Transfers in the critical zone through water-rock interactions and biological activity

Regolith encompasses the range of materials found between unweathered bedrock and the earth's surface and represents the critical zone where metal transfer processes between ore deposits and the surface environment occur. Regolith may be comprised of materials that have been weathered in-situ or it can be transported e.g. alluvium and colluvium. The regolith is therefore a product of processes such as erosion, transportation, and sedimentation as well as weathering through water-rock interactions and biological activity. Deeply weathered profiles, commonly ferruginous and/or bauxitic towards the surface, although in some places covered by overburden, are widespread in northern and South America, Africa, Australia and India (Fig 4). The thickness of these weathered profiles may be over 150 m depending on the age of the land surface, tectonic activity, climate history and the nature of the bedrock. In many areas, a thick and complex regolith presents particular challenges to mineral exploration.

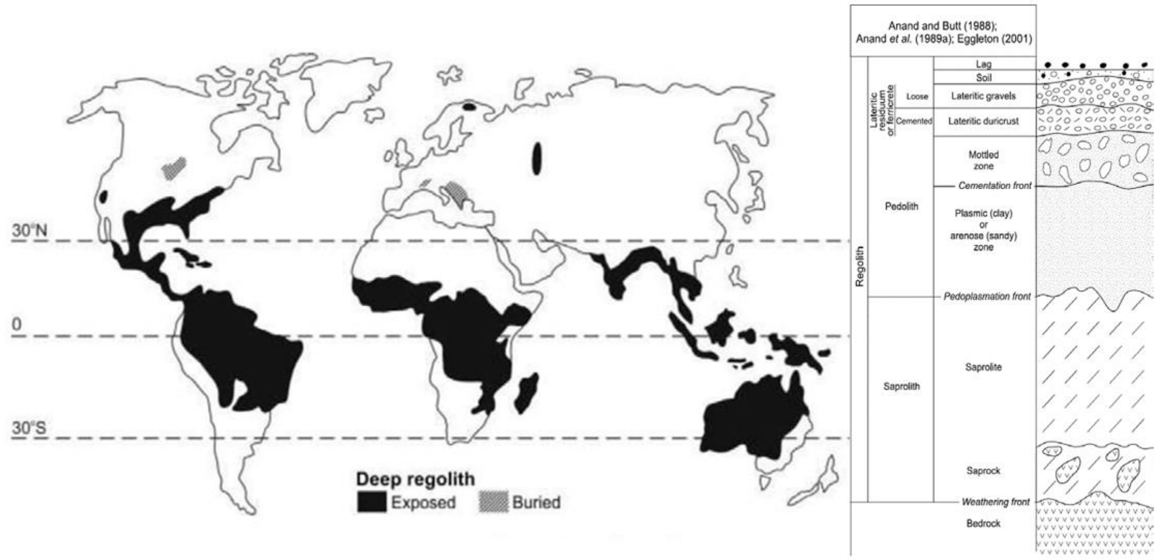

Figure 4. Regolith world distribution *(after Bardossy and Aleva, 1990)* ***and definitions*** *(after Anand and Paine, 2002).*

Regolith can be divided into four different broad types of materials; in-situ, transported, lag and soils. In-situ regolith is the weathered basement that has not undergone transport. The typical in-situ weathering profile consists of the saprolith and the overlying pedolith. The saprolith retains evidence of original rock textures. The boundary between the saprolith and the pedolith is termed the pedoplasmation front; above this boundary the pedolith does not display any original textures and is subject to soil forming processes. The saprolith can be sub-divided into the saprock and saprolite. The saprock is a slightly weathered horizon where less than 20 % of the weatherable minerals are altered. The saprolith retains the original rock fabric expressed by the primary minerals of the protolith and has more than 20 % of the weatherable minerals altered as a product of isovolumetric weathering (Anand and Paine, 2002). The pedolith has been subjected to soil forming processes that result in the loss of the parent rock fabric and the development of a new fabric by collapse and the precipitation of introduced materials. The principal horizons in the pedolith are the plasmic and arenose zones, the mottled zone, the lateritic residuum and/or ferricrete (Fig. 4).

The identification of mineral deposits in the regolith requires precise mapping and an understanding of the impact of the various processes involved in regolith development in terms of concentration or dispersion of elements (Anand and Butt, 2010; Anand et al. 2014). In erosional regimes, soil and lag sampling are generally effective for detecting mineralization. In relict regimes, lateritic residuum dominated by iron oxides can scavenge and concentrate ore-related elements and is therefore an effective geochemical sampling medium. Sampling of lateritic nodules and pisoliths has contributed to the discovery of Au and VMS deposits (Smith and Perdrix, 1983; Smith et al., 1989; Smith and Anand, 1992; Anand et al., 1993b; Smith et al, 2000; Anand, 2001; Anand et al., