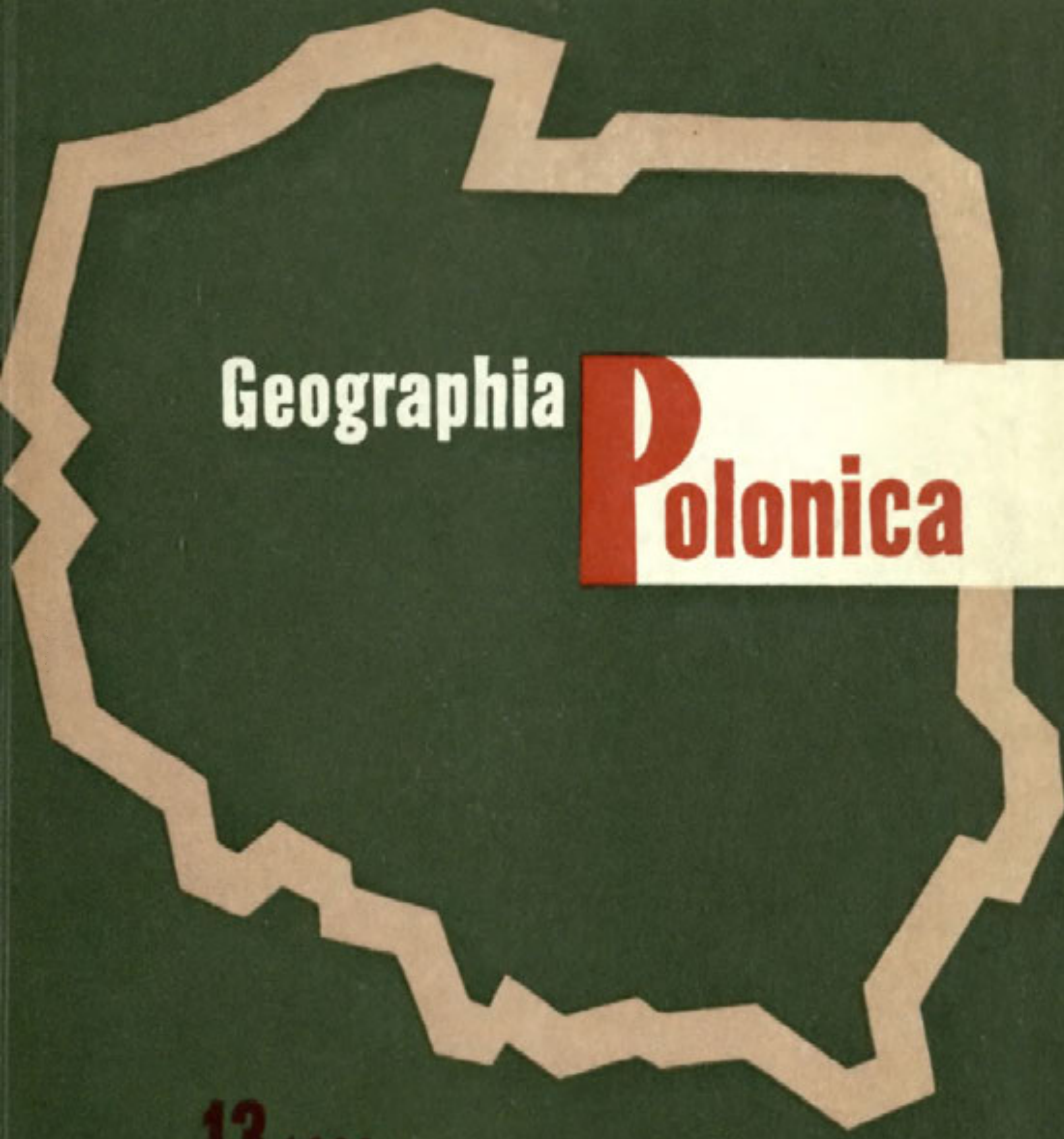
Geographia Polonica



13 1968

INSTITUTE OF GEOGRAPHY
POLISH ACADEMY OF SCIENCES

Geographia Polonica

13

PWN — Polish Scientific Publishers
Warszawa 1968

Address of Editorial Board

Krakowskie Przedmieście 30, Warszawa 64
POLAND

PAŃSTWOWE WYDAWNICTWO NAUKOWE
(PWN — POLISH SCIENTIFIC PUBLISHERS)
WARSZAWA 1968

CONTENTS

Str.

Stanisław Pietkiewicz: Differential Isochrones: A map of temporal accessibility 5

Alfred Jahn: Denudational balance of slopes 9

Danuta Kosmowska-Suffczyńska: Development of subaerial relief during the Tertiary Period in the area to the North East of the Holy Cross Mountains 31

Stefan Jewtuchowicz: Accumulation in stagnant ice, with the Spitsbergen glaciers as example 49

Mieczysław Hess: A new method of determining climatic conditions in mountain regions 57

Tadeusz Wilgat: Distance from water — an index of the density of a hydrographical network 79

Leszek Kosiński, Andrzej Gawryszewski: Map of the population distribution in Poland in 1960 91

Stanisława Bartosiewiczowa, Irena Czarnecka: Daily commuting to work . . 101

Władysław Tomaszewski: A method of industrial location 123

DIFFERENTIAL ISOCHRONES: A MAP OF THE PROGRESS OF TEMPORAL ACCESSIBILITY

STANISŁAW PIETKIEWICZ

The history of maps of temporal accessibility, from its beginnings in 1881 [1] to the present day, contains various kinds of cartographic document with information about the duration of travel from a certain point, generally the main centre of a region, to all other points of this region. Sometimes several main points were considered, and temporal distances were shown from each one up to the line on which travel from either neighbouring central point lasts equally long [4, 10]. This method was employed when the areas of influence of these points were to be delimited. The actual time of travel was considered by only some of the authors [4, 5, 9, 10]; others [1, 3, 8] used calculated or estimated average speeds according to the various means of transportation available. Two authors [3, 8], paying particular attention to suburban traffic, took in consideration even the average waiting-time between consecutive train departures, and one [9] — also studied the different approach routes to various railway stations of the city of departure, taking its centre as the starting point. As to the completeness of the communication apparatus considered, the first studies were quite unsatisfactory. They did not take into account the accessibilities of the gaps between the main tracks investigated such as steamship routes and railway lines [1, 6]. The primitively schematic design of the isochrones in the gaps only gradually developed as the subsidiary means of communication were considered: at first only cart traffic on roads and pedestrian movement outside them, with different speed standards for plains and hilly areas. Some authors paid particular attention to mountains, even taking data from alpine guidebooks. Several authors accounted also for the time required to cross rivers. One [7] showed certain marshes as "almost inaccessible". Then bus transportation appeared, and so the full picture of modern terrestrial communication was formed. When carefully constructed, such maps gave the true duration of travel to every point in the country, and also a differentiated general picture of its accessibility: the broader the strips between neighbouring isochrones, the better the accessibility, and vice versa.

A single map of this kind is valid for a given date only, and most isochronic maps were of this type. Attempts have been made to draw some maps derived from the simple isochronic maps, such as a map of "chrono-isanomaly" [5]. Attempts at a cartographic comparison of isochronic pictures of successive stages in the development of the transportation systems and of the accessibility of a country were also made [5, 9]. Two approaches were possible here — either the direct presentation of the shifting of single isochrones [9], or the calculation and mapping of the accessibility change, i.e. of its progress or regression [5]. The resulting maps aim at as clear as possible a graphic presentation of the changes which have occurred in the given interval. Schjerning, who chose the first method, first constructed isochrone maps representing travel time from Berlin at four dates (1819, 1851, 1875, 1899). He then chose one of his isochrones — the 5-hour one — and on his fifth map showed its consecutive positions at the dates under consideration. Such a solution was simple and clear, but only partial. It did not offer the possibility of evaluating the actual accelerations in travel to different points of the country. These should be most interesting from the economic point of view, as they represent the gain of time obtained.

This gain of time is shown on the map made by the second author [5], but this map has also a rather partial character, because it gives only the improvements, that are due to the introduction of new bus lines during the 5-year period under consideration.

The author of the present paper endeavoured to obtain as complete a picture as possible of the increase in accessibility in Poland over a period of ten years, between 1952 and 1962. Basic isochrone maps were prepared for each of these years, in exactly the same manner. All kinds of land transport except private cars were taken into consideration. On railways and bus lines, the time-table was used as a source of information, and the stopping places of express trains and fast buses regarded as secondary centers. From these centers local train and bus connections were calculated in every direction, not excluding return along the same line if it gave a shorter journey. For points accessible by two routes, both were calculated and compared. A pedestrian velocity of 5 km/h was assumed as a rule on roads, 4 km/h on foot path, and 3 km/h in mountainous areas. Narrow-gauge railways and steamboats or motor-boats proved generally to be slower than buses, so with a few exceptions (ferries, with an assumed velocity of 2 km/h) they found practically no place on our maps.

The isochrones so obtained had then to be correlated. This required special care in places where "islands" i.e. closed curves appeared round the stopping places of express trains and fast buses. To reduce complications in such places, the isochrones were slightly shifted in some places, but not by more than 2—3 minutes travel-time, so as to reduce the number of "islands" where they were small and approached prominences of homonym isochrones. This agrees with the principles of cartographic generalization.

Once these maps (Figs. 1 and 2) [1] were ready, we proceeded to the construction of the progress map. For this purpose, we had first to superimpose both base maps and to transfer the isochrones from both to a workmap. Then, with the workmap divided into a net of small sectors, we defined for each one the difference between its isochronic value on the first and second map. In this way, we obtained values of these differences for every sector expressed in full hours, e.g. one hour in a sector laying between isochrones 3 and 4 of the first base map of the same sector lay between isochrones 2 and 3 of the second map. It occurred sometimes that neighbouring sectors gave values differing by two hours, or that sectors with alternating values formed a chessboardlike tangle. In such cases the resulting picture was complicated and difficult to read (Fig. 3). To make it clearer, we attributed the difference values to points chosen in the middle of each sector (long sectors were divided into shorter ones for this purpose), and then traced isarithms between them. In this way a clearer picture was formed (Fig. 4) of the zones of improved accessibility. But zones of regress also appeared, either as a result of an increase in the number of train stops, especially on secondary railways, or of cancelling adjustments in local junctions. The last case was for the most part a result of the competition between the connexions with the capital (p r o t o c e n t r i c) connexions and the local (a l l o c e n t r i c) connexions. A particularly prominent case of regress is to be seen along a trunk line from which the express trains were shifted to another trunk line in consequence of its electrification.

A thorough analysis of the progress map in comparison with both base maps permitted several conclusions to be drawn concerning the factors at present influencing evolution of the communication system in the country. In particular:

a) apart from aviation, express trains exert the strongest influence on accessibility progress, as diesel and electric traction is introduced;

b) branch railway lines play a subordinate role here, since their trains are adjusted to the trunk express schedule;

[1] The full maps with their more detailed description have been published in Przegląd geogr., XXXVIII, 2, 1966.

c) narrow-gauge railways play no role in accessibility improvement;

d) bus transportation, competing successfully with railways, plays the main role in improving the accessibility of faraway areas.

Faculty of Cartography
Warsaw University

References

[1] Galton F., Isochronic Postal Charts. *Report of the 55-th Meeting of the British Association*, York 1881, p. 740.

[2] Galton F., On the Construction of Isochronic Passage Charts, *Proc. of the Royal Geogr. Soc.*, N.S. III, London 1881, pp. 657—8.

[3] Hassinger H., Beiträge zur Siedlungs- und Verkehrs-Geographie von Wien, *Mitt. d. K.K. Geogr. Ges. in Wien*, 53, 1910, No 1, pp. 5—88 (maps in No 2).

[4] Kubijowicz W., Izochrony południowej Polski (Isochrones of Southern Poland), *Prace Instytutu Geogr. Uniw. Jagiell.* 1, Kraków 1923.

[5] Paczosa J., L'autobus comme facteur d'accélération des communications, *C.—R. du Congrès Internat. de Géographie, Varsovie 1934*, III (1937), pp. 133—140.

[6] Penck A., Isochronen-Karte der Österr.-Ungarischen Monarchie. *Deutsche Rundschau für Geographie u. Statistik*, IX, 1887, pp. 337—341.

[7] Rewieńska W., Izochrony Wilna (Isochrones of Wilno), *Prace Zakładów Geol. i Geogr. Uniw. St. Batorego*, 4, Wilno 1929.

[8] Riedel J., Neue Studien über Isochronen-Karten, *Petermann's Geogr. Mitt.* 57, 1911, I. Halbbd., 6, pp. 281—4.

[9] Schjerning N., Studien über Isochronen-Karten, *Zeitschr. d. Ges. f. Erdkunde zu Berlin*, 1903, pp. 693—705, 763—783.

[10] Wąsowicz J., Mapy izochron wojewódzkich (Isochrones maps of the voivodships), *Czasop. geogr.* XII, 1934, pp. 165—8.

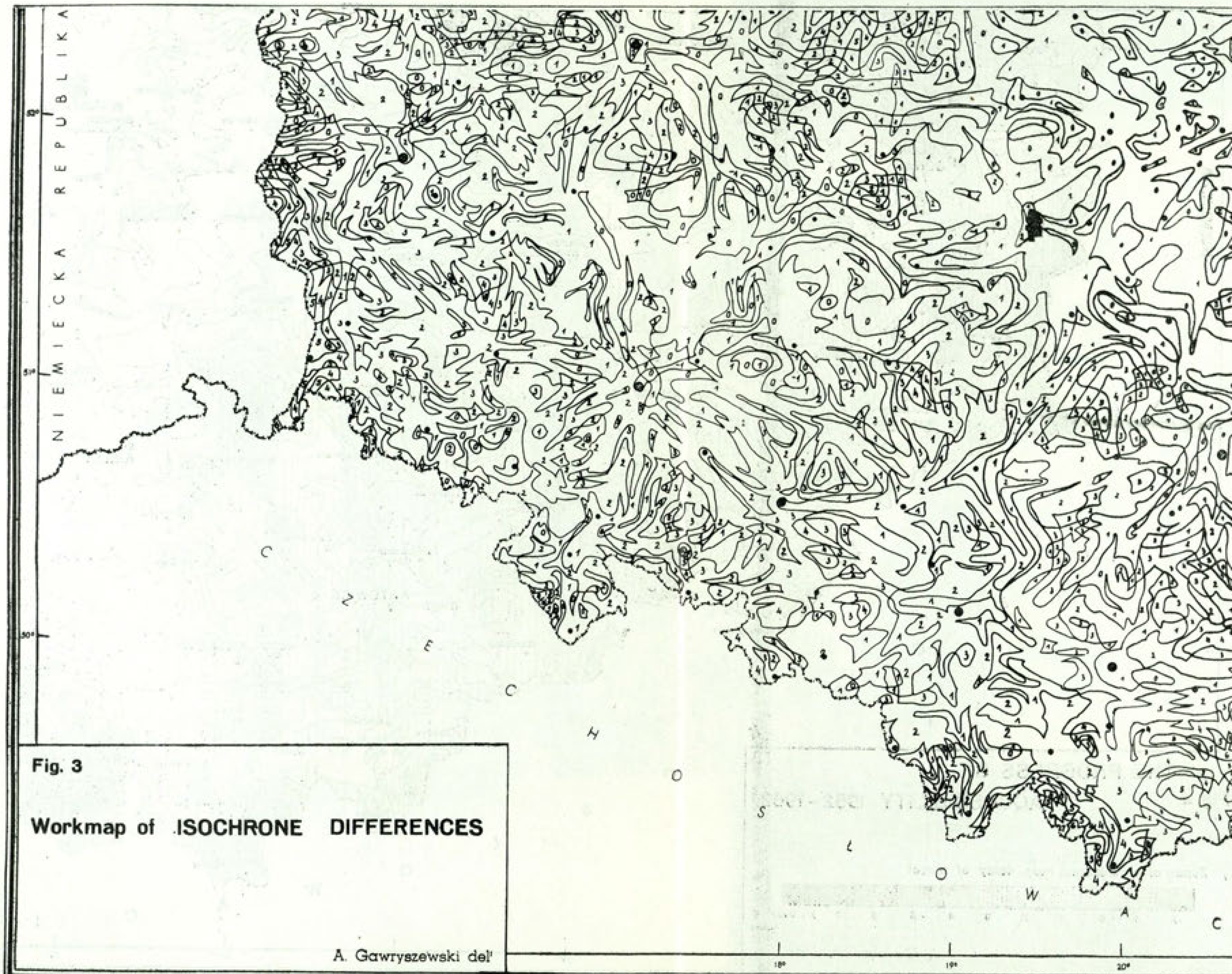
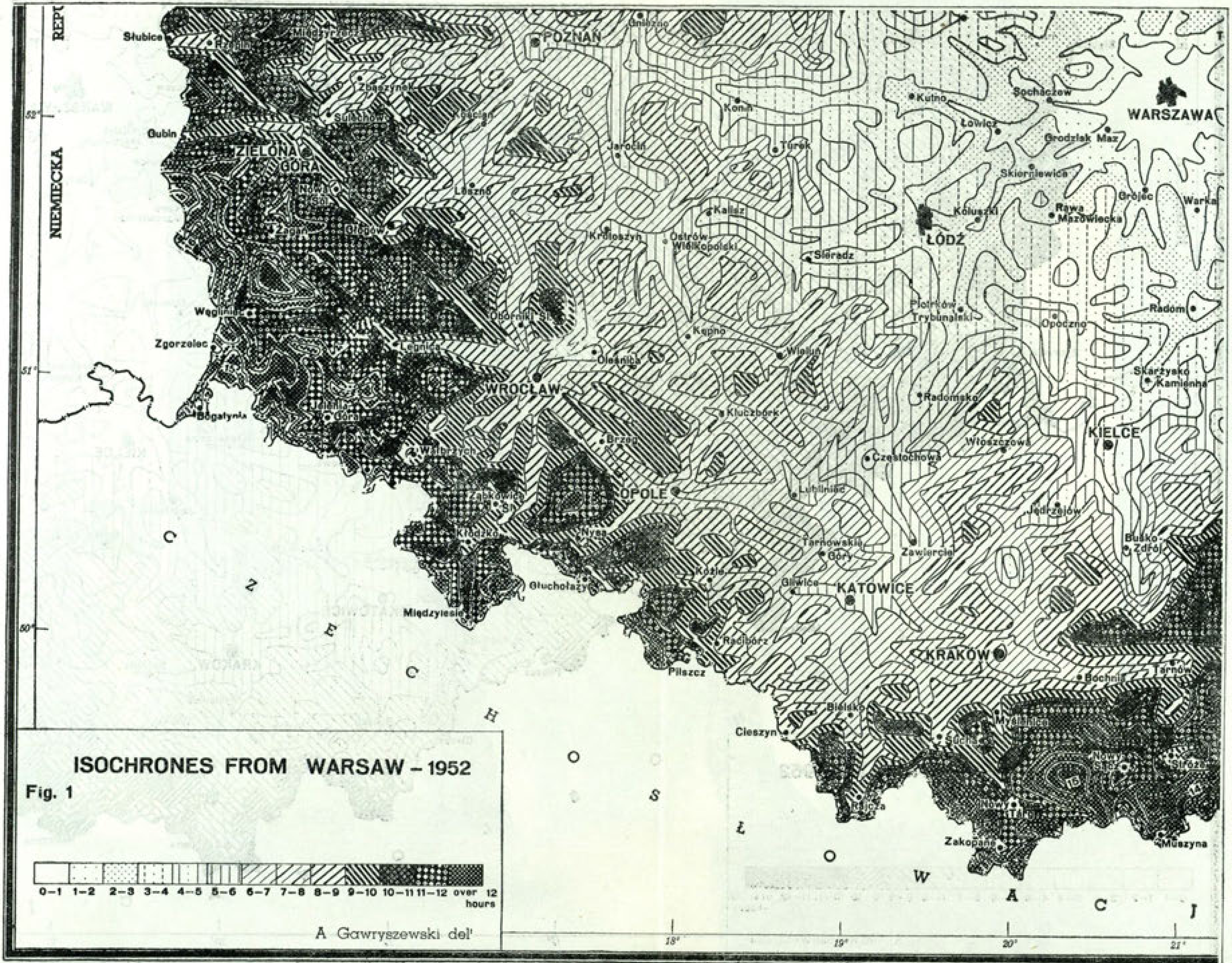


Fig. 3

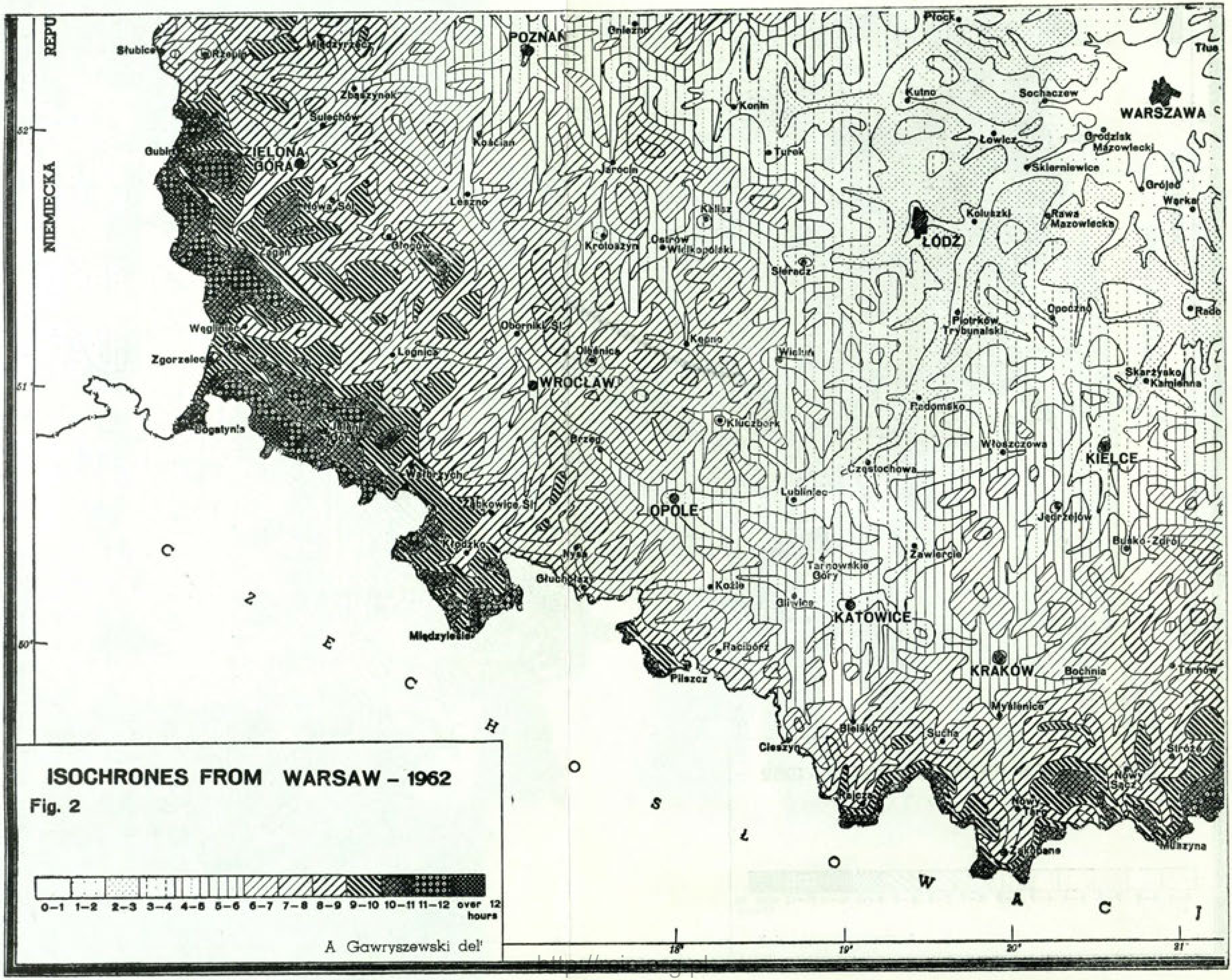
Workmap of ISOCHRONE DIFFERENCES

A. Gawryszewski del



ISOCHRONES FROM WARSAW – 1952

Fig. 1



ISOCHRONES FROM WARSAW – 1962

Fig. 2

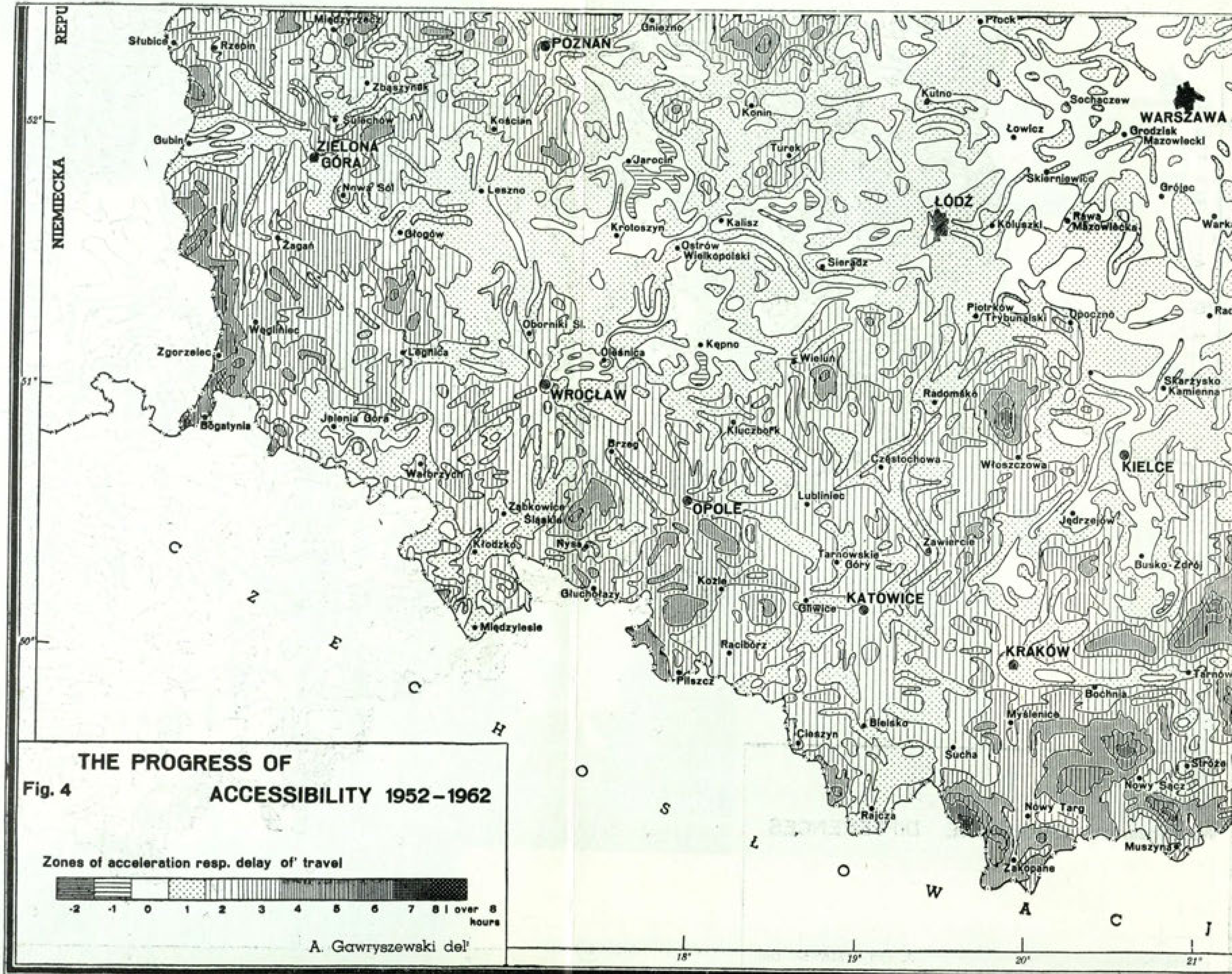


Fig. 4 THE PROGRESS OF ACCESSIBILITY 1952–1962

DENUDATIONAL BALANCE OF SLOPES

ALFRED JAHN

From the Editor

Twelve years ago in the Polish geographical journal "Czasopismo Geograficzne" (Vol. XXV, 1954) was published a paper by A. Jahn under the same title as the present one. Although published in Polish, the paper stimulated great interest among geomorphologists from different countries, who learned its content from the short French summary. The summary gave no comprehensive idea of the author's thesis, and not all readers adequately understood from it the problem of the "denudational balance of slopes" — as we know from the author. Therefore it was suggested that the paper be reprinted in English, and this is being done with the approval of the author.

1. THE PROBLEM OF SLOPES IN GEOMORPHOLOGY

A slope is a morphological surface that can be defined by the fact of its being inclined, and by the type of processes active on its surface. It suffices, in general, to state that it is a slanted surface, without giving detailed data as to its angle of inclination. At the most a minimum slant may be mentioned, that is, the lower limit of the angle of earth masses movements (2—3°). Active on slopes are denudation factors like: rain-water, wind, and — above all — gravitational movements of earth masses. These are widespread forces affecting the slope surface, not linear but dependent on: geological structure of the deposits, the advance of rock weathering, climate, vegetation, angle of inclination and length of incline. They are also dependent upon the position of the main base of denudation at the slope bottom (the bottom of the valley), as well as the local bases of denudation along the slope line (convexities in the slope profile).

It seems unjustified to treat slopes and sides as identical, because the term slope or incline (an inclined surface) undoubtedly carries a wider meaning. Slopes may be the sides of a valley or depression, slanting mountain areas, escarpments not connected with valleys; they may also constitute inclined denudation surfaces (denudation peneplains), monadnock top plains, pediments. Slopes may be contrasted with surfaces of slight inclination resulting from the direct action of continuous or seasonal water flow, of marine waves and of glaciers, in other words valley bottoms, plains of erosion and accumulation, abrasive surfaces, and the like. Slopes can not be differentiated merely by the gradient of morphological surfaces, because valley bottoms may have a higher gradient at one place than at another. Undoubtedly the morphological moment, that is, the type of morphological agencies bearing on a given surface (like denudation) is of greater importance in defining slopes than inclines. Even so, it should be added, that the boundary between a slope and what can no longer be called a slope is at times blurred to such extent, that it becomes impossible to distinguish the two surfaces. These remarks refer principally to arid desert-like areas, semi-deserts and periglacial regions, where denudation takes first place among exogenic agencies.

In spite of the fact that the slope is a dominant element in the morphological landscape of continents [1], especially of mountains and uplands, the extent of knowledge about it and the problem of its investigation — as justly pointed out by Dylik [11] — have failed to receive due attention in literature considering the magnitude of existing slope surfaces. So far, the morphology of valley bottoms and the action of rivers and glaciers are still regarded as key problems. This attitude may be justified by two considerations of which, however, only the first can be truly valid: 1) valley bottoms, being the main bases of denudation, determine the evolution of slopes, 2) forms of valley bottoms are easier to define morphogenetically because of their being typical and readily identified, while any slope shows non-typical forms, and due to the complexity of the agencies bearing on its evolution, its morphogenesis is usually uncertain.

The problem of slopes failed to attain its due position during the golden period of the splendid development of geomorphology at the end of the 19th and beginning of the 20th century, when Gilbert [13] was the only author who treated this topic in any detail. At that time some interest was around by denudation processes acting on slopes, while the matter of slope forms was usually left out of consideration. An essay by Götzinger [15] is worth mentioning where, more attention than else-

[1] Subaqueous slopes, marine and lacustrine as well as fossil and paleomorphological slants should also be born in mind. but their discussion is outside the scope of the present paper.

where, has been given to their morphogeny apart from processes acting on slopes.

The form of slopes was dealt with, though only incidentally during the period of animated discussions on the origin of a landscape of monoclinal structures ("Schichtstufenland"). Schmidthenner's [27] opinions on this subject, especially his theory regarding denudation troughs ("Dellen"), introduced new elements of denudational morphogeny. It is worth stressing that the exponents of classic morphology at the end of the 19th century definitely repudiated Schmidthenner's concept. An example is Philippson [25] with his critical attitude to the Dellen theory.

He was unable to imagine any widespread morphology without the action of great masses of flowing water such as rivers, (which is typical of the trend of thinking of the last century's geomorphologists). Elusive denudation agencies and, the shallow minor slope forms connected with them, were at that time considered too negligible, in the scale of large morphological transformations, to be granted prime rank and acknowledged as more important than the work done by rivers.

A new chapter in geomorphology was undoubtely initiated by Walter Penck [24] who made slopes the object and starting point of his creative and fruitful morphological analyses. From then on, more importance has been assigned to the form of slopes, so that one can speak in these terms of the morphogeny of a landscape and of tectonic movements. Thus the question of the evolution of large scale morphology acquired a firm footing, until then all the evidence sought had consisted merely of changes in valley bottoms, the effects caused by river flow, high gravel sheets and valley terraces.

This is how the modern trend in morphogenetic studies came into existence, in which the slope came to be the key problem in the evolution of land relief. In the thirties and the forties a number of papers of high value appeared, amongst which — to mention only papers of outstanding importance — were the following: Lawson [22], Baulig [3], Birot [4], Sobolev [28], Strahler [29] . In the early fifties the work of all these authors was reported and commented on by J. Dylik [11] and L. Pierzchałkówna [26].

H. Baulig [3] gave an analysis of a convex-concave slope which he considered, in contrast to W. Penck [24], to be an element of morphological uniformity. He opposed Lawson's [22] concept, ascribing the concave form of an upper slope section to denudation processes (slopewash), and the lower concave part to diluvia accumulation. In Baulig's opinion, denudation processes are active all over the slope surface. He perceived differences in the manner of denudation between that in the convex part, where the action of what he called dispersed surface-flow of rainwater proceeds together with mass movements, and denudation in the lower concave section of the slope, where eroding runnels (erosive gullies), concentrated in small grooves, are predominant.

Birot [4] reverts in his slope concept to Walter Penck's theories; but in his analysis he modifies them, principally by taking into account mass movements in the slope debris. Birot emphasizes justly the different rate of movement observed in the vertical profile of the regolith cover, because this, he believes, leads to important effects in slope morphology, since it contributes to the formation of concave slope sections.

Sobolev [28] presents a mass of material, both observations and reflexions with regard to slope forms in loose material. Similarly, Strahler [29] took the slopes of the „badlands", which are formed mainly from loose rocks, as the object of his analysis. He put forward his concept of a slope equilibrium proving, with slopes of young valleys as example, that the maximum inclination of a surface is a function of the local conditions as regards climate, geology and landscape relief. Therefore, according to Strahler, there is an equilibrium relation between the sum total of slope-forming factors and the inclination of the slope surface.

2. Denudational balance of slopes

Slope processes may be divided into two groups. The first is weathering, that is, rock disintegration due to climatic agencies (Penck's "Gesteinsaufbereitung"). It should be stressed that weathering is by no means a process reducing the amount of rock by disintegrating and removing it, but rather a symptom of local alteration, a process of production (waste debris production) or accumulation (eluvial accumulation), preparing the rock for its direct displacement by gravity or by the action of water, ice or wind. The second group is that of denudation processes: their importance in direct rock destruction is negligible (corrosion, rock "rotting"), if it need be considered at all. Its principal role is a downward transportation of rock material over the slope surface, i.e., slope transport.

The groups differ as to the direction in which they act. Weathering acts perpendicularly to the slope surface, denudation parallel with the inclination, that is, parallel with the slope.

Each place in a slope can be analyzed separately as to the direction which loose material follows while subject to denudation transport. Here the two directions of slope processes must be taken into account, that is, perpendicular to and parallel with the slope. An increase in both quantity and thickness of waste on the slope indicates that denudation transport is sluggish, and the surface of the rock becomes progressively separated from the influence of atmospheric conditions by an increasingly thick insulating layer. Thus, the direction of the action perpendicular to the slope surface prevails over the direction along the slope inclination. This case occurs when waste production (eluvial accumulation) proceeds at a higher rate than the action of denudation, or when movements of earth masses over the slope slows down or stops altogether; the latter happens, for instance, at less steeply inclined lower parts of the slope, resulting in an accumulation of loose material (diluvial accumulation). The opposite result will appear in analyses of those parts of a slope, where denudation transport prevails over processes of loose material accumulation (Fig. 1).

