Catena 111 (2013) 122–131

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Down-slope change in soil hydrogeochemistry due to seasonal water table rise: Implications for groundwater weathering

Erick A. Bestland [a,*], Grant Stainer [b]

[a] School of the Environment, Flinders University, Adelaide, SA 5001, Australia
[b] Dept. of Agriculture and Food, WA, Merredin, Western Australia 6415, Australia

ARTICLE INFO

Article history:
Received 23 January 2012
Received in revised form 2 July 2013
Accepted 23 July 2013

Keywords:
Toposequence
Weathering
Regolith
Strontium isotopes
Groundwater

ABSTRACT

Landscape-scale chemical weathering has gone through a fundamental re-think due to: 1) the acknowledgement that a majority of solutes in most soils originate from wet fall and dry fall; and 2) that the zone of active weathering in many landscapes is much deeper than previously thought. With the goal of better understanding where weathering is occurring, a toposequence of five soil/regolith profiles from ridge crest to valley bottom in the Mt Lofty Range of South Australia was investigated using whole soil geochemistry, soil exchange pool and soil pore water hydrochemistry; stream water and groundwater hydrochemistry were analysed as well. This investigation aimed to: 1) trace water through soils, into the groundwater, and to the stream; and 2) investigate soil and regolith weathering hydrochemistry. The toposequence consists of podzolic Alfisols or texture-contrast Red-Brown Earths/Brown Chromosol soils which grade into saprolite which in turn grades into Precambrian meta-sedimentary bedrock. The groundwater table is shallow in the valley bottom, deepens upslope and has at least one metre seasonal rise and fall due to winter wet season recharge and summer dry season draw-down. Strontium isotope analysis of the groundwater, stream water, soil pore water, and soil exchange pool has established that the stream water is a mix of soil water and groundwater. This mix varies seasonally due to large changes in soil water input. Furthermore, in the down-slope soil sites, strontium isotope ratios of the soil exchange pool demonstrate a contribution to this pool from the bedrock groundwater. Up-slope soil sites that are well removed from the water table have exchange pool strontium isotope ratios that are much the same as the soil pore water. Thus, the dissolved solids in up-slope soils are dominated by wet fall–dry fall input whereas the dissolved solids in lower slope soils are dominated by weathering of high ratio Precambrian rock and saprolite transported by the groundwater system. This weathering is thought to be concentrated in the vadose zone at the transition between bedrock and saprolite.

1. Introduction

Chemical weathering is a fundamental Earth surface process, which is involved with the carbon cycle, soil geomorphology, soil productivity, and catchment hydrochemistry. Quantifying this system has seen major in-roads with the 1) identification and quantification of the atmospheric component of catchment hydrochemistry (Chadwick et al., 1999; Graustein and Armstrong, 1983; Kennedy et al., 1998), and 2) the analysis of where chemical weathering is taking place in a landscape (Anderson and Dietrich, 2001; Miller and Drever, 1977; Pavich, 1986; Yoo et al., 2007). Deciphering this complex system has direct implications for 1) landscape-catchment scale weathering analysis and models (Gaillardet et al., 1999; Godderis et al., 2006), and 2) catchment hydrograph separation analysis and models (Ladouche et al., 2001; Pinder and Jones, 1969; Sklash and Farvolden, 1979), both of which are linked to fundamental processes such as the carbon cycle and hydrologic cycle.

Chemical weathering can be the dominant source of solutes in stream water, groundwater and soil water. The sources of these solutes have been investigated for many years by several distinct disciplines in the Earth Sciences. Hydrologists have investigated flow path ways in catchments and groundwater systems with a main aim to separate stream hydrographs into components of source water (groundwater, soil water, and overland flow for example) for the purpose of understanding catchment hydrology (Buttle, 1998; Pearce et al., 1986; Sklash et al., 1976). Biogeochemists have investigated catchment systems in terms of elemental and nutrient sources and cycling in soils and catchments including carbon budgets and carbon transfers (Kendall, 1998; Schiff et al., 1997; Taylor and Fox, 1996). Environmental scientists have made substantial contributions to the understanding of the soil-stream hydrochemical system with studies of acid deposition and transport in soil, stream, and lakes (Driscoll et al., 1989; Kirchner, 1992; Kirchner and Lydersen, 1995; Likens et al., 1996; Norton and Vesely, 2003; Wesselink et al., 1995). A consensus has formed from

---

* Corresponding author.
E-mail addresses: Erick.Bestland@flinders.edu.au (E.A. Bestland), Grantley.stainer@agric.wa.gov.au (G. Stainer).

