aus anderen Teilen der Südost-Sahara erzielten gleiche Ergebnisse und erhärten das gefundene Schema des klimatisch-morphologischen Raumgefüges.

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THE MOUND TOPOGRAPHY OF THE THIKA AND ATHI PLAINS OF KENYA: A PROBLEM OF ORIGIN

With 1 figure and 2 plates

FRANCIS F. OJANY

Zusammenfassung: Die Kleinhügeltopographie der Thika- und Athi-Ebenen von Kenya: das Problem ihres Ursprungs.

Der Aufsatz untersucht den Ursprung von kleinen, aber zahlreichen Hügeln, die auf den vulkanischen Ebenen unmittelbar im Osten und Nordosten des Flughafens Nairobi gut entwickelt sind. Frühere Erklärungen zum Problem des wahrscheinlichen Ursprungs dieser Kleinhügel (Gilgais und Reste von Termitenhügeln) haben sich nach Überprüfung als unzulänglich erwiesen.

Auf Grund der äußeren und inneren Morphologie der Kleinhügel wie auch des Befundes ähnlicher vom Verfasser untersuchter Erscheinungen in anderen vulkanischen Landschaften Nordtanzanias werden sie als umgelagerte vulkanische Schlammstromhügel erklärt. Sie erinnern an die gewaltigen vulkanischen Eruptionen und ihre Folgeerscheinungen, vom denen die Landschaft sich eben erst erholt.

Das hier behandelte Problem dient auch als Beispiel für die Notwendigkeit fortgesetzter interdisziplinärer Zusammenarbeit in der Forschung.

Introduction

The areas to the southeast, east and northeast of the City of Nairobi is dominated by four well-defined lava plains which are known locally as the Kapiti, Athi, Embakasi and Thika Plains (named from sooutheast to northeast). Elsewhere, the present author (1966) has simply termed these plains the Kapiti and Thika Plains. As might be expected, these plains are the constructional features of fissure lava eruptions which filled a region which was before that time, probably an irregular low-Lying plain with a very gentle slope to the west and northwest (see GEVAERTS 1965).

Although the details of the evolution of the areas was more complex, than can be gone into in this paper, it is fairly safe to generalise and say that the four plains mark different lava eruptions with the Kapiti Plains (consisting mainly of phonolites), which erupted some 13 million years ago, being the oldest. The Thika Plain is almost as old, except that its surface has been affected by later eruptions. The lavas whose surface now form the Athi Plains are much younger (Nairobi phonolites being only about 5 million years old) while the Embakasi plains, are even younger still. Thus the rocks get progressively younger northwestwards from the Kapiti Plains towards the Aberdare Ranges where the Limuru Trachytes are only about 1.7 million years old.

From the foregoing paragraph, it is evident that the four plains have been exposed to subaerial erosion for different durations so that each plain might be expected to have attained a different stage of erosion. This in fact is the case, and the area affords a unique environment in which to illustrate the relationship between time, process, and rate of erosion. The Kapiti Plain, having been exposed over a longer duration has now reached a stage which must be described as late youth. The Athi Plains surface is now in early youth while the Embakasi Plain is still so much unaltered by the agencies of erosion, that it must be described as still being in its initial stage.

The above plains are rimmed between the higher ground formed by the Turoka and Kikuyu Uplands to the west and northwest on the one side, and the older Machakos residual hills to the east. The plains thus form a narrow belt of topographical low which also shows as a drier corridor which receives a mean annual rainfall of between 500 mm. in the south, and 800 mm. in the north, near Thika township. The adjoining higher areas receive much higher mean totals (over 1400 mm. in the Aberdare Ranges and over 1,000 mm. in the higher parts of Machakos hills). These climatic aspects have been well-examined by Thompson and Sansom (1967).

The mound topography

On parts of the Thika and Athi Plains are developed numerous little mounds which give a peculiar and puzzling relief feature known locally as the mound topography of the Thika and Athi Plains. The features have engaged the attention of a number of pedologists and geologists and the present author has since late 1963 examined them mainly as a geomorphologist.

The mounds are best developed around the Nairobi Falls and in the Juja area from where their occurrence extends eastwards as far as Tala Market, near Kangundo in the Machakos District. To the west and northwest of the above area, the features are also found extensively preserved between Kahawa and Thika Township on either side of the Nairobi-Thika Road. Figure 1, illustrates this development.

