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Geomorphological traces of conflict in high-resolution elevation models

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ABSTRACT

High-resolution digital elevation models, often derived from airborne lidar, are rapidly gaining importance in both archaeology and geomorphology, in particular where these two disciplines overlap in their interest in anthropogenic changes to the relief of the earth surface ("archaeogeomorphology"). Inter-group and inter-state conflict are one aspect of human behaviour which commonly causes such relief changes. Conflict archaeology and conflict geomorphology, which are both young sub-disciplines within their scientific fields, have until now only touched upon a small part of the wide range of issues which they can encompass. While conflict archaeology has for a long time been almost synonymous with battlefield archaeology, the few papers explicitly discussing conflict geomorphology are mainly concerned with the impact of bombing on soil geomorphology. The application of high-resolution digital elevation models in investigating past conflicts can and should, however, encompass all geomorphological traces of conflict. These include defensive structures such as earthworks, primary and secondary traces of warfare itself (e.g. bomb craters and rubble mountains), conflict-related traces associated with military training and weapons testing facilities as well as, potentially, traces of conflict sustenance (e.g. conflict-related mining and infrastructure). Examples highlight the potential of high-resolution digital elevation models for the detection, mapping and quantification of conflict-related relief changes and thus for the understanding of conflicts. As suitable data are becoming increasingly available, the study of prehistoric and historic conflicts will benefit across the discipline boundaries between archaeology and geomorphology. In the field of heritage management, the detection, visualisation and protection at landscape-scale of what is often seen as "dark" heritage is expected to gain importance.

Introduction

Traces of past conflicts are common features in the present-day landscape. They are, however, frequently unrecognised, overlooked or regarded uninteresting and thus often underrepresented in registers of archaeological sites. For example, out of the presumably thousands of relicts of the Word War II "Siegfried Line" ("Westwall") along Germany's western border (not counting trenches, approx. 3500 structures had been built in today's federal state Baden-Württemberg; Kieser, 2010) only 25 (all of them bunkers) have been recorded in the state-wide archaeological data base of Baden-Württemberg as of November 2012. Only in recent years, their historical and archaeological significance has been recognised (Fings & Möller, 2008b), and an effort is made to map and compile information on the remnants of the "Siegfried Line" (Kieser, 2010). Recognising traces of past conflict can help to improve our understanding of these conflicts, including their spatial extent and their temporal development or the strategies and technologies employed. In many cases, comprehensive mapping of conflict-related features within a given area is desirable to provide sufficient data for analysis.

The study of geomorphological traces of past conflicts is *per se* a transdisciplinary endeavour as it combines elements of geomorphology and archaeology, but also military geography and peace and conflict studies. Conflict archaeology as a sub-discipline of archaeology has been rapidly evolving since the late 1990s, and since 2005 the Journal of Conflict Archaeology is dedicated to this field of research. Conflict archaeology has, however, to a large part been concerned with battlefield archaeology, and battlefield archaeology has been the primary interest of the founding editors of the Journal of Conflict Archaeology. As recognised by the founding editors, this focus on one aspect of conflict, battlefields,

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does not address the full breadth of the subject which is now becoming evident from the papers published in that journal (Pollard & Banks, 2005). Transdisciplinary links between conflict archaeology and geomorphology, however, are still uncommon.

In contrast to conflict archaeology, conflict geomorphology as a sub-field of archaeogeomorphology (cf. Thornbush, 2012) is represented by only a few papers (e.g. Hupy & Koehler, 2012; Hupy & Schaetzl, 2006, 2008; Stal et al., 2010), and does not yet appear to be recognised as a scientific term or as a sub-discipline of geomorphology. As of September 03, 2012, a Google Scholar search resulted in 271 entries (excluding citations) containing the search term "conflict archaeology", but none for "conflict geomorphology". The combination of the search terms "conflict archaeology" and "geomorphology" returned only seven results. This apparent lack of interest is surprising, given the abundant and sometimes drastic impacts of conflict on the Earth surface. Often this is due to the fact that geomorphological impacts of conflict are not explicitly discussed. The few papers so far published explicitly on conflict geomorphology have mainly been concerned with the impact of bombturbative processes on the soilscape (Hupy & Schaetzl, 2006, 2008). In the field of conflict research, environmental concerns have largely focused on ecology, negative impacts on biological diversity and pollution (e.g. Francis, 2011; Gorsevski, Geores, & Kasischke, 2013; Hanson, 2011; Hanson et al., 2009; Machlis & Hanson, 2008) rather than on geomorphological impacts.

The aim of this paper is to outline the intersecting field of conflict archaeology and geomorphology ("conflict archaeogeomorphology"), to provide an overview of geomorphological impacts of past conflicts and to emphasise the potential of high-resolution digital elevation models (DEM) in the study of morphological traces of past conflicts. It will become apparent that landscape approaches, in which such DEM are valuable tools, are indispensable in the study of past conflicts. Finally, the paper addresses aspects of the management of negative or "dark" heritage related to past conflicts.

