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Retrospective

A tribute to Rohdenburg (1970): Morphodynamic activity and stability phases instead of pluvial and interpluvial times

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1 Scientific background

In 1970 Heinrich Rohdenburg (Rohdenburg, 1970) published an article entitled "Morphodynamic activity and stability times instead of pluvial and interpluvial times", which had a lasting influence on the disciplines of Quaternary geology and geomorphology up to the present day. At that time, Quaternary geologists and geomorphologists had hardly any reliable data on palaeoclimatic conditions and effects of the subtropical and tropical zones. For this reason, Rohdenburg's publication is based primarily on hypothetical considerations and conceptual models that he developed against the background of the state of research at that time. It was assumed that during the Quaternary period, and especially during the last cold period in Central Europe, the climate was characterized by cyclical changes. This finding was the basis for the division of the glacial periods into stadials and interstadials. However, he observed that the glacial climate fluctuations, as assumed for Central Europe, could not be transferred to tropical and subtropical zones due to a lack of detailed stratigraphic evidence from these zones. With his publication, based on his own observations, Rohdenburg was one of the first to postulate effective morphodynamic Quaternary climate fluctuations for the subtropics and tropics.

In his early years Heinrich Rohdenburg was considered to be an admirer of Julius Büdel's theses. With the inclusion of relevant scientific disciplines, he was able to significantly deepen Büdel's basic idea of climatic geomorphology and present this new concept in his textbook *Introduction into climate-genetic geomorphology* (*Einführung in die klimagenetische Geomorphologie*; Rohdenburg, 1971, reprint in 2006). In doing so, he partially refuted Büdel's theses. In contrast to Büdel, who attributed the relief of the tropics to processes operating up to 100 million years and who assigned older processes of landform development mainly to epirogenic deformation (Büdel, 1981, p. 198), Rohdenburg proposed that climate and climate change were the most important factors controlling landform development. He recog-

nized that in the mid-latitudes, the glacial periods, with powerful thermal fluctuations, resulted in landform change during periglacial conditions. In particular, he recognized that recent studies of loess–palaeosol sequences from Central Europe revealed multiple climatic changes over the last glacial period. Rohdenburg assumed – correct according to current understanding – that changes in morphodynamics in the tropics and subtropics were not likely to be controlled by such processes but instead mainly by precipitation changes. However, according to the concepts prevailing at that time, it was still assumed that erosion in the lower latitudes was continuous and that changes in geomorphological activity were mainly triggered by tectonic impulses (e.g. uplifted marine terraces).

Rohdenburg was able to comprehensibly refute this thesis by using the evidence from calcareous crusts in subtropical arid regions. As a result of intensive scientific discussion with colleagues working on soil formation, Rohdenburg proposed a new concept for the origin of calcareous crusts in subtropical drylands, for which he regarded alternations of climate as a basic condition for their development. According to the state of knowledge at that time, it was still assumed that $CaCO_3$ crusts in drylands were formed by ascending soil water, in which $CaCO_3$ is dissolved in the subsoil and transported to, and precipitated at, the surface by rising soil water movement. Rohdenburg, on the other hand, inferred that the $CaCO_3$ crusts were formed under more humid conditions by percolating water (p. 84) decalcifying the soil parent material. He then proposed that subsequent aridity would result in a thinner vegetation cover, leading to erosion of the topsoil, and the $CaCO_3$ horizon would be exposed and subsequently hardened by overland flow. Based on subsequent detailed studies of calcareous crust formation in the subtropical zones, this finding has become widely accepted, although incomprehensibly, many still assume that most of the calcareous crusts in arid regions are the result of ascending groundwater.

