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CONTENTS

THE DISTRIBUTION AND ANNUAL COURSE OF THE ALBEDO IN POLAND

Teresa Kozłowska-Szczęsna

The purpose of this work is to describe the areal distribution and the changes over time of the albedo in Poland. The reflection of solar radiation from a given surface is defined by the so-called coefficient of reflection α and depends on the type of surface. The albedo is the integral of the coefficient of reflection integrated according to the wave length within the short wave band (0.3–3.0.μ). The albedo is usually expressed as a percentage ratio between the incoming and the reflected radiation. The size of the albedo is influenced by both general climatic factors and local factors. It is not surprising, therefore, that the value of the albedo of a particular surface given in the literature shows wide variations. Thus they must be taken as approximations, and when comparing or calculating these values one must only select those found under similar geographical and climatic conditions.

The first attempt to work out the areal distribution of the albedo in Poland was done in 1965 (T. Kozłowska-Szczęsna and J. Paszyński). An indirect estimation method was used because of the lack of direct measurements. The present work uses direct measurements of the value of the albedo over various natural and agricultural surfaces: moreover the accuracy of the calculation of the average albedo values was increased by using smaller units of reference (*poviats*). Many measurements under different climatic conditions and during different periods of vegetative growth had to be made in order to fully comprehend the areal and seasonal changes of the albedo. This is because the albedo depends above all on the type and state of development of plant cover in its vegetative period, as well as on the duration of snow cover in winter. The albedo measurements were made over the years 1966–1968, mainly around Warsaw, on the experimental plots of the Research Station of the Institute of Water Economy in Borowa Gora, and around the Central Geophysical Observatory of the Polish Academy of Sciences in Belsk. Thanks to the variety of agricultural land use data could be collected for most of the agricultural areas in Central Poland. To validate the values obtained measurements were also taken under differing geographical conditions, in the Świętokrzyskie Mts. A portable albedometer on a theodolite tripod was used for the measurements. It was constructed in the Department of Climatology of the Institute of Geography of the Polish Academy of Sciences. It has two Kipps sensing devices of the CM-3 type, numbers 1598 and 1609, and an electric of the GSA-1 type, number 7863. Each thermopile is covered by a single hemispherical glass screen which limits spectral sensitivity to a range of 0.3 to 2.8 μ. Janiszewski's reversible field albedometer 3×3 No. 96635 D/10690 with a milivoltmeter of the GSA-1 type No. 6841 was also used. The gauges were 150 cm from the ground. Measurements were taken over the following surfaces: grain crops, leguminous crops, root crops, pasture crops, vegetable crops, meadows and pastures, fallow and waste land, snow-covered areas and industrial areas. Measurements of the albedo and the conclusions drawn from them were done according to accepted methods. On average ten readings were taken over each selected surface, and from these the average values of the albedoes were found. The series of measurements were repeated every 15 minutes from 11.00 a.m. to 3.00 p.m. These were done on days which were not overcast or which had a uniform cloud cover of the Cs type. The measurements taken around noon were the most useful because it is at this time that the total solar radiation is most intense and the value of the albedo in the thermal economy is greatest. 4500 series of measurements over the different surfaces were made during the three-year study of the albedo. The results, in the form of average values, were used to make up a catalogue of albedoes of the various natural and cultivated surfaces of Poland. (T. Kozłowska-Szczęsna and M. Kluge 1969). One may add that the albedo values obtained by our method are comparable to those found in the literature which were obtained using similar methods and under similar climatic conditions (E. P. Barashkova *et al.* 1961; V. L. Gaievsky 1953; N. J. Goisa 1962; V. V. Mukhenberg 1963; G. F. Prikhotko, A. V. Tkachenko and N. V. Babichenko (eds) 1967; M. V. Sitnikova 1964; Spravochnik po klimatu 1966; H. V. Tooming 1960). The albedo values were also compared to the results of studies done in Poland by S. Bac and S. Baranowski (1968); M. Kluge (1963): M. Kluge and B. Krawczyk (1964, 1966); and B. Łykowski (1967, 1967 a, 1968, 1970). However, any differences between the figures for the same surfaces were not thought important.

It is obvious that not all kinds of active surface could be measured, especially areas with "tall" vegetation (forests, orchards, etc). Thus some data had to be taken from the available literature. Otherwise one would have to measure the albedo of forests either from an aeroplane or helicopter or by attaching the istrument to a balloon or a suitably high tower, as done by B. L. Dzherdzheyevsky and J. L. Raunier (1960), C. A. Federer (1967), L. W. Gay (1969), A. R. Konstantinov and S. F. Fiedorov (1960), A. Orlicz (1972), Z. I. Pivovarova and B. I. Gulaiev (1958) nad others. Data for coniferous forest was taken from the work done in Poland by A. Orlicz (1972), and the albedo values for deciduous forest, orchards and water areas were taken from other sources (S. Bac and S. Baranowski 1968; E. P. Barashkova *et al.* 1961; A. I. Chudnovsky *et al.* 1967; B. L. Dzherdzheyevsky and J. L. Raunier 1960, 1962; C. A. Federer 1967; A. R. Konstantinov and S. F. Fedorov 1960; V. V. Mukhenberg 1963; Z. I. Pivovarowa and B. I. Gulaiev 1958; N. I. Piatovskaya 1961; T. T. Pleshova 1955; J. W. Posey, and P. F. Clapp 1964; G. F. Prikhotko, A. V. Tkachenko and N. V. Babichenko (eds) 1967; N. I. Rudniev 1965; F. Sauberer and O. Härtel 1959; Spravochnik po klimatu 1966).

As well as taking measurements we made use of some basic source materials, namely: the data given by the Central Statistical Office (Główny Urząd Statystyczny or GUS) concerning land use and sown area; data given by the State Institute of Meteorology and Water Economy on the dates of the appearance of the basic phenological phases in different plants and on the duration of snow cover. Since the GUS data are compiled by administrative divisions we had to use the *poviat* unit as the basis of our work. The collected statistical data for 1960 in hectares was calculated as percentages of the area of a given *poviat*. In order to get some idea of the direction of change we then looked at the proportion of the important types of cultivation in the total sown area in the years 1950, 1960 and 1965 (R. Kulikowski 1969; Rozwój gospodarczy 1967). Using the statistical material in this way enabled us to define the structure of land use and to describe the predominant forms of land use by *poviat*. Next, in order to ascertain the length of the period of development of particular plants, the average dates over ten years of the appearance of the basic phenological phases of these plants were calculated. We also calculated the average number of days with snow cover over the period 1951–1960. Phenological data was taken from some typescripts (J. Sokołowska 1964, 1966, 1967b) and some published material (R. Gumiński 1947; T. Kosińska 1963; M. Molga 1951; K. Panecka 1960, 1963; Roczniki Fenologiczne 1951–1960; J. Sokołowska 1961, 1962, 1963, 1965, 1967, 1967a; H. Szpringer 1953, 1955; Z. Wierzbicki 1949). Moreover the ten-year average dates of the appearance of the basic developmental phases of the folowing types of vegetation, so far unconsidered, were worked out: trees, oats, sugar beet, lupins, flax and grass (T. Kozłowska-Szczęsna and J. Sokołowska 1970). The calculated ten-year average phenological data and the average number of days with snow cover were mapped, so constructing isolines showing their distribution over the country. Using these phenological maps and the maps in the works cited above, the ten-year averages of the dates of appearance of the different growth phases of selected types of vegetation were read off for those points lying roughly in the centre of each *poviat*. Similarly with the snow cover; from the maps the average number of days with snow cover in successive winter months for each *poviat* was read off. We also used writings and maps on the types of forest and soil in Poland. (L. Dreszer 1949; K. Konecka-Betley and R. Truszkowska 1957; L. Mroczkiewicz 1952; F. Tomaszewski (ed) 1950; F. Uhorczak 1969).

Thus we gathered the following initial material: (1) a list or catalogue of albedo values, (2) a compilation of the average dates over ten years of the appearance of the phenological phases of selected indicator-plants, and of the average number of days with snow cover by *poviat*, (3) data on the sown area and land use in each *poviat*, (4) data on the types of forest and soil. From all these the monthly albedo values over various types of surface were calculated. Above all, to calculate the total albedo (α_{ct}) the albedos in the list, which depend on the phenological period of a given type of crop, were multiplied by the cultivated area of the crop (P_i) in order to calculate the total albedo (α_{ct})

$$\alpha_{ct} = \alpha_i P_i$$

The value of the albedo of a particular surface in a given place was calculated as follows: the albedo was summed for each day, five or ten day period depending on the dates of appearance of the separate phenological phases of a given type of vegetation; secondly the sum obtained was divided by the number of days or periods. For the winter months it was accepted that the albedo depends on the length of snow cover (G. F. Prikhotko, A. V. Tkachenko and N. V. Babichenko (eds) 1967). The albedo of various surfaces in each month defined as above was used to calculate the average weighted albedo values over its annual course by administrative unit (396 *poviats*).

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} \alpha_i P_i}{\sum_{i=1}^{n} P_i} = \frac{\sum_{i=1}^{n} \alpha_{ct}}{100}$$

(i is the type of surface, varying from 1 to n).

Using these average weighted values of the albedo for the period 1951–1960 the annual course of the albedo over Poland was mapped (T. Kozlowska-Szczęsna, J. Paszyński 1965). The albedo for the year and for the cold (November–March) and warm (April–October) periods could also be calculated from this data. Figures 1–3 and 5–7 were constructed by the isoline method by interpolating from the centres of the *poviats*, but excluding urban areas (*poviat* towns) since these are specific surfaces which on the whole have greatly differing albedo values to those of the surrounding areas.

The albedo shows its greatest areal variation in the winter months and at this time one can also observe its highest values of the year. In January (Fig. 1) the highest values are found in the north-east and south-east of the country, in the Świętoskrzyskie Hills and in the Carpathians, and greatly exceeds 50%. The lowest values are found in the north-west of the country where it varies between 30% and 35%. A similar distribution of the albedo occurs in the remaining winter months.

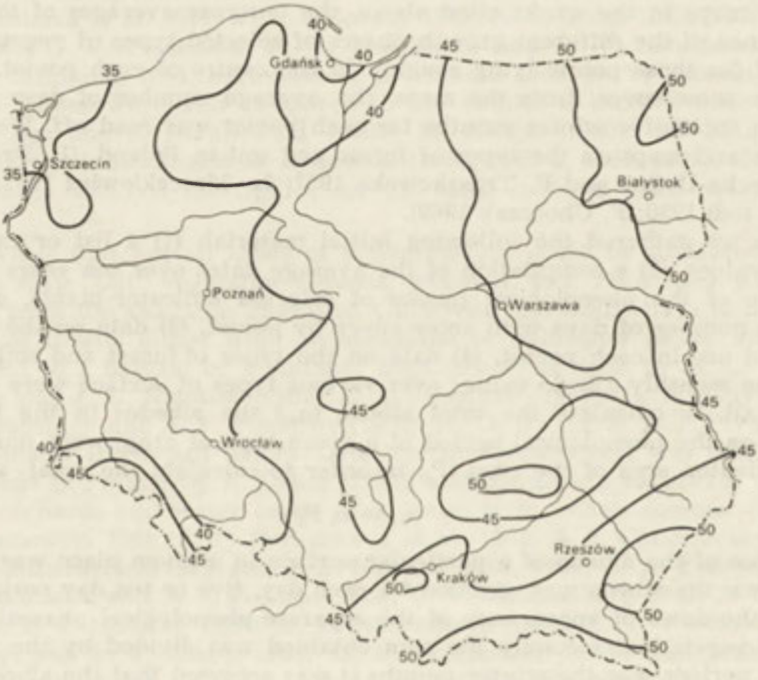

Fig. 1. Geographical distribution of the mean monthly albedo in January

In the spring the albedo values fall and remain within the limits 15% to 20%; their areal variation is only weakly marked.

In the summer months the values of the albedo greatly exceed those of the spring (Fig. 2), no doubt caused by changes in the development of the vegetation cover, and approach 25%. Lower values generally occur over forested areas.

In autumn the albedo values in Poland, apart from over some small areas, are lower, from 15% to 20%, increasing in November when the distribution approaches that of the winter months. This means that the values increase from west to east.

The map of the annual course of the albedo (Fig. 3) resembles the situation in the winter months because here we also see an increase in the values from west to east. In the west the values fluctuate around 20%, caused on the one hand by the short period of the snow cover in these areas, and on the other by the many forests. The highest average yearly values of the albedo of 30% are found in the north-east and south-east of Poland because these areas have the longest duration of snow cover.

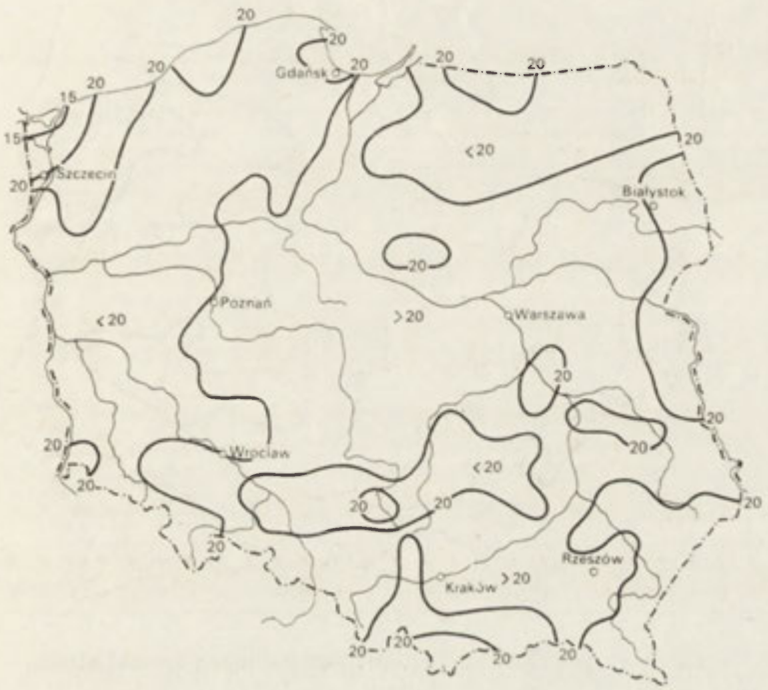

Fig. 2. Geographical distribution of the mean monthly albedo in July

A point worth emphasizing is that both the monthly and yearly values of the albedo are high in most large towns probably due to the comparatively large albedo values of building materials and buildings in general and to the fewer green areas. The winter months are an exception. At this time the albedo values are generally lower than those in the surrounding areas; this is obviously related to the short duration of snow cover. In the towns and their immediate environs the length of the snow cover is shorter. Moreover the snow is contaminated, whereas the pure snow in those places away from the urban areas and from industrial establishments has a much higher albedo. Mountain areas are also a special type since their climate influences both the phenological phases and the duration of snow cover, and therefore also the value of the albedo.

To derive the annual course of the albedo over the country the weighted average values for each month were calculated for the whole of Poland. This is shown in Figure 4. The highest values occur in the winter months, from about 30% to 40%, after which there is a fall until the first (spring) minimum of a little above 18% in April. The following months show a small increase from a little over 20% in July followed by another fall and a second minimum in the autumn (October) to about 17%. In November the values fluctuate around 19% and increase significantly in December. A similar annual course of

Fig. 3. Geographical distribution of the mean annual albedo

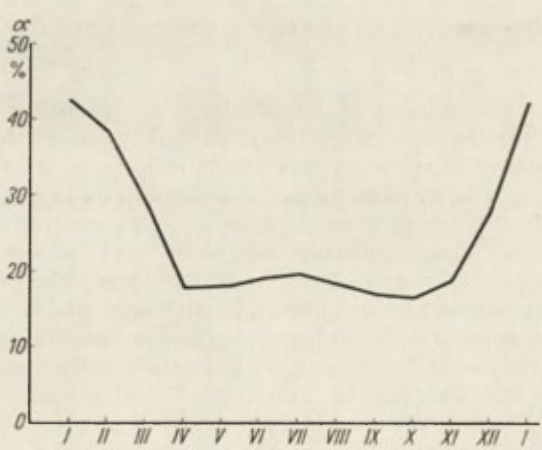

Fig. 4. Annual course of the albedo in Poland

the albedo is confirmed from other areas, for example from the western European parts of the Soviet Union at the Vysoka Dubrava Station (E. P. Barashkova *et al.* 1961), in Kiev (A. R. Konstantinov *et al.* 1966), and in Hungary (A. Borhidi, Z. Dobosi 1967). However around Copenhagen the course of the graph from May to the onset of snow cover is more or less level apart from a slight rise in August (H. C. Aslyng and B. F. Nielson 1960). A comparison of the annual courses in Poland and around Copenhagen suggests that their differences are a result of the dominant influence of the continental over the oceanic climate in Poland.

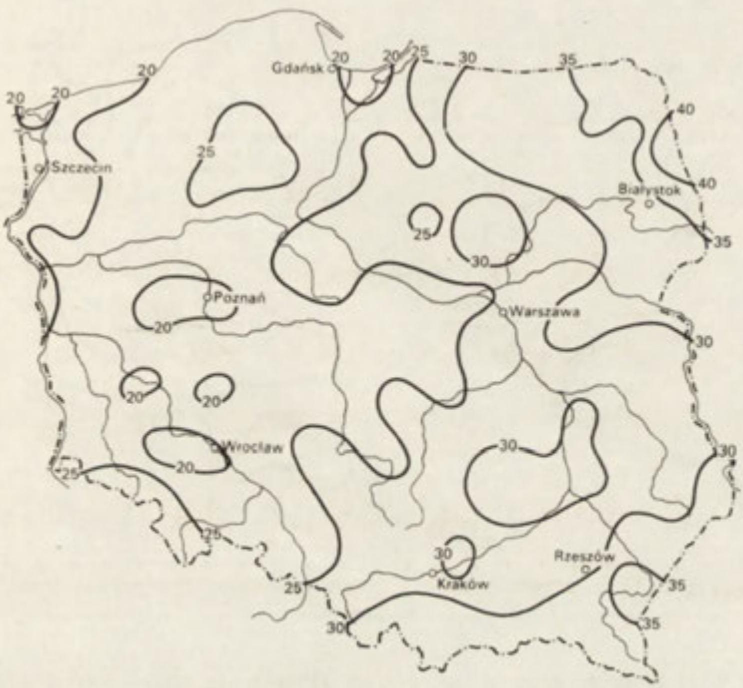

Fig. 5. Mean annual amplitude of the albedo

In order to get some idea of the size of the albedo changes the yearly amplitudes were also calculated. These are given in Figure 5. These amplitudes fluctuate from less than 20% to over 40%, the lowest values being in the west and north-west of the country and the highest in the north-east. High amplitudes are also found in the mountains; in the Sudetes they exceed 25%, in the Carpathians and Świętokrzyskie Mts. 30%, and in the south-east corner of Poland about 35%.

Two basic periods were distinguished from the course and distribution of the albedo and from its amplitudes: a cold period from November to March, and a warm period from April to October.

A marked east-west direction of the isolines is typical of the cold period (Fig. 6), resembling the isotherm map for the winter months and also the map of the duration of snow cover in Poland. The highest values of the albedo (over 40%) are found in the coldest areas of the country (north-east) where the snow cover lasts longest. The lowest values (below 28%) are found in the warmest areas (west and south-west) where the snow cover is shortest and spring comes earliest. The mountain areas usually have higher values (32% to 36%) due to the longer snow cover.

Fig. 6. Geographical distribution of the mean albedo in the period from November to March

In the warm period the values of the albedo are small and fluctuate from about 16% to over 20%. The vegetation cover obviously plays a leading part in the areal distribution of the albedo during this period. The north and north-west have the highest values, about 20%, and the south of Poland is about 18%. Forested areas have a lower albedo than their surrounding regions.

Apart from these two cold and warm periods one can also distinguish two transitional periods on the basis of the albedo's annual course: a period between the cold and warm periods from April to May, and that between the warm and cold periods in September and October. These transitional periods have the lowest albedo values of the year.

A comparison of our albedo maps with those in the atlas of the thermal and moisture balances in the Ukraine (A. R. Konstantinov, N. I. Goisa (eds) 1966) does not reveal any significant differences for either the monthly or yearly values.

From our results it can be stated that:

(1) The areal distribution of the albedo during the year is as follows; the lowest values of around 20% are found in the west and the highest, approaching 30%, in the east of the country;

(2) The areal distribution of the albedo depends in the warm period (April–Oc-

Fig. 7. Geographical distribution of the mean albedo in the period from April to October

tober) on the type of land use and above all on the degree of afforestation. In the cold period (November-March) it depends on the duration of the snow cover;

(3) The average monthly albedo values vary over Poland from somewhat below 18% in the spring and autumn to around 50% in winter;

(4). The annual course of the albedo typically has two maxima, a main one in winter and a secondary one in summer, and two minima, in spring and autumn.

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DEGLACIATION IN THE ŚWIĘTOKRZYSKIE MTS

Cecylia Radłowska and Elżbieta Mycielska-Dowgiałło

Many interesting answers to the problems of deglaciation, inspired in those areas of Poland with a young glacial relief, have been found in those parts of the country which were submitted to earlier glaciations. The investigations done here, however, followed a different line.

Analysis of the lowland Würm relief continuously adds to the list of genetical forms developed during the process of deglaciation and helps explain how they developed during the areal decline of stagnating and dead ice masses.

Since the begining of the study of deglaciation investigations of the older, post-glacial relief, especially in the old mountain and highland zone of central Poland, have necessarily been linked with the morphology of the parent rock. This is because here every postglacial landform is an accessory element of the relief, and not one of its essentials.

In the lowlands, where the thickness of Pleistocene sediments reaches 200 m, it is not easy to investigate the relations between the course of deglaciation and the former relief. There are not enough borings and there is more than one interpretation of the stratigraphy of the Pleistocene formations (Galon 1967). It would be easier to try to explain the genesis of phenomena and their successive development using the criterion of spatial relations of forms and thus in a horizontal sense. The reason for the location of particular landforms is largely unsolved. It is, however, a less thankless task in the old mountain and highland zone.

The problem of deglaciation has several distinct lines of approach, depending on the area of where the investigations are carried out.

Studies on deglaciation in Poland are carried out on a wide scale. There are many publications also concerned with the late Pleistocene relief (Bartkowski 1967, Galon 1969, Kondracki and Świerczyński 1961, Kondracki and Pietkiewicz 1967, Niewiarowski 1959, 1963, 1965, Olszewski 1969), as well as with the relief of old glaciations (Jahn 1963, Jahn and Szczepankiewicz 1967, Klajnert 1969, Klimek 1966, Mojski 1967, 1969, Rywocka-Kenig 1966, Walczak 1957, 1969). Large areas have already been synthetically investigated, such as the Sudetes (Jahn 1963, 1969, Walczak 1957, 1969) and the northern part of the Silesia-Cracow Plateau (Klimek 1966, 1969), whereas the Świętokrzyskie Mts. are still barely known. The signs of ancient deglaciation have somehow been overlooked.

Their north-west slope has been studied in detail by Lindner (1970, 1972). He was able to distinguish some marginal kame terraces which revealed the course of the transgression and deglaciation on the outward side of the mountains during the Riss glaciation.

Investigations of small sections of this area have been done (Jurkiewiczowa 1965, Żołnierz 1971), but the problem as a whole is still open.

The problem of the relation between glaciation and deglaciation in the Świętokrzyskie Mts. and the relief of the substratum has been studied by S. Z. Różycki (1972a). He reconstructed the incursions of the Mindel glaciation into the mountain area by analysing the distribution of erratics local origin (tortonian limestone) occuring *in situ* on the south-east part of the mountains. In another article on the quaternary problems of the Świętokrzyskie Mts. Różycki also attaches great importance to the features of relief and the changing direction of the mountain ranges, and again stresses the advisability of following the transport routes of local materials, especially those which are found over a limited area (1972b).

The present paper gives the results of our investigations in the western and central areas of the Świętokrzyskie Mts. (Fig. 1).

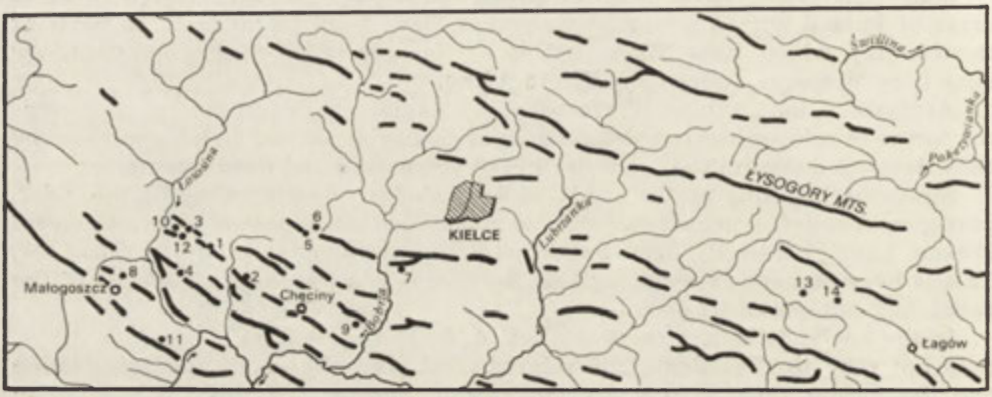

Fig. 1. Location of the analysed landforms in the Świętokrzyskie Mts.

1, 2, 3, etc.. — observation points: 1 — Miedzianka; 2 — Polichno; 3, 10, 12 — Zajączków; 4 — Milechowy; 5, 6 — Zgórsko; 7 — Posłowice; 8 — Grabki; 9 — Radkowice; 11 — Gorgolowa; 13 — Makoszyn; 14 — Belno

The Świętokrzyskie Mts. are composed of a series of ridges, trending WNW–ESE and NW–SE and divided by longitudinal depressions. The rock substratum is petrographically highly differentiated and its relief is largely Tertiary in origin. An important part of the relief are the stratified sand formations in the mountain passes and high up on the slopes and along the bottoms of the intra-mountain depressions. Their location in the passes is most important as it clearly indicates that they owe their accumulation to the process of deglaciation. Stagnant and dead ice could easily develop in these longitudinal depressions.

The first stage of deglaciation was marked by sediments and landforms within passes. An example from Mt. Miedzianka will be discussed in detail. In the pass between Mt. Miedzianka (358.5 m) and Mt. Sowa (304,1 m) lies a cover of sand up to 318 m (Fig. 1, pnt 1 and Fig. 2). In the outcrops one can see stratified sands cut by faults and covered with gravitational and solifluctional materials (Fig. 3). Measurements in places which have a more orderly sand structure indicate that the strata dip in south or south-east direction.

The level reached by these sands, 318 m is much higher than that at Mt. Sowa, 304,1 m and testifies to the fact that during the accumulation which took place here Mt. Miedzianka constituted one slope, whereas the other one was glacier ice and not Mt. Sowa. This second slope most probably covered the pass and at least the lower mountain parts, including Mt. Sowa (Fig. 2).

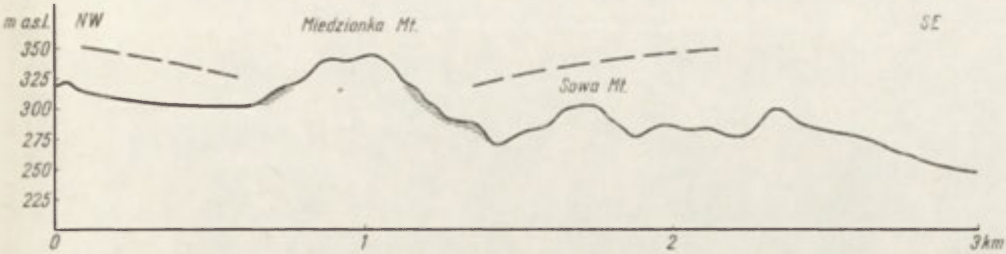

Fig. 2. Kame terrace in the pass under Miedzianka Mt. Broken line — supposed ice cover

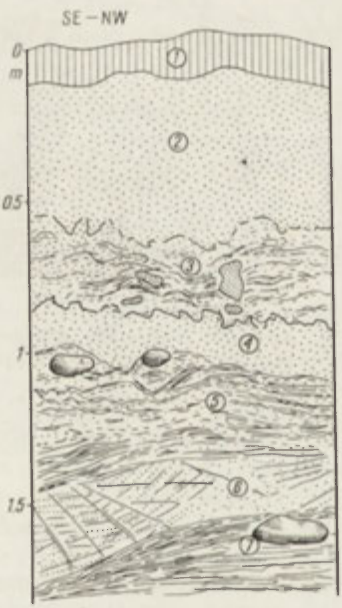

Fig. 3. Exposure in kame terrace at Miedzianka pass (318 m a.s.l.):

1 — soil; 2 — cream-coloured structureless sands; 3 — light-brown silty sands with a fluidal structure, containing sandy erratic pebbles; 4 — fine grained structureless sands; 5 — silty sands with a fluidal structure with pebbles of local limestones; 6 — stratified sands, strongly dissected by fissures; 7 — silty sands with fluidal structure at the top

The presence of the sands above one of the peaks crowning the pass, plus the fact that they are fissured and cut through dislocation, also support a connection between the origin of the sediment and mountain deglaciation. The presence of moraine loam is not necessary to support the argument. The landform in the pass near Mt. Miedzianka is a kame terrace.

Sediments of kame terraces were also found in a pass site in the Polichno Hills, in Polichno (Fig. 1, pnt 2; Photo 1), and in Zajączków (Fig. 1, pnt 3), in Zgórskie Mts. (Fig. 1, pnts 5 and 6), and in Grząby Bolmińskie, a village of Milechowy (Fig. 1, pnt 4).

In Zajączków, at the most outlying point the pass kame terrace (Fig. 10, pnt 3) has a sediment whose features are more recently formed compared with others. But as elsewhere the dips of the strata in the investigated western part of the mountains is mostly SE.

Photo 1. Polichno — a test pit in a kame terrace in a mountain pass. The parallel stratification of fine grained sand deposits (fine grained medium sand as defined by Doeglas, 1968) can be seen

The kame terraces on the Świętokrzyskie Mts. passes are genetically similar to those in the Sudetes (Jahn 1963, 1969, Walczak 1957, 1969). The relief of these mountains is different however. The longitudinal ridges and their dividing depressions gave rise to a more complex deglaciation than in Sudetes. In all the mountain ranges might one expect kame terraces in the passes and not only on the outer ranges as in the Sudetes, where the continental glacier broke through the passes into the intra-mountain troughs. This was a continental glacier of the Riss glaciation.

The kame terraces on the Świętokrzyskie Mts. passes were not all necessarily formed at the same time or even within one glaciation; it depends on local conditions.

The next group of forms are the sandy shelves on the rocky slopes of the longitudinal depressions. These kinds of terrace have been found on the southern slope of the Posłowskie Mts. at Posłowice (Fig 1, pnt 7), in the Przedborsk-Małogoszcz Range at Grabki (Fig. 1, pnt 8), and near Zajączków (Fig. 1, pnt 12).

The terrace at Posłowice (Fig. 4) has a fairly flat surface at a level up to about 280 m. The outcrop has sands interstratified with silts and coarser slope-sediments. Near the base of the series there are stony packets in the sand. The accumulation level at Posłowice is a kame terrace, overhanging the foothills and is about 48 m above the neighbouring gorge of the Bobrza river. The river terraces of the Świętokrzyskie Mts. do not attain such altitudes.

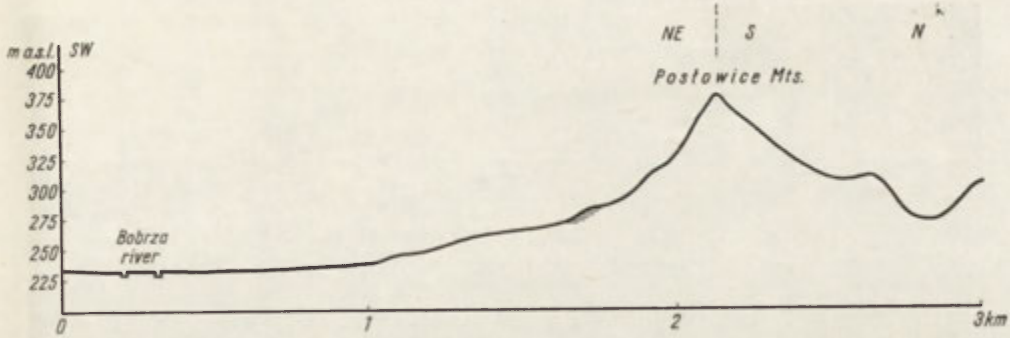

Fig. 4. A slope kame terrace in Posłowice

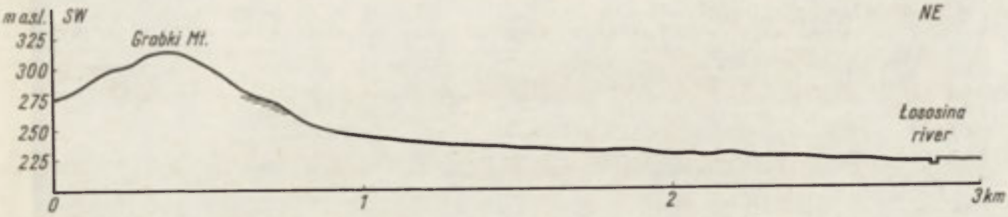

Fig. 5. Kame terrace in Grabki, in the Przedbórz-Małogoszcz range

Fig. 6. Topographical map of an esker type crevasse landform near Radkowice

P.A. P.B. — lines of cross sections

Photo 2. Grabki — general view of an exposed kame terrace

Photo 3. Grabki — fragment of the exposure. Parallel stratified sands in kame terrace can be seen

The kame terrace at Grabki (Fig. 5, Photos 2, 3 and 4) is found at a similar altitude of about 280 m above sea level. In a sand pit dug here sands and silts crop out, as well as petrographically similar solifluxial sediments. By thoroughly analysing the material in can be established that several phases of sedimentation took place, which periodically underwent dislocation, subsidence, tilting and gravitation-solifluxional processes. The whole series did not con-

Photo 4. Grabki — The variable character of the sedimentation can be seen. Fragment of exposure

tinually undergo these disturbances. Tilting of dislocated packets and subsiding is northerly presumably in the direction of the dead ice lying in the longtitudinal depression. In the examined section this was taken advantage of a tributary of the Łososina; a terrace is found about 30 m above this tributary.

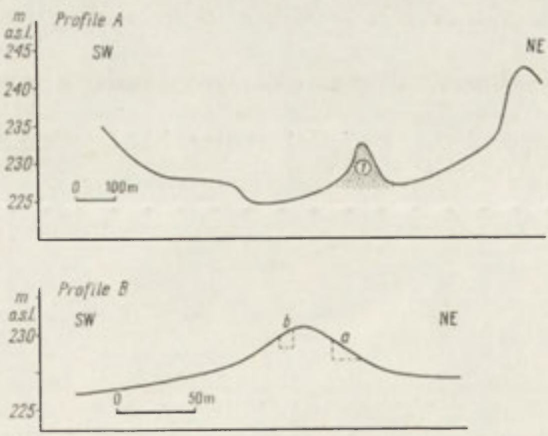

Fig. 7. Transverse sections across an esker type crevasse landform near Radkowice

P.A. — section across Chęciny valley north of Radkowice, 1 — esker type crevasse landform, P.B. — section across esker type crevasse landform with exposure marked (a, b)

Photo 5. Radkowice — one of the longitudinal hillocks of an esker type crevasse landform

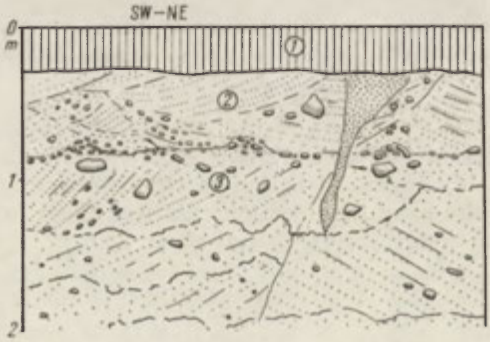

Fig. 8. Exposure in southern wall of an esker type crevasse landform near Radkowice

1 — soil; 2 — stratified sands, gravels and angular débris. Much chert, pink sandstones and slates. Stratification emphasized by position of gravels and by hornstone streaks. Visible uneven relief of top surface; 3 — top surface of series full of mounds containing gravel cores. Medium grained sands with slightly marked stratification. Slight gravel admixture

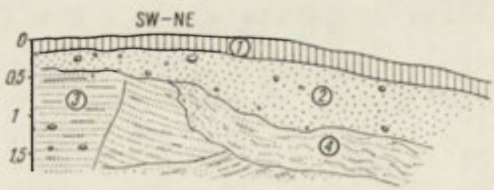

Fig. 9. Exposure in northern wall of an esker type crevasse landform near Radkowice

1 — soil; 2 — structureless deposit (sand with gravel admixture); 3 — stratified sands with solitary small gravel grains and pebbles, dissected by fissures. One can see push and drag movements of compacted sand blocks. Streaks emphasized by hornstone bands

Another argument in favour of the kame origin of the terrace is the moraine loam on the slope, over 250 m above sea level.

Various hillock-shape fissure forms in intramontane longitudinal depressions bear witness to the third and last stage of deglaciation.

Photo 6. Radkowice — the interior structure of an esker type crevasse landform

Photo 7. Radkowice — fragment of the exposure shown in Fig. 8

To this kind of formation belong the hillocks, arranged in a slightly circular series for 1 km along the axis of the depression of the so-called "Chęcińska Valley", near the village of Radkowice (Fig. 1, pnt 9). Their position is shown on the topographical sketch (Fig. 6) and on Photo 5. In the road-cuting 2–3 m in depth, layered sands with gravel admixture crop out. These are often covered by unlayered brecciated or gravelly sandy forms. The gravels are also composed of local Świętokrzyskie Mts. material as in the northern one. In Figs. 7, 8, 9 and in Photos 5, 6, 7 one can see the structure of these forms.

The dip of layers of the undisturbed series is generally easterly and is almost concordant with the morphological axis of the zone of uplift.

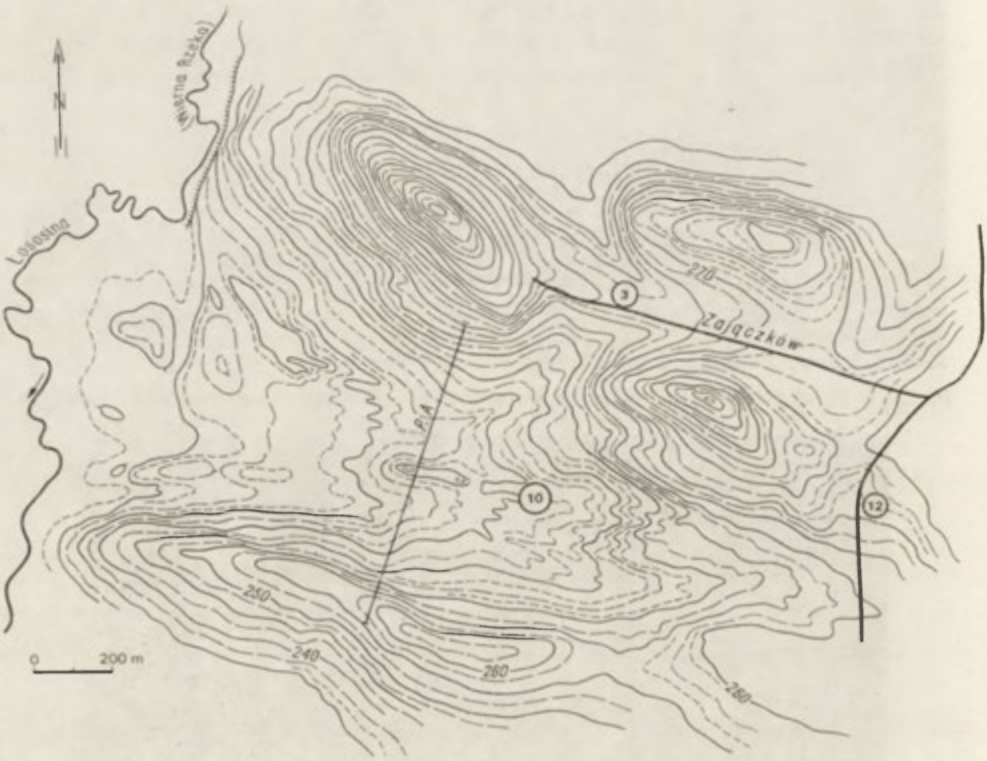

Fig. 10. Topographic map of hillocks and kame terraces near Zajączków

3 — pass kame terrace; 10 — kame hills; 12 — slope kame terrace (nos. refer to those in Fig. 1); P.A. — section across kame hills

The described forms are not overlaid by material where the substratum is elevated, and to not run across but along the axis of the depression. Thus they have not the character of a kame ridge found in areas of similar relief, as for instance in the Cracow-Częstochowa Jura (Klimek 1966, 1969) or in the Sudetes (Jahn 1969). They may rather be classified as fissure forms of the esker type (Baraniecka 1969, Boerman 1950, Charlesworth 1957, Flint 1957, Lliboutry 1965, Radłowska 1969).

