THE RHYZOSPHERE, BIOLOGY AND THE REGOLITH

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The regolith has been broadly defined as *"the layer of unconsolidated (non-cemented) material, including rock fragments, mineral grains and all other superficial deposits that rest on unaltered, solid bedrock"* (Allaby 1998). Eggleton (2001) provides a more detailed definition: *"the entire unconsolidated or secondarily recemented cover that overlies more coherent bedrock, that has been formed by weathering, erosion, transportations and / or deposition of the older material. The regolith thus includes fractured and weathered basement rocks, saprolites, soils, organic accumulations, volcanic material, glacial deposits, colluvium, alluvium, evaporitic sediments, aeolian deposits and ground water."*

At large scales, patterns in regolith can be observed in relation to geology and climate (e.g., Costin 1954). However, at smaller scales regolith characteristics can be dependent on local changes in geology, aspect and topography that can result in patterns of transported and *in situ* regolith (Stace *et al.* 1968, Noble & Randall 1998). At even smaller scales there are characteristic patterns in the regolith, especially the surficial soil horizons, that reflect microclimate and biological activity, particularly patterns in litter accumulation, the activity of plant roots and other indicators of biogeochemical nutrient cycling (Hamilton 1972, Noble & Randall 1998, Anderson 2001, Little 2001). In fact, it can be argued that processes such as tree fall, root growth, nutrient uptake, litter fall and decomposition, and microbial activity all have important roles in rock weathering and regolith formation.

REGOLITH FORMATION

Rocks usually form at high temperatures and pressures under the earth's surface and will begin to break down on exposure to the atmosphere, at the low temperatures and pressures and in the presence of O_2 and H_2O. Rocks can be physically and chemically decomposed, both by biological factors, and if these processes exceed erosion then regolith will begin to form (Gray & Murphy 1999). The regolith will develop over time, essentially depending on the prevailing climate. According to Allaby (1998), the regolith will reach its greatest development in the humid tropics where temperature and humidity provide good conditions for rapid and deep decomposition. While there is abundant literature on chemical and physical weathering processes, there have been relatively few attempts to quantify the important roles biota can have in rock weathering and regolith formation processes.

BIOLOGY AND THE REGOLITH

Regolith formation is driven by a number of factors; climate, geology, topography, biological activity and time (Gray & Murphy 1999). Biological activities can have physical, chemical and other biological effects on the regolith. On examining spatial characteristics of surficial regolith, it becomes clear that trees, in particular, can have a strong influence on physical and chemical regolith properties (Zinke 1962, Hamilton 1972, Noble & Randall 1998, Little 2001). For example, processes of litter accumulation, stem flow and canopy drip in south eastern Australian dry sclerophyll forests can result in concentric patterns in soil chemical properties that are centred about tree boles (Hamilton 1972, Hedenstroem 1993, Little 2001).

THE RHIZOSPHERE

Plant roots play particularly important, direct and indirect, roles in physical and chemical weathering processes throughout the regolith. Because of constraints such as time, money and our inability to control nature, past examinations of rhyzosphere processes like nutrient uptake, secretion and exudation have usually occurred under laboratory conditions (Curl & Truelove 1986, Neumann & Martinoia 2002). Further, the focus of rhizosphere research has traditionally focussed on agronomy and forestry issues like "how the soils and regolith affect nutrient and water uptake". In many cases these examinations were carried out without any thought as to how these processes might actually impact on the regolith. Nevertheless by understanding the activities of the plant root, an insight can be gained into potential effects of the root on mineral weathering and the regolith in general.

The rhizosphere is a location where biological activity, in particular, the activity of plant roots, is a major factor in rock weathering and regolith forming processes. Plant roots take up nutrients from the regolith and secrete or exude organic compounds such as ligands, organic acids, sugars and starches, physically break down the regolith and also provide habitat for soil and regolith microbial populations (Curl & Truelove 1986, Neumann & Rommheld 2001, Pinton *et al.* 2001).

