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A tribute to Büdel (1951): The climatic zones of the ice age

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1 General background of Julius Büdel's paper

It may look as a coincidence that Julius Büdel published this paper at the introduction of the journal *EGQSJ* exactly 70 years ago. Climatic geomorphology is a subject that characterizes especially the focus of his early scientific work, while later Büdel was also known for his work on fluvial geomorphology. Although this paper is marked as a benchmark paper by the present-day editors of DEUQUA, it is striking that Büdel himself did not refer to it in his internationally famous book on *Klimageomorphologie* (climate geomorphology; Büdel, 1977; translated into English in 1982), but he preferred to refer to his slightly earlier lecture ("The system of climatic geomorphology" in 1948) at the "Geographentag" (day of geography) in München that was apparently the foundation of the present paper in *EGQSJ*.

Looking at the publication list of Büdel, it is clear that the *EGQSJ* paper was not an expression of sudden insight but should be considered as a first effort of general synthesis of his earlier papers on climatic zonation. Many other papers followed in the following years tackling specific cases of morphogenesis with strong links to climatic conditions in different climatic environments. Much later (1977) a new general synthesis appeared in his book *Klimageomorphologie* summarizing all his previous experience on the same subject and not limited solely to the (mostly periglacial) environments in the ice age. That work is much better known than his *EGQSJ* paper, especially after its translation into English (Büdel, 1982). As such, the *EGQSJ* paper may be considered as a precursor of that later famous book.

As the link between climate and morphogenesis was the main thread in Büdel's work it may be considered as an exponent of "climatic geomorphology". Apparently, Büdel was not the founding scientist in Germany to stress the importance of climate for morphological processes. In fact, he acquired this legacy from his tutors at university, Eduard Brückner and Albrecht Penck. Originally, this focus was a counterweight to the American school of geomorphological evolution theory, manifested by W.M. Davis, that was especially characterized by erosion on a tectonically predestined landscape. Büdel shared the focus on climate for landscape evolution with other famous European colleagues, like for instance Tricart (1954), while this philosophy of "climatic geomorphology" was traditionally kept alive in Germany, for instance by a younger generation of famous geomorphologists, like for instance Horst Hagedorn, his successor at Würzburg.

Later on, this climatic geomorphological approach was succeeded by more process-oriented strategies following advances made in dating and other analytical techniques and rather stressing quantification and physical and mathematical basics. They were clearly manifested in fluvial and hillslope geomorphology (e.g. Hack, Kirkby, Schumm, and Chorley to name only a few). But, even in those more recent approaches climate has not lost its principal role as a steering factor in the evolution of landscapes. In this respect, it is illustrative that Schumm in his famous 1977 monograph on the fluvial system devoted a whole chapter to "climate change and paleohydrology", while similarly, Chorley et al. (1984) in their geomorphology monograph included a full part on "climatic geomorphology".

2 The paper of Büdel

The present paper is especially remarkable since it approaches the geomorphological evolution during ice ages in its full complexity by the spatial shift in climatic zones from poles to Equator, rather than stressing the temporal evolution at specific locations in much research nowadays. In this respect, Büdel links the July temperature to the snowline elevations, in particular the 10.5 °C July isotherm. This gives him the link with the vegetation cover, in this case the tree line. It is the more particular that, according to Büdel, this line shows a nice E–W orientation despite strongly differing degrees of continentality. Further, Büdel concluded that the different regional positions of the limit of the treeless tundra with respect to the ice-sheet border were climatically derived (summer temperatures) and not the result of the proximity of the ice sheet. However, later it was demonstrated that other temperature values (mean annual or winter temperatures) or rates rather than summer temperatures characterize the ice-age climate and its extent.

Another link to the glacial climate than the polar tree line proposed by Büdel is the distribution of loess and the processing of loessic material starting from other fine-grained sediment. Büdel distinguishes a northern (or higher) zone dominated by frost weathering and slope processes and a southern (or lower) zone where loess is accumulated. The belt of loess deposition coincided with regions of (forest) steppe-like to tundra vegetation. The sharp northern margin of the loess deposition belt was well observed by Büdel (but its origin is still at present an unresolved problem) and facilitated by a tundra carpet and thus of climatic origin. He also observed very well that the zone between the polar forest and the ice border was much larger during the ice age than it is today. In addition, he emphasized that this zone was strongly diverse and should be subdivided in a frost-weathered zone, a forest tundra, loess tundra, loess steppe, and loess forest. A main element in Büdel's climatic geomorphological concept is his, quite provocative, link between climate (or altitudinal) zones and geomorphological processes, for instance processes of solifluction and cryoturbation in the higher zones versus windblown loess blankets in the lower zones. Later on, this strong relation between climate and process was contested in many cases and thus appeared too simple.