In the pseudo-valley depression lying south of Zajączków is a kame field with numerous small hillocks (Fig. 1, pnt 10). The detailed topographical sketch map shows a whole wealth of these miniature forms, built of sands and gravels of fluvial origin. Boulders from the north as well as local ones can be found on the surface (Figs. 10 and 11).

The kame hillocks at the foot of the Gorgolowa Mt. in the Małogoszcz Range are similar (Fig. 1, pnt 11 and Fig. 12), but their origin is not entirely understood.

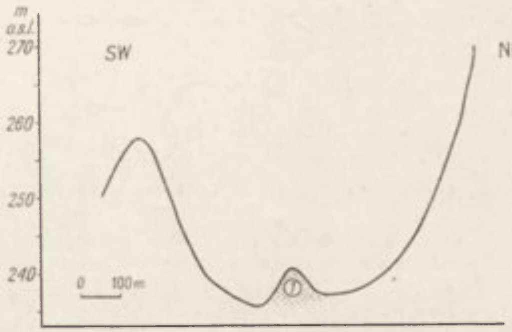

Fig. 11. Transverse section across valley south of Zajączków

1 — kame hillock landform

All these examples of various types of kame landform and esker-type and our observations on the trend of the dip of the strata and of the relief features suggest the following hypothesis into this part of the western Świętokrzyskie Mts. the ice came most probably from the NW, first filling the longitudinal depressions and then irrupting into the mountain passes. This subject can be looked at again when the results of laboratory analyses of samples, taken from various landforms caused by deglaciation, are known.

For comparison two longitudinal raised landforms discovered in the depression of the Łagowska Trough will also be discussed. This trough lies in the central part of the mountains.

It lies south of the Łysogóry, the main range of the Świętokrzyskie Mts. The bottom of the trough is coated with Pleistocene sediments, originating from various types of aggradation: glacial, glaciofluvial and fluvial, as well as secondary Pleistocene, supplied to the trough depression by processes of denudation. In these Pleistocene archives, glacial landforms and sediments may also be distinguished. They seem sometimes to have been skeletoned by fluvial erosion, which has partly remodelled the bottom of the trough. The expression "partly" is used here to stress the existence since this time of a watershed.

In Makoszyn /Belnianka, (Fig. 1, pnt 14; Fig. 13) an oval-shaped hill trending parallel with the morphologic axis is found north of the village. Its general appearance is shown in Photo 8. In the open cuts down to 2.5 m ortstein sands with erratic boulders in the top are visible, but deeper down they are cross-stratified in thin layers. The sands have many faults. A repeated dip of the layers may be seen in the WNW sector. The inner structure of the landform is illustrated in Photo 9. This elevated form in Makoszyn has the features of a kame-hill.

The structure of the ridge in Belno (Fig. 1 pnt 13; Fig. 14) looks a little different, and can be seen in Photos 10, 11 and 12. In the top down to 1.5 m are loam packets, sands and gravels, sometimes a stratified but generally an unstructured material. Below this is a sandy-gravel series, with fine grained gravel but a prevalence of sand. Numerous faults and fissures are visible,

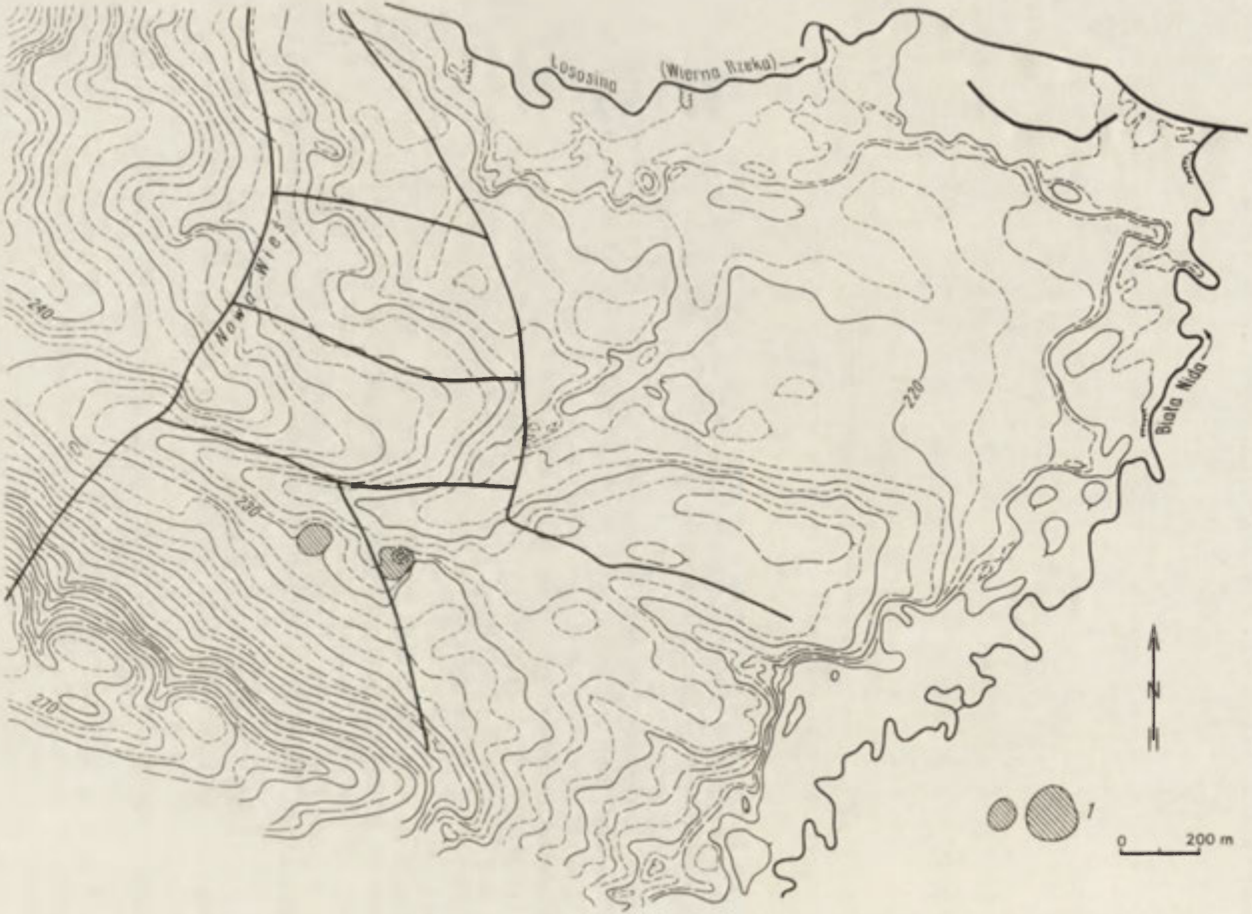

Fig. 12. Topographic map showing the kame landforms south of the Gorgolowa ridge

1 — kame forms

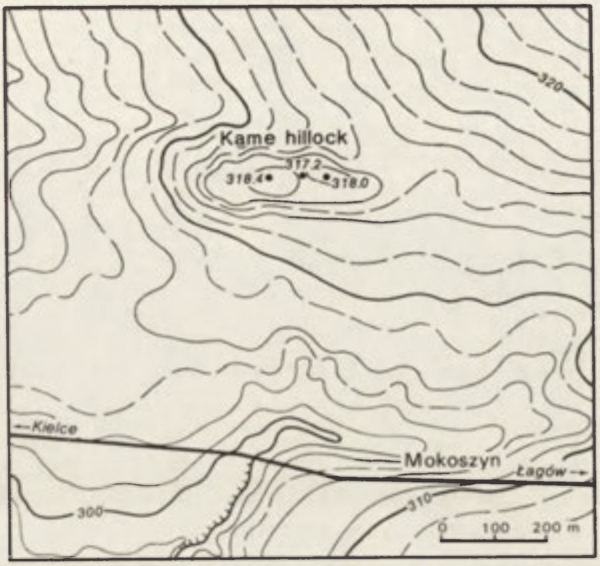

Fig. 13. Topographic sketch of a kame mound in Makoszyn

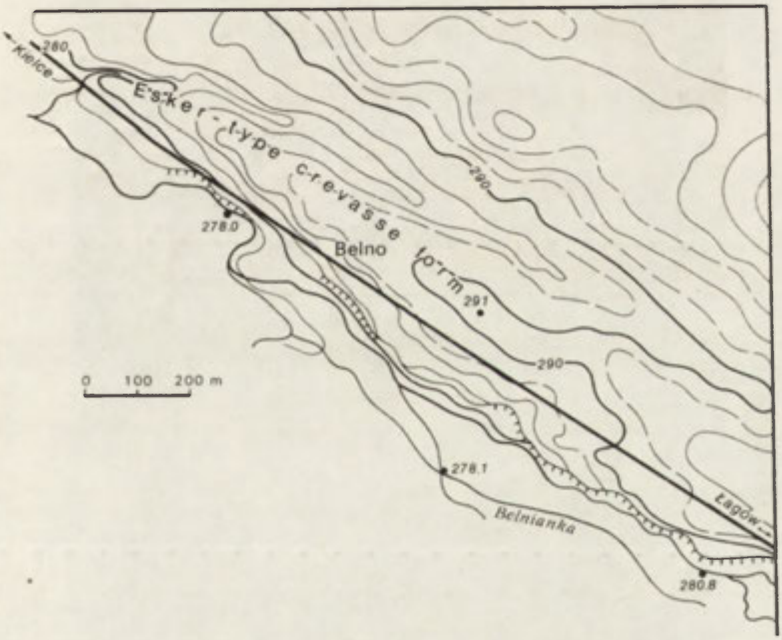

Fig. 14. Topographic sketch of an esker type crevasse landform in Belno

along which the sediment has subsided (Photo 12). At the base a barely stratified thick-grained gravel series (average diameter 3–6 cm), crops out. Tortonian limestone (lithotamnian), originating from the south-east margin of the Świętokrzyskie Mts. is found in this sediment. The presence of gravel, sands, loam pocket and locally a continuous loam cover suggests that the origin of the Belno ridge may be connected with crevasse accumulation. Its present form

Photo 8. Makoszyn — general view of kame hill

Photo 9. Makoszyn — infrastructure of a kame hill

Photo 10. Belno — cross section of an esker type crevasse landform. At the base there is an outcrop of the substratum rocks

Photo 11. Belno — inner structure of an esker type crevasse landform. One can see a loam-gravel coating
1 — sandy-gravel series — 2, and coarse gravels at the bottom — 3, in which Tortonian limestone pebbles were found

points to an erosion-denudation origin, whereas the preserved internal structure is connected with deglaciation. Numerous measurements of the sand-gravel series show the dip of the strata to be westerly, but varying from NE to SW direction.

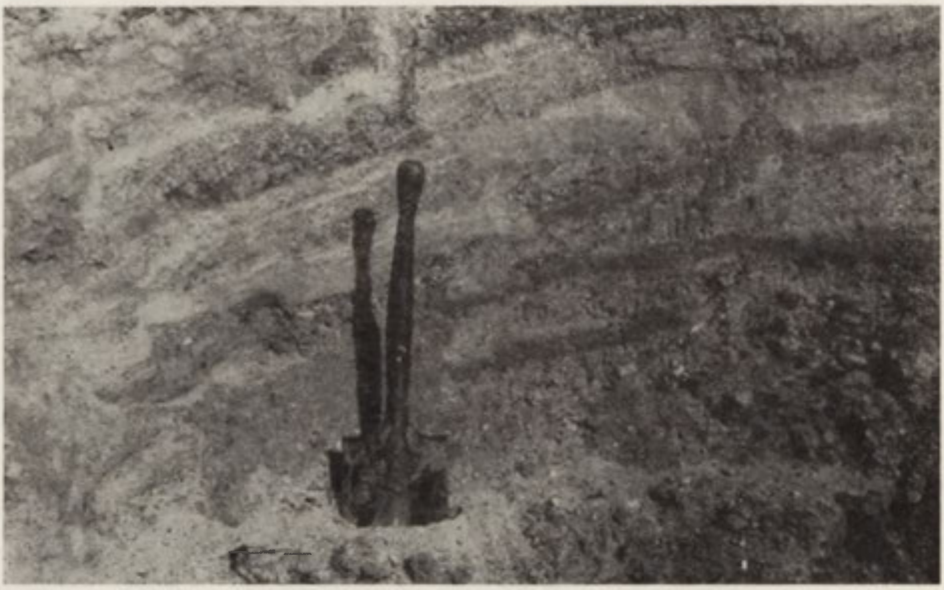

Photo 12. Belno — sandy-gravel series cut by faults with visible shifting of the banks away from the axis of the landform. Samples were taken from the sand and gravel layers for analysis

Since the layers of both forms from the Łagowska Trough incline in a westerly direction, the supply of material therefore came from the east, and this is confirmed by the presence of tortonian limestone in the Belno ridge.

In order to describe more precisely the sandy sediments occurring under various morphological situations in the central and western part of the Świętokrzyskie Mts., detailed laboratory investigations were carried out. Samples were taken in such a way as to be wholly representative of the sediment series of a given landform. This was facilitated by the sediment usually being a little differentiated. The depth of sampling varied from 1 to 5 m below the level of the arable ground. Only layers whose structure was undisturbed by ground and weathering processes were selected.

The following analyses were carried out: granulometric, the degree of rounding, mineralogical and petrographic.

By using granulometric analysis we obtained curves of frequency showing the ratio of the percent of a given fraction to the accepted insterstitial unit (Fig. 15). The latter might be 1 mm or, as in this case, the unit Φ. It shows a grannulometric similarity between the sandy sediments in mountain passes on the slopes and in convex shaped dikes forming in the wide intramontane parallel depressions.

This similarity between the sediments is particularly marked in the western part of the investigated area (Fig. 15, Nos. 1–10). All the curves here are bimodal, with two maxima in the fractions of 0.315–0.4 mm and 0.2–0.25 mm. There is very little admixture of the coarser and finer grains; this gives narrow and high maxima on the diagram and indicates that the whole sediment has been thoroughly sorted.

The curves showing the frequency of the sandy sediment in the central part of the area, where a much larger variability may be seen, are a little different (Fig. 15 Nos. 11–14). The regional similarity of the deposits, and their

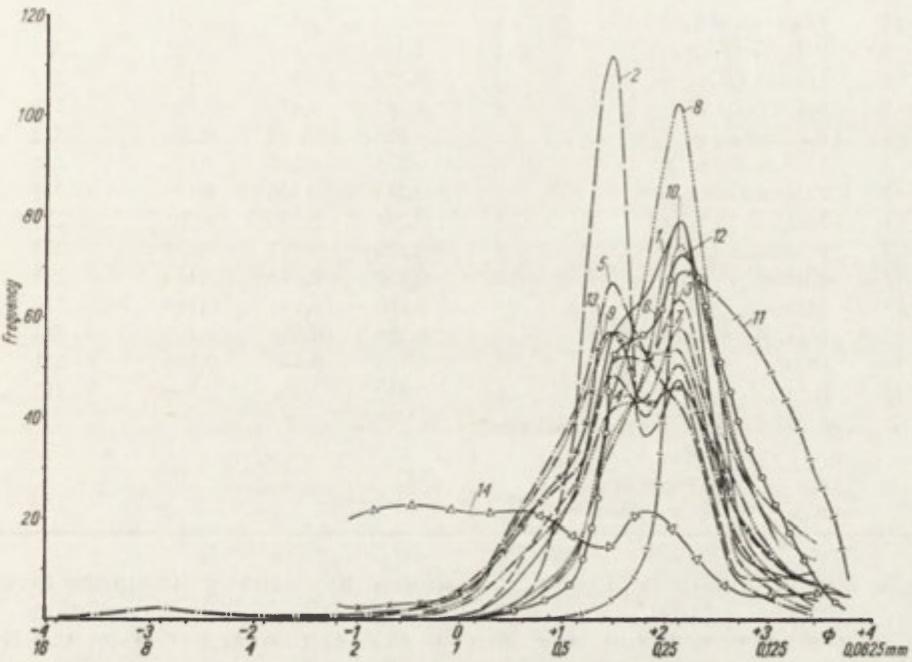

Fig. 15. Size frequency of granulometric composition of investigated sediments (nos. refer to those in Table 1)

inter-regional differentiation, hint at a variety sources of the based material for the western and eastern parts of the area. On the other hand, the similarity between the sandy deposits found under various topographical situations in the western part but that they compose genetically different forms, suggests that this source was the same for all the group.

A similar picture is found when one compares the medians and quartiles, as well as by Doeglas' classification of deposits (1968). The sandy sediments from the western part of the Świętokrzyskie Mts. whatever type of genetic forms they build, are poorly differentiated and may be assigned to three granulitic classes: medium sands, fine grained medium sands and medium sandy fine sands. In the central part of the area where the variability is greater we find: very fine sandy fine sands, medium sandy fine sands, coarse sandy medium sands and very fine gravel medium sands (Table 1).

The coefficients of grain abrasion (*Wo*) and irregularity of abrasion (*Nm*) of the sediment were calculated by analysing them with Krygowski's graniformameter (1964). The fraction 0.5–0.8 mm from 10 samples of the western part of the Świętokrzyskie Mts. was taken from various genetic forms connected with

TABLE 1

No. of point in Fig. 1	Name of outcrop and genetic description of landform	Analysis number	Md	Q_1 in mm	Q_3	Numerical determination of sediment after Doeglas (1968) in Φ units
11	Gorgolowa t.k.z.	1	0.262	0.350	0.215	223
2	Polichno t.k.p.	2	0.340	0.390	0.230	223
8	Grabki t.k.z.	3	0.261	0.365	0.198	233
9	Radkowice o.	4	0.285	0.410	0.200	223
9	Radkowice o.	5	0.350	0.480	0.260	222
4	Milechowy t.k.p.	6	0.225	0.285	0.158	233
3	Zajączków t.k.p.	7	0.245	0.360	0.175	233
1	Miedzianka t.k.p.	8	0.240	0.300	0.205	233
7	Poslowice t.k.z.	9	0.320	0.435	0.235	223
12	Zajączkôw t.k.z.	10	0.230	0.295	0.170	233
13	Makoszyn p.k.	11	0.150	0.190	0.110	334
13	Makoszyn p.k.	12	0.215	0.280	0.160	233
14	Belno o.	13	0.320	0.440	0.200	221
15	Belno o.	14	0.940	2.200	0.360	212

o — ekser type crevasse landform
p.k. — kame hill
t.k.z. — slope kame terrace
t.k.p. — pass kame terrace

deglaciation (Fig. 16). The degree of abrasion of the quartz grains in the investigated sands showed that the index *Wo* had high values and little variation.

The coefficient of grain abrasion (*Wo*) was calculated basing on the Krygowski's formula (1964)

$$Wo = 2400 - \frac{(n \cdot k)\, 100}{N}$$

where *N* — is the size of the analyzed sample, *n* is the size of the angular classes, *k* is the mean angle of a given angular class.

The values of the abrasion coefficient vary from 1265 to 1423 (Fig. 16). In accordance with the classification of the degree of abrasion coefficient given by Krygowski, the sands of the western part of the Świętokrzyskie Mts. may be classified as mature ones, showing distinct grain abrasion.

The coefficient of irregularity of abrasion of a sediment (*Nm*) was calculated using the formula:

$$Nm = Q_3 - Q_1$$

where Q_1 and Q_3 are quartiles corresponding to 25% and 75% read from the cumulative curve of abrasion.

The index *Nm* has high walues, from 7.4–10, in the sediments examined (Fig. 16). This shows that there is great differentiation in the degree of abrasion of the particles in the investigated sands. The reason for this is difficult to establish; it could be due to characteristic differences in the base materials (glacier forms), or to a contribution of local material.

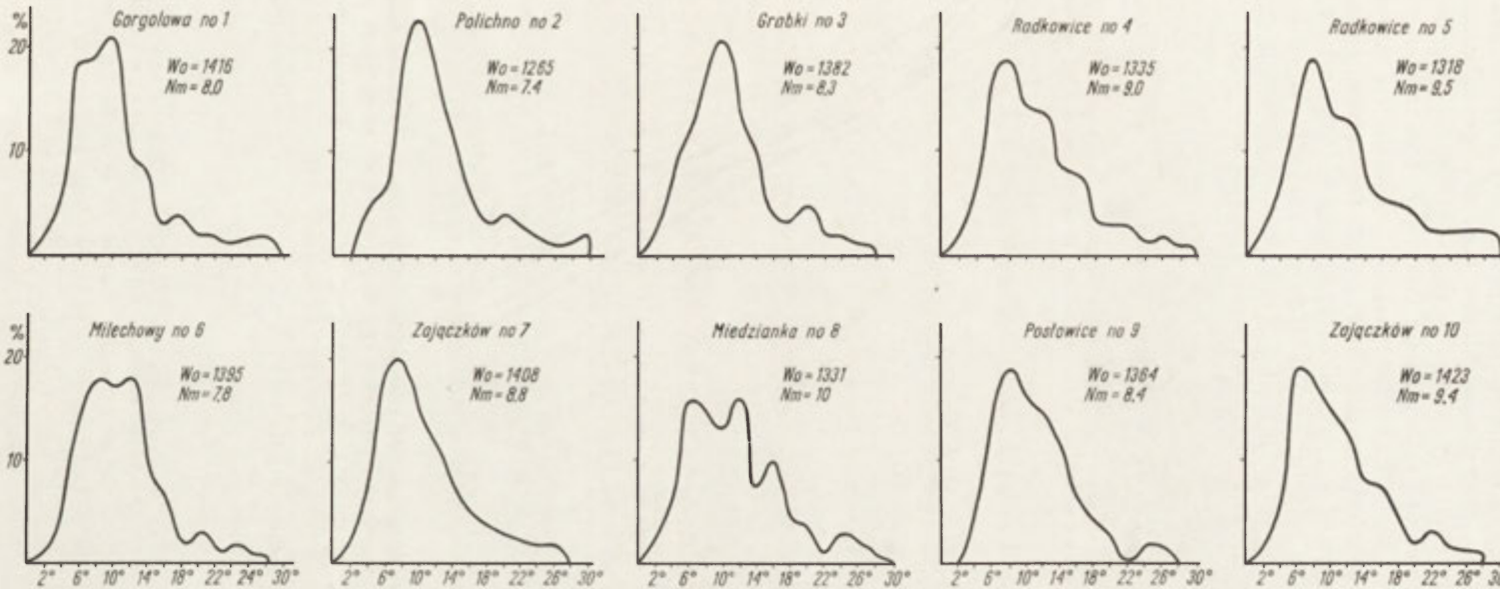

Fig. 16. Curves compiled from histograms of sand grain abrasion

Interesting data was obtained from probability scale diagrams. These diagrams were obtained from the cumulation curves of granulation of the investigated sands (Figs. 17–21) as done by Visher (1969) for genetically differentiated fluvial, marine and aeolian sands. They were constructed according to the principle suggested by Moss (1962, 1963) that ever fluvial or aeolian sediment is a mixture of three or less populations with log-normal distributions, is the picture of the effect of various kinds of transport. Inman (1949) and Bagnold (1956) have distinguished three main kinds of transport: suspension, saltation and surface creep. For the fluvial medium the most important is saltation (Gilbert 1914), and is often the only means of material transport.

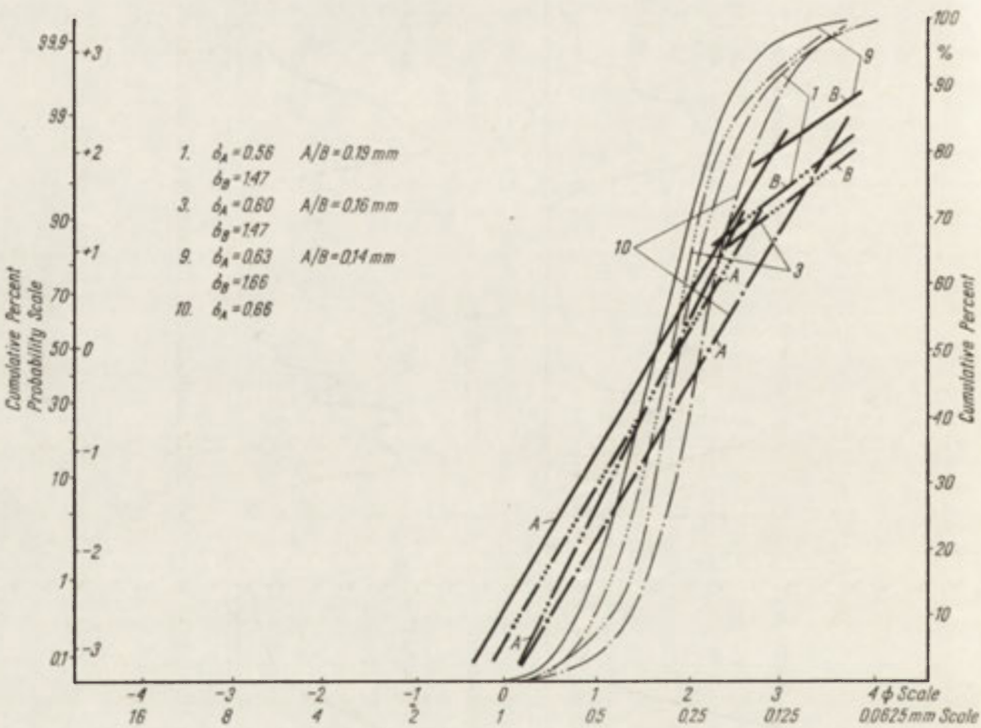

Fig. 17. Curves and diagrams of cumulation in percentages along a probability scale for sediments of slope kame terraces. On the right side of the left scale is the percent of cumulation of units along a probability scale and on the left of this scale, the percent in routine units

3 — Grabki; 9 — Posłowice; 10 — Zajączków; 1 — Gorgolowa; A — saltation population; B — suspension population

It should be stressed that in the probability scale the log-normal distribution represents a straight line. In accordance with this, each grain population will reflect various kinds of straight segments truncating one another. The number of assemblages, the degree of their sorting and the truncation point of the suspension and saltation populations, according to Visher (1868), defines the kind of flow.

To numerically sum the degree of sorting of a particular set, its standard deviation σ, was calculaterd using a formula from the log normal distribution:

$$\frac{1}{\sigma} = \frac{\Delta y}{\Delta x}$$

where Δy is the accretion of ordinates expressed along the scale of probability, and Δx is the accretion of the abscissae (expressed along the scale Ψ) on any arbitrarily chosen segment of the line.

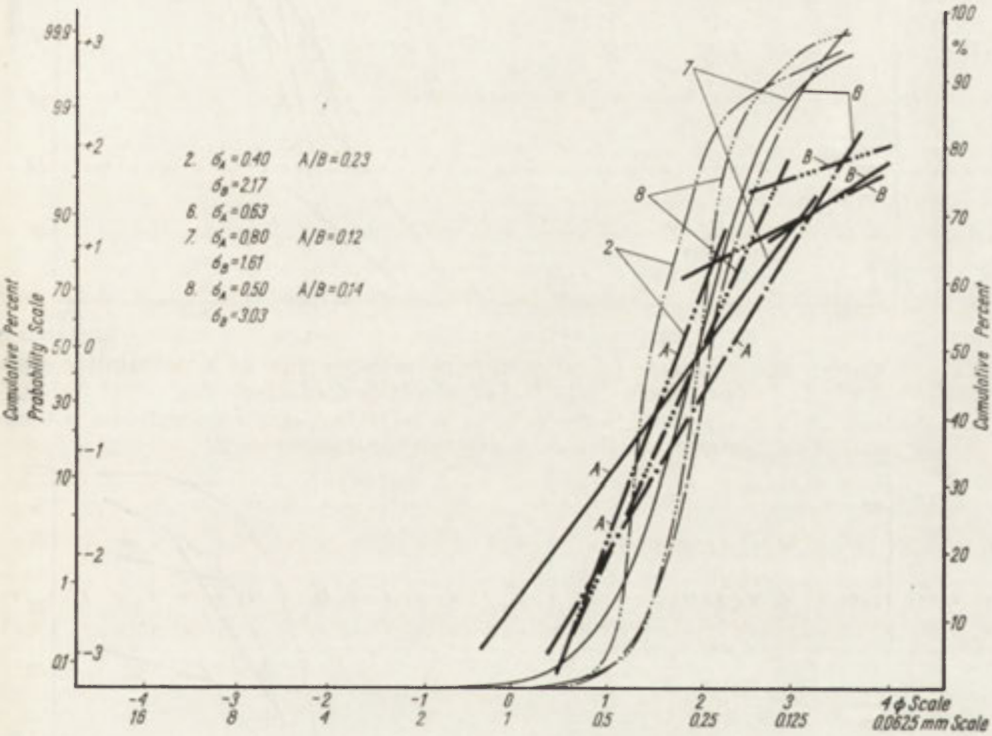

Fig. 18. Curves and diagrams in cumulative percentages and on probability scale for sediments of pass kame terraces

8 — Miedzianka; 3 — Zajączków; 4 — Milechowy; 2 — Polichno; A — saltation population; B — suspension population

Next, sediment diagrams from four genetically different forms connected with deglaciation in the Świętokrzyskie Mts. were compared (kame terraces on passes and slopes, kame hills and crevasse forms of the esker type in the wide intermontane depressions). This gave some interesting data to investigate the dynamics of water which helped to form them. The diagrams are most similar for formations composing the slope kame terraces (Fig. 17). The saltation assemblages (*A*) of the sediments from the four investigated forms show an almost identical degree of sorting, as shown by their similar standard deviations (σ_A, within the limits 0.56–0.66). The percentage content of the suspension assemblage is different, although its degree of sorting is similar (σ_B = 1.47–1.66). The truncation point of both assemblages (*A* and *B*) falls within the fraction 0.14–0.19 mm.

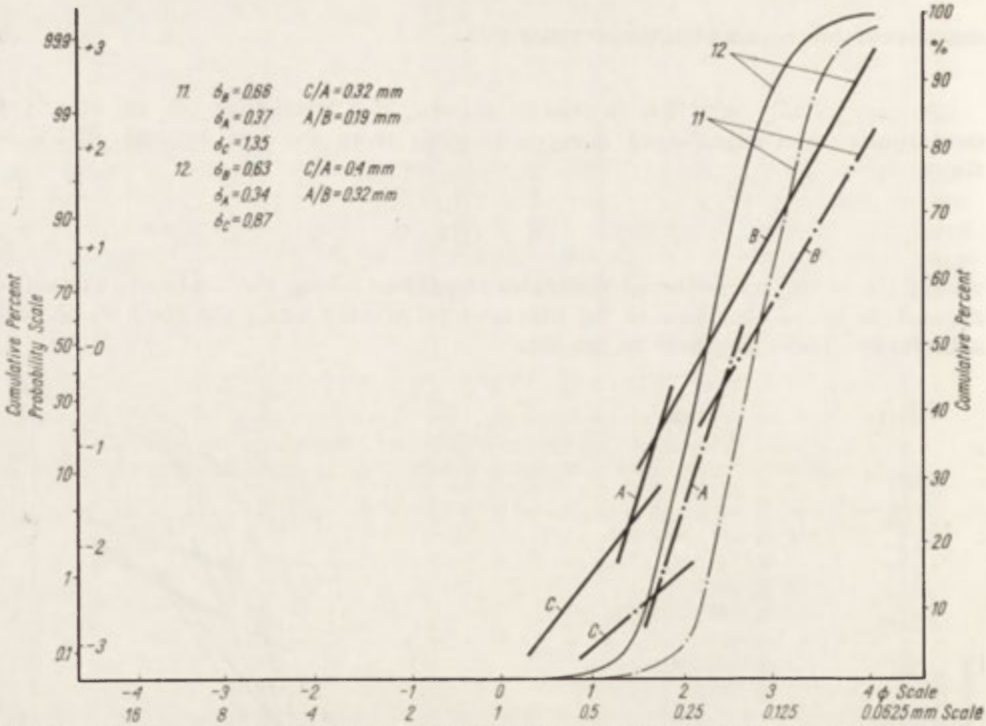

Fig. 19. Curves and diagrams in cumulative percentages and on a probability scale for sediments of the kame hill in Makoszyn

11 — sediment of 1.5 m depth; 12 — sediment of 2.3 m depth; A — saltation population; B — suspension population; C — surface creep population

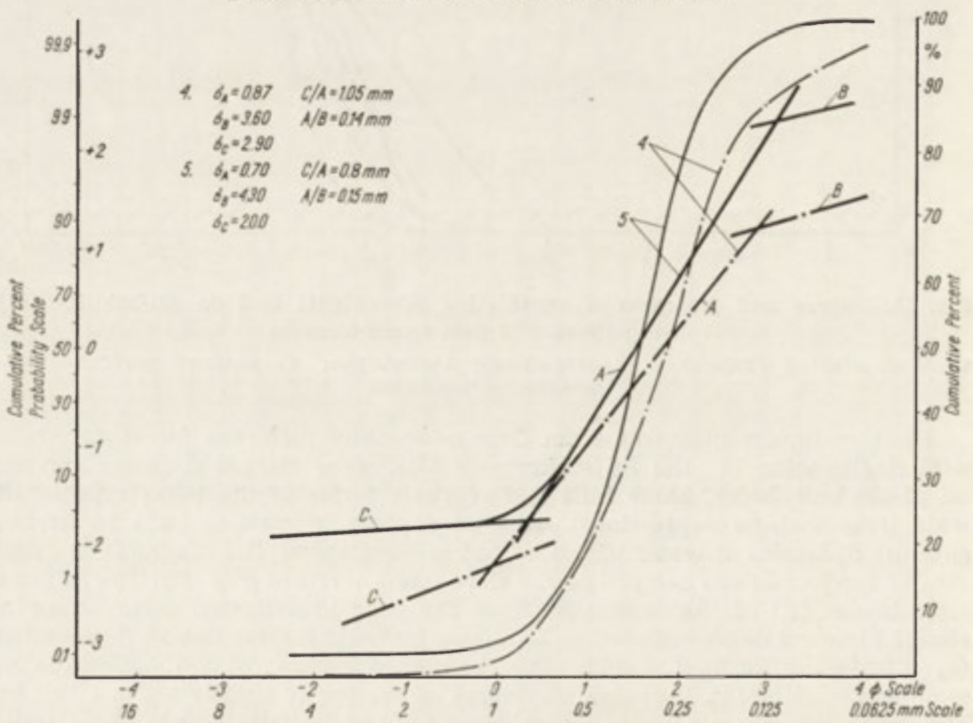

Fig. 20. Curves and diagrams in cumulative percentages and on a probability scale for sediments of the esker type landform at Radkowice

A — saltation population; B — suspension population; C — surface creep population

It should be mentioned here, that the origin of hills recognized in the Gorgolowa range, is not easy to elucidate (Fig. 1, pnt 11; Fig. 17 No. 1). They were originally taken to be kame hills (Radlowska and Mycielska-Dowgiałło 1972). The granulometric diagram of the sediments composing the form is, however, similar to that of the kame slope terraces. The sediments composing the four pass kame terraces are much more differentiated, although even here we find only saltation (*A*) and suspension (*B*) assemblages (Fig. 18). The degree of sorting of population *A*, expressed by the standard deviation value (σ) varies between 0.40–0.80. The values for population *B* (σ_B) also show a high variability. These range within limits 1.61–3.03. This indicates a weaker sorting than in case of slope kame terraces.

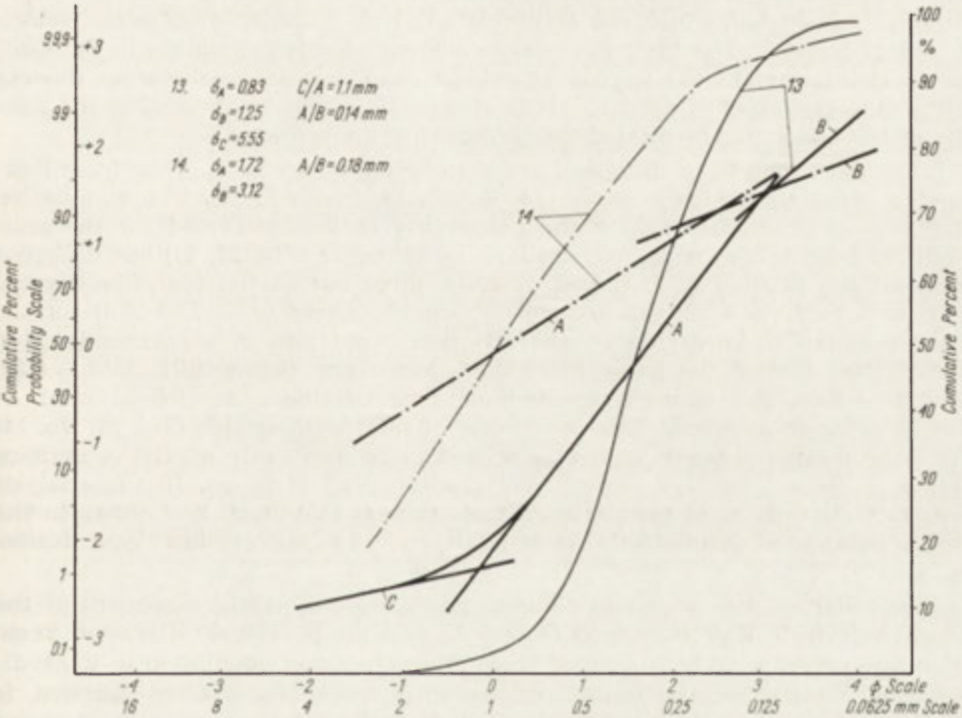

Fig. 21. Curves and diagrams of cumulative percentages and on a probability scale for sediments of the esker type landform at Belno

A — saltation population; B — suspension population; C — surface creep population

The truncation point of the saltation and suspension assemblages fall within the fraction 0.23–0.12 mm.

In spite of a slightly higher variability in the course of granulation diagrams of pass kame terraces, which may be the result of local conditions, the sediments of both investigated genetic groups (slope and pass kame terraces) are similar. Thus it might generally be concluded that in both the character of the flowing water was similar.

The granulometric diagrams given here (Fig. 17, 18) are similar to those presented by Visher (1969), as characteristic of fluvial sands composing various types of forms in riverbeds.

The kame hill, in our area of investigation near Makoszyn (Fig. 1, pnt 13; Fig. 13, Photo 8), is a distinct one. The cumulation granulometric diagrams along the probability scale present a different picture from those previously discussed (Fig. 19). The greatest difference is shown by the presence of the population of creep transport (*C*), plus a large suspension population (*B*) in discussing fluvial series. Visher (1969) stresses that the population of creep debris appears only in the deepest parts of riverbeds, where the current is most rapid. When one compares the diagrams of sediment granulation for kame terraces and hills one can defect a shift towards a finer fraction. It is difficult to find greater current movement here but rather a different character to the movement. The flow must have been more concentrated here, which enhanced the bed-load transport by rolling or dragging along the river bed. It also must have been characterized by marked changes, as evidenced by the large population in suspension, which can accumulate during a sudden drop in the velocity of the current. The high percentage content of this population in the sediment, also points to the important role of suspension in meltwaters flowing within the crevasses of dead ice. It is also possible that by increasing the density of the water this facilitated the transport of the bed load.

The next group to be discussed are the esker type crevasse forms from Radkowice and Belno (Fig. 1, pnt 9, 14, Fig. 6, 14, Photo 6, 10). The cumulation diagrams of granulation along the probability scale constructed for the sediments of both these forms, are similar to each other (Fig. 20, 21) but different from all the previously discussed ones. In three out of the four investigated sediments there is a well developed but weakly sorted ($\sigma_c = 2.90–20.0$) surface creep population, bordering on the saltation population in a coarser fraction than is the case of the kame hillock of Makoszyn (kame hill: $C/A = 0.32$, 0.4 mm, esker type forms from Radkowice and Belno $C/A = 0.8–1.1$ mm). It should be mentioned here, that in the case of the fourth sample (Fig. 21, No. 14) the lack of a population *C* can be assumed to be the result of its occurrence within a coarser fraction beyond our granulometric division. In the analysis the degree of sorting of population *A* (saltation) is also much lower than in the above mentioned kame hill (kame hill: $\sigma_A = 0.34–0.37$, esker type forms: $\sigma_A = 0.70–1.72$).

