny dolnej Wisły (Res.: Sur l'histoire de la formation de la vallée de la Basse Vistule), *Fol. Quater.*, 29, 97–108.
- Schumm, S. A., 1972, Fluvial paleochannels, in: *Recognition of ancient sedimentary environments*, Soc. Econ. Paleont. Mineral., Special Publ., 16, 98–107.
- Szupryczyński, J., 1963, Relief of the marginal zone of Werenskioldbreen, *Norsk Polarinstitut — Årbok*, 89–107.
- Woldstedt, P., 1954, *Das Eiszeitalter: Grunlinien einer Geologie des Quartars*, 1, Stuttgart.
- Zaborski, B., 1927, Erozyjny charakter rozszerzenia doliny Wisły pod Grudziądem (Erosive nature of the widening of Vistula River valley near Grudziądz), in: *II Zjazd Słowiańskich Geografów i Etnografów w Polsce*, Sec. II, 207–208.



# ORIGIN OF THE VISTULA WATER-GAP BETWEEN THE PŁOCK AND TORUŃ BASINS

EDWARD WIŚNIEWSKI

## INTRODUCTION

The Vistula valley between Warsaw and Toruń has been considered in the geomorphological literature to be a *pradolina* reach linking the Niemen-Biebrza and Narew *pradolina*, or the Vilnius-Warsaw *pradolina*, with that of the Noteć-Warta. Along that huge course running from the Lithuanian Lake District through the Polish Lowland and the Meklemburg Lake District were to flow, at the decline of the Pomeranian stage, combined meltwaters and fluvial waters. The functioning at that of the Noteć-Warta *pradolina* and its eastern part, i.e. the Drwęca *pradolina* has been assumed by R. Galon (1961), S. Kozarski (1962, 1965), S. Kozarski and J. Szupryczyński (1958), W. Niewiarowski (1968) and E. Wiśniewski (1971), while the problem as to whether or not synchronously waters flowing from the south along the Vistula valley merged here has not been considered in detail. In spite of this, opinions on this mergence of waters coming from the south to the Noteć-Warta *pradolina* are often encountered in literature (M. D. Domosińska-Baraniecka, J. E. Mojski 1960; R. Galon 1933, 1961, 1968a, 1968b, 1972a, 1972b; W. Laskowska-Wysoczańska 1964; J. Kondracki 1965; W. Niewiarowski 1968, 1973; S. Skompski 1969; P. Woldstedt 1950).

The Vistula valley between Warsaw and Toruń is about 160 km long and consists of three basin-like widenings as well as two short and narrow water-gaps between those basins.

Farthest to the south lies the Warsaw Basin. West of it, between Płock and Włocławek is another widening of the Vistula valley called the Płock Basin, and further still, 25 km north of that basin begins the third one called the Toruń Basin.

It was S. Lencewicz who pioneered in 1927 the work on the geomorphological development of the Vistula valley between Warsaw and Bydgoszcz. The author of the present paper has for many years studied a valley fragment, between the Płock and Toruń Basins which has the character of a water-gap of the lowland type. The aim of the study was to learn the geomorphological development of the valley fragment and to get an answer to the question as to whether in fact, during the ice-sheet stoppage on the line of the moraines of the Pomeranian stage the waters flowing from the south along the Vistula valley had already joined the them functioning Noteć-Warta *pradolina*.

Within the ice-marginal valley of the Noteć-Warta R. Galon (1961) has distinguished five terraces, and has shown that the two highest represent a phase of outwash run-off that took place through the outwash plain of the

Brda the object of earlier studies by him. Within the valley and the outwash plain of the Brda, R. Galon (1953) distinguished 11 terraces. The two highest i.e. terraces XI and X, being in fact outwash levels, were formed during the recession of the ice-sheet from the moraines of the Pomeranian stage. These are in contact with the Noteć-Warta *pradolina* at a level of 80 m and 74 m a.s.l. On the level of the lower terraces i.e. IX, VIII and VII (III, II and I in the Noteć-Warta *pradolina*) there happened, according to R. Galon a bifurcation, i.e. the waters headed for the west along that ice-marginal streamway and, at the same time, to the north along the valley of the lower Vistula. On the level of terrace V there started the exclusive flow of the waters to the north. W. Niewiarowski (1968) in working out the geomorphological development of the *pradolina* and the valley of the lower Drwęca also distinguished 11 terraces there, which agrees with the number given by R. Galon (1953) for the Brda valley.

In 1969, S. Skompski after the completion of geological and geomorphological surveys in the Płock Basin, where he distinguished several terraces, expressed an opinion that it was only on the level of the uppermost terrace (I) at 97 m a.s.l. that the flow of meltwaters towards the Warsaw Basin took place, and starting with level II at 93 m a.s.l. there could have occurred a flow to the north towards the Noteć-Warta ice-marginal streamway. He relates that level to the uppermost terrace which, as is known, developed during the Pomeranian stage. The author did not assume an attitude towards the possibility of relating that level to a terrace in the Warsaw Basin. Considering that the terrace from the Pomeranian stage lies at a height of 82-83 m a.s.l. (S. Z. Różycki 1961, 1967, 1972) while in the region of Wyszogród, as is assumed by H. Ruszczyńska-Szejnach (1964), the accumulation terrace from the Baltic glaciation is at 67-68 m a.s.l., we are faced with a difficult puzzle as to whether during the Pomeranian stage there took place along that reach of the Vistula valley a flow of meltwaters and fluvial waters north of the Toruń Basin, and then on to the Noteć-Warta streamway where a terrace of that age is found at 80-81 m a.s.l. Before the author presents his own view on that matter let us discuss some paleogeomorphological problems relating to the reach of the Vistula valley in question.

#### PALEOGEOMORPHOLOGICAL PROBLEMS

The fragment of the Vistula valley linking the Płock Basin with the Toruń Basin is some 25 km long and 7-8 km wide. East of it lies the Dobrzyń morainic plateau, the height of which near the valley ranges from 95-100 m a.s.l. while to the west there is the Kuyawy morainic plateau at 90-95 m a.s.l.

In order to examine the relation of the present-day valley form in respect to the configuration of the sub-Quaternary surface a relief map on the basis of 408 geological profiles was drawn (Fig. 1). This shows that the present-day water-gap of the Vistula valley closely follows the course of a fossil valley cut across Tertiary sediments. The top of the sediments within the morainic plateau adjacent to the Płock Basin lies at a height a little above 80 m a.s.l. The thickness of the Quaternary deposits here is small and amounts to some 20 m. To the north the top of the Tertiary sediments is considerably lower, i.e. at 40-50 m a.s.l. These conditions are found too, along the further course of this buried valley to the north. At an identical height this surface is to be found to the south and east of Toruń (A. Wilczyński 1973). In analyzing the relationship of the present-day Vistula valley towards the fossil valley one can observe differences in the dimensions of their development.

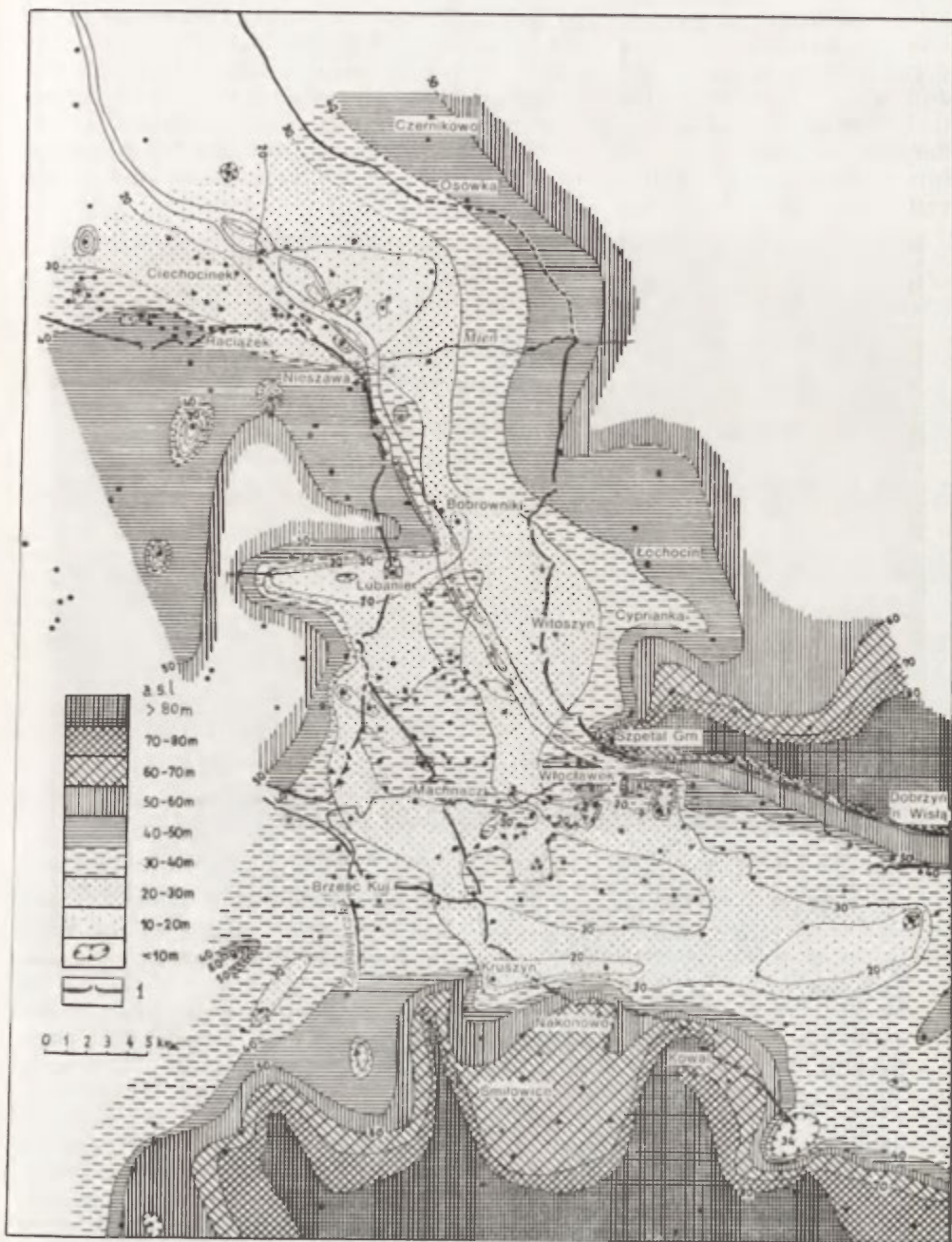


Fig. 1. Map of the sub-Quaternary relief (Sites of deeper geological profiles are marked by dots)

1. edges of the present Vistula valley



With the initial fragment of the Vistula water-gap being narrower than the fossil valley, the situation is reversed farther to the north. This is due to the much earlier functioning of a valley along which the flow of waters to the north occurred before the formation of the present-day relief. Although it is difficult to judge the beginning of the development of that valley it is, nevertheless, positive that it must have existed prior to the last glaciation, i.e., in the Eemian interglacial. Evidence for this has been provided by geological investigations of the hillside of the Kuyawy moraine plateau, and of its valley terraces.



Fig. 2. Submoraine fluvial deposits at a gravel pit south of Nieszawa

Undoubtedly, the most interesting exposures in the side of that plateau can be seen 1–2 km south of Nieszawa near Przypust. In the first one, near Nieszawa, there occur exclusively deposits of water accumulation (Fig. 2). Z. Kurlenda (1971) has described them as sands and gravels of glaciofluvial origin. The deposits which are 20 m thick overlie Neogene sediments. At the top there occurs a 2 m thick layer of silts and a 0.5 m layer of brown clay. Subsequent studies showed that the whole series was overlain with two beds of boulder clays, 1 and 2 m thick, separated by a sandy layer about 1 m thick. On the second exposure there are also sandy and gravelly deposits overlain by boulder clay. Structural investigations found that the deposits under the boulder clay were accumulated by waters flowing from the south. This fact seems to be a sufficient proof for rejecting their glaciofluvial origin. It is to be added that in that series whole specimens of the snail *Paludina diluviana* were found, characteristic of an inland interglacial, whose habitat was the cool waters of streams. After F. Różycki (1952) *Paludina diluviana* comes from a period older than the Eemian, while according to M. Limanowski (1922) and Z. Lamparski (1964) it is connected with the Eemian interglacial. The facts presented above point clearly to a fluvial character of sandy deposits occurring at gravel-pits south of Nieszawa.

These deposits are also visible at many other places in the hillside of the Kuyawy morainic plateau, and are also part of the geological structure of the ground in the water-gap of the Vistula valley. To the east of Lubanie at the level of the 67 m a.s.l. terrace these occur beneath the boulder pavement (Fig. 3). At Bobrowniki at the level of the 72 m a.s.l. terrace they are overlain by a 1 m thick layer of brown clay which, in turn, is covered by a thin layer of morainic pavement derived from the washing out of boulder clay (Fig. 4). The frequency of occurrence within the valley of fluvial deposits beneath the boulder clay or boulder pavement is sufficient evidence that in a period prior to the transgression of the last ice-sheet the Vistula valley also ran here. The top of those deposits lies most often at 60-66 m a.s.l.



Fig. 3. Fluvial deposits overlain with boulder pavement in the 67 m a.s.l. terrace, east of Lubanie

As a result of the advance of the ice-sheet and the blocking of the river course there formed in the valley a dammed lake in which the deposition of brown clays so frequently encountered within the area in question beneath the upper boulder clay started, underlain with Eemian fluvial sands and gravels.

The brown clays in this area the subject of studies by many authors (e.g. R. Błachowski 1939; R. Galon and E. Passendorfer 1948; S. Lenciewicz 1922, 1927; J. Lewiński 1924 a, 1924 b; M. Limanowski 1922, 1924; J. E. Mojski 1960, 1967; H. Ruszczynska-Szejnach 1964; J. Samsonowicz 1924; S. Skompski 1969). Their origin has usually been referred to the retreat of the Middle Polish glaciation, and even to the formation of a sea bay in the Vistula valley during the Eemian interglacial. Only a few authors suggest an earlier age for the brown clays and J. E. Mojski (1960), for example, considers them to be the oldest deposits connected with the Baltic glaciation and J. Łyczewska (1960) relates them to the accumulation brought about by the advance of the Baltic glaciation, this idea is also shared by the author of the this article.

In summarizing the above considerations one should state that the reach of the Vistula valley under consideration is dependent on the relief prior to the last glaciation. This opinion was stated earlier by R. Galon (1967) and referred to the Notec-Warta *pradolina* and the Vistula valley. The portion of the Vistula valley in question was not during the advance of the last ice-sheet fully filled up by deposits of fluvial accumulation, and was followed by that in a dammed lake, and eventually by a morainic one. In that not completely concealed valley were, therefore, created conditions for the further survival of dead ice after the ice-sheet retreated from that area.



Fig. 4. Brown clay on sandy and gravelly deposits at Bobrowniki (the 72 m a.s.l. terrace)

#### TERRACES OF THE VISTULA VALLEY BETWEEN THE PŁOCK AND TORUŃ BASINS

During the recession of the last glaciation the concavity in the incompletely filled Eemian Vistula valley between the Płock and Toruń Basins became an area for the activity of meltwaters and later on of fluvial waters. The stages of the activity of these waters were recorded in the form of erosional levels and of terraces of varying development (Fig. 5). The enumeration of the ter-



races was taken after R. Galon (1953) and was first introduced by that author in the case of the outwash plain and valley of the Brda stream, as was mentioned in the introductory chapter of this article and later used by W. Mrózek (1958) in the Toruń Basin and W. Niewiarowski (1961) in the valley of the lower Drwęca. This refers, of course, to those terraces in the

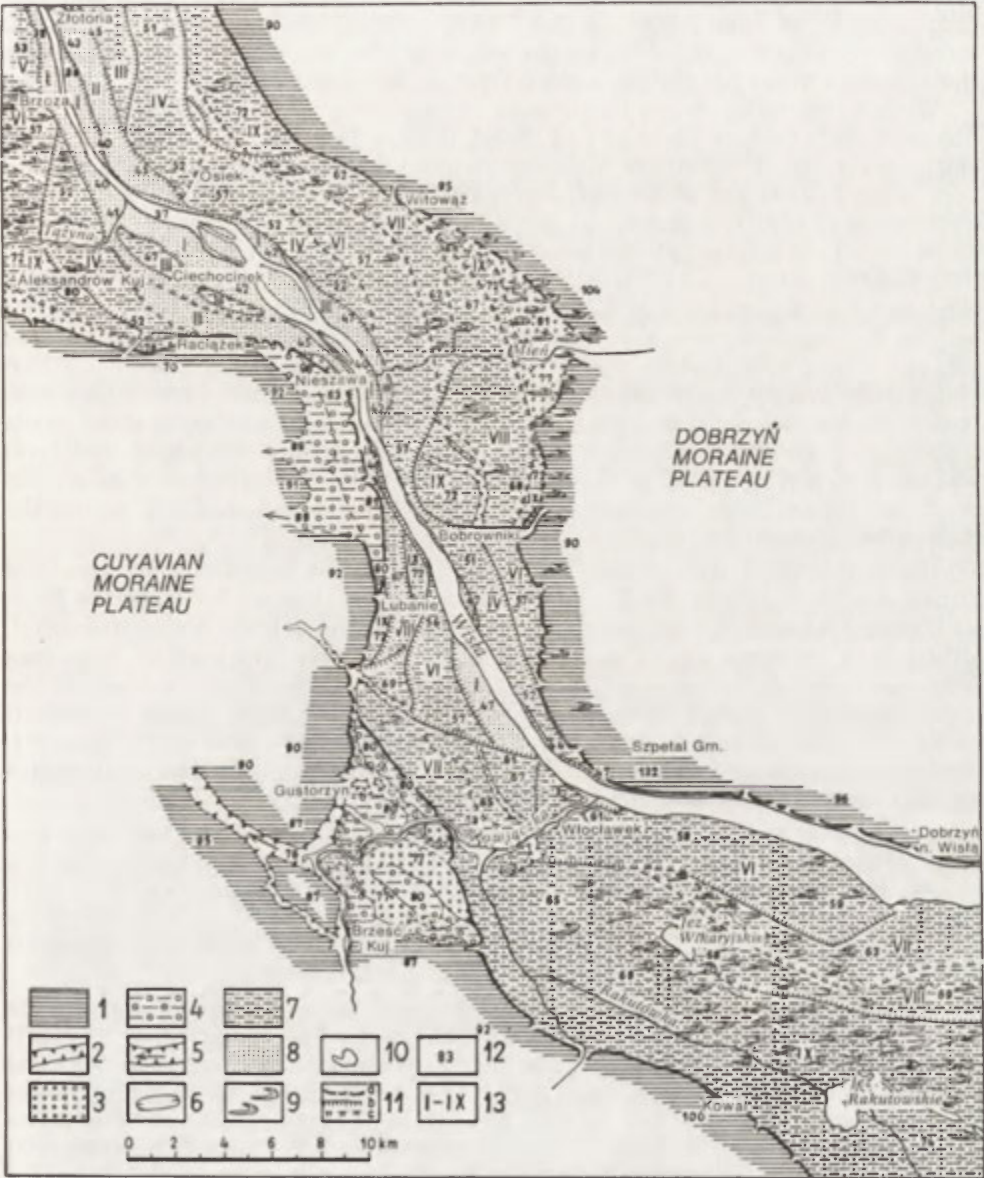


Fig. 5. Geomorphological map of the Vistula valley between the Płock and Toruń Basins

1. moraine platenau,
2. subglacial channels,
3. outwash plain,
4. erosional plains of meltwaters,
5. meltwater valleys,
6. kettles,
7. late glacial erosional terraces,
8. accumulation terraces,
9. dunes,
10. lakes,
11. edges: a) of moraine plateau, b) and c) of terraces (b. distinct, c. indistinct),
12. number of terraces

gap reach of the Vistula valley which might be linked with those already known from the Toruń Basin. It appeared in the course of studies that the possibility of such a connection existed exclusively for terraces from IX downwards (E. Wiśniewski 1973). Fragments of the higher levels or terraces which were additionally distinguished here, are difficult to be correlated with the high terraces (XI and X) in the Toruń Basin. Whilst discussing the surfaces shaped by running water the author applied two terms, i.e., levels and terraces. The first one refers to the surfaces affected mainly by meltwaters, the other to those by fluvial waters flowing from the south.

Within the valley reach in question the following levels and terraces were distinguished: (a) the 88–89 m a.s.l. level, (b) the 80–84 m a.s.l. level, (c) levels at the junction of the Mień valley with the Vistula valley at 80 m a.s.l. and 75–77 m a.s.l., (d) the 78 m a.s.l. level, (e) the 72 m a.s.l. (IX) terrace, (f) the 67–69 m a.s.l. (VIII) terrace, (g) the 62–63 m a.s.l. (VII) terrace, (h) the 57–59 m a.s.l. (VI) terrace, (i) the 51–52 m a.s.l. (IV) terrace, (j) the 45–47 m a.s.l. (III) terrace, (k) the 43–45 m a.s.l. (II) terrace and (l) the inundation terrace (42 m a.s.l. in the vicinity of Ciechocinek).

The highest level (88–89 m a.s.l.) reveals the character of a ground moraine step marked, in the valley-adjacent part of the Kuyavy plateau, with a gentle and hardly visible transition between the elevation and the level mentioned. It is built on the surface of boulder clay, in places, also of fine-grained sands 2–3 m thick. An argument taken into consideration on distinguishing that level was that it corresponded with the bottom of the initial fragment of an old erosional valley of meltwaters called the Parchańska valley, along which the meltwaters flowed westwards.

The lower level occurs over a distance of 12 km between Nieszawa and Lubanie, and is inclined to the south from 84 m a.s.l. near Nieszawa to 80 m a.s.l. near Lubanie. In the northern part this is still a little distinctive level, although to the south the hillside between it and the Kuyavy plateau, adjoining from the west, becomes more perceptible. In the geological structure of the level concerned fine-grained sands are often found, their depth, however, being inconsiderable, i.e., 1 m. They overlie boulder clay. Most often, however, the surface layer is boulder clay on which a considerable number of stones and pebbles washed out from this are found.

At the junction of the Mień and Vistula valley there have survived two quite distinct levels at 80 m and 75–77 m a.s.l. Their morphological situation shows that these are probably the fragments of a fan created by then more abundant, waters which in some periods drained into the Vistula valley along the valley of the Mień. The geological structure of these levels, now obscured with dunes, reveals mainly the share of fine-grained sands.

In the vicinity of Nieszawa, at the contact of the gap reach of the Vistula valley with the Toruń Basin, there has survived a small fragment of the level at 78 m a.s.l. Structural measurements of the sandy and gravelly deposits building that level showed that they were accumulated by running water flowing from the south-east. The deposits contain remnants of Eemian fauna transported by the ice-sheet from the north which suggests their glacio-fluvial origin.

The terraces distinguished below the level at 78 m a.s.l. in the water gap of the Vistula valley may without special difficulties be linked with terraces in the Toruń Basin. The highest of them is the 72 m a.s.l. terrace occurring both on the left and right bank of the Vistula. It corresponds to the terrace IX in the Toruń Basin. This is a typical erosional terrace, like those lying lower

i.e. VIII, VII, VI, IV and III. Terrace II (lower supra-inundational) are of an accumulative character. In the reach of the Vistula valley in question a terrace which would correspond in height with terrace V in the Toruń Basin is lacking.

It has been mentioned whilst discussing particular levels and terraces that it is only through terrace IX that one can observe the connection between the Płock and Toruń Basins which means that at that height there took place a clear flow of water from the south. The problem as to whether such a flow could also exist on higher levels can be undoubtedly solved by geomorphological investigations of the conditions in the environs of Brześć Kujawski.

#### THE GEOMORPHOLOGY OF THE ENVIRONS OF BRZEŚĆ KUJAWSKI

The area north of Brześć Kujawski is a distinctly lowered trough in relation to the adjacent Kuyavy plateau although suspended above the Vistula valley. The determination of the boundaries between the area and the already mentioned morainic plateau causes considerable difficulty, as they are not bounded by clear hillsides. There occur, however, in the area in question levels well-developed by water which are of great value in considering the origin and age of the Vistula water-gap between the Płock and Toruń Basins. The area under consideration is crossed from west to east by the valley of the Zgłowiączka stream. South of it there are found two distinct levels (T. Celmer 1969; E. Wiśniewski 1973, 1974). The higher one at 80–81 m a.s.l. is developed in the form of isolated patches. This is built of boulder clay, though in places, a 2 m thick cover of sandy and gravelly deposits is to be found. The lower level lies at 75–76 m a.s.l. and is most often built of sandy and gravelly deposits of up to 3 m thick, underlain with brown clays (Figs. 6, 7). Between the clay mentioned and the overlying deposits there is a boulder pavement i.e., the residue of a layer of boulder clay.



Fig. 6. The level at 75–76 m a.s.l. south of the Zgłowiączka valley with brown clay boulder pavement on the surface

<http://rcin.org.pl>



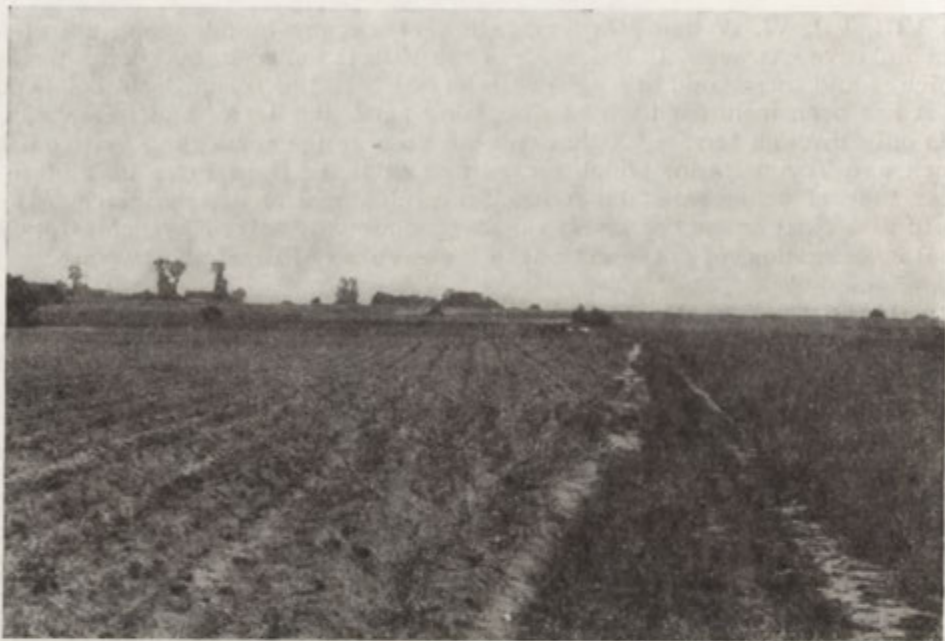


Fig. 7. Contact between the 75–76 m a.s.l. level and the 80–81 m a.s.l. south of the Zgłowiączka valley

To the north of the Zgłowiączka valley there is also an erosion at the level of 80–81 m a.s.l. and also, along the eastern side of the channel near Gustorzyn there occur at the 77–78 m a.s.l. level, and in places even higher, sandy and gravelly deposits 3–7 m thick overlying the boulder clay.

Structural measurements performed in those deposits south of the Zgłowiączka valley showed clearly that their accumulation was due to waters flowing from the region of the Plock Basin, while investigations carried out north of that valley found, in turn, that their deposition was brought about by waters flowing from the north. The sands and gravels contain numerous remnants of Eemian fauna which was the basis for their qualification as glaciofluvial deposits.

## CONCLUSIONS

The country in the environs of Brześć Kujawski seems to be a clue to the geomorphological developments which were taking place in the reach of the Vistula valley in question during the retreat of the Baltic glaciation. The finding, north of the Zgłowiączka valley and east of Gustorzyn, of traces of the flow of meltwaters from north to south, at heights lower than terrace XI, on a level at which, during the Pomeranian stage, meltwaters were draining to the west along the Noteć–Warta *pradolina*, denies suggestions on the mergence of that course of waters flowing along the Vistula valley. Glaciofluvial deposits east of Gustorzyn are the result of meltwaters flowing from the north, the source of which should be seen in the ice-sheet stagnating on the line of moraines of the Kuyavy phase, where it had stopped for a time during its recession from the limit of its maximum reach. In all probability that flow started at 88–89 m a.s.l. Part of the waters proceeded southwards and part to the west

through the Parchańska valley. After a relatively short flow of meltwaters on that level there took place an incision down to the level of about 84 m a.s.l. which put an end to the functioning of the new undeveloped Parchańska valley, and caused the waters to flow to the south.

Simultaneously, from the area of the Płock Basin those waters freed of the patches of dead ice left there, and which cannot be excluded, nourished by meltwaters striving for that basin through the outwash plain of the Skrwa stream, were flowing to the north, and in the vicinity of Brześć Kujawski they met waters heading from the opposite direction. Whether at this phase there was in operation a connection between the Warsaw and Płock Basins seems impossible to decide at the moment. It is possible that it still did not take place, as one should remember that the eastern part of the Płock Basin might have been barred by an ice-morainic rampart of the maximum reach of the Baltic glaciation, to which attention has been paid by M. D. Domosiłowska-Baraniecka and J. E. Mojski (1960).

Meltwaters gathering in the region of Brześć Kujawski were heading westwards along the Bachorza valley. The south-bound trend of the meltwaters between the Toruń and Płock Basins continued, probably also during the retreat of this ice-sheet from the moraines of the Kuyavy phase to the line of moraines of the Krajna or Wąbrzeźno phase, as well as during the retreat with which were e.g. genetically linked the outwash plains of the Chełmno morainic plateau (W. Niewiarowski 1968). According to W. Niewiarowski the meltwaters were drained through the valley of the lower Drwęca to the Toruń Basin. He suggests their further flow southwards to the Płock Basin.

What was taking place in the reach of the Vistula valley under question during Pomeranian stage remains within supposition. One point, however, seems certain, that the breach of the Vistula from the Płock Basin to the Toruń Basin was not yet in operation. But still unknown is the geomorphological development of the Mień valley entering the Vistula valley opposite Nieszawa. There are some reasons (the already mentioned levels at 80 m a.s.l. and 75-77 m a.s.l. at the mouth of the Mień valley) suggesting that the waters flowing along that valley were the last ones to take part in the tracing of the course between the basins which was initiated by meltwaters during the Kuyavy and Wąbrzeźno phases. More abundant waters entering into the Vistula valley along the Mień valley, the source of which were the melting patches of dead ice in channels, moraines and other depressions probably divided within it, into two branches. They might have headed to the west towards the Noteć-Warta marginal streamway, and towards the Płock Basin. This presumable bifurcation could have been favoured by the melting of dead ice left in the incompletely filled Eemian Vistula valley. This process certainly played, among other things, a considerable role in the final spilling of waters from the Płock to the Toruń Basin.

As the continued flow to the west along the valley of the Bachorza stream became more and more difficult, probably due to the vertical movements of the earth's crust in the axis of the Kuyavy-Pomeranian anticlinorium (E. Wiśniewski 1974), the breaching became inevitable. An explanation is needed here that this valley runs across that geological structure.

In the light of the position represented i.e. that the connection between the Płock and Toruń Basins can only be observed on the level of the 72 m a.s.l. terrace corresponding with the terrace IX in the Toruń Basin and considered to be the first terrace of bifurcation, the author states that in the Pomeranian stage there was no junction between the *pradolina* of the Niemen-Biebrza and Narew and that of the Noteć-Warta through the Vistula valley. It is to be

hoped that many relevant matters may be accounted for by geomorphological investigations of the Vistula water-gap between the Warsaw and Płock Basins.

Coming back to the geomorphological problems of the Vistula water-gap in question it is to be added that after the Vistula had completed the gap it started a quite rapid incision, and successive erosional terraces came into being. In view of the possibility of linking them with the terraces in the valley of the lower Vistula below Fordon one can assume, due to the results of palynological analyses (E. Drozdowski 1974; L. Roszkówna 1968) as well as of the archeological data from the region of Ciechocinek, that terrace III at 45–47 m a.s.l. is also of late glacial origin (higher supra-inundation). The formation of terraces II and I can be connected with the period of the Holocene.

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# REFERENCES

- Błachowski, R., 1939, *Próba stratygrafii utworów dyluwialnych na prawym brzegu Wisły między Toruniem a Modlinem* (Zsf.: Versuch einer Stratigraphie der Diluvialbildungen am rechten Weichselufer zwischen Toruń und Modlin), *Bad. Geogr.*, 20, Poznań.
- Celmer, T., 1969, Konin–Ślesin–Sompolno–Piotrków Kujawski–Radziejów–Brześć Kujawski–Włocławek, in: *Przewodnik XLI Zjazdu PTGeol.*, Konin, 188–191.
- Domosławska-Baraniecka, M. D., Mojski, J. E., 1960, Z problematyki geologii czwartorzędu Mazowsza i Kujaw (Sum.: Quaternary geology of Mazowsze and Kujawy), *Przegl. Geol.*, 8, 4, 195–200.
- Drozdowski, E., 1974, *Geneza Basenu Grudziądzkiego w świetle osadów i form glacialnych* (Sum.: Genesis of the Grudziądz Basin in the light of its deposits and glacial forms), *Prace Geogr. IG PAN*, 104.
- Galon, R., 1933, *Krajobraz geograficzny Torunia* (The geographical landscape of Toruń), in: *Dzieje Torunia*, Toruń.
- Galon, R., Passendorfer, E., 1948, *Przewodnik XXI Zjazdu Polskiego Towarzystwa Geologicznego na Kujawach i Pomorzu w roku 1948* (Guide des excursions de la XXI réunion de la Société Géologique de Pologne en Couyavie).
- Galon, R., 1953, *Morfologia doliny i zandru Brdy* (Sum.: The morphology of the Brda valley and outwash sand plain), *Studia Soc. Sci. Torun.*, C, 1, 6.
- Galon, R., 1961, *Morphology of the Noteć–Warta (or Toruń–Eberswalde) ice marginal streamway*, *Prace Geogr. IG PAN*, 29, Warszawa.
- Galon, R., 1968 a, *Ewolucja sieci rzecznej na przedpolu zanikającego lądolodu* (Sum.: Evolution of fluvial system in foreland of retreating ice sheet), in: *Ostatnie zlodowacenie skandynawskie w Polsce*, *Prace Geogr. IG PAN*, 74, 101–120.
- Galon, R., 1968 b, *Nowe fakty i zagadnienia dotyczące genezy pradoliny Noteci–Warty i dolin z nią związanych* (Sum.: New facts and new problems about the origin of the Noteć–Warta pradolina and its tributary valleys), *Przegl. Geogr.*, 40, 4, 791–810.
- Galon, R., 1972 a, *Główne etapy tworzenia się rzeźby Niżu Polskiego* (Main stages in the formation of Polish Lowland relief), in: *Geomorfologia Polski*, 2, *Niż Polski*, Warszawa, 35–110.
- Galon, R., 1972 b, *Pojezierze Pomorskie i przyległe wysoczyzny jeziorne* (The Pomeranian Lake District and the adjacent moraine lake plateaus), in: *Geomorfologia Polski*, 2, *Niż Polski*, Warszawa, 129–156.