Conditions governing the movement of earth masses on a slope can be presented in the form of a balance equation, analogous to the water balance reflecting the course of water movement in nature. As in the water balance where precipitation is on one side of the equation, and the

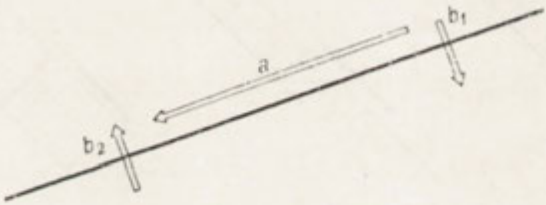


Fig. 1. Directions of action of slope processes
a — transport, b_1 — eluvial accumulation, b_2 — deluvial accumulation

corresponding amount of surface runoff and losses on the other, so in a slope balance by analogy with precipitation there will be local accumulation (accretion) of earth masses on the one side, and on the other a decrement of these masses by processes of direct mass movement, like slopewash (ablation) or deflation (wind action). Accumulation of earth masses means a gradual growth of the residual-diluvial cover in a direction perpendicular to the slope, by an in situ production of waste and by inflow of material from above.

The mutual arrangement of these three values yields the following three alternatives:

$$A = S + M,$$
$$A < S + M, \text{ and}$$
$$A > S + M, \text{ where}$$

A = accumulation of slope material, S = processes of slopewash and surface deflation, and M = mass movements.

On this basis, one may call the dynamic forces occurring on a slope surface the denudational balance of that slope. This represents the sum and, at the same time, the rate of all exogenic processes sculpturing the slope form, there in consist the geomorphological role of a slope balance.

Each of the alternatives given above expresses a different ratio of waste formation to slope transport. An equilibrium balance is represented by a constant formation of the regolith layer of a constant thickness (Fig. 2A). A positive balance clearly shows a predominance of the rate of denudation transport over that of waste production, resulting in a reduction of the thickness of the waste layer. The ultimate result of denudation prevailing over weathering is the uncovery of bare rock which is freely

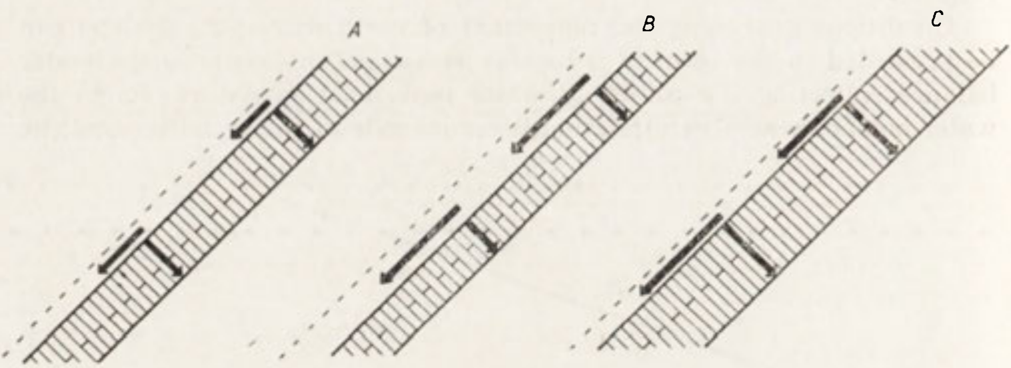


Fig. 2. Denudational balance of slopes

A — equivalent, B — positive, C — negative. Arrow length equivalent to the intensity of weathering production and denudational transport

exposed to weathering on the surface. This in turn accelerates the action of the weathering processes (Fig. 2B). Finally, a negative denudational balance finds its expression in a steady accretion of the thickness of diluvial material — a phenomenon which slows down the rate of weathering (Fig. 2C).

Let us now consider the theoretical changes in the denudational balance taking place on the surface of a uniform slope, with its upper end (the initial point) clearly defined. The action of weathering and denudation at the upper end of the slope surface, that is, the initial slope profile, is decisive. Assuming that this point has a strictly defined equilibrium of its denudational balance, then each point of the slope surface situated below the initial point, will show a negative balance. Production of weathered material at these lower points will be retarded by the earth material that has moved downward and has thus increased the thickness of the local waste layer.

This example demonstrates, that the denudational balance has a value depending not only on the potential waste production and denudation transport at a given point. but likewise on the position this point occupies on the slope.

Let us assume that the upper slope part shows a definite predominance of denudation over weathering. In this case, the denudational balance has a positive value, with the effect that some section of this particular part of the slope will be deprived of its waste cover. The length of this section will depend on the magnitude of the balance: it will be the greater the more is the excess of denudation over weathering. Here the rate of removal of the weathering products bears not only on the rate of slope lowering, but also on the extent of the rock surface that will be laid bare on the slope. A retarded downward denudation transport and an accumulation of weathered material mean that an increasingly thicker waste layer will insulate the rock surface from the action of atmospheric factors. Consequently, the ratio of weathering and slope transport suffers changes while proceeding downwards, and both values gradually come to equal each other, resulting in an equilibrium balance. This significant slope point or, rather, slope section is called the flexure point of the slope ("point of change" or Lawson's [22] "critical point of the hill profile", or Baulig's [3] "point d'inflexion"). Below this slope point, the slope process shows a negative balance expressed by a waste accumulation.

So far I have dealt with the denudational balance of slopes built of hard rock, on which weathering plays an important part by "predisposing" the rock for slope transport. Slopes built of loose material suffer similar changes, as far as the general character and the type of processes are concerned — with the proviso, however, that here the changes occur more rapidly then on slopes of hard rock. The section of a positive balance lies where the loose material is continuously being removed by denudation, while the section with coarse diluvia in the lower slope part constitutes the zone of a negative balance.

The above discussion refers principally to slopes on which the main transport process is a gravitational mass movement. Where slope transport is chiefely determined by slopewash by precipitation waters, the denudational balance may reveal different values and the pattern and the extent of the three differentiated balance types are also bound to be different. The water flowing over the slope surface increases in quantity downwards, and therefore the slopewash material depends on the extent of this surface, especially on its length. With uniform slope inclination, and uniform soil and vegetation conditions, the lower slope sections show a positive balance while, the upper ones have a negative balance. This pattern is the reverse of the conditions existing with gravitational transport of the earth masses without slopewash. Where slopes are built of loose material readily washed away, the latter balance pattern is typical. In agricultural regions, with slopes continually scarified by plant cultivation, slopewash is the predominant process in slope denudation; such regions provide a classical example of the pattern of balance sections discussed above. On the other hand, under normal conditions both processes of transport act simultaneously on a slope, the denudational balance becoming more complicated.

3. Geomorphological significance of denudational balance

It is worth considering whether the rate of slope destruction, of its lowering and flattening, is interrelated with the three types of denudational balance distinguished above.

To be exact, the denudational balance by no means expresses the rate of morphological changes suffered by slopes, because it merely denotes the mutual relation of processes, not their force of action. Thus an intensive slope degradation (a lowering and recession of slopes) occurs when weathering and denudation proceed rapidly, that is, when both sides of the balance equation show high values. This happens, when the denudational balance is in equilibrium, or — in other words — when the intensity of weathering equals that of transport. To be sure, it might seem that a positive denudational balance should be considered a symptom of the most intensive degradation — and this actually is so, but cannot be taken to be the rule. The morphological consequences on a slope are bound to be more marked when the balance is positive, because both weathering and denudation proceed rapidly. But even when they take place at a slower rate, if weathering happens to be less intensive than denudation, their action causes conditions for a positive balance on a slope.

A negative denudational balance is most often caused by accretion on slopes due to accumulation of diluvial products. This type of balance is typical on the lower part of a slope where the gradient is less steep. Such sections with a negative denudational balance correspond to higher slope sections with an equilibrium balance or a positive balance.

A further fact worthy of note is that a negative denudational balance is not constant in value; rather it represents a transition stage in morphological slope evolution. The section of diluvial accumulation, that is, of a negative balance, increases in the upslope direction at the rate at which degradation progresses. This increase takes place at the cost of a shortening of the section with an equilibrium or positive balance, and thus brings about a restitution of the "point d'inflection" in Baulig's [3] conception. However, processes of destruction do not spare this new surface where the gradient is indeed less inclined but where the accumulated material is loose and more readily moved by slope transport. In the section with a negative balance a new cycle of degradation follows, with the diluvia of the preceding cycle as a basis. In this new phase, the diluvial part of the slope is apt to show an equilibrium or positive balance, characterized by a decrement of earth masses on the slope surface.

The above reflexions indicate, that the denudational balance of a slope must be looked upon as a feature of a definite period, i.e., of some stage in slope evolution. Only development occuring at the same time can be connected with one another since they represent a temporary state of the slope balance, depending on the forces active at that time. In this manner our analysis of the denudational balance has brought us to the notion of a slope equilibrium; this concept was defined by Strahler [29] in terms of the inclination of the slope surface. The pattern of the balance for the sections corresponds, in the first place, to climatic conditions in which a slope is developing. because the climate determines the effectiveness of the balance components, such as weathering, mass movements, slopewash, etc. There may thus exist an equilibrium in the denudational balance of a slope as expressed by a pattern of balance sections correlated to the climatic conditions then existing. Any change in climate leads to changes in the components of the balance and this, in turn, bears on size and slope position of the individual balance sections. And here let us once again refer to problems treated in the literature. Baulig [3] was right to consider morphological slope changes as the results of changes in climate. When the climate turns humid, his point of flexure on the slope ("point d'inflexion") moves upwards, and the lower (concave) section of the slope increases at the expense of the upper, convex section. The inverse is the case when the climate becomes arid. Baulig [3], like Strahler [29], assigns first place to slope form and inclination. This is justified and necessary in a morphological analysis, although — and our critical remark applies to both scientists — such an approach fails to recognize the dynamics of change in slope processes. Baulig's [3] concave slope section, with concentrated water rivulets acting upon it, is hardly homogeneous all the time; its character changes in conformity with the changes in climate. However, this difference comes to light only when the type of denudational balance is taken into consideration. Thus it is not the change of form and inclination, but the movement of earth masses on the slope, in other words, their balance that is essentially expressive of the change in climatic conditions.

Baulig [3] criticizes Lawson's [22] slope concept, because the latter ascribed the formation of the concave slope section merely to processes of accumulation. Lawson held that the denudation material removed from the upper slope part, which thereby assumes its convex form, is deposited (washed down) in the lower concave part of the slope; and this lower slope part would be a section with a negative denudational balance. In this matter Baulig [3] argues differently. His concave section also suffers a degradation, although a different one from that on the upper convex section, and therefore his concave slope part is a section with a positive denudation balance. Both these scientists seem to be right, because both types of balance are characteristic of a concave slope section. The type of balance actually occuring at a given period is determined by the climatic conditions then existing, as well as the extent to which the slope has adjusted itself to these conditions (the state of slope equilibrium). Herein consist the polygenesis of the slope surface which, being a homogeneous unit because it has been made so by the climate prevailing at the given period, actually is composed of different sections each having its own evolutionary history. This matter is taken up later in the article, where the slope is considered as a problem of climatic morphology.

Still, the question must be raised whether there exist slopes homogeneous to such an extent, that the same type of denudational balance applies to the whole of the slope surface. In the author's opinion there are such slopes. Gravitational slopes may be considered to be a specific example of such homogeneity. These are rock-debris slopes with a distinct equilibrium in denudational balance. The rock surface is covered with fairly thin debris, of which slope transport removes an amount equal to that which accrues due to weathering. The equilibrium of the denudational balance is illustrated by the uniform slope inclination, reflecting the natural angle of repose of the weathered debris.

There are slopes which show a positive denudational balance all over their surface. This may be brought about by purely local causes, such as for instance the continuous undercutting of a slope by a river, whereby a relatively steep slope gradient is maintained and any material of slope transport is promptly removed. In this instance, the river prevents the formation of a section with a negative denudation balance, such as a talus cone. Thus, the interference of erosive agencies (which may include glaciers) obstructs the formation of all the elements of a slope profile.

Finally, slopes occur with an almost uniform negative balance. These are immense talus cones, that is, gravitational debris surfaces (well known in the arctic regions), which at times grow large enough to cover entire mountain ranges up to their summits and crest lines. Examples of cones of this kind are cited by Högbom [19]. Similar cones are also characteristic of some desert regions, where the marked predominance of weathering over denudation transport has the effect that rock forms become completely buried in debris. However, the upper sections of slopes of this type usually show an equilibrium balance, and therefore they belong to the category of gravitational rock-debris slopes.

Uniform slopes are rare. Under natural conditions, when the geological structure is complex and the climate varies during relatively short periods of time, non-uniform slopes are produced whose typical feature is a multi-sectional denudational balance. Slopes of this type show alternating convex and concave sections with either a negative or a positive balance. Slope convexities (those, for instance, due to a more resistant substratum) constitute local bases of denudation. These influence the evolution of the concave slope sections lying above them. Here the diluvia are principally piled up at the slope bases, that is, at the boundary line between slopes and valley bottoms; nevertheless in every slope there also exist numerous minor cavities, sometimes small hollows, barely perceptible, which become places of a negative denudational balance. This very complicated image of locally differing denudation conditions represents the natural slope form, that is, the slope evolution which tends to attain denudational uniformity and an equilibrium in the ultimate slope form. We can see here a perfect analogy with the longitudinal profile of a river, with its continuous evolution and its tendency to arrive at an ideal curve of erosion, and an equilibrium profile.

Apart from natural conditions, man's activity constitutes an agency particularly responsible for non-uniformity in slopes. A slope on which a forest has been cut down and agricultural work has been started, changes its denudational balance. The new balance depends on the type of tillage and of crops as well as on the type of roads and buildings constructed on the slope.

Slope evolution is of great importance in the development of morphological erosion surface. This topic is of exceptional significance today in view of the theory of pediplanation claiming that extensive pediments are being developed by the recession of mountain and upland scarps. Davis's classical concept of peneplains and processes of relief peneplanation failed to solve the question of how morphological peneplains originated. After all, it is hard to believe that a process of erosion (denudation), gradually decreasing in intensity at the rate at which river gradients and inclinations of valley slopes are being reduced, should have brought about the formation of planes with altitude amplitudes as small and inclinations as slight as are observed on some of the older morphological surfaces. For this reason, much attention is paid to papers dealing with the formation of submountain erosion surfaces in regions with continental, desert, semi-desert and periglacial climates, i.e., the problem of pediments (Tator's [30] noteworthy synthetic paper should be mentioned here). Pediments are gently inclined morphological surfaces. The mechanics of their formation is more accessible to observation and — still more important — easier to understand on the basis of the physical laws that govern exogenic processes on the Earth's surface, than is the mechanism of the peneplain evolution. Recently attempts have been made to interpret vast mountain planations as ancient widespread pediments (Howard [17], [18]).

What is the essential difference between peneplanation and pedimentation? A peneplain is formed by the lowering of relative altitudes of the landscape owing to denudation agencies which work in the downslope direction and tend to eliminate convexities in the land. The result is a lowering of mountain ridges which brings them nearer to the valley floors. A pediplain, i.e., a surface of coalescent pediments, is formed by eroding (denuding) agencies which eliminate slope convexities laterally and from bellow; it is a recession of slopes based on a permanent or slightly changing base of denudation. In short, a pediment is what has been left behind by lateral slope motions, and shows signs of its origin.

Consequently, the essence of peneplanation and pedimentation processes depends on the manner in which slopes develop in the landscape. And the mechanism of the evolution of slopes can most easily be expressed by means of their denudational balance. Peneplanation occurs due to the denudation of slopes in the downward direction, by degrading their upper sections. Hence the slope inclination decreases, the slope itself being flattened. It is a process, the mechanism of which shows a positive denudational balance. — The course of pedimentation is different. Slope recession can take place only when a fairly steep slope inclination is kept constant. This seems possible solely on gravitational slope built of rock debris, typically with an equilibrium of denudational balance; and this type of balance is characteristic of pedimentation processes. This shows that the denudational balance of slopes is significant as an index of morphological transformations taking place in the landscape, because this index stresses the essential difference between morphological peneplanation and pedimentation.

4. Methods of investigating the slope denudational balance

A slope, being a polygenetic element, is the result of denuding agencies that were active in the past. At the same time it is the place where present-day denuding agencies are constantly at work. This description of the part played by a slope indicates the necessity of applying a twofold method of investigating the slope denudational balance: a static method must be used to find the balance that existed in the recent past of the slope, and a dynamic method in order to understand contemporary slope processes. Hence the component elements of a slope balance must be examined: these comprise weathering, movements of earth masses, and slopewash due to precipitation.

1. The static method is based on the detailed examination of the cross-section of the slope cover which consists of waste (regolith). The texture and the structure of these deposits is of high importance for studying the history of a slope. It should be ascertained whether the weathered profile shows a normal soil profile, that is, whether it contains the main soil levels (with humus, eluviation and illuviation zones) in the standard vertical sequence. The profile may be disturbed (intermixing of soil layers), which would indicate vertical movements within the waste. An absence of the top layers of the soil (the humus, for instance) would be evidence of mechanical soil erosion by rainwater or wind. The waste profile might be of either eluvial or diluvial type; this question can be cleared up by investigating the structure of the cover and its petrographical relation to the substratum.

The static method, relying on numerous test pits on the slope, can yield an analysis of both texture and structure of the diluvial cover and define the mobility of the slope material, the number and frequency of phases of earth movements, or the amount and rate of accumulation of diluvial material. Diluvial strata, intercalated by regolith layers, indicate the number of such phases, and indirectly the number of successive climatic changes. It is a matter of high importance to distinguish within the diluvial series their climatic indices, so as to determine whether they represented a rapid solifluxion downflow in a cool climate, or sluggish slope phenomena typical of a moderate climate.

Since the slopes of Poland's morphological landscapes have suffered particularly intensive changes in their periglacial climatic environment (Dylik [10], Jahn [20]), slope examination in Poland should be based on a thorough knowledge of the entire range of periglacial soil structures (solifluxion types, involutions, frost wedges, etc.).

2. Dynamic methods can be applied for investigating current morphological changes of slopes. Here attention should be paid to two different types of slope transport: the movement of earth masses, and the action of rainwater and wind.

a) When investigating movements of earth masses, the mobility of the material and the factual evidence for movements occurring on the slope surface must be taken into account. The mobility can be determined by laboratory examinations, by granulometric analyses and by computing certain physical properties of the material, such as its limit of plasticity and fluidity. Actual movements can only be observed by field methods;

even so it must be kept in mind that any movement over a slope surface is extremely slow, requiring observation extending over a number of years.

Vertical movement of waste cover may be initiated by changes in volume, that is, by freezing and unfreezing or by transition from a wet to a dry state or inversely. The former changes should be investigated by Professor Bac's method [1], by installing motometers consisting of steel rods with discs. It is necessary to determine the depth to which the soil freezes, its water content and, depending on water content and mechanical composition, the degree of swelling of the material caused by freezing. Swelling is characteristic of silty materials.

Changes in volume caused by passing from a wet to a dry state and vice versa can be determined by computing the degree of material shrinkage.

In Poland vertical movements due to freezing and to increased water content, in other words, cold and warm changes, are both of marked importance in horizontal waste movements. Any movement of particles in the cover of a slope which is inclined at some angle is bound to result in a slight lateral movement. Thus every particle of material raised in a direction perpendicular to the slope surface fails to return to its previous place, but drops vertically under gravity, moving down along a slightly zigzag track. Under Polish climatic conditions the early spring saturation by meltwater and subsequent drying are probably of the most significant factors for slope movements of waste material.

The results of this waste slope-creep ("Gekriech" in German) can be determined by observation of the slope movement of specific objects like large boulders, the initial position of which can be established in relation to absolutely rigid objects such as outcrops of bedrock. Further, waste movements can be measured by driving into the ground stakes or pickets at different intervals. Where waste movements are relatively rapid, flow tongues of earth masses are developed on slopes. These are land slides or slumps, that is, forms that can be detected by surface observation. Such movements can be investigated in the same manner as glacier movements. Across any slide tongue pegs are driven in along a straight line, their position being referred to some fixed points. Any change in the peg position with regard to the initial straight line is an indication of the movement that has taken place.

If the slope surface reveals traces of movements caused by frost action on the uppermost waste sheet, say the turf layer, the mass movement can be detected and quantitatively determined by deposition, on top of the surface, of wooden cubes slightly embedded in the cover material (an example of this method is given in a paper by Krumme [21]). These cubes are arranged in figures such as squares or rectangles, and any change in their position is apparent in deformations of these geometrical figures. On steeper slopes, repeated temperature changes around the zero point (night frosts and daily melting) in autumn or early spring are likely to effect distinct deformations of the original figures. Attention must be paid here to the fromation of needle ice between the turf cover and the soil.

b) Surface downwash, ablation. Lawson [22] and Baulig [3] ascribed much significance to this factor in the slope balance. It is precisely in consideration of the Baulig concept of slope processes that attention should be paid to both these types of flow of precipitation water over the slope, i.e., dispersed and concentrated waters. "Dispersed waters" are waters carried in a very thin layer over the slope surface, while "concentrated waters" gather on a slope in rills or gullies. Because dispersed ablation occurs in upper slope sections and concentrated flow in lower sections, field examinations should indicate how high the gullies reach. Apart from these observations of the micro-relief of the slope surface, investigations should be made on the basis of a quantitative estimate of denudation processes on the slope. In this study, two different methods are in use, depending on the type of material of which the slope is built.

On loess surfaces or on slopes built of silty regolith clays or sands, which are easily washed away, the magnitude of ablation is estimated by measuring lengths and depths (i.e., the volumes) of the slope rills which have been made by precipitation waters. Details of this method have been given by Sobolev [28]. Tracts of fixed dimensions are marked out on a slope, preferably strips 1 m wide and 25 to 100 m long. The strips are oriented parallel with the contour lines. Within each one the number and depth of fresh rills or gullies are measured to establish the volume of material removed by ablation. This represents the annual loss of material per unit of slope surface.

Different methods of examination are used on slopes built of more resistant material not subject to gully erosion but rather to surface slopewash. Here longitudinal rectangular fields are laid out, oriented parallel with the slope inclination. These fields are separated from the remaining slope surface by furrows or by the use of wooden boards as partitions. The lower margin of each field is raised and terminated by converging boards, forming a sort of funnel. Below this funnel-shaped outlet are placed, stepwise, several boxes made of metal or boards in which the material washed downslope by rainwater or meltwater is accumulated. The material collected from the boxes should be dried and weighed, and in this manner the magnitude of ablation per unit of slope surface is determined.

5. The denudational balance as a problem of climatic morphology

For many years scientists have been aware of the exceptional importance of climatic zones in differentiating between geomorphological regions, and this topic is becoming increasingly urgent. Apart from the local effects of rock resistance and tectonics upon relief forms, and the variety of elements in the modern relief which are associated with paleomorphology, it is generally accepted that every landscape is morphologically affected by its climate, the factor of climatic morphology being supreme. Cholley [6] calls it the "erosive (denudative) system" of every climate. Its action referred to as the climatic geomorphological process leaves a decisive imprint on the prevailing micro- and macrorelief.

The influence of climate on relief forms is evident primarilly in processes of weathering and denudation. Combined, these factors are decisive as to slope morphology. The two agencies should therefore form the principal subject-matter in any studies of the geomorphological climatic process.

Recent years brought a number of valuable papers dealing with climatic morphology such as those by Grigoriev [16], Cotton [7], Troll [31, 32], Büdel [5] and particularly, Peltier [23] whose notable though perhaps premature, synthesis has been commented on by Dylik [10] and Galon [12]. In all these papers problems of slope morphology and slope processes are given a prominent place.

Our attempt to cosider slope morphology in terms of dynamic slope processes, as expressed by the denudational balance of slopes, may be used as basis on which to differentiate between morphological regions according to climatic zones. The essence of this problem is as follows: every point of a slope surface has its individual denudational balance depending on the local conditions, that is geological structure, soil, vegetation cover, angle of inclination, and surface exposure. The sum total of all local balances yields the denudational balance of the entire slope, and the sum of all these slope denudational balances presents, in turn, the denudational balance of the landscape [2]. This may well be called a climatic function, because in the sum-total one can distinguish and exclude all local influences and determine a more general principle characteristic of the influence of climate upon a rock surface for a given zone.

[2] The quantitative effect of denudation, commonly defined by the quantity of rock material carried off by rivers in suspension or solution, calculated for the area of the drainage basin, fails to yield adequate information on the quality of the denudational process — and the latter is important for a climatic — morphological characteristic of the relief.

The notion of climatic-morphological zones is based on the fact that in each of the zones distinguished the action of the climate on rock, differs in both intensity and manner. It is precisely the slope denudational balance that tells us as much about the action of climate, because it describes the ratio of waste production to slope transport. A powerful and penetrating weathering by the chemical action of water, characteristic of tropical regions, combined with a relatively insignificant slope transport due to vegetation gives a negative balance. Dry climates, whether hot (desert-type) or cold (periglacial), lead to either an equilibrium or a positive balance. These are, of course, extreme cases, and in between there is a wide range of climatic-morphological types of slope dynamics depending on a variety of climates. It therefore seems justified to make a generalization which, with others may serve to distinguish between climatic regions. As applied to slope morphology, this generalization will run as follows: regions with identical geological conditions and identical relative altitudes (heights of slopes above their surroundings) have, in different climates, different denudational balances of slopes and different slope forms. Every change of climate in regions of a definite geological structure and definite range of altitudes leads to changes in the processes, balance and finally even the morphology of its slopes.

This is a conclusion based on theoretical conciderations, a precise statement which can be verified by field observations.

6. Investigations of slope balance in Poland

In Poland, the principal geomorphological problem studied in the Departments of Physical Geography of our universities is the "Geomorphological Map of Poland". This presents wide prospects for work in the domain of genetic identification and the pin-pointing of Poland's relief forms.

Any extention of geomorphological research would demand studies not yet adopted in Polish geography and supplementary to the geomorphological map: specifically studies dealing with dynamic geomorphology.

The necessity of undertaking work of this kind mainly follows from the fact that in our geomorphology the morphogenetic line of research is steadily growing in importance. However, pursuing morphogenesis is hardly conceivable without a thorough knowledge of the outer geomorphological process, reflecting climatic conditions at a given locality.

In this research first place should be assigned to studies of morphogenetic slope processes which might be examined in detail with the problem of the slope denudational balance. Studies of this kind would have to be carried out regionally, that is, with due consideration of Poland's natural regions of land relief. It must be admitted that no significant differences in slope balance can be expected within the horizontal extent of the country, since morphological and climatic conditions are fairly uniform all over Poland. On the other hand, vertical differences should be noticeable. Accordingly, four altitude zones should be distinguished: the high-mountain Tatra zone, the medium-high mountain zone of the Carpathians and the Sudetes, the zone of Central Poland's uplands, and the zone of lowlands and diluvial elevations of North Poland.

The Poland's landscape is that of a country under cultivation, in which man's activities are the outstanding current morphogenetic factor. We must therefore try to locate sectional regions in which natural conditions of geomorphological processes have survived, and the relation between slope denudational balance and climate must be assessed here. This search is no easy matter, and it is probably only in natural forest regions such as that in the Carpathians, in Roztocze and in Pomerania, that natural conditions of this kind can be found.

Man's economic activity embracing land cultivation and deforestation, that is, changes in natural conditions of soil and its vegetation cover, considerably accelerate slope denudation processes. Where this mode of action progresses at an excessive rate, it assumes the features of a dangerous phenomenon called soil erosion. Slope morphology readily reacts to such changes in denudational balance. Slopes inexpertly cultivated, dissected by erosive gullies, or transversely terraced by yearly ploughing, or slopes cut by roads, escarpments of clay pits, sand and gravel exploitation, etc. — all these initiate rapid morphological changes not comparable with any natural process. All the same, these are changes highly interesting to a geomorphologist, and worth careful study. Hence the question arises how to evaluate the relation of such changes produced by man's activities to those occurring due to natural geomorphological processes under Poland's climatic conditions. The natural process must be defined first so as to be able to estimate by comparison the degree of deviation from, and acceleration of, the denuding effect due to man's interference.

Remarkable results have already been achieved in investigations of soil erosion in Poland. Papers by Bac, Ostromęcki, Roniger, Dobrzański, Malicki, and Ziemnicki, published in recent volumes of *Soil Erosion* [2, 8], contain valuable data not only on the economic role played by this destructive process, but also on its geographical and geomorphological significance and, indirectly, on its bearing on the slope denudational balance. Investigations made by agronomists and drainage experts aim at a very accurate determination of the quantity of material flushed down by slopewash which, in cultivated areas with a substratum of loose rock is the principal process of slope denudation. Experiments made by Professor S. Ziemnicki on loess slopes of the Lublin Upland, at Sławinek near Lublin, where for the first time in Poland equipment has been installed for catching products of slopewash [3], have already supplied interesting and extremely valuable data on slope denudational balance.

The discussion presented above refers to investigations of current slope processes in Poland which, to a high degree, are speeded up by man's agricultural activities. Another problem is the study of the denudational balance that existed in the recent geological history of our country. Periglacial research on the Lublin and Łódź Uplands [9, 20] has revealed that in many places crioturbational periglacial structures are buried, directly underneath today's slope surfaces. This would seem to indicate almost negligible destructive action by postglacial processes. The periglacial slopes have been preserved until today, mainly due to forest growth on their surfaces. Similar phenomena were also discovered by the author in the Sudetes where some sections of periglacial slopes have not been transformed at all during postglacial times.

Consequently it becomes necessary to pay more detailed attention to what are called "fossil" slopes. In this respect, much valuable material is contained in the above mentioned paper by Dylik [10]. He clearly distinguishes the consequences brought about by a variety of slope processes on the periglacial slope surfaces of the Łódź Upland, and differentiates denuded slope sections (positive denudational balance in the terminology introduced here from sections built of correlated solifluxional deposits (negative denudational balance). From these examples it appears that a determination of the denudational balance of periglacial slopes can be obtained by applying static geological methods.

The Department of Physical Geography of Wrocław University has initiated far-reaching collective studies of denudational balance and slope morphology in the Sudetes. Its variegated geological structure and long morphological evolution, and the evidence of the enormous morphological transformations suffered here under periglacial climatic conditions make this intramountain region particularly suitable for carrying out the research in question. The program of these studies encompasses detailed static observations (slope geology and examination of regolith and dilu-

[3] This equipment was demonstrated at a conference on soil erosion, held at Puławy and Lublin in 1953.

vial slope covers) as well as observations of current geomorphological processes.

The present paper puts forth a number of theoretical suggestions connected with this research.

The first steps have been taken. One season of field work (1953) has been dedicated to gaining experience in slope studies, in the Jelenia Góra Depression, the Karkonosze complex and the Kaczawa valley near Wojcieszów. A field course organizated at Sobieszów and Trzciniec for university students specializing in geomorphology was closely linked with this preliminary work. The methodological and didactic results of this course have been discussed in a separate paper published by St. Szepankiewicz. Nor should we fail to mention here a training course for scientifically active geography teachers, organized at Kłodzko on behalf of the Polish Geographical Society in 1953 by Professor J. Czyżewski, where the present author made the problems of slope morphology and methods of slope examination a principal topic of his lectures and field work.

Department of Geography
University of Wrocław

References

[1] Bac S., Ruchy warstw gleby wskutek zmarzania i tajania (Movements of Soil Strata due to Freezing and Unfreezing), *Wiad. Służ. Hydrol. i Meteor. P.I.H.M.*, Warszawa 1950.

[2] Bac S., Ostromęcki J., *Badania nad erozją gleb w Polsce* (Studies of Soil Erosion in Poland), Warszawa 1950.

[3] Baulig H., Le profil de l'èquilibre des versant, *Annal. de Géogr., 49,* 1940.

[4] Birot P., *Essai sur quelques problèmes de morphologie générale,* Lizbona 1949.

[5] Büdel J., Die klima-morphologischen Zonen der Polarlander, *Erdkunde, 2,* 1948.

[6] Cholley A., Morphologie structurale et morphologie climatique, *Annal. de Géogr.,* 1950.

[7] Cotton C. A., *Climatic Accidents in Landscape-making,* 1947.

[8] Dobrzański B., Malicki A., Ziemnicki S., *Erozja gleb w Polsce,* (Soil Erosion in Poland), Warszawa 1953.

[9] Dylik J., Struktury peryglacjalne w plejstocenie środkowej Polski (Periglacial Structures in the Pleistocene of Central Poland), *Biul. PIG,* 66, 1952.

[10] Dylik J., O peryglacjalnym charakterze rzeźby środkowej Polski (On the Periglacial Character of the Relief of Central Poland), *Łódzk. Tow. Nauk. Wydz. III, 24,* Łódź 1953.

[11] Dylik J., Cechy rozwoju najnowszej geomorfologii (Evolution Features of the Most Recent Geomorphology), *Przegl. geogr.*, 25, 1954.

[12] Galon R., Zagadnienie powierzchni zrównań wg Bauliga (Problems of Peneplains after Baulig), *Czasop. geogr.,* 23—24, 1954.

[13] Gilbert G. K., *Geology of the Henry Mountains,* 1877.

[14] Gilbert G. K., The Convexity of Hilltops, *Journ. of Geol*, 17, 1909.
[15] Götzinger G., Beiträge zur Entstehung der Bergrückenformen, *Geogr. Abhandl.*, Leipzig—Berlin, 1907.
[16] Grigoriev A. A., *Subarktika, opyt kharakteristiki osnovnikh tipov fizikogeograficheskoy sredi* (Subarctica. An Attempt to Characterize Principal Physiogeographical Types of the Environment), Moskva—Leningrad 1946.
[17] Howard A. D., Rocky Mountain Peneplains or Pediments, *Journ. of Geomorph.*, 2, 1941.
[18] Howard A. D., Pediment Passes and the Pediment Problem, *Journ. of Geomorph.*, 5, 1942.
[19] Högbom B., Über die geologische Bedeutung des Frostes, *Bull. Geol. Instit. Uppsala* 1914.
[20] Jahn A., Zjawiska krioturbacyjne współczesnej i plejstoceńskiej strefy peryglacjalnej (Crioturbational Phenomena of Contemporaneous and Pleistocene Periglacial Zones), *Acta Geol. Pol.*, 2, 1951.
[21] Krumme O., Frost und Schnee in ihrer Wirkung auf den Boden im Hochtaunus, *Rhein-Mainische Forschungen*, 1935.
[22] Lawson A. C., Rain-wash erosion in Humid Regions, *Bull. Geol. Soc. Amer.*, 43, 1932.
[23] Peltier C., The Geographic Cycle in Periglacial Regions as it is Related to Climatic Morphology, *Ann. Assoc. Amer. Geogr.*, 40, 1950.
[24] Penck W., *Die morphologische Analyse*, Stuttgart 1924.
[25] Philippson A., *Grundzüge der allgemeinen Geographie*, Leipzig 1924.
[26] Pierzchałkówna Ł., Zagadnienie rozwoju stoku w świetle prac Bauliga, Birota i Sobolewa (Problems of Slope Evolution in the Light of Studies Made by Baulig, Birot and Sobolev), *Przegl. geogr.*, 25, 1953.
[27] Schmitthenner H., Die Enstehung der Dellen und ihre morphologische Bedeutung, *Ztschr. f. Geomorphol.*, 1925.
[28] Sobolev S. S., *Razvitiye erozionnikh processov na territorii evropeyskoy chasti SSSR i borba s nimi* (Evolution of Erosiv Processes in the European part of the Soviet Union and the Ways of cotraction), Moskva—Leningrad 1948.
[29] Strahler A. N., Equilibrium Theory of Erosional Slopes Approached by Frequency Distribution Analysis, *Am. Journ. Sc.*, 248, 1950.
[30] Tator Ben A., Pediment Characteristic and Terminology, *Bull. Geol. Soc. Amer.*, 63, 1952.
[31] Troll C., Die Formen der Solifluction und die periglaziale Bodenabtragung, *Erdkunde*, 1, 1947.
[32] Troll C., Der subnivale oder periglaziale Zyklus der Denudation, *Erdkunde*, 2, 1948.

DEVELOPMENT OF SUBAERIAL RELIEF DURING THE TERTIARY PERIOD IN THE AREA TO THE NORTH EAST OF THE HOLY CROSS MOUNTAINS

D. Kosmowska-Suffczyńska

Geomorphological studies carried out on the NE side of the Holy Cross Mountains, from the Jeleniów Ridge to the northern boundary of the 1 : 100 000 map of the Opatów region, have led to some new conclusions on the development of relief in the period before the Quaternary [11].

In contrast to the southern part of the Holy Cross Mountains, the area picked for research has been part of a land mass without interruption from Upper Turonian times (Upper Cretaceous) to the present day and is particularly suitable for studies of land processes taking place in the Tertiary.

The conclusions reached are based on geological and geomorphological observations. The greatest attention was paid to analyses of sediment type and the way of its accumulation.

Present relief and geological structure

In the northern slope of the Holy Cross Mountains various morphological units are clearly evident from the quartzite Jeleniów Ridge to the denudational plain in front of the mountains. From south to north the areas are made up of younger and younger stratigraphic elements and steadily lose the character of real mountains (Figs 1 and 2).