The collected data seems to point to much more dynamic movement of the fissure waters in the esker type forms, than in the previously discussed kame hills. The presence of both surface creep and suspension population in the sediments at Radkowice and Belno, with a shift towards a coarser fraction, is evidence of a great variability in the flow and of great changes in the force of the current.

The granulometric analysis of the sediments (shown on the diagrams along a probability scale) shows they have differences in accordance with their genetic classification, independent of their regional localization. This is most striking when comparing sediments of the esker-type crevasse landform from Radkowice and Belno.

As an experiment the Visher method (1969) was applied to deglaciation; until now it was used to analyse granulometrically fluvial, marine and eolian sediments. By this method one can defferentiate the kinds of transport, suspension, saltation and surface creep. These categories were found in the accumulated sediments derived from melt waters during deglaciations. The relations between the granulation populations and their degree of sorting proved to be different for different types of genetic forms.

Other interesting data was found by petrographic and mineralogical analyses of the light and heavy fractions (Fig. 22) carried out for the western part of the Świętokrzyskie Mts.

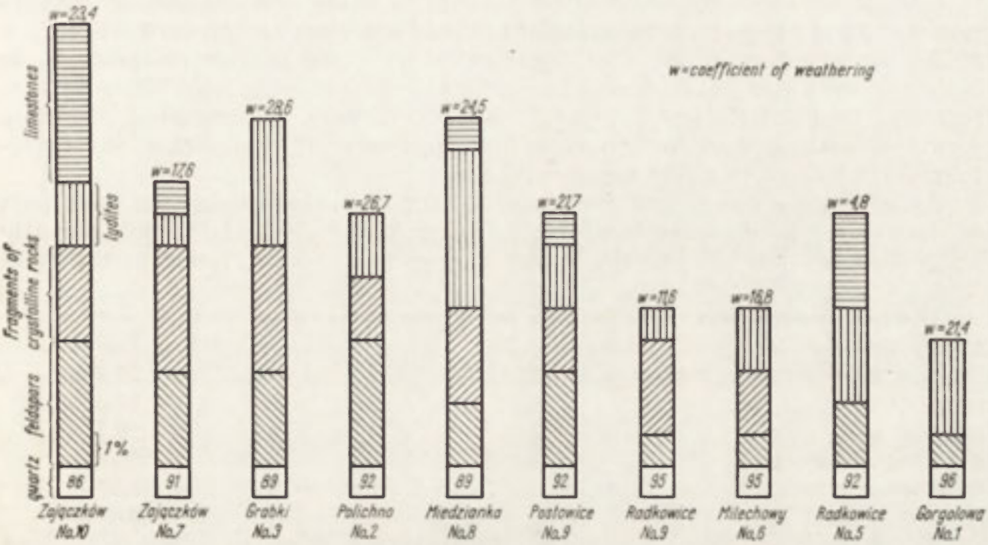

Fig. 22. Petrographic composition of sands on basis of an analysis of the 0.5–0.8 mm fractions

Petrographically the richest sediments are from Zajączków, Grabki, Polichno, Miedzianka and Posłowice (Fig. 1, pnt 3, 12, 8, 2, 1, 7), with at the same time a high weathering coefficient (W), indicating some relation between the durable, average durable and non-durable heavy minerals.

According to Racinowski and Rzechowski (1969) the weathering coefficient is determined by the following formula

$$W = \frac{St}{T} N$$

where T is the durable minerals, resistant to weathering (zircon, tourmaline, rutile, staurolite, disten, andalusite), St — the average durable minerals (garnets, epidote, clinozoisite), N — perishable minerals (augite, hornblende, actinolite, biotite).

The present group of sediments (from Zajączków, Grabki, Polichno, Miedzianka and Posłowice) contains between 86 and 92% quarts, 2–4% of feldspar, 2–4% detrital crystalline rocks, 1–5% of lydites and 0–5% limestone.

The coefficient of weathering ranges from 17.6 to 28.6 and indicates the presence of heavy non-resistant minerals in the assemblage, but there are relatively few of them (Fig. 22).

The second group of sediments compose the sands from Radkowice and Milechowy (Fig. 1, pnt 9,4), which contain from 92 to 95% quartz, 1–2% feldspar, 0–3% detrital crystalline rocks, 1–3% lydites and 0–3% limestones.

Their coefficient of weathering is much lower (4.8–16.8) indicating that heavy non-resistant minerals are insignificant in the assemblage.

The sands from the Gorgolowa Range are different from these two groups (Fig. 1, pnt 11). They are petrographically poor with about 96% quartz, 1% feldspar, 3% lydites but contain quite a few heavy non-resistant minerals ($W = 21.4$).

One cannot draw far-reaching conclusions from the few analyses so far carried out. It is however, interesting that those sediments in farthest SE corner of the western part of the area (Radkowice) have the poorest composition, in both the light and heavy fractions, while the sediments in the NW part (the region of Łososina-Zajączków, Grabki) are much more differentiated. The data seems to indicate that the supply of materials same to this part of the Świętokrzyskie Mts. from a NW direction.

An analysis of the gravel fraction of the sediments composing the main part of the esker type crevasse landform in Belno (photos 10 and 11) gave, equally interesting results; 150 gravels, with a diameter of 2-6 cm found in the fraction.*

The petrographic composition of gravels was as follows:

quartzites	33.0%
limestones, dolomites, marls	30.4%
schists	17.3%
sandstones	10.7%
granites and gneisses	6.7%
fragments of small calcite veins and silificated limestones	1.3%
flints	0.6%.

As in the first group, in the second (quartzite, limestones, dolomites and marls) the main material comes from the neighbourhood around the site, and typically shows very weak rounding. To a large degree this is weathering debris. Limestones of the upper Jurassic and the Miocene (lithothamnic limestones of the lower Tortonian) have been transported some distance. Their presence is particularly interesting. It indicates that the direction of transport of the gravels is from the E and SE where, within a zone surrounding the Świętokrzyskie Mts., lower Tortonian limestones is found *in situ*. In accordance with the criteria applied by Różycki (1972), it is possible, on the basis of the presence of lithothamnian limestones, to consider the origin of the esker type landform in Belno to date from the Mindel glaciation.

The results of our petrographic investigations suggested that the movement of ice to the central part of the mountains came from two directions. In the western part it came from the NW and in the central part from the E. The continental glacier made use of the relief of the area, which in general is concordant with the present relief. In the remaining petrographic groups of gravel sediments from the Belno, rock from the neighborhood around the site is also prevalent. Only small percent is made up by rocks which have been transported some distance (including Scandinavian rocks — granites and gneisses — which are usually strongly weathered and well rounded, and sandstones and flints brought here from the northern borderline of the Świętokrzyskie Mts.).

Another characteristic feature of the investigated gravels is the importance in their composition of rock detrital of very low resistance (schists and marls). This should indicate a short transport in a medium of flowing water and frequent freezing of the material transported (a pebble, looking like lake chalk was recognized).

* We express our thanks to Dr. J. Głazek who helped us to determine the gravel fraction.

The material collected in the area of the deglaciated Świętokrzyskie Mts. has only a fragmentary value; it does not justify synthetical opinions, especially on the age of the discussed forms.

According to most opinions so far expressed our investigated area was submitted only to the Mindel glaciation. The Riss glaciation did not intrude upon

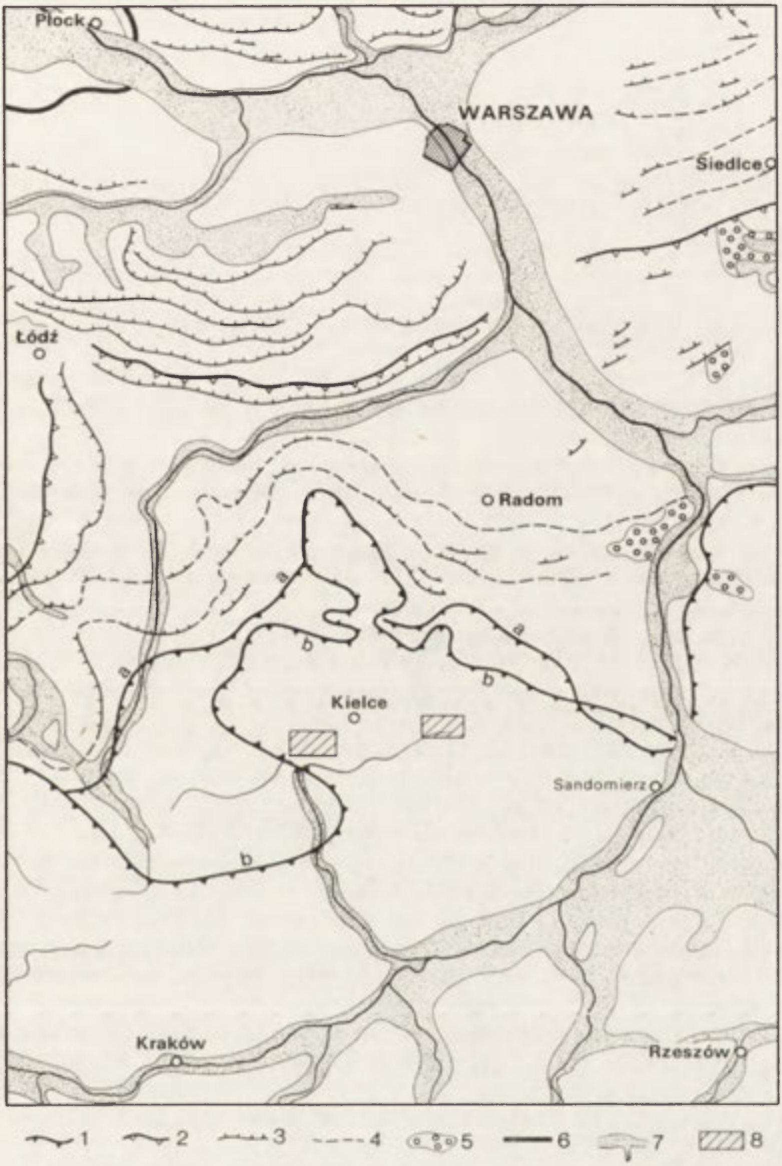

Fig. 23. Extent of the Riss glaciation in central Poland according to Galon and Roszkówna (1967)

1 — maximum extent of the Riss glaciation (a) according to S. Z. Różycki, (b) according to W. Karaszewski: 2 — Warta stage; 3 — stage of recession; 4 — supposed course of continental glacier front; 5 — outwash fan, 6 — Wurm glaciation; 7 — valleys and *pradolinas*; 8 — areas investigated by the present authors

the inner mountains, only smaller or larger lobes reached the periphery, especially along the NW side of the mountaine (Fig. 23; Filonowicz 1972, Łyczewska 1972, Różycki 1972, Galon and Roszkówna 1967).

It may thus be assumed that the visible traces of deglaciation date from the Mindel period. This should be stressed, since until now deglaciation of this age has not been described for Poland. The preservation of the forms is probably due to its location on remonte passes and longitudinal depressions, where no violent processes of degradation over took place.

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THE CLASSIFICATION OF GLACIAL TILLS. A FACTOR ANALITICAL STUDY

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The recognition of the economic potentials of Glacigenic sediments has provided much stimulus for their further study in Poland. In particular the mineralogical and chemical investigations of Stankowska and Stankowski (1969) are an interesting extension of the work of Dreimanis and his associates (1953) in Canada. These studies attempt to distinguish older from younger glacial sediments by means of qualitative and semi-quantitative methods. In this paper the technique of factor analysis has been used in an attempt to describe the spatial characteristics of some Weichselian tills from the north of England (Vincent 1969). This technique also provides the user with an objective method of classification and in this context would be a useful tool for grouping tills of doubtful age and characteristics with their nearest petrological, chemical or sedimentological equivalents.

The methods of factor analysis were developed as a tool in psychometric research at the turn of the century of Spearman (1904) and have, until recently, been neglected by those studying glacial sediments although they are now well established in the fields of regional and economic geography. The reasons for the usefulness of such a technique are easily understood by the following example. Let us suppose we have measured 25 variables for each of 52 areas or sampling sites. It would be possible to map each of the 25 variables separately such that each of the 25 variables could be looked at individually and also compared two at a time, three at a time and so on, as desired. Distributions that showed similar trends over the surface of the maps would be seen to correlate. Cole and Smith (1967) advance several reasons why such visual exercises run into difficulties. Firstly, to view all possible combinations of the 25 maps it would be necessary to consider 100,000,000 combinations. Allowing 10 seconds to consider each combination this would take a person about 200 years. Secondly, any combination of more than three or four variables view together become very difficult to handle visually. Thirdly, there seems to be no assurance that the individual viewers will not see correlations they expect to see rather than correlations that exist. Factor analysis does the work of combining the 25 maps and attempts to identify the characteristics which variables have in common and which result in their intercorrelation. Factor analysis is, therefore, a reasonably objective method of grouping and simplifying the number of intercorrelated variables thus allowing a meaningful classification to be made.

In order to familiarize the reader with the essential details of the technique of factor analysis a brief account is provided. Those interested in the mathematical details of the method should consult a suitable textbook such as Harman (1967).

Factor analysis may be carried out in two distinct but related procedures. in R-mode factor analysis attention is focussed on an $n \times n$ matrix of relationships (usually taken as product moment correlations) between all pairs of

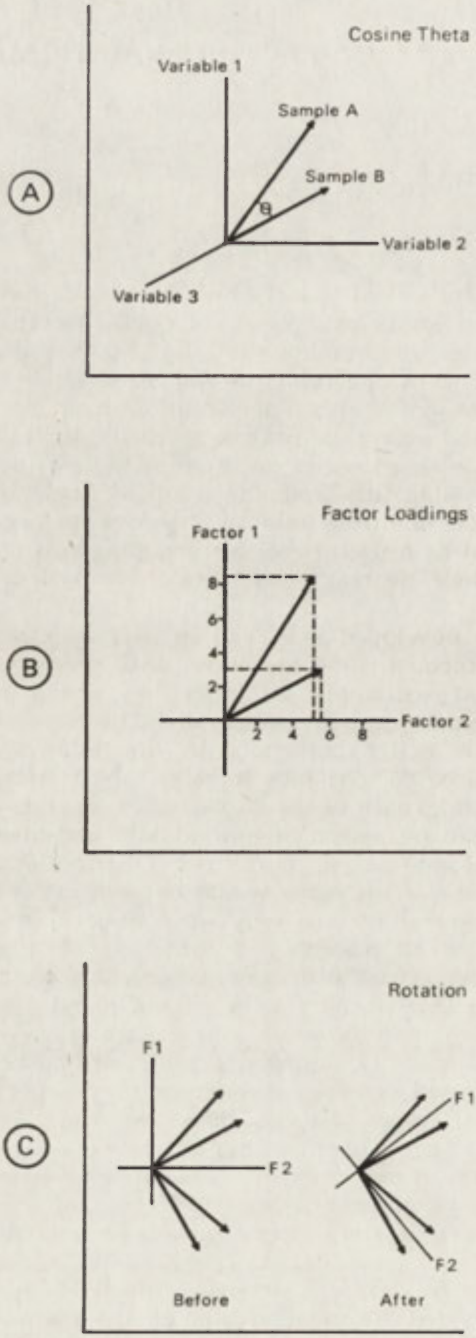

Fig. 1a, 1b, 1c. A geometrical explanation of cosine theta, factor loadings and factor rotation measured variables. In Q-mode analysis attention is focussed on N samples and results follow from an inspection of an $N \times N$ matrix of relationships between all pairs of samples. In Q-mode analysis cosine-theta coefficients are used to represent correlations in matrix. This can be illustrated graphically in the simple case by considering the correlation of two samples (A and B) represented as vectors in a coordinate system of three variables (Fig. 1a). The angle Θ is a measure of the similarity between two vectors. The smaller the angle Θ the greater the similarity between two vectors. Algebraically this concept may be expanded into n dimensional space, where n represents the number of measured variables.

Very probably, many sample vectors may lie relatively close together in the n dimensional space. In order to simplify this complex n dimensional structure factor axes are constructed which project mathematically into this coordinate system. Lines projected perpendicularly from the sample vectors onto the factor axes of unit length are called factor loadings (Fig. 1b). Vectors with higher factor loadings lie closer to a factor axis than do vectors with lower loadings. Using this information it is possible to deduce which samples lie near to each factor axis.

There are various methods of fitting factor axes to similarity coefficient matrices (Harman 1967). A common method of fitting factor axes is that of principal components in which the first axis is positioned so that the sum of squares of the factor loadings is maximized. Geometrically this may be thought of as placing the first factor axis in the centre of gravity of the vector system. The next factor axis, which is orthogonal to the first, is positioned so that the sum of squares of the factor loadings on it is also maximized. Subsequent axes are positioned in a similar manner. In order to simplify interpretation of the factor loadings it is common practice to rotate the factor axes after they have been established (Fig. 1c). The purpose of rotating factor axes is to position them in such a way that they lie close to any distinct clusters which may exist in the similarity coefficient matrix. A simple way of showing the associations of the samples is to plot the factor loadings graphically, the ordinate and the abscissa representing the factors.

Once the factor axes and loadings have been computed it is then required to know which particular variable, or groups or variables, is substantially represented by each factor. In Q-mode analysis this may be done by inspection of the factor weightings. The weightings indicate how the N samples, which are distributed in space about factor axes vary with respect to the n variables. Thus high factor weightings on a variable indicate that a factor is highly associated with that variable and vice versa.

In as much as the Q-mode analysis emphasizes relationships among samples, it provides an important method for classifying sedimentological and petrological information. In the present study a Q-mode analysis was performed on data collected from 52 samples of till from the northern Pennines (Fig. 2). Each sample consisted of 2 kg of unweathered sediment aggregated from four random samples. It is known from other studies that at least two tills are present in the study area. One is often reddish in colour and was deposited by an easterly moving ice-sheet which issued from an ice-cap developed over the igneous and metamorphic mountains of the Lake District (Fig. 2). The other is typically a drab grey colour, free of igneous and metamorphic erratics and was produced by local ice produced within the Pennine Hills which are almost entirely composed of sedimentary strata of Carboniferous Age. However, there exist other tills which have the properties of the reddish tills and also of the local grey tills. In the present study it was hoped that factor analysis might help structure this continuum of reddish, intermediate and grey tills.

In the laboratory as much information as possible was gathered from routine sedimentological, chemical and petrological investigations. A total of thirty separate items of information were available for each sample of sediment (Table 1).

As a preliminary stage in the analysis the raw data were transformed by dividing each value by the highest observed value for that particularly constituent. This transformation gives equal weight to each variable; such a transformation is useful because not all variables were measured on a percentage scale, e.g. pH, Φ mean. No additional transformations are necessary in Q-mode analy-

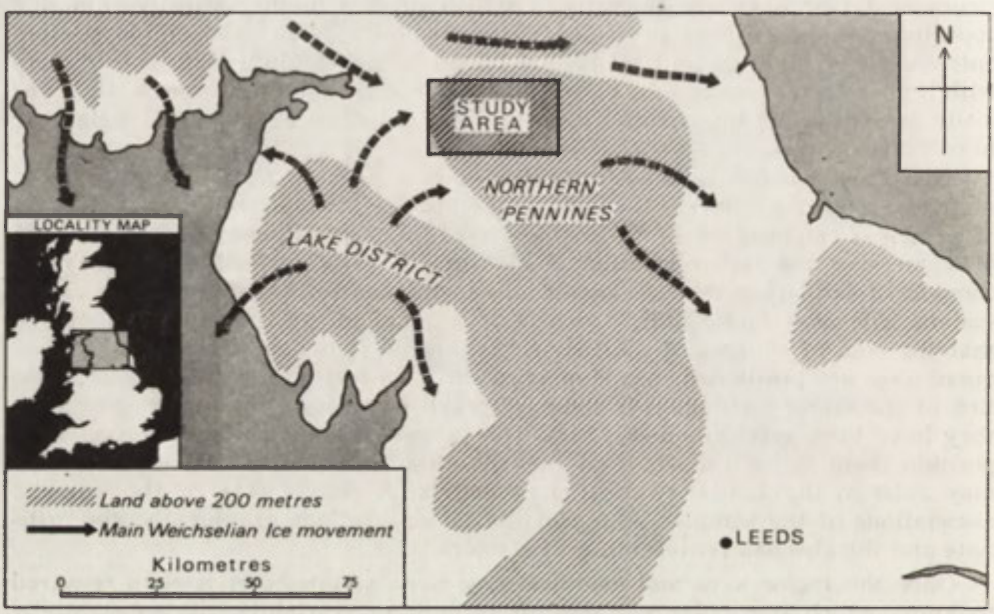

Fig. 2. Location of study area

sis because the correlation matrix is built up from cosine-theta and not product moment correlation coefficients. The cosine theta matrix thus consisted of a 52×52 array, thirty variables being measured for each of the 52 till samples. At this stage the usefulness of the factor analytical approach is clear. It would be difficult, if not impossible, to visually assess such a matrix of coefficients. Here the high speed computer is invaluable. In this study a factor analysis was performed on the IBM360/67 computer at Durham University using a Fortram program written by Klovan. This program allows the abstraction of up to ten factors from a cosine theta matrix.

After a varimax rotation of the factor axes the first three factors accounted for 81% of the variance of the cosine-theta matrix and for this reason it was decided to limit further study of the results to these three factors. Examination of Table 1 indicates which of the thirty variables are most closely related to each factor and thus characterize the factor axis. The variables which appear most closely related are as follows:

Factor I Hematite, limonite, pH, ferric iron, phi sorting, phi mean, per cent day, silt, and gravel, per cent shale.
Factor II Amphibole, pyroxene and tourmaline, per cent erratics, ilmenite, magnetite, par cent sand and clay.
Factor III Per cent sandstone.

TABLE 1. Factor weightings for the first three variables

Variable	Factor I	Factor II	Factor III
Per cent sandstone	0.5492	0.2721	5.2935
shale	1.3702	−0.8425	0.8574
erratics	−0.5286	2.2105	−0.0902
limestone	0.1550	−0.3008	−0.1211
coal	−0.0973	0.3409	0.0005
pH	2.0182	0.7365	−0.4004
Coal in matrix	0.5890	−0.2079	−0.2594
Ferric Iron	1.8156	−0.0712	−0.3563
Carbonate	0.7079	−0.1667	−0.1545
Per cent gravel	1.1248	−0.2816	−0.2708
sand	1.3174	1.3126	−0.2435
silt	1.4061	−0.2527	−0.3286
clay	1.4312	1.4413	−0.2529
Phi mean	1.5497	1.0249	−0.2741
Phi sorting	1.6264	0.8143	−0.2391
Sphene	−0.1059	0.4154	−0.0452
Monazite	−0.3544	0.8815	0.0245
Garnet	−0.2481	0.8420	−0.1000
Biotite	−0.1326	−0.0103	0.1078
Rutile	0.0396	0.0798	0.1001
Zircon	−0.1859	0.3570	0.0059
Staurolite	−0.3603	0.4701	−0.1073
Kyanite	−0.1409	0.0245	0.2082
Epidote	−0.2826	0.6844	0.2464
Amphibole/Pyroxene	−0.5972	2.5180	0.1248
Tourmaline	−0.5088	2.4934	0.0093
Sillimanite	−0.0950	−0.5185	−0.1400
Hematite/Limonite	2.4437	−0.2375	0.1019
Magnetite/Ilmenite	−0.3962	1.6036	0.1668
Pyrite	0.1406	−0.4776	0.1569

Having decided on the make-up of the factors it is necessary to examine the factor loadings to see which samples are most strongly associated with each factor. The loading on each of the first three factors for the 52 samples are illustrated graphically in Fig. 3. Inspection of Fig. 3a would seem to indicate that three reasonably distinct categories of till are to be found in the study area.

Category 1. This group, which contains the majority of the samples analysed, loads heavily on Factor I and relatively lightly on Factor II. The sediments included in this category are associated with high pH values, high Ferric Iron contents, high shale percentages in the stone counts and with high hematite and limonite percentages in the heavy mineral fraction. These variables suggest a strong influence of Pennine rock on the tills.

Category 2. This group loads most heavy on Factor II and relatively lightly on Factor I. Factor II, it will be remembered, is associated with high percentage of tourmaline, amphibole and pyroxene minerals in the sand fraction. This factor then is an expression of those variables which are particularly char-

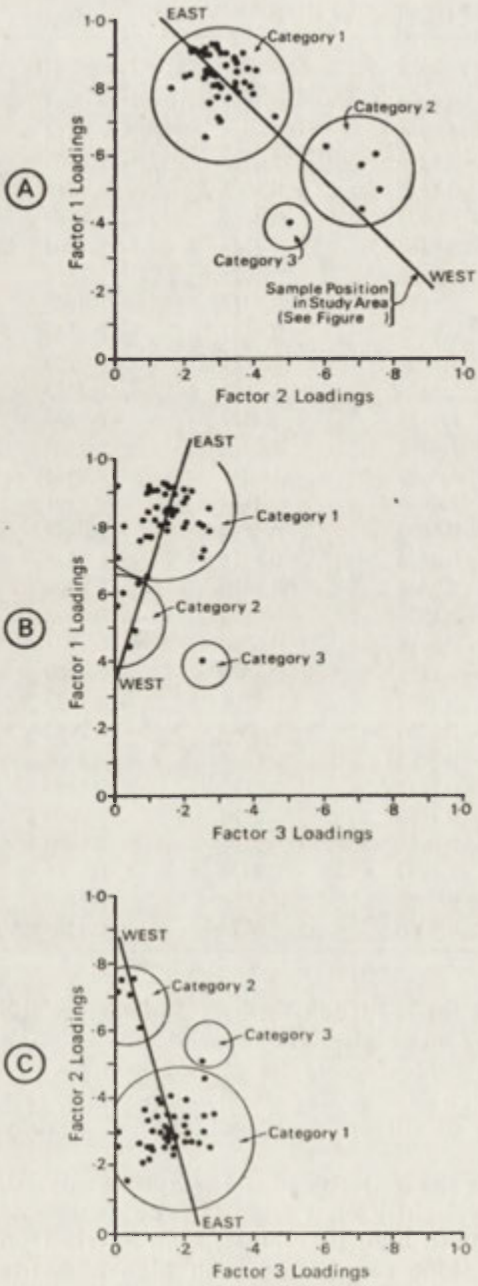

Fig. 3a, 3b, 3c. Graphical plots of the factor loadings for the first three factors acteristic of tills which are not of Pennine provenance and which have retained much of their extra-Pennine character.

Category 3. This consists of one sample which loads relatively lightly on both Factors I and II.

The existence of these three groups of samples is further demonstrated when the loading Factor II are plotterd against Factor III (Fig. 3c). These two factors together only accounted for 19.7 per cent of the total variance and are, therefore, rather weak explantations of the total correlation matrix. However, it is shown that three groups of samples are still reasonably distinct.

Broadly speaking the usefulness of such factor analysis studies within the study area, as demonstrated here, may be seen to be twofold.

a) As a tool for classification

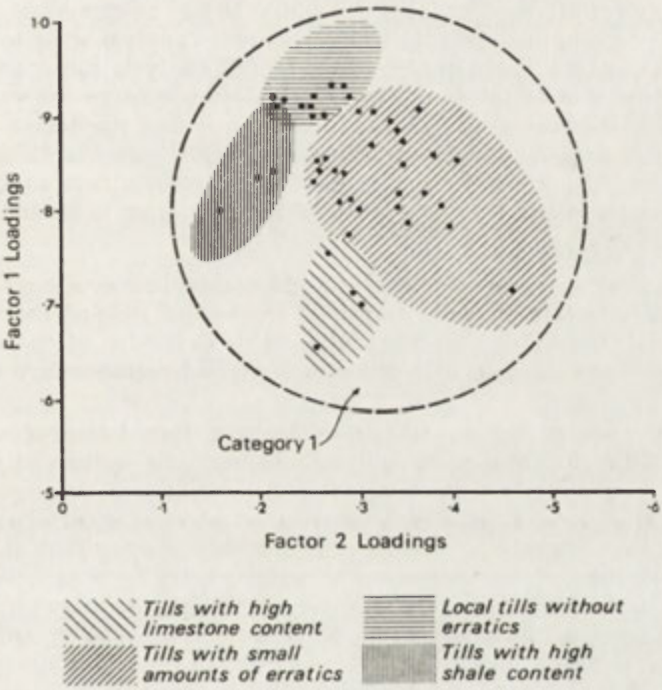

Fig. 4. Subdivisions of sediment types within Category 1

Geographers, in company with other scientists, are finding it increasingly useful to classify and order the immense amount of data which are being amassed day by day. The Geomorphologist may find it useful to classify the sediments he has studied so that additional information, if collected at a later date, may be included with some organized framework and its relevance within the conceptul framework judged.

In the example presented here it is possible to arrive at a reasonably objective classification of till samples analysed in the laboratory. It has already been suggested that it is possible to classify 52 samples of till, collected by the writer, into three broad categories representing those tills which are essentially of Pennine provenance, those which are essentially of extra-Pennine provenance and one sample which is not strongly associated with either of these two groups. The latter, anomalous, sample may be interpreted as being very poorly mixed and may not have been removed far enough from its bedrock source for it to have acquired proper Pennine characteristics. Alternatively, it may be solifluction sediment of some type. In either case the analysis has thrown up an anomaly not noticed in the field which requires further investigation.

Further useful sub-division and classification of the tills is possible. An example is illustrated in Fig. 4 where category 1 has been further subdivided into four:

1. Tills with high shale contents,
2. Tills with high limestone contents,
3. Local tills without erratics,
4. Tills with small amounts of erratics.

It is essential to keep the number of such sub-division as small as possible since a further sub-division defeats the whole object of classification. The question arises as to whether or not it is worthwhile analysing so many variables in order to classify tills. In this context factor analysis has many benefits. It has been shown that factor axes are associated with groups of variables which themselves are correlated and that by examination of the factor weightings it is possible to find out which are the most significant variables. Once these have been decided upon it would be possible to concentrate analysis on fewer significant variables and thus allow many more samples to be analysed.

(b) *Factor analysis in the study of provenance*

In its simplest terms provenance may be considered as a simple binary system. One end member of such a system represents tills of the source region of ice dispersal, the other represents those tills down-ice of the source region. In the example presented in this paper the two end members are in fact factors I and II.

Now, if we accept the premise that an incursive ice-sheet will gradually incorporate sediment into its base it follows that the nature of that sediment will change in a down-ice direction. If it is possible to arrange the samples, in terms of their overall sedimentological and petrological characteristics as measured by factor analysis, within such a binary system then it is possible to indicate broad lines of ice movement. Such a binary axis can be identified in the present study (Fig. 3a). Till samples with high loadings on Factor II are found in the west of the study area while the most easterly samples (those in a down ice-direction) are those which load most heavily on Factor I.

Of more importance than the general direction of sediment transport, which can be deduced from simple field methods, is the information gained as to the overall rates of evolution of the sediment characteristics in a down-ice direction. If comparative studies could be made we might learn much of the erosive capacity of former ice sheets and the influence of various rock types and structure on their advance.

The statistical results in this paper indicate that tills are more sedimentologically organized that is usually supposed by visual examination and that factor analysis is a useful method of analysing such deposits. However, it is useful to remind ourselves of the dangers of dealing with mere mathematical extractions and the need to put such results in their geomorphological context. This cannot be done without recourse to an initial appraisal based on field work.

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THE RETREAT OF ALLUVIAL RIVER BANKS IN THE WISŁOKA VALLEY (SOUTH POLAND)

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The banks of the rivers dissecting the northern slope of the Polish West Carpathians and its foreland are being eroded in many places. The young oxbows found in both the narrow Carpathian valleys and in the broad valleys in the foreland are examples of bank migration. The relation between the structure and size of these alluvial banks and their mode of retreat is still an unsolved problem.

The article presents the results of research on the mode and rate of retreat of the alluvial banks of the Wisłoka river. Repeated observations were made over the period 1970–1972 in a chosen sector of the valley.

CHARACTERISTICS OF THE GEOGRAPHICAL ENVIRONMENT OF THE WISŁOKA DRAINAGE BASIN

The Wisłoka valley (a tributary of the Vistula) trends meridionally and cuts secondary geological-geomorphological units of the northern slope of the Polish West Carpathians and its foreland, the Lower Beskid Mts. 700–850 m a.s.l., the Carpathian Foothills 400–550 m a.s.l. and the Sandomierz Basin 150–260 m a.s.l. (Fig. 1). The course of the Wisłoka valley in the Carpathians is to a great extent conditioned by the structure and resistance of the flysch substratum. Widenings of the walley separated by narrow breaches, are found along its course. Within the widenings of the valley the Wisłoka channel is cut predominantly across alluvial deposits, while in the narrower parts it cuts into a shaly-sandstone substratum. In the foreland of the Carpathians the Wisłoka channel is cut mainly into Quaternary alluvial deposits and in places into underlying clayey-shaly Miocene sediments.

The Wisłoka channel has predominantly a meandering course. In the Carpathians the meanders are controlled by the structure of the substratum. In the Carpathian foreland free meanders occur. The mean longitudinal slope of the water-level in the Wisłoka is as follows: over 6‰ in the Lower Beskid Mts., up to 3,9‰ in the Jasło–Sanok Depression, up to 0.8‰ in the northern part of the Carpathian Foothills, and 0.5-0.6‰ in the Carpathian Foreland (Fig. 2) (K. Klimek, L. Starkel 1972).

The Wisłoka channel is accompanied by a relatively narrow flood plain consisting of several steps 0.5–4 m above the mean water level. The lower steps of the flood plain are mostly covered with osierbad and alder. The higher steps are under cultivation. The *rendzina* terrace, which varies from a height of 4 m in the foreland of the Lower Beskid Mts. to 10 m in the Carpathian foreland, in many places makes up the valley-floor proper and is nearly everywhere under cultivation. On the surfaces of the flood plain and the *rendzina*

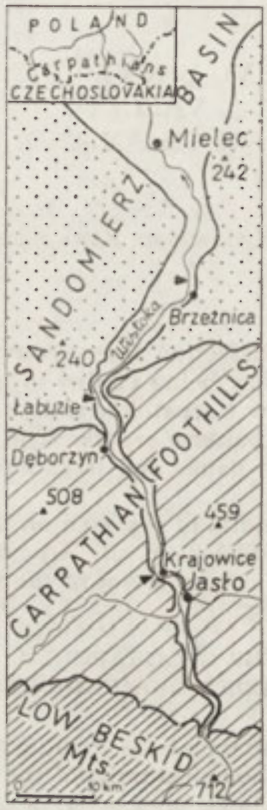

Fig. 1. The Wisłoka valley and the main geological-geomorphological units of the Carpathians and its foreland

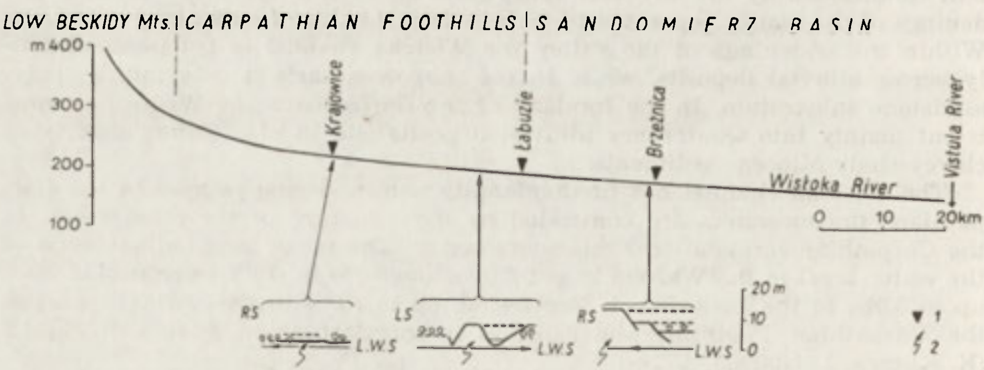

Fig. 2. The longitudinal slope of the Wisłoka water-level: 1 — water-gauges mentioned in the text, 2 — analysed bank undercuttings, RS — right side, LS — left side, LWL — low water-level

terrace dry ox-bows with differing radii of curvature occur. Despite their differences in height, some of the flood plain and *rendzina* terrace steps have a similar structure (M. Klimaszewski 1958, L. Starkel 1960). Lying on the gravels and sands of the channel deposits there is a silty complex of flood plain deposits. In Polish these clayey-silty deposits are called *mada*. In the Wisłoka valley *mada* is composed of dusty deposits, mostly of particles below 0.05 mm in diameter and locally even below 0.02 mm. Its thickness increases as the height of terrace steps increases. Within the flood plain the average thickness of *mada* cover is 1–2 m. In the upper part of the *rendzina* terrace its thickness is usually more than 3–4 m. Because of the *mada's* cohesion the undercut banks usually have steep walls.

About 62% (2547 km^2) of the Wisłoka drainage basin is situated within the Carpathians. The area receives from 700 mm of precipitation p.a. (in the Carpathian Foothills) to 900 mm (in the Low Baskid Mts.) (M. Hess 1965, W. Wiszniewski 1957). The mean specific runoff from the Carpathian part of the Wisłoka drainage basin (water-gauge Krajowice) is 10.8 $l/s/km^2$. The mean discharge of the Wisłoka in the Carpathian Foothills (water-gauge Krajowice) is 22.5 m^3/s.* and in its lower course (Mielec) it exceeds 30 m^3/s.** The variable distribution of precipitation throughout the year results in a high variability of the discharge (I. Dynowska 1972). The subzero temperatures of the winter season give a duration of snow cover over 100 days in the Low Beskid Mts., over 65 days in the Carpathian Foothills and up to 50 days in the Sandomierz Basin (W. Milata 1937, M. Hess 1965). The relatively small vertical range of the Wisłoka drainage besin (about 700 m) causes the simultaneous melting of the snow cover throughout its area. Therefore, each year in March and April, melt water floods occur on the Wisłoka, during which the maximum discharge in its lower course rises to 670 m^3/s. In addition there are rainfall floods every few years in the summer months, during which the discharge in the lower course of the Wisłoka is over 1100 m^3s.** Throughout the year there may be several high water-stages caused by heavy rainfall or winter thaw. The floods or raised water-levels play a decisive part in bank erosion.

THE MODE AND RATE OF BANK RETREAT.

The vegetation cover protects the Wisłoka banks effectively against erosion. The root system of trees and shrubs plays a decisive role. The roots bind loose alluvial deposits, and prevent them from liquefying or slumping. Therefore, active erosional undercuts usually appear along banks without riverain bushes. The *rendzina* terrace, which is everywhere under cultivation, is nearly always undercut where it is adjacent to the river channel. Great vertical erosion occurs in these sectors of the valley, and this also effects the banks covered by river bushes. The subsidence of the water-level in the river brought about by the great deepening of the channel is such that its low and middle stages drop below the dense root system. This disturbs the stability of the channel banks and thus facilitates their slump or collapse.

A good index of the rate of vertical erosion in the Wisłoka valley is a tendency of minimum water-levels to become lower. An analysis of the minimum levels for the period of sixty years between 1912 and 1972 has shown that at some water-gauging stations the levels become lower due to the successive

* Data for 1961–1970.
** Data for 1951–1960.