Another hitherto highly disputed problem of periglacial climate tackled by Büdel is the aeolian dust supplying wind direction. Büdel derived that the aeolian sediments were supplied by westerly storm winds, although those winds were possibly less frequent than the easterly winds. Only the lighter (finer-grained) loess may have been supplied by northern and eastern winds. This wind direction was later confirmed by model experiments (Renssen et al., 2007).

A remarkable point is also Büdel's statement on the independency of the extent of the ice sheet from the glacial climate. More particularly, he stresses the delay of the ice-sheet melting with respect to the maximum cold conditions. Indeed, the atmospheric cooling was the paramount process. Because of this inertia of the glacial ice-sheet expansion, growth and decay of that sheet cannot be used for a climatic subdivision. His suggestion to use loess appearance in the glacial stratigraphy is not so clearly elaborated and, moreover, not always accepted in recent loess studies. Büdel appears to observe a certain sedimentary regularity in loess deposition in a specific ice age reflecting climatic conditions, namely starting with a solifluted loess in a humid (oceanic) setting and ending with an aeolian loess in dry (continental) conditions. At present, this conclusion seems also to be an oversimplification (e.g. Schaetzl et al., 2018).

Finally, Büdel devotes a short paragraph to fluvial development in a glacial period. He distinguishes two terrace levels during the ice age, the oldest one dating from the maximum cold phase, the younger one from the declining cold phase (Late Glacial). Here it seems that a more precise treatment is severely hampered by the absence of absolute dating. His work on fluvial evolution is discussed in much more detail in other and later publications (Büdel, 1972, 1977).

3 Significance of Büdel's paper

Although the introduction of climatic geomorphology had taken place before the publication of Büdel's 1950 paper, it represents a clear landmark in the reconstruction of past environments. The idea of the shifting climatic zones – clearly illustrated in Fig. 1 of his paper – was a significant novelty that contributed to the understanding of climatic changes during the Quaternary in general. It illustrates the growing belief in the middle of the previous century that the present landforms were not generated in the present-day climatic conditions (Louis, 1961). In his paper, Büdel focused on the last ice age by specifying characteristics of the periglacial environment, but the principals of the climatic zonation theory could be applied to all other climatic zones. Büdel's contribution is still relevant in modern times as the present-day climatic change – although artificially induced in contrast

to the natural palaeoclimatic changes described by Büdel – will probably also invoke a poleward shift of climatic zones, accompanied by associated shifts of geomorphological environments and ecosystems. Certainly, at the time of writing his paper, Büdel did not realize that his approach of the shifting past climatic zones could contribute to understanding the implications of present-day climatic changes.

Without doubt, Büdel was a man of his time by the way he conceptualized this paper. It followed the tradition of deductive scientific thinking of his predecessors. It means he forwarded a reasonably thought out scientific theory and looked for proofs that could sustain his theory. At first sight, the paper looks very unusually structured in comparison with present-day usance of paper publishing. In fact, there is no formal structure as it is written in one single continuous text without any subdivision. This study did not start from a series of collected data, followed by their analysis and conclusions. It does not mean there are no proposed research objectives, nor background or final conclusions. No, they are present but not clearly delineated in separate sections as in present-day papers. For instance, results were mixed up with partial conclusions underway. This approach explains also the absence of any sedimentary analyses or systematic morphological descriptions. As a conclusion, it looks more like an opinion paper rather than a paper based on research strategy. I presume it would have been difficult for Büdel to get this paper accepted in a present issue of *EGQSJ*.

When reading this paper again, one should realize that, at that time, absolute and relative dating of sediments and detailed stratigraphy were still in their infancy. For instance, Büdel was still adhering to the number of four glacial periods within the Quaternary. This explains the quite rough stratigraphic positioning of loess series and terrace settings. In addition, also the use of sedimentological and biotic (e.g. pollen) analyses in palaeo-environmental reconstructions became familiar only at a (much) later stage.

Despite these particularities that were inherent to the time of his paper, Büdel supplemented a few remarkable conclusions that confirm his profound visionary spirit. I mention, for instance, the principle of delayed climatic impact on morphology and environments which was only fully exploited later on in fluvial geomorphology (Schumm, 1977; Vandenberghe, 1993). Another example is Büdel's, presently still valid, conclusion that all palaeoclimatic subdivision should be carried out by multidisciplinary analyses (Vandenberghe et al., 1998).

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