The Jeleniów Ridge, being an extension of the main Łysogóry Ridge, is made up mainly of quartzites and quartzite shales of the Cambrian age. It has a clearly mountainous character, reaching 550 m above sea level (Fig. 3). Its slopes are steep and covered with weathering material overgrown with fir forests. Towards the north the steep rocky slope of the Jeleniów Ridge disappears under the Quaternary loess deposits of the Sandomierz Upland and from there to the Kamienna River it can only be seen in the sides of deep erosion cuttings (Fig. 4). The basement rock here is made up of Silurian, Triassic and Liassic rocks. Lithologically shales and sandstones predominate, with a falling decline towards the NE. Of the Quaternary formations loess has the greatest thickness, and gives the area a characteristic appearance. The usual height of the loess summit plains is 270 to 290 m above sea level. To the north of the undu-

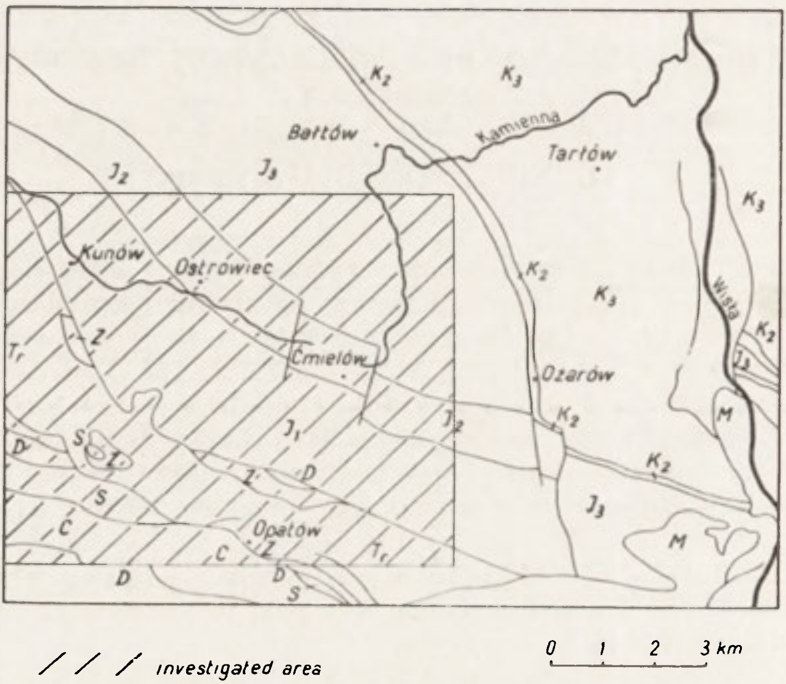


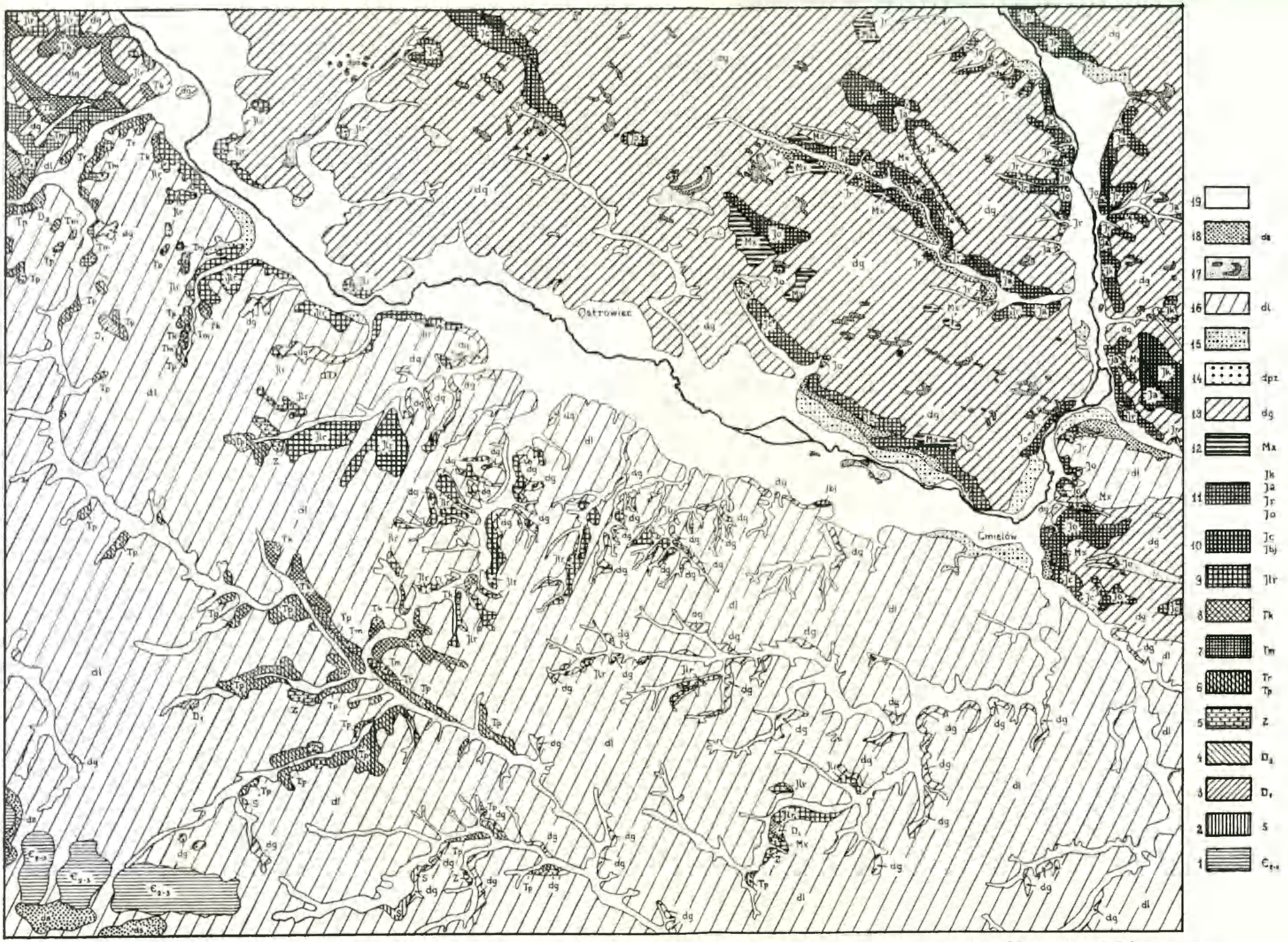
Fig. 1. Geological sketch

C — Cambrian, S — Silurian, Ordovician, D — Devonian, Z — Zechstein, Tr — Triassic, J_1 — Lower Jurassic, J_2 — Middle Jurassic, J_3 — Upper Jurassic, K_2 — Middle Cretaceous, K_3 — Upper Cretaceous, M — Marine Miocene deposits

lated loess upland a flat denudational plain extends with hillocks of the older bedrock and fossil valleys which are no longer active. For the most part the land here is 190—200 m above sea level, Quaternary deposits have an insignificant thickness, and there is a complete absence of loess. There are frequent outcrops of pre-Quaternary rubbles, almost exclusively of limestone from the Middle and Upper Jurassic periods.

The boundary between the loess uplands and the denudational plain is formed by the Kamienna River valley.

Up to now detailed research has been concentrated mainly on the stratigraphy and lithology of the Paleozoic and Mesozoic rocks [21]. Work



based on J.Czarnocki and J Samsonowicz

Fig. 2. Geological map of the area investigated

1 — Middle and Upper Cambrian, 2 — Ordovician, Silurian, 3 — Lower Devonian, 4 — Middle Devonian, 5 — Zechstein, 6 — Bunter Sandstone, Roethian, 7 — Muschelkalk, 8 — Keuper, 9 — Lower Jurassic (Jlr — Liassic), 10 — Middle Jurassic (Jbj — Bajocian, Bathonian, Jc — Callovian), 11 — Upper Jurassic (Jo — Oxfordian, Jr — Rauracian, Ja — Astartian, Jk — Kimmeridgian), 12 — Miocene, 13 — Glacial Boulder clay, 14 — Sands and gravels, 15 — Terrace sands, 16 — Loess, 17 — Dunes and blown sands, 18 — Deluvial fan, 19 — Alluvia

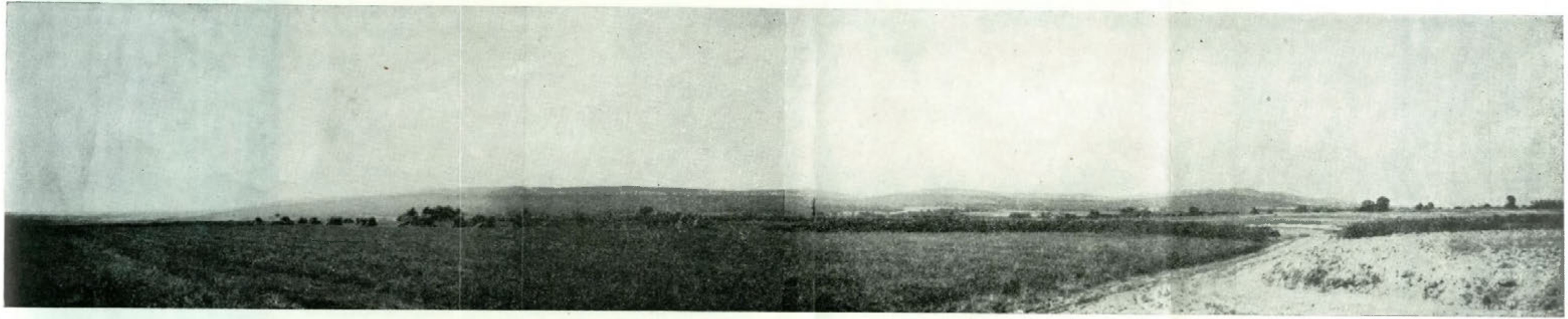


Fig. 3. The Jeleniów Range of the Holy Cross Mountains from the north, with a loess plateau in the foreground

Ph. D. Kosmowska-Suffczyńska

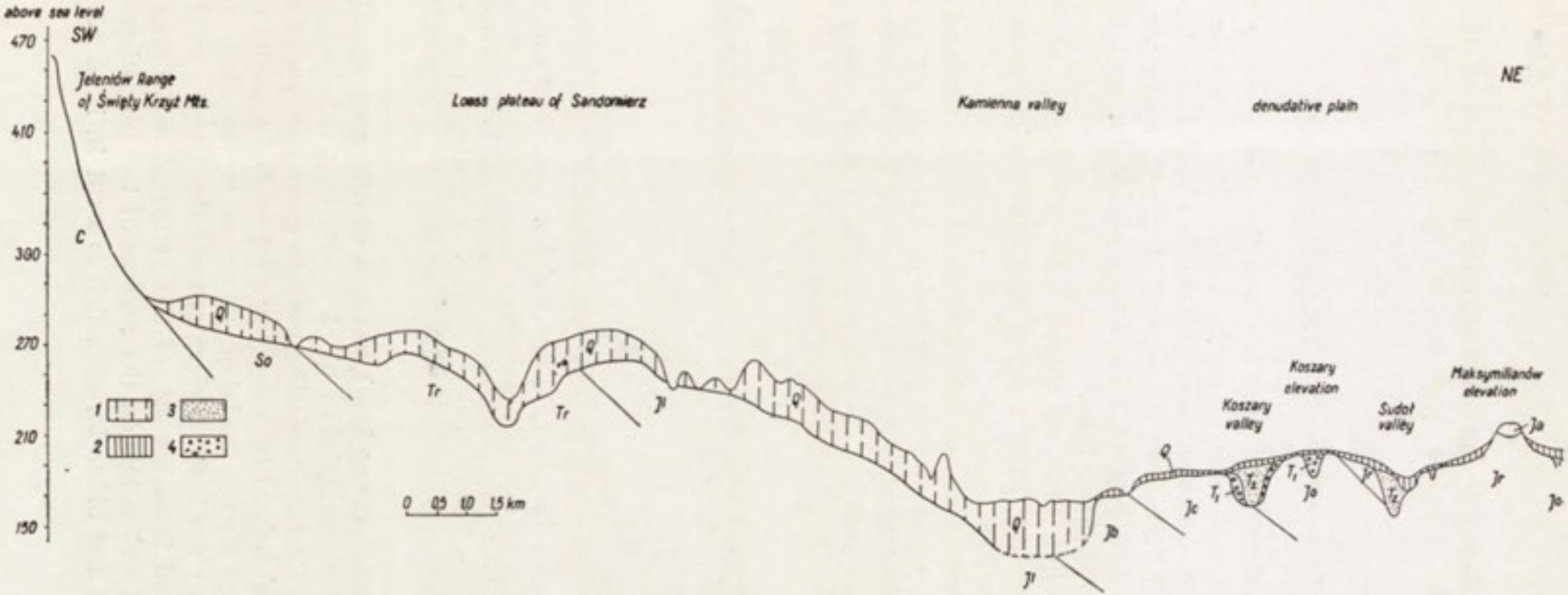


Fig. 4. Topographical and geological cross-section through the NE slope and marginal zone of the Jeleniów Ridge of the Holy Cross Mountains

C — Cambrian, S — Silurian, Ordovician, Tr — Triassic, Jl — Liassic, Jb — Bajocian, Bathonian, Jc — Callovian, Jo — Oxfordian, Jr — Rauracian, Ja — Astartian, T_1 — Paleogene, T_2 — Neogene, Q — Quaternary, 1 — boulder clay, sands and gravels covered by loess sediments, 2 — remnants of boulder clay, sand and gravels, 3 — sands with debris and clay admixture, 4 — rock debris with clay and silt on the terrestrial deposits and morfogenetic processes of the Tertiary has been negligible. A clear gap is also apparent in the work on Tertiary tectonics.

Development of Paleogene relief

The Turonian Upper Cretaceous sea was the last to cover the whole of the Holy Cross Mountains [17]. In the Upper Cretaceous period at the end of Maestrichtian and beginning of Danian times Laraminian movements took place, which caused the retreat of the Turonian sea. Amongst other land massifs the present Holy Cross Mountains and the Sandomierz Upland emerged at this time.

The subaerial relief, then, developed from the decline of the Cretaceous to the Quaternary Epoch, when the area which is now Poland was covered by glaciers.

Tertiary gradation processes belong without doubt amongst the most important of those which influenced the development of relief. They have caused the removal of a range of Paleozoic and Mesozoic deposits from this terrain, the partial destruction of the original geological struc-

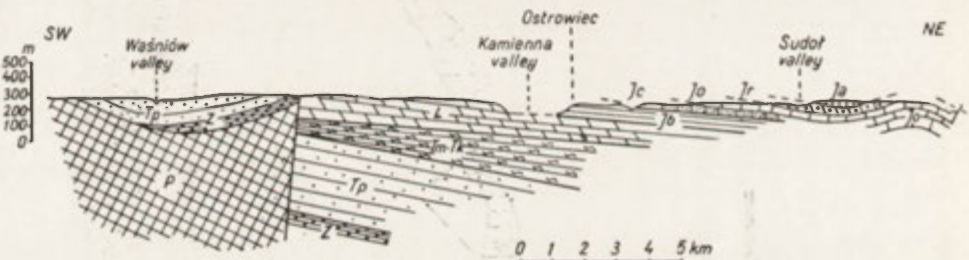


Fig. 5. Geological cross-section along the line Waśniów—Ostrowiec Świętokrzyski—Lemiesze

P — Paleozoic, Z — Zechstein, Tp — Bunter Sandstone, Tm—Tk — Muschelkalk, Keuper, L — Liassic, Jb — Bajocian, Bathonian, Jc — Callovian, Jo — Oxfordian, Jr — Rauracian, Ja — Astartian

ture and the exposure on one level of rocks of different ages (from the Cambrian to the Kimmeridgian) and of contrasting lithological properties (Figs 1 and 5). Earlier gradation periods (post-Hercynian and post-early Kimmeridgian) helped by removing part of the deposits earlier.

A period of very strong gradation occurred in the older Paleogene and the planation surface is the surface of the older Paleogene (Paleocen). This may be deduced from the age of the youngest destructed element, the oldest sediment which lies on the surface of the planation and from the karst, erosional and other forms which are cut in it. A certain confirmation of the Paleocene age of the planation surface would be the occurrence of altered clays on the Paleozoic floor which have been identified as probably pre-Helvetian.

S. Lencewicz [12], W. Pożaryski [15] and M. Klimaszewski [17] deal with the Paleogene surface in the Holy Cross Mountains and their Mesozoic surrounding without closer dating. According to Lencewicz two denudational flats were formed in the Paleogene, at 400 m and 350 m above sea level. Lancewicz's explanation applies mainly to the central and southern parts of the Holy Cross Mountains. A comparison of the

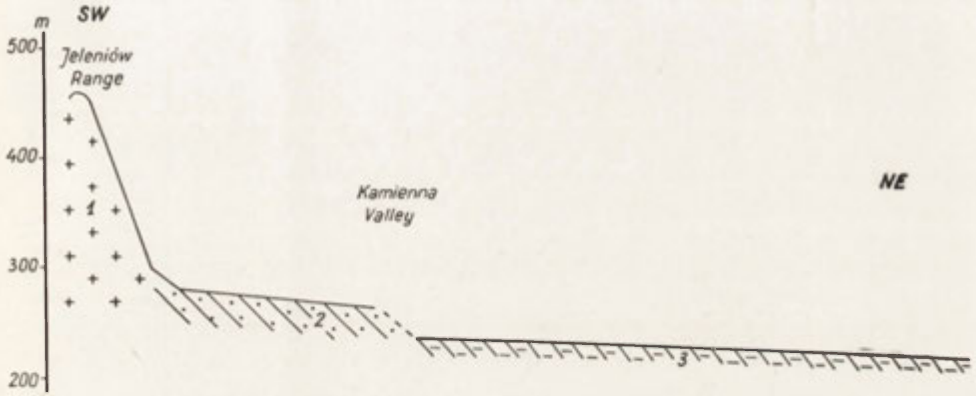


Fig. 6. Inclination of the Paleogene surface north of the Jeleniów Range of the Holy Cross Mountains

1 — Quartzites, 2 — sandstone, slates, clays, 3 — limestone

altitude of the Paleogene surface, which in the NE part of the mountains does not rise more than 280 m above sea level, with the levels of 400 m and 350 m described by S. Lencewicz [12] reveals an unmistakeable lack of agreement. A similar situation is found when comparing these surfaces with the Paleogene levels on the Miechów [4] and Silesian [5] Uplands, where their altitude is 370 to 400 m. The Paleogene level on the NE slope of the Holy Cross Mountains can be clearly seen to lie appreciably lower than the neigbouring terrain. An analysis of the extent of the Miocene seas shows that the changes in altitude of the Paleogene surfaces in the Holy Cross Mountains must have taken place after the end of the Miocene period.

The Paleogene surface from the forefield of the area under investigation was treated in detail by C. Radlowska [18]. She confirmed the existence of one destruction level of Paleogene origin at 240—200 m above sea level. It is fossilised to the north, where it is covered by Oligocene sediments [19].

On the investigated profile corresponding to that of C. Radłowska a lack of continuity is clearly evident in the Paleogene surface which has been traced. It is obviously broken, and the line of the break lies along what is now the Kamienna Valley. The zone where the gradient changes is also generally speaking the boundary between the areas of occurrence of different geological facies (Fig. 6), since the east-west stretch of the Kamienna River is bounded on the north by an area 210—230 m above

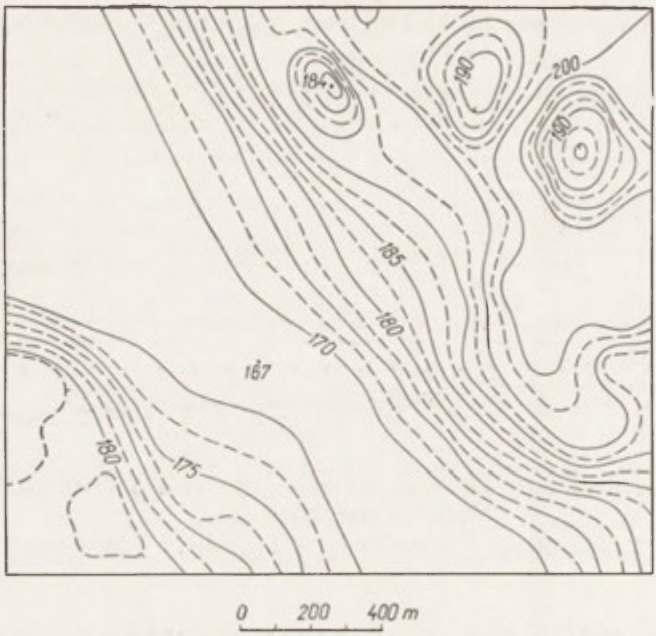


Fig. 7. Paleomorphological contour map of Eocene relief of Koszary—Kąty Denkowskie area

sea level, made up mainly of limestone or similar formations, while to the south sandstones, shales and clay predominate, and the altitude is about 260—280 m above sea level. Above this surface rise at first gentle and then steep slopes of quartzite outlier, which form the Jeleniów Ridge. It is interesting to speculate whether this incline structure of a Paleogene surface is the result of mountain-forming movements causing the differences in altitude or of development dynamics depending mainly on the type of rock subjected to gradation. It appears resonable to assume that chemical weathering in a very wet and warm climate must transform and wear down a limestone surface much more severely than one composed of sandstone, shale and clay. The best evidence for the varied severity of gradation processes depending on lithology is provided by the

Łysogóry quartzitic ridge, which has the character of a monadnock. It is also possible that the change in this surface may be connected with the extent reached by the Upper Cretaceous seas which, apart from the Turonian sea according to W. Pożaryski [17], stopped more or less along the line of the present Kamienna River between Starachowice and Ćmielów. The Tertiary differentiation of the land on the higher and lower parts undoubtedly had an influence on the further development of these areas, which today have a completely different relief and differently formed Pleistocene deposits.

The problem of the basic nature of the Paleogene planation surface on the forefield of the Holy Cross Mountains is not easy to solve. C. Radłowska [18] feels that it is difficult to accept it as a pedyplain since it came into being mainly in hot and humid conditions. M. Klimaszewski [7]

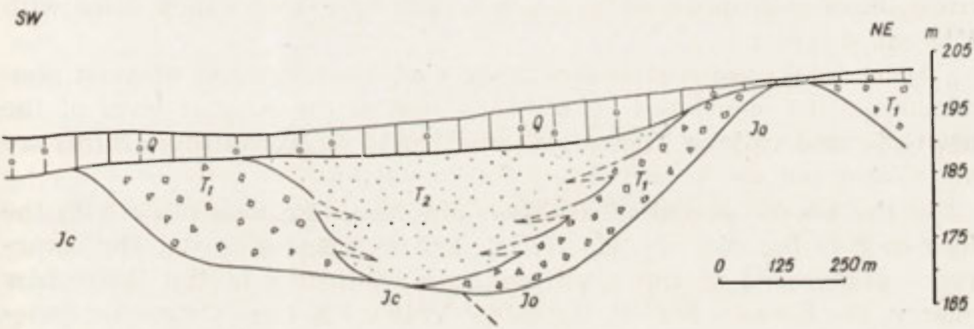


Fig. 8. Cross-section through Koszary valley near the villages of Koszary and Kąty Denkowskie

Jc — Callovian sandstone, Jo — Oxfordian limestone and dolomites, T_1 — Lower Tertiary (Paleogene) rock debris with clays and silts, T_2 — Upper Tertiary (Miocene) sands with rock debris, clays and silts admixture, Q — Quaternary boulder clay and sands

on the other hand thinks that it was not a peneplain, but embraced areas at different stages of development. W. Pożaryski [15] asserts that in Paleogene times the surface appeared more or less as it does today. It seems impossible to settle the problem definitely, since the surface in question is polygenetic and has been formed by many mechanisms acting at different times, often in widely varying climatic conditions. For this reason it is easier to say what the surface is not, than it is to accomodate its formation to one of two opposed conceptions — those of the peneplain and pedeplain, which are in a way theoretical constructions assuming the most appropriate climate for the processes involved. An additional difficulty in defining the character of a Paleogene plain in the Central and Southern Polish Uplands is their geological construction. For the most part they are made up of limestones, sandstones and shales, which according to L. C. King [6] do not lend themselves to the development of the type of relief described.

The formation of the plain surface provided a basis for the further development of its relief and the genesis of various forms, of which the oldest date from the Eocene period. Eocene erosion and karst forms (Fig. 7) are known on the northern slopes of the Holy Cross Mountains, as are a series of altered rocks which provide evidence of a subtropical climate with high temperature and humidity, in which intensive chemical weathering took place.

Numerous bore holes have provided evidence of Eocene valleys of depths down to 35 m and widths to 1.5 km. One of them is the Koszary fossil valley, in Callovian sandstone and Oxfordian limestones (Fig. 8). Its Eocene date may be assessed on the basis of its being filled with silicified limestone rubble, which again is split by a deep valley filled with Miocene deposits.

Apart from erosion processes this period has left traces of karst phenomena, which developed on the sides and at the summit level of the newly formed valleys. Their depth reached 15 m. Today these forms are not visible and are known only from bore holes.

In the Eocene period silicification processes also took place with the formation of limonite ore and ferrous and manganese crusts. The occurrence of deposits of this type has been confirmed in the Bodzechów quarry, the Koszary Valley, the Sudoł Valley NE from Ostrowiec Świętokrzyski, and in other places. The greatest controversy in the literature concerns the period of the silicification. The work of the present author confirms the old, more or less isolated view of W. Pożaryski [15] and the last view of S. Z. Różycki [20] as to the Eocene date of this phenomenon. The accumulation has been confirmed of a considerable amount of strongly silicified rubble in the karst and erosion hollows sited in the previously cut levels made up of Callovian and Oxfordian rocks. On the basis of the fauna identified it can be asserted that these rubbles derive from the Upper Jurassic rocks exclusively. They therefore form an allochtonic deposit, not an autochtonic one as M. Franczyk thought [3].

Brachiopod species predominate, Zeilleria of humeralis Rom. from the Astartian layer, Septaliphoria pinguis astieriformis (Wiśniewska) occuring in the Rauracian and Kimmeridgian, Septaliphoria astieriana (d'Orbigny) being guide fossil of the Rauracian, together with many others from the Kimmeridgian, Rauracian and Astartian. Silicification of the rocks must have taken place after a major gradation period (Paleocene) which uncovered the Upper Jurassic rock. and before their deposition in erosion and karst depressions (Eocene — Oligocene). So the process can be dated precisely and falls in the Eocene period. The rubble is cut by a new valley form filled with Miocene deposits, which fixes the date of accumulation.

A pre-Miocene date for the silicification in this area is also indicated by the character of the surface zone of Oxfordian limestone, covered with an allochtonic series of rubbles, followed by sands and Miocene clays. M. Franczyk carried out a geological survey of the Koszary — Kąty Denkowskie area [3] which is relevant here. She found that the Oxfordian limestone shows a very strong siliceous and dolomitic metasomatosis. The siliceous metasomatosis shows itself according to M. Franczyk most strongly in the upper parts of the limestone, while the dolomitic type goes down to a depth of 55 m.

How far the Oligocene sea reached is open to discussion. Although there are certain indications that it extended further than is now shown by the occurrence of a dense cover of Oligocene sand, the problem has not yet been finally decided. It may be that the valleys that were formed in the Eocene period still existed in the Oligocene and were filled with rubble then.

After the relief was dissected, which the present author considers took place in the Eocene period, and after its leveling by accumulation in the hollows (Eocene — Oligocene), the renewed activity of relief-forming processes is noted. They were probably initiated by one of the phases of mountain-forming movements of the Upper Oligocene or Lower Miocene periods. At the same time the orogenetic movements in the Carpathians reached their maximum.

Development of relief in the Neogene period

Traces of erosion phenomena at the beginning of the Neogene period are clearly recorded. The existence of Miocene valleys has been confirmed along the lines of old Eocene erosion depressions (Fig. 9). The direction of descent of these valleys was from NW to SE and they probably opened into the Miocene sea which lay to the south and east of the area under discussion (Fig. 10). The depth of the Miocene valleys sometimes exceeded that of the Eocene ones. They ran more or less parallel to one another. Some are visible in the present day relief, while others are fossil forms and known only from bore holes. The farthest to the north is the "proto-Sudoł" valley on the same site as the present one. Its width reached 0.7 km, with a depth exceeding 35 m, the bottom in the neighbourhood of Sudoł village was about 162 m above sea level. The valley cut the line of the present Kamienna River at about the site of Ruda Kościelna and ran further to the SW along the present dry gullies near Folwarczysko village.

The second, Koszary Valley, is not visible in present relief. Its existence has been confirmed only by means of bore holes. On the surface some evidence of its occurence may perhaps be provided by the series of dunes at some distance from the Kamienna river which contain an appreciable admixture of Miocene sands. The Koszary Valley cut the valley of the Kamienna river in the same way as the pre-Sudoł valley

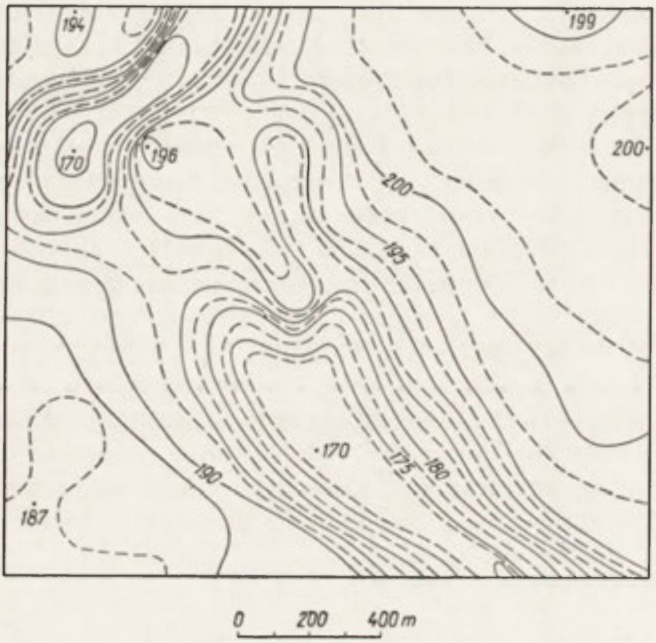


Fig. 9. Paleomorphological contour map of the Miocene relief of Koszary—Kąty Denkowskie

and continued in the direction of Ożarów along the wide dry Korycizna Valley [9], and then along the upper stretch of the Czyżów Valley. In the neighbourhood of Koszary the bottom of the valley lay at an altitude of 170 m above sea level.

The third valley which is probably Miocene is today completely exhumed. This is the valley of the Kamienna River from Kunów to Ćmielów. It may be dated from the Tertiary on the basis of the remnants of Miocene sands in its side near the villages of Kraszków and Wólka Bodzechowska. The southern stretch of the Kamienna from Ćmielów to Bałtów had not yet come into existence in the Miocene and the river probably flowed along what is now the wide dry Wyszmontów Valley and the lower stretch of the Gierczanka Valley.

The watersheds between the Miocene valleys are visible today as ridges running NW — SE at 270 m (Koszary elevations) and 224 m (Maksymiliany elevations) above sea level. These hills do not have a cuesta character, as to the north of the area under discussion, nor that of typical monadnocks, resulted from their geological structure. These forms are connected with denudational processes, in turn connected with the existence of deep valleys.

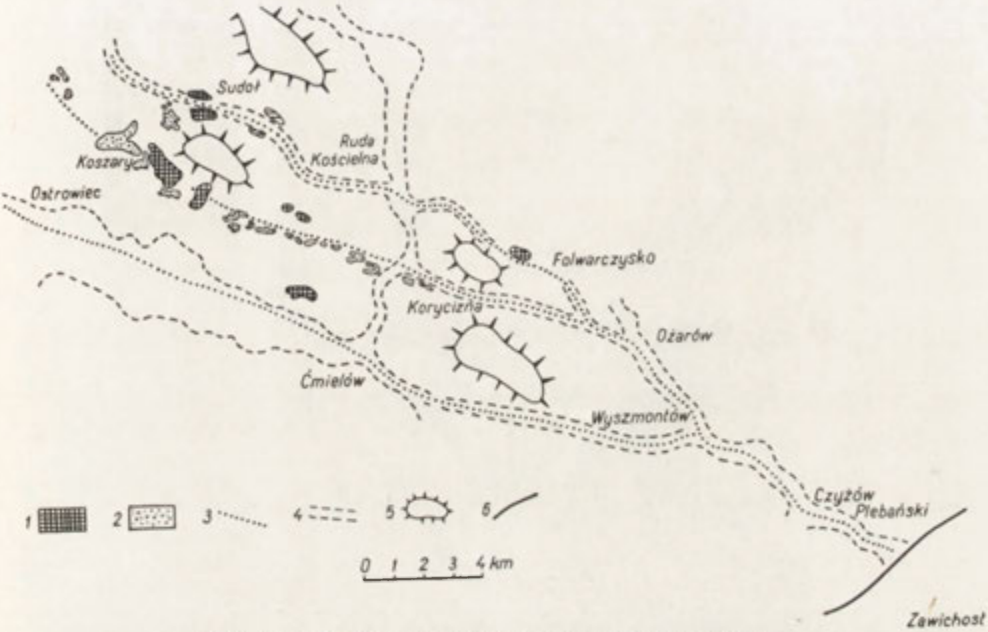


Fig. 10. Sample reconstruction of Miocene valleys

1 — Miocene terrestrial sands, 2 — sand dunes, 3 — presumed course of Miocene rivers, 4 — present day course of valleys, 5 — watershed elevations, 6 — shore of Miocene Sea

Apart from the above mentioned processes, karst phenomena show evidence of very energetic activity in the Miocene. In the area under discussion funnel forms predominate (Fig. 11) sited in the upper stretches of the sides of the Miocene valleys. They often occur on the sites of old karst forms of well type. Some of the funnels are fossilised, others have been reproduced in Quaternary material not itself subject to karst phenomena, and are visible in the present day relief. Examples can be seen along the Sudoł Valley (Fig. 12).

The variety of processes occurring in the Miocene period, demanding different climatic conditions, is striking. The changeability of the Miocene climate shows itself also in the lithological development of Miocene sediments, which have been deposited in very varied series. Miocene deposits are among the best developed and documented of Tertiary deposits on land.

Miocene deposits occur in the form of allochtonic and autochtonic deposits. In the area under discussion these are: well washed quartz sands, mainly white, grey or light yellow; next fat clays, plastic, of various colours from white to pink, grey, greenish and black; and next various

Photo D. Kosmowska-Suffczyńska

Fig. 11. Karst funnel in Bodzechów quarry filled with Miocene sands and clays

types of silt, also of various colours. Fragments of Miocene wood, Glyptostroboxylon tenerum [21], are found in the quartz sands and clays. Some authors include rubble of appreciable thicknesses which lie under the sands and clays to the Miocene deposits (according to the author they date from the Paleogene).

The Miocene accumulation played an important role in the formation of the Tertiary relief. Terrain of exceptionally varied relief and large depressions was changed by the filling up of the hollows into an area of plains, above which rose the old watershed elevations.

Photo D. Kosmowska-Suffczyńska

Fig. 12. Karst kettle with stagnant water in the Sudoł valley

The tectonic movements linked with the formation of the Carpathian mountain complex should be remembered in connection with the development of the Miocene relief. In the area under consideration it is difficult to determine the period and nature of the possible dislocations. They could have caused the subsidence of the areas to the north of the east-west stretch of the Kamienna River or the elevation of the areas to the south of it, and so interrupted the continuity of the Paleogene surface. It is possible that the high position of the clays described as probably Helvetian is due to these dislocations. W. Pożaryski [14] is inclined to regard the Lower Miocene movements as the origin of the dense network of fault lines in the part of the Mesozoic sheath nearer the Holy Cross Mountains made up of Triassic and Liassic deposits. M. Klimaszewski [7] writes that in the Miocene the Holy Cross Mountain range was lifted, divided, and partially reduced to 300 m above sea level. In conclusion the view of C. Radłowska [18] appears reasonable, that the NE border of the Holy Cross Mountains lay as it were in the shadow of the major tectonic changes which affected the south and central parts of the mountains.

In the Pliocene the whole of Southern Poland and the central uplands were land. According to the view hitherto generally accepted, the lowlands were covered by the large Pliocene Lake which has left its traces in the clays known as variegated. S. Z. Różycki [20] gives a new idea as to how these clays came into being. According to him there was no lake in Central Poland but a swampy area, to which a vaste amount of clay material was washed down. This originated with Tertiary weathering of rocks in the Małopolska uplands and was carried by streams formed by torrential rains in the warm dry Pliocene climate. The steppe type climate of the Upper Pliocene is confirmed by relatively numerous fauna sites.

The marks left by the Pliocene climate are of two types. One is associated with gradation processes which lead to a lowering of the surface. The other involves the exhumation of old erosion forms and the development of new valleys.