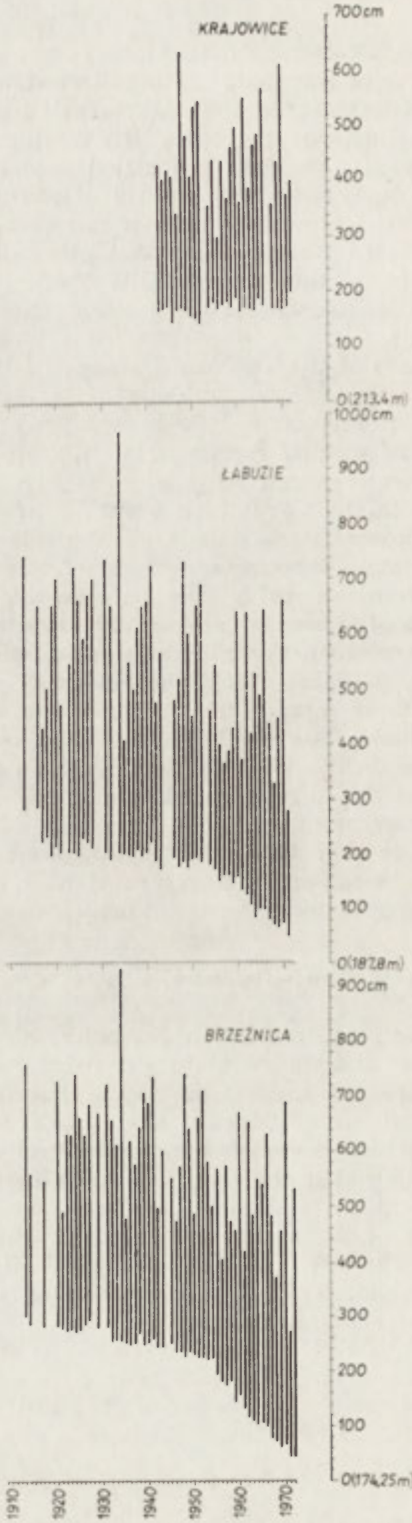

Fig. 3. Annual water-level variations of the Wisłoka in the period 1912–1972 (water-gauges at Krajowice, Łabuzie, Brzeźnica)

deepening of the channel floor (Fig. 3). This is particularly well marked in the direct foreland of the Carpathians, and was earlier noted by L. Starkel (1960) and B. Osuch (1968). About 20 years ago an acceleration in the vertical erosion took place so that today, the deepening of the Wisłoka channel averages 10 cm per year. Besides neotectonic and climatic reasons and changes in the land utilization of the Wisłoka drainage basin, the exploitation of gravels and sand also greatly influences the deepening of the Wisłoka bed. Flood-control works also affect this process. The local exploitation of gravels or sands from the bottom of the river bed disturbs the equilibrium of the river profile. This is a stimulus for deep erosion to move quickly upstream. The narrowing of the river bed causes local increases in the velocity of the current; it speeds up the removal of bed load thus causes local deepening of the channel bottom.

The study of the mechanism and rate of erosion of alluvial banks of varying height was carried out in three selected parts of the Wisłoka valley—near Krajowice, Dęborzyn and Brzeźnica (Fig. 1, 2).

THE KRAJOWICE SITE

At Krajowice the Wisłoka channel cuts across alluvial deposits in the examined stretch of the valley (Fig. 4). The valley floor (215–220 m a.s.l.) 0.5–1 m wide, is a flood plain consisting of a few steps up to 3.5 m in height above the mean water-level. The *rendzina* terrace, which forms the valley-floor in the western part of the stretch under examination, rises from 5 to 7.5 m above the mean water-level in the channel. Active undercutting of the 2 m turfed flood-plain is going on the right-hand side of the channel (Fig. 5). In the lower part

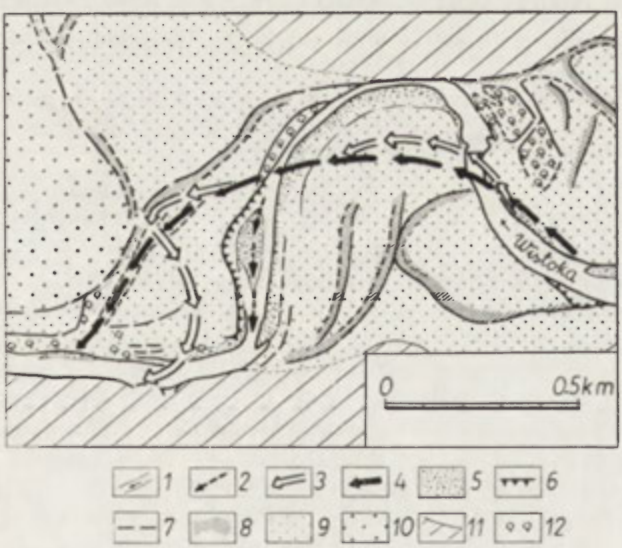

Fig. 4. A geomorphological sketch of the Wisłoka valley-floor near Krajowice: 1 — present channel, 2 — axis of channel in 1964, 3 — axis of channel in 1880, 4 — axis of channel in 1885, 5 — gravel bars, 6 — active bank undercuts, 7 — edges of inactive undercuts, 8 — ox-bow filled with silt and peats, 9 — steps in the flood-plain, 10 — *rendzina* terrace, 11 — valley sides, 12 — major patches of riverain vegetation (osier-bed, alder)

of the undercut bank there are sandstone gravels, mostly 0.4–8 cm in diameter. Their upper height is irregular from 0 to 1,2 m above the mean water-level. The gravels are overlain by a consistently loamy *mada* 0.8 to 2 m thick (Fig. 6) and with a predominance of particles below 0.02 mm in diameter (58%). In this portion of the valley the annual fluctuation in the water-level is about 2 m. Every few years floods occur, then the water-level rises by about 3 to 4.5 m (Fig. 3). During this period the flood-plain is inundated.

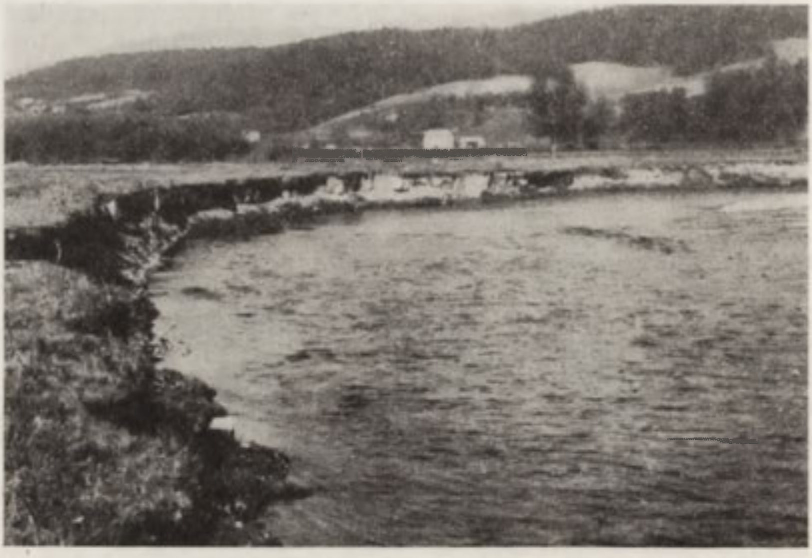

Fig. 5. Upstream view of an active undercut in the flood-plain at Krajowice (Photo K. Klimek, Febr. 1972)

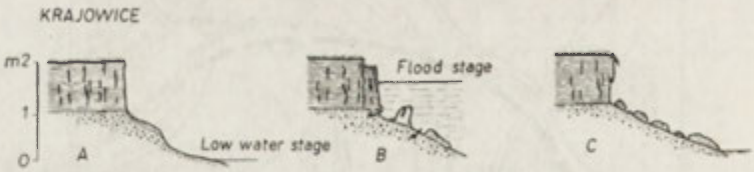

Fig. 6. A developmental scheme (A, B, C) of the Krajowice undercut. Arrows show the direction of waters infiltrating from the channel

Detailed observations of the undercut bank were carried out in July and October of 1971 and in February and August of 1972, a few days after meltwater and rain floods. During the bankful stages water percolates into sandy-gravel channel deposits as well as into the overlying *mada* complex (Fig. 6B). It loosens the sandy-gravel complex and liquefies the *mada*, mainly in its lower parts. This causes block slamping of the *mada;* much more rurely columnar slumping occurs. Bank slumping also takes place at the raised water-level, reaching barely a few centimetres above the base of the *mada* (Fig. 8). Where the grass on the flood plain has a well developed root system, niches 0,5 m deep develop in the undercut banks. The falling blocks of *mada* are slowly washed away by the flowing water. After the passage of the flood-wave, one usually finds a gravel point bar overlain by fallen blocks of *mada* at the (already) low water level at the foot of the retreated bank (Fig. 6C). As a result of alternate drying out and moistening by rainfall, these blocks gradually desintegrate into smaller fragments. Through a prolonged process of weathering they decay into clayey covers that mentle the top of the gravels (Fig. 6A). During the successive raising of the water-level the weathering of *mada* blocks removes the gravels and their loamy covers. This slow process of removing the material from the foot of the croded bank increases the bank's relative height; this in turn facilitates its erosion as the water-level becomes higher.

Fig. 7. The structure of the 2 m undercut in the flood plain at Krajowice. Remnants of the loamy cover caused by the desintegration of *mada blocks* can be seen on the gravels of the channel deposits (Photo K. Klimek, Febr. 1972)

One can get a rough idea of the rate that some stretches of the bank have retreated by comparing the 1855, 1880 and 1964 positions with the results of the 1972 study. In the lower part of the examined valley stretch (Fig. 4) the axis of the river channel shifted to the left by about 200 m over the years 1855–1880. The rate of retreat of the left side of the Wisłoka channel at this point averaged 8 m per year. Between 1964 and 1972 a central bar was formed in the axis of the channel caused by the braiding of the channel into two arms. The right arm shifted by 90 m in relation to the channel axis of 1964. The bank reach which was most rapidly destroyed, 100 m long, retreated on average 10–11 m a year. From this sector of the bank as much as 2000 m^3 of alluvial material is supplied to the channel each year.

Fig. 8. Krajowice. At the raised water-stage there is intense bank slumping. *Mada* blocks falling to the bed are gradually washed away by the water (Photo K. Klimek, Febr. 1972)

THE DĘBORZYN SITE

In the vicinity of Dęborzyn the Wisłoka valley passes from the Carpathians to the Sandomierz Basin. In widens to 1 km and the valley floor lies at a height of 188–205 m a.s.l. (Fig. 9). In the investigated sector of the valley the Wisłoka channel is cut into alluvial deposits. A narrow flood plain rising in steps up to 4 m above the mean water-level runs adjacent to the river channel. In this sector the *rendzina* terrace, which is 7-8.5 m high, forms the valley-floor proper. Active bank undercutting about 900 m in length is taking place on the convex side of the meander, including a 200 m long undercutting of the 8 m *rendzina* terrace (Fig. 10). A silty complex dating from the last glaciation is found on the lower part of the deposits building up the terrace. There is a complex of gravels and sands, 2.5–3 m thick, passing upwards into sands 1.5–2 m thick, on the irregular surface of the silts (Fig. 11A). The upper part of the terrace is composed of a compact *mada* with particles mainly less than 0.02 mm in diameter (K. Klimek, K. Mamakowa, L. Starkel 1972).

Each year variations in the water-stages in this stretch of the valley are between 2 and 3 m (Cf. Fig. 3), the Łabuzie water-gauge). During flooding the water-level rises to 5 m. Detailed observations of this undercutting were car-

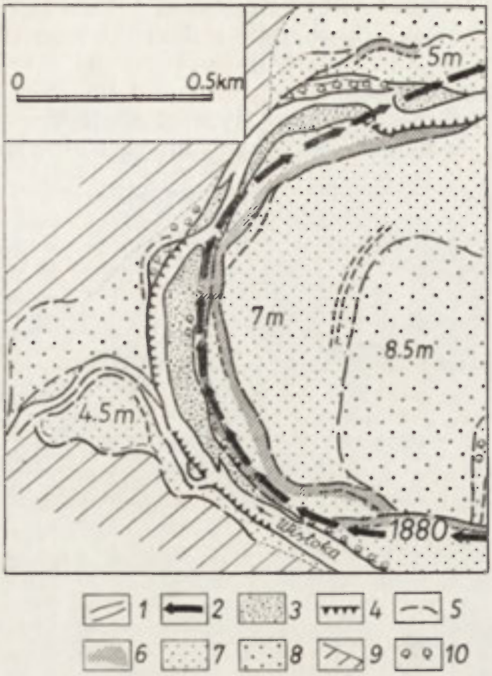

Fig. 9. A geomorphological sketch of the Wisłoka valley in the region of Dęborzyn: 1 — present-day channel, 2 — axis of channel in 1880, 3 — gravel bars, 4 — active bank undercuts, 5 — edges of inactive undercuts, 6 — ox-bow, 7 — steps in the flood plain, 8 — *rendzina* terrace, 9 — valley sides, 10 — major patches of riverain vegetation (osier-bed, alder)

Fig. 10. Dęborzyn. An active undercutting of the 8 m *rendzina* terrace (Photo K. Klimek, August 1972)

ried out in July and October and in August of 1972, a few day after the flood. During the high water stage the water reached the base of the *mada* and percolated into the gravels and overlying sands of the lower part of the bank. This loosens the compactness of the gravel and liquefies the sand. Thus disturbing the stability of the overlying layer of *mada* brings about it slumping (Fig. 12). The slumping blocks are usually up to 1 m wide and a few meters

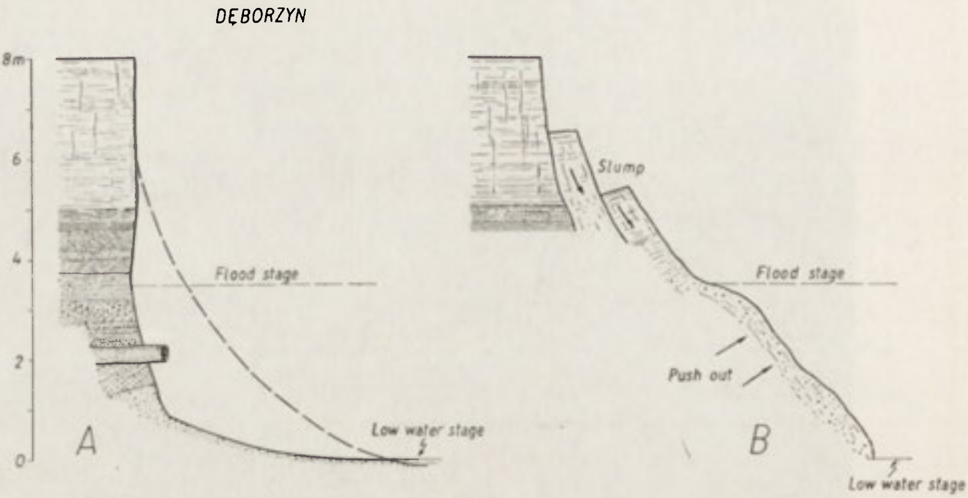

Fig. 11. Profiles of an undercutting in the 8 m *rendzina* terrace at Dęborzyn after the passage of the flood wave. A — undercutting without efflux of ground-water, B — undercutting with the efflux of ground-water causing bank slumping

Fig. 12. Dęborzyn — an undercutting in the 8 m *rendzina* terrace after the passage of flood wave. Slumping blocks of *mada* cause squeezing of the underlying sands and gravels (Photo K. Klimek, August 1972)

long. During a high water-level the rapid current is able to carry the slumping sands and gravels downstream and can push smaller blocks of *mada* over. The larger blocks of *mada*, remaining on the spot, are readily washed away. The quick removal of material from slumping lets water further infiltrate into the bank, thus speeding up its retreat. Observations carried out 3 days after the passage of the flood wave, at the already low water-level, revealed that the slumping of some parts of the undercut bank was still going on. The slumping was in progress where ground waters from the gravels and sands making up the lower part of the terrace flowed into the Wisłoka channel. This efflux of ground water during the high-water stage percolate through the deposits in the lower part of the *rendzina* terrace either from the channel or from the Jodłówka, a small left-side tributary of the Wisłoka.

This efflux of ground water loosens or liquefies the sandy-gravel series after the passage of the flood wave. It was found that at low water-level where the Wisłoka current was directed under the bank undercuttings some of the sloughed material was removed. In other places, at the foot of the slumping banks, there were swellings composed of material squeezed out by the slumping lumps of *mada* (Fig. 11B, 12).

Where there was no efflux of ground water, the profiles of the bank undercuts were nearly vertical (Fig. 11A). Nevertheless, the tendency for the gravels and the dried sand to fall away leads to a slow accretion of heaps at the foot of the bank. After a longer spell of low water, the originally steep undercutting is transformed into a talus cone. But the bank slumping and the development of heaps tend to stop the process of bank recession. During the high water stages some of the material is removed due to slumping or falling off. However, it is only during inundation that the material deposited at the foot of undercut bank is completely removed, and this facilitates its further retreat.

By comparing the maps for the years 1880, 1964 with the 1972 observations one can see that about 90 years ago the channel axis in the investigated reach of the Wisłoka valley passed about 100 m to the right of the present one. The clear edges of many ox-bow lakes in the flood plain testify to this old course of the Wisłoka channel (Fig. 9). The floors of the ox-bows are 2-3 m higher than the present river channel. Thus, it follows that the retreat of the left bank of the Wisłoka in this sector of the valley, has been going on for at least 90 years. The mean velocity of this retreat, is 1 m each year. The undercutting of the *rendzina* terrace, 200 m long and 8 m high, suplies 1600 m^3 of alluvial material each year, i.e. 800 m^3 per year from a 100 m sector of the bank.

THE BRZEŹNICA SITE

The Brzeźnica Site is situated in the Sandomierz Basin, at a distance of 5 km from the Carpathian escarpment (Fig. 1). In the investigated reach of the Wisłoka valley, 4–5 km wide and at a height of 177–186 m a.s.l., the channel is cut across Pleistocene or Holocene alluvial deposits (K. Mamakowa, L. Starkel 1972). On the right side of its course the Wisłoka undercuts a 4 m flood plain, the 9 m *rendzina* terrace and the 14 m Pleistocene terrace. In the lowermost part of the undercut Pleistocene terrace has flysch gravels, with a predominance of those below 2 cm in diameter. The gravels are overlain by a 5–6 m complex of cohesive clayey silt, interbedded locally with fine-grained sands. These in turn are covered by a complex of stratified sands making up the upper part of the undercutting (Fig. 13).

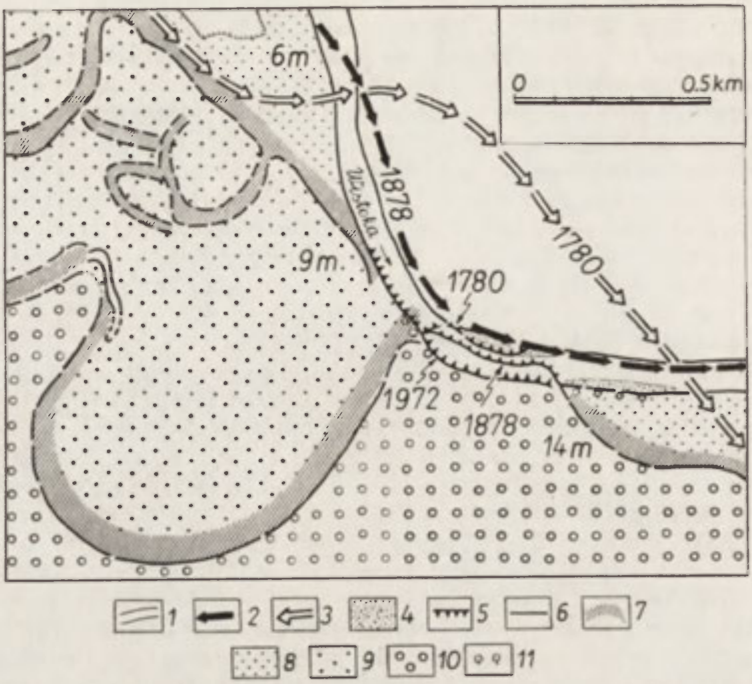

Fig. 13. A geomorphological sketch of the Wisłoka valley near Brzeźnica: 1 — present-day channel, 2 — axis of channel in 1878, 3 — axis of channel in 1780, 4 — sandy-gravelly bars, 5 — active bank undercuts, 6 — edges of inactive undercuts, 7 — oxbow filled with loams and peats, 8 — flood plain, 9 — *rendzina* terrace, 10 — Pleistocene terrace, 11 — bushes of willow or alder

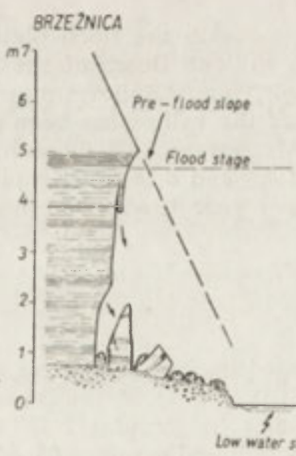

Fig. 14. Profile of the lower part of an undercutting in the 14 m Pleistocene terrace at Brzeźnica

In the valley sector under consideration the annual average range of the water-level is 2–2.5 m (Fig. 3). During flooding the water-level rises by 5–6 m. Observations of this undercut bank were made in June 1970, July 1971 and in May, August and September of 1972. Before the flooding in August 1972 the undercut bank had a slightly concave profile. At its base there are numerous sandy talus cones. During the flood of 22 August 1972 the water-level at the foot of the undercutting rose by 5 m without reaching the top of the silt complex. After the passage of the flood wave an undercutting in the lower part of the bank could be seen consisting of a set of niches 4-5 m high and a few metres wide (Fig. 15, 16). These niches were much like those thermocarst features that are formed in the banks of rivers flowing through areas of permafrost (J. McCloy 1970, J. Dylik 1971, T. Czudek, J. Demek 1972). On the surface of a narrow gravel bar at the foot of the undercut there are blocks of silt, 0.5-1 m in diameter. They were mainly silty and rounded in shape due to desintegration. However in numerous places there were also fresh sharp-edged blocks with a rough surface (Fig. 15). Falling could still be observed few days after the passing of flood wave. Such a geomorphological situation points to bank destruction. After the removal of the sandy heaps the flood waters under pressure infiltrated the gravels underlying the loamy complex. This helped loosen their compactness and also washed them. A considerable thickness of the loamy complex does not favour the slumping of lumps along the slip-surface so as to pass through this width. Thus blocks broke off the bottom part of the complex. Therefore, after the passage of the flood wave the undercut bank in many places acquired the profile of an overhung wall. In certain places the break-off blocks form the above mentioned niches. The caverns of most niches were fresh with a rough surface indicating their rapid development after the passage of the flood wave. Some of the falling blocks were transported straight to the

Fig. 15. Brzeźnica — an undercutting in the 14 m Pleistocene terrace. In the lower part one can see a set of niches caused by the flood of 22 August 1972 (Photo K. Klimek, Sept. 1972)

bed due to the quick removal of the lower portion of gravels. Here even at the low water-stage they were always submerged. Channel soundings have shown that these blocks lie several metres from the vertical wall.

Observations carried out before the flood suggest that the disappearance of these niches is due to slow process of break-off. Changes in temperature and humidity smooth the niche walls and the blocks lying at their base. The blocks desintegrate gradually into smaller fragments and the niches become shallower. In many places these landforms are preserved by the sands falling down from the upper part of the undercut bank. During the successive raised water-stages part of the sandy material making up the heaps by falling is usually removed. Nevertheless, occasionally the niches were exposed and thus altered. It is only a subsequent flood that causes considerable bank recession.

Fig. 16. Brzeźnica — a niche formed by the break-off of blocks from the lower part of the loamy complex making up the 14 m Pleistocene terrace. At the foot of the undercutting are blocks of loam which fell during the high water-stage, and sharp-angled blocks that fell after the passage of a flood wave (Photo K. Klimek, Sept. 1972)

If one compares the maps for the years 1780–1878 and the results of the 1972 investigations one can determine the average rate of bank retreat (Fig. 13). From 1780 to the present day the axis of the Wisłoka bed has moved 300–450 m to the south. The Pleistocene terrace has been eroded and its north-most extent is now 50–90 m south of its position in 1780. The mean lateral migration of the Wisłoka channel to the south of 3–3.5 m a year means that even by 1878 its axis passed along the line of the ancient scarp of the Pleistocene terrace. At this time active undercutting was already going on. In the years 1878–1972 a further migration of the Wisłoka channel axis to the south took place together with an average bank retreat of 50 m. Hence, it can be assumed that the mean rate of retreat of the undercut bank has recently been about 0.5 m a year. Up to 2800 m^3 of mineral material is being supplied to the Wisłoka channel each year from an undercutting 400 m long and 14 m high. This is 700 m^3 each year from a 100 m sector of bank. In the last twenty years the rate of retreat of this undercutting has possibly increased. Vertical erosion has further deepend the channel by 1.8–1.9 m and this has exposed the lower part of the gravelly series, which in 1957 was still not visible at the low water level.

RESULTS

The Wisłoka channel in the Carpathian Foothills and its immediate foreland is clearly being deepened. This trend has been increasing over the last 20 years, due to a great extent by the direct or indirect interference of man. The increase in the relative height of the Wisloka's banks today plus the large variations of the water-level in the bed are the direct cause of the intense bank erosion. This process of bank erosion is also encouraged by agricultural utilization of the valley-floor.

The mode of retreat of the Wisłoka bank depends on its geological composition and height. During the high water-stage and also immediately after the subsidence of the flood wave there is locally a differentiated process of slumping or falling-off of the clayey-silty part of the bank. This confirms the reported observations and conclusions by L. B. Leopold and J. P. Miller (1956), A. Sundborg and J. Norrman (1963), C. R. Twidale (1964) and J. M. McCloy (1970) on the very important role of slumping and falling-off in the process of the erosion of alluvial banks. At the low water-stage tiny particles fall from the over-dried bank undercuttings for a long time after the processes of slumping and falling off. The falling material builds up heaps at the foot of the eroded banks which causes a gradual change in the bank profile.

The rate of bank erosion depends mainly on the height of the banks and the frequency of high water. Low banks are eroded much more quickly than high banks at the same frequency of water-level fluctuation. More mineral material is supplied to the Wisłoka from a 100 m undercut stretch of low bank than from a 100 m stretch of high bank. Thus the rate of bank retreat (R) and the volume of mineral material supplied from this undercutting to the river channel is reversely proportional to the height of bank (H).

CONCLUSIONS

The intense erosion of the Wisłoka banks in recent years has resulted from a disturbance of the equilibrium profile due to the activity of man. If this deepening of the Wisłoka channel continues the relative height of banks will further increase. Consequently, the rate of bank recession and at the same time the amount of material supplied to the channel from contemporary undercutting will decrease. However, a further deepening of the channel will lead to undercutting of the banks now held fast by riverain vegetation. Their rapid retreat may supply the bed with so much material that locally the Wisłoka's transporting capacity will be exceeded. Consequently, the river will tend to develop a new profile of dynamic equilibrium described by W. M. Davis (1902) and by J. H. Mackin (1948), i.e., the equilibrium between bed load and discharge.

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REGIONALIZATION METHODS: A SET-THEORETICAL EVALUATION

LESZEK PERNAROWSKI

INTRODUCTORY REMARKS

Recent years have witnessed a growing interest in the problems of regional geography, especially in the methods employed in regionalization and classification of geographic space. Several methods of regionalization called qualitative (Grano 1953; Isachenko 1965; Mikhaylov 1967; Milkov 1967; Preobrazhenskii 1966) or mathematical (Pernarowski 1968; Romer 1949) have been proposed. An analysis and evaluation of these methods seem to be indispensable.

As qualitative methods are known to employ mainly qualitative notions it is necessary to interpret them mathematically in terms of those mathematical disciplines which employ qualities too. The theory of sets is such a discipline. In this paper it is used for developing a method of dividing territories into definite areas and subsequently for comparing it to the previous qualitative and mathematical methods thus providing a final evaluation of them.

The meanings of the symbols used in this paper are the following:

$\in$ = "is an element of" $\quad$ $\bigcup$ = addition of subsets

$\supset$ = inclusion $\quad$ $\bigcap$ = multiplication of subsets.

$\setminus$ = subtraction of subsets

Capital letters stand for sets and subsets, lower-case letters denote elements of these subsets and sets, φ and λ are the geographic coordinates.

A SET-THEORETICAL METHOD OF TERRITORIAL DIVISION

The epigeosphere can be treated as a set of geographic phenomena occurring in the atmosphere A, anthroposphere C, zoosphere Z, phytosphere F, hydrosphere H, on the topographical surface P_t, in the pedosphere P and in the lithosphere L. Thus the epigeosphere E can be written as the sum of subsets of phenomena in these spheres:

$$E = A \cup C \cup Z \cup F \cup H \cup P_t \cup P \cup L. \tag{1}$$

None of these subsets has any element such that would also be an element of another subset:

$$A \cap C \cap Z \cap F \cap H \cap P_t \cap P \cap L = 0 \tag{2}$$

which means that all these subsets are independent sets of elements.

Such sets of the constituent spheres of the epigeosphere can in turn be treated as sums of all territorial subsets:

$$\begin{gathered} A = \bigcup^{n} A_n, C = \bigcup^{n} C_n, Z = \bigcup^{n} Z_n, F = \bigcup^{n} F_n, \\ H = \bigcup^{n} H_n, P_t = \bigcup^{n} P_{t_n}, P = \bigcup^{n} P_n, L = \bigcup^{n} L_n. \end{gathered} \tag{3}$$

All subsets A_n, C_n, Z_n, F_n, H_n, P_{t_n}, P_n, L_n fulfill equation 2. These subsets can be identified in virtue of two facts: first, because the geographic environment is spatially differentiated, and moreover because definite geographic phenomena occur simultaneously with one another in the individual spheres of the epigeosphere. These phenomena, which include definite geographic objects too, are elements of sets and subsets in our set-theoretical analysis.

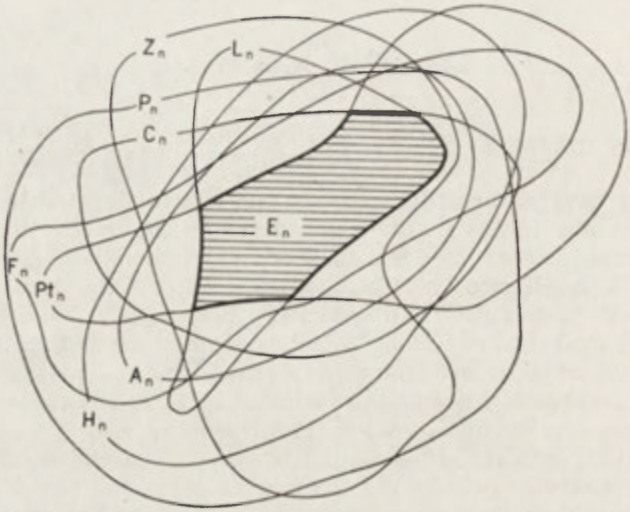

Fig. 1

Figure 1 shows the territorial extent of each of the subsets A_n, C_n, Z_n, F_n, H_n, P_{t_n}, P_n, L_n: their respective contents are defined by the elements they include. All subsets occur in the hatched area. The contents of this area, which is equivalent to the contents of this fragment of the epigeosphere E_n, a total of the contents of all subsets:

$$E_n = A_n \cup C_n \cup Z_n \cup F_n \cup H_n \cup P_{t_n} \cup P_n \cup L_n. \tag{4}$$

However, as each of these subsets has a limited territorial extent only, to each corresponds a separate subset of points of definite geographic situation. The sets of points of properties of the given subsets are denoted as $A_n(\varphi, \lambda)$, $C_n(\varphi, \gamma)$, $Z_n(\varphi, \lambda)$, etc. Figure 1 shows that the area $E_n(\varphi, \gamma)$ is always smaller than or equal to the area of the subset of the smallest extent and moreover it is equal to the product of the territories of all subsets:

$$E_n(\varphi, \lambda) = A_n(\varphi, \lambda) \cap C_n(\varphi, \lambda) \cap Z_n(\varphi, \lambda) \cap F_n(\varphi, \lambda) \cap H_n(\varphi, \lambda) \cap \\ \cap P_{t_n}(\varphi, \lambda) \cap P_n(\varphi, \lambda) \cap L_n(\varphi, \lambda) \tag{5}$$

The delimited area $E_n(\varphi, \lambda)$ is a territorial unit (or units) which can be either of regional or of typological character. Hence it follows that the contents of the identified territorial units is described by the sum of elements of the subsets pertaining to each of the spheres of the epigeosphere (equation 4) whereas the situation in space of those units is determined by multiplying their specific subsets of geographic coordinates (equation 5). The extent of each such unit can coincide — in its different fragments — with the extent of any of the subsets of the set E_n.

Let us identify a definite number of subsets of elements of each sphere of the epigeosphere in any arbitrary area, $A_1, A_2, A_3, \ldots, A_n$; $C_1, C_2, C_3, \ldots, C_n$; $Z_1, Z_2, Z_3, \ldots, Z_n$; and so on. Then equation 2 still holds between the subsets of the spheres but now the subsets can have some elements in common within one sphere, that is to say, an element $x_A, x_C, x_Z, \ldots$, or a subset $X_A, X_C, X_Z, \ldots$, such that may also be an element or subset of the other subsets of the given sphere of the epigeosphere can be identified:

$$\begin{aligned} X_A &= A_1 \cap A_2 \cap \ldots \cap A_n & X_H &= H_1 \cap H_2 \cap \ldots \cap H_n \\ X_C &= C_1 \cap C_2 \cap \ldots \cap C_n & X_{P_t} &= P_{t_1} \cap P_{t_2} \cap \ldots \cap P_{t_n} \\ X_Z &= Z_1 \cap Z_2 \cap \ldots \cap Z_n & X_P &= P_1 \cap P_2 \cap \ldots \cap P_n \\ X &= F_1 \cap F_2 \cap \ldots \cap F_n & X_L &= L_1 \cap L_2 \cap \ldots \cap L_n \end{aligned} \tag{6}$$

Equations 6 suggest that to identify areas with internally differentiated (nonhomogeneous) contents it suffices to create subsets such that do not include the elements which occur permanently and which constitute subsets X_A, X_C, X_Z, X_F, X_H, X_{P_t}, X_P, X_L, that is:

$$\begin{aligned} A'_n &= A_n \setminus X_A & H'_n &= H_n \setminus X_H \\ C'_n &= C_n \setminus X_C & P'_{t_n} &= P_{t_n} \setminus X_P \\ Z'_n &= Z_n \setminus X_Z & P'_n &= P_n \setminus X_P \\ F'_n &= F_n \setminus X_F & L'_n &= L_n \setminus X_L \end{aligned} \tag{7}$$

Subsets A'_n, C'_n, Z'_n, ..., are sets of points in space identical with subsets A_n, C_n, Z_n, ..., that is:

$$\begin{aligned} A_n(\varphi, \lambda) &= A'_n(\varphi, \lambda) & H_n(\varphi, \lambda) &= H'_n(\varphi, \lambda) \\ C_n(\varphi, \lambda) &= C'_n(\varphi, \lambda) & P_{t_n}(\varphi, \lambda) &= P'_{t_n}(\varphi, \lambda) \\ Z_n(\varphi, \lambda) &= Z'_n(\varphi, \lambda) & P_n(\varphi, \lambda) &= P'_n(\varphi, \lambda) \\ F_n(\varphi, \lambda) &= F'_n(\varphi, \lambda) & L_n(\varphi, \lambda) &= L'_n(\varphi, \lambda) \end{aligned} \tag{8}$$

The areas of these subsets can overlap neither in their whole nor in part in any of the spheres of the epigeosphere:

$$\begin{aligned} A'_1(\varphi, \lambda) \cap A'_2(\varphi, \lambda) \cap \ldots \cap A'_n(\varphi, \lambda) &= 0 & H'_1(\varphi, \lambda) \cap H'_2(\varphi, \lambda) \cap \ldots \cap H'_n(\varphi, \lambda) &= 0 \\ C'_1(\varphi, \lambda) \cap C'_2(\varphi, \lambda) \cap \ldots \cap C'_n(\varphi, \lambda) &= 0 & P'_{t_1}(\varphi, \lambda) \cap P'_{t_2}(\varphi, \lambda) \cap \ldots \cap P'_{t_n}(\varphi, \lambda) &= 0 \\ Z'_1(\varphi, \lambda) \cap Z'_2(\varphi, \lambda) \cap \ldots \cap Z'_n(\varphi, \lambda) &= 0 & P'_1(\varphi, \lambda) \cap P'_2(\varphi, \lambda) \cap \ldots \cap P'_n(\varphi, \lambda) &= 0 \\ F'_1(\varphi, \lambda) \cap F'_2(\varphi, \lambda) \cap \ldots \cap F'_n(\varphi, \lambda) &= 0 & L'_1(\varphi, \lambda) \cap L'_2(\varphi, \lambda) \cap \ldots \cap L'_n(\varphi, \lambda) &= 0 \end{aligned} \tag{9}$$

By virtue of equations 8 and 9 and using formula 5, the territorial units differing in contents from the neighbouring units can be described thus:

$$\begin{aligned} E_n(\varphi, \lambda) = {} & A_n(\varphi, \lambda) \cap C_n(\varphi, \lambda) \cap Z_n(\varphi, \lambda) \cap F_n(\varphi, \lambda) \cap H_n(\varphi, \lambda) \cap \\ & \cap P_{t_n}(\varphi, \lambda) \cap P_n(\varphi, \lambda) \cap L_n(\varphi, \lambda) = E'_n(\varphi, \lambda) = A'_n(\varphi, \lambda) \cap C'_n \varphi, \lambda) \cap \\ & \cap Z'_n(\varphi, \lambda) \cap F'_n(\varphi, \lambda) \cap H'_n(\varphi, \lambda) \cap P'_{t_n} \varphi, \lambda) \cap P'_n(\varphi, \lambda) \cap L'_n(\varphi, \lambda). \end{aligned} \tag{10}$$

This equation shows that the territorial unit $E_n(\varphi, \lambda)$ differs from $E'_n(\varphi, \lambda)$ only by its contents and not by its territorial extent, because

$$E_n = A_n \cup C_n \cup Z_n \cup F_n \cup H_n \cup P_{t_n} \cup P_n \cup L_n \quad (11)$$

and it is described not only by the elements differentiating the individual subsets of the epigeosphere, A'_n, C'_n, Z'_n, ..., but also by those common to them, X_A, X_C, X_Z, ..., (see equation 7); whereas in the case of E'_n

$$E'_n = A'_n \cup C'_n \cup Z'_n \cup F'_n \cup H'_n \cup P'_{t_n} \cup P'_n \cup L'_n \quad (12)$$

and it is described only by the smallest number of elements which differentiate the individual territorial units from each other, that is by A'_n, C'_n, Z'_n, ...

In virtue of equations 6, the whole territory submitted to the division can be described by the sum of elements of the identified subsets X_A, X_C, X_Z, ..., that is:

$$X = X_A \cup X_C \cup X_Z \cup X_F \cup X_H \cup X_{P_t} \cup X_P \cup X_L \quad (13)$$

whereas the set of locations of the points with such characteristics can be written:

$$X(\varphi, \lambda) = \bigcup_1^n E_n(\varphi, \lambda) = \bigcup_1^n E'_n(\varphi, \lambda). \quad (14)$$

Furthermore, in virtue of equations 11, 12 and 13 it can be said that the following relation holds between E_n, E'_n and X:

$$E_n = E'_n \cup X \quad (15)$$

or that

$$E_n \supset E'_n \quad \text{and} \quad E_n \supset X. \quad (16)$$

Equation 15 says that each divided area is composed of an invariable subset X and of a number of variable subsets E'_n. The description of each subset E_n is a sum of descriptions of these two subsets.

Subsets X may also be used as the foundation for dividing an area, for within its individual parts each comprising several basic territorial units E_n we can distinguish subsets, say X_1, X_2, X_3, moreover describe their contents:

$$X_1 = E_1 \cap E_2 \cap E_3, \quad X_2 = E_4 \cap E_5 \cap E_6, \quad X_3 = E_7 \cap E_8 \cap E_9 \cap E_{10} \quad (17)$$

and delimit their areas:

$$X_1(\varphi, \lambda) = \bigcup_1^3 E_n, \quad X_2(\varphi, \lambda) = \bigcup_4^6 E_n(\varphi, \lambda), \quad X_3(\varphi, \lambda) = \bigcup_7^{10} E_n(\varphi, \lambda). \quad (18)$$

These areas can in turn be integrated into one whole with the following contents:

$$X = X_1 \cap X_2 \cap X_3 \quad (19)$$

and with the following area:

$$X(\varphi, \lambda) = \bigcup_1^3 X_n(\varphi, \lambda). \quad (20)$$

Thus, from what has been said it follows that the subsets E_n (or E'_n) are the foundation for dividing an area into the basic territorial units, whereas the subsets X_n are the foundation for integrating the basic territorial units into bigger wholes.