Previous work on the Mounds

Stephen, Bellis and Muir (1956) made a special study of these mounds and regarded them as being gilgai phenomena in Tropical Black Clays. Later, Scott (1963) described the examples near Tala and Fairburn (1963), described those in the Juja Estate area. On air photographes, the mounds show as island features in the sea of plain (see Plate 1). The Plate is a reproduction of an airphotograph at the scale of 1 : 25,000 that was flown in January 1966, at an average height of about 18,000 feet above the ground level. It covers an area which is about two miles to the south of Kenyatta College (see actual position marked 1 in Figure 1). Despite the great height, at which the aircraft was flying, the mounds still show clearly and the pattern which they make can hardly be said to fit into a particular arrangement. It is nonetheless, clear from the Plate that the mounds are best developed on the crests of the ridges which are here separated by the well-developed drainage channels.

Scott described the mounds in the area which he studied as "rising from about 1 to 2 feet above the general land surface and having a diameter of about 20 yards across". He also confirmed the observations which had been made by Stephen, Bellis and Muir seven years earlier that the mounds support more palatable grasses and better crops when under cultivation. Describing those near Juja, Fairburn wrote: "They are usually about 20 to 50 yards in diameter, at 50 to 100 yards internal and develop a stronger growth of vegetation than the surrounding depressions." He also noted that their distribution is not haphazard but "occur in crude radiating pattern", and that the mounds are usually composed of cemented brecciatied material. Plate 2 helps to confirm some of these early observations. The photograph was taken by the author by the roadside opposite Kenyatta College (see position of Plate 2, in Figure 1). It clearly helps to indicate the exact relative size and the distance apart between one mound and the next as well as the gentle curve of the crest of the mounds, and the fact that they support better vegetation.

The present author therefore was not able to confirm that the distribution of these features conforms to any definite pattern. However, he concurred with the previous authors on the general size and the composition of the mounds. Many of them were found to be composed of agglomeratic lava material of mixed debris and other fragments all of different sizes intermingled with soil. The rock fragments resembled tuffs of the Aberdare suite. It was also noticeable that the sizes of these mounds are much smaller further east where they occur on flat, ill-drained parts. Around Tala Market, towards Koma Rock, instead of the mounds developing, only volcanic boul-

