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CONTENTS

INTERREGIONAL LINKS OF THE SHIPBUILDING INDUSTRY IN POLAND

EWA ADRJANOWSKA

The interregional links of the manufacturing industries are one of the essential problems of economic geography [8]. These links are particularly extensive in the machine building and transport equipment industries. The necessity of setting up extensive links between different plants and, consequently, between different regions grows in proportion to the number of elements constituting the final product [3].

As the modern ship is one of the most complex of industrial products with an enormous diversity of functions, it is necessary to include the products of nearly all branches of manufacturing in its construction. The assembly of these products is effected in the shipyard [5]. Accordingly, shipyards are plants inducing an exceptionally broad range of passive interregional links.

This paper analyses the interregional production links of the two biggest shipyards of the Gdańsk voivodship, the Lenin Shipyard at Gdańsk, and the Paris Commune Shipyard at Gdynia. The analysis has been carried out on original source materials, in this case the invoices sent in to the shipyards from the suppliers throughout 1965. Supplies from all industries have been analysed. As the basic measure, the value of supplies has been selected, for none of the remaining indices makes possible a comparison of the highly diverse products used in the shipbuilding industry [10]. To trace the changes in time, the supplies of the last years of two successive five-year plans, that is of 1960 and 1965, have been analysed. To illustrate the degree of dispersion of the suppliers the Lorenz curve has been used for the calculation of the concentration coefficient. The distribution of the supliers from some basic industries is shown in the circular structural cartodiagrams. Cartograms have been used to illustrate the shares of the particular voivodships in the total shipments to the two shipyards. A map of distance zones shows the extent to which the distance from the shipyard determines the importance of the links. The zones have been delimited on the basis of equidistants plotted at 50 km intervals and of isochrones based on average commodity train speeds from Gdańsk at 6-hour intervals [2]. As boundaries of the zones the administrative boundaries of the poviats situated within the two above isolines have been assumed.

Shipbuilding can be economically justified only in a country advanced in manufacturing industries. The total output and the development of the particular industries determine both the size and the kind of vessels built. The highly complex fishing vessels, in the production of which Poland specializes, could be constructed only after a definite level of industrialization had been reached.

The dependence of Poland's ahipbuilding industry on the development of other industries is illustrated, among others, by the decrease in the share of imported products in the total supplies to the shipyards. Whereas in the first years of the production of vessels 45 per cent of the supplies were imported products, in 1965 this index was only 11 per cent.

The analysis of the interregional links of the shipyards for the years 1960 and 1965 shows rapid developments in this respect, both in time and in space. The total tonnage of the vessels commissioned by the two shipyards during the period in question grew from 168,038 GRT to 225,321 GRT. Simultaneously, the total value of deliveries grew by 2/3. There was a fundamental shift in the predominant type of the vessels built. Specialization in the construction of ships for the fishing industry has been started. This resulted in changes in the variety of supplies and, consequently, also in the interregional links of the shipbuilding industry. In view of technological change, the supplies of some products increased markedly between 1960 and 1962. For instance, air-conditioning equipment showed a 6-fold, washing--machines a 4-fold, and cold storage equipment a 2-fold increase in the value of supplies. Accordingly, the links of the shipyards with some production centres have been substantially strengthened. The value of supplies from the Rzeszów voivodship had an 8-fold increase, mainly owing to the deliveries of aggregates for cooling works from Dębica. The supplies from the Białystok voivodship were doubled in connection with the production at Białystok of some appliances for fish processing. The growing demand of insulating materials resulted in setting up tight links between the shipyards and some production centers of the Katowice voivodship, such as Krywałt, Krupski Młyn and Gliwice. Increased supplies of joiner's board established new links with Bydgoszcz, Pisz and Czarna Woda.

The long-term plans for the development of Poland's shipbuilding will induce a number of further changes in the spatial links. The modernization in this branch of industry means the increase in the tonnage of the vessels, their speed, the automation of the power stations, the board equipment and of the unloading facilities [11]. The further use of substitute materials, including mainly new plastics and high-endurance steel, is assumed. Therefore it is expected that supplies from the machine-building, electrotechnical, metallurgical and chemical industries will showbit the highest increases in value.

In connection with the highly diversified demand of the shipyards, shipbuilding contributes to the development of nearly all industries. The share of the value of supplies to the two shipyards is particularly high in the machine-building industry, where in 1965 it amounted to 2.49 per cent. In the ferrous and non-ferrous metallurgical industry this share reached 1.15 per cent of the annual output, in the electrotechnical industry 1.21, in the metal industry 0.94, in the timber industry 0.48, and in the chemical industry 0.20 per cent. Altogether in 1965 the two shipyards absorbed 0.5 per cent of the total output of Poland's industries.

The value of supplies from the particular industries show that 86.4 per cent of the total supplies in 1965 were covered by the products of six branches of manufacturing, of which the machine-building industry supplied 36.2, metallurgy 22.0, the electrotechnical industry 11.9, the metal industry 9.3, the timber industry 3.7, and the chemical industry 3.2 per cent. The shares of the particular supplying regions are roughly proportional to the output of the mentioned industries on their territories. Thus, 82,5 per cent of the value of supplies of the machine-building industry come from Poznań-city and from the voivodships of Katowice, Rzeszów and Gdańsk (Table 1). The joint total output of the machine-building

TABLE 1. The value of supplies from the fundamental industries, by voivodships in 1965 (percentages)

Voivodships	Total	Ferrous metallurgy	Machine-building and metal structures	Electro-technical	Metal	Chemical	Timber
			industry				
Poland	100	100	100	100	100	100	100
Gdańsk	23.57	9.20*	19.95	23.75	15.59	38.83	47.65
Warsaw-city	2.32	0.01	1.08	5,15	9.16	3.45	0.06
Cracow-city	5.46	9.48	0,61	9.17	0.31	0,89	–
Łódź-city	0.72	–	–	1.81	0.15	0.89	0.05
Poznań-city	16.98	0.29	40.22	14.00	2.68	2.06	3.36
Wrocław-city	0.76	–	0.36	0.05	0.10	3.59	0.13
Białystok	0.38	–	0.66	0.02	0.07	0.02	3.47
Bydgoszcz	7.92	0.04	8.92	19.43	8.48	0.94	16.19
Katowice	26.05	61.74	11.67	20.14	26.45	37.74	0.42
Kielce	0.88	3.07	0.05	0.03	1.43	1.14	0.09
Koszalin	1.93	–	1.42	0.82	5.56	0.10	5.07
Cracow	0.42	0.05	0.15	0.78	0.91	1.72	–
Lublin	0.06	–	0.01	–	–	–	0.18
Łódź	0.47	–	0.39	0.84	1.65	1.27	0.71
Olsztyn	0.48	0.01	0.42	–	1.97	0.03	3.01
Opole	1.27	2.10	1.17	0.05	2.68	0.05	3.68
Poznań	0.88	0.02	0.25	1.09	1.94	0.70	9.68
Rzeszów	4.88	2.89	10.66	0.06	0.06	1.46	0.05
Szczecin	2.18	0.90	1.65	1.50	8.41	4.77	0.82
Warsaw	0.20	–	0.23	0.42	0.16	0.03	1.04
Wrocław	1.66	0.20	0.13	0.39	12.07	0.35	2.10
Zielona Góra	0.53	–	–	0.25	0.17	–	2.24

* Including purchases from wholesale dealers.

industry of these voivodships in 1965 amounted to 42.1 per cent of the corresponding national total (Fig. 1). The voivodships with the biggest metallurgical production – the voivodship of Katowice and Cracow-city, yielding 81.7 per cent of the total output of Poland's metallurgy – supplied 81.22 per cent of the value of supplies in this branch of manufacturing (Fig. 2). 90 per cent of the electrotechnical products came from the voivodships of Gdańsk, Katowice, and Bydgoszcz, and from three city-voivodships – i.e. Warsaw, Cracow and Poznań. These regions accounted for 55.6 per cent of the total national output in the electrotechnical industry. 86.6

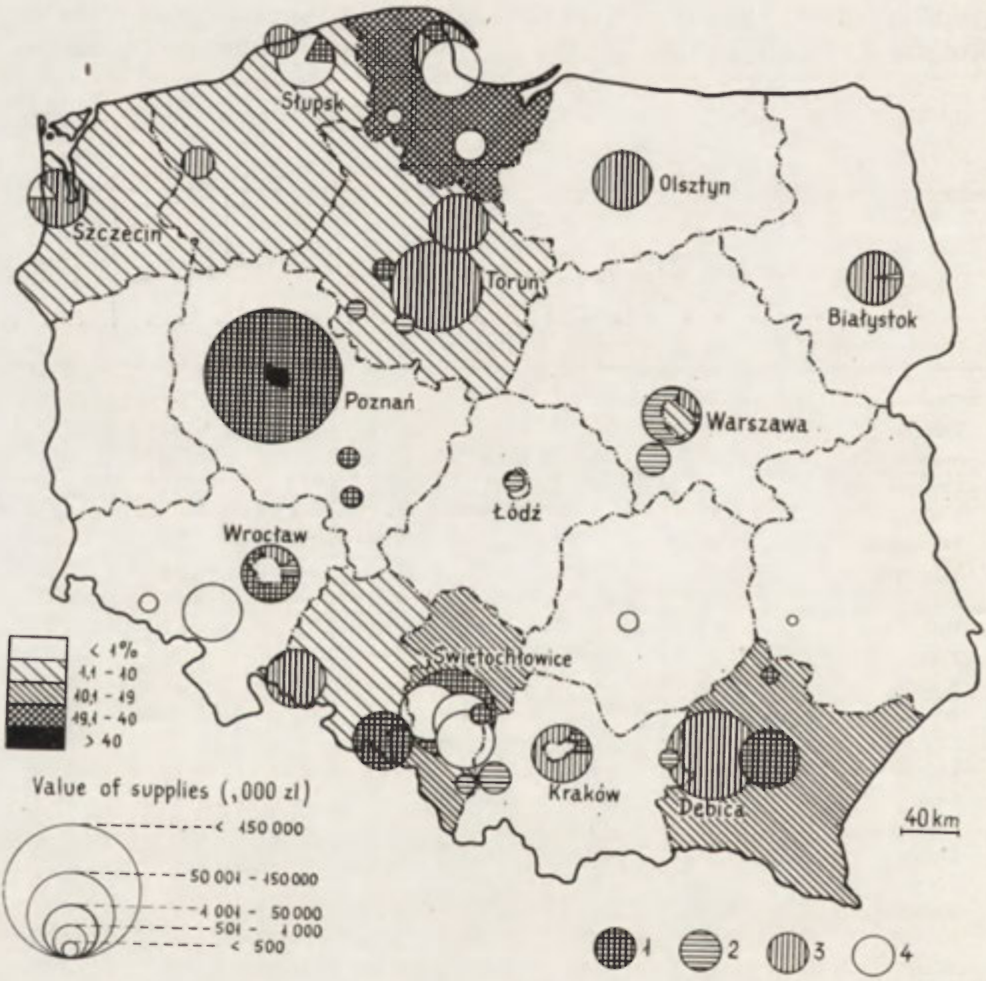

Fig. 1. The spatial structure of the supplies of machinery in 1965. The percentage values are given for the individual voivodships and city-voivodships

1 – engines and electric machines, 2 - metal working machine tools and appliances, 3 – branch-type machines and appliances, 4 – others

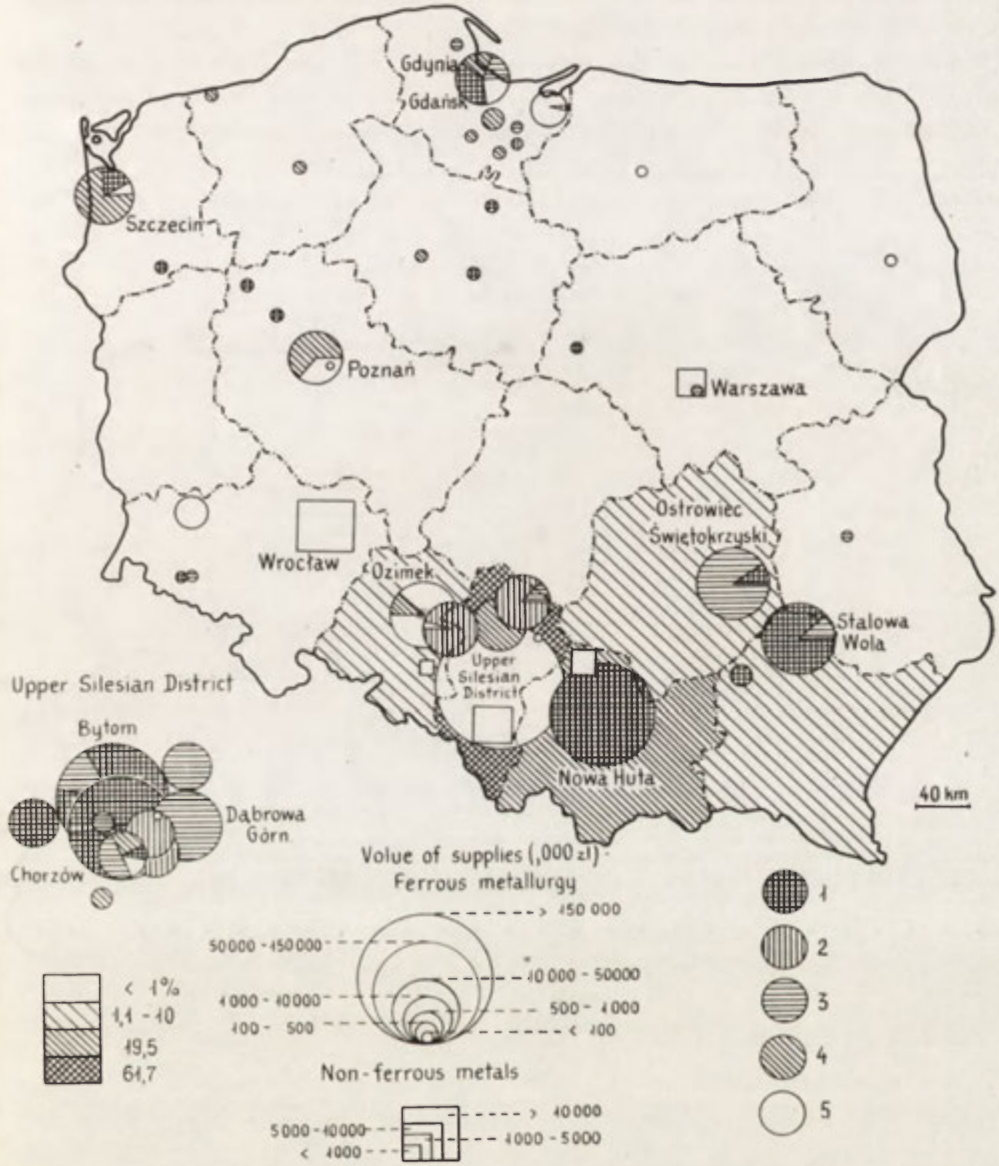

Fig. 2. The spatial structure of the value of supplies of metallurgical products in 1965. The percentage values are given for the individual voivodships and city-voivodships

1 – rolled products, 2 – steel pipes, 3 – profiles, 4 – scrap and pig iron, 5 – others

per cent of value of supplies of chemical products came from four voivodships: Katowice, Gdańsk, Warsaw-city and Wrocław.

The production links of such establishments as shipyards are to some extent a consequence of the spatial and branch structures of manufacturing industries Accordingly, the voivodships with the highest industrial development have the biggest shares in the supplies to the shipyards (Fig. 3). The small diversity of production and still weak industrialization of the voivodships of eastern Poland ac-

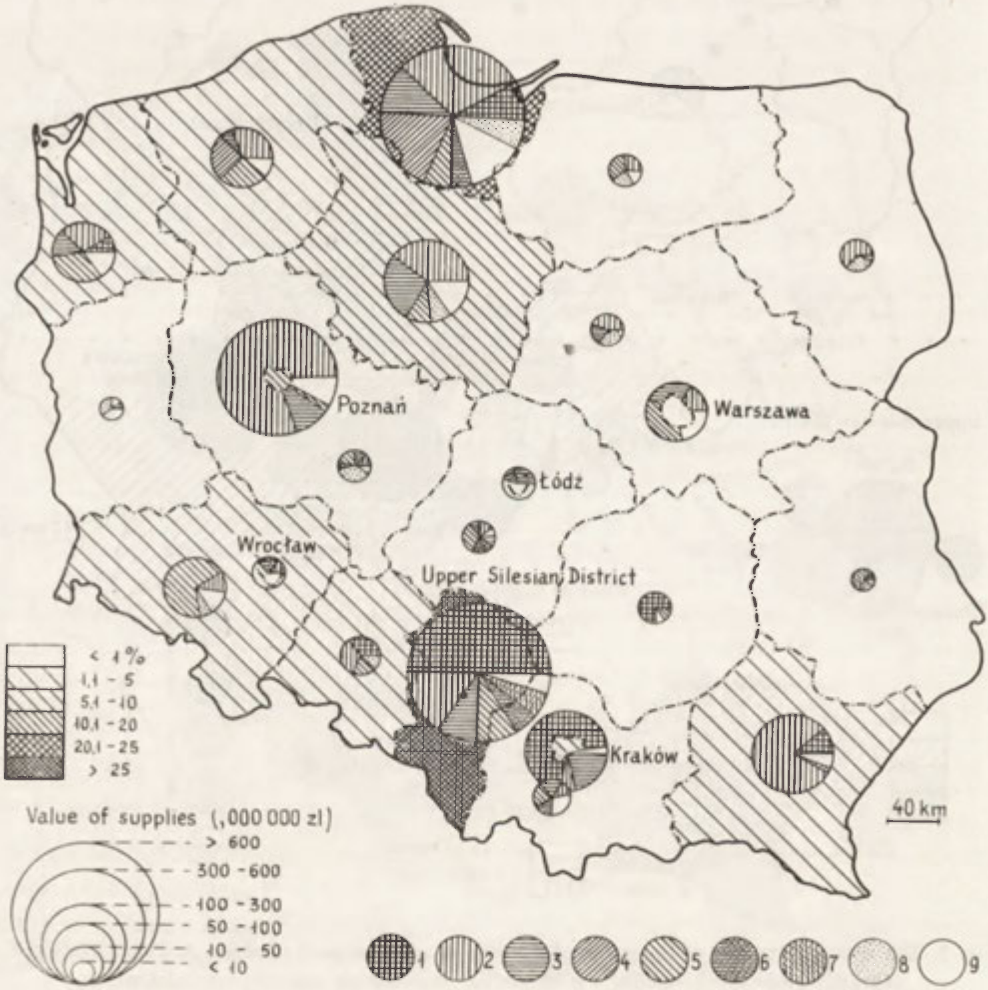

Fig. 3. The spatial structure of the total supplies in 1965. The percentage values are given for the individual voivodships and city-voivodships

1 – ferrous metallurgy, 2 – machine-building and metal structures industry, 3 – electrotechnical industry, 4 – transport equipment industry, 5 – metal industry, 6 – chemical industry, 7 – building materials industry, 8 – timber industry, 9 – other industries

count for their inconsiderable share of 0.44 per cent in the total supplies to the shipyards [9], out of which the voivodship of Lublin supplies mainly cement, and that of Białystok – sawn timber. In contrast to this, the highly diversified production of the western voivodships resulted in an increase in total supplies up to 2.62 per cent, coming from as many as sixteen branches of industry. The high diversity of the supplies from big cities reflects the industrial structure of the latter. For instance, Warsaw-city supplies products of all the industries located within its boundaries. The remaining city-voivodships supply products of 10 to 12 branches of manufacturing.

The passive adaptation of the production links of the two shipyards to the existing spatial structure of the national industry is a consequence of several factors and as such it is economically justified. Among these factors there are the follwing; the unique character of production of some articles, the high specialization of the producer and the high demands on quality from the shipyards, insurance companies and classificatory agencies, the frequency of ordering of an individual product, and a number of other technological and economic factors. On the other hand, there are several factors affecting adversely the interregional links of the shipyards. Within this group of factors there are the regulations charging the supplier with the the costs of freight, or too low prices assessed for some unique products and the resulting reluctance of some factories to cooperate with the shipyards. Consequently, not infrequently the latter have to order the same kind of products from more than one producer. Moreover, as the shipyards are not charged with the costs of freight, a high dispersion of the suppliers is observed and the commodity flows are being lengthened considerably.

Thus, the analysis of the structure of the production links of the two shipyards shows that the distribution of the production centers of a given branch and the origins of supplies are mutually correlated. The most conspicuous examples are the supplies from the timber industry (Fig. 4) and metallurgy (Fig. 2). The concentration coefficient of the centers of supplies of sawn timber in 1965 equalled 0.382, and that of iron sheets reached 0.929. In this year Poland had 26 ironworks and 1,442 sawmills. An analogous correlation is also traceable in the supplies of many other products. Where there is a broad choice of suppliers, the corresponding concentration coefficients exhibit remarkable decrease, and conversely.

The interregional links of the shipyards account also for the inducing effect of the shipbuilding industry on the supplier centres and regions. Through the supplying factory, this effect is conveyed to all branches of the socio-economic life of the respective region. Assuming a great simplification of analysis, the share of the supplies in the total industrial output of the region may be taken for the indicator of the stimulating effect of the shipyards. The highest values in this respect are achieved by the voivodship of Gdańsk and Poznań-city. In 1965, 4.04 per cent of the total industrial output of the Gdańsk voivodship and 3.69 per cent of that of Poznań-city were destined for the two shipyards. The remaining voivodships have smaller indexes, not exceeding 1 per cent of their total industrial outputs. Much higher indexes are exhibited by the shares of supplies from the particular industrial branches from some voivodships. To mention but a few, the two shipyards used up 18.4 per cent of the value of the total output of machine-building industry and 8.8 per cent of the electrotechnical industry of Poznań-city; 1.1 per cent of the total output of the machine-building industry, 1.5 of that of the metallurgical industry, 2.2 of the electrotechnical industry and 1.1 of the metal industry of the Katowice voivodship; 5.8 per cent of the machine-building industry, 2.4 of

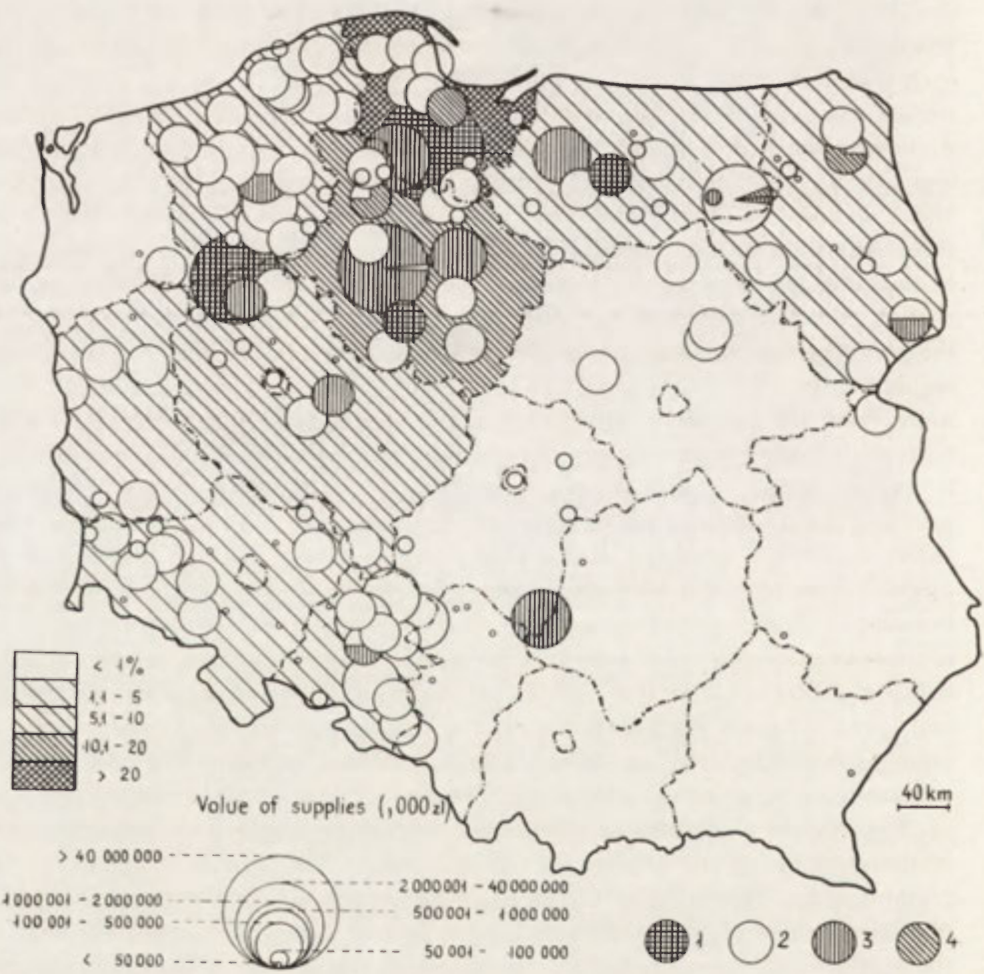

Fig. 4. The spatial structure of supplies of the products of the timber industry in 1965. The percentage values are given for the individual voivodships and city-voivodships

1 – final products, 2 – sawn timber, 3 – other semiproducts, 4 – others

the electrotechnical industry and 11.7 per cent of the total output of the metal industry of the Koszalin voivodship. These as well as other indexes cast some light on the stimulating role of the shipbuilding industry with regard to the economic regions of Poland, this influence being also transmitted to the sub-contracting firms which are often located in other regions.

The factors determining the spatial structure of the production links of the two shipyards are moreover responsible for the fact that transport often becomes of secondary importance. But long-haul transportation is economically justified only in case of bringing in unique supplies, from highly specialized factories or from the sole producers. Contrariwise it is not economical to disregard this aspect of economic distance, which is a direct consequence of the existing tax and price systems.

The map of the distance zones (Fig. 5) shows that the shipyards have strong production links with three zones at the distance of 450 to 600 km from Gdańsk. These zones which are located between the isochrones of 30 and 42 hours, gave 44 per cent of the total supplies in 1965. In these supplies the predominant share belongs to the products of the metallurgical, machine-building and electrotechnical industries, but there are also those of nearly all the remaining branches of manufacturing. The most distant centres of small supplies are located in a zone more than 600 km from Gdańsk, beyond the isochrone of 42 hours. They supply the products of the timber industry from Przemyśl and the chemical industry from Jedlicze. Whereas some of the former are economically justified, the latter ought to be substitited by another center. Both a producer of wooden handles of tools and one of paints and varnishes can be found at a considerably smaller distance from Gdańsk.

Some of the economic decisions already permitted the severance of several of the links with suppliers located in distant places in 1960 to 1965. In consequence, at present 49 per cent of the supplies come from three zones located within the 250 km equidistants and the 18-hour isochrone. The necessity of reducing the economic distance of supplies is in close connection with the commonly known problem of the social costs [4]. Besides the costs of freight also the costs of contacts between the cooperating plants such as costs of the technical control of the classificatory agencies, complaints, business correspondence, business travel ets. which increase with the growth of distance. This type of contact acquires particular significance in plants of the assembly-type production, to which belong shipyards [5].

The measures taken in 1960 to 1965 with respect to the most distant sources of supply produced some changes in the spatial structure of the interregional links of the shipyards. Both the number of suppliers and the absolute value of supplies from the closest zones have grown, which contributed to the economic development of a number of areas in the northern territories of Poland. There is a tendency to a concentration in this region of cooperating machine-building plants. In 1965, the five voivodships of northern Poland (those of Gdańsk, Bydgoszcz, Koszalin,

Fig. 5. The value of supplies of products from the basic industries by poviats within distance zones in 1965

1 – less than 300,000 zlotys, 2 – 300,000 to 1,000,000 zlotys, 3 – 1,000,000 to 10,000,000 zlotys, 4 – 10,000,000 to 100,000,000 zlotys, 5 – more than 100,000,000 zlotys, 6 – equidistants at 50 km intervals, 7 – boundaries of zones, 8 – boundaries of voivodships, 9 – boundaries of poviats

Olsztyn, and Szczecin) provided 32.35 per cent of the total value of the supplies from the machine-building industry. Together with the supplies from Poznań-city, this percentage increases to 72.6. Furthermore, the closest zones supplied 45.5 per cent of all domestic products of the electrotechnical industry, 44.7 per cent of the chemical industry, and 40.0 per cent of the metal industry.

The extent to which shipbuilding contributes to the development of the economy of northern Poland is illustrated by the shares of supplies in the total output of some branches of manufacturing. The region of northern Poland, including Poznań-city, supplied 11.6 per cent of its total machine-building output to the two shipyards, as well as 4.1 per cent of the electrotechnical industry, 0.6 per cent of its chemical industry, and 2.6 per cent of the metal industry. The stimulating effect becomes still more conspicuous if the supplies from other industries and the value of industrial services for the benefit of the shipyards are taken into account.

The increase in the supplies from the closet zones is particularly rapid in some of the industries. The value of the supplies from the machine-building industry has grown by about 75 per cent, that of the chemical industry has shown a 6-fold, and that of the metal industry a 4-fold increase. In effect, the value of the total supplies has increased by 50 per cent.

Among the northern voivodships, in 1965 the largest supplies came from that of Gdańsk. They covered 23.6 per cent of the total value of the supplies of domestic products. Within these, the predominant share belongs to top-quality products of the machine-building (30.6%), the electrotechnical (11.3%), and the transport equipment (19.5%) industries. Next comes the voivodship of Bydgoszcz with 7.9 per cent of the value of all domestic supplies. Of this, 40.7 per cent constitute products of the machinebuilding and 29.4 per cent of the electrotechnical industries. The voivodship of Szczecin supplied 2.2 per cent of the total supplies, with a predominance of the metal industry (35.81%) and the machine-building industry (27.3%). Special mention is due to the particularly strong activating effect of the shipyards on the voivodship of Koszalin. Although since 1960 the value of the total supplies has been slightly below the 2% level, their share in the total output of some branches of manufacturing is relatively big (as has been shown before). The predominating supplies in this case come from the transport equipment (30.5%) and the metal 26.8%) industries. The weakest links in 1965 were those with the industries of the Olsztyn voivodship; these latter gave but 0.5 of the total supplies, of which 38.4 per cent were products of the metal industry, and 31.7 per cent of the machine--building industry.

The most important role in increasing the supplies from the zones near to the two shipyards is played by what is called "internal cooperation" plants, which are controlled by the same Trust of Shipbulding that controls the two shipyards. All of them are located in the northern voivodships, and they give about 20 per cent of all supplies, on the average. Smaller in value, but also important are the supplies from about 200 factories run by local authorities or by cooperatives. The management units of the shipbuilding industry as well as the local administrations of the northern voivodships implement policies aimed at a further tightening of the links between the shipyards and other plants of this region. Accordingly, the existing plants are being adapted to this purpose by modernizing the machinery, training the workers, putting up construction design offices, testing centers, laboratories etc. Organizational efforts towards the development of a network of what is called "patronage plants" are in progress: big specialized plants of internal cooperation will concentrate around them a number of smaller ones to secure technological and organizational aid from them. Also, a project for the establishment of a "concern" of shipyards and internal cooperation plants is being developed.

The present analysis of the interregional production links of the two biggest shipyards of the voivodship of Gdansk is intended to elucidate some of the complex spatial problems of the development of shipbuilding in Poland. These problems pertain to the spatial structure of the hinterland of the shipyards and to interrelationships between the development of the shipbuilding industry and the country's industrialization.

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APPLICATION OF MEASURE OF CONCENTRATION IN INVESTIGATIONS OF DENSITY OF SETTLEMENTS

KAROL BROMEK, IRENEUSZ KWIECIEN

In investigations of rural settlements made in the period between 1918 and 1939, geographers in a number of countries paid close attention to problem of concentration and dispersion of the settlements. This interest found its expression in studies undertaken by the Commission for Rural Settlement of the International Geographic Union, and in papers read at the International Geographical Congresses held in Warsaw in 1934 and in Amsterdam in 1938. Concentration and dispersion were considered from a quantitative point of view, and for calculations a variety of formulae were applies. As a rule, the methods used comprised two conventional limit values:

1) the maximum distance between dwellings admissible in settlements classified as concentrated,

2) the minimum number of dwellings admissible in groups considered concentrate settlements.

However, the authors of the methods applied adopted different values for what they considered "conventional", and this is why the results of particular studies failed to be mutually comparable.

H. Steinhaus [3] made in attempt at eliminating conventional values in his investigations of the concentration or dispersion of settlements, and of the lowest number of dwellings in a group considered a concentrated settlement. For this purpose he presented in 1936 a mathematical method, by which he subdivided an area of 36 sq. km into a successively increasing number of square land units. From the number of dwellings in the particular units he compiled the function of the *Lexis* index. The curve thus obtained he called the "density characteristic" from which the tendency of dwelling concentration could be calculated. However, the method suggested by Steinhaus is rather unsuitable in geographic research, because or the tedious calculations involved in this complicated formula; moreover, the results of all these calculations presented in the form of curves were found to serve only for a comparison of their shapes.

In 1947 Steinhaus put forward a different method which virtually is based on the notion of concentration and renders a quantitative solution [4]. In this method, the settlement area under consideration – it might be that of a particular village – is subdivided into as many square land units as the number of dwellings the whole area contains. Next, the number of dwellings in each unit is counted and the index of concentration or dispersion is determined by means of the formula:

$$\omega = \frac{1}{N} \sum_{i=1}^{N} a_i^2 - 1$$

where: N = number of land units,
a = number of dwellings per land unit.

In this method proposed by Steinhaus, the drawing of the network of square units which must be separately plotted for each area and for each period of time is rather cumbersome.

In 1969 Kostrubiec suggested what he calls a universal method for investigating settlement patterns of different classes, starting out from the internal arrangement of dwellings within villages and extending to the settlement system of the whole country [2]. This author bases his method on measurements of distances between all the elements in the area under investigation. However, this method proved to be very tiresome and unprofitable for investigations of the concentration of rural settlements.

THE PROPOSED METHOD

Rural settlement, being the creation of social activity in the domain of material production, is marked by its non-uniform distribution in geographic space. The human dwellings which are here considered to be the principal element of the farm are irregularly situated all over a village. At some points they stand in groups at others they are widely separated. Looking upon grouping in a relative sense one may speak a degree of concentration for a given village. From this view it appears that for defining the degree of either clustering or dispersion of a rural settlement, not only by description but especially by some sort of a numerical conception – and therefore in a manner easy to correlate – it is logical to apply some hind of concentration index.

For detailed investigations of rural settlement, the authors applied their method on maps drawn in 1 : 2880 or 1 : 10,000 scale. The object of the analysis is to determine the arrangement of dwellings within the confines of a village.

The most difficult, yet the most important problem in the application of this method lies in choosing the most suitable size for the units into which the area of a village is to be divided. This unit should be applicable to examinations of this type for all of Poland. Ultimately a square with 400 m side lengths, thus of 16 ha size was adopted. This value seems to be correct from both a genetic and a functional point of view since at the time of rural colonization, it was the area of a typical farm holding in Poland.

The working programme of this method involves:

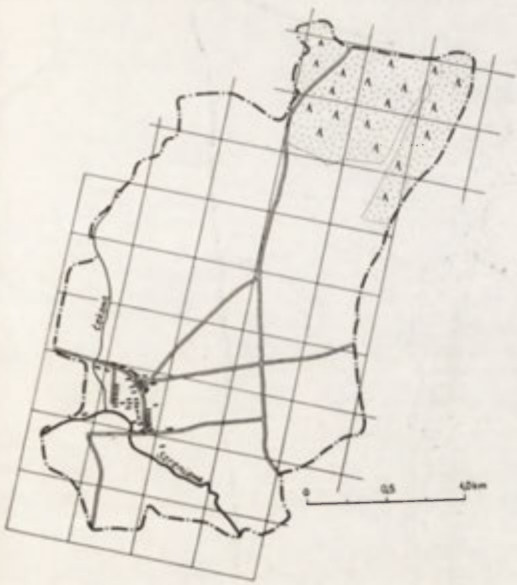

Fig. 1. Bobin 1890

Fig. 2. Bobin 1968

1) a preliminary general investigation of the spatial structure of settlement for the given village,

2) superimposing the map of the village with a grid of 400 m squars in such manner, that:

a) the pattern of the grid corresponds with the direction of the principal axis of the village settlement (provided a principal axis exists),
b) the core of the village settlement occupies a central position in the grid, and that the arrangement of the adjoining unit squares ties in with the central core or with the main axis,
c) a definite number of squares contains a maximum number of dwellings i.e. that the position given to the grid should not distort the true concentration of dwellings,

3) fragmentary squares next to the village border should be complemented into full squares by combining them with adjoining fragmentary squares,

4) the total number of squares should equal the quotient of the village area by the number area of the basic square,

5) conforming to the statistical principle ruling the index of concentration, the summing up of the number of dwellings in successive squares yields successively increasing statistical series of the number of dwellings and of squares, followed by cumulative series; and finally to be calculated are the cumulative per-cent values for the area and the corresponding per-cent values for the number of dwellings,

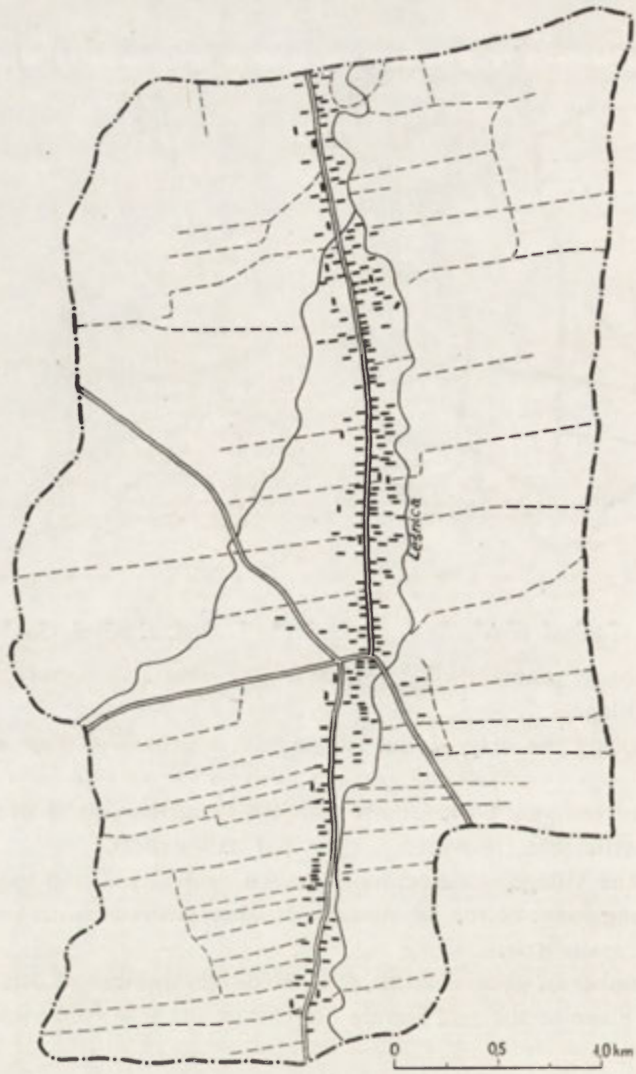

Fig. 3. Gronków 1964

6) from the figures obtained in this manner, the Lorenz curves of concentration are compiled (Fig. 9),

7) the concentration values illustrate accurately the degree of concentration of settlement for the given village.