The delimited territorial units are also regional units only if the sets of points of their location $E_n(\varphi,\lambda)$ or $X_n(\varphi,\lambda)$ constitute a unique, closed and indivisible area and thus the contents of this unit, E_n or X_n, does not occur in any other delimited area of the world. If this is not the case, that is when their contents can be found in many other areas in the world, the delimited territorial units are typological units.

* *
*

The above method of making territorial divisions in terms of the set theory can be fully adequate only when we take into account all elements describing the constituent spheres of the epigeosphere within the territory to be divided (the criterion of identity is meant here). If we neglect to identify all such elements or else if we select them without strictly observing the rules of the above method the procedure becomes arbitrary and the results obtained cannot but be arbitrary too. An unequivocal result can be obtained by delimiting the basic territorial units E_n (or E'_n). The delimitation of the higher-order units $X_n(\varphi, \lambda)$ is simple and methodologically adequate but it is not always unequivocal. Let us consider an example.

Suppose we have an area $X_1(\varphi, \lambda)$ with contents $X_1 = \bigcup_{1}^{n-1} E_n = \{a, b, c\}$, and another area $X_2(\varphi, \lambda)$ with contens $X_2 = \bigcup_{1}^{n+m} E_n = \{c, d, e\}$. Suppose moreover that in between these two areas there is the basic territorial unit $E_n(\varphi, \lambda)$ which has in its contents element c, that is $c \in E_n$ (see Fig. 2). This basic territorial unit cannot simultaneously be an independent unit of higher order, it has to be incorporated either into area $X_1(\varphi, \lambda)$ or $X_2(\varphi, \lambda)$. This unit is clearly of intermediary character and hence it would be highly arbitrary to incorporate it into either area. This example shows that in the set-theoretical method of dividing territories has a slight trace of arbitrariness, especially when it is necessary to join the basic units into bigger wholes. Hence it follows that this method cannot be recognized as fully objective, either.

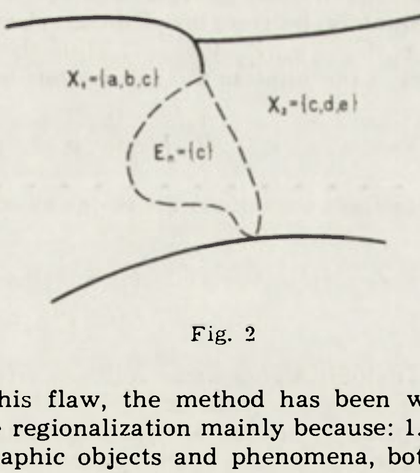

Fig. 2

Notwithstanding this flaw, the method has been widely employed in the methods of qualitative regionalization mainly because: 1. as elements of sets can be treated both geographic objects and phenomena, both their qualitative and quantifiable features, 2. areas characterized by definite contents can be easily delimited by superimposing the extents of the individual elements on one map, 3. the contents of the delimited areas are equivalent to the sum of the elements occurring within each of them.

THE QUALITATIVE METHODS VS. THE SET-THEORETICAL METHOD OF DIVIDING TERRITORIES: A CRITICAL COMPARISON

The simplest method is that of the leading factor (Isachenko 1965; Mikhaylov 1967; Milkov 1967). It consists in delimiting areas according to one leading element a which fulfills the equation:

$$X = \bigcap_{1}^{n} E_n = \{a\} \tag{21}$$

and is identical with the leading factor. The area is in this case delimited by the extent of the leading factor a, that is:

$$X(\varphi, \lambda) = \bigcap_{1}^{n} E_n(\varphi, \lambda) = a(\varphi, \lambda). \tag{22}$$

Neither the contents nor the extents of the areas of subsets E_n need be known in this case. A territory can be divided into areas if two conditions are fulfilled: 1. the areas of occurrence of the characteristic elements a, b, c, ..., must not overlap, and moreover 2. the sum of those areas must be equal to the area P of the territory to be divided. This entails that the following two conditions be fulfilled simultaneously:

$$\begin{aligned} a(\varphi, \lambda) \cap b(\varphi, \lambda) \cap c(\varphi, \lambda) \cap \ldots \cap z(\varphi, \lambda) &= 0 \\ a(\varphi, \lambda) \cup b(\varphi, \lambda) \cup c(\varphi, \lambda) \cup \ldots \cup z(\varphi, \lambda) &= P(\varphi, \lambda) \end{aligned} \tag{23}$$

Equations 23 are easily fulfilled when elements a, b, c, ..., pertain to one sphere of the epigeosphere only; otherwise they do not hold easily.

J. G. Granö (1953) has used the method of superimposing boundaries of the extents of different subsets to regionalize Finland. He delimited the regional subsets of the individual spheres of the epigeosphere and next, simplifying the method rather inadequately, he recognized these subsets as elements of new sets, namely that $A_n = a_n$, $C_n = c_n$, $Z_n = z_n$, ... Thus the delimited basic units E_n had their contents not in the total or the subsets but in a subset of elements and therefore:

$$E_n = \{a_n, c_n, z_n, f_n, h_n, h_n, p_{t_n}, p_n, l_n\} \tag{24}$$

whereas the area of this subset (equations 27) is described by the following set of points:

$$E_n(\varphi, \lambda) = a_n(\varphi, \lambda) \cap c_n(\varphi, \lambda) \cap z_n(\varphi, \lambda) \cap f_n(\varphi, \lambda) \cap h_n(\varphi, \lambda) p_{t_n}(\varphi, \lambda) \cap \\ \cap p_n(\varphi, \lambda) \cap l_n(\varphi, \lambda) \tag{25}$$

It becomes impossible to delimit higher-order units in virtue of equations 6 and 13 though formally we could use equations 16–19. This circumstance makes the method strongly dependent on the adequate delimitation of the regional units of the individual spheres of the epigeosphere. Because there are many regional divisions of the individual spheres of the epigeosphere they may be used in the process of regionalization in different combinations in effect of which many nonuniform regional divisions of one area are obtained.

The same method has been used by P. Supino (1959) to delimit the landscape-typological regions of Italy. He delimited the landscape units of the individual selected spheres of the epigeosphere, recognized them not as subsets of elements but as elements themselves and subsequently used these latter to delimit and describe the landscape units.

The superimposing of the territorial subsets of the lithosphere, the pedosphere, the hydrosphere, the phytosphere and, occasionally, the anthroposphere, which gives in effect areas of repeated occurrence of sets, i.e. "landscape-typological" units, within definite regional units has been called the method of filling the regional units with typological units (Milkov 1967). This method can be helpful not only in describing and specifying the regional units from the point of view of landscape but also in regionalizing.

This is the essence of the method of delimiting regional landscape complexes (Preobrazhenskii 1966). According to Preobrazhenskii, the regional complex is a spatial set of overlapping territorial units of the same character.

Suppose that within the territory to be divided we have delimited 7 landscape types: $e_1, e_2, ..., e_7$, and next we joined them on a map into three regional complexes with the following contents:

$$X_1 = \{e_1, e_3, e_7\} \quad X_2 = \{e_2, e_3, e_5, e_7\} \quad X_3 = \{e_4, e_5, e_6\}. \tag{26}$$

Since each type of e may occur more than once in several regional complexes, the area of these units can be written thus:

$$\begin{aligned} X_1(\varphi, \lambda) &= \left(\bigcup e_{11}(\varphi, \lambda)\right) \cup \left(\bigcup e_{31}(\varphi, \lambda)\right) \cup \left(\bigcup e_{71}(\varphi, \lambda)\right) \\ X_2(\varphi, \lambda) &= \left(\bigcup e_{22}(\varphi, \lambda)\right) \cup \left(\bigcup e_{32}(\varphi, \lambda)\right) \cup \left(\bigcup e_{52}(\varphi, \lambda)\right) \cup \left(\bigcup e_{72}(\varphi, \lambda)\right) \\ X_3(\varphi, \lambda) &= \left(\bigcup e_{43}(\varphi, \lambda)\right) \cup \left(\bigcup e_{53}(\varphi, \lambda)\right) \cup \left(\bigcup e_{63}(\varphi, \lambda)\right) \end{aligned} \tag{27}$$

The further integration of the areas and their contents can be effected by virtue of equations 17–20.

The circumstance that the typological units occur within the regional complexes with uneven frequency has been taken into account in two studies: in Milkov's method of repeated occurrence of specific landscape complexes (1967) and in the attempt to describe regional units by means of indexes characterizing the features of landscape elements made by Preobrazhenskii, Fadeev and Mukhina (1961). Neither of these studies takes recourse to the set theory but they provide a statistical vindication of the territorial division made.

Isachenko's method of joint analysis of regional components (1965) consists in delimiting territorial complexes: lithological-geomorphological, hydrographical-climatic and soil-geobotanical complexes which can obtain both a typological and a regional meaning. These complexes are very strongly interrelated with each other but they characterize only six of the eight spheres of the epigeosphere. Let:

$$L_n \cup P_{t_n} = a_n, \quad H_n \cup A_n = b_n, \quad P_n \cup F_n = c_n \tag{28}$$

where a_n, b_n, c_n are subsets of elements of the considered spheres of the epigeosphere and are treated as elements themselves. As in the method of Granö, these elements superimpose upon each other and hence the basic territorial units E_n are subsets

$$E_n = \{a_n, b_n, c_n\} \tag{29}$$

of areas

$$E_n(\varphi, \lambda) = a_n(\varphi, \lambda) \cap b_n(\varphi, \lambda) \cap c_n(\varphi, \lambda). \quad (30)$$

The units of the next higher order can be found in virtue of equations 17–20.

A GENERAL EVALUATION OF THE QUALITATIVE METHODS

None of the qualitative methods has been commonly accepted or employed in research practice (Fochler-Hauke 1962). The flaws of each of them have made some geographers encourage the joint use of all of them (Isachenko 1965; Mikhaylov 1967). In each case of joining different methods together we enrich the number of elements which are the foundation for regionalization thus bringing those methods closer to the principles of the method of dividing territories in terms of the set theory.

A comparison of the qualitative methods of regionalization with the set-theoretical method of dividing territories shows that the principles of the former methods are actually based on the set theory. Thus the qualitative methods appear to be essentially mathematical methods based on the set theory too.

The application of different qualitative methods for the division of one territory fails to yield identical results for none of them fulfills the condition of identity. Though each of them takes for its starting-point subsets of elements of the individual spheres of the epigeosphere the subsets are recognized as indivisible elements rather than as sets at one or another level of integration.

It has already been mentioned that even the set-theoretical method of dividing territories itself is not entirely flawless, especially when territorial units have to be joint into bigger or higher-order units which in some cases can only be arbitrary.

Thus every typological or regional division based on any of the above methods is, to some extent, arbitrary, which incidentally is confirmed by practice.

MATHEMATICAL METHODS AS DERIVATIVE METHODS OF THE SET-THEORETICAL METHOD OF TERRITORIAL DIVISION

Provided the set-theoretical method of territorial division is correct we can, in order to bring out the natural boundaries between different territories, differentiate equation 1 according to the variable distance *s*:

$$\left|\frac{d\mathbf{E}}{ds}\right| = \left|\frac{dA}{ds}\right| \cup \left|\frac{dC}{ds}\right| \cup \left|\frac{dZ}{ds}\right| \cup \left|\frac{dF}{ds}\right| \cup \left|\frac{dH}{ds}\right| \cup \left|\frac{dP_t}{ds}\right| \cup \left|\frac{dP}{ds}\right| \cup \left|\frac{dL}{ds}\right| \quad (31)$$

This in turn means that the gradient of the epigeosphere $\left|\frac{dE}{ds}\right|$ is in each of its points a total of the gradients of the phenomena occurring in its individual spheres. If we determine the gradient of epigeosphere in every point of the Earth we can subsequently represent the intensities of these gradients by isogradients. By interpreting the cartographic picture of the isogradients we obtain a definite division of the epigeosphere or of one of its constitutent spheres. This method has been employed by Romer (1949) in his climatic regionalization of Poland.

Assuming that the variation of geographic environment is experienced not as a sum of changes occurring in the epigeosphere but as a sufficiently pronounced change in the elements of one sphere the present author recognized the "megigradient", i.e. the gradient of the highest value in some vicinity, as the boundary line seperating two territorial units of different contents (Pernarowski 1968). Accordingly, equation 31 assumed the following form:

$$\left|\frac{dE}{ds}\right|_{max} = \left|\frac{dA}{ds}\right|_{max} \cup \left|\frac{dC}{ds}\right|_{max} \cup \left|\frac{dZ}{ds}\right|_{max} \cup \left|\frac{dF}{ds}\right|_{max} \cup \left|\frac{dH}{ds}\right|_{max} \cup \left|\frac{dP_t}{ds}\right|_{max} \cup \left|\frac{dP}{ds}\right|_{max} \cup \left|\frac{dL}{ds}\right|_{max} \quad (32)$$

The cartographic picture of megigradients is a network of lines of equal value. The interpretation of the course and the value of the lines which represent the differentiation of the geographic environment has furnished the foundation for performing the physico-geographic regionalization of Poland (Pernarowski 1968).

As it follows from formulas (31) and (32), these methods do not allow for including qualitative elements which must be expressed by one most characteristic quantifiable feature.

These methods, which are called mathematical, as well as the method of dividing territories in terms of the set theory fulfill the condition of identity for they employ elements of sets characterizing the individual spheres of the epigeosphere. Thus the territorial divisions obtained by these methods are unarbitrary and unequivocal.

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AN ECONOMIC REGIONALIZATION OF AUSTRALIA USING THE POINT COLLECTION METHOD

STANISŁAW OTOK

Our economic regionalization of Australia was based on six criteria: 1. density of population, 2. percent of urban population, 3. number employed in industry and mining (extraction) per 1000 inhabitants, 4. number employed in service industries per 1000 inhabitants, 5. the value of the agricultural production per km^2 (of the total area of the territorial unit), in 1965 prices, 6. length of railways per 100 km^2. Various combinations of these criteria characterize the Australian economy in the lower reference units such as statistical divisions. These criteria or indices were selected from a group of 10 by eliminating the least typological. Apart from there obvious merits these selected criteria had to fulfill certain stastistical requirements; they had to show a low level of correlation and a large areal differentiation. To check that these requirements were met Pearson product-moment correlation coefficient and the coefficient of variance were calculated.

To ensure that the calculated coefficient r is a valid result, that any two criteria are significantly correlated and that neither error nor chance causes the value r to be sufficiently different from zero, further investigations were carried out. For this purpose we used that statistical hypothesis concerning the correlation which states that $H_o : \varrho = 0$. [1] (The Students' t distribution statistic can also be used for this purpose [2]). The selected criteria were subjected to further calculations — their normalization and their functional ordering.

From the many taxonomical methods used in regional studies we selected that of functional ordering. Through this method we can further stastistically group units with similar values according to the "index of the size of individuals" bearing in mind the given order of the criteria. [3] If we have to order those units defined by a statistical series of criteria then these criteria are called a group (of criteria), and because of this group the linear ordering will depend on the finding of the sum of the criteria, i.e., a function which depends on all the criteria of the group. This sum will be called the ordering function.

Since in regionalization one often has to deal with differing criteria such as density of population, value of agricultural production, and the level of urbanization, and therefore with values whose sums cannot be found, one's crite-

[1] J. Perkal, *Matematyka dla przyrodników i rolników* (Mathematics for natural scientists and agronomists), vol. 3, Warszawa 1967.

[2] S. Gregory, *Metody statystyki w geografii* (Statistical methods in geography), Warszawa 1970.

[3] For a description of the method see J. Perkal, op. cit., vol. 2.

ria must first of all be normalized before one can find their sum. When the criteria have been normalized one can then find the ordering function according to the following:

$$F = 1/n(\xi_1 + \xi_2 + \xi_3 + \dots \xi_n)$$

The values obtained are called the indices or coefficients of location depending on the given grouping of the criteria. The indices of location are used for grouping territorial units by the method of point collection. J. Perkal's work formed the background to this method. All six criteria on which this study is based were taken as equal in importance. Thus the basic division of the points (territorial units) should be done according to the vector value, i.e., the value of the ordering function. To geometrically illustrate the vector value of the points we used circles whose radii depend on the values as follows: 1. the lowest value has a radius of O; thus the point for this value will be the centre of all the circles; 2. other values of the points have radii of corresponding size. In this way we get concentric circles illustrating the distribution of the vector

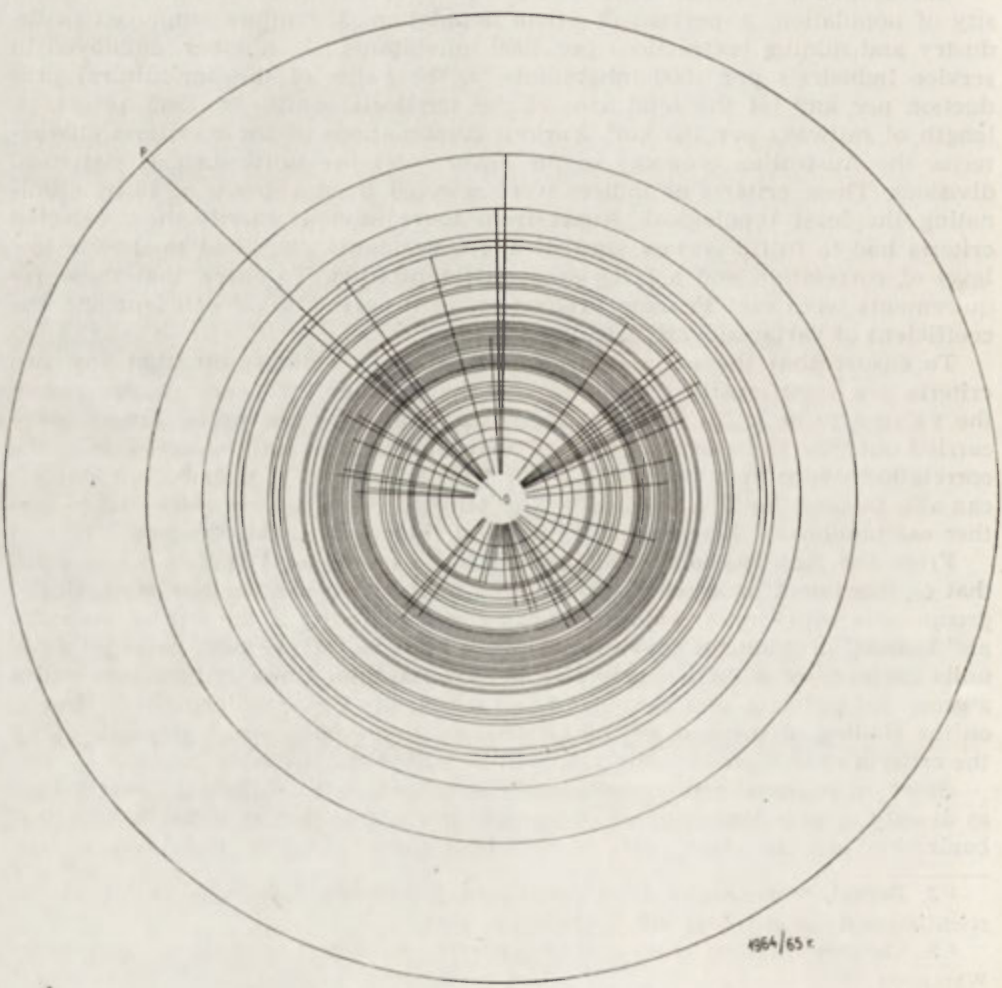

Fig. 1

value of all the points, which allows us to single out several groups separated by radial distances (Fig. 1). To show the values of each criterion of the points we used a similar method to Perkal's.[4] Instead of calculating the location of the points in six-dimensional Cartesian space as suggested by Perkal we geometrically marked out the directions of the vectors $\overrightarrow{OP}$ in such an arrangement that it could be treated as a projection onto a suitably chosen plane of an arrangement of co-ordinate axes of six-dimensional space. Our previously mapped concentric circles were drawn on this plane. On the plane one of the six axes (because there are six criteria) is drawn every 30°. Since we have both "positive" and "negative" values for the criteria we take as positive revolutions of the axis those revolutions of the rays lying in the upper half of the plane, and

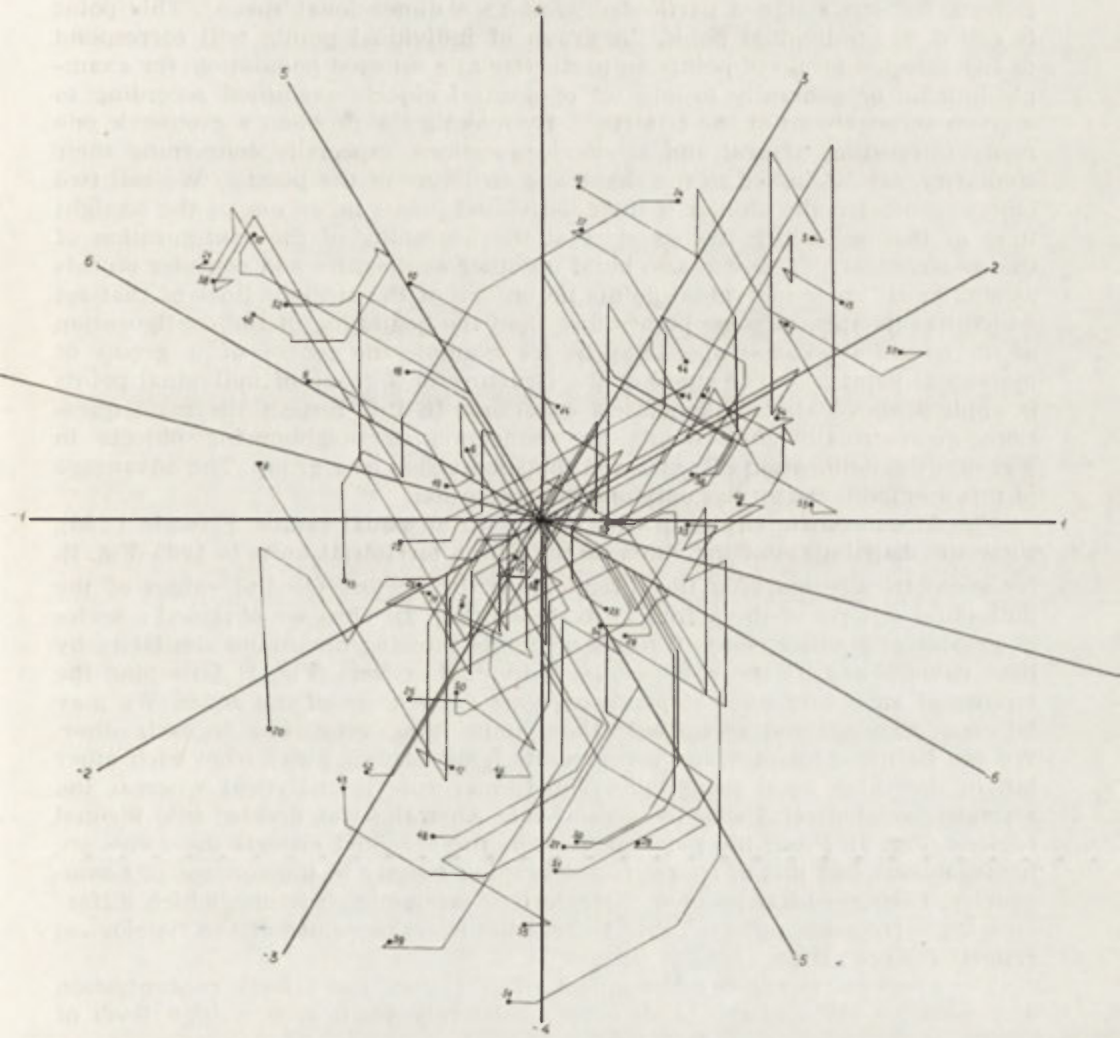

Fig. 2

[4] J. Perkal, O zbiorach punktów materialnych i abstrakcyjnych w badaniach przyrodniczych (The point collection of materials and abstracts in the natural sciences), *Spraw. Wr. TN*, 1957.

as negative those lying in the lower half (Fig. 2). After separately sketching the vectors $\overline{OP}$, their directions are transferred to the circle diagram and on the circle corresponding to point P the location of this point is marked. One can take the vectors in any order since their arrangement is commutative and inter-linked. However one must keep the correct direction and revolution. Since we are concerned only with the direction of a vector $\overline{OP}$, because its length is already known to us and we can read it off from the circle diagram anyway, any scale can be used for the criteria values as long as this is the same for each point. In this way we may assign a particular point in six-dimensional space to each unit belonging to the grouping of six features. In general we can say that to each object investigated, according to the arrangement of n criteria we can assign a particular point to n dimensional space [5]. This point is called the individual point. "A group of individual points will correspond to any selected group of points, in particular to a selected population, for example human, or generally to any set of natural objects examined according to a given arrangement of the criteria" [6]. By making the problem a geometric one many interesting natural and economic questions, especially concerning their similarity, can be linked to the shape and structure of the points. "We call two objects geometrically similar if their individual points lie on one of the straight lines of that set which has its apex at the beginning of the configuration of the co-ordinates" [7]. One can also build up other similarities and consider objects as similar if "their individual points lie on one of the straight lines of that set which has its apex at some point other than the beginning of the configuration of the co-ordinates; this apex may be for example the centre of a group of individual points..." [8] The study of the structure of a group of individual points is applied above all to taxonomical questions. In this respect the main questions, geometrically phrased are: the connection of neighbouring objects in a group; the delineation of types and the subdivision of a group. The advantage of this method is that it has only one interpretation.

The 57 concentric circles drawn, each with an equal radius, F (scale 1 : 50), show the distribution of the values from all the territorial units in 1965 (Fig. 1). By geometrically marking the directions of the vectors $\overline{OP}$ the values of the individual criteria of the points were shown (Fig. 2). Thus we obtained a series of greater or smaller concentrations of points showing maximum similarity by both value F and by the value of the individual criteria (Fig. 1). Grouping the territorial units into zones depends on what we require of the zones. We may be more rigorous and group only those units lying very close to each other. We can be more tolerant and accept units lying further away from each other but in the same zonal magnitude. The former rule is analytical whereas the second is synthetical. Using the second rule Australia was divided into 9 zonal regions (Fig. 3). From the point of view of the accepted criteria the zones are homogeneous, but this of course is not keeping strictly to the concept of homogeneity. Each zone has its own characteristic economic structure, which differentiates it from the others. Table 1 gives the average values of the typological criteria for each zone.

The great metropolises make up zone I. This zone has a large concentration of population (58% of the total) over a relatively small area, a high level of

[5] Ibid., p. 6.

[6] Ibid.

[7] Ibid.

[8] Ibid., p. 8.

urbanization and well developed services and industry. Zone II has the largest mining and metallurgical conurbation in Australia and is second by concentration of population. Zone III is an area of developed agriculture. It is the largest and most important compact area in Australia of highly commercial agricultural production. Zones IV and VI are also agricultural but because of

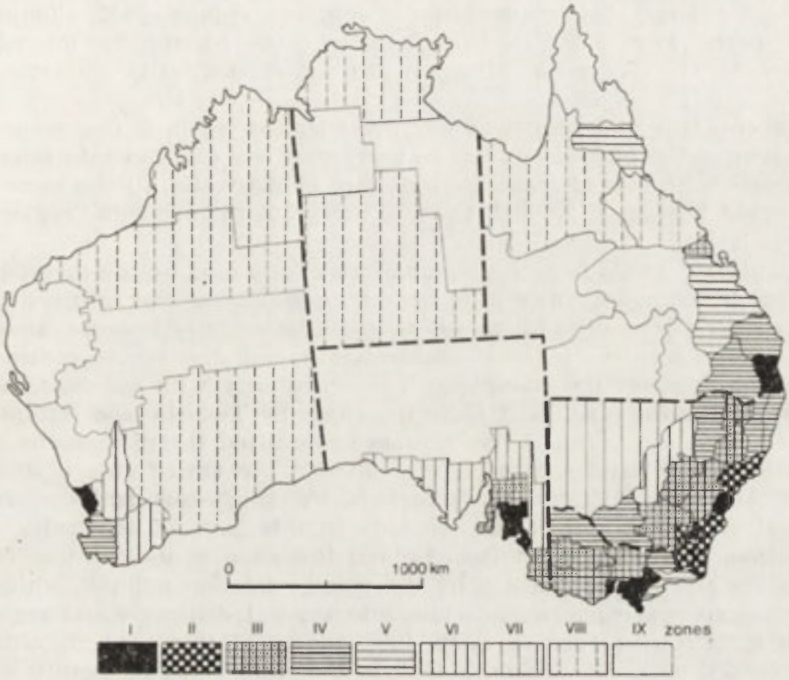

Fig. 3

TABLE 1. The average values of the typological criteria of the zonal regions 1964/1965

Zone	Density of popula-tion	% of urban popula-tion	Employment in srvice industries (per 1000 inhabitants)	Employment in industry (per 1000 inhabitants)	Value of agricultural production (per 100 km²) $ A	Length of railways per 100 km²
I	168	93	219	111	1045	4.1
II	8.5	78	145	109	701	1.6
III	3.5	59	142	57	2387	2.9
IV	2.4	55	137	50	1128	1.9
V	2.2	64	138	72	650	1.3
VI	0.9	47	116	50	793	1.3
VII	0.2	65	118	105	1712	0.3
VIII	0.2	65	181	121	73	0.2
IX	0.1	30	136	57	130	0.2
Australia (average)	11.8	58	150	73	285	1.7

their natural conditions their economic production is smaller. Zone V is agricultural and industrial, its agriculture largely monocultural and plantational. The basis of the economy of Zone VII is the exploitation of non-ferrous metal deposits and the rearing of high quality merino sheep. Mining and pasture is typical also of Zone VIII, but because of the less favourable natural conditions the economic results of cattle rearing and of a small number of sheep are very low. There is large scale exploitation of iron ore, copper, gold, aluminium and bauxite in this area. Zone IX has extensive cattle rearing in the north and sheep rearing in the south. Minerals are not economically important in this zone.

After checking the results of our investigation against the actual spatial distribution of the phenomena we may say that our division into zonal regions corresponds to the areal economic structure of Australia. In the same way the method used in this study enables us to carry out the economic regionalization of Australia.

The question arises how the regionalization obtained by the method of point collection differs from other attempts at regionalizing the continent by Australian authors. It is difficult to assess this satisfactorily because, among other reasons, there are few regional studies embracing the whole continent done in Australia. Most of the studies are concerned only with one State, and their main purpose is for planning [9]. Only the study by Tweedie and Robinson takes in the whole of Australia [10]. The authors generalized the phenomena they studied mainly from land use maps, and divided the entire area of the eastern coast of Australia into two zonal regions, the south-east and the north-east. The areal differentiation of the economy in this part of Australia is much greater than is suggested by Tweedie and Robinson in their work. These differences are shown very clearly by the point collection method, which divides the coastal area of eastern Australia into several distinct zonal regions. The work of R. H. Greenwood supports the validity of this aproach, although he was concerned only with Queensland. [11] In the other areas the results of regionalization are similar. The only differences are those in the boundaries of the zones in certain parts and this is caused by the different bases and units of reference used in these studies. One must underline that Tweedie and Robinson's regionalization is descriptive, whereas the point collection method gives results which are more accurate and can be numerically measured. Thus the accuracy and measurability of the point collection method of regionalization is an important contribution to a better understanding of the areal economic structure of Australia.

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[9] Examples of these include R. H. Arnot and E. J. Thomson, *Division of New South Wales into regions and districts for planning*, Sydney 1966.

[10] A. D. Tweedie and K. W. Robinson, *The regions of Australia*, Adelaide 1965.

[11] R. H. Greenwood, *Queensland's landscapes and production patterns*, Brisbane 1961.

THE ANTICIPATION OF URBAN EXPANSION *

CHRISTOPHER R. BRYANT

I. SOME IMPLICATIONS FOR AGRICULTURAL LAND USE PRACTICES AND LAND USE ZONING

1. INTRODUCTION

Urban expansion, part of the total process of urbanization, generates a complex of factors that may affect agricultural land use practices. These include increasing taxation of farmland in urbanizing areas, pollution, trespass, rural fragmentation, speculation and increasing land values, and an atmosphere of instability, as well as certain more positive influences such as market expansion. The impact of urban expansion on agricultural production, therefore, is partly related to the immediate loss of land consequent upon the physical expansion of the urban area and partly related to the operation of forces such as increasing land values which affect the profitability of agricultural investment, and hence agricultural productivity rather than removing large areas from agricultural production. [1] Some attempt has been made to treat the conversion of agricultural land to non-agricultural use in the framework of the traditional von Thünen model. [2] However, it is clear that urban expansion has a greater impact on agricultural production than the sole consideration of physical losses would suggest. Hence, Gertler and Hind-Smith [3] conclude that all the centres they studied showed a substantial area of "urban shadow" (either sterilized farmland or land under pressure to move out of agricultural production) such that the "unseen" influence of the city appears more important than the tangible evidence of land used for planning. But it is only recently that any attempt has been made to develop a conceptual framework for investigating certain of these other factors.

This paper considers one of these factors, that relates to the potential expansion of the urban area and hence the anticipation of the conversion of agricultural land to non-agricultural uses. That this may have an effect upon agricultural land use practices has been recognized by several authors. This factor

* Editor's note: The model introduced reflects conditions characteristic of western market economies.

[1] See for instance L. O. Gertler and J. Hind-Smith, The impact of urban growth on agricultural land: a pilot study, in *Resources for Tomorrow*; Suppl. Vol. (Ottawa, the Queen's Printer, 1962), pp. 155–180; and R. R. Krueger, Changing land-use patterns in the Niagara Fruit Belt, *Trans. Roy. Can. Inst.*, Part II, Oct. 1959, pp. 39–101.

[2] See, for instance, R. F. Muth, Economic change and rural-urban land use conversions, *Econometrica*, 29, 1961, pp. 1–23.

[3] Gertler and Hind-Smith, op. cit., p. 173.

may partly account for a deterioration of agricultural land around cities; hence, Wibberley writes,[4] "Knowing that the land is soon to be taken, the occupier may begin to farm 'to quit' ", so that the "unused residue of fertility is at a low point when the land is finally taken". Further, Clawson, considering the farmer, notes[5] that "If he has high fixed investment in land improvements such as an orchard, it will pay him to operate it as long as he can", i.e., at the edge of urban expansion. Recently, then, interest in this topic has been taken a step further, and Sinclair[6] has made an attempt to investigate the effects of this anticipation in a more formal way. Sinclair's model, despite certain criticisms, is a valuable contribution. Hence, this initial framework is reviewed, and an extension to it presented, which, it is suggested, can partly account for the development of idle land near expanding urban areas. Finally, the relevance of the consideration of this factor in relation to land use zoning in metropolitan areas is considered.

2. A REVIEW OF SINCLAIR'S MODEL

Sinclair argues[7] that the relative importance of location factors in agriculture has changed dramatically in certain areas during the twentieth century, particularly the decline in transport costs and the initiation of almost continuous urban expansion in some regions. Hence, as the urbanized area is approached, the degree of anticipation of urban expansion increases, and consequently the ratio of urban to rural land values decreases. As a result, capital and labour investment in agriculture decreases.[8] Hypothetical value curves are shown in Figure 1;[9] use (*a*) is more intensive than (*b*), giving a higher net

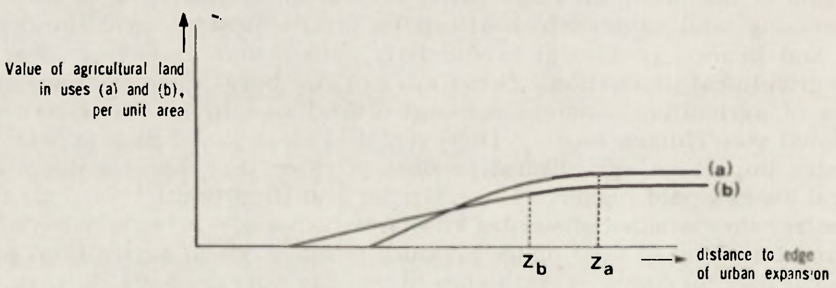

Fig. 1. Hypothetical value curves when only the anticipation of urban expansion is considered

[4] G. P. Wibberley, *Agriculture and Urban Growth: a study of the competition for rural land* (London: M. Joseph Ltd., 1960), p. 65.

[5] M. Clawson, Urban sprawl and speculation in suburban land, *Land Econ* 33, May 1962, p. 107.

[6] See R. Sinclair, Von Thünen and urban sprawl, *Ann. Ass. Amer. Geogr.* 57, 1967, pp. 72–87. Comments and criticism have been made by J. R. Peet, The present persistence of Von Thünen theory; R. J. Horvath, Von Thünen and urban sprawl; R. Sinclair, Comment in Reply, *Ann. Ass. Amer. Geogr.*, 57, 1967, Annals Commentary, pp. 810–815; and M. Chisholm, The relevance of Von Thünen, *Ann. Ass. Amer. Geogr.*, 59, 1969, Annals Commentary, p. 401.

[7] Sinclair, 1967, op. cit., p. 76–77.

[8] Ibid, p. 78.

[9] This formulation makes the usual simplifying assumptions with respect to homogeneous conditions as the classical case.

return per unit area under normal conditions; but under conditions of continuous urban expansion, in areas near the city the value of agricultural investment such as represented by use (*a*) declines rapidly relative to the more extensive use (*b*). A slightly different interpretation to that of Sinclair[10] is given to the points z_n where the value curves flatten out. Sinclair interprets this as the point where anticipation of urban land prices becomes zero; in the present context, to retain consistency with the extension presented below, it is interpreted as that point where the estimated time available for agricultural use is so long that "normal" conditions of amortization pertain for that particular

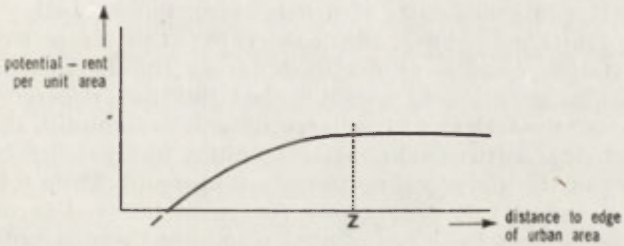

Fig. 2a. Hypothetical potential-rent curve for an agricultural use when transport costs are excluded and a linear TLFA schedule is used

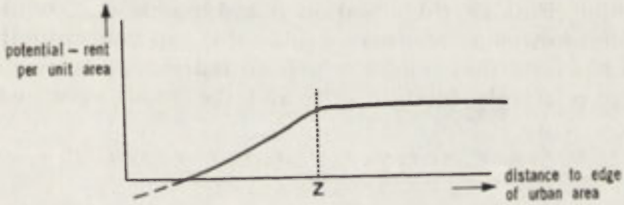

Fig. 2b. Hypothetical potential-rent curve for an agricultural use when transport costs are excluded and a non-linear TLFA schedule is used

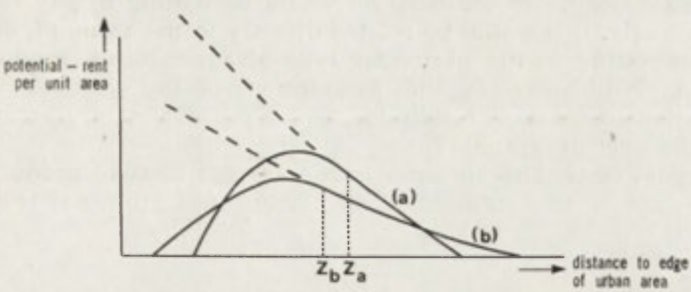

Fig. 2c. Hypothetical potential-rent curves for agricultural uses when transport costs are included and a linear TLFA schedule is used

[10] Sinclair, op. cit., 1967, Figs. 5 and 6, p. 79.

use. Clearly, for uses where there is a high degree of capital-fixity and long amortization periods, this point will be found further out than for uses where there is a low degree of capital-fixity and short periods of amortization; hence, the relative positions of z_a and z_b in Figures 1 and 2c. Transport costs being ignored accounts for the parallel curves after the point of "normal" conditions is reached.