2 Climate fluctuations and morphodynamic effects

Climatic geomorphology (Rohdenburg, 2006) refers exclusively to the relief formed by fluvial processes (*fluviale Abtragungsrelief*). Mensching (1955) introduced this concept and assumed that climate induced changes in relief in the subtropics based on the presence of "very old" slope debris covers, which were considered to have been deposited in a pluvial period. This concept of pluvial periods originates from the idea that during glacial periods the climatic zones shifted southwards so that, for instance, the Mediterranean region was characterized by a climate like that of Central Europe today. Rohdenburg strongly doubted and rejected this assumption because he predicted that climate fluctuations would also occur in the Mediterranean region within a "pluvial period" – analogous to stadials and interstadials in Central Europe. He concluded that geomorphological activity, and in particular rates of slope formation, is a response to climate change. From this basic reasoning Rohdenburg developed the concept of times of morphodynamic activity and stability. The "morphodynamic active phase" is characterized by pronounced denudation, erosion and surface runoff under semi-arid conditions, while a "morphodynamic stable phase" is characterized by soil formation and linear incision of the fluvial system with a more humid climatic regime.

According to Rohdenburg, there is no actualistic counterpart for morphodynamic activity. He assumed more accentuated precipitation for this morphodynamic active phase, with high surface runoff and strong soil erosion, especially during heavy rainfall events. He postulates that these conditions do not occur anywhere at present largely because he had no access to numerical dating that could have provided a time span for the "event-related arid morphodynamics" and an estimation of the duration of their total forming power.

3 Originality from today's perspective

The topicality of Rohdenburg's publication, which was both innovative and groundbreaking for its time, is not only demonstrated by the concept of alternating, climatically induced, morphodynamic "activity and stability phases" but also by the many suggestions which today stimulate scientific discussion, something that could not be perceived at the time. Examples of this are as follows:

- He made clear in his article that a multidisciplinary approach has many advantages (p. 84), the approach that underpins modern research in geosciences.
- The "tipping over" of the ecological system anticipates the term "threshold" and the recently much-cited term "tipping point" (p. 87, Lenton et al., 2019).
- Rohdenburg attributes the "overturning" of the system to self-reinforcing processes within the geomorphodynamic system which are in particular climatically induced.
- The so-called "pluvial period" north and south of the Sahara, but also in the Mediterranean region, was characterized by significantly higher aridity (pp. 92 and 94) with high annual variation in precipitation and morphodynamically effective heavy rainfall events. Rohdenburg subsequently rejected the term "pluvial period".
- Climate change and morphodynamic changes are asynchronous. However, morphodynamic activity becomes out of phase with climate forcing because vegetation cover can delay the response of the geomorphological system (see also Vicente-Serrano et al., 2013). With respect to the effects of vegetation cover Rohdenburg used the expressions "with its exceedingly effective capacity" (p. 88) and great "fighting power" (p. 93). The idea

of a time lag between climate change and system change is highly relevant today.

- Rohdenburg stressed the importance of vegetation as a central controlling factor for geomorphological systems, and today, numerous research projects are focused on the role of biology in earth surface processes. This importance is also reflected in the increasing importance of biogeomorphology.
- The so-called geomorphological partial activity (*Teilaktivität*) marks a spatial and/or temporal system transition, a topic that determined the scientific debate as the motto of the DEUQUA conference in Dresden in 2016.

The list stresses that Rohdenburg always endeavoured to integrate aspects of soil science, vegetation science and climatology into his understanding of morphodynamics. This reflects his contacts with highly regarded scientists such as Ernst Schönhals from Giessen and Brunk Meyer from Göttingen, who mainly worked on soil formation, as well as with the geobotanist Heinz Ellenberg from Göttingen, Quaternary geologist Arno Semmel from Frankfurt and, last but not least, with the well-known climatologist Hermann Flohn from Bonn. Heinrich Rohdenburg emphatically stressed how much he benefited from neighbouring disciplines and called for active interdisciplinary cooperation in order to strengthen the disciplines of landscape ecology and geomorphology in general.

