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Badlands in marl lithologies: A field guide to soil dispersion, subsurface erosion and piping-origin gullies

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ABSTRACT

Field scientists studying badland processes in Mediterranean and Semi-arid climates require assurances that the material in which gullies are presented is not dispersive. A dispersive context means; first, infiltration rates may be radically changing in very short periods due to swelling and deflocculation of clays; second, surface crusts could be the result of translocation of sodium into subsurface positions; third, rills may be formed or at least exacerbated by shallow subsurface erosion; fourth, large gullies with substantial up-channel headcuts, including so-called 'bank gullies', may have formed because subsurface pipes have collapsed; and fifth, that network connectivity and evolution may be principally internal, being effected by subsurface pipe capture network integration; and most importantly, the bulk of the sediment moving around in the landscape is not being lost from the surface.

This paper presents a decision-support tool to assist the effective diagnosis of a landscape's principal genetic process suite. The soil's behaviour in response to its geochemistry in marls with high exchangeable sodium percentages (ESPs) is outlined in simple terms with minimum use of laboratory or field chemical investigations. Using examples the paper then presents a simple set of form indicators that can be used in the field to diagnose the possibility that subsurface process are dominating landscape erosion. Surface crust character, ephemeral rills, and large subsurface tunnel settings are explained and classified. In a final section, the geomorphological implications of piping in gullied landscapes are explored by reference to the literature on connectivity.

1. Introduction

In the period from 1980 to 1992, considerable revision of the role of piping in gully development occurred (Alexander, 1982; Baillie et al., 1986; Bryan and Yair, 1982; Gerits et al., 1987; Harvey, 1982; Imeson, 1983; Imeson and Kwaad, 1980; Jones, 1981). Subsequent papers by Parker and Higgins (1990), Benito et al. (1993), Naidu et al. (1995) and Sumner and Stewart (1992) specifically linked the preoccupation of sodium on the exchange complexes of sodic (dispersive) marls to piping, and accelerated gully erosion. In a parallel development, Bocco (1991) attested that over 60% of badlands in Europe showed evidence of piping. High rates of soil loss due to piping on Luvisols on collapsible loess have been reported by Verachtert et al. (2011b); and in Verachtert et al. (2011a) these are found to be as much as 4 times greater than soil loss by wash processes. Soil loss calculations on marls have yet to be undertaken, but in situations of good connectivity and/or uplift, must be assumed to be high.

Consequently, the scale of the general involvement of dispersion-origin pipe development in rill initiation and gully erosion has been the focus of considerable research on the sodic and dispersive marine-sourced marl sediment in semi-arid or Mediterranean climates of several central and southern European sedimentary basins (Benito et al., 1991; Calvo-Cases and Harvey, 1996; Calvo-Cases et al., 1991; Calzolari et al., 1993; Chilton et al., 2008; Farifteh and Soeters, 1999; Faulkner et al., 2000, 2003a, 2003b, 2007; Gutierrez et al., 1997; Kasanin-Grubin and Bryan, 2007; Lopez-Bermudez and Romero-Diaz, 1989; Torri et al., 2002). The current author (Faulkner, 2006) has argued from this research that a large proportion of the badlands in the Mediterranean are on either collapsible loess, or dispersive marls. The evidence for this claim is the good accord between Jan De Ploey's (1989) map of badland distribution in Europe (Poesen et al., 2006), and a map of the Xerosols forming on marls and the Luvisols on collapsible loess of Southern Europe (Fig. 1A and B).

1.1. Hortonian processes vs. piping

Despite this literature, geomorphologists often assume that a Hortonian model applies to geomorphic development in badlands. For instance, recent papers exploring scale-dependency on sediment production in semi-arid badland areas hardly mention sediment production

