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Review

Tomáš Uxa

Past and Present Permafrost and Active-Layer Phenomena as Indicators of Late Quaternary Environmental Changes

doctoral dissertation submitted to the Faculty of Science, Charles University,
in the study programme Physical Geography and Geoecology

The candidate's doctoral dissertation submitted for evaluation constitutes a collection of seven individual peer-reviewed publications and is accompanied by a summarising introduction addressing, among others, the underlying incentive, research questions, and aims of the research conducted. This introduction is solely written by the candidate, whereas the individual articles (except one) are co-authored and already published in well-established journals relevant for the chosen field of research. Two articles (papers #1 and 4) base on impressive maps, two constitute comments/discussions on other work (papers # 3 and 6), and 3 are original research articles. For each article the individual contribution of the candidate is described in detail and additionally summarised as percentage. The current reviewer has no doubts that the amount and quality of work delivered by Tomáš Uxa by his doctoral dissertation is more than appropriate for to fulfil the related expectations.

The doctoral dissertation covers an important and highly relevant topic within the broad field of active morphodynamic processes and their significance for palaeoenvironmental reconstructions. The potential of permafrost and periglacial features related to active-layer processes is still considerably undervalued within the scientific community focused on palaeoclimatic research and past, present, and future environmental change. Despite some inevitable shortcoming with the utilisation of such permafrost-related landforms as palaeoenvironmental indicators in comparison with glacier-related ones, for example the well-known problem of obtaining numerical age constraints, often longer response times to climate changes, or considerable long time periods for their (initial) formation and possible cyclicities, the candidate made a wise selection with this topic

because more knowledge is urgently required and the potential to explore is huge. The research objectives developed by the candidate logically base on his described motivation and can easily be followed by anyone interested in this field of research.

The study areas chosen for the investigation of past permafrost conditions and related landforms, Central European Uplands and Mountains north of the European Alps, are also in the focus of some more recent research activity. Although some early work on the Late Quaternary environment had been carried out in the late 19th and early 20th century, that work primarily targeted former local glaciations and mostly ignored any periglacial features. After a long period of limited research activity, partly hampered by existing borders and many works published as "grey literature" without easy access, just the last few years saw an increasing number of studies re-visiting these 'classical' locations, partly thanks to progress within the field of numerical dating techniques and remote sensing/morphometric analysis. But to obtain a full inventory and comprehensive morphological analysis of permafrost-related landforms is still lacking in many parts of these uplands/mountain regions and the candidate can be congratulated to significantly having contributed to this topic. In order to interpret these landforms, a comparative approach including modern-day permafrost environments is a logical attempt to relate certain permafrost and active-layer conditions driven by climatic factors to specific morphological processes. It needs, however, a critical assessment as to whether the modern-day permafrost environments studies by Tomáš Uxa are completely representative for the past environments he investigated.

The summarising introduction servicing as connective envelope for the individual articles starts with a definition of permafrost and periglacial landforms, but without an unnecessary depths that could easily distract from the main purpose and lead to a lengthy literature review. On the contrary, the candidate nicely elaborates his motivation and points towards open questions with the interpretation of Late Quaternary environmental changes effecting permafrost in the light of recent changes in modern-day permafrost regions. One of his ideas is to compare those recent permafrost degradation and active-layer thickness changes with the situation around Termination 1 in the Central European uplands/mountains. Overall the research objectives described address the highlighted existing research deficits perfectly and justify the work conducted, including the selected study areas that are briefly described in this context. The spectrum of methods applied with the individual investigations is quite broad and includes among others 'classical' geomorphological mapping of periglacial features (ground-based and utilising remote sensing), morphometric analysis with DEM, in situ measurements of surface and sub-surface morphology, sedimentological analysis, active layer modelling and statistical analysis. This broad range is quite impressive and in times when more and more early career scientist methodologically specialise themselves beyond a sensible boundary, it should be praised and highlighted. The overview about the individual papers nicely summarises their main aims and results. It is definitely more than only their collected abstract and leads to one of the most important parts of the doctoral dissertation, section 5 'Discussion, conclusions, and outlook', the latter assessed in the concluding section of this report.