High-resolution digital elevation models in archaeogeomorphology

Acquisition techniques

In recent years, high-resolution digital elevation models have rapidly gained importance in the fields of both archaeology and geomorphology. This is due to rapid technological advances leading to an increasing availability and quality of such data and to growing possibilities for data manipulation and analysis. The main technological advance has been the development of airborne lidar (light detection and ranging), also known as ALS (airborne laser scanning). It can rapidly provide high-resolution topographic data sets for very large areas. Canopy penetration by the laser beam and subsequent analysis of sequential signal returns or of the full waveform of the individual laser signals allows filtering algorithms to remove non-surface points (e.g. vegetation) from the data sets (cf. Doneus & Briese, 2011; for an overview of recent progress).

As the work with high-resolution lidar data and DEMs entails the acquisition and processing of enormous amounts of data, the increasing computing power of modern PCs plays an important role in the growing use of such data sets. The readily available computing power has also led to a surge in software products and applications of multi-view photogrammetry (structure from motion), often using consumer-grade digital cameras (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012). In particular in areas lacking vegetation cover, this approach can be used to generate digital elevation models of very high resolution. Other sources for intermediate- to high-resolution digital elevation models are airborne or satellite synthetic aperture radar (SAR), for example the results of the SRTM mission with a ground resolution of approximately 30–90 m (USGS, 2006) and the more recent TerraSAR-X/TanDEM-X with a ground resolution of 12 m in regular acquisition mode (Krieger et al., 2007) and a ground resolution better than 2 m in spotlight acquisition mode (Maurer, Zimmermann, Mrowka, & Hofmann, 2012). While the resolution of these SAR-based elevation models is still coarser than provided by airborne lidar, they are useful for larger features and can be an important supplementary data source for the study of topography and landscape around known sites.

Visualisation techniques

In addition to the increasing availability of lidar-based and other high-resolution elevation data and progress in the fields of spatial resolution and vegetation filtering algorithms, there has been rapid development of new and adoption of existing visualisation techniques. Besides the "conventional" Shaded Relief (cf. Imhof, 2007), high-resolution DEM can be visualised using numerous techniques. Each of these techniques has advantages and disadvantages with respect to particular types of relief features and landscapes. For example, Shaded Relief is very adaptable to different topographic settings and relief features but suffers from poor visibility of linear features aligned parallel to illumination azimuth and from optical illusions (inverted relief) for azimuths between 90° and 270°. Sky-View Factor, on the other hand, is well suited for the visualisation of small topographic depressions and features on slopes but will produce poorer results for low relief features on horizontal surfaces. Below, an overview of a variety of currently used visualisation techniques is given.

Shaded Relief visualisation simulates directional illumination of the DEM from a point light source at a specified illumination azimuth and elevation (Imhof, 2007). By changing illumination direction, visibility of selected relief features can be enhanced. *Principal Component Analysis* can be applied to a set of multiple Shaded Relief images; the first few principal components can be used as visualisations which combine the visible relief features from all input images (Devereux, Amable, & Crow, 2008). Like Shaded Relief, *Exaggerated Relief* simulates directional illumination from a point light source; however, it is a multi-scale approach in which illumination elevation is locally adapted to maximise feature visibility at each scale (Rusinkiewicz, Burns, & DeCarlo, 2006). In contrast to Shaded Relief, *Sky-View Factor* visualisation simulates a diffuse illumination of the DEM from a homogeneously bright hemisphere centred over each DEM pixel (Kokalj, Zakšek, & Oštir, 2011; Zakšek, Oštir, & Kokalj, 2011). Similar to Sky-View Factor, *Openness* visualisation is based on diffuse illumination of the DEM; however, it is extended to also allow illumination from negative elevation angles, i.e. based on a full sphere instead of a hemisphere (Yokoyama, Shirasawa, & Pike, 2002). *Trend Removal* algorithms (e.g. subtraction of a low-pass filtered DEM from the original DEM) can be used to highlight small topographic differences. *Local Relief Models* are computed by an advanced trend removal algorithm (Hesse, 2010). *Local Dominance* visualisation depicts how dominant an observer is with regards to its local surroundings, i.e. the average steepness of the angle under which an observer placed at a DEM pixel would look down onto the surrounding pixels within a specified radius range (Hesse, forthcoming). *Cumulative Visibility* depicts the percentage of the area (surrounding each pixel within a given radius) which is visible for an observer positioned at that pixel (Hesse, forthcoming). *Accessibility* visualisation is based on an algorithm which, for every pixel in the DEM, computes the maximum radius of a sphere that could be placed on the surface at this position without being impeded by the heights of surrounding