0341-8162/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.catena.2013.07.007

this work that catchments are complicated, heterogeneous systems which vary significantly even in similar settings. No comprehensive process model has yet explained in detail overall catchment hydrochemical interactions (Kirchner, 2003). And importantly, fundamental discoveries of this critical zone are still being made (Brooks et al., 2009; Calmels et al., 2011; Chadwick et al., 2009).

One common confounding issue when dealing with soil and catchment hydrochemistry is the spatial and temporal heterogeneity of many of the components of the system (Bestland et al., 2009; Bullen and Kendall, 1998; Kirchner, 2003). Spatial heterogeneity of soil-regolith hydrogeochemistry varies with depth, changes in parent material, changes in drainage characteristics, and changes in terms of topography and vegetation (Lin, 2010). This paper documents groundwater–soil hydrochemical interactions, which have important implications for catchment hydrograph models. According to the findings presented in this study, the groundwater-baseflow component determined from hydrochemical parameters of stream waters may overestimate the component of groundwater due to storage and release of solutes in the soil-regolith exchange pool reservoir. That is, vadose zone soil-regolith in toe-slope-valley bottom settings may have hydrochemical signatures dominated by groundwater sources and not soil water sources. Thus, what has been interpreted as "piston flow or kinematic waves or transmissivity feedback" of groundwater–stream response to a precipitation event may have a significant component of water from the vadose/saprolite/soil zone with groundwater hydrochemical signature. In other words, during a hydrologic event a component of the "old water" in the base flow could actually be vadose zone event water which has taken on an "old water" hydrochemical signature from the exchange pool.

To understand catchment hydrology and flow-paths, sources of solutes in the system need to be investigated. To this end the contribution of solutes from different weathering environments (soil, saprolite, bedrock) has become important considerations for catchment-scale hydrograph models (McDonnell et al., 2007) and for models of chemical weathering rates (Godderis et al., 2006). In some catchments, it has been shown that significant weathering occurs in the below-saprolite-bedrock (Anderson and Dietrich, 2001; Anderson et al., 1997a, b). How widespread this deep groundwater weathering is to the contribution of river water chemistry is largely untested (Calmels et al., 2011). In this study, whole catchment weathering is investigated through the examination of a soil-saprolite toposequence combined with analyses of stream water, groundwater, and solids (soil, rock and saprolite).

Previous toposequence studies in the Mount Lofty Ranges have documented groundwater influence on soils and soil water (Cox et al., 2002; Fitzpatrick et al., 1996). Both of these case studies identify soil water changes due to rising groundwater. One site has saline sulfidic soils developed due to groundwater rise caused by dryland salinity and waterlogging (Fitzpatrick et al., 1996). Another site has large changes in soil water salinity due to seasonal groundwater rise of saline groundwater (Cox et al., 2002).

In the study presented here, the soil exchange pool has been investigated to a depth of three metres. This pool is assumed to time average seasonal pore water changes caused by flushing of soil water during the wetting phase followed by rising groundwater during the main wet season. Importantly, this study through the utilisation of strontium isotopes identifies the source of the solutes. The two main sources are: 1) weathering of minerals ultimately from the bedrock; and 2) wet fall–dry fall.