Describing a theoretical zonation of increasingly intensive agricultural land use outwards from the central city, Sinclair then considers briefly the modifications brought by non-zonal factors such as non-uniform fertility, chaotic urban sprawl and zoning policies. [11] Finally, he cites evidence showing a decline in intensity near cities, but also notes studies showing an increase in intensively cultivated enterprises in some areas of urban expansion as well. [12]

A number of points may be made concerning this framework. Firstly, although transportation costs have declined during the twentieth century, it would be a gross exaggeration to consider that this has affected all agricultural enterprises equally and to such a large extent. [13] Secondly, the geographical scale at which this anticipation factor operates has yet to be specified. Thirdly, the nature of the above value curves are in doubt. They refer to aggregate land uses above, but this generates a source of internal inconsistency in the model in the sense that their configuration implies there is nothing to prevent use (*a*) from expanding to infinity, clearly an impossible situation. It may be more appropriate at present to view these curves as the indifference schedules of individuals rather than those of aggregated land use types. Fourthly, the mechanism linking anticipation of urban expansion to changes in agricultural land use is not specified clearly; if one is to derive hypotheses, it is essential that this be done. Finally, the situation is a dynamic one, while the model itself is a static one; however, one may bridge the gap conceptually by distinguishing between the conditions under which an individual farmer has to make a decision, often a relatively binding one, and the total view which is the market situation.

3. AN EXTENSION [14]

It is assumed reasonable that a farmer wishing to acquire a new farm, to make an extension to an existing unit, to alter his enterprise combination or to undertake any combination of these actions, will assess the probable costs of agricultural production in various locations, and will obtain some estimate of the price (analogous to bid-rent) he would be willing to pay for the use of such land. Clearly, this would be related directly to the value of, or anticipated return on, investing in the particular type of agricultural production under consideration. While retaining the assumptions of the classical von Thünen case in relation to constant conditions, two types of cost are assumed to vary systematically over geographic space.

(a) transport costs. This includes both transport costs of product to market, and, in the case of an extension to an existing unit, internal transport costs.

[11] Ibid, pp. 80–83.

[12] Ibid, pp. 83–87.

[13] Peet, op. cit., p. 810.

[14] This extension was made for use as an interpretative device in connection with field work carried out in the Paris Region, 1967/1968, during the preparation of the author's Ph.D. thesis. Acknowledgement is made to the Central Research Fund, University of London, for partial funding of this research.

This does not preclude the possibility that for some enterprises this cost component is now unimportant.

(b) a cost component whose size is influenced by the possibility of future urban expansion and loss of land to non-agricultural uses. The particular cost component suggested as being relevant is the replacement cost that has to be paid back by productive years on certain types of "sunk" investment. In the case of orchards, this type of investment would include an amount attributable to care and preparation during the initial unproductive period which may range from 3 to 10 years in length.

Thus, the size of this cost component depends upon a sum invested per acre and the estimated number of unproductive and productive years of agricultural use left in any location. In the simplest case, the *total* cost of such a component over its "full life" is of the general form ($A+YB$). A refers to a fixed amount per acre expended, for instance, on seeds, plants, labour of preparation and soil treatment; the exact composition of A depends on the nature of the enterprise under consideration, but generally it would include those cost components which do not enter immediately and wholly into the production cycle, and are hence spread over a number of years. However, the case of much machinery depreciation is rather different because of the mobility of machinery and the possibility of resale. B is a yearly expenditure on labour and treatment in the unproductive period and is assumed constant in this simple case, and Y is the estimated number of unproductive years. Hence, this particular formulation is especially appropriate for orchards. A more realistic formulation would also have to consider, for instance, interest rates.

Now, one of the most important factors in determining how large this cost component will be for a particular agricultural system is an estimation of the "time left for agriculture" in a particular location. Clearly, in the extreme case for an enterprise under a system of cultivation whereby all costs are recuperated in a year,[15] it matters little whether the estimated time left for agricultural use is one, two or more years; on the other hand, it would be of great concern to a farmer considering planting an orchard in a particular location. In the first instance, this time-left-for-agriculture (TLFA) schedule is assumed to increase with distance from the edge of urban expansion. This corresponds to the idea that the probability or degree of anticipation of urban expansion is distributed in some systematic fashion over geographic space.[16] As a first approximation, it is assumed that everyone has the same idea of this schedule,[17] although this does not mean that the exact course of urban expansion is known!

Before deriving the form of the bid-rent or value curves, it seems appropriate to consider this cost component further. Is this factor operative under all, or only certain types of structures and conditions of the land market? Is this a real cost under conditions of relatively unrestrained market forces, compulsory purchase without due compensation, or compulsory purchase with adequate compensation procedures, with or without measures to prevent specu-

[15] This extreme case is obviously a hypothetical one, since although expenditures on certain types of fertilizer and certain types of labour input may be considered as being recuperable in a very short time, most enterprises involve factors of production whose costs are in effect spread over a number of years.

[16] See also Chisholm, op. cit., p. 401.

[17] The effect of farm size and other farmer and farm characteristics might eventually have to be considered in relation to the nature of this schedule.

lative activity on the part of the farmer? From a consideration of these different conditions, it seems that a farmer would adjust his enterprises and/or system of cultivation where possible to accord with the estimated parameters of urban expansion as long as he is motivated by a desire to make as much money as possible. [18] The only type of situation, *a priori*, where this mechanism would probably not work is under conditions of compulsory purchase with adequate compensation but where no measures prevent the farmer from taking advantage of the compensation laws by, for example, planting orchards in the face of urban expansion. However, this still requires thorough investigation.

4. THE INDIVIDUAL

Given the type of enterprise and system of cultivation, one may examine the performance of the two cost components over geographic space and their influence on the value of land in agricultural use. Studying the second cost component in isolation, it would be theoretically possible to calculate the value of land or bid-rent under a particular agricultural system if all relevant data were available. A linear TLFA schedule would produce [19] a rising curve (Figure 2a) with increasing distance whose rate of increase declines to become parallel eventually to the abscissa when the estimated time available for agriculture is so long that "normal" conditions pertain [20] and this component becomes a constant. If the TLFA schedule is non-linear, such that the estimated time increases rapidly after a certain distance has been reached, then the value curve would assume the general form as in Figure 2b; indeed, one may consider a limiting case where the degree of anticipation of urban expansion is so great that the curve is zero or negative over a certain area. This negative value of bid-rent implies that in order for the farmer to undertake this particular type of farming, money would have to be paid to him. If this is true for all the potential enterprises in that location and for continuation of the existing operation, then the land is left idle. Hence, this framework does in fact provide *one* reason why farmland may become abandoned in areas of urban expansion.

When the transport component is considered, potential rent depends upon the marginal rates of change of both cost components. The maximum point in this function is where the marginal cost (due to transport) and the marginal savings in cost (due to a smaller urban expansion potential) of moving out an extra unit of distance are equal; and, abstraction made of land costs, this corresponds to the minimum cost point. At the point where the rate of change in the cost component affected by potential urban expansion becomes zero, the form of the function becomes as in the classical case (see Figure 2c, where z_a and z_b are the same as explained above for Figure 1). This suggests that the difference between the two models may merely reflect a change in the minimum physical scale at which factors lead to spatial differentiation.

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[18] Clearly, certain ethnic and cultural characteristics in some areas may undermine this assumption. Further, the very large potential gains due to speculative land prices in certain areas may completely eclipse the savings in operational costs obtained by "disinvesting" in agriculture so that, unless one adheres strictly to this assumption, the motivation to realize such savings may be unimportant.

[19] The data used were hypothetical, as was the TLFA schedule.

[20] Note: this need not be at the point where anticipation of urban expansion is zero as mentioned previously. In practice, this is further complicated by the fact that different types of investment have different replacement periods.

With different enterprises and systems of cultivation, then different value curves would be generated. For the individual, comparison with other uses will determine the range within which he would practice a given enterprise and system of cultivation. [21] The cost component affected by potential urban expansion may be termed the degree of capital-fixity, and this is useful in considering statements relating to the location of increases in "intensively" cultivated enterprises in areas of urban expansion both near to and distant from the edge of urban expansion. [22] As a general statement, intensity may be either labour or capital-based. Labour intensive enterprises need not be those that require much capital to be tied up over a long period, and hence may possess a low degree of capital-fixity. Hence, certain intensive enterprises may become more developed near the expanding city (such as certain vegetable enterprises where investment is often of a short-term nature), while others (such as orchards) may expand at some distance.

The derivation of these bid-rent or value curves depends upon a common view of the TLFA schedule by those concerned. Perhaps it would be more realistic to say that each farmer has his own particular idea of the schedule, influenced by a variety of personal characteristics. This being the case, these curves would still rise and fall, but no regular patterning could be hypothesized. Obviously in practice one would expect differences between individuals, but the extent of this has yet to be investigated. On the other hand, the possibility of location leaders or dynamic entrepreneurs may mean that only a small number of entrepreneurs might undertake a full assessment of the various costs involved at different locations. Other entrepreneurs in the same community may then model their decisions on this (these) "pioneer" decision(s).

This general approach may also be set into the dynamic situation. Since the parameters vary temporally, it is difficult for an equilibrium situation to be attained. As time passes, and a different set of ideas concerning the rate of future urban expansion are formulated, these are acted upon again either by the original entrepreneurs or by others. The cumulative result of this process may then be a breaking down of zonal arrangements altogether, if in fact they ever existed, giving way to an increasingly diversified and intensive land use pattern outwards.

There still remain a number of defects with this framework. In effect, the foregoing discussion has considered demand only; one might equally suppose that the anticipation of future urban expansion would affect the supply of land, particularly due to speculative motives; this may reinforce the foregoing discussion, since speculators may prefer to rent out land temporarily for uses requiring little capital investment. Also, anticipation of urban expansion need not be directly related to distance from the urban area, particularly since the urban expansion process may be spatially developing from a limited number of origins. Thus, one might visualize a value surface for each individual. Furthermore, there is the question of the measurement of anticipation, which is essential for an adequate testing of the model, and the effect of city size upon this anticipation.

Finally, the problem of equilibrium and the market solution arises in this dynamic situation. Treating the value curve as an indifference curve of an in-

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[21] In the case of a unit considering the extension of its existing production capacity by acquiring extra land, the range of possible locations in more restricted since an extra element of transport costs is involved.

[22] Sinclair, 1967, op. cit., p. 86.

dividual for a specific requirement, one may visualize the envelope of the upper-bounded parts of the individuals' value curves for a specific use as giving the most likely bounded area within which conversions to that use will take place when matched against the envelope value curves of other land uses. Equilibrium conditions of supply and demand can still be met under these conditions. This may then be given a probabilistic interpretation, which, although not solving the problem of the theoretical progression from the individual to the market solution, bypasses it. Some degree of success has already been obtained by developing a simple probabilistic model to demonstrate the existence of the urban anticipation factor [23], but considerable preliminary work still needs to be undertaken.

5. THE RELEVANCE OF THE ANTICIPATION FACTOR IN LAND USE ZONING

The general problem with urban encroachment upon agricultural land is not so much the preservation *in toto* of prime agricultural land, but rather that, in relatively unconstrained conditions of urban expansion, an area of land is affected that is much larger than the area of land that will be actually used for development. Hence, Gertler and. Hind-Smith [24] found that the area under urban shadow ranged from five times the area actually used for urban development for Kingston to 25% more than actually used for Lindsay while Krueger [25] estimates for the Niagara Fruit Belt that for every one acre of land used for urban purposes, two extra acres are ruined for all intents and purposes for agricultural use. The anticipation of urban development is one of the factors that may lead to such a decline in agricultural productivity and an increase in the costs of agricultural production. Speculation, also related to this anticipation, compounds these effects. Hence, from the agricultural point of view, the anticipation factor discussed in this paper is not the only source of argument in favour of the specification of the area for future urban growth.

Specification of this area can theoretically reduce potential urban development beyond so that anticipation of urban development would be very small, and hence unnecessary resource waste would be eliminated. At the same time, land values there would be less likely to reflect potential urban use, so that amalgamation of individual farm units might take place; this further has effects upon taxation of farmland. This delimitation of areas of urban growth therefore appears an important consideration given current trends in metropolitan planning where "open space" is emphasized. A precondition for the existence of such spaces is that they must be viable, both in economic and social terms. Such space is not always exclusively agricultural, but where this is so, the agriculture must be internally viable. For this, a major consideration involves guaranteeing a stable economic atmosphere, and hence especially security of tenure so that agricultural investment plans may be made accordingly. If such a zoning measure were violated, then this requires recognition of the real costs involved to the farmer in terms of investment not recuperated in some form of

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[23] Bryant, C. R., *Urbanization and agricultural change since 1945; a case study from the Paris Region.* Unpublished Ph.D. dissertation, University of London; London, 1970; pp. 129–168 (Chapter 3, Part B, The conversion of arable land to orchards: a locational analysis).

[24] Gertler and Hind-Smith, op. cit., pp. 160–172.

[25] R. R. Kruger, *Recent changes in the Niagara Fruit Belt* (unpublished manuscript, Department of Geography, University of Waterloo, 1968), p. 20.

compensation procedure.[26] This idea is also found in the suggestion[27] that a procedure be adopted for certain agricultural areas destined for urban development around the Paris agglomeration such that the farmer is assured of a certain period of time in order to rationalize investment plans, with a provisor for adequate compensation if the land is required for development prior to the termination of this period. This has the additional benefit of allowing the farming community concerned a period in which plans may be made for when the land is finally converted.

Hence, the simple model presented in this paper represents an initial step towards developing a more formalized structure which relates one aspect of urban expansion to changes in agricultural land use. Adequate testing of the model depends upon further formalization, particularly in terms of the aggregation to a market solution, the possibility of obtaining valid information relating to anticipation and the possibility of separating out the changes induced by this anticipation factor from those induced by other factors; this suggests that a simulation procedure would be in order. The results of several studies, such as Krueger,[28] Gertler and Hind-Smith,[29] and Bryant,[30] have suggested the existence of this anticipation factor; this present paper has attempted to provide a clearer conceptual framework within which further investigations can take place. In terms of practical significance, it seems clearly desirable to investigate this factor further, and to be able to quantify the spatial extent of its effects. The major argument put forward for this relates to the fact that agriculture is perhaps the major use of, and hence the most important "manager" of, rural open space in metropolitan areas. In such circumstances, anything which can lead to decline or stagnation within the agricultural structure merits attention for this can presage the development of land abandonment and thereby the failure of an "open space". This can potentially affect large areas; for instance, Coleman[31] notes that in the two counties adjoining Ottawa, 109,000 acres (or 13% of the land resource of that region) of idle land have been recorded, all of which is formerly productive land. Furthermore, it is clearly not restricted to North America, witness Sermonti[32] who notes considerable land abandonment in the Roman Compagna, a substantial amount of which is good quality farmland. The importance of stable land use zoning is clear, since

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[26] To a certain extent, recent events in France, and especially in the Paris region, demonstrate how this may be handled. Of particular interest is Law Number 62-933 of the 8th August, 1962, complementary to the law of agricultural orientation, Article 10, and, in relation to compensation procedures, S.A.R.E.S., *Aéroport de Paris. Evaluation dès préjudices causes aux exploitations agricoles par l'emprise de l'aéroport Paris-Nord* (Paris, S.A.R.E.S., 1965).

[27] Chambre d'Agriculture de la Seine-et-Oise, *Zone agricole de Cormeilles-en-Parisis* (Versailles, unpublished report, Chambre d'Agriculture, 1968).

[28] Krueger, 1959, op. cit.

[29] Gertler and Hind-Smith, op. cit.

[30] Bryant, loc. cit.

[31] Coleman, A., *The planning challenge of the Ottawa area*, (Department of Energy, Mines and Resources, Geographical Branch, Geographical Paper No. 42; Ottawa, The Queen's Printer, 1969), p. 3.

[32] Sermonti, E., Agriculture in areas of urban expansion: an Italian study, *J. Town. Plann. Inst.*, 46, 1968, pp. 16–17. Clearly, other factors, such as the drain on agricultural labour into urban employment have also contributed to these situations.

it is the only way to ensure a stable economic atmosphere for agriculture through eliminating the negative forces of the anticipation of urban development on agriculture; clearly, other types of support-intervention such as through taxation of land would be part of some package intervention. Perhaps the most important theme for further investigation into this topic is the clear delimitation of the spatial extent, and the factors affecting the spatial extent, of the influence of this factor, since without this information, attempts to control for such influences using land use zoning must remain illusory.

II. THE EFFECTS OF THE ANTICIPATION OF URBAN EXPANSION UPON SELECTED ASPECTS OF FARM STRUCTURE: A CASE STUDY FROM THE NORTHERN SUBURBS OF THE PARIS AGGLOMERATION

1. INTRODUCTION

It was suggested in part I that in addition to transport costs of agricultural produce to market, another cost has become important in many regions undergoing rapid urban expansion, viz., the effect of potential urban expansion on agricultural investment. This factor was suggested as affecting the value of agricultural investment, so that where anticipation of urban development was high, the value of agricultural investment in such capital intensive agricultural enterprises as orchards would not be high. In a situation of continuous urban expansion, then, it might be expected that a decrease in the importance of enterprises with a high degree of capital-fixity [33] would be found near the urban area, and *vice versa.*

The objective of part II is to develop certain simple hypotheses from the somewhat theoretical discussions cited above in order to test the effects of the anticipation of urban expansion on selected aspects of farm structure in the communes of Groslay and Deuil-la-Barre, two fruit-farming suburbs of the Paris agglomeration. First, the characteristics of the study area pertinent to the present problem are outlined, and the hypotheses developed. Then, the methodology and analytic techniques used are introduced and briefly discussed, and, finally, the results of the analyses are presented and interpreted in relation to the conceptual schema developed earlier. [34]

The agriculture of the two communes of Groslay and Deuil-la-Barre is based essentially on orchard farming, particularly pears and to a lesser extent, apples. This intensive agricultural system has its origins in the eighteenth century through the adaptation of a peasant, agricultural system [35] to the special demands of the Paris agglomeration, viz., vines, vegetables and fruit to a lesser extent initially. With increasing competition from other regions in the nineteenth century, and the catastrophic vine diseases of the nineteenth and early

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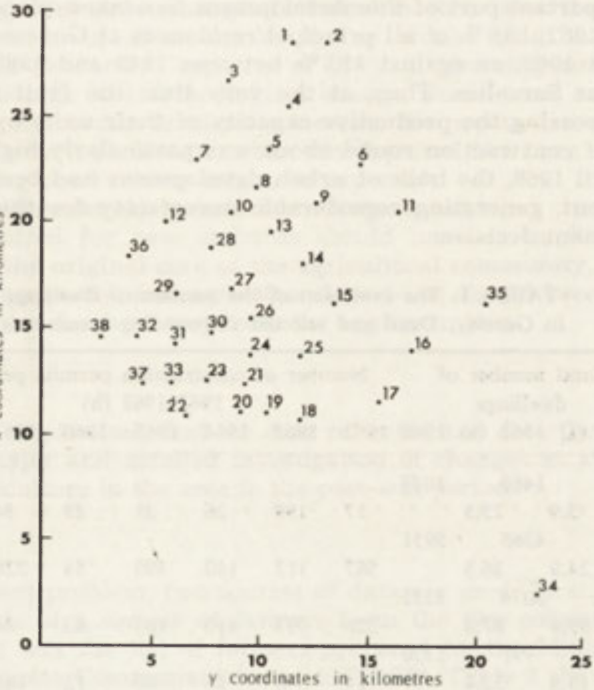
[33] I.e. enterprises whose cost structure is characterized by a high proportion of costs in long-term investment, such as buildings, installations, fruit trees, and so forth.

[34] Sinclair, op. cit.; See also J. R. Peet, op. cit.; R. J. Horvath, op. cit. and M. Chisholm, op. cit. (footnote 6).

[35] Accounts of the area's historical development are to be found in: M. Phlipponneau, *La vie rurale de la banlieus parisienne: Etude de géographie humaine,* Doctoratès-Lettres, Paris, École Pratique des Hautes Etudes, 1955; and J. Tricart, La culture fruitière dans la région parisienne, *Centre National de la Recherche Scientifique, Etudes et Mémoires,* Vol. II, Paris, 1951.

twentieth centuries, the region (especially Groslay) began specializing more and more in fruit, taking advantage of the growing Paris market so that, for example, in 1942[36] 240 out of the 290 ha cultivated by Groslay farmers were in orchards of which 70% were in pears. For Groslay, orchards accounted for 62% of the area farmed in 1913, 82% in 1942, 95% in 1954 and 96% in 1967. By the latter date, vegetables were of very minor importance, and were concentrated on the very smallest units. The area presents generally a very favorable physical environment for orchards. The limon of the plateaux is generally good, except where decalcified in the extreme south of the plain, while the soil formed by the mixture of limon, limestone and sands on several of the slopes in the area is very favorable. Climatic conditions are good, except on the more central parts of the Plaine de France, where climate is harsher; nevertheless,



Key to communes :

1	Viarmes	14	Ecouen	27	Piscop
2	Seugy	15	Villiers le Bel	28	Domont
3	St. Martin du Tertre	16	Gonesse	29	Andilly
4	Belloy-en-France	17	Bonneuil-en-France	30	Montmorency
5	Villaines s/Bois	18	Stains	31	Soisy
6	Mareil-en-France	19	Pierrefitte	32	Eaubonne
7	Monsoult	20	Villetaneuse	33	Enghien
8	Attainville	21	Montmagny	34	Gagny
9	Mesnil Aubrey	22	Epinay s Seine	35	Roissy-en-F.
10	Moisselles	23	Deuil-la-Barre	36	St Prix
11	Fontenay-en-Parisis	24	Groslay	37	St. Gratien
12	Bouffemont	25	Sarcelles	38	Ermont
13	Ezanville	26	St. Brice		

Fig. 3. Centroids of the communes used in the standard distance and mean arithmetic centre analyses

[36] Tricart, op. cit., Chapter 3, L'Organisation de la Production Fruitière.

physical conditions are far from deterministic, witness recent extensions of orchards into the Plaine de France. The market forces had already led to the extension of orchards into the communes to the north (see Figure 3), such as Ecouen, Sarcelles, and Villiers-le-Bel, by 1945, a movement which has increased in the last ten years. The increase in the metropolitan market for fruit has clearly provided an incentive for farmers of the area to increase their productive capacity.

On the other hand, a contradictory force has appeared in the area, viz., urban expansion. The post-war housing crisis, especially in the late 1950's, has led to an increasing rate of conversion of orchard land to non-agricultural uses. In the period 1954 to 1962, Deuil's population increased by 30% and Groslay's by 15% [37] while the number of dwellings increased by 24.9% and 5.9% respectively. Construction in the surrounding communes has been high also (see Table 1): an important part of this development has taken place since 1958: for example, until 1962, 18,9% of all principal residences at Gonesse were built between 1958 and 1962, as against 31.7% between 1949 and 1962; and 54.4% as against 76.1% at Sarcelles. Thus, at the very time the fruit farmers studied below were increasing the productive capacity of their units by acquiring new land, the rate of construction round about was particularly high. Furthermore, in this area until 1968, the bulk of urban development had been largely piecemeal development, generating considerable uncertainty for the farmer having to make investment decisions.

TABLE 1. The evolution of the number of dwellings in Groslay, Deuil and selected surrounding communes

	Total number of dwellings					Number of construction permits per year 1962–1968 (b)							Total 1962–1968
	1954	(a)	1962	(a)	1968	1962	1963	1964	1965	1966	1967	1968	
Groslay	1397		1480		1858								
		5.9		25.5		17	199	26	21	29	34	52	378
Deuil	3494		4365		5951								
		24.9		36.3		567	113	140	380	54	226	106	1586
Gonesse	1572		3074		5155								
		95.4		67.8		226	773	810	103	63	88	18	2081
Ecouen	876		997		1320								
		13.8		32.4		14	5	16	80	12	186	10	323
Villiers-le-Bel	1682		3612		6614								
		114.7		83.1		33	853	1676	261	120	33	26	3002
Sarcelles	2853		9316		13453								
		226.5		45.4		153	1153	421	775	548	1067	110	4227

(a) Figures between the columns give the percentage change in dwellings between the two dates
(b) *Source*: provided by the Mission d'Etudes d'Amenagement Rural de la Region Parisienne

This anticipation of urban development could influence costs of agricultural production by the effects it would have on the amortization period of certain types of agricultural investment. Clearly, if the degree of anticipation of urban development is high the anticipated "life" of an investment could be much shorter than "normal"; consequently, the costs of agricultural production in

[37] Based on data from the *Recensements de la Population* of 1954 and 1962.

that location would be much higher than normal. The importance of this cost depends essentially upon the anticipated "life" for agricultural production in a specific location and on the importance of costs which have long amortization periods under normal conditions for a specific enterprise.

Fruit production from orchards represents an extreme case, given the non-productive period of care and attention lasting anywhere from three to ten years. Thus, generally the type of investment affected by this factor includes those whose productive life covers several years, particularly if it represents "sunk" investment. Transport costs can still be important for some agricultural enterprises; in the present study, where one is dealing with increases in the productive capacity of already existing units, internal transport costs may be considered as the limiting factor in the locational decision of the farmer of where to acquire extra land. A number of simple hypotheses can now be developed concerning very gross changes in farm structure over the late 1950's and 1960's. In such an area, where market forces would tend to encourage the expansion of the productive capacity of the fruit farming community, where general social change and technological change would tend to encourage and permit respectively certain farmers to increase the productive capacity of their own units, and where piecemeal urban development has been rapidly expanding, the following observations might be expected:

(a) farm holdings should become more fragmented,

(b) land acquired for new orchards should increase in distance from the farmsteads and the original core of the agricultural community, and away from the urban area generally; and agricultural land use should become more diversified and intensive further away from the agglomeration.

2. METHODOLOGY

It should be emphasized that the data collected and described below formed but part of a major and detailed investigation of changes in all the structural elements of agriculture in the area in the post-war period.[38]

The data

For the present problem, two sources of data are used. First, a questionnaire survey was made of a sample of farmers from the two communes; the sampling frame used was the list of farmers prepared by the Ministry of Agriculture for the Enquête Communautaire in 1967–1968. Table 2 shows the stratified structure used (conforming with the Ministry design in the area in order to have comparable data for purposes other than those of the present analysis), and the numbers taken in the sample. Although there was a high non-response rate from stratum C, supplementary data was obtained from Ministry sources that was sufficient for present purposes; indeed, most of the non-response was due to the inclusion on the Ministry lists of ficticious or non-existing farm units (gardens, farms whose operator had died and whose holdings had been subsequently amalgamated with others, and so forth) so that it was estimated that only 53% of the registrations in stratum C were of real farmers (full or part-time farmers) and 78 per cent for stratum B. [39] In this survey, all transactions of land since the war were noted, together with the date, size, location,

[38] Bryant, 1970, op. cit., pp. 57–175.

[39] A detailed study of changes in farm registrations was made elsewhere (Bryant, op. cit., pp. 67–76).

pre and post-transaction use of the parcel(s) of land. While concern over potential urban development was expressed as a factor in acquiring potential orchard land elsewhere, it was decided that because of the difficulties of assessing decisions made as much as 20 years ago analysis would concentrate on form or structure, changes in which could then be assessed according to whether or not they conformed to the conceptual framework outlined previously. A second source of data concerns the distribution of land cultivated by each farmer in each commune. For 1955, this information was abstracted from files held at the Institut National de la Statistique et des Etudes Economiques (collected in conjunction with the Agricultural Census at that date) for all the registered farmers in the two communes; for 1967, the same information was collected just for the sample units' files held in the departmental prefecture offices at Cergy-Pontiose, owing to the fact that lengthy hand calculations were needed to abstract this data.

TABLE 2. Structure of the questionnaire survey, Groslay and Deuil, in 1967–1968

Size class	D	C	B	A	Total
in hectares	1	1–5	5–20	20	
Total numbers of farms registered	35	80	36	4	155
Number in sample	8	17	8	3	36

The Selection of Analytic Techniques

One set of hypotheses relates to changes in the distribution of land farmed by these farmers, and hence demands some technique of locational analysis Essentially, the distribution of land farmed by any one farmer is a two-dimensional distribution; it is possible to describe changes in such patterns over time by the centre of gravity, or arithmetic mean centre, and the standard distance,[40] the spatial analogies of the mean and standard deviation. Briefly, for a system of points within a grid framework with orthogonal axes, the centre of gravity is represented by the intersection of the arithmetic means of the x and y coordinates, such that $\bar{x} = \sum x_j/n$ and $\bar{y} = \sum y_j/n$ where x_j and y_j are the two coordinates of point j, and n is the number of points (or in this case the number of communes in which the specific farmer has farmland). In the present problem, each point is the centre of a commune (see Figure 3), and is associated with the area cultivated in that commune by each farmer; with a relatively large number of points, the errors introduced by representing areas by points tend to cancel each other out.[41] Then, the centre of gravity is at the intersection of the weighted means of the x and y coordinates, so that $\bar{x} = \sum e_j x_j/\sum e_j$ and $\bar{y} = \sum e_j y_j/\sum e_j$ where e_j is the area farmed on commune j (i.e. e_j is the

[40] See R. Bacchi, Statistical analysis of geographical series, *Bulletin de l'Institut International de Statistique*, 36, 1957, pp. 229–240; and D. S. Neft, Statistical Analysis for Areal Distributions, *Monograph Series*, 2, 1966 (*Regional Science Research Institute*, Pennsylvania), pp. 27–29 and pp. 55–58.

[41] Neft, op. cit., p. 23.

"block" of land farmed in commune j by the specific farmer under consideration). [42]

The centre of gravity is very sensitive to changes in the distribution, and together with the standard distance, presents a clear descriptive statement, with quantitative significance, of the changes in a geographic distribution over time. Using these two measures, the changes in distribution of each farmer's land over time can be analysed, as well as changes in the distribution of land farmed by the two communities as a whole or by strata.

The other expectation concerns changes in the degree of fragmentation of farms, and for this a number of different indices of fragmentation is used. Fragmentation is a relative concept, and it is necessary to consider several aspects such as the number of blocks of land farmed (again, in this analysis, the land farmed by each farmer is grouped by commune, such that if farmer X has 5 ha on commune A and 2 ha on commune B, he is considered to have two blocks of land of 5 ha and 2 ha respectively), the sizes of those blocks, and the distances between them. Each index used relates to a different aspect of fragmentation; they are noted here, and commented upon further during the analysis. First, standard distance is used; this is an index of dispersion around the centre of gravity. Thus, a very large movement in the centre of gravity can be observed while at the same time the standard-distance decreases (e.g., if the acquisitions of land are of very large blocks of land). Secondly, Symon's Fragmentation Index [43] was also used. This index is calculated for each farm as:

$$\text{F.I.} = \frac{\sum_{j=1}^{n} a_j^2}{A^2}$$

where a_j is the area farmed by a specific farmer on commune j, A is the total area farmed by that specific farmer, and n is the number of blocks or number of communes in which that farmer cultivates land. A lower value of the index indicates a greater degree of fragmentation. Clearly, no distance factor is involved here; the index is very much influenced by the number of blocks involved. With a farm of 20 ha, for example, if there are two blocks of land, maximum fragmentation would ensue if each block were 10 ha giving F.I. = 0,5; if the same farm had four blocks, maximum fragmentation would ensue if each block were 5 ha, giving F.I. = 0.25. Therefore, the relationship between the minimum value of F.I. (representing the maximum degree of fragmentation that could be obtained given the number of blocks) and the actual F.I. is also investigated; if the ratio is 1.0, then the farm has the maximum degree of fragmentation; if less than 1.0, then the farm is less fragmented than the maximum possible.

Essentially, then, the aim is to observe changes in certain of the aspects of agricultural structure in the area, and to see whether these observations are consistent with the simple hypotheses or expectations outlined above.

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[42] The standard distance is calculated as:

$$\text{S.D.} = \sqrt{\frac{\sum_{j=1}^{n} e_j(x_j-\bar{x})^2 + \sum_{j=1}^{n} e_j(y_j-\bar{y})^2}{\sum_{j=1}^{n} e_j}}$$

[43] J. Symons, An index of farm structure, with a Nottinghamshire example, *E. Midlands' Geogr.*, Vol. 3, No. 21.

3. THE ANALYSIS

The total area farmed by the Deuil and Groslay farmers has definitely increased; hence, the total land controlled by farmers registered in these two communes was 536 ha in 1955 (337 and 199 at Groslay and Deuil respectively), while in 1967 this had increased to 622 ha (396 and 226 respectively). The overall net increase of 86 ha accords with the information provided by the sample survey. Within this increase of the total area cultivated, there has also been an upward shift in the size distribution of farms [44]. While the accent in the late 1940's was in the class of 1 to 5 ha, in the late 1960's in terms of numbers of farms the emphasis had become evenly divided between this class and that of between 5 and 20 ha (the most important in terms of total area farmed). Table 3 shows the interclass movements for farmers whose farms were registered in the town halls in both 1955 and 1967, together with the number that have been taken off the lists and those that have been added to the lists in the period 1955 to 1967. The overall increase in land farmed by farmers of these two communes has been accomplished for the most part by the acquisition of arable land on which new orchards have been planted.

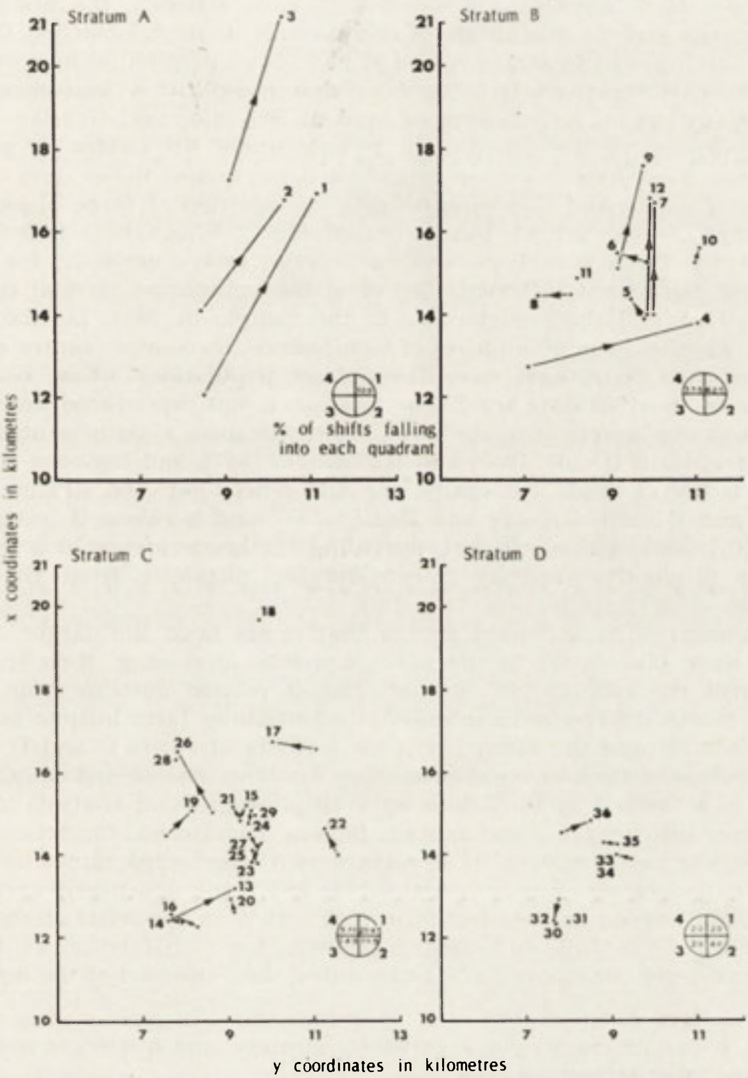
TABLE 3. Changes in size-structure of registered farms, by size-class in hectares, between 1955 and 1967 for Groslay and Deuil

	Entries since 1955	Exits	1968 class or subsequent class 1 3–2.5	2 2.5–5	3 5–7.5	4 7.5–10	5 10	Row totals
1955 1	29	53	32	5	2			39
class 2	16	17	7	14	7	3	1	32
or 3	4	5	5	2	6	3	3	19
initial 4	3	2		2	2		3	7
class 5	2	1					1	1
Column totals	54	78	44	23	17	6	8	98

The movements in the centres of gravity, 1955 to 1967, for the sample units are shown in Figure 4, and for each stratum, the orientation of the movements is given in percentages by quadrant; here, an orientation of more than 180° indicates a move towards the agglomeration. For stratum A, the movements are large and all oriented to the north-east. This reflects two trends: (a) the loss of a certain amount of land, by expropriation, for housing development schemes, especially in the communes immediately around the home communes (e.g., Montmorency, Epinay, and Deuil) in the early 1960's, and (b) the acquisition of large amounts of land (a gross addition of approximately 73 hectares for this stratum) at a large distance from the farmsteads. The reasons for such land purchases were largely connected with the loss, actual or potential, of land to non-agricultural uses. Three transactions, concerning 28 ha were made in 1962 immediately after expropriation, and represented a means of securing this investment, while locating in an area unlikely to undergo urban expansion. For stratum B, only 62.5% of the moves are found in the north-east quadrant, although all the important ones are there. The units that increased their

[44] Bryant, op. cit., pp. 67–76.

productive capacity largely did so in order to improve their living standards or simply as a response to the expanding market opportunities for fruit during this period. Of the gross 27 ha acquired by these farmers, 66 per cent was acquired beyond the ring of immediately encircling communes at Domont, Ecouen, Attainville, Ezanville, Villaines-sous-Bois and Roissy-en-France. Other acquisitions were made near their farmsteads, but these are distinguished from the first ones mentioned in that they represent amalgamations (*via* leasing) with existing orchard units, so that the general hypotheses would not be contradicted, such land already having been amortized for the most part. The



N.B. Only those on both lists have shifts in centres of gravity. The point with farm number attatched is the 1967 centre.

Fig. 4. Movements of the mean arithmetic centres of land farmed for each sample unit between 1955 and 1967

movements towards the agglomeration are explicable either in terms of those units being run by part-time farmers, or, in one case, a unit whose operator had acquired another farm in another département. In such cases, constraints imposed by other interests largely prevent extensions of productive capacity at any considerable distance from the farmsteads themselves. Stratum C presents a very heterogeneous picture, with the majority of the moves being found in quadrant 4, representing similar situations to those just mentioned above (especially part-time farmers), or units which are little more than gardens; similarly with stratum D.

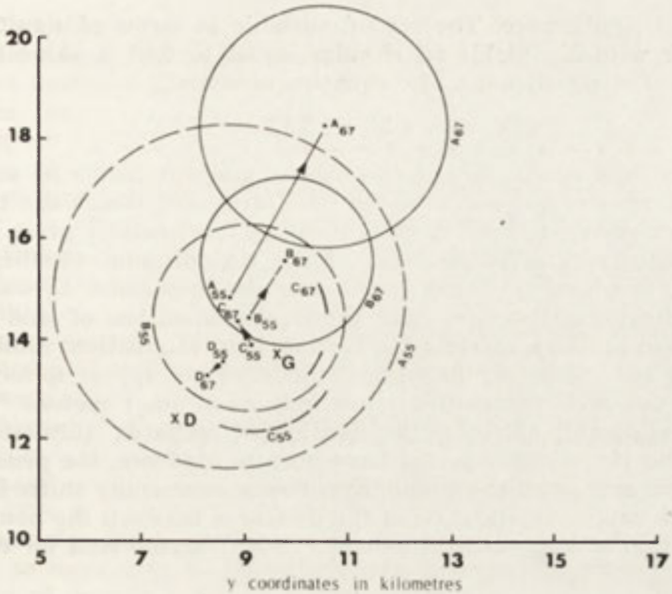
Figure 5 shows overall movements for the sample units grouped by stratum, with the standard-distances associated with each centre [45], the orientation of the movements and the magnitude of the movements (in kilometres). Generally, the units now present in strata A and B have been dominated by a movement towards the north-east, while C has been dominated by a movement to the north-west (reflecting large losses of land at Sarcelles and Groslay for construction purposes [46]); the distribution of land under the control of stratum D has withdrawn towards the urban zone. The dispersion of the centres of gravity has decreased for A and B (which reflects the addition of large blocks of land to these farms — see below), but increased for C. Since these merely reflect sample results, further analysis was undertaken to see whether, for instance, there was a significant difference between the population, strata centres of gravity in 1955 and those pertaining to the sample in 1967, i.e. the question posed was whether, at a given level of significance, the sample centre of gravity for each stratum could have been taken from populations whose real centres were those of the 1955 data set. [47] The analysis is not reproduced here for lack of space, but one notes, at a 1% level of significance, a significant difference between stratum B (Deuil, 1955) and B (sample, 1967), and between A (sample, 1967) and B (Deuil, 1955). Generally, the differences between stratum A (sample, 1967) and B (both Groslay and Deuil, 1955), and between B (sample, 1967) and B (Deuil, 1955) are significant, providing further evidence of a substantial increase in productive capacity at considerable distances from the original farmsteads.

