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PIPING AND PSEUDOKARST FEATURES IN THE TROPICAL LOWLANDS OF NEW GUINEA

With 3 figures and 3 photographs

Ernst Löffler

Zusammenfassung: Röhrenerosion und Pseudokarsterscheinungen im tropischen Tiefland von Neuguinea

Röhrenerosion ist ein bisher wenig beachteter Erosionsvorgang, bei dem unterirdische, röhrenförmige Entwässerungskanäle in unlöslichem Gestein entstehen. Eng verbunden damit sind karstartige Erscheinungen wie dolinenartige Vertiefungen und kurze „Trockentäler". Geländebeobachtungen im tropischen Tiefland von Neuguinea zeigten, daß Röhrenerosion und damit verbundene Pseudokarsterscheinungen nicht nur vorkommen, sondern unter bestimmten topographischen Voraussetzungen relativ häufig sind. Das Vorkommen von Röhrenerosion in diesem feuchttropischen Gebiet ist ein weiterer Hinweis, daß dieser unterirdische Erosionsprozeß nicht wie früher angenommen auf aride und semiaride Gebiete beschränkt und an das Vorhandensein von quellbaren Tonmineralien gebunden ist, sondern daß er unter sehr verschiedenen klimatischen Bedingungen stattfinden kann. Die wichtigsten Voraussetzungen für die Röhrenerosion sind starkes hydraulisches Druckgefälle über kurze Entfernungen, das Vorhandensein von unverfestigten oder wenig verfestigten feinkörnigen Sedimenten, sowie Permeabilität des Untergrundes. Als geomorphologischer Prozeß ist die Röhrenerosion eng mit der Gullyerosion verbunden, indem sie in starkem Maße an der rückschreitenden Ausweitung der Gullies beteiligt ist, sowie in vielen Fällen die Gullyerosion einleitet.

Studies of landforming processes by geomorphologists tend to focus on superficial processes such as slope wash, soil creep, landsliding and slumping as they are generally readily observable and their effects obvious. With few exceptions relatively little attention has been paid to subsurface erosion such as piping or tunneling except of course in karst areas and the lack of information is expressed in the fact that modern handbooks on geomorphology do not or only briefly mention subsurface erosion. Civil engineers and other scientists concerned with soil mechanics however, have for some time realised the significance of subsurface erosion as it has important repercussions on the stability of dams, dikes and other earthworks (Terzaghi & Peck 1948). Piping as known to the engineers is a process by which water from a reservoir percolates through the foundation of the dam and starts a process of erosion at its downstream side which leads to the formation of a tunnel shaped passage or pipe through the dam undermining its structure and eventually causing its collapse (Terzaghi & Peck 1948).

A very similar process of subsurface erosion can however under certain conditions also occur in natural landscapes. Piping as a natural feature has been defined as a process which produces tubular subsurface drainage in insoluble clastic rocks (Parker et al 1964). These pipes are very unstable compared to karstic conduits and collapse in a relatively short time as the pipe extends. Closely associated with the development of pipes is the formation of karst-like features such as blind valleys and sinkholes collectively termed Pseudokarst (Parker et al 1964). In contrast to true karst where the removal of material is by solution ion by ion, pipes are formed by the removal of solid clastic rock particles in suspension (Parker et al 1964).

The first comprehensive study of this problem from the geomorphological point of view was by Parker (1963) who used the term piping in preference to other loosely used terms such as tunneling, subcutaneous erosion, pothole gullying and tunnel gully erosion.

Natural piping was thougt to be associated with arid and semi-arid environments particularly where the vegetation is sparse and where the original vegetation cover has been denuded and destroyed by overgrazing, burning, cutting or other destructive means (Parker 1963, Downes 1946, Mears 1963). Piping also seemed to be closely related to the presence of montmorillontic clay minerals the shrinking and swelling of which lead to the development of cracks and fractures making the essentially non permeable material temporarily permeable and allowing removal of the highly dispersed clays at depth. When wet enough the swelling clay minerals cause the cracks to close at the surface but at depth pipes have already developed too large to be closed (PARKER et al 1963).