The gradation processes led to the uncovering on the same surface of Tertiary deposits of different ages and litology, which had filled the depressions in the Mesozoic basement rock. The occurrence of Miocene deposits (to the north of Ostrowiec Świętokrzyski) to an altitude of 200 m above sea level, means that this was the lower boundary of Pliocene denudation. The survival of karst and erosion forms dating from the Miocene indicates that the gradation was relatively mild. This is also confirmed by the relatively small thickness of sharp-edged post-Miocene rubbles. However it is possible that these rubbles are

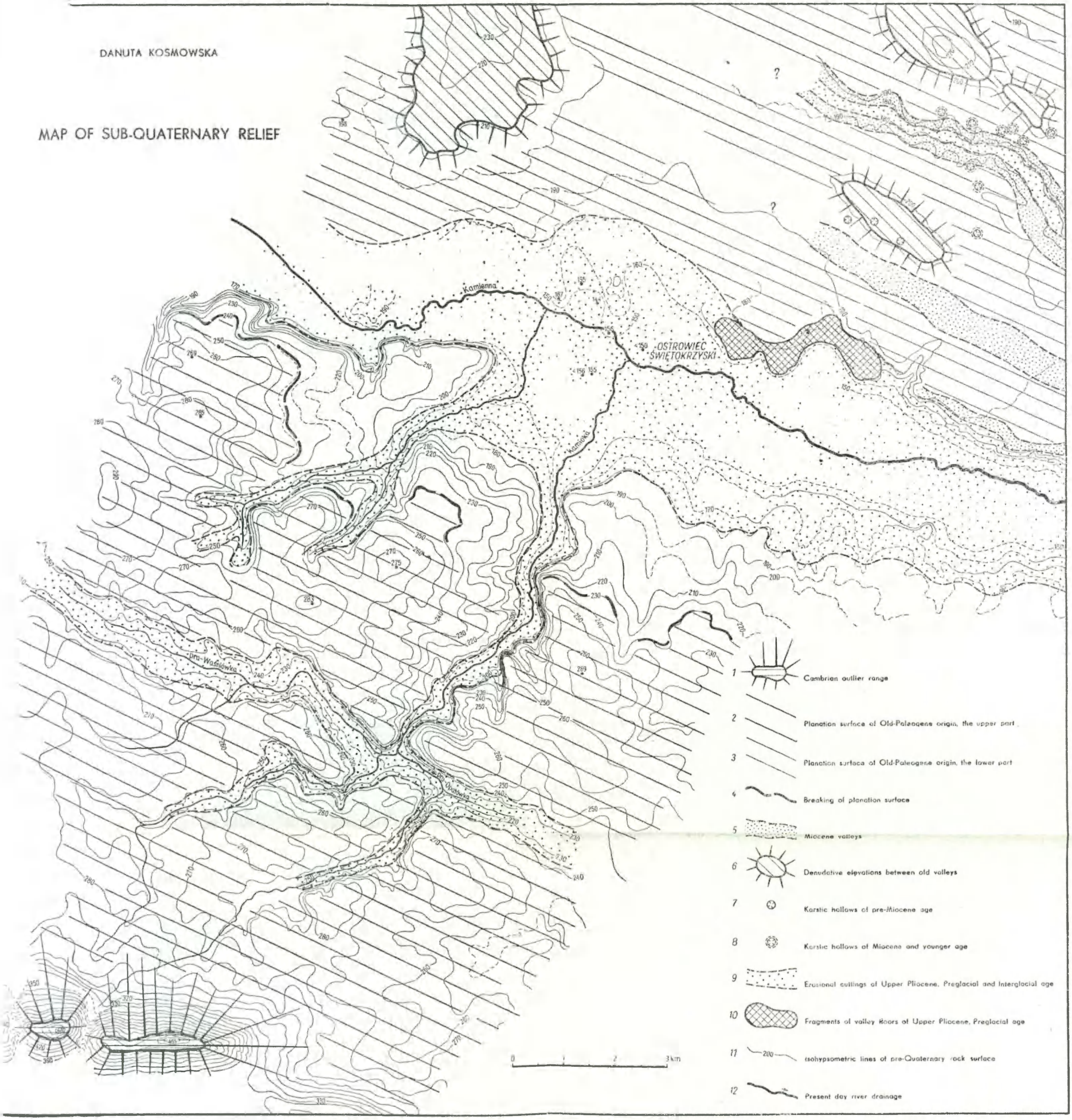


Fig. 13. Map of sub-Quaternary relief

associated with the advance of the ice cap and are somewhat more recent than the Pliocene. Certainly the Pliocene climate, which was markedly dry, did not cause severe gradation in limestone regions. According to Birot [1] limestone is more resistant than granite in a hot dry climate and subject to denudation processes at an appreciably slower rate, leaving surfaces exposed at a greater height.

Pliocene denudation did not efface the main features of the relief in this region which had come into existence in the Paleogene and Miocene, and it is even possible that it emphasised some of them. Pliocene gradation is not here genetically connected with the Pliocene planation surface, which did not cover this area.

The Pliocene planation surface of the forefield of the terrain in question was considered in detail by C. Radłowska [18]. According to her the Lower Pliocene planation surface has the features of a pedyplain. Its altitude is 160 m to 180 m above sea level and it reaches to the foot of the Paleogene surface.

The formation of deep valleys is generally associated with the Upper Pliocene period. The increased erosion processes may be put down to the Rhone phase of mountain-forming movements. At this time the deep fault of the Vistula on the stretch from Zawichost to Puławy [16], which stimulated erosion on the Uplands, must have come into existence.

The river network on the NE surrounding of the Holy Cross Mountains is considered by C. Radłowska. She writes on the formation of the lower Kamienna River, Krępianka and Iłżanka valleys and the origin of the Kamienna gap in the stretch from Ćmielów to Bałtów. These rivers must have discharged into the gate stretch of the Vistula Valley and the author assigns them to the Upper Pliocene Age. She states that Upper Pliocene erosion reached a depth of 40—50 m in the area she investigated, but emphasises that the confirmed fragments of Upper Pliocene valley bottoms always occur at a higher level than that of the present day valleys.

E. Mycielska-Dowgiałło [13] mentions the existence of fossil Upper Pliocene valley levels in the upper course of the Koprzywianka and Gorzyczanka rivers in the SE part of the Sandomierz Upland. R. Czarnecki [2] writes of the pre-Quaternary Opatów Valley in the Sandomierz Upland.

Pliocene erosion is responsible for the removal of the Miocene deposits from the Kamienna Valley. They can now be found only in poorly preserved traces high on the sides of the valley.

In the valley of the middle course of the Kamienna River, on its north bank about 3 km east of Ostrowiec Świętokrzyski, a rocky "washboard" occurs which by analogy with the lower Kamienna River and

Table I

Comparison of pre-Quaternary relief with present day relief

Number on map	Pre-Quaternary elements of relief	Present day relief
1	Cambrian outlier ridge, 460—430 m above sea level.	Jeleniów Range of the Holy Cross Mountains.
2	Planation surface of Old-Paleogene origin — upper part made up of shales, clays and sandstone, 280—260 m above sea level.	Loess upland.
3	Planation surface of Old-Paleogene origin — lower part made up of limestone, 230—210 m above sea level.	Denudational plain.
4	Boundary between upper and lower surface.	South slope of Kamienna River valley.
5	Valleys cut in debris or rocky Jurassic floor with an accumulation of Miocene sands.	Valleys: Sudoł and Kamienna.
6	Denudational elevation between old valleys.	Elevations: Koszary, Maksymilianów and Karczma.
7	Pre-Miocene karst forms.	Fossil forms not visible in present day relief.
8	Miocene and younger karst forms	Partially visible, mainly along the Sudoł valley.
9	Erosional cuttings of Upper Pliocene, Preglacial and Interglacial age, with accumulation of Quaternary sediments.	Valleys: Sudoł, Kamienna, Kamionka, pre-Waśniówka, pre-Opatówka and others.
10	Fragments of valley floor of Upper Pliocene and Preglacial age.	Flattening on north slope of Kamienna River valley in vicinity of Denków and Wólka Bodzechowska.

other valleys further to the north may be dated in the Upper Pliocene. It is 175 m above sea level, about 5 m higher than the Kamienna meadow terrace, about 20 m higher than the rock bottom hidden under the present Kamienna Valley, and about 14 m under the rocky summit level.

Exhumation of the old relief took place in the Sudoł Valley as in the Kamienna Valley. In the former the cut was of the order of 15 m and one may judge that the Pliocene erosion caused the separation of the Miocene deposits on the remnants occurring on the sides and bottom of the valley. The valley found to have existed in the stretch Koszary — Kąty Denkowskie was at that time completely inactive and it is not visible in the relief of today.

In the Pliocene new deep valleys also came into existence. One of them was the Vistula Valley from Zawichost to Puławy which has already been mentioned, as has the Kamienna Valley between Bałtów and Ćmielów. No doubt the southern valley of the Kamionka River and other valleys discharging into the Kamienna were also formed then. The bottoms of the Pliocene valleys lay somewhat higher than at present, and appreciably below the rock surface at the summit level.

In the area under discussion no deposits have been found which could with certainty be connected with the pre-glacial period.

Comparing the present relief with the pre-Quaternary one may state that the main features of the NE slope and surrounding of the Holy Cross Mountains came into existence in the Tertiary (Tabl. I, Fig. 1). The exhumed Tertiary relief is easily seen in the area lying to the north of the Kamienna River between Ćmielów and Kunów. To the south of the Kamienna the old Tertiary relief is covered by a relatively thick mantle of Quaternary formations, of which loess is the thickest. These products do not in any fundamental way alter the main elements of relief originating in the Tertiary, but they may be said to reproduce them 20 to 40 m higher up [10].

Institute of Geography
Polish Academy of Sciences
Warsaw

References

[1] Birot P., Essai sur quelques problèmes de morphologie générale, Centro Estudos Geogr., 8, Lizbona 1949.

[2] Czarnecki R., Studia nad krajobrazem geograficznym środkowej części dorzecza Opatówki (A study of the Geographical Landscape of the Central Part of the Opatówka Basin), Doctorate thesis in typescript Warsaw University, Warszawa 1964, 665 pp.

[3] Franczyk M., Zdjęcie geologiczno-techniczne terenów krasowych okolicy Koszar i Kątów Denkowskich koło Ostrowca Świętokrzyskiego (Technical Geological Survey of Karst Areas in the Neighbourhood of Koszary and Kąty Denkowskie near Ostrowiec Świętokrzyski), Arch. Dok. Źródł. IG, Warszawa 1954.

[4] Gilewska S., Rozwój morfologiczny wschodniej części Wyżyny Miechowskiej (Sum. The geomorphological development of eastern part of the Miechów Plateau), Prace geogr. IG PAN, 13, Warszawa 1958, 90 pp.

[5] Gilewska S., Rzeźba progu środkowotriasowego w okolicy Będzina (Sum. Relief of the Midtriassic escarpment in the vicinity of Będzin), Prace geogr. IG PAN, 44, Warszawa 1963, 135 pp.

[6] King L. C., Canons of landscape evolution, Bull. Geol. Soc. Am., 64, 1953, pp. 721—751.
[7] Klimaszewski M., Rozwój geomorfologiczny terytorium Polski w okresie przedczwartorzędowym (Sum. The geomorphological development of Poland's territory in the Pre-Quaternary Period), Przegl. Geogr., 30, 1, Warszawa 1958, pp. 3—33.
[8] Kosmowska D., Studia nad geomorfologią i hydrografią dorzecza górnej Opatówki (A Study of the Geomorphology and Hydrography of the Upper Opatówka Basin), Dok. Geogr. IG PAN, 6, Warszawa 1958, pp. 83—142.
[9] Kosmowska D., Objaśnienia do mapy hydrograficznej 1 : 50 000 ark. M 34—44 Ożarów (Explanation of the 1 : 50 000 Hydrographic Map), Dok. Geogr. IG PAN. 2, Warszawa 1963, 68 pp.
[10] Kosmowska D., The paleomorphology of loess gullies. Report of the VI INQUA Congress, Łódź 1963, pp. 181—187.
[11] Kosmowska D., Rozwój rzeźby w trzeciorzędzie okolic Ostrowca Świętokrzyskiego i Ćmielowa (Sum. Tertiary evolution of relief of region of Ostrowiec Świętokrzyski and Ćmielów), Prace geogr. IG PAN, 54, Warszawa 1966, 114 pp.
[12] Lencewicz S., Pisma wybrane z geografii fizycznej Polski (Selected Texts on the Physical Geography of Poland), Warszawa 1957, 486 pp.
[13] Mycielska-Dowgiałło E., Rozwój geomorfologiczny południowo-wschodniej części Wyżyny Sandomierskiej w górnym miocenie i pliocenie (The geomorphological evolution of the south-east part of the Sandomierz Upland in the Upper Miocene and Pliocene). Przegl. Geogr.. 37, 4, Warszawa 1965, pp. 638—649.
[14] Pożaryski W., Jura i kreda między Radomiem, Zawichostem i Kraśnikiem (Jurassic and Cretaceous between Radom, Zawichost and Kraśnik), Biul. Państw. Inst. Geol., 46, Warszawa 1948, 1—141 pp.
[15] Pożaryski W., Odwapnione utwory kredowe na północno-wschodnim przedpolu Gór Świętokrzyskich (Decalcified Cretaceous Products on the North East Foreland of the Holy Cross Mountains), Biul. Państw. Inst. Geol., 75, Warszawa 1951, 1—70 pp.
[16] Pożaryski W., Plejstocen w przełomie Wisły przez wyżyny południowe (Sum. The pleistocene in the Vistula gap across the Southern Uplands), Prace Inst. Geol., 9, Warszawa 1953, 114 pp.
[17] Pożaryski W., Atlas geologiczny Polski. Zagadnienia stratygraficzno-facjalne. Kreda (Sum. Geological Atlas of Poland, Stratygraphic and facial problems), Inst. Geol., Warszawa 1962, 17 maps.
[18] Radłowska C., Rzeźba północno-wschodniego obrzeżenia Gór Świętokrzyskich (Res. Relief de la bordure Nord-Est des Montagnes de S-te Croix), Prace geogr. IG PAN, 38, Warszawa 1963, 178 pp.
[19] Radłowska C., Fossil pleistocene relief in central Poland, Geogr. Polon., 6, Warszawa 1965, pp. 75—83.
[20] Różycki S. Z., Guide-Book of Excursion from the Baltic to the Tatras, part II, 1, Middle Poland, INQUA VI Congress Poland 1961, 116 pp.
[21] Samsonowicz J., Objaśnienie arkusza Opatów ogólnej mapy geologicznej Polski w skali 1 : 100 000 (Explanation of the Opatów Sheet of the 1 : 100 000 General Geological Map of Poland), Państw. Inst. Geol., Warszawa 1934, 117 pp.

ACCUMULATION IN STAGNANT ICE, WITH THE SPITSBERGEN GLACIERS AS EXAMPLE

STEFAN JEWTUCHOWICZ

During his stay on Spitsbergen in 1959, the author observed accumulation processes on several glaciers (Fig. 1). These glaciers are fringed by wide zones of stagnant ice, usually covered by a layer of debris. Initially, while the layer is thin, rock fragments are warmed more readily

Fig. 1. Map showing position of the glaciers discussed
1 — Bungebreen, 2 — Keilhaubreen

and hasten the melting of te ice. Later, the increased thickness of the layer of rock fragments shields the ice against rapid decay. The uneven thickness of the debris layer, as well as the unequal exposure of different

Fig. 2. Bungebreen. Surface of stagnant ice zone

Fig. 3. Bungebreen. Accumulation in open ice crevasses

parts of it, leads to variations in the rate of melting and evaporation, resulting in the formation of rills, pinnacled ice cones, crevasses and kettles. (Fig. 2).

Accumulation in the stagnant ice zone is by no means limited to the glacier margin, but proceeds simultaneously all over the zone. This process has also been discussed as it occurs on Spitsbergen by M. Klimaszewski [4].

Crevasses in the ice give rise to marked differentiation in the process of accumulation. Open crevasses are filled in by surface moraines (Fig. 3). In shallow crevasses a subsequent phase of ablation may displace the debris layer on the ice surface. Large quantities of water from melting ice flush the debris material away. In deep crevasses, where larger masses of debris have accumulated, ablation often fails to destroy the forms that have developed. Even so, the lowering of the base of these forms during melting of the buried ice causes some distortion in the structure of the deposit.

More pronounced accumulation can be found at high ice walls. During intensified ablation, rock material slides down over the ice wall forming ridges or debris cones leaning against the ice wall at the bottom. Melting of the ice and the ensuing loss of support for the deposits bads to folds in the deposit layers, slides and slumps, and such processes produce structural deformation in the deposits. If a ridge or a cone has been resting on ice, its melting leads in turn to settling and so to additional deformations of the previously disturbed strata.

In the initial stage of accumulation, the rock material laid down on the ice becomes water-logged and flows downward as mud streams. The multiple displacements of debris during ablation, taking place at numerous sites in the stagnant ice zone, lead to a gradual leveling of the surface (Fig. 4).

In glacier sections only slightly inclined, the ice melting of underneath a moraine causes the formation of numerous depressions in the shape of kettles. In the final stage of the morphological evolution of the stagnant ice zone, melt-kettle processes lead to the formation of isolated hollows often filled with water; this produces landscapes of lake-district character (Fig. 5).

In a zone of stagnant ice, water flow takes place either over the ice surface or subglacially. The greatest amount of water leaves the glacier by surface flow. Any differentiation in the intensity of ablation causes irregularities of water flow. The streams are shallow, the amount of flow in their channels depending on the intensity of ice melting. Where a fluvioglacial stream meets an obstruction to its flow, it burrows its way through the ice (Fig. 6). Every tunnel hollowed out by water is

Fig. 4. Bungebreen. Surface leveled by flow of debris
1 -- leveled surface of ablation moraine, 2 — morainic ridge, 3 — outwash

Fig. 5. Bungebreen. Moraine surface, after melting of ice covered by debris
1 — moraine, 2 — outwash

Fig. 6. Bungebreen. Transition from surface flow tu subglacial drainage

Fig. 7. Keilhaubreen. Glacier margin
1 — crevasse forms emerging from the ice

Fig. 8. Keilhaubreen. Surface forms in glacier forefield
1 — accumulation ridge, formed at line of glide plane, 2 — ridges squeezed into ice crevasses

gradually widened by the melting of ice from inside. Simultaneously melting proceeds from the surface down. After a time, the roof of the ice tunnel thins down and breaks under the load carried. Such caving-in causes marked structural deformations in the overlying deposit layers.

A remarkable relief form may at present be seen in the forefield of Keilhaubreen, a glacier extending along the east side of Sörkapp. The Keilhaubreen snout is low (Fig. 7). In spite of the glacier's retreat no debris layer covers the ice here, as is the rule on other Spitsbergen glaciers. This indicates that the interior of Keilhaubreen contains little rock material. So the forms extending from the ice must rather be ascribed to material accumulated at the glacier base.

The forefield of Keilhaubreen shows low ridges, running gridwise almost at right angles made up of boulders and fine gravel (Fig. 8). Some of these ridges are marked merely by strips of small quantities of debris (Fig. 9); such convex forms are separated by flat stretches filled with mud and fine sand.

The gridewise pattern of the ridges in the Keilhaubreen forefield probably give a true reflection of the glacier's structure. The ridges that run perpendicular to the main axis of the glacier tongue probably developed from material accumulated along glide planes (Fig. 8). The ridges

Fig. 9. Keilhaubreen. Surface forms in glacier forefield
1 — debris squeezed into ice crevasse, 2 — debris strip, produced at line of glide plane

parallel to the axis on the other hand, must have been squeezed into bottom crevasses of the glacier during its stagnation. The height of these forms, not exceeding 2 m, seems to prove that the crevasses must have been relatively narrow.

The examples of glacial accumulation cited above show that under conditions of stagnant ice this process leads to a differentiation in land relief. Ridges, cones and lakes may occur in close proximity to flat areas. Accumulation takes place principally on the ice surface. Afterwards, its melting out is the main cause of structural deformation of the deposits. Under certain conditions of accumulation, the pattern of the land-forms may reflect the previous structure of the glacier.

Section of General Geomorphology
Institut of Geography
Polish Academy of Sciences
Łódź

References

[1] Ahlmann H. W., Über das Entstehen von Toteis, *Geolog. Foren. Förh.*, 60, 3, 1938
[2] Flint R. F., The stagnation and dissipation of the last ice sheet, *Geogr. Rev.* (1929).

[3] Jewtuchowicz S., Studia z geomorfologii glacjalnej północnej części Sorkappu (Glacial morphologic studies in nothern Sorkapp. The morphological effect of glacier ablation), *Acta Geogr. Lodz.*, 11, Łódź 1962.

[4] Klimaszewski M., Studia geomorfologiczne w zachodniej części Spitsbergenu między Kongs-Fjordem a Eidem-Bukta (Geomorphological research in West-Spitsbergen, between Kongsfiord and Eidem-Bukta) *Zesz. Nauk. Uniw. Jagiellońskiego, Prace geogr.*, 1, 1960.

[5] Ward W. H., The physics of deglaciation of central Baffin Island, *Journ. of Glaciol.*, 2, 1952.

GEOGRAPHIA POLONICA 13, 1968

A NEW METHOD OF DETERMINING CLIMATIC CONDITIONS IN MOUNTAIN REGIONS (WITH THE WESTERN CARPATHIANS AS EXAMPLE)

MIECZYSŁAW HESS

Any investigation of climatic conditions in mountain regions is always fraught with difficulties. The reason is not only the scarcity of climatic stations, but principally the great variety of climatic phenomena. E. Romer seems to have been fully justified in ommitting the mountains from his synthesis of Poland's climate [20] for this very reason. In order to determine the mountain climate clearly, the macroclimatic differentiation of the mountains in their vertical profile (their climatic floors), must first be recorded and then the mesoclimatic differences observed at identical altitudes above sea level (such as the mesoclimates of dales, valleys, peaks, plateaus, slopes of different exposures, etc. must be classified, together with microclimatic mosaic depending on differences in the vegetation cover of the land. A number of studies have been carried out on these three fundamental topics by the Climatological and Meteorological Laboratory of the Jagellonian University (M. Hess [7, 8, 11, 12], B. Obrębska-Starklowa [17, 18] and T. Niedźwiedź [16]), aiming at a detailed examination of the climate of the Polish Carpathians.

The study of macro-, meso- and microclimatic conditions occurring in mountain regions would entail considerable effort and expense, so in spite of its importance very little work has hitherto been done on the climate of mountains. The vast majority of relevant papers deal with individual elements of the climate and with specific points (climatological stations), whereas little attention has so far been paid to the spatial differentiation of the climate. This also applies to the Polish Carpathians, although here the network of climatological stations is one of the densest in the world.

In order to learn the changes undergone by the climate with growing altitude, the author applied a method in his paper dealing with climatic floors in the Carpathians [7] which enabled him to define the values of the individual climatic elements and indices at any place of the vertical profile of these mountains. This method of analyzing quantitative data was not limited to climatological stations nor to descriptions of the climate only in their immediate vicinity, that is, to a finite number of points. The records of the stations were used to construct a visual, physically justifiable spatial picture of the differentiation of the climate. In this way it was possible to determine the altitudes at which the various climatic elements attain values which correspond to the boundaries between the climatic stages distinguished. At the same time the quantitative interdependence was determined between many climatic elements and indices. This made it possible to distinguish definite climatic floors on the basis of a complex function, derived from a wide range of climatic elements and parameters.

In laying down the coditions which this function should fulfill, it was kept in mind that it should be unambiguously defined, simple and comprehensive — in other words, it should faithfully reflect as many climatic elements and parameters as possible. It was found that all these conditions are met very well by the mean annual temperature. This became the backbone of an entire classification system, around which are gathered a large number of climatic elements and indices, connected with the mean annual temperature by close functional interdependence. The author was able to establish the usefulness of the mean annual temperature — in its quantitative interrelation with other climatic elements and indices — for defining the climatic conditions of a variety of sites and regions. The necessary data is easily accessible referring to one of the components of the thermal regime [8, 10]. It is even possible to reconstruct many of the climatic elements and indices of past geological periods [9].

The next step was felt to be the study of the climatic differentiation brought about by differences in land relief. It was therefore necessary to study the mesoclimates of convex and concave land forms and slopes of different exposures. The qualitative effect of land relief and exposure on local climatic modifications are fairly well known, but little attention had been given previously to the quantitative differentiation of the climate due to differences in land forms, although this is of high importance for many domains of pure and applied science. Problems like these are encountered whenever the climatic usefulness of a region for various economic purposes has to be assessed. Knowledge of the quantitative differentiation of the climate due to land relief and exposure is also necessary for preparing detailed climatic maps.

Previous publications dealing with this problem [1—4, 6, 13—15, 17—19, 21] were mostly limited to a number of examples illustrating this differentiation under selected weather conditions, taking only single weather elements and very limited areas into consideration. The data given does not lead to any general idea of the rules governing the differentiations in question.

As generally accepted, "climate" means the weather regime over a period of many years, while the comprehensive result of all weather conditions is the "annual course" or the "annual values" for individual climatic elements. This means, that the characteristic of the mesoclimates for different land forms cannot be fully described by giving a few examples of differentiation under selected weather conditions and for particular climatic elements. Further, in publications of this type known to the author, comparisons have been made between values of given parameters from stations situated at different altitudes, the effects of which required elimination. Attempts to do this, especially for stations situated in different land forms and on slopes of dissimilar exposure, usually led to faulty conclusions. At the same time, the failure to eliminate the effect of altitude differences which were usually present, rules out any pure account of the influence of different land forms on the climate. Moreover, it should be remembered that mesoclimates of individual elements of land relief develop under definite macroclimatic conditions and are closely dependent upon them. It must therefore be assumed that mesoclimates of similar land forms occuring in different macroclimates (that is, in different climatic floors) cannot be analogous in character.

In previous papers [11, 12] the author has tried to define quantitatively the differences in Southern Poland between mesoclimates of convex and concave land forms and of mountain slopes of different exposure, bearing in mind the very divergent macroclimatic conditions of this mountain region. This proved possible in view of the dense network of climatological stations situated at different altitudes and within different land forms. Thus the author was able to select suitable pairs of stations placed at similar and often identical altitudes, but within different forms of land relief (on convex and in concave land forms, or northern and southern slopes). This made possible a straightforward quantitative assessment of the influence of land relief and exposure on the climate. For determining the effect of the land relief [11] the author made use of the 1954-1958 annual values of individual climatic elements and indices recorded at 8 pairs of stations situated in the vertical profile of Southern Poland, from 200 m (Vistula valley) to 1400 m above sea level (Morskie Oko in the Tatras). In each pair, one station was situated on a convex land form (a peak, a plateau, a flattened ridge), the other in a concave form (a valley, or a basin bottom). To establish the influence of the exposure on the climate [12] analogous values were utilized, recorded at 15 pairs of stations situated in similar altitude classes. In each of these 15 pairs of stations one has northern, the other southern exposure [1]. These data provided the material for a quantitative description of the mesoclimates of convex and concave land forms as well as of sites of southern and northern exposures, all under markedly divergent macroclimatic conditions. This was possible because the vertical profile of Southern Poland lies within three climatic floors: a moderately warm, a moderately cool, and a cool floor. For comparison it might be added that the Carpathian climatic floors correspond to the climatic differentiation found in the European lowlands between 50° and 70° geographical latitude [7].

Analysis of the abundant material assembled (and presented in the papers previously mentioned) convinced the author, that a close interdependence exists between the values of the investigated climatic elements and indices obtained from convex and concave land forms and from exposures on northern and southern slopes, and that these dependences are linear. On the basis of these regularities a number of equations have been developed (see [11], [12]) illustrating by linear functions the annual values of many elements and indices. The climate in valleys of dales can be deduced from appropriate data obtained from correlated convex land forms (or vice versa). In the same way phenomena on southern slopes can be predicted from records obtained on northern slopes (or vice versa), provided they have been collected from stations situated at identical altitudes. In the paper under discussion the conclusion was also reached that the validity of these interdependences applies to wide categories, taking in all convex and concave land forms and all northern and southern slopes occurring in the vertical profile of Southern Poland, ranging from the Vistula valley upwards to some 1600 m above sea level.

It was also concluded that the differences in values found on the different relief forms are by no means constant but dependent on altitude — that is, on macroclimatic conditions.

This discovery prompted an attempt to define the character of the interdependence between the mesoclimatic values resulting from mountain relief, and those derived from macroclimatic conditions. This meant

[1] The author did not take into consideration any other exposures, nor different slope inclinations nor differences in the size of concave relief forms, because suitable comparative data were lacking. These are problems which can not be studied on the background of the whole mountain massif, because they would require a special system of measuring stations. This also explains why this problem is not dealt with in the present paper.

finding whether the magnitude of the mesoclimatic differences (between convex and concave land forms or between northern and southern slopes) can be related quantitatively to the macroclimatic conditions. The discovery of a dependence of mesoclimatic on macroclimatic conditions should, in turn, enable us to define the mesoclimatic differentiation on the basis of given macroclimatic conditions. Earlier in this paper it was mentioned that the mean annual temperature is a useful parameter in this sort of work.

So on the basis of data given in [11] and [12] the author attempted to establish the interdependence between the mean annual temperature and the values of the various climatic elements and indices for convex and concave land forms and for slopes of northern and southern exposures. Obviously only those parameters were taken into consideration, which are closely linked to the mean annual temperature. In the papers cited [11], [12] correlations with precipitation and wind action in the different land forms were also presented. In the present paper the relation between temperature and precipitation is omitted because it is contingent upon agencies of a dynamic character. Apart from this, the study is limited to annual values of the different climatic elements and indices.

In Figs 1, 2, 3 and 4 examples are given of the interdependence between the mean annual temperature and certain components of the thermal regime on convex and in concave land forms and on slopes with norther and southern exposures. In the range of the vertical profile of the Western Carpathians, from 200 m to 1700 m above sea level, the mean annual temperature varies from some 8° to some 1°, with relatively strong divergences depending on forms of land relief (Fig. 5). For this range the relations between the mean annual temperature and other climatic elements and indices shown in the Figures mentioned and in Tables 1. and 3. are valid. These data do not refer, however, to the highest part of the Tatra Massif, because there are not enough stations there to enable us to ascertain the relevant interdependences.

Straight-line relationships are found between the mean annual temperature and the values of the discussed climatic elements and indices occurring on convex and in concave land forms and on slopes of northern and southern exposures. Thus these interdependences can be defined by the general straight-line equation $y = ax + b$, where the independent variable x equals the mean annual temperature (t), and the dependent variable y represents the different climatic elements and indices occurring at the respective land forms. Close correlations exist between all these values as shown by the coefficients obtained.

Table 1. gives the correlation indices (r) and the equations computed by the least squares method, from which one can obtain the annual values

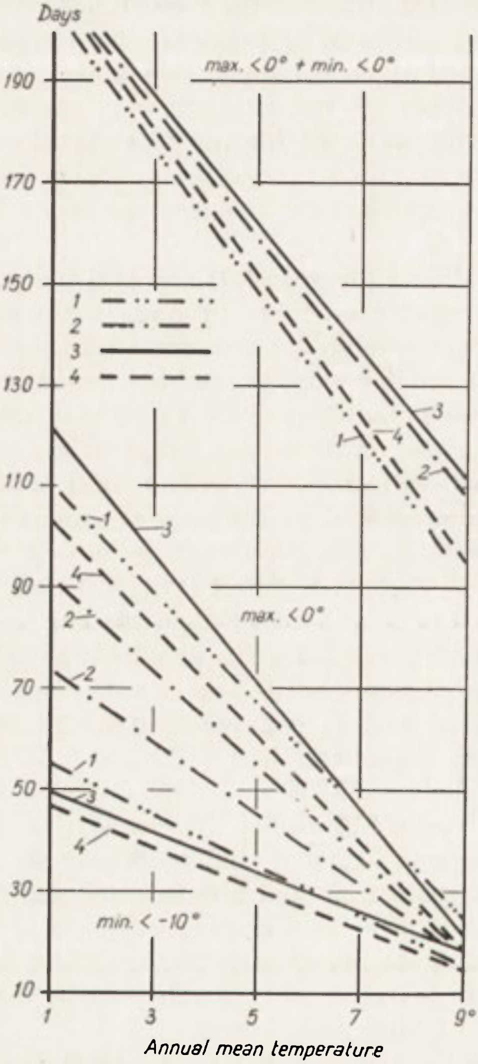


Fig. 1. Relation between mean (1954—1958) annual temperature and number of days with temperature minima < —10° and maxima < 0°, and maxima + minima < 0°, on convex (1) and in concave (2) land forms, as well as on slopes of northern (3) and southern (4) exposure in the Western Carpathians

of a number of climatic elements and indices for the different land forms mentioned if the mean annual temperature is known. Thus, from the mean annual temperature and the equations given in Table 1. one can gain detailed characteristics of the thermal regime and of the number of days with a snow cover; in other words one can define accurately the

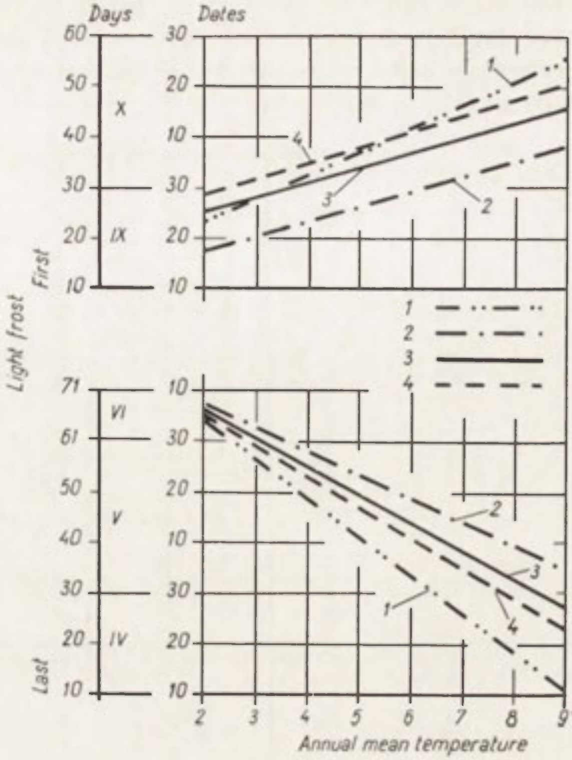


Fig. 2. Relation between mean (1954—1958) annual temperature and mean dates of last and first light frosts on convex (1) and in concave (2) land forms, as well as on slopes of northern (3) and southern (4) exposure in the Western Carpathians

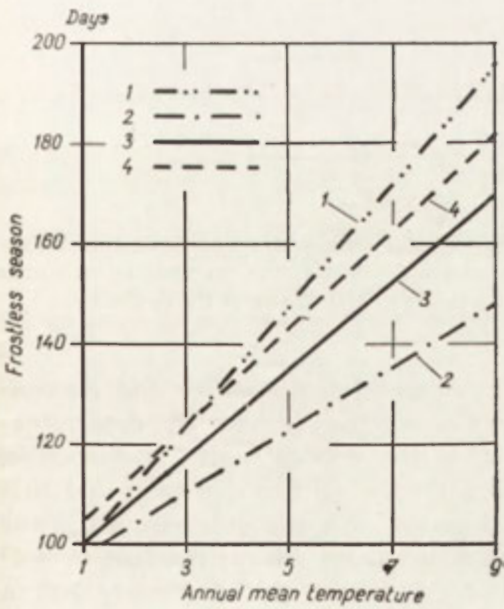


Fig. 3. Relation between mean (1954—1958) annual temperature and duration of period without light frosts on convex (1) and in concave (2) land forms, as well as on slopes of northern (3) and southern (4) exposure in the Western Carpathians

most important components of the mesoclimate for all convex and concave land forms and for northern and southern exposures within the vertical profile of Southern Poland, from the Vistula valley to some 1700 m above sea level.