From these results, it would appear that it has been the larger farms of 1955 that have taken part in the move towards increasing their productive capacity over the 1955 to 1967 period. This is related both to their financial status and to the difference in interest in maintaining farm income as between full-time farmers and the often part-time farmers of strata C and D. The fact that the process of farm-size expansion has not been distributed equally among the farms is witnessed by the following multiple regression analysis of changes in farm-size, 1955 to 1967, and certain factors considered important in this process. This is performed on 21 observations (those sample units in strata A, B and C that were also present on the 1955 lists); the dependent variable (X_4) is the positive change in area per farm (calculated on the basis of the positive net changes per commune for each farmer, i.e., for each farmer, we know the area cultivated per commune for the two dates; thus, the sum of the net changes

[45] The standard distances here refer to the dispersion of farm centres of gravity around the centre of gravity for a particular stratum, and hence are smaller than if the "blocks" themselves had been used.

[46] This illustrates the fact that it is only possible to interpret such changes in these statistics with a knowledge of the local situation.

[47] See Neft, op. cit., p. 140, for an explanation of the procedures to use in such a situation.



D.G: the centroids of Deuil and Groslay respectively.
A.B.C.D: refers to the respective strata (see text).
67,55: refers to date of the respective stratum centre

N.B. The radii are the respective standard distances (not standard errors) and refer to the distribution of farm centres of gravity.
The centres for 1955 are not the 1955 population strata centres, for they refer to units at present in the respective strata in the sample and which consequently need not have been in the same strata in 1955

Fig. 5. Standard distances and mean arithmetic centres for the sample units combined by strata between 1955 and 1967

Shifts in the strata centres

Stratum	Degrees (a)	Distance (kms.)
A	118	3.89
B	120	1.33
C	59	0.52
D	316	0.30

(a) Reading clockwise, a reading of greater than 180° indicates a contraction towards the urban area. Obviously, these readings are not invariant with the grid-orientation.

between these two dates that are positive is considered as the total positive change in area, which is used as a surrogate for gross additions of farmland). The independent variables are: negative change in farm area per farm (X_1; calculated in a similar fashion to variable X_4); the registered farm-size in 1955 (X_2), and farmer-status (X_3; 1 if the registered farmer is in fact a farmer, full or part-time; and O otherwise). The results of a stepwise regression show that variables X_2 and X_3 are significant. The simple correlation coefficients are: $r_{12} = 0.56$; $r_{14} = 0.29$; $r_{13} = -0.27$; $r_{24} = 0.68$ and $r_{34} = 0.46$. The r^2 value for the most significant variable (X_2) is 0.45 with an F value significant at the

0.1% level of significance. The second variable in terms of significance is X_3, and together with X_2, yields an r^2 value equal to 0.60, a value significant at the same level of significance. The equation becomes:

$$X_4 = -4.33 + 1.72X_2 + 5.32X_3$$

The analysis thus indicates that the most important factor in accounting for increase in farm-size has been the "initial" farm-size, which can be considered as acting as a surrogate for financial viability (particularly given the relatively homogeneous enterprise structure of the region), and whether the registered farmer is a bona fide farmer or not is also important. X_1 was included to act as an indicator of financial gains consequent upon loss of land which might be expected to act as a catalyst for further land acquisition; although specific cases of this were found in the survey, this does not appear to have been generally so in this area, contrasting with findings in other regions. [48]

Thus, considerable shifts in the location of orchards cultivated by these farmers in the 1955 to 1967 period have been in evidence, the general direction of which have supported the simple hypotheses concerning shifts in land farmed. Further, a rapid investigation of the distances between the home communes and the location of these acquisitions of "virgin" arable land for orchards over

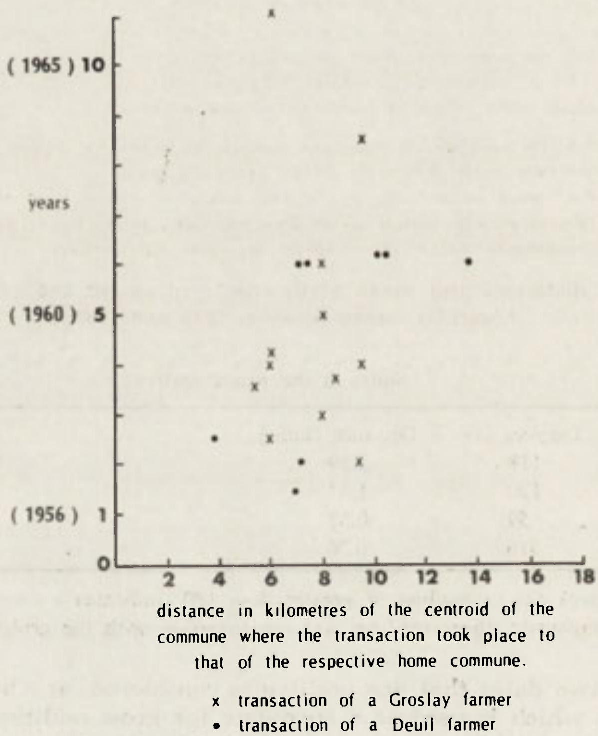


Fig. 6. Land acquisitions of arable land of more than 1 ha between 1955 and 1966 by the sample units: date of acquisition against distance of acquisition from the "home" communes

[48] C. R. Bryant, L'Agriculture Face à la Croissance Métropolitaine: le Cas des Exploitations de Grande Culture Expropriées par l'Emprise de l'Aéroport Paris-Nord, *Econ. Rur.*, No. 95, 1973, pp. 25–35.

time shows that they have become greater (see Figure 6). All these particular conclusions have been supported by independent analysis of the region [49], using for the region between Groslay and Gonesse, and from Bonneuil-en-France to St. Martin du Tertre (an area of approximately 170 square kilometres) data derived from air photo coverage for 1949, 1950, 1955 and 1968. A simulation model was constructed to simulate the conversion of arable to orchard land; while it was demonstrated that distance from the farmsteads is a limiting factor, and that size of parcels available for conversion is also important, it was also evident that a complete interpretation of the conversion process could not be made without introducing the influence of potential urban development.

The question of how this movement has affected farm fragmentation is a difficult one owing to the various dimensions of fragmentation. Clearly, it should be noted that any increase in farm size could result in a greater degree of farm fragmentation; unfortunately, it is difficult to find a control situation. The first index applied is the standard distance measure of dispersion. It is interesting to note how the relationship between standard distance and farm size has changed over time. In 1955, farm size accounts for 54% ($r = 0.74$; $n = 66$) and 39% ($r = 0.63$; $n = 111$) of the variation in the standard distance values per farm for Deuil and Groslay respectively, showing the tendency for larger farms to have a greater degree of dispersion of their holdings relative to the centres of gravity. But in 1967, for the 36 sample units, r^2 is only 0.22 ($r = 0.47$); given the fact that several of these farms have increased in size considerably, one must conclude that the increase in farm size has not necessarily led to an increase in standard distance, and that even the reverse has occurred. This is easily explainable; in fact, the process of farm size increase has often been accomplished by the acquisitions of parcels of land whose sizes represent a considerable proportion of the "new" units; consequently, the degree of dispersion relative to the new centre of gravity has decreased.

Using Symon's Fragmentation Index (F.I.), a significant relationship exists between this index and farm size for Deuil in 1955 ($r = -0.67$; $r^2 = 0.45$) indicating a tendency for larger farms to be more fragmented; but no such relationship exists for the Groslay farms at that data ($r = 0.004$; $r^2 = 0.00001$). The difference is related to the fact that the Groslay farmers had already acquired substantial blocks of land prior to 1955 which clouds the relationship between farm size and fragmentation. For the sample data, $r = -0.49$ and $r^2 = 0.24$.

TABLE 4. Relationship between increase in farm size and fragmentation for sample units identifiable in both 1955 and 1967

	Tendency towards consolidation	Stable	Tendency towards greater fragmentation (a)	Total number of units
Increase in farm size	3	1	10	14
Stable		1		1
Decrease in farm size	10	1	6	17
Totals	13	3	16	32

(a) I. e., a decrease in Symons' Fragmentation Index between 1955 and 1967.

[49] Bryant, 1970, op. cit., pp. 129–169.

The difference between the levels of explanation for Deuil in 1955 and the 1967 results may well be affected by the fact that the two communes have been combined at the latter date. Nevertheless, the signs and coefficients for Deuil and the sample data indicate that there is a tendency for the degree of fragmentation to increase with increase in farm size. This is confirmed by Table 4.

Thus, generally, according to this index, farms which have increased their farm size have become more fragmented. However, this is biassed to an extent, given that the index is influenced considerably by the number of blocks of land on a farm and that larger farms might be expected to have a greater number of blocks than the smaller farms. Hence, another index (minimum possible value of F.I. divided by the actual value of F.I.) was calculated, and its relationship with farm size investigated over time. The relationship seems to have changed considerably: for the sample units, $r = -0.52$ and $r^2 = 0.27$; for Deuil, 1955, $r = -0.59$ and $r^2 = 0.36$; and for Groslay, 1955, $r = 0.36$ and $r^2 = 0.13$. Thus, despite the combination of the two communes at the latter date, the relationship is now definitely an inverse one, indicating that in the process of farm size increase here, some of the land acquisitions have been very large and have had more influence on this fragmentation index than the increased number of blocks. These larger parcels are partly related to a greater degree of mechanization and, given that the farmers have had to acquire land at considerable distances from the farm owing to problems associated with potential urban development, the additional parcels have had to be larger to make the extra travelling time worthwhile. These results again appear compatible with the simple hypotheses outlined earlier.

4. CONCLUSIONS

In terms of the actual mechanisms through which the anticipation of urban development affects agricultural land use practices, much work clearly remains to be done at the level of the individual farm unit. This paper has taken a more traditional geographical approach, by formulating simple hypotheses relating to change in agricultural structure in areas undergoing urban development, and by evaluating whether or not the observations are compatible with the hypotheses and the conceptual framework presented. Urban expansion has led to an increased market for fruit produced in this area. But, in order to increase the productive capacity of their units, certain farmers have had to acquire the necessary "virgin" arable land at considerable distances from their original farms. The evidence presented above is compatible with the conceptual framework; a shift in orchard cultivation was observed away from the urban area, and the extent of the shift increased over time. Essentially, this has led to a diversification and intensification of agricultural land use at some distance from the immediate urban fringe. Further, this would appear to have led to an increase in fragmentation, at least in absolute terms (using Symon's Fragmentation Index); on the other hand, relative to the new centres of gravity, the larger farms appear in effect to have a smaller degree of dispersion, and further, in relation to the maximum possible degree of fragmentation given the number of blocks per farm, it appears that the larger farms have the least degree of fragmentation. These latter observations do not contradict the hypotheses for reasons outlined above; it means rather that care must be taken when discussing fragmentation owing to the various dimensions of the phenomenon. It would now seem worthwhile to investigate the actual mechanisms by which the anticipation of urban development affects agricultural land use, and to attempt to substantiate the arguments outlined in this and other papers by undertaking micro-studies of farmers and their investment decisions in urban fringe areas.

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A MODEL OF THE INTERNAL STRUCTURE OF THE MEDIUM-SIZED POLISH CITY

Andrzej Werwicki

Among the theories concerned with the internal structure of cities the following three seem to be best known: E. W. Burgess's theory of the concentric structure (1925, 1929), H. Hoyt's sector theory (1939) and the theory of the polynuclear structure worked out by Ch. D. Harris and E. L. Ullman (1945). Each has its own spatial model. The first two theories are concerned with the explanation of social differentiation in urban areas, whereas the third is an attempt to explain the distribution of certain phenomena occurring in towns. All three theories refer to two types of functional zones, namely the central business districts and the residential zones; other districts are dealt with only incidentally. This approach seems to be connected with an implicit belief that business (service) and residential districts are the basic elements, conditioning the internal structure of cities, and that the influence of the remaining functional zones is unimportant.

The present study of medium-sized Polish cities was carried out in the Department of Settlement and Population Geography of the Geographical Institute of the Polish Academy of Sciences. Research was started in 1965 with the formulation of certain notions particularly of the internal structure of towns. The latter was defined as the overlapping of and interaction between the pattern of the distribution of the various types of activities (including their fixed assets) and that of the distribution of population (including housing). The patterns were analysed against the background of the town layout. Thus, all functional zones found in Polish towns were taken into consideration. The findings have been described in three studies (A. Jelonek, A. Werwicki, 1971; A. Werwicki, C. Guzik, 1971, A. Werwicki, 1973). Altogether eight towns were investigated, of which seven are regional administrative and services centres (Białystok, Kielce, Koszalin, Olsztyn, Opole, Rzeszów and Zielona Góra) with a relatively low level of industrialization, and the eighth — Tarnów — is an industrial city.

The analysis included not only urban areas *sensu stricto*, i.e., lying within the city's administrative boundaries, but also its outer zone, which can also be referred to as the zone of diminishing urbanization. Thus the whole settlement system of the town was taken into consideration.

The research technique was as follows. Urban areas of the investigated towns were divided into basic squares, while the basic spatial units in the outer zone were villages. All the data were collected for each unit. Two methods were used to analyse the distribution of the structural components. The first one used the Lorenz curve to determine the concentration of the town's functional

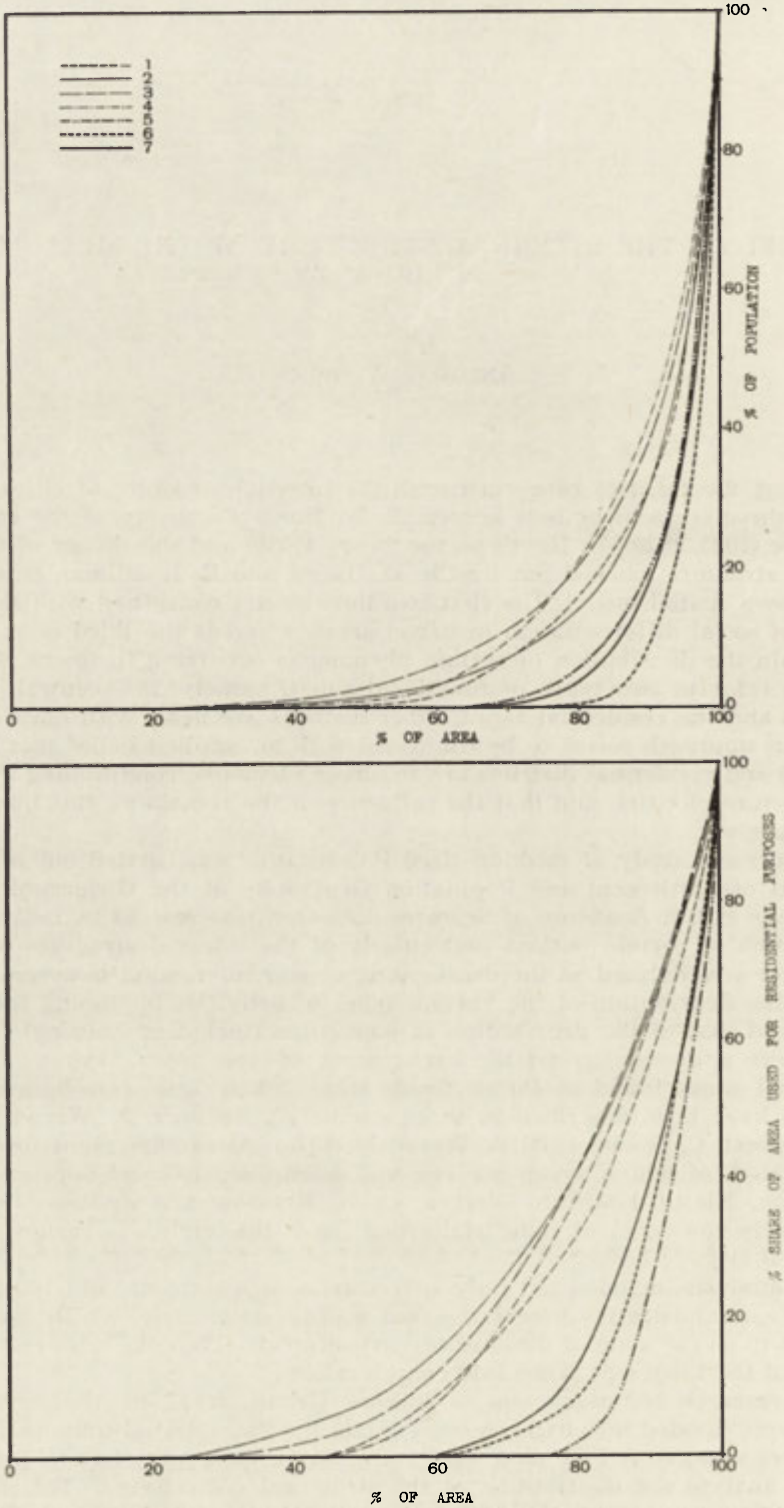

Fig. 1. Concentration curves for the population (1960) and for the area of residential districts (c. 1970)

components. The second one was a classification of the basic squares according to the concentration of the analysed components (types of use).

Cumulation series were made for every town except Tarnów, and concentration curves of the separate components were drawn. Their comparison revealed that the concentration curves tend to fall into two groups which always contain the same cities (Fig. 1), and that each group of curves corresponds to another type of the concentration of components. The curves for Białystok, Kielce, Opole and Rzeszów were longer and less steep than the others. They corresponded to the patterns of the distribution of the components found almost everywhere in the city; such structures were termed "filled-up". The remaining curves (for Koszalin, Olsztyn and Zielona Góra) corresponded to the patterns of the distribution of the components occurring only in certain parts of the city. This phenomenon was characteristic of those cities in which open areas account for over 50% of the administrative area. This structure was therefore termed "island-like", taking into consideration also some other features characterizing the distribution of the analysed components. In order to investigate the differences between the two differentiated types of internal structure in greater detail a synthetic index, called the concentration degree S_k, was calculated. This index shows the contrast within the city's administrative boundaries between 10% of its area (comprising squares with the highest concentration of a given phenomenon) and the remaining part. The index was obtained by the following formula:

$$S_k = \frac{A}{B}$$

$$\text{where} \quad A = \sum_{i=1}^{n} a_i, \quad \text{and} \quad B = \sum_{i=1}^{n} b_i$$

The indices for the filled-up structure were much lower than for cities with the island-like structure.

Through these methods of arranging the squares according to the concentration of the components it is possible to determine the various functional districts, mainly those with specialized functions. The procedure was based upon a comparison of data assembled for the basic squares with the accepted specialization indices, established during detailed analytical and comparative studies. As far as services were concerned the specialization index was 60 service establishments to the basic square. All the squares which had more than 60 and those whose area occupied by services was bigger than 10% of the total square, were classified as specialized in services. For other functions the specialization index was 25%, of the area used for a particular function.

Groups of squares specialized in a given function were treated as functional districts, and groups of such districts as functional zones. The three types of functional districts differentiated within the administrative boundaries of the town were service, residential and industrial. Service districts were further subdivided into central and special (i.e., administrative, academic and health service districts). As none of the investigated cities had any larger area used for transport no corresponding district was differentiated. The above districts form the following four functional zones: I — central, II — transition III — internal industrial and residential, and IV — marginal (or peripheral).

The central zones account for only 0.6 to 3.7% of the area under the settlement system, but are the most densely populated and have significant percentage of the town's population (Table 1 at the end of the volume). The average density is between 9100 and 16,000 people per km². At the same time the main service centre, with usually over 50% of all service establishments, is also situated in the central zone, and therefore fulfils two functions, that of a service and that of a residential district.

The transition zone is not always found as its development is connected with one of two opposed processes, (1) the ageing of fixed assets, and (2) their destruction during hostilities. The transition zone does not appear in those towns which were badly damaged during the war (Rzeszów) or those which have been recently developed (Kielce). The area of the transition zone depends on the size of the city core as well as upon the age and type of the buildings. The functions of the transition zone in the medium-sized city are mixed; they combine residential, service and industrial functions, the biggest role being played by the first, which accounts for the high density of population (from 5100 to 9700 people per km^2).

The internal industrial and residential zone occupies the largest part of the core of every settlement system and has the highest percentage of its population (Table 1). Two or three districts, with different size of industrial and storage areas, as well as single specialized service districts, may be found in this zone.

Most industrial and storage areas are situated in the industrial sector. The population living in that area is however small, and its density is therefore also low (from 300 to 1900 people per km^2). The industrial sector is an area fulfilling highly specialized functions, but it is not found in every town.

The industrial and residential sector occurs more frequently. Where industrial establishments and werehouses are found only within the core of the city, between 50% and 90% of all industrial and storage areas of a particular settlement system are situated in this sector. If, however, they are found along with an industrial sector, the percentage falls to about 25. The industrial and residential sector also fulfils a residential function, and from 17% to 32% of the city's population live there (or from 13.6% to 24.0% of the total population of a particular settlement system); the average density of population varies between 1200 and 3000 people per km^2. The sector may occupy up to 45% of the city's total area, or up to 22.7% of the area of a settlement system.

The residential sector is the most common type. Housing is its main function although this may be combined with some other much less important functions. Irrespective of the unilaterally developed housing functions, the density of population is lower than in the industrial and residential sector (Table 1). The size of both sectors are however very similar. Sometimes special service districts have developed within the residential sector.

The last of the functional zones occurring within the city's administrative boundaries is the peripheral zone. Its size is related to the degree of concentration of its internal structure. In the "filled-up" structures (Werwicki 1973) the peripheral zone does not extend over more than 40% of the city's administrative area (22.3% of the area of the total settlement system) and does not appear in the form of a continuous belt surrounding the internal industrial and residential zone. In the "island-like" structures the peripheral zone is much larger and accounts for 55–69% of the city's administrative area (25.8–58.0% of the total area of the settlement system). Its main components are a belt of open area, and the peripheral industrial and residential zone (Table 1) which may also have separate residential districts and separate structural units. The population inhabiting these two components of the peripheral industrial and residential zone is small (from 2 to 5% of the population of the total settlement system); so too is the density of population (a few hundreds per km²). However the industrial and storage areas of the separate structural units sometimes account for as much as 36%–64% of their total in the whole city.

The fifth fuctional zone of every settlement system, called the outer or suburban zone, lies outside the administrative boundaries of the city. Its size varies according to type [1]. The area of the outer zone within an open system is much larger than that of all the other structural components together. The undeveloped types account for only 15% of the total area of the settlement system. In elongated outer zones, situated usually along main transport lines, two types of areas are found. Semi-urbanized rural areas, inhabited by agricultural and non-agricultural population (the non-agricultural population just exceeding 50% of the total), are the most common type. The second, much less frequent type, are neighbouring independent production centres, small towns and industrial towns. The average density of population in the outer zones is between 100 and 400 per km².

When the degree of concentration of the internal structure and of the functional zones in medium-sized Polish cities is known, spatial interrelations be-

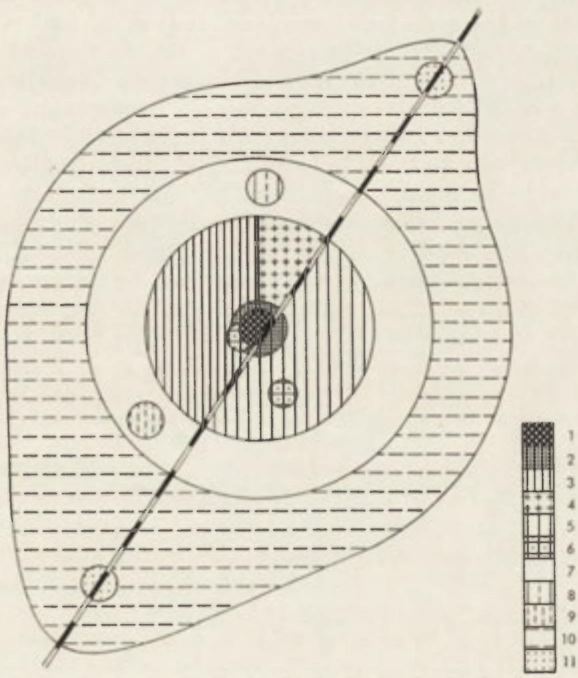

Fig. 2. A model of the internal structure of the medium-sized Polish city

1 — central zone, 2 — transition zone, 3 — industrial and residential sector, 4 — industrial sector, 5 — residential sector, 6 — special service districts, 7 — open areas of the marginal zone, 8 — separate residential districts of the marginal zone, 9 — separate structural units of the marginal zone, 10 — semiurbanized rural areas of the outer zone, 11 — independent production centres of the outer zone

[1] The author differentiated three basic types of outer or suburban zones: open, closed and undeveloped. In type I the outer zone of one town merges with the outer zone of another similar urban centre and can therefore not easily be delimited. In type II the outer zone is an easily differentiated complex, surrounded on all sides by non-urbanized agricultural land.

tween the separate zones can be analysed; in other words a model of their internal structure can be constructed.

Research carried out so far has included only those cities which are regional service centres, and one industrial town. Recently, investigations have been started into a two-functional town, Inowrocław, which is an industrial centre and a health resort. Even from the limited amount of data gathered together so far one can venture that, irrespective of its economic base, the pattern of the functional zones can be represented in one model, namely the concentric-sectoral-polynuclear model (Fig. 2). Its concentric components are: I. city centre, II. transition zone, III. internal residential and industrial zone. IV. peripheral zone, and V: outer zone. Sectoral components occur only in the internal industrial and residential zone and include 1. industrial, 2. mixed industrial and residential and 3. residential sectors. The industrial sector is the only one which is typically sectoral, whereas the other two are often shaped as interlaced rings. Service districts and peripheral settlement centres of the peripheral and outer zones make up the polynuclear elements. The genesis of their polynuclear character is however completely different. In the case of service districts it has been caused by localization tendencies, typical of service establishments, whereas the polynuclear character of the marginal industrial and residential zone is due to the history of the settlement system of the area in which the city lies, and in particular to the rate of its spatial expansion. The character of the peripheral zone in a developing town resembles a protoplasm, as it is a part of the town *in statu nascendi.* The gradual formation of new districts takes place within its boundaries; the districts may appear as belts situated along the transport lines or develop as planned locations of new industrial works and residential estates. The polynuclear character of the peripheral zone is therefore identical with that associated with the elements contained in the model constructed by Ch. D. Harris and E. L. Ullman (1945).

The model presents the ideal pattern, and the internal structure of the medium-sized Polish cities analysed so far, is similar. Differences in the economic

TABLE 2. Relative size of functional zones in industrial and service cities

Zone	Industrial city (Tarnów)		Service city (7 voivodship cities)	
	area %	population %	area %	population %
Total settlement system (zones I–V)	100	100	100	100
I. Central zone	0.6	18.1	1.8	29.0
II. Transition zone	.	.	2.4	9.8
III. Internal industrial and residential zone	7.6	36.2	21.3	38.2
IV. Marginal zone, total	31.8	22.5	24.3	2.3
of which: (A) separate structural units	6.7	9.7	2.0	1.2
(B) separate residential districts	10.0	12.8	0.7	1.1
City within its administrative boundaries, total (zones I–IV)	40.0	76.8	49.8	79.3
V. Outer zone	60.0	23.2	50.2	20.7

base do not cause any great deviation from the model, but make the functional zones or their components (Table 2) vary in size. This phenomenon is illustrated in Fig. 3, and is compiled on the assumption that the area and number of inhabitants are equal in both types of the cities. From the picture obtained one can see the differences in the internal structures of the cities, resulting from their varied economic bases.

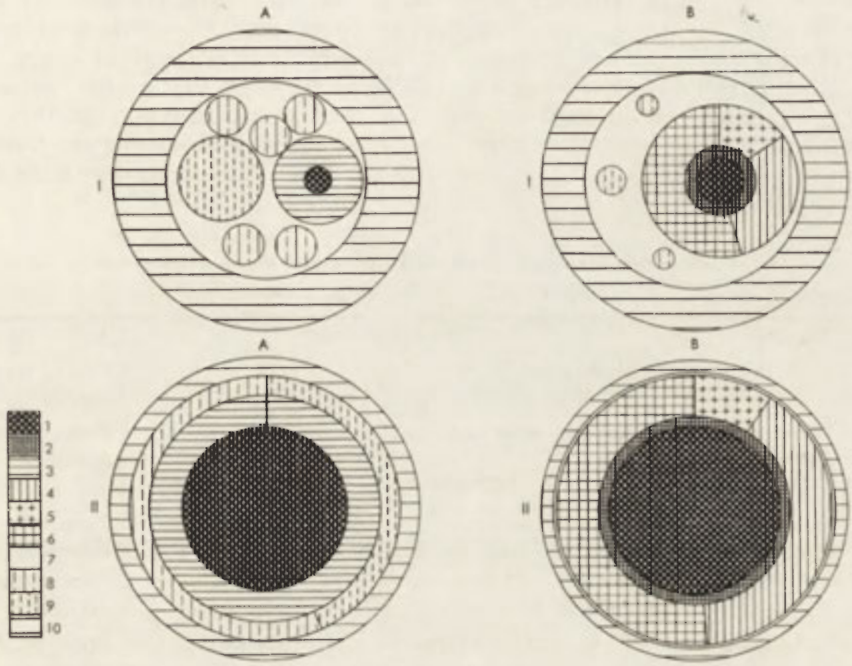

Fig. 3. Relative size of functional zones in industrial and service cities

I — in relation to the areas: A — industrial city, B — service city, II — in relation to the population: A — industrial city, B — service city, 1 — central zone, 2 — transition zone, 3 — internal industrial and residential zone of the industrial city, 4-6 — internal industrial and residential zone of the service city: 4 — industrial and residential sector, 5 — industrial sector, 6 — residential sector, 7-9 — marginal zone, 7 — open areas, 8 — separate residential districts, 9 — separate structural units, 10 — outer zone

The most striking difference is the much larger area of the city centre in service towns than in industrial towns. The percentage of population in the centre was however almost the same in both types of towns.

The service towns are characterized by a much larger internal industrial and residential zone and by a greater population in this zone. This is particularly evident in the residential sector. Their peripheral zone (Table 2), the separate structural units and residential districts (Fig. 3) in particular, are smaller. In the industrial towns the above mentioned components of the peripheral industrial and residential zone are much larger, especially their separate structural units where big industrial works have been located. The percentage of population in the peripheral zone is also much higher in industrial towns than in service towns.

Differences in the size of the outer zone in both fuctional types, covered by the described analysis, are negligible. However, the industrial town has a slightly larger outer zone; its population is also more numerous (Table 2).

To complete these remarks on the model of the medium-sized Polish town it seems worth while pointing out that this study was based upon completely different data to those used in the American models mentioned at the beginning of the paper. In the concentric scheme the main emphasis is laid on the social differentiation of urban areas, and not on economic differences. The main objective in the sectoral scheme is the delimitation of residential sectors, corresponding to residential districts inhabited by various social classes. The polynuclear scheme mainly serves to explain the genesis of the settlement system of the studied cities and not to determine their current internal structure.

Because of the different approach to the problem of the internal structure of cities the Polish model does not resemble the American. Although there are similarities in the terminology of the functional zones, those terms are however semantically different, which is clearly evident from Table 3 (cf. the definitions of the zones).

TABLE 3. Functional zones in Tarnow and the 7 studied cities compared with the Burgess model

<table>
<tr><th></th><th>Tarnów</th><th colspan="3">7 voivodship cities</th><th>E. W. Burgess</th></tr>
<tr><td rowspan="3">Central zone (A)</td><td>Centre proper (1)</td><td colspan="3">Central zone (I)</td><td>Central business district</td></tr>
<tr><td>Mixed industrial and residential ring (2)</td><td colspan="3">Transition zone (II)</td><td>Zone of (in) transition</td></tr>
<tr><td>Industrial and storage sector (3)</td><td colspan="2">Residential sector (3)
Mixed industrial and residential sector (2)
Industrial sector (1)</td><td>Internal industrial and residential zone (III)</td><td>Zone of independent working-men's homes</td></tr>
<tr><td rowspan="3">New urban zone (B)</td><td>Intermediate ring</td><td colspan="2">Belt of open area (1)</td><td rowspan="3">Marginal zone (IV)</td><td rowspan="3">Zone of better residences</td></tr>
<tr><td>New industrial and storage zone (6)</td><td>Separate structural units (a)</td><td rowspan="2">Marginal industrial and residential zone (2)</td></tr>
<tr><td>New residential and service zone (5)</td><td>Separate residential districts (6)</td></tr>
<tr><td colspan="2">Transition zone (C)
Outer zone (D)</td><td colspan="3">Outer zone (V)</td><td>Outer zone (Commuters' zone)</td></tr>
</table>

The model of the internal structure of the medium-sized Polish city is neither purely concentric, sectoral or polynuclear. The elements of all the three patterns are reflected in the model and this is evidence that the separate functional components are distributed within the city according to various spatial schemes. However the dominant form is the concentric pattern resulting from the distance separating such areas from the centre of the settlement system. The shorter the distance the greater the concentration of its functional components and the greater the integration of the individual districts of the city. Consequently there are few elements of the polynuclear pattern within the core of the settlement system, but they occur more frequently in the peripheral areas of the city, i.e. in the peripheral industrial and residential zone. Sectors (in zone III, see Table 1) are related to localization tendencies, characteristic of the separate functional components of the city.

The Polish model is therefore based upon the same main principle as the model constructed by P. D. Salins (1917), namely upon the co-appearance of the three so far known forms of the city's internal structure.

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THE SPATIAL INFLUENCE OF THE GDAŃSK AGGLOMERATION

JERZY DĘBSKI

INTRODUCTION

Port towns have their own specific type of production, resulting from the concentration of several aspects of economic life around the loading and storage activities of seaports. Most of the enterprises concerned with the economy of the sea are located in the port or its hinterland and include production and repair dockyards, fishing and fish processing (industry), building and assembly enterprises (building), sea navigation, enterprises concerned with loading and unloading, customs control and despatch of goods, and sea administration (transport), and the headquarters of agencies for foreign trade (trade turnover). In addition we also find enterprises which are partly or not at all concerned with the sea. Thus one can speak of a port-oriented economy and an urban-oriented economy (or "neutral" with respect to the port) and also an intermediate economy. This division, which emphasizes the characteristic production of ports, differs from the classical division into exo- and endogenic groups. One must emphasize at this point that enterprises which are port-oriented and neutral can equally belong to both groups. In contrast with the concepts used in the theory of the economic base the economy of a port will be divided not into groups but into sectors with a defined orientation. Intermediate type enterprises may also be included in the neutral sector since they can be located both at the coast and far inland. The flow of goods which links the economy of coastal centres with their hinterlands define the size of the port and neutral functions. Not enough has been written about the characteristic function of ports using this approach [1]. Geographers have concentrated mainly on monographs and on the influence of ports on their hinterlands and forelands [2]. The functional structure of seaports has received far less study, and then mainly by economists rather than geographers. The study of this topic was first taken up by P. de Rousiers and continued by J. Courtois, A. Bown, J. Tonegrais and others who continued using his concept but introduced certain additions and modifica-

[1] The terminology was borrowed from the work of D. Krafft (1966), who studied the spheres of economic life in selected towns in West Germany. In the port oriented spheres he included those branches which have a much faster rate of development in port towns than in towns which are not port oriented. E. Adrjanowska (1971) studied the spatial productive links of the Gdańsk shipyards. Her work showed that 2/3 of the supplies to these shipyards come from southern and central Poland.

[2] For example A. J. Sargent (1938), G. G. Weigend (1958), A. Piskozub (1961), J. Mikołajski (1964), W. Barczuk (1966) and K. Piotrowski (1969).

tions [3]. In general the available literature has been limited to the affairs of the port and its influence on the hinterland and foreland, and has isolated these questions from the totality of the port's activity. Therefore the purpose of the present study is to investigate the spatial links in the economy of the Gdańsk Agglomeration [4] and its hinterland. To do this we looked at the flow of goods. The choice of the Gdańsk Agglomeration as our object of study was dictated by its being the largest settlement structure on the coast and thus the port and neutral functions could be more easily compared and contrasted.

INTRODUCTORY MATERIALS AND THE METHOD USED

The statistical investigation required by our topic necessitated gathering data on the following: 1. employment in the socialized economy of the Gdańsk Agglomeration, in 1965, 2. incoming and outgoing goods in the area of the settlement group mentioned.[5] For both of these the basic statistical unit was the place of work. Two quantitative criteria were looked at: employment and goods

TABLE 1. The objects and field of the statistical investigations (1965)

No.		Unit	Features studied	Field of investigation
1	Socialized economic units of the Gdansk Agglomeration	Factory	Number of employed excluding apprentices	The 7 towns of the agglomeration
2	Goods sent out from the Gdansk Agglomeration and goods brought in	Factory	Tonnage above 1 ton Value above 100,000 zl per factory	Poland by voivodships

[3] According to P. de Rousiers the port fulfills three functions: (a) a regional function, in relation to incoming and outgoing goods, which represent the size of the production and the consumption potential of the surrounding region, (b) an industrial function, in relation to raw materials and semi-manufactured goods arriving by sea to factories located in the port, to be processed and refined, (c) a trade function, in relation to goods arriving by sea, and which after several trade procedures are re-exported to other ports. T. Szczepaniak looks at this in detail (1967, pp. 12–16), and also distinguishes a transport function of a port concerned with loads.

[4] The Gdańsk Agglomeration includes the core, i.e., Gdańsk, Sopot, and Gdynia, and an internal zone taking in Pruszcz Gdański, Reda, Rumia and Wejherowo. An external zone (according to E. Iwanicka-Lyra 1969, p. 70) was excluded from this study.

[5] The statistical data on goods flows (for 1965) was collected from 25 despatch centres and regions of the Polish National Railways, from 5 centres of the National Despatch Company, and from 8 public and trade car transport enterprises within the Gdańsk Agglomeration. The loads transported, which were investigated using estimates, make up 92–95% of all incoming and outcoming external flows. Since the lowest goods flow figure was 102,000 zl for one factory for one year, any economic unit with a value exceeding 100,000 zl was assigned to the group of external factories.

tonnage, the latter being converted into monetary units (W. Morawski 1967). Goods flow presented in these units most accurately expresses the economic character of the links between towns and ports and their hinterland (Table 1).

Our method of investigation required us to define the extent of the external economy of the Gdańsk Agglomeration, i.e., to establish the number of enterprises (according to employment) involved in one way or two-way links with the area of the country. We could establish the size of the port or neutral oriented sectors within the framework of the external economy, only after we had carried out such a division. One must emphasise that the external group cannot be identified with the economic base of a town. It is merely a part of the exogenic group within our understanding of the theory of the economic base, since only the Gdańsk Agglomeration's goods links with its hinterland and not its whole external influence were investigated.

The next step was to calculate the extent of the spatial links of both sectors; as our starting data the following quantities were used:

(a) the average distances ("weighted") of each voivodship from the "zero point", i.e., the geometric centre of the agglomeration (D_1, D_2.....D_{17});

(b) the values of the goods flow (t_1, t_2.....t_{17});

(c) the total mass in each voivodship involved in the links with the agglomeration (z_1, z_2......z_{17}).

Standardized flows were established according to the equation:

$$k_n = \frac{t_n}{z_n}; \quad (n = 1, 2, \dots 17); \tag{1}$$

After calculating the linear distances of the voivodships from the "zero point" we calculated the index of flow weighting (V):

$$V_n = D_n \cdot k_n \tag{2}$$

The variable k_n can be interpreted as the potential generated in the n-th voivodship by the total mass of the agglomeration. Taking the gravitation potential model formulated by J. Q. Stewart (see Z. Chojnicki 1966, p. 25).

$$P_a = \frac{G \cdot M}{d} \tag{3}$$

where G is a constant, M is the mass of the object generating the potential and d is the distance from the point to this object, we than have:

$$P_a \cdot d = GM = \text{a constant}, \tag{4}$$

In our case:

$$V_n = k_n \cdot d_n = \text{a constant}. \tag{5}$$

Under these conditions all the points (n,V_n) must lie on a straight line which has the equation V = a constant.

We took the arithmetic average (m) of the variable V as the value for comparison, and for measuring the dispersion — the variation. To measure the dispersion we used the coefficient of variance (W_z) which is an approximate measure:

$$W_z = \frac{\sqrt{s^2(v)}}{m}$$

Next, using the Chi-square test[6] we established the relationship between the size of the links of each voivodship and the distance of each voivodship from the Gdańsk Agglomeration.

The last stage was to test the correlation between the active and passive links for each sector.