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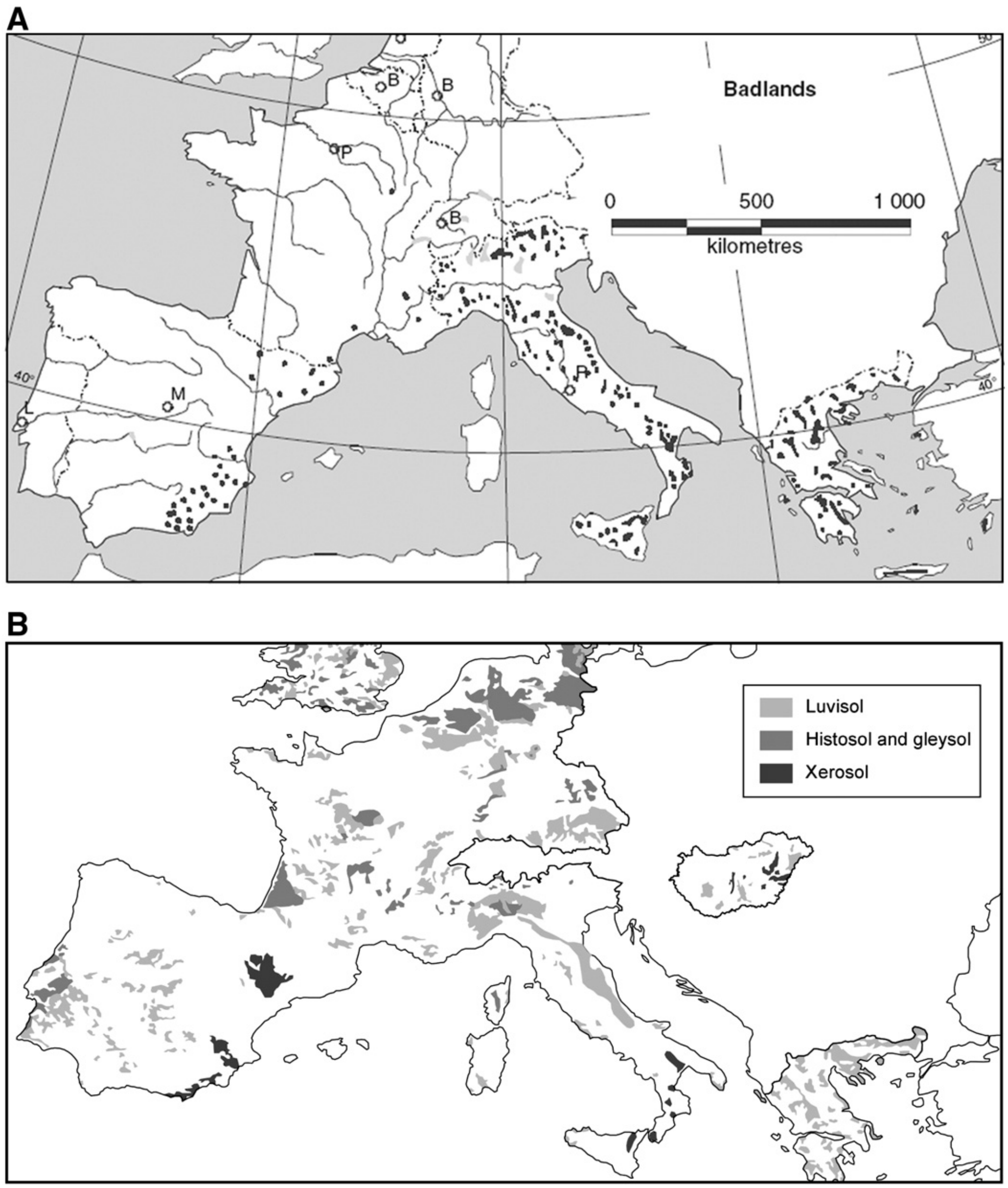

Fig. 1. A: Map of Western Europe indicating regions with dense gully networks in badlands. B: Map of Western Europe indicating distribution of three types of piping-prone materials in Europe. Note the similarity between the distribution of badlands on Fig. 1A, and the distribution of Xerosols of the southern Mediterranean, and the Luvisols of central Europe (included in Faulkner H, Ch 2.06 in Boardman, J and Poesen, J (Eds) *Soil Erosion in Europe*).
From de Ploey, J *Soil Erosion map of Europe*, 1989, reproduced with permission of Catena-verlag GmbH, and included in Boardman, J and Poesen, J (Eds) *Soil Erosion in Europe*, Ch 2.5.

from pipes at all (Canton et al., 2011; Mayor et al., 2011; Nadal-Romero et al., 2011a, 2011b). Therefore despite a wide occurrence in Europe of marls that disperse, and a general recognition of their importance in sediment production, a heavy emphasis on sediment loss from the surface still persists in most badland literature.

This may be because not all contemporary marl badlands still exhibit pipes. For instance, in the El Cautivo badlands (Tabernas, Almería, Spain), pipes are not apparent despite the fact that Alexander et al. (1994) demonstrated that these marls are dispersive at depth. At this very mature badland site, piping probably had a considerable role in the early expansion of the site, but its slow disconnection from regional base level changes has allowed a long period of morphological and geochemical stabilisation (Alexander et al., 2008; Faulkner, 2008). Another reason for the lack of geochemical research is that researchers often find that currently, high intensity rainfall is still exceeding infiltration rates, thereby assuming that in the long-term a Hortonian runoff, surface-wash model for geomorphic evolution must dominate. Yet Solé-Benet et al. (1997) and Canton et al. (2001) found very low surface sediment yields at Tabernas, and they noted that although water was in places infiltrating, most sediment was being produced from shallow subsurface rills similar to those associated with dispersive layers beneath a non-dispersive crust.

Sceptics also argue that exposed marls in northern Europe do not develop pipes. This can be easily explained by the extreme mobility of sodium, which is lost so rapidly from the materials by leaching in a humid climate that the dispersive role on the clay complex does not persist (Churchman and Weissman, 1995). Additionally, in climates with higher rainfall totals, we can assume that the organic matter remains a structuring agent within the topsoil and that organic acids buffer the action of sodium on the clay complex. By contrast, clay is frequently the only structuring agent in drier climates, so its dispersion has a dramatic impact; indeed, Bryan and Jones (1997) observed that pipes in semi-arid areas can be up to four times larger than those in other climatic areas.

Field scientists embarking upon any investigation into the processes involved in badland development consequently require assurances