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A combination of two definitions can be used to describe the rhizosphere. First, the rhizosphere is that part of the regolith *"immediately surrounding plant roots, which is altered by their growth, respiration, exchange of nutrients, etc."* (Allaby 1998). The second has another approach, which defines the rhizosphere as the regolith being *"in the immediate vicinity of the plant roots in which the abundance or composition of the microbial population is affected by the presence of roots"* (Eggleton 2001). So, if the definitions are combined, the rhizosphere is "that part of the regolith immediately surrounding the plant root which provides habitat for microorganisms, and is altered by processes like root growth, respiration and nutrient uptake".

PHYSICAL WEATHERING AND PLANT ROOTS

Over time, parent rock can be physically broken down without any chemical alteration of the minerals. The most commonly observed forms of physical weathering include crystal growth (e.g., water as ice), insolation weathering (diurnal temperature changes) and pressure release (Allaby & Allaby 1990). Although less commonly observed, the regolith can also be physically altered by plant roots, which can exploit small cracks in the bedrock and as they grow the root will expand the crack, eventually leading to the bedrock breaking along the crack. Plant roots are responsible for binding and stabilising the regolith, and slowing drainage and therefore increasing the residence time of water in the regolith. They can also create pores in the regolith and add organic matter, through root cell death and decomposition (Gray & Murphy 1999). These physical effects can also have implications for other weathering processes by providing greater surface area and time for chemical reactions to occur, and by providing habitat for microorganisms that can chemically alter the regolith (Noble & Randall 1998, Pinton *et al.* 2001).

CHEMICAL WEATHERING AND PLANT ROOTS

Chemical weathering has been broadly defined as *"the action of a set of chemical processes operating at the atomic an molecular levels to break down and reform rocks and minerals…"* (Allaby & Allaby 1990.). A more detailed and meaningful definition was provided in Eggleton (2001), that is: *"The process of weathering by which chemical weathering reactions (such as hydrolysis, hydration, oxidation, carbonaion, ion exchange, and solution) between minerals, air, water and its dissolved chemicals transform rocks and minerals into new chemical combinations more stable under conditions prevailing at or near the Earth's surface; e.g., the alteration of orthoclase to kaolinite, or the solution of the calcium carbonate in limestone by carbonic acid derived from rainwater containing carbon dioxide".*

Some of the more common means by which plant roots can directly affect chemical weathering processes are through nutrient uptake, cell respiration, release of organic matter in the form of sloughed off cells, exudates and secretions (Kimmins 1996, Gray & Murphy 1999, Uren 2001). These life processes can be particularly important in changing regolith properties like nutrient content, pH (Figure 1) and redox potential, and drive forward chemical weathering reactions like oxidation, dissolution, hydrolysis and hydration (Kimmins 1996, Gray & Murphy 1999, Young & Young 2001). Some physical effects, like increases in water retention can also indirectly affect chemical weathering processes, by increasing, or decreasing the time available for chemical weathering reactions to occur (Pinton *et al.* 2001).

MICROORGANISMS IN THE RHIZOSPHERE

The rhizosphere is also an habitat for microbial populations that feed on mineral nutrients and organic materials in regoith. In many cases there are direct symbiotic relationships between plant roots and microorganisms, mycorrhiza, that enable more efficient uptake of nutrients that might otherwise be unavailable for plant growth, e.g., phosphorous (P) and potassium (K) (Young & Young 2001). In addition, there are symbioses where elements and ions such as N, specifically as NO_3 and NH_4 are actively added to the regolith. The chemistry of the system must then include the action of these ions, e.g., add H_2O to NO_3 and acidification of soils results. So, in addition to the direct physical and chemical effects of plant roots, there are many indirect associations between them and the regolith, especially by providing habitat for microorganisms. Further, microorganisms are essentially responsible for the decomposition of leaf litter and other organic materials in the regolith, while requiring elements from weathering in order to carry out vital life processes. Microorganisms can have an influence on reactions like pH, redox potential, hydrolysis and dissolution, amongst other chemical weathering reactions.