The first article of the doctoral dissertation presented in its appendix is a geomorphological map of patterned ground with its description and morphometric analysis for three massifs of the High Sudetes. They had been locally glaciated during the LGM (mostly isolated cirque glaciers) and represent a typical Late Quaternary periglacial environment. The mapped and reported relatively widespread occurrence of patterned ground, features not typically associated with mountain glaciations, is clearly promoted by the gross morphology: wide summit plateaus with low slope angles. This is clearly shown be the morphometric analysis and the spatial distribution of different types of patterned ground. The map is nicely presented and its value is that it constitutes the first comprehensive compilation of such patterned ground features in the study regions. It, furthermore,

allows interesting comparisons with other mountain regions of similar gross morphology, e.g. in Scandinavia.

Article # 2, which also includes an interesting methodological approach, is a well presented case study of relic sorted polygons in the Krkonoše Mts. of the High Sudetes. These features developed in tabular clasts on older cryoplanation terraces are morphometrically analysed and an altitudinal gradient with better sorting towards increasing elevation is detected. This altitudinal gradient is explained my microclimatic conditions as other potential influences such as different parent substrate can be excluded. The conclusions are meaningful and in line with research elsewhere. Unfortunately, it was not possible to give any timing or time frame for the development of these features.

The comment (article # 3 of this doctoral dissertation) on an article published by a different working group claiming the existence of remnants of Pleistocene permafrost in the High Sudetes purely by geophysical measurements is an interesting read. The author collective lead by Tomáš Uxa convincingly rejects that statement and provides conclusive explanations for the apparent misinterpretation of the abovementioned geophysical measurements. The overall conclusion that geophysical data alone bears a potential danger of misinterpretation if not accompanied with detailed ground investigation using alternative approaches is correct and cannot be stressed enough.

The second major geomorphological mapping project conducted by the candidate is presented in the forth article of his doctoral dissertation, again in form of a publication in the Journal of Maps combining the map with a comprehensive description and morphometric analysis. The map represents a complete inventory of rock glaciers in the Western and High Tatra mountains and classifies the features, among others parameters such as elevation, talus-/debris-sourced, or size, into relict and intact features. This work is of high value as similar inventories only exist for a limited number of regions, most located in well-studied mountain ranges (e.g. European Alps, Scandinavia), and give a good indication of the distribution of such features in Central European mountains north of the Alps. Furthermore, it constitutes an ideal basis for the subsequent calculations about the potential lower limits of permafrost in the region and its climatic forcing. Summarising, the article is an impressive and comprehensive study on rock glaciers and a significant contribution beyond regional scale for the investigation of rock glaciers.

The modern-day periglacial environment in Svalbard is the study area for article # 5. Active sorted circles and polygons are investigated, partly in the same way as those relictic features in the Krkonoše Mts. (second article). The morphometric parameters of the patterned ground are related to the active-layer thickness and climatic parameters. The decrease of sorted circles with increasing elevation is an interesting outcome and the interpretation of this altitudinal gradient as mainly caused by a thinner active layer makes sense. The calculated ratio between the diameter of the sorted circles and the depth of the active layer falls within the range reported in the literature and verifies existing models. Accepting this conclusion the authors indicate that the morphology of sorted circles can be used to reconstruct former active layer thickness and ground thermal regimes. It needs, however, to be considered that these features may develop over longer periods of time and, once they have been stabilised, may not necessarily represent the current properties of the permafrost in every case.

Calculations of active layer thickness by Wilhelm et al. (2015) are questioned by the sixth article of the doctoral dissertation. The candidate clearly points towards the shortcomings of these calculations that lead to a substantial overestimation of the active layer thickness that is,

furthermore, unreasonable given the environmental parameters. The line of arguments used in the rejection of the calculations is very convincing and the comment well executed.

The concluding seventh article of the doctoral dissertation investigated the active layer thickness on John Ross Island of the Antarctic Peninsula. Long-term monitoring series of air and ground temperatures are analysed and a slight increase in air temperatures is met with a slight decrease of the ground temperatures. Because the cooling reported over the ten year period took place in summer, the melting season shortened and the active layer thickness decreased, albeit at low values and with some uncertainty regarding the validity of a 10-year period for to demonstrate long-term trends. But methodologically the applied model for active-layer thickness is a substantial improvement and may help future studies on active layer thickness modelling.