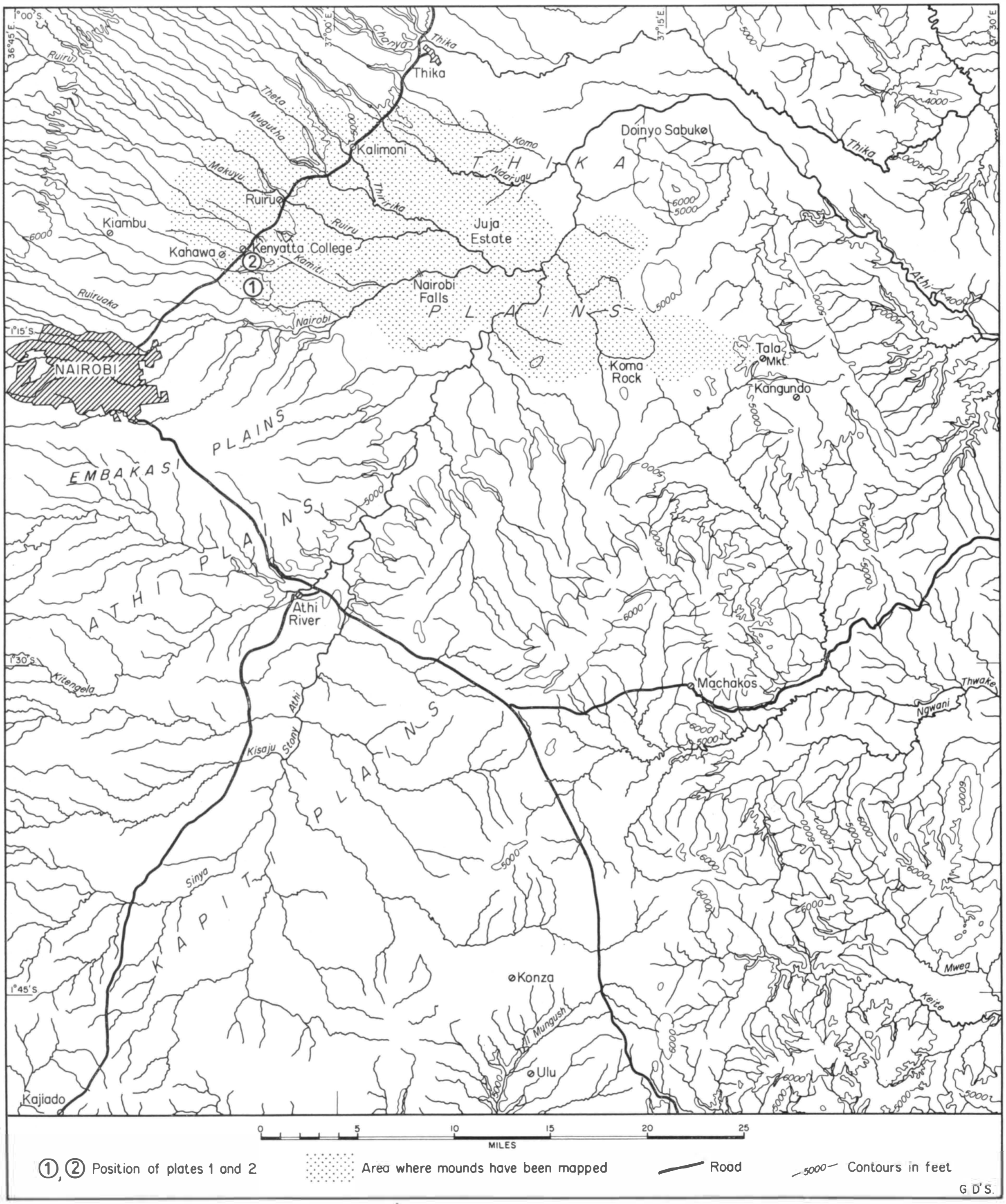

Fig. 1: Location and General Reference map

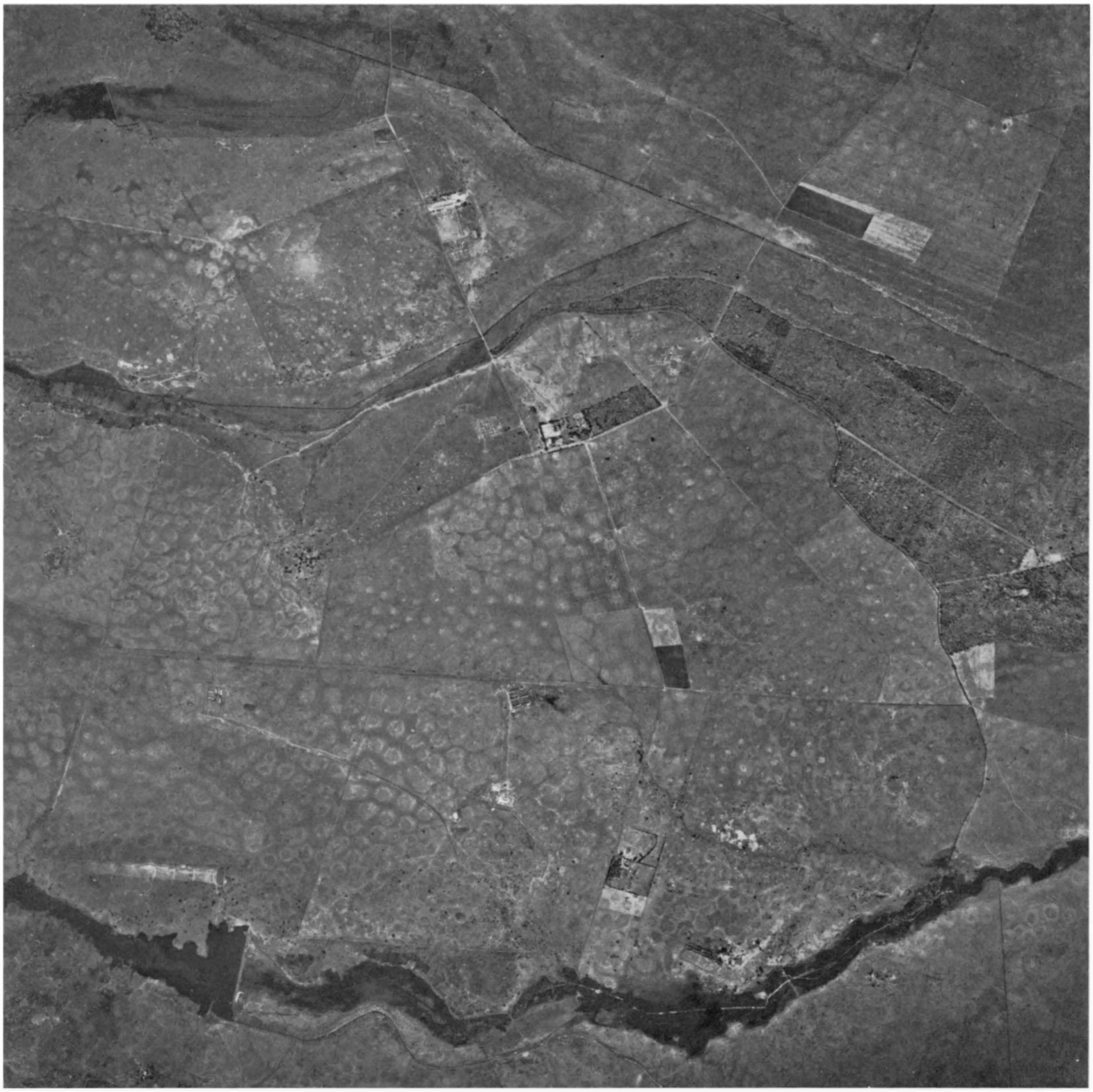

Plate 1: Air photograph showing the occurrence of the mounds

ders (some loose), are found littering the surrounding area in which much laterite has developed.

The origin of the mounds

The origin of the mounds has been the focus of considerable uncertainty and continues to puzzle many students. Thus to this end, a number of possible explanations have been advanced. The more seriously advocated interpretations are re-examined below:

(i) Gilgai-origin: STEPHEN, BELLIS and MUIR, regarded these features as due to gilgai phenomena in tropical black clay soils similar to the other gilgaies which had been reported from Australia by HALLSWORTH, ROBERTSON and GIBBONS (1955). But, SCOTT rejected the gilgai origin for the present features. He noted the fact that the present mounds are too big compared to the so-called gilgaies reported from Australia. He further pointed out that even the other gilgaies which have been reported from other parts of Africa which were also quoted by STEPHEN and his colleagues, are all much smaller features than the mounds which can be seen in the Thika and Athi River Plains area. Another fact which should be born in mind here is that according to the evidence from

Plate 2: A close up of the mounds, near Kenyatta College

Australia, the gilgaies there are known to be still forming and that even if one is graded, it will rebuild again. After more than four years of observation, the present author agreed that the Thika-Athi River mounds are certainly "fossil" features.