Recently however, it became apparent that these restrictions do not necessarily apply as widespread piping was observed in moorland and marshes of the United Kingdom (JONES 1971) and in weathered quartz diorite in a tropical environment in Colombia (FEININGER 1969). In addition piping has been reported from other temperate humid areas such as Austria (ZEITLINGER 1959) and New Zealand (BLONG 1965) and from periglacial environments in the United States (SMITH 1968). The present author observed widespread piping and associated pseudokarst features in the humid tropical lowlands of southern Papua New Guinea. None of the environmental factors listed by PARKER (1963) are involved here and montmorillonitic clays are not present. The occurrence of pipes has also been briefly mentioned by RUXTON (1969) and BLAKE (1971) in a similar environment in Papua New Guinea. These observations clearly indicate that natural piping is not restricted to any particular climate or particular clay minerals but seem to be primarily a process due to certain hydraulic conditions.

This paper is based on field observations made during a land resources survey with the Division of Land Research, CSIRO in May 1972. As the survey was strictly on a reconnaisance level, little quantitative data could be collected. However, in view of the geomorphic significance of piping and the general lack of information on it, it is hoped that this more qualitative approach will add to the understanding of this little known process.

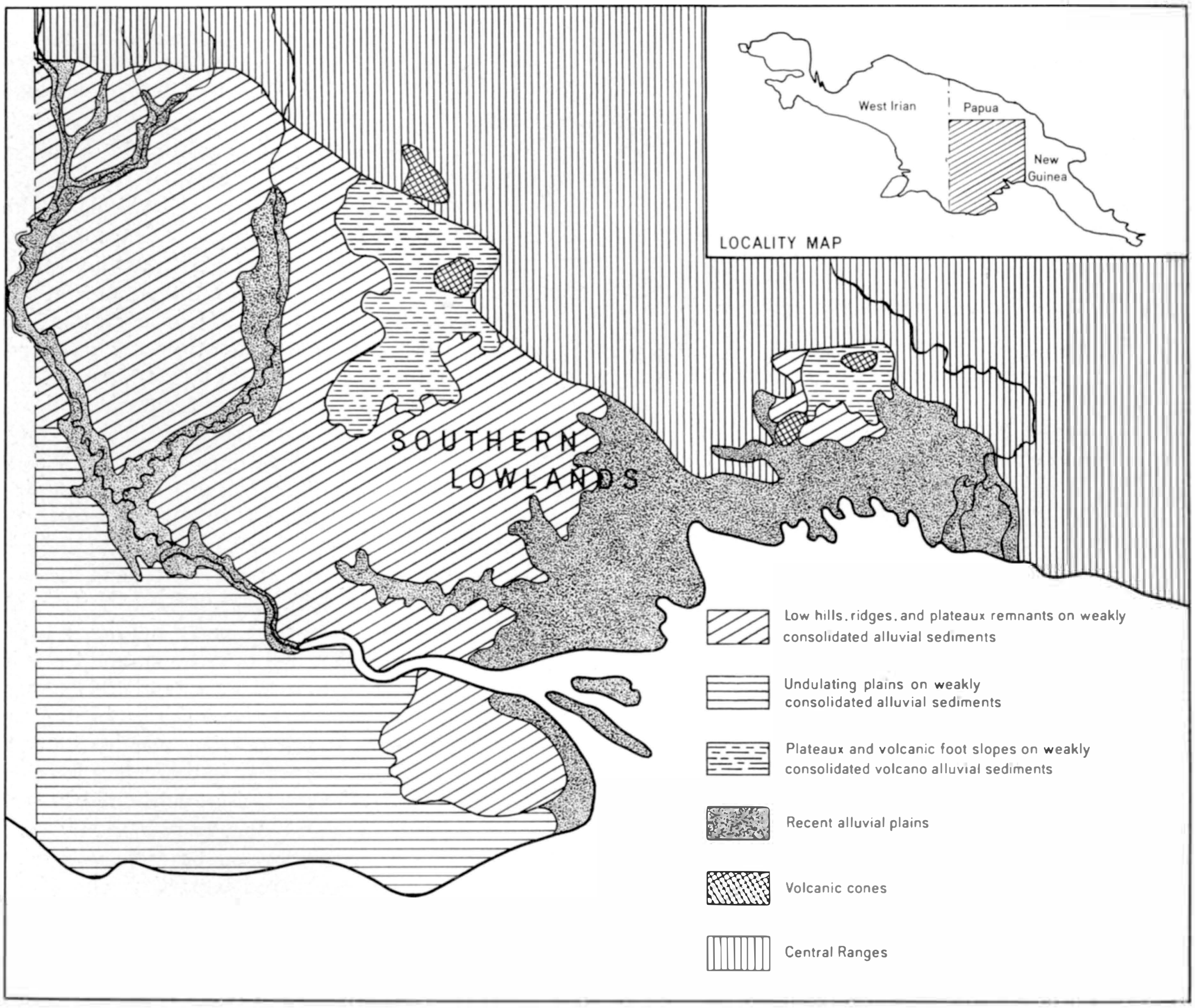

Fig. 1: Locality map

General Setting and Environmental Characteristics

The area in which piping has been observed is part of the southern lowlands of New Guinea, a large area of low relief (10–30 m) to the south of the central ranges predominantly formed on poorly consolidated alluvial and volcano alluvial sediments (Fig. 1). The area formerly a continuous depositional plain is now in various stages of dissection. The dominant landforms are low, closely spaced hills and ridges to the northeast of the Fly River and gently undulating plains to the southwest. Large areas of plateau and plateau remnants (Photo 1) are also prominent, particularly in the northeastern part of the area where extensive volcano alluvial fans are developed. It is here that piping and pseudokarst features are most common, although they have been observed throughout the hilly part of the lowlands. There is a significant change of climate in the southern lowlands from a strongly seasonal tropical savanna type at the coast with a rainfall of some 2–2.5 m to a wet tropical type further inland with a rainfall of some 5 m and more distributed fairly evenly throughout the year. Piping occurs in both climatic environments although it is more prominent to the north where topographic conditions are more favourable. Temperatures are uniform throughout the year with an average of 27 °C. The vegetation is savanna and monsoon forest in the southwest and closed rain forest averaging 35 m in height in the northeast and is largely undisturbed due to the fact that the area has a very low population density (l person per 5 km²) and that large areas are completely uninhabited.

Occurrence and Form of Pipes and Pseudokarst Features

Piping most typically occurs at or near the edges of plateaux (Photo 1), plateaux remnants and terraces