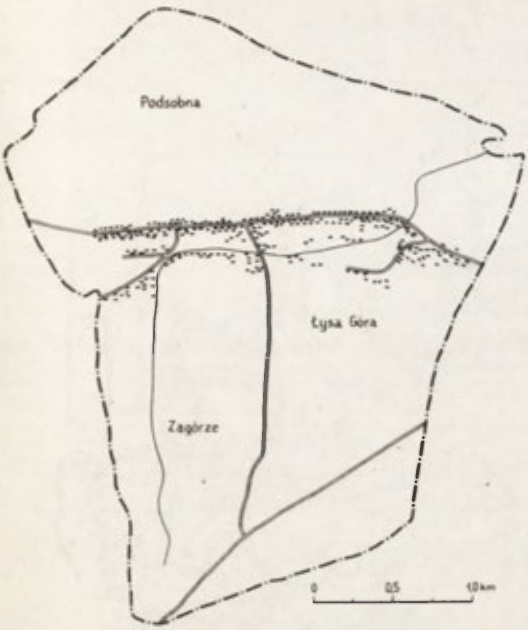

Fig. 4. Kaszów 1890

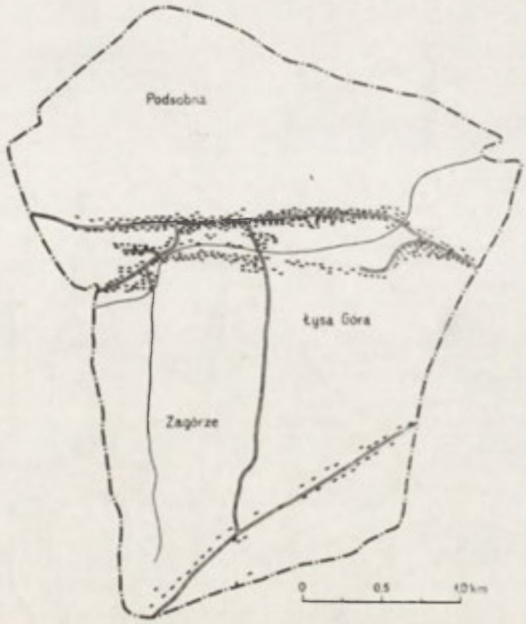

Fig. 5. Kaszów 1964

PRACTICAL VERIFICATION OF THE PROPOSED METHOD

The application of the measure of concentration to investigations of the pattern of rural settlement has been tested for several villages of the Kraków region, namely for:

1) Bobin village, situated in an area of fertile loess soils – a village initially densely settled, now a loosely-built multi-road village (Figs. 1,2),

2) Gronków, situated in the Podhale region – a village in forest clearings (Fig. 3).

3) From the suburban zone of Kraków:

a) Kaszów – a developed one-street village (Figs. 4, 5),

b) Janowice – a dispersed settlement (Fig. 6),

c) Swoszowice – a loosely-built multi-road village in a dispersed pattern (Figs. 7, 8).

Table 1 illustrates the comparison of the values of the ratio of concentration (η). This table gives evidence of the usefulness of this method for investigations of the evolution of rural settlement and, in this particular instance, for the process of dispersion of rural settlement.

The comparison of the maps of particular villages (Figs. 1–8) with the figures indicating their ratio of concentration as shown in Table 1, and the graphs characterizing concentration (Figs. 9–13) imply, that application of the method may be useful for classifying and typefying rural settlements. However, this assumption

Fig. 6. Janowice

Fig. 7. Swoszowice 1914

Fig. 8. Swoszowice 1964

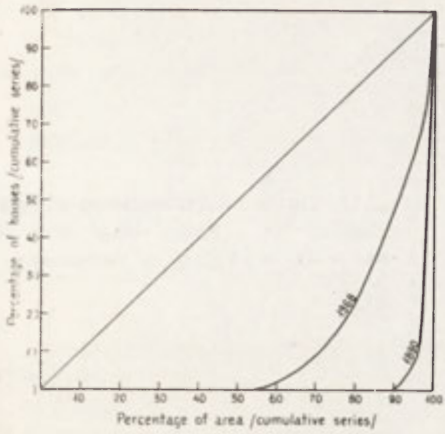

Fig. 9. Curves of concentration of rural settlement for a basic village area of 400 × 400 m. Village of Bobin

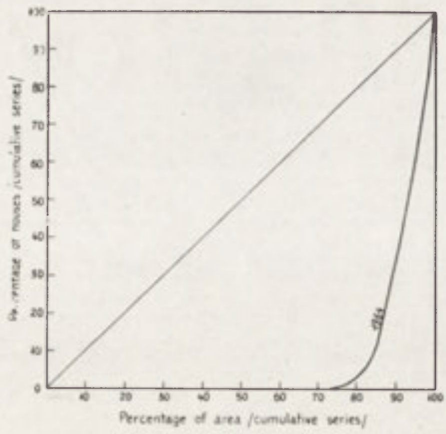

Fig. 10. Curves of concentration of rural settlement for a basic village area of 400 × 400 m. Village of Gronkow

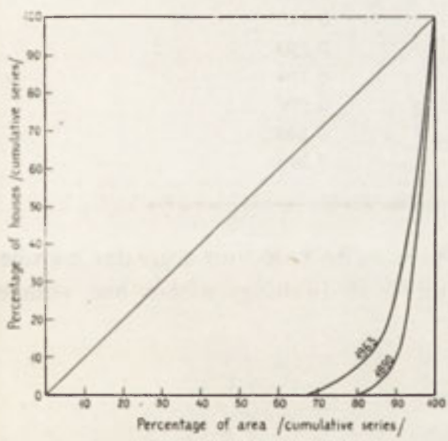

Fig. 11. Curves of concentration of rural settlement for a basic village area of 400 × 400 m. Village of Kaszow

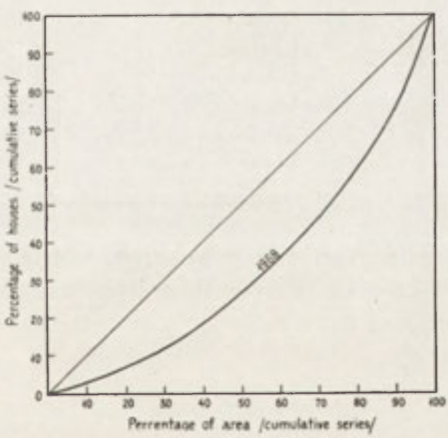

Fig. 12. Curves of concentration of rural settlement for a basic village area of 400 × 400 m. Village of Janowice

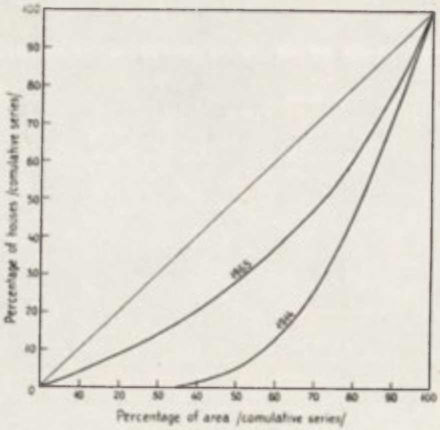

Fig. 13. Curves of concentration of rural settlement for a basic village area of 400 × 400 m. Village of Swoszowice

TABLE 1. Ratio of concentration

Name of village	Year	Ratio of concentration(η) for a basic area of 400 × 400 m
Bobin	1890	0.955
Bobin	1968	0.762
Gronków	1964	0.848
Kaszów	1963	0.850
Janowice	1968	0.338
Swoszowice	1914	0.579
Swoszowice	1939	0.340
Swoszowice	1965	0.298

requires further confirmation, which would have to be based on a greater number of case studies covering diverse spatial patterns of dwellings within one village, selected from different parts of Poland.

CONCLUSIONS

The method under discussion has been presented by the authors in its application to detailed investigations of the concentration of rural settlement. The results obtained may be considered favorable, because:

1) the ratio of concentration or dispersion is expressed by a numerical value between 0 and 1;
2) one can compare the degree of concentration of different villages by means of numerical values and graphs;
3) the changes and their importance in the structure of rural settlement are fully illustrated and expressed by definite numerical values;

4) the general trends in the spatial structure of rural settlement can be defined in a measurable way;
5) with abundant data on hand, the method makes it possible to classify rural settlement in an accurate manner on the basis of respective ratios of concentration.

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POLARIZATION THEORY: SOME BASIC NOTIONS AND CONCEPTS

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1. INTRODUCTION

The concepts involved in what is called the theory of polarized regional development have been receiving increased attention in both the theory and practice of space economy for some time now. The theory of polarized development of regions, or briefly the polarization theory, is one of the theories of development in the spatial aspect. According to J. Paelinck [33, p. 47], the polarization theory is "a theory formulating the conditions of the growth of regions"; its significance is said to consist primarily in „indicating the conditions in which accelerated regional development may occur".

The present paper is an attempt to order and elucidate the most fundamental notions of this theory. Before proceeding to this task, however, let us observe that:

– The polarization theory cannot be recognized as a complete theory. Its components are being continually modified and extended. Among the more recent attempts to outline this theory are the studies by J. Paelinck [33] and J. Friedmann [19]; both are fairly comprehensive and difficult to compare in some of their specific points, and sometimes in general.

– The polarization theory is neither coherent nor clearly delimited. Apart from its original formulations, it borrows, adapts and develops certain elements from some recent theories such as those of location, growth, or space organization as well as other theories of regional development.

– The principal developments of the polarization theory are due to the French school. Accordingly, attention will be focused primarily on the notions used by the French or by other authors writing predominantly in that language.

2. SPACE. LOCALIZATION AND DELOCALIZATION

The phenomena studied by the polarization theory are situated both in a geographic and an economic (strictly: socio-economic) space[1].

The geographic space is most closely connected with the type of geonomic spaces.

[1] The necessity to distinguish between the particular types of space has in Poland been pointed out by K. Dziewonski [17] who – following the French – introduced the term "economic space" into Polish geographic literature.

These latter are spaces of connections (geometric or geodetic) between points, lines, areas and volumes. They cover anything that has physical dimensions. F. Perroux [36] calls them "banal" spaces, i.e. spaces coresponding to the common meaning of space. K. Dziewoński [18] suggests to substituting for the somewhat derogatory term "banal spaces" the term "concrete spaces" as this implies a reference to the concrete reality of the material world.

Some authors, such as J. R. Boudeville [3, 5], regard the notions of geographic space and of the geonomic or banal spaces as synonymous. This is doubtless a simplification. True, the concept of geographic space is far from being univocal. It approaches closely the concept of geonomic space in its narrower sense of denoting the area in which an element occurs (e.g. the type of relief, a definite population density etc.). But if geographic space is defined only as "expressing the character and differentiation of the natural environment of the Earth (of the geographic environment)" [18, p. 36] it immediately goes beyond the notions of the "container" and its contents that are customary in the geonomic spaces. Besides, geographic space may also mean the multifarious relations, which in their total are called the geographic complex by P. George [20]. This meaning of geographic space is much broader: H. Beguin [1] calls it the "complete space".

In contrast to the concrete geographic space, the economic space is most frequently defined as an abstract or formal space. The economic space is defined by "the economic relations that exist between the economic elements" [36, p. 231]. There are different categories of economic space. As many categories of economic space can be distinguished "as there are objects of economic science and the abstract relationships defining each of them" [36, p. 228]. F. Perroux [36, 40] distinguishes three principal categories of economic space: 1) economic space as defined by the plan, 2) economic space as a field of forces, and 3) economic space as a homogeneous aggregate. F. Perroux [36] explains the meanings of these categories on the example of the relations of a big firm with the surrounding space. To avoid too simplified a picture, only some of the activities of the firm can be located in the concrete space (in this case it can be termed the technological space as its dimensions are determined by technological factors): buildings, machines, raw materials, employees. This is a concrete location. Numerous elements have their location only in the economic space. The economic space of a firm in the sense of the object of its plan of activities is equivalent to the entire system of its relations with the customers and suppliers; this space is largely independent of the concrete space. The economic space of a firm defined as a field of forces (polarized space) is a result of the activities of this firm as a centre (pole, focus) from which definite centrifugal forces emanate and towards which definite centripetal forces tend; in this process a zone of economic influence of the enterprise develops, and it may or may not coincide with the boundaries of the topographic zone of influence. Finally, the economic space of a firm may be defined as a homogeneous system considering e.g. the prices being offered; from this point of view, different firms may be located in the same economic space irrespective of their specific localization in the concrete space.

The particular cases of employing any of these three categories are of course more numerous. F. Perroux [36] discusses in these terms the national economy as a whole and even supra-national economies.

Although they constitute separate types of space, the geographic space and the economic space are linked by reciprocal relationships and thus cannot be completely isolated from each other. A close linking of the concrete geographic space with the abstract economic space, as well as a linking of the individual elements of the latter with one another, are at present being discussed. Many observations concerning their linking are found in the studies of H. Beguin [1], R. Domański [15] and K. Dziewoński [17, 18]. Attempts to link the concrete space with the abstract space by all magnitudes characterizing the particular elements as vectors or tensors were made by J. R. Boudeville [5, 6].

F. Perroux [40, p. 267] points out that the "three fundamental types of economic space [...], even if analysed separately, must be considered together in order to understand and elucidate the dynamic processes of development". We think that H. Beguin's [1] broader requirement, namely that it is necessary to use both the concepts of geographic and economic space together, is correct. As a matter of fact, F. Perroux [36, p. 230] is essentially of the same opinion in that he agrees that "geonomic localizations [...] have economic consequences".

In connection with the notion of space a few remarks on the notions of "localization" and "delocalization" seem to be useful.

It is not necessary to deal any closer with the term "localization". "Localization", or frequently "location", are often used synonymously with "distribution" or "situation". The scope of these notions and the extent of their variability have been discussed in many studies. Here let us only point out that some authors, e.g. F. Perroux [36], employ the term "localization" (also used in the plural) only with reference to facts occupying a definite place in the concrete space. Localization, or localizations, mean concrete (banal, geonomic) localizations.

The term "delocalization", on the other hand, does not seem to be widely used. This term and its derivatives are used by F. Perroux [36] in such contexts as e.g., "acts of delocalization of economic activity in the contemporary world", "degree of delocalization". He employs "delocalization" as opposed to "localization". Delocalization as used by F. Perroux implies separation from the concrete space.

These conceptual distinctions appear to require some comment. It seems that the notion of "localization" must not be confined to concrete localizations only. Even within an abstract space, e.g. the economic space, phenomena have their localization (or localizations), though in different dimensions than in a concrete space [16]. In my opinion, the term "localization" can be safely employed with reference to all spaces provided that it is always qualified by an appropriate adjective to specify the localization (i.e., the respective space) to which it refers. Consequently, the notion of "delocalization" must of course be defined in a somewhat different way.

3. DOMINATION. THE LEADING UNIT

The polarization theory is closely connected with the ideas of domination. The notions of quantitative and qualitative domination as well as the notion of dominants have for a long time been known and used in the biological sciences. In the 1920's these ideas were for the first time developed in sociology within its "ecological" trend. After the second world war the concept of domination has been extensively used by F. Perroux in his economic analyses [35, 37]. For a dynamic interpretation of the economic life he suggested the notions of "effect of domination" and "the dominant economic unit" or "the leading unit"[2]. Together with some notions borrowed from the concept of urban economic base, these notions have furnished the foundation on which the conceptual apparatus of the polarization theory began to develop.

F. Perroux [37, p. 247] defines the effect of domination as follows: "The effect of domination consists in [...] an irreversible or partially reversible influence exercised by one unit upon another. An economic unit exercises this effect by reason of its size, its negotiating strength, the nature of its activity or because it belongs to a zone of dominant activity".

In speaking of a "leading unit", a unit of manufacturing is primarily (but not exclusively) meant.

The leading unit may be simple or complex (macro-unit). It may be a big firm, called the leading firm. The term "big firm" is often used to denote a group of firms of manufacturing.

A leading unit may by a group of manufacturing firms, either institutionalized or not, or else a whole branch of manufacturing collectively defined as "the leading industry". The notions of the dominant industry, the „industrializing" industry or the leading sector are equivalent to that of the leading industry.

In this context, the terms "key industry" or "key sector" are also used but not synonymously with "leading industry". According to L. E. Davin [12], a leading industry "engenders activities in other industries, either suppliers or customers for merchandise or services", whereas a key industry "determines the maximum increase of these activities". Thus conceived, a definite industry may be both a leading and a key industry at the same time. The application of the terms "key industry" or "key sector", which are commonly employed by the language of the industrializing

[2] F. Perroux [40] suggested translating the term "unite motrice" into English as "propulsive unit". As far as we know, however, the more common use of the English writers is the „leading industry".

or nationalizing policies, is strongly refuted by F. Perroux [40] in that he points out their excessively metaphoric and vague connotations.

The leading unit affects the development of other units by engendering processes of stimulation (induction) or inhibition. Accordingly, the leading industry (equivalent to the leading unit) is also defined as the inducing industry. Those who distinguish between the leading and the key industries regard each of them as inducing industries.

· As it has been mentioned, the notion of a leading unit is not exclusively associated with manufacturing, for the specific features of the leading unit may also occur in units of other sectors of the national economy, both within the sphere of material production and outside it. Hence, apart from the notion of "leading industry" and its substituents, the broader notion of "leading activity" is also used. Without diminishing the significance of the manufacturing activities it is thought that, for instance, in the most advanced economies the service industries acquire an increasing stimulating power. Of course this does not refer to the "common" but to the rare services or to services of higher order [29, 30]. It is attempted to isolate the service industries into a separate, fourth sphere[3], comprising the services of a leading character [7].

The diverse influences of the leading unit are classified by F. Perroux [40] within one of the four groups:

1) influencing by prices, flows, anticipations;

2) domination influences, leading influences;

3) influencing the propensity to consume, to saving, to investments; influencing the fundamental propensity to work and to innovation;

4) influences on growth, development, advance[4].

In the most general terms, the effect of the leading unit is brought down to different relations resulting from anticipations and innovations. The leading unit exercises its influence by anticipations, that is, it anticipates the changes in the total demand and adjusts itself to these anticipations by increasing or diminishing the volume of output. The leading unit exercises its influence by innovations, that is, it changes its production coefficients and becomes a driving force of economic advance. For comparison, let us quote J. Kleer's [26, p. 169] definition of the leading branches of manufacturing: "By the leading branches of manufacturing are meant

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[3] In Polish studies the term "sector" is more frequent. But the term "sphere" seems to be more relevant, especially with reference to the Polish classification of national economy. In this latter, the highest level of division is also the sphere: the sphere of material production and the sphere of activities outside it. The term "sector" is reserved for the social structure of the economy.

[4] The notion of "economic advance" is used here in its narrower meaning as "the advance of a group of factors achieved along the lines (of activity) regarded as profitable." More comprehensively it means "the optimal spreading of innovations and its effects (investments, commodities), at lower economic and social costs, in a whole assuming an all-embracing character" [40, p. 257].

those branches that: a) exhibit the highest growth rates, that is, have a growing share in the industrial output; b) have a higher growth rate in productivity as compared to the others; c) contribute to the technological changes in the remaining branches of manufacturing and even in the whole economy; d) significantly contribute to the creation of a new structure of both the producer and the consumer demands and thus exert a decisive influence on the character of the market, which is in turn indispensable to securing the growth of advanced economy in capitalist conditions".

The four types of influence of the leading unit result in the creation of the system of relations between the leading unit and its environment. Various detailed structures of such a system can be obtained by analysing the tables of intersectoral flows (input-output analysis).

However, the specific effects of the leading units differ from region to region depending on the dynamics of the environment. By the dynamics of the environment F. Perroux [40, p. 268] means " a definite fusion of three forces of growth (population, innovations, institutions) acting upon the system in which the region is a subsystem". In particular regions the rate and components of the population growth are different, and so are the developments in their population and social structures. The degree and form of urbanization differ too. The development of technological innovations results in new discoveries of the region's natural resources or in furnishing new localization benefits. There are also differences in the system of regional institutional forces (local units of economic and social administration).

In analysing the problem of the effect exerted by the environment J. C. Perrin [34] introduces the notion of responsive ability of the environment. If the effects of the influence of the leading unit are to be fully disclosed, the environment must be able to respond positively to the stimulations coming from it. This responsive ability is expressed by the rate of dispersion of the stimulations, that is, the speed of what is called motorial propagation.

Other authors put still stronger emphasis on the influence exerted by the environment. Morando even thinks that there are no leading industries "in general". "The industries localized in a definite environment may become leading industries. If localized somewhere else, they may not evoke the expected induction" [10, p 22]. A similar view is expressed by F. Vito: "Recognizing an industry as 'industrializing' is a matter of an *a posteriori* appraisal rather than an assumption that can be proved *a priori*" [10, pp. 21f].

In discussing the regional differences in the effects of the leading unit it is necessary to take into account the element of time. In particular it must be remembered that:

(1) The notion of leading unit changes with time. At different periods, the features of leading units (or the different intensities of their occurrence) are shifted from some activities onto others. This finds its expression in the common notions of old (traditional) and new (modern) kinds of leading activities. The previously

leading activities may have completely lost the features of leading units and become declining activities.

(2) Only after a sufficiently long period can the effects of the leading unit be grasped. The duration of this period differs from unit to unit and moreover depends on the type of influence.

So far we have discussed the leading unit as a unit of economic activity. But the leading unit may also be treated as a spatial unit, that is, as a definite part of the geographic space. This brings us to considering the effect of the leading unit as a growth pole.

4. THE GROWTH POLE. THE ZONE OF GROWTH AND THE AXIS OF GROWTH

The leading unit (or, more frequently, a group of leading units) acts within a definite environment as a pole of growth.

The term "pole of growth" is associated with different concepts the provenance of which may often be very different. For this reason the concept of growth pole has evoked many heated controversies. Moreover, etymological and semantic considerations add to the conceptual confusion. The polarization theory employs the term „pole" in a meaning different from the common use of this word in many languages, including Polish. As applied in the polarization theory, a pole means a protruding swelling on a homogeneous surface rather than one of two opposing extremes [32]. M. Penouil [10, pp. 15f] narrows the different concepts of growth pole to two principal ones: the sectoral and the geographic.

The sectoral concept of growth pole originates from the economic theories attempting to elucidate the process of economic growth. This concept is primarily associated with the name of F. Perroux. The now classic study of this author [38, p. 309] contains the following statement: "Growth does not appear everywhere and all at once; it appears in points or growth poles, with varying intensity; it spreads along diverse channels and with varying terminal effects for the whole of the economy"[5]. In another study [39]. F. Perroux gives the following functional definition of the growth pole as "a group of leading units which has a stimulating effect on other economically or territorially determined groups". Within the context of the concept of growth pole the leading unit (or a group of leading units) is principally an economic unit (or group of economic units) falling within the scope of a leading activity. The leading unit is here located primarily in a polarized economic space.

The geographic concept of the growth pole (which I suggest calling the regional concept) is, roughly speaking, related to the theory of economic region and to

[5] As far I know, it was in this study that F. Perroux used the term "growth pole" for the first time. In his earlier studies Perroux applied synonymously the terms "pole" and "centre" in the same meaning [36].

that of regional development. Within the regional concept, the leading unit functioning as a growth pole is a spatial unit, a unit localized primarily in the geographic space. Such a unit is most frequently an urban centre with different branches of the leading activity and with a well-developed infrastructure.

Depending on whether the two concepts are analysed from the point of view of economic or regional analysis, they differ very strongly one from another. In its simplest form, the sectoral concept of growth pole explains the effect of the leading units of the economy engendering the development of other branches; it exposes and develops the thesis that the role of driving force is performed by definite dynamic activities. In the other concept, however, the regional point of view prevails. Here, the notion of growth pole refers to a total of investments localized in a certain place as well as to the development of an infrastructure capable of transforming the economic structure of the region and thus effecting its development.

In both concepts the term "growth pole" is often used synonymously with "pole of development", even by those authors who attach different meanings to the words "growth" and "development". This use is additionally illegitimate because – especially within the context of the regional concept of growth pole – "growth" in the strict sense of quantitative changes in economic indexes is less frequently meant than "economic development" or even "socio-economic development" in the broad sense.

In connection with the notion of growth pole are used the notions of "zone of growth" and "axis of growth". The term "zone of growth" is used synonymously with the words "zone" or "region of development". L. E. Davin [12, p. 17] defines the growth zone as a functional zone "in which economic, commercial and technological relations, adjusted to one another, are multiplying". The same author gives also other descriptions [13, p. 83; 12, p. 7) of the growth zone (region of development), specifically that it constitutes "a geographic group of branches of activity, its technological-economic adaptation being of stretegic importance for the vitality of a larger economic space" or that it is "a functional group of various polarized branches of activity, the boundaries of which are difficult to delimit".

The notion of "axis of growth" is complementary to those of "growth pole" and "growth zone". "Growth axis" is used synonymously with "axis of development". According to L. E. Davin et al. [13, p. 83], the growth axis is "the whole auxiliary infrastructure that contributes to the flexible functioning of a given industrial group, especially to the free flow of commodity streams". The axis of growth links the individual growth poles one to another. F. Perroux [40, pp. 303f] emphasizes that "it is not an axis of transports but a territorial combination of leading units and induces units". In his opinion, "the growth axis differs from the growth zone only in that it implies a principal and lasting channelling of movement (of services, commodities, capital)". The growth axis is thus associated with the notion on a certain functional network.

5. POLARIZATION

The effect of the growth pole as a group of leading units is defined by the term "polarization". In a narrower sense, by polarization the process of enlargement of a pole is meant. In virtue of the aforementioned functional definitions of the growth pole, a more comprehensive definition of polarization may be tentatively suggested: namely, it is a stimulating effect resulting in a progressing integration of space.

Polarization assumes different forms. Most frequently they are classed within one of 4 groups, also called the types of polarization. These groups are: technological polarization, polarization by incomes, psychological polarization, and geographic polarization. Complete analyses of the types of polarization have been made, amongst others, by L. E. Davin [12, pp. 19–31] and J. Paelinck [33, pp. 36–41].

Polarization is a highly complex phenomenon. Its particular types mutually penetrate one another. Out of the 4 types, technological polarization is considered to be the most important, the decisive one. L. E. Davin [12, p. 31] indicates it as the *primum movens* of all polarization. In his opinion, the particular types decrease in importance in the same order in which they have been mentioned above, that is: technological, income, psychological, and geographic polarization. Each type is more dependent on the preceding than on the following one.

(a) Technological polarization. This type of polarization conditions the growth of different branches of activity as a result of the technological relations established between them. A distinction is made between investment polarization, which is an immediate consequence of investments in the economic infrastructure and other productive fixed assets, and the polarization of functioning resulting from stimulating the vertical and the horizontal technological and organizational relations.

(b) Income polarization. This type of polarization (or: polarization by incomes) results from the multiplier effects brought about by the increasing demand for consumer goods. Some authors, as L. E. Davin [12], strongly emphasize in this connection the development of the service industries. To determine polarization by incomes we most frequently take as our points of departure the Keynesian income multiplier and the accelerator principle equation of A. Aftalion together with their derivations.

(c) Psychological polarization. Psychological polarization occurs in effect of psychological factors that affect the investment decisions and enhance the attractive power of a given growth pole. Among the psychological factors there is the (frequently subconscious) imitation of the innovatory attitudes of the leading units by small and medium-sized firms. Considerable psychological effects are achieved by well-organized information and propaganda systems (especially on the level of region), in particular as regards the technological data concerning the conditions of investments, production and marketing. Another major psychological factor is the existence of detailed projects for regional developments.

(d) Geographic polarization. This type of polarization results from a definite spatial distribution of the leading units constituting growth poles. L. E. Davin [12, p. 19] defines this polarization as the increasing of regional income in effect of "a progressive concentration of new branches of activity". L. E. Davin [12, pp. 29f] gives a more detailed definition of geographic polarization as "the emergence and expansion of intermediate centres, their number sufficing for the appearance, concentration or conversion of the leading branches in limited areas with easy availability of manpower resources. This polarization postulates the existence of a principal centre (agglomeration of technological character) in which some of the induced branches are more prone to localize in the peripheries. Sometimes they localize outside the area, where they may benefit from the favourable local conditions and create centres or poles of support". Thus, it is not concentration in one or in a few places that is meant here. To some extent, H. Beguin's interpretation that geographic polarization in this sense refers even more to "the decongestion of important centres by transferring the growth to the secondary periphery centres" seems to be acceptable.

The geographic polarization is of particular importance to spatial development policies. In his analysis of this aspect of polarization J. Paelinck [33, p. 38] points out that "the polarization theory can be flexibly associated with a regional development of space due to the fact that it is not a theory of concentration". Further he indicates that a region "may organize itself into geographic central poles and geographic auxiliary poles so as to avoid any superconcentration[...] In this way, the optimal localization possibilities (area, power resources) and the best transport conditions can be made use of".

6. THE REGION IN THE POLARIZATION THEORY

Within the context of the polarization theory, by the notion of region a polarized region is usually meant.

This theory often treats the notion of polarized region as a derivative of one of the three fundamental categories of economic space distinguished by F. Perroux, that is, economic space as a field of forces or else a polarized space. The "leading regions" employed by F. Perroux [40] in his spatial model of growth are such derivatives.

The widely known interpretations of the notion of polarized region given by J. R. Boudeville, however, are somewhat more intricately related to Perroux categories of economic space. True, J. R. Boudeville adopts a division into homogeneous space, polarized space and space as defined by the plan and it may seem that his three categories of economic regions, i.e., the homogeneous, the polarized and the planning (or program) regions, are parts of the corresponding abstract economic spaces. But these regions are actually derived from a somewhat different concept of economic space used by this author. In his opinion, the economic space is the application of an abstract mathematical space on or in a geographic space. Consequently, J. R. Boudeville places the economic region within the geographic space as a geographically continuous construction. One of Boudeville's definitions reads that [4, p. 42] "the polarized region constitutes a spatial unity of elementary areas (countries, towns, regions etc.) maintaining with one of them, called the pole, more relations than with the remaining poles of the same order".

Thus, the polarized region is an economic region fitting into the concept of region of flows, the nodal (or functional) regions. The functional character of the polarized region is emphasized by the use of the notions of "organized region" or even "organic region" as synonymous with polarized region. B. Kayser's [23, pp.306f] definition includes three fundamental features of an organized region: "the existence of relations between its inhabitants, organization around a centre marked by some self-dependence, and functional integration into the national economy". Incidentally, this author considers the organized region to be the only genuine region, a region in the strict sense, that is, a region "in general".

The polarized region is founded on the existence of "privileged points in space" and their zones of influence. By privileged points of space are meant the places of concentration of a leading activity (that is, the geographic growth poles). The scope of the zone of influence depends on the polarizing power of these places, that is, on the attractive power of the leading activity localized in it, and, on the other hand, on the degree of the social and economic development of the area in question. The mere polarizing power of the "privileged place" is not sufficient; it is moreover necessary for the surrounding area to respond to the polarizing power, to "be suitable for polarization". For it is only then that functional relations indispensable for the existence of a polarized region may be established. Therefore the notion of polarized region may be applied only with reference to the areas that had attained a definite level of economic and social development [23, 24, 31, 42].

The notion of polarized region is strongly connected with that approach to the delimination of regions which emphasizes the need of a territorial division, of "the division of space into units depending on the dominant aspects which determines the unity of organization by man" [7, p. 2]. Many of the authors using the notion of polarized region seem to conceive of it primarily as an instrument with the features of a more comprehensive theoretical model, and they emphasize the postulative character of this model. "Even in the industrialized countries some regions are not polarized [...] The planning is aimed at their transformation, structuralization and division into polarized regions" [7, p. 10]. The (polarized) region as a unit of space organization "has no definite dimension by itself but one depending on the problem considered, the area concerned, and the period covered" [7, pp. 7, 11].

7. FINAL REMARKS

As has been mentioned at the outset of this paper a considerable part of the development of the polarization theory has been due to the French school. This is not to say, though, that the achievements of other schools especially in the English-speaking countries, are insignificant. Some even say that the Anglo-Saxon contribution has been recently gaining in importance.

Recently, several studies have been published discussing all of the accomplishment of the polarization theory. The studies by J. R. Lasuen [32] and D. F. Darwent [11] must primarily be mentioned here. Some criticism of the polarization theory is contained in the studies by H. Beguin[1] and P. Claval [8, 9]. These discussions are of some practical significance as they are closely connected with the search for efficient theoretical instruments for the policies of space planning and development. In this connection we should mention the studies by N. M. Hansen [21], and H. Körner [27], those carried out under the auspices of the EFTA [41], but above all the UNRISD studies carried out as part of a program for regional development. In this program particular attention was paid to the role of growth poles and centres in regional development [28]. This problem was studied by Ph. Bernard [2], T. Hermansen [20], L. H. Klaassen [25], T. Di Tella [14] and others.

Within the context of the polarization theory all terminological considerations are additionally of practical significance. What is at stake is a clear understanding of notions that may possibly serve as a foundation of actual actions. Since the considerable heuristic value of this theory is no longer disputed, its notions may already serve as a valuable instrument of scientific analyses, and their normative importance will grow together with their increasing precision and in proportion to the development of the mathematical and statistical possibilities of verifying the polarization concepts.

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ARTIFICIAL HEAT OVER THE TERRITORY OF POLAND

MARIA W. KRAUJALIS

Apart from natural source of heat which is solar radiation, heat emission from man-made sources is becoming an important term in the energy balance of the earth surface.

The combustion of fuels for industrial and transportation purposes constitute the main sources of artificial heat which is emitted into the ambient air. This component of the heat balance equation value, and its comparison with the solar radiation over the Poland's territory is the object of this investigation.

This aims of the study are:

1) to calculate the amount of heat emitted by the combustion of fuel all over Poland in various branches of economic life;

2) to estimate its share in the heat balance on the interface earth-atmosphere;

3) to investigate the spatial distribution of this component of heat balance.

GENERAL CHARACTERISTIC OF THE METHOD

Two different methods of accomplishing the author's aim had to be taken into consideration. The first involved the detailed calculation of all heat emitted in relatively small areas of differing degrees of urbanization and industralization. These have been selected as typically representative areas, so as to arrive at generalized conclusions. The second method is deductive in character; it is based on a general theoretical concept and supported by information gained from statistics, which supply data on the kind and the scale of those economic processes which lead to the intensive release of heat energy stored in the various fuels.

After consideration of both these methods the author chose the second. The theoretical concept mentioned is based on the assumption that the combustion of fuels is the principal source of artificial heat, and that practically all the energy stored in fuels is transformed by combustion into heat emitted into the ambient air.

The amount of energy retained in the commodities produced, as well as in incombustible parts of the fuels, like ashes and soot or in gaseous compounds, depends on the kind of fuel, the character of the processes of transformation, and the thermal efficiency of the equipment used.

The sum of information which serves as a starting point for further reflections refers to:

(1) the quantity of fuel consumed per unit of time and area,

(2) the properties of the fuels used, expressed in caloric values,

(3) the character of the processes by which the fuels are transformated into heat, where in these transformations each of the processes applied has its own thermal efficiency.

If then the information obtained from (1) is supplemented by additional data pertaining to (2) and (3), it will be possible to answer the basic question how large are the totals of heat emitted.

The principal difficulty met with in collecting the statistical material for small spatial units, explaining the quantity and the characteristic properties of the fuel used, lay in the information, available for the three group mentioned above, being inequally detailed.

In all the accessible statistical records reffering to (1), the units of time and space are very large: full years, and the whole country or whole voivodships. For spatial units as large as this there is no way of analysing spatial distribution of the

TABLE 1. Properties and indices of fuels and of combustion processes, adopted as constants in estimates of heat emission from artificial heat sources in Poland

Index	Fuel type:						
	1	2	3	4	5	6	7
Index of transforming fuel into heat (*b*)	0.95	0.95	0.95	0.95	0.95	1.0	1.0
1) in production processes	0.95	0.95	0.95	0.95	0.95	1.0	1.0
2) in transportation	0.90	–	0.90	–	–	–	1.0
3) in domestic and communal hearts and in power plants							
a) rural consumers, group *A*	0.80	0.80	0.80	0.80	0.80	1.0	1.0
b) rural cunsumers, group *B*	0.70	0.70	0.70	0.70	0.70	0.70	1.0
c) urban consumers, group *A*	0.90	0.90	0.90	0.90	0.90	1.0	1.0
d) urban consumers, group *B*	0.80	0.80	0.80	0.80	0.80	1.0	1.0
caloric value (*c*), in kcal/kg and kcal/cu. m	5262	2000	6500	2500	2000	4000	10000

Note: the following kinds of fuel were distinguished: 1 – bituminous coal, 2 – brown coal, 3 – coke, 4 – peat, 5 – wood- 6 – gas, calculated for 4000 kcal/cu. m heating value, 7 – liquid fuels.

phenomena under investigation. The information in group (2) is more detailed, reporting the properties of the fuels used; but the differences in the way combustion takes place are enormous. Every domestic fireplace, every furnace operated in industry and in communal heating plants has a different efficiency in converting the fuel into heat. In consequence it became necessary to apply some rules: going into greater detail for some of the available data and assuming more general interpretations for other data. Hence, in calculating the quantity of fuel used, the author subdivided large areas into smaller spatial units such as poviats and city-poviats, while she took averaged values for the character of the combustion processes. The latter were divided into several types on the basis of their thermal efficiency (see Table 2). The economic data used pertain to 1965. For this particular year the Central Statistical Office prepared an inventory which made it possible to draw up balances of energy on a fairly detailed scale; data from earlier or later years fail to supply this sort of information.

For establishing the share of the artificial heat in the natural heat balance, the author compared the artificial heat (marked by symbol S) with the incoming global, radiation (marked by symbol Q). The data on the annual totals of this radiation and its spatial distribution over Poland was taken from: J. Paszyński and L. Kuczmarska [4] and from the Atlas of Radiation Balance [1] compiled by the Department of Climatology of the Institute of Geography PAN. The results obtained are presented in maps and in Table 1. In a similar way the total artificial heat was compared with the previously computed annual totals of the outgoing long-wave radiation [3] (Table 2).

GENERAL EQUATION FOR TOTAL HEAT EMITTED FROM ARTIFICIAL SOURCES

The artificial heat emitted in all-Poland from economic processes may be defined as the sum:

$$S = \sum_{j=1}^{396} \sum_{i=1}^{7} (P_{ij} + L_{ij} + T_{ij}) \text{ kcal} \cdot \text{cm}^{-2} \cdot \text{year}^{-1},$$

where: P_{ij} — heat emission in poviat (city-poviat) j from fuel i used for industrial purposes,

L_{ij} = heat emission in poviat j from fuel i used for communal and household purposes,

T_{ii} — heat emission in poviat j from fuel i used for freigh and passenger transport.

It should be noted that these branches of the national economy account for more than 95% of the total artificial heat emitted.

Were the available data uniform in character (in other words, if the figures supplied by separate economic branches would refer to identical spatial units and to identical periods of time), the sum total of emitted artificial heat could be expressed by the product of the kinds of fuel used, their caloric values, and their thermal efficiencies. This would appear in the form of the following equation:

$$S = \sum_{j=1}^{396} \sum_{i=1}^{7} x_{ij} \cdot c_i \cdot b_i,$$

where: x_i = the quantity of fuels i, in kg or cu.m, consumed in economic processes,

b_i — the efficiency of converting fuel into heat, assumed as the characteristic of basic heat-emitting branches of the economy,

c_i = caloric values, in kcal/kg or in kcal/ cu.m.

TABLE 2. Annual figures for artificial heat S and for values of indices S/Q and S/E in selected towns, for 1965

Group	Town	Values of S		S/Q	S/E
		in Tca l kcal·10^{10}	in kcal · cm^{-2} · $year^{-1}$		
S less than 50 kcal·10^{10}	Zakopane	17.0	0.2	0.2	0.7
	Sopot	36.0	2.0	2.4	6.6
$50<S<100$	Rzeszów	97.5	2.5	3.0	8.6
	Zielona Góra	88.0	1.6	1.9	5.1
$100<S<200$	Białystok	156.2	2.2	2.6	7.6
	Kielce	111.8	2.6	3.0	8.6
$200<S<400$	Lublin	316.0	3.4	4.0	10.6
	Opole	296.8	5.6	7.0	17.6
$400<S<800$	Łódź	727.6	3.4	4.2	11.3
	Poznań	770.0	3.5	4.3	11.3
	Wrocław	787.5	3.5	4.3	11.3
$800<S<1200$	Katowice	818.0	8.2	10.8	26.7
	Zabrze	1 032.0	12.9	17.2	41.6
$1200<S<1600$	Szczecin	1 234.1	4.3	5.4	14.5
	Warszawa	1 561.0	3.5	4.4	11.4
$1600<S<2000$	Kraków	1 794.0	7.8	9.3	29.2
	Wałbrzych	1 928.2	31.1	38.9	103.7
$S<2000$	Chorzów	2 029.5	61.5	83.1	198.4
	Częstochowa	2 033.2	22.1	27.6	74.7

ANNUAL SUMS OF HEAT FROM ARTIFICIAL SOURCES, AND THEIR SPATIAL DISTRIBUTION

1. Total heat obtained from fuels used for productive purposes

Among the artificial heat sources, industrial processes take first place. On an all-Poland scale they release 44% of all the artificial heat emitted when converting fuel into energy.