The term "gilgai" was first used in Australia by HALLSWORTH and others (1955), and is said to be an Aboriginal word meaning a "small water-hole". Other terms for similar features are "melon-hole", "devil-devil", and "Bay of Biscay country" (see PRESCOT 1932). From the descriptions by these early authors, one gets the impression that the features are nothing more than small-scale undulations on the surface of the land that might more appropriately, be compared in size, to pingoes that are sometimes found in periglacial and related environments. That black clay soils can expand considerably under certain conditions is not disputed here. What is questioned is the topographical effects of such limited swellings. COSTIN (1956), was probably very right when he remarked on the similarities between gilgaies and deep-frost soils. Even from the measurements of the puffs (or hummocks) and the hollows (or shelves) given by those who have examined gilgaies in other continents (see references cited), the overriding impact on scale is that they are small features. In the present area (see actual measurements reported by all who habe studied the Kenya examples), it is thought here that the expansion of the clay minerals cannot result in such huge mounds. Their diameters alone are considerably greater than those of most anthills that the present author has seen over much of East Africa, while their low height above the ground is not suggestive of growth from below but might be more simply explained if one regarded them as material falling to the ground with some impact.

(ii) Relic Termite Anthills" – origin: The possibility that these mounds are "relic termite anthills" were considered by STEPHEN and his colleagues. However, SCOTT discounted this possibility because as he explained, it is difficult, to see why termite mounds should be arranged in a definite pattern and also because no termites were found in any of those which he examined in details.