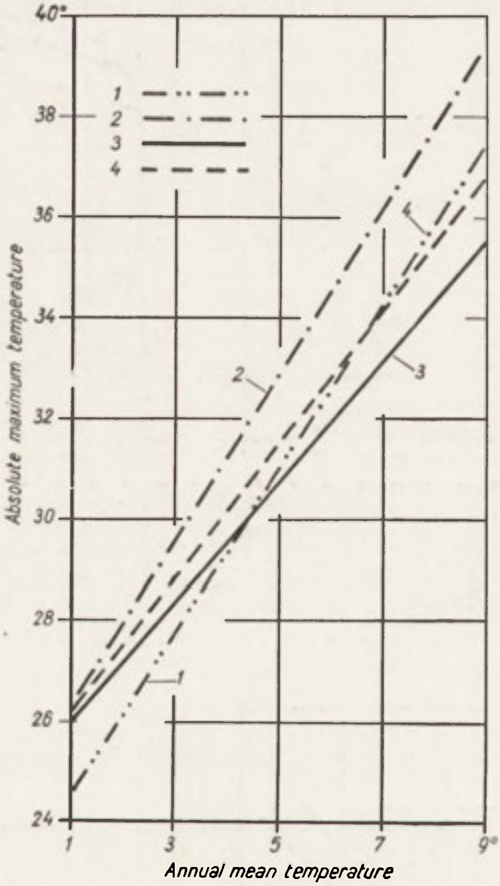


Fig. 4. Relation between mean (1954—1958) annual temperature and absolute maximum temperature on convex (1) and in concave (2) land forms, as well as on slopes of northern (3) and southern (4) exposure in the Western Carpathians

The method is based on the mean annual temperature and its connection with further elements and indices of the climate. The determination of this temperature at any point of the vertical profil is, therefore, of fundamental significance. In paper [7] the author demonstrated that the mean annual temperature over a period of many years varied in the vertical profile of the Western Carpathians from +8° at the foot to —4° on the highest Tatra peak. Thus it decreases by 0.5° for every 100 m altitude above sea level. This is the mean vertical temperature gradient referring to the whole of the Western Carpathians, but it would be a serious error to draw conclusions as to mean annual temperatures in the individual parts of the profile from this gradient, because in fact the

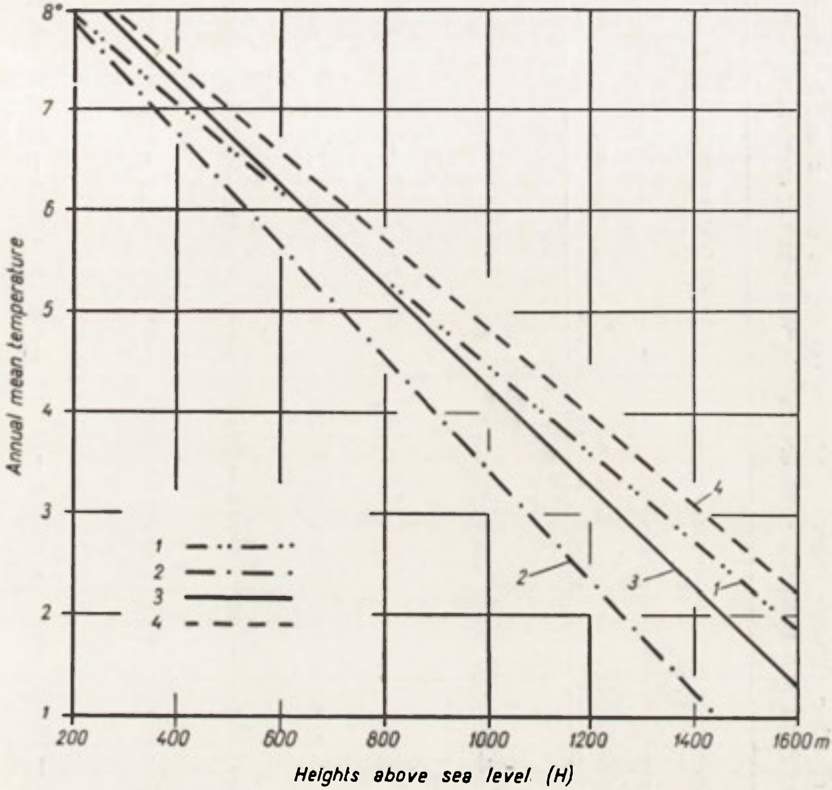


Fig. 5. Relation between altitude and mean (1952—1961) annual air temperature on convex (1) and in concave (2) land forms as well as on slopes of northern (3) and southern (4) exposure in the Western Carpathians

vertical temperature gradient is much differentiated, being a direct illustration of the influence of individual elements of land relief upon thermal conditions.

In order to obtain an accurate value for the mean annual temperature at any given point at any given altitude and for each of the discussed elements of land relief, the author has defined, on the basis of data given in [7], the dependence on altitude of the mean annual temperature on convex and in concave land forms and on slopes of northern and southern exposures. This interdependence differs for each of the land forms discussed (Fig. 5),

Table 1

Correlation coefficients (r) and straight-line equations $y = ax + b$, defining the interrelation between the mean annual temperature (t) and the values of a number of other climatic elements and indices (y) on convex and in concave land forms and on slopes of northern and southern exposure in the Western Carpathians

Climatic elements and indices (y)	Convex land forms		Concave land forms		Slopes with northern exposure		Slopes with southern exposure	
	r	Equation	r	Equation	r	Equation	r	Equation
Mean annual minimum temperature	0.99	$y = 1.04\,t - 4.1$	0.92	$y = 0.96\,t - 4.7$	0·94	$y = 0.65\,t - 2.0$	0·94	$y = 0.72\,t - 1.9$
Mean annual maximum temperature	0.99	$y = 1.12\,t + 3.4$	0.97	$y = 1.14\,t + 4.5$	0·98	$y = 1.13\,t + 3.2$	0·98	$y = 1.00\,t + 4.5$
Absolute annual maximum temperature	0.99	$y = 1.58\,t + 23.2$	0.98	$y = 1.64\,t + 24.6$	0·97	$y = 1.20\,t + 24.7$	0·97	$y = 1.32\,t + 24.9$
Number of days with min. temp. $< -10°$	—0.95	$y = 60.0 - 5.00\,t$	—0.90	$y = 81.6 - 7.20\,t$	—0·83	$y = 53.7 - 3.83\,t$	—0·84	$y = 52.0 - 4.00\,t$
Number of days with max. temp. $< 0°$	—0.99	$y = 121.4 - 10.80\,t$	—0.99	$y = 102.0 - 8.50\,t$	—0·95	$y = 134.0 - 12.50\,t$	—0·96	$y = 114.3 - 10.67\,t$
Number of days with max. temp. + min. temp. $< 0°$	—0.98	$y = 219.0 - 14.00\,t$	—0.87	$y = 221.8 - 12.60\,t$	—0·98	$y = 223.3 - 12.54\,t$	—0·99	$y = 223.4 - 14.20\,t$
Mean dates of last light frosts *)	—0.99	$y = 81.6 - 7.80\,t$	—0.79	$y = 79.0 - 5.00\,t$	—0·94	$y = 79.7 - 5.83\,t$	—0·94	$y = 78.3 - 6.17\,t$

Mean dates of first light frosts **)	0.99	y = 4.30 t + 15.4	0·92	y = 2.80 t + 12.4	0.80	y = 2.83 t + 19.3	0.80	y = 3.00 t + 23.0
Mean duration of frost-less period	0.96	y = 12.00 t + 87.0	0·81	y =6.20 t + 91.4	0.98	y = 8.67 t + 91.7	0.98	y = 9.67 t + 94.7
Duration of period with:								
mean diurnal temperature < –5°	–0.89	y = 97.0 — 15.00 t	–0·81	y = 108.5 — 14.75 t	–0.86	y = 94.5 — 13.25 t	–0.80	y = 82.0 — 13.00 t
mean diurnal temperature < 0°	–0.99	y = 206.6 — 17.20 t	–0·99	y = 206.6 — 17.20 t	–0.99	y = 208.0 — 18.00 t	–0.99	y = 208.0 — 18.00 t
mean diurnal temperature > 0°	0.99	y = 17.23 t + 158.2	0·99	y = 17.23 t + 157.9	0.99	y = 18.00 t + 157.0	0.99	y = 18.00 t + 157.0
mean diurnal temperature > +5°	0.98	y = 11.40 t + 123.8	0·98	y = 11.40 t + 123.8	0.99	y = 11.20 t + 122.6	0.99	y = 10.50 t + 132.0
mean diurnal temperature > +10°	0.98	y = 17.30 t + 27.4	0·98	y = 16.70 t + 35.6	0.99	y = 14.80 t + 47.4	0.99	y = 15.30 t + 48.4
mean diurnal temperature > +15°	0.92	y = 30.33 t — 134.6	0·92	y = 30.33 t — 134.6	0.98	y = 31.00 t — 147.5	0 90	y = 31.00 t — 147.5
Number of days with snow cover	–0.98	y = 230.3 — 20.66 t	–0·96	y = 237.7 — 20.83 t	–0.98	y = 233.6 — 20.69 t	–0.96	y = 228.2 — 21.53 t

*) counting from April 1 on

**) counting from September 1 on

Note: 1) the data for period with mean diurnal temperature < –5° apply for annual temperature +6.5°
2) the data for period with mean diurnal temperature > +15° apply for annual temperature > +5.0°

and this is a proof of the marked difference in the mean annual temperature depending on these elements of the land relief. For instance: at altitude 200 m, the mean annual temperature reaches +8.4° on southern slopes, while it is only +7.9° in concave land forms. With increasing altitude the difference in the mean annual temperature grows larger between the different land forms, reaching as much as 1.4° at 1500 m above sea level. On southern slopes the mean annual temperature rises to 2.2°, while in concave land forms it is only 0.8° (Fig. 5).

The influence of the various land forms on the dependence of the mean annual temperature on the altitude is also the reason why the vertical gradients (γ) of the mean annual temperatures differ considerably. On convex land forms $\gamma = -0.43°/100$ m, in concave forms it is —0.55°/100 m; on northern slopes $\gamma = -0.49°/100$ m, while on southern slopes it is —0.44°/100 m. Hence, the mean annual temperature drops quickest in concave land forms, and most slowly on convex forms and on southern slopes. This is one reason for the marked climatic asymmetry found between northern and southern mountain slopes [7].

As shown by the coefficients, a close linear relationship exists between altitude and mean annual temperature for all important elements of the mountain relief. This interdependence can therefore be expressed by straight-line equations of pattern $y = ax + b$, where the independent variable x represents the altitude (H) and the dependent variable y is the mean annual temperature (t). These equations and correlation coefficients, computed by the method of least squares, are tabulated in Table 2.

Table 2

Equations and correlation coefficients (r) defining the relation between the altitude (H) in metres above sea level and the mean (1952—1961) annual temperature (t) in degrees Celsius for different forms of land relief in the Western Carpathians with H varying from 200 to 1700 m

Land form	Equation	Correlation coefficient (r)
convex	$t = 8.82 - 0.00433\,H$	— 0.986
concave	$t = 9.02 - 0.00552\,H$	— 0.977
N slopes	$t = 9.24 - 0.00496\,H$	— 0.994
S slopes	$t = 9.27 - 0.00441\,H$	— 0.991

With the aid of the above equations and the altitude of a given place as read from any topographical map, one can determine in a very simple manner and with great accuracy the mean annual temperature for any of the elements of the mountain relief. Inserting this value in the relevant equation of Table 1, one can obtain exact values for many climatic elements and indices referring to convex and concave land forms and to northern and southern exposures at any level of the vertical profile of the Western Carpathians, within the range from 200 to 1700 m above sea level.

From the above relationship it appears that the decisive factor in determining the mesoclimatic differences between given land forms and their dependence on position within the vertical mountain profile are the general climatic conditions represented by a definite mean annual temperature and the further relation of this temperature with climatic elements and indices occuring at specific land forms (Figs 1—4). It follows that the mesoclimatic differentiation between the discussed land forms is by no means uniform over the entire range for which the relations hold, that is, over the full vertical mountain profile, but that it changes with increasing altitude. To give an example: the difference in the number of days with heavy frost occuring in concave land forms and on southern slopes is, with a mean annual temperature of +1°, 27 days, while with a mean annual temperature of +8° it drops to 5 days — a fivefold change (Fig. 1). The opposite tendency may be observed in the interdependence between the mean annual temperature and the period without light frost (Fig. 3). At low temperatures the difference in this duration is only slight for all the different land forms, while with rising temperatures the difference increases steadily: with a mean annual temperature of +1° it is barely 6 days, but at +8° the duration increases to 42 days — a sevenfold increase. However, this differentiation with altitude does not apply to all climatic elements and indices. Some of them, like the number of days with frost and light frosts (Fig. 1), show almost uniform values throughout the range for which the relationships are valid.

In order to illustrate more clearly the relationships that have been found, the annual values of some of the climatic elements and indices for convex and concave land forms and for slopes with northern and southern exposures have been computed for several points in the vertical profile of the Carpathians. These data are given in Table 3. The actual values may be read directly and their differences at the different altitude stages can be calculated without difficulty.

This table does not require any special comment, and a few remarks will suffice. It can be seen that the difference of values are closely dependent on the general thermal background. For instance: comparing the number of days with snow cover we note that, at 200 m above sea level where the number of such days is low, the difference between the land forms reaches 26 days. With increasing altitude, that is, under changing

Table 3

Mean (1954—1958) annual values of certain climatic elements and indices on convex (1) and in concave (2) land forms, as well as on slopes of northern (3) and southern (4) exposures at different hypsometric stages of the Western Carpathians

Altitude (in m above sea level)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	mean annual temperature				absolute maximum temperature				number of days with minimum temp. $< -10°$				number of days with maximum temp. $< 0°$			
200	8.0	7.9	8.2	8.4	35.8	37.6	34.5	36.0	20	25	22	18	35	35	32	25
500	6.7	6.3	6.8	7.1	33.8	34.9	32.9	34.3	26	36	28	24	49	48	49	38
800	5.4	4.6	5.3	5.8	31.7	32.1	31.1	32.6	33	48	33	29	63	63	68	52
1100	4.1	3.0	3.8	4.4	29.7	29.5	29.3	30.7	40	60	39	34	77	77	86	67
1400	2.8	1.3	2.3	3.1	27.6	26.7	27.5	29.0	46	72	45	40	91	91	105	81
1700	1.5	−0.4	0.8	1.8	25.6	23.9	25.7	27.3	52	84	51	45	105	105	124	95
	number of days with max. and min. temp. $<0°$				number of days with min. temp. $<0°$				mean dates of last light frosts				mean dates of first light frosts			
200	107	122	120	104	72	87	88	79	19 IV	10 V	2 V	26 IV	20 X	4 X	12 X	18 X
500	125	142	138	123	76	94	89	85	29 IV	18 V	10 V	4 V	14 X	30 IX	8 X	14 X
800	143	164	157	141	80	101	89	89	10 V	26 V	19 V	12 V	9 X	25 IX	4 X	10 X
1100	162	184	176	161	85	107	90	94	20 V	3 VI	28 V	21 V	3 X	21 IX	30 IX	6 X
1400	180	205	194	179	89	114	89	98	30 V	11 VI	5 VI	29 V	27 IX	16 IX	26 IX	2 X
1700	198	227	213	198	93	122	89	103	9 VI	20 VI	14 VI	6 VI	22 IX	11 IX	22 IX	28 IX
	mean duration of period without light frosts				duration of period with mean diurnal temp. $< -5°$				duration of period with mean diurnal temp. $<0°$				duration of period with mean diurnal temp. $>0°$			
200	183	140	163	176	·	·	·	·	69	71	60	57	296	294	305	308
500	167	130	151	163	·	16	4	·	91	98	86	80	274	267	279	285
800	152	120	138	151	16	41	24	7	114	128	113	104	251	237	252	261
1100	136	110	125	137	36	64	44	25	136	155	140	129	229	210	225	236
1400	121	100	112	125	55	89	64	42	158	184	167	152	207	181	198	213
1700	105	89	99	112	74	114	84	59	181	214	194	176	184	151	171	189
	duration of period with mean diurnal temp. $> 5°$				duration of period with mean diurnal temp. $>10°$				duration of period with mean diurnal temp. $>15°$				number of days with snow cover			
200	215	214	214	220	166	168	169	177	108	105	107	113	65	73	64	47
500	200	196	199	207	136	141	148	157	69	56	63	73	92	106	93	75
800	185	176	182	193	121	112	126	137	29	5	17	32	119	142	124	103
1100	170	158	165	178	98	86	104	116	·	·	·	·	146	175	155	134
1400	156	139	148	165	76	57	81	96	·	·	·	·	172	211	186	162
1700	141	119	132	151	53	29	59	76	·	·	·	·	199	246	217	189

macroclimatic conditions and with the number of days with a snow cover growing correspondingly, the difference gradually increases and at 1700 m above sea level it is as much as 57 days.

For each contour line it is easy to obtain four groups of the following combinations of differences

1) Convex form — concave form
   Convex form — N slope
   Convex form — S slope

2) Concave form — convex form
   Concave form — N slope
   Concave form — S slope

3) N slope — convex form
   N slope — concave form
   N slope — S slope

4) S slope — convex form
   S slope — concave form
   S slope — N slope

Examples of the differences between certain climatic elements at the top and bottom of the Carpathian profile are given in Table 4. This table gives a picture of the mesoclimatic differences between the elements of the mountain relief. If, for instance, we compare the number of days with light frosts (minimum temperature < 0°), we note that the differen-

Table 4

Differentiation of values of certain climatic elements between different land forms at two points of the vertical Carpathian profile

Altitude above sea level	Land forms	Differences in number of days with heavy frost (t min. < — 10°)				Differences in number of days with light frost (t min. < 0°)				Differences in duration of vegetative period (period with mean diurnal temp. > + 5°)				Differences in number of days with snow cover			
		Land forms				Land forms				Land forms				Land forms			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
200 m	1	0	+ 5	+ 2	— 2	0	+15	+16	+ 7	0	— 1	— 1	+ 5	0	+ 8	— 1	—18
	2	— 5	0	— 3	— 7	—15	0	+ 1	— 8	+ 1	0	0	+ 6	— 8	0	— 9	—26
	3	— 2	+ 3	0	— 4	—16	— 1	0	— 9	+ 1	0	0	+ 6	+ 1	+ 9	0	—17
	4	+ 2	+ 7	+ 4	0	— 7	+ 8	+ 9	0	— 5	— 6	— 6	0	+18	+26	+17	0
1700 m	1	0	+32	— 1	— 7	0	+29	— 4	+10	0	—22	— 9	+10	0	+47	+18	—10
	2	—32	0	—33	—39	—29	0	—33	—19	+22	0	+13	+32	—47	0	—29	—57
	3	+ 1	+33	0	— 6	+ 4	+33	0	+14	+ 9	—13	0	+19	—18	+29	0	—28
	4	+ 7	+39	+ 6	0	—10	+19	—14	0	—10	—32	—19	0	+10	+57	+28	0

Legend: 1 — convex land forms   3 — N slopes
2 — concave land forms   4 — S slopes

ces in the number of such days are variable for the land forms discussed, and that they not only grow, but also change their sign with increasing altitude. While it is true that at each point of the vertical profile most of the days with light frosts occur in concave land forms, large differences still appear, particularly between northern and southern slope exposures. Thus, at 200 m above sea level, less light frosts occur on southern slopes than on northern ones, but at 1700 m a.s.l. light frosts are more frequent on southern than on northern slopes.

From the data given in Table 3. it appears that the numbers of days with light frosts for northern and southern slopes are equal at approximately 800 m above sea level. This means that at the mountain base and in the lower part of the mountains more light frosts [2] occur on northern slopes, whereas in the upper part of the mountains light frosts are more frequent on southern slopes. This dependence on altitude upsets the opinion held so far, that light frosts always occur more often on southern than on northern slopes.

Since there is a linear relationship between altitude and mean annual temperature (Fig. 5, Table 2.), and also between the mean annual temperature and the values of other climatic elements and indices (Figs 1—4, Tables 1. and 3.), such a straight-line relation must also exist between the altitude and the values of the respective climatic elements and indices. This fact makes it possible to compute the vertical gradients of all these climatic parameters (Table 5.). In the vast majority of cases, the greatest gradient (the largest difference per 100 m altitude) is found in concave land forms. This is the reason, why at a given altitude the largest climatic differences are observed between concave and other land forms.

The data given in Table 5. also indicate how much the gradients of given climatic elements and indices differ, depending on the land form. It is obviously inadmissible to calculate the gradients of climatic elements from any pair of stations that are situated differently, and to apply these gradients when interpolating for altitudes where no station exists. On the other hand, Table 5. makes it possible to determine the values of the climatic elements and indices for each of the discussed four groups of elements of the mountain relief, and to refer these values to any point of the investigated vertical profile of the Western Carpathians. In order

[2] I obtained the number of days with light frosts (minimum temperature $< 0°$) by deducting the number of days with frost (t max. $< 0°$) from the number of days with frost and light frost (t max + t min $< 0°$). This procedure is very practical by reason of the very close dependence of the number of days with frost and light frost on the mean annual temperature in all land forms. On the other hand, the dependence of the number of days with light frost on the mean annual temperature — especially on slopes — is less close.

to do this, it suffices to determine the mean annual temperature for any given land form at any point of the vertical profile (Table 2.), and then to establish on the basis of the equations given in Table 1. the corresponding values of the desired climatic elements and indices, so as to obtain on the basis of the gradients determined (Table 5.), the data desired for any point of the discussed vertical profile of the mountains.

It also seems worth while verifying how far the values of the different climatic elements and indices, calculated from the equations given above, agree with the results obtained from direct measurements at stations. For this purpose four climatological stations have been selected (Luboń Wielki,

Table 5

Vertical gradients (differences per 100 m) of mean annual values of certain climatic elements and indices on convex (1) and in concave (2) land forms and on slopes of northern (3) and southern (4) exposures in the Western Carpathians

Climatic elements and indices	convex forms (1)	concave forms (2)	N slopes (3)	S slopes (4)	mean gradient
Mean annual temperature	—0.43°	—0.55°	—0.49°	—0.44°	—0.48°
Absolute maximum temperature	—0.68°	—0.92°	—0.59°	—0.57°	—0.69°
Mean minimum temperature	—0.45°	—0.53°	—0.32°	—0.32°	—0.40°
Mean maximum temperature	—0.50°	—0.63°	—0.55°	—0.43°	—0.53°
Number of days with min. temp. < —10°	+2.2 days	+3.8 days	+1.7 days	+1.8 days	+2.4 days
Number of days with max. temp. < 0°	+4.7 „	+4.7 „	+6.0 „	+4.7 „	+5.0 „
Number of days with min. temp. > 0°	+1.3 „	+2.3 „	+0.2 „	+1.7 „	+1.3 „
Number of days with max. and min. temperature < 0°	+6.0 „	+7.0 „	+6.2 „	+6.4 „	+6.4 „
Mean date of last light frosts	+3.5 „	+2.7 „	+2.8 „	+2.7 „	+2.9 „
Mean date of first light frosts	—1.8 „	—1.5 „	—1.3 „	—1.3 „	—1.5 „
Mean duration of period without light frosts	—5.2 „	—3.3 „	—4.2 „	—4.2 „	—4.3 „
Period with mean diurnal temp. < —5°	+6.4 „	+8.1 „	+6.7 „	+5.8 „	+6.8 „
Period with mean diurnal temp. < 0°	+7.5 „	+9.5 „	+8.8 „	+7.8 „	+8.4 „
Period with mean diurnal temp. > 0°	—7.5 „	—9.5 „	—8.8 „	—7.8 „	—8.4 „
Period with mean diurnal temp. > 5°	—5.0 „	—6.3 „	—5.5 „	—4.7 „	—5.3 „
Period with mean diurnal temp. > 10°	—7.5 „	—9.3 „	—7.3 „	—6.7 „	—7.7 „
Period with mean diurnal temp. > 15°	—13.2 „	—16.7 „	—15.0 „	—13.5 „	—14.6 „
Number of days with snow cover	+8.8 „	+11.5 „	+10.2 „	+9.5 „	+10.0 „

Table 6

Comparison of annual values of certain climatic elements and indices obtained from measurements and calculated from equations (1954—1958)

Morphological position	Source of data	Mean annual temperature	Absolute max. temperature	Mean max. temperature	Mean min. temperature	Number of days with temperature:				Mean date of light frost		Duration of period without night frost	Duration of period with mean daily temperature				Number of days with snow cover
						min. < −10°	max. < 0°	min. < 0°	max. + min. < 0°	last	first		<0°	>0°	>5°	>10°	
convex land form	from measurements: Luboń Wielki — 1024 m	4.1	30.4	7.6	1.0	38	79	84	163	23 V	7 X	136	141	224	171	103	146
	from equations: for annual temp. = 4.1°		29.7	8.0	0.2	39	77	85	162	21 V	3 X	136	136	229	170	98	146
	difference		—0.7	+0.4	—0.8	+1	—2	+1	—1	—2	—4	0	—5	+5	—1	—5	0
concave land forms	from measurements: Chochołów Valley — 1028 m	3.4	29.5	8.1	—0.8	55	73	106	179	28 V	17 IX	111	146	219	163	90	165
	from equations: for annual temp. = 3.4°		30.2	8.4	—1.4	57	73	106	179	1 VI	22 IX	112	148	217	163	92	167
	difference		+0.7	+0.3	—0.6	+2	0	0	0	+3	+5	+1	+2	—2	0	+2	+2
slope with northern exposure	from measurements: Kuźnice — 1023 m	3.8	30.1	8.1	—0.3	46	80	96	176	27 V	22 IX	117	141	224	167	102	152
	from equations: for annual temp. = 3.8°		29.3	7.5	0.5	39	86	90	176	28 V	30 IX	125	140	225	165	104	155
	difference		—0.8	—0.6	+0.8	—7	+6	—6	0	+1	+8	+8	—1	+1	—2	+2	+3
slope with southern exposure	from measurements: Gubałówka — 1000 m	4.8	30.7	8.8	1.1	38	68	92	160	16 V	6 X	142	125	240	180	120	129
	from equations: for annual temp. = 4.8°		31.2	9.3	1.6	33	63	92	155	19 V	7 X	141	122	243	182	122	125
	difference		+0.5	+0.5	+5.0	—5	—5	0	—5	+3	+1	—1	—3	+3	+2	+2	—4

Chochołowska Valley, Kuźnice and Gubałówka) situated at similar altitude, each representing one of the land forms discussed. The mean annual temperature recorded at each of these stations was substituted in the relevant equations to give a number of climatic elements and indices for each of the land forms encountered. The mean annual temperature was not calculated from formulae, because the equations had been based on a 10 — year period, while only 5 — year records were available for the stations discussed, so that the respective values would not have been comparable. The results obtained were compared with the data recorded by each of the stations (Table 6.). Thus Table 6. serves two purposes: 1) it indicates the differentiation in the climate at about 1000 m above sea level corresponding to the land relief and its exposure, recorded by direct observations of the given stations; 2) it enables us to compare these data with those derived from our equations, that is, not from clearly defined points in the mountain profile, but rather from types of land forms.

In most cases there are differences between the measurements and the values obtained from our equations. However, they are rather insignificant ones, of the order of a few per cent at the most. Here and there, the figures calculated from the equations are identical with those obtained from measurements. Certain discrepancies between the calculated and the measured values may be caused by the fact that in no instance is the coefficient of correlation between altitude and mean annual temperature, or between mean annual temperature and other climatic elements and indices, exactly equal to unity even though they approach it (see Table 1). On the other hand, part of the discrepancies may also be ascribed to less accurate measurements and observations at particular stations; this principally refers to the measurements and observations which depend on the personnel's estimate, such as the number of days with a snow cover. The equations presented in Tables 1 and 2 are derived from a great number of stations, so that arbitrary estimates will have been averaged out. Therefore the equations may at times be useful for correcting results recorded by individual stations.

The comparison of records from climatological stations with values calculated from the equations seems to demonstrate the usefulness of the method presented for climatic conditions in mountain areas. It is also of use in determining the mesoclimate of minor physiographical units, because the network of climatological stations can never attain a density which would provide every one of such units with data from a definite station (as postulated by R. Geiger [5]); anyway, in the light of the results obtained, this would involve a great waste of efforts and funds.

It also seems to the author, that the method set out here is the first to supply a key to the mesoclimatic conditions of various elements of mountain relief in relation to differences in macroclimatic conditions depending on altitude.

Department of Physical Geography
Climatological and Meteorological Laboratory
Jagiellonian University
Cracow

References

[1] Boniecka-Żółcik H., Częstość inwersji temperatury powietrza w Krynicy Zdroju w okresie 1956—1960 (Frequency of Air Temperature Inversion at Krynica Zdrój during 1956—1960). *Przegl. geofiz.*, 8 (16), 1—2, 1963.

[2] Burg-Zaleska J., Schodzenie pokrywy śnieżnej w terenie urzeźbionym w zależności od wystaw i nachyleń (Descent of Snow Cover in Sculptured Regions, depending on Exposure and Slope Inclination), *Pam. puławskie*, 12, 1964.

[3] Chomicz K., O wpływie warunków lokalnych na przebieg elementów meteorologicznych (On the Influence of Local Conditions on the Cours of Meteorological Elements), *Przegl. geofiz.*, 8 (16), 1—2, 1963.

[4] Figuła K., Untersuchungen über die Wasser- und Warmebilanz des Hanges, *Wiss. Ztschr. K. M. Univ. Leipzig*, 13. 4, 1964.

[5] Geiger R., *Das Klima der bodennahen Luftschicht*, Braunschweig 1961.

[6] Gumiński R., Wpływ ekspozycji na klimat (Effect of Exposure on Climate), *Wiad. met. i hydr.*, 9, 1930.

[7] Hess M., Piętra klimatyczne w polskich Karpatach Zachodnich (Climatic stages in the Polish Western Carpathians), *Zesz. Nauk. UJ, 115, Prace geogr. 11*, Kraków 1965.

[8] Hess M., Częstość występowania różnych wartości średnich temperatur dobowych powietrza w poszczególnych piętrach klimatycznych polskich Karpat Zachodnich (Frequency of Occurrence of Various Values of Mean Diurnal Air Temperature in the Individual Climatic Stages of the Polish Western Carpathians), *Przegl. geofiz.*, 10 (18), 3—4, 1965.

[9] Hess M., Meteorological Basic Data for the Reconstruction of Paleoclimatic Conditions of Southern Poland, *Bull. de L'Acad. Pol. d. sci, geol. et geogr.*, 13, 4, 1965.

[10] Hess M., Znaczenie średniej temperatury roku dla poznawania warunków klimatycznych (Significance of Mean Annual Temperature in investigating Climatic Conditions), *Przegl. geogr.*, 38, 1, 1966.

[11] Hess M., O mezoklimacie wypukłych i wklęsłych form terenowych w Polsce Południowej (On the Mesoclimate of Convex and Concave Land Forms in Southern Poland), *Przegl. geofiz.*, 11 (19), 1, 1966.

[12] Hess M., O wpływie ekspozycji terenu na klimat w Polsce południowej (On the Effect of Exposure on Climate in Southern Poland), *Przegl. geofiz.*, 11 (19), 3, 1966.

[13] Innerebner F., Über den Einfluss der Exposition auf die Temperaturverhaltnisse im Gebirge, *Met. Ztschr.*, 50, 9, 1933.

[14] Michalczewski J., Długotrwale zastoiska mrozowe Kotliny Podhalańskiej. Zagadnienia klimatyczne Kotliny Podhalańskiej (Persistent Frozen-ground Pockets in the Podhale Depression. Climatic Problems of the Podhale Depression) *Łódzkie Tow. Nauk.*, IIIed., 82, Łódź 1962.
[15] Milata S., Częstotliwość inwersji względnych temperatury powietrza w Krakowie w latach 1954, 1955 i 1957 (Frequency of Relative Inversions of Air Temperature at Cracow in 1954, 1955 and 1957), *Przegl. geofiz.*, 4 (12), 1, 1959.
[16] Niedźwiedź T., Klimat pogórskiego odcinka doliny Raby, ze szczególnym uwzględnieniem okolic Gaika-Brzozowej (The Climate of the Foothill Section of the Raba Valley, with Special Attention paid to the Gaik-Brzozowa Region), *Zesz. nauk. UJ, Prace geogr. 14,* 1967.
[17] Obrębska-Starklowa B., Charakterystyka termicznego reżimu powietrza w lesie lipowym i jodłowym przy niektórych sytuacjach pogodowych (Characteristics of the Thermal Air Regime in Lime and Fir Forest under Certain Weather Conditions), *Czasop. geogr.*, 36, 3, 1965.
[18] Obrębska-Starklowa B., Klimat Babiej Góry. W: *Babiogórski Park Narodowy* (The Climate of Babia Góra. Chapter in: The Babia Góra National Park), Kraków 1963.
[19] Orlicz M., Orliczowa J., Inwersje temperatury na północnym skłonie Tatr (Temperature Inversions on the Northern Slope of the Tatras), *Przegl. meteor. i hydr.*, 8, 3—4, 1955.
[20] Romer E., Regiony klimatyczne Polski (Climatic Regions of Poland), *Prace Wrocł. Tow. Nauk., Ser. B.*, 16, Wrocław 1949.
[21] Weiss J., Jahreszeitliche Klimagegensatze auf der Nord- und Südseite des Riesengebirges, *Wetter u. Leben*, 4, 1952.

GEOGRAPHIA POLONICA 13, 1968

DISTANCE FROM WATER — AN INDEX OF THE DENSITY OF A HYDROGRAPHICAL NETWORK

TADEUSZ WILGAT

Problems of hydrographical or river networks have frequently been the topic of scientific literature since 1873, when Belgrand attempted to demonstrate the differentiation in river density in the Seine drainage basin [3]. Scientists concentrated their attention mainly on why the density of a river system is diversified. According to L. Neumann [6], who studied this problem in detail, the inequality in the density of river systems depends on factors like: type of substratum, gradients of slopes, vegetation cover of the land, and precipitation. He assigned first place to precipitation, defining a quantitative relationship between the total annual precipitation and the density of a river system. Later investigations [2, 17] revealed that the type of substratum may be of greater importance than precipitation and that the magnitude of precipitation affects the density of a dry valley networks rather than the systems of permanent streams. In the district of the River Lahn F. Tichy [3, 12] established a distinct dependence of the density of the river system on the permeability of the substratum. With an annual precipitation of the order of 600 to 700 mm, the extreme density values show a proportion of 1 : 3.7, depending on the type of rock substratum. The lowest density of the river system is associated with areas of high permeability; where water infiltration into the soil is obstructed, the river system is better developed.

Thus the density of a river system, and even more the density of all surface waters, is to some extent a function of the circulation of water. At the same time, it influences this circulation. The more extensive the surface of flowing or stagnant water, the larger are the losses by evaporation, assuming climatic conditions to be identical. The density of a hydrographical network might therefore be considered as an index of the magnitude of losses by evaporation, as has been pointed out by Wundt [17].

Hence, the density of a hydrographical network constitutes an interesting problem, both from a geomorphological and a hydrological point of view. All kinds of surface water are essential elements of the landscape, and their density bears to a large extent on the type of processes shaping the natural environment. Thus, a differentiation of this hydrographical network is apt to become the basis for distinguishing different natural landscape units [3]. The hydrologist pays attention to the density of the pattern of streams and valleys because of its influence on water runoff. On the other hand, the density of all kinds of surface water constitutes an important problem, because it is connected with conditions of water infiltration and the magnitude of losses in the water balance.

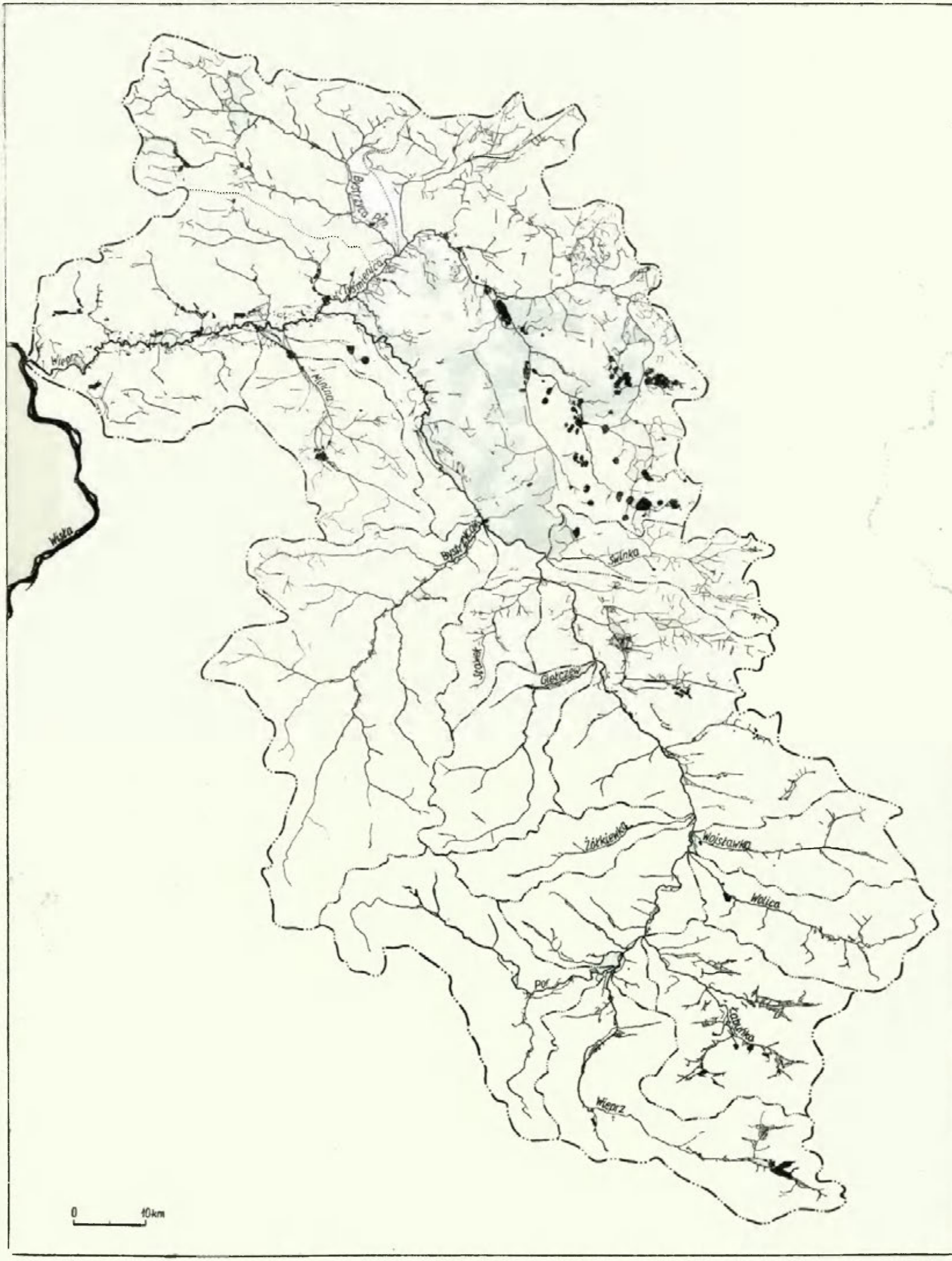
It was A. Wallen who attempted to determine the effect of stagnant water on the magnitude of balance losses; in his formula for the deficit in water runoff in Southern Sweden he took into account, apart from the mean temperature during the vegetation period (T_v), the per cent share of the surface of lakes (S): $D = 0.82S + 22.8T_v + 65$ [14].

There seem to be wide opportunities in looking for numerical combinations of this kind. It seems particularly worth while attempting to relate conditions of infiltration and losses due to evaporation within a drainage basin, to the density of the hydrographical system. The relevance of such studies is the more obvious, since direct measurements of soil permeability and evapotranspiration yield information which is valid only for the place of measurement, and attempts to extrapolate of these results for greater areas may prove futile.

However, in order to be able to treat the density of a hydrographical system as an index to be applied in hydrological computations, this density must be defined in a satisfactory and unambiguous manner. Of the methods so far applied, none seems quite right as far as our problem is concerned. The first method, introduced in 1900 by Neumann [6], looks upon the density of a fluvial network as the ratio of the sum of the lengths of all streams in a given area to the surface of the respective area. By virtute of its clarity, this method gained universal acceptance, and has very often been applied and modified [3, 8, 9, 10, 16]. The modifications were mainly concerned with the application of areas of reference. In Neumann's work there were minor drainage basins, while his successor applied meshes of a geographical network and geometric figures of various shapes. These differences have an important bearing on the results obtained and, to be exact, the methods suggested by Neumann's successors should not be linked with his name at all. Even so, all of them are called Neumann's method.

It has frequently been argued against this method that it fails to give a precise definition of the density of a hydrographical system. In the first

Fig. 1. Equidistants from water in the Wieprz drainage basin



http://rcin.org.pl

Fig. 2. Hydrographical map of the Wieprz drainage basin

place, it disregards differences in the rank of streams: 1 km a small brook is allotted the same numerical value as 1 km of a large river. Secondly, Neumann based his method on maps on which the course of rivers is simplified, and seldom simplified in a uniform way. To be sure, this does not discredit the method itself, but it influences results and thus diminishes its usefulness. Neumann's method presents considerable difficulties in its application which effects the results obtained. Doubts arise in measuring meanders, in considering or neglecting canals and oxbows, in measuring braided channels of rivers, etc. The method was subjected to a general critical investigation in the Polish literature by A. Malicki [4] and later by T. Wilgat [15] and A. Chałubińska [1] The latter author presented evidence, that Neumann's method should not be applied at all to lowland regions.

In spite of numerous and long-standing reservations, Neumann's method continues to be used and presented as the only one in existence by many textbooks, even by some of recent date [1].

This longevity must presumably be ascribed to the obvious nature of the definition of a hydrographical network density. This same method is most successfully applied for computing densities of all kinds of linear objects, for example lines of transportation and cables. Consequently Neumann's method would seem to be suitable for rivers also to anybody who had not himself tried to apply it for this purpose.

A method based on a different principle was suggested in 1937 by A. Malicki [4]. Here the number of streams per unit area expresses the density of a hydrographical system. This method was used by B. Szalkiewicz for establishing the density of the Wisła—Bug interfluve and, for comparison with Neumann's method [11]. This experiment revealed difficulties in forming a proper estimate of the number of streams in an area where man's activities had made changes in the hydrographical network. But further reservations must be made against Malicki's method, as has been demonstrated by Wilgat [15]. Like Neumann's method, it disregards the rank of the different streams making no distinction between the smallest brock and a major river; nor does it take into account river curvatures, which definitely bear on the density. In fact, the density within any basic area along one well developed river may be greater than where several minor creeks occur. Malicki's method also presents difficulties when presenting the information on a map, because in areas of low density it precludes an application of the isarithmic method [15].

[1] For example: Chebotarev A., General Hydrology (in Russian), Leningrad 1960; Keller R., Gewässer und Wasserhaushalt des Festlandes, Leipzig 1962; Réméniéras G., L'Hydrologie de l'ingénieur Paris 1965; Roche M., Hydrologie de surface, Paris 1963; R. de Wiest. Geohydrology, New York 1965; Wundt W., Gewässerkunde, Berlin 1953.

To a certain extent the methods suggested both by Neumann and by Malicki do characterize the density of a river system, but they cannot take stagnant water into account. The distinction between these two categories of water surfaces is most important. In a water balance all water surfaces influence the rate of loss; therefore it is methodologically wrong to look for a relation between the density of a river system and the loss. This is obvious especially where lake-districts are concerned. This kind of relation, as well as the correlation between permeability of the substratum and density of a hydrographical network should rather be investigated with all water surfaces taken into consideration; and for this type of study neither Neumann's nor Malicki's method is applicable.

In 1947 a different method was suggested by T. Wilgat [15]. According to him the criterion defining the density of a hydrographical network is the distance from water: the smaller this distance, the greater the density. The author describes what may be called the "distance method" as follows. The grid of a rectangular mesh is superimposed upon an equidistant map of distances from water. Within each mesh there is one point farthest away from the nearest water; of course the water may lie outside the given mesh also. The distance of the point farthest away from water is the value assigned to the given grid mesh. The points thus found provide the basis for interpolation in drawing the isarithmic map [2].

The map showing equidistants from water gives an excellent picture of the density of a hydrographical network. However, it does not lead itself to the making of direct quantitative comparisons, because the determination of the maximum distance from the nearest water within a given region or drainage basin is not enough to characterize the density of a hydrographical system.

The application of the "distance method" avoids the objections made against the methods discussed above. The category of a stream, is of no importance nor is there any trouble with meanders, oxbows, or branch river channels. Moreover, this method — unlike the preceding ones — makes it possible to take into consideration all surface waters, artificial basins included, although it may also be applied exclusively to flowing water. The principal imperfection of the method as presented in 1947 was the necessity of using geometrical basic units which slightly distort actual conditions. Some distortion also results — much as in Neumann's method — from the application of the isarithmic method to a phenomenon which lacks uninterrupted continuity. And the equidistants alone, as has

[2] In practice one can omit the plotting of equidistants and forthwith determine the point farthest away from water.

been mentioned, do not provide a satisfactorily precise expression for the quantitative aspect of the density feature.

Mention should also be made of the method applied by A. Chałubińska [1] for illustrating the density of Poland's hydrographical system. This method shows the percentage of basic gird units on the 1 : 100 000 map (of 4 sq. km each) which lack water altogether. This produced an interesting picture of Poland's "water resources", but the method can only be used for preparing general maps showing the density of hydrographical systems for large areas.

As shown above, none of the methods discussed treats the problem of the density of a hydrographical or river network in a manner suitable for investigating the interrelation between this feature of a drainage basin on the one hand, and water losses and ground permeability on the other. For this reason a new attempt was made to assign a numerical value to the density of a hydrographical system. This attempt was based on the same presupposition already used by Wilgat, that is, that distances from the nearest water can serve as an index for the density of a hydrographical system.

The first phase of the procedure involves drawing a map of equidistants from water. This sort of map was prepared, to take an example, for the drainage basin of the River Wieprz (Fig. 1). As a basis the 1 : 300 000 hydrographical map was used (Fig. 2). This was compiled from F. Uhorczak's hydrographical map of Lublin Voivodship to a scale of 1 : 100 000 and photographically reduced to 1 : 300 000 [13]. Evidence gained during many years' hydrographical mapping in Lublin Voivodship shows that the topographical maps which form the base of Uhorczak's map, present a picture of the complete hydrographical network without quantitative generalization. The 1 : 300 000 map therefore proved suitable for use as a basis for the new survey. In principle, any density measurements of a hydrographical system should be made on large scale maps which illustrate accurately every occurrence of surface waters. However, in this instance the departure from this rule seemed justified by the accuracy of the 1 : 300 000 map, which was adequate for demonstrating the features of the proposed method, and by the saving in time.

In view of the map scale, equidistants at 1 km intervals were adopted. A number of secondary drainage areas were then distinguished within the total basin. The next step was to determine zones of equal distance from water for the whole drainage basin, by planimetring within these minor basins. The result of this work is shown in Table 1.

The hydrographical density can also be defined by the percentage share of the individual distance zones in the total drainage area.

Area of zones at different distances from

Distances of zone from water (in km)	Wieprz		Upper Wieprz		Por		Łabuńka		Wolica		Wojsławka	
	km²	%	km²	%	km²	%	km²	%	km²	%	km²	%
0 — 1	6048.9	58.6	264.6	42.1	220.5	37.0	279.9	54.4	157.5	44.3	114.3	40.4
1 — 2	2631.5	25.5	156.6	24.9	178.2	29.9	150.3	29.9	107.1	30.1	95.4	33.75
2 — 3	1166.4	11.3	118.8	18.9	107.1	18.0	66.6	12.9	73.8	20.8	56.7	20.1
3 — 4	359.2	3.5	62.1	9.9	64.8	10.9	16.2	3.15	16.2	4.6	13.5	4.8
4 — 5	101.7	1.0	23.4	3.7	23.4	3.9	1.8	0.35	0.9	0.2	2.7	0.95
5 — 6	8.1	0.1	2.7	0.4	1.8	0.3	—	—	—	—	—	—
Total	10315.8	100.0	628.7	100.0	595.8	100.0	514.8	100.0	355.5	100.0	282.6	100.0
0 — 0.5			135.9	21.6			180.9	35.1				
1 — 1.5			81.9	13.1	90.9	15.8					47.7	16.9

Where there is an abundance of surface water, the percentage of zones near water assumes higher values. On the other hand, the less frequent the occurrence of water, the higher the percentage of zones further away from water. To cite an example, the Świnka drainage basin shows 85.7% distant up to 1 km, while in the Żółkiewka basin this figure is only 30.25%.

These relations can be illustrated by a diagram in which zonal surfaces are represented as abscissae, and distances from water as ordinates. Joining all points of this coordinate system by a continuous line one obtains a curve showing the distance from water for the whole drainage basin. But areas can also be expressed by percentages instead of by absolute figures. Then the unequal surfaces of the drainage basins are not of importance. In Table 2 are shown the total values of the percentage share of the individual zones, separated by equidistant contour lines.

The graph (Fig. 3) shows the conditions which exist in the different drainage basins. The slower the rise of the curve, the higher is the percentage of areas near water, — in other words, the greater is the hydrographical density. The height to which this curve rises depends on the maximum distance occurring within a given drainage basin.

Curves like these make it possible to read the coordinates for any point, indicating the percentage of the basin which lies at a distance from water nearer than the distance of that point. The ordinate of a point representing 50% of the basin surface on the x-axis, indicates the value of the equidistant dividing the drainage basin into two equal parts. All

Table 1

water in the Wieprz drainage basin

Żółkiewka		Giełczew		Stawek		Świnka		Bystrzyca		Bystrzyca Pn		Minina	
km²	%	km²	%	km²	%	km²	%	km²	%	km²	%	km²	%
64.8	30.25	155.7	43.1	87.3	50.0	232.2	85.7	560.7	43.15	519.3	71.05	283.5	67.3
62.1	29.0	116.1	32.2	43.2	24.75	38.7	14.3	394.1	30.3	180.9	24.75	109.8	26.1
56.7	26.5	66.6	18.5	27.0	15.5	—	—	229.5	17.7	27.9	3.8	27.9	6.6
25.2	11.75	18.9	5.2	13.5	7.7	—	—	78.3	6.05	2.7	0.4	0.0	0.0
5.4	2.5	3.6	1.0	2.7	1.55	—	—	34.2	2.6	—	—	—	—
—	—	—	—	0.9	0.5	—	—	2.7	0.2	—	—	—	—
214.2	100.0	360.9	100.0	174.6	100.0	270.9	100.0	1299.6	100.0	730.8	100.0	421.2	100.0
				52.2	29.9	152.1	56.1	217.8	16.75	278.1	38.1	171.9	40.8

points of one half of the basin lie nearer to water, and all points of the other half lie farther from it, than the distance indicated. The numerical value thus obtained is the median of that distribution series, in which the

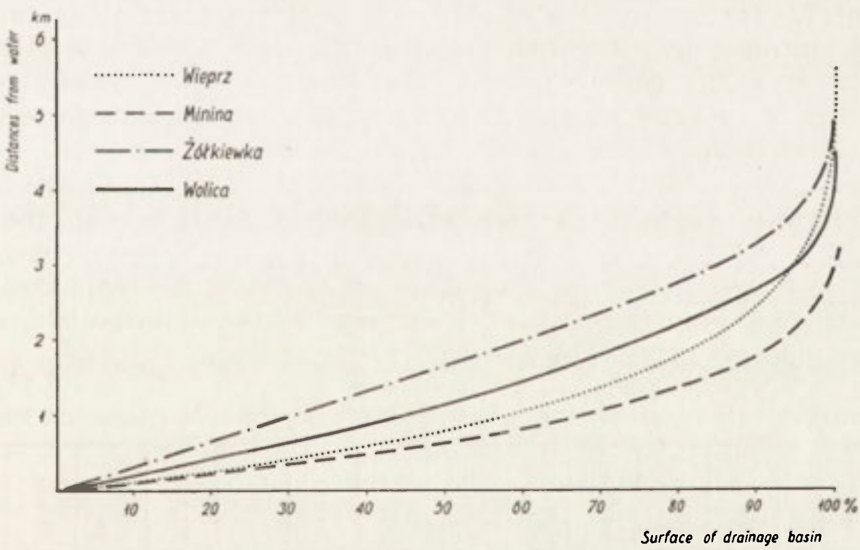


Fig. 3. Distances from water in different drainage basins

distances from water of all points of the drainage basin have been included. This value of the equidistant halving the basin may be called the medial distance, d_m or $d_{50\%}$.

Table 2

Percentages by area of the Wieprz drainage basin, within given distance from water

Distance less than	Wieprz	Upper Wieprz	Por	Łabuńka	Wolica	Wojsławka	Żółkiewka	Gielczew	Stawek	Świnka	Bystrzyca	Bystrzyca Pn	Minina
0.5 km		21.6		35.1			15.1		29.9	56.1		38.1	40.8
1 „	58 6	42.1	37.0	54.4	44.3	40.4	30.25	43 1	50.0	85.7	43.15	71.05	67.3
1.5 „		55.2	52.8			57.3					59.9		
2 „	84.1	67.0	66.9	83.6	74.4	74.15	59.25	75.3	74.75	100.0	73.45	95.8	93.4
3 „	95.4	85.9	84.9	96.5	95.2	94.25	85.75	93.8	90.25		91.15	99.6	100.0
4 „	98.9	95.8	95.8	99.65	99.8	99.05	97.5	99.0	97.95		97.2	100.0	
5 „	99.9	99.5	99.7	100.0	100.0	100.0	100.0	100.0	99.5		99.8		
6 „	100.0	100.0	100.0						100 0		100.0		

In order to ascertain whether the wide intervals between the equidistants affected the accuracy of the medial distance assessment, further work was carried out. In certain drainage basins, especially those where d_m is less than 1 km, zones with 0.5 km equidistants were calculated. For other basins, the zones between the 1 km equidistant and an additional one at 1.5 km were computed. The results obtained are shown in the tables. In some cases such additional points made it easier to plot the curves correctly, especially in their lower sections. This demonstrates the necessity of applying smaller intervals between equidistants for certain types of drainage basins.

Characteristic distances from water within the Wieprz drainage basin and its component basins are set out in Table 3. Apart from d_m the distance at which 1/4 of the drainage basin lies ($d_{25\%}$, or "lower quarter distance") has been shown, as has that at which 3/4 of the basin area lies ($d_{75\%}$ or "upper quarter distance"). For each of the drainage basins the

Table 3

Characteristic distances from water for the Wieprz drainage basin (in km)

	Żółkiewka	Por	Upper Wieprz	Wojsławka	Gielczew	Bystrzyca	Wolica	Stawek	Łabuńska	Minina	Bystrzyca Pn	Świnka	Wieprz
$d_{25\%}$	0.8	0.65	0.6	0.6	0.6	0.55	0.55	0.4	0.35	0.3	0.3	0.2	0.35
d_m	1.7	1.4	1.3	1.25	1.2	1.2	1.15	1.0	0.9	0.65	0.65	0.45	0.8
$d_{75\%}$	2.6	2.4	2.35	2.05	2.0	2.0	2.0	2.0	1.65	1.2	1.1	0.75	1.55
d max	4.6	5.1	5.6	4.6	5.4	5.4	4.2	5.6	5.0	3.2	3.3	2.0	5.6

maximum distance from water (d_{max}) has also been computed. In contrast with the two preceding tables, the succession of basins adopted for Table 3 is not in agreement with the succession of the Wieprz tributaries. The component basins have been arranged in order of increasing percentage of zones at shorter distances from water, — that is, proceeding from the smallest to the greatest density of the hydrographical network. This pattern of grouping yields a decreasing sequence of d_m values. From this it may be concluded that the medial distance gives a satisfactory indication of the density of a hydrographical system. Despite the relatively slight differentiation in distances within the basins of the upland part of the Wieprz basin, the values shown in the table appear in logical order. This seems to demonstrate the sensitivity of d_m as an index of the density of the hydrological system.

The table shows that the maximum distances from water do not appear in drainage basins having the highest proportion of areas far from water. Nor do the d_{max} values change parallel with d_m values. This is evidence of a smaller dependence of maximum distances on the density of a hydrographical system, which in turn, diminishes the feasibility of using maximum distances as data in comparative studies. It should also be emphasized that any errors will bear predominantly on the resulting value of the maximum distance from water. Thus, to give an example: if in the drawing of equidistants a minor water basin has been omitted, the influence of this omission on the d_m value of the entire drainage basin will be negligible; on the other hand, supposing the omitted basin is situated in the watershed zone, far from any water, the error may alter the value of d_{max} considerably. And it is an open question, whether irregularities in the order of d_{max} figures in the table may not be due, in part at least, to the omission of minor water objects which might have been lost in reducing the 1 : 100 000 map to 1 : 300 000.

It seems from the above that the medial distance from water may be adopted as numerical index for the density of a hydrographical system. It should be stressed, that it is easy to visualize this index, and that it reflects conditions as they really are. The numerical value means that one half of the area under investigation lies at the distance from zero to d_m from its nearest surface water, while for the second half this distance ranges from d_m to d_{max}. A further advantage of this index is that it can be calculated either for the entire drainage basin, or for any arbitrary regions or geometrical areas. This fact may be of significance when applying the index to a variety of regions, or when it is required to maintain basic areas of uniform size. A further advantage may be seen in the fact that this method can be used for measuring the density of all kinds of existing water surfaces, or of rivers exclusively. When necessary, waterlogged areas can also be included in these investigations.

It seems worth mentioning, that in computing distances from water one can take into consideration the dimensions of surfaces water, a matter of significance in regions containing lakes and ponds. For the Wieprz basin this was neglected, since the water surfaces constitute only a negligible part of the whole basin area. Lakes cover 28 sq. km and ponds 17.7 sq. km [5], while the surface of flowing water can be assumed to be about 30 sq. km. This means, that water covers a total of about 75 sq. km, only some 0.7% of the whole basin area as established by planimeter measurements. Taking this into account would reduce the 0 to 1 km zone from 58.6% to 57.9% — a difference without effect on the shape of the curve and on the value of d_m.

When d_m values vary little in the region under investigation, additional values may be worth considering, such as $d_{25\%}$ and $d_{75\%}$, or d_{max}, provided there is no doubt that all existing water surfaces have been taken into account.

For particularly detailed studies it may also be advisable to determine the mean distances d_{mean} from the plotted curves and to compare them with the d_m values. This would show whether the hydrographical density is uniform within the drainage basin or not. Similar values of d_{mean} and d_m would indicate an insignificant variation in the density. On the other hand, a large difference between d_{mean} and d_m may be expected for drainage basins containing both regions with a dense network and extensive waterless areas.

Department of Regional Geography
Maria Curie-Sklodowska University
Lublin

References

[1] Chałubińska A., Gęstość sieci wodnej w Polsce (Zus. Die Dichte des Wassernetzes in Polen), *Ann. UMCS S. B.*, 9, 2, 1956.

[2] Gönnwein M., Untersuchungen über die Flussdichte schwäbischer Landschaften, *Erdgeschichtl. u. landeskundl. Abh. aus Schwaben u. Franken*, 13, 1913.

[3] Keller R., *Gewässer und Wasserhaushalt des Festlandes*, Leipzig 1962.

[4] Malicki A., W sprawie metody konstrukcji map gęstości sieci rzecznej (Zus. Über die Konstruktionsmethoden der Flussdichtenkarten), *Czas. Geogr.*, 15, 1937.

[5] Monografia hydrologiczna dorzecza Wieprza (Hydrological monograph of Wieprz drainage basin), *Prace PIHM*.

[6] Neumann L., Die Dichte des Flussnetzes im Schwarzwalde, *Gerl. Beiträge z. Geoph.* Leipzig 1900.

[7] Pardé M., *Potamologie*, Grenoble 1949.
[8] Puls L., *Vergleichende Untersuchungen über Flussdichte*, Hamburg 1910.
[9] Schaeffer W., *Die Flussdichte zwischen Teutoburgerwald und Fichtelberge*, Dresden 1912.
[10] Suerken J., Die Flussdichte im östlichen Teile des Münsterchen Beckens, *Zeitschr. f. Gewässerk.*, 9, 1909;
[11] Szalkiewicz B., Gęstość sieci rzecznej międzyrzecza Wisły i Bugu (Res. La densité du reseau fluvial entre la Vistule et le Bug), *Ann. UMCS S B.*, 2, 6, 1947.
[12] Tichy F., Die Lahn. Geographische Grundlagen einer Wasserwirtschaft, *Marburger Geogr. Schr.*, 2, 1951.
[13] Uhorczak F., *Atlas Regionalny Lubelskiego. Mapa Użytkowania Ziemi 1 : 300 000. Wody* (Atlas of Lublin Region. Land Use Map to a scale of 1 : 300 000. Hydrography), Warszawa 1951.
[14] Wallen A., Eau tombée, débit et évaporation dans la Suéde meridionale, *Geografiska Ann.*, 3, 1927.
[15] Wilgat T., W sprawie metody pomiarów gęstości sieci wodnej (Res. Sur la méthode du mesurage de la densité du reseau hydrographique), *Ann. UMCS S. B.*, 2,7.1947.
[16] Wolff W., *Die Flussdichte im Gebiet der Ahr, Erft und Roer*, Bonn 1912.
[17] Wundt W., Niederschlag und Abfluss in Zusammenhang mit der Temperatur und der Lage der Trockengrenze, *Petermanns Geogr. Mitt.*, 83, 1937, 73 pp.

MAP OF THE POPULATION DISTRIBUTION IN POLAND IN 1960

LESZEK KOSIŃSKI, ANDRZEJ GAWRYSZEWSKI

INTRODUCTION

The map accompanying this article, as well as another unpublished map of 1950, was prepared at the Section of Population Geography, Polish Academy of Sciences. The map was based on the data of the population Census of 1960, for the smallest administrative units — gromadas [6]. The map of built-up areas, one of the series of General Land Use Maps by F. Uhorczak (4) was also used. The work was iniciated by K. Dziewoński, who supervised it during the first period. Subsequently the project was carried forward under L. Kosiński. Cartographic work was executed by Genowefa Ozga and Bogumiła Rokicka. Editing was done by A. Gawryszewski. Introductory information concerning the map has already been published [1].

The method used is that recommended by the IGU Commission on a World Population Map, then chaired by W. William-Olsson [5]. The method is similar to those employed earlier in Swedish cartography. The final decision as to the method, and in particular the type of symbols to be employed, was preceded by a series of discussions at Commission meetings, where the results of psychophysical tests carried out at Stockholm School of Economics were taken into account [2].

Accordingly population was represented by dots (one dot for 200 people) and for larger concentrations by circles or rather projections of spheres whose volume was proportional to the number of inhabitants according to the formula $d = 0.5 \sqrt[3]{10 \text{ population}}$, where d is the diameter of the circle. The population was also indicated numerically in the circles, as were the names of the largest cities. The general rule was modified on the Polish map where dots were used for rural and circles for urban population [1]. The distribution of dots was based on the map of built-up

[1] Urban population includes the inhabitants of units which have the status of towns and cities (miasta) together with those with the status of urban settlements (osiedla). The latter have been formed since 1955.

areas. However, the Commission's suggestion was accepted to group the dots in the case of larger settlements.

The map shows distribution of de facto population, registered on the spot during the census of December 6th, 1960. Population centrally registered and not divided according to administrative units was ignored [2].

In order to facilitate reference administrative boundaries of units of the first order (voivodship) and second order (poviats), were added as they were on January 1st 1962. Some rivers were also shown. Further topographical information (e.g. main transportation lines, relief, land use) would contribute greatly to better interpretation of the population distribution, but would at the same time confuse the map, and so it was not introduced. It is hoped that the map finally produced is clear and legible.

The map was drafted on the scale 1 : 500,000 and then photographically reduced to the scale 1 : 1,000,000 suggested by the Commission.

Population of Poland in 1960

According to the 1960 census the population of the country amounted to 29,800,000. This was 4,800,000 more than during the previous census carried out a decade earlier, and 5,800,000 more than during the first postwar census of 1946. Nevertheless the population of Poland was still lower than before the war. The present territory of Poland was inhabited in 1939 by 32,100,000 people. Despite a very rapid population increase the period of 15 years was not sufficient to make up for the losses and consequences of the war. In 1960 the country was divided into 17 voivodships of different area. Five of the largest cities were also treated separately as cities-voivodships for administrative purposes. However, for better comparability we shall consider them together with the surrounding voivodships. The population of individual voivodships ranged between 700,000 in Koszalin and 3,500,000 in Warszawa. The second largest population was in Katowice, where the largest urban complex is situated. The two largest voivodship owed their leading positions to to their large urban populations, while the next two positions were occupied by those voivodships (Kraków and Poznań) with a very large rural population, in addition to quite large urban population.

Variations in area and population were reflected in population density, varying from 38 per sq km in Białystok voivodship to 344 in Katowice, the national average being 96.

[2] This part of the population amounted to 370,000, or 1.2% of the total population.

Table 1

The population of Poland according to the Census of December 6th, 1960
(de facto population)

Voivodship	Area Sqkm	Population				
		Total		Urban		Rural
		000'	per sqkm	000'	%	000'
Poland — total	311730	29 775.5*	96	14 206.1	47.7	15 199.6
Białystok	23146	1 090.2	47	327.8	30.1	762.4
Bydgoszcz	20798	1 708.3	82	820.8	48.0	887.5
Gdańsk	10978	1 222.8	111	811.5	66.4	411.3
Katowice	9518	3 274.5	344	2 480.0	75.7	794.5
Kielce	19469	1 815.7	93	495.7	27.3	1 320.0
Koszalin	17974	687.9	38	307.0	44.6	380.9
Kraków incl. the city	15800	2 471.7	159	1 033.8	41.8	1 437.9
City of Kraków	230	481.3	2 092	481.3	100.0	×
Voivodship	15350	1 990.4	130	552.5	27.8	1 437.9
Lublin	24829	1 801.4	73	444.6	24.7	1 356.7
Łódź incl. the city	17277	2 304.7	133	1 213.5	52.7	1 091.2
City of Łódź	212	709.7	3 348	709.7	100.0	×
Voivodship	17065	1 595.0	93	503.8	31.6	1 091.2
Olsztyn	20996	881.3	42	315.7	35.8	565.6
Opole	9506	929.0	98	354.2	38.1	574.8
Poznań incl. the city	26943	2 400.9	89	1 126.3	46.9	1 274.6
City of Poznań	220	408.1	1 855	408.1	100.0	×
Voivodship	26723	1 992.8	75	718.2	36.0	1 274.6
Rzeszów	18657	1 586.2	85	387.0	24.4	1 199.1
Szczecin	12677	757.9	60	470.3	62.0	287.6
Warszawa incl. the city	29816	3 454.1	116	1 867.2	54.0	1 586.9
City of Warszawa	446	1 139.2	2 554	1 139.2	100.0	×
Voivodship	29370	2 314.9	79	728.1	31.4	1 586.9
Wrocław incl. the city	19052	2 236.8	117	1 368.9	61.2	868.0
City of Wrocław	225	430.5	1 913	430.5	100.0	×
Voivodship	18827	1 806.3	96	938.3	51.9	868.0
Zielona Góra	14514	782.3	54	381.9	48.8	400.5

* Includes 369.8 centrally registered and not distributed according to administrative units.
Source: Biuletyn Statystyczny, Seria L, No. 23, Warszawa 1964, pp. 5—6.

The postwar period was characterised by a very rapid growth of urban population from 7,500,000 in 1946 and 9,600,000 in 1950 to 14,200,000 in 1960. At the same time rural population decreased from 16,100,000 in 1946 to 15,000,000 in 1950 and during the subsequent decade experienced only a very limited increase to 15,200,000 in 1960. As a result the percentage of urban population, a generally accepted measure of the degree of urbanisation, increased from 31.8 in 1946 to 39.0 in 1950 and 47.7 in 1960. The percentage of urban population varied in different voivodships — in eight voivodships it exceeded the national average: Katowice, Gdańsk, Szczecin, Wrocław, Warszawa, Łódź, Zielona Góra and Bydgoszcz. In the first six voivodships urban population exceeded 50%.

Urban population was concentrated in 746 towns and cities and 143 urban settlements. In 1950 the number of towns was limited to 706. The total number of urban units increased by 183 and their average population rose from 13,600 to 16,000. The distribution of towns and urban settlements according to their size is shown on Fig. 1, where the number of towns in each size category and their population has been indicated in each voivodship. Corresponding data (in per cent) are given in Tables 2 and 3.

Table 2

Distribution of towns and urban settlements according to their size and their population in 1960

	Size of towns and urban settlements in thousands of inhabitants							
	below 5	5—10	10—20	20—50	50—100	100—200	200 and more	Total
Number of towns and urban settlements	405	236	138	68	20	13	9	889
Urban population in thousands	1.208	1.652	1.880	2.081	1.273	1.885	4.227	14.206
Percentage of total population in each size class	4.1	5.6	6 4	7.1	4.3	6.4	14.4	48.3
Percentage of urban population in each size class	8.5	11.6	13.2	14.6	9.0	13.3	29.8	100.0

Source: Rocznik Statystyczny (Statistical Yearbook) 1966, table 5 (24), pp. 23—24.

The large majority of the urban population was living in towns and cities. Urban settlements accounted for less than 5%. As far as the number of urban units was concerned, the smallest ones predominated; however, their population was only a relatively small fraction of the total urban population. The cities with more than 100,000 inhabitants contributed almost half the urban population.

Again the situation in individual voivodships varied a great deal. Not all size categories were represented everywhere. The highest percentage of the metropolitan population (living in cities above 100,000) occured in the most urbanised voivodships. On the other hand more than a half of the urban population was concentrated in small towns and settlements (below 20,000) in those voivodships with low or average percentage of urban population — Białystok, Olsztyn, Koszalin, Zielona Góra, Opole.

Table 3

Percentage of urban population in towns and urban settlements according to their size in 1960 by voivodships

Voivodships	Total urban population	Towns and cities	Urban settlements	Size of towns and urban settlements in thousands of inhabitants						
				below 5	5—10	10—20	20—50	50—100	100—200	above 200
Poland — total										
1950	100.0	100.0	—	11.1	11.6	10.8	15.9	8.6	17.1	24.9
1960	100 0	95.2	4.8	8.5	11.6	13.2	14 6	9.0	13.3	29.9
Białystok	100.0	97.6	2.4	15.2	17.7	23.5	6.7	—	36.9	—
Bydgoszcz	100.0	99.1	0.9	10.4	13.3	13.8	5.7	15.6	12.8	28.3
Gdańsk	100.0	97.9	2.1	4.9	4.7	3.2	24.1	9.5	18.3	35.3
Katowice	100.0	90.8	9.2	3.7	8.1	8.1	15.3	10.2	43.7	10.9
Kielce	100.0	96.4	3.6	10.9	15.3	7.7	21.8	18.0	26.3	—
Koszalin	100.0	99.3	0.7	14.3	30.0	16.3	21.8	17.6	—	—
Kraków incl. the city	100.0	94.4	5.6	7.5	13.9	9.2	10.7	12.1	—	46.6
City of Kraków	100.0	100.0	—	—	—	—	—	—	—	100 0
Voivodship	100.0	89.4	10.6	14.0	26.1	17.3	20.0	22 6	—	—
Lublin	100.0	97.3	2.7	11.1	11.5	18.7	17.8	—	40.9	—
Łódź incl. the city	100.0	99.4	0.6	3.9	4.9	8.6	15.2	9.0	—	58.5
City of Łódź	100.0	100.0	—	—	—	—	—	—	—	100.0
Voivodship	100.0	98.6	1.4	9.3	11.7	20.7	36.6	21.7	—	—
Olsztyn	100 0	96.8	3.2	16.5	27.9	34.0	—	21.6	—	—
Opole	100.0	90.1	9.9	18.2	13.9	21.6	28.4	17.9	—	—
Poznań incl. the city	100.0	98.3	1.7	14.0	11.5	18.8	13.2	6.2	—	36.3
City of Poznań	100.0	100.0	—	—	—	—	—	—	—	100.0
Voivodship	100.0	97.4	2.6	21.9	18.1	29.4	20.8	9.8	—	—
Rzeszów	100 0	97.2	2.8	19.9	12.9	14.8	36.3	16.1	—	—
Szczecin	100.0	99.4	0.6	12.4	14.9	8.3	7.0	—	—	57.4
Warszawa incl. the city	100.0	94.2	5.8	3.2	7.5	17.5	10.8	—	—	61.0
City of Warszawa	100.0	100.0	—	—	—	—	—	—	—	100.0
Voivodship	100.0	85.1	14.9	8.1	19.3	44.9	27.7	—	—	—
Wrocław incl. the city	100.0	90.9	9.1	10.6	15.5	15.3	13.9	4.7	8.6	31.4
City of Wrocław	100.0	100.0	—	—	—	—	—	—	—	100.0
Voivodship	100.0	86.7	13.3	15.4	22.6	22.4	20.3	6.8	12.5	—
Zielona Góra	100.0	95.2	4.8	16.1	23.2	17.2	13.7	29.8	—	—

Based on the data contained in reference (3).

In 1960 there were in Poland 22 cities with a population exceeding 100,000 as compared to 11 in 1946 and 17 in 1950. With the exception of two, almost completely destroyed during the war (Warszawa and

Wrocław — both about 80% destroyed) all the cities had more inhabitants than before the Second World War. First place was occupied by the capital but the largest urban complex, consisting of several units, was the Upper Silesian Industrial Area with a population in excess of 1,500,000. Second (or third) place was occupied by Łódź. In general the dominating position of the largest city is not so pronunced in Poland as in many other countries.

The rural population has not changed very much during the decade under consideration. In 1960 a large portion of it was concentrated in the southeastern voivodships.

Table 4

Population of the largest cities in Poland, 1939—1965 (in thousands)

	Years				
	1939	1946[a]	1950[b]	1960[c]	1965[d]
Białystok	107	57	69	121	140
Bydgoszcz	141	135	163	232	257
Bytom	101	93	174	183	191
Chorzów	110	111	129	147	154
Częstochowa	138	101	112	165	175
Gdańsk	250	118	195	287	321
Gdynia	120	78	103	148	166
Gliwice[e]	114	96	133	150	163
Katowice[f]	134	149	225	270	286
Kielce	69	50	61	90	103
Kraków	259	299	344	481	520
Lublin	122	99	117	181	204
Łódź	672	497	620	710	744
Poznań	272	268	321	408	438
Radom	86	69	80	130	144
Ruda Śląska[g]	—	33	110	132	141
Sosnowiec	130	78	96	132	140
Szczecin	268	73	179	269	312
Toruń	81	68	81	105	115
Wałbrzych	64	73	94	117	125
Warszawa	1289	479	804	1139	1253
Wrocław	621	171	309	431	474
Zabrze	126	104	172	190	199

a Data of the Census of February 14th, 1946; administrative division of April 1st, 1947.
b Data of the Census of December 3rd, 1950; administrative division of April 15th, 1951.
c Data of the Census of December 6th, 1960.
d Estimate at the end of the year.
e Since 1950 including Łabędy.
f Since 1946 including Szopienice.
g Including Nowy Bytom.
Source: Rocznik Statystyczny (Statistical Yearbook) 1966, tabl. 8, p. 28.

The basic administrative unit in the countryside is the gromada. In 1960 there were 5,245 gromadas in Poland. The most common were those of 2—3,000 inhabitants (1828 units with 4,500,000 inhabitants).

Rather less of the rural population was concentrated in 1,130 larger gromadas of 3—4,000 (3,900,000), followed by 591 gromadas of 4—5,000 (2,600,000) and 344 gromadas of more than 5,000 (2,000,000).

A relatively large number (1321) of smaller units of 1—2,000 contained inhabitants 2,100,000 and only 26,500 people were living in 31 gromadas smaller than 1,000. The larger units occured most frequently in the voivodships of Kraków and Lublin.

Distribution of urban and rural population

The largest concentrations of urban population occured around the largest cities: in Upper Silesia, around Warszawa, Łódź, Kraków, along the Bay of Gdańsk, around Poznań, Wrocław, Wałbrzych and Szczecin. Voivodship Katowice alone contained 17.4% of the national urban population and together with Warszawa voivodship accounted for more than 30%. However, the urban network in those voivodships varied a great deal. In the latter the capital dominated with 61% of the voivodship's urban population, whereas in the former the high concentration of urban population was due mainly to the 37 towns of 20—200,000.

The urban network of the country dates back to the feudal period. It was developed during the period of the industrial revolution and since then has remained more or less unchanged.

The highest density of the urban network was found in two highly industrialised voivodships, those of Katowice and Wrocław, but densities higher than national average occured also in two other southern voivodships, Kraków and Opole, in the centre of the country (Poznań) and in the north (Gdańsk). The high density was not only associated with industry but also with efficient agriculture, served by relatively well developed and densely distributed centres. The density was lowest in the east (Białystok, Lublin), north (Olsztyn, Koszalin) and in Kielce voivodship.

It has already been mentioned that interpretation of the distribution of rural population is difficult, since there is not much topographical information on the map. However, it is quite clear that the density is much lower in the north and west, where a large proportion of the land is covered by forests and partly by marshes, and where there are many lakes. Arable land is limited there and rural economy less intensive. The density of rural population is very frequently as low as 40 or even 30 persons per sq km.

Table 5

Density of urban network in voivodships in 1960

Voivodships	Area Sq km	Number of towns and urban settlements			Urban units per 1000 sq km
		Total	Towns	Urban settlements	
Poland — total	311,730	889	746	143	2.85
Białystok	23,146	34	32	2	1.47
Bydgoszcz	20,798	58	56	2	2.79
Gdańsk	10,978	31	25	6	2.82
Katowice	9,518	93	52	41	9.77
Kielce	19,469	37	33	4	1.90
Koszalin	17,974	35	34	1	1.95
Kraków *	15,580	55	44	11	3.53
Lublin	24,829	32	29	3	1.29
Łódź *	17,277	40	38	2	2.31
Olsztyn	20,996	39	35	4	1.86
Opole	9,506	37	28	9	3.89
Poznań *	26,943	102	97	5	3.79
Rzeszów	18,657	46	42	4	2.46
Szczecin	12,677	40	38	2	3.15
Warszawa *	29,816	70	57	13	2.35
Wrocław *	19,052	98	70	28	5.14
Zielona Góra	14,514	42	36	6	2.89

* Including city — voivodships.
Sources: Rocznik Statystyczny (Statistical Yearbook) 1963, table 5, pp. 15—23; Biuletyn Statystyczny (Statistical Bulletin), Ser. L, No. 23, Warszawa 1964, pp. 5—6.

In the central part of the country the largest concentrations of the rural population are to be found south-west of Warszawa, around the largest cities and also scattered in voivodships Kielce, Łódź, Poznań and Bydgoszcz, especially in those areas with higher agricultural productivity.

However, the largest areas with relatively high density of rural population are to be found in the south with the exception of the extreme south-east. The high density is due both to the fragmentation of agricultural land and to industrialisation based partly on commuting from the overpopulated countryside. Here the spatial pattern of population agglomerations corresponds to a great extent with the relief.

In the overall picture of the distribution of population in Poland parallel zones are a very characteristic feature. This long lasting situation is associated with the spatial pattern of economic life, with the distribution of industry and types of farming.

Changes of population 1960—1965

Since 1960 Poland experienced a further growth in population, to 31,551,000 at the end of 1965. The growth of urban population was more rapid and as a result its percentage increased to 49.7% (15,681,000) and during 1966 exceeded half of the population. Despite the proportional decrease of the rural population it actually grew significantly to 15,870,000. Overall density was 101 persons per sq km in 1965.

An important role was played in urban growth by internal migrations, estimated during the last five years at + 565,000 (natural increase + 703,000, administrative changes + 81,000, external migrations — 69,000) [3]. Migration into towns had an important effect on the distribution of population. The effect was less marked in the case of migration from rural to rural areas.

Detailed analysis of the actual distribution of population will be possible only when data from the next census becomes available. For comparing the two distributions and analysing the changes a pattern of comparable units is necessary. Such experiments based on a hexagonal network have already been made in Poland with reference to the decade 1950—1960 [1].

Institute of Geography
Polish Academy of Sciences
Warszawa

Bibliography

[1] Dziewoński K., Kosiński L., „Changes in the distribution of population in Poland in 1950—1960", Geogr. Polon. 7 (1965), pp. 69—79.

[2] Ekman G., Lindman R., William-Olsson W., „Psychophysical Study of Cartographic Symbols", Geogr. Ann. 45 (1963), 4, pp. 262—271.

[3] Ludność Polski w latach 1945—1965 (Population of Poland in the Years 1945——1960), Warszawa 1966, pp. 210.

[4] Uhorczak F., General land use map of Poland, sheet Settlements, Warszawa 1957, scale 1 : 1 M.

[5] William-Olsson W., „The Commission on a World Population Map: History, activities and recommendations", Geogr. Ann. 45 (1963), 4, pp. 243—250.

[6] Wyniki wstępne spisu ludności z dn. 6.XII.1960 r. wg podziału administracyjnego z dn. 1.I.1962 (Provisional results of the population census of December 6th, 1960, based on the administrative divisions as at January 1 st, 1962) Warszawa 1963.

DAILY COMMUTING TO WORK

STANISŁAWA BARTOSIEWICZOWA, IRENA CZARNECKA *

1. FORMULATION OF MODEL

The econometrical method of "input-output analysis" (also called the method of analyzing interbranch flow) is well known. The method, or rather the concept of presenting the mutual linking of branches of the national economy by means of a checkerboard pattern can also be applied when recording and analyzing the type of habitual flow of some of the population, commonly called "commuting to work". The use of this pattern grants a perspicuous insight into the relations occurring between settlements of a region, examined from the point of view of daily commuting of its inhabitants to their places of work.

Any application of the method suggested in the present paper first requires a clear delimitation of the region to be examined; the geographical boundaries determine the collection of settlements to be included in the study. Two sets must be defined: 1) that of the inhabitants of the region working outside agriculture, subdivided into separate subsets for each of the settlements, and 2) the set of all work-places within the region, again subdivided into separate subsets for the work-places of each individual settlement. Work-places and the set of inhabitants are expressed by the number of "workers" and "residents".

To show how this method works, the present paper uses the collection of settlements connected with the Turoszów industrial and residential agglomeration [1]; this comprises 19 settlements.

For the present purpose, the following definitions are employed; 1) the population of inhabitants comprises only those who are actively employed outside agriculture. They will be referred to simply as "inhabitants"; 2) the

* I. Czarnecka is the author of the second part of the paper "Application of the model".

[1] Czarnecka I., Commuting to work as linking factor in the development of industrial and settlement agglomerations (in Polish), Acta Universitatis Wratislaviensis No. 47, Studia Geogr. VIII, Wrocław 1966.

set of work-places comprises only those employed in non-agricultural establishments within the given settlement. The individuals of this set will be referred to as "workers".

The following symbols are used:

$X_{i.}$ the number of inhabitants actively employed outside agriculture, living in settlement i (with $i = 1, 2, \ldots m$), where i indicates both the successive number and the name of the respective settlement. Thus the number of settlements is indicated by m (in our case $m = 19$);

$X^{(i)}$ the total number of inhabitants of the given region as defined above;

$X_{.j}$ the number of non-agricultural work-places in settlement j (with $j = 1, 2, \ldots n$), where n indicates the number of settlements in the given region in which places of work are situated (in our case $n = 9$);

$X^{(j)}$ the total number of work-places within the given region (see the above definitions);

x_{ij} the daily commuting (outflow and inflow) of inhabitants employed in non-agricultural establishments, from place of residence i to place of work j, expressed as the total number of people commuting;

$x^{(ij)}$ the total collection of daily commuters living within the given agglomeration.

It would be difficult to imagine a region so sharply delimited that commuting would take place exclusively within its boundaries, that is, that none of its inhabitants would travel to work outside its boundaries, nor would anybody arrive to work in the region from beyond these boundaries. So we also need the symbols:

$x_{i.}$ the number of inhabitants of settlement i in the agglomeration investigated who commute daily to work outside its boundaries.

$x^{(i)}$ the population of inhabitants of the given region who daily commute to work outside its boundaries.

$x_{.j}$ the number of workers employed in settlement j who daily arrive to work from outside the region under investigation.

$x^{(j)}$ the total number of workers employed within the given region, who daily arrive to work from outside its boundaries.

With these symbols we are able to construct in a checkerboard pattern the following table, which will in future be referred to as the extended Matrix of Daily Commuting (Table 1).

From Table 1. follow basic equations:

(1) $X_{i.} = \sum_{j=1} x_{ij} + x_{i.}$ (where $i = 1, 2, \ldots m$);

(2) $$X^{(i)} = \sum_{i=1}^{m} X_{i.} = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} + \sum_{i=1}^{m} x_{i.};$$

(3) $$x^{(i)} = \sum_{i=1}^{m} x_{i};$$

(4) $$X_{.j} = \sum_{i=1}^{m} x_{ij} + x_{.j} \text{ (where } j = 1, 2, \ldots n);$$

(5) $$X^{(j)} = \sum_{j=1}^{n} X_{.j} = \sum_{j=1}^{n} \sum_{i=1}^{m} x_{ij} + \sum_{j=1}^{n} x_{.j};$$

(6) $$x^{(j)} = \sum_{j=1}^{n} x_{.j};$$

(7) $$x^{(ij)} = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} = \sum_{j=1}^{n} \sum_{i=1}^{m} x_{ij}.$$

Equations (1) show how the collection of the inhabitants of settlement i is subdivided into separate subsets according to their places of work; here the first term of the right side of the equation: $\left(\sum_{j=1}^{n} x_{ij}\right)$ indicates the number of inhabitants of the investigated region employed within the given region, while the second term: $(x_{i.})$ shows the number of inhabitants who travel daily to work outside the region.

Table 1

Extended Matrix of Daily Commuting

i	$X_{i.}$	x_{ij} 1	2	...	n	$x_{i.}$
1	$X_{1.}$	x_{11}	x_{12}	...	x_{1n}	$x_{1.}$
2	$X_{2.}$	x_{21}	x_{22}	...	x_{2n}	$x_{2.}$
...	...	...	...	...	...	...
m	$X_{m.}$	x_{m1}	x_{m2}	...	x_{mn}	$x_{m.}$
	$x^{(j)}$	$x_{.1}$	$x_{.2}$	...	$x_{.n}$	$x^{(i)}$
	$X^{(i)}$	$X_{.1}$	$X_{.2}$	...	$X_{.n}$	$X^{(j)}$

Equation (2) shows how the population of all inhabitants of the given region is subdivided into those commuting within the region: $\left(\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij}\right)$, and commuters traveling beyond the region $\left(\sum_{i=1}^{m} x_{i}\right)$. Since, in conformity with equation (7), the first term of the sum is given by $x^{(ij)}$ and, in conformity with equation (3), the second term is given by $x^{(i)}$, equation (2) can also be written as Version (2^{+}):

(2^{+}) $$X^{(i)} = x^{(ij)} + x^{(i)};$$

Any relation based on a system of equations (4) expreses the subdivision of the collection of workers from settlement j into separate subsets showing, first, the places of work occupied by inhabitants of settlement j $\left(\sum_{i=1}^{m} x_{ij}\right)$ and, secondly, by workers commuting from outside the region $(x_{.j})$.

Equation (5) shows how the workers employed in the region investigated are subdivided into intra-regional commuters $\left(\sum_{j=1}^{n} \sum_{i=1}^{m} x_{ij}\right)$ and inflow from outside the region $\left(\sum_{j=1}^{n} x_{.j}\right)$. Making use of equations (6) and (7), equation (5) may also be written as Version (5^+):

$$(5^+) \qquad X^{(j)} = x^{(ij)} + x^{(j)}.$$

Finally, equation (7) represents the common part of sets $X^{(i)}$ and $X^{(j)}$, that is, the product of these sets. Graphically Equation (7) can be shown as in Fig. 1.

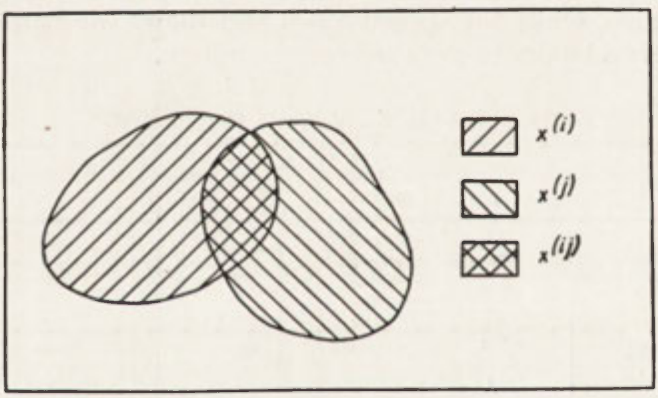


Fig. 1. Equation (7)

Inspection of the extended Matrix of Daily Commuting immediately shows that the collection of settlements falls into two subsets. The first consists of n first settlements which possess working places — we shall call them "work-place settlements"; the second embraces m-n settlements with no work places, — called "residential settlements".

Further, the extended Matrix of Daily Commuting can be used for constructing two types of matrices: 1) one giving coefficients of the distribution of the inhabitants according to their places of work (A):

(8) $a_{ij} = \frac{x_{ij}}{X_i}$ and $a_{i.} = \frac{x_{i.}}{X_{i.}}$; and 2) a second one giving the coefficients of the derivation of the workers according to their dwelling places (B):

$$(9)\ b_{ij} = \frac{x_{ij}}{X_{ij}} \text{ and } b_{.j} = \frac{x_{.j}}{X_{.j}} .$$

The forms of both these matrices are given below:

$$A = \begin{vmatrix} a_{11}\, a_{12} \ldots a_{1n}\, a_1 \\ a_{21}\, a_{22} \ldots a_{2n}\, a_2 \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ a_{m1}\, a_{m2} \ldots a_{mn}\, a_m \\ \end{vmatrix} \qquad B = \begin{vmatrix} b_{11}\, b_{12} \ldots b_{1n} \\ b_{21}\, b_{22} \ldots b_{2n} \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ b_{m1}\, b_{m2} \ldots b_{mn} \\ b_1\, b_2 \ldots b_n \end{vmatrix}$$

The coefficients of distribution of the inhabitants indicate the proportion of the total number of inhabitants of a given settlement i commuting from i to j. At the same time $a_{i.}$ gives the share of outflow from a settlement to work beyond the given agglomeration. These coefficients add up by lines to unity, and therefore:

$$(10) \qquad \sum_{j=1}^{n} a_{ij} + a_{i.} = 1 .$$

The coefficients of derivation of the workers according to their place of residence show, in turn, the share of the total number of places of work in settlement j occupied by inhabitants of settlement i who commute to j. Similarly $b_{.j}$ gives the share of inflow of commuters to a given settlement from outside of the region being investigated. Hence, summing these coefficients by columns, we obtain unity in each case:

$$(11) \qquad \sum_{i=1}^{m} b_{ij} + b_{.j} = 1.$$

It is seen that the lines of matrix A present the structure of the distribution of the inhabitants of individual settlements i according to their places of work j, while matrix B gives the structure of places of work according to the settlements where the workers reside.

By considering both these matrices together one can analyze the problem of commuting to work in detail. A few typical cases will now be taken as examples.

a) If the elements in matrix A of type a_{ii} have high values, i.e. near 1, this indicates that the inhabitants are predominantly employed in the settlement where they live. The comparison of these coefficients with the coefficients of derivation of the workers of type b_{ii} indicates whether it has been possible to fill the places of work adequately with local inhabitants. If a high coefficient a_{ii} is associated with a low coefficient b_{ii}, it means that the local inhabitants have been insufficient to fill the places of work in the settlement, and so the necessity arose of supplementing them with inhabitants from other settlements. This indirectly indicates a lack of correlation between places of work and number of inhabitants within a given settlement. Conversely, a high coefficient a_{ii} associated with a high coefficient of derivation of workers b_{ii} indicates that the majority of places of work in a given settlement have been filled by local inhabitants.

b) If elements of matrix A of type a_{ii} approach zero, and if at the same time elements of matrix B of type b_{ii} are also close to zero, this would indicate that employment of residents in the given settlement is low due to the small amount of work available. If, however, the elements of matrix B are close to 1, it would mean a high ratio of the total number of places of work to the number of resident workers.

Consequently, by using coefficients a_{ii} and b_{ii}, we can classify the individual settlements of the investigated region according to two criteria: 1) the degree of self sufficiency of the settlements, i. e. their ability to fill their places of work with their own inhabitants (b_{ii}) and 2) the degree of stability of the inhabitants (a_{ii}).

The quotient

$$c_i = \frac{a_{ii}}{b_{ii}} = \frac{X_{.j}}{X_{i.}} \tag{12}$$

represents the joint characteristic of a settlement, taking into account the prevalence of either the number of the inhabitants over the number of work-places, or the reverse. This new coefficient may therefore be called the coefficient of the degree of balance between places of work and labour force in the settlement i.

If this coefficient equals 1, the settlement enjoys full quantitative self sufficiency. This concept of quantitative self sufficiency can be expressed by the simple equation $X_{i.} = X_{.j}$, meaning that in a given settlement $(i = j)$ the number of places of work equals the number of inhabitants. However, this does not mean at all, that the qualitative side of self sufficiency has also been considered. If in a settlement the occupational structure of the employees does not correspond with the occupational structure of the residents, there must be some commuting from outside, although the number of the inhabitants would have been sufficient to cover the local labour demand. Nor does this coefficient take into account the autonomy of the labour market, or the personal decision of individual employees on where they want to work.

If the coefficient of degree of balance between work-places and man power is higher than 1, this indicates a labour shortage in the settlement. With the coefficient below 1 there would be a surplus of man power.

When considering the agglomeration as a whole, the value corresponding to coefficient c_i is the coefficient of balance between places of work and man power for the whole agglomeration investigated:

$$C = \frac{X^{(j)}}{X^{(i)}}.$$

The interpretation of this equation is the same as that given above for (12).

The problem of commuting sensu stricto will now be considered, that is, with coefficients a_{ij} and b_{ij} where $i \neq j$. It is for the analyst to establish arbitrarily such values for these coefficients as he may consider the most appropriate. For instance, he may think it advisable to consider only coefficients which are not less than 0.1. This will enable him to distinguish tendencies in the outflow of inhabitants and the inflow of employees, which are significant from the point of view of the given settlement. Here it should be stressed that commuting (outflow or inflow) may be important to one settlement, let us say as inflow, but at the same time unimportant as outflow for the settlement from which the commuters travel. Hence, the intra-settlement bond is by no means always symmetrical [2]. The determination of significant tendencies in commuter flow reveals groups of settlements which are mutually connected by symmetrical bonds. It also indicates the range of influence exerted by each settlement, whether attracting workers or releasing its inhabitants for outside work.

This kind of analysis of commuting sensu stricto makes it possible, in turn, to apprehend commuting in a synthetic way.

Let $d_i^{(1)}$ denote the coefficient mobility within the investigated agglomeration for the inhabitants of settlement i. Let d_i be their coefficient of total mobility including commuting beyond the area. Then we have:

(13) $$d_i^{(1)} = \sum_{\substack{j=1 \\ j \neq i}}^{n} a_{ij} \quad \text{and}$$

(14) $$d_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} a_{ij} + a_i.$$

By definition, high values of both these coefficients must be associated with low values for the coefficients of stability for the inhabitants. Also,

[2] Cf: Czarnecka I., op. cit.

the less the difference between coefficients d_i and $d_i^{(1)}$ the higher the degree of employment of the inhabitants of settlement i within the area.

$$f_j^{(1)} = \sum_{\substack{i=1 \\ i \neq j}}^{m} b_{ij} \tag{15}$$

We may call the coefficient of coverage of the labour demand by the inhabitants of the investigated agglomeration, and

$$f_j = \sum_{\substack{i=1 \\ i \neq j}}^{m} b_{ij} + b_j \tag{16}$$

the total coefficient of coverage of the labour demand.

Similarly, high coefficients of coverage of the labour shortage from outside are associated with low coefficients of self sufficiency of settlement j, and conversely.

The difference $f_i - f_i^{(1)}$ gives an indication of the degree to which labour requirements are met by inhabitants traveling from other settlements in the investigated area. This degree is highest when the difference is lowest.

The matrices of commuting need not be limited to the above methods of treating the various settlements of the investigated region but may be applied to the investigated region as a whole.

When applied to the whole region, the coefficients corresponding to a_{ij} and b_{ij} will be:

(17) $A_i = \frac{x^{(ij)}}{X^{(i)}}$ and (18) $B_i = \frac{x^{(ij)}}{X^{(j)}}$.

The former we shall call the coefficient of the linking power of the inhabitants of the region, the latter the coefficient of its self sufficiency. Coefficient A_i can also be expressed as the sum of two coefficients, one being that of the stability of the inhabitants of the region given by equation:

$$A_i^{(1)} = \frac{\sum_{i-1}^{n} x_{ii}}{X^{(1)}}, \tag{19}$$

the other being the coefficient of the intra-agglomeration mobility of the inhabitants, given by the equation:

$$A_i^{(2)} = \frac{x_{ij} - \sum_{i=1}^{n} x_{ii}}{X^{(i)}}. \tag{20}$$

The difference between unity and the sum of these two coefficients (19) and (20) is the coefficient of "emigration" for the inhabitants of the whole region:

(21) $$A_i^{(3)} = \frac{x^{(i)}}{X^{(i)}} \cdot$$

On the other hand, the coefficient of self sufficiency of the region will be brought up to the value 1 by adding to it the coefficient of employment from outside, given by equation:

(22) $$B_j^{(1)} = \frac{x^{(j)}}{X^{(j)}} \cdot$$

An area for which $A_i = B_j$ may be considered quantitatively self sufficient — with reservations as to qualitative self sufficiency as mentioned earlier. An area for which $A_i > B_j$ is an outflow area, while an area with $A_i < B_j$ is one with a predominance of commuter inflow.

The values of these coefficients, together with that of coefficient C previously discussed, may serve as criteria for checking whether the boundaries of the investigated area have been drawn correctly. When the values are close to 1 (theoretically equal to 1), the boundaries may be considered as established correctly. In this case the region is well compacted and self sufficient since practically all daily commuting to work (both in inflow and outflow) takes place within the boundaries of the region investigated. Obviously, in this instance compactness and self sufficiency refer solely to the daily migration of commuters to their places of work.

2. Application of the model

Table 2. serves as a basis for the study of commuting to work. It gives an empirical illustration of the matrix shown in Table 1. The detailed discussion above allows the successive equations (1) to (7) to be considered without further introduction.

Equation (1) can be read from the individual lines. For instance the division of the collection of the inhabitants of Turoszów into separate subsets by places of work within the investigated agglomeration and the subset of commuters traveling daily beyond the investigated area, is shown by the equation:

$$140 = (120 + 1 + 6 + 2) + 11.$$

In all, there are 19 equations of this type.

Table 2

Daily commuter flow of workers for the Turoszów industrial and residential agglomeration (conditions in 1960)

No.	Place of residence in the agglomeration	Number of persons actively employed outside agriculture	Locality of work within the agglomeration, and number of persons employed									Number of persons commuting outside the agglomeration
			Turoszów	Trzciniec with Zatonie	Bogatynia	Biedrzychowice	Opolno-Zdrój	Sieniawka	Rybarzowice	Radomierzyce	Zgorzelec	
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Turoszów	140	120	1	6	2	—	—	—	—	—	11
2	Trzciniec with Zatonie	1,911	704	1,173	27	1	—	5	—	—	1	—
3	Bogatynia	4,576	1,350	270	2,919	21	—	6	3	—	7	—
4	Biedrzychowice	154	83	5	17	40	—	5	3	—	1	—
5	Opolno-Zdrój	592	269	155	95	3	70	—	—	—	—	—
6	Sieniawka	2,552	75	1,970	166	1	31	307	2	—	—	—
7	Rybarzowice	212	48	18	34	30	7	1	74	—	—	—
8	Radomierzyce	244	—	—	1	—	—	—	—	238	5	—
9	Zgorzelec	5,341	288	170	148	—	12	—	—	—	4,563	160
10	Jasna Góra	47	33	2	12	—	—	—	—	—	—	—
11	Porajów	587	430	84	20	2	—	50	—	—	1	—
12	Strzegomice	66	58	4	4	—	—	—	—	—	—	—
13	Wigancice	382	364	7	11	—	—	—	—	—	—	—
14	Działoszyn	132	69	21	34	—	—	—	—	—	—	8
15	Bratków	24	16	7	—	—	—	—	—	—	1	—
16	Kopaczów	28	22	2	4	—	—	—	—	—	—	—
17	Krzewina	29	23	—	4	—	1	—	—	—	—	1
18	Posada	22	19	1	2	—	—	—	—	—	—	—
19	Jędrzychowice	51	—	—	—	—	—	—	—	—	43	8
Number of workers arriving from beyond the agglomeration		1,076	274	200	97	8	66	6	—	—	425	188
Number of non-agricultural workplaces		17,090	4,245	4,083	3,608	108	187	380	82	238	5,047	17,978

Note: The above data were assembled by the author.

Equation (2) is taken from column 3 of Table 2; it gives the total number of employed inhabitants of the agglomeration, amounting to 17,090.

Equation (3) gives the sum of figures in the last column of Table 2, recording the number of workers commuting beyond the agglomeration. Their number is 188.

Equation (4) can be read from the individual columns. For instance, for Turoszów the division of the collection of employees into separate subsets according to places of residence and employees dwelling outside of the agglomeration appears thus:

$$4\,245 = (120 + 707 + 1350 + 83 + 269 + 75 + 48 + 288 + 33 + 430 + 58 + 364 + 16 + 69 + 22 + 23 + 19) + 274.$$

There are 9 equations of this type.

Equation (5) gives the sum of figures in the bottom line of Table 2, representing the total sum of work-places within the agglomeration. This figure is 17 978.

Equation (6) gives the sum of the figures in the last but one line of Table 2. This is the total number of workers arriving from outside the agglomeration, which comes to 1 076.

Equation (7) gives the total of workers commuting within the investigated agglomeration. This is found from Table 2 by summing data extracted from columns 4 to 12, or by summing sub-totals obtained by lines from columns 4 to 12. This gives the number of workers dwelling within the agglomeration and working within it as 16,902.

The map (Fig. 2) illustrates the geographical distribution of the settlements constituting the agglomeration under investigation. The diagrams of the individual settlements each show two overlapping squares which represent two sets: the number of inhabitants actively employed outside agriculture, and the number of non agricultural work-places [3]. In addition the diagrams record the number of inhabitants employed in the settlement where they live, together with the number of workers arriving to work or leaving for outside work (Explanations in Fig. 2). Obviously settlements with no non-agricultural work show only one square, expressing the number of inhabitants employed outside agriculture who commute to work. Some of the settlements are conspicuous for their considerable shortage of labour, for example Turoszów, where a large open-cast brown coal mine is being enlarged, and Trzciniec (with Zatonie), where an electric power station is being built. Other settlements are remarkable for the large number of inhabitants employed outside agriculture, for example Sieniawka, Opolno-Zdrój, Porajów and Wigancice. Of the total number of 19 settlements which make up the investigated agglomeration, 9 have non-agricultural work-places. The remaining 10 are residential settlements.

[3] These diagrams may be augmented by adding further elements Cf: Czarnecka I., op. cit.

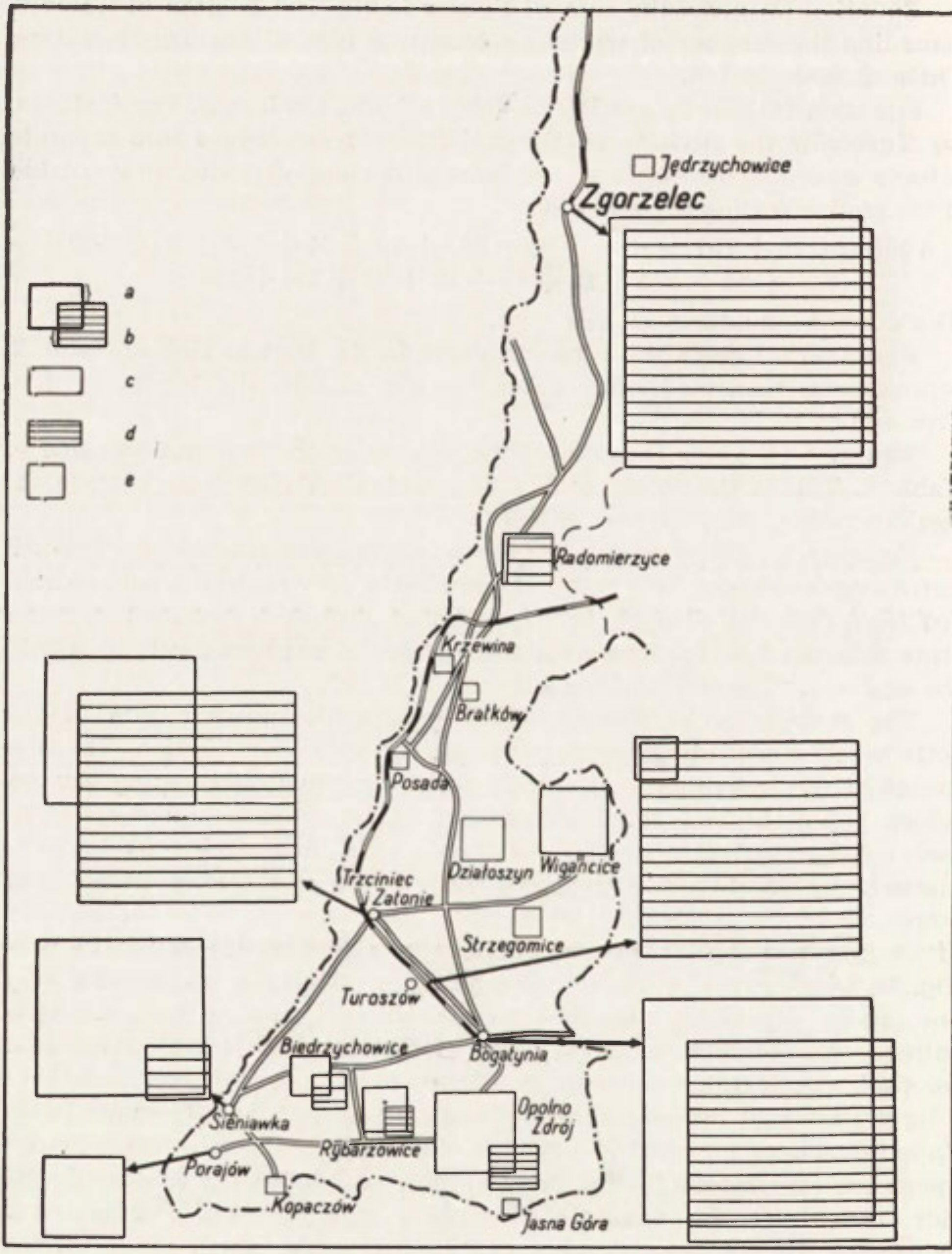


Fig. 2. Turoszów productive and residential agglomeration, 1961

a — number of departures, b — number of arrivals, c — number of inhabitants actively employed outside agriculture, d — number of non-agricultural work-places, e — 100 persons

In accordance with the first section of this paper a matrix was constructed from Table 2. showing coefficients of distribtution of the inhabitants of individual settlements according to their places of work, together with a second matrix of coefficients of employees origin according to their place of residence. These two coefficients have been calculated from Equations (8) and (9) and tabulated in Tables 3. and 4.; these tables constitute the matrices *A* and *B*. In accordance with Equations (10) and (11), all lines of Table 3. and all columns of Table 4. total 1. The comparison of Tables 3. and 4. leads to the following conclusions:

a) In Table 3. the element of type a_{ij} is of highest value for Turoszów, Radomierzyce and Zgorzelec, indicating that most of the inhabitants of

Table 3

Coefficients of distribution of the inhabitants of individual settlements, grouped according to their places of work

No.	Place of residence	$a_{ij} = \frac{x_{ij}}{X_{i.}}$									
		Turoszów	Trzciniec with Zatonie	Bogatynia	Biedrzychowice	Opolno—Zdrój	Sieniawka	Rybarzowice	Radomierzyce	Zgorzelec	$a_{i.} = \frac{x_{i.}}{X_{i.}}$
1	2	3	4	5	6	7	8	9	10	11	12
1	Turoszów	0.857	0.007	0.043	0.014	0	0	0	0	0	0.079
2	Trzciniec with Zatonie	0.368	0.615	0.014	0	0	0.003	0	0	0	0
3	Bogatynia	0.295	0.059	0.639	0.005	0	0.001	0	0	0.001	0
4	Biedrzychowice	0.541	0.032	0.110	0.260	0	0.032	0.019	0	0.006	0
5	Opolno-Zdrój	0.455	0.262	0.160	0.005	0.118	0	0	0	0	0
6	Sieniawka	0.029	0.773	0.065	0	0.012	0.120	0.001	0	0	0
7	Rybarzowice	0.226	0.085	0.160	0.142	0.033	0.005	0.349	0	0	0
8	Radomierzyce	0	0	0.004	0	0	0	0	0.976	0.020	0
9	Zgorzelec	0.054	0.032	0.028	0	0.002	0	0	0	0.854	0.030
10	Jasna Góra	0.702	0.043	0.255	0	0	0	0	0	0	0
11	Porajów	0.733	0.143	0.034	0.003	0	0.085	0	0	0.002	0
12	Strzegomice	0.878	0.061	0.061	0	0	0	0	0	0	0
13	Wigancice	0.953	0.018	0.029	0	0	0	0	0	0	0
14	Bratków	0.666	0.292	0	0	0	0	0	0	0.042	0
15	Działoszyn	0.522	0.159	0.258	0	0	0	0	0	0	0.061
16	Kopaczów	0.786	0.071	0.143	0	0	0	0	0	0	0
17	Krzewina	0.794	0	0.138	0	0.034	0	0	0	0	0.034
18	Posada	0.864	0.045	0.091	0	0	0	0	0	0	0
19	Jędrzychowice	0	0	0	0	0	0	0	0	0.843	0.157

Table 4

Coefficients of the derivation of workes, according to their places of residence

No.	Place of residence	$b_{ij} = \frac{x_{ij}}{X_{.j}}$								
		Turoszów	Trzciniec with Zatonie	Bogatynia	Biedrzychowice	Opolno-Zdrój	Sieniawka	Rybarzowice	Radomierzyce	Zgorzelec
1	2	3	4	5	6	7	8	9	10	11
1	Turoszów	0.028	0.000	0.002	0.019	0	0	0	0	0
2	Trzciniec with Zatonie	0.166	0.286	0.007	0.009	0	0.013	0	0	0
3	Bogatynia	0.317	0.066	0.813	0.194	0	0.016	0.037	0	0.001
4	Biedrzychowice	0.020	0.001	0.005	0.370	0	0.013	0.037	0	0
5	Opolno-Zdrój	0.063	0.040	0.026	0.028	0.375	0	0	0	0
6	Sieniawka	0.018	0.480	0.046	0.009	0.166	0.807	0.024	0	0
7	Rybarzowice	0.000	0.004	0.009	0.278	0.037	0.003	0.902	0	0
8	Radomierzyce	0.011	0.000	0	0	0	0	0	1.000	0
9	Zgorzelec	0.068	0.042	0.041	0	0.064	0	0	0	0.906
10	Jasna Góra	0.008	0.000	0.003	0	0	0	0	0	0
11	Porajów	0.101	0.021	0.006	0.019	0	0.132	0	0	0
12	Strzegomice	0.014	0.001	0.001	0	0	0	0	0	0
13	Wigancice	0.086	0.002	0.003	0	0	0	0	0	0
14	Bratków	0.004	0.002	0	0	0	0	0	0	0
15	Działoszyn	0.016	0.005	0.009	0	0	0	0	0	0
16	Kopaczów	0.005	0	0.001	0	0	0	0	0	0
17	Krzewina	0.005	0	0.001	0	0.005	0	0	0	0
18	Posada	0.005	0	0	0	0	0	0	0	0
19	Jędrzychowice	0.000	0	0	0	0	0	0	0	0.009
	$b_{.j} = \frac{x_{.j}}{X_{.j}}$	0.065	0.050	0.027	0.074	0.353	0.016	0	0	0.084

these settlements work locally. However, the corresponding coefficients of type b_{ii} in Table 4 have values like 0.028 for Turoszów, 0.906 for Zgorzelec and 1.000 for Radomierzyce. This indicates that Turoszów suffers a labour shortage and obtains workers from outside, while at Radomierzyce all places of work, and at Zgorzelec nearly all, are occupied by local people.

b) The element of type a_{ii} for Opolno-Zdrój is near zero (0.118), while the elements of type b_{ii} is also low, being only 0.375. Therefore this settlement has little opportunity of employing its inhabitants locally, and they must look for work elsewhere.

In Table 5 elements of type a_{ii} and type b_{ii} are set out together with the coefficient of the degree of balance between work-places and labour resources, computed according to Eqution (12). From column 5 of

Table 5

Coefficients of balance between work-places and labour resources

No.	Name of settlement	a_{ii}	b_{ii}	$\frac{a_{ii}}{b_{ii}}$
1	2	3	4	5
1	Turoszów	0.857	0.028	30.7
2	Trzciniec with Zatonie	0.615	0.286	2.1
3	Bogatynia	0.639	0.813	0.8
4	Biedrzychowice	0.260	0.370	0.7
5	Opolno-Zdrój	0.118	0.375	0.3
6	Sieniawka	0.120	0.807	0.1
7	Rybarzowice	0.349	0.902	0.3
8	Radomierzyce	0.976	1.000	0.9
9	Zgorzelec	0.854	0.906	0.9
10	Jasna Góra	0	0	0.0
11	Porajów	0	0	0.0
12	Strzegomice	0	0	0.0
13	Wigancice	0	0	0.0
14	Bratków	0	0	0.0
15	Działoszyn	0	0	0.0
16	Kopaczów	0	0	0.0
17	Krzewina	0	0	0.0
18	Posada	0	0	0.0
19	Jędrzychowice	0	0	0.0

Table 5 we can see that Turoszów suffers an acute labour shortage, with a coefficient as high as 30.7. In Trzciniec with Zatonie the coefficient is also greater than unity, being 2.1, so there is a certain shortage of labour here also.

It can also be seen that to a greater or lesser degree 7 settlements have a surplus of labour, while Bogatynia, Radomierzyce and Zgorzelec provide local employment for their own inhabitants, since the degree of balance is close to 1. The remaining settlements have no work for their non-agricultural inhabitants at all. All these conclusions are confirmed by Fig. 2.

For the productive and residential settlement agglomeration as a whole, the degree of balance between work-places and labour resources is

$$C = \frac{X^{(j)}}{X^{(i)}} = \frac{17978}{17090} = 1.05,$$

so the region does show an inflow of labour from outside, but only a very small one.

Table 6. forms the basis for a sensu stricto analysis of the inhabitants mobility, calculated from Equations (13) and (14), and of the coefficients of coverage from outside of the labour shortage, calculated from Equations (15) and (16). In both cases the interrelations between settlements

Table 6

Coefficients of the mobility of inhabitants, and of the coverage of labour shortage from outside

No.	Name of settlement	$d_i^{(1)}$	d_i	$d_i - d_i^{(1)}$	$f_i^{(1)}$	f_i	$f_i - f_i^{(1)}$
1	2	3	4	5	6	7	8
1	Turoszów	0.064	0.143	0.079	0.907	0.972	0.065
2	Trzciniec with Zatonie	0.385	0.385	0	0.664	0.714	0.050
3	Bogatynia	0.361	0.361	0	0.160	0.187	0.027
4	Biedrzychowice	0.740	0.740	0	0.556	0.630	0.074
5	Opolno-Zdrój	0.882	0.882	0	0.272	0.625	0.353
6	Sieniawka	0.880	0.880	0	0.177	0.193	0.016
7	Rybarzowice	0.651	0.651	0	0.098	0.098	0
8	Radomierzyce	0.024	0.024	0	0	0	0
9	Zgorzelec	0.116	0.146	0.030	0.010	0.094	0.084
10	Jasna Góra	1.000	1.000	0	0	0	0
11	Porajów	1.000	1.000	0	0	0	0
12	Strzegomice	1.000	1.000	0	0	0	0
13	Wigancice	1.000	1.000	0	0	0	0
14	Bratków	1.000	1.000	0	0	0	0
15	Działoszyn	0.939	1.000	0.061	0	0	0
16	Kopaczów	1.000	1.000	0	0	0	0
17	Krzewina	0.966	1.000	0.034	0	0	0
18	Posada	1.000	1.000	0	0	0	0
19	Jędrychowice	0.843	1.000	0.157	0	0	0

within the agglomeration and links with outside regions have been taken into consideration. Columns 3 and 4 of Table 6 indicate, that for the majority of the settlements the intra-agglomerational mobility and the overall mobility is equal or close to unity. The exceptions are Turoszów, Trzciniec with Zatonie, Bogatynia, Radomierzyce and Zgorzelec, all settlements with numerous places of work. The remaining settlements of high mobility are to a greater or lesser extent residential settlements of people employed principally within the agglomeration: as shown in column 5, few of the inhabitants of the agglomeration commute to work outside the area investigated. The coefficients of coverage of labour demand from outside are recorded for Turoszów and Trzciniec with Zatonie (columns 6 and 7). These are the localities were the surplus of work--places is greatest. The settlements with zero coverage of labour demand from outside are those which have no establishments requiring non-agricultural labour. The difference shown in column 8 is negligibly low, as is that in column 5. This confirms the very small part played within the agglomeration by labour from outside the area investigated.

Coefficients calculated from Equations (17) and (18), refering to the agglomeration as a whole, are:

$$A_i = \frac{16902}{17090} = 0.908$$

$$B_j = \frac{16902}{17978} = 0.907$$

That they are close to unity indicate strong bonds between the inhabitants within the agglomeration (A_i), as well as a high degree of self sufficiency for the whole agglomeration so far as the demand for labour is concerned (B_j).

The number of inhabitants in non-agricultural work, residing within the investigated agglomeration, is 16 902. Of these, 9504 fill places of work in their own settlements, while 7398 commute daily to work in one of the remaining settlements within the agglomeration. Thus, the coefficient of stability of the inhabitants of the agglomeration (Equation (19)) is:

$$A_i^{(1)} = \frac{9504}{17090} = 0.556,$$

a value not much higher than the coefficient of the intra-agglomerational mobility which is (Equation (20)):

$$A_i^{(2)} = \frac{7398}{17090} = 0.432.$$

The coefficient $A_i^{(3)}$ of "emigration" of the inhabitants ("emigration" in the sense of daily commuting outside the agglomeration) can be found (Equation (21)) by taking the difference between unity and the sum of $A_i^{(1)}$ and $A_i^{(2)}$. It is very low:

$$A_i^{(3)} = \frac{188}{17090} = 0.012.$$

The coefficient of "immigration" from outside (Equation (22)) is:

$$B_j^{(1)} = \frac{1076}{17978} = 0.058.$$

The sum of this and the coefficient of self sufficiency of the region (B_j) is unity. This coefficient also is very small, since only 1076 workers arrive daily from outside the agglomeration, a percentage very low compared with the total number of available work places.

The synthetic coefficients for the whole agglomeration investigated show convincingly that the boundaries of the region have been drawn correctly. The coefficient of balance of work-places within the whole area (C), the coefficient of the linking power of the inhabitants of the area (A_i), the coefficient of self sufficiency of the region (B_j) and the coefficients $A_i^{(2)}$ and $B_j^{(1)}$ all confirm this.

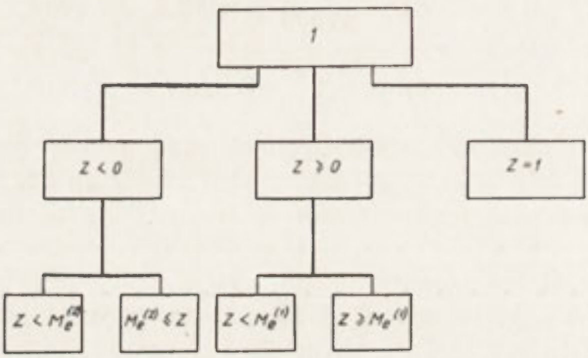


Fig. 3. Scheme of settlement classification

1 — all settlements, $Z < 0$ — settlements with labour deficit, $Z \geqslant 0$ — settlements with labour surplus, $Z = 1$ — residential settlements, $Z < M_e^{(2)}$ — productive settlements of rank I, $M_e^{(2)} \leqslant Z$ — productive settlements of rank II, $Z < M_e^{(1)}$ — productive residential settlements, $Z \geqslant M_e^{(1)}$ — residential producitve settlements

Finally, an attempt has been made to classify settlements on the basis of two variables: 1) the difference between the number of inhabitants employed outside agriculture and the number of non-agricultural work-places in other words, the absolute labour surplus; and 2) the ratio of this difference to the number of inhabitants employed outside agriculture, in other words, the relative labour surplus.

Settlements with non-agricultural centres of employment may have a labour shortage or surplus and this will be expressed by the difference $|X_{i.} - X_{.j}|$ mentioned in item "a", which distinguishes settlements by their absolute labour surpluses and shortages.

Here the author is compelled to introduce an arbitrary subdivision of settlements into groups, according to the scale of existing differences.

The relative labour surplus or shortage $\frac{|X_{i.} - X_{.j}|}{X_{i.}} = Z$, mentioned in item "b", enables us to distinguish the following types of settlements:

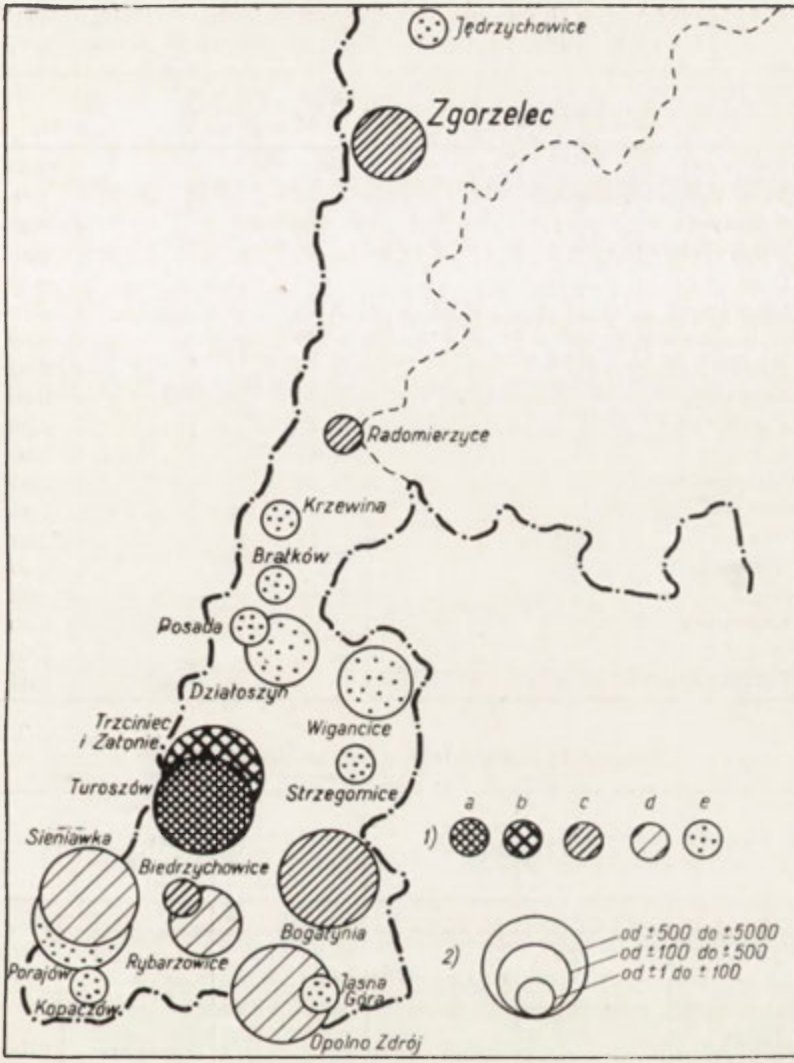


Fig. 4. Types of settlements in the Turoszów productive and residential agglomeration, 1961

1 — types of settlements: a — productive of rank I, b — productive of rank II, c — productive-residential, d — residential-productive, e — residential; 2 — surplues and deficits of labour

Residential settlements for which $Z = 1$ are devoid of non-agricultural centres of employment merely serving as dormitory areas for workers commuting to outside work. This type leaves nothing open to doubt. Considerable differences may exist between settlements with $Z < 0$ or $Z \geqslant 0$. These in turn may be subdivided into two groups by using the medians of the index Z. Consequently we obtain, for $Z < 0$, settlements with

Table 7

Settlements grouped according to absolute and relative differences between actively employed inhabitants and places of work

No.	Name of settlement	$x_{i.} - x_{.j}$	$\frac{x_{i.} - x_{.j}}{x_{i.}}$
1	Turoszów	— 4,105	— 29.30
2	Trzciniec with Zatonie	— 2,172	— 1.10
3	Bogatynia	+ 968	+ 0.20
4	Biedrzychowice	+ 46	+ 0.30
5	Opolno-Zdrój	+ 405	+ 0.70
6	Sieniawka	+ 2,172	+ 0.80
7	Rybarzowice	+ 130	+ 0.60
8	Radomierzyce	+ 6	+ 0.03
9	Zgorzelec	+ 293	+ 0 06
10	Jasna Góra	+ 47	+ 1.00
11	Porajów	+ 587	+ 1.00
12	Strzegomice	+ 66	+ 1.00
13	Wigancice	+ 382	+ 1.00
14	Bratków	+ 24	+ 1.00
15	Działoszyn	+ 132	+ 1.00
16	Kopaczów	+ 28	+ 1.00
17	Krzewina	+ 29	+ 1.00
18	Posada	+ 22	+ 1.00
19	Jędrzychowice	+ 51	+ 1.00

Table 8

Classification of settlements

$\frac{x_{i.} - x_{.j}}{x_{i.}} = z$ / $x_{i.} - x_{.j}$	$z < Me^{(2)}$	$Me^{(2)} \leqslant z < 0$	$0 \leqslant z < Me^{(1)}$	$Me^{(1)} \leqslant z < 1$	$z = 1$
large from 500 to 5000 persons	Turoszów	Trzciniec with Zatonie	Bogatynia	Sieniawka Opolno-Zdrój	Porajów
medium-sized from 100 to 500 persons			Zgorzelec	Rybarzowice	Wigancice Działoszyn
small from 1 to 100 persons			Radomierzyce Biedrzychowice		Jasna Góra Strzegomice Bratków Kopaczów Krzewina Posada Jędrzychowice
types	productive of I rank	productive of II rank	productive-residential	residential-productive	residential

greater or less relative labour shortage. The former we shall call productive settlements of rank I, the latter productive settlements of rank II. Proceeding in a similar way with $Z \geqslant 0$ we obtain settlements called productive residential and residential productive, respectively.

The pattern of the above reasoning is shown in Fig. 3., while an empirical image of the classification is given in Tables 7. and 8., as well as in Fig. 4., — the latter representing the synthesis of Fig. 2. of rather an analytical character.

In the example cited, the very large labour shortage occurring at Turoszów and at Trzciniec with Zatonie is worthy of note. Both are places of focal significance for new industrial development.

Department of Economic Geography
College of Economics
Wroclaw

A METHOD OF INDUSTRIAL LOCATION

WŁADYSŁAW TOMASZEWSKI

This article is concerned with the presentation of a method, based upon mathematical programming, which seems to be useful for the analysis of industrial location problems of the following pattern.

In a territory K during the time T, as well as during the time T + 1, the maximum capacity of different production points of a product Y [1] is known, as well as either the quantity of supplied raw material X, used for its production or its total demand (the selection of the appropriate element depends on the basis of the analysis which can be either the distribution of raw materials or of demand points). The total anticipated supply of the raw material X (the total demand for the product Y) during the time T + 1 is greater than the total maximum capacity during the time T, measured in units of the raw material X (the product Y). The resulting deficit should be met by constructing new factories, and/or by developing or redeveloping the existing ones. The number of points in the territory where the construction of new factories could be considered is known, as well as all the variants of their size. The variants in size have to be adjusted to the number of points in such a way as to permit of the analysis of their economic justification and selection of some defined variants of capacity. Similarly if development or redevelopment are planned, appriopriate variants of the size of such enterprises must be taken into consideration. Moreover, when we know the transportation costs per unit of the raw material X from different points of supply to various existing or potential points of production (the unit cost of transportation of the product Y from different points of production to various points of demand), and the current and investment costs per unit, computed as either mean values of the given class of productive capacity (if the differences which occur in different points of potential location do not affect local conditions), or individually for separate points (if those differences

[1] The maximum capacity should be corrected with deficits and gains, if any, incurred during organizational and technical activities between periods T and T + 1.

are substantial) — it remains to select such a method for choosing locations of increased production which will help to reduce during time T + 1 the total transportation, investment and current costs to the minimum.

The proposed method is explained in this article by means of a theoretical example of finding locations for new grain mills. Having enumerated factors which determine their location the author discusses methods of solving this problem on the national and regional scales. In the last part of his paper he analyses a concrete problem of location of new grain elevators in Łódź voivodship during the period up to 1980, and describes the method used by the Computing Centre of the Polish Academy of Sciences, which was actually a variant of the proposed method.

Factors which determine the location of new grain mills in the territory of the country in the period T + 1 are as follows: (1) the total demand for flour in the period T + 1 and the distribution of demand points; (2) total production capacity of grain mills in the period T corrected in the appropriate way with losses and gains incurred during organizational and technical activities in the period between T and T + 1 and also the distribution of those mills; (3) transportation costs per unit of flour from the places where grain mills already operate, or could be constructed, to the places of flour demand.

The number of sites where grain mills have been or could be constructed and of flour demand points being too great to be taken into consideration in such an analysis, the assumption has been made that the country is divided into regions. In every region there exist a point (or points) in which grinding capacity of mills operating in this territory, is concentrated, a point (or points) is which new mills could be constructed to compensate for the lacking capacity, and finally a point (or points) in which the regional demand for fluor is concentrated.

When all above mentioned elements are known the task will consist in finding points of potential location of new mills and establishing their appropriate sizes in such a way as to secure minimal total costs of transportation of flour during the period T + 1. As location on the national scale is analysed from the point of view of global increase of grinding capacity in separate regions and not in connexion with individual objects, it is not necessary to consider investment and current costs.

The method presented below is explained by means of some theoretically assumed figures.

Let us accept for the sake of this analysis that the country is divided into two regions. In the first region there are two points (1 and 2)[2] in which existing grinding capacities were concentrated in 1965. The figures denoting their capacities were duly corrected with losses and gains incurred during organizational and technical activities, and/or during development or redevelopment carried out in the period up to 1970. These two points will also be taken into consideration for the location of new mills to meet the deficit in grinding capacity. In the first region there exists, moreover, a single point (No. 1) in which the demand for flour in 1970 is concentrated. In the second region, however, there are the following: one point (No. 3) in which all grinding capacity is concentrated, another one (No. 4) for the potential location of the deficit capacity, and two other (2 and 3) where flour demand is concentrated. The theoretically assumed figures in this respect are included in Table 1. The costs of

Table 1

i \ j	1	2	3	$65^a i$
1	3	4	6	70
2	5	3	5	90
3	7	6	8	140
$70^b j$	120	180	100	300 \ 400

flour transportation per unit are shown in the inner part of the table. For the sake of further comparative analysis both flour (wheat and rye) demand and grinding capacity are expressed in units of grain weight ($70^b j$ and $65^a i$ respectively). The deficit capacity amounts, therefore, to 100 grain weight units (400—300).

The selection of sites in which new grinding capacities ought to be localized to eliminate this deficit, should begin with solving the problem presented in Table 2 by means of a transportation algorism[3]. Column 4 of this table represents a fictitious consignee. Parallel lines 1′ and 2′ enable analysis to be made of some additional locations of grinding capacities in such points in the territory of the first region where its 1965 grinding capacity is concentrated. For the second region this function is fulfilled by point No. 4 (line 4). Table 3. provides the solution of the problem.

[2] Numbers of respective lines or columns of the tables are given in brackets.

[3] The explanation of the transportation algorism can be found in a publication by W. Sadowski, *Teoria podejmowania decyzji* (The Theory of Decision-making), Warszawa, 1960, PWE (Polish Economic Publishers).

It shows that new grinding capacities should be located entirely in the first region, in its points 1 and 2, and that they should amount to 50 units each. Such locations will guarantee the minimal costs of flour transportation in 1970.

Table 2

i \ j	1	2	3	4	$_{65}a'_i$ *
1	3	4	6	M	70
1'	3	4	6	0	100
2	5	3	5	M	90
2'	5	3	5	0	100
3	7	6	8	M	140
4	6	5	6	0	100
$_{70}b_j$	120	180	100	200	600

* The symbol $65^{a'}$, which appears as from Table 2. onwards, denotes grinding capacity in 1965 in point i, or its total deficite of grinding capacities.

Having established the global increases of grinding capacity in both regions, we proceed to locate concrete variants of grinding capacity in the territory of both regions, but this time we have to take into consideration not only transportation but also investment and current costs.

Table 3

i \ j	1	2	3	4	$_{65}a'_i$
1	70				70
1'	50			50	100
2		90			90
2'			50	50	100
3		90	50		140
4				100	100
$_{70}b_j$	120	180	100	200	600

New locations of additional grinding capacity being already known, let us assume that a region R will have to increase it global grinding capacity by 50 units. The analysis on the national scale shows that such an increase in the region R will secure the balance between the regional grinding capacity and local demand for flour. If such a balance is not achieved, i.e. where there is for example a surplus supply, demand will have to be increased by means of directing flour to neighbouring regions selected on the basis of the national location scheme.

In the further course of our analysis we should assume that in 1965 in the territory of region R we have one mill in operation (No. 1) and two points of flour demand (1 and 2). Theoretically assumed figures denoting 1965 grinding capacity, 1970 flour demand and the flour transportation costs per unit from the mill to consignees are presented in Table 4.

Table 4

i \ j	1	2	$65^{a}i$
1	7	5	50
$70^{b}j$	25	75	50 \ 100

Our next assumption is that in region R there exist two points where new mills could be located (Nos. 2, 2′, 3 and 3′)[4]. Their distance to the points of flour demand is expressed in units of transportation costs in-

Table 5

i \ j	1	2
2	4	6
3	7	5

Table 6

i \ j	The variant of capacity	
	20	30
2	25	18
3	30	21

Table 7

i \ j	1	2	3	$65^{a'}i$
1	7	5	M	50
2	29	31	0	20
2′	22	24	0	30
3	37	35	0	20
3′	28	26	0	30
$70^{b}j$	25	75	50	150

Table 8

i \ j	1	2	3	$65^{a'}i$
1		50		50
2			20	20
2′	25	5		30
3			20	20
3′		20	10	30
$70^{b}j$	25	75	50	150

[4] Each of these points has a double numeration to indicate two variants of grinding capacity of mills to be located.

cluded in Table 5. Their grinding capacity can be either 20 or 30 units per annum. The task consists in choosing such locations as to quarantee in 1970 minimum transportation, investment and current costs. Table 6. presents unit investment and current costs for both variants of capacity, computed separately for each point of potential location.

To solve the problem we first apply the transportation algorism, using Table 7. as the starting point. Results can be found in Table 8.

The answer thus obtained is that to secure minimal investment, current and transportation costs the mill with a capacity of 30 units should be located in point No. 2 and that with a capacity of 20 units in point No. 3, provided that it has the same investment and current costs as the mill with a capacity of 30 units if localized in that place. Following this assumption in line 3′ of Table 7. we rewrite values included in its line 3. and again solve the new arised task. Results obtained are presented in Table 9. It appears that when investment and current costs of mills with grinding capacities of 20 and 30 units are the same, it is more profitable to locate a mill with a capacity of 20 units in point No. 2. Consequently, on the basis of results obtained in table Nos. 8 and 9 we reach the conclusion that mills of both capacities, i.e. of 20 and 30 units, should be located in point No. 2.

Table 9

i \ j	1	2	3	$65^{a'}{}_i$
1		50		50
2		20		20
2′	25	5		30
3			20	20
3′			30	30
$70^{b}{}_j$	25	75	50	150

The above described procedure can be applied, however, only to minor location problems, that is when we are dealing with small numbers of demand and supply points. When the number of such points is greater, such a procedure would be too long and laborious. But it can be modified according to the structure of each actual task. A modified method is

[5] The problem was formulated by the Subcomittee, headed by the author, which had been organized by the Ministry of Food Industry, within its Commission of Perspective Planning. The Subcommittee was entrusted with the task of preparing the programme of optimal distribution of grain economy. The programm for the computor was prepared by Mr R. Solich, M. A., from the Computing Centre of the Polish Academy of Sciences.

presented by means of the example of location of grain elevators in Łódź voivodship, up to 1980 [5].

The initial data are as follows: calculations were made for only 39 of the 177 grain purchase stations actually existing in Łódź voivodship. The amount of grain to be purchased in 1980 was estimated for each station which usually consists of five neighbouring points. Those points were analysed as potential locations of new elevators with capacities of 20, 25, 30 or 35 thousand tons. Average current and investment costs were calculated for each class of proposed capacity. Calculation of transportation costs per unit was based upon the transport network linking those 39 points in such a way that road tariffs were used for distances up to 50 kilometres and railway tariffs for distances over 50 kilometres. The total capacity of elevators needed in the territory of Łódź voivodship by 1980 was established. The programming task consisted in defining such sizes and locations of new elevators that the total investment, current and transportation costs in 1980 would be at their lowest.

To start with, the problem was limited by a further elimination of 23 points as the result of the analysis of the transportation costs per unit, which had revealed that they were relatively high. Then, the maximum, most common transportation cost per unit was compared with the differences between investment and current costs in elevators with a capacity of 20 and 25 thousand tons and those with a capacity of 30 and 35 thousand tons. This comparison led to the elimination of elevators with 20 and 25 thousand tons capacities. After all these preliminary calculations the initial task with which the computor *Ural II* was fed concerned 39 grain purchasing stations plus one fictitious station and 16 points of new locations with 35 thousand ton capacity. A subsequent analyzis of the result obtained, aloud a further elimination of 4 points as unprofitable (it appeared that the capacity of elevators would be used to a minimum degree only). Out of the remaining 12 points, in 9 cases the capacity would be utilized in more than 60 per cent, and in 3 cases less than 60 per cent. Thus, the final problem was narrowed to 39 purchase stations + 1 fictitious and 9 points of potential location with use of elevator capacities greater than 60% and 1 with a smaller utilization. All those data formed the basis of three problems next solved by the computor. The final answer gave the location which would secure the lowest transportation investment and current costs.

The example described shows that to solve location problems on a large scale it is necessary to use a computor.

Institute of Geography
Polish Academy of Sciences
Warsaw

References

[1] Birman I. J., *Transportnaya zadacha linieynovo programirovanya* (Transportation problems in linear programming), Moscow 1962.

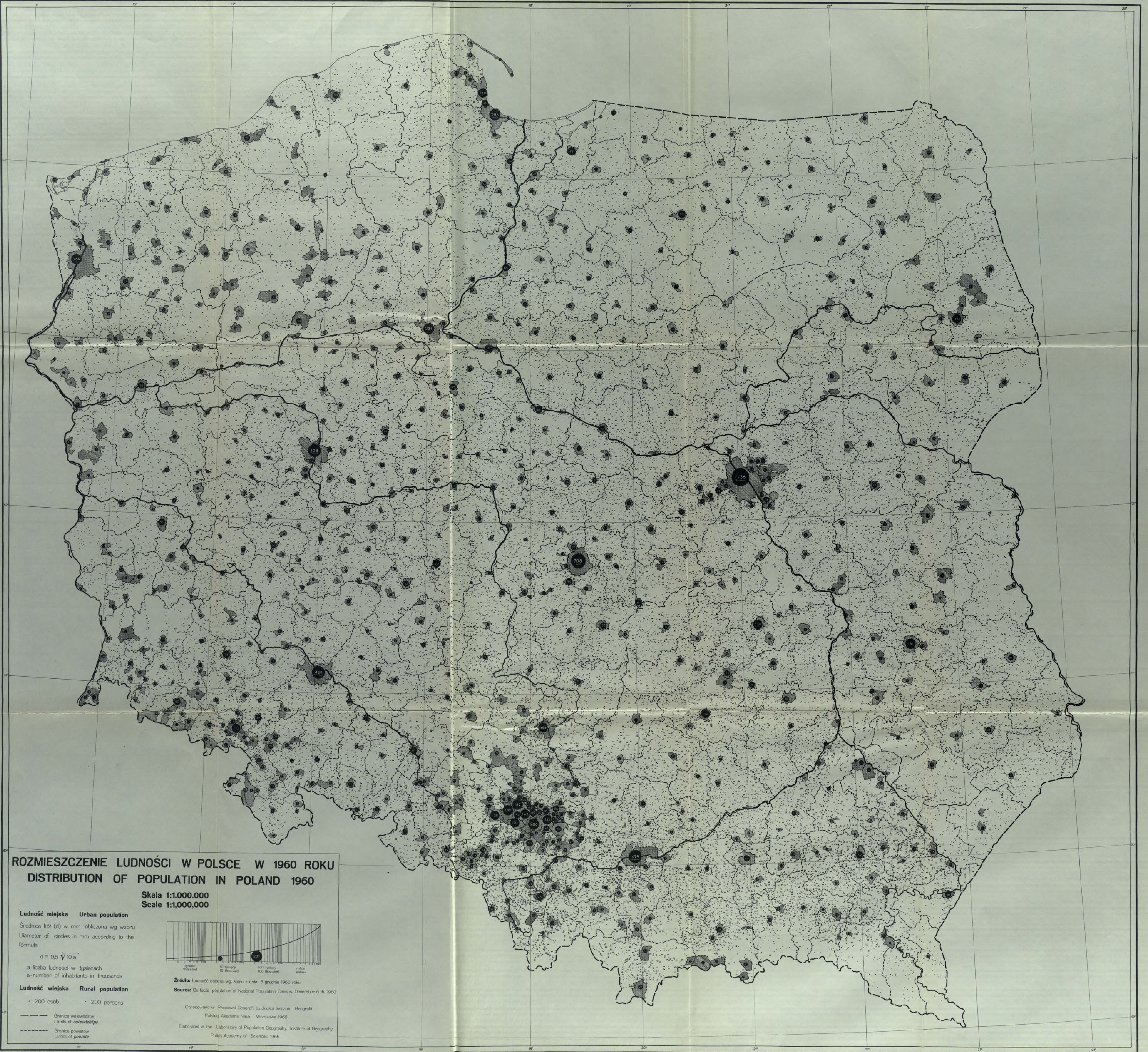
[2] Gass S., *Programowanie liniowe* (The linear programming), Warszawa 1963.

[3] Sadowski W., Wykorzystanie programowania liniowego w decyzjach lokalizacyjnych (Linear Programming Applied to Location Decisions) *Ekonomista*, 2, 1963.

[4] Tomaszewski W., Wybór lokalizacji dodatkowych zdolności produkcyjnych metodą programowania liniowego (Linear Programming Applied to Select Additional Production Capacities), *Ekonomista*, 3, 1963.

ERRATA

page	item: from above	item: from below	is	should be
49		3	ke	the
60	20		valleys of dales	valleys or dales
67		2	$+6.5$	$<+6.5$
89	3		Fichtelberge	Fichtelgebirge
94	Table 2,2		in thousands	is millions
103	2		$x^{(i)}=\sum_{i=1}^{m} x_i;$	$x^{(i)}=\sum_{i=1}^{m} x_{\cdot i};$
103		5	$\left(\sum_{i=1}^{m} x_i\right)$	$\left(\sum_{i=1}^{m} x_{i.}\right)$
104	4		$?\left(\sum_{i=1}^{m} xij\right)$	$i\left(\sum_{i=1}^{m} xij\right)$
105	1		$aij=\frac{xij}{Xi}$ (1)	$aij=\frac{xij}{Xi.}$ (1)
108	11		$fi-fi$	$fj-fj$
113	Table 3,1		0.857	0.875
115	3		Eqution	Equation
117	2		were	where
117	8		refering	referring
118	15		producitve	productive
119		7	surplues	surpluses
99		10 and 9	1945 — 1960	1945 — 1965



Druk PPWK - W-wa, Solec 18, Zam. 7024/C/67 - 4. 1. 67-3700 egz.

Cena zł 36.—

CONTENTS OF VOLUMES
GEOGRAPHIA POLONICA

Vol. 1. 11 papers devoted to the present status of geography in Poland and 3 papers giving the results of research. List of Polish geographers, geographical institutions and geographical periodicals, 262 pp., 20 Figures, 1964, $ 4,75

Vol. 2. 34 papers prepared by Polish geographers for the XXth International Geographical Congress in London, July 1964, 259 pp., 91 Figures, 1964, $ 6.65

Vol. 3. Problems of Applied Geography II. Proceedings of the Second Anglo-Polish Seminar at Keele — Great Britain, September 9—20, 1962. Co-edited by the Institute of British Geographers. 21 papers by British and Polish geographers, 274 pp., 69 Figures, 1964, $ 14.80

Vol. 4. Methods of Economic Regionalization. Materials of the Second General Meeting of the Commission on Methods of Economic Regionalization, International Geographical Union, Jablonna — Poland, September 9—14, 1963. Reports, communications and discussion, 200 pp., 6 Figures, 1964, $ 4.15

Vol. 5. Land Utilization in East-Central Europe. 17 case studies on land use in Bulgaria, Hungary, Poland and Yugoslavia, 498 pp., 104 Figures, 16 colour Maps, 1965, $ 10.00

Vol. 6. 14 papers prepared by Polish geographers for the Seventh World Conference of INQUA in U.S.A., September 1965, 150 pp., 86 Figures, 1965, $ 3.35

Vol. 7. 10 papers on the geography of Poland, mostly dealing with the economic-geographical problems of Poland, 132 pp., 46 Figures, 1965, $ 2.75

Vol. 8. Aims of Economic Regionalization. Materials of the Third General Meeting of the Commission on Methods of Economic Regionalization IGU, London, July 23, 1964. Report and 5 papers, 68 pp., 7 Figures, 1965, $ 1.25

Vol. 9. Colloque de Géomorphologie des Carpathes. Materials of the geomorphological symposium held in Cracow and Bratislava, September 17—26, 1963. Report, 7 papers, 2 sumfaries, 116 pp., 22 Figures, 1965, $ 2.25

Vol. 10. Geomorphological Problems of Carpathians II. Introduction and 6 papers by Rumanian, Soviet, Polish, Hungarian and Czech geographers, 172 pp., 68 Figures, 1966, $ 3.50

Vol. 11. 11 papers prepared by Polish geographers dealing with the history of Polish geography, Polish studies on foreign countries and different economic-geographical questions concerning Poland, Ca 160 pp., 36 Figures, 1967

Vol. 12. Formation et l'Aménagement du Reseau Urbain. Proceedings of the French-Polish Seminar in urban geography, Teresin, Poland, September 20—30, 1965. Papers by French and Polish geographers, discussion. 298 pp., 51 Figures, 1967

Subscription orders for the GEORGRAPHIA POLONICA should be placed with

FOREIGN TRADE ENTERPRISE ARS POLONA

Warszawa, Krakowskie Przedmieście 7, Poland
Cables, Arspolona, Warszawa