The spatial differences occurring in the consumption of energy in processes of production are reflected in analogous differences in heat emission due to these processes. On the whole, these differences are consistent with the spatial structure of industry and, first of all, with the degree of concentration of production in the most energy-consuming industrial branches. Hence this gives a picture of the spatial structure of industry characterized by the amount of energy consumed. To give

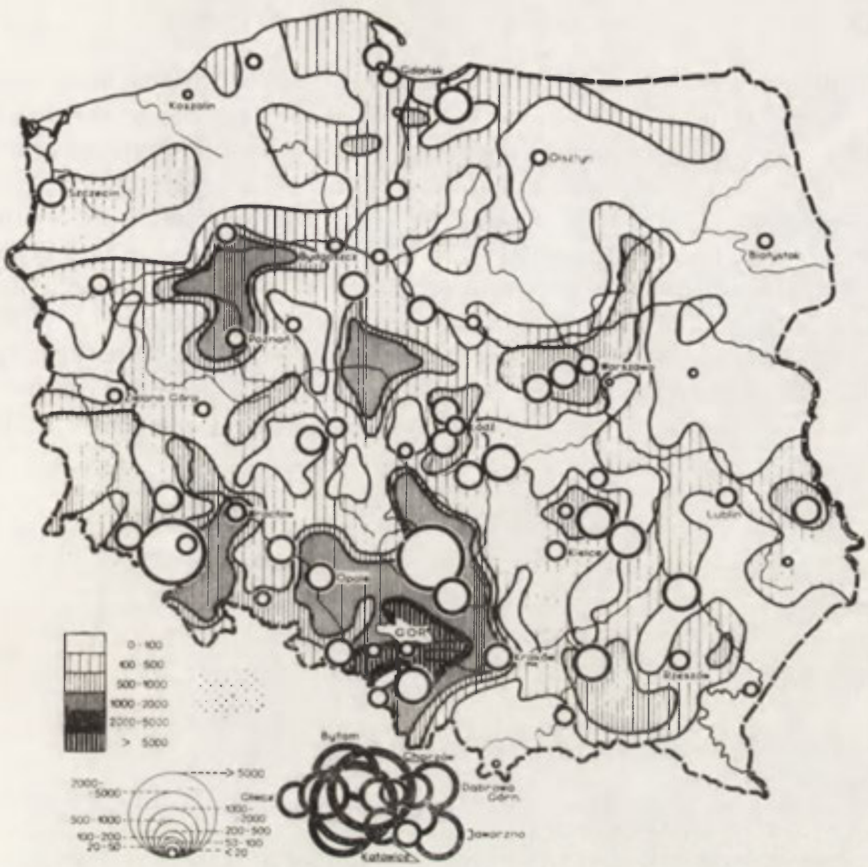

Fig. 1. Heat emission from fuel used for production purposes in 1965

hachure marks annual sums for poviats (in kcal·10^6/sq·km) circles mark annual sums for cities (in kcal·10^8/sq·km)

an example, areas where metallurgical plants, which consume great quantities of energy, are concentrated, show the highest indices of artificial heat (Fig. 1).

It seems worth while to mention the figures obtained for the cities situated in the Upper Silesian Industrial District, where the annual totals of artificial heat created are from about 1000 kcal $\cdot 10^8 \cdot km^{-2} \cdot year^{-1}$ for Gliwice and Zabrze to about 6000 kcal $\cdot 10^8 \cdot km^{-2} \cdot year^{-1}$ for Świętochłowice and Chorzów.

In industrial regions the share of the industry in the total heat emission is very much higher than Poland's mean index. However, industrial expansion leads also to a rise in the remaining two most important groups of heat sources: household and communal fuel consumption, and transportation. As result of the process of industrialization the absolute figures of total artificial heat emitted from regions and centres with concentrated industries are many times higher than for the remaining areas of the country (Fig. 4).

2. *Total heat obtained from fuels used for domestic and communal purposes*

The distribution of these kinds of heat shows a picture slightly more uniform for all-Poland than the heat emitted by the remaining branches of the economy. On the average, fuel consumption for domestic and communal purposes generates 36% of the total artificial heat, thus taking second place after industry.

As mentioned above, heat emission from this source grows with expanding industrialization; however, here the index rises at a much slower rate than the index for industrial production. Where population is much concentrated, the use made of the energy is more economical than in a dispersed economy. With the process of urbanization the index of consumption of energy and heat emission is growing. At a certain stage, however, this growth slows-down due to the construction of central heating systems and by the use of more efficient equipment for home

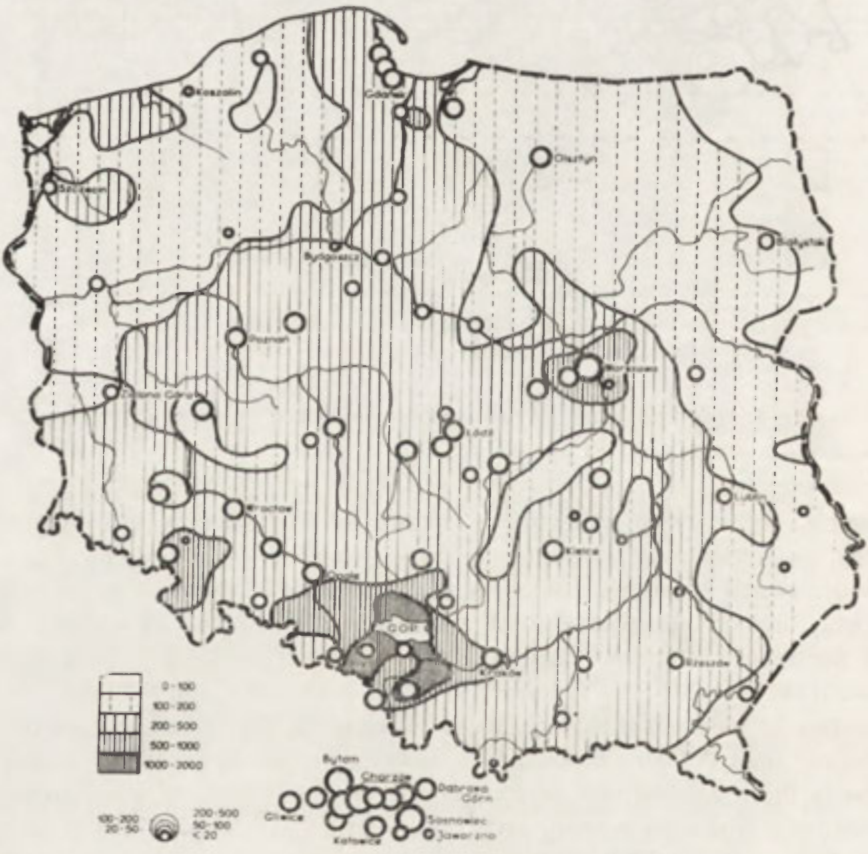

Fig. 2. Heat emission from fuel used for communal and domestic purposes in 1965

hachure marks annual sums for poviats (in kcal·10^6/sq·km) circles mark annual sums for cities (in kcal·10^8/sq·km) heating and kitchen service in the modern housing developments. Fuel used by collective consumers for heating, and for cooking in mess halls maintained for factory workers and schools, and by large restaurants – all this raises the efficiency of fuel consumption and lowers the mean caloric value of the fuel used per unit of land surface. In particular this applies to the largest cities like Warsaw, Łódź, Wroclaw, Poznań and Cracow where the mean heat emission per square kilometer of urban area is much smaller than in the majority of industrial towns in which heat emission is high in relatively small areas.

3, Total heat obtained from fuels used by transportation

Heat emission from means of transport (Fig. 3) illustrates the importance of the main arteries of the passenger and freight service of the railway system with its large switching yards and junction stations, as well as of the bus network. The

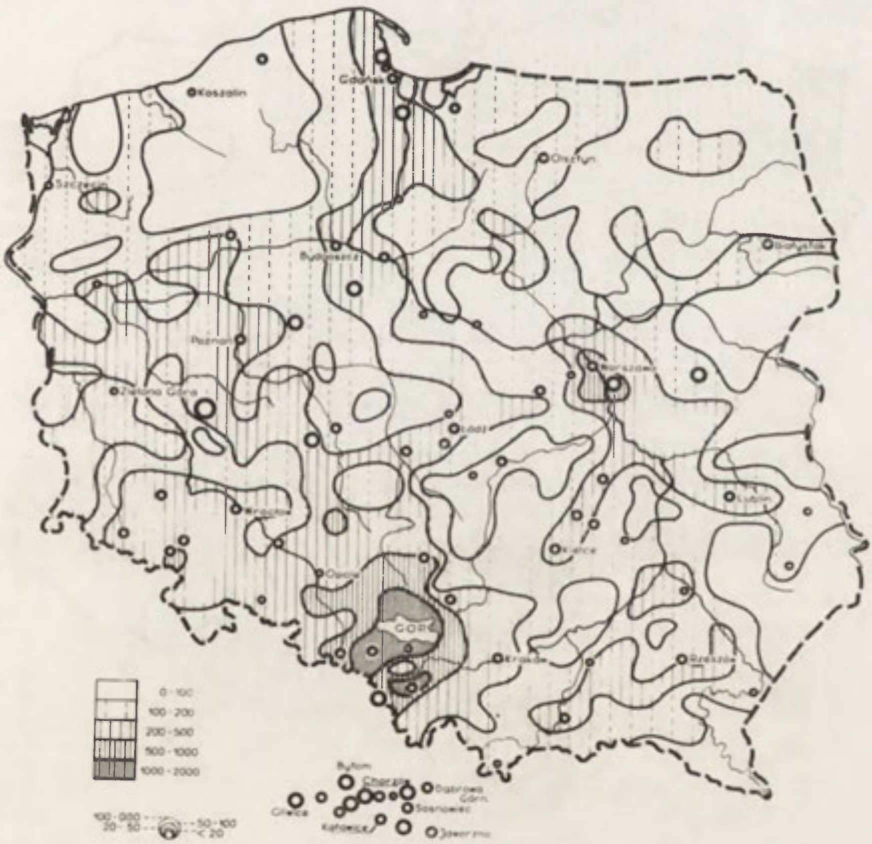

Fig. 3. Heat emission from fuel used for transportation in 1965

hachure marks annual sums for poviat (in kcal·10^6/sq·km) circles mark annual sums for cities (in kcal·10^8/sq·km) part played by the State Autobus Service is particularly conspicuous in areas where industrialization is less advanced and from which people commute to larger centers. Białystok and Bochnia poviats may serve as examples. In general, transportation is responsible for 14% of the artificial heat emitted.

4. Total figures for artificial heat in Poland in 1965

The quantities od artificial heat emitted from economic processes are much varied all over Poland. In areas outside towns the figures are of the order of $50 \cdot 10^6$ $\text{kcal} \cdot \text{km}^{-2} \cdot \text{year}^{-1}$ for the north-eastern part of Poland. They rise to more than $5000 \cdot 10^6\ \text{kcal} \cdot \text{km}^{-2} \cdot \text{year}^{-1}$ for Upper Silesia. The annual total of heat emitted in Poland in 1965 is $621 \cdot 10^3$ Tcal, in the mean, this is $0.2\ \text{kcal} \cdot \text{cm}^{-2} \cdot \text{year}^{-1}$. This figure is ten times higher than the global mean for the whole Earth, as has been estimated by Budyko, Drozdow and Judin [2].

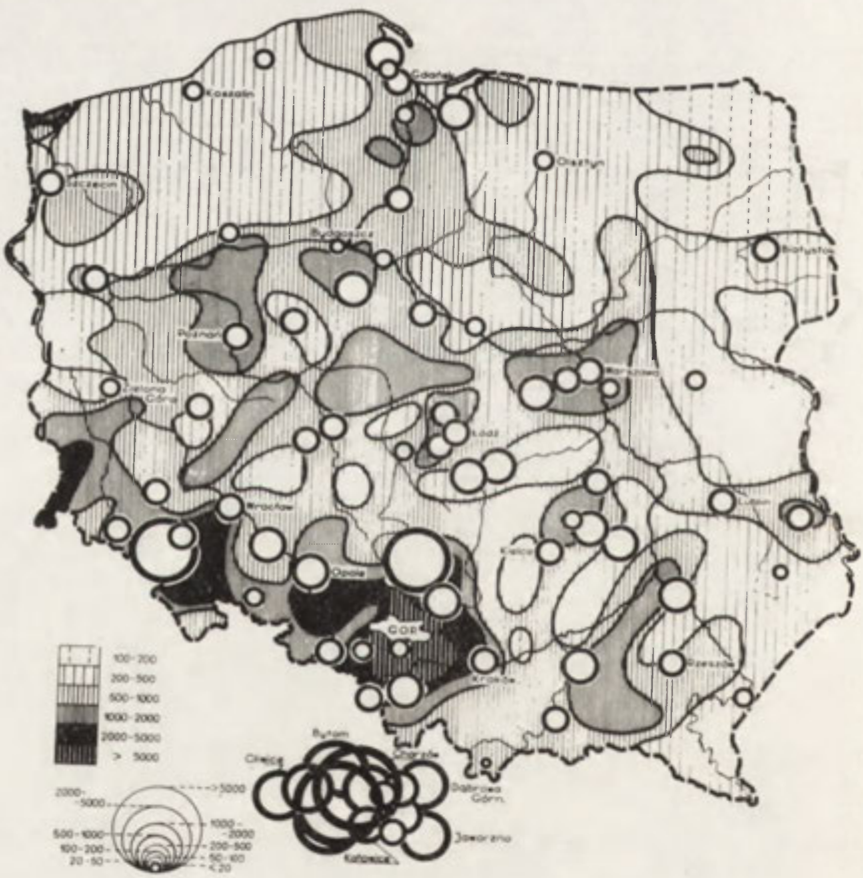

Fig. 4. Emission of artificial heat in Poland in 1965

hachure marks annual sums for poviats (in $\text{kcal} \cdot 10^6/\text{sq km}$) circles mark annual sums for cities (in $\text{kcal} \cdot 10^8/\text{sq} \cdot \text{km}$)

RATIO OF TOTAL ARTIFICIAL HEAT (S) TO SELECTED COMPONENTS OF THE RADIATION BALANCE

For illustrating the share of artificial heat in the heat balance on the interface earth-atmosphere the author chose two indices: S/Q and S/E. They indicate the quantitative ratio of artificial heat to the two most important components of the radiation balance: global radiation (Q) and effective radiation (E).

An mentioned before, the mean emission of artificial heat in Poland is 0.2 kcal $\cdot$ $\cdot$ $cm^{-2} \cdot year^{-1}$ this represents about 0.30% of the heat energy absorbed on the average on Poland's area from solar radiation, about 0.25% of the global radiation, dispersed and direct, arriving from the Sun, and about 0.66% of effective radiation, the latter taking account of the loss of heat by out-radiation in the long-wave range, and the return radiation of the atmosphere. The ratio of the total heat S emitted, to the discussed components of the radiation balance was obtained by making use of the available data on sums of global radiation Q (1,4) and of the results of the author's earlier work [3]. Some of the findings are included in Table 2.

The high figures of artificial heat emission determined for relatively small but densely populated areas of industrialized towns in Upper Silesia are reflected in the magnitude of the S/Q ratio, which at an annual scale rises here to some 50% or more, and of the S/E ratio which exceeds 100%. It is probable, that periods occur in the course of the year when the figure for S is higher than the figure for Q, this may take place during the cool season when the figures of the mean monthly radiation drop to 1.2 kcal $\cdot$ cm^{-2}, while the emission of artificial heat is at its maximum due to domestic heating. The increase of the S/Q values bears the character of an exponential function: the values are negatively correlated. This is due to the fact, that over industrialized regions radiation is weakened due to air pollution. Usually higher values of emitted heat go parallel with an increased air pollution, and this in turn reduces the inflow of short-wave radiation. This is particularly conspicuous in areas of high industrial concentration.

The pattern of the S/Q values (Fig. 5) illustrates the degree of intensification of economic processes, expressing the intensity of the changes in energy effected by man, and their effect upon processes of transformation of energy as are taking place in a natural way on the interface earth-atmosphere.

The 0.1 isoline shown in Fig. 5 defines in a characteristic way those areas in which the phenomena mentioned appear particularly intensive. Here the value of the S/Q index emphasizes the extent of this type of area more distinctly than is shown by the mere figures for S (Fig. 4). Occasionally the sums of heat emission calculated for individual towns (Fig. 1–4) may be questionable and the same may pertain to some of the indices. However, it should always be kept in mind, that the compared values are relative ones referring to the areas of the towns examined. These areas vary greatly, from compact and densely built towns like Świętochłowice, embracing barely 13 sq. km, to widespread, rather loosely settled urban

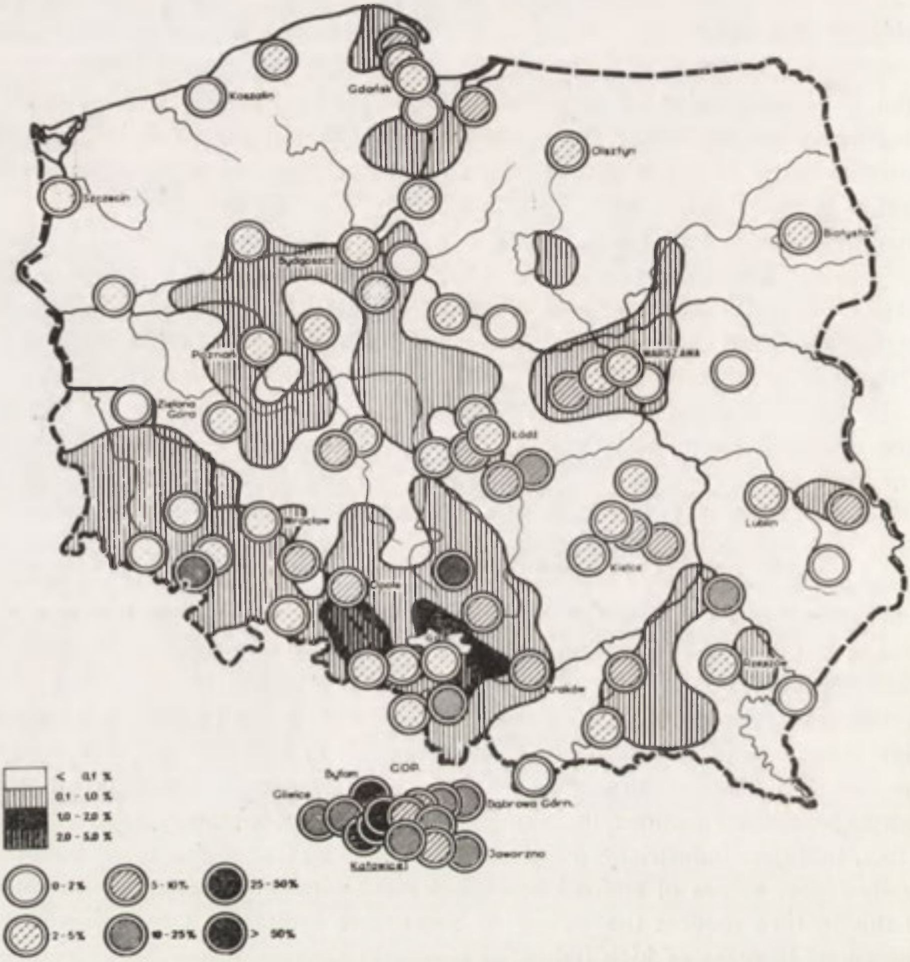

Fig. 5. Ratio of artificial heat to solar radiation in Poland, in %

hachure marks annual sums of artificial heat in % of solar radiation, for poviats and for cities (circles)

centres like Bydgoszcz with its 116 sq. km area, or some of the most extensive urban areas like Poznań covering 220 sq. km, Łódź (214 sq. km), Wrocław (225 sq. km), Cracow (230 sq. km) and Warszawa with its 446 sq. km urban area.

This is why often for different towns the total heat emission of the same order, calculated per unit area, yields figures widely differing from each other (Table 2). It therefore is necessary to stress the relativity of the values presented which, however, supply an unbiased comparison of the values of both man-created and natural energy processes on the interface earth-atmosphere, considered in their spatial pattern.

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THE IMPACT OF THE RAILWAY ON THE DEVELOPMENT OF POLISH TOWNS FROM 1860 TO 1910

ALICJA KRZYMOWSKA-KOSTROWICKA

The study of the relationships between the processes of urbanization and the development of the transport network has some tradition in geographical literature [e.g., 1–5]. This problem is most often dealt with in discussing the effect of transport on the landscape and on man's economic activities. Usually, though, the authors confine themselves to general statements illustrated by examples. But there are few studies dealing with the interdependencies between urbanization and the transport networks based on more comprehensive sets of data and the employment of precise research techniques.

This paper presents the results of studies on the role of railway transport in the development of Polish towns towards the end of the 19th and at the beginning of the 20th centuries. The studies covered the period 1860 to 1910, for it was at that time that Poland went through the processes of industrialization and urbanization, which are known as the first industrial revolution. One of the essential characteristics of the latter was the rapid extension of the railway network. This yielded a new dimension of economic space within which processes of spatial concentration started to set in, which in turn resulted in changes of the urban settlement network. Thus it is possible to study the impact of the railway network on the development of urban centres *in statu nascendi*. Here, it is rather important that in this 50-year period (after 1864) there were no wars on Polish soil, for war usually results in population losses in urban centres, and consequently encumbers the study of the effect of other factors on the population change.

The impact of railway networks on urban centres has been studied on the basis of a comparative analysis of the developmental trends of the population of the towns under examination. These analyses covered 496 settlements, which between 1860 and 1910 had at least once reached the population figure of 2000 and about which complete statistical materials were at hand.

For the basic variable in our study the percentage of population increase of the particular towns, in successive decades and in the whole 50-year period in question, has been taken. These data were used to calculate the mean population increases in four groups of towns defined on the basis of the character of their links with the railway network[1]: (1) towns without railway lines, (2) towns – terminal stations

[1] The types of stations correspond to the classification adopted in railway traffic to denote the location of a station along the railway line.

with traffic in one direction only, (3) towns – intermediary stations with traffic in two directions, (4) towns – junction stations where railway lines from three or more directions meet.

Because of the size of the set, the mean increase was calculated by the weighted mean formula:

$$M = \frac{f_i x_i}{N}$$

where f_i denotes the number of units in the i-th class, x_i stands for the center of the class, and N is the total number of the units.

To find out the dispersion of the observations, the standard deviation was used, it is calculated from the formula $\frac{x^2}{N}$, where x^2 denotes the sum of squares of the particular deviations from the standard.

The statistical analysis of the set examined, carried out on this way, established the relationships between the values of population increase in the particular towns and the character of their respective links with the railway network (junction, intermediary-station, terminal-station towns and towns without railway lines).

The analysis of the mean population increase has shown that:

(1) The population increase in towns without railway lines was lower than the mean increase of all towns throughout the period in question: 82.3 as compared to 134.1 per cent.

(2) The population increase in the towns with terminal or intermediate stations for each decade exhibited both positive and negative deviations with respect to the total mean. On the whole, though, the 50-year population increase in the group of terminal stations (90.0%) and the intermediary stations (103.6%) was below the total mean, but to a smaller extent than that of the towns without railway lines.

(3) Among the towns with railway stations, only the junction towns had a population increase significantly exceeding the total mean in each of the successive 10-year periods. For the whole period from 1860 to 1910 it amounted to 181.4 per cent.

The relationships between the population increase and the particular types of towns are presented in the form of correlation diagrams (Fig. 1 and 2). Figure 1 shows that among the towns with a negative population increase i.e., with a decrease in the population number, 50 per cent were towns without railway lines; whereas in the group of towns with a big increase the junction towns were in the majority (57.2%), and in cases of an extreme population increase the junction towns definitely predominated (76.7%).

The next diagram (Fig. 2) illustrates the distribution of towns with a given rate of increase within the particular groups examined. Considering that the mean population increase of all towns amounted to 134.1 per cent, it can be said that $^3/_4$ of towns without railway lines and with terminal and intermediary stations had an increase below the total mean. The junction towns were in a different situation:

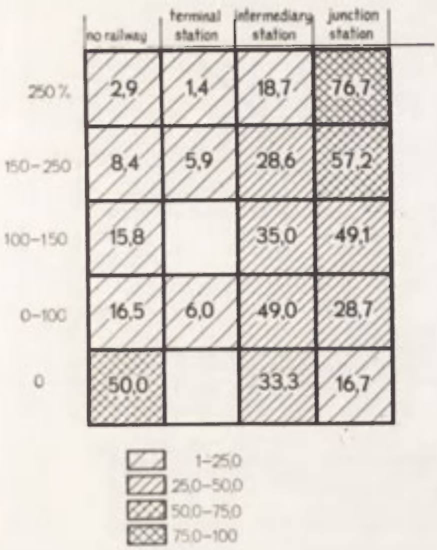

Fig. 1. A diagram of correlation between the number of towns with particular railway facilities and the mean population increase of Polish towns between 1860 and 1910. Numbers refer to the percentage of all towns in the class of increase

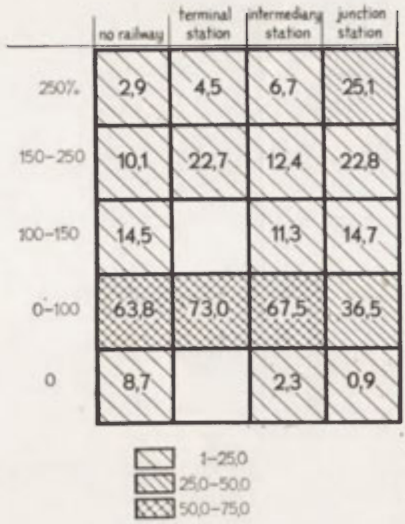

Fig. 2. A diagram of correlation between the number of towns with particular railaway facilities and the mean population increase in Polish towns between 1860 and 1910. Numbers refer to the percentage of all towns in the given group

in nearly half of them (47,9%) the increase exceeded the total mean, and 25.1 per cent of these towns had the highest increase, i.e. more than 250 per cent.

The resulting picture exhibits a distinct correlation between towns with different types of links with the railway network and the population increase. This correlation is most evident in the case of the junction towns and those without railway lines. But if the towns included in the examination are considered *en bloc*, without differentiating their size, it is impossible to establish whether the high population increase in the junction towns results actually from the impact of the railway or is connected with the size of the town. Therefore the size of the towns has also been studied. The analysis carried out disclosed a meaningful correlation between the size of the town and the population increase in the junction towns up to 100,000, in towns with intermediary stations up to 15,000, and in towns without railway lines up to 12,000 population. These differences are illustrated by the curves of the medians referring to the particular groups of the towns examined (Fig. 3).

The next step has been to investigate the effect that building a railway line to a town has on the town's development rate. Accordingly, the analysis has been limited to small urban settlements largely deprived of the inherent developmental

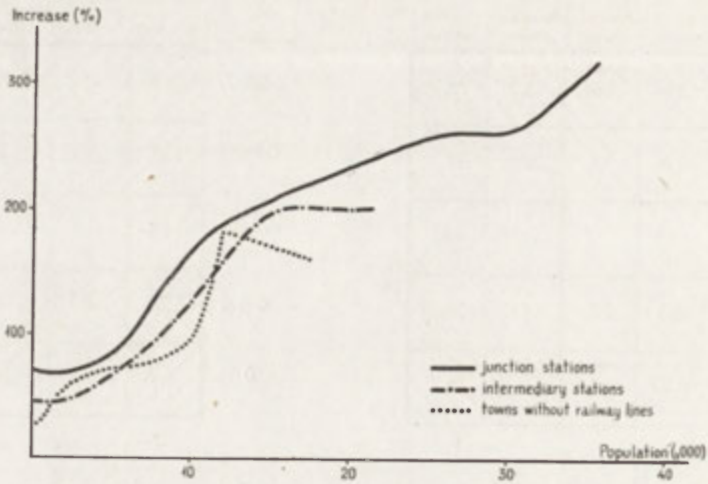

Fig. 3. The median curves of the groups of towns depending on the size and the rate of growth of the population

forces which are, to a smaller or wider extent, typical of a larger urban center. Hence, the establishment of a railway station, especially of a junction, in a smaller town may directly contribute to its development, and thus to the growth of its population. If it were assumed that the railway exerts no influence, it should be expected that the distribution of the towns in the class of small increase will not reveal differences as to the type of railway facilities available. But the analysis of towns with 2–10,000 population (362 towns, which makes 72.9% of the whole set examined) has shown that there are distinct differences between the rates of increase of the junction towns on the one hand, and of the intermediary-station towns and those without railway lines on the other (Fig. 4).

The diagrams indicate that most towns of the intermediary station and no railway types had a population increase of 0–100 per cent in the period 1860 to 1910, and thus must be regarded as rather stagnant towns. On the other hand, the percentage of stagnant towns is considerably smaller among the junction towns, and the number of towns with an increase of 100-250 per cent grows. The differences between the shares of the intermediary station towns and of the small towns of this group are insignificant, but they are very conspicuous in the group of towns without railway lines (within the smaller values of increase the share of small towns exceeds the mean value, while in the classes of greater increase there are few towns without a railway). The general pictures of the shares of small towns with intermediary-stations and those without railway lines are very similar to each other, the only differences being that the share of towns with a negative increase in the no-railway type of towns is 4 times as big as that in the intermediary towns, and that the no-railway towns

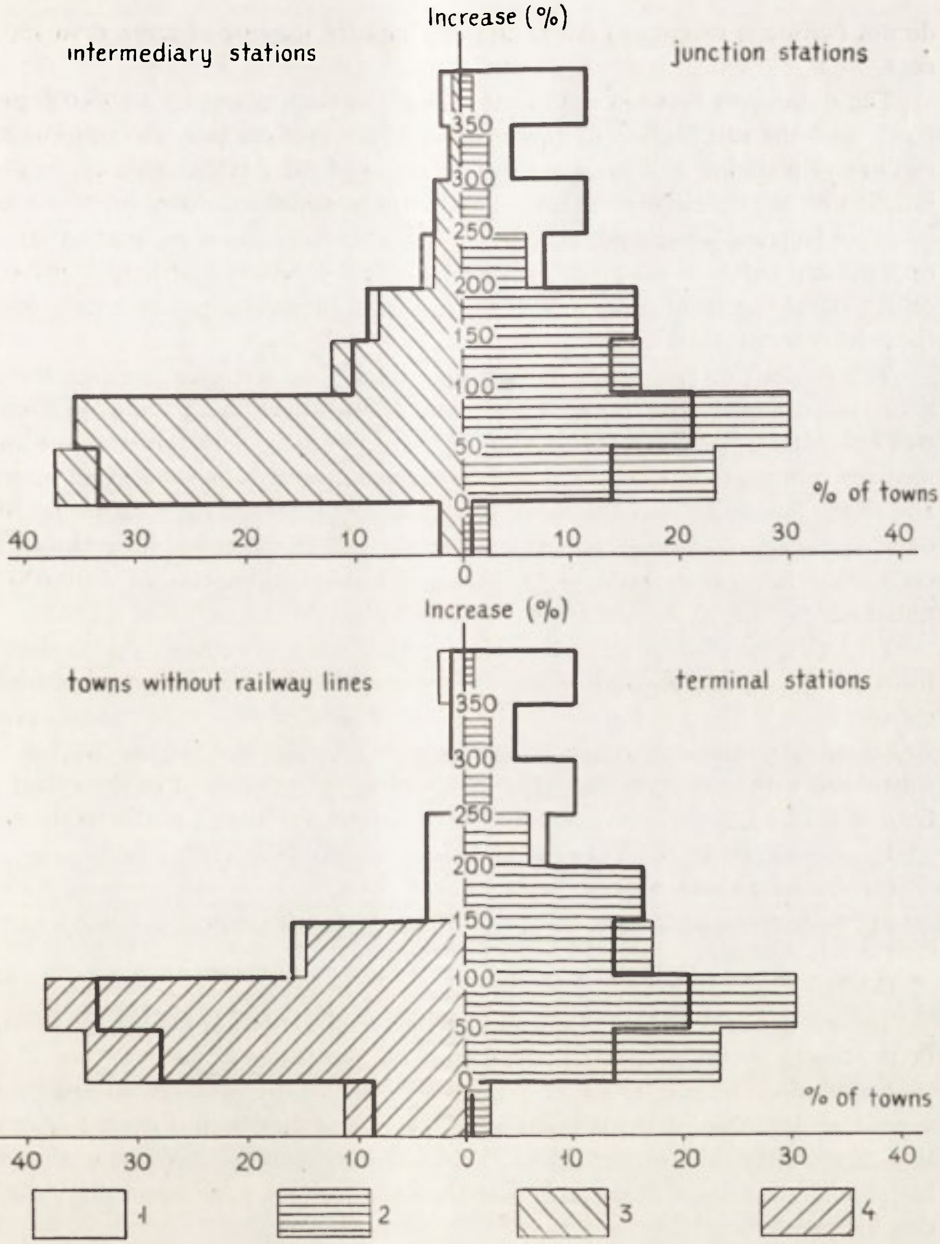

Fig. 4. The differences between the share of the junction towns in the particular classes of population increase and the share of towns with intermediary stations and towns without railway lines

1 – the distribution of the share of all towns of a definite type of railway link, 2 – the distribution of towns with junction stations of 2–10,000 population, 3 – the distribution of towns with intermediary stations of 2–10,000 population, 4 – the distribution of towns without railway lines of 2–10,000 population

do not (with one exception) fall at all in the class of increase of more than 150 per cent.

The differences between the distribution of junction towns up to 10,000 population and the distribution of towns without railway lines and with intermediary stations of a similar size suggest a distinct effect of the establishment of a railway junction on the developmental rate of small towns, which manifests itself in a more intensive increase in their population. On the other hand, the mere putting through of a railway line to a town, without establishing a junction, had hardly any effect on the development of these towns, except that it sometimes checked their decline (i.e., it reduced their negative increase).

The results obtained by employing the comparative statistical method revealed a certain regularity: in the towns without railway lines the population increase was below the total mean increase of all towns; in those with terminal and intermediary stations the increase did not deviate significantly from the mean increase, and in the junction towns the increase considerably exceeded the total mean. More detailed studies, including consideration of the size of the town, have shown that correlation is most meaningful for the small urban settlements of 2–10,000 population.

To define the character and the extent of the impact of railways on the development of towns, a comparative morphographical method has been employed. It consists in an analysis of the curves of population increase and of the changes evoked by extending a railway line to a town. The effect of building a railway line has been considered with respect to the shape of the curve of growth and to the extent and frequency of its deviations occuring after the advent of railway traffic to the town.

Four main types of deviation have been distinguished (Fig. 5):

(1) An immediate positive deviation;

(2) A positive deviation, with a time-lag up to 10 years;

(3) No deviation;

(4) Negative deviation.

These types of deviation of the curve served as the criterion for the classification of the towns by the gradual elimination of the particular diviations.

Calculations have shown that in more than half of the towns examined (58.4%) a positive deviation of the population increase curve has been observed after putting through the railway line (in 46.3% immediately, and in 12.1% with some time lag). Simultaneously, differences between junction stations and intermediary stations can be traced.

Thus, the percentage of towns with positive deviation was significantly larger in the junction-town group (73.9%) than in the group of intermediary stations, whereas the percentage of towns with negetive deviation predominated in the intermediary station town group (intermediary stations – 22.5%, and junction towns – 2.8%). These latter were mostly stagnant towns, in which a decrease in the population growth rate often occurred after establishing the railway junction. For so-

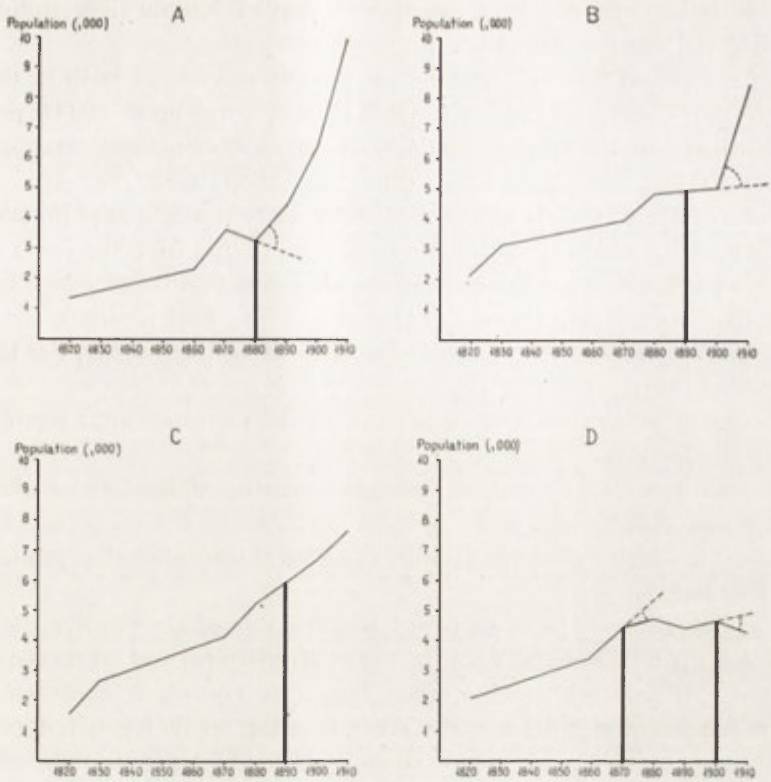

Fig. 5. Examples of deviations of the curve of population growth in towns after building a railway line

A – Jasło – an example of an immediate positive deviation, B – Lubartów – an example of a positive deviation with a time-lag, C – Parczew – an example of the absence of deviation after putting through a railway line, D – Czaplinek – an example of a negative deviation occurring twice

metimes the railway line facilitated out-migration, leading eventually to the depopulation of these towns.

The present study included also the examination of the structure of deviations of the curve in towns of different size. In 1860 to 1910, in the group of junction and intermediary station towns, these with 2–10,000 population were predominant. In these towns the distribution of deviations of the curve was different in the two types of station. Whereas in the junction stations most towns had an immediate positive deviation (57.7%), and the share of negative deviations was very insignificant (4.3%), among the intermediary stations towns with zero deviation were most frequent (35.4%), and there was a relatively high share of negative deviations (23.4%). In the group of junction stations in all classes of size, towns with an immediate positive deviation predominated, whereas in that of intermediary stations towns with zero deviations predominated.

All of the above types of deviation of the curve occurred both in the case of junction stations and intermediary stations only in towns up to 20,000 population; above this limit, in the junction stations the negative deviations disappeared, and above the 100,000 limit there were no zero deviations either.

A more detailed analysis was carried out with reference to the junction towns, especially those in which an immediate positive deviation from the curve of growth set in after putting through the railway line. It seems that these towns, being most sensitive to the establishment of railway traffic, may best illustrate the character of the impact of railways. To grasp the differences in this impact, the towns have been devided into:

(a) towns in which a positive deviation occurred each time after putting through a railway line to them,

(b) towns in which a positive deviation occurred at least twice after putting through a new railway line, and

(c) towns in which a positive deviation occurred at least once after putting through the railway line.

The examination of junction towns with an immediate positive deviation revealed a distinct difference between the towns of group (a) and (c) on the one hand, and of those of group (b), on the other. This is by no means accidental, for it reflects the fundamental differences between the effect of the specific types of links on small towns (which predominate in group (a) and (c) and on those of medium-sized or big towns) most of these occur in group (b). Whereas in the case of small towns the building of a railway line quickly affects the town, in the case of medium-sized towns this effect is considerably lower and does not occur each time after the establishment of a new line to the town.

It may be concluded that the opinion of some authors that the railway nearly always exerts a positive influence on urban development has not been fully confirmed in the present study. This influence is rather complex and diversified. It depends both on the type of link the town has with the railway and on the size of the town. There are substantial differences between the role played by the particular types of railway links in the development of the towns. Only the existence of junction stations in the town is a stimulating, distinctly city-building factor, whereas the effect of intermediary or terminal stations is rather inconsiderable.

