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The process of ghost-rock karstification and its role in the formation of cave systems

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ABSTRACT

This paper presents an extensive review of the process of ghost-rock karstification and highlights its role in the formation of cave systems. The process integrates chemical weathering and mechanical erosion and extends a number of existing theories pertaining to continental landscape development. It is a two stage process that differs in many respects from the traditional single-stage process of karstification by total removal. The first stage is characterised by chemical dissolution and removal of the soluble species. It requires low hydrodynamic energy and creates a ghost-rock feature filled with residual alterite. The second stage is characterised by mechanical erosion of the undissolved particles. It requires high hydrodynamic energy and it is only then that open galleries are created. The transition from the first stage to the second is driven by the amount of energy within the thermodynamic system. The process is illustrated by detailed field observations and the results of the laboratory analyses of samples taken from the karstotype area around Soignies in southern Belgium. Thereafter, a series of case studies provide a synthesis of field observations and laboratory analyses from across western Europe. These studies come from geologically distinct parts of Belgium, France, Italy, and the United Kingdom. The process of ghost-rock karstification challenges a number of axioms associated with the process of karstification by total removal. On the basis of the evidence presented it is argued that it is no longer acceptable to use karst morphologies as a basis with which to infer specific karstogenetic processes and it is no longer necessary for a karst system to relate to base level as ghost-rock karstification proceeds along transmissive pathways in the rock. There is also some evidence to suggest that ghost-rock karstification may be superseded by karstification by total removal, and vice versa, according to the amount of energy within the thermodynamic system. The proposed chemical weathering and subsequent mechanical erosion of limestone suggest that the development of karst terrain is related far more closely to the geomorphological development of aluminosilicate and siliceous terrains than is generally supposed. It is now necessary to reconsider the origin of many karst systems in light of the outlined process of ghost-rock karstification.

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Contents

1. Introduction

This manuscript presents the first comprehensive review of the process of ghost-rock karstification and highlights its role in the formation of cave systems. It is a process that has been investigated intensively by researchers from the Francophone karstological community since the mid-1990s. However, as most of the studies have been published in French, this review also enables the process of ghost-rock karstification to be presented to the wider karstological and geological communities for the first time. The process of ghost-rock karstification offers an alternative to the traditional paradigm that exists within karstological research, that of karstification by total removal, by separating chemical dissolution and mechanical erosion into two very distinct stages. It has long been known that chemical weathering of crystalline rocks leaves the less soluble materials — this process is commonly recognised at or near the surface to form, for example, sandy regoliths or lateritic soils (Bisdom, 1967; Meunier, 1977). This paper aims to demonstrate that the same fundamental process also occurs in karst regions and that this process may extend to great depths.

It is well known that dissolution phenomena occur when calcium carbonate comes into contact with water catalysed acid (Bögli, 1964; Caro, 1965; Roques, 1967; Thraikill, 1968; Bakalowicz, 1975; Morse, 1983; Dreybrodt, 1987). Moreover, any type of acid can enhance the rate of chemical dissolution, and this may come from the surface (e.g. soil and air), from depth (e.g. hydrothermal), or from within the rock itself (e.g. bacterial oxidation). The in situ weathering of limestone produces a residual material called alterite and this process is called ghost-rock karstification due to the fact the rock retains the same physical appearance despite having been greatly altered. Ghost-rock features have been found in limestone (Schmidt, 1974; Martini, 1985; Quinif et al., 1993), dolomite (Bini, 2002; Bruxelles, 2002a,b) and chalk (Rodet, 1996). There was no direct evidence to link ghost-rock karstification to the formation of cave systems until ten years ago despite strong observational support (Rodet, 1999; Bruxelles, 2001; Bruxelles and Bruxelles, 2002; Rodet, 2002, 2003, 2004; Quinif et al., 2006). It was finally demonstrated experimentally following the discovery of Quentin Cave in southern Belgium (Quinif and Maire, 2007; Quinif et al., 2014).

The first part of this manuscript describes the processes of karstification by total removal and ghost-rock karstification then, for each, outlines their thermodynamic regime and their structure and feature geometry. The second part details the ghost-rock features and analytical properties of the alterite found around Soignies in southern Belgium. The third part illustrates the process of ghost-rock karstification in geologically distinct parts of western Europe: Belgium (the siliceous limestone of Tournai and the oolitic limestone of Engis); France (the bioclastic limestone of Aquitaine; the limestone of Burgundy; the oolitic limestone of Charente; the dolomite of Les Grand Causses; and the chalky limestone of Normandy); Italy (the silico-clay limestone of Lombardy); and the United Kingdom (the argillaceous limestone of Pembrokeshire). The manuscript concludes with a discussion of some of the implications of this process. It is, in particular, suggested that there are far greater similarities between the processes operating on karst and non-karst terrain than is generally appreciated.

2. Background

2.1. The traditional process of karstification by total removal

The pioneering cave explorations carried out by the father of modern speleology, Édouard-Alfred Martel (e.g. Martel, 1894, 1900, 1928), have led to the study of innumerable karst systems around the world