- Kondracki, J., 1965, *Geografia fizyczna Polski (Physical geography of Poland)*, Warszawa.
- Kozarski, S., Szupryczyński, J., 1958, Terasy pradoliny Noteci między Nakłem a Milczem (Sum.: Terraces of the Noteć pleistocene old valley between Nakło and Milcz), *Przegl. Geogr.*, 30, 4, 671–684.
- Kozarski, S., 1962, *Recesja ostatniego lądolodu z północnej części Wysoczyzny Gnieźnieńskiej a kształtowanie się pradoliny Noteci–Warty* (Sum.: Recession of last ice sheet from northern part of Gniezno Pleistocene Plateau and formation of the ice-marginal valley of the rivers Noteć–Warta), Pozn. Tow. Przyj. Nauk, Wyd. Mat.-Przyr., Prace Kom. Geogr.-Geol., II, 3.
- Kozarski, S., 1965, *Zagadnienie drogi odpływu wód pradolinnych z zachodniej części pradoliny Noteci–Warty* (Sum.: The problem of outflow way of pradolina waters from the west part of the Noteć–Warta pradolina), Pozn. Tow. Przyj. Nauk, Wyd. Mat.-Przyr., Prace Kom. Geogr.-Geol., V, 1.
- Kurlenda, Z., 1971, Geology of the North Middle Kujawy, *Acta Geogr. Debrecina* 1969/70, vol. 15–16, ser. 8–9, 85–113.
- Lamparski, Z., 1964, Zarys stratygrafii czwartorzędu i morfologia dorzecza dolnej Skrwy (Res.: Précis de la stratigraphie du quaternaire et morphologie de la basse Skrwa (Mazovie-Pologne septentrionale), *Acta Geol. Pol.*, 14, 3, 415–436.
- Laskowska-Wysoczańska, W., 1964, Przekrój geologiczny przez utwory czwartorzędowe na linii Wyszogród–Sochaczew (Res.: Coupe géologique à travers les sédiments du quaternaire sur la ligne Wyszogród–Sochaczew), *Acta Geol. Pol.*, 14, 3, 361–374.
- Lencewicz, S., 1922, O wieku środkowego Powiśla (Sur l'âge du bassin de la Vistule moyenne), *Posiedz. Nauk. PIG*, 3, Warszawa, 21–24.
- Lencewicz, S., 1927, *Dyluwium i morfologia środkowego Powiśla* (Res.: Glaciation et morphologie du bassin de la Vistule moyenne), Prace PIG, 2, 2, Warszawa.
- Lewiński, J., 1924 a, Czwartorzędowe ruchy tektoniczne i „morena dolinowa” w okolicach Włocławka (Mouvements tectoniques quaternaires et la moraine de fond dans la vallée de la Vistule aux environs de Włocławek), *Posiedz. Nauk. PIG*, 7, Warszawa, 3–4.
- Lewiński, J., 1924 b, O wieku i pochodzeniu ilów wstęgowych Niżu polskiego (Sur l'âge et la genèse des argiles rubanées du Bas-Pays de la Pologne), *Posiedz. Nauk. PIG*, 8, Warszawa, p. 7.
- Limanowski, M., 1922, O znaczeniu ilów wstęgowych (warwowych) Chełmna dla stratygrafii dyluwjum Pomorza (Les argiles à varves de Chełmno (Kulm) et la stratigraphie du „diluvium” de la Basse-Vistule), *Spraw. PIG*, 1, 4–6, Warszawa, 337–371.
- Limanowski, M., 1924, O badaniach geologicznych na dolnem Powiślu w roku 1923 (Sur les recherches géologiques dans la région de la Basse-Vistule), *Posiedz. Nauk. PIG*, 9, Warszawa, 14–15.
- Łyczewska, J., 1960, Uwagi na temat czwartorzędu Kujaw wschodnich (Sum.: Remarks on the quaternary of eastern Kujawy), in: *Z badań czwartorzędu w Polsce*, 9, 245–258.
- Mojski, J. E., 1960, Schyłek plejstocenu w zachodniej części Kotliny Płockiej (Sum.: Decline of pleistocene in western part of Płock depression (Central Poland), *Kwart. Geol.*, 4, 1025–1038.
- Mojski, J. E., 1967, Wisła w Kotlinie Płockiej (The Vistula in the Płock Basin), in: *Z biegiem Wisły (Przewodnik Geologiczno-Krajoznawczy)*, Warszawa.
- Mrózek, W., 1958, Wydmy Kotliny Toruńsko-Bydgoskiej (Dunes of the Toruń-Bydgoszcz Basin), in: *Wydmy Śródlądowe Polski*, Warszawa, 1–59.
- Niewiarowski, W., 1968, *Morfologia i rozwój pradoliny i doliny dolnej Drwęcy* (Sum.: Morphology and evolution of pradolina and valley of the river Drwęca), *Studia Soc. Sci. Torun.*, C, 6, 5.

- Niewiarowski, W., Tomczak, A., 1973, Morfologia i rozwój rzeźby obszaru miasta Torunia i jego okolic (Sum.: Morphology and relief development of town area and vicinity of Toruń), *Acta Univ. Nicolai Copernici, Geografia* 10, Toruń, 41–91.
- Roszkówna, L., 1968, Z historii rozwoju doliny dolnej Wisły (Res.: Sur l'histoire de la formation de la vallée de la Basse Vistula), *Folia Quater.*, 29, 97–108.
- Różycki, F., 1952, Paludina diluviana i jej znaczenie dla stratygrafii czwartorzędu (Sum.: Paludina diluviana and its importance for the quaternary stratigraphy), in: *Z badań czwartorzędu w Polsce*, 65, 1, 75–119.
- Różycki, S. Z. 1961, *Middle Poland, Guide-Book of Excursion from the Baltic to the Tatras*, Part 2, vol. INQUA VIth Congress.
- Różycki, S. Z. 1967, *Plejstocen Polski Środkowej na tle przeszłości w górnym trzeciorzędzie* (The Pleistocene of Middle Poland), Warszawa.
- Różycki, S. Z., 1972, Nizina Mazowiecka (The Mazovian Lowland), in: *Geomorfologia Polski*, 2, *Niż Polski*, 271–317.
- Ruszczyńska-Szejnach, H., 1964, Plejstocen w okolicach Wyszogrodu nad Wisłą (Res.: Le pleistocene aux environs de Wyszogród sur la Vistule), *Acta Geol. Pol.*, 14, 3, 341–362.
- Samsonowicz, J., 1924, Zastoiska lodowcowe nad górną i środkową Wisłą (Lacs engigués glaciaires sur la Haute et Moyenne Vistule), *Posiedz. Nauk. PIG*, 1, Warszawa, 8–9.
- Skompski, S., 1969, Stratygrafia osadów czwartorzędowych wschodniej części Kotliny Płockiej (Sum.: Stratigraphy of quaternary deposits of the eastern part of the Płock depression), in: *Z badań czwartorzędu w Polsce*, 12, Warszawa, 175–258.
- Wilczyński, A., 1973, Budowa geologiczna okolic Torunia (Sum.: The geological structure of the region of Toruń), *Acta Univ. Nicolai Copernici, Geografia* 10, Toruń, 13–39.
- Wiśniewski, E., 1971, *Struktura i tekstura sandru ostródzkiego oraz teras doliny Górnej Drwęcy* (Sum.: Structure and texture of Ostróda outwash and terraces of upper Drwęca valley), *Prace Geogr. IG PAN*, 83, Warszawa.
- Wiśniewski, E., 1973, Zagadnienie przełomu Wisły pomiędzy Kotliną Płocką a Kotliną Toruńską (The problem of the Vistula water-gap between the Płock and Toruń Basins), *Kwart. Geol.*, 17, 4, 907–908.
- Wiśniewski, E., 1974, Dolina Bachorzy — problem jej genezy i znaczenia w okresie wczesnośredniowiecznym (Sum.: The Bachorza valley — the problem of its development and its significance during the early middle ages), *Przeegl. Geogr.*, 46, 2, 263–282.

## FREQUENCY AND FORCE OF INTERDEPENDENCES BETWEEN COMPONENTS OF THE GEOGRAPHICAL ENVIRONMENT

ANDRZEJ RICHLING

With the area of Białystok voivodship as an example, the author analyzed the interdependences between the basic components of the geographical environment. This voivodship, covering 23,153 sq.km, contains areas genetically connected with both the Baltic and the Middle Polish Glaciations and, in consequence, reveals wide varieties in its geographical environment. The wide extent of this area made the author decide upon an all-embracing scale for his pertinent maps, and he chose the 1 : 300,000 scale because at this scale a fairly ample source material is on hand for the area in question.

He started his analytical studies by compiling a map of what he calls basic fields, obtaining a picture of these fields by transferring from his own specific maps of components to his cumulative map the outlines of particular components. However, because usually the specific maps failed to tally to some extent, he had to modify the observed discrepancies. As basic sources for his synthetic map the author had first to prepare and use a number of specific maps indicating basic components such as: relief types, surfaces deposits, soils, hydrographical conditions, and types of land utilization including forest and meadow vegetation. He first prepared the relief types map; for the other maps he prepared drafts which he rectified as required during the further stages of the work. The one element shown on all the maps was the outlines of valleys and of undrained depressions.

By following this procedure the author obtained a map of basic fields which hereafter shall be called "geocomplexes". Hence each geocomplex signifies one relief type, one kind of surface deposit, one soil type, a definite depth of ground water, and one type of land utilization. After this the synthetic map was completed, the author marked all his geocomplexes by successive numbers. In this manner 5,751 separate geocomplexes were identified within the boundaries of the Białystok voivodship. A fragment of this map is shown in Fig. 1.

The next step was the application of suitable symbols (codes) to each field. With the specific analytical maps as a basic the author marked successively his geocomplexes with numerals, each denoting its features according to the five distinguished components. Next, a special list was prepared, in which characteristic features of the geocomplexes were arranged in accordance with the serial numbers of the geocomplexes. The survey of the results obtained in this manner disclosed, that in the area under investigation 478 different types of geocomplexes exist, i.e., 478 field areas differing from each other as to their characteristic features. In typology of the geocomplexes no attempt was made to distinguish outstanding factors, — all features were treated as identical in importance.





Fig. 1. Fragment of map of geocomplexes  
 Note: For very small surfaces, serial numbers were omitted

Listing the number of geocomplex types made it possible to determine the number of cases in which particular features of the components are interrelated. For indicating these interdependences between components the author applied what is called the entropy measure. However, in his calculations he left out of consideration the area covered by each geocomplex; obviously it would have been possible to apply definite weights to each of these areas, but this would have involved a great increase in tedious labour, and the results obtained might not show any greater precision. In view of the great number of basic fields the divergences from a mean area are bound to be rather small — and, as it is, the calculations cover as much as some five and a half thousand separate geocomplexes.

Up to now this sort of investigation embracing analytical studies of the number, the surface area, and the frequency of occurrence of basic units has been carried out for the most part in the Soviet Union. Usually the purpose of such studies was to verify units prevailing with regard to their areas, or the frequency of their occurrence, or to define the degree of similarity between the geocomplexes and the physico-geographical regions (Л. Mukhina, V. Preobrazhenskiy, N. Fadiyeva 1968, Л. Ivashutina, V. Nikolayev 1969, K. Gerenchuk, I. Gorash, A. Topchiyev 1969). A full survey of statistical methods for determining the homogeneity of geocomplexes and the interdependence between geocomplexes and between components forming geocomplexes, has been supplied in studies made by T. Aleksandrova (1967, 1969). For signifying the interdependence between components this author made use of K. Pearson's coefficient of correlation (where the elements to be correlated are of a numerical nature) or of K. Pearson and A. Chupurov's multiple index of correlation (where elements are correlated as to their quality).

Another method sometimes applied for solving problems of this kind is an informative analysis of the structure of the geocomplexes (K. Gerenchuk, A. Topchiyev 1970). These authors started out defining the numerical quantity of information contained in one random variable  $x$  about a second variable  $y$ . In the cases when the two variables  $x$  and  $y$  are interrelated, one can calculate

the probability of to what extent a definite value of variable  $y$  might exist for a definite value of variable  $x$ . On the other hand, provided the two variables are not interrelated, the number of data equals zero. This procedure is called entropic because, the dimmer the pattern of probability, the greater is its entropy (cf. M. Arbib 1968 and V. Pugachev 1962).

This method has been applied by the present author for calculating the interdependence between the five analyzed components, — hence for determining the interdependences observed between his analytical maps. He calculated the numerical quantity of data revealed in one of these specific maps about a second specific map, using the equation suggested in V. Pugachev's paper (1962):

$$I_{(x,y)} = \sum_{i=1}^m \sum_{j=1}^n p_{ij} \log_2 \frac{p_{ij}}{p_i p_j}, \text{ where}$$

- $I$  = number of data
- $p_i$  = probability of occurrence of 1, ...,  $n$  features of component  $i$
- $p_j$  = probability of occurrence of 1, ...,  $n$  features of component  $j$

The author defines the probabilities  $p_i$  and  $p_j$  by referring the number of interdependences between successive pairs of features to the total number of all interdependences taken into account in his calculations. Thus the sum of probabilities of patterns of particular pairs of components equals 1. For each of these patterns he prepared a separate table in which the rows correspond to successive features of one of the two components, and the columns to successive features of the second component. In the individual squares of this table the author entered the values of the ratio of the number of determined interdepend between features (the number of geocomplexes which simultaneously contain both analyzed features) to the total number of all interdependences (thus to the total number of all geocomplexes). The sum of these values for successive rows and columns he considers the probability of the occurrence of 1, ...,  $m$  features of component  $i$  (in the rows) and of 1, ...,  $n$  features of component  $j$  (in the columns). Ultimately he obtained the following results (in binary digits):

(1) relief to kind of substratum	9 845
(2) relief to soils	10 413
(3) relief to depth of water table	7 184
(4) relief to land utilization	6 804
(5) kind of substratum to soils	14 603
(6) kind of substratum to depth of water table	6 694
(7) kind of substratum to land utilization	8 607
(8) soils to depth of water table	6 294
(9) soils to land utilization	7 727
(10) depth of water table to land utilization	5 774

From the above it appears, that the greatest number of data result from the interdependence between the kind of substratum and the soils; that next in line are relief and soils, followed by relief and kind of substratum; this means that for these three pairs of components the interdependences are the strongest. But at the same time these data are evidence that relief has the strongest interdependences with soils, the lithological substratum also with soils, soils with the substratum, the water table with the relief, and land utilization (including types of vegetation) also with the kind of substratum. This implies, that soils and kind of substratum are the crucial or key elements in the pattern under discussion.

Next the author determined the frequency of interdependences between pairs of components. In his analyzing features of pairs of components he calculated how often particular features of these components appear in this interrelation. To give an example: from the correlation of relief types with the geological structure it came to light in how many cases plains are connected with a gravel substratum, in how many with sandy ground or with loamy ground etc. By the same procedure the interdependence of wavy plains with particular types of the substratum was revealed and, afterwards, of low and high hills and of all kinds of hillocks. Finally, taking the sum of all geocomplexes to be 100%, he determined for all kinds of interdependences between two components (such as between relief and geological structure) their percentage of occurrence.

The results of these calculations are presented in five diagrams expressing the most important interdependences between a given component and the remaining components. To make correlation easier, to each one of these diagrams is added a diagram of the marginal pattern of the given component. In these studies the author took into account only those interdependences which occur most frequently, omitting all those for which the frequency of occurrence is less than 5% (always keeping in mind that each correlated component might have 100% interdependence with every other one). Evidently, elements appearing in very small percentages in the diagrams of marginal patterns do not matter at all in our diagrams of frequencies of interdependences. For illustrating this procedure, the author presents in Fig. 2 a chart indicating the interdependence between the relief and the remaining components.

These regularities, i.e. the most frequent interdependences, have an economic importance, those which are rare are eliminated, those that occur most commonly only being taken in account. The author believes, that any analysis of these sort of chains of interdependences should precede any decision about land utilization. The importance of this type of analyses has been stressed, among other authors, by J. Saushkin (1972) in whose opinion the concept of "geographical chains of relationships" originated from studies of territorial systems — and by V. Preobrazhenskiy (1965) who, emphasizing the branches of geographical science that often deal with the interdependences of two components, looks upon the determination of chains of relationships between many components as one of the fundamental tasks of physico-geographical research.

The diagram presented by the author, as well as some other similar ones referring to the remaining components, reflect the interdependences between one of the elements of the environment and the remaining elements. Were the data resulting from all these diagrams exhibited in the form of a single diagram (incidentally in this case a different graphical elucidation would be required), this diagram could be looked upon as some model of the structure of the given environment. In fact, this would be a simplified model, yet it would illustrate the most important relations for which the selection would ensure automatically.

A more lucid and more accurate model of the structure of the geographical environment can be obtained from assuming the interdependences between all components to be 100% and from calculating the share of the particular chains of interdependences; hence, for instance, from calculating the percentage, value in which, compared with all interdependences, occurs the system: wavy plains — loose sands — podsolized soils — deep water table — withered primeval forest. For technical reasons this sort of calculation would be difficult. Hence, for illustrating this procedure, the author confined his calculations to systems containing three components.



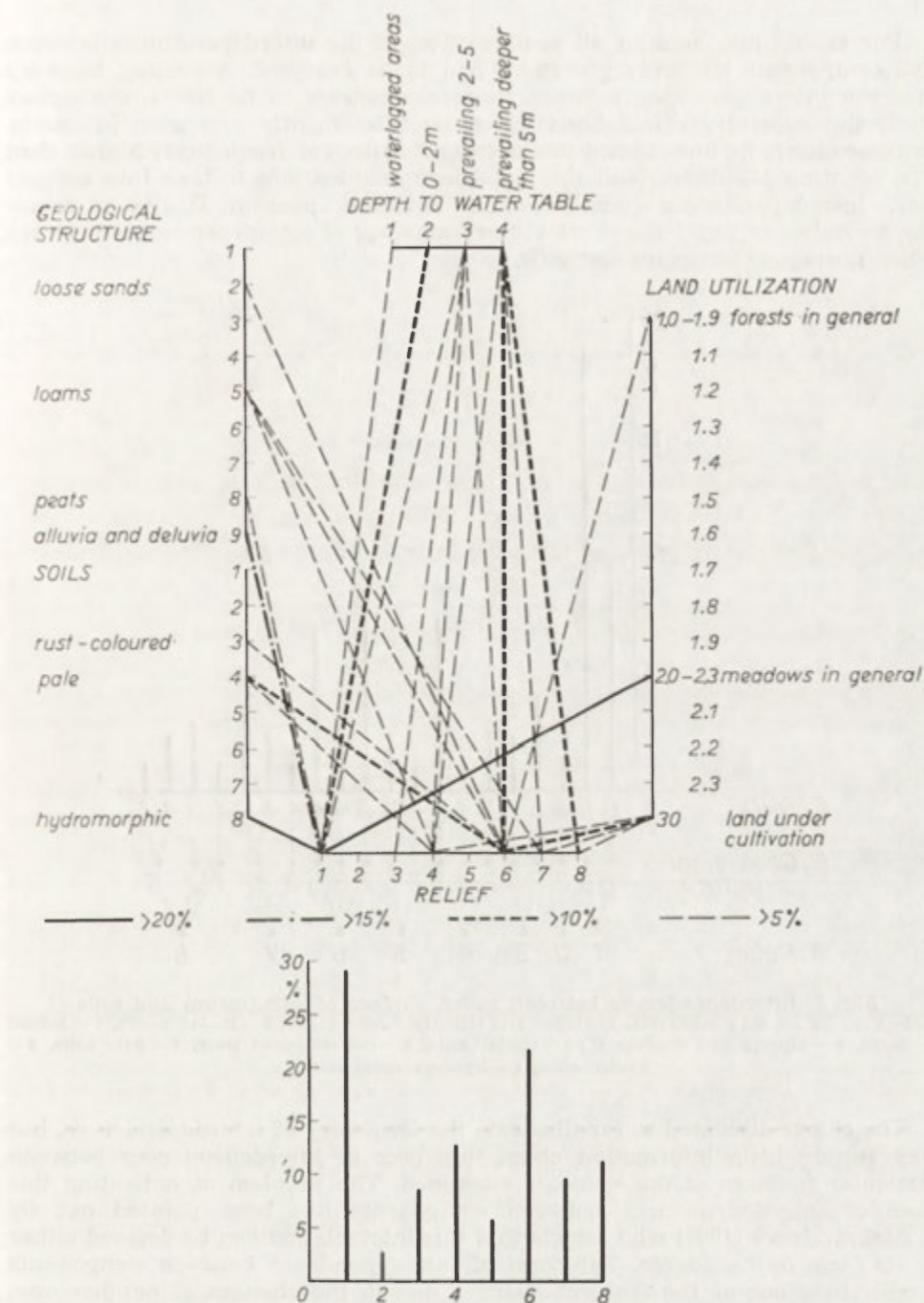


Fig. 2. The most important interdependences between relief and the remaining components of the geographical environment

Types of relief: 1—plane valley floors and depressions, 2—plains outside valley regions, 3—wavy plains, 4—low hills, 5—high hills, 6—low widespread hillocks, 7—low narrow hillocks, 8—high hillocks types

The diagram below represents the frequency of the occurrence of particular relief types

For taking into account all combinations of the interdependences between five components ten ternary systems had to be analyzed. Assuming in every case the interdependence between three components to be 100%, the author made the necessary calculations which he subsequently presented in charts. In these charts he only shows the interdependences of frequencies higher than 1%, omitting all others; and this procedure enabled him to take into account many interdependences which so far had not been apparent. To give an example, he shows in Fig. 3 the chart of the frequency of interdependences between relief, geological structure and soils.

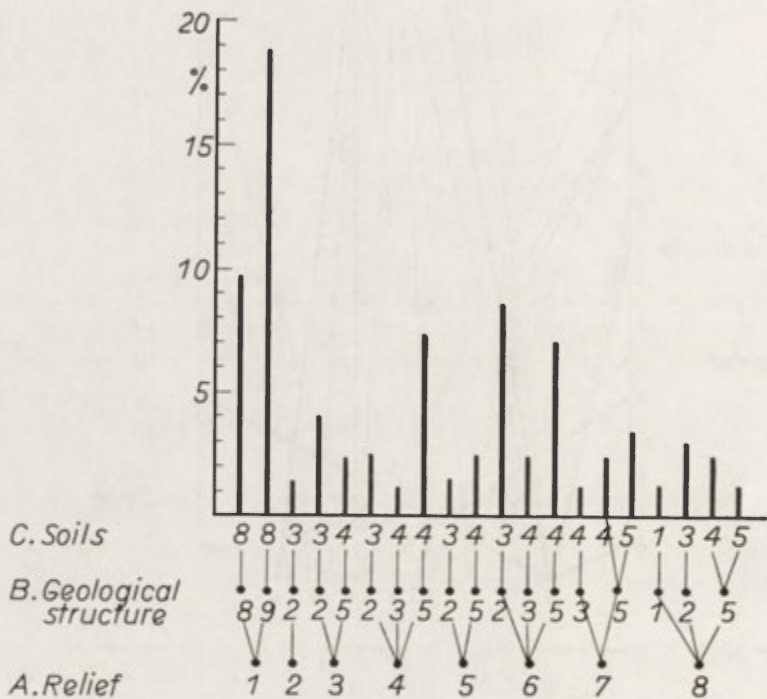


Fig. 3. Interdependences between relief, surface of substratum and soils  
A : 1—8 cf. Fig. 2. B : 1 — gravels, 2 — loose and slightly loamy sands, 3 — loamy sands, 5 — loams, 8 — peats, 9 — alluvia and deluvia C : 1 — initial soils, 3 — rust-coloured soils, 4 — pale soils, 5 — brown soils, 8 — hydromorphic soils

The charts discussed so far illustrate the frequency of interdependences, but they supply little information about the force of interdependences between particular features of the elements examined. The problem of indicating this force of interdependences between components has been pointed out by T. Aleksandrova (1967) who asserts that this interrelation can be defined either by its form or its degree. The form of interdependence between components reveals how one of the features changes due to the changes of another one, whereas the degree of interdependence shows the force by which the change of one feature depends upon the change of a second feature. The form of interdependence finds its expression by indices calculated from established formulae.

For calculating the force of interdependence between a pair of features some criterion must be adopted with regard to which the rate of interdepend-

ence can be defined. It seems that this criterion can be determined as the maximum number of cases in which a given interdependence might occur. However, the adoption of this point of view also throws light upon the force of interdependence in cases which occur rarely and which have been neglected in our previous discussion. In conformity with what was said before, the author calculated the force of interdependences as the ratio of the number of determined interdependences between two variables  $x$  and  $y = f$ , to the total number of those geocomplexes within which in the area of Białystok voivodship one of the above mentioned variables ( $x$  or  $y$ ) appears; and here it is noteworthy, that into account should be taken that variable which appears within the boundaries of a lesser number of geocomplexes. The value thus obtained is called the index of the force of interdependences  $Wsk_{mp}$ . Hence:

$$Wsk_{mp} = \frac{f}{x} \text{ when } x < y, \text{ or } Wsk_{mp} = \frac{f}{y} \text{ when } y < x.$$

The values of this index oscillate between 0 and 1.

As mentioned before, by means of the above equation one can correlate rare dependences as well as those that occur frequently. Hence this procedure brings a type of standardization of index values referring to any pair of variables.

As an example let us assume that for  $x < y$  the values are:  $f_1 = 500$ ,  $x_1 = 1000$ ,  $y_1 = 2000$ , and for  $y < x$ :  $f_2 = 5$ ,  $x_2 = 12$  and  $y_2 = 10$ . In this case the theoretically possible maximum number of interdependences are for the former equation 1000, and 10 for the latter. Calculating the index of the force of interdependences we find  $500/1000 = 0.5$  and  $5/10 = 0.5$ .

In this way the author calculated the index of the force of interdependences between all pairs of features of the components and arranged them in a table; in his report he presents this table in an abbreviated form (Table 1). The value of this index is here shown in three subdivisions: 0.01–0.33; 0.34–0.66; 0.67–1.00 — with the first set looked upon as a weak, the second as an average, and the third set as a strong form of interdependences.

The calculation of the index of the force of interdependences served as a means for defining the interior consistency of the geocomplexes — a consistency for which the correct gauge is believed to be the mean value of the force of interdependences between the particular features of components observed in all types of the geocomplexes.

In the above calculations the author disregarded land utilization and types of vegetation. Lacking pertinent source material the map of types of vegetation fails to show a distinct division of forests and meadows into types. In consequences, in his calculation of the index of the force of interdependences the author had in some cases to refer particular features of components to all forests and meadows, in other cases to some of definite type. It can be readily seen, that the relation of a definite feature of a random component to forests in general can in no way be considered identical with the relation of this some feature to some definite forest type. For instance, it is a fact that the index of dependences between waterlogged areas and forests in general is 0.14, and for older forests 0.83. Hence, it is inadmissible to demarcate forest geocomplexes in river valleys (lacking a definition of the type of forest) by the relation of forests in general to valley floors in general, because the values obtained would be altogether too low. Anyway, it is futile to try a correlation between forests of an unidentified type and other components. The resulting pattern might very often be incidental and very much dependent on man's economic actions. All these considerations apply also to meadows of an unidentified type. In our discussion so far made, geocomplexes which do not consist of meadows or



TABLE 1. Force of interdependences of particular components

		B. Geological structure								C. Soils								D. Depth to water table				E. Land utilization and types of vegetation															
		1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	1	2	3	4	1.0-1.9	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0-2.1	2.1	2.2	2.3	3.0
A. Relief	1							x	x									x	x	-		-															-
	2	-	x	-	-	-					-	-	0	-	-				x	-		0			-	-	-										0
	3		0	-	-	-					-	-	0	0	-	0			x	-		0		-	-	-	-	-	-								0
	4	-	-	-	0	-					-	-	x	-					0	0		-		-	-	-	-	-									x
	5	-	-	-	-	0	-				-	-	-	0	-				-	x		-		-	-	-	-	-									x
	6	-	0	-	0	-	0				-	-	0	0	-				0	0		0		0	0	-	-	-	-								0
	7	-	-	-	0	x	-				-	-	-	0	0	0				0	0		-		-	-	-	x	-								x
	8	0	-	-	0	-	-				x	-	-	0	-				-	x		-		-	-	-	-	-	-	-							x
B. Geological structure	1										x	-	-	-	-				-	x		-		-	-	-	-										x
	2										-	x	x	-	0				-	x		0		x	x	x	0	-	-								0
	3										-	-	-	x	-					0	0		-		-	-	-	-	-								x
	4										0	-	0							-	x		x		0		-										-
	5													x	x	0				0	0		-		-	-	0	x	x								x
	6													x						x	-																x
	7													x	-					-	-	x															x
	8																			0	0	-															-
	9																			x	x		-														
C. Soils	1																			x		0		-	-	-	-										0
	2																			0	0		x		-	-	-	-									-
	3																			-	x		0		x	0	0	0	-	-							0
	4																			0	0		-		-	-	-	0	0	x						x	
	5																			0	0		-		-	-	-	0	-							x	
	6																			0	0		0														0
	7																			-	0	0															-
	8																			x	x	-															
D. Depth to water table	1																					-															
	2																					-															
	3																					-															
	4																					0		0	-	0	0	0	0	0							0

x = strong interdependences 0.67–1.00  
0 = average interdependences 0.34–0.66  
– = weak interdependences 0.01–0.33

A. Relief

1. plane valley floors and depressions
2. plains outside valley regions
3. wavy plains
4. low hills
5. high hills
6. low widespread hillocks
7. low narrow hillocks
8. high hillocks

B. Geological structure

1. gravels
2. loose and slightly loamy sands
3. loamy sands
4. dune sands
5. loams
6. clays
7. silty deposits
8. peats
9. alluvia and deluvia

C. Soils

1. initial
2. podsolized soils and podsoles
3. rust-coloured
4. pale
5. brown
6. black and grey soils
7. marshy alluvia
8. hydromorphic soils

D. Depth to water table

1. waterlogged areas
2. areas with water at 0–2 m depth
3. areas with water prevailing at slightly less than 2 m, never deeper than 5 m
4. areas with water prevailing much deeper than 2 m, usually lower than 5 m

E. Land utilization and types of vegetation

1.0–1.9 forests in general, in particular:

- 1.1 healthy primeval forest
- 1.2 withered primeval forest
- 1.3 apruce primeval forest
- 1.4 mixed primeval forest
- 1.5 mixed forest
- 1.6 deciduous forest
- 1.7 paludinal forest
- 1.8 alder forest
- 1.9 swampy forest

2.0–2.3 meadows in general, in particular:

- 2.1 meadows subject to flooding
- 2.2 swampy meadows
- 2.3 dry-soil meadows
- 3.0 land under cultivation

forests were assumed to be geocomplexes of cultivated land; but this concept also lacks precision, the more so that this concept also implies urbanized areas and wasteland. Moreover, these sort of areas also occurs in interdependence with almost all geocomplex features, hence they might be called ubiquitous and their patterns, like those of forests and meadows in general, are to a large extent fortuitous. In view of all these arguments the author limited his definition of the consistency of geocomplexes to four components. By this procedure he reduced the number of types of geocomplexes from 478 to 170.

Marking the successive components by *a*, *b*, *c* and *d*, every geocomplex will now contain the following interdependences: *a—b*, *a—c*, *a—d*, *b—c*, *b—d*, and *c—d*. Summing up the values of the indices of the force of interdependences previously determined, and calculating their arithmetical mean, the author obtained this mean value as the index of the interior consistency of the geocomplexes. For the area of Białystok voivodship this index oscillates between 0.23 and 0.94.

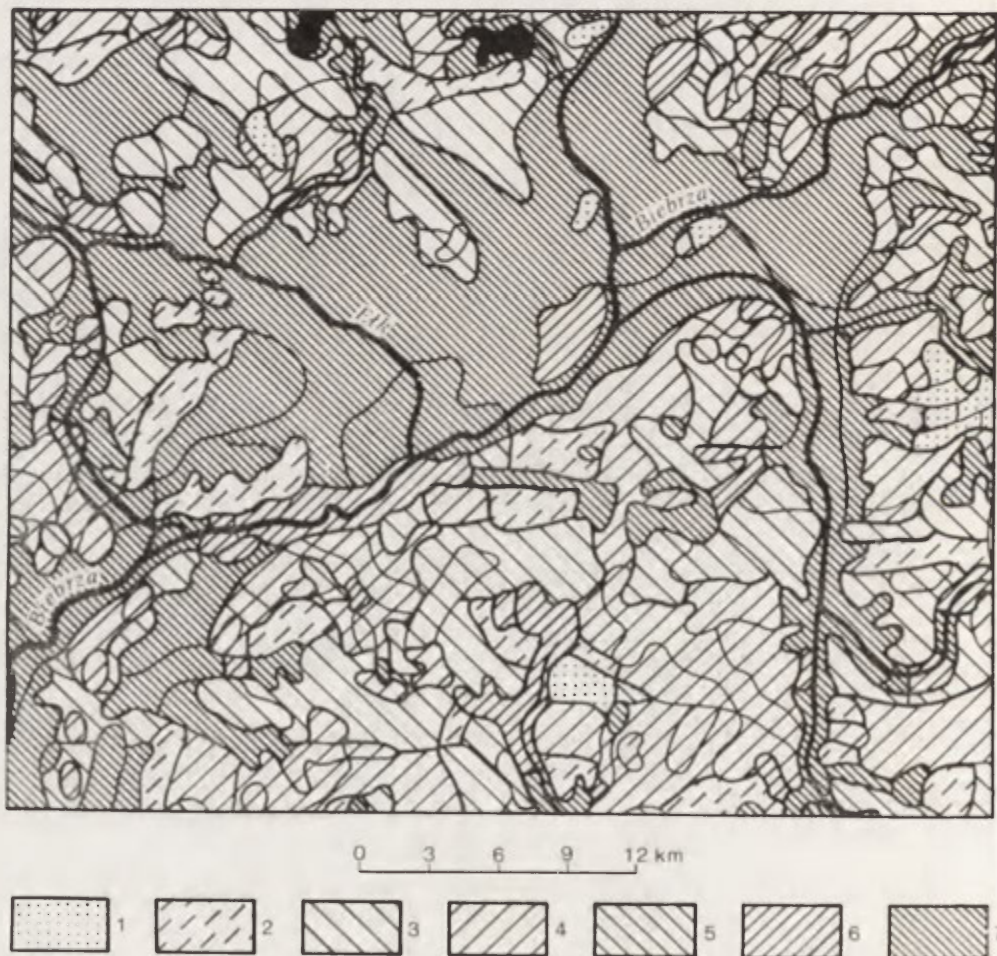


Fig. 4. Consistency of geocomplexes

Value of index of interior consistency: 1 — 0.31–0.40, 2 — 0.41–0.50, 3 — 0.51–0.60, 4 — 0.61–0.70, 5 — 0.71–0.80, 6 — 0.81–0.90, 7 — 0.91–1.00



The value of the index depends for the most part upon the typical character of the given type of geocomplex. Because the force of interdependences between — let us say — loose sands and rusty soils happens to be of the same order as between loams and pale soils, the value of the index cannot be contingent on the kind of substratum and the kind of soil. One notices a similar lack of direct dependence upon relief or depth of the groundwater table. All that can be asserted is, that essential differences exist between hydrogenic areas, i.e., valley floors and depressions, and lithogenic areas. The former reveal much higher values of the index of interior consistency than the latter.