DEFINING THE ECONOMY OF THE GDAŃSK AGGLOMERATION BY GOODS FLOW

The economic activity of a large port like the Gdańsk Agglomeration requires the transport of a certain mass of goods, connected with wide production and consumption. The volume of the transported goods depends on the type of economic activity of the productional and non-productional units which act as customers for the transport enterprises. The participation of these enterprises in the total volume of goods varies and partly depends on their type of transport. Thus industrial enterprises located in the port agglomeration take in above all fuel, raw materials, semi-manufactured goods, machinery and equipment, which are then used for the final product (the shipbuilding industry for instance). Finished goods and local semi-manufactured goods must be taken out, as must also useful and unwanted productional by-products going to other industrial enterprises and warehouses storing scrap and by-products. It must be pointed out that since we are studying only the spatial links between the Gdańsk Agglomeration and its hinterland we are omitting the end effect (ships) of the productional activity of the dockyards.

The next branch of the economy, building, like industry embraces different fields of work, but unlike industry the elements of production in building must be brought to the building site and not the enterprise. Building activity in a town requires:

(1) A supply of machinery and equipment, building and prefabricated materials, installation equipment and various other useful materials.

(2) Removal of earth from the site and of the machinery and building equipment after they have been used. Also the site must be cleared and tidied after building has been completed. A characteristic feature of supply in building is the large tonnage of the loads, arising not out of economic exchange but having the character of technological transport.

The external transport links of the next branch of the economy of the Gdańsk Agglomeration is defined by two types of goods flow.[7] First, there is the flow connected with the productional activity of the transport units and with the maintenance and extension of railways and roads. These units include the despatch section of the Polish National Railways, engine sheds, enterprises which upkeep transport and communications, car agencies, port administrations, districts operating public roads etc. Second, there is the flow embracing goods directed to and from the port. Recipient and sender in both cases are the despatch enterprises.

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[6]
$$\chi^2 = n \sum_{n=1}^{3} \sum_{j=1}^{3} \frac{\left(n_{ij} - \frac{n_i \cdot n_j}{n}\right)^2}{n_i \cdot n_j}$$

(M. Fisz, 1967, pp. 473–476).

[7] Excluding postal communications, because we exclude parcels which are typical of this division.

A different kind of flow arises out of the activity of foreign trade agencies. These agencies are allocated to the division of "goods turnover" in the classification of the National Economy (*Klasyfikacja*... 1967, p. 29). Trade enterprises which supply ships with commestible and industrial articles order goods straight from the producer, from the wholesaler and from inland warehouses. Part of the flow is derived from the import and export of goods, which is the concern of the head office of foreign trade and of the export agencies of internal turnover.[8] To this division of "goods turnover" belong also those enterprises of internal trade found within the Gdańsk Agglomeration, whose activity is connected with three types of flow. The first type of goods transport results from the central market which supplies industrial enterprises, building sites and other productional units with essential equipment and materials. The second type is that connected with the supply of consumer goods to the population of the Agglomeration. This flow is made up of that from places where products can be bought and of that from wholesalers and industrial enterprises to the warehouses in the Gdańsk Agglomeration. This flow is further extended from the warehouses to the retailers, restaurants, etc. (internal transport is no longer within our field of interest). Wholesalers not only receive but also despatch a large part of their goods, for example the Central Fish Enterprise which supplies local centres throughout the country with fish and fish products. The third type of flow arises from the servicing of the enterprises involved in the internal turnover. They order from other towns equipment, packaging, fuel and other essential materials for the correct functioning and development of the enterprises.

The four divisions so far mentioned, industry, building, transport and goods turnover, despatch and receive from inland 99.7% of the total goods turnover of the economy of the Gdańsk Agglomeration.

Divisions of the economy	Percentage value
Industry	22.7
Building	1.7
Transport	52.5
Goods turnover	22.8
Other	0.3
Total	100.0

Those spheres of the economy whose share of the total flow did not exceed 0.1% were included in the "other" category. These are: agriculture and forestry from the sphere of material production, and all those outside the sphere of material production[9].

As Table 2 shows, the divisions of "transport", "industry" and "goods turnover" have the largest share of the transport of goods. "Transport" easily occupies first place, and this is connected with the external links where the turnover of ports is the chief influence.

165,000 or 66.4% of the total number of 247,000 people employed in the socialized economy of the Gdańsk Agglomeration are workers in factories in-

[8] For example: CSO Export-Import Agency, The Meat Industry Export Services Agency, The Central Sea Supply Agency, The Circulation of Imported Commestibles Enterprise (POSTI) and so on.

[9] This sphere includes: communal economy and housing, education, science and culture, health, social security and physical culture, public administration and justice, finance and insurance institutions, political, social, religious and other organizations (Klasyfikacja..., 1967, p. 11).

volved in the goods links with the hinterland. This part of the external economy was divided into two sectors: port oriented and neutral.

To the first sector were included all those factories having direct links with port activities and whose location outside the area of the agglomeration is economically unsuitable. In the case of industry these will be: (1) factories concerned with shipbuilding, i.e., construction dockyards and some units belonging to the Union of Shipbuilding Industries which act within a framework of so-called internal co-operation; (2) factories concerned with navigation and sea fishing, i.e., repair dockyards and units subordinate to the Union of Sea Repair Dockyards, and enterprises concerned with fishing and fish processing; (3) factories connected with unloading and loading, which include units that repair and hire out the necessary equipment, cold storage units, places where southern fruits can ripen and factories which process easily perishable goods unloaded at port.

TABLE 2. Number of employed and the value of the flow for each economic division of the Gdansk Agglomeration (1965)

Division	Employed in factories			Flow in million zl (according to factories)			Index 6/3
	Together	External		Together	External		
		Number	%		Number	%	
1	2	3	4	5	6	7	8
Industry	94,253	86,608	91.9	17,289.1	14,310.1	82.7	165.2
Building	24,617	19,325	78.5	1,518.8	1,109.5	73.0	57.4
Transport	43,380	31,765	73.2	33,802.6	33,360.9	98.7	1050.2
Goods turnover	26,389	20,434	77.4	16,240.3	14,519.6	89.4	710.5
Other	58,405	7,051	12.1	294.7	217.9	73.9	30.9
Total	247,044	165,183	66.4	69,154.5	63,518.0	91.8	384.5

In the case of building we included in the port oriented sector those building-assembly enterprises which carry out specialized port and sea dockyard work. In transport we include those enterprises concerned with sea transport and despatching (port administrations, ship brokers, charterers, freight consignors, lifeboat points, etc.), but only if they are directly involved in the external links. Apart from enterprises concerned with foreign trade and agencies of sea traffic goods, to the port oriented sector of the "goods turnover" division we also include from an organizational point of view those agencies belonging to the central direction of buying, marketing and wholesaling.

Those remaining economic units unconnected or only indirectly connected with port activities were included in the neutral sector. The whole group of "remaining" activities belong to this sector. A neutral character is found in agriculture and forestry, communal economy and housing, administration [10] institutions of justice and others (political, social and religious organizations). Only education, science and culture and health and social security can be in any way port oriented, but their offices do not have (mass) goods links with

[10] According to the Central Statistical Office (Klasyfikacja..., 1967, p. 58) sea administration belongs to the division of transport.

the hinterland. Thus all the enterprises belonging to the "remaining" spheres must be considered as neutral.

The division of the economy of the Gdańsk Agglomeration done above shows that:

— In the port oriented sector the transport and industry divisions have by far the most workers.

— In the neutral sector the building and goods turnover divisions easily employ the most number of people.

TABLE 3. Number of employed and size of flow in the port oriented and neutral sectors in 1965 (in absolute values)

Division	Port oriented sector			Neutral sector		
	Employment	Flow in million zl	Index 3/2	Employment	Flow in million zl	Index 6/5
1	2	3	4	5	6	7
Industry	53,598	6,039.7	112.7	33,010	8,270.4	250.5
Building	1,825	63.5	34.8	17,500	1,046.0	59.8
Transport	21,386	33,066.2	1,546.2	10,379	294.7	28.4
Goods turnover	2,859	7,795.5	2,726.7	17,575	6,723.9	382.6
Other	—	—		7,051	217.9	30.9
Total	79,668	46,965.1	589.5	85,515	16,552.9	193.6

TABLE 4. Number of employed and size of flow in the port oriented and neutral sectors in 1965 (in %)

Division	Employment			. Flow		
	Sector		Total	Sector		Total
	port oriented	neutral		port oriented	neutral	
Industry	61.9	38.1	100.0	42.2	57.8	100.0
Building	9.4	90.6	100.0	5.7	94.3	100.0
Transport	67.3	32.7	100.0	99.2	0.8	100.0
Goods turnover	13.9	86.1	100.0	53.7	46.3	100.0
Other	—	100.0	100.0	—	100.0	100.0
Total	48.2	51.8	100.0	73.4	26.6	100.0

— The "other" category is neutral in relation to the port. The size of the employment in both sectors is similar, with the neutral sector having a slightly more. The values of the external links of both sectors (arrival and despatch) are arranged rather differently.

— Port oriented industry has weaker links with the hinterland than neutral oriented industry.

— Enterprises concerned with goods turnover and transport which are port oriented have stronger links with the hinterland than those neutrally oriented enterprises belonging to the same divisions.

— The reverse situation occurs in the building and "other" categories where neutral oriented enterprises have the stronger links.

— The port oriented sector has by far the stronger two-way links with the hinterland.

The division into transport and goods turnover so far used in the first sector is not suitable for the next stages of this study. Enterprises belonging to these two divisions are connected with the loading and unloading activity of seaports and should therefore be considered together since their spatial links define the size and extent of the hinterland. Apart from this there are similarities in production between the industry and building divisions, which H. H. McCarty and J. B. Lindberg drew attention to (1969, p. 241).

In building goods flow is nearly completely tied up with the activities of building and essembly enterprises, and thus the generalization used earlier is still suitable. Finally both sectors of the Gdańsk Agglomeration were divided as follows:

Neutral oriented sector	Port oriented sector
(1) Spheres of production of materials (industry, building)	(1) Same as under neutral
(2) Spheres of transport and turnover of materials (transport and goods turnover)	(2) Same as under neutral
(3) Other spheres	

The spatial links of the port and neutral oriented sectors will now be considered with this modified division of the economy into groups of spheres and not spheres in mind. Using the methods of measurement described below we wanted to establish whether the strength of the links increases or not with increasing distance from the agglomeration.

THE SPATIAL LINKS OF THE PORT AND NEUTRAL ORIENTED SECTORS

Before the spatial links of the port and neutral oriented sectors could be investigated a central (zero) point from which measurements could be made has to be fixed. This "zero point" is the geometric centre of the Gdańsk Agglomeration, and is located between Kamienny Potok in Sopot and Orłowo in Gdynia. To measure distances from this point straight lines were drawn linking each settlement centre in Poland which had goods links (one-way or two-way) with the agglomeration. This measure does not of course correspond to the actual routes of the transport arteries but is the same for all settlement units. Using the distances of each centre from the agglomeration the average distances of each *poviat* and the average (weighted) distances of each voivodship were calculated. The "weight" was the area of a *poviat* taking part in the goods flow; the average was the distance of the n-th voivodship.

Next the average distances of the voivodships were arranged in order of increasing distance from the zero point.[11] The size of the goods flow between

[11] The voivodships arranged by average distance D are: 1. Gdańsk (52 km), 2. Koszalin (148 km), 3. Olsztyn (152 km); Bydgoszcz (154 km), 5. Szczecin (264 km), 6. Poznań (270 km), 7. Warszawa (278 km), Białystok (302 km), Łódź (316 km), 10. Zielona Góra (334 km), 11. Wrocław (404 km), 12. Kielce (414 km), 13. Opole (428 km), 14. Katowice (456 km), 15. Lublin (458 km), 16. Kraków (508 km), 17. Rzeszów (548 km).

TABLE 5. The goods links of the port oriented sector by voivodships (in million zl) in 1965

Voivodship No.	Industry and building		Transport and goods turnover		Together	
	receiving	despatch	receiving	despatch	receiving	despatch
1	626.0	120.2	715.3	97.8	1,341.3	218.0
2	190.5	154.6	125.0	556.9	315.5	711.5
3	700.0	112.9	225.0	534.7	925.0	647.6
4	211.5	132.2	1,955.5	831.5	2,167.0	963.7
5	116.6	63.9	374.0	317.5	490.6	381.4
6	313.4	236.2	1,522.6	1,466.9	1,836.0	1,703.1
7	85.4	104.7	1,348.3	2,033.8	1,433.7	2,138.5
8	14.5	21.0	173.7	171.0	188.2	192.0
9	91.5	94.4	2,144.5	4,351.6	2,236.0	4,446.0
10	61.9	49.9	262.8	541.1	324.7	591.0
11	191.9	106.5	988.7	1,633.0	1,180.6	1,739.5
12	137.6	34.2	661.2	549.0	798.8	583.2
13	69.5	37.9	334.7	737.2	404.2	775.1
14	943.9	114.9	1,071.0	3,729.6	2,014.9	3,844.5
15	75.4	32.5	377.5	460.0	452.9	492.5
16	374.8	118.8	1,615.4	764.9	1,990.2	883.7
17	171.6	75.2	389.8	319.6	561.4	394.8
Total	4,376.0	1,610.0	14,285.0	19,096.1	18,661.0	20,706.1

TABLE 6. The goods links of the neutral sector by voivodships (in million zl) in 1965

Voivodship No.	Industry and building		Transport and goods turnover		Other		Together	
	receiving	despatch	receiving	despatch	receiving	despatch	receiving	despatch
1	645.6	347.0	623.4	271.6	12.4	10.8	1,281.4	629.4
2	170.5	305.1	89.7	25.8	6.8	3.8	267.0	334.7
3	241.9	209.9	368.6	215.6	8.4	0	618.9	425.5
4	295.5	421.3	407.3	208.8	28.3	0.5	731.1	630,6
5	144.2	210.5	259.1	25.4	2.2	2.6	405.5	238.5
6	224.5	421.4	204.8	111.3	6.1	0.1	435.4	532.8
7	537.1	644.8	284.7	132.8	10.4	0.5	832.2	778.1
8	183.2	81.5	49.4	110.3	11.9	5.3	244.5	197.1
9	274.8	288.0	576.4	42.0	12.8	0.2	864.0	330.2
10	93.1	97.7	80.2	16.3	1.6	0	174.9	114.0
11	272.9	410.6	420.5	72.9	9.4	0	702.8	483.5
12	100.5	95.2	260.1	110.7	0.7	0.5	361.3	206.4
13	132.9	36.2	178.9	13.7	3.0	0	314.8	49.9
14	573.9	415.2	738.5	215.2	46.5	4.1	1,358.9	634.5
15	108.2	114.3	81.7	105.6	8.9	0.2	197.8	220.1
16	410.1	249.0	421.8	39.5	7.6	5.4	839.5	293.9
17	80.7	127.9	74.9	47.9	3.4	0	159.0	175.8
Total	4,489.6	4,475.6	5,119.0	1,765.4	180.4	34.0	9,789.0	6,275.0

each voivodship and the sectors and economic divisions of the Gdańsk Agglomeration is set out in Tables 5 and 6, and on Figs 1–4.

Because each voivodship which has links with the agglomeration has a different mass the absolute sizes of the flows cannot be compared. The flows were therefore standardized (using equation 1) using the number employed in the socialized economy of the n-th voivodship [12]. In selecting an index of mass the following were taken into account:

(a) the size of the employed in the socialized economy of each voivodship corresponds to the mass of a voivodship.

Fig. 1. Passive links (received goods) of the port oriented sector with each settlement centre in Poland

1, 2, 3, 4, 20 — isolines of 10, 20, 30, 40 and 200 million zl. Numbers standing close to the names of the biggest towns express that the passive links of the port oriented sector reach their highest values. GOP = Upper Silesian Industrial District

[12] The number of employed in the socialized economy of each voivodship in 1965 (in thousands): Gdańsk 171.1, Koszalin 192.8, Olsztyn 213.6, Bydgoszcz 438.4, Szczecin 264.7, Poznań 643.0, Warszawa 1037.2, Białystok 194.4, Łódź 674.3, Zielona Góra 243.5, Wrocław 782.9, Kielce 352.6, Opole 291,6, Katowice 1357.0, Lublin 318.4, Kraków 683.0, Rzeszów 329.5.

(b) a more accurate index would be to weight the population of a voivodship by looking at national income per person, but this would be difficult to obtain.

(c) it would be confusing to use other indices, such as the value of industrial production or the size of investment, since each voivodship has a different economic structure and level of investment.

(d) the movement of goods between each sector and the rest of the country is carried out through the socialized economy. This also includes agricultural produce despatched by socialized agencies (buying enterprises).

One should point out that the number employed in the Gdańsk voivodship was reduced by 247,044 people who work within the agglomeration, since the links investigated were the external ones.

When the flows had been standardized and the distances of each voivodship from the zero point were known, it was possible to calculate weighted indices of flow (equation 2). Under ideal conditions, i.e., when the strength of

Fig. 2. Active links (despatched goods) of the port oriented sector with each settlement centre in Poland

1, 2, 3, 4, 20 — isolines of 10, 20, 30, 40 and 200 million zl. Numbers standing close to the names of the biggest towns express that the active links of the port oriented sector reach their highest values the links decrease with increasing distance from the agglomeration, the values of this index will lie on the straight line according to the equation V = a constant.

The course of the variable V is shown on Fig. 5. The first two graphs show the active (despatch) and passive (receiving) links of the port oriented sector, and the last two the same links in the neutral sector.

The lines linking up the individual points on the graphs should be used only as an aid because of the discontinuities in the phenomena studied. The continuous line shows the values for the whole sector, while the long broken lines show the values for transport and goods turnover and the shorter broken lines the values for industry and building. In our investigation, as the level of comparison of the variable V we took its average, and to measure dispersion — its variation (equations 6 and 7). Because the phenomena looked at are found on different levels, we used the coefficient of variance, which is an approximate measure of the dispersion, to measure its distribution (equation 8). Zero varia-

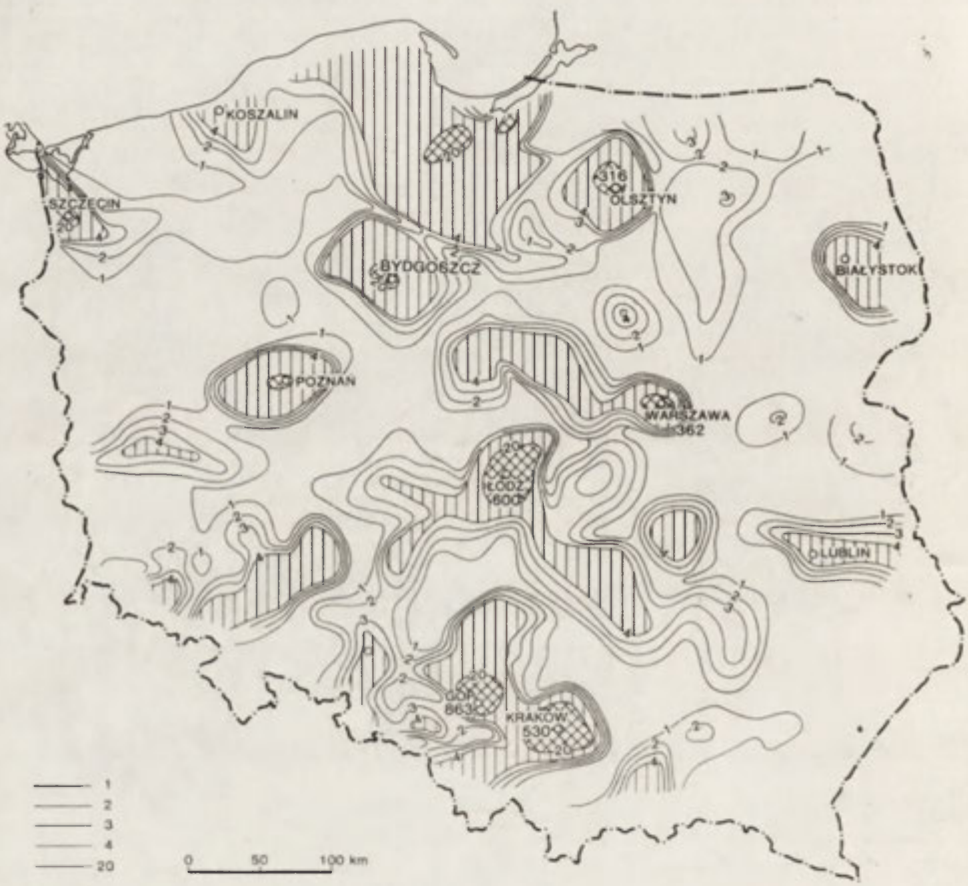

Fig. 3. Passive links (received goods) of the neutral sector with each settlement centre in Poland

1, 2, 3, 4, 20 — isolines of 10, 20, 30, 40 and 200 million zl. Numbers standing close to the names of the biggest towns express that the passive links of the neutral sector reach their highest values tion occurs when all the deviations from the average are zero. This is possible if all values of the variable V are equal and these values are the same as their averages. We may speak of a total lack of variation in the variable V. However, the larger the variation and thus the larger the coefficient of variance, the greater will be the differentiation of the index studied and the greater will be the deviation from the links which become weaker with increasing distance.

From Table 7 one can see that the active links of the port oriented sector have the largest coefficient of variance (59%). This is explained by the large positive deviation of the variable V from its mean (see Fig. 5). The passive links of this sector have a somewhat smaller coefficient of variance (41%). Port oriented transport and goods turnover have a higher deviation for despatch ($s/m = 67\%$) than for receiving ($s/m = 56\%$); port oriented industry and building shows the opposite situation. This is because the passive links of industry (and also of port oriented building) reach far into the country. This is evidenced by the positive deviation of the variable V for areas at some dis-

Fig. 4. Active links (despatched goods) of the neutral sector with each settlement centre in Poland

1, 2, 3, 4, 20 — isolines of 10, 20, 30, 40 and 200 million zl. Numbers standing close to the names of the biggest towns express that the active links of the neutral sector reach their highest values

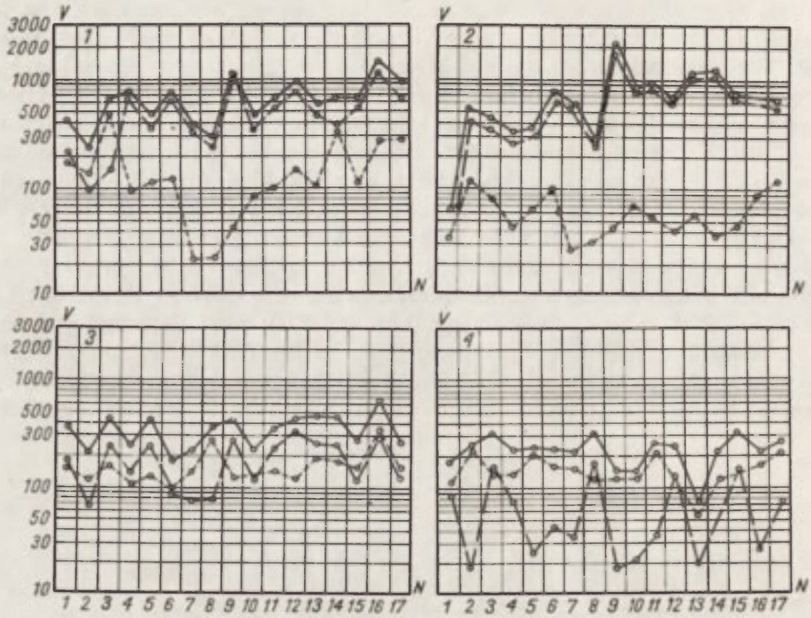

Fig. 5. Active and passive links of the port oriented sector (1–2) and active and passive links of the neutral sector (3–4)

N — voivodships (1–17) arranged in order of increasing average distances ("weighted") from the "zero point", V — coefficient of potential created in n-th voivodship by the mass of Gdansk Agglomeration multiplied by the average distance ("weighted")

TABLE 7. The average values of the variation and coefficient of variance of the variable V

Sectors and groups of division		m	s^2	s/m
		Port oriented sector		
Industry and building	*r*	157.8	14,509	0.764
	d	62.8	837	0.460
Transport and goods	*r*	511.7	81,375	0.558
turnover	*d*	663.7	200,942	0.675
Total for the sector	*r*	669.4	79,546	0.412
	d	723.9	182,621	0.590
		Neutral sector		
Industry and building	*r*	162.8	2,889	0.329
	d	157.1	2,013	0.286
Transport and goods	*r*	184.0	7,463	0.469
turnover	*d*	68.9	2,590	0.739
Other	*r*	6.4	23	0.750
	d	2.0	5	1.150
Total for the sector	*r*	353.2	12,846	0.321
	d	227.4	3,636	0.265

r — receiving, *d* — despatch

tance from the zero point (the Katowice, Kraków and Rzeszów voivodships). On the other hand the active links of these two divisions, omitting their influence on the foreland of course, are partly local in character (co-operative links). Because of this the coefficient of variance for receiving is almost double that for despatch. In the neutral sector the coefficient *s/m* is much smaller because of the small positive and negative deviations of the variable *V* from its mean. This is true mainly of despatch where the coefficient of variance is half that of the port sector (26% : 59%). Particularly notable is the high coefficient for transport and goods turnover (which have far reaching links), which is nearly three times greater than that for industry and building which have mainly local links. The "other" category has very high *s/m* values. This is a result of the discontinuity of the links of this group, since only 12 voivodships have any active links.

Thus only in the neutral sector, which has small values of the coefficient *s/m*, can one expect to find some relation between the size of the links of each voivodship and distance from the agglomeration. To test the validity of this phenomenon we used the Chi-square statistic dividing the voivodships as follows: close ones, whose average distance is below 200 km (zone I); medium, from 201 to 400 km (zone II); distant voivodships, over 401 km (zone III). They were also divided by the activity of their links into high (1), medium (2) and low (3).

(1) Highly active voivodships are those for which:

$$x_{min} + \frac{2}{3}(x_{max} - x_{min}) < x \leqslant x_{max} .$$

(2) Medium active voivodships:

$$x_{min} + \frac{1}{3}(x_{max} - x_{min}) < x \leqslant x_{min} + \frac{2}{3}(x_{max} \quad x_{min})$$

(3) For little active voivodships:

$$x_{min} < x \leqslant x_{min} + \frac{1}{3}(x_{max} - x_{min})$$

Using the Chi-square test we then tested the dependence between the distance and activeness of the links (see footnote 6).

After substituting the data:

$$n_I = 4, \quad n_{II} = 6, \quad n_{III} = 7$$

$$n_1 = 8, \quad n_2 = 1, \quad n_3 = 8$$

For the received goods we get: $\chi^2_{[4]} = 3.19$

Because the number of degrees of freedom is $(3-1)(3-1) = 4$, then using the tables:

$$P(\chi^2_{[4]} \geqslant 3.19) \approx 53.0\%$$

Similarly, after substitution we obtain for the despatched goods:

$$n_I = 4, \quad n_{II} = 6, \quad n_{III} = 7$$

$$n_1 = 7, \quad n_2 = 4, \quad n_3 = 6$$

then:

$$\chi^2_{[4]} = 4.67$$

$$P(\chi^2_{[4]} \geqslant 4.67) \approx 33\%$$

There is a large probability of non-dependence (greater than 1/2) in the case of received goods, and thus there are no grounds for believing that the size of the links of each voivodship in the neutral sector of the Gdańsk Agglomeration in any way depends on the distance from the zero point. For despatched goods (active links) there is such a dependence; the probability of there being no dependence is smaller (33%), but is much greater than the 5% level of significance generally used in statistics. In relation to the port oriented sector the increment of the neutral sector is undoubtedly of a more local character.

Therefore we may say that there is no dependence between the arrangement of the active spatial links of both sectors and between the passive links. In statistics a measure of this dependence is the correlation coefficient (with values $-1 \leqslant \varrho \leqslant 1$), which can be calculated by the equation given by M. Fisz (1967, p. 98)[13].

In calculating the correlation coefficients for the passive links the following symbols are employed:

$N_{n.}$ = received goods to the neutral sector from the n-th voivodship,

$P_{n.}$ = received goods to the port oriented sector from the n-th voivodship.

Thus: $$\varrho_{N.P.} = \frac{Cov(N.P.)}{S_{N.} \cdot S_{P.}} = + \frac{2348681}{2915151} = +0.865$$

The correlation coefficient for the active links can be similarly calculated:

$N_{n,}$ = despatched goods from the neutral sector to the n-th voivodship,

P_{n} = despatched goods from the port sector to the n-th voivodship.

Thus: $$\varrho_{N,P,} = \frac{Cov(N,P,)}{S_{N,} \cdot S_{P,}} = - \frac{128624}{1058070} = -0.122$$

From the above we can see that the correlation coefficient for the passive links is high (positive correlation), and for the active links very low (negative). Thus we can say there is no dependence whatever.

SUMMARY

The investigation shows that all the economic divisions of the Gdańsk Agglomeration, although not all the factories, have external links. Moreover over 99% of the goods flow is connected with four productional divisions: industry, building, transport and goods flow.

The "external" units belonging to these divisions may be considered as the basis of the material activity of the agglomeration studied, since they are the cause of the origin and flow of goods. They have 64% of the total employed in the socialized economy of the Gdańsk Agglomeration.

Dividing the external economy into the two sectors, and then comparing them, showed that the neutrally oriented factories, having most of the employment, nevertheless had a weaker spatial influence than the port oriented factories. This is expressed by the percentage ratio of 26.6 : 73.4. In these links

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[13] $$\varrho_{NP} = \frac{1}{17} \sum_{n=1}^{17} \frac{(N_n - m_1)(P_n - m_2)}{S_1 \cdot S_2}$$

where m_1, m_2, S_1^2, S_2^2 are the appropriate average values, and the variations of the variables N and P, having values for both the port and neutral oriented sectors.

two zones of influence may be distinguished. The first zone has a very local character and concerns links of the neutral sector, although only in despatching can one find a more or less continuous decrease in the strength of the flow with increasing distance from the zero point (see the results of the Chi-square test). This is mainly true of industry, whose products largely go to satisfy the regional market. Building, however, uses local raw materials and supplies. The second zone has links of a national character and concerns those links with the port oriented sector. Typical of these links is the wide disproportion between the influence of the seaport and that of port industry and building. If one takes the value of the flows between the port and its hinterland as 100, then the values for the other divisions of the port oriented sector are 14.7% for industry and 1.5% for building. This is because the ports of Gdańsk and Gdynia supply needs to the whole country, as opposed to the mainly one-sided passive links of industry and building.

The correlation coefficients show that there is a large dependence between the passive links of the port and neutrally oriented sectors (+0.865), testifying to a common source of raw materials and supplies. At the same time, measurements of the intensification of the goods flow showed similar values for both sectors, i.e., high values of the coefficients of variance. Therefore the source of raw materials could be common to both sectors, and at some distance.

The active links present the reverse situation. The coefficients of variance show differences, being large for the port sector and small for the neutral sector. Their correlation is very weak (-0.122), and so one can talk about a complete lack of dependence between the phenomena looked at. Thus the markets for both sectors are different; they are distant in the case of the port oriented sector and close for the neutral sector. The above points to the fact that specialized functions, that is the port activities and industry (port oriented), having dispersed country — wide links, dominate the economy of the Gdańsk Agglomeration. Equally the typical functions of large towns (goods turnover and transport of the port-neutral sector) are not merely regional. Apart from the building of houses only industry which is not port oriented has simply a local sphere of influence. This can be taken as evidence of its small productional potential, which is concentrated within the agglomeration with weak links with the rest of the country.

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ERRATUM

to the article by Andrzej Werwicki, p. 124, Table 3.

"Intermediate ring" and "Belt of open area (1)" categories should be included in "Central zone (A)".

Geographia Polonica 28, 1974

TABLE 1. Numerical characteristics of functional zones in studied structures

Functional zones	Areal type 1	Białystok: Areal percentage	Białystok: Percentage of the concentrated functional components	Białystok: Percentage of the total population	Białystok: Population density in thousands per km²	Kielce: Areal percentage	Kielce: Percentage of the concentrated functional components	Kielce: Percentage of the total population	Kielce: Population density in thousands per km²
I. Central zone	A	3.2	39*	23.0	12.5	3.2	80*	30.0	16.0
	B	1.9		20.7		1.2		22.5	
II. Transition zone	A	10.1	·	34.0	5.1	—	—	—	—
	B	6.1		30.8		—	—	—	—
III. Internal industrial and residential zone	A	49.6	49**	37.0	·	63.7	85**	68.0	·
	B	29.9	·	33.6	·	20.3	·	51.0	·
1. Industrial sector	A	—	—	—	—	14.0	60**	14.0	1.9
	B	—	—	—	—	4.5		10.5	
2. Mixed industrial and residential sector	A	26.1	49**	25.0	2.1	22.7	25**	26.0	2.5
	B	15.7		22.7		7.2		19.5	
3. Residential sector	A	23.5	·	12.0	1.0	27.0	·	28.0	1.5
	B	14.2		10.9		8.6		21.0	
IV. Marginal zone	A	37.1	29**	6.0	0.7	33.1	16**	2.0	0.5
	B	22.3		5.4		10.5		1.5	
1. Belt of open area	A	23.0	—	—	—	24.0	—	—	—
	B	13.8	—	—	—	7.6	—	—	—
2. Marginal industrial and residential zone	A	14.1	29**	6.0	0.7	9.1	16**	2.0	0.5
	B	8.5		5.4		2.9		1.5	1.4
a) Separate structural units	A	14.1	29**	6.0	0.7	9.1	16**	2.0	0.5
	B	8.5		5.4		2.9		1.5	
b) Separate residential districts	A	—	—	—	—	—	—	—	—
	B	—	—	—	—	—	—	—	—
V. Outer zone	B	39.8	·	9.5	0.3	68.0	·	25.0	0.3
1. Semiurbanized rural areas		·	·	5.6	4.0	·	·	15.0	0.3
2. Independent production centres		·	·	3.9	0.2	·	·	10.0	0.4

Functional zones	Areal type 1	Opole: Areal percentage	Opole: Percentage of the concentrated functional components	Opole: Percentage of the total population	Opole: Population density in thousands per km²	Rzeszów: Areal percentage	Rzeszów: Percentage of the concentrated functional components	Rzeszów: Percentage of the total population	Rzeszów: Population density in thousands per km²
I. Central zone	A	6.0	56*	38.0	9.1	3.0	60*	36.6	13.2
	B	0.6		17.6		1.2		27.0	
II. Transition zone	A	0.3	·	22.0	9.7	—	—	—	—
	B	0.3		10.2		—	—	—	—
III. Internal industrial and residential zone	A	52.0	57**	36.0	·	77.0	91**	63.4	·
	B	5.8	·	16.7	·	26.2	·	46.5	·
1. Industrial sector	A	9.0	30**	3.0	0.3	—	—	—	—
	B	1.0		1.4		—	—	—	—
2. Mixed industrial and residential sector	A	24.1	27**	26.0	1.2	45.8	91**	53.0	1.1
	B	2.7		12.0		15.6		39.0	
3. Residential sector	A	18.9	·	7.0	0.6	31.2	·	10.4	0.5
	B	2.1		3.3		10.6		7.5	
IV. Marginal zone	A	39.0	36**	4.0	0.6	20.0	—	—	—
	B	4.3		1.8		6.8	—	—	—
1. Belt of open area	A	27.0	—	—	—	20.0	—	—	—
	B	3.0	—	—	—	6.8	—	—	—
2. Marginal industrial and residential zone	A	12.0	36**	4.0	0.6	—	—	—	—
	B	1.3		1.8		—	—	—	—
a) Separate structural units	A	12.0	36**	4.0	0.6	—	—	—	—
	B	1.3		1.8					
b) Separate residential districts	A	—	—	—	—	—	—	—	—
	B	—	—	—	—	—	—	—	—
V. Outer zone	B	89.0	·	53.7	0.2	66.0	·	26.5	0.3
1. Semiurbanized rural areas		·	·	40.3	0.2	·	·	19.2	0.2
2. Independent production centres		·	·	13.4	0.2	·	·	7.3	0.4

Functional zones	Areal type 1	Olsztyn: Areal percentage	Olsztyn: Percentage of the concentrated functional components	Olsztyn: Percentage of the total population	Olsztyn: Population density in thousands per km²	Zielona Góra: Areal percentage	Zielona Góra: Percentage of the concentrated functional components	Zielona Góra: Percentage of the total population	Zielona Góra: Population density in thousands per km²
I. Central zone	A	4.3	65*	42.0	8.3	4.1	64*	40.0	11.8
	B	3.7		41.2		1.7		32.1	
II. Transition zone	A	1.7	·	8.0	8.9	·	·	·	·
	B	1.5		7.8		·	·	·	·
III. Internal industrial and residential zone	A	39.0	60**	47.0	·	32.2	60**	55.0	·
	B	33.1	·	46.1	·	13.5	·	44.2	·
1. Industrial sector	A	9.5	60**	3.0	0.5	—	—	—	—
	B	8.2		2.9		—	—	—	—
2. Mixed industrial and residential sector	A	—	—	—	—	9.3	60**	17.0	3.0
	B	—	—	—	—	3.7		13.6	
3. Residential sector	A	29.5	·	44.0	2.0	23.6	·	38.0	0.8
	B	24.9		43.2		9.8		30.6	
IV. Marginal zone	A	55.0	—	3.0	0.6	63.0	—	5.0	0.5
	B	46.0	—	2.9		25.8	—	4.3	
1. Belt of open area	A	53.0	—	—	—	54.0	—	—	—
	B	44.2	—	—	—	22.1	—	—	—
2. Marginal industrial and residential zone	A	2.0	·	3.0	0.6	9.0	·	0.5	0.5
	B	1.8		2.9		3.7		4.3	
a) Separate structural units	A	0.9	·	0.2	0.6	—	—	—	—
	B	0.8		0.1		—	—	—	—
b) Separate residential districts	A	1.1	·	2.8	0.6	9.0	·	0.5	0.5
	B	1.0		2.8		3.7		4.3	
V. Outer zone	B	15.7	·	2.0	0.1	59.0	·	19.4	0.2
1. Semiurbanized rural areas		·	·	2.0	0.1	·	·	15.7	0.2
2. Independent production centres		—	—	—	—	·	·	3.7	0.2

Functional zones	Areal type 1	Koszalin: Areal percentage	Koszalin: Percentage of the concentrated functional components	Koszalin: Percentage of the total population	Koszalin: Population density in thousands per km²	Tarnów: Areal percentage	Tarnów: Percentage of the concentrated functional components	Tarnów: Percentage of the total population	Tarnów: Population density in thousands per km²
I. Central zone	A	2.7	59*	46.0	11.5	1.7	74.5*	23.5	10.7
	B	2.3		41.9		0.6		18.1	
II. Transition zone	A	3.1	·	22.0	5.5	·	·	·	·
	B	2.6		20.0		·	·	·	·
III. Internal industrial and residential zone	A	25.2	82**	32.0	·	22.3	30**	47.2	2.2
	B	21.3		29.0	·	7.6	·	36.2	
1. Industrial sector	A	12.8	82**	11.0	0.6	·		·	·
	B	10.8		10.0		·		·	·
2. Mixed industrial and residential sector	A	—	—	—	—	·		·	·
	B	—	—	—	—	·		·	·
3. Residential sector	A	12.4	·	21.0	1.2	·		·	·
	B	10.5		19.0		·		·	·
IV. Marginal zone	A	69.0	—	—	—	76.0	68**	29.3	0.4
	B	58.0	—	—	—	31.8	·	22.5	
1. Belt of open area	A	69.0	—	—	—	26.6	—	—	—
	B	58.0	—	—	—	15.1	—	—	—
2. Marginal industrial and residential zone	A	—	—	—	—	41.7	68**	29.3	0.4
	B	—	—	—	—	16.7	·	22.5	
a) Separate structural units	A	—	—	—	—	17.7	64**	12.6	0,8
	B	—	—	—	—	6.7	·	9.7	
b) Separate residential districts	A	—	—	—	—	23.7	4**	16.7	0.3
	B	—	—	—	—	10.0	·	12.8	
V. Outer zone	B	15.8	·	9.1	0.4	60.0	·	23.2	0.2
1. Semiurbanized rural areas		·	·	0.3	0.1	60.0	·	23.2	0.2
2. Independent production centres		·	·	8.8	0.4	—	—	—	—

A — in relation to the administrative area of the main city
B — in relation to the area of the total settlement system
* — service establishments
** — land for industrial use and storage

Annex to article by A. Werwicki

Cena zł 35.—