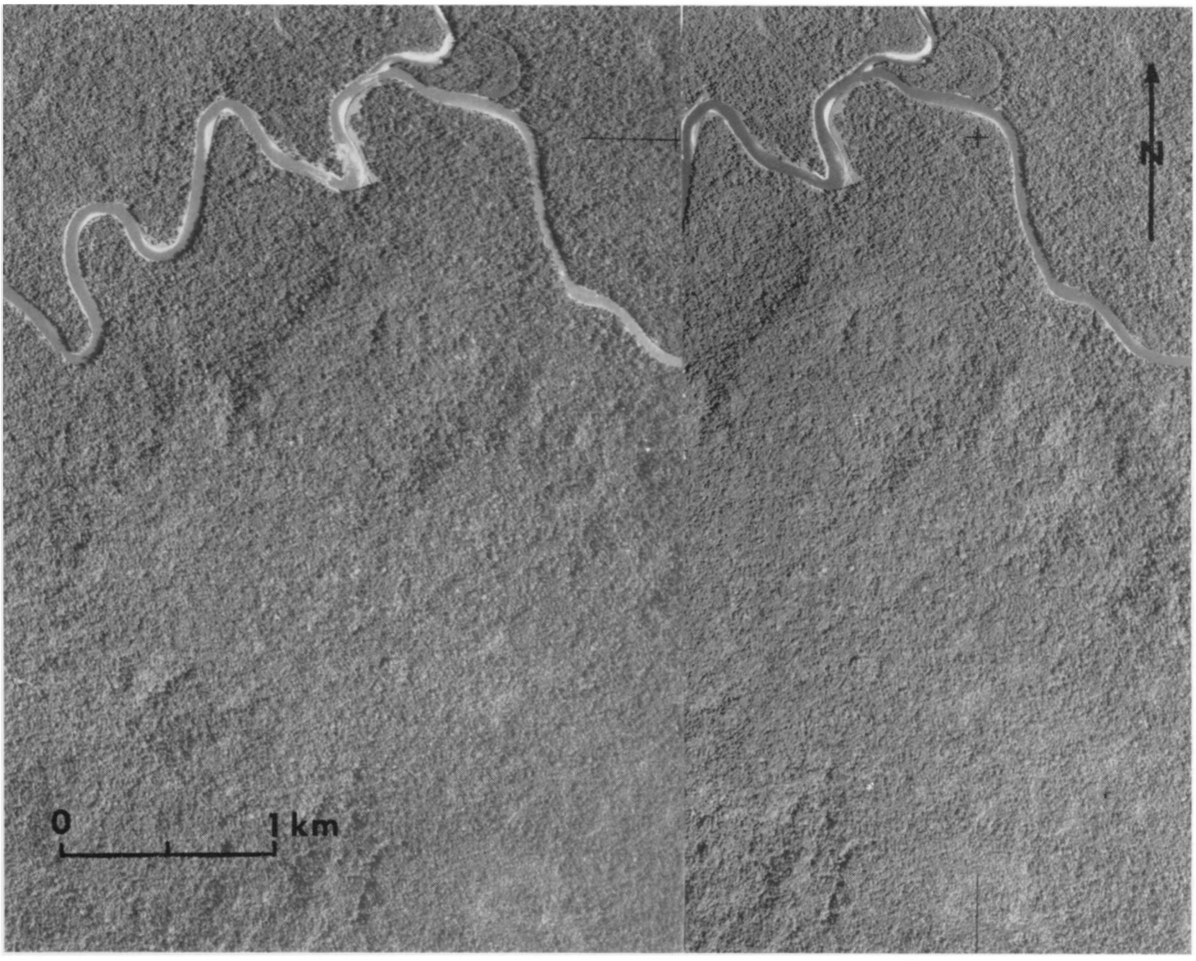

Photo 1: Stereo pair showing part of the volcano alluvial fan of Mt. Duau and illustrating the topographic situation in which piping and associated pseudokarst features frequently occur. They are most common along the irregular front of the fan and are important factors in the headward extension of the gullies. The features are too small to show up through the dense forest canopy.

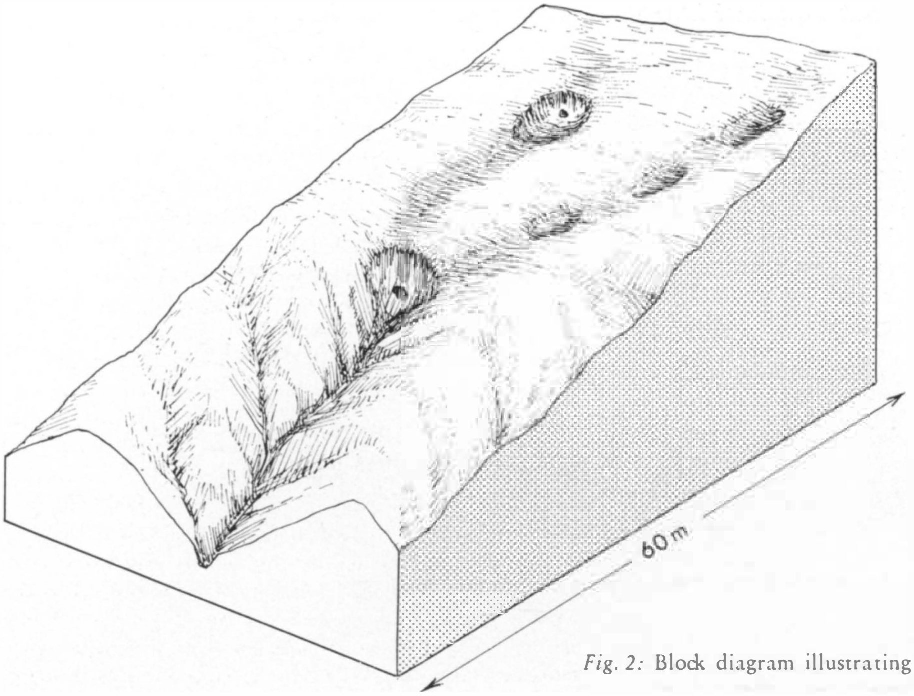

Fig. 2: Block diagram illustrating features of piping on slopes

but also on gentle and moderately steep (up to 25°) slopes (Fig. 2). Local relief must be at least 5 m but is generally 10–30 m. The discharge ends of the pipes are situated regularly at the headwalls or sidewalls of gullies which indicates the close relationship between gullying and piping. These pipe outlets do not enter the gullies at any particular level, mostly it is near the gully floor but it can also be halfway between gully floor and general surface. In no instance was it observed that the pipe outlet was associated with any particular sediment layer.