A number of further objections can be listed against the anthill origin. It is difficult to explain what could have eliminated the ants. Also, in cases which the present author examined, the internal form of these mounds showed no ant tunnels. The dominance of agglomerates and other large tuff boulders indicated that the features are "in situ" and have not undergone any significant remoulding since being formed. This latter fact is particulary well-brought out by the boulders which are scattered near Tala Market. Again, if these are anthill features their general height about the ground would be higher and not alsways the smooth curve which tends to be typical on most of these mounds. Thus the internal composition and the smooth curve of the mounds do not support the work of ants.

From the foregoing consideration, the present author favours SCOTT's conclusion that the present features are neither gilgaies nor relic termite anthills. What other features can they then be? It is probable that their origin is tied up with the volcanic episodes that have affected the region.

(iii) Volcanic mudflow mounds (lahars) – origin: The present author suggests these features are probably volcanic mudflow mounds similar to the lava mudflow which have been reported from Java by ESCHER(1925) and also from New Zealand by COTTON (1952). Similar lava mounds are not unknown in other volcanic environments in East Africa. The present author has examined the equally striking mound topography which is beautifully developed in the Sanya Plains, a little way before going into Moshi from Arusha. These Sanya mounds have since been interpreted as lahar mounds associated with the Kibo lava mudflow by Wilcockson, Downie and others (1965). Similar mound topography was also examined by the author during a Department Field Class with students from the Geography Department, University College, Nairobi in 1965 in the northeastern slopes of Mount Meru towards Ngara Nanyuki from Usa. These latter type are associated with Mount Meru mudflows. To look at, both the Sanya and Ngara Nanyuki lava mounds are very similar morphologically with the mounds which are founds in the Thika-Athi Plains of Kenya.

Suggested mode of evolution for the Thika and Athi Plain mounds

It is known that the evolution of the present volcanic landscape around Thika was characterised by sporadic mudflow episodes. This fact, it is suggested may give the clue for a rational interpretation of the origin of the Thika mounds. Some of the tuffs in the area were probably distributed during phases of scoria eruption and deposition. It is quite usual for mudflow and other debris to be distributed over wide areas far from the source of the volcanic cone during such violent phases of volcanic eruption. Cotton (1952), pointed out that this is the origin of the Java mudflow or lahars ("lahars" is a Javanese word for mudflows which is now in use as a general term in volcanology).

Cotton also pointed out that "rain falling" in the ordinary course of events, expecially tropical rain, may be quite sufficient to cause extensive sliding and re-distribution of unconsolidated ash by mudflows. Sheet wash is also known to be capable of aiding in re-distributing "cold-lahars" and help in the formation of the mound or hummocky landscape (lahar landform) in areas close to large volcanoes.

It is possible therefore that the present mounds are lava mudflow mounds similar to those described by Cotton from New Zealand, and to the "ten thousand hillocks" of Tasikimalaja in Java, described by Escher and also referred to by Cotton. This view is strengthened by the occurrence of lahar mounds in Northern Tanzania. Besides those already referred to by the present author, others have also been noted by the author in the Southern end of the floor of Ngorongoro Crater. The Ngorongoro examples have clearly been resorted by rain and sheet-wash. The Kibo and Meru lahars have been described by Downie and his colleagues (1965) in the Explanatory notes on the Geological Map of Kilimanjaro.

A view is advanced here that in the Thika and Athi Plains area, the mudflows have been re-distributed over a long period mainly by rain expecially during the slightly wetter period during the Kenya "pluvial phases" of the last one million years. The mudflows are here thought to have come from the later eruptions of the Aberdare volcano. These eruptions are known to have been accompanied by considerable avalanches of tuffs which covered much of the Nairobi area. It was not always possible to differentiate the tuffs which form the bulk of the mounds but many of these are thought by the present author to be Upper Kerichwa Valley tuffs although in the higher parts towards Kiambu town, it was not possible to say whether these were Limuru trachytes or not.

Conclusion

The morphological similarities of the mounds in the Thika area with those already identified from Northern Tanzania as being lahars mounds gives the strongest case for interpreting the Kenya examples as being lava mudflow. Also the reasons already advanced against the "gilgai" and "fossiltermite anthills" seem to be impelling. If the above suggestion is tenable, then it is reasonable to conclude also that the Thika mounds are a little older than the Arusha-Moshi examples.