The impact of the railways is different with respect to towns of different size. This is best seen in the case of small urban settlements (2–10,000 population), in which the establishment of a railway junction is, as a rule, a factor stimulating further growth. In the larger towns (of more than 100,000 population) the possible effect of the railway cannot be distinctly grasped, especially owing to the obscuring role of other factors.

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CARTOLOGY

LECH RATAJSKI

A characteristic feature of the recent development of scientific study is the growing exchange of experience and achievements between different fields of research work. This results in the reciprocal enrichment of particular branches of knowledge in new ideas and methods and, on the other hand, leads occasionally to drastic revisions of the notions of the subject matter of a science or even to the emergence of new scientific disciplines. The adaptation of such ideas leads to a renewal of a science, to a change or modification of previous views, which is not always accepted without some resistance. The advances in mathematical methods, in the theory of information, in semiotics, psychology and technology during the last twenty years contributed considerably to a revision of the traditional views on cartography and, at the same time, produced some confusion in the understanding of the role and essence of this scientific discipline.

The term "cartography" has been attributed different meanings by cartographers in different scientific centers. These differences are manifest in some recent definitions of cartography.

"Cartography is the science dealing with the study, elaboration and publication of geographical maps. It is divided into scientific-technical disciplines: mathematical cartography, the compilation (*sostavlenye*) of maps, and the publication of maps"[1].

"Cartography, the transcription on a plane of the geographical order"[2].

"The subject-matter of cartography is the geographical map as a specific manner of representing reality. Among its tasks cartography includs the extensive study of the essence of geographical maps and the development of the methods and processes of their production and utilization. At present, cartography as a science is divided into several disciplines: map knowledge, mathematical cartography, compilation and editorial preparation of maps, graphical execution (*oformlenye*) of maps, publication of maps ... The term 'cartography' is also applied to cartographic production and its results, e.g., 'Soviet cartography', 'state cartography'. In this meaning of production of maps, the term 'cartography' is included in the state

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[1] L. S. Garayevskaya, *Kartografia*, Geodezizdat, Moskva, 1952, p. 5.

[2] J. Bertin, La cartographie dans la „civilisation d'informatique", *Bulletin du Comité Français de Cartographie*, 1 (1968), 9.

cartographical-geodetic service of the Soviet Union (Central Office of Geodesy and Cartography)"[3].

"Cartography – the art, science and technology of making maps, together with their study as scientific documents and works of art. In this context maps may be regarded as including all types of maps, plans, charts and sections, three-dimensional models and globes representing the earth or any heavenly body at any scale"[4].

It is however difficult to accept the definition of H. Schmidt-Falkenberg who maintains that cartography is "the science dealing with the graphical representation of results of observations and investigations"[5]. From the pattern of the scheme that he presents it seems to folow that he means the results of observations and investigations in geodesy, geography and astronomy. With respect to the number of sciences included that is too little, from that of the tasks – too much.

The above definitions show that there is even no univocal agreement as to whether cartography is a science or only a skill. Moreover, some are of the opinion that cartography is also connected to printing activity, the results of this activity to schools and research trends[6] or to administrative operations. Depending upon the approach to cartography in different milieux, its scope and division are variously defined. The current development of cartography and the vigorous growth of demand for cartographical works in various domains of life, resulted in an extension of its interests. Moreover, there are indications that the process of extension of the subject-matter will continue. Hence, the definition itself of cartography must not be too detailed and the classification of cartography ought to be sufficiently flexible to permit the introduction of new categories in it if necessary. In view of what has been said, the following definition is proposed:

Cartography is a field of human activity comprising the *creation* and *functioning*[7] of all forms of cartographic transmission. This activity assumes a scientific and an operative aspect.

To realize fully the meaning of this definition we have to elucidate the concept of "cartographic transmission" and operative cartographic activity. This is to be done below.

At first, for the sake of clarity, let us distinguish between the scientific and the operative aspects of cartography. Briefly, the operative activity consists in the transmission of information by adequate material cartographical products, and in making them available to the receivers of the information, whereas the scienti-

[3] K. A. Salishchev, *Kartografia*, Izd. Vysshaya Shkola, Moskva, 1966, 21–22.

[4] *ICA Multilingual Dictionary of Technical Terms in Cartography. Compiled and submitted by ICA – Commission II. A provisory edition for the ICA conference at New Delhi*, 1968.

[5] H. Schmidt-Falkenberg, Grundlinien einer Theorie der Kartographie. *Nachrichten aus dem Karten- und Vermessungswesen*, 22, (1962), 10.

[6] For instance, in Poland the term "Romer's cartography" has come into common use.

[7] The functioning of the map is to be understood as a human activity intended to distribute, use and study the processes and effects of maps on the users.

fic activity is aimed at studying the processes resulting from, and involved in, the cartographical practice, and in the development of methods that are subsequently employed in the operative activity.

Traditionally, scientific cartography is called theoretical cartography in contrast to applied cartography. In my opinion, theoretical cartography has by now not been a uniform system in actual practice; it has only been a denomination of research work in the domain of cartography. Without refuting or defying this term, I suggest a new concept and term – *cartology*. By cartology[8] I suggest to denote *a system of theoretical cartography* from the point of view of functioning of the transmission of cartographic information and, moreover, the theoretical superstructure of applied cartography. In this sense, it may be admitted that cartology is a synonym of a definite system of theoretical cartography or a synonym of scientific cartography.

Analogies supporting the introduction of this term can be found in other branches of knowledge, e.g., distinction had been made between hydrography and hydrology, oceanography and oceanology, cardiography and cardiology, between morphography (of land) and (geo)morphology etc. The disciplines with the suffix "-graphy" describe and study states, or conditions, whereas those with "-logy" study phenomena and processes. It seems worth while recalling that hydrography and oceanography are considered to be parts of geography, whereas hydrology and oceanology are independant geophysical sciences. Analogically, many people regard cartography as a branch auxiliary to geography, which seems to be right if we mean its auxiliary role manifesting itself mainly in the operative activities and if we consider that geography studies phenomena in their spatial structure and cartography represents such spatial structure in the form of maps. It is different with cartology: this is a theoretical science providing the applied cartography with new methods and searching after laws and regularities governing the processes of cartographic transmission.

AN OUTLINE OF THE PROBLEMS OF CARTOLOGY

Thus, cartology has its subject in the study of the process of transmitting information on the spatial distribution of facts (objects and phenomena) by means of cartographical products, the disclosing of principles and methods allowing the optimization of the cartographic transmission, and the location of cartography within the total system of sciences.

The external world constitutes an inexhaustible source of information on *pro-*

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[8] French cartographers employ the term „cartologie" as corresponding to „map knowledge" (German: Kartenkunde), and in this meaning has it been proposed to the *ICA Multilingual Dictionary of Technical Terms in Cartography*. The French definition of the term "cartologie" in that dictionary reads: "Science de l'étude théorique et pratique des cartes".

cesses (physical, chemical, biological, intellectual etc.) and *states* or conditions (past or present). One feature of the latter is the distribution of the facts in the space examined. The information concerning the distribution of these facts in the *geographical* space[9] may be treated as *chorological information*[10], and the transmission of this informations *chorological transmission*[11].

Depending on the receiver, which may be either a man or an apparatus, there are different forms of such transmission. But since the apparatus may be regarded as an intermediary link between the original source of information and the ultimate receiver, i.e. man, the cognition of reality is conditioned by man's senses. Hence the forms of chorological transmission may, depending on the sensory receptors, be visual, audible, tactile, olfactory, or thermic. The information about the place of a burning fire can be received by looking at it, hearing the crackling of twigs in the fire, smelling the burning resin, or feeling the warmth of the air in the direction of the fire. W. Bunge points out a quite different form of chorological transmission in his reflections on metacartography, namely mathematics[12]. This form is based on intellectual speculations with the exclusion of the sphere of sensory perception, although it is subsequently represented either visually or audibly.

Here we confine our interest to two forms of the chorological transmission: the visual and, sometimes, the tactile (maps for the blind). The visual transmission of chorological information occurs by means of a system of signals (signs) that are registered by the receiver. We have to deal either with sensory cognition, if there occurs a relation of cognition between the cognizing person and the cognized thing (*sensory information*), or with extra-sensory cognition (*extra-sensory information*), if the same relation occurs between an apparatus and the cognized thing. It has to be expected that the advance of technology and of computer methods will require a deeper study of extra-sensory information.

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[9] Cf. K. Dziewoński, Zagadnienie integracji analizy kartograficznej i statystycznej (Sum.: Problems of integration of cartographic and statistical analysis in geographical research), *Przegląd Geograficzny*, 1 (1965), 585 – 597.

[10] Chorology – the science of the geographical and topological distribution of organisms on the earth; term coined by Haeckel (*Słownik wyrazów obcych*, PIW, Warszawa, 1955).

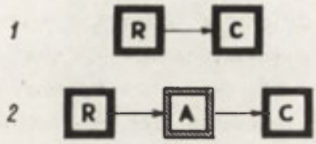
[11] In: Zagadnienie ogólnej definicji mapy w świetle dotychczasowych sformułowań (The problem of a general definition of a map in the light of the existing formulations), *Przegląd Geodezyjny*, **39**, (1967), and in: *Kształtowanie się mapy wsi w Polsce do końca XVIII w.* (The development of the map of Polish villages in Poland till the end of the 18th century), Ossolineum, Warszawa–Wrocław–Kraków, 1969, 29 – 35, J. Gołaski suggests the term "topographic transmission". This is, however, too narrow for our considerations as it informs only about "the mutual location of objects connected with the Earth's surface". Besides, by being associated with the term „topography" it may be confined by the reader to informing merely about objects (the principal substance of the topographical map) and not about phenomena (the principal substance of thematic maps).

[12] W. Bunge, Theoretical geography. *Lund Studies in Geography, Series C*, 1, (1962).

The term "apparatus" is here understood in the broad sense of any tool facilitating the cognizance of reality by man. In the chorological transmission this tool operates by codes and algorithms programmed by man. Thus it can be spoken of apparatuses programmed for the collection (registration) of information, for the transformation of information, and for its transmission. Considering the existence and operation of an apparatus in the process of transmitting information we may distinguish between *direct* (sensory) *information* and *indirect information*, that is, information by a means of transmission – the apparatus (Fig. 1).

Fig. 1

1 – direct information, 2 – indirect information; *R* – reality, *C* – man, *A* – apparatus or transmission set



In visual chorological transmission the role of the apparatus is fulfilled by different forms of systems of visual signs: writing, *pictures* (photography) or *maps* and map-like objects[13]. In this latter case we have to deal with a specific kind of chorological transmission – with the *cartographic transmission of information*[14], which is essentially different from the other forms. Namely, it is "one of those transcriptions (*ces transcriptions*) that by itself involves all the properties of the geographical order (*l'ordre geographique*). It is a homothetic transcription. These properties secure the usefulness of topographical maps (*cartes d'inventaire*) making possible direct registration and use without additional descriptions, thus rendering these maps effective instruments of the study of the land surface"[15]. A somewhat different approach is presented by M.K. Bocharov[16], who indicates that the cartographic transmission "has the specific property of a direct visual transmission of the mutual distribution of the designations of objects on any surface", and that "each cartographical representation of the earth's surface involves in itself a unity of contents and form, an agreement between the substance of information and the signs".

This specific character of the cartographic transmission results from the special principles and laws governing it and from the employment of a relevant code, that is, a system of signs. This code includes *semantic signs*, both *arbitrary* and *motivated*[17]. In contrast to writing, the system of cartographic signs has, in its form

[13] Globes, plastic models, panorams, anaglyphs, orthophotomaps etc.

[14] The cartographic transmission of information is to be understood as a process. The form of this transmission is the map.

[15] J. Bertin, *op. cit.*, p. 9.

[16] M. K. Bocharov, *Osnovy teorii proyektirovania sistem kartograficheskikh znakov*, Izd. Nedra, Moskva, 1966, 20–21.

[17] Cf. T. Milewski. *Językoznawstwo* (Linguiestics), PWN, Warszawa, 1969, p. 15.

of a map, a structure that is continuous (each point on the map is meaningful) and two-(map) or three-dimensional (globe, plastic model). Furthermore, an essential feature of the map is a specific isomorphism[18], which consists in that a given map reflects only such a set of points of the represented area that is significant to the receivers of the map. "Correspondingly, it is a fact that many physical systems have been found whose behavior can be similarly 'mapped'. Having made a limited number of highly accurate observations of these systems, one is in a position to formulate a theory with the help of which one can draw, in appropriate circumstances, an unlimited number of interferences of comparable accuracy[19]". This is the difference between a map and a photograph. The difference between a map and a picture consists in that in the latter we have to deal with signs that are uni-univocal, that is, individual signs, whereas in the cartographical transmission with signs that are uni-multivocal, that is, signs that permit us to denote a larger number of objects marked by certain features common to them.

Thus, it becomes necessary to outline a theory of the cartographic transmission of information. This theory is contained within the framework of the general information theory. In accordance with the latter, the form of cartographic transmission (i.e., the map) can be treated as a channel through which the chorological information is transmitted from the sender (the author, or the editor of the map) to the receiver (the user of the map). To present this process more clearly a special model can be used[20]. The *model of cartographic transmission* presented here (Fig. 2) is partly based on the scheme of Kolacny[21] and on T. Wojcik's scheme of the system of message cognition[22].

Reality (*R*) is understood as the *source of chorological information*, i.e., as such a set of existing facts in our environment that are marked by the feature of spatial distribution. Each time we shall be interested only in those facts that are connected with the expected subject of the map. This reality is cognizable by the perception of a complex of natural signals (signs). This recognition occurs by the *informative emission* (*Er*) conceived of as the relative product of two relations: the emission and the perception[23]. The source of information (*R*) exists independently of the direct receiver of the message (*K*), and the information inherent in it is direct (sen-

[18] T. Wójcik, *Prakseosemiotyka. Zarys teorii optymalnego znaku*, (Praxeosemiotics. The outline of the theory of optimal sign), PWN, Warszawa, 1969, 30–33.

[19] S. Toulmin, *The philosophy of science*, London, Hutchinson, 1953 (quoted from: W. Bunge, *op. cit.*).

[20] Models of information transmission have before been presented by: C. Board, Maps as Models, in: *Models in geography*, ed. by R. B. Chorley, P. Haggett, Methuen, London, 1967, and A. Kolácny, *Cartographic information, a fundamental concept and term in modern cartography*, Czechoslovak Committee of Cartography, Praha, 1968.

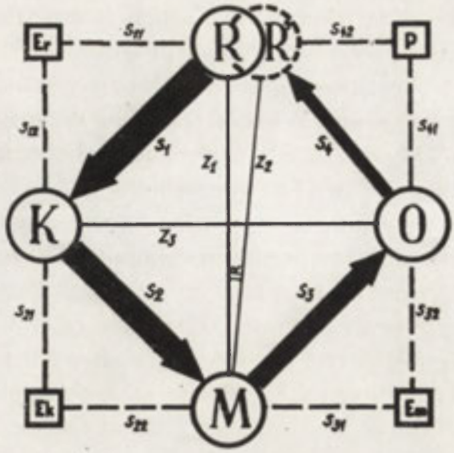
[21] A. Kolacny, *op. cit.*

[22] T. Wójcik, *op. cit.*, p. 41.

[23] *Ibidem*, p. 36.

Fig. 2. Model of cartographic transmission

R – reality as source of direct information, Er – informative emission of direct source, s_1 – relation of the direct cognition, s_{11} – relation of direct emitting, s_{12} – relation of the direct perceiving, K – the cartographer, the sender of message, Ek – informative emission of sender (message emission), s_2 – relation of message creation, s_{21} – relation of message emiting, s_{22} – relation of message perceiving, M – map or the message informant, Em – informative emission of a map, s_3 – relation of indirect cognition, s_{31} – relation of indirect emiting, s_{32} – relation of indirect perceiving, O – receiver (map user), P – mental transmutation (mental processes), s_4 – relation of reconstitution of the reality image (relation of cognition), s_{41} – relation of recalling, warning s_{42} – relatilon of imagination z_1 – message relation z_2 – relation of identification (of map efficiency) z_3 – relation of making available (of informing the receiver), α – degree of the transmission correctness



sory) *information* as it is perceived directly through the observer's senses. The reception of this information depends only on the training of the receiver; to put it differently, it depends on whether it will be perceived and understood, that is, whether a sufficient number of signals will be received to make up a correct picture of the reality (R). In the course of the *informative emission of the direct source* (Er) a definite selection of the substance of the primary information is occurring; this is conditioned both by external factors and by the receiver's (in this case, K's) psychophysical factors, and thus independent of his intentions. This emission consists of both the emitting of the source itself and the perceiving by the observer. The *direct emitting* (s_{11}) is dependent on external factors (darkness, light etc.), whereas the direct perceiving (s_{12}) – on the receiver's intrinsic condition (tiredness, discernibility of the eye, sensitiveness to color etc.). The factors mentioned here prevent all the information inherent in the source being perceived. Consequently, we may speak about the effectiveness of emitting. The effectiveness (capability) *of the informative emission* of the direct source can be defined by a ratio expressed as a logical-mathematical formula:

Effectiveness

$$Z_1 = \frac{s_{11} \cdot s_{12}}{S_1}, \tag{1}$$

where

$$s_{11} = k \cdot S_1 \qquad \text{for } 0 < k \leqslant 1, \tag{2}$$

$$s_{12} = 1 \cdot S_2 \qquad \text{for } 0 < 1 \leqslant 1. \tag{3}$$

The effectiveness of emitting determines the *loss of information*. In virtue of (1), this loss may be expressed thus:

$$U_1 = S_1 - \frac{s_{11} \cdot s_{12}}{S_1}. \tag{4}$$

In result of the loss of information in the course of the transmission, the next source of information, which is now the cartographer (K), has a certain entropy, that is, a certain amount of ignorance[24].

The cartographer becomes acquainted with the reality by its manifestations, or symptoms. What he transmits are messages, which are only his direct information usefully prepared. The relation between the informant and the cognized reality changes now. The *symptomatic relation*, which is a direct relation of extraconventional nature, is superseded by the conventional or *message relation*[25]. This observations is of paramount importance to the cartographic transmission. What we represent on the map are not things but messages constructed on the basis of symptoms of these things. For instance, we cannot show man on a map but only his manifestations (symptoms) such as the distribution of a human community, the distribution of a number of anthropological features etc. Hence it follows that by means of a map only those facts can be transmitted whose symptoms exhibit a spatial arrangement and can be transformed into messages written down by a cartographic code.

The messages in cartographic transmission are transmitted from the sender (K) to the receiver (O) through a channel (apparatus) of transmission, that is, the map (M). The capacity of the map, which is conditioned by its scale, destination and technical limitations, determines that not all of the substance of the information known to the cartographer (K) can be transmitted. Therefore the coding must be preceded by a selection from the substance and its generalization, and only afterwards can the relevantly prepared messages be coded, that is, written down by a system of cartographical signs employed in the map. The relation between the sender (K) and the means of transmission (M) is called the *message emission* (Ek). The *message emitting* (s_{21}) comprises the process of selection, the whole generalizing procedure and the coding within the given system of signs, whereas the *message perceiving* (s_{22}) comprises the technical operations leading to the creation of a map (drawing, printing). To put it simply, what is defined as the idea of the map, the author's concept, and the editorial preparation of the map program, is included in the notion of message emitting, whereas the operations leading to the final graphic and material form of the map are contained in the notion of message perceiving. In each of these procedures, a further loss of information occurs in dependence on the effectiveness of the message emission. In analogy to (1) and (4), these two values can be written thus:

Effectiveness of message emission:

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[24] The value of entropy may be interpreted as the average quantity of information per elementary unit produced by the source or as the average uncertainty of the observer before he notices the output of the source (N. Abramson, *Teoria informacji i kodowania*, translated from English, PWN, Warszawa, 1969, p. 26).

[25] T. Wójcik, *op. cit.*, p. 40.

$$Z_2 = \frac{s_{21} \cdot s_{22}}{S_2}, \tag{5}$$

the conditions for s_{21} and s_{22} being analogous to those for the corresponding values in (2) and (3).

Loss of information in the message emitting

$$U_2 = S_2 - \frac{s_{21} \cdot s_{22}}{S_2}. \tag{6}$$

Thus the total loss of information will be the sum of losses in the relations $R \to K$ and $K \to M$, that is,

$$U_M = U_1 + U_2. \tag{7}$$

Furthermore, the effectiveness of the whole transmission in the relation $R \to K \to M$ will be determined by the ratio of the product of the effectivenesses of the partial informative emissions to the message relation:

$$Z_M = \frac{Z_1 \cdot Z_2}{z_1}. \tag{8}$$

As the third source of information in succession, now already to the receiver (O), the map has therefore a greater entropy, which is the sum of the entropy of the primary source (R) and the sender (K) that has emerged in the relation $R \to M$. It may be observed here that the entropy that emerged in the relation $K \to M$ is also the sum of the entropy of the substance of the map and the entropy of the legend. This latter appears particularly in thematical maps resulting from qualitative generalization.

Although the map is made for a more or less definite group, or category of receivers, its content is differently received. This is a consequence of the individual perceptive capability of the map user. If a map is to be fully and correctly read, a number of conditions must be fulfilled, above all the following:

1) The receiver ought to:
   a) know the code of the map, that is, the system of signs employed and generally the theory of the map contents and form,
   b) understand the notions noted down on the map, that is, have some knowledge of the problems of the branch to which the map refers.
2) The map must not contain substantial or technical mistakes.
3) The form of the map ought to secure the full legibility of the information included in the map, that is, it must fulfill the requirements of the theory of map form.
4) Each type of maps is to be read in conditions that are optimal for itself.

But, in practice, these conditions are never fulfilled entirely. Moreover, the substance of the map as a continuous transmission is never read in full, i.e., it never happens that each and every point of the map is identified or recognized. Therefore in the course of the transmission from the map (M) to the receiver (O), that is, in the map *emission* (*Em*), a further reduction of the original information takes place. In the relation of *indirect emitting* (s_{31}) adverse effects are produced by possible substantial errors, the defective form of the map, and by technical imperfections. In the relation of *indirect perceiving* (s_{32}) the success of the reception is conditioned by the preparation of the receiver and by external conditions of map reading (e.g., the lighting). Analogous to the previous stages of the transmission, the successive loss of information can be determined from the difference between the relation of indirect recognition (S_3) and the effectiveness of this recognition (emission):

Effectiveness of the map emission

$$Z_3 = \frac{s_{31} \cdot s_{32}}{S_3}, \tag{9}$$

the conditions for s_{31} and s_{32} being analogous to those in (2) and (3).

Loss of information

$$U_3 = S_3 - \frac{s_{31} \cdot s_{32}}{S_3}, \tag{10}$$

or

$$U_3 = S_3 - Z_3.$$

The intermediary stage of the map in the transmission of information from the sender (*K*) to the receiver (*O*) causes that the information emitted reaches the receiver in a more or less distorted form, which results from a number of disturbances both in the course of the relation *Ek* and in that of *Em*.

The total value of these disturbances, which manifests itself in the losses of information, is determined by the difference between the *relation of informing* the receiver, (z_3) and the effectiveness of the transmission in the order: $K \to M \to O$:

$$D = z_3 - \frac{Z_2 \cdot Z_3}{z_3}. \tag{12}$$

The picture obtained by the receiver is thus encumbered with a further amount of ignorance, which adds to the total entropy.

In virtue of the information received from the map, and by identifying the signs, understanding the messages contained in them and comparing them with the remembered (learnt) meanings, the receiver creates in his mind an *imagination of reality* (*R*') by intellectual associations. Depending on the scope of his memory and the ability of logical association this image will be a more or less adequate reflection of the reality (*R*). Since the ultimate result of the correctness of the image (*R*') depends on the ability of recalling (s_{41}) and on the *ability of imagination* (s_{42}), the effectiveness of the imagination can be written as the formula:

$$Z_4 = \frac{s_{41} \cdot s_{42}}{S_4}. \tag{13}$$

The degree of correctness of the image, that is, the degree of the transmission efficiency (α) is composed of the effectiveness of the successive stages of the transmission of information, which can be expressed thus:

$$Z = \prod_{i=1}^{4} \frac{s_{i1} \cdot s_{i2}}{S_i}\,, \tag{14}$$

and the corresponding logical-mathematical formula of the information loss in cartographic transmission:

$$U = \sum_{i=1}^{4} S_i - \frac{s_{i1} \cdot s_{i2}}{S_i} \tag{15}$$

for a set i, which in our case equals 4.
These two formulae (14) and (15) are the fundamental general formulae of the theory of information transmission.

It seems that the above considerations are of essential significance to the authors and editors of maps, and the study of the effectiveness (efficiency) of the particular stages of cartographic transmission is a problem of particular interest to cartology.

It seems worth while mentioning that the model described here confirms one of the contentions of the definition of cartography put forward in this paper; namely, it indicates the sphere of creating a map and the sphere of its effect, in other words – of its functioning. The sphere of map creation is located within the relations of the field *RKM*, whereas that of functioning is in the relations of the field *MOR'*[26].

But this model as presented above does not indicate any other relations or problems that are of interest to cartology. By completing this model another one, namely the *model of cartology*, can be obtained (Fig.3).

In both spheres of activity – that of creating the map and that of its functioning – participate not only the cartographer himself and the direct user of the map but additionally a number of specialists from different scientific or professional branches. The achievements of those branches are of importance to the development of cartography.

The cartographer obtains his information about reality directly (field measurements), or from source materials, either primary (statistical sources, maps or descriptions) or in the form of preliminary studies made by other specialists (author's concepts or drafts), e.g., by geographers, geologists or historians. The cartographer uses these studies for his own purposes as direct sources, although the information given by those specialists is furnished in the form of finished messages. These messages, however, need not be conveyed in a cartographic language. Accordingly, in this latter case the cartographer's task consists in giving an adequate cartographical form to the substance conveyed by those specialists, in formulating correct cartographic messages, and coding them in an adequate system of cartographic signs. Therefore, to secure efficiency to his work the cartographer must acquire a sufficient amount of substantial knowledge in the given domain. This makes it often necessary for him to select a narrower thematic specialization.

[26] The term "relation of the field" ought to be treated in the abstract sense as a space in which occur all logical relations and connections resulting from the model.

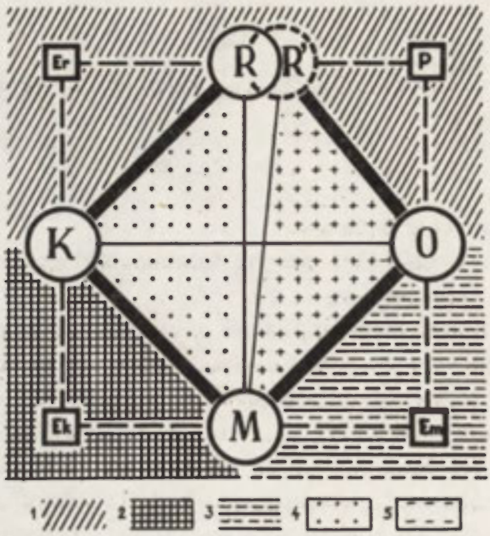

Fig. 3. Model of cartology

1 – auxiliary substantial branches, 2 – auxiliary methodical branches, 3 – auxiliary branches of training, 4 – applications of cartology, 5 – map knowledge

Thus, the neighbouring, or the more distant but cooperating, branches of knowledge perform the role of substantial foundation as auxiliary to cartography. Consequently, it seems to be legitimate to define the whole group of such sciences and branches as the *auxiliary substantial branches*. These branches enter a reciprocal cooperation with cartography: the latter uses the substantial achievements, whereas the former utilize the cartographic research methods and ready cartographic products. As auxiliary to cartography, these branches oparate in the relation $R \rightarrow K$ and are located in the relations of the field *RErK*.

The transformation of the direct information into messages, the elaboration of systems of cartographic signs, the anticipation of projection deformations and their effects, the anticipation of disturbances in receiving, the working out of principles of generalizing and the preparation of the map to the reproductive processes as well as the reproduction itself require a knowledge of and cooperation from still other branches of science and professional skills. By way of example, we may mention here mathematics, automatics, semiotics, psychology, aesthetics, printing, economics of production etc. But the cooperation of these branches with cartography retains its reciprocal character to a smaller extent than in the former case. Since the achievements of these branches of knowledge make possible a steady improvement of the methodical aspect of cartographic transmission and technological processes of creating the map, we shall call the whole group of these sciences the *auxiliary methodical branches* of cartography. Within our model they are located in the relations of the field *KEkM*.

The conditions of a correct reception of the map contents have been given before. To fulfill them the map user has to acquire a number of skills, starting with the skill of reading. These skills are acquired in the course of a versatile training at school and at work. Here it is unnecessary to mention all of the subjects and specializations to be taught, but it seems useful to indicate that these may include even some of the branches of either of the two above groups, although only with respect to the problems involved in the programs of vocational training of the map user. The group of branches that prepare the user to read the map will be called the *auxiliary branches of training*. Their interaction with cartography is also of the reciprocal type. They operate in the relation $M \rightarrow O$, and therefore on the model they are located in the relations *MEmO*.

In the final stage of the process of information transmission the receiver ought to "return" in his imagination to the original information, that is, to the image of reality. Of course, he ought to see that reality in terms of the branches of cognition and to express his imagination in their languages. In this he may be aided by those branches of knowledge that had been the substantial foundation to the sender (*K*). Hence, in this stage of the information transmission the connection and interaction with the auxiliary substantial branches become conspicuous. It is for this reason that the auxiliary substantial branches are located within the relations of the field *OPR'*.

In the upper part of the model there are all those branches of knowledge that, on the one hand, determine the map contents and, on the other, make use of the experience of cartography and utilize maps either as research instruments or as illustrations of scientific inquiries and results. As it has been said, this is a reciprocal effect. The connections of the auxiliary branches located in the relations of the lower part of the model are much weaker, that is, one-way effects in favor of cartography predominate.

To complete the picture, there are two more fields of research interest to cartology, map knowledge and the applications of cartology.

Map knowledge is to mean the knowledge of concrete material cartographic works (products) and of cartographic activities. Thus conceived, this concept comprises also the history of cartography which studies these works in the aspect of their historical development as well as systematic map knowledge which studies them from the point of view of their functioning within definite groups of map users.

The *applications of cartology* assume concrete shape in the scientific elaboration of the principles and norms for the practical implementation of the theoretical results.

To come back to our model, it has to be pointed out that the applications of cartology are closely connected with the editorial procedures leading to the creation of a map. Thus they are located in the relations of the field *RKM*. Map knowledge, on the other hand, is a result of the knowledge of the final product, and thus implies the map user. Therefore its place in the model is in the relations of the field *MOR'*.

Such a location of these two domains in the model by no means suggests the exclusiveness of the spheres of activity. The contiguity of the two fields should rather be treated as an indicator of the common points of research. This results if only from the fact that the experience of map knowledge affects the applications of cartology, and conversely. Moreover, through *M*, that is, from the point of view of evaluating the map as a final material product, map knowledge influences the relations of the field *KEkM* and is itself influenced by it.

In this way, the scheme has been used to indicate in rough outlines the problems of cartology and, additionally, to illustrate its relations to the other branches of knowledge and practice.

It is obvious that the problems discussed so far do not comprise all cartographic activities cited in the definition given at the beginning of this paper. But we may make another step forward in our considerations and venture an extension of the present model so as to obtain a model of cartography (Fig. 4).

The activities in practical cartography manifest themselves in three main domains: in *the teaching of cartography*, the *production of cartographical works*, and in the *collecting and distribution* of these works. The teaching comprises the knowledge of the whole process of cartographic transmission, and therefore the interplay of theory and practice occurs at every moment of this process. Accordingly, the field of the mutual relations will encircle the model of cartology. The remaining two domains have more definite locations. The production of cartographic works is connected both with the process of transmission in the relation $R \rightarrow K \rightarrow M$ and with the applications of cartology, and thus it will have its closest relations with the left-hand part of the model. The collecting and distribution of cartographic works refer already to final material products and occur in connection with the relation $M \rightarrow O$; accordingly, it will have connections with the right-hand part of the model.

Now let us consider a few issues in connection with the term "theory" and with the distinction between the theory of cartography and theoretical cartography. Above all it seems worth reflecting on the scope of matacartography, which arouses currently so many controversial opinions. As it is presented by W. Bunge, metacartography can be treated as a theory determining the place of cartographic transmission in the theory of chorological transmission. But metacartography does not deal with the problem of functioning of the cartographic transmission itself, nor does it study the links with other sciences that contribute – directly or indirectly – to the efficiency of this process or affect the substance or form of the map as well as participate in the advance of the theory of cartographic transmission. Furthermore, metacartography disregards in its considerations map knowledge and the practical applications of theory as well as the relationship of operative

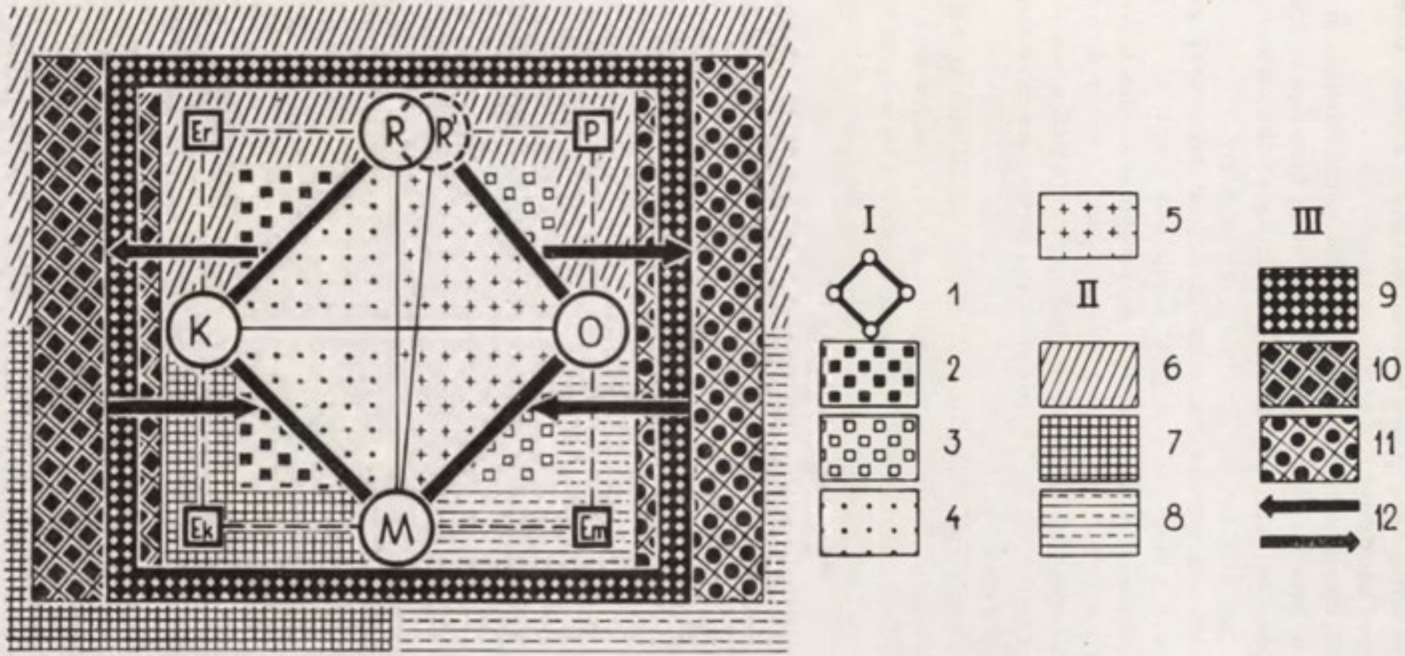

Fig. 4. Model of cartography

I. Cartology: 1 – theory of cartographical transmission, 2 – processes of creation, 3 – processes of receiving, 4 – applications of cartology, 5 – map knowledge;
II. Auxiliary branches of cartology: 6 – substantial, 7 – methodical, 8 – of training;
III. Operative cartography: 9 – teaching in cartography, 10 – production of cartographical works, 11 – collecting and distribution of cartographical works, 12 – relations of cartology with the operative cartography

cartography to theoretical cartography. Thus, metacartography is a theory covering only one narrow aspect of cartography.

The theory that would comprise all substantial and functional relations in cartography as well as those between cartography and the other branches of science and human activities from the point of view of functioning of the cartographic transmission of information is therefore the *theory of cartology*.

Cartology conceived of as a specific theoretical science of cartography would thus contain in itself both the subject of metacartography and the *theory of cartographic transmission* understood as the theory of its functioning. This latter, in turn, would contain both the *theory of the map substance*, which would determine its capacity in the broad sense, and the *theory of the map form*, which would determine its efficiency. Hence follow further consequences concerning the more specific items of research work for cartology.

In conclusion it is to be emphasized that the present considerations are not intended to oppose cartology to applied cartography. It is fully realized that practical activities and scientific and theoretical appraisals constitute an integral whole determining the advance of cartography. I am also aware of the fact that a correct and developed theory directly contributes to the level and quality of cartographic products. Thus it is expected that the problems of cartology and its theory as presented here will, to some extent, appear useful in laying down the modern research trends in cartography.

Warsaw University

GEOGRAPHIA POLONICA 21, 1972

REMARKS ON THE RANGE AND METHODS OF RESEARCH OF THE GEOGRAPHY OF SEA TRANSPORT

JERZY ZALESKI

1. INTRODUCTION

The sea has been a very important object of geographical investigation from the very beginning; perhaps it was the process of mastering the sea by man that laid the primordial foundations for the development of geography as a science[1].

With time, the development of civilisation and particularly of technical progress in ahipping facilitated relations between countries far apart from each other. The ocean then became a factor which, instead of being an obstacle that separated them, brought people together, and made their coexistence easier. Alongside these processes, the geographic aspect of the investigation of the sea underwent profound transformations. The main forces transforming the attitudes towards the importance of the sea area were the economic processes, the dynamic contents of which occupied an important place in the geographic investigations.

In a discussion on the subject of geography as a whole, and particularly of economic geography[2], the problematics of geographic research concerning transport evokes an exceptional amount of controversy. "Round the geography of communication – Matznetter writes – there is such a lot of dispute, as round hardly any other discipline of our science. It concerns not only the geographic grounds of reasoning but also – and first of all – the matter of its independence as a special branch of activity"[3].

The reason for these disputes may be tied up with the relatively short period of time which has elapsed since the geography of transport was first defined as

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[1] J. Gottman says, that "... there were two categories of reasons, which conditioned the begin ning of geographical investigations: selfdefence and shipping..." Cf: Historique de la géographie appliquée. Une definition, les premieres realisations. La géographie appliquée. Compte rendu d'un symposium tenu a l'Institut de géographie de l'université Laval du 14 au 19 nov. 1958, *Cahiers de Géographie de Quebec*, 3, No 5, 8–12.

[2] A further description of this discussion does not belong to the scope of this work. Cf: R. Hartshorne, *The nature of geography*, New York 1946, and by the same author: *Perspective on the nature of geography*, Chicago, 1959.

[3] J. Matznetter, *Grundfragen der Verkehrsgeographie, Mitteilungen der Geographischen Gesellschaft in Wien* 1930, vol. 95.

a separate branch of geographical sciences. It is even now not fully accepted and one may still discern various tendencies to support the geographic investigation of transport on some other leading phenomenon. This is the result of the former state when geographic studies on transport used to appear as a rule on the margin of settlement[4], trade[5] and other disciplines.

The geography of sea transport, as a specialist branch of the geography of transport has another still weaker methodological substructure. This is because owing to the particular character of the object of investigations and its degree of difficulty, the participation of the economic geographers in the investigation od sea transport is so far only small, and their achievements in the field of theoretical research are especially modest[6]. This subject is in a formative stage and its scope is being established in discursive papers.

Although Hettner[7] and Braun[8] already started fragmentary discussions on the theoretical foundations of this branch, throughout the following decades none of the investigators undertook any broader discussion on this subject as a whole. Theoretical deliberations of a complex character are represented in several papers in less known languages[9].

After the World War II, owing to the development of sea transport on a scale never known before, several studies of fundamental importance were published e.g. Alexandersson[10]. Carfi[11], Vigarie[12], Zaleski[13]. It is an interesting fact that the majority of these do not consider the theoretical problem at all.