It is naturally much more difficult to retain a "red line" in a doctoral dissertation and present overarching conclusions developed from the research objectives and based on the outcomes of all conducted studies if the work primarily constitutes a collection of individual articles and not a "traditional" monograph. Tomáš Uxa needs, therefore, to be congratulated for having achieved this challenging task in his work. The articles themselves with their topics, applied methods, and results make it easy to follow their see scientific connection. Patterned ground in its dependency on the distribution of permafrost is a good choice as palaeoclimatic and palaeoenvironmental indicator, and its comprehensive mapping in former periglacial environments is a logical first step for any further analysis. The morphometric analysis of individual patterned ground features subsequently revealed important relationships between their morphology and the thickness of the active layer, itself in turn depending on the permafrost conditions. Finally, the detailed study of the ratio between modern-day patterned ground features and the attempt to improve the modelling of active layer thickness both lead to some useful tools and improved knowledge about how the relictic patterned ground in those Central European uplands/mountains formerly affected by severe climate during the last cold periods can be interpreted. Whereas patterned ground is the main topic of almost all articles, the rock glacier inventory in the Western and High Tatra Mts., seems on the first view a bit like out of line, but such a discourse is welcomed as rock glacier are equally applied as indicators of past and recent permafrost.

At the end of the abovementioned introduction to the individual articles the candidate summarises his major findings alongside a brief discussion and an outlook about future research directions. This parts reads very well and it can be agreed on the statement that the doctoral dissertation provides new insights into permafrost and periglacial landforms in the Central European study areas selected. To avoid repetition with this chapter the main findings and highlights of this doctoral dissertation can be summarised as:

(1) A comprehensive detailed mapping, inventory, and classification of periglacial landforms (patterned ground and rock glaciers) indicative for permafrost in the High Sudetes and Western/High Tatra accompanied with an analysis of their spatial and altitudinal distribution.

(2) A detailed analysis of the morphology of patterned ground in past and modern periglacial environments in relation to active layer thickness, microclimatology, and permafrost conditions.

(3) An improvement of the utilisation of patterned ground for the calculation and subsequent reconstruction of active layer thickness, hence an improvement of the palaeoclimatic interpretation of periglacial landforms in regions formerly affected by permafrost.

It should be highlighted that some remaining uncertainties are pointed out as well in this paragraph, for example obtaining chronological constraints for the relictic patterned ground and rock glaciers. Another issue that could be up to discussion during the defence is the problem that

the morphology of patterned ground may not be representative for the current permafrost conditions but inherited from former periods of higher morphodynamic activity. A similar problems may emerge with the interpretation of rock glaciers that may undergo several periods of activity/inactivity in their formation process. Especially with small talus-derived rock glaciers recent studies from Norway have indicated that some features may constitute "transitional landforms" between the glacial, periglacial, and nival process-systems. It would be interesting to explore such uncertainties further in future work to confirm the conclusions reached by the candidate. In this context, one could recommend that certain Scandinavian or Eastern Canadian mountain regions would perhaps be equally or even better suited for the comparison of patterned ground in the High Sudetes by means of gross morphology than Svalbard or the Antarctic Peninsula. But in the light of available data and logistics, the selection of the latter as modern-day periglacial environments cannot be criticised.

Summarising, through his contribution with seven published peer-reviewed articles and the accompanying introduction/summary the candidate demonstrates an impressive knowledge of the selected methods and obtained valuable research data. The analysis of both field and analytic-statistical data is comprehensive, sound, and coherent. I rate the candidate's doctoral dissertation as valuable and significant contribution to the study of past and present permafrost and active-layer phenomena as indicators of Late Quaternary environmental change. It constitutes a good example for the application of well-selected approaches and state-of-the-art methodologies. The thesis has a lot of strength with very few weaknesses.

Therefore, I recommend that the doctoral dissertation of Tomáš Uxa should be accepted and the candidate proceed to defend his thesis.

(Professor Stefan Winkler, Würzburg, 12.08.2020)