Most of the previous research students who have tried to examine the origin of these features have tended to restrict their own outlooks far too much by the research techniques in their own disciplines. Thus they have in most instances, not contained or taken into account other environmental considerations which might have a bearing or even give clues to their subject matter. Thus the soil scientists have been content with detailed laboratory analysis to the complete exclusion of the fact that the area has only recovered from severe volcanic disturbances. Perhaps the intriguing nature of the features illustrate the need which is only now becoming more and more recognised of inter-disciplinary co-operation in research. Here the techniques of the soil pedologist, the geologist, the geomorphologist an indeed the geochronologist. It is hoped that the present contribution may throws some new light to the better understanding of the features of our environment.

Acknowledgements

The author wishes to record his gratitude to the University College, Nairobi for the financial assistance towards the cost of the illustrations and field work. His thanks also go to the Director of Surveys, Kenya for permission to use airphotography No. 750 (here reproduced as Plate 1). Lastly, he must thank those of his friends who have made useful comments and suggestions to the paper. The shortcomings must however remain his alone.

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The Editors

DER WASSERHAUSHALT DES TITICACASEES NACH NEUEREN MESSERGEBNISSEN

Mit 3 Abbildungen und 4 Tabellen

Albrecht Kessler und Felix Monheim [1])

Summary: The water budget of Lake Titicaca, after new measurements.

Since 1956, there have been 37 precipitation gauges in the Titicaca Basin (Peru and Bolivia). Apart from these, discharge measurements have been carried out since 1957 on the most important streams flowing into Lake Titicaca and on the Desaguadero. In addition, both authors have carried out their own observations. With the help of all these a map of annual precipitation for the 1957–1961 period was prepared and, using the water budget balance, evaporation, until now only estimated, was calculated.

The picture of precipitation distribution is particularly surprising, with a pronounced maximum of 1150 mm over the northern part of Lake Titicaca, partly explicable in terms of relief (lower height of the east Cordillera between Cordillera Real and the Apolobamba cordillera). Above all, however, the nightly land wind with convergence of ground winds over the lake and higher humidity there, contribute to this maximum.

The water budget of the lake was calculated for the five individual years 1957 to 1961. The moisture receipts of the lake are accounted for 58 % by precipitation and 42 % by surface inflow, the losses 2 % from discharge and 98 % (1480 mm) from evaporation. The mean annual level of the water budget components shows that evaporation has the lowest monthly variation in comparison to precipitation and inflow. In conclusion, the water budget of the Titicaca Basin is examined and a mean discharge coefficient of 0,21 calculated.

In seinen Untersuchungen zur Klimatologie und Hydrologie des Titicacabeckens zeigte F. Monheim 1956, daß in der bisherigen Literatur sehr unterschiedliche Auffassungen über den Wasserhaushalt des Titicacasees und über den Abfluß durch den Desaguadero bestehen, der z. B. von A. Forti zu 140 m^3/sec berechnet wurde, von F. Monheim aber nur zu 20 m^3/sec [2]). Die damaligen Wasserhaushaltsberechnungen beruhten freilich auf unvollkommenen Unterlagen, da der Zufluß zum See noch nicht gemessen wurde und auch die Niederschläge wegen der Weitmaschigkeit des Beobachtungsnetzes und manchmal auch wegen mangelnder Schulung der Beobachter nicht mit der nötigen Genauigkeit bekannt waren.

Im Zusammenhang mit den schon länger diskutierten Projekten zur Nutzung des Wassers des Titicacasees zur Elektrizitätsgewinnung und zur Bewässerung in der pazifischen Küstenwüste haben nun Peru und Bolivien seit 1956 zahlreiche neue meteorologische Stationen im Titicacabecken errichtet. Außerdem werden in beiden Ländern seit 1957 Abflußmessungen in den wichtigsten Zuflüssen des Titicacasees und im Desaguadero durchgeführt. Dieses Material konnten die Verfasser 1962 auf einer gemeinsamen Forschungsreise einsehen und dann 1966 auf der La-

[1]) F. Monheim: Einleitung und Niederschlag; A. Kessler: Zuflüsse und Wasserhaushalt.

[2]) F. Monheim, 1956, S. 94.