At the present stage of research there is a need of a theoretical discussion, which is vital for every new branch of science. A particular theoretical problem that has

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[4] One of the first works on the geography of transport between the elements of settlement was that of J. G. Kohl, *Der Verkehr und die Ansiedlungen der Menschen in ihrer Abhängigkeit von der Erdoberfläche*, Leipzig, 1841.

[5] E. Otremba is a follower of this opinion: *Allgemeine Geographie des Welthandels und des Weltverkehrs*, Stuttgart, 1957, p. 8

[6] Assessment of the scientific achievements of the geography of transport in all countries are consistently stressed.

[7] A. Hettner, Der gegenwärtige Stand der Verkehrsgeographie, *Geographische Zeitschrift*, 1897, 3.

[8] G. Braun, *Bemerkungen über die Verkehrsgeographie im allgemeinen und die der Ostsee im besonderen, Beiträge zur Kenntnis des Ostseegebietes*, Berlin, 1912.

[9] J. Zaleski, Transport morski w badaniach geograficzno-ekonomicznych (Sea transport in economic-geographical research), *Przegląd Geograficzny* (Geographical Review – Warsaw), 1965, 1 (in Polish). Many references are quoted.

[10] G. Alexandersson, G. Norström, *World shipping. An economic geography of ports and seaborne trade*, Stockholm, 1963.

[11] F. Carfi, *Geografia economica a sociale del mare*, Livorno 1959.

[12] A. Vagarie, *La circulation maritime*, Paris, 1968.

[13] J. Zaleski, *Ogólna geografia transportu morskiego w zarysie* (An outline of general geography of sea transport), Warszawa, 1967.

not yet been solved is the demarcation of the range of the geography its of sea transport from other disciplines interested in sea transport.

The phenomena in which the geography of sea transport is interested can be and are investigated by various disciplines of science, whereas each of them – having the same subject of investigation: transport – examines it from its own point of view. The relation of the economic geographer, who does research work on sea transport, to the historian and economist interested in the same subject, brings forward most of the problems in dispute. Needless to say, their approaches differ from each other as to the aspect and methods of research.

2. FIELD OF RESEARCH

It seems that the geography of sea transport can be defined as the branch of economic geography, which investigates the development and spatial differentiation of sea transport (shipping and ports), in a reciprocal relation with the conditions of the environment, on the backgroung of other phenomena of economic life and a geographical division of labour.

Is a definition of this sort justified?

The geography of sea transport, as are all the branches of economic geography, is a section of an analytic discipline. Its task – in the face of the main aim of geography – is to present a spatial picture of the elements of sea transport to facilitate a territorial synthesis. Subordinating himself to this purpose, a geographer of seaborne transport investigates the distribution and connections of transport routes on the background of and in connection with the natural conditions existing on the sea, the character and type of transport junctions (sea ports), their hinterland and foreland. Finally, he analyses the cargo traffic (directions, structure, intensity and seasonality), as well as the goods – freight market, as a symptom of economic interdependencies of countries and regions, of specialisation and a geographic division of labour[14].

It can be seen that the range of research[15] presented here, owing to the nature of sea transport, is different from the problematics appearing in the workshop of a geographer of land transport. Considering the matter from the geographical point of view, there is the direct influence of environmental conditions on the process of transport and the lack of a net of roads in the technical meaning. In the

[14] The problems of shipbuilding, fisheries and other economic forms of utilising the sea should not be confused with sea transport. They may constitute the subject of studies of what some authors call "sea regions". See: R. Lutgens, *Die Produktionsräume der Weltwirtschaft*, Stuttgart, 1952, p. 197.

[15] A. Hettner (*op. cit.*, p. 629) saw in the geography of sea transport the following elements for research: a) development of the shipping of various nations; b) description of the seacoast from the point of view of its utility for the building of ports; c) transport routes.

case of land transportation the routes are examined by the geographer mostly from the point of view of filling-out a given territoty (such features as density and distribution are studied). In land transport the road has a defined direction, length and technical character.

The sea area, on the other hand, offers in this respect many alternative solutions. The course of the ship, depending on the chosen variant of the route may be shorter or longer, it may run through areas of a various physical character[16]. Thus, if the problematics of investigation of transportation by road is of a comparatively static character in land transport, it is a dynamic one in the case of sea transport[17].

The method of investigating roads, which is popular among the economic geographers, and is based on finding optimal models of the transport network, has no application in sea transport. The seaway is a transport route only in a potential meaning and not in fact. Every sea presents in itself a route to be operated by man. It will remain, however, a deserted unadministered space as long as no ship sails on it, and no cargo is carried. This route in the general sense does not deteriorate in the technical meaning, and does not lose its value.

The most economic direction of a sea route means the minimising of its length. It appears to be an important factor of the economic effectiveness of a voyage especially in the case of the triangular or multiangled freighting where the composition of the cargo is heterogenous.

Another field of investigation is the carrying of passengers and cargoes – the principle phenomenon in transport. Transport does not exist without that sort of carriage, although it can exist without routes and developed junction[18]. Thus, in most geographic-economic investigation concerning transport the problematics of carriage should always occupy a leading place.

The early development of shipping, as it may be supposed, was connected with the need of movement – primarily of people, implements or arms, then of goods for exchange. At present the role of transport as an extension of the production process is increasing, and that is why in contemporary research especial attention is called to the transport of the bulk cargo, which engages the greater part of the tonnage operated on the seas of the world. The carriage of these cargoes creates a network of cargo-flows, the size of which is composed according to perceivable regularities. Numerous production centres constitute the source of excess goods in some areas of the globe, in others centres of consumption are located, which are the market for their sale. The activities of both may be compared to the work of double-acting pumps taking in and letting out flows of cargo.

These streams of goods are, however, a dynamic phenomenon and do not always

[16] All artificial canals are kinds of sea routes although their participation in the total length of a ship's voyage is only a slight one.

[17] One may notice here a certain analogy with air transport.

[18] W. Behrmann *Verkehrs- und Handelsgeographie eines Naturvolkes,* Frankfurt a/M., 1925, p. 4.

create permanent flows of shipment; sometimes they arise and disappear depending upon the markets, which are a condition of their vitality.

The features of the cargo – and the character of the route – condition the choice of the ship, which is to serve the given route. The examining of these features is, as a rule, the basis for studies on the economic factors dealing with the composition of a given type of vessel. They decide the measurements of the ship, its deadweight tonnage, speed, dimensions of the hatch openings, deck equipment etc. The proper assessment of the stowage co-efficient of the structural cargo is very important as well. In the case of various loading variants (e.g. triangular freighting) and numerous ports of call, the problems to be solved are particularly complex.

Similarly as the cargo has an influence on the type of the exploited cargo vessels, the passenger has an influence on the passenger ship serving the given line, her size (carrying capacity), speed, equipment, as well as the organisational forms of the line.

The route may also be characterised to a certain degree by the type of transport which services it. This form of examining the route is often adapted in cases when a lack of adequate statistics does not allow the quantity of cargo to be estimated, but information concerning the traffic of tonnage on the route is accessible. It is of importance mainly on the marginal lines, where a lack of statistics dealing with the carriage of general cargo and passengers does not allow the estimation of the size and structure of carriage.

Apart from the size of the carriage, directions and cargo structure of the route, the factor of seasonality of transport i.e. non-equality of cargo supply is of great importance in the geographic research. A geographer is interested not only in the climatic seasonality, but the comercial and productive one, which gives rise to the cyclic oscillations in the carriage and work of the ports.

The port of departure and of destination (the transport junction) is an independent component of a sea route. The cargo appearing in the route has its beginning in one or in a group of loading ports, either universal or specialised ones, and a port is its aim. Here is concentrated the visible process of tonnage traffic, shifting it from the sea-route to the land route. This process may be a simple one (shifting by means of a crane or other transhipment arrangement from land to ship and/or the opposite) or a compound one (sorting, repacking, containerisation etc before loading). The port problematics, owing to its magnitude, constitutes a separate area of geographic-economic investigation, together with a number of accompanying phenomena[19].

Among the problems connected with the geographical research on ports the problem of the hinterland is an outstanding one. About the middle of the XIX century

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[19] Well-known are examples of rather busy transport routes, which do net take advantage of ports in the technical meaning of the word, i.e. equipped quays, transhipments arrangements, railway junctions, warehouses and other features characteristic of a sea port.

the ports underwent the process of gaining independence, and ceased being a fragment of a port town. The shifting of the means of disposing of the cargo mass sometimes far inland contributed to this situation. The port is a function of the hinterland and embraces not only the port town but also a larger territory.

The character of the hinterland is of decisive importance both as a factor having an influence on the choice of the localisation of a port as well as when determining its economic-operating aspect. A hinterland may be described as a natural sales market rendering services to a given port, however there is often an overlapping of several hinterlands, and the importance of the territory to the port becomes less the farther away from the port it is located.

The features of the geographic shaping of the hinterland have played a leading role in the regional structure of the location of the ports. The majority of the major European ports are located from the point of view of natural communication connections, at the mounth of rivers or along tranversal valleys leading towards the seacoast. Quite often the rivers running perpendicularly towards the sea have been connected by means of canals, thus forming a dense network of natural and artificial roads, which in an excellent manner make more efficient the contact of each point of the hinterland with the port.

The concept of port hinterland can be contrasted by the notion of foreground (foreland) area, which represents the influence of the port on the land area separated from the port by a sea. It is a rule, that an area with a poorly developed industry is a foreland for a universal port, whereas a highly industrialised area tends to contact with ports specialising in the export of raw materials.

The hinterland is more constant that the foreland which can change very often depending upon the directions of foreign trade, and only extended observation allows to conclusion as to its shape to be drawn.

The theoretical studies on the port problematics are most advanced. This is result of the fact that the problem of localising ports depends on the natural conditions and the problem of the hinterland and foreland are closer to a geographic point of view. In this field the achievement of the geographers are represented by the work of Boerman[20], Kautz[21], Mecking[22], Morgan[23], Sargent[24], and Weigend[25].

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[20] W. E. Boerman, The need for special examination of particular aspects of port geography, *Tijdschrift voor economische en sociale geograpie*, 1951, 12.

[21] E. A. Kautz, *Das Standortsproblem der Seehäfen*, Jena, 1934.

[22] L. Mecking, *Die Seehäfen in der geographischen Forschung*, *Petermann's Geographische Mitteilungen 1930*, Erg. Heft 209 and: Die Grosslage der Seehäfen insbesondere das Hinterland. *Geographische Zeitschrift*, 1931, 1.

[23] F. W. Morgan, Observations on the study of hinterlands in Europe, *Tijdsschrift voor economische en sociale geografie*, 1951, 12.

[24] A. J. Sargent, *Seaports and hinterlands*, London 1938.

[25] G. G. Weigend, Les nations d'arriere-pays et d'avant-pays dans l'etude des ports, *Revue*

A fourth group of problems, which is the object of investigations of the geography of sea transport is the broad subject of goods-freight markets[26]. Only in connection with the economic changes in the world – (a distinct comprehension of the emergence or the disappearance of the new centres of freight activity, the regional analyses of the partial markets) – is it possible to understand the substance and genesis of the transport routes, as well as the changes in the structure of port hinterland or influence on the particular fragments of the foreground.

An examination of this field borders with a synthesis and requires detailed studies in the range of international economic and political relations. This calls for a penetrating observation and proper assessment of the changes in the economy of many countries in the world relating to the freight situation in specific markets[27].

3. METHODS

The variety of the problems encountred in the geography of sea transport calls for adequate methods of work. Unlike a naturalist, an economic geographer has little possibility to carry out an experiment, and unlike an economist he seldom applies general methods of conclusions in order to obtain theoretical opinions on a higher level of abstraction. At his disposal there is the concrete material of facts, figures and events, which he has to define, analyse, compare, verify and to mark on the map.

The traditional method of description may be useful when assessing the whole of the examined phenomenon as the introduction and support, for the further stages of work. A historical description constitutes a valuable initial research instrument.

The analytic stage ought to be preceded by a critical assessment of the data, a proper grouping of statistical values, accepting certain indicators. The statistical analyses is based on en efficient utilisation of the accessible material. This field is full of difficulties, caused first of all, by incomplete data and a lack of uniform criteria, which fact leads to the necessity of utilising various sources which often contradict each other. It is not always possible to investigate these divergencies, to explain or to remove them. Of particular importance is to utilize the current statistical data, since the rate of variation in the international sea-borne trade is exceptionally large. During a very short time transport routes either emerge or

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de la Porte Oceane, 1955, 113 and: Some elements in the study of port geography, *Geographical Review*, 1958, 2.

[26] The difference between the accepted category of an abstract freight market and the goods-freight market is that: a) the criterion of separation is the region not the cargo; b) the main subject-of examination is commodity structure and direction of cargo, not the whole of negotiations and agreements connected with the handling of the cargo over for carriage.

[27] The concept of the market ought to become the centre of research according to E. Otremba, *op. cit.*, p. 32.

disappear, change their directions, and the volume of goods carried changes substantially.

In results there is a need to apply the method of comparative retrospection. The method of comparisons is particularly useful when analysing the competitiveness of the good-freight markets. There is a lack so far of more important efforts in this respect.

In order to examine this problem general studies dealing with world trade are helpful, when they deal with productive or commercial specialisation of the markets on a regional or commodity basis. Unfortunately, these studies seldom treat the problem from the viewpoint of of an analysis of the cargoes participating in the transport by sea.

Any comparisons made in this respect ought to be based on an analyses of the partial markets, with consideration of their value in foreign trade as of complementary partners. Alexander[28] has presented some examples in which he tried to find solutions in this respect. On the background of a statistical and cartographic analysis of contrasting structures, he differentiated an interesting group of markets following the criteria of proximity and complementarity. These problems are at the base of any further investigation which aims at obtaining probabilities as regarde the trade turnover in the future, this being the foundation of any plans for the development of shipping[29].

A similar method should be adapted to examine the seasonality of transport by sea. It is necessary to observe the intensity of freighting and the demand for tonnage on a given route this, confronted with the natural conditions of the route and the agricultural raw materials which are the subject of transportation, will allow the drawing of correct conclusions as to the reasons and amplitudes of seasonal oscillations.

A statistical analysis is a basis for the conclusions. However, there is very often a necessity for further precision of the reasoning which cannot be attained without applying elements of advanced mathematics. The idea of introducing into economic geogrephy methods accepted in economics[30] and in this the necessity of applying – apart from quantitative-statistical methods – mathematical methods, is not a novelty. It is a fact that mathematical methods have undisputably found a place in economic investigations. It seems that they must at present be acknowledged as indispensable in the economic-geographical investigation of sea transport.

The statistical methods may be enriched by elements of mathematics particularly in the range of aggregating data and other means faciliting and defining the spatial analyses. In the field of transportation connected with the regional struc-

[28] J. Alexander, International trade selected types and world regions, *Economic Geography*, 1960, 2, p. 106.

[29] H. Jürgensen, Die Welthandelsströme der Zukunft, *Der Volkswirt*, 1961, 51/52.

[30] M. B. Ballabon, Putting the "economic" into economic geography, *Economic Geography*, 1957, 3, p. 49.

ture and geographical division of labour it is possible to apply certain types of models (linear programming, diffusion models etc.).

Interdependencies between the distant spatial units can be analysed with the help of hypothetical schemes based on the examination of the gradients of complementary specialisation. When investigating ports, their hinterland, range of influence, specialisation etc., it is worth while examining the links in relation to the concept of a central place. One may apply here gravity and potential models.

More and more often economic geographers are engaged in examining the optimisation of the transport solutions in relatoin to the production to the cargo mass. In the field of these investigations there is a need for more precise methods, such as linear programming and input-output. An investigator has a vast choice in formulating conclusions concerning a rational utilisation of tonnage. Marschak[31] proved this by analysing the demand for and supply of tankers in connection with the needs and degree of increase in the production of oil refineries in the United States. On the basis of this investigation, the oil refining industry on the Gulf of Mexico has been shifting from tanekrs to lorries-cisterns and pipelines. Thus a maximisation of production and optimisation of transporting the vast amounts of crude oil and petroleum products was attained. In the model there were applied 195 equations and 1555 variables and although the accepted coefficients surely contain mistakes, this model fulfils an important role for study and methodic purposes.

However, it is not always necessary to apply advanced mathematical methods. The character of mathematics is axiomatic and its algorithms are to a certain extent stiff, effective in rather limited sections, only in those which are appointed by accepted axioms. A quantitative analyses must be subordinated to a qualitative one and only a selection of cause-reason connections creates the possibility of explaining and therefore foreseeing economic events. It is not the pattern and a formalistic set of mathematical symbols but the statement and map that will remain the main form in which a geographer expresses himself. This gives rise to the importance of cartographic methods.

According to Barański the transport phenomena "...invite themselves to be placed on the map..."[32]. This terse phrase correctly describes the role of cartographic methods in representing transport. Owing to the spatial composition, the phenomena of sea transport expressed in the routes of carriage and sea ports constitute appreciated material for a cartographic and cartometric interpretation. A map is an implement of a spatial analysis. The form of flow diagrams is tradi-

[31] T. A. Marschak, *A spatial model of U.S. petroleum refining*, RAND, Research Memorandum 1958 (June)

[32] N. N. Baranski, *Ekonomicheskaya geografia, ekonomicheskaya kartografia* (Economic geography, economic cartography), Moskva, 1960, p. 343 (in Russian).

tionally accepted; when they are completed by numeric data they facilitate the analysis and instructively deepen it.

Ullman[33] devoted much of his work to the methods of presenting the problems of sea transport in a cartographic form. Several interesting attempts aimed at obtaining a cartographic synthesis have been made by the Bremen Institute of Shipping Research. The result is a map presenting the passage of ships on sea routes of the world[34], based on loading space of ships as a function of the increasing demand.

Jonasson's conceptions[35] present interesting proposals dealing with the solution of this problem. These studies have brought forward certain conclusions and concern the necessity to investigate and to improve the symbols which are applied. In the atlas, for example, elaborated by Theel[36] there is a valuable index which determines the character of the goods mass in a very general way. However, the symbols applied directly on the maps are of a doubtful value from the point of view of practice. The sectors of a circle with a structural division applied by Alexandersson and Norström[37] are better, although far from being perfectly clear.

The cartographic method may be applied more effectively in the case of an analysis of the spatial structure of the hinterland, as it has been indicated by Morgan[38]. He presented a picture of a specific hypsometer, illustrating the "slowing down" of the streams of cargo flowing from the hinterland, as it is more and more distant from the port.

The fact, that only a limited number of methodical works in this field exist, can be explained by the difficulties encountered when these rules are applied in practice. Considerable trouble is caused by the fact that it is imposible to obtain comparative statistical material following uniform criteria, although the quantity and quality of this material have recently improved[39].

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[33] E. L. Ullman, Mapping the world's ocean trade, *The Professional Geographer*, 1941, 1.

[34] *Der Internationale Seeverkehr* (a wall map) edited by Institut fur Schiffahrtsforschung, Bremen, 1958.

[35] O. Jonasson, *Atlas of the world commodities*, Goteborg, 1961.

[36] G. A. Thell, *The world shipping scene. Atlas of shipping, shipbuilding, seaports and seaborne trade*, Munich, 1963.

[37] G. Alexandersson, G. Norstrom, *op. cit.*, e.g. p. 127.

[38] F. W. Morgan, *op. cit.*, p. 111.

[39] One should mention here the efforts of the Weston Agency (London) which publishes the valuable *Westinform Shipping Reports*, the Norwegian shipbrokers entreprise Fearnley and Egers Chartering Co (Oslo) the editors of yearly publication *World Trade and Bulk Carriers*, the *Maritime Statistical Yearbook* published by the Maritime Institut (Gdansk – in Polish) and the *Maritime Transport* (Paris) edited by the Organisation of Economic Co-operation and Development.

4. CONCLUSIONS

Sea transport is an object which offers vast new research perspectives for the economic geographers. It is very necessary to increase the utility of the work which is undertaken, especially in the range of theory, in order to increase interest in these branches. It is important to establish the most purposeful directions of work, methods of research and forms of co-operation with representatives of other sciences. The geography of sea transport, as an applied science, can reveal a vivid initiative in this field. The succes which variouss economic institutions, transport enterprises, port managements and shipowners have to their credit, and which encouraged research conducted under the slogan of applied geography, are a proof of the considerable practical value and effectiveness of the geographical approach to the problems.

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THEORETICAL BASIS FOR THE COEFFICIENT OF SPATIAL CONCENTRATION

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1. INTRODUCTION

Socio-economic categories are subject to continuos change both in time and in space. It can readily be seen that the same socio-economic category assumes different values, depending on whether we investigate it at different periods for an identical geographic area, or for different geographic areas but in identical periods of time, or finally, for both different periods of time and different geographic areas.

Hence let us consider, as an example, a socio-economic category like employment in industry. It is obvious, that the value of this category depends on the period of time studied and on the area for which this category is investigated. In consequence one might expect, that for 1967 employment in industry in Katowice voivodship was different from what it was in Warsaw voivodship. In a similar way, industrial employment in Katowice voivodship was different in 1950 from what it was in 1967, etc.

The above reasoning shows, that any correct analysis and planning of the values of socio-economic categories should take into account both time and space. One of the basic indices of the latter frequently applied in establishing the effect upon the value of the socio-economic category under investigation, is the coefficient of spatial concentration.

Like any other kind of conclusion, conclusions arrived at on the basis of the coefficient spatial concentration can be useful only when ounded upon a full understanding of the theory of the subject. Where the coefficient of spatial concentration is concerned, there is a lack of a suitable theoretical foundation, and therefore the present paper is devoted to reflexions upon this theory. It introduces some new elements, which are likely to throw light upon the character of the coefficient of spatial concentration. Moreover, this paper formulates some conclusions designed to guard against errors in the practical application of the coefficient of spatial concentration. Finally, the paper also indicates the directions in which further theoretical studies should be undertaken.

2. CURVE AND COEFFICIENT OF CONCENTRATION, AND THEIR PROPERTIES

Definition 2–1. Let us assume a function $y = f(x)$ which is continuous and fit to be at least twice differentiated[1] by intervals in the interval $0 \leqslant x \leqslant 1$. If $f(x) \geqslant 0$ and $f(1) = 1$, and if $f'(x) \geqslant 0$[2] and $f''(x) \leqslant 0$, then we shall call function $y = f(x)$ a curve of concentration[3].

The accumulation of all conceivable curves of concentration forms what is called a "family". In this family two curves of concentration should be signled out: one we shall mark by symbol $g(x)$, the other by $h(x)$. These curves are characterized by the following property: any freely chosen curve $f(x)$ of our family satisfies the inequality:

$$g(x) \leqslant f(x) \leqslant h(x) \tag{2–1}$$

for every $0 \leqslant x \leqslant 1$.

Definition 2–2. That function $h(x)$ which satisfies Equation (2–1) shall be called the curve of ideal concentration, and function $g(x)$ the curve of ideal dispersion.

On the basis of Definition 2–1 it can be shown that

$$g(x) = x \tag{2–2}$$

and

$$h(x) = 1 \tag{2–3}$$

This is so because the following theorems are correct:

Theorem 2–1. If in the interval $a \leqslant x \leqslant b$ we have $f''(x) \leqslant 0$, then function $f(x)$ lies in the interval ab no higher than the tangent to it at any point of this interval.

One might also speak of a "relative" curve of spatial concentration. For example, this sort of curve appears when x denotes the total population and y its employment, and when both these values refer to identical areas, such as the same voivodship or the same group of voivodships. Then $y = f(x)$ is the curve of spatial concentration of employment with the total population taken into consideration.

For the sake of clarity it should be added that for curves of concentration both the independant variable x and the dependent variable y are undimensional (non--denominational) values. Both these variables are relative values because, for example, they may denote the ratio of the surface of a given area to the surface of the

[1] The definition of a function which in a certain interval can be differentiated by intervals, is analogous to the definition of a function which in a certain interval can be differentiated continuously [4, p. 76].

[2] For those values of x in the interval $0 \leqslant x \leqslant 1$ for which $f'_{-}(x) \neq f'_{+}(x)$, the assumption that $f'(x) \geqslant 0$ is understood to be $f'_{-}(x) > f'_{+}(x) \geqslant 0$.

[3] For example, when x denotes an area and y employment, the further course of this paper will show that $y = f(x)$ is the curve of the spatial concentration of employment. Similarly, when x denotes an area and y the urban population, $y = f(x)$ is the curve of spatial concentration of the urban population, etc.

whole country, and the ratio of employment of the same area to the employment for the whole country.

Proof[4]. In accordance with B. Taylor's Equatilon, we have for an optional c in an interval ab and for an optional $h \neq 0$, that is, $a \leqslant c + h \leqslant b$:

$$f(c+h) - f(c) - hf'(c) = \frac{1}{2} h^2 f''(c + \Theta h), \tag{2–4}$$

where Θ is a suitably chosen number so that $0 < \Theta < 1$.

Because $a \leqslant c + h \leqslant b$, there also is $a \leqslant c + \Theta h \leqslant b$. Hence, in accordance with the assumption of our theorem, there will be $f''(c + \Theta h) \leqslant 0$.

Thus Equation (2–4) assumes the form

$$f(c+h) - f(c) - hf'(c) \leqslant 0 \tag{2–5}$$

If therefore $h > 0$, then we can write, on the basis of the inequality (2–5):

$$\frac{f(c+h) - f(c)}{h} \leqslant f'(c);$$

but if $h < 0$, then

$$\frac{f(c+h) - f(c)}{h} \geqslant f'(c).$$

This is proof, that in the whole interval ab the function $f(x)$ lies no higher than the tangent to it at any optional point of this interval.

Theorem 2–2. If $f(x)$ is any optional curve of concentration in the sense of Definition 2–1, there is $f(x) \geqslant x$ for every x in the interval $0 \leqslant x \leqslant 1$.

Proof. Let us assume that for a certain $0 \leqslant x_o < 1$ there is: $f(x_o) - x_o < 0$. Then two alternative cases are possible: $f'(x_o) = 0$, or $f'(x_o) > 0$. In the former case $f'(x) = 0$ for $x_o \leqslant x \leqslant 1$ because for $0 \leqslant x \leqslant 1$ we have $f'(x) \geqslant 0$, and $f''(x) \leqslant 0$.

Hence it results[5], that for $x_o < x < 1$ we have $f(x) = \text{constant}$, and hence $\lim_{x=x_0+0} f(x) = \text{constant} = \lim_{x=1-0} f(x)$. On the other hand, since function $f(x)$ is constant in the interval $0 \leqslant x \leqslant 1$, there must be $f(x_o) = \text{constant} = f(1) = 1$, or $f(x_o) = 1$ in spite of the assumption that $f(x_o) < x_o < 1$. Therefore $f(x)$ must be $\geqslant x$. We now can prove our theorem for the second case. Let be $f'(x_o) > 0$. Because $f''(x) \leqslant 0$ for every $0 \leqslant x \leqslant 1$, function $f(x)$ must lie, in accordance with Theorem 2–1, below the tangent to it at any optional point of the interval $0 \leqslant x \leqslant 1$. Hence this function lies also below the tangent in point x_o. We therefore have:

$$(1 - x_o) f'(x_o) + f(x_o) \geqslant 1.$$

However, because in accordance with our assumption $-f(x_o) — x_o$, it results from the above that

[4] For furnishing this proof use was partly made of the proof to the theorem found in K. Kuratowski [4, p. 146].

[5] Cf Theorem 2 in K. Kuratowski [4, p. 113].

$$(1-x_0)f'(x_0) \geqslant 1 - x_0,$$

or

$$f'(x_0) \geqslant 1. \tag{2–6}$$

On the other hand, the tangent to curve $y = f(x)$ at point x_0 intersects the x axes at point of the abscissa, which satisfies the condition that

$$-f(x_0) = f'(x_0)(x - x_0).$$

From this we obtain

$$x = \frac{x_0 f'(x_0) - f(x_0)}{f'(x_0)}.$$

In consideration of the assumption of our theorem, Equation (2–6) and the assumption that $f(x_0) - x_0 < 0$ give us

$$x \geqslant \frac{x_0 - f(x_0)}{f'(x_0)} > 0. \tag{2–7}$$

If we now take into account that function $f(x)$ lies below the tangent to it at point x_0, then, in accordance with Equation (2–7), there is $f(x) < 0$ for every x of the interval $0 \leqslant x \leqslant \dfrac{x_0 - f(x_0)}{f'(x_0)}$.

The result thus obtained disagrees with the assumption that $f(x)$ is a curve of concentration. From this it appears that $f(x) \geqslant x$ for $0 \leqslant x < 1$. However, since in accordance with Definition 2–1 $f(1) = 1$, we ultimately obtain $f(x) \geqslant x$ for $0 \leqslant x \leqslant 1$, and this completes the proof of our theorem.

Theorem 2–3. If the function $f(x)$ is any optional curve of concentration in the sense of Definition 2–1, then there is $f(x) \leqslant 1$ for every x in the interval $0 \leqslant x \leqslant 1$.

Proof. Let us assume that for a certain yet clearly defined x_0 of the sort that $0 \leqslant x_0 < 1$, we have $f(x_0) > 1$. Because in the interval $0 \leqslant x \leqslant 1$ we have $f'(x) \geqslant 0$, there also is $f'(x) \geqslant 0$ for the interval $x_0 \leqslant x \leqslant 1$.
This means that in the latter interval the function $f(x)$ does not decrease, i.e. that

$$f(1) \geqslant f(x_0) > 1,$$

or that

$$f(1) > 1,$$

in spite of Definition 2–1 according to which $f(1) = 1$. Hence from this and from Definition 2–1 it results, that $f(x) \leqslant 1$ for $0 \leqslant x \leqslant 1$, thus proving the correctness of our theorem.

Definition 2–3. If the function $f(x)$ is a curve of concentration in the sense of Definition 2–1, and if the function $g(x)$ is defined by Equation (2–2), then we shall call the coefficient of concentration an equation of the form:

$$k_f = \frac{\int_0^1 f(x)dx - \int_0^1 g(x)\,dx}{\int_0^1 g(x)\,dx} \tag{2-8}$$

Since on account of Equation (2–2) $\int_0^1 g(x)\,dx = \int_0^1 xdx = \frac{1}{2}x^2\Big|_0^1 = \frac{1}{2}$, we also can assign to the coefficient of concentration (2–8) the form:

$$k_f = 2\int_0^1 f(x)\,dx - 1 \tag{2-9}$$

From the above Equation we note, that the value of the coefficient of concentration depends in the analytical expression of the curve of concentration $f(x)$.

On the basis of Equations (2–1) – (2–3) one can show that the coefficient of concentration k_f satisfies the inequality

$$0 \leqslant k_f \leqslant 1. \tag{2-10}$$

For this purpose let us note that, as already proven above, the denominator in Equation (2–8) is a positive number. As far as its numerator is concerned we can, in consideration of the first part of the inequality (2–1), write as follows:

$$f(x) - g(x) \geqslant 0.$$

Hence

$$\int_0^1 [f(x) - g(x)]\,dx \geqslant 0$$

and therefore

$$\int_0^1 f(x)\,dx - \int_0^1 g(x)\,dx \geqslant 0.$$

This is proof to the correctness of the first part of the double inequality (2–10). For proving the correctness of its second part we shall use the second part of the inequality (2–1) because, in accordance with the inequality (2–1) we have

$$f(x) \leqslant h(x)$$

and therefore

$$\int_0^1 f(x)\,dx \leqslant \int_0^1 h(x)dx$$

which, linked with Equation (2–3), gives us

$$\int_0^1 f(x)\;dx \leqslant \int_0^1 dx = 1.$$

From this, making use of Equation (2–9), we obtain

$$k_f = 2\int_0^1 f(x)\,dx - 1 \leqslant 2 - 1 = 1,$$

which proves the correctness of the second part of the double inequality (2–10).

3. CURVE AND COEFFICIENT OF SPATIAL CONCENTRATION

In chapter 2 we have limited ourselves to general reflexions on the curve and the coefficient of concentration. Due to their general character these reflexions do not allow us to calculate the coefficient of spatial concentration for some definite socio-economic category. We shall now define the curve of spatial concentration for some specified socio-economic category and that limited coefficient of spatial concentration which corresponds to this curve. Here the basis of our reflexions will be the assumption maintaining, that an area (for instance the area of the whole country) investigated from the viewpoint of a definite socio-economic category comprises[6] areas showing a constant density of this category. For example, if as the socio-economic category we consider the population of that area, then the density of this category will be represented by the population per 1 sq.km of the surface of this area.

Let us assume that the combined surface of the area P considered is composed of m separate areas with the surfaces $p_1, p_2, ..., p_m$. Let us now assign to an area P the positive number $Q(R)$, and to the areas $p_1, p_2, ..., p_m$ non-negative numbers[7] which correspondingly are $q_1(r_1), q_2(r_2), ..., q_m(r_m)$ so chosen, that $Q(R) = \Sigma q_i (\Sigma r_i)$. And let us agree that $p_o = 0$ and that $q_o(r_o) = 0$; then we can show that the functions of the form[8]:

$$f_1(x) = \frac{q_i/Q}{p_i/P}\left(x - \frac{p_1 + p_2 \dots + p_{i-1}}{P}\right) + \frac{q_1 + q_2 + \dots + q_{i-\Omega}}{Q} \tag{3–1}$$

$$\text{for } \frac{p_1 + p_2 + \dots + p_{i-\Omega}}{P} < x \leqslant \frac{p_1 + p_2 + \dots + p_i}{P},$$

where $i = 1, 2, ..., m$ and

$$f_2(x) = \frac{q_i/Q}{r_i/R}\left(x - \frac{r_1 + r_2 + \dots + r_{i-\Omega}}{R}\right) + \frac{q_1 + q_2 + \dots + q_{i-\Omega}}{R} \tag{3–2}$$

$$\text{for } \frac{r_1 + r_2 + \dots + r_{i-\Omega}}{R} \leqslant x \leqslant \frac{r_1 + r_2 + \dots + r_i}{R}$$

---

[6] Cf W. Isard [1].

[7] The assumed non-negativeness refers here only to the a_i numbers for $i=1, 2, ... m$. On the other hand, as to the numbers $r_i = 1, 2, ... m$ we assume their being positive.

[8] At times they are called Lorenz curves, although in the sense of the present paper the latter in reality are merely approximations of a curve of concentration (as an example cf S. Szulc: *Metody statystyczne* (Statistical methods) Warszawa, 1961, 251–271).

where $i = 1, 2, ..., m$ are curves of concentration in the sense of Definition 2–1, f the corresponding inequalities are correct:

$$\frac{q_i/Q}{p_i/P} > \frac{q_{i+1}/Q}{p_{i+1}/P} \tag{3-3}$$

for $i = 1, 2, ..., m-1$ and

$$\frac{q_i/Q}{r_i/R} > \frac{q_{i+1}/Q}{r_{i+1}/R} \tag{3-4}$$

for $i = 1, 2, ..., m-1$.

For this purpose we have to prove, that

3–1. the functions $f_1(x)$ and $f_2(x)$ are continuous in the interval $0 \leqslant x \leqslant 1$,

3–2. $f_1(x) \geqslant 0$ and $f_2(x) \geqslant 0$ in the interval $0 \leqslant x \leqslant 1$ and $f_1(1) = 1$ and $f_2(1) = 1$,

3–3. $f_1'(x) \geqslant 0$ and $f_2'(x) \geqslant 0, f_1''(x) \leqslant 0$ and $f_2''(x) \leqslant 0$ in the interval $0 \leqslant x \leqslant 1$. At least in the interval $0 \leqslant x \leqslant 1$ these functions can be (twice) differentiated.

Proof 3–1. On the basis of Equations (3–1) – (3–2) we conclude, that the functions $f_1(x)$ and $f_2(x)$ are defined in the interval $0 \leqslant x \leqslant 1$ and that they are linear in intervals and that as such they are continuous functions.

Proof 3–2. This will be omitted as being too simple.

Proof 3–3. Because in accordance with Equation (3–1) for every $i = 1, 2, ..., m$ the function $f_1(x)$ is linear in the interval

$$\frac{p_1 + p_2 + ... + p_{i-1}}{P} \leqslant x \leqslant \frac{p_1 + p_2 + ... + p_i}{P},$$

therefore its derivative in this interval equals $\frac{q_i/Q}{p_i/P}$. This results directly from the Equation cited. As can be seen, this derivative is a non-negative number, because $q_i \geqslant 0$ and $p_i > 0$ for $i = 1, 2, ... m$. However, considering the fact that in the interval $0 \leqslant x \leqslant 1$ the function $f_1(x)$ can be differentiated by intervals because at the points

$$x = \frac{p_1 + p_2 + ... + p_i}{P}$$

where $i = 1, 2, ..., m-1$ there is

$$f'_{-1}\left(\frac{p_1 + p_2 + ... + p_i}{P}\right) = \frac{q_i/Q}{p_i/P}, \quad f'_{+1}\left(\frac{p_1 + p_2 + ... + p_i}{P}\right) = \frac{q_{i+1}/Q}{p_{i+1}/P}, \tag{3-5}$$

therefore we still have to make sure whether in accordance with footnote 2 there is

$$f'_{-1}\left(\frac{p_1 + p_2 + ... + p_i}{P}\right) > f'_{+1}\left(\frac{p_1 + p_2 + ... + p_i}{P}\right) \geqslant 0.$$

The correctness of this inequality results directly from Equations (3–3), (3–5), the non-negative value of q_{i+1}, and the positive value of p_{i+1} for $i = 1, 2, ..., m - 1$.

There still remains to be proved the occurrence of $f''_1(x)$ in the interval $0 \leqslant x \leqslant 1$, and the proof that in the case under consideration this derivative is a non-positive value. These two proofs follow directly from the analytical presentation of the function $f_1(x)$ expressed by Equation (3–1). Here it should only be mentioned that, in spite of the non-continuity of the function $f'_1(x)$ at points of the form

$$x = \frac{p_1 + p_2 + ... + p_i}{P}$$

for $i = 1, 2, ..., m - 1$, the second derivative $f''_1(x)$ occurs in the whole interwal $0 \leqslant x \leqslant 1$.

We omit corresponding proofs in the matter of the function $f_2(x)$, because they are analogous to what has above been proven for the function $f_1(x)$.

From the above we conclude that the fuhctions defined by the Equations (3–1) and (3–2) are in fact curves of concentration, if the inequalities (3–3) and (3–4) are true. The former function we shall call the curve of spatial concentration, the latter the relative curve of spatial concentration of the socio-economic category "Q" with regard to the socio-economic category "R". Let us further note, that the Equations (3–1) and (3–3) as well as the Equations (3–2) and (3–4) already make it possible to draw the corresponding curves of spatial concentration.

The following theorem is true:

Theorem 3–1. If, for a socio-economic category consider, $f_1(x)$ is an arbitrary curve of spatial concentration referring to areas for which the density of this category is not necessarily constant, and if $F_1(x)$ is the curve of spatial concentration of the same socio-economic category, but referring to areas of constant density, then $f_1(x) \leqslant F_1(x)$.