The spatial distribution of geocomplexes with different indices of consistency is illustrated in the fragment of the map of Biatystok voivodship shown in Fig. 4. On this map geocomplexes with a consistency index lower than 0.50 have been marked by a separate symbol. These geocomplexes, nowhere appearing in larger areas, occur in the form of isolated contours surrounded by units of higher consistency. The remaining geocomplexes are very distinctly subdivided into two groups. Of these, group one consists of units with an index extending from 0.51 to 0.70; in most cases they contain lithogenic areas and appear in larger and coherent surfaces. Group two consists of hydrogenic areas exclusively, and here the consistency is always above 0.80. From an analytical study of the map one can conclude, that the value of the index of interior consistency is also contingent on the spatial distribution of the geocomplexes. Usually geocomplexes of identical or similar type lie next to each other and cover larger areas; they show indices of consistency higher than those which appear within isolated contours. This shows their close connection with the typical character of geocomplexes.

In concluding his mediations about the consistency of geocomplexes the author voice the opinion, that the index of consistency might be a gauge of the power of resistance of a given geocomplex. Following up the change of an arbitrary element within a geocomplex (such as, maybe, the lowering of the groundwater table), there sets in a disturbance of the equilibrium which had existed in the given unit. Obviously this is reflected in the index of interior consistency. Gradually there must develop another type of equilibrium — in other words, a new mutual adjustment of particular components of the given geocomplex — a change bound to affect the value of the index of consistency. As a matter of fact, typical geocomplexes, that is those that occur most frequently and reveal the most usual kinds of interdependences are the most stable units and to the highest degree compliant with existing conditions. Hence, as explained above, the value of the index of consistency depends for the most part on the typical character of the geocomplexes, and this implies that this index can serve as an index of the power of resistance, or the lasting quality, of the geocomplexes.

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#### REFERENCES

- Aleksandrova, T. D., 1967, Opyt statisticheskovo izucheniya stepeni sviazi komponentov pri landshaftnykh issledovaniyakh (The problem of statistical investigation of the interdependence between components in landscape studies), *Izv. AN SSSR, Ser. Geogr.*, 3.
- Aleksandrova, T. D., 1969, Statisticheskiye metody i landshaftovedeniye (Statistical methods and landscape science), in: *Metody landshaftnykh issledovaniy*, Izd. Nauka, Moskva.

- Arbib, M. A., 1968, *Mózg, maszyna, matematyka* (Brain, machinery, mathematics), PWN, Warszawa.
- Armand, A. D., 1972, The application of information theory to geographical division into areas, in: *Mathematical methods and modern geography*, Kazan University.
- Armand, D. L., Preobrazhenskiy, V. S., Armand, A. D., 1969, Prirodnyye komplekсы i sovremennyye metody ikh izucheniya (Geocomplexes, and modern methods of investigating them), *Izv. AN SSSR, Ser. Geogr.*, 5.
- Bartkowski, T., 1974, O możliwości zastosowania metody nakładów-wyników do przedstawienia współoddziaływania systemu społeczno-ekonomicznego i środowiska geograficznego w zakresie metabolizmu geotechnicznego (Sum.: On the applicability of the input-output method for demonstrating the interaction between the socio-economic system and the geographical environment in the sphere of geotechnical metabolism), *Przegl. Geogr.*, 46, 4.
- Dorywalski, M., 1968, Maps of natural geographical environment, *Geogr. Pol.*, 14.
- Gerenchuk, K. I., Gorash, I. K., Topchiyev, A. G., 1969, Metodika opredeleniya nekotorykh parametrov morfologicheskoy struktury landshaftov (Methodology of determining certain parameters of the morphological structure of landscapes), *Izv. AN SSSR, Ser. Geogr.*, 5.
- Gerenchuk, K. I., Tophiyev, A. G., 1970, Informatsyonnyi analiz struktury prirodnkh kompleksov (Informative analysis of the structure of natural complexes), *Izv. AN SSSR, Ser. Geogr.*, 6.
- Ivashutina, L. J., Nikolayev, V. A., 1969, K analizu landshaftnoy struktury fiziko-geograficheskikh regionov (On problems of analyzing the landscape structure of physico-geographical regions), *Vestn. Mosk. Univ, Geografia*, 5.
- Kondracki, J., 1967, Landschaftsökologische Studien in Polen, *Wiss. Abh. Geogr. Gesell. DDR*, 5, Leipzig.
- Kondracki, J., 1969, *Podstawy regionalizacji fizyczno-geograficznej* (Principles of physico-geographical regionalization), Warszawa.
- Kondracki, J., Richling, A., 1972, Synthetic physico-geographical research, *Geogr. Pol.*, 22.
- Milkov, F. N., 1970, *Landshaftnaya sfera zemli* (The landscape cover of the earth), Izd. Mysl, Moskva.
- Oktaba, W., 1974, *Elementy statystyki matematycznej i metodyka doświadczalnictwa* (Elements of mathematical statistics, and methodology of experimental research), 3rd ed., PWN, Warszawa.
- Preobrazhenskiy, V. S., 1966, *Landshaftnyye issledovaniya* (Landscape investigations), Izd. Nauka, Moskva.
- Pugachev, V. S., 1962, *Teoriya sluchaynykh funktsii* (Theory of random functions), 3rd ed., Gos. Izd. Fiz-Mat. Lit., Moskva.
- Richling, A., 1972, *Struktura krajobrazowa Krajny Wielkich Jezior Mazurskich* (Sum.: Landscape patterns of the Great Mazurian Lake Country), *Prace i Studia IG UW*, 10, *Geogr. Fiz.*, 4.
- Richling, A., 1973, O sposobach przedstawienia urzeźbienia w terenach młodoglacjalnych (Sum.: On methods of exhibiting relief forms in young-glacial regions), *Przegl. Geogr.*, 45, 1.
- Richter, H., 1968, Beitrag zum Model des Geokomplexes, *Petermanns Geogr. Mitt.*, 271.
- Saushkin, J. G., 1972, System analysis in geography, in: *Mathematical methods and modern geography*, Kazan University.
- Sochava, V. B., 1974, Geotopologiya kak razdel ucheniya o geosistemakh (Geotopology as a department of teaching geosystems), in: *Topologicheskkiye aspekty ucheniya o geosistemakh*, Izd. Nauka, Novosibirsk.

## HYDROLOGICAL MAP OF THE WORLD, SCALE 1:2,500,000

ANTONI DOBIJA, IRENA DYNOWSKA, ALICJA TLĄKA, KAZIMIERZ TRAFAS

Hydrological maps of a land drawn on general and atlas scales can be divided into two groups:

- (1) Analytical maps representing particular water phenomena.
- (2) Complex and synthetic maps showing several water phenomena, usually appropriately interpreted.

Analytical maps include, for example, river networks with water divides. These are the simplest maps containing comparatively little information. An example may be the hydrographic map in the *Atlas of Poland* (1954). Maps of the individual elements of run-off are placed in the atlases of the USSR republics (*Atlas Armyanskoy SSR*, 1961; *Atlas Azerbaydzhanskoy SSR*, 1963; *Atlas Gruzinskoy SSR*, 1964; *Atlas Tadzhikskoy SSR*, 1967, *Atlas Uzbekskoy SSR*, 1963; *Atlas Voronezhskoy Oblasti*, 1968). These are maps of specific yield, minimum run-off and of other characteristics of run-off represented by the use of the isarithmic method on the scale from 1:1 M to 1:4 M. Sometimes, the cartogram method is applied (*Atlas Československe Socialistické Republiky*, 1966). In order to show the variability of discharge, cartograms are often used (*Atlas Gruzinskoy SSR*, 1964; *Atlas Tadzhikskoy SSR*, 1968; *Fitzroy Region Resources*, 1965).

Other types of maps are complex and synthetic maps representing many water phenomena on a single map. There are as yet, very few examples of these maps. Examples of such maps are:

A map by L. M. Lvovitch (*Fizikogeograficheskij Atlas Mira*, 1964) which refers to the types of water regime in the whole world, scale 1:60 M. The chorochromatic method was used to show the patterns of water supply to the rivers (rain, snow, glacial and ground supply) in three classes varying in intensity of colour, while hachures were used to show the distribution of river run-off in particular seasons of the year, expressed in percentages.

The map by R. Keller (*Die Regime der Flüsse der Erde*, 1968) for Central Europe, scale 1:3 M, represents specific patterns of water supply with reference to Pardé's classification (pluvial, nival, glacial, karst-ground supply etc.). Coefficients of discharge oscillations were represented by bands drawn along the rivers. A similar map was compiled by R. Keller and K. R. Nippes for the Nile basin, scale 1:5 M (*Die Regime der Flüsse der Erde*, 1968) and by D. Dukić for Yugoslavia, scale 1:2.5 M (*Les regimes fluviaux en Yougoslavie*, 1972).

The map of Europe by F. Grimm (*Das Abflussverhalten in Europa. Typen und regionale Gliederung*, 1968), scale 1:5 M, shows maximum run-off by surface method, secondary maximum by the point method, while the duration of low run-off and specific yield was represented by hachures.

However, maps which show only the boundaries of hydrological regions (the information of which is given in the form of a text description, *Prace i Studia Komitetu Gospodarki Wodnej*, 1958), do not constitute a sufficient



cartographic synthesis. From the list of hydrological maps on general scales, one can see that apart from the map compiled by Lvovitch there is a lack of world hydrological maps. The maps available refer only to specific regions and their contents as well as scope are very differentiated.

At the symposium organized by the Section of Cartography and Geodesy of the Technological University of Dresden, April 1973, the authors presented a project of the hydrological map. The symposium was devoted to subject maps drawn on a base map of the World Map, scale 1:2.5 M. The 1:2.5 M World Map had been compiled by the topographic survey of the following countries: Bulgaria, Czechoslovakia, the German Democratic Republic, Hungary, Poland, Rumania and the USSR. The project of the hydrologic map was discussed in Dresden and remarks of the graphic solution of its elements were taken into consideration in compiling the present version of the map.

On editing the map the authors followed the following principles:

(1) Phenomena presented should reveal physical connections and always remain in some interdependence. Their presentation on a single map cannot therefore be a random set of different information.

(2) The map should be clear and so should not be overburdened with excessive information. A meaningful choice of elements is therefore necessary.

(3) The initial material for the map must be accurate, i.e. so that the representation of water phenomena is possible at least on the scale 1:2,500,000.

The numerical data for compiling the base map relate to mean annual values for many years. It is advantageous that this information is taken over an appropriately long period of time (at least ten years). The availability of suitable materials on a global scale may still present considerable difficulty.

The contents of the map should, according to the authors, include the following information:

I — resulting from the contents of a base map,

II — data of water resources of the rivers and their basins,

III — information about the pattern of the prevailing water supply to the rivers,

IV — the variability of discharge.

#### I. INFORMATION RESULTING FROM THE CONTENTS OF A BASE MAP, SCALE 1:2,500,000

The contents of the base map contains information on natural water phenomena such as: river networks, waterfalls, lakes, marshes, ice-sheets and mountain glaciers, as well as artificial constructions such as canals and major reservoirs.

The river network on the 1:2.5 M map is more detailed than on most maps in this scale. The density of a river network can be visually estimated from the map, and so it is possible to draw conclusions about the permeability of the substratum, as well as about the climate. Water divides result from contour maps. The authors propose to introduce continental water divides with a distinction draw between divides separating drainage areas of the oceans and those separating drainage areas of particular seas. The authors assume water divides of the first order for main rivers emptying directly into the sea with a surface of the basin well over 50,000 sq.km. That rule cannot, however, be applied too rigidly. In the case of basins of the great rivers it would be suitable to introduce water divides of lower orders. In places where a water divide is interrupted by a canal or ramifying watercourses, a break sign was

placed on the divide. The authors propose to introduce divides for endoreic areas, the surface of which is usually larger than 10,000 sq.km and exceptionally for smaller surfaces.

## II. INFORMATION RELATING TO WATER RESOURCES OF THE RIVERS AND THEIR BASINS

Information on water resources of the rivers is contained in the amount of mean discharge, while that of the resources of the basins in the amount of specific yield, the depth of run-off and in the run-off — precipitation ratio.

The mean discharge of rivers ( $\text{m}^3/\text{sec}$ ) indicates how much water flows, on an average, across a given cross-section of the river channel. This information is obtainable from the direct measurement of discharge carried out at gauging stations. The mean discharge of rivers on a global scale varies, and is shown therefore in semi-logarithmic scale. Information so presented although far from precise provides a general picture of the water capacity of particular rivers.

Water resources of the basins can be presented directly by the specific yield and the depth of run-off as well as indirectly by the ratio of run-off to precipitation.

The specific yield ( $\text{l}/\text{sec}/\text{km}^2$ ) indicates how many litres of water flow from one sq.km of surface area per second.

The depth of run-off (mm) is the depth of water flowing from a basin area in one year. The term is most often used in balance calculations.

Both values relate to the surface and can be interdependently calculated because one  $\text{l}/\text{sec}/\text{km}^2$  is the equivalent of 31.5 mm depth of annual run-off.

The specific yield and the depth of run-off are to be shown with the aid of the same isolines, and the surfaces between them were shaded in various tones of blue, forming a colourful background of the map. This element, therefore, dominates the contents of the map. This is justified by the great importance of the amount of run-off in water conditions.

The run-off to precipitation ratio is expressed as an undimensional number, or in percentages. It informs what part of the precipitation is converted into run-off. This coefficient is a relative value and, therefore, only indirectly makes it possible to draw an inference about resources in a given area. In order to calculate that element it is necessary to know the depth of run-off and, additionally, the amount of precipitation for the same catchment basins.

## III. INFORMATION ON THE PATTERN OF THE PREVAILING WATER SUPPLY TO THE RIVERS

With reference to the concept of M. I. Lvovitch (*Fizikogeograficheskii Atlas Mira*, 1964) the authors have distinguished four patterns of river supply: from rain, snow, glacial and ground.

Rain supply consists of the over-landflow of waters from rainfall of considerable intensity. These waters flow directly to the river channels.

Snow supply consists in the over-landflow of water from the melting of the snow cover during thaws. Glacial supply is the result of the melting of glaciers under the influence of temperatures above  $0^\circ$ . It is concentrated and confined only to rivers whose headwaters are glaciated.

Ground supply consists of precipitation and water from the melting of the snow cover which infiltrated into the ground. The water reaches the river

channels from springs and from the direct drainage of underground water horizons.

To obtain information about the supply is not easy, as it requires detailed and laborious analyses of the hydrograms of daily discharge and of the chosen meteorological elements.

Rivers are, usually, characterized by a complex regime of water supply. The authors distinguish three classes of basic supply by using different colours and direction of hachuring:

- (1) over 70% of total run-off,
- (2) 50 to 70% of total run-off,
- (3) below 50% of total run-off but more than any other separate pattern of supply.

If the secondary supply is considerable and exceeds 30% of the total run-off it is introduced into the map. The secondary water supply may occur only when the share of the principal kind of supply is less than 70%. In the case of equilibrium or small differences between the two patterns of supply, an equivalent signature is introduced (the class below 50%).

#### VARIABILITY OF DISCHARGE

Important information characterizing the river regime is the distribution of run-off throughout the year. This variability is shown with the aid of graphs of the coefficient of monthly discharge. The coefficient of monthly discharge is the ratio of discharge in particular months to the annual discharge. These coefficients represent a relative value, and are therefore comparable for rivers of varying values of discharge. On choosing the sites for which the graphs of the coefficients were drawn the authors followed their representativeness with reference to a major region.

In accordance with the proposed contents of the hydrological map of the world a key was compiled, and a map of Poland was presented as an example. The rule was to follow the availability of basic material and to make use of material earlier processed (*Typy reżimów rzecznych w Polsce*, 1972).

The authors are fully aware that in the course of the elaboration of the hydrological map of the world a number of difficulties and doubts will emerge. Certainly, it may sometimes be reasonable to change the classes, or to introduce additional information. If basic data is lacking it may even be necessary to leave blanks on the map.

The authors assume that at present there may be serious troubles in obtaining sufficiently accurate basic material for the whole world. The situation will, however, improve in the future owing to co-operation within the International Hydrological Programme (*Report of ... 1972*).

Jagellonian University

#### REFERENCES

- Atlas Armyanskoy SSR*, 1961, Ak. Nauk Armyanskoy SSR, Erevan-Moskva.  
*Atlas Azerbaydzhanskoy SSR*, 1963, Ak. Nauk Azerbaydzhanskoy SSR, Inst. Geogr., Baku-Moskva.  
*Atlas Československe Socialistické Republiky*, 1966, Ústřední Správa Geodézie a Kartografie.  
*Atlas Gruzinskoy SSR*, 1964, Ak. Nauk Gruzinskoy SSR, Inst. Geogr., Tbilisi-Moskva.



- Atlas Polski* (Atlas of Poland), 1954, 2, CUGiK, Warszawa.
- Atlas Tadzhikskoy SSR*, 1968, Ak. Nauk Tadzhikskoy SSR, Dushanbe-Moskva.
- Atlas Uzbekskoy SSR*, 1963, Ak. Nauk Uzbekskoy SSR, Tashkent-Moskva.
- Atlas Voronezhskoy Oblasti*, 1968, Glav. Upravl. Geodezii i Kartogr., Moskva.
- Dukić, D., 1972, Les regimes fluviaux en Yougoslavie, in: *Run-off regimes and water balance II*, Freiburger Geogr. H., 12.
- Dynowska, I., 1972, *Typy reżimów rzecznych w Polsce* (Types of river regimes in Poland), Zesz. Nauk. UJ, 268, Prace Geogr., 28.
- Dynowska, I., 1972, Problematyka opracowań map odpływu (Problems of work on run-off maps), *Folia Geogr., Ser. Geogr.-Physica*, 7.
- Fitzroy Region Resources*, 1965, Dept. of National Development, Canberra.
- Fizikogeograficheskii Atlas Mira* (Physico-geographical Atlas of the World), 1964, Moskva.
- Grimm, F., 1968, *Das Abflussverhalten in Europa. Typen und regionale Gliederung*, Wiss. Veroff. Dtsch. Inst. Landerk., N.R., 25/26.
- Guidebook on the preparation of hydrological maps*, UNESCO (typescript).
- Horodyski, B., 1966, O Mapie Świata w skali 1:2 500 000 na podstawie wydanych arkuszy (Sum.: Comment on the 1:2,500,000 World Map, on the basis of sheets issued so far), *Przegl. Geogr.*, 38, 3.
- Keller, R., 1968, Die Regime der Flüsse der Erde, in: *Run-off regimes and studies of the water balance*, Freiburg i.Br.
- Michalski, T., 1971, Geneza Mapy Świata 1:2 500 000 (Origin of the World Map 1:2,500,000), *Pol. Przegl. Kartogr.*, 3, 1.
- Nordenson, T. I., 1968, *Preparation of co-operated Precipitation, Run-off and Evaporation Maps*, Reports on WMO/IHD Projects, Geneva.
- Prace i Studia Komitetu Gospodarki Wodnej* (Proceedings and Studies of the Committee on Water Management), 1958, vol. 2, part 2, PWN, Warszawa.
- Report of the director-general on the long-term programme in the field of hydrology*, 1972, UNESCO, General conference, 17th session, Paris.

These books, written by Richard D. White, Jr., and published by the University of California Press, are a valuable addition to the literature on the history of the American West. The first book, *The American West*, is a general history of the region, covering the period from the early 19th century to the present. The second book, *The American West and the American Mind*, is a more detailed study of the role of the West in the development of the American psyche. Both books are written in a clear, concise, and engaging style, and are highly recommended for anyone interested in the history of the American West.

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## AN ATTEMPT AT THE APPLICATION OF THE FROSTLESS PERIOD AS A GUIDING CRITERION IN THE TYPOLOGY OF MESOCLIMATIC CONDITIONS IN THE MOUNTAINS

MIECZYSLAW HESS, TADEUSZ NIEDZWIEDZ and  
BARBARA OBRĘBSKA-STARKŁOWA

### INTRODUCTION

The analysis and planning of agricultural production require a thorough knowledge of the habitat conditions which restrict or enable the cultivation of particular crops. Much information on these requirements is provided by the maps of the elements of the geographical environment.

In Cracow, during the last two decades the principles of detailed geomorphological and hydrographical mapping have been elaborated and the initiative was undertaken to create a legend to such outline maps for the whole world.

Climatology has to make up for the lack of uniform methods of mapping climatic conditions. The Department of Climatology of the Jagellonian University tries to take a part in filling this gap. During the last decade the present authors published a number of papers on the typology of climate in mountainous territories, and on the construction of climatic maps of various scales. The reader may find these methods discussed in their paper published in *Geographia Polonica*, vol. 31.

The authors established that the mean annual air temperature is of good use in the characterization of the macroclimate of whole mountain massives, in which climatic conditions occur in pronounced vertical zones, because it changes with the altitude above sea level according to the straight linear dependence, and together with that mean the whole complex of climatic elements and indices standing in close relationships with the annual temperature changes. These correlations are different for convex and concave forms, and for the slopes exposed to the north and to the south (Hess 1968, 1969).

In the mesoclimatic scale, it was the minimum air temperature, the mean temperature at night, the number of days with frost and slight frost, and the duration of the frostless period which were established as the best typological indices. The values of these indices depend not only on the height above sea level but also on the elevation above the valley bottom (Obrębska-Starkłowa 1969, Niedźwiedź and Obrębska-Starkłowa 1972, Niedźwiedź 1973).

Under the conditions of the Polish Carpathian Mts. which are sufficiently humid, and in their upper parts even excessively wet, it is the air temperature which seems to be the very element of the climate which exercises a major influence upon agricultural crops.

From the ranks of the numerous elements of the thermal *régime*, the frostless period rises as a very susceptible instrument to estimate the mountainous territories with respect to agroecology (Hess, Niedźwiedź, Obrębska-



Starkłowa 1975). As it stands in a close relationship with the other elements of the natural environment it was considered by the present authors as a guiding complex indicator in the typology of the mesoclimatic relationships to be utilized in agriculture.

In the present paper the authors submit a method of constructing a detailed climatic map for agricultural use based on the duration of the frostless period. The study area lies in the Polish part of the Carpathian Mts. (the Lower Beskid range and its foreland), which mainly represents low mountains and uplands.

#### A CHARACTERIZATION OF THE TERRITORY INVESTIGATED

The Lower Beskid range forms a transversal lowering in the arch of the West Carpathian Mts. through which the flow of air masses is facilitated meridionally. At the advection from the west, this range is left in the wind shade of the ranges of the Sądecki and Wyspowy Beskids. In the valley of the Lower Beskid there prevail winds blowing from the south. The SE, S and SW winds exceed 50% of all cases. The winds from the north and its near directions form about 20%. Thus, the valleys of the Lower Beskid are well ventilated.

In the territory investigated there is no shelter of high mountains. Few calms occur during the year (Barwinek 1%, Wysowa 8%), and the mean annual wind velocity oscillates about 3 m/sec. In the foreland of the Beskid range and at the bottoms of its valleys foehn effects are observed. These violent changes in the daily course of temperature and air humidity occur mainly in the winter months. There are 60–80 days with the foehn wind blowing during one year (Obrębska-Starkłowa 1973).

The elevation of the Lower Beskid are of the character of isolated hills attaining the height of 700–850 m a.s.l.; in their highest part they do not exceed 1000 m (Lackowa 997 m a.s.l.). The bottoms of the river valleys lie 300–400 m lower and are distinguished by a considerably variegated course. They are composed of alternating longitudinal and transversal sections. This entails a differentiation of the climatic conditions, above all in the meso- and microscale.

The foreland of the Lower Beskid range is formed of the Jasło-Sanok Depressions, the Strzyżów Foothills, and a section of the Cieżkowice Foothills (relative heights being of the order of 200 m). The Jasło-Sanok Depressions are composed of a number of irregular basins and low foothills (relative heights ranging from 50 to 70 m). On cloudless and windless nights they often become an extensive reservoir of cooled air flowing down from the neighbouring mountains.

In the groups of mountains forming the ranges of Beskid Sądecki, Beskid Wyspowy (Insular Beskid) and Beskid Niski (Lower Beskid) there are two climatic vertical zones. Up to the height of 750 m a.s.l. there reaches the temperature warm vertical zone, in which the mean annual air temperature varies from 7.5°C to 6.0°C. Above, there extends the temperature cool vertical zone in which the mean annual temperature falls to about 4°C (Hess 1965). The isotherm of 7°C runs along the boundary between the Foothills and the Beskids.

The annual sums of precipitation range from 600 to 900 mm in the territory investigated, and if the mechanical and structural qualities of the soils are favourable they meet the demand for water in plants.

In the scale of the mesoclimate, the contrast between the convex and the concave forms of the territory becomes greater as the relative height above the

TABLE 1. Characteristics of the thermal conditions at the boundary between moderate warm and moderate cool climatic vertical zone in the Lower Beskid range

Element	Relief form	
	convex	concave
Altitude a.s.l. (m)	650	450
Mean annual air temperature °C	6.0°	6.0°
Mean annual maximum temperature	10.1°	10.8°
Mean annual minimum temperature	2.5°	1.0°
Daily amplitude of air temperature	7.6°	9.8°
Mean monthly maximum temperature in February	−0.7°	1.0°
Mean monthly minimum temperature in February	−7.2°	−8.5°
Mean monthly maximum temperature in May	15.4°	16.5°
Mean monthly minimum temperature in May	6.4°	4.3°
Mean monthly maximum temperature in July	20.5°	21.8°
Mean monthly minimum temperature in July	11.5°	9.7°
Mean monthly maximum temperature in October	12.0°	12.3°
Mean monthly minimum temperature in October	4.5°	2.8°
Duration of frostless period in days	168	120
Probability of days (in %) with the air temperature $t_{max} > 25^{\circ}$ in the growing season	6.5	10.0
Probability of days (in %) with the air temperature $t_{min} < 0^{\circ}$ in the growing season	7.5	11.0
Probability of days (in %) with the air temperature $t_{max} > 20^{\circ}$ in May	19.0	27.0
Probability of days (in %) with the air temperature $t_{max} > 25^{\circ}$ in May	2.0	3.0
Probability of days (in %) with the air temperature $t_{min} < 0^{\circ}$ in May	5.0	13.0
Probability of days (in %) with the air temperature $t_{max} > 5^{\circ}$ in winter	12.0	10.0
Probability of days (in %) with the air temperature $t_{min} < -20^{\circ}$ in winter	1.0	8.0

valley bottoms grows. Table 1 supplies information, by way of examples, about the differences in the values for the particular thermal indices in the Lower Beskid range.

MATERIALS AND METHOD OF ELABORATION

In their present work the authors elaborated the results of daily measurements of air temperature performed in the period 1951–1970 on 15 meteorological stations, 8 of which represent convex, and 7 concave forms of the territory. The probability of occurrence of the determined values of temperatures for the particular months and the chosen periods of the year were calculated by means of the “Odra 1204” computer. Next, the nomographs of probability of occurrence of extreme and mean daily temperatures and of those measured at certain hours (7<sup>h</sup>, 13<sup>h</sup> and 21<sup>h</sup>) lower than the determined values were executed, depending on the height a.s.l. and with the convex and concave forms of the territory being taken into account.

Considering its significance for agriculture, the authors concentrated in their present elaboration on discussing the extreme values of air temperature. Of the very numerous data which characterize the thermal régime they only chose that part of the material which concerned the critical periods in the development of plants. Therefore, they represent the principal theses of their method by using the month of May as an example, in which the vegetation is highly threatened by slight frosts. In Figs. 1 and 2 they submit the nomographs of probability of the maxima and minima of air temperature in May. On the basis of these nomographs one can determine the probability of occurrence of any value of extreme temperatures depending on the height above sea level and the forms of the relief. This enables the construction of detailed maps of probability of the values of air temperature important for agriculture. Take as an example the map representing the endangerment by slight frost in May (Fig. 3), in which the probability of occurrence of negative minimum temperatures is submitted. Most threatened by slight frosts in that month are the bottoms of the Beskid valleys situated above 400 m a.s.l. (10–15% of days with slight frost). In the concave forms of the territory, in the hypsometric zone of 300–400 m that probability amounts to 5–10%. The same values for the probability of occurrence of slight frosts are characteristic of the Beskid ridges

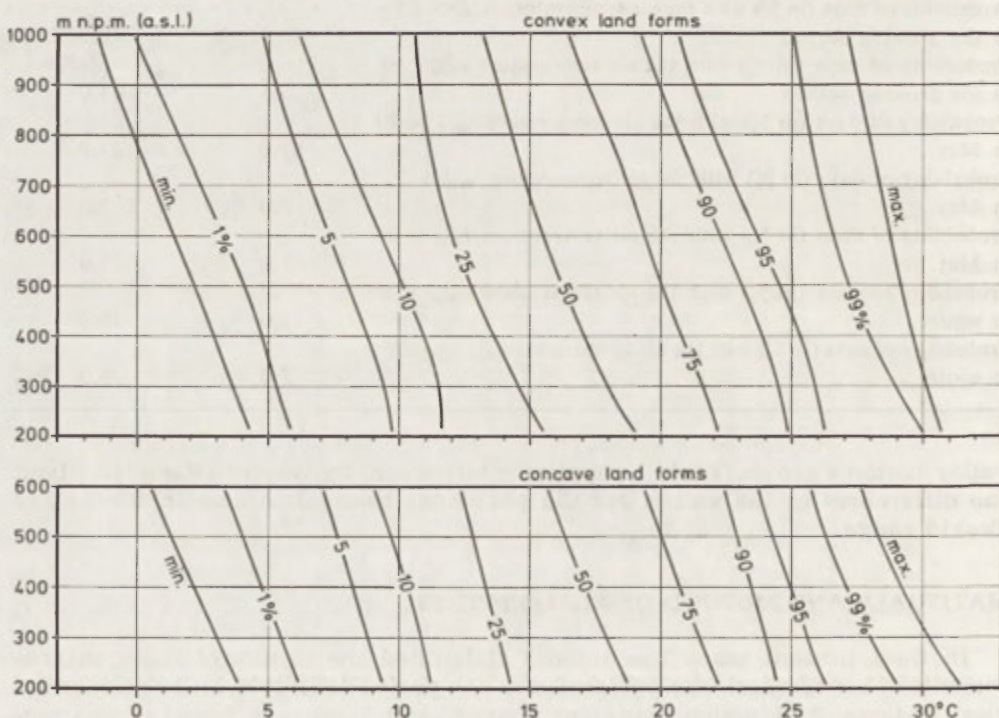


Fig. 1. Probability (%) of the occurrence of maximum air temperature below determined values in May in the Lower Beskid range

exceeding 650 m a.s.l. The convex forms of the territory lying below that height and the bottoms of valleys below 300 m a.s.l. are distinguished by the least endangerment by slight frosts (the probability being only 2–5%).



The nomographs discussed above seize in a complex manner the differentiation of all the occurring extreme temperatures and are very simple and useful in the determination of the endangerment by slight frosts of particular crops. For example, if it appears that a temperature lower than  $-20^{\circ}\text{C}$  is noxious for a certain plant, then, by using the nomograph, one can determine the probability of occurrence of that temperature and indicate the parts of the territory in which it may occur most often.

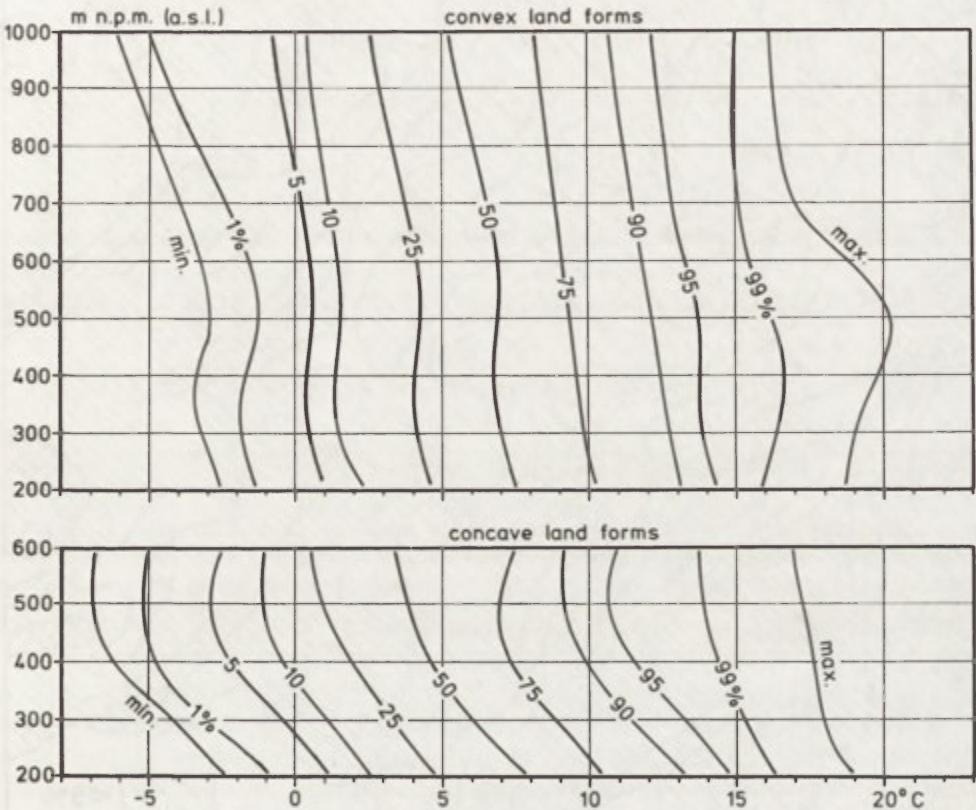


Fig. 2. Probability (%) of the occurrence of minimum air temperature below determined values in May in the Lower Beskid range

The differentiation of the maximum air temperatures mainly depends on the height above sea level (Fig. 1). The influence of the form of relief is very slightly marked. This is also shown on the example of the map of the probability of occurrence of maximum air temperatures exceeding  $20^{\circ}\text{C}$  in May (Fig. 4). This probability decreases from over 40% at the height of 250 m to less than 10% at the height exceeding 900 m a.s.l.

