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Jäckli, H. 1957: Gegenwartsgeologie des bündnerischedn rheingebietes. Ein beitrag zur exogenen dynamik alpiner gebirgslandschaften

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Classics in physical geography revisited

Jäckli, H. 1957: *Gegenwartsgeologie des bündnerischen Rheingebietes. Ein Beitrag zur exogenen Dynamik alpiner Gebirgslandschaften (Exogene dynamics of an Alpine landscape)*. Beiträge zur Geologie der Schweiz, Geotechnische Serie 36, 136 pp. and 5 maps.

Figure 1 Heinrich Jäckli

I Introduction

Although Leopold *et al.* (1964) lean heavily on the work of Heinrich Jäckli in attempting to assess the relative importance of various geomorphic processes, the original Jäckli text has been rarely consulted and has only recently enjoyed a revival among researchers based in Germany, Austria and Switzerland (eg, Hinderer, 2001; Schrott *et al.*, 2003). In the interim between 1964 and 2000, the only English-language paper that gave prominence to Jäckli (1957) was Barsch and Caine (1984), in which the sediment fluxes as calculated by Jäckli were discussed and compared with those of Rapp (1960) and Caine (1976). Indeed, so little has been written about Jäckli (1957) that Marston and Pearson (2004), who wrote the most recent definition of sediment budgets, consider Dietrich and Dunne (1978) to be the pioneers.

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By contrast, the work of Anders Rapp (1960) has been widely celebrated (eg, Luckman, 2000, in this series). Because we know that Rapp visited Jäckli in the field and drew inspiration from his work (Rapp, 1960: 146), we thought it timely to re-examine Jäckli's pioneering paper, to discuss his intellectual evolution and to establish how original was the contribution that he made. The senior author translated the text of Jäckli (1957), conversed with Jäckli's widow in Zürich and also contacted several of Jäckli's former colleagues, who continue to be associated with the family firm (Dr Heinrich Jäckli AG, Zürich).

For many years, the junior author had assumed uncritically that the Jäckli paper had resulted from the Horton (1945) call for a reorientation of the science of geomorphology around the hydrology and morphometry of river basins. It was a chance comment by Bruno Messerli, University of Berne, which forced us to re-evaluate that assumption. The chance comment was that Jäckli taught entirely in German and that, as far as Messerli knew, Jäckli had little connection with the English scientific literature. If that were the case, then it would seem probable that the Jäckli paper and the concepts behind it were more original than we had thought. We have been unable to find any evidence that would suggest that Jäckli was aware of or influenced by Horton. We therefore looked to Jäckli's personal intellectual evolution to ascertain major influences on his thinking.

II Jäckli's intellectual evolution and context

In 1934, Jäckli started his geological studies at ETH, Zürich, and, until the publication of his doctorate thesis in 1941, was greatly influenced by his supervisor, Professor R. Staub. Staub was a tectonic geologist who was much interested in the morphology of the Alps. Jäckli's thesis research was a fine piece of conventional stratigraphic geological mapping, but with no particular originality of concept. In 1940, Jäckli joined the Geological Survey of the Swiss army and it would seem that his experience in explaining geological background conditions to fellow engineers was a source of inspiration for him, moving him in a totally different research direction. When he returned to Zürich in 1945, he wasted no time in establishing his own firm, which still exists today, providing consulting services in geotechnique, geology and groundwater hydrology. He published on the rate of movement of deep-seated slides in the upper Rhine valley (Jäckli, 1948) and seems to have come increasingly under the influence of Professor O. Lütschg, Chair of the Department of Hydrology at ETH. Lütschg was interested in process quantification, postglacial deposition in Lake Davos, rates of glacial erosion through field experiments, snow avalanching and the carbonate content of the rivers of Graubünden. There were other influences which are specifically acknowledged in his Habilitation, such as F. de Quervain, who conducted experiments on the rate of rock weathering. Jäckli submitted his Habil in 1954; in 1955 he started teaching as a Dozent in Engineering Geology at ETH and in 1957 his Habil was published in the form that we have it (Jäckli, 1957). This was his 23rd refereed scientific paper.

The other acknowledgements in Jäckli's thesis focused on the Swiss authorities in charge of water resources, torrent control, building codes, forestry, agriculture and traffic planning. Many of these contacts were established in the course of his consulting work. This, we are convinced, was a key ingredient in Jäckli's originality: a superb mix of academic and resource management connections. River regulation of the Rhine and private and community-based torrent control works in Switzerland had started in the middle of the nineteenth century (Versell and Schmid, 1928). Since at least the 1920s there had been huge efforts to protect the Rhine valley between Chur and Lake Constance because of the rapid rise of the riverbed and accelerated flood hazard. Improvement of road and rail connections, control of debris flows and slides and torrent control in the mountainous parts of Switzerland were priorities at an early stage. Engineers dealing with torrent control were used to thinking in terms of volume of debris moved and the Rappengraben and Sperbelgraben watershed hydrology experiments provided important data (Burger, 1943). In addition to all this, monitoring of the rate of accretion of the Rhine delta into the Bodensee from 1885 onwards (Krapf, 1919), quantitative measurements of suspended and bedload in Swiss rivers (Collet, 1916) and the historical records of the incidence of rock avalanches ('Bergstürze') (Heim, 1932) provided data the quality of which was probably unique in the world in the immediate post-second world war period.