Proof. Let us assume, that the whole area investigated from the viewpoint of spatial concentration of a definite socio-economic category is the sum of "n" separate areas of constant density of this category. The generality of our reflexions is maintained, if we arrange these separate areas by decreasing densities. If then x_o is an arbitrary number, provided it is so chosen that

$$\frac{p_1 + p_2 + ... + p_{l-1}}{P} \leqslant x_o \leqslant \frac{p_1 + p_2 + ... + p_l}{P}$$

where $1 \leqslant l \leqslant n$,
then substituting

$$a_j = \frac{q_j/_Q}{p_j/_P}$$

for $j = 1, 2, ..., n$
and marking by x_j a part differing from 0 (not necessarily the appropriate part) of the j–th area of constant density, this part referring to the whole investigated area for which

$$x_o = \sum_{\omega_2} x_j$$

where $\omega_2 = \{j_1, j_2, ..., j_k\}$ (the finite sequence $j_1, j_2, ..., j_k$ is here some rising sub--sequence of the finite sequence 1, 2, ..., n), and marking by $\bar{x}_j$ a part (not necessarily the appropriate part) of the j-th area referred to the whole area, this part so chosen that $\bar{x}_j = \frac{p_j}{P}$

for $j = 1, 2, ..., l-1$

$$0 \leqslant \bar{x}_l \leqslant \frac{p_l}{P},$$

whereby

$$x_o = \sum_{\omega_1} \bar{x}$$

where $\omega_1 = \{1, 2, ..., l\}$,
we then can write, on the basis of Equation (3-1)

$$f_1(x_o) = \sum_{\omega_2} a_j x_j \tag{3-6}$$

and

$$F_1(x_o) = \sum_{\omega_1} a_j \bar{x}_j. \tag{3-7}$$

Let us assume $\omega = \omega_1 \; \omega_2$. Then

$$\sum a_j x_j = \sum_{\omega} a_j x_j + \sum_{\substack{j \varepsilon \omega \\ j \varepsilon \omega_2}} a_j x_j \leqslant$$

which, in consideration of the arrangement of the area of constant density, gives us in its further course

$$\leqslant \sum_{\omega} a_j x_j + a_l \sum_{\substack{j \varepsilon \omega \\ j \varepsilon \omega_2}} x_j = \sum_{\omega} a_j x_j + a_l \Big[\sum_{\substack{j \varepsilon \omega \\ j \varepsilon \omega_1}} \bar{x}_i + \sum_{\omega} (\bar{x}_j - x_j) \Big] \leqslant$$

but for every $j_{\varepsilon \omega_1}$ we have $a_j \geqslant a_l$, and therefore

$$\leqslant \sum_{\omega} a_j x_j + \sum_{\substack{j \varepsilon \omega \\ j \varepsilon \omega_1}} a_j \bar{x}_j + \sum_{j \varepsilon \omega} a_j (\bar{x}_j - x_j) = \sum_{\varepsilon \omega_1} a_j \bar{x}_j.$$

This means, in consideration of the Equations (3–6) – (3–7), that

$$f_1(x_o) \leqslant F_1(x_o).$$

In this manner the proof for our theorem has been completed. There is no difficulty in formulating and proving an analogous theorem for the relative curve of spatial concentration, and therefore this problem will not be dealt with further. However, keeping in mind the above reflexions we note, that for the investigated socio-economic category of spatial concentration a coefficient of concentration exists which may be called the limit coefficient. This is the coefficient of spatial concentration besed on the limit curve of spatial concentration $F_1(x)$. This sort of coefficient is for the given period of time the only appropriate coefficient of spatial concentration which defines the socio-economic category under consideration. In contrast, every other coefficient of spatial concentration based on a curve of spatial concentration $f_1(x)$ different from the curve $F_1(x)$ will assume values lower than the limit value of the coefficient of spatial concentration of the investigated socio-economic category.

In fact, if $f_1(x)$ differs from $F_1(x)$ then, in accordance with our theorem 3–1, for at least one interval $a \leqslant x \leqslant b$ such for which $0 \leqslant a < b \leqslant 1$, there must be $f_1(x) < F_1(x)$. Hence the primary function of the function $F_1(x) - f_1(x)$ is increasing in the interval ab, meaning that

$$\int_a^b [F_1(x) - f_1(x)]\, dx > 0.$$

Since

$$\int_0^1 [F_1(x) - f_1(x)]\, dx = \int_0^a [F_1(x) - f_1(x)]\, dx +$$

$$+ \int_a^b [F_1(x) - f_1(x)]\, dx + \int_b^1 [F_1(x) - f_1(x)]\, dx$$

and since in accordance with Theorem 3–1 in the interval $0 \leqslant x \leqslant 1$ we have $F_1(x) - f_1(x) \geqslant 0$, therefore

$$\int_0^1 [F_1(x) - f_1(x)]\, dx > 0.$$

Hence ultimately

$$k_f = 2 \int_0^1 f_1(x)\, dx - 1 < 2 \int_0^1 F_1(x)\, dx - 1 = k_F.$$

From the above we arrive at the conclusion, that the coefficient of spatial concentration of type k_f is only approximate to the limit coefficient of spatial concentration, hence to the coefficient k_F. However, the initial data available in practice make it possible only to obtain coefficients of concentration of the type k_f. Keeping this in mind there arises the question, whether or not one can arrive at conclusions by operating with coefficients of spatial concentration of type k_f. To be more exact, whether the correlation of coefficients of spatial concentration of type k_f.

3–1 for the same socio-economic category, for the same country, and obtained on the basis of an identical subdivision of that country, and referring to the same period of time;

3–2 for different socio-economic categories, for the same country, and obtained on the basis of an identical subdivision of that country, and referring to the same period of time;

3–3 for identical socio-economic categories, considered for different countries but for the same period of time; makes it possible to draw conclusions as to the behaviour of appropriate limit coefficients of spatial concentration, i.e. coefficients of spatial concentration of type k_F.

The answer to this question is negative in character, and hereafter we shall prove this. For this purpose let us concentrate our attention upon the first of the cases mentioned above. As has been empirically shown by W. Isard [1], the ratio $\frac{k_f(t)}{k_f(t+T)}$ depends on the territorial subdivision of the country which has been taken as basis for calculating the coefficients of spatial concentration $k_f(t)$ and $k_f(t+T)$.

Hence, as a rule, this ratio differs from the ratio $\frac{k_F(t)}{k_F(t+T)}$ which is a constant value for definite values of t and T and for a determined socio-economic category.

This is why it would be incorrect to draw conclusions based on coefficients of spatial concentration of type k_f which refer to the same socio-economic category considered for different periods of time, and which are calculated on the basis of an identical territorial subdivision of the country, because this prevents an appraisal of the real changes which have occurred during the periods considered. These changes can only be perceived by making use of the limit coefficient of concentration, that is the coefficient of type k_F. Similarly it is easy to ascertain, that correlating the coefficients of spatial concentration of type k_f in the second case, i.e. for different socio-economic categories and, likewise, in the third case, i.e. for identical categories but for different countries, is incorrect insofar as that this sort of does not allow the drawing of correct conclusions with regard to the real spatial concentration of the investigated socio-economic categories.

4. CONCLUSIONS AND RECOMMENDED TRENDS OF FURTHER RESEARCH

4–1. In drawing conclusions based on the coefficients of spatial concentration of type k_F a very cautious attitude should be maintained.

4–2. For the future it seems advisable to undertake research work in order to:

(a) determine for the most important socio-economic categories the concept of constant densities of these categories;

(b) gain a full understanding of how the coefficient of spatial concentration k_r behaves for a particular socio-economic category, when the areas on which this coefficent is based are decreasing in such manner, that the areas to which the succeeding value of this coefficient refers, are parts of the areas which led to its preceding value;

(c) determine, wheather there is any advantage in making use of the relative curve and of the relative coefficient of spatial concentration;

(d) specify, if possible, the concepts of the relative curve and the relative coefficient of spatial concentration for cases, when the socio-economic category "of reference" assigned to certain areas (in Equation (3–2) this would be the category "R") assumes zero values.

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THE ROLE OF CATASTROPHIC RAINFALL IN THE SHAPING OF THE RELIEF OF THE LOWER HIMALAYA (DARJEELING HILLS)

LESZEK STARKEL

INTRODUCTION

In the monsoon climate of Assam and Bengal the amount of precipitation in the course of 4-6 months exceeds 3000 mm. In the marginal patr of the Eastern Himalaya there simultaneously occur uplift movements, reaching 1000–2000 m in the Quaternary. Moreover, this area is lying in the zone of active overthrusts and earthquakes [29]. The aim of the present study was to determine the role of heavy rainfall in the rate and trend of evolution of slopes and valleys in the young uplifted mountains.

This was made possible by observations of the consequences of the catastrophic rainfall amounting to 700–1100 mm, which took place between the 2nd and 5th October 1968. The author was statying in the region of Darjeeling from the 25th to the 28th November 1968 and again from the 17th December 1968 to the 3rd January 1969, when the damage on the slopes and changes in the valley bottoms were fresh, since after the 5th October no heavy fall of rain occurred. The observations assembled concerned the amount and intensity of the rainfall (each tea estate has a raingauge), the water phenomena, and the morphological consequences of the downpour. The author tried to map these forms and processes on the available maps or sketches in the scale of 1 : 8000–1 : 16000. Unfortunately, the material is fragmentary, owing to the lack of topographic bases and to the inaccessibility of the terrain after the downpours (bridges carried away, roads damaged by slips). These materials were supplemented by photographic documentation, measurements of height with an altimeter, interviews with the local population, and articles, published in the press or in journals. The majority of the detailed materials come from the tea estates of Bannockburn, Chongtong, Poobong, and Ringtong, and from the wooded areas in the source area of the Little Rangit valley. Owing to the existing works on landslides formed during the preceding catastrophic rainfall (1950) and to the photographic documentation, it was possible to compare these similar phenomena. Moreover, the region of Darjeeling has a well known geological structure and a long tradition of climatological observations (over 80 years).

SITUATION OF THE AREA OF INVESTIGATIONS

The Darjeeling Hills represent the lower part of the Sikkim Himalaya (fig. 1), lying immediately to the north of the vast Bengal Plain, forming not only an element of the foreland graben, but also a gate between the Deccan Plateau and the Assam

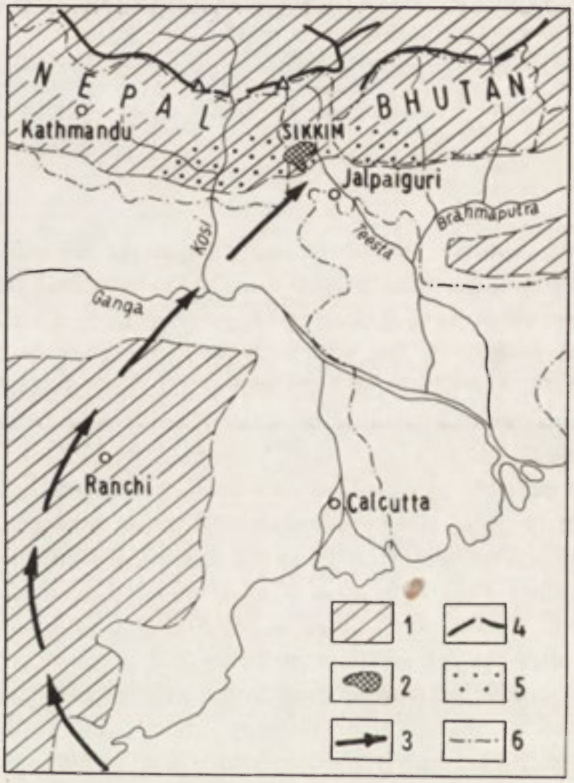

Fig. 1. Position of Darjeeling Hills and track of cyclone at the begin of October 1968

1 – mountains and highlands, 2 – area of investigations, 3 – track of cyclone, 4 – main Himalayan ridge, 5 – zone of heavy rainfall at 2–5 Oct. 1968, 6 – state boundaries

Upland (Khasi-Jaintia Hills). Masses of moist air have here an easy access to the border of the Himalayas. The Great Himalaya of Sikkim, constituting a climatic barrier, is composed of the mighty mountain massifs of Kanchenjunga (8581 m above sea-level) and Pauhunri (7130 m.). On the foreland of these massifs and of the Upper Tista Basin dividing them the wide (up to 30 km) zone of the Darjeeling Hills extends, forming part of the Lower Himalaya (Plate 1), They culminate in the summits of Sandakphu (3639 m), Tonglu (3303 m), and Tiger Hill (2580 m), being dissected by the Tista valley. These hills rise in the form of a distinct step over the narrow (5 km), densely dissected zone of the Sub-Himalaya of an altitude up to 1200 m, which in turn falls away abruptly towards the Ganga-Brahmaputra Plain. Thus, the Darjeeling Hills, falling also to the north towards the Upper Tista Basin, form a separate mountain group with relative heights of the order of 1500–2000 m.

THE GEOLOGICAL STRUCTURE, ITS REFLECTION IN THE RELIEF AND IN THE CHARACTER OF SOILS

The Darjeeling Hils together with the narrow Sub-Himalaya zone build four overlapping rock series (figs. 2 and 3). On the border of the Young-Quaternary alluvial plains and of fragments of higher alluvial cones the narrow Siwalik zone occurs, built of arkosic and micaceous sandstones and siltstones with intercalations of unconsolidated conglomerates, representing the Younger Tertiary and Lower Quaternary [23, 20]. These rocks dip towards the North (20–50°) under the overthrust Damuda series (lower element of Gondwana) composed of quartzitic sandstones with shales and conglomerates. These rocks of Permo-Carboniferous age also dip northwards and north-westwards at an angle of up to 80°. They appear again in the tectonic window of the inversional Upper Tista Basin ([21], fig. 2). A thick overthrust series of metamorphic palaeozoic and Precambrain rock lies on them, bent in the form of a wide syncline (fig. 3). Its lower series (Daling) is built of slate phyllites with a large share of chlorite and biotite, intercalations of quartzite and greywacke, metamorphosed to a slight degree. Towards the top of the Daling series the metamorphism increases up to the Darjeeling gneisses with a share of garnet and sillimanite. This is why Gansser [20] considers that the Daling and Darjeeling series are not divided by an area of overthrust, but constitute a single vast nappe of inversed strata. The most resistant rocks occur at the top. Although the gneisses and shales are strongly folded, in the general picture within the Darjeeling Hills they form a wide syncline, dipping from the border of the mountains, from the Tista and Great Rangit valleys towards the centre at 20–60°. They are strongly fractured. Among the fractures investigated in the region of Darjeeling those running NNE – SSW (vertical), NW – SE (dipping at about 60° towards the NE), or NNW – SSE, and others [42, 15] are numerous. The fractures are related to the tectonic activity of the region, which experiences frequent earthquakes belong [29].

The resistance of rocks and the style of tectonics are reflected in the relief, this being noted by Heim and Gansser [23] and Kar [27]. In spite of the youthful stage of the relief, a zone of hog'back was formed on the monoclinically lying Siwalik and Damuda series (Tindharia region). The resistant Darjeeling gneisses rise in a distinct structural escarpment over 600 m in height, limiting the high central highland. At the foot of the escarpment a zone of lower ridges extends, which also accom-

TABLE 1 Chemical analyses of Darjeeling gneisees and Daling schists *)

Series	Locality	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MgO	CaO	MnO	Na_2O	K_2O	$+H_2O$	$-H_2O$	Total
Darjeeling	Sukiapokhri	66.70	13.55	0.79	0.81	4.22	1.87	0.87	0.08	4.11	6.25	0.87	0.07	100.19
Darjeeling	Mahanadi--Kurseong	63.97	15.41	0.76	0.68	4.04	2.13	0.89	0.15	4.59	6.06	1.71	0.18	100,59
Darjeeling	Mahanadi--Kurseong	69.78	12.08	0.92	0.97	4.32	1.58	1.26	0.07	3.62	2.92	1.11	0.35	98.98
Daling	unknown	54.73	22.39	0.80	3.05	4.01	1.61	0.59	0.02	1.79	5.43	5.42	0.18	100.02

* Analyses of Darjeeling series after Chakraborty [9], of Daling one after Gansser [20]

TABLE 2 Mechanical and some chemical characteristics of soils*)

No	Locality altitude a.s.l.	Geomorphological locality	Grain size			pH		K_2O	P_2O_5	Mg	Fe
			>1.0 mm	1.0–0.1 mm	<0.1 mm	H_2O	KCl	in mg per 100 g of soil			
6	Sukiapokhri 2050 m	NW slope, inclination about 30°	6.7	66.0	27.3	4.7	3.9	8.0	0.5	1.50	70.0
14	Mani Bhanjan--Tonglu 2200 m	NE slope, inclination about 20°	0.9	77.8	21.3	5.3	4.2	4.0	0.1	0.66	27.5
15	Ringtong 1150 m	W gentle slope	11.3	68.5	20.2	4.9	4.0	4.0	0.1	0.96	49.0
16	Bannockburn 920 m	E slope, inclination about 25°	13.8	69.4	13.8	4.8	3.9	4.0	0.3	1.05	47.5
17	Chongtong 1320 m	flat elevation of Chongtong Spur	2.0	74.7	23.3	5.0	3.9	6.0	0.1	0.36	47.5

* Mechanical composition made by A. Welc and chemical analyses by J. Kaźnica in Cracow.

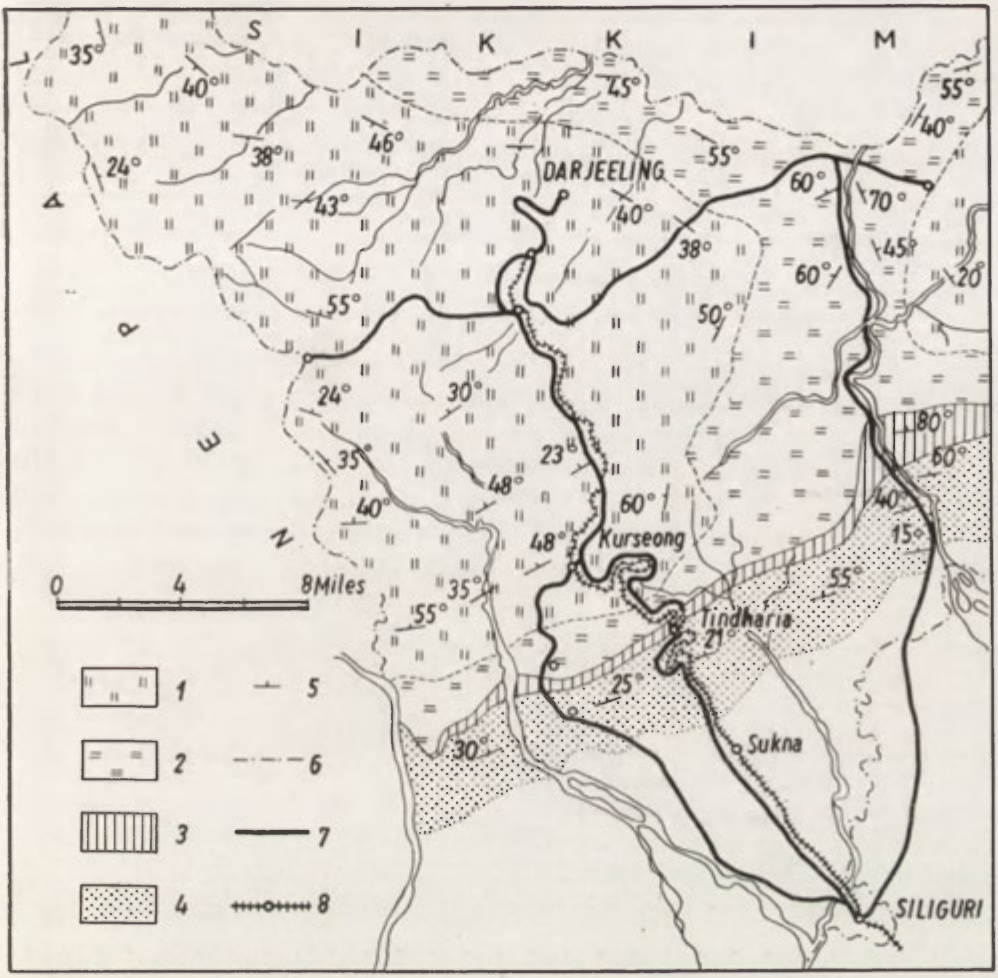

Fig. 2. Geological map of Darjeeling Hills (after Ganser and others)

1 – Darjeeling gneisses, 2 – Daling series, 3 – Damuda series, 4 – Siwaliks, 5 – dip od beds, 6 – state boundary, 7 – roads, 8 – railway line

pany the transversal valley gorge of the Tista river, lying on the axis of a transversal elevation [32, 21]. These ridges represent the zone of less resistant shales of the Daling series. Within the inversive central highland the rectilinear course of many ridges and valleys relates also to the structures – hence the frequent NNE – SSW directions [27]. Thus, the ridge on which the town Darjeeling lies is synclinal and that of Kurseong monoclinal.

Geomorphological observations were carried out by the author chiefly within

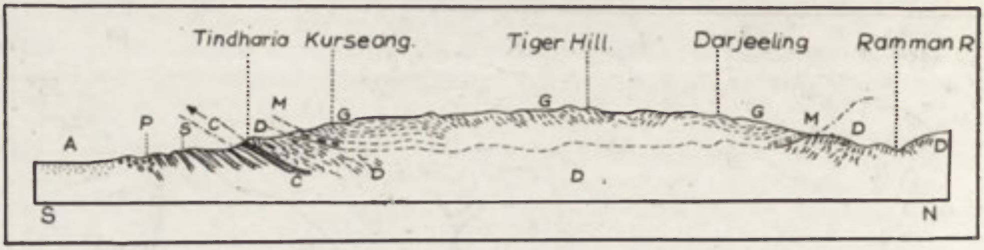

Fig. 3. Geological section across Darjeeling Hills (after Heim 1939)

A – Alluvium, P – Pleistocene boulders, S – Siwaliks, C – Damuda series, D – Daling phyllites and slates, M – Mica schists, G – Darjeeling gneisses

the Darjeeling gneisses (partly on the Daling shales). The character of these rocks as material being subject to weathering and denudation, is therefore described more fully. Table 1 shows that silica prevails among gneisses (63–70 per cent), the share of Al_2O_3 being smaller (12–17 per cent), while that of iron, potassium, and sodium is also significant. In the less resistant Daling shales the content of SiO_2 is much lower (55 per cent) and that of Al_2O_3 higher (>22 per cent).

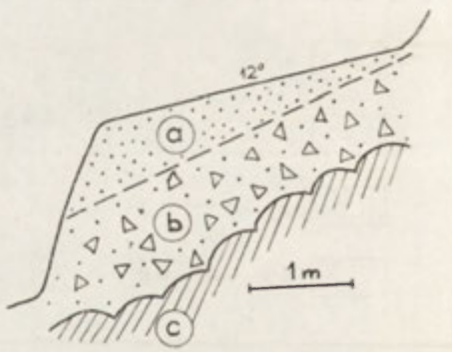

Fig. 4. Section across the typical narrow farming terrace west of Darjeeling

a – sandy – loamy soil, b – sandy eluvium with unweathered derbis, c – weakly decomposed gneisses

In spite of the steep slopes, the rocks are fairly deeply weathered. The thickness of the waste covers amounts to 0.5–2.0 m on the steep deforested slopes, to 2–4 m on the more gentle ones and in the forests, and even to 6–10 m on the flattened spurs below the height of 1500 m above sea-level. On the terraced cultivated terrains (cf fig. 4) it varies greatly on a short section. The soil as a rule changes slowly into a weathered solid rock. On gneisses it is very sandy and the rock fragments are often weakly decomposed, which is related to the intensive degradation of soils. The sandy fraction represents about 70 per cent (Table 2). While on the steep slopes in shallow soils the content of debris is high, on the flattened spurs and in the dense forests the share of clay and silt matter increases (sometimes up to 30 per cent). Red soils approaching in laterites character prevail here. Owing to the mechanical composition, the water capacity and permeability of soils is considerable [31], their

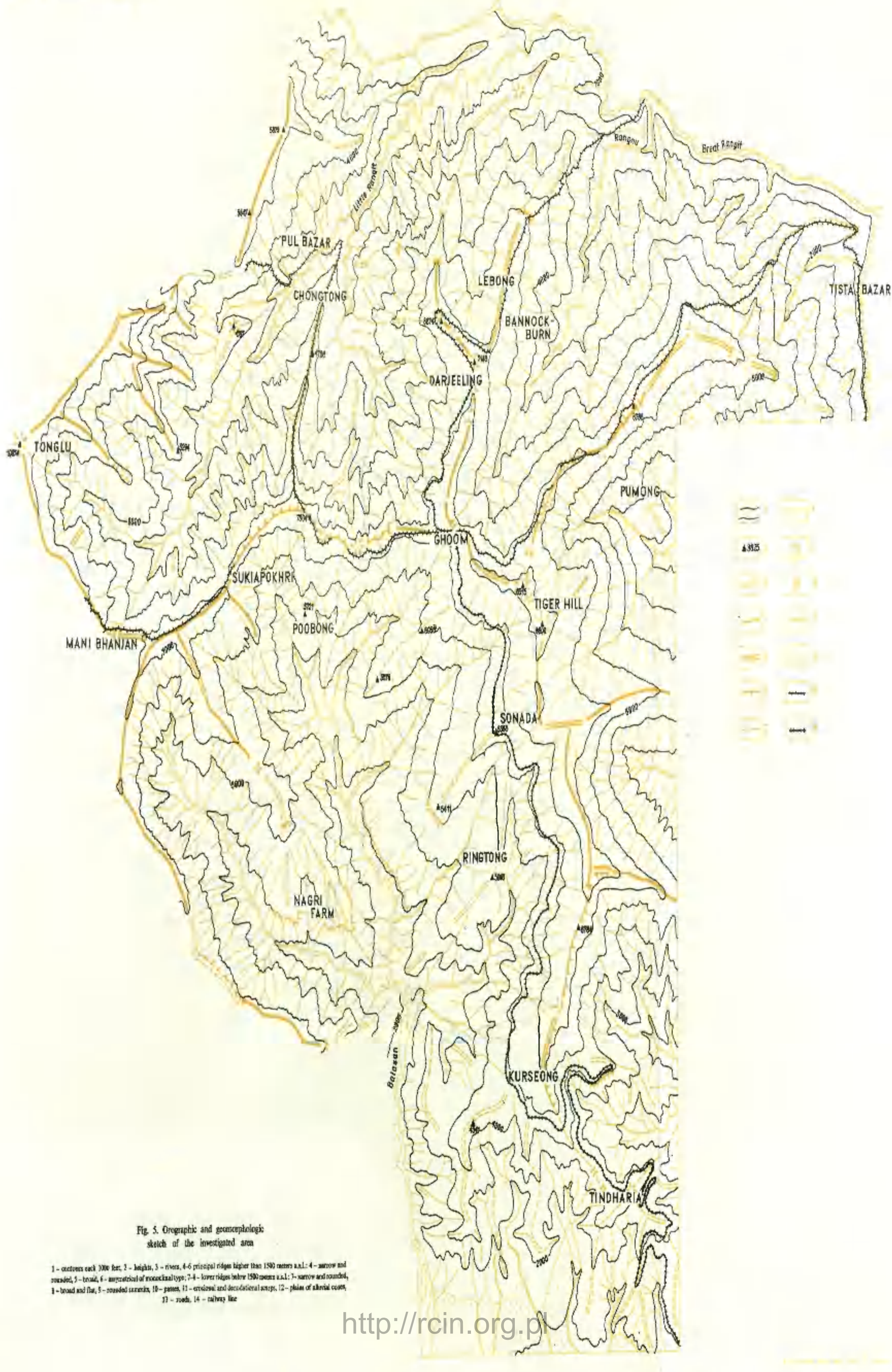

Fig. 5. Orographic and geomorphologic sketch of the investigated area

1 – contours each 1000 feet, 2 – heights, 3 – rivers, 4-6 principal ridges higher than 1500 meters a.s.l.: 4 – narrow and rounded, 5 – broad, 6 – asymmetrical of monoclinal type; 7-8 – lower ridges below 1500 meters a.s.l.: 7 – narrow and rounded, 8 – broad and flat, 9 – rounded summits, 10 – passes, 11 – erosional and denudational scarps, 12 – plains of alluvial cones, 13 – roads, 14 – railway line

plasticity ranges from 25 to 35, and the fluidity from 35 to 55. According to Dutta [15], debris soils on steep slopes have an angle of repose of 30–40°. The soils show an acid reaction (pH of water 4.7–5.3), they are rich in potassium and iron [43]. (Table 2).

The soils on the Daling shales are much more clayey anf subject in greater measure to flows [26].

GEOMORPHOLOGICAL CHARACTERISTICS

The part of the investigated Darjeeling Hills between the valley of the Tista in the east and the border of the Nepal in the west is composed of the central highland, (with a type of middle mountains relief with ridges of an altitude of 2200–3000 m, dissected by valleys 1000–1500 m deep), the wide zones of the Great Rangit and Tista valleys bordering it, and the Sub-Himalaya zone. The Tista and Rangit valleys lie at an altitude of 100–300 m. the denivelations therefore jointly exceed 2000 m. The Sub-Himalaya zone south of a height of 900–1200 m above sea-level has an energy of relief of 500–800 m.

The pattern of ridges is the result of dissection by dendritic valley patterns (Fig. 5). The central part is composed of the meridionally elongated Sandakphu – Tonglu hump (3000 m above sea-level), to which the Tiger Hill (2850 m) mountain junction is joined by the Sukiapokhri dividing ridge 2200–2300 m high and running W–E (between the basin of the Little Rangit and Balasan). This junction is composed of a meridional hump diversified by single peaks of a course Darjeeling – Kurseong. In the northern part numerous branches depart from it, breaking at a height of 1800–1500 m on escarpments several hundred metres high, lying at the front of outcropping Darjeeling gneisses (Fig. 3). The central area is dissected by a net of valleys mostly obsequent in relation to the structure, often of a NNE – SSW course and a depth increasing with the course of the valleys from 700 to 1500 m

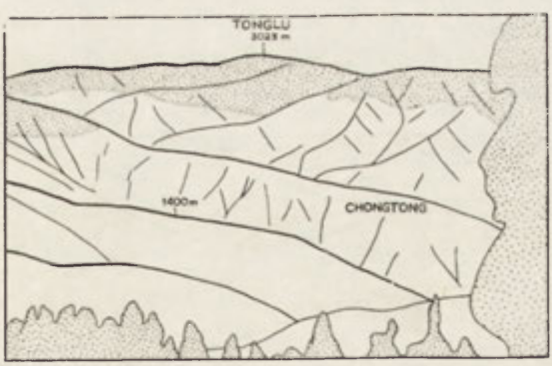

Fig. 6. View from Darjeeling to the South – west. Upper part of the Little Rangit river basin. Between valleys flattened spurs at the altitude about 1300–1600 m a.s.l.

The net of these main valleys is sparse. They are accompanied by distinct steps in the form either of wide flat spurs (with an axis inclined at 3–10°) often 2–4 km long, or of flat segments above breaks on slopes (15–25°). These fragments jointly mark out the vast destructional level, which penetrates deep into the valleys in the area of gneisses, especially along the Little Rangit and Balasan to a height of over 1500 m above sea-level (Figs. 6, 7 and 8). This level also developed along the Tista and Rangit (at an altitude of 900–1000 m [27]) and in the Sub-Himalaya zone on less resistant rocks. Numerous valleys are incised into it, having their sources on

Fig. 7. Lower segment of Little Rangit valley. View from Chongtong to the North. Above wide river channel and undercuttings there are visible fragments of two levels at relative hight of about 200 and 800 m.

slopes of the highest ridges (Fig. 6). Along the large rivers Tista, Great Rangit, and Balasan a lower level also runs, of a relative height of 200–300 m (600–1000 m above sea-level), described above the Tista by Kar. In the smaller valleys, as e.g. those of Rangnu or near Ringtong, breaks as knick points on slopes probably correspond to it (Fig. 9).

When analysing this terrain the first thing noticed is the scarce system of large

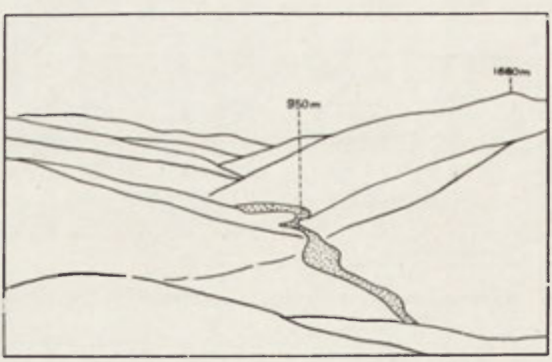

Fig. 8. Balasan valley to the South of Poobong. Above convex volley sides are ranging wide and flattened spurs

and deep valleys (Fig. 5; Table 3 shows by way of example features of some of the investigated drainage basins), whose density does not reach even 300 m length per sq.km. If we take into account the dissections of slopes of a depth of over 50 m, it will increase to 600 m per sq.km. This is distinctly related the considerable depth of the valleys (700–1500 m), the great length of the slopes (1–3 km) and their steepness (20 – 40°). The slopes and at the same time the sides of valleys are usually rectilinear or convex, undercut at their base, this being related to the lowering erosional base. There also occur stepped slopes, which may be connected either with the structure (different resistance of the beds of gneisses and shales) or with the occurrence of benches of old levels. The gentle sections have then an inclination of 15–25°, whereas the upper sections of slopes are steep. This is related to the dissection of the lower parts by slope gullies, and „sapping" of the higher parts. Convex-concave slopes are encountered in sections of valleys with a small fall of channels (hanging) and scarp-slopes on the border of the central highland.

As was mentioned earlier, the degree of dissection density of slopes of big valleys is often insignificant. This is illustrated by a sketch of the upper section of the Rangnu valley, on which we see the (elaborated by Jahn's method [25]) very small degree of dissection density (Fig. 10). However, if we take into account all slope dissections 5 to 50 m in depth and of an inclination of axis approximate to the fall of the slope, the density of dissection by valleys will increase to nearly 1.8 km/km^2. This suggests that there does not occur here a fragmentation but a back-wearing of slopes, taking place only with the participation of erosion. The same refers to many other valleys. Site observations show, however, that the surface of slopes is greatly diversified by shallow (1–3 m deep) troughs, often running parallel to each other at a distance of some twenty metres.

The gradients of valley bottoms of smaller and larger streams are uneven, decreasing downstream from 50 to 5 per cent (Little Rangit, Balasan) (Fig. 11). The bottom is occupied by a wide channel covered with rock debris, or locally cut in

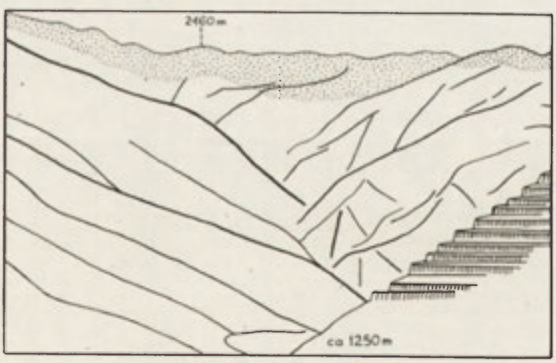

Fig. 9. Valley head of Pachim creek near Sonada and Ringtong. Breaks in slope profiles give the sign of the rejuvenation of valleys

TABLE 3. Morphometrical characteristic of some surveyed catchment basins

Catchment basin (locality)	Posam (Poobong T.E)	Pachim (Ringtong)	Rangnu (Bannockburn)	Little Rangit	
				upper segment	middle segment (near Pul – Bazar)
catchment area in sq. km	5.3	9.0	33.1		
lenght of main river in km	1.9	5.1	8.1	6.3	16.5
total length of creeks, dissecting slopes deeper than 50 m	1.3	–	39.0		
total length of creeks, incising slopes less than 50 m	5.5	5.7	11.4		
density of valleys (deeper than 50 m) in km per 1 sq. km	0.604	0.566	0.586		
total density of drainage system (valleys) in km/sq. km	1.641	1.200	1.764		
relative heights in valley head in meters		700	800	900–1200	–
relative heihgts in lover segment in meters	1350	300–500	100–1250	–	600–1400
gradient of main river in percent (upper segment)	50	40	24	25	–
gradient of main river in percent (lower segment)	25	12	10	–	5
mean length of slopes in km	0.5	1.0–1.5	1.5–3.0	1.0–2.0	0.5–2.5
inclination of slopes in valley head in degrees	25–40	25–30	20–35	25–35	–
inclination of slopes in lover segment in degrees	–	12–25	23–31	–	15–30
types of slope profiles (most frequent)	convex	convex-concave, convex	step-like, convex	convex	convex

Fig. 10. Upper part of drainage basin of Rangnu river (near Bannockburn)

– river pattern, 2 – isohypses each 1000 feet, 3 – dimension of slope retreat measured as dissection by valleys (method presented by Jahn [25])

solid rock. It is accompanied by small banches of terraces 5 to 10 m high (sometimes higher), usually preserved as cones at the outlets of affluents, built of gravel and sandy covers with single boulders 5 to 10 m in diameter. In valleys of larger rivers the channels of a slightly winding course are accompanied by undercuts of slopes (walls often 10 to 30 m high), testifying to a considerable discharge of rivers and accentuating the share of lateral erosion in the formation of convex slopes.

The Darjeeling Hills, therefore, have features of a young relief with deepened V-shaped valleys and convex of rectilinear slopes. The development of the relief shows a deepening of valleys occurring by stages, this being related with the period of the uplift of mountains after the last orogenetic phase in the Lower Quaternary [29, 20].

THE CLIMATE

The heights and exposure to southern rain-bearing winds determine the distribution of thermal conditions and precipitation. While Bagdogra, lying in the Ganga and Brahmaputra Lowland, notes extremes of maximum and minimum temperatures of +42° and+4°C, in Darjeeling, situated at a height of 2100 m, they amount to +27° and –5°C. At an altitude above 2000 m the author often observed ground frost and needle ice, which shows that on uncovered surfaces frost weathering takes place. The seasons are related to the course of the

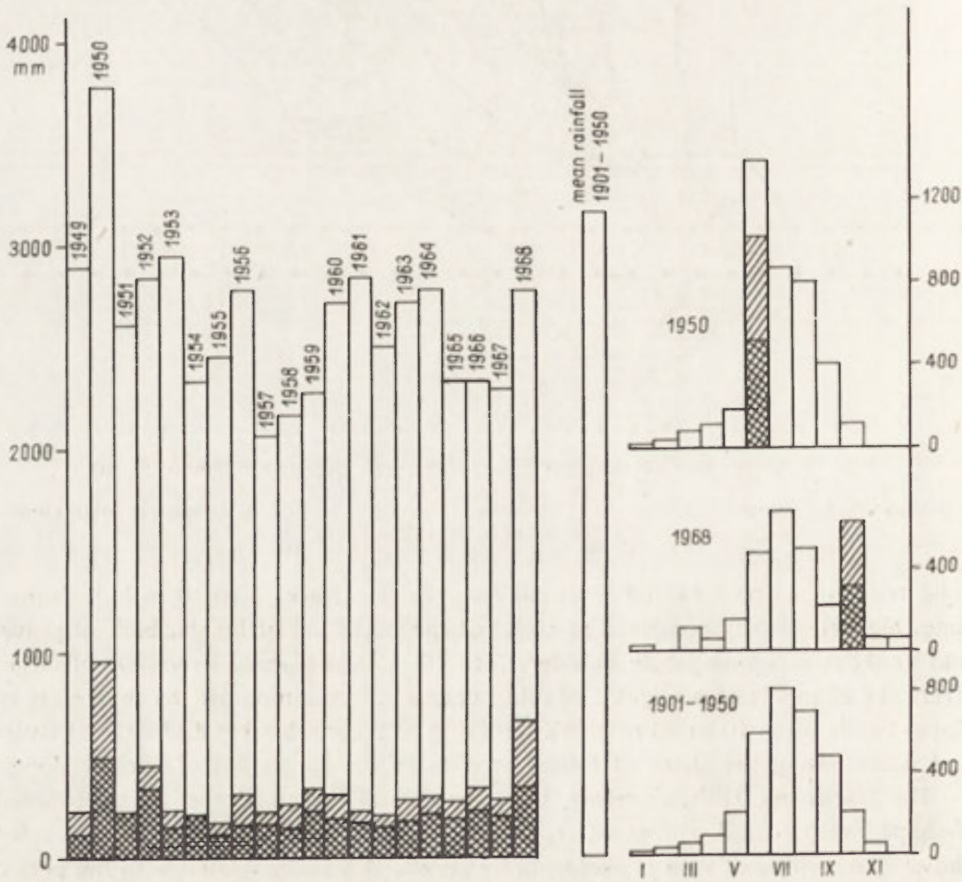

Fig. 11. Precipitations in Darjeeling

On the left annual rainfalls in the years 1949–1968, On the right monthly distribution of rainfall in the years 1950, 1968 and mean value for 1901–1950. With cross – hatched signature maximal annual rainfall in 24 hours, with hachured one – in 72 hours

Fig. 12. Areal differenciation of precipitation in Darjeeling Hills

1 – main ridges, 2 – rivers, 3 – roads, 4 – boundary of India, 5 – passes and peaks, 6 – rain gage station, 7 – automatic raingage stations

In frames going from top: mean annual rainfall in 1901–1950, total amoung of precipitation during heavy rain 10–14 Juni 1950, amoung of precipitation during heavy rain 2–5 Oct. 1968

No value in frames means no information

summer and winter monsoon. The annual rainfall in Darjeeling amounts on the average to 3092 mm.[1] In winter, during anticyclonic weather, rain is a rarity. About 95 per cent of the total amount of rain falls in the half-year including the summer monsoon. The periods of the beginning of the summer monsoon (May, beginning of June) and of the break of the monsoon (October) the high temperatures and storms accompanying it are important from the morphological point of view. The most intensive downpours occur at that time [4]. From June to September it rains almost every day (20–27 days each month), the highest fall being noted in July. On the records of the Darjeeling-Planters' Club station deviations were calculated for the years 1949–1968 from the mean annual precipitation, which amounted at that time to 2560 mm. At a differentiation of the annual total of precipitation from 2069 to 3941 mm the mean average deviation is ± 290 mm. Assuming that a rainfall of great intensity can be morphologically active, as well as long-lasting downpours, the author calculated that in the present twenty-year period 11 days with a rainfall of over 2 inches (50.8 mm) were noted annually on the average, the number of these days varying from 5 to 25.70 per cent of cases were below the mean. The mean heaviest rainfall in 24 hours amounted to 74–511 mm, hence on the average to 173 mm (again 65 per cent cases below the mean). The heaviest rainfall during 3 successive days varied from 115 to 965 mm (273 mm on the average in the course of a year). In 70 per cent of cases it was also below the mean. This analysis shows that the exceptional years 1950 and 1968 were of great consequence for these means.