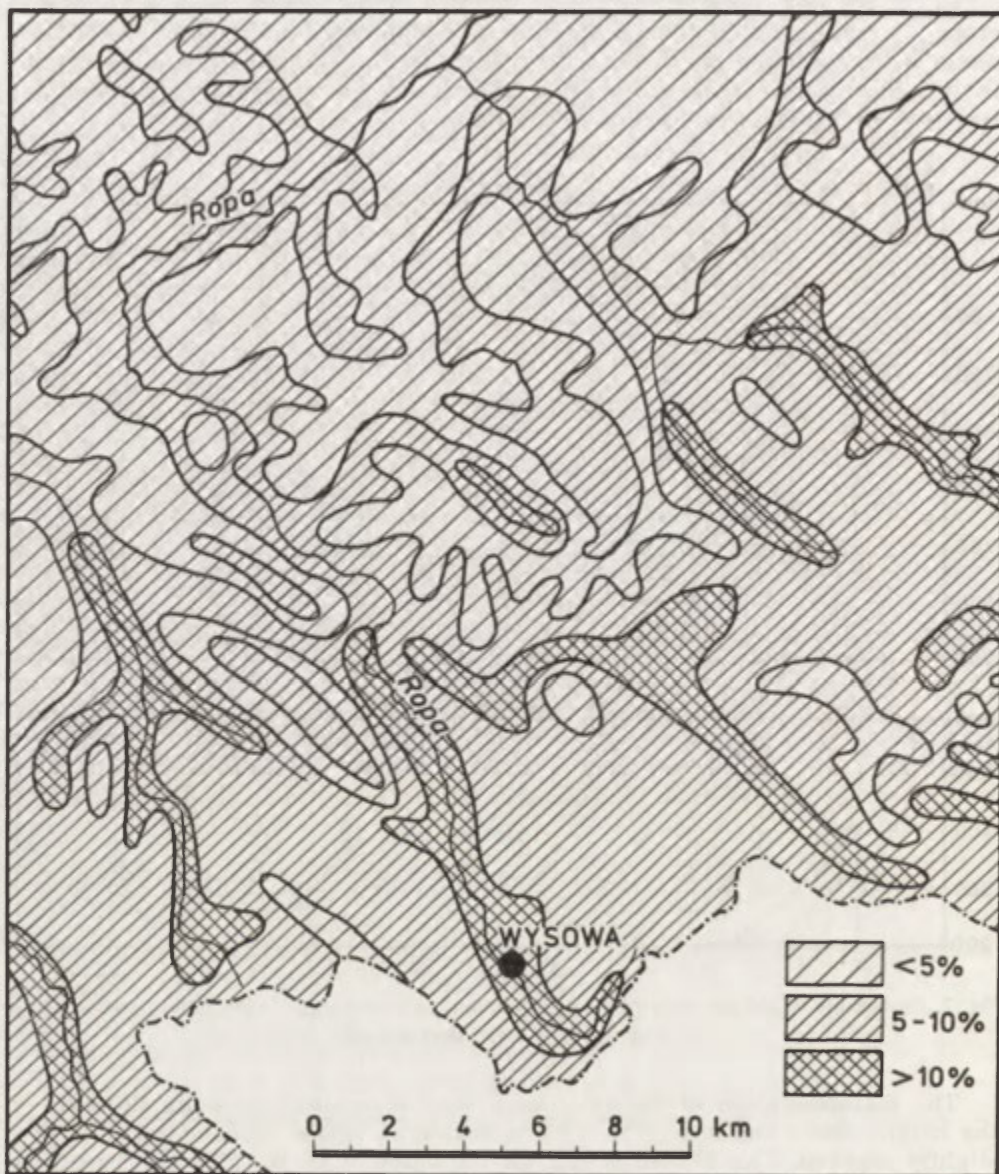


Fig. 3. Probability (%) of the occurrence of days with slight frost in the western part of the Lower Beskid range





Fig. 4. Probability (%) of the occurrence of maximum air temperature higher than 20°C in the western part of the Lower Beskid range

THE FROSTLESS PERIOD AS A BASIS FOR THE AGROECOLOGICAL ESTIMATION OF MOUNTAINOUS AREAS

The duration of the frostless period is one of the most differentiated elements of the mesoclimate in the Lower Beskid range. At the height of 500 m a.s.l. the difference in the duration of that period in the convex and the concave forms exceeds 50 days. Slight frosts during the growing season form a



TABLE 2. Dependence of the duration of the frostless period ( $y$ ) on some geographical and meteorological parameters ( $x$ ) in the Lower Beskid range

Element ( $x$ )	Convex forms				Concave forms				Regardless of the relief form			
	equation	$b_s$	$r$	$t_r$	equation	$b_s$	$r$	$t_r$	equation	$b_s$	$r$	$t_r$
Altitude a.s.l. $H$	$y = 166 - 0,0148H$	$\pm 10$	-0.374	>10%	$y = 198 - 0,1714H$	$\pm 8$	-0.922	0.1-1%	$y = 154 - 0,0162H$	$\pm 20$	-0.164	>10%
Mean annual air temperature $t_r$	$y = 131 + 4,0183t_r$	$\pm 9$	0.497	>10%	$y = 21,9810t_r - 12$	$\pm 7$	0.945	0.1-1%	$y = 82 + 9,8210t_r$	$\pm 17$	0.518	5-10%
Mean annual minimum air temperature $t_{rm}$	$y = 131 + 9,8212t_{rm}$	$\pm 7$	0.714	5-10%	$y = 100 + 17,3096t_{rm}$	$\pm 7$	0.946	0.1-1%	$y = 104 + 17,9429t_{rm}$	$\pm 10$	0.879	<0.1%

$b_s$  — standard error of unknown quantity

$r$  — correlation coefficient

$t_r$  — level of significance of the correlation coefficient according to the test  $t$  of Student

TABLE 3. Dependence of some climatic indices ( $y$ ) on the duration of the frostless period ( $x$ ) in the Lower Beskid range

Element ( $x$ )	Convex forms				Concave forms				Regardless of the relief form			
	equation	$b_s$	$r$	$t_r$	equation	$b_s$	$r$	$t_r$	equation	$b_s$	$r$	$t_r$
Probability (%) of $t_{min} < y = 25 - 0.1183x$ < 0° in the period from May to September	$y = 25 - 0.1183x$	$\pm 2\%$	-0.599	> 10%	$y = 33 - 0.1753x$	$\pm 1\%$	-0.968	0.1-1%	$y = 28 - 0.1366x$	$\pm 1\%$	-0.897	< 0.1%
Probability (%) of $t_{min} < y = 24 - 0.1289x$ < 0° in May	$y = 24 - 0.1289x$	$\pm 2\%$	-0.608	> 10%	$y = 46 - 0.2762x$	$\pm 1\%$	-0.976	< 0.1%	$y = 40 - 0.2266x$	$\pm 2\%$	-0.940	< 0.1%
Probability (%) of $t_{min} < y = 2 + 0.0089x$ < -20° in the period from December to February	$y = 2 + 0.0089x$	$\pm 2\%$	-0.047	> 10%	$y = 17 - 0.0752x$	$\pm 1\%$	-0.841	1-5%	$y = 18 - 0.0918x$	$\pm 2\%$	-0.747	0.1-1%
Mean annual minimum air temperature	$y = -5.8 + 0.0535x$	$\pm 0.6^\circ$	0.673	5-10%	$y = -4.8 + 0.0507x$	$\pm 0.4^\circ$	0.950	0.1-1%	$y = -3.9 + 0.0423x$	$\pm 0.5^\circ$	0.870	< 0.1%

 $b_s$  — standard error of unknown quantity $r$  — correlation coefficient $t_r$  — level of significance of the correlation coefficient according to the test  $t$  of Student

serious threat, especially to plants in this stage of growth. Therefore, the duration of the frostless period is accepted by the authors as a guiding typological criterion of the climatic relationships in mountainous territories in the estimation of the mesoclimate for agriculture.

The duration of the frostless period shows pronounced connections with the mean annual minimum air temperature ( $t_{rm}$ ; Table 2), which in turn is linked up with the mean annual air temperature ( $t_r$ )<sup>1</sup>.

(I) For concave forms

$$t_{rm} = 1.21 t_r - 6.1^\circ \quad r = 0.950$$

while the error of unknown quantity amounts to  $\pm 0.4^\circ\text{C}$ .

(II) For convex forms

$$t_{rm} = 0.56 t_r - 1.0^\circ \quad r = 0.954$$

the error of unknown quantity amounts to  $\pm 0.2^\circ\text{C}$ .

(III) If the form of the relief is not taken into account

$$t_{rm} = 0.76 t_r - 2.7^\circ \quad r = 0.821$$

the error of unknown quantity amounts to  $\pm 0.6^\circ\text{C}$ .

The correlation coefficients ( $r$ ) submitted above are essential on the level of 0.1% according to Student's test  $t$ .

Thus, based upon the mean annual minimum of air temperature the mean length of the frostless period can be determined with an accuracy of  $\pm 7$  days. The small importance of the coefficient of correlation for convex forms is most probably connected with the fact that the length of the frostless period on these forms depends to a considerable degree on the relative height at which the measurement stations are situated. The dependence of the length of the frostless period on the mean annual minimum air temperature and the altitude above sea level are essential for the stations situated in the concave forms of the territory, the localization of which can be determined more unmistakably.

On the basis of the duration of the frostless period it also is possible to determine the probability of the occurrence of minimum temperatures lower than  $0^\circ$  during the growing season (Table 3) with an accuracy of  $\pm 1\%$ , as well as the probability of the occurrence of slight frosts in May and of very severe frosts ( $t_{min} < -20^\circ$ ) in winter (from December to February) with an accuracy of  $\pm 2\%$ . On the other hand, there are no close relationships between the duration of the frostless period and the probability of the occurrence of maximum air temperatures.

#### MAP OF THE EVALUATION OF CLIMATIC CONDITIONS

The choice of the frostless period as the fundamental criterion of the estimation of climatic conditions in the mountains is justified by its essential peculiarities. From the point of view of agroecology, the duration of the frostless

<sup>1</sup> The mean annual air temperature ( $t_r$ ) can be calculated with an accuracy of  $\pm 0.3^\circ\text{C}$  on the basis of the height above sea level ( $H$ ) by using the regression equation determined for the Lower Beskid range as follows:  
for convex relief forms

$$t_r = 9.0^\circ - 0.0048H \quad r = -0.973$$

for concave relief forms

$$t_r = 9.5^\circ - 6.0075H \quad r = -0.944$$

Michna and Paczos (1973) submit the following formula for the West Bieszczady Mts.

$$t_r = 9.42^\circ\text{C} - 0.0067H$$



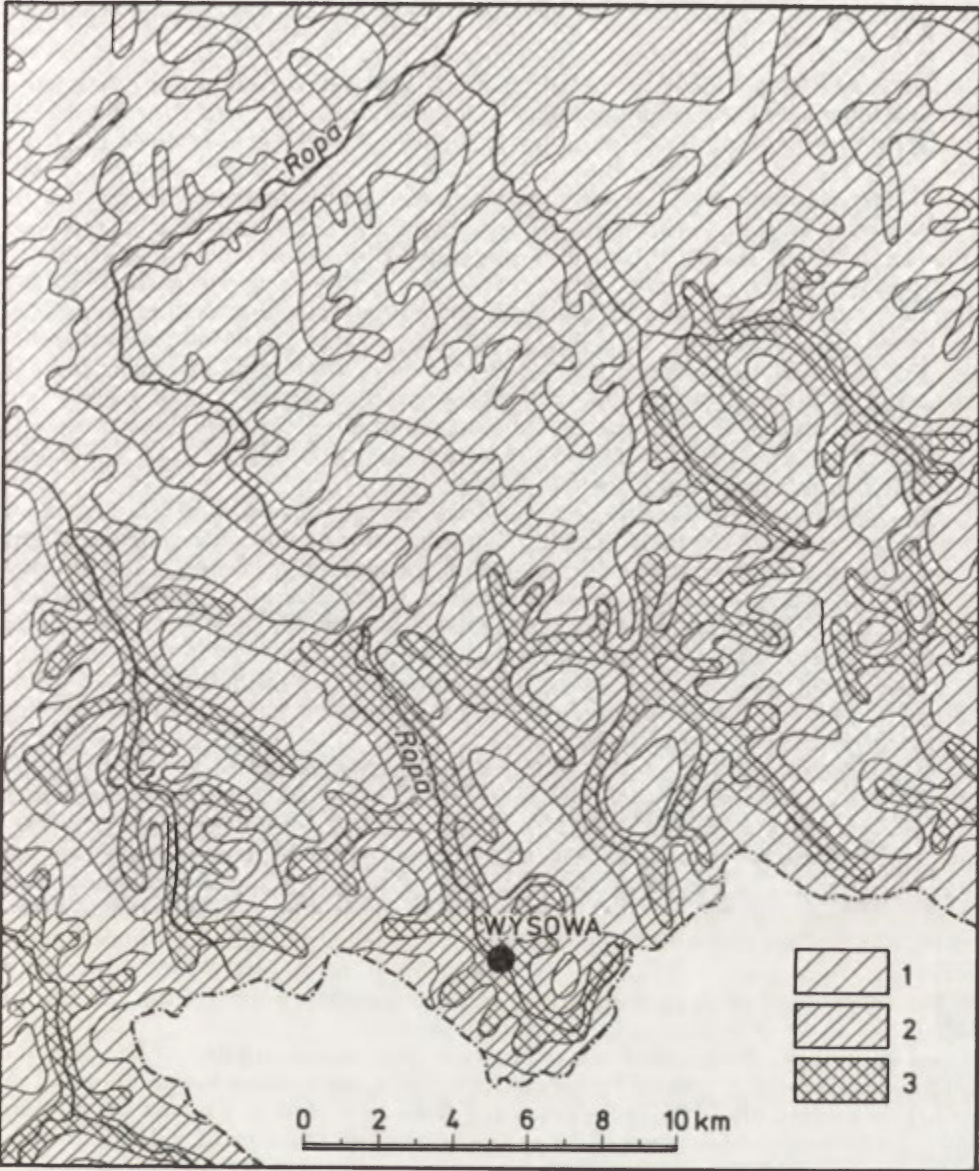


Fig. 5. Map of the climatic evaluation of the western part of the Lower Beskid range

Sign. on map	Areas	Duration of frostless period in days	Probability of days (in %)					
			$t_{min} < 0^{\circ}$ IV-IX	$t_{min} < 0^{\circ}$ V	$t_{max} > 25^{\circ}$ IV-IX	$t_{max} > 20^{\circ}$ V	$t_{min} < -20^{\circ}$ XII-II	$t_{max} > 5^{\circ}$ XII-II
1	Favourable	>160	6	4	8-20	12-20	2	8-22
2	Moderately favourable	120-160	6-10	4-10	10-18	30-40	2-8	12-18
3	Unfavourable	<120	10	10	4-10	30	8	12

period is one of the most important factors in agriculture. On the other hand in climatology this is a complex index due to its close relations with the probability of the occurrence of minimum temperatures in various seasons of the year.

Taking into account these circumstances the authors executed a map of the evaluation of climatic conditions of the Lower Beskid range and its foreland (Fig. 5), in which they distinguished the categories of territory as follows:

(I) Favourable areas in which the frostless period lasts for more than 160 days. There, the probability of the occurrence of slight frosts during the growing season amounts to less than 6%, and in May to less than 4%. The probability of the fall of temperature below  $-20^{\circ}\text{C}$  in winter is small and does not exceed 2%. In these territories, depending on their altitude above sea level, the probability of the occurrence of maximum temperatures exceeding  $5^{\circ}\text{C}$  in winter oscillates between 8 and 22%, and that of hot days ( $t_{\max} > 25^{\circ}\text{C}$ ) in the growing season varies from 8 to 20%.

(II) Moderately favourable areas in which the duration of the frostless period ranges from 120 to 160 days. The probability of the occurrence of slight frost during the growing season lies within an interval of 6–10%, and in May of 4–10%. The days with a very severe frost in the winter months are characterized by the probability of 2–8%. In that season the days with a maximum temperature exceeding  $5^{\circ}\text{C}$  may form 12 to 18%.

During the growing season, hot days occur with a probability of 10–18%, and in May the probability of days with a maximum temperature exceeding  $20^{\circ}\text{C}$  may range from 30 to 40%.

(III) Unfavourable areas, in which the frostless period lasts less than 120 days. There, the probability of the occurrence of slight frost in the growing season as well as in May exceeds 10%. In the former period there is the probability of the occurrence of 4–10% of days with a maximum temperature exceeding  $25^{\circ}\text{C}$ , while in the latter (May) the days with a temperature exceeding  $20^{\circ}\text{C}$  form less than 30%. In this class of areas the winter season is distinguished by the highest probability of the occurrence of days with a minimum temperature lesser than  $-20^{\circ}\text{C}$ , i.e. exceeding 8%, and a fairly low probability of the occurrence of days with a maximum temperature exceeding  $5^{\circ}\text{C}$  (up to 12%).

As is seen on the map of the evaluation of climatic conditions the favourable areas lie on the convex forms of the relief at elevations lower than 900 m a.s.l. The moderately favourable areas are situated in concave forms lower than 450 m. The unfavourable areas lie at the bottom of the Beskid valleys at altitudes exceeding 450 m a.s.l.

## CONCLUSIONS

The method discussed above enables the determination on a detailed scale of the mesoclimatic conditions on the basis of standard data provided by a network of measurement stations to be applied to agriculture. The passage from the data available at certain points and obtained from meteorological stations to spatial conceptions leads along the determination of the relationships between the altitude above sea level, the kinds of form of the relief, and the thermal indices of the climate. Resulting from this data, the duration of the frostless period is a sensitive index in the scale of the mesoclimate, besides all the other indices connected with the minimum air temperatures.

The nomographs applied by the authors make it possible to construct climatic maps useful in agriculture for any kind of crops for which the critical



values of air temperatures at a given stage of their development are known. Thus, the map of the evaluation of climatic conditions constructed by means of these nomographs should — with the maps of other elements of the geographic environment — form a basis for the elaboration of an agroecological map of habitats.

This method of constructing a map of the evaluation of climatic conditions can be applied to all mountain territories, in which a network of measurement stations enables the determination of the interdependencies between the chosen thermal indices and the altitude above sea level, and the distinction of the impact of the convex and concave forms.

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#### REFERENCES

- Hess, M., 1965, *Piętra klimatyczne w polskich Karpatach Zachodnich* (Sum.: Vertical climatic zones in the Polish Western Carpathians), Zesz. Nauk. UJ, Prace Geogr., 11.
- Hess, M., 1968, A new method of determining climatic conditions in mountain regions (with the Western Carpathians as example), *Geogr. Pol.*, 13.
- Hess, M., 1969, *Główne problemy klimatologiczne Karpat* (Sum.: Principal climatological problems of the Carpathians), Zesz. Nauk. UJ, Prace Geogr., 25.
- Hess, M., Niedźwiedź, T., Obrębska-Starkel, B., 1975, The methods of construction of climatic maps of various scales for mountainous and upland territories exemplified by the maps prepared for southern Poland, *Geogr. Pol.*, 31.
- Hess, M., Niedźwiedź, T., Obrębska-Starkłowa, B., 1977, Ekstremalne zjawiska termiczne w Beskidzie Niskim i ich wpływ na roślinność (Sum.: Extreme thermic phenomena in Beskid Niski range and its influence on vegetation), in: *Studia nad województwem rzeszowskim, Prace Geogr. IG PAN*.
- Michna, E., Paczos, S., 1972, *Zarys klimatu Bieszczadów Zachodnich* (Short characteristics of climate of the Western Bieszczady range), Wrocław.
- Niedźwiedź, T., 1973, *Temperatura i wilgotność powietrza w warunkach rzeźby pogórskiej Karpat (na przykładzie doliny Raby koło Gaika-Brzezowej)*, (Sum.: Temperature and air humidity of a hilly landscape (as exemplified by the Raba valley near Gaik-Brzezowa)), Zesz. Nauk. UJ, Prace Geogr., 32.
- Niedźwiedź, T., Obrębska-Starkel, B., 1972, Beispiel der Anfertigung einer mesoklimatischen Karte für die Karpaten, *Studia Geogr.*, 26, Brno.
- Obrębska-Starkel, B., 1969, Some results of investigations of meso- and microclimatic conditions in small mountain drainage areas in the Beskides (Polish West Carpathians), *Acta Univ. Szeged.*, pars: *Acta Climatol.*, 8, 1-4.
- Obrębska-Starkłowa, B., 1973, Stosunki mezo- i mikroklimatyczne Szymbarku (Sum.: Meso- and microclimatic conditions at Szymbark), *Dokum. Geogr. IG PAN*, 5.





## MESOCLIMATIC CARTOGRAPHY OF CLOUDINESS

WITOLD LENART

The urgent need of an accurate cognizance of the spatial structure of atmospheric precipitation assigns to cloud climatology new tasks, setting bounds to the feasibility of making exclusive use of the present-day system of weather observations. This necessity arises not only from the shortcomings of this system (deformations caused by the presence of a physiological firmament, errors in identifying clouds), but also from the very definition of clouding (the cloud screen covering the firmament). This matter affects very much the value of cloudiness maps published at present, compiled on the basis of averaged values of the cloud amount. By averaging these amounts for an investigated period of time we really apply constantly changing visual ranges of clouds. The area from above which clouds do affect the cloud amount, covers from a score to several thousand square kilometres, depending on the altitude of the cloud base. Under such conditions any interpolation between points of observation simplifies the image excessively.

Our meteorological stations, for the most part operating in towns, are nephologically recording "urban cloudiness" and, although to this day we continue ignoring how far these records may differ from "non-urban" cloudiness, any attempt on our part of applying urban observations to surrounding regions seems questionable. It would be advisable to limit oneself to tabulated data, or to enter the urban meteorological data in a cartographical climatogramme, containing circular diagrammes of diameters proportional to the areas for which clouds affect values of the cloud amount.

Best of all would be a reconsideration of the planes of reference for clouds suspended in the troposphere. From a geographical point of view it would be more useful to imagine the morphology of cloudiness in an identical way as the geomorphology — and in this case the reference plane would be represented by the Earth. From this concept sprang the idea of compiling cloud maps, in other words, of creating a geographical picture of projections of clouds perpendicular to the Earth's surface. Every change in these projections introduces a difference in the measure of cloudiness: sky cloudiness (heretofore called the cloud amount) is replaced by Earth cloudiness, meaning the partial covering of some unit of the Earth's surface by perpendicular cloud shadows. These plane units may be of an arbitrary size and shape — hence they might be physico-geographical units as well.

The requirements of actinometry with regard to the reference plane for clouds are different. Here the most suitable plane would be a physical firmament in other words, a ball-shaped canopy. Carrying into effect the idea of a cloud map makes it possible also to fulfil this demand.

Here in Poland we prefer the method of making photographic recordings of sky conditions from which we obtain a picture of a suitably large scale, lack-

ing the known shortcomings of satellite photography or radar methods. A cloud map can be obtained by appropriate transformations of the picture representing a projection of the clouds upon a physical firmament. The need of reducing costs to a minimum prompts us to use the system of photographing the whole sky (called the ALL SKY SYSTEM). This system is based on making use of what is called a sky mirror, meaning a silvered glass canopy which yields a picture of the sky photographed by the use of an ordinary camera. By this method one obtains space pictures of a visual angle equal to  $360^\circ - A$ , where  $A$  denotes the visual angle of the camera lense. The basic rules of the techniques as to how to photograph the whole sky, of the method of overlapping the negatives into composite cloud maps, as well as some of the techniques of interpreting shots have been published before, and in our present study we are omitting them (cf. our list of references). We shall deal in greater detail with cartographical methods of exhibiting the material gained from photographic investigations of cloudiness.

From a single shot of the whole sky one can obtain, estimating the altitude of the base of the clouds, a circular map of clouds in a radius depending upon the altitude of this cloud base. By limiting the angle of the cloud altitude to  $10^\circ$  above the horizon, a map can be compiled for *Alto cumulus* clouds of some 4,300 m altitude for a range shown in Fig. 1a. Shots of *Cumulus* clouds, taken from this same position with their bases at 1,700 m altitude, limit the radius of our cloud map to some 10 km (Fig. 1b). Finally, the occurrence of *Stratus* clouds (800 m altitude) enables us to draw maps of a very narrow range (Fig. 1c). The outlines of *Ac len* and *Cu med* clouds are simplified and refer mainly to cloud assemblages. The zones which are obliquely hatched are blocked out by ground obstacles.

By forsaking questionable estimates of the altitude of cloud bases and by using an appropriate formulae, the particular photographs can be interpreted by what is called the method of cloud roses. For individual sectors, cloudiness on the physical firmament is determined by taking into account particular stages and types of clouds. The possibility of identifying cloudiness on the physical firmament with an accuracy of up to 10% prompted the decision of introducing the method of photographing the whole sky into the programme of observations at those meteorological stations which perform daily observations. We already mentioned the necessity of obtaining such data for actinometry; but this way of accurately estimating the degree of sky cloudiness may also serve other research purposes, such as the cognizance of the effect of bedding upon cloudiness.

Of outstanding importance in compiling cloud maps is the system applied for combining the negatives taken from adjoining sky mirrors (W. Lenart 1973, 1975). By combining these shots one obtains an accurate reading of the altitude of the cloud base at any spot and, for two to four km distance between points of observation, the error in placing a given cloud on the map is of the order of barely some 50 or so metres — thus very much less than the horizontal dimensions of an average *Cumulus* cloud. With cloud maps for successive time intervals (Fig. 2) on hand one can scan and picture the development of clouds above a given region, discovering conceivable effects of the Earth's surface upon cloud formation. The difficulty of tracing changes in a great number of successive cloud pictures induces the introduction of what might be called a summarized cloud map. This sort of map is compiled by overlapping successive pictures and by adding up in a lattice all points indicating clouding. The result is a pattern of isolines illustrating the period for which clouds were adrift above a given area. Any disregard of changes in cloud position between succes-



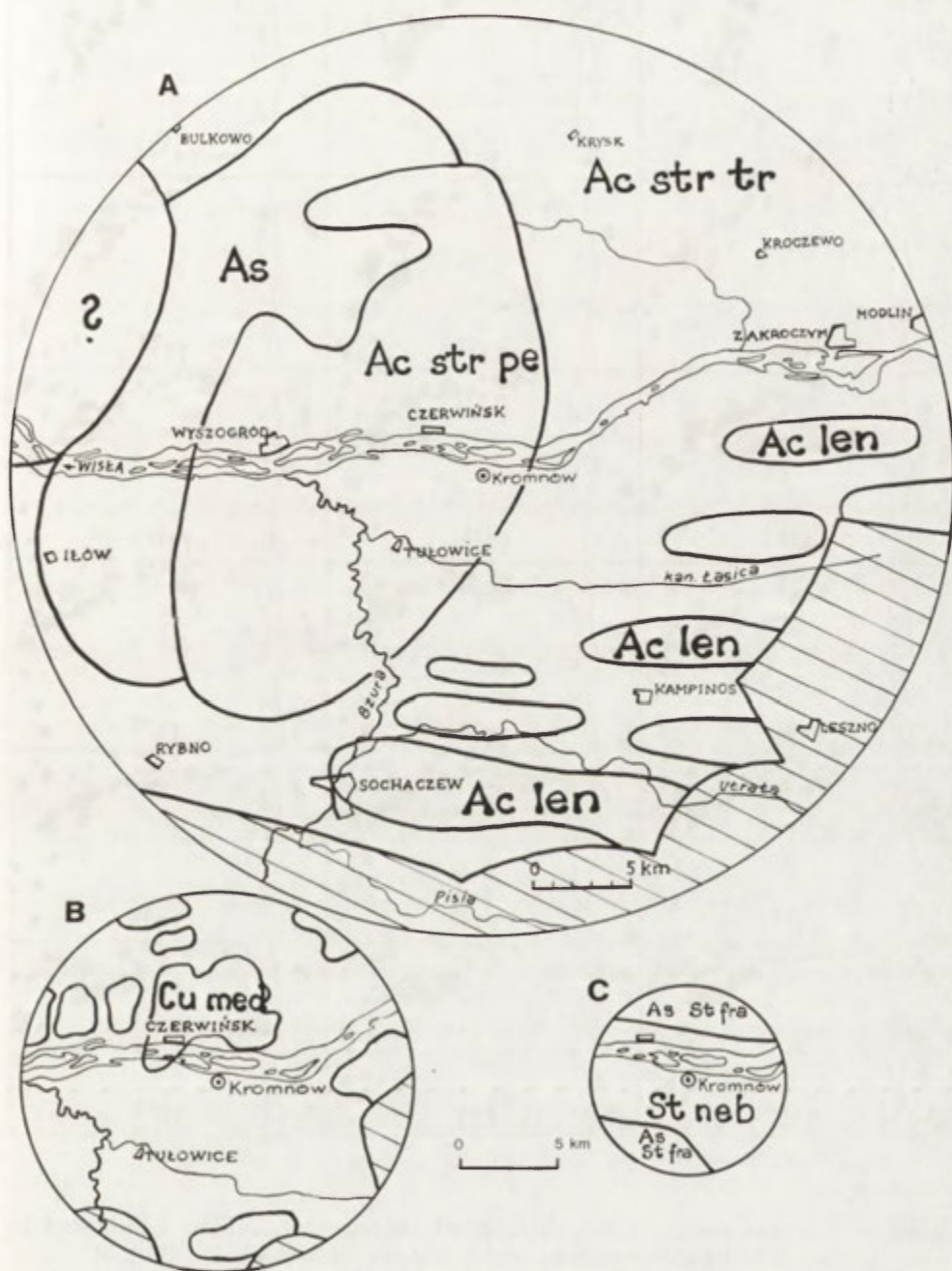


Fig. 1.

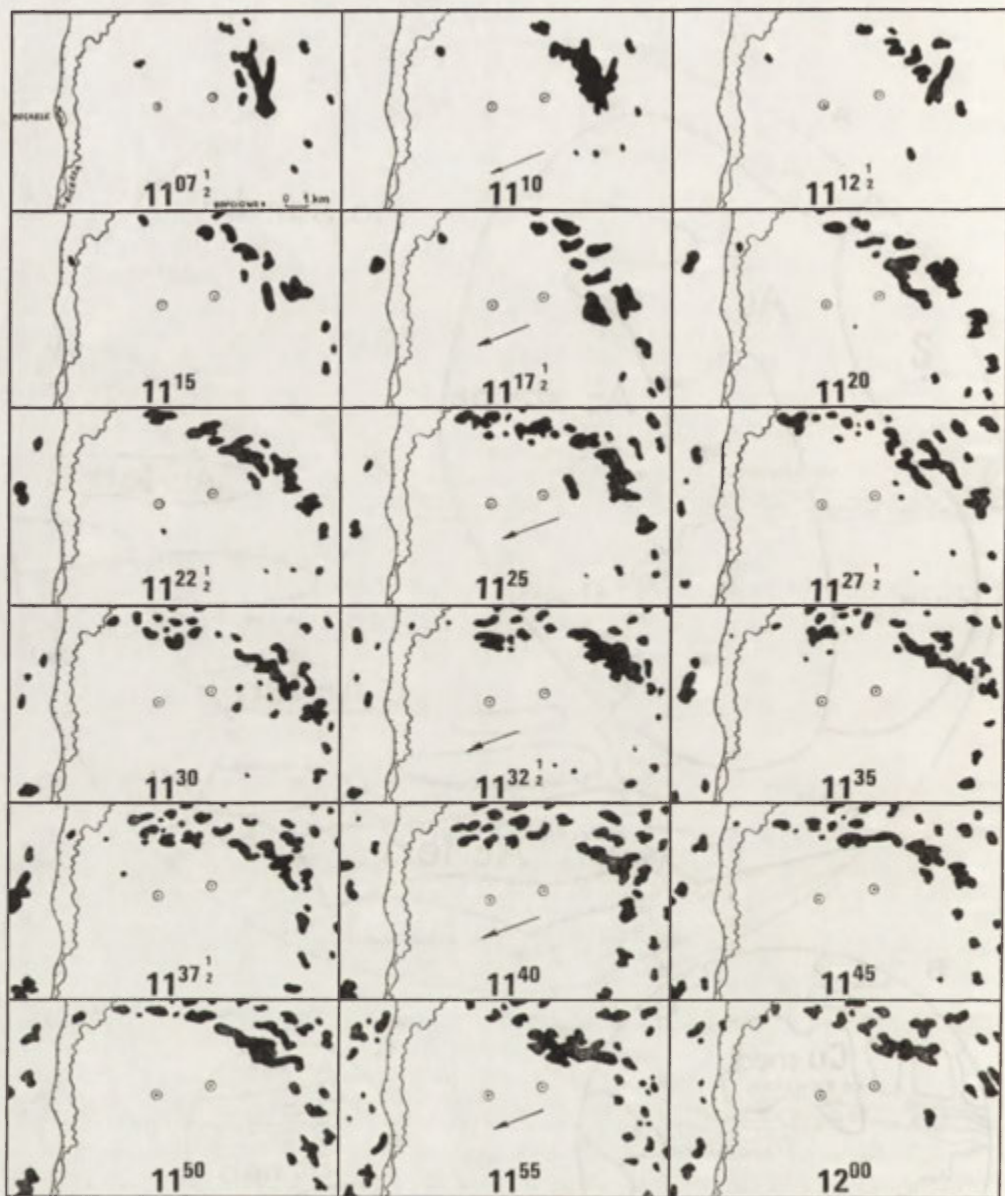


Fig. 2.

sive shots causes errors in this method which however, can be eliminated by constructing a map for the time in which the zenith was shaded (Fig. 3).

By introducing upon a topographical basic print the corresponding outlines of clouds, including the particular data on when successive shots were taken (Fig. 3a), an illustration of changes in the position of the clouds is obtained. By estimating the direction in which the cloud outlines move, one can by interpolation and generalization construct upon the basic print a new cloud map with shorter time intervals, between shots than those actually applied. Practi-



Fig. 3.

cally sufficient are one-minute intervals, as shown in Fig. 3b, as the result of transforming what was shown in Fig. 3a. From the overlapping of particular cloud outlines one can establish the time for which the zenith has been veiled by given clouds (Fig. 3c). By treating in the same way all clouds which for definite periods of time move across the investigated area, one obtains a map of zenith shading (Fig. 3d). The values of successive isolines are given in minutes, and the summing up of the periods of shading is done for nodal points and centres in a one-kilometre lattice. This kind of map showing zenith shading represents the most accurate cartographical scrutiny of a mean cloud distribution; however, the fact that to produce it is exceptionally tiresome, precludes this procedure being commonly applied.

