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Controls of the spatial variability of Cr concentration in topsoils of a central French landscape

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Abstract

The aim of this study is to determine the factors that control the spatial variability of chromium in the topsoil at the landscape scale by using a combination of both individual soil pit informations and systematic soil sampling analyses. The 11 ha study area, located in Massif Central (France), includes contrasted bedrock and topography.

In a first approach we determined the relation between the concentrations in chromium and other major elements reflecting the soil pedogenic processes and some particular minerals indicating the original materials the soils are derived from. For this purpose, we used data collected at the catena scale from 10 soil profiles in two toposequences matching all geological and topographic situations. In a second approach, we studied the spatial variability of Cr in both topsoil and alterite through a systematic sampling study.

Chromium concentrations range between 16 and 355 mg kg^{-1} in the alterite, and 31 to 129 mg kg^{-1} in the topsoil. Chromium concentration in alterite presents a complex spatial distribution governed principally by the geological origin of the alterite. Two major differences between chromium concentration in the alterite and in the topsoil may be deduced. First, topsoil chromium distribution depends on topography. Increased weathering together with selective erosion of the topsoil resulted in smaller chromium concentration in the concave compared to the convex area. Secondly, chromium concentration in the topsoil varies spatially much less than in the alterite. Such differences can probably be observed in similar geomorphic conditions and for other chemical elements that can be considered as geochemically immobile through weathering.

Keywords: Chromium; Toposequence; Systematic sampling; Metamorphic rocks; Erosion; Homogenisation

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1. Introduction

The trace element chromium (Cr) is indigenous in most soils. Anthropogenic input of Cr to soils is mainly connected to emissions of the iron and steel industry. It is also present as impurity in some fertilizers and in industrial or domestic sewage sludge (Bourrelier and Berthelin, 1998). Many countries have adopted rules to limit sewage sludge input to a reasonable level: this input is prohibited when total Cr concentration in soils exceeds between 30 and 400 mg kg^{-1}, depending on the country (Smith, 1996).

In order to monitor Cr addition to soil, it is necessary to have knowledge of the distribution of Cr in unpolluted soils, the so-called pedogeochemical background (Baize, 1997). Natural Cr concentration in soils is highly variable, from nearly zero to several thousands mg kg^{-1} in soils developed from ultramafic rocks (McGrath, 1995; Paz-Gonzalez et al., 2001). The mean Cr concentration in the soils of the world is estimated to be 84 mg kg^{-1} (Ure and Berrow, 1982). In France, Cr concentration in soils commonly ranges between 10 and 90 mg kg^{-1} (Baize, 1997). Cr in soils is essentially located in either primary or secondary minerals through isomorphic substitution with Fe^{3+} and Al^{3+} (Andersson, 1977; Huisman et al., 1997). Some Cr may also be contained in insoluble hydroxides and oxides (Esser et al., 1991). Further studies of soils at the horizon or profile scale have shown that Cr is mostly present in the residual fraction (e.g. Gasser et al., 1995; Kaupenjohann and Wilcke, 1995; Wilcke and Amelung, 1996). Thus, Cr is widely considered to have a very low geochemical mobility (Taboada Castro et al., 1998). Consequently, Cr may be regarded as a conservative tracer chiefly indicating mechanical redistribution such as erosion and accumulation of soil material.

The spatial distribution of Cr and to a larger extent of trace element background levels has been assessed at various scales. Low density sampling has been used over large areas (McGrath and Loveland, 1992; Vrana et al., 1997; White et al., 1997) to give a snapshot of the trace elements distribution in soils. In these studies, the processes affecting trace element variability in soils often only refer at best to the major parent material types. Studies at the landscape scale (Wopereis et al., 1988; Atteia et al., 1994; Webster et al., 1994; Paz-Gonzalez et al., 2001; Bourennane et al., 2003) have attempted to identify those processes: trace element concentrations were mapped using geostatistical tools, but only hypotheses about their variability could be given. At the other end, detailed studies on soil profiles (Middelburg et al., 1988; Esser et al., 1991; Bédard, 1993; Gasser et al., 1995) have clearly illustrated some of the processes responsible for trace element variability in soils.

There is thus a need to regionalise the information collected from those individual soil pits to landscapes as a contribution to better understand the complex bio-geochemical processes at the landscape scale. Thus, the aim of this study is to combine both individual soil pit informations and systematic soil sampling analyses in order to assess the main factors affecting the spatial variability of Cr in soils.

This is achieved by assessing the influence of parent materials and topography on the spatial distribution of Cr at the landscape scale. For this purpose, an 11 ha area located in a rolling landscape of the northern part of Massif Central (France) has been studied. Contrastive bedrock (mainly amphibolite and gneiss) was chosen to assess the influence of parent material on soil Cr distribution. As the underlying lithology is not readily accessible, the influence of parent material has been studied through the sampling and analysis of the C horizon or alterite (Lozet and Mathieu, 1997). Alterite is considered to be the horizon with geochemical properties closest to that of the parent material (Berrow and Reaves, 1981). The influence of topography on the redistribution of chromium was evaluated through the study of both convex and concave slopes. Bourennane et al. (2003) have shown, using factorial kriging analysis, that the variability of major and trace elements in the subsoil seems to be due to the alterite type effect, whereas in the topsoil, the alterite type effect on the spatial pattern of chemical properties was partly hidden, but the reasons for that fact were not clearly assessed. In this study, we are focusing more particularly on Cr concentration, in order to elucidate what are the soil forming factors explaining the spatial distribution of Cr.