The distinct differentiation of precipitation in the vertical profile is related to the exposure. While the mean annual rainfall in the years 1901–1950 for Bagdogra and Siliguri in the lowland was 2103 and 3620 mm, in Kurseong lying on the border of mountains at a height of 1500 m, it amounted to 4052 mm, and in Darjeeling situated farther to the interior and on a culmination, to 3092 mm (Fig. 12). A similar inversion of precipitation also appears in the particular years; e.g. from 1963 to 1968 Kurseong noted from 3770 to 5290 mm, while the heaviest rainfall there in 24 hours in 1968 reached 640 mm (in 1950 960 mm fell there in the course of 36 hours). Apart from inversion, the rain shadow is still more distinctly marked. The stations situated in deep valleys and further from the front of mountains receive by 30–50 per cent less rain than those on slopes with a southern exposure (Fig. 12). According to the data presented in the Working Plan of the Darjeeling Forest Division, the mean amount of precipitation in the years 1930–1950 varied from 1763 to 3464 mm.

[1] Data of the Observatory of the Meteorological Department of the India Government for the years 1901–1950 [35].

THE CHARACTERISTIC OF WATER CONDITIONS

The analysis of precipitation indicates that water falls on the earth's surface chiefly during the period of the summer monsoon. Its amount is spatially differentiated, varying from 2 to 5 million m^3/km^2/year. During a heavy rainfall up to 0.2–0.5 million m^3 per sq.km falls in 24 hours (at a fall of 200–500 mm). At a full saturation of the soil the coefficient of run-off may amount to 100 per cent, which equals a mean discharge of 5.8 m^3/sec./km^2. The run-off on steep slopes occurs rapidly in ravines cutting them. In the sandy waste mantle conditions permit the run-off of water percolating in the soil. The slope of stream beds (5–50 per cent) and the concentration of the run-off at the confluence of valleys favour a considerable specific discharge. On occount of the lack of investigations in the region of Darjeeling, the author will report the values of measurements from catchment basins lying east of the Tista valley in an area of similar geological structure [14] (Table 4). In 1952 four rivers of this terrain of an area of 50–160 sq.km (annual precipitation of 5000–6000 mm) carried at the most from 1.8 to 5.2 $m^3/sec/km^2$. Assuming that the intensity of precipitation often noted here is 1 mm/min, it follows that the unit discharge can amount to 16.7 $m^3/sec/km^2$. This is difficult to explain. When the intensity of rainfall is higher (during orographic downpours e.g. in the region of the Caucasus 9–10 mm/min are noted [47], a sudden expelling of water from soils and a support of beds by landslides can occur, both resulting in an increase of discharge.

TABLE 4. River discharge of some rivers in Kalimpong Subdivision in the year 1952

(after G. N. Dutt [14])

River	Drainage area in sq. km.	Forests in percents of area	Maximum discharge in cu.m. per sec.	Maximum run-off in cu.m. per sec. per sq. km.	Minimum discharge in cu.m. per sec.	Maximum : : minimum ratio	Annual rainfall in drainage area in inches
Lish	49.2	37	254.7	5.176	0.25	1000	192
Gish	160.6	42	630.2	3.922	0.08	7423	212
Chel	103.6	47	184.5	1.777	0.06	3260	240
Neora	134.7	69	242.1	1.797	2.4	101	250

Although floods occur here every year, rainfall bringing about catastrophic floods is most frequent at the beginning and end of the summer monsoon. As was reported by Chaudhury and Das [16], of the 22 investigated floods in the neighbouring Assam 10 occurred at the break of monsoon and 6 were related to the migrating cyclonic centres from above the Bay of Bengal, usually during the abatement of the monsoon.

Waters sometimes flow impetuously from the mountains to the foreland, often in the form of a billow overfilled with material /flash flood). Large quantities of material are carried away [2]. Observations from the neighbourhood of Kalimpong [14] indicate that some rivers, as e.g. Chel lift their cones by about 45 cm every year. The river Manas and other Himalayan tributaries of the Brahmaputra give annually about 670 m^3 of suspended load from 1 sq.km [15]. During their high-water period rivers often carry 1000–7000 times more water than at their lowest stages (Table 4). As a result of these fluctuations they often alter their channels -within their cones, as e.g. the river Tista, which till 1787 flowed in three channels and was a tributary of the Ganga [29, 46].

VEGETATION AND LAND USE

The Darjeeling Hills lie within belts of evergreen tropical forests. To the height of 900 m this is a tropical forest, the so-called Lower Hill Forest (according to the Working Plan of the Darjeeling Forest Division [37]), within which 3 types are distinguished: a sal forest (with Shorea, Schima), a dry mixed forest (Engelhardtia, Castanopsis), and a wet mixed forest. The drier forests are related to deep valleys lying in the rain shadow [7]. From 900 to 1500 m a jungle with mixed vegetation (Schima, Engelhardtia, Castanopsis, Machilus, and others) grows. From 1500 to 2850 m the Upper Hill Forest extends with rich mixed forests (Betula, Alnus, Bucklandia, Quercus, Magnolia, Acer, Juglands, and many others). Worthy of note is Alnus nepalensis, which is the first to penetrate into the areas of landslides [45]. The large range of thees not welcoming the dry season is related to the considerable

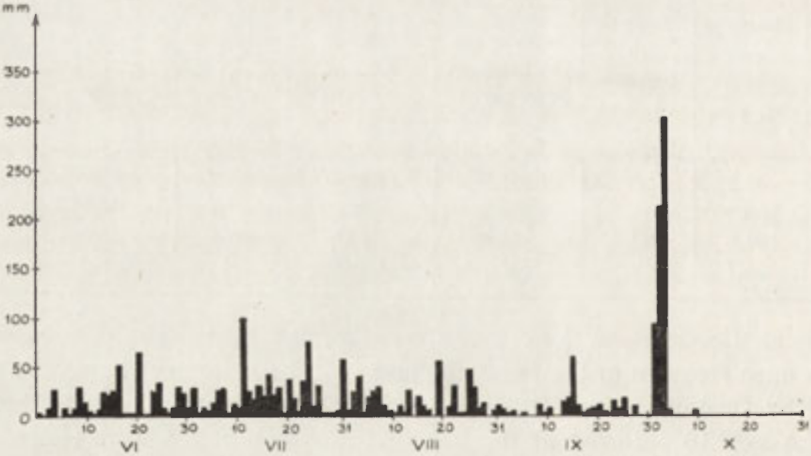

Fig. 13. Daily rainfall records during summer period 1968, at Darjeeling (Planters Club Station)

air moisture and abundant occurrence of fog and dew [5]. Above 2700 m coniferous trees prevail.

The natural altitudinal floristic belts underwent considerable changes caused by man. The specific composition was altered, 50 per cent of species being brought in [7]. The share of forests is fairly large (>50 per cent) in the lower belt; plantations of teak tree are also frequently found here. The forests were devastated particularly in the middle belt, where in 1840 tea bushes were introduced, having a dense but shallow (about 0.5 m) root system. In 1866 39 tea gardens were already established in this region. Nowadays they occupy on the average 50–70 per cent of the area of slopes, reaching a height of 2100 m. Apart from them, there occur fields under crop and bamboo thickets, whose virtue is a very deep root system, holding firmly the soil. Dense forests were preserved in the upper belt on steep slopes, especially on the northern ones, beginning from height of about 1900–2100 m above sea-level (Fig. 6).

Considerable changes in the environment were brought about in the last century by the building of numerous roads and highways, and of a railway line to Darjeeling (in the years 1879-1881), as well as of a dense network of side roads on the terrain of tea gardens and in the forests. The many undercuts of slopes not only disturbed the equilibrium of masses but cut across and partly drained the ground-water reservoirs in the sandy waste mantle. Owing to the construction of terraces between the fields (frequent shelves 2–3 m wide and 3–4 m high; cf. figs. 4 and 9), slopes of a primary inclination of 20–25° changed into steps of flattenings with an inclination of 10–15°, appropriate for cultivation, but separated by almost vertical breaks exceeding the angle of repose.

THE COURSE OF THE HEAVY RAINFALL BETWEEN THE 2ND AND 5TH OCTOBER 1968

The summer monsoon in 1968 did not abound in precipitation (Fig. 13), since to the end of September 2044 mm fell, including 7 days with a rainfall exceeding 50 mm. Towards the end of September a stormy cyclonic front began to develop over the Bay of Bengal, which after being transformed into a deep cyclone, reached the Himalaya (Fig. 1). The rainfall covered not only the Sikkim Himalaya but also the eastern Nepal and western Bhutan. After a local fall in the afternoon of the 2nd October 1968, at 8 p.m. the rain set in (Figs. 14 and 15). Its intensity slowly increased in the course of the 3rd October, reaching in the night of the 3rd/4th October 15–20 mm/h. It abated in the morning and increased again in the afternoon of the 4th October, reaching its culminating point at 8–12 p.m. The mean intensity at that time amounted to 40–55 mm/h, and at 15 minutes intervals exceeded 1 mm/min. Then the intensity suddenly decreased to 5–10 mm/h and in the morning of the 5th of October the rain stopped completely. The pluviograms from Nagri Farm and Kalimpong (Fig. 15) give a good insight into the course of the rainfall. Cha-

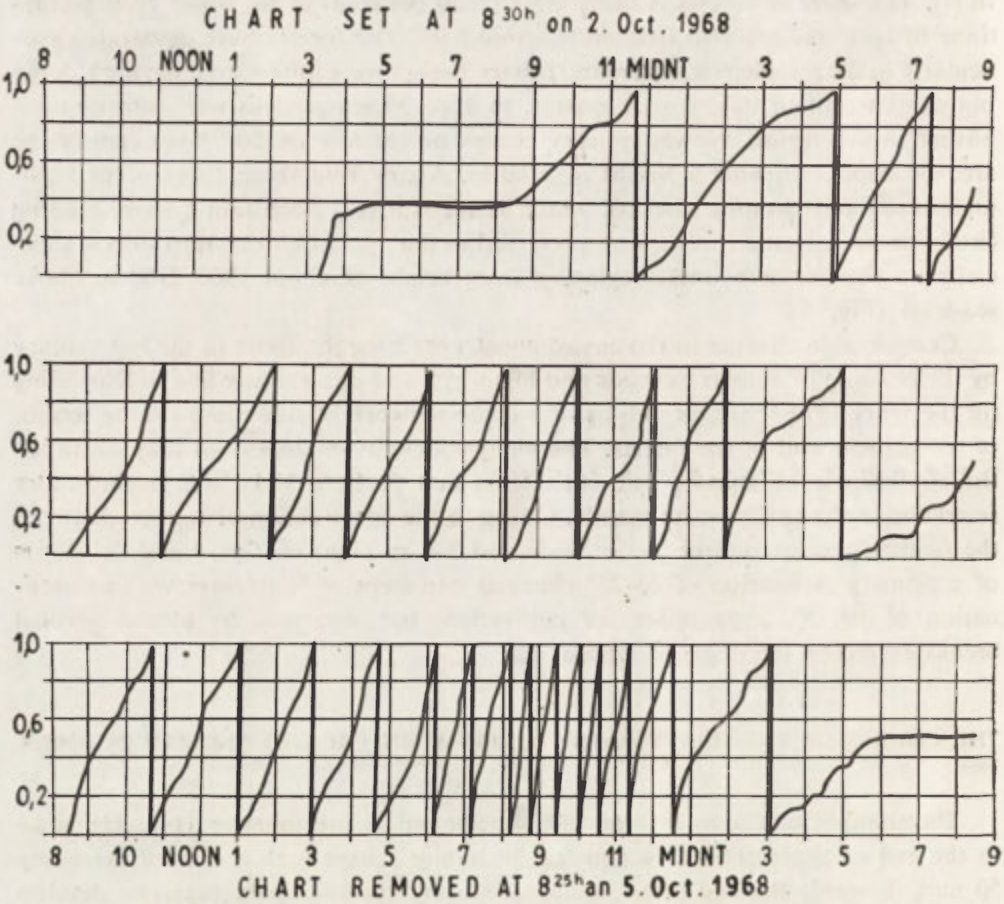

Fig. 14. Pluviogram from automatic rainfall station in Nagri Farm (set on 2 Oct. and removed on 5 Oct. 1968). By permission of Dr F. Rahman from Tea Research Station

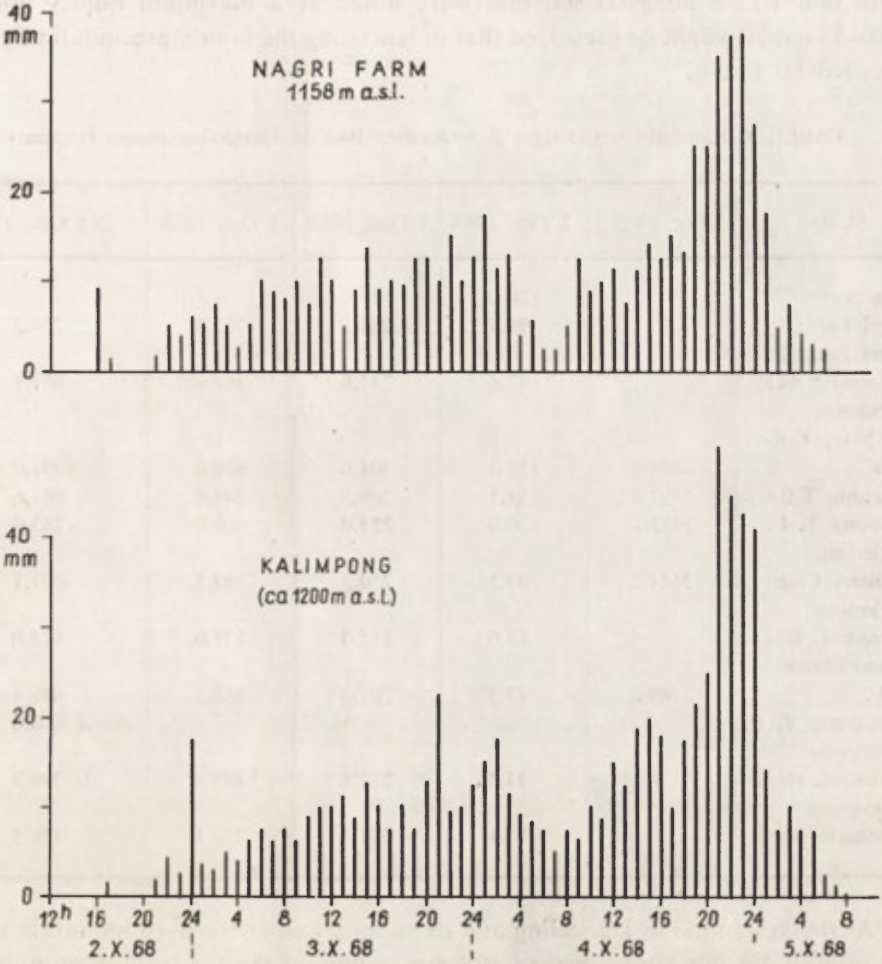

Fig. 15. Rainfall intensity per hour during heavy rain at 2–5 October 1968. The diagram besed on the automatic records (pluviograms) from Nagri Farm (Tea Reseach Station) and Kalimpong (Meteorological Dept. of the Govt. of India)

rasteristic here is the full concordance of both curves in spite of the two stations lying 29 km apart. On the basis of still other data it was possible to learn the areal differentiation of the rainfall (Table 5). The heaviest occurred on the edge of mountains in the neighbourhood of Kurseong (1091 m) and in the Upper Tista Basin (according to the information of the Meteorological Department). If in Nagri Farm and Kalim pong700–800 mm were noted at a maximum hourly intensity of 40–55 mm, it might be presumed that in Kurseong the hourly precipitation greatly exceeded 60 mm/h.

TABLE 5. Rainfalls in the days 2–5 October 1968 in Darjeeling region (in mm)

Station	For 1968	2 Oct. 1968	3 Oct. 1968	4 Oct. 1968	2–5 Oct. 1968
Jaipalguri		120.0	113.0	–	–
Nagri Farm		91.4	260.1	382.8	734.3
Nagri Farm (automatic rec)		87.6	241.6	368.9	697.1
Kurseong (St. Mary College)	4878.5	152.0	301.0	638.0	1091.0
Ringtong T.E.	3197.8	151.1	209.5	241.0	601.6
Poobong T. E.	3975.1	110.0	255.0	400.0	765.0
Darjeeling (Planters Club)	2651.2	93.5	210.3	303.3	607.1
Darjeeling (Meteorol. Obs.)		85.0	215.0	275.0	575.0
Bannockburn T. E.	2689.6	83.3	207.0	356.1	646.4
Chongtong T. E.					above 650.0
Kalimpong (Meteorol. Obs.)		73.4	257.8	465.1	796.3
Kalimpong (automatic rec.)		71.1	261.3	456.1	788.5

At the same time in Darjeeling and its vicinity and in the deep mountain valleys the rainfall did not always exceed 600 mm, while on the foreland of mountains it amounted to about 400 mm. The characteristic trait of the 60-hours' rainfall occurring towards the end of the summer monsoon when the soil was saturated with water, was the increasing intensity and strongest accent at the end of the downpour (Fig. 13 and 15).

RECONSTRUCTION OF THE RUN-OFF OF WATER

The course of the run-off can be reconstructed (since direct measurements are lacking) on the basis of reckonings of the rainfall, taking into account the slope gradients, the character of the substratum and the morphological effects on the slopes and in the channel (size of bed load, height of the flood wave). During this downpour the rainfall on an area of 1 sq.km amounted on the average to 0.6–-1.0 million m^3.

From the 4–days' break in the rainfall before the 2nd of October (Fig. 13) it follows that the surface layer of soil was dried out, being capable of absorbing still large quantities of water. During the rainfall of an intensity of 10–20 mm the water retaining capacity of the waste covers was probably filled and the water began to percolate within the soil under the influence of seepage pressure. The lack of furrows or of other traces of slope wash suggests an almost exclusive subsurface percolation. The excess of water infiltrated along joints to the eweathered gneisses or flowed in the channels of small steep valleys cutting into the slopes. When in the evening of the 4th October the intensity increased, the water infiltrating into the sandy soil as into a sponge and not being able (apart from a few exceptions) to store up in the deeper fissure water reservoirs, began under pressure to cut and widen channels in the deposits on the slopes (turbulent filtration) and gush out in the form of springs. These gave rise to the displacenent of liquefied soils. The author observed numerous traces of such sufosional (piping) channels. Where water penetrated deeper, large deep landslides formed or new springs appeared, from which during the period of his observations the discharge of water was still considerable.

The water from the slopes, often in the form of mudflows (siels, Murren), accumulated in the beds of creeks, which at a gradient of 10–50 per cent flowed over the whole width of the bottom. The height of the wave increased down the creeks, amounting to 2–5 m (Table 6). The discharge of water in the forests was slower,but here also the author observed in slope guilles traces of a flow of a 1-metre layer of water. The power of water is evidenced by the fact of its carrying boulders 3–5 m in diameter, and in a few cases even 6 to 12 m. If one would draw conclusions from the attempts to calculate the velocity of discharge from the particle size of load (Table 6, [18, 33]), the water in the valley of the stream Pachim near Ringtong could have carried during the culmination ca. 120 m^3/sec., which corresponds to a specific run-off of 14.3 m^3/sec/km^2. In the Posam valley near Poobong, where 5-metre boulders were carried, the velocity by comparison ought to amount to 13 m/sec and the discharge to 780 m^3/sec, this corresponding to 156 m^3/sec/km^2. At Pul-Bazar in the large valley of the Little Rangit the discharge reached 5625 m^3/sec.

If, basing on the results of investigations carried out in the USSR on the turbulent "siel" (mudflow) with a load amounting to 1.8 t/m^3 and slope of channels smaller than the angle of repose of masses [3, 56], we reduce these values by half, they will still be considerable, exceeding 3–5 times the highest noted intensity of precipitation (about 1 mm/sec). As follows from the accounts of the local population and observations of the results of the flood, there occurred on the 4th October at about 11 p.m. a violent flow of masses from the slopes and a rise of flood. This was probably followed by a release of immense masses of water confined in the covers (seepage pressure). With the additional damage of the channels by landslides and superposition of flood waves it seems that the values of the unit run-off of the order of 50 $m^3/sec/km^2$ are not overestimated for some catchment basins.

TABLE 6. Characteristic of discharge and size of boulders in some river channels

River (locality)	Width of channel in m.	Gradient of river in %	Depth of river in m. (4 Oct.)	Average size of boulders in m.	Mean velocity in m. per sec.	Discharge in cu.m. per sec.	Specific run-off in cu.m. per sec. per sq. km.
Posam (Poobong)	30	25	2–3	5–6	13	780	156.0
Pachim (Ringtong)	10	10	2	2	6	120	14.3
Little-Rangit (Pul-Bazar)	150	5	5	2–3	7.5	5625	75.0
Tista (Tista-Bazar)	250	0.2	20	2	5.5*)	27500	3.8

* The same values have been measured and computed from the size of boulders

During the decreasing of the flood wave, probably also occurring suddenly (large boulders were not covered with fine material), the inflow of water from slopes rapidly decreased, while the springs related to the deeper retention continued to be active.

The violent water rise also occurred in large rivers. According to the information obtained, the level of water in the Tista rose locally to 80 feet. At Tista Bazar near Anderson's bridge which was carried away at about 11.30 p.m. the author noted that the high-water level was 18 m higher than that observed towards the end of November 1968. The water overflowed the bridge. If one takes into account the mean velocity of flow of the flood wave reported by the press as amounting to 5.5 m/sec (to the Seroka bridge the water flowed 12 miles in the time of an hour). which is in occordance with the size of bed load, the flood discharge at Tista Bazar was about 27,500 m^3/sec. This equals a unit discharge of 3.8 m^3/sec from 1 sq.km (the catchment basin occupying an area of 7200 km^2). [2] The value of the Tista

[2] In the preliminary report [52] 3,6 m^2/sec were wrongly given.

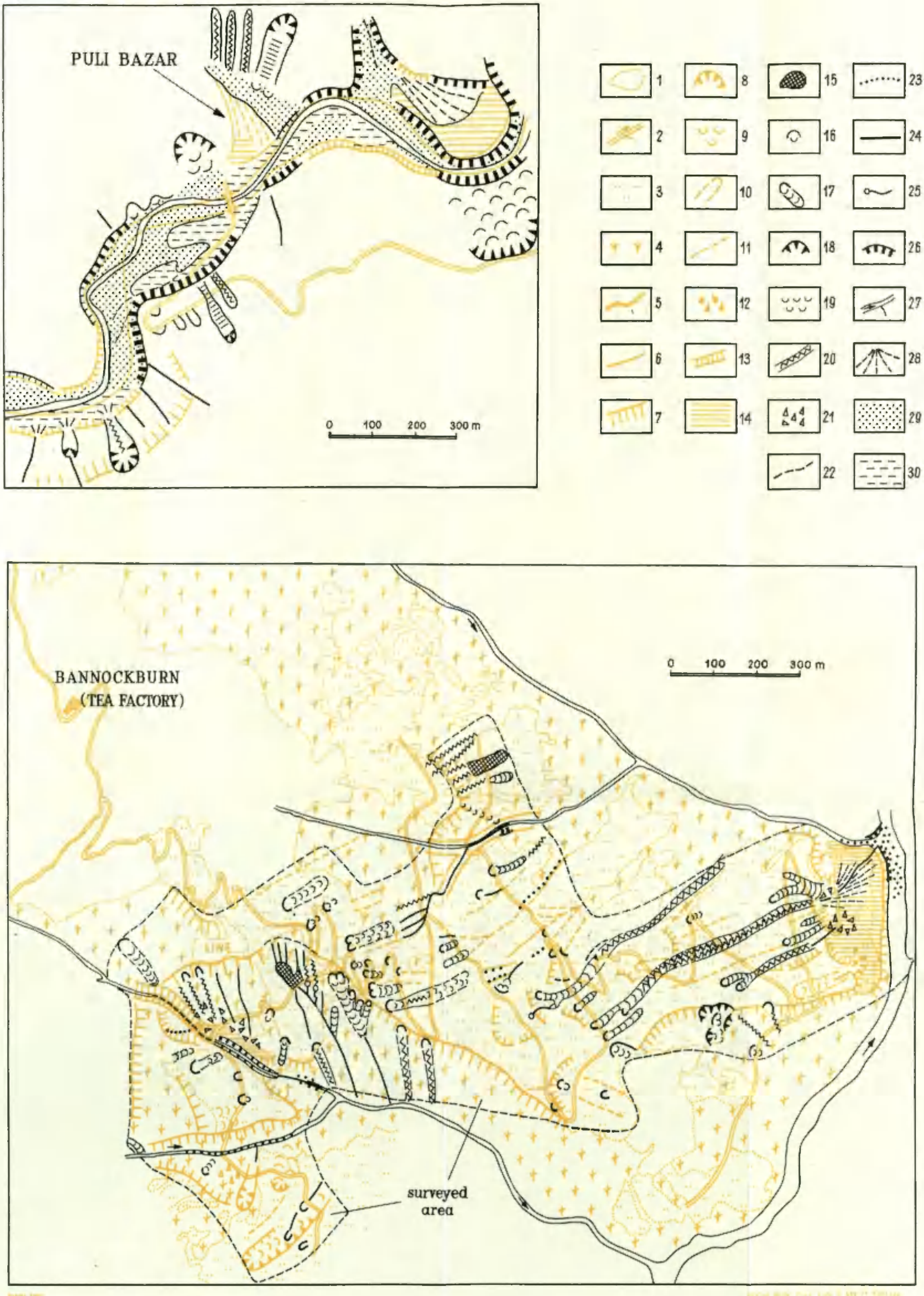

Fig. 16. Examples of transformation of relief during catastrophic rainfall October 1968. Geomorphological maps of fragment of valley floor (Little Rangit near Pul Bazar) and long slope (Bannockburn T.E).

1 – boundaries of types of land use (also of former valley floor of Little Rangit), 2 – rivers, 3 – tea bushes, 4 – jungle 5 – roads, 6 – V-shaped valleys, 7 – edges and scarps, 8 – scars of landslides, 9 – tongues of landslides, 10 – gentle slope valleys (traces after mudflow tracks), 11 – small inactive gullies, 12 – debris – torrential fans, 13 – waterfall step; 14 – terrace plains, 15 – soil cover degraded by slope wash, 16 – small slumps on the sides of roads, 17 – small mudflows and slides, 18 – scars of big landslides, 19 – landslide tongues, 20 – tracks of mudflow with erosional furrows, 21 – debris – torrential fans, 22 – older slope valleys, dissected in Oct. 68, 23 – older slope valleys with traces of fluvial transport, 24 – new gullies, 25 – gullies of sufosional origin, 26 – cliffs formed by lateral erosion, 27 – river channels, 28 – alluvial fans, 29 – accumulation in channel facies (boulders, gravels), 30 – accumulation in terrace facies (sands and gravels)

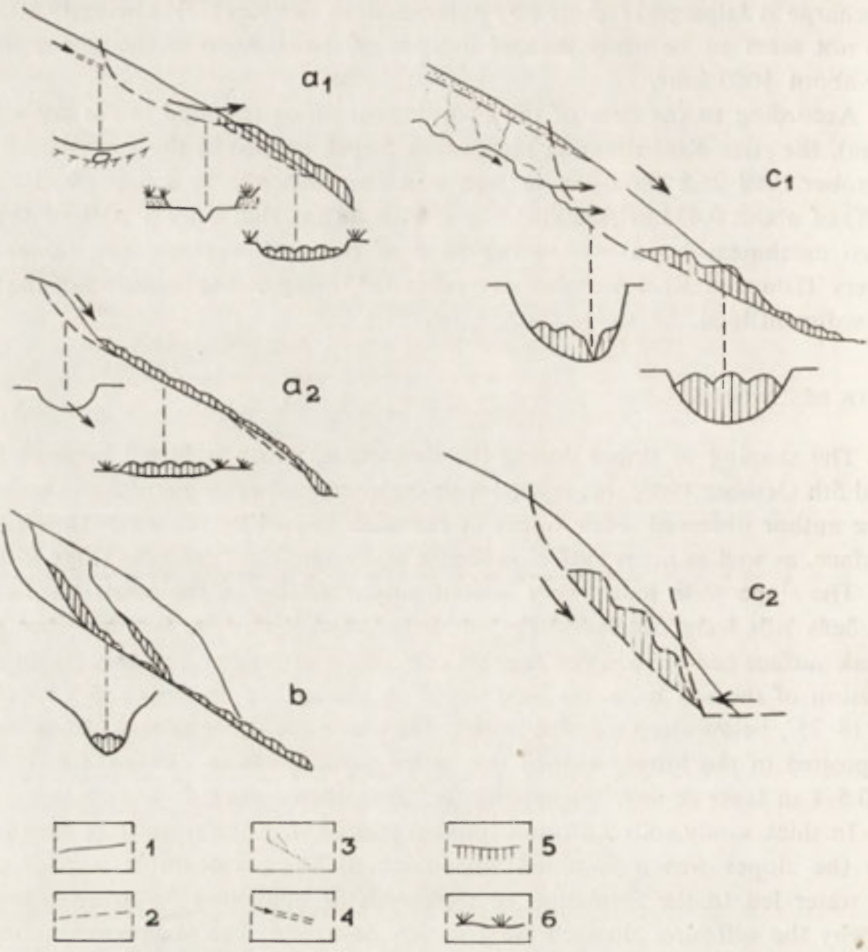

Fig. 17. Types of mass movements during heavy rain October 1968

a_1 – Mudflows connected with suffosional channels, a_2 – slumps – mudfows, b – mudflows directed by slope gullies, c_1 – debris – rock slides connected with deep percolation, c_2 – landslides and slumps created by lateral erosion
1 – slope surface before movement, 2 – new erosiosal profile, 3 – joints conducting ground waters, 4 – sufosional channel, 5 – flowing or sliding material, 6 – soil cover with tea bushes

corresponding to the thickness of the waste mantle), a long gully like channel usually with a torn down layer of soil about 0.5 m thick, corresponding to the depth of rootage of the tea bushes. The channel with steep margins was from several to 40 m wide, being often centrally or marginally cut by a furrow 0.5–2 m deep, sometimes cut into the rock. The fall was variable; the flowing mass overcoming the unevenness of the slope had a varying velocity, slowing down and spreading wider on flattenings (10–20°). The winding course of the gully and preserved single trees (sometimes tea bushes as well) on the axis of the flow suggest that it was a liquefied mass, behaving like a liquid (Plate 3). On long slopes some flows reached a length of 600–1000 m (Fig. 16, Plate 4). The front of tongue often moved down as far as the valley bottom, coming then to a stop on a terrace, where in the final phase of the downpour it was washed away, forming alluvial cones with an inclination of 10–15° (Plate 5). The best preserved were tongues of flows which had been held up by tea bushes on slope shelves. Inclinations of the order of 15–20°, characteristic of accumulations of tongues, correspond to the angle of internal friction of loamy sands saturated with water.

The flows described were formed under the influence of the seepage pressure of percolating water circulating in the waste mantle. The water gushing out under pressure together with the liquefied mass flowed over the slope. That is why many courses of flows were simultaneously cut by streams of water flowing from suffosion channels (Plate 6). The cutting could have continued towards the end of the downpour after the formation of the flow (cf. Rapp [41]), as like as the retreat of the niche (fig. 17).

At smaller inclinations of 12–20° flows formed on the gentle slopes of Chongtong Spur, where in the more clayey thick soils liquefaction occurred more rapidly.

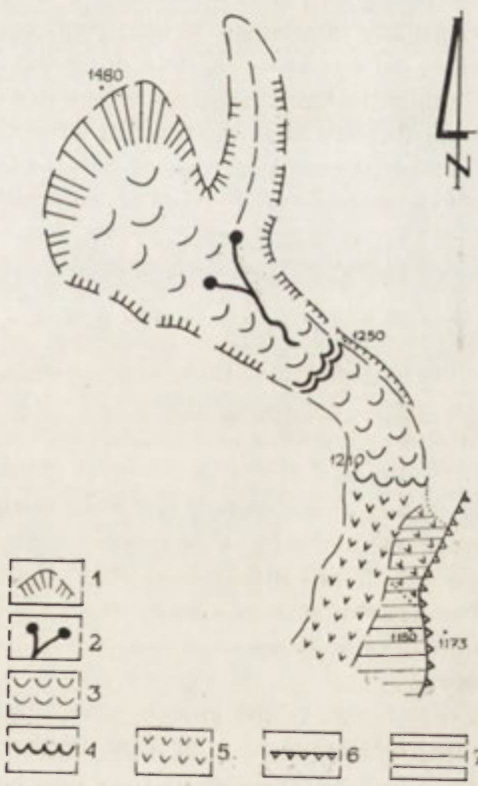

Fig. 18. Geomorphological sketch of a big landslide in Poobong Tea Garden about 350 m long. Upper part – rock slide, in the lower earthflow

1 – niches and scarps, 2 – springs and erosional furrows dis secting the sliding blocks, 3 – sliding mass, 4 – forehead. of sliding mass, 5 – earthflow, 6 – lateral erosion of Posam creek, 7 – terrace plain 8 m high, partly covered by flow

a^2) The mudflows of the second type with a considerable share of coarse material (debris flows) were started by slope slumps on steep slopes (Fig. 17), usually on structural breaks, edges of destructional levels, or on undercuts of roads (Plate 7). and edges of field terraces. The mass of waste mantle saturated with water could not hold on at an inclination of 35–50° (greatly exceeding the angle of repose of the waste mantle imbibed with water). It slumped taking on the way the imbibed soil, and became transformed into a mud-debris flow. Many of these slumps-flows began at the crest of ridges forming narrow strips several metres long. Sometimes the zone of break was supplied with water percolating from the upper parts of slopes, and then in the thinned out jungle slips developed (Plate 4), changing downslope into muddy tongues, spreading among the trees and bushes. Sometimes the slumping masses were very large and mobilized rock masses on a steep slope. In this way part of the village Pul-Bazar was buried under a layer of debris about 10 m thick.

b) A separate type are flows directed by gullies existing on slopes before the downpour (Plate 8). These gullies of an inclination of 40–60% drain the slopes, collecting masses of small and larger flows and slumps from the upper parts of long slopes. The gradients of the gullies, exceeding the limiting angles of friction of earth masses, afforded possibilities for considerable velocities of these masses, surpassing the velocity of water, as well as for the transportation of large blocks. They were particularly threatening in road cuts. The artificial supporting barriers across the gullies did not as a rule hold down the masses, but still prevented the deepening of gullies. In the forest areas only water carrying fine gravels flowed off in gullies earlier formed, while the few flows reaching here were impeded by the vegetation.

c) Large and deep rock or debris-rock slides formed in places either of deep infiltration of rain waters or of undercutting by flood waters.

c^1) The deep infiltration of water led to the formation on slopes with an inclination of 25–35° of large rock slides 0.5–1 km long and of an area exceeding 20 ha. One of these slides in the forest near the road to Poobong formed on a slope of an inclination of 35° (Plate 9). Another one at Poobong (Fig. 18, Plate 10). formed on the side of a small slope valley, destroyed several houses, and then moved down to a terrace and partly to the bed of the stream Posam. It was composed of two parts: a rock and an earth part. The rock part forms a distinct front, while on its foreland a washed out long tongue of liquefied earth mass is extending. The large blocks are often rounded, this being related to the deep chemical weathering and formation of the so-called corestones [6]. Springs gushing still during the period of observations (24th December) cut in the upper masses of the landslide and continue to activate it. Masses of another rock slide at the undercut of a road in the forest near Sukiapokhri moved down along the bed of the valley dissecting the slope.

c^2) Another type of movement was observed by the author in areas where undercutting by large rivers took place. Big rock and earth slides on the Tista and Little Rangit formed on slopes overlain with thick covers of waste material and decom-

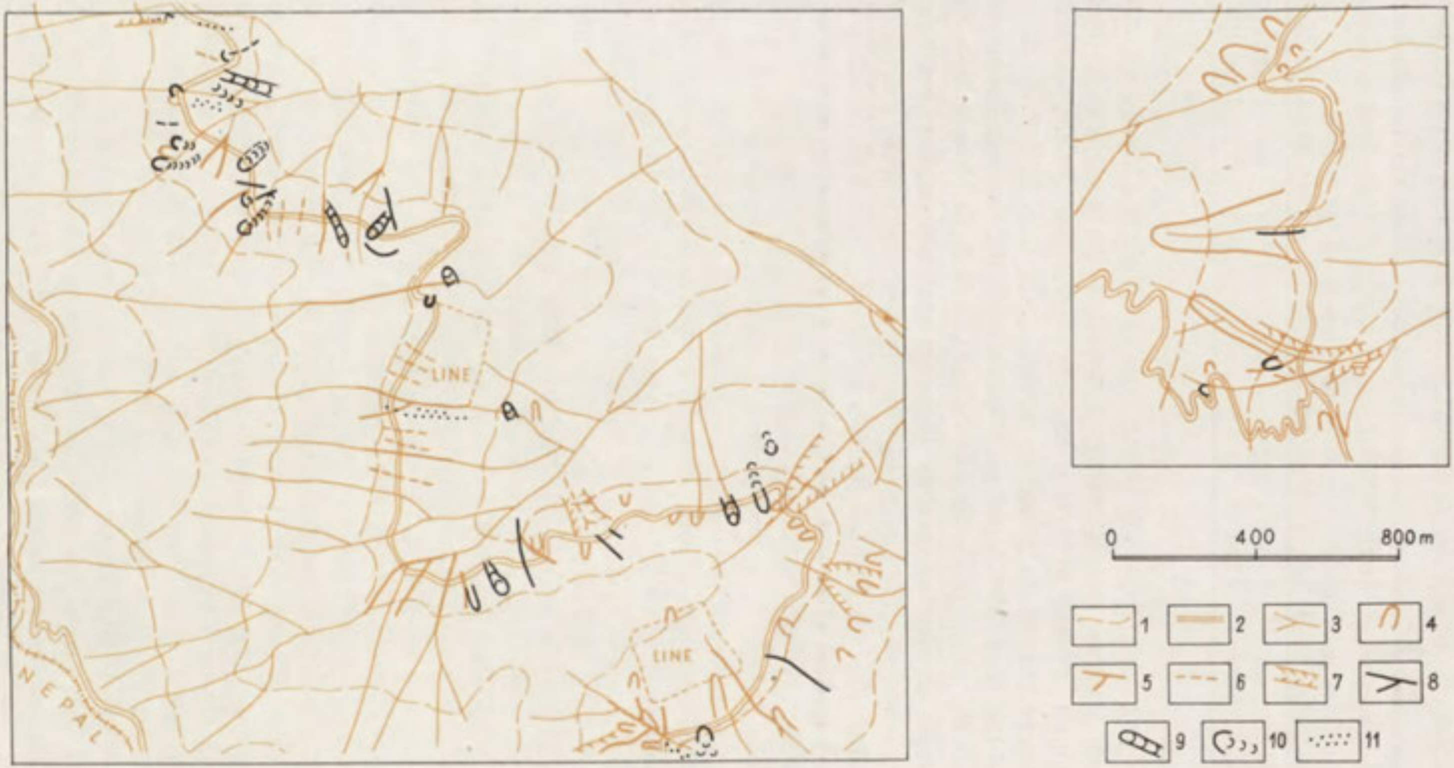

Fig. 19. Two examples of mapping of forest areas in Little Rangit Block. New changes ofter October 1968 underlinće by red colour

1 – contour lines each 500 feet, 2 – roads, 3 – creeks, 4 – slips and flows formed in 1950, (mapped by forest officers – cf. 37) 5 – V – shaped valleys, inactive in Oct. 68, 6 – inactive gullies, 7 – breaks and scarps, 8 – new gullies, 9 – channel – like mudflows, 10 – landslides, 11 – boulders accumulated in valley bottoms

among landslips and dissections encountered along roads as many as 32 were inactive during the downpour, 8 underwent rejuvenation, in 6 a fresh transportation or accumulation of gravels was recorded, and only 6 new furrows had formed. Thus, the forest inhibited the process of waste flow, the action of water being limited to the deepening of channels. However, it had no effect on deep landlides.