By using the same source material one can obtain a map showing the mean cloud cover above the Earth ( $Z$ ). Fig. 4a illustrates an example of the distribution  $Z$  (heavy lines) on the background of cloud projections for a one time unit. Here the investigated area was a region north of Suwałki, with a variegated lake-studded landscape and clearly marked moraine plateaus. In circles, placed next to the abbreviations of given stations, are marked the degrees of simultaneously observed and visually estimated cloud amount ( $N$ ). The differences between  $N$  and  $Z$  appear to be considerable. The highest values for  $N$  seen at Smolniki (Sm), Sidory (S) and Leszczewo (L) suggest a NW-Se motion of the zone of intensified cloudiness, whereas in reality these kind of zones are arranged at right angle to the assumed direction.

The interrelation between Earth cloudiness ( $Z$ ) and sky cloudiness seen on a physical firmament is a complicated problem, because in practice one does not determine  $Z$  for the area from above which the clouds bear upon the estimate of  $N$ . Even so, if this were done,  $N$  would always be larger than, or equal to  $Z$ . For convective clouds the  $N-Z$  differences are higher than for the remaining clouds and total some 10 to 20% (W. Okołowicz, W. Lenart 1973).





Fig. 4.

A correlation of the distribution of Z for different, mutually unconnected periods of time should not be attempted by calculating mean values; and this is why the author suggests compiling a map showing the arrangement of isonephs Z. By imposing upon each other the isonephs Z for six successive (but removed from each other) dates of photographing the sky (Fig. 4b), the author tried to determine for particular basic fields the predominant directions of the run of these lines Z (Fig. 4c). Passing on to continuous lines we obtain a pattern of the isonephs Z arranged as shown in Fig. 4d. "Coilings" indicate areas where *Cumulus* clouds react more strongly upon the impact of bedding.

The next group of methods worth mentioning is an analysis of the tracks followed by convective clouds. Here two types of tracks should be distinguished:

- straight-line tracks, obtained by joining tracks of displacement of cloud centres or of groups of clouds, and
- true tracks, taking into account the horizontal cloud dimensions and their changes during cloud motion.

Track analyses are meant to detect deformations in cloud motion; they make it possible to define the rate of cloud motion, and they represent the first stage in the construction of track density maps. An example of this map, with straight-line tracks indicated, is shown in Fig. 5a and, with true-line tracks, in Fig. 5d. By counting the number of intersections of basic fields by tracks

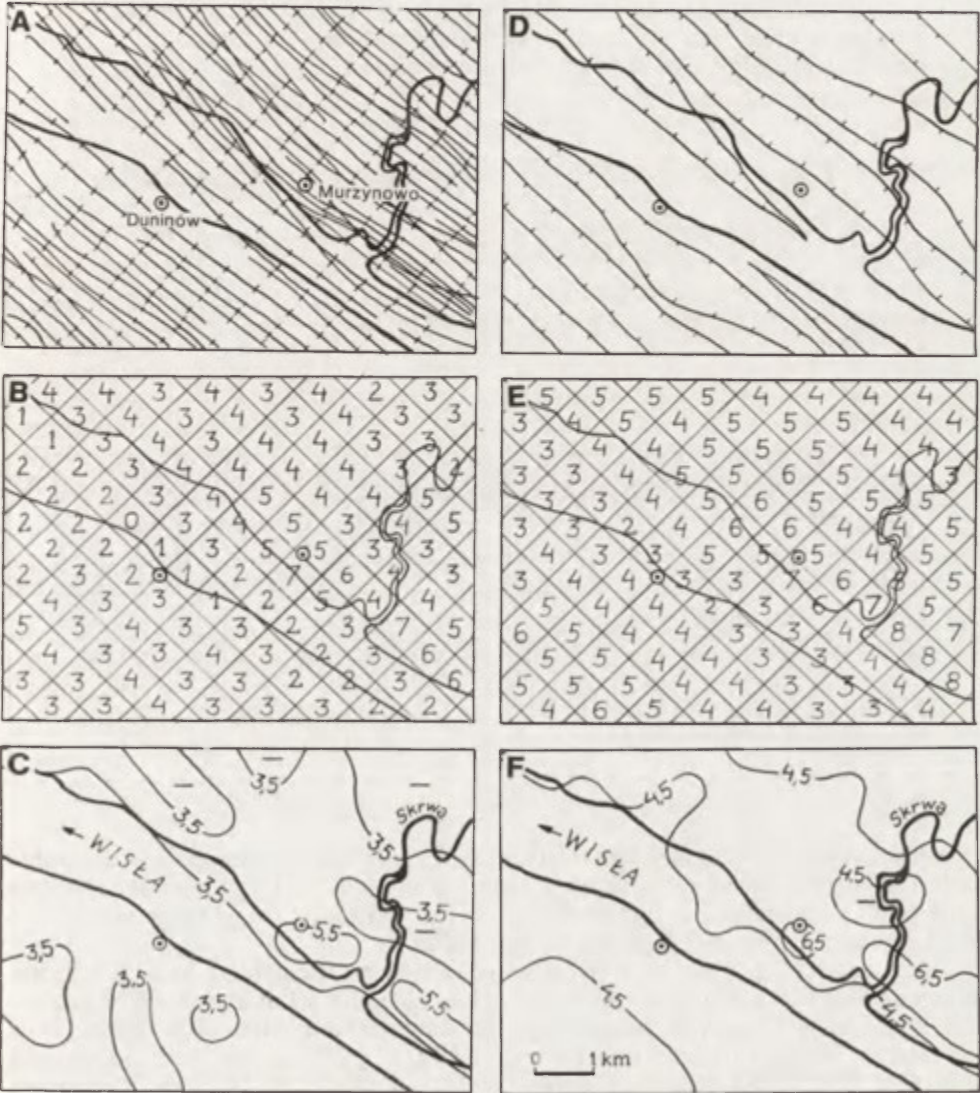


Fig. 5.  
<http://rcin.org.pl>



(Fig. 5b and 5e) one can draw an isarhythmic map (Fig. 5c and 5f). Worth noticing is the difference in the pattern of the density of the straight-line and the true tracks (here the analysis has been performed using the same material).

The method of true tracks is applied for compiling a map of tendencies of cloud development. A series of cloud maps is always analyzed in pairs: two pictures taken at adjoining dates are entered onto a common base map (Fig. 6a, 6b and 6c), and by suitable identification (numbering of clouds) one obtains a picture of changes in the position and shape of the horizontal projection of each cloud. By taking stock of the nature of the changes observed, one classifies the periods of development of a given cloud into separate types of tendencies. In Fig. 6d the author shows by different hatchuring the following types of tendencies:

- horizontal lines — a weakening cloud development,
- cross-hatching — an increase in horizontal cloud dimensions,
- oblique lines — a tendency towards stagnation,
- dotted marking — a lack of definite changes.



Fig. 6.

Because the development of convective clouds usually comprises a combination of all the above tendencies, an abundant statistical material is indispensable so as to perceive territorial differences in the structure of these tendencies and to obtain a picture of climatological value.

After collecting a set of maps thus compiled as illustrated in Fig. 6d, one stakes out on the warp of a one-kilometre lattice chart the structure of particular tendencies (Fig. 7a). In each of the squares the particular fields, in a downward order, conform successively with: a growing tendency (darkened fields), a decreasing tendency (white fields), a tendency towards stagnation (darkened fields), and indefinite conditions (white fields). After availing oneself



of the material prepared in this way, one can now draw isolines of the proportional share of particular tendencies regarding all cases observed. In Fig. 7b this share is drawn for tendencies of increase, in Fig. 7c for tendencies of decrease, and in Fig. 7d for tendencies towards stagnation. The material taken into consideration in this example is derived from the middle reach of the Vistula valley, where it was possible to detect distinct interrelations between the ground surface and the development of convective clouds and other low-level clouds. Particularly well illustrated is the pattern formed by cases of cloud stagnation, showing clearly a maximum value above the high right-hand bank of this valley.

For minor differences in the stages of the formation of particular Cu clouds, favourable results are obtained by analyzing the number of these clouds. Another example of a fairly simple procedure is detecting spots where clouds are forming and where they disappear.

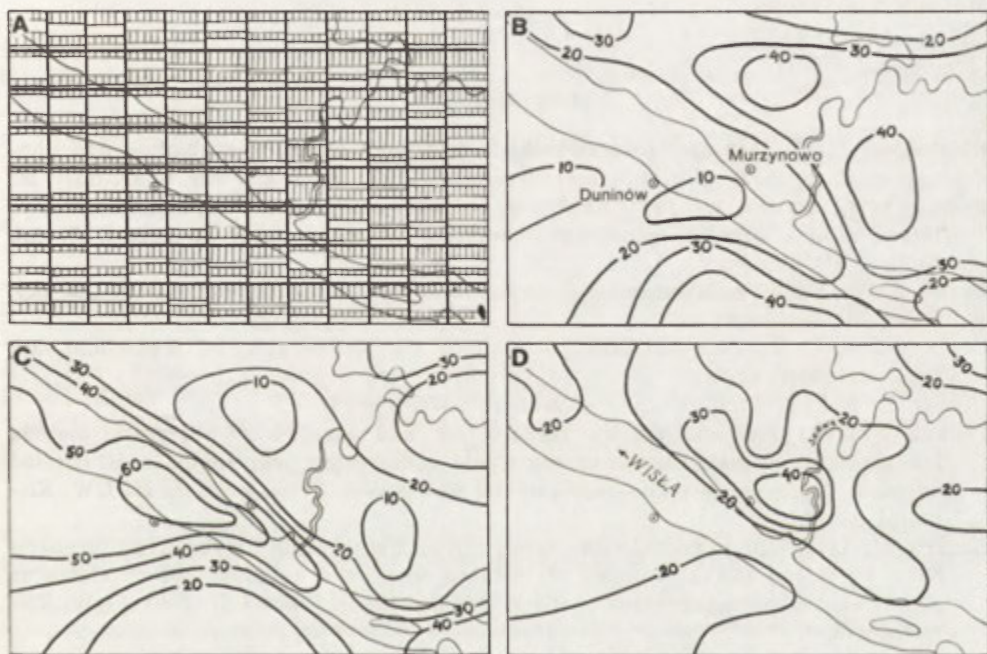


Fig. 7.

The discussed maps indicating periods of zenith shading can be transformed into maps showing periods of sun shading — yielding interesting comparisons with results obtained from heliographic and actinometric measurements.

Cloud maps may also serve as a means for non-cartographical studies; interesting in this respect are isopleths of changes in relative cloud dimensions, charts showing changes in the structure of clouding, or cloud-forming patterns. The chances of contriving new methods of interpretation and display seem unlimited.

The purpose of every geographical study is a cartographical synthesis. In our present report we aspire after a cloud-forming regionalization. This is done separately for selected weather types or selected synoptical conditions, and for a given type or given types of clouds. A comprehensive regionalization reflecting the climatological nature of cloudiness above a given area requires a

series of observations of longer duration than those which have illustrated the examples discussed above.

We anticipate a steady growth in the part played by photographic methods of cloud investigation, among them also by earthbound methods treated preferentially in our present study. The understanding of the mechanics of disparities in cloudiness and precipitation under conditions prevalent in different landscapes takes for granted the transition to the system of cloud maps and the Earth cloudiness. However, expanding and improving our techniques of sky photographing must be combined with a definite system of cartographical interpretation of the results obtained, and with an interlinking of the newly introduced method with all traditional methods and all other contemporaneously developing methods.

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#### REFERENCES

- Balabuyev, A. G., 1962, O fotograficheskikh metodakh izucheniya oblakov (On photographic methods of clouds measurement), *Tr. Inst. Geogr. AN Gruz. SSR*, 20.
- Bednarek, J., Lenart, W., 1973, Naziemna rejestracja związku zachmurzenia z podłożem (Sum.: Ground recording of relation of cloud cover to earth), *Przegl. Geofiz.*, 3-4.
- Carin, A. V., 1950, Photographic measurement of amount of cloudiness in the sky, *Bull. Am. Met. Soc.*, 5.
- Deppermann, C. E., 1949, An improved mirror for photography of the whole sky, *Bull. Am. Met. Soc.*, 8.
- Georgi, J., 1957, The photographic sky-mirror, *Weather*, 4.
- Lenart, W., 1973, Badanie rozmieszczenia chmur nad niewielkimi obszarami metodą łączonych zdjęć całego nieba (Sum.: Cloud distribution over small areas, studied by method of joining photographs of the whole sky), *Prace i Studia IG UW, Klimatologia*, 7.
- Lenart, W., 1975, Wpływ podłoża na rozwój chmur *Cumulus* nad wybranymi terenami Nizy Polskiego (Sum.: Impact of bedding upon the development of *Cumulus* clouds above selected regions of the Polish Lowland), *Prace i Studia IG UW, Klimatologia*, 9.
- Okołowicz, W., Lenart, W., 1973, O ocenie kolichestva oblachnosti po raznym metodam (Sum.: On measuring the amount of cloudiness by different methods), *Idöjárás*, 1.
- Okołowicz, W., Lenart, W., 1970, *Metoda zdjęć całego nieba w badaniach zachmurzenia* (Sum.: The All Sky System for the study of clouds), *Prace PIHM*, 100.

MILD WINTERS IN CRACOW AGAINST THE BACKGROUND OF THE  
CONTEMPORARY CIRCULATION PROCESSES

JANINA TREPINSKA

Interesting changes in the course of circulation processes, noticed by climatologists are worth discussing in detail. Climatic fluctuations noticed on the basis of the data from the 19th and 20th centuries in large areas of Europe, Asia and North America, reveal first of all great in those variations in the mean annual temperatures, especially for winter months. These depend more on the type of atmospheric circulation than on the temperature as do the summer months (Girskaya *et al.* 1970; Ryzakov and Tomskaya 1974). According to the statements of explorers from various countries, the mean monthly anomalies of the last decades' temperatures show particularly the intensity of the recent rise of temperature in Europe, recorded also in Poland at the beginning of this century (Merecki 1915; Romer 1947). Thermal anomalies grow from the subtropical territories to the higher latitudes, however, increase or decrease of temperatures in polar latitudes do not cause such a process in lower latitudes. A particularly distinct trend of temperature increase was recorded in the polar and temperate latitudes in the 1920s and the 1940s tapered, but this trend tapered off in the next few years.

The increases in temperature after the small glacial period, ended in the 19th century, and apart from the closely connected changes in pressure and moisture in the troposphere, caused all sorts of other processes of a geomorphological, oceanographic and botanical nature simultaneously in large areas. They are as follows: the retraction of the Alpine, Spitsbergian and other polar archipelagical glaciers, a change in the icecovered seas, especially in the North and Baltic seas, a raising of the level of the oceans, as well as of individual water reservoirs, changes in the flow of rivers, timber increment, and so on.

Within centuries, the centres of atmospheric activity were dislocated in the atmosphere, which caused a change in the direction of the air flow over certain areas (Budyko 1967; Okołowicz 1948; Smirnova 1968). Furthermore, those processes were the reason for the forwarding or decaying "oceanization" of the climate of certain areas. The trend towards "oceanization" of the climate in Central and Northern Europe at the turn of the 19th and 20th centuries, was first revealed in the several mild winters, the decrease in the amplitude of the annual temperature, and the increase in rainfall in the warm season (Rubashev 1974; Merecki 1915; Wiszniewski 1950; Trepińska 1971).

A special intensity in the variation of circulation processes from 1970, which was the reason for unprofitable economic phenomena, such as longlasting droughts in Sahel, cool and snowy springs in large agricultural areas of Canada, cool rainy years in the greater part of Europe, quicker melting of ice fields in the Arctic, the cause of a reduction in the temperature of the Mid-Atlantic waters, disastrous floods in the agricultural territories of India, Pa-



kistan, the United States and Japan (in February 1975 — disastrous flood of the Middle Nile), induced intensive research as to the reason and trends of these climatic changes on the part of climatologists. Many works on these subjects are published by Russian scientists, who stated, that the changes in the circulation processes were of the greatest intensity over the Eurasian areas.

The main reason for the changes in the atmosphere are certain cyclic processes which take place partly in the photosphere and partly in the chromosphere of the Sun. Furthermore, those processes produce changes in the geomagnetic field, which affect the direction of atmospheric currents (Mustel 1974). The differentiation of the impact of these processes, defined as solar activity, are not so easily found, due to the fact, that other factors have an influence on their activity, among which human activity in industry and communication are of growing importance.

The majority of scientists agree that the 80- and 90-year cycles of solar activity, often called secular cycles, have a basic influence on the forming of changes in the course of air temperature (Loginov 1969; Loginov and Sukhomazova 1971; Sazonov and Loginov 1968; Valnicek 1965). Those cycles are divided into four "quarters" (often having a different number of years; Willet 1966), depending on the intensity of the processes producing emission of corpuscular radiation of the Sun. Such "quarters" range from 18 to 22 years and, the occurrence of definite climatic trends should be related to their course. Thus, the cooling and, in the second and third quarter — the warming-up, appear in the first and fourth quarters of the secular cycle of solar activity. Nevertheless, this dependence, is not so simple as we might think, mainly due to the interference of other factors (e.g. the increase in the quantity of carbon dioxide and other gases, originating from volcanic eruptions and the work of millions of combustion engines). In the zone of latitude from  $N\ 20^\circ$  to  $55^\circ$  the winter temperatures have an increasing trend, together with a secular decrease of solar activity, and a decreasing trend in other latitudes (Loginov 1971; Rubashev 1974). Nevertheless, the greatest thermal changes appeared in Europe and in the seas surrounding Europe from the North, the influence of the 11-year cycle of solar activity being the greatest.

The research of the Russian scientists, based mainly on an examination of the air pressure and temperatures anomalies, suggest a segregation of certain forms of atmospheric circulation (Girs 1974; Dzerdzyevskii 1962). In the period from 1900 to 1928 zone circulation (W) dominated, appearing in the increased flow of the moist air from the West, so the summers in Europe were cool and rainy and the winters mild. Heavy frosts over the Arctic Ocean were recorded. At the same time the process of oceanization of the European climate increased. It commenced first in the western territories of Europe and within several decades covered the eastern areas (Merecki, 1915; Romer 1947). In the years 1929-1939 there appeared the epoch of meridional circulation, first of the eastern type (E), bringing over Europe cool air from the Arctic and Siberia, and between 1940 and 1948 — the epoch of meridional circulation of the type C, characterized by warmer, moist air. From 1949 on, there followed the epoch of mixed circulation type  $E + C$ , which has continued to the present time. Extremely complicated and yet insufficiently explored processes rule the appearance of the above mentioned epochs, however, scientists have made considerable progress in attempts at forecasting changes (Girs 1974; Willet 1966), and climatic trends appearing in the atmosphere and hydrosphere.

The question arises, what is the course of temperature in Poland, against this roughly presented background of most important results of some scientific research. Cracow, situated on  $50^\circ$  latitude N, can be treated as a good represent-

ative point. Moreover, are a series of continuous meteorological observations taken within the last 150 years, by the Astronomical Observatory of Jagellonian University at scientists disposal. This Observatory, placed 12 m above ground level, at a window of the second floor of the university building, is still working.

As was previously mentioned, the particularly essential indicator for the research of thermal climate trends, are the temperatures of the winter months, whose standard deviation values  $\sigma$  are about three-times greater than  $\sigma$  of the summer months. The average annual temperature in Cracow, according to my researches (Trepńska 1971, 1973) from the beginning of the period under examination, that is from 1826, has systematically increased. This situation was mostly caused by higher spring and autumn temperatures, as well as by the increasing number of mild winters. According to the data given by the Cracow Observatory concerning 31 winters (out of 150 years) with the mean temperature  $\leq -4.0^\circ$  only 10 of them were noticed in the 20th century, and four in the short period 1939–1947. Out of the 32 winters with a mean temperature  $\geq 0^\circ$ , 21 were noticed in this century.

A series of frosty winters, which appeared in Poland in the period 1939–1947, have been treated by some climatologists (Kosiba 1956), as a sufficient sign of the cooling-down of our climate, but have had no influence, nevertheless, on the change of the thermal trend. Furthermore the mean annual temperature has been increasing, and the evidence of some mild winters confirms the existence of the process of recent rise of temperature in Central Europe (Trepńska 1973).

The exceptionally mild winters, noticed in 1973/74 and 1974/75 made the problem of "mild" winters in our climate more interesting. Therefore, it is worth looking closer at the thermic anomalies of the winters, and to connect it simultaneously, with the variation of circulation processes, already presented.

In the classification of winters, a very important problem, is the criterion upon which it should be based. In this work I did not use a detailed and universal assortment of criteria, which usually apply to specific needs (Kosiba 1956; Lyall 1971) and I took into consideration only the mean temperatures of the winters (December, January and February), partly because most of the considerations for the reasons of existing climatic anomalies are based on the mean temperatures of those months, or on their standard deviations.

According to the modified classification of Wiszniewski (1948) I distinguish: very frosty winters — with a mean temperature of two winter months  $\leq -10^\circ$ , frosty winters — with a mean temperature of one winter month  $\leq -10^\circ$ , or a mean temperature of three months  $\leq -5^\circ$ , medium frosty winters — with a mean temperature of the three months oscillating between  $-4.9^\circ$  to  $-3.0^\circ$ , light-frosty winters — with a mean temperature of three winter months oscillating between  $-2.9$  to  $-1.0^\circ$ , mild winters — with a mean temperature of three winter months oscillating between  $-0.9^\circ$  to  $+1.0^\circ$ , very mild winters — with a mean temperature of three winter months  $> 1.0^\circ$ .

Very objective, but slightly formalized thermal criteria of Chapman (Kosiba 1956), based on mutual relations of the mean temperature with the standard deviations of individual temperatures, do not allow to distinguish more exactly mild winters, owing to the fact, that the mean temperature deviations of frosty winters, are in extreme cases, more than twice, as great as the temperature deviations of mild winters, which means that the "severity" of frosty winters exceeds twice the "mildness" of the mild winter temperature.

The mean temperature of the winter in Cracow amounts to  $-2.1^\circ$ . Within the last 150 years, the winters have a big range of temperatures — oscillating

from  $-10.3^{\circ}$  to  $+2.1^{\circ}$ . The number of winters having mean temperature analogous to the mean temperature of the 150-year period, amounts only to 41. A greater number of winters can be found in the next section of mild winters (Table 1). In Table 2 we can see, that only five winter months (once December, once February and three-times January) had mean temperatures lower than  $0^{\circ}$ , nevertheless, in each case those temperatures were higher than the mean temperature of many years. In five cases December proved to be the warmest month of the winter, also in five cases February was the warmest month of the winter and only once, was January recorded as the warmest month, and

TABLE 1. Classification of winters in Cracow (1826–1975)

Type of winter	Number	%
Very frosty winters	1	0.7
Frosty winters	13	8.7
Medium-frosty winters	38	25.5
Light-frosty winters	41	27.3
Mild winters	46	30.7
Very mild winters	11	7.3

TABLE 2. Very mild winters in Cracow (1826–1975)

Year	Mean temperature						Extreme temperature	
	winters	XII	I	II	winters		max.	min.
					max.	min.		
1833/34	1.1	2.8	1.0	−0.5	4.0	−1.4	12.9 (II)	−16.4 (I)
1842/43	1.8	1.1	−0.6	5.0	4.4	−0.7	15.6 (II)	−14.6 (II)
1898/99	1.3	2.2	1.2	0.5	4.5	−1.6	14.4 (II)	−16.4 (II)
1909/10	1.2	1.0	0.2	2.4	4.2	−1.7	14.0 (II)	−13.6 (I)
1914/15	1.1	2.4	0.0	0.9	3.7	−1.6	11.9 (II)	−13.2 (II)
1915/16	1.8	2.8	2.3	0.4	4.7	−1.0	14.9 (XII)	−12.6 (XII)
1924/25	1.6	−0.8	1.3	4.4	4.7	−1.4	16.9 (II)	−9.7 (I and II)
1956/57	1.0	0.2	0.7	3.3	3.5	−1.3	11.8 (XII)	−14.9 (XII)
1960/61	1.1	3.1	−2.4	2.6	3.8	−1.9	13.9 (XII and II)	−20.2 (I)
1973/74	1.4	0.3	0.8	3.2	4.4	−1.1	14.7 (II)	−13.7 (XII)
1974/75	2.1	3.2	3.5	−0.3	5.2	−0.2	12.3 (XII)	−9.1 (II)



this happened in 1975. The coolest winter month among the months considered in Table 2 was January (in four cases), December and February (in three cases), but once (in 1956) it happened that November proved to be the coolest month and also once (in 1915) it happened that January and March had exactly the same mean temperature. The absolute maximum winter temperatures noticed in December or February, have never appeared in January.

The greatest thermal contrasts appeared during the winters in 1842/43 and 1960/61. During the latter, the shortlasting frosts, exceeding  $-20^{\circ}$  in January were not able to reduce effectively the mean temperature of the whole winter, because high temperatures were recorded both in December and in February. In 1961 the range of the extreme temperatures exceeded  $34^{\circ}$ . A very warm February, with a mean temperature of  $5.0^{\circ}$  was noticed in 1843. It was the warmest February within the said 150 years, and its mean temperature was higher than any other April mean temperature in the same period (Trepiańska 1971).

The high temperatures of the winter months 1974/75 undoubtedly qualify this winter as the most mild winter of the 150-year period. It was mainly caused by the high mean temperature of January 1975, which, it is true, is equal to the mean temperature of January in 1921 (winter in 1920/21 is classed among mild winters), but, the minimum mean temperature in January 1975 was higher, moreover, it had less rainfalls and more sunshine. Therefore, the January of 1975 has priority.

A great fluctuation between temperatures of the winter months in Cracow, their different distribution, the appearance of warm air mixed with frosty air, all these factors make great difficulties in the attempts at connecting thermal air currents of our winters with the results of the Russian scientists' research, previously presented.

Nevertheless, the course of the winter temperatures in Cracow shows the existence of the process of recent rise of temperature. We can also confirm the observation that the milding-up of the climate at our latitudes was coming from the west (Okolowicz 1948). Winters in 1890/91 and 1892/93 recognized in the European part of Russia as very frosty, were also frosty in Poland. But, the winters in 1906/07, 1907/08, 1908/09 considered as very frosty in Russia, were not so frosty in Poland, because in these years the process of the oceanization of the climate had appeared in Poland. I should also mention a very interesting fact concerning the extension of the autumn, and which is connected with this, the shift of the dates of the beginning and the end of the winter, although, we can notice at the same time, during the last decades a shortening of the thermal winter (Hess 1967).

Fig. 1 shows the cumulated values of the mean deviations  $v_i$  of the mean winter temperature in Cracow within these 150 years. Numerous bendings of the curve in different years of the 19th century shows the great winter temperatures range. The short periods of the warmer winters appeared in the thirties, the fifties, at the end of the sixties, and a little more clearly in the eighties. The quinquennial 1881–1885 had the greatest mean winter temperature since the beginning of the century. In spite of these facts, the general direction of the thermal trend of the winters in the 19th century was falling. And only in the nineties did there appear a sudden turn of the climatic trend, especially strong from 1909. The inclination of the curve of Fig. 1 greatly increased, which shows the intensification of the investigated process. Three greater changes of the trend direction in the following years were caused by the very frosty winter in 1928/29, by the series of frosty winters during the Second World War, as well as by a very frosty winter in 1962/63. There was no precise direction

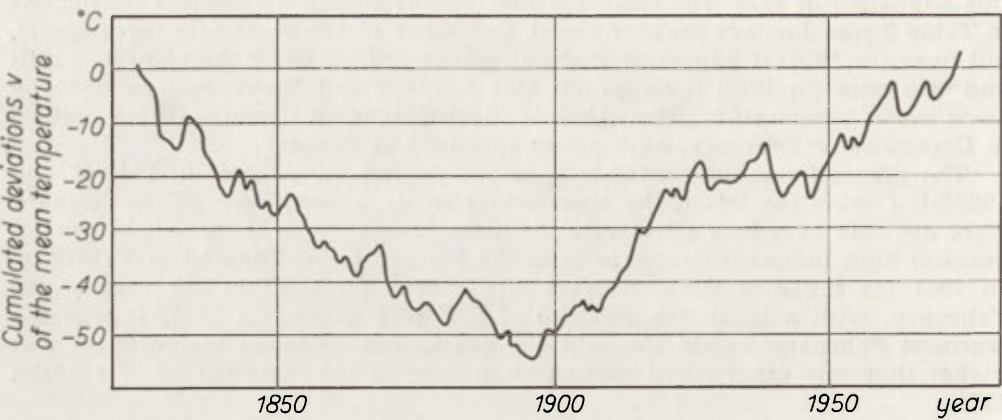


Fig. 1. Course of the mean *v* temperature deviations of winters in Cracow (1826–1975)

of the air flows in our country during the circulation epoch of the years 1940–48, contrary to the other parts of Europe (Girs 1974), because in this short period there appeared frosty winters in 1939/40, 1941/42, 1946/47 and mild ones — in 1942/43, 1943/44, 1947/48 and 1948/49. The last period of twenty years is classed among the most turbulent periods as far as the forming of winter temperatures is concerned, however, the general trend of their increasing still remains. The variation of the winters in this period tells of the predominance of the meridional circulation of mixed type.

Attempts to connect the winter temperatures in the larger areas with the cycles of solar activity lasting 90-year, confirms the influence of those cycles on the appearance of the winter temperature anomalies (Rubashev 1974; Valniček 1965). We can see similar dependences in the investigations of the appearance of the frosty and mild winters in Cracow in the particular “quarters” of the 90-year cycles (Trepínska 1973; Table 3). Nevertheless, in the case of the appearance of frosty and mild winters in the last period, it means in the first “quarter” of the 90-year cycle, in which according to the forecasts the climate should be cooled — we do not observe such climatic trends. Maybe, the influence of solar activity is disturbed by other processes, and here, it is necessary to mention human activity.

TABLE 3. Comparison of the observed climatic trends with the appearance of frosty and mild winters in Cracow (1826–1975)

Quarters of the secular cycle of solar activity	Climatic trend in Europe	Number of the winters in Cracow with the mean temp.			
		≤ −5°	≤ −4°	≥ 0°	> 1°
III (1830–1847)	warming-up	3	6	3	2
IV (1848–1870)	cooling down	1	6	4	0
I (1871–1893)	..	4	8	3	0
II (1894–1917)	warming-up	0	1	5	4
III (1918–1936)	..	1	2	6	1
IV (1937–1957)	cooling down	4	5	6	0
I (1958–1979?)	..	reg. 1	2	6	3

Fig. 2 shows the relations between the secular (90-year) cycle of solar activity and the course of the winter temperatures in Cracow. The curve *a* shows the course of the greatest mean numbers of Wolf out of consecutive 11-year cycles. It was equalized by the computation of the quaternary consecutive mean temperatures, which were composed of the maxima from 1816. The curve *b* shows the course of the mean winter temperatures equalized by computation of the 35-year consecutive mean temperatures (from 1826 to 1974).

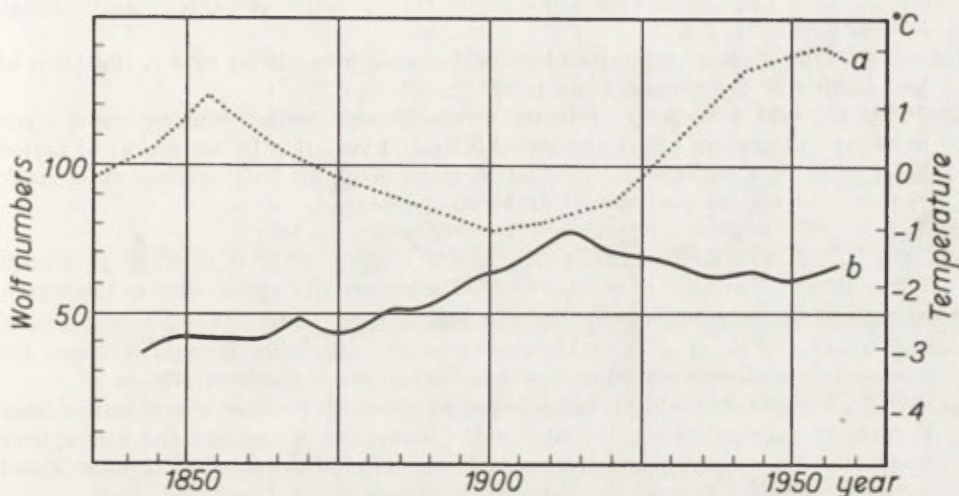


Fig. 2. Comparison of the secular cycle of solar activity with the course of mean winter temperatures in Cracow

*a* — highest mean Wolf numbers (1816–1969), equalized by the consecutive quaternary, *b* — mean winter temperatures (1826–1975), equalized by 35-year consecutive mean

In the period of the maximum blotting of the Sun — the winter temperatures were lower, and in the period of minimum blotting of the Sun, the winters were mild, however, a certain delay in the appearance of the determined winter temperatures in relation to the extremes of solar activity can be noticed.

The above mentioned dependences are not so simple and further research should discover their complicated nature and the course of these relations.