4 Critical points

Heinrich Rohdenburg repeatedly pointed out that there was a lack of quantitative analyses to distinguish, for example, morphodynamically active phases in the dry subtropics and dry tropics from those of the semi-humid and inner tropics and the Mediterranean subtropics. The relationship between erosion rates and the mean annual precipitation had already been demonstrated quantitatively by Langbein and Schumm (1958). Rohdenburg refers to this in Fig. 1 of his article and states that in desert margins, mean annual precipitation would have to increase to generate morphodynamic activity, whereas in the (semi-)humid tropics of the tree savannas it would have to decrease to allow comparable processes to take place. The validity of this statement is readily apparent from the diagram in Langbein and Schumm (1958, Fig. 2). Thus, without doubt, the decrease and increase in the mean annual precipitation can lead to the same geomorphological effects depending on the climate of the reference point. Rohdenburg's thoughts remain open as to whether the climatic conditions for activity times during the Quaternary were synchronous in the corresponding climatic zones, for instance in the course of the shift of the climatic zones.

Although Rohdenburg had extensive international contacts, these were primarily with his colleagues in geomorphology and Quaternary geology. For this reason, the concepts of "rhexistasia" and "biostasia", which Erhart (1955) published in a remarkable essay, were unnoticed by Rohdenburg. Erhart (1955) anticipates Rohdenburg's considerations and states that under favourable climatic conditions soil formation takes place under a stable vegetation cover ("biostasy"), whereas more arid conditions result in thinning of the vegetation and increased soil erosion ("rhexistasia"). Since there was little contact with French soil scientists and biologists, Rohdenburg had no knowledge of this essay.

The lack of numerical dating at that time meant that Rohdenburg was unable to grasp the significance of duration for a morphodynamic process, and duration was therefore neglected in Rohdenburg's hypothetical discussions or was viewed from a strongly actualistic perspective. Ultimately, the lack of quantitative analyses and the lack of reliable data made a continuation and verification of Rohdenburg's conceptual model – as he himself noted – impossible at the time.

5 Implications for today's geosciences

The concept of alternation between phases of morphodynamic activity and those of morphodynamic stability is nowadays widely accepted as an indispensable part of geomorphological knowledge. Rohdenburg was mainly interested in the geomorphological process with respect to an alternating climate and less with the dating of the morphodynamic phases. Today, the dating and timing of morphodynamic phases has become possible due to significantly improved methodology. Climate archives, which are available with very good chronological resolution (e.g. Svensson et al., 2008), provide a reference. This has shifted the scientific focus to a comparison with well-dated sedimentary sequences, particularly with respect to the synchronicity of measurable geochemical or geophysical features that show similar cyclic patterns in the respective archives. These relationships are often uncritically interpreted as synchronous events, even though the archives are located in different climatic zones. Rohdenburg addresses this problem in his paper in a prescient way, suggesting that climate change can generate different morphodynamic processes in different climatic zones ("divergence phenomenon" according to Schumm, 1991). Using the example of soil water balance, he shows that climate change can lead to an improvement in soil water balance with associated soil formation in one climatic zone and to increased erosion with unfavourable soil water conditions in an adjacent climatic zone (p. 81), thus resulting in contrary morphodynamic processes. Furthermore, Rohdenburg assumes that the morphodynamic system changes in the tropics and subtropics caused by Quaternary climate change may not have occurred simultaneously.

Rohdenburg's concept is nowadays cited not only in the context of longer climatic cycles but also with respect to short-term climatic fluctuations in the Holocene (Faust and Wolf, 2017). The idea of alternating morphodynamic phases

is as ingenious as it is timeless, and Rohdenburg's concept explains the change in geomorphological processes through time within a climatic zone and in relation to a certain geomorphological form (e.g. glacis). Basically, Rohdenburg developed his ideas on the basis of his own observations and fieldwork. It is due to his scientific creativity and his holistic perspective that we today have several groundbreaking conceptual essays (cf. Rohdenburg, 1983). Likewise, hypothetical discussions and the development of concepts published in large numbers in the German Quaternary journal *Eiszeitalter und Gegenwart* (*E&G*; today *EGQSJ*) have stimulated long-lasting scientific progress.

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