Considerable changes occurred along roads. E.g. along the Siliguri-Darjeeling highway over 200 new landslips were recorded (a large one near Godabari on the Daling shales).

A differentiation though less distinct also appears between areas of varying amount of rainfall. In Ringtong, where the slopes are often more mature (Plate 12), and well drained by dissections, the fall of rain amounted to only 602 mm. In spite of the steep valley head, the stream rose only slightly. The percentage of destruction on the plantation was 2–3 times lower than e.g. at Poobong, where the fall amounted to 765 mm. There also appears a differentiation in the transformation of slopes in the longitudinal profile of rivers. In valley heads earth flows directed by furrows were more frequent, leading even to a dissection (fragmentation) of slopes (Plate 13), whereas down the rivers, with the increasing erosional force the undercutting of slopes played a more important role.

Assuming on the average that on 20 per cent of the surface of deforested slopes in the altitudinal belt of 900–2200 m above sea-level flows and other types of mass movements occurred, and that the mean thickness of the displaced layer was 1 m, it follows that the whole surface of slopes was lowered by 20 cm on the average. If we take into account the forest areas, the average degradation in the region of Darjeeling will amount to 10 cm, which equals the removal of about 100 thousand m^3 from 1 km^2. This value will increase by 15 thousand m^3 if we take into consideration the actual surface of slopes of an inclination of 20–40° and not the one projected on the horizontal surface.

The distribution of fresh furrows of flows and slides on slopes throws light on the tendency of the transformation of slopes of the Darjeeling Hills. The prevailing convex profile of the whole slopes gives evidence of the role of incision and

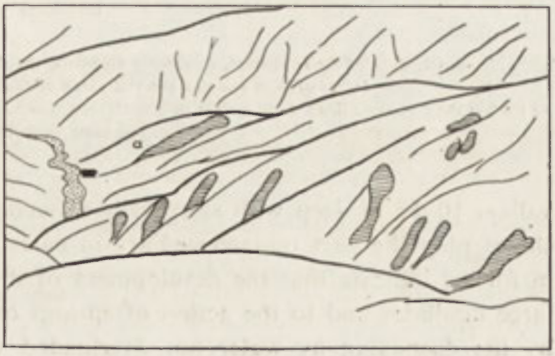

Fig. 20. Convex profiles of slopes forming by many mudflows. Valley side of Posam creek in Poobong

a – great landslide near tea factory in Poobong (cf. Fig. 18) lateral erosion of large streams (Fig. 20). During the flood the sides of valleys were undercut to a height of 10–30 m (usually slightly above the reach of the flood wave), and on both sides even of meander channels. Apart from a few sections, where at the base of slopes fragments of terraces above the flood plain occur, the river carried away almost 100 per cent of the material brought down from the slopes. The steep upper sections of slopes retreated, whereas the more gentle (usually middle) sections were lowered by the flows. The slopes as a whole are subject to a distinct back-wearing. This is also evidenced by rocks occurring on convex slope breaks. The occurrence of traces of old furrows after flows and the formation of new ones in other places indicates that by the alternate denudation of the particular stripes of slopes their retreat makes progress. Whether this is a frontal or undulating retreat is determined by the density of valleys dissecting the slope (Fig. 21). The erosional

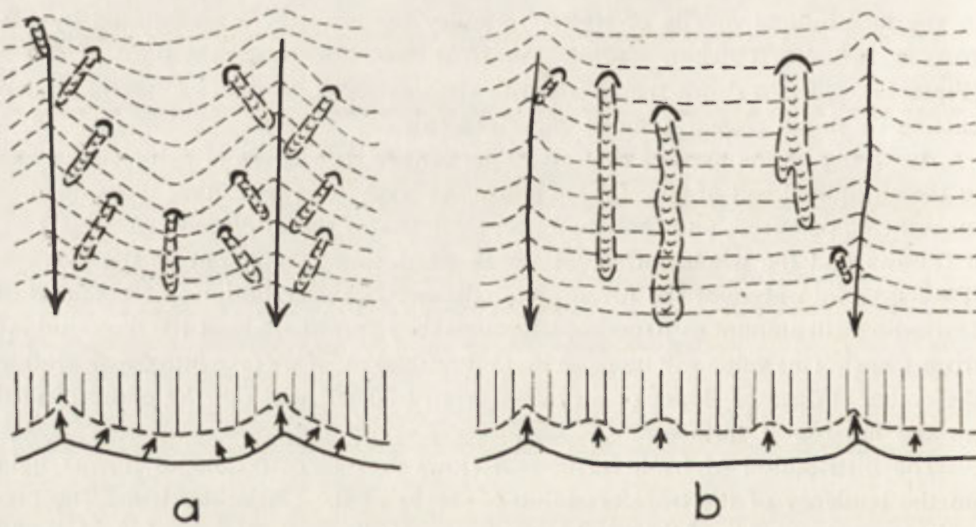

Fig. 21. Two ways of valley side formation during catastrophic rainfall (independent of lateral erosion)

a – with participation of linear erosion, frequently dissecting the slopes and directing the mudflows, b – by superficia degradation it remains the flat slope surface (by spersely dissected slopes)
At the top the contour – lined slope surface with mudflows, down the transversal slope sections indicating the tendencies of slope evolution

valleys 10–15 m deep with steep falls dissecting the middle and lower sections of slopes play the part of intermediary in carrying away the material. Observations in forests indicate that the development of these valleys was often started due to large landlides and to the action of springs released by flows, and was continued by the deepening by water not overloaded with material.

PROCESSES IN VALLEY BOTTOMS

No less excessive changes occurred in the valley bottoms, where the impetuous flood wave, carrying masses of debris load, both deepened and widened the channels often depositing masses of material. The differentiation of these processes will be illustrated by some examples of creeks of various magnitude of discharge and gradient.

Valleyhead segments dissecting slopes with a gradient of 40–50 per cent constituted furrows in which material of any size was transported. In forest areas either coarse gravel at the most was carried away, or else there occurred a deepening of channels in the rock up to 2–3 m. Headcuts with waterfalls formed on hard rocks (often 20–40 m high) did not retreat but were preserved. On the other hand, in deforested terrains, (among others, in those of the Poobong tea estate), they constituted furrows for transporting large masses of mudflows, which undercut slopes and mobilized new masses (in the Soviet literature the so-called bounded or structural siels; (Plate 13). Their velocity was considerable. At the outlet of these slope valleys fans were not formed, since the removed mass often eroded and was carried away by the water of a larger river. The older torrential fans were dissected or even removed altogether.

The larger valleys with a slope of 10–25 per cent were transformed in varying degree. The stream Pachim at Ringtong of a gradient of 10% (Table 6) carried material up to 2 m in diameter, weakly eroding in its sediments. Larger boulders 4–8 m in diameter, lying in the bed, were not moved. The flow of water during this downpour was of in considerable velocity. On the other hand, the wide terrace plain 8–10 m high, built of a crushing of boulders, gravels and sand, became heaped up with fans and tongues of masses from slopes, forming a surface of glacis type with an inclination of 10–15°.

Catastrophic changes occurred in the Posam valley of the affluent Balasan at Poobong, where the gradient of the channel varied from 15 to 30 per cent. Masses flowing from slopes and along axes of valleyhead segments were deposited in the form of a thick debris cover (Plate 14), which subsequently was sorted by water. There occurred here a transition from the bounded flow of masses to a turbulent movement of the overloaded stream, which permits the discrimination of 2 essential types of "siel" streams [19, 56]. The whole bottom was covered with rounded blocks of gneisses 2–5 m in diameter on the average (Plate 15). The evidence of the turbulent movement of water in this section (Plate 16) rather than a mudflow is not so much the rounding associated with the weathering and smoothing of the "corestones" during transportation, as the lack of a finer fraction and numerous traces of parts of the boulders being broken off at the corners and their imbrication. The stream during its rise changed its course in some sections cutting marginally a furrow up to 7 m deep, and partly in solid rock (Fig. 22, Plate 17), This must have occurred suddenly, as evidenced by the lack of covering of large boulders

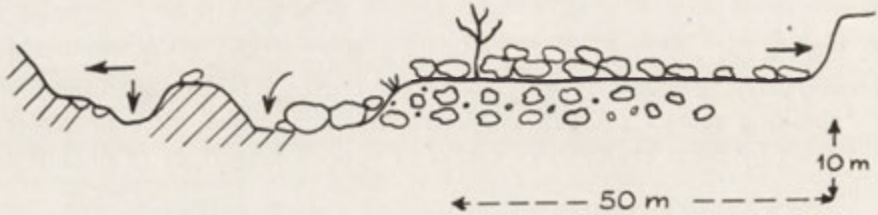

Fig. 22. Transformation in the river channel of Posam creek. On the right former valley floor covered by boulders. On the left incision in the bedrock (plate 17)

with a finer material in the lowered bottom of the valley. Below, in the Balasan valley, accumulation prevailed at a smaller gradient (of the order of 5 per cent).

An example of a large valley in the investigated section, with a gradient of 5 per cent and drainage basin of about 75 sq. km, is the Little Rangit near Pul-Bazar (Figs. 16 and 23). Before the flood the river bed was 25–100 m wide and in the valley

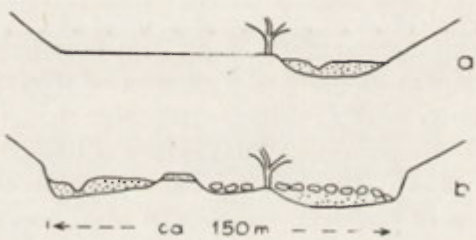

Fig. 23. Transformation of valley floor of Little Rangit to the southwest of Pul – Bazar

a - schematic section of valley floor before flood. b – erosion and accumulation during floor on 4th Oct. 1968

bottom were rice fields. In 1965 a new ferro-concrete bridge 13 m high and 35 m long was constructed. The river during its rise widened its bed up to 80–200 m, and in some sections from 30 to 180 m. The stream, flowing in December over a width of 5–8 m, during the flow could not hold in the bottom and undercut the slopes. Their back-wearing came up to 50 m. The bridge was an additional obstacle in this section. The river-bed became covered here to a height of 10 m with boulders 2–3 m in diameter on the average (Plate 18). The bridge abutments were destroyed. The water overflowed the bridge and part of Pul-Bazar was flooded. Below the bridge the river eroded for the most part, while the side affluents partly poured their fans on the preserved fragments of a 6–10 metres high terrace and partly dissected it (Plate 11). In the Little Rangit valley one can observe sediments resulting from the various phases of the flood. While during the flood crest boulders 8–12 m in diameter could have been rolled, during the subsidence features of bars with a material 1–2 m in diameter were definitely shaped. These bars sometimes cover fine gravels probably lying there before the phase of culmination. During the further subsidence of water the lower parts of channels were covered again with a much finer material. The author observed such a fraction under 0.2–0.5 m at a distance from the main flow, on higher surfaces. This was a counterpart of a terrace facies of rivers with a less turbulent flow. The reconstructed velocities of 7.5 m/sec do not seem to be excessively overestimated if e.g. in Erivan in Armenia the recording showed that at a similar inclination of 4–5 per cent a stream with a velocity of 5 m/sec carried boulders 2 m in diameter [47].

Observations of the bed of the river Tista draining the whole Sikkim Himalaya were carried out by the author in the region of Tista – Bazar, where on the 4th October at 11.30 p.m. Anderson's bridge constructed in 1933 was swept away. The force of water during the culmination of the flood (27,500 m^3/sec) is evidenced by the elements of the bridge of many tons weight being transported over tens and hundreds of metres. The bilateral undercuttings of slopes in the Great Rangit and Tista valley (Plate 19) show that the 20 metres high layer of water carried away the whole material, undercutting both slopes and mobilizing landslides (Fig. 24). This is best emphasized by the destruction of the vegetation. During the lowering of the flow wave alluvial fans from the side affluents were heaped further from the main flow and gravel bars became exposed, continuing to be transported (the author noted differences between the state on the 28th November and on the 27th December 1968). On account of the lack of observations, the volume of the material carried away by the river Tista could not be estimated.

However, on the basis of these fragmentary observations, the picture emerges of the scale of changes which occurred in the valley bottoms. The abundant delivery from slopes in the whole longitudinal profile of rivers of the Darjeeling Hills brought about an overloading of the rivers with material. In the source sections in the forests the beds were little eroded, and in the deforested terrains they were a prolongation of the gravitational transportation of masses from the slope. A channel with a big gradient simply became an element of the slope. Lower, at inclinations of 20–30 per cent, transportation by water markedly prevailed (unbounded turbulent "siel" streams); the waters washed the delivered material, cut out channels, and undercut the slopes. Downstream, at an inclination of the order of 5 per cent, accumulation decidedly prevailed in some sections (rise of the level of channels up to 10–12 m), or else incision (of the order of several metres). The fact of sectional transportation during high stages, known from river valleys of mountain areas, and being one of the causes of the uneven longitudinal profile of the channel, was confirmed here. The rivers, not adapted to big flows, often changed their current. The main river Tista, in spite of its evened slope, did not accumulate. Its waters, not being able to keep in the channel, carried avay masses of gravels and sands to the foreland of mountains.

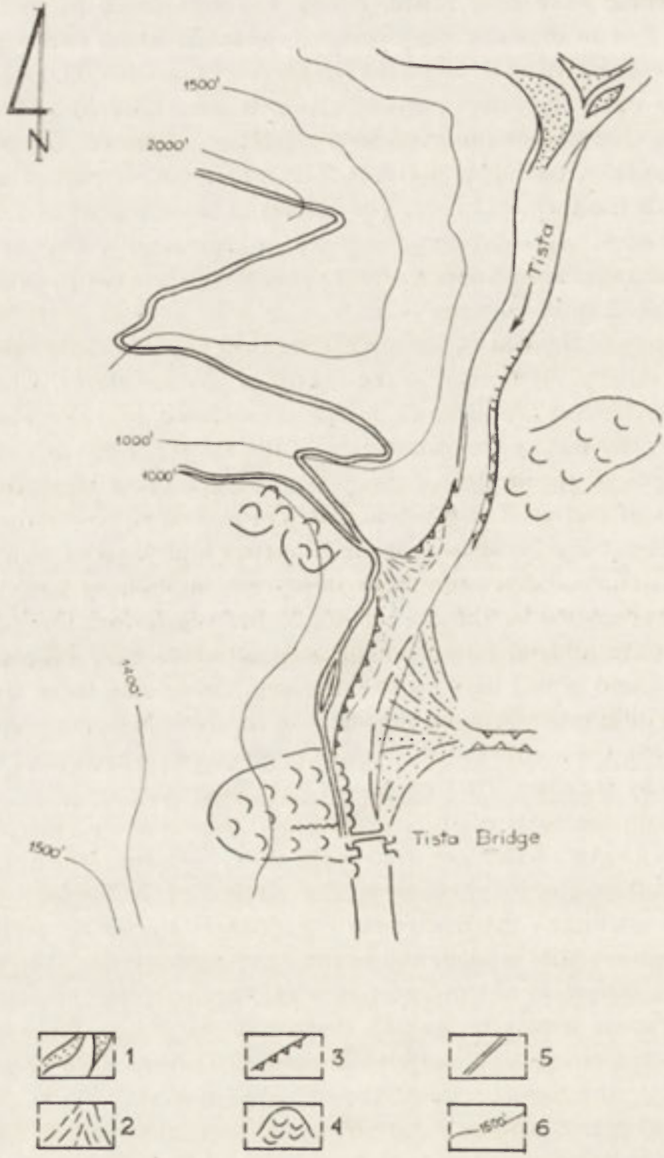

Fig. 24. Geomorphological sketch of Tista valley bottom near destroyed Anderson bridge

1 – river bed with levees and bars, 2 – aluvial fans formed in Oct. 1968, 3 – intensive lateral erosion, 4 – big landslides, 5 – road Darjeeling – Kalimpong, 6 – contour lines

THE CONSEQUENCES OF THE HEAVY RAINFALL BETWEEN THE 2ND AND 5TH OCTOBER 1968

New forms developed during the rainfall and an activization of processes took place. An average of 20 per cent of deforested slopes and about 1 per cent of wooded ones were transformed by the flow and other processes. The layer of waste mantle 0.5–2.0 m thick was mostly torn away. The distribution of new forms in relation to the whole slopes indicates that there occurs a slow slope back-wearing directed by gullies and small valleys. In the bottom of valleys with an unevened slope the material was carried away in the form of thick boulders. The contrasts of gradient between the particular sections of the longitudinal profile increased owing to the violent concentrated erosion or accumulation. In the big valleys the floors were widened by the undercutting of slopes. On the foreland of mountains braided rivers burst their banks, covering a vast extent of alluvial fans.

Similar changes, though often on a different scale, occurred in the neighbouring areas: in the southern Sikkim, eastern Nepal, and western Bhutan. Apart from the changes in the relief, the economy of the region suffered heavy losses. In Western Bengal itself more than 2000 people perished, 800 ha of tea gardens were destroyed (and a much larger area of fields under crop on the foreland of mountains), dozens of bridges were carried away, hundreds of houses collapsed, many roads were disrupted, as well as the railway to Darjeeling (it is doubtful whether it would pay to reconstruct it [12, 53]).

INFORMATION ON MORPHOLOGICAL CONSEQUENCES OF SIMILAR CATASTROPHIC RAINS IN THE DARJEELING REGION

From the geological and climatological literature, as well as from the inhabitants of Darjeeling one can gather detailed information on the previous catastrophic rains which have fallen in the past 70 years. At least two other cases of similar intensity of precipitation and of geomorphological processes occurred during this period. This shows that the catastrophe of 1968 was not exceptional.

In 1899 a downpour was recorded during which the rainfall amounted to 497 mm in 24 hours (Darjeeling), Dutta [15] reports numerous landslides of the Schutt – sturz type, which had formed in the region of Darjeeling and were mentioned in several works (by Criesbach in 1900, Hayden in 1912, and others).

In 1934 many landslides occurred during an earthquake [29], being particularly numerous and extensive in the region of Kalimpong [14].

In 1950 there was a catastrophic rainfall during which many landslides occurred, examined and described in detail by geologists. The rain fall from the 10th to the 14th of June, at the beginning of the summer monsoon (Fig. 25). Darjeeling noted about 1000 mm. The heaviest rainfall, amounting to about 450 mm, occurred here on the 12th of June. Kurseong noted in the course of 36 hours between the 9th

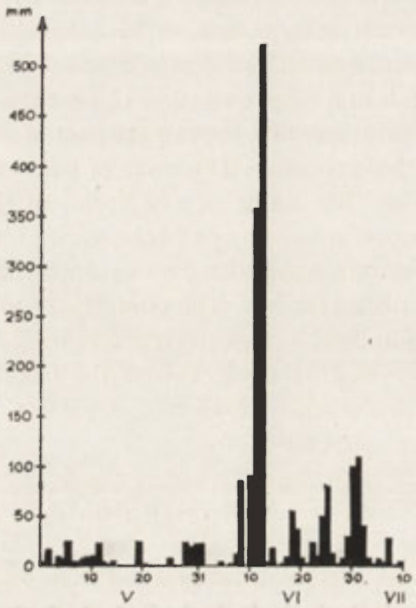

Fig. 25. Daily rainfall records before and after catastrophic rain on 10–14 Juni 1950 in Darjeeling (Planters Club Station)

and 10th of June up to 960 mm. Thus, the precipitation was distributed unevenly both in space, since the fall was from 278 to about 1500 mm (Fig. 12), and in time, the maximum rainfall occurring on different days. The rise of waters in the rivers was considerable if, according to Krishnan [29], the Tista carried on the foreland of mountains about 18,700 m^3/sec.

A large number of new landslides were formed in the region of Darjeeling itself, where the rain greatly exceeded the maximum for 1968 and the town, moreover, had a poor sewage system. Whole slopes with houses built on them descended at that time (Plate 20). In the geological-engineering works of Ray – Sarma [42], Dutta [15], Nautival [36] and others one can find many details about the slides formed then, which for the most part occurred on slopes with an inclination of 30–35°. Ray – Sarma distinguished 3 types of slides: debris–slides, rock-slides, and slow soil creep. Dutta dealt with the causes of the formation of earth-rock flows, laying stress on the role of "seepage pressure of percolating water." The classification of these forms was very correct. Large flows, according to Dutta, occurred in tea gardens, where flow-tracks up to 30 m wide were formed. A big slide formed at Sonada [36], becoming active again in 1968. The Working Plan of the Darjeeling Forest Division [37] contains sketches of forest districts, on which slides formed in 1950 are marked (Fig. 19). They must have been very large and numerous since the foresters recorded them. Worthy of note is the concentration of these slides near roads, which was also observed by the author in the same regions in 1968. In 1950 near Manai Bhawan in the source section of the Little Rangit they were more numerous and larger than in 1968. Observations from forest terrains and tea gardens in Bannockburn and Darjeeling, where the author had at his disposal photographs taken in 1950 (Plate 20 and 21), permit the general conclusion that earth and debris flows which occurred in 1950, of a similar outline to those appearing on photographs taken in 1968, soon became overgrown by vegetation and were not rejuvenated in 1968. New landslips formed in the neighbourhood but not in the same places. Hence, to the formation of a flow the rock had to be weathered to an appropriate depth, 18 years being a period too short for this to occur. The slopes remodelled in 1950 did not therefore overstep again the limiting angle of repose.

In 1952, towards the end of the monsoon period, downpours occurred but of smaller intensity. The heaviest rainfall was noted by Kuresong (on the 22nd September), amounting to 626,4 mm. Hazra [22] reported that near Lebong a large landslide had formed at that time (25th September 1952).

THE ROLE OF CATASTROPHIC PRECIPITATION AND OF THE ANNUAL MONSOON RAINFALL IN THE EVOLUTION OF THE RELIEF OF THE DARJEELING HILLS

The steep slopes of the Darjeeling Hills, intensive weathering and no less readily overstepping the limits of stability, as well as the valleys with considerable and unevened gradients are particularly sensitive to precipitation of a catastrophic type. As can be seen from the review of the last 70 years, changes of an order similar to those which occurred in 1968 took place twice (in 1899 and 1950), while others had a rather local range. Dutt [14] described from the region of Kalimpong the consequences of downpours of small range which had occurred in other years. Thus, it can be assumed that similar changes take place on the average once in 20–25 years, i.e. a removal of material of the order of 100,000 m^3 from 1 km^2 of the surface of slopes. In this case their mean degradation can amount to 1 m in the course of 200 years. Deforestation played an important part in the extent of degradation. Under natural (forest) conditions having at least a 10–20 times smaller denudation the surface of slopes will be lowered by 1 m only after a lapse of at least 2000 years. In valley bottoms incision and lateral erosion lead to the removal of masses of the order of several hundred thousand m^3 per 1 km of the course of a river, which, when converted to 1 km^2 of the catchment basin, gives another 100 thousand m^3. The removal prevails over the delivery from slopes, this being a characteristic trait of young landscapes. However, these calculations are complicated by the sectional accumulation in the valley bottoms, related, among others, with deforestation.

When discussing the processes occurring on slopes and in valley bottoms, the author laid stress on the trends of evolution of these forms. Linear erosion on slopes co-operates with gravitational processes. The result of the action of the latter are gullies on slopes, exploited by precipitation, which with time transforms some of them into small erosional valleys rarely exceeding a depth of 20–50 m. These gullies of a considerable slope direct the removal of the material gravitationally

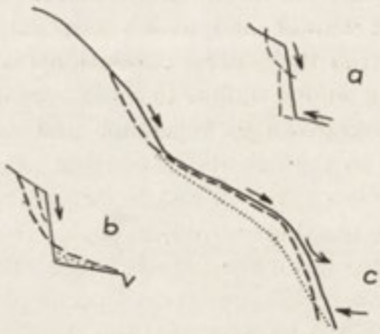

Fig. 26. General tendencies of slope evolution in Darjeeling Hills

a – Simple slope developing by lateral erosion and mass movement, b – Simple slope retreating by mass movement with agradation at the base (usually on the terrace plain), c – Step-like slope, typical for many valleys. Retreat of free-face with help of erosion more intensive than degradation of gentle segments by mudflows

displaced, outdistancing in this sense and facilitating the frontal back-wearing of slopes (Plate 8). The author speaks of back-wearing, since edges of old valley forms and those near channels undercut by flood waters are degraded the soonest (Fig. 26)[3]. Accumulation at the base of slopes is exceptional. The modelling of flat sections of slopes between the that occasionally cut into them valleys (e.g. every kilometre) occurs by the advancing destruction of the deeper weathered longitudinal zones of the slope. As a result, the whole slope is degraded (Fig. 21). The deepening of main valleys taking place by stages and the differences in the resistance of rocks, favour the occurrence of steps on slopes and their sometimes independent back-wearing (steep sections are more intensively degraded than the gentler ones dividing them). On the other hand, the sudden flows and slides descending from the watershed up to the valley bottoms tend to destroy the steplike profile of slopes, leading to the formation of slopes of similar inclination (plate 10, 11).

The valley bottoms also show traits of youth, i.e. a lack of stability. In the valley heads deepening continues, in which large debris-flows co-operate (Fig. 27). In larger valleys one observes a tendency (increased by deforestation) towards the widening of valley bottoms and evening of gradient by undercutting the sides and filling the valley bottoms. The mature box-shaped transversal profiles of valleys are slowly shaped (Fig. 27).

Against the background of changes directed by catastrophic precipitation the problem arises of the role of the annual monsoon rainfall, which also often amounts to 100–200 mm in 24 hours. In a normal year during the summer monsoon there may occur flows and slides but of a limited range. Newly formed concave forms develop if a sufficient amount of spring water is secured for them. The slide forms become stabilized, the lower ones of slips and above all the walls of erosional undercuts attain equilibrium (usually 30–40°). The rapidly penetrating vegetation favours infiltration and the reconstruction of the soil profile through chemical weathering. The washed out fine suspended load and gravels carried by streams form at the

[3] This corresponds to the back-wearing of slopes through the formation of gullies, to which Savigear [44] drew attention.

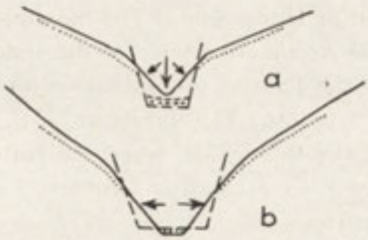

Fig. 27. Transformation of valleys during catastrophie rainfall in Darjeeling Hills

a – Deeping and extension of valley floor in upper segments of longitudinal profile, b – Extension of valley floors by lateral erosion and steeping of slopes in lower segments of longitudinale profile

outlets of side valleys alluvial fans, which are dissected and carried off in the years of catastrophic rains (Plate 11). During the insignificant annual high stages the streams are not capable of moving the large boulders, which as a pavement wrap up the channels. These boulders are covered with fine material. Alluvial plains are evened and agraded and it is only from their structure that one can deduce that the beginning of their formation was related to the deposition in the channel of bars of large boulders or tongues of earth-debris flows (Plate 15). The next catastrophic flood widens again or deepens the valley. The annual high stages also carry away beyond the range of mountains considerable amounts of suspended load. Transposing the results of measurements from the neighbouring terrains (Desai [13] and others) it appears that, about 600–700 m^3/km^2 are moved away every year, which equals a mean degradation by about 0.6–0.7 mm/year. This corresponds to the values reported by Menard [34], who estimates the denudation of the Himalaya Mts at 0.9 mm/year. These are therefore figures of a different order (than those of denudation after catastrophic precipitation), giving for a hundred years values equal to the destruction in the course of a single catastrophic downpour occurring 4–5 times in century. Unfortunately, there is a large gap in these estimates on account of the lack of observations of the cubic content of the bed and dissolved load carried avay by the Tista or by the other neighbouring big rivers.

FINAL REMARKS

The morphological consequences of the catastrophic rainfall which occurred in the region of Darjeeling in 1968 are not an exceptional phenomenon as far as this concerns the denudation of mountains on a world scale. From the terrain of the Himalayas themselves other downpours and high waters are known, the most dangerous of which are related to the support of rivers by big landslides, followed by a sudden breaking of barrages, as e.g. was the case in the Indus valley in 1841 and in the Birch Ganga valley in 1934 [29, 39]. The last mentioned during the overflow of the lake had a discharge of about 17,500 m^3/sec and a considerable velocity of water amounting to 9–13.5 m/sec. Catastrophic high waters are known from the mountains of Central Asia [47]. Similar downpours of the order of 700 mm in 24 hours were reported by Berry and Ruxton [6] and Chak – Lam – So [8] from the region of Hong Kong. The maximum high waters in the mountains of Europe and of the Arctic are related to the sudden melting of snow during a heavy rainfall [55], and the Iceland jökulhlaups with the melting of glaciers under the effect of volcanic eruptions (Thorarinsson [54]. Malde [33] describes a Late-glacial overflow of Lake Bonneville, when the cutting of a large gorge of the river Snake was caused by a wave carrying boulders 3–4 m in diameter, and flowing at a velocity of 6–9 m/sec.

The region of the Darjeeling Hills is one of the most heavily degraded on a world scale. However, the order of magnitude of destruction here is analogous to that in the other parts of the Himalayas, and in other tropical, humid areas with a distinct monsoon period. In the Sub-Himalaya zone towards the west, in spite of the smaller amount of rainfall, denudation on the folded, less resistant Siwalik series is very intense. The same applies to the Assam Upland (Khasi – Jaintia Hills). In a humid climate where thick weathering covers occur, flows play a most important role. This was stresses by Berry and Ruxton [6], as well as by Wenworth [59], who wrote about soil avalanches on steep volcanic cones in the Hawaiian Islands. This author established that the slopes are lowered by about 0.8 mm annually on the average. He estimated the denudation in New Guinea at 1.2–1.6 mm/year. Similar values were reported by Verstappen [58] from Java – 0.5–2.0 mm/year. In the region of Darjeeling including the morphological yield of catastrophic precipitation (4–5 x in a hundred years) at the present state of deforestation, the mean degradation can be estimated at 5 mm/year. The role played by vegetation is most important. Investigations carried out at the station of Sholapur near Bombay [48] showed that it takes 15 years to wash down 20 cm of soil on cultivated land whilst on terrains overgrown with natural forest vegetation it takes over 400 years (degradation comparatively 13 mm and 0.5 mm/year).

Of the other regions of the world similar conditions (as concerns the type of the relief and abundant rainfall) prevail in the lower belts of the part of the Caucasus lying on the Black Sea, where the annual precipitation amounts to 3000 mm (Siels in the SSSR [47]).

An intensive degradation is known from the mountains of Central and West Asia, where in a semi-arid climate the vegetation is poor, while the intensity of downpours amounts to 9.5 mm/min (Transcaucasia – [47]). In Armenia and in Azerbaijan the flow sometimes amounts to 7–8 $m^3/sec/km^2$, and the magnitude of denudation in the eastern part of the Great Caucasus to 0.4–0.5 mm/year on the average, reaching in some catchment basins 1.6 mm/year [1, 47]. During a single downpour masses of the order of 20 thousand m^3/km^2 are sometimes carried away by a siel stream, which corresponds to a mean lowering of the catchment basin by 20 mm. The difference, compared with the region of Darjeeling is that while in the semi-arid areas heavy rainfall is the only morphogenetic agent bringing about a considerable annual intensity of processes (excepting the role of earthquakes), in the humid monsoon climate of the eastern Himalaya catastrophic precipitation constitutes an essential, though not very frequent occurence accompaning the yearly progressing denudation of less intensity and the constant intensive chemical weathering.

The comparison with mountains of the temperate zone (Alps, Carpathians, partly the Caucasus) encounters difficulties. Not only is the extent of denudation smaller here (French Alps after Corbel [10] – 0.3–0.4 mm/year, basin of the Upper Rhine after Jackli [24] – 0.58 mm/year, basin of Salzach after Pippan [38] – 0.44 mm/year, Polish Flysch Carpathians after Starkel [50] and others – 0.05–0.15 mm/year). The winter season and the snow-melt period also play an important part, especially above the timber line. The material subject to movements was prepared by processes in the Pleistocene periglacial climate. These processes can therefore be compared with the conditions in the upper altitudinal belts of the Himalayas [28]. In mountains of the temperate zone there occur catastrophic processes, such as the violent rainfall in June 1957 in the French Alps described by Tricart et al. [55], a similar one in the Italian Alps in November 1968, and the catastrophic flood in Roumania in 1969. Here also, in the temperate zone, catastrophic phenomena are events setting the tendency of the evolution of the relief [30]. The transportation in lower mountains with more mature slopes results in that the material from slopes is deposited for the most part at the base of slopes, while rivers draw a new material mostly from undercuts and channels. Hence Tricart's [55] thesis on the short-section transportation and independence of the development of slopes and valley bottoms. A contrary situation is to be observed in the Himalayas: a close correlation, which among others, is an evidence of the youth of these mountains.

In the higher belts of mountains above the timber line and in the mountains of the arctic regions we observe the phenomenon of slow short-section displacement on slopes and washing of weathering and gravitational covers by the flowing water. Here also the processes are concentrated in part of the year [40, 49]. However, they are not synchronized in time as is the case during a long-lasting downpour in the tropical climate. In the course of the polar summer a distinct sequence of processes takes place [40,11]. That is why we observe, among others, in valleys an intertonguing of fluvial and solifluctional covers. Meanwhile, during the catastrophic rainfall in Darjeeling there occurred in the course of several hours violent changes of all forms: slides and dissections on slopes were formed, rivers eroded to the interior and laterally, carried away large quantities of material, above all that removed from the slopes. This type of modelling, of a synchronized degradation of slopes and clearing of material from mountains was rendered possible (apart from the intensity of the rainfall) by the steep gradient of slopes and river beds, and the less resistant weathering covers.

The mechanism of the development of the Darjeeling Hills described above and the high rate of changes occurring during catastrophic downpours is, in the author's opinion, characteristic of an area of young, intensively uplifted mountains in a humid monsoon climate, where weathering and processes of denudation accelerated by deforestation, as well as transportation by rivers, are of considerable intensity. Catastrophic processes producing contrasts and disturbing the equilibrium of forms are the motive power of transformations of the relief. In the light of the rate of present-day transformations it seems entirely justifiable to date the fragments of levels and of old valley bottoms of a relative height of 300 and 600 m as younger than the phase of Lower Quaternary foldings and overthrusts in the marginal part of the Himalayas.

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Plate 1. Kamchenjunga massiv. View from Darjeeling
(photo Das Studio, Darjeeling)

Plate 2. The group of mudflows at the southern slope in Ringtong
(photo taken 23 Dec. 1968)

Plate 3. Fragment of the winding mudflow tongue at Ringtong
(photo taken 23 Dec. 1968)

Plate 4. Middle part of 800 meters long mudflow at Bannockburn T. E. In the upper right corner two slope slumps in the jungle
(photo taken 30 Dec. 1968)

Plate 5. Colluvial – aluvial cones overlaying the terrace of Rangnu river. In the black circle 3 persons (as a scale). In the ground dead mudflow tonque formed in June 1950 (photo taken 30 Dec. 1968)

Plate 6. Simultaneity of earth flow and formation of erosional furrow. Ringtong T.E. (photo taken 23 Dec. 1968)

Plate 7. Mudflow created on artifical undercutting near garden road at Poobong T.E.
(photo taken 24 Dec. 1968)

Plate 8. Gullies transformed by mudflows in the valley head of Posam creek. Pussimbing T.E.
(photo taken 24 Dec. 1968)

Plate 9. Great landslide an the forested slope near Poobong (photo taken 24 Dec. 1968)

Plate 10. New landslide in the Poobong tea garden. Upper rocky segment and beginning of the earth flow (photo taken 24 Dec. 1968)

Plate 11. Fragment of Little Rangit valley to the north of Chongtong. Deforested slopes full of mudflows. Valley bottom covered with debris

(photo taken 2 Jan. 1969)

Plate 12. Gentle slopes dissected by inactive gullies. No mudflows
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(photo taken 24 Dec. 1968)

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(photo taken 24 Dec. 1968)

Plate 16. Size of blocks transported by Posam creek at 4 Oct. 1968 Breaking off of some boulders indicate to the turbulent flow in the channel

(photo taken 24 Dec. 1968)

Plate 17. New channel of Posam creek incised in the bed rocks. On the top of residual rock 7 m high remained big rounded boulder. Poobong T. E.

(photo taken 24 Dec. 1968)

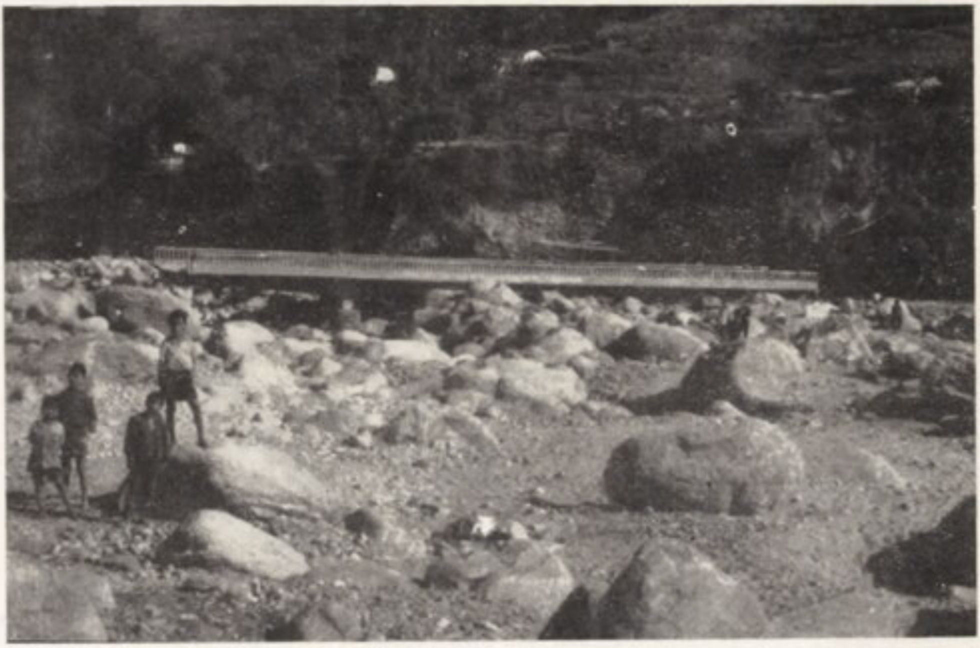

Plate 18. New bridge in Pul Bazar 40 feet high. After flood it looks like a island ranging a little above boulder plain

(photo taken 2 Jan. 1969)

Plate 19. Tista valley upstream the joininng with Great Rangit. The limit of flood water underlined by lateral undercuttings

(photo taken 27 Dec. 1968)

Plate 20. Big landslides in the the centre of Darjeeling after heavy rain in June 1950 (photo Das Studio, Darjeeling)

Plate 21. Complex debris flow crossing the road Ghoom – Darjeeling. Result of heavy rain in June 1950
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Plate 22. Section of the 8–10 meter high terrace of Pachim creek. Sediments connected with catastrophic flood are overlying by finer ones deposited during normal monsoon floods. Ringtong T.E.

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