A shallow surface depression, saucer shaped in cross section generally leads upslope from the pipe end to one or a series of sinkholes which are interconnected by pipes thus resembling a dry valley of a karst area (Fig. 2). Sinkholes on flat topped plateau areas can also be randomly distributed without any obvious connecting surface depressions. The diameters of the pipes observed vary from a few cm to about 30 cm (Photo 2) and their maximum length is in the order of 10–15 m. The sinkholes on the plateau areas are large and deep (5–10 m diameter, 4–6 m depth) mostly funnel shape, somewhat asymmetric in cross section with the steeper face near the outlet pipe (Photo 3). The sinkholes on the slopes are more elongated in the general slope direction and are less deep (1–1.5 m). The lower and upper ends of the holes are generally oversteepened and still partly covered by an overhanging dense rootmat clearly an indication of the active extension, upslope and downslope, of the holes.

The principal geomorphic effect of piping is the initiation, backward cutting and undercutting of gullies. It is thus accelerating the general headward retreat

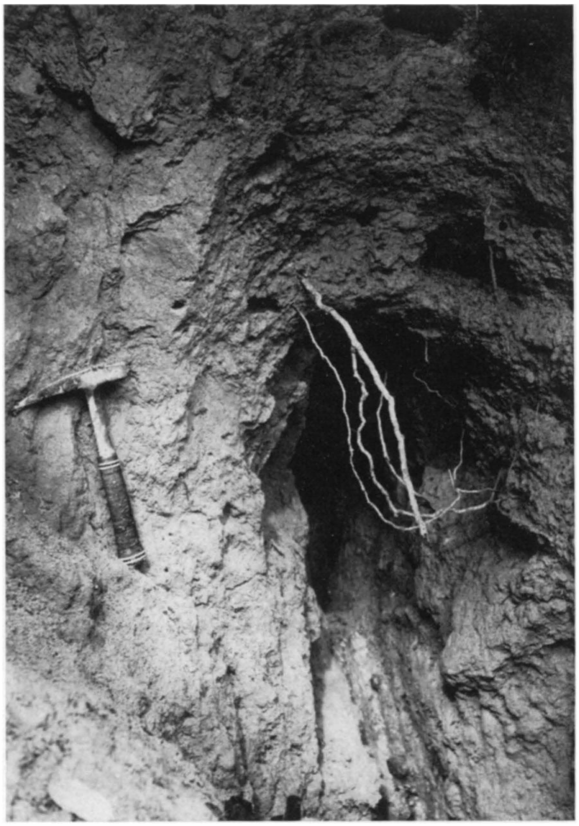

Photo 2: Discharge end of a large pipe leading into a sinkhole. Several smaller pipes are also developed but are not very active as most of the flow is concentrated in the major pipe.

Photo 3: Deep sinkhole near the edge of flat topped plateau area of volcano alluvial fan of Mt. Duau shown on Photo 1. The hole is 8 m in diameter and 5 m deep and is drained by large pipe which can be seen at the bottom of the hole.

of the gullies and the linear slope incision. Piping seems to be of particular importance as a process dissecting plateaux. Sinkholes are often forerunners of gully heads and eventually take over the function of the active gully head as the gully recedes headward by collapse of the pipe or simple headward erosion.

Physical Properties of Soils and Sediments in which Piping Occurs

The sediments in which piping has been observed are all young, weakly consolidated alluvial or volcano alluvial deposits predominantly of fine grain. Clay and silt are the most commonly occurring grain sizes (four samples analyzed showed an average of 60% clay and 40% silt) and occasionally some gravel is interbedded. Clay mineral analysis by x-ray diffraction of four soils in which piping was observed showed that the dominant clay minerals were halloysite or disordered kaolin[1]). The samples also contained a small amount of gibbsite and of very poorly crystalline goethite and hematite. As to be expected in this humid tropical environment there were none of the swelling montmorillonitic clay minerals present.

The permeability of soils could not be measured quantitatively however, according to qualitative field estimates they were slow (0.25–1 cm/h) to moderate (1–6 cm/h) (P. BLEEKER personal communication) but this is based purely on criteria of soil texture and structure and does not take into account the presence of pipes.

[1]) It could not be established wheather the dominant clay minerals were halloysite or kaolin, however both are very similar belonging to the kaolin group of clay minerals and the distinction is unimportant for the question of piping.