An additional example, at a very different timescale, could well be in the study of fossil rhizosphere features such as "root channels" in ferricretes and alucretes.

DIRECTIONS

While there is a solid knowledge of some of the processes involved in biological weathering and regolith formation, little is known about the rate at which these process are occurring throughout the landscape. Many previous studies of soil – root interactions have simply focused on the processes involved in nutrient uptake by the plant root, under controlled conditions, without any thought about the implications for rock and mineral weathering or regolith development. Other studies, Like Anderson (2001) have examined the physical turnover, or bioturbation, of regolith in dry sclerophyll forests, but as yet the amount of mineral nutrient turnover that occurs in regolith under eucalypt forests has not been quantified. Further, In almost all cases the complex relations of microorganisms in the rhizosphere have been simplified. Therefore, while it is now increasingly being accepted that biology plays an important role in regolith formation, an examination of the processes that enable biological activity, especially plant roots, to alter the regolith is warranted.

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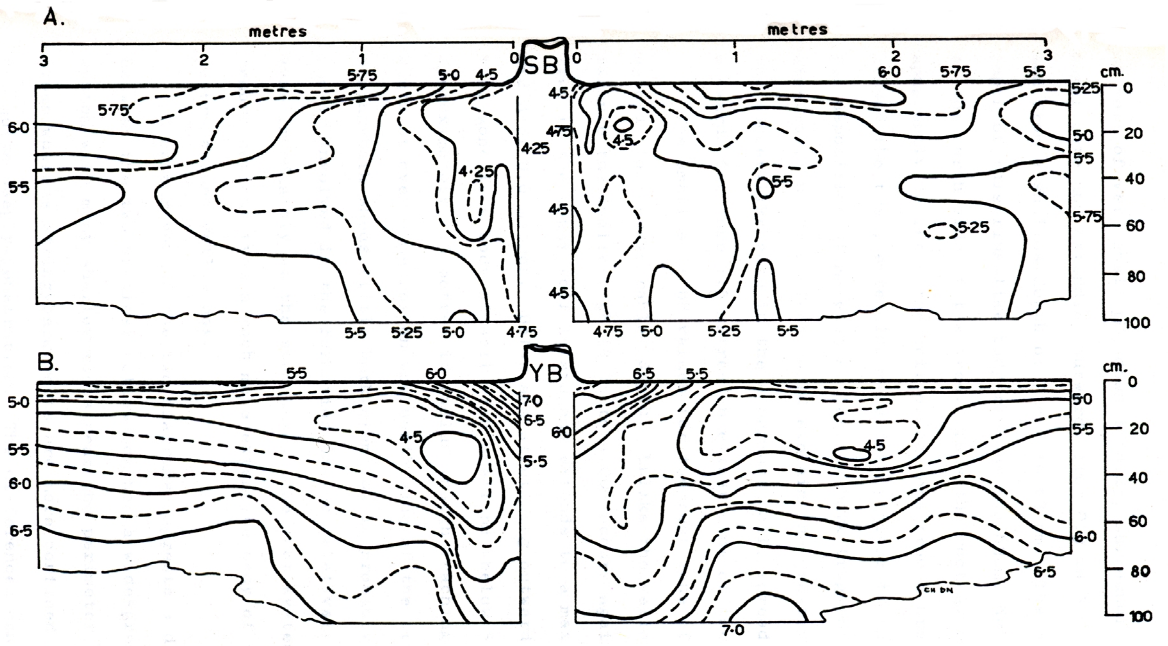

Figure 1. Patterns of soil pH under two species of eucalypts: A Stringy bark (SB) *E.macrorhynca*; B. Yellow box (YB) *E. melliodora* (Hamilton 1972).