III Analysis of contents of this 'classic'

The uniqueness of Jäckli's study is twofold: (i) the comprehensive analysis of contemporary processes in a river drainage basin of 4307 km² and an average altitude of 1950 m in order to understand its geological evolution; and (ii) the determination of rates of denudation and deposition of sediment as an aid to engineers and planners. The goal of his research was 'a quantitative analysis of the dynamics of a mountainous area'. In pursuing this goal, Jäckli developed a new term, 'geological mass transfer', which he defined as the product of sediment mass times transport distance divided by time. The core of Jäckli's contribution is that it is the first published account of the sediment budget of a large river basin and it is innovative in methodology as well as concept. Within the fluvial section of his discussion, Jäckli makes the working assumption that the upper Rhine basin above Lake Constance (Bodensee) is a geological system in which erosion and deposition of clastic sediments are balanced and the only net output is dissolved matter.

He recognized that, from the historical record, the rate of deposition of sediment in the Rhine delta at Lake Constance was 4.07 million tonnes per year and that a further 584,000 tonnes of dissolved material were evacuated per year. He calculated a net denudation figure of 0.58 mm/yr for the 4,307 km² basin. This then provided an upper boundary condition for the two different ways of estimating distributed rates of erosion (described below).

The two strategies for assessing distributed rates of geological mass transfer were: (i) estimating rates of operation of individual geomorphic processes; and (ii) identifying five 'sediment contributing areas' or categories of land unit.

Under his first strategy, he encountered problems in that he could find no data for rockfall *sensu stricto* and aeolian processes and he felt that no responsible estimate could be made; his estimates of solifluction rates are manifestly too high; for nival processes, he used average thickness of annual deposits which were converted to rates of geological mass transfer that Rapp (1960) later showed to be too high; for glacial transport he also estimated the average thickness of annual deposits in the glacial forefield, but his calculated rates were better constrained because of the detailed history of changing glacier mass balances since 1850; and for the contribution of deep-seated slides in the Bündner schists, on which he had completed extensive research (Jäckli, 1948; 1953), he was troubled by his inability to determine an average value that could be representative. On the other hand, he was able to refer to a wealth of information on the incidence of rock avalanches (11 events between 1805 and 1950); he had studied 17 rock glaciers in some detail (1949–56) and instrumented two of them; for slow creep of slope debris he used published data on damage to bridge abutments and measurements by the Swiss topographical survey of the movement of one survey point (1917–48) and by the Swiss building authorities in two large slide areas.

Several comments on this first strategy are in order. This appears to have been the first attempt to address systematically each active contemporary process of sediment production and is important for that reason alone. However, the strategy reveals more problems than solutions, especially the following: (i) the need for more experimental work to establish rates of operation of certain processes; (ii) the need for more careful delimitation of 'process domains'; (iii) the problem of comparing geological mass transfer by a debris flow event that occurred in 1944, the prehistoric Flimser Bergsturz and semi-continuous fluvial processes; and (iv) the general and continuing problem of magnitude and frequency of operation of geomorphic processes.

Under his second strategy, Jäckli engaged the issue of 'process domains' and 'sediment contributing areas' perhaps for the first time at the scale of a large drainage basin. He made a semi-quantitative assessment of the dominant process, whether depositional or erosional, in five distinct spatial units of the basin: (i) areas of dominant deposition; (ii) areas of erosion that are self-contained and do not contribute directly to the Rhine river sediment yield; (iii) areas of intensive erosion; (iv) areas of moderate erosion; and (v) areas of little erosion. Areas of dominant deposition defined themselves as lakes, flat valley floors, fans of tributaries and areas of artificially induced deposition through check dams and other torrent control service measures. Areas of erosion that are self-contained were drainage basins of lakes and closed depressions. He noted that existing natural lakes within the study area had no or very small deltas and concluded that the estimate of Lütschg (1944) of postglacial deposition in Lake Davos was probably representative of areas of little erosion throughout the region (0.01 mm/yr). Areas of intensive erosion, by contrast, comprised all torrenting catchments as defined by Versell and Schmid (1928) and yielded a mean denudation rate of 12.4 cm/yr. The area of moderate erosion, which comprised vegetation-covered slope deposits, and loose debris in valley bottoms, on glaciers and in glacier forefields, was assigned an average rate of denudation of 1 mm/yr, intermediate between areas (iii) and (v).

On the basis of this segmented approach to the determination of geological mass transfer in the Upper Rhine basin, Jäckli concluded an aggregate rate of erosion of 0.9 mm/yr plus 0.08 mm/yr in solution.

Comments on this second strategy are: (i) these aggregate rates are significantly higher than those calculated from average contemporary sediment delivery rates to the Rhine delta; (ii) there are several possible reasons for this apparent overestimate, the first of which is likely to be the importance of storage within the sediment-producing land units (see Schrott *et al.*, 2003, for critical analysis here); (iii) second, the area of the basin under moderate erosion was probably overestimated; (iv) nevertheless, this approach is one of the earliest recognitions of the concept of 'process domains' which has proved to be so seminal in recent drainage basin dynamics research.

A final point to note is that Jäckli was apparently the first to employ estimates of geomorphic work (in Joules/km^2/yr) carried out by each geomorphic process. In the case of the Upper Rhine, the fluvial and geochemical systems dominate. But the originality of Jäckli's thinking has been recognized by the adoption of this idea by others (eg, Caine, 1976; Barsch and Caine, 1984; Rapp, 1985) and this approach provides a valid basis for comparison of geomorphic work at differing time and space scales.

IV Conclusion

This paper is a classic in physical geography. It was possible because of the original mind of Heinrich Jäckli, the excellence of the interdisciplinary earth science context of ETH, Zürich, the experience of the consulting activities and the risk engineering in the army during the second world war and the superb level of mountain region management achieved by the major Swiss agencies responsible for river and torrent management.

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