2. Setting

The soil toposequence investigated is located in the Mount Lofty Ranges (MLR), Scott Creek area of South Australia (Fig. 1). This area has a Mediterranean temperate climate with cool moist winters and warm dry summers. Average temperatures range from 14–27 °C in summer to 8–14 °C in winter. The MLR receives strong seasonal rainfall, with 85% of rainfall falling in winter between May and September (Bureau of Meteorology: Climate Statistics for Australian sites, 2007). A yearly rainfall average of 804 mm/yr has been collected at the site (Scott Bottom rainfall collector) at an elevation of 210 m, which has been in operation since 1991 (James-Smith & Harrington, 2002). Evaporation of 1555 mm/yr is measured at the nearest Class A evaporation pan at Mt. Bold, where evaporation exceeds rainfall from October to May. Except for Scott Creek, all other streams and drainages are ephemeral with winter flows of a few weeks duration during drought years and 4–6 months duration in average and above average precipitation years. The study site is typical of MLR catchments having 100–300 m of relief, moderately steep slopes in many areas and narrow riparian-floodplain zones.

The study area, like most of the MLR, is underlain by metamorphosed late Precambrian sedimentary rocks consisting of pelites, quartzite, and minor carbonate units (Preiss, 1987). The hydrogeology of the area is that of a fractured rock aquifer (FRA) with large variations in both hydraulic conductivity and groundwater salinity (Banks et al., 2009; Barnett et al., 2002; Cranswick, 2005; Furness, 2006; Harrington, 2004a, 2004b).

The Scott Creek area has four landscape-soil types: 1) a narrow and shallow alluvial bottom land with sandy silty and clayey–silty soils and deposits; 2) moderate gradient slopes underlain by metamorphosed shales with clayey duplex soils of the Red Brown Earth to Red Podzolic soil types (Taylor et al., 1974); 3) quartzite dominated moderate to steep slopes with Yellow Podzolic and skeletal stony and sandy soils; and 4) broad ridge tops with eroded relict and podsolized lateritic soils (Fig. 1). Of these four landscape areas, the clayey duplex soils and yellow podzolic soils comprise the vast majority of the catchment. Soil thicknesses of 1–2 m are typical. Weathered bedrock or regolith of several metres in thickness typically occurs beneath the soil horizons (Fig. 2). A number of 3–4 m deep backhoe trenches have been dug in the area and combined with bore drill logs have established regolith thickness and type (Milgate, 2007; Stainer, 2006). Where the regolith occurs over pelite, it consists of a stony massive, heavy clay. And where the regolith occurs over quartzite, it consists of a silty stony sand with some clay. Small quartzite outcrops occur scattered along steep side slopes and narrow ridge tops. Pelite bedrock crops out only on the steepest side slopes.

The Scott Creek catchment has a mix of vegetation and land-use. Most of the catchment was cleared when the area was first settled in 1838, with the main aim being to clear the land for framing and to provide construction material for Adelaide (James-Smith and Harrington, 2002). The conservation areas contain native vegetation, re-grown from clearing and logging, and invaded to varying degrees by introduced plants such as blackberries along riparian courses. Private landholdings consist of pasture grazing, orchards, and eucalypt woodland. In the conservation areas human impacts consist of land clearance on lower gradient slopes with duplex soils, a few farm dams, and bulldozed fire tracks on most ridge tops. Native vegetation in this area mainly consists of eucalyptus trees (predominately stringybarks) with some acacia species. Most clayey soil sites have been cleared to some extent, and are now being replanted with native trees and shrubs. These areas are presently a mix of thick grass and large (up to 30 m) eucalyptus trees comprising an open savanna-like landscape. Most sandy soil sites have not been extensively cleared or logged and consist of shorter trees (5–10 m) and an understory of shrubs, heath and scattered grasses comprising a woodland. Deep sandy soils have areas of bracken fern. Rocky sandy soils have Xanthorrhoea (Yakkas) and casuarinaceae (sheoaks) in addition to eucalypts.

3. Methods

Backhoe trenches of between 2.5 m and 3.5 m deep and at least 5 m long were dug at the five toposequence sites (Fig. 1). Samples for whole soil geochemistry and soil exchange pool extraction were taken from all