Hydraulics of Piping

The topographic position of the observed pipes suggests that the principal conditions for their development is, as for pipes in other climatic environments and on artificial earthworks, the existence of a steep hydraulic gradient and an outlet in the form of a gully head or an escarpment where the water can readily escape and discharge its suspended load of dispersed soil particles. As time goes on small holes will develop, which will then concentrate more and more of the groundwater flow as they extend backwards from the free face. At a favourable position a major pipe will eventually develop and grow at the expense of the others. As the pipe increases in length its erosive capacity will also increase due to the greatly increased area of intake and eventually subsidence will occur at some distance from the discharge end of the pipe. The reason for this is shown in Figure 3 which illustrates the theoretical situation in terms of contour lines of the water table (equipotential lines) and flow lines of the infiltrating water (perpendicular to contour lines of water table) (TERZAGHI & PECK 1948); (a) shows the situation where only a small hole is developed and the flow lines only bend slightly, towards the pipe. The intake area is still very small. With increasing length the situation changes drastically. A great num-

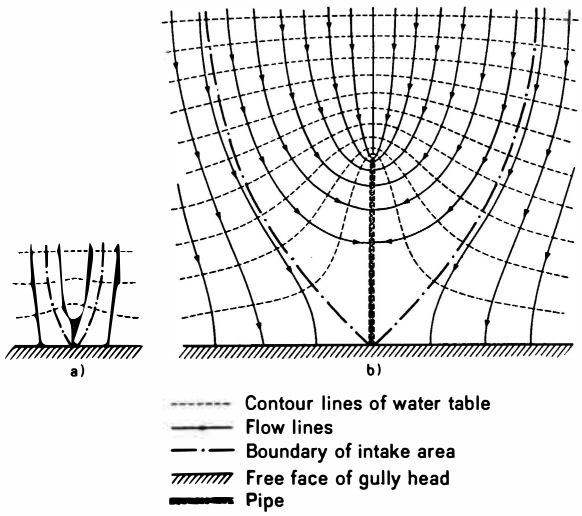

Fig. 3: Theoretical flow nets as they develop with increasing length of pipe. (a) A small and short hole is developed and only a few flow lines are diverted thus contributing to the pipe. (b) With increasing length the number of diverted flow lines increases greatly as does the area of intake. Consequently the discharge becomes much greater and the erosive capacity increases dramatically (after TERZAGHI & PECK 1948).

ber of flow lines are being diverted and of course a much greater area of intake contributes to the pipe. Subsidence and eventual collapse of the pipe will follow.

The infiltration of water into the ground is clearly not aided as in arid and semi-arid areas by the development of fractures due to shrinking and swelling of montmorillonitic clay minerals but seems to be mainly a function of the permeability of the soils and sediments. Although this appears to only be slow to moderate the very substantial amount of rainfall and the relatively slow run off on the plateau areas and gentle sloping areas, impeded by the relatively dense vegetation, seem to allow enough water to percolate through the sediments to have an erosive effect. Infiltration is probably also favoured by biotic activity. Decaying roots may be responsible for the initiation of some pipes, but they can not account for the very extensive pipe systems observed in particular as piping occurs generally below the usually very shallow root system.

Conclusion

Field observations in the southern lowlands of New Guinea during a reconnaissance survey showed that piping and associated pseudokarst are widespread erosional features in this area, though they are always of limited extent. The occurrence of piping in this humid tropical environment is a further indication that piping is not restricted to drylands and the presence of swelling clay minerals but can occur in a great variety of climatic conditions ranging from periglacial, humid temperate, semi-arid, arid to humid tropical. The principal condition for its development appears to be a steep hydraulic gradient, the presence of unconsolidated or weakly consolidated sediments of predominantly fine grain (clay and silt) that disperse readily and an appreciable permeability of the material. As a geomorphic process piping is closely associated with gullying, where it is largely responsible for the initiation and headward extension of the gullies.

Acknowledgement

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VERGLEICHENDE UNTERSUCHUNG DER EINZELHANDELSSTRUKTUREN DER STÄDTE BURSA, KIEL UND LONDON/ONTARIO

Mit 4 Abbildungen

Reinhard Stewig

Summary: Comparative Analysis of the Retail Structure of the Cities of Bursa (Turkey), Kiel (West-Germany) and London/Ontario (Canada).

The structure of retail trade in the Islamic-Oriental city of Bursa turned out to consist of a simple, two-fold gradation. While the mass of retail establishments for various needs is concentrated in the bazaar area, a great number of small retail centres for everyday needs is spread throughout the rest of the city.

In contrast to this structure the retail pattern of the West European city of Kiel showed a four-fold gradation