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#### REFERENCES

- Budyko, M. I., 1967, *Izmeneniya klimata* (Climate variations), *Meteorol. Gidrol.*, 11.
- Dzerdzeyevskii, B. L., 1962, *Obshchaya cirkulatsiya atmosfery kak neobkhodimoye zveno v cipi: Solnce — kolebaniya klimata* (General atmospheric circulation as the necessary element in the Sun chain — climate fluctuations), *Izv. Vsesoyuz. Geogr. Obshch.*, 94.
- Girs, A. A., 1974, *Solnechno-atmosfernyye svyazi i ikh rol v dolgosrochnykh gidrometeorologicheskikh prognozakh* (Relations between the Sun and atmosphere and their meaning in the longlasting hydrometeorological forecasts), in: *Solnechno-*



- atmosferhyye sviazi v teorii klimata i prognozakh pogody*, Gidrometeoizdat, Leningrad, 327–332.
- Girskaya, E. I., Loginov, V. F., Sazonov, B. I., 1970, Rezhim temperatury shirotnykh poyasov severnogo polushariya (Temperature regime of the latitudes zones on the North Hemisphere), *Uchen. Zap. Univ. im. Zhdanova*, 342, Ser. Geogr. Nauk, 20.
- Hess, M., 1967, O stosunkach termicznych Krakowa (1780–1963) (On thermal conditions of Cracow, 1780–1963), *Przegl. Geofiz.*, 12, 3–4.
- Kosiba, A., 1956, Zagadnienie klasyfikacji zim (The problem of winter classification), *Przegl. Geofiz.*, 1, 3–4.
- Kosiba, A., 1962, Zagadnienie ostatniego ochłodzenia klimatu po 1939 r. (Problem of last cooling of the climate after 1939), *Czas. Geogr.*, 33, 1.
- Lamb, H. H., 1966, Izmeneniya klimata v istoricheskii period, izuchayemye s pomoshchyu diagramm i kart cirkulatsii (Climatic variation in the historical period built with the diagrams and circulation maps help), in: *Solar variations, climatic change and related geophysical problems*, Leningrad.
- Lyll, I. T., 1971, English winters since 1950, *Weather*, 26, 10.
- Loginov, V. F., 1969, Osobennosti proyavleniya vekogo tsikla solnechnoy aktivnosti v troposfere (Character of secular cycle of solar activity appearance in the troposphere), *Izv. Vsesoyuz. Geogr. Obshch.*, 101.
- Loginov, V. F., 1974, O prichinakh sovremennykh izmenenii klimata (Reasons for contemporary climate variations), *Trudy G.G.O. im. Voyeykova*, 274.
- Loginov, V. F., 1974, O realnosti solnechno-atmosfernykh svyazey v probleme Solnce — nizhnaya atmosfera (On the reality of connections of the Sun and atmosphere under the Sun — lower atmosphere problem), in: *Solnechno-atmosfernyye sviazi v teorii klimata i prognozakh pogody*, Gidrometeoizdat, Leningrad, 19–21.
- Loginov, V. F., Sukhomazova, G. I., 1971, O realnosti solnechno-atmosfernykh svyazey (On the reality of the relations between the Sun and atmosphere), *Geomagnetizm i Aeronomiya*, 11, 3.
- Majdanowski, S., 1955, Zagadnienie ogólnej cyrkulacji atmosferycznej w czasie ostatniego zlodowacenia (General atmospheric circulation during the latest glacial age), *Przegl. Geogr.*, 27, 1.
- Merecki, R., 1915, *Klimatologia Ziem Polskich* (Climatology of Polish Lands), Warszawa.
- Mustel, E. R., 1974, Sovremennoye sostoyaniye voprosa o realnosti korpuskularno-atmosfernykh svyazey (Contemporary state of the problems concerning the reality of corpuscularly-atmospherical connections), in: *Solnechno-atmosfernyye sviazi v teorii klimata i prognozakh pogody*, Gidrometeoizdat, Leningrad, 7–18.
- Okołowicz, W., 1948, Uwagi o zmianie klimatu w Polsce (Some remarks upon the climate in Poland), *Gosp. Wod.*, 8, 9.
- Romer, E., 1947, O współczesnej oceanizacji klimatu europejskiego (On the recent growing oceanic influence on the climate of Europe), *Przegl. Geogr.*, 21.
- Rubashev, B. M., 1974, Proyavleniye dolgovremennykh periodov kolebanii solnechnoy aktivnosti v atmosfernom davlenii i temperature (Long periods of solar activity fluctuations in the atmospherical pressure and temperature), in: *Solnechno-atmosfernyye sviazi v teorii klimata i prognozakh pogody*, Gidrometeoizdat, Leningrad, 44–55.
- Ryzakov, L. J., Tomskaya, A. S., 1974, O sootnoshenii kolebanii temperatury vozdukha nad severnym polusharyem v vekovom i 11-letniem solnechnykh tsiklakh (Relations in the fluctuations of the air temperature over the Northern Hemisphere in the secular and 11-years cycle), in: *Solnechno-atmosfernyye sviazi v teorii klimata i prognozakh pogody*, Gidrometeoizdat, Leningrad, 62–69.

- Sazonov, B. I., Loginov, V. F., 1968, Vozmozhnyye prichiny poyavleniya ustoychivyykh temperaturnykh anomalii (On the possible reasons of analyzing the stable temperature anomalies), *Solnechnyye Dannyye*, 9 (1967).
- Schmuck, A., 1964, Czy klimat Polski ulega ochłodzeniu? (Does the climate of Poland suffer cooling?), *Czas. Geogr.*, 35, 1.
- Smirnova, K. A., 1968, O proyavlenii tsiklov solnechnoy aktivnosti v nekotorykh zimnykh temperaturnykh kharakteristikakh sredney Evropy, (On the manifestation of the solar cycles in some winter temperature. Characteristics of the Middle Europe), *Solnechnyye Dannyye*, 10.
- Trepińska, J., 1971, The secular course of air temperature in Cracow on the basis of the 140-year series of meteorological observations (1826–1965) made at the Astronomical Observatory of the Jagellonian University, *Acta Geoph. Pol.*, 19, 3.
- Trepińska, J., 1972, Surowe zimy w naszym klimacie (Frosty winters in our climate), *Wszechświat*, 2.
- Trepińska, J., 1973, Zmiany w przebiegu temperatury powietrza w Krakowie w XIX i XX wieku (Changes in the course of air temperature in Cracow in the 19th and 20th century), *Przegl. Geofiz.*, 18, 1–2.
- Valnicek, B., 1965, The 89-year period of solar activity and winter temperatures in Prague, *Bull. Astronom. Inst. Czechoslovakia*, 16, 6.
- Willet, H. C., 1966, Kharakter sviazi solnechnykh i klimaticheskikh yavlenii (Character of the relations between solar and climatical phenomena), in: *Solar variations, climatic change and related geophysical problems*, Gidromet. Izdat., Leningrad.
- Wiszniewski, W., 1950, Wahania temperatur miesięcy zimowych na tle długich serii obserwacyjnych (Fluctuations of the winter months temperatures against the background of the long observation series), *Gaz. Obserw. PIHM*, 2.
- Wiszniewski, W., 1948, Pogoda naszych zim (Weather of our winters), *Gaz. Obserw. PIHM*, 3.





# RESEARCH PROBLEMS OF THE FIRST MONGOLIAN-POLISH PHYSICAL GEOGRAPHICAL EXPEDITION TO THE KHANGAY MTS. IN 1974

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and TSESEMIN SUGAR

The Khangay is one of the mountain ranges of Central Asia extending over a distance of more than 700 km and attaining in its main ridge a mean height of 3000-3500 m. The highest peak, Otgontenger-uul reaches 4031 m. The ridge of the Khangay represents a continental water divide between the basin of the Arctic Ocean and the endereic areas of Central Asia. On its southern slope runs the boundary between the zones of forest and steppe; forests grow on north-facing slopes and the zone of steppe and semi-deserts is to the south. From the main range branch a number of secondary mountain ridges of lower altitude (Fig. 1).



Fig. 1. Location of investigated area on the background of Khangay Mts. (Mongolia)  
Onomastics according to *Britannic Atlas*, Chicago 1970

## PHYSICAL GEOGRAPHICAL PROBLEMS OF THE KHANGAY

The Khangay is a rigid block of Caledonian folds dissected by younger granitic intrusions and bordered on all the sides by zones of tectonic depressions and horsts (Fig. 2) (I. B. Fillipova, L. P. Zonenstein, V. A. Armantov, E. V. Michailov 1973). The Paleozoic relief of that area has since been modelled under subaerial conditions. Situated as it is in the centre of the Asiatic continent that mountain massif has since at last the Cretaceous period been under an extremely continental climate (E. G. Ravski 1972). The relief of the Khangay is characterized by vast plateaus in the centre of the massif, and well developed pediments on its margin. Correlative deposits associated with the destruction of the massif fill in tectonic depressions situated on its margin. The problem of age and origin of these dominant and no doubt very old landforms as well as their reference to the correlative deposits on the edge of the Khangay has not yet been established (E. M. Murzayev 1952, E. S. Selivanov 1972).

In the Quaternary the Khangay was glaciated as evidenced by deep corries, glacial troughs and moraine ramparts, as first reported many years ago (J. G. Granö 1910; E. M. Murzayev 1952). The Quaternary was at the same time a period of the development of subsurface glaciation of that area which is expressed in the occurrence of permafrost (G. F. Gravis, A. M. Lisun 1974). The

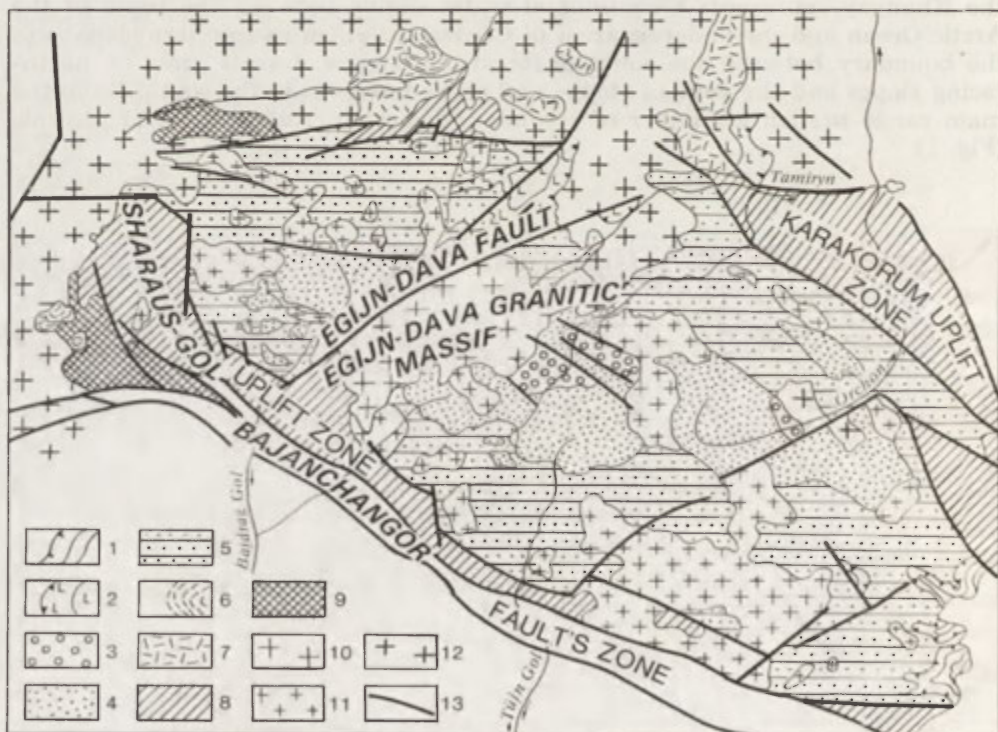


Fig. 2. Geological sketch of the Khangay block (after L. P. Zonenstein)  
 1—Jurassic sedimentary rocks, 2—Jurassic volcanic rocks, 3—Permian deposits, 4—upper-Khangay series, 5—lower Khangay series, 6—lower-Carboniferous series, 7—Palaeozoic sedimentary-volcanic deposits, 8—lower Palaeozoic sandy-shale deposits, 9—lower-Cambrian deposits, 10—younger-Mesozoic granits, 11—upper-Palaeozoic Khangay granodiorites, 12—upper-Palaeozoic granitoids, 13—faults

southern limit of the permafrost runs nowadays along the southern foot of the Khangay (G. F. Gravis 1974). This is at the same time the southern most limit of permafrost on the northern hemisphere. Judging by the occurrence of the two horizons of permafrost in Siberia (V. V. Baulin et al. 1973) it is possible that the shallow permafrost of the southern Khangay came into being after the Holocene climatic optimum. The course of climatic changes in the Quaternary, the number of glaciations and their synchronization with the glaciations in particular mountain groups of the Khangay, have as yet been very little studied and still present open scientific problem (E. M. Murzayev 1942; G. F. Gravis, A. M. Lisun 1974).

The Khangay represents a very interesting country to investigate present-day processes of the circulation of energy and matter under continental climatic conditions. That continentalism finds expression in very large daily and annual ranges of air temperature, in the low air humidity, very strong winds and low precipitation (200–400 mm) falling during the short summertime. This determines the meso- and microclimatic conditions and the ecosystems of slopes and mountain valleys with a negative heat balance of the ground, the course of mechanical weathering and of the mode of removal of rock waste mantle beyond the mountains. The only detailed investigations on the types and vertical zonation of the environment were carried out by a German expedition (G. H. Haase, H. Richter, H. Barthel, 1964). The water resources of that region, are also little known, especially the regime and means of alimentation of rivers draining the Khangay (N. T. Kuznetsov 1968).

The Khangay mountains have for centuries been the most densely populated region of Mongolia. At present the density of population there amounts to 1.5 persons per km<sup>2</sup>. The majority of these have been and still are nomads pasturing flocks of horses, yaks, sheep, goats and camels. The pastoral farming practised for centuries has brought about changes in the original vegetation cover and soil of the area. Knowledge about problems of the influence of pastoralism on the geographical environment and a possibility of its further development are of great practical importance for the economic advance of that part of Mongolia.

#### PURPOSES AND ORGANIZATION OF THE MONGOLIAN-POLISH PHYSICAL GEOGRAPHICAL EXPEDITION TO THE KHANGAY, 1974.

The Mongolian-Polish Physical Geographical Expedition to the Khangay in 1974 was organized within the framework of scientific cooperation between the Institute of Geography, Polish Academy of Sciences and the Institute of Geography and Geocryology, Academy of Sciences of the Mongolian Peoples Republic, as a first stage of two years expeditionary investigations. The main purpose of the expedition was to learn about the resources of the geographical environment on the southern slope of the Khangay from the viewpoint of possible advances in the national economy especially its animal husbandry. Fifteen scientists representing various branches of the earth sciences participated in the expedition. These were:

(1) Ass. prof. Kazimierz Klimek — leader of the expedition, geomorphologist, Institute of Geography, Polish Academy of Sciences, Cracow,

(2) Batsuchin Avirmid, climatologist, Institute of Geography and Geocryology, Academy of Sciences of the Mongolian People's Republic, Ulan Bator,

(3) Mr Zygmunt Babiński, geomorphologist-hydrographer, Institute of Geography, Polish Academy of Sciences, Toruń,

(4) Dr. Wojciech Froehlich, geomorphologist and hydrologist, Institute of Geography, Polish Academy of Sciences, Cracow,



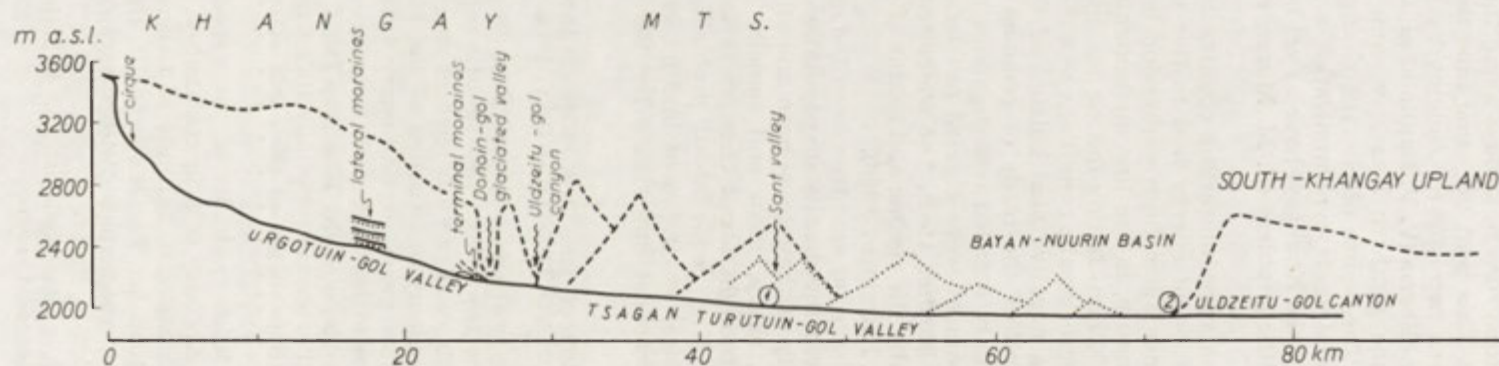


Fig. 3. Longitudinal profile of Urgotuyn-gol and Tsagan-Turutuyn-gol on the background of South Khangay slope

1 — base of the expedition, 2 — sub-base of the expedition

- (5) Dr. Adam Głodziński, surgeon, Medical Academy, Cracow,
- (6) Mr Marek Grześ, hydrologist, Institute of Geography, Polish Academy of Sciences, Toruń,
- (7) Ass. prof. Alojzy Kowalkowski, pedologist, Institute of Forestry, Warsaw,
- (8) Radnarin Lomborintchen, geomorphologist, Institute of Geography and Geocryology, Academy of Sciences of the Mongolian People's Republic, Ulhan Bator,
- (9) Dr. Tadeusz Niedźwiedz, climatologist, Geographical Institute, Jagellonian University, Cracow,
- (10) Dr. Anna Pacyna, botanist, Institute of Botany, Jagellonian University, Cracow,
- (11) Dr. Kazimierz Pękala, geomorphologist, Geographical Institute, Marie Curie-Skłodowska University, Lublin,
- (12) Dr. January Słupik, hydrologist, Institute of Geography, Polish Academy of Sciences, Cracow,
- (13) Tsesemin Sugar, leader of the Mongolian group, hydrologist, Institute of Geography and Geocryology, Academy of Sciences of the Mongolian People's Republic, Ulhan Bator,
- (14) Prof. Leszek Starkel, deputy leader of the expedition, geomorphologist, Institute of Geography, Polish Academy of Sciences, Cracow,
- (15) Mr Roman Zapolski, geodesist, Geographical Institute, University of Toruń.

The expedition left Ulhan Bator on 11 June, 1974 accompanied by three lorries and after driving some 750 km across steppe and semiarid areas of the southern foot of the Khangay reached the study area on June 14, 1974. The main base of the expedition was established at the mouth of the valley of the Tsagan-Turutuin-gol, where it passes from the mountains into the foreland at about 2100 m. A sub-base of the expedition was founded in the southern part of the submontane basin of Bayan-nurin-hotnor situated in the foreland of the Khangay at a height of 1960 m (Fig. 3). The work of the expedition in the Tsagan-Turutuin-gol basin lasted from June 15 to July 31, 1974. The study area was left on August 1, 1974 and after travelling some 1000 km along the northern slope of the Khangay the expedition came back to Ulhan Bator.

The study area of the expedition included the catchment basin of the Tsagan-Turutuin-gol, the surface of which is 2176 km<sup>2</sup>. At the expedition base a climatological station and a hydrologic station were established. Owing to the location of the base it was possible to perform studies also in the Khangay and on the nearby mountain foreland. At the sub-base there were in operation additional climatic and hydrologic stations. Owing to this location, base studies were carried out in the southern part of the Bayan-nurin-hotnor basin (Fig. 3). The expedition gathered abundant observational material which after analysis will be partly presented in a special publication (Bull. of the Polish Academy of Sciences). The present article deals only with fundamental research problems of the expedition and presents initial results of the studies.

#### RESEARCH PROBLEMS AND PRELIMINARY RESULTS OF THE EXPEDITION

The mountainous character of the research area caused the participants to divide into two problem teams one working within mountain slopes and other within valley and basin bottoms. In view of the large size of the research area and at the same time the necessity of satisfactorily detailed acquaintance with various elements of the geographical environment and the processes at work there, in both teams carried out parallel investigations of both general and detailed character.

The "slope" party under the guidance of L. Starkel first of all carried out detailed investigations of nearly all the elements of the geographical environ-

ment and relations among them in the Sant valley opening to the valley of the Tsagan-Turutuin-gol in the marginal (southern) portion of the Khangay. The investigations aimed at discovering the mutual relationship between relief, macroclimatic conditions, water circulation, soil and plant cover on north and south-facing slopes in various climatic-vegetation belts. Outside the Sant valley the participants of that group also performed general or comparative studies on slopes in other parts of the Tsagan-Turutuin-gol basin.

The "valley" party led by K. Klimek carried out general and detailed studies the aim of which was to learn geomorphological problems, climate, water conditions and certain present-day geomorphological processes, mainly in the valley of the Tsagan-Turutuin-gol and in the valleys of its major tributaries.

Both parties were at the same time facing practical tasks. For the slope party such a task was to become acquainted with the types of geo- and ecosystems, their abundance, and the degree of their degradation as the consequence of the intensification of animal husbandry.

The principal task of the valley group was, on the other hand, to determine water resources and the possibility of its supply to animal husbandry as well as to villages and the processing industry.

In the vicinity of the base, over an area of some 40 km<sup>2</sup> L. Starkel, R. Lomborintchen and S. Zhigzhs carried out a geomorphological survey on scale 1 : 25,000, aimed at learning the pattern of evolution and relief in the marginal part of the southern slope of the Khangay. That area is made up of granitic-granodioritic intrusions of Permian-Carboniferous age except for its north-western part built of Palaeozoic shales and sandstones, locally with a cover of Neogene basalts. In the vicinity of the Tsagan-Turutuin-gol valley the broad flattened ridges of the southern slope of the Khangay become more dissected into narrow ridges capped with tors. It is dominated by long convex-concave slopes with long footslops below (Fig. 4). The levelled axes of ridges at 2700-2800 m as well as at some 2400 m point to the stages of an old planation. The



Fig. 4. South slopes of Khangay Mts. near the camp of the expedition (Photo by L. Starkel)



bottom of the basaltic bed (probably pre-Quaternary) at 105 m in the contemporaneous channels has confirmed the opinion held by E. J. Selivanov (1972) of the Tertiary age of the valleys.

The relief bears traces of transformation under a cold periglacial climate as testified by the high-altitude ( $> 2400$  m) and now inactive steps of cryoplanation terraces. In the lower belt the slopes, especially southern ones, are cut by now inactive corrasion channels with pediments accompanied by monadnocks at their feet; their inclination is  $5-15^\circ$ . Their lower parts are mantled with colluvial covers descending to the level of the three systems of terrace at 30–40 m, about 20 m and 8–15 m. The dissection of these landforms by gullies as well as the development of mature soils of them point to a relationship of slope and fluvial covers with periods colder than the present one. The periglacial cooling of climate was followed by the shifting of cryonival belt by some 500 m upward and the survival of permafrost patches solely on northern slopes and in valley bottoms. Observations of the effects of the 1972 downpour are indicative of their role in the contemporaneous morphogeny in addition to frost weathering and deflation.

Geomorphological investigations in the Tsagan-Turutuin-gol valley carried out by K. Klimek and Ts. Sugar aimed at learning paleogeographical problems of that valley and at determining the kind and role of present-day geomorphological processes modelling its floor. In the valleys of the Tsagan-Turutuin-gol tributaries which dissect the main ridge of the Khangay, very distinct traces of glaciations of valley type were found. This is manifested in the occurrence of large corries and glacial troughs in addition to terminal moraines and lateral moraines (Fig. 5). The floors of most corries lie at 2900–3100 m. These corries correspond in height with predominantly typical glacial troughs up to 15 km long and 500–700 m deep. Glaciers descending those corries amounted to 26 km in length. On the sides of glacier troughs are encountered clear benches of lateral moraines mounting to 200 m above the contemporaneous floors of these valleys.

In the middle course of the Tsagan-Turutuin-gol valley, especially where it widens there occur glaciofluvial deposits of gravel and boulders forming typical valley outwash train (Fig. 6). Within them there is a very clearly marked



Fig. 5. Glaciated valley Urgotuun-gol in Central Khangay (Photo by K. Klimek)



Fig. 6. Glaciofluvial and fluvial deposits (gravels and boulders) in the middle course of Tsagan-Turutuin-gol (Photo by K. Klimek)

network of dry braided channels presumably surviving from a period of the close of Khangay glaciation.

The lower trace of the Tsagan-Turutuin-gol runs within depression basins bordering the Khangay massif from the South Khangay Upland. The northern part of the Bayan-nurin-hotnor basin is mantled with a west fan deposited by the Tsagan-Turutuin-gol during Khangay glaciation. Further to the south deposits of that fan merge into clayey limnological sediments. The middle and



Fig. 7. Fault-line scarp of South Khangay Upland (Photo by A. Pacyna)

southern part of that basin is filled up by clayey limnological sediment of unknown depth and by deposits connected with the tectonic uplift of the South Khangay Upland (Fig. 7).

In the upper course of the Tsagan-Turutuín-gol valley there takes place at present a rather intensive washing out of fine material (clayey-sandy) from the moraine deposits and glaciofluvial deposits which are deposited there. In the lower course of that river the dominant process is the erosion of river banks which is specially intense in the zone of frozen clays and alluvial deposits.

Investigations of climatic conditions were carried out by B. Avirmid and T. Niedźwiedź at a station at the camp and by Z. Babiński and M. Grześ at a station at the sub-base. At the climatological station at the base there were carried out, every three hours (starting at 2:00 a.m., Ulhan Bator mean time) measurements of actinometry, duration of insolation, temperature and air humidity, precipitation, temperature of ground surface, temperature at 2, 5, 10, 15, 20, 25 and 50 cm beneath the ground, direction and force of wind as well as of the pattern of cloudiness. At the station at the subbase there were taken 3 times per 24 hours (8, 14, 20 Ulhan Bator time) measurements of temperature and air humidity, temperature of ground surface, temperature of ground at 2, 5, 10 and 50 cm down, precipitation, direction and wind force and the pattern of cloudiness. These station records were supplemented with sporadic observations of the temperature and air humidity in the higher portions of the Khangay. According to preliminary calculations by B. Avirmid and T. Niedźwiedź the station at the base recorded during July as many as 237 hours of sunshine and the intensity of direct radiation had reached a maximum value of 1.59 cal/cm<sup>2</sup>/minute. Throughout the time of measurements (46 days) the temperature of the air at base oscillated between 2.4°C and 26.0°C. The temperature of the ground surface was at that time between 0.4°C and 60°C respectively. At the outlet of the Tsagan-Turutuín-gol valley from the mountains typical valley winds were observed with a clear diurnal cycle. During the research period the station at the base recorded twice only 2% of the calm while the station at the sub-base as much as 15% of calm. Throughout the whole period there were recorded at the base 15 days with a precipitation over 0.1 mm and 3 days with one over 10 mm. There were recorded in all 105 mm of precipitation which constituted presumably more than 50% of the annual total precipitation in that region of the Khangay.

Studies of water circulation in the mountainous part of the Tsagan-Turutuín-gol basin were carried out by W. Froehlich, J. Słupik and Ts. Sugar and those in the Bayan-nurin-hotnor basin by Z. Babiński and J. Grześ, their aim being to learn water resources and to establish the mode of alimentation of rivers draining the Khangay.

During the observation period (June 20th–July 31st) discharge in the Tsagan-Turutuín-gol was on the average 5.79 m<sup>3</sup> per sec. The min discharge (June 30th) was 0.67 m<sup>3</sup> per sec. i.e. 0.52 liters per sec. per sq.km. The minimum diurnal discharge from the mountainous part of the Tsagan-Turutuín-gol basin was 61,670 m<sup>3</sup> and the maximum one 4,155,300 m<sup>3</sup>.

At the same time the temperature of the water ranged between 5.8 and 18.3°C. The station at the sub-base, situated some 50 km downstream was recording a 24 hours' delay in the course of water stages in respect to the station at the sub-base.

The low discharge at the camp on June 21st (1.16 m<sup>3</sup> per sec.) corresponded with a low discharge at the sub-base on June 22nd (1.53 m<sup>3</sup> per sec.). Similarly, a high discharge at the camp on July 4th (19.1 m<sup>3</sup> per sec.) was correspondent with a high discharge at the sub-base on July 5th (7.0 m<sup>3</sup> per sec.). The differ-



ence in the river's discharge between its outlet from the mountains and from the intramountain basin points to a retentive role of the Bayan-Nurin-hotnor basin in the circulation of water.

Investigations on the transport of suspended and dissolved material were performed by W. Froehlich and Ts. Sugar, their purpose being to establish the rate of contemporaneous denudation of the mountains in that climatic zone. During low water stages in the Tsagan-Turutuin-gol the removal of material at the base station was 2-4 g per m<sup>3</sup> while at that at the sub-base it was 8-12 g per m<sup>3</sup>. During the low water stages in the upper part of the Tsagan-Turutuin-gol supplied 123 kg of material per day while the high ones as many as 207, 765 kg of mineral material in the form of suspended matter. The detailed studies carried out in the Bayan-nurin-hotnor basin attempted at learning the role of permafrost in the formation of relief in the area in question.

Detailed investigations by Z. Babiński and J. Grześ (Report... 1974) aimed at learning the depth of occurrence and the mode and rate of permafrost degradation in the summertime. On the basis of 90 boreholes carried out during the research period they found that the top of the permafrost lay in that area at a depth of 0.5 to 4.2 m. The greatest summer degradation of permafrost was found beneath the river channels and basins of cave-in lakes. Considerable differences in the ground temperature on north- and south-facing slopes of those lakes, 10-15°C on the average and 30°C in extreme cases, were the cause of a quick thermokarst destruction of certain parts of the banks and of change in the position of the bank.

Investigations of W. Froehlich and K. Klimek (Report... 1974) conducted in the Bayan-nurin-hotnor basin attempted to explain the mechanism and the rate of erosion of river banks of the Tsagan-Turutuin-gol in circumstances of permafrost present. It was found that a factor influencing the rate of the erosion was the exposure of the banks and the course of the dynamic axis of the channel. Mineral material melted down from the banks is removed either in suspension or in the form of fine bed load. In dependence on the possibility and rate of removal there are revealed fresh portions of the frozen bank which under the action of sunshine or heat of flowing water are subject to further intense melting down. Due to the different height of the bank and the development of plant routage the banks vary in profile and liability to erosion. Observations of an alluvial plain have shown that in such climatic conditions with a relative insufficiency of water thermal erosion is the principal agent causing quick lateral migration of river channels.

Investigations of the "slope" team were concentrated in a dry valley of the Sant, some 3 sq.km in area. The valley reveals many transitional features between the steppe of the basins and foreststeppe and the Alpine belts of the mountains which results from its situation on the southern margin of the Khangay, remarkable height differences (2030-2712 m) and its parallel course. The homogeneous geological structure (granites) made it possible to study the causes of contrasts between the two opposite slopes. Investigations in 1974 were concentrated on working out a typology of the main elements of the geographical environment and on physical geographical processes there at work due to mapping on scale 1 : 10,000, cross-section studies (some 30 trial-pits and risers) as well as observations and measurements of the processes.

The foundations of the mapping were the surveying of cross-section and a plane-table survey of the valley on scale 1 : 10,000 carried out by R. Zapolski with the assistance of other participants of the expedition.

On the cross-sections and the map were located all the measurement sites

and, for chosen plots with installed recording devices, additional measurements were performed (Some of these will be repeated in the summer of 1975).

Studies in the evolution of relief as well as the geomorphological mapping carried out by L. Starkel with the assistance of S. Zhigzhe found a considerable contrast between steep and gently concave south facing slopes inclined predominantly at 40-50% and northern slopes with lesser inclination (20-35%) and slightly convex profiles. The reason for that asymmetry results already from a set of joint fissures, among which very common are those with a dip 50-60° S favouring denudation and abruptness of south-facing slopes. Cold periods with active permafrost on the southern slopes led also to their retreat due to debris avalanches. Material of those avalanches has strewn the valley bottom thus producing a step-like profile.

The northern slope undercut by them has gained convex profile being at the same time lowered at the ridge by cryogenic processes. The present-day patches of permafrost on the northern slope mantled with a compact cover of plants favour active solifluction. On the opposite dry slopes there took place washing away of covers and the deposition of material derived from there in the shape of colluvial filling in of hollows in the long profile of the slope.

Investigations of the soil cover were carried out by A. Kowalkowski with the aid of R. Lomborintchen (Report... 1974). Their aim was to become acquainted with and to determine particular genetic units of the soils as well as the relationships between their toposequence and soil mosaics on height above sea level, exposure, geological structure and morphogenetic processes in addition



Fig. 8. South slope of Sant Valley (Photo by L. Starkel)

to the relationship between present-day plant communities and soil types. Other subjects of investigation were water properties and physical-chemical characteristic of these soils. It was found that a feature of the dry Sant valley is its transitional character between the zone of dry steppe with chestnut soils and the forest-steppe with chestnut, brown forest and chernozem like soils. On slopes with permafrost processes of intense mechanical weathering occur (granite grits). On north-facing slopes and those with similar exposure there were brown forest and dark chestnut soils developed on solifluction covers (with permafrost present). On south-facing slopes light-chestnut, strongly stony and, often degraded para-rendzinas prevail. In the valley-floor on debris sludge-deposits there occur stony soils while on humus delluvia steppe (*chernozems*) are found. On the patches of shallow-lying permafrost meadow peat soils are developed. The spatial distribution of those soils was shown on maps of soil types, on scale 1 : 10,000.

Investigations of present-day morphogenetic processes conducted by K. Pękala consisted in observations of weathering processes and of rock-waste. The effects of frost weathering were recorded by means of traps installed at the foot of rock-walls. It was found that exfoliation and microgelivation are the principal processes at work in that vertical zone. Macrogelivation occurs only above 2500 m. Therefore in the higher portions of the mountains edges of rocks are angular. In the rock-waste three phases of intense frost weathering and of transport were recorded. The effects of waste-mantle washing down were measured with the use of rods. After the July precipitation it was found that the mean lowering of the ground surface upon the turfed clayey debris hillside was 0.95 mm while on the granular waste-mantle it was 0.34 mm. The intensity of eolian processes was studied with the use of three experimental deflation meters. The creeping of waste-mantle was recorded by special rods and pegs. It was found after a month that the displacement measured on the north-sloping afforested hillside was 1–2 cm, while that on the same slope but above the tree-line amounted to 2–12 cm. Measurements of the movement of solifluction lobes caused by frost thawing as well as of creeping of large blocks and the development of polygonal fissures were also performed. K. Pękala, at the same time carried out also comparative studies of frost processes in the higher belts of the Khangay.

Research into the elements of water circulation was performed by J. Słupik. It consisted of measurements of precipitation, infiltration, and surface down-flow. These investigations were supplemented by records of extreme temperatures on the ridge and opposite slopes of the Sant valley (B. Avirmid, T. Niedźwiedz) and by measurements of precipitation at 6 sites situated on different levels. In all, it was found that precipitation increase with altitude.

Measurements of water infiltration by means of the Burger cylinder (J. Słupik, R. Lomborintchen) showed that the highest values occurred on stony slopes (from 1.1 to 3.8 mm per min. on the surface to 78.6 mm per min. at a depth of 20 cm) while the smallest ones were found in the valley-floor (0.8–0.9 mm per min.). During the highest daily precipitation of some 20 mm, the surface down-flow as measured at 15 sites was inconsiderable (1.3–6.5 liters in a belt some 75 cm wide). It was only on rock surfaces that it amounted to a few hundred liters (up to 23 mm water layer).

Investigations of plant communities carried out by A. Pacyna consisted, in the first stage, in gathering and marking genera and species of plants and in phytosociological survey. The presence of larch forests on north-facing slopes of the Sant valley reveals a clear dependence on microclimatic conditions and on the occurrence of multi-annual permafrost. The age structure of the trees



points to the influence of the intensity of animal husbandry on changes in the spatial extent of forest communities.

The Khangay represents a mountain massif poorly known regarding its physical geographical characteristics. Few permanent hydrologic and meteorological stations are installed on its edge. Therefore the study of only certain elements of the geographical environment and, especially of physical geographical processes in its interior without the simultaneous acquaintance with other elements of this environment will meet within failure. It seems that in so poorly known a region as thus, only a complex analysis of a great number of the elements of the geographical environment can produce a reliable basis for more precise studies of geomorphological climatic, hydrologic, pedological and vegetation problems. The expedition continued their work in 1975.

The preliminary results of the studies carried out also prove that in order to learn the mechanism of contemporaneous processes and the tendencies of changes in the geographical environment it is essential to consider also the transformations of this environment in the past.

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### REFERENCES

- Baulin, V. V., Dubikov, G. J., Uvarin, J. T., 1973, Osnovnye cherty stroyeniya i razvitya vechnomerzlykh tolshch Zapadno-Sibirskoy Ravniny (Outline of structure and evolution of the frozen ground in Western Siberia Plain), *Papers II Intern. Confer. Permafrost*, 2, Yakutsk, 10-17.
- Fillipova, I. B., Zonenstein, L. P., Amantov, V. A., Michailov, E. V., 1973, Mongolo-Zabaikalskaya skladchataya system (Mongol-Transbaikial folded system), in: *Geology of Mongol. Peoples' Rep.*, Ed. Marinov, Moscow, 590-609.
- Granö, J. G., 1910, Beiträge zur Kenntnis der Eiszeit in der Nordwestlichen Mongolei und einigen ihren Sibirischen Grenzgebirgen, *Fennia*, 28.
- Gravis, G. F., 1974, Geograficheskoye razprostraneniye o moshchnost mnogoletnykh gornykh porod (Geographic extent and thickness of permafrost), in: *Geocryological conditions Mongol. Peoples' Rep.*, *Soviet-Mongol. Scient. Res. Geol. Exped.*, 10, Moscow, 30-48.
- Gravis, G. F., Lisun, A. M., 1974, Ritmostratigrafia chetvertichnykh otlozhenii Mongolii po palinologicheskim danym i istoria razvitya mnogoletnyemyerzlykh gornykh porod (Rhythmic stratigraphy of Quaternary deposits in Mongolia by palynologic data and history of permafrost evolution), in: *Geocryological conditions Mongol. Peoples' Rep.*, *Soviet-Mongol. Scient. Res. Geol. Exped.*, 10, Moscow, 148-186.

- Haase, G. H., Richter, H., Barthel, H., 1964, Zum Problem landschaftsökologischer Gliederung dargestellt am Beispiel Changai-Gebirges in der Mongolischer Volksrepublik, *Wiss. Veröff. Dtsch. Inst. Länderk.*, 21/22, Leipzig, 489-516.
- Kuznetsov, N. T., 1968, *Vody Centralnoy Azii* (Waters of Central Asia), Moskva.
- Murzayev, E. M., 1952, *Mongolskaya Narodnaya Respublika* (Mongolian Peoples' Republic), Moskva.
- Report of the Mongolian-Polish Physical-Geographical Expedition to the Khangay Mts.*, 1974 (typescript).
- Ravskii, E. Y., 1972, *Osadkonakopleniye i klimaty vnutriyennoy Azii v Antropogenye* (Precipitation and climate of Central Asia during Quaternary), Acad. Sci. USSR, Geol. Inst., Moskva.
- Selivanov, E. J., 1972, *Neotektonika i geomorfologia Mongolskoy Narodnoy Respubliki* (Neotectonics and geomorphology of the Mongolian Peoples' Republic), Moskva.
- Tsegmid, Sh., 1969, *Mongol orny fizik gazar zui* (in Mongolian), Ulhan Bator.

## CLIMATOLOGICAL CRITERIA FOR THE EVALUATION OF SNOW CONDITIONS FOR THE PURPOSE OF RECREATION AND WINTER SPORTS, WITH SOUTH-EASTERN POLAND AS AN EXAMPLE

EDWARD MICHNA and STANISŁAW PACZOS

### GENERAL REMARKS

Climatological literature covers a significant number of papers dealing with the snow cover, the depth of snow, and duration, its effect on soil and plant climate or on the selected branches of economy (e.g. land transport). More rarely, even sporadically, works on nival conditions used for the estimation of periods and areas particularly suitable for recreation and winter sports are appearing. The works consider the problem of nival conditions for the common use of recreation and not for organized sports purposes (Leszczycki 1931; Michna and Paczos 1971; 1972).

Recently much attention has been paid to the importance of an active holiday during the winter. Exceptionally favourable bioclimatic conditions which are related to the snow cover occurrence are used for skiing and sledging. Since the snow cover increases the participation of ultra-violet waves, it effectively raises the brightness and intensity of solar radiation activity, and also purifies the lower troposphere from infectious bacteria.

Aside from the character of local atmospheric circulation and thermic conditions, the formation of the snow cover, the depth of snow, and duration depend also, to a great extent, on the topographic and microclimatic conditions (Kosiba 1949; Michna and Paczos 1972).

Characteristic to south-eastern Poland are: significant hypsometric differentiation, great variability of land configuration and spatial variability of the ground. As a whole these factors create the conditions for a great variability of the snow cover duration, formation and disappearance.

Snow cover studies are much more complex than the evaluation of other climatological elements. This follows from the distribution peculiarity of the meteorological stations providing the measuring data. The majority of stations are located in the valleys and depressions, sometimes on densely built up sites. Hence snow measurements and particularly snow depth measurements give ground to the fear that due to the blowing and compression process they are deformed. In addition the number of meteorological stations located in the highest regions of south-eastern Poland (Roztocze and the West Bieszczady Mts.) is decidedly too small. Also the cartographical maps, illustrating the depth of the snow cover and its persistence are less than precise.

The main purpose of our considerations is to indicate the essential criteria for the estimation of snow conditions by means of a statistical and cartographical approach, which enable the elaboration of a nival-evaluation map. The defining of the correlative dependence between some (basic) characteristics of the snow cover and the height a.s.l., latitude and longitude, and the illustration



of these dependencies in a graphic way or in the form of function, will enable the easy and fast calculation of the mean values of these characteristics for randomly selected locality in south-eastern Poland.

#### SOURCES DATA AND PROCESSING METHODS

The primary materials were the measuring data covering the period 1950-1970 for 184 meteorological stations belonging to the Institute of Meteorology and Water Management (IMWM). The material published in the Meteorological Yearbooks and manuscripts from the archives of the IMWM in Warsaw was used<sup>1</sup>. The choice of the measuring period was not an accidental one. It resulted from the fact that the collection of data on snow precipitation from the greatest possible number of observation posts, which were simultaneously uniformly distributed in the area of south-eastern Poland, was necessary.

No data were considered from the decade 1941-1950, since significant gaps in the records were observed in this period, in which the number of meteorological stations was also smaller.

It is worthwhile adding that not all 184 meteorological stations which were considered in the paper were in the possession of the full measuring data covering the twenty-year period. In a number of stations (27) regular records were started as late as in 1954-1955. In several cases (9) data from the stations that had measuring data covering the period of 10 to 14 years, and in one case a 9-year period only (Ustrzyki Górne) were taken into account. To get full comparability of data the numbers relating to shorter periods were reduced to the basic period, i.e., 20 years. Slight, usually just a few-days, observational gaps were supplemented by the interpolation methods based on data from measuring posts located close by, at the sites of similar topography.

In the present paper the correlative relationships and regression equations for individual characteristics of the snow cover were calculated. Based on the method of least squares, due to which the equation for the functional dependence was defined the interdependences were evaluated between:

- (1) number of days with snow cover and the height a.s.l.,
- (2) number of days with snow cover and the height a.s.l., latitude and longitude (jointly),
- (3) number of days with a snow cover of 20 cm and the height a.s.l.,
- (4) number of days with a snow cover of 20 cm and the height a.s.l., latitude and longitude (jointly),
- (5) number of days with a snow cover of 20 cm and the total number of days with snow cover,
- (6) maximum depth of snow cover and the height a.s.l., latitude and longitude (jointly).

Correlation coefficients and regression equations were calculated on the electronic computer "Odra 1204" in the Department of Numerical Methods at the Marie Curie-Skłodowska University, Lublin.

#### FREQUENCY AND DISTRIBUTION OF DAYS WITH SNOW PRECIPITATION

After L. Bartnicki and Z. Wierzbicki (1962) snow precipitation in Poland ranges from 10 to 12% of the yearly mean of precipitation. The yearly mean number of days with snow precipitation varied in the investigated area from 40 in the Lublin Plateau to 60 in the Lower Beskid Mts. and in the Western

<sup>1</sup> Following the recommendation of the World Meteorological Organization in working out data on the snow cover for 1950-1970 the period from August 1st to July 31st was adopted as the winter.

Bieszczady Mts. On average the first snow precipitation was recorded at the earliest (as early as in the second half of October) in the area of the Bieszczady Mts. and the latest, in the last 10 days of November (in the Lublin Plateau and on the Tarnobrzeg Plain). From the analysis of the low atmosphere synoptic charts it appears that the first snow precipitation in the investigated area usually occurs at the inflow of the cool air from the North or North-East. The masses, rising to the windward side of the Świętokrzyskie Mts. and Roztocze, are cooled adiabatically, bringing onto the hills precipitation in the form of snow. Falling towards the Sandomierz Basin the air warms up dynamically; if such conditions cause simultaneously precipitation, it probably occurs in the form of snow or rainfall. To support the above assumption we observe that the area contained in the junction of the Vistula and the San river, to which from the north-through the Vistula river bed without obstacles the inflow of cool air, brings the occurrence of the first snow precipitation several days later, than on the Tarnobrzeg or Biłgoraj Plain. In spring the last precipitation occurred at the earliest data in the Lublin Region, on an average in the first 10 days of April, but in the Carpathian Foothills and the Roztocze Region, toward the end of the second 10 days of April. The latest snow precipitation to be recorded was in the third 10 days of April (on an average) in the Lower Beskid Mts. and in the Bieszczady Mts.

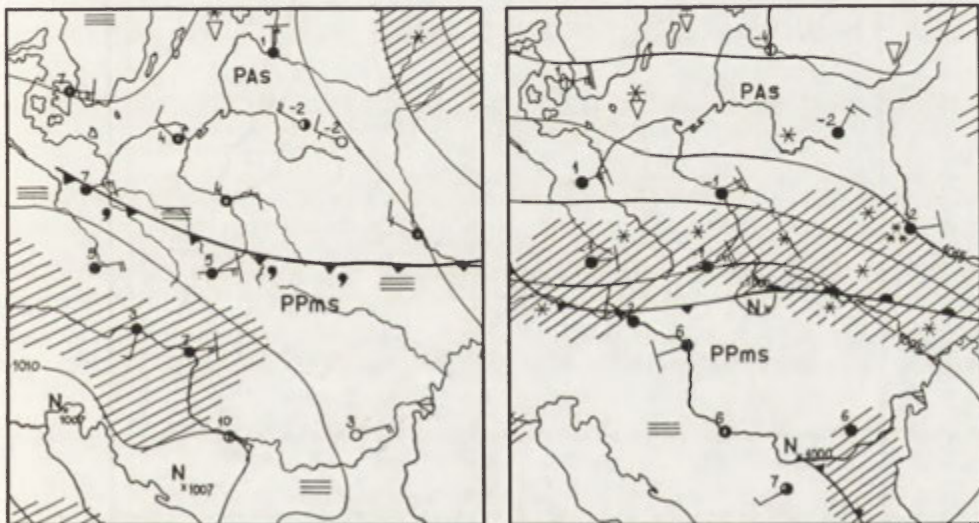


Fig. 1. Synoptic condition in Middle Europe on the days 11-12 November 1965 at 01 GMT (a section of synoptic chart issued by the Hydrological and Meteorological Institute)

#### SNOW COVER ON THE AREA OF SOUTH-EASTERN POLAND

The appearance of the snow cover in south-eastern Poland is observed on an average between the third 10 days of November and the first 10 days of December, but on an area of over 600 m a.s.l. it forms as early as in the second 10 days of November. The snow cover formed during these periods is usually temporary and disappears in a few days. The consolidated snow cover, that is that which persists for seven and more days appears on an average in the second half of December, but in the Roztocze Region, in the Lower Beskid Mts.,

in the Świętokrzyskie Mts. and the Bieszczady Mts. and on the windward afforested slopes it is recorded as early as in the first half of December.

The end of the snow cover in the northern regions of south-eastern Poland occurs on an average in the first half of March, and in the southern, highest parts of the investigated area, towards the end of the third 10 days of March. From the measuring data it follows that the potential period of consolidated snow cover persistence in the north part of the Lublin Plateau amounts to c. 85 days (from 15 December to 10 March) but in the Lower Beskid Mts. and in the Bieszczady Mts. c. 105 days (from 5 December to 20 March).

Following data from the period 1950–1970 the mean yearly number of days with snow cover amounted from c. 70 days in the north-western parts of the Lublin voivodship to 90 days in the Roztocze Region, and over 100 days in the Świętokrzyskie Mts., Lower Beskid Mts. and low parts of the Bieszczady Mts.

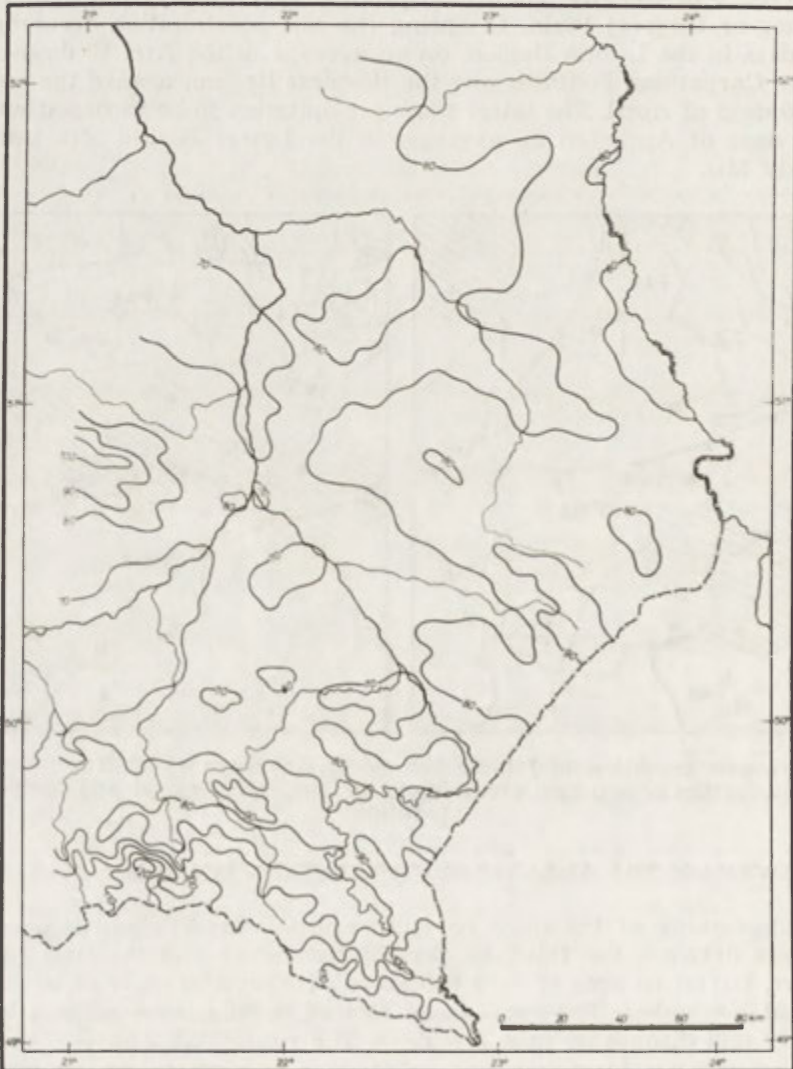


Fig. 2. Mean number of days with snow cover (in winter) in south-eastern Poland  
<http://rcin.org.pl>



From the measuring data and the appropriate recounting of the respective equations it is found that the mean number of these days in the Higher Bieszczady Mts. ranges from 120 to 160 (Fig. 2).

In the discussed twenty-year period there were winters, in which the snow layer persisted for extremely long periods, while in other winters it did not remain long. The variability could well be illustrated by the measuring data from two winters in Lublin. During the winter of 1963/1964 119 days with snow cover which is nearly 200% of the mean from the twenty-year period, were recorded, but during the winter of 1960/1961 only 36 days with snow cover which is c. 55% of the mean value from the observed period. Similar examples could be listed too, for numerous other localities situated in various regions of south-eastern Poland. Such significant discrepancies in the nival conditions of individual winters during the period of 1950-1970 are no doubt the result of a considerable variability in the frequency of inflow and persistence of indivi-

TABLE 1. Mean number of days with snow cover (in winter) and maximum depth of the snow cover against the height a.s.l. according to definite intervals

Height interval	Mean station height	Number of stations	Number of days with snow cover		Maximum snow cover depth
			total	≥ 20 cm	
101-150	138	10	78.0	12.7	53
151-200	175	58	75.3	13.4	50
201-250	221	54	77.0	18.3	58
251-300	278	25	81.5	24.5	68
301-350	322	8	79.4	22.5	73
351-400	377	5	90.7	35.1	85
401-450	427	9	91.9	36.6	91
451-500	473	4	96.5	45.9	96
501-550	527	5	105.4	54.4	102
551-600	576	3	109.6	64.3	113
601-650	633	2	108.1	50.3	114
651-700	700	1	111.8	61.2	139

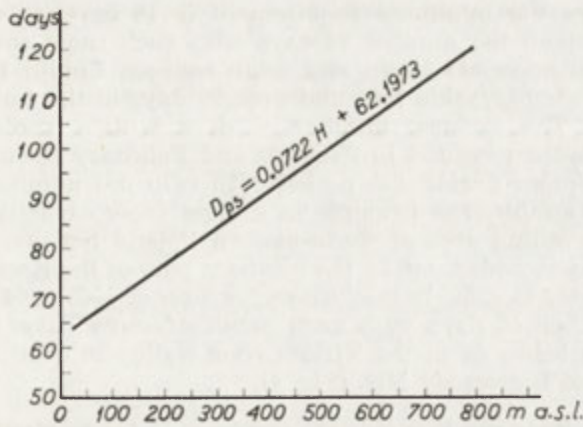


Fig. 3. Dependence between mean number of days with snow cover (in winter) and the height a.s.l.

dual air masses and the relevant thermic regime. Frequent inflow of polar air masses from the sea, which brings an air temperature rise and thawing is the main cause of the short period of the snow cover.

The number of days with snow cover depends not only on the height a.s.l. but also on the exposure and the kind of vegetation the investigated area is covered with, and the local atmospheric circulation. Dispersion of the points illustrating the dependence between the number of days with snow cover and the height a.s.l. has proved the significance of the other factors effect (Table 1). This dependence has the character of a linear function. The linear relationship between the number of days with snow cover and the height above sea level (Fig. 3) was found earlier, among others by the following authors: K. Chomicz (1953), M. Hess (1965, 1968), A. Kosiba (1949), E. Michna and S. Paczos (1971, 1972). The linear regression equation presenting the height function mean number of days with snow cover in south-eastern Poland takes the shape:

$$D_{ps} = 0.722H + 62.1973r = 0.8039$$

where:  $D_{ps}$  — number of days with snow cover (in winter),

$H$  — height of a defined point a.s.l. in metres,

$r$  — correlation coefficient.

In our opinion the use of this equation provides good results in the estimation of the number of days with snow layer. Solely the height a.s.l. of the locality the calculations are made for is necessary. A more precise dependence ( $r = 0.8829$ ) was obtained after the introduction to the equation of two other parameters, that is latitude and longitude:

$$D_{ps} = 0.1004H + 5.4902\varphi + 2.510\lambda - 271.8946$$

where:  $D_{ps}$  — number of days with snow layer,

$H$  — heights in metres a.s.l.,

$\varphi$  — latitude <sup>2</sup>,

$\lambda$  — longitude <sup>3</sup>.

For the stipulated and recommended expansion of tourism and winter sports more attention should be paid to the measurements and evaluation of the depth of snow cover. On the knowledge of this characteristics depends to a great extent the evaluation of individual regions suitability for the purpose of winter recreation. If the criterion, that adequate conditions for sledging and skiing exist already at a snow cover  $\geq 20$  cm is assumed (M. Hess 1965) — in selected countries the minimum requirement is 15 cm — it appears that in south-eastern Poland the number of days with such snow cover varies from 10 days in the Sandomierz Basin and south-western Lublin Plateau to over 50 days in the Świętokrzyskie Mts. and over 70 days in the Lower Beskid and Bieszczady Mts. The greatest number of days with a snow cover of the depth  $\geq 20$  cm were recorded in January and February (from 2 to 23 days). In individual winters during the period 1950–1970 the number of these days was extremely variable. For example in a “low snow capacity winter”, 1956/1957, in the prevailing area of south-eastern Poland not one day with such a snow depth was recorded, but in the southern part of the Rzeszów voivodship such days amounted to c. 50. In the “snowy” winter of 1963/1964 the differentiation of the number of days with such depth of snow cover was extremely significant, from below 10 in the Vistula river valley to over 120 days in the Lower Beskid and Bieszczady Mts. (Fig. 4).

<sup>2</sup> Minutes of latitude and longitude are expressed in the hundreth parts of a unit (for instance  $13' = 0.22$ ).

<sup>3</sup> Cf. footnote 2.

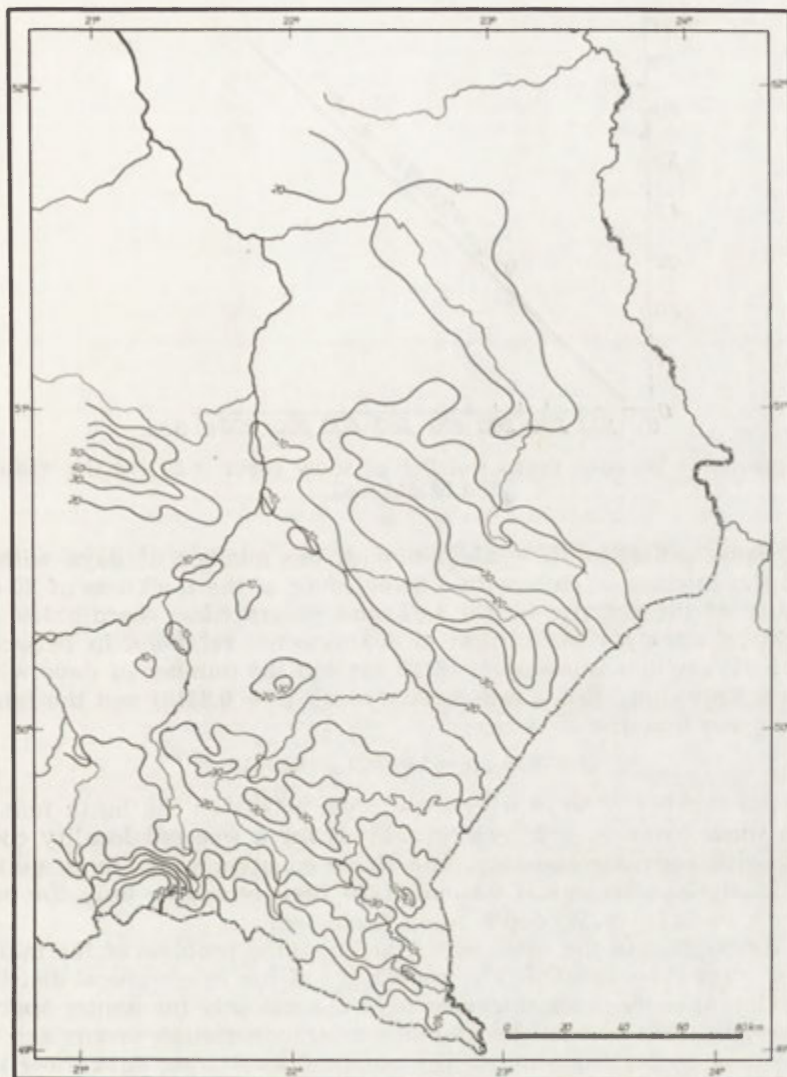


Fig. 4. Mean number of days with snow cover  $> 20$  cm (in winter) in south-eastern Poland

The dependence of the number of days with a snow cover of the thickness  $\geq 20$  cm, and the height a.s.l. (Fig. 5) has proved to be essential ( $r = 0.8821$ ). The formula presenting this dependence in the linear function is:

$$D_{ps} \geq 20 \text{ cm} = 0.1019H - 4.2387$$

where:  $D_{ps} \geq 20$  cm — number of days with snow cover of the thickness amounting to at least 20 cm (in winter),  $H$  — height in metres a.s.l.

Also the dependence between the number of these days and the height a.s.l., latitude and longitude were evaluated. It was proved that the correlation coefficient is high ( $r = 0.8851$ ), and the equation takes the following form:

$$D_{ps} \geq 20 \text{ cm} = 0.1081H + 1.1092\varphi + 0.8336\lambda - 64.5538$$



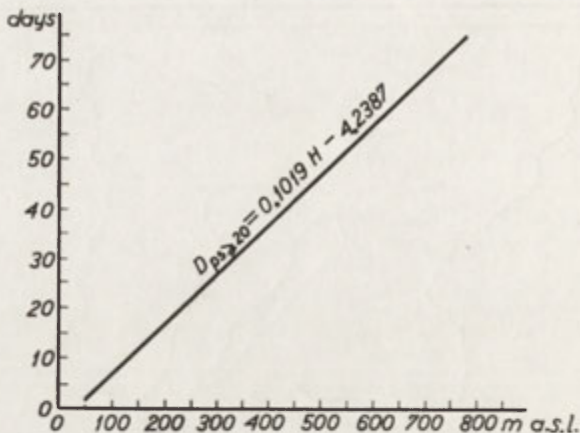


Fig. 5. Dependence between mean number of snow cover  $\geq 20$  cm (in winter) and the height a.s.l.

These equations allow the calculation of the number of days with snow cover and the number of days with a snow cover of the thickness of 20 cm for each locality of the definite height a.s.l. and geographical coordinates.

In addition attempts were made to evaluate the relationship between the number of days with a snow cover of 20 cm and the number of days with any snow cover. This study had a satisfactory result ( $r = 0.8318$ ) and the following dependence was found:

$$D_{ps} \geq 20 \text{ cm} = 1.0708 D_{ps} - 64.5538$$

When the number of days with snow cover is known the mean number of days with snow cover of  $\geq 20$  cm (in winter) for a selected locality could be calculated with adequate accuracy. The above equation seems to be quite useful, since many meteorological stations have been recording only the number of days with snow layer, its depth being neglected.

In the description of the snow cover thickness the problem of the maximum snow depth cannot be omitted. The knowledge of the geographical distribution of the maximum snow cover thickness is of use not only for winter sports and tourism purposes but also in the planning of transportation means and in the development of recreation centres. The obtained measuring data show that in south-eastern Poland on the areas located higher than 500 m a.s.l. The snow layer depth may reach 150 cm (the Lower Beskid and the Bieszczady Mts.), but in the other regions of the same area (including the Sandomierz Basin) in the analogical period it does not exceed 40 cm<sup>4</sup> (Fig. 6).

The analysis of the interdependence of the maximum snow cover depth and the height a.s.l. has revealed the importance of this interdependence ( $r = 0.8580$ ). The equation is:

$$D_{\max} = 0.1516H + 24.6242$$

where:  $D_{\max}$  — maximum snow cover depth in cm  
 $H$  — height in metres a.s.l.

<sup>4</sup> Since for the areas over 700 m a.s.l. the measuring data are lacking it may be assumed that the maximum snow cover depth in higher parts of the Lower Beskid and Bieszczady Mts. will be slightly higher than the ones submitted in the paper.

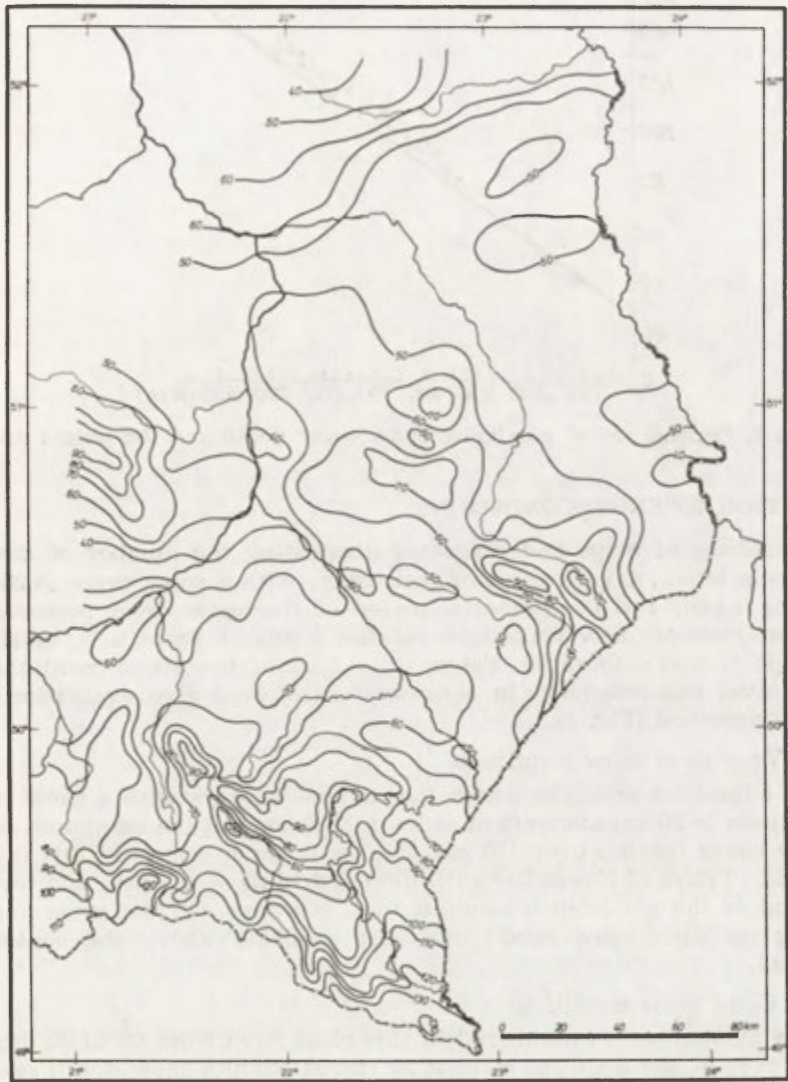


Fig. 6. Maximum depth of snow cover in south-eastern Poland

The equation allows the calculation of the maximum snow cover depth for each optional point of a defined height a.s.l. (Fig. 7).

An attempt to estimate the correlation between the maximum snow cover depth and the height a.s.l., latitude and longitude has proved the substantial relationship between these parameters. The correlation coefficient is slightly higher than in the case when the interdependence of the maximum snow cover depth and the height a.s.l. is defined, and, amounts to 0.8582. The equation which enables us to culculate the maximum snow cover thickness for a randomly selected locality is as follows:

$$D_{\max} = 0.1481H - 0.7024\varphi - 0.2214\lambda + 65.8587$$

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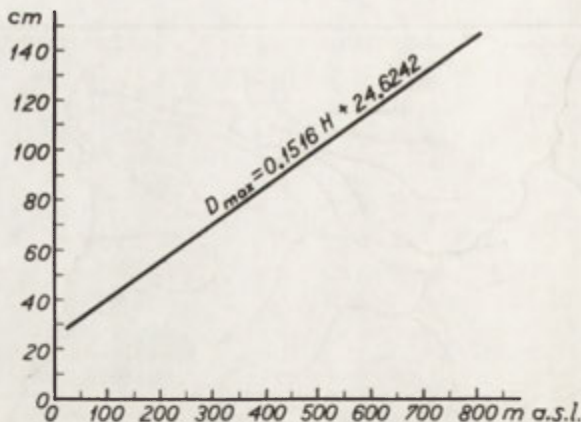


Fig. 7. Dependence of maximum snow cover depth and the height a.s.l.

### EVALUATION OF SNOW CONDITIONS

On the base of maps and diagrams illustrating the number of days with snow precipitation, days with snow cover days with a snow cover  $\geq 20$  cm, its maximum depth, and the potential period of the snow cover persistence, an evaluation map of snow conditions for the needs of recreation, tourism and winter sports was elaborated. Taking into account the above mentioned substantial nival characteristics in south-eastern Poland five evaluation classes were distinguished (Fig. 8).

#### *Class I: Very good snow conditions*

Class I includes areas, in which the number of days with a snow cover of the thickness  $\geq 20$  cm amounts to at least 90 days, and the maximum depth of the snow cover reaches over 150 cm. The snow cover occurs in this case from the second 10 days of November until the third 10 days of April, and the potential period of the persistence amounts to c. 160 days. On the areas numbered in this class such snow conditions exist probably above the contour line 900 m a.s.l.

#### *Class II: Good snow conditions*

On an average areas numbered in this class have from 60 to 90 days with a snow cover of the depth of at least 20 cm. Maximum snow depth reaches in these areas from 120 to 150 cm. The snow cover occurs during the break of the second and third 10 days of November and lasts till the second 10 days of April. The potential period amounts to c. 150 days. In this class were numbered the Higher and Lower Bieszczady Mts. and the Lower Beskid Mts. (550–900 m a.s.l.).

#### *Class III: Average snow conditions*

To this class areas located of the height from 300 to 550 m a.s.l. were numbered. These are the lower parts of the Bieszczady Mts., the Lower Beskid Mts., the Świętokrzyskie Mts., and the Dynów and Przemyśl Foothills. In the area of the Roztocze and Tarnogród Plain such snow conditions were observed already at a height of above 200 m a.s.l. The number of days with snow cover of the depth of at least 20 cm is from 30 to 60, and the maximum thickness may reach 100 cm. The snow layer persists here from the third 10 days of November to the first 10 days of April, and the potential period of its duration is c. 140 days.



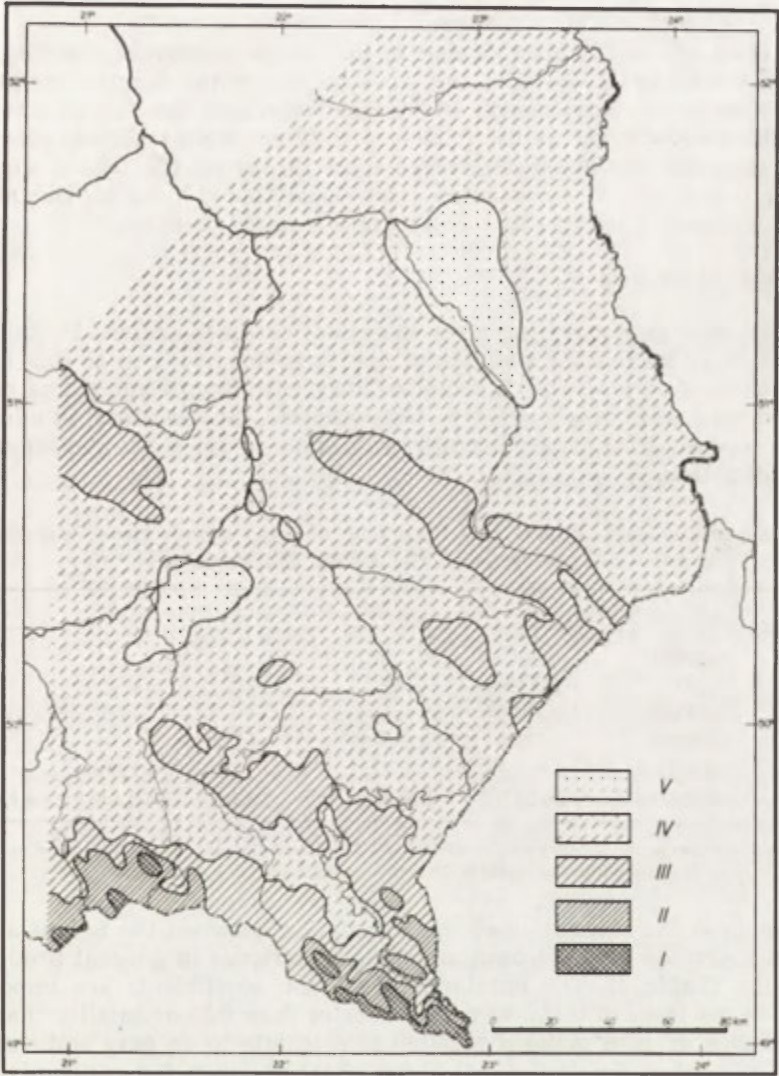


Fig. 8. Evaluation of snow conditions for skiing, tourism and winter sports purposes in south-eastern Poland (I — very good, II — good, III — average, IV — poor, V — very poor snow conditions)

*Class IV: Poor snow conditions*

The areas included in this class have a number of days with a snow cover of the depth of at least 20 cm (on an average) from 10 to 30 during winter time. In most cases the maximum snow cover depth does not exceed 60 cm. The snow layer appears in the first 10 days of December and disappears in the third 10 days of March. The potential period of its duration amounts to c. 120 days. This class covers almost the whole of the Lublin voivodship except for the Roztocze, Tarnogród Plain and Łęczna Lake area, the eastern part of the Kielce voivodship, except for the Świętokrzyskie Mts., the prevailing part of the Sandomierz Basin, Kolbuszowa Upland, Ciężkowice Foothills and the Jasło-Sanok Basin.

### Class V: Very poor snow conditions

This class covers the area located in the middle section of the Wieprz river including the Łęczna Lake area, the western part of the Sandomierz Basin and the small enclaves at the mouth of the San river, and the Vistula river valley. Days with a snow cover of the thickness  $\geq 20$  cm were recorded sporadically: in total they did not amount to more than 10 during the whole winter. The potential period of the snow cover occurrence is c. 100 days. The maximum depth of the snow cover on this area ranges from 30 to 40 cm.

### FINAL REMARKS

This attempt at elaborating a classification for south-eastern Poland in view of the needs of recreation and winter sports is the first one of this type. The results obtained do not bring a complete answer to the questions and postulates presented by a wide group of users. Nevertheless, they indicate, in our opinion, the most essential criteria for the evaluation of the snow conditions in the investigated area.

TABLE 2. Correlation coefficients between the number of days with snow cover, its maximum depth and the height a.s.l., latitude and longitude

	1	2	3	4	5	6
1	+1.0000					
2	-0.7075	+1.0000				
3	-0.2043	+0.3630	+1.0000			
4	+0.8040	-0.3345	+0.0799	+1.0000		
5	+0.8821	-0.5826	-0.1213	+0.8319	+1.0000	
6	+0.8580	-0.6217	-0.1888	+0.7017	+0.8442	+1.0000

Explanations: 1 — height a.s.l., 2 — latitude, 3 — longitude, 4 — number of days with snow cover, 5 — number of days with snow cover  $\geq 20$  cm, 6 — maximum snow cover depth

Attempts at the estimation of the correlation between the height a.s.l., latitude and longitude and the basic nival characteristics in general brought positive results (Table 2). The obtained correlation coefficients are important as early as on the level of 0.1% at values greater than 0.30 or smaller than -0.30. The equations derived make it possible to calculate in an easy and simple way means (for winter) on individual snow characteristics for randomly selected localities, if the height a.s.l. is known. For the receipt of more precise data it would be advisable (in some cases) to know the latitude and longitude values.

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### REFERENCES

- Bartnicki, L., Wierzbicki, Z., 1962, *Udział opadów stałych w ogólnej sumie opadów w Polsce* (Sum.: The share of precipitation in solid shape in the general total of precipitation), Prace PIHM, 66.  
Chomicz, K., 1953, O pokrywie śnieżnej w Karpatach (La couverture de neige dans les Carpathes), *Przegl. Meteor. Hydrol.*, 6.

- Hess, M., 1965, *Piętra klimatyczne w Polskich Karpatach Zachodnich* (Sum.: Vertical climatic zones in the Polish Western Carpathians), Zesz. Nauk. UJ, Prace Geogr., 11.
- Hess, M., 1968, *Metoda określania ilościowego zróżnicowania mezoklimatycznego w terenach górskich* (Sum.: A new method of quantitative determination of the mesoclimatic differentiation in mountain areas), Zesz. Nauk. UJ, Prace Geogr., 18.
- Kosiba, A., 1949, *Częstość szaty śnieżnej na ziemiach Śląskich* (Frequency of snow cover in Silesia), Prace Wrocł. Tow. Nauk., Ser. B, 21.
- Leszczycki, S., 1931, *Współczesny stan badań niwalnych w Polsce* (Les travaux contemporaines sur la nivologie en Pologne), *Wiad. Geogr.*, 9, Kraków.
- Michna, E., Paczos, S., 1971, *O warunkach śniegowych Roztocza w świetle potrzeb turystyki i sportów zimowych* (Sum.: Die Schneeverhältnisse von Roztocze in Hinsicht auf Touristik und Wintersport), *Fol. Soc. Sci. Lublin.*, 12.
- Michna, E., Paczos, S., 1972, *Zarys klimatu Bieszczadów Zachodnich* (An outline of the climate of Western Bieszczady Mts.), Ossolineum, Wrocław.
- Schulz, L., 1965, *Über die Ursachen von schneereichen und schneearmen Winter im Harz*, *Meteor. Rund.*, 18.





## THE EFFECT OF THE RESERVOIR NEAR WŁOCŁAWEK ON THE GEOGRAPHICAL ENVIRONMENT

JAN SZUPRYCZYŃSKI

The planning of the river control of the lower sector of the Vistula was finalized at the beginning of the nineteen-sixties. This sector which is 431 km long, is called the Lower Vistula despite the fact that part of it belongs to the middle sector of the river. The plan takes into consideration the "canalization" of the Vistula from Warsaw to its mouth. This sector concentrates about 30% of the stock or resources of energy in this country and 65% of the aquatic resources of the Vistula. The plan foresees the building of nine dams with waterfalls along the Lower Vistula which are to be built near the following localities: Warszawa, Wyszogród, Płock, Włocławek, Ciechocinek, Solec Kujawski, Chełmno, Nowe and Tczew. The following aspects have been taken into consideration in choosing the locations of the dams:

- (I) To keep a free water way for transport.
- (II) To take advantage of the Vistula waters for the irrigation of fields in the neighbourhood and for the production of electrical energy.
- (III) To protect the neighbouring areas from flooding.
- (IV) To use the dams for bridging the river.
- (V) To use the reorganized sector for tourist and recreational purposes.

From this outlined plan there materialized one dam reservoir in the neighbourhood of Włocławek. It was erected during the years 1963 to 1969. It is the largest investment, in the line of reservoirs in Peoples Poland. The cost amounted to 2.1 milliard złoty. Two thousand people worked on the site at the peak of the working activity. 12 million m<sup>3</sup> ground was shifted and 380 thousand m<sup>3</sup> of concrete used. The expenses for this investment would have been amortised within six years providing the hydro-electric works had been able to function at full speed.

The erection of the Włocławek dam changed the landscape of the Lower Vistula in a radical way. Above the dam there came into being the largest reservoir in Poland. At its longest it is 58 km and its mean width is 1.2 km. Its area involves 70.4 km<sup>2</sup>. 70% of it covers the former bed of the Vistula within the reach of high water, i.e., the terrains which were not cultivated for farming. The remaining 30% of the reservoir involves former cultivated soil. The total of the flooded area amounts to 2,165.4 ha of land. Over 50% of the flooded land consisted of cultivated soil. The quality of the land for farming was not very high. It was mostly light soil upon a sandy and clayey substrata belonging mainly to the fifth and sixth soil class. In this area 186 farms and cottages have been expropriated, of which 146 stood on the territory of the Bydgoszcz voivodship and 40 on the Warsaw voivodship.

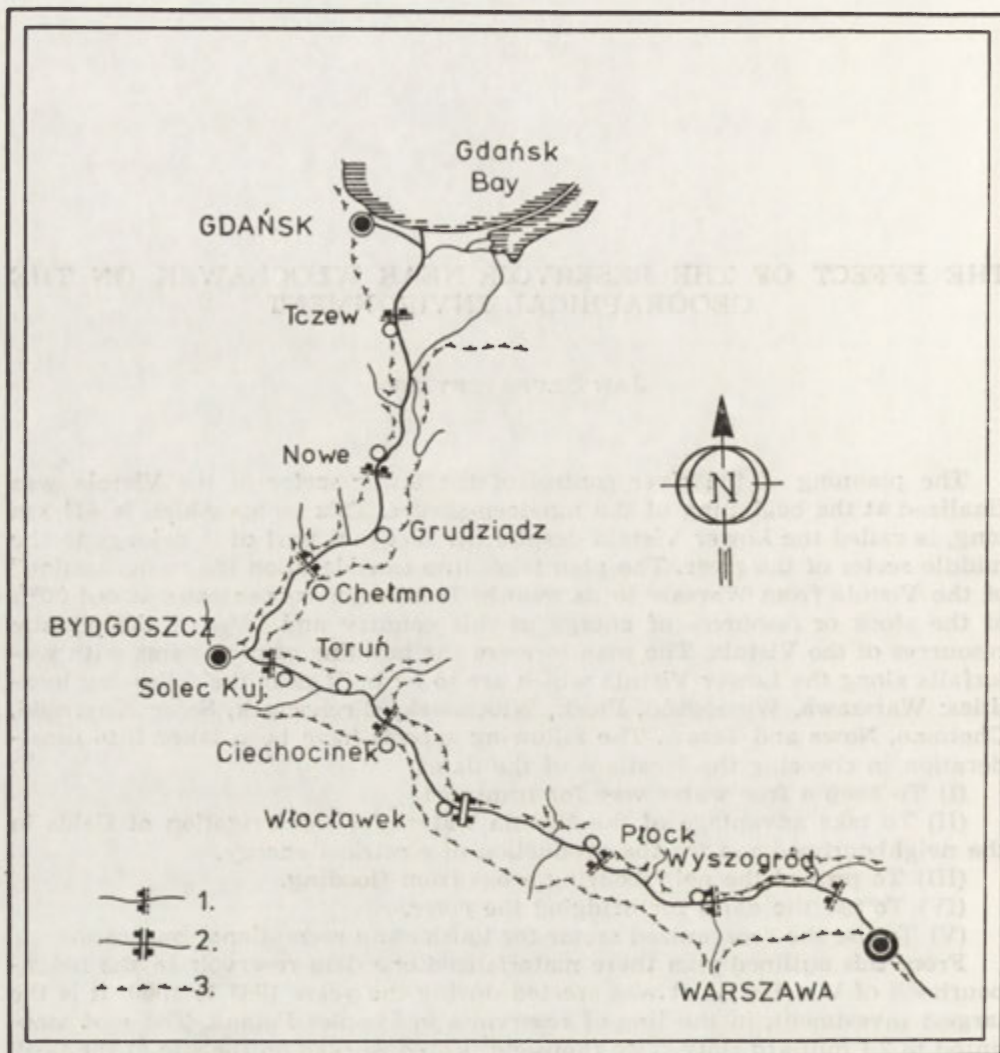


Fig. 1. Scheme of a plan of regulating the Vistula river  
1 — projected steps; 2 — existing step; 3 — edges of the valley

The dam of Włocławek consists of the following objects counted from the left banks: a sluice gate 14 m wide for 1000 t barges, a channel for fish, a power house with six turbines of 160 MW strength, a relief dam with 10 bays 20 m wide and the head or frontal dam having a length of 626 m.

The electric works at Włocławek, the largest of this type in Poland will not reach full productive strength until the erection of the equalizing dam at Ciechocinek. Owing to the 1968 general plan for the country regarding water management, elaborated by the Central Board of Watermanagement (*Centralny Urząd Gospodarki Wodnej*), the erection of the dam at Ciechocinek is not foreseen until 1980. Until then only 56% of the electric potential (i.e. 90 MW) will be produced. The total power of all the electric works erected on the dams in the Lower Vistula will amount to 820 MW and the yearly production of



electric energy to 4 milliard KWh. The water level in the reservoir is kept to about 57.3 m above sea level. This value exceeds the normal water level of the Vistula by 11 m near the dam, before the damming up, and by about 7 m in the middle part of the reservoir. In order to protect the ground depressions situated on the left part of the reservoir within the water of the rivers Rybnica and Zuzanka against flooding a side wall 10 km long has been erected and also a system of drainage ditches. In the area of the left hand bank attached to the reservoir, the arrangement of the hydrographic-net has been changed to a large degree. The Main Canal, which is 10.8 km long plays a most important part in this system, and also the so-called surrounding ditch running along the side wall at its base on the outer side of the reservoir. The Main Canal goes, at a distance of 100-600 m, off the side wall, and its mouth to the Vistula is below the dam. The Canal "catches" the surface and ground waters flowing from the area of the *pradolina* and also the waters filtrating from the reservoir. The waters are brought to the canal by way of gravitation through a net of ditches.

The Reservoir effected milder amplitudes of the Vistula levels and balanced the flows through the Włocławek region. During the 35 years (1919 to 1954) the amplitudes of the water levels at Włocławek Station amounted to 6.3 m. The yearly mean flow during that time amounted to 933 m<sup>3</sup>/sec. During the individual years the yearly mean flows balanced within the marks of 544 m<sup>3</sup>/sec (1943) up to 1443 m<sup>3</sup>/sec (1941). The maximum was noticed on the 30 March 1924 at 8305 m<sup>3</sup>/sec, the minimum on the 13 January 1933 at 141 m<sup>3</sup>/sec. The Reservoir does, in some ways, disturb the natural behaviour of the River. The high amplitudes of the water levels have become lower and the extreme flows flatten. It was supposed that the oscillation of the water table in the Reservoir would not exceed 2 m. However, the retention ability of the Reservoir is rather small. The Reservoir, as an independent unit, may soften the flood wave by 7000 to 8000 m<sup>3</sup>/sec for several hours. Full protection against floods will not be obtained until all the dams are erected and organizationally connected.

What then are the economic effects resulting from the building of the Reservoir at Włocławek?

The water transport conditions on the Vistula between the towns of Płock and Włocławek have been improved. Also the possibility of producing electric energy has been given. Now along the dam runs a road, which reduces the traffic on the bridge at Włocławek. The water retained in the Reservoir supplies the necessary amount of water required for the existing industrial enterprises, and offers the possibility of building further branches of various industries which depend on a supply of water. The water in the Włocławek Reservoir is, however, greatly polluted. Owing to this, hopes of organizing recreational and sailing facilities in the surrounding places have been undermined, as well as the improving and organizing of fishing enterprises. It had been assumed that the area of the Reservoir would be used as mass recreation grounds not only for the population of Włocławek but also for other regions in the country, such as for example the large industrial town of Łódź. It had been hoped that the Włocławek Dam Reservoir would become something like the Zegrze Dam Reservoir, with sailors' camps, swimming pools, anglers' centres, etc. beckoning tourists and other people. Owing to the permanent pollution of the Vistula by the neighbouring industrial enterprises, however, all these hopes had not materialized. It is thought that these pollutions also affect the microclimate of the area but, as yet, no investigations have been started in this direction. Part of the sewerage settles directly in the Reservoir, because part of its water has a stagnant character. The flow of the water in the Reservoir regulated by sluiceways in the dam may be inadequate which might cause a

decline of the fauna. Recently cases of poisoned fish and aquatic birds have been reported.

The plan to organize fishing on an industrial scale did not succeed either. Until recently there lived in the Vistula besides typical river fish, also fish of the salmon type, and also sporadically the western surgeon. Data registered by the Department of Agriculture and Forestry in the Bydgoszcz Voivodship Office (*Wydział Rolnictwa i Leśnictwa Prezydium WRN*), during the years 1960 to 1967 showed that 16 kg fish per 1 ha in the year were caught in the Vistula. In the previous years the amount of the catch was higher, amounting to 20 kg per ha. It had been expected that after the erection of the Dam Reservoir the catch would increase to 25–30 kg per ha. Recently fishing has been stopped entirely in the Reservoir because the fish are not fit for consumption.

I mentioned that the erection of the Włocławek Dam Reservoir was finished in the year 1969 (the damming up began in March and continued until August 1970). In the same year the Department of Geomorphology and Hydrography of Lowlands, Institute of Geography of the Polish Academy of Sciences, Toruń (now the Department of Physiography of Poland) started a series of investigations in the region of the Reservoir on the topic: "Changes in the geographic environments of the Vistula Valley between the Płock and Toruń Basins under the influence of the changes in the aquatic regime". When undertaking this topic we did not intend to give a full characteristic of the geographic environment but only to register changes in the forms (relief) and the aquatic conditions within the valley and the neighbouring areas. We had been induced by the actual building engineers, eager to gain a certain amount of scientific material which might be of use in further projects and dam building, to start these investigations. Within the framework of this topic following research works have been undertaken:

(I) The effect of a Reservoir on the changes of aquatic conditions in the Vistula Valley — by R. Glazik started in January 1969, to be finalized by December 1975.

(II) The effect of the Reservoir at Włocławek on the changes of the aquatic conditions below the Reservoir — started in May 1971, by Z. Babiński to be finalized after 1975.

(III) Development of sliding forms on the slopes in the Vistula Valley between the town of Płock and Włocławek — by M. Banach started in July 1969 — to be finished in 1975.

(IV) Development of erosional forms on the slopes in the Vistula Valley between the towns of Płock and Włocławek — this topic was begun in July 1972 by E. Drozdowski, it will be finished after 1975.

(V) The geomorphologic development of the Vistula Valley between the Płock and Toruń Basins — started January 1970 by E. Wiśniewski to be finished in December 1975.

(VI) Changes in the Vistula bed during historical times (the sector situated from the Płock Basin to the Toruń Basin) — started in January 1970 by L. Koc and now finalized.

(VII) Investigating the rate of silting in the Dam Reservoir at Włocławek. This research is being carried out by K. Więckowski from the Department of Transformations of the Geographical Environment in the Institute of Geography of the Polish Academy of Sciences in Warsaw.

It would be impossible to present in this short statement the full results of the investigations but I shall give a short outline of the results of some the investigations.



From the south, the Reservoir adjoins the low terrace-like levels of sandy, permeable forms. This area is investigated in order to examine the quantitative and qualitative changes of the aquatic situations in the grounds adjoining the Reservoir. The investigations involve a belt of c. 25 km in length and c. 8 km (180 km<sup>2</sup>) in width running along the Reservoir. During the first year, investigations and survey works were carried out on an area twice as large.

The largest changes in the hydrographic net and in the hydrologic relations occurred in the zone directly adjoining the Reservoir (1-2 km). It has been found that in this zone, resulting from the damming, the water table of ground waters rose by 1-2 m. The levels of surface and ground waters depend on the level in the Reservoir and their amplitudes "softened" in comparison with the time before the damming. The rise of the ground waters caused a rise of some subflooding in the lowest grounds situated between the side wall of the Reservoir and its Main Canal. At high levels in the Reservoir and during rain, the ground water penetrates to the surface. It would be advisable to erect some pump works in the regions mostly endangered (e.g., in the village of Skoki Wielkie). Advancing towards the south the ground rises and gradually the table of ground waters also decreases — the effects of the damming decline and the hydrologic situation is regulated solely by the normal meteorologic factors.

The waters flowing off the Reservoir caused an increase of erosion within the river bed in the zone situated below the Reservoir. This erosion was particularly active during the first period of the existence of the Reservoir, i.e., from the year of 1969 till 1971. The maximum erosion occurred at the first profile situated about 600 m below the dam and, according to the calculations of Z. Babiński, amounted to 2033 m<sup>3</sup> which, taking into consideration the width of the bed which is over 1000 m, resulted in the lowering of the river bed mean by 2 m. From a 9 km sector of the river bed there was carried away 4,195,152 m<sup>3</sup> of material which, taking into consideration the width of the river bed of about 850 m, resulted in an erosion of the depth of about 0.55 mm. The deepest erosion has been noticed in the direct neighbourhood of the dam. The erosional process in this sector decreased at the end of 1971 as the result of the stabilization of this section of the river bed. The dam offers the possibility of controlling the flow of the Vistula waters as demonstrated by the general flattening of the short-termed flood wave and the daily oscillation of the water levels. The dam has changed also the direction of the main stream towards the left bank of the River. Previously the main stream flowed near the right hand bank.

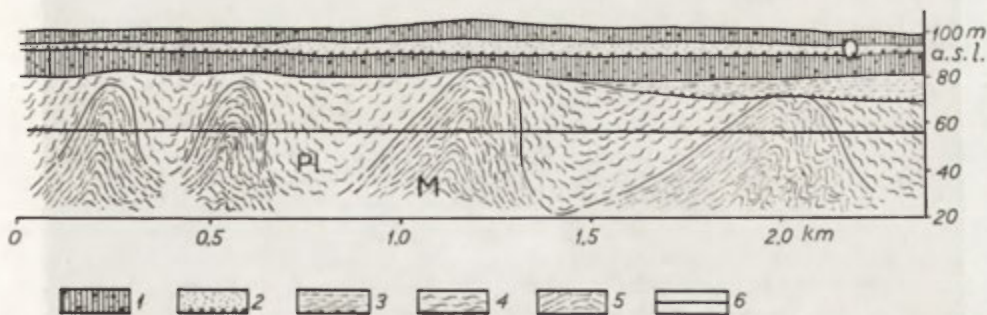


Fig. 2. Pattern of geological structure of the Vistula valley at Dobrzyń (after M. Banach)

1 — boulder clay; 2 — glacifluvial deposits; 3 — lake-ponded deposits; 4 — Pliocene sediments; 5 — Miocene sediments; 6 — water level of Vistula, after ponding



From the north the Dam Reservoir at Włocławek directly adjoins the Dobrzyń Plateau. The altitude of the slope is 50 m and the angle 10–50°. The general outline of the geological structure is as follows: at the surface there occur Quaternary deposits represented by two boulder clays and fluvio-glacial sediments. The upper boulder clay of a red-brown colour was accumulated during the period of the Baltic Glaciation, the lower one is classified as belonging to the Mid-Polish Glaciation. Under the Quaternary deposits there are exposed, in a slope strongly disturbed, undulating deposits of the Miocene and the Pliocene. The Miocene is represented by a formation of brown coal which is chiefly sandy, whereas the Pliocene by the so-called Poznań clays. Within the Neogene there occur disturbances of the folding type, particularly visible and clear in the Miocene deposits. The Vistula slope is disturbed by deep and wide sliding recesses. The occurrence of mass sliding movements is clearly marked. According to M. Banach, within the Miocene zone slides mainly developed, whereas within the antyclines of the Miocene, subsides or sinks developed.

By comparing the actual situation with old cartographic and photographic material, M. Banach has found that the right hand bank of the Vistula is shifting gradually towards the Dobrzyń Plateau. During the period from 1891 till 1961, in the neighbourhood of the village of Glewo, resulting from a side erosion of the Vistula, a belt of a slope of 150 to 200 m in width has been destroyed. The Góra Zamkowa (Castle Mountain) at Dobrzyń receded, between 1907 and 1970, by about 20 m.

Directly after the damming there has been observed a strain in the development of mass movements. Zones of anticlinal elevations of the Miocenic formations are now the object of very intense destruction. At the village of Bachorzewo, in July 1971, there fell a large amount of Quaternary and Neoge-



Fig. 3. Slope of Vistula valley with slide forms penetrating moraine plateau

nic material of volume of 20 thousand m<sup>3</sup>. The edge of the plateau receded by 25 m. A similar event took place in November 1970 on the Góra Zamkowa at Dobrzyń with 24 thousand m<sup>3</sup> of material being involved.

Within the synclinal depressions there are developing slides. One of them, observed by M. Banach since 1970, involves 1.5 ha. It is situated to the east of the Góra Zamkowa at Dobrzyń, and is always active. Survey points, installed in July 1970 on the top of it, shifted, up to February 1973 by 1.5 m to 15.0 m. The largest changes are taking place in the bed, and amount to 6.2–15.0 m. One of the survey points has shifted towards the Vistula from 1959 till 1970 at a speed of 2.6 m yearly, and after the damming, from September 1970 till February 1973, it has been and still is shifting at a speed of 3.4 m yearly. These facts demonstrate an intense destructive action of the right hand bank of the Reservoir.

Within the same range it is intended to begin investigations on the development of erosional forms on the Vistula slope. For investigations of the stationary erosional forms there have been chosen several characteristic valley forms and an artificial slope (a road escarpment) at the village of Zarzeczewo. Detailed plans of these forms (to the scale of 1 : 5000 and 1 : 1000) and also their exact profiles, elongated and diagonal have been prepared. The aim of these investigations will be to define in a qualitative and quantitative manner the natural conditions and the speed of development of the erosional forms.

Institute of Geography and Spatial Organization  
Polish Academy of Sciences, Toruń

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# HYDROLOGICAL MAP OF THE WORLD on example of Poland

Elaboration: A. Dobija, I. Dynowska, A. Tlatka, K. Trafas  
GEOGRAPHICAL INSTITUTE OF THE JAGIELLONIAN UNIVERSITY  
KRAKÓW, POLAND

## EXPLANATIONS:

### I. WATERSHEDS

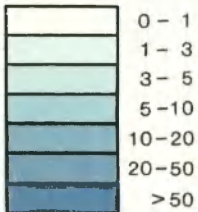
- 1. Watersheds separating catchment areas of different oceans
- 2. Watersheds separating catchment areas of different seas
- 3. Watersheds of the I-st order
- 4. Watersheds of the II-nd order
- 5. Watersheds of the III-rd order
- 6. Endorheic catchment areas
- 7. Gap in the watershed

### II. WATER RESOURCES OF THE RIVERS

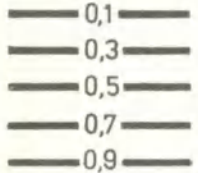
- 1. Discharge in cu. m./sec.



- 2. Runoff  
Specific yield, l/s sq. km

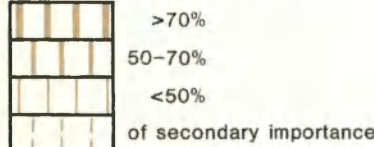


- 3. Ratio of runoff to precipitation:

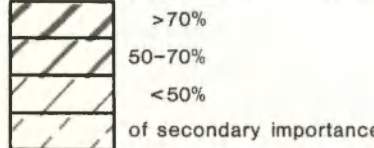


### III. KINDS OF RIVER SUPPLY

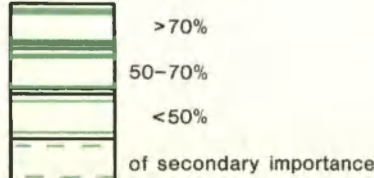
- 1. Groundwater supply:



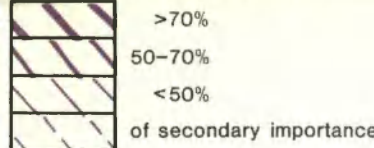
- 2. Supply from snow-melting:



- 3. Supply from rain:



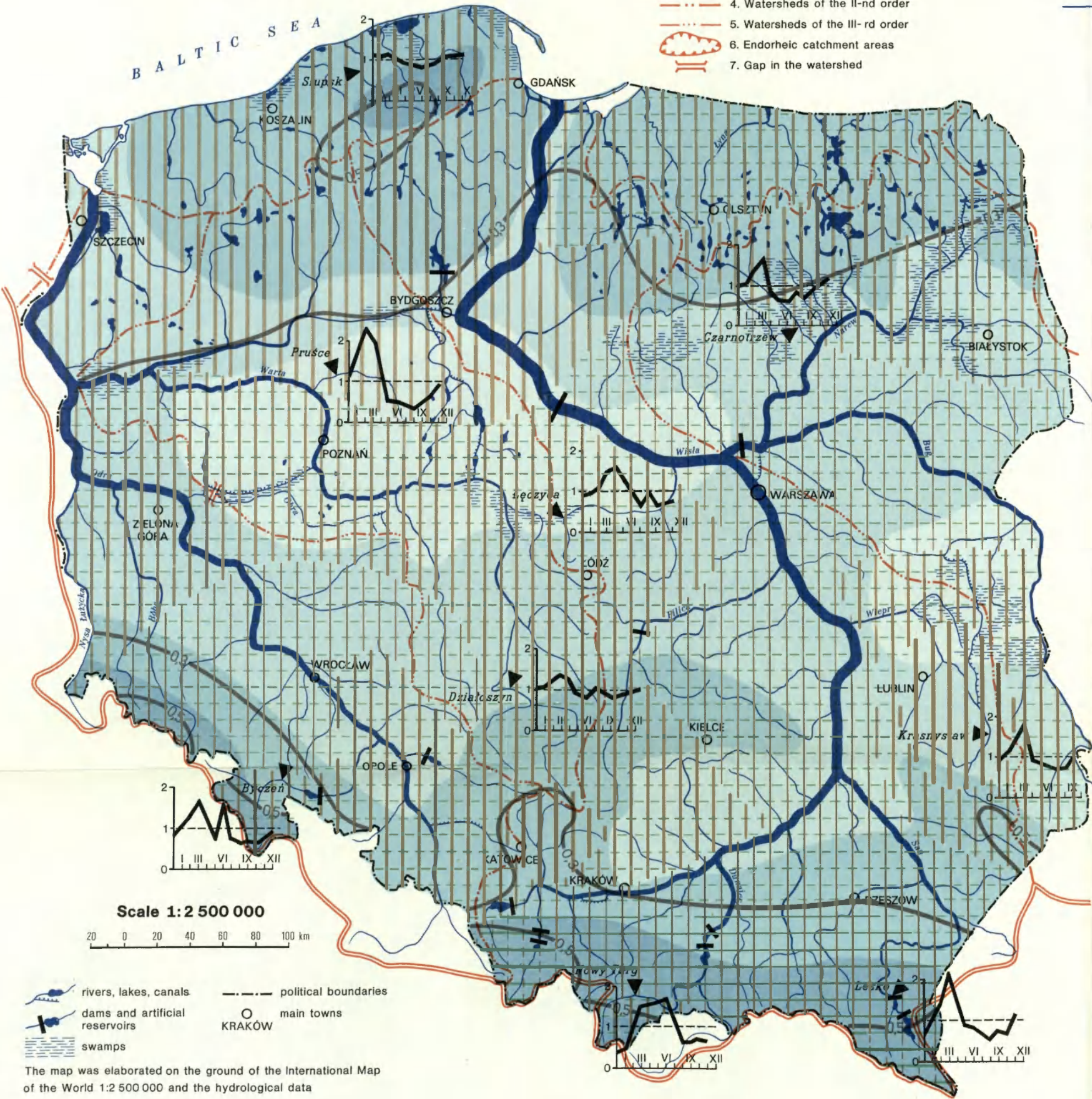
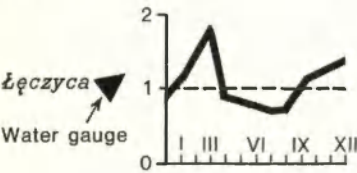
- 4. Supply from glacier:



- 5. Supply of equal rate:



### IV. COEFFICIENT OF MEAN MONTHLY DISCHARGES (RELATIVE VALUES) FOR SELECTED WATER-GAUGES





# GEOMORPHOLOGICAL OUTLINE MAP OF THE SILESIA UPLAND (SOUTHERN POLAND)

## B. Monocline-structure upland

- High-relief upland of plateau-type with remnants of a pre-Badenian degradation surface
- Undulating upland ridges
- Low-relief upland with remnants of Pliocene and Quaternary degradation surfaces cut in weak rocks

## II. Smaller landforms and their elements

### A. Tectonic landforms

- Flexure and fault scarps of Miocene age
- Obsequent fault-line scarp of Pliocene age
- Down-warped area

### B. Denudational landforms

Cuesta of Pliocene age consisting of:

- limestones
- limestones and dolomites
- conglomerates and sandstones
- Denudational outlier

### C. Fluvial landforms

#### C1. Erosional landforms

- Wind-gap
- Water-gap
- Small erosion-denudational valleys having alluvial floors

#### C2. Depositional landforms

- Alluvial plain
- Upper Pleistocene river terrace
- River terrace of Riss age

### D. Landforms of Riss glacial- and glacio-fluvial deposition

- Residual moraine hummock
- Residual kame mound
- Degraded outwash plain

### E. Karstic landforms

- Remainder hill heavily modified by karst processes
- Doline pitted limestone area
- Cave mouth

### F. Aeolian landforms

- Dune area, plant-covered



## EXPLANATORY NOTES

### I. Great convex tectonic landforms of erosional-denudational relief

#### Types of morphostructures:

- A. Horst-structure upland (Hercynian massif exhumed from beneath the capping Mesozoic strata)

- Horst of plateau-type with remnants of a pre-Badenian degradation surface

## EXPLANATORY NOTES

### I. Great convex neotectonic landforms (positive neotectonic tendencies, erosional-denudational relief)

#### Types of morphostructures:

##### A. Folded flysch mountains (formed after the Paleogene)

- Highest areas (monadnock summits, ridges de résistance) showing high relative relief (300-400 m.)
- Mountains and high uplands with fragments of intramontane planation surfaces
- Uplands with fragments of a Pliocene planation surface
- Lower foothills with fragments of a Lower Quaternary planation surface

### II. Smaller landforms and their elements

#### A. Tectonic landforms

- Areas showing positive tectonic movements (axes of uplift)

#### B. Denudational landforms

- Mountain ridges and escarpments of relative relief below 250 m.
- Mountain ridges and escarpments of between 250 m. and 800 m.

- Synclinal ridges
- Monoclinical ridges
- Other ridges de résistance
- Ridges independent of résistance
- Outliers
- Passes
- Cuestas
- Escarpments formed on front of nappes
- Monoclinical ridges with slope of cuesta-type

- Landslide areas

#### C. Fluvial landforms

##### C1. Erosional landforms

- Antecedent gaps
- Structural and headwater gaps
- Greater river-cliffs

##### C2. Depositional landforms

- Accumulative valley floors (Holocene terraces, partly together with Upper Pleistocene terraces)
- Upper Pleistocene low terraces

# GEOMORPHOLOGICAL OUTLINE MAP OF THE POLISH FLYSCH CARPATHIANS



Part of Skawa river basin (West Carpathians)



Part of Dunajec river basin (West Carpathians)



Part of upper San river basin (East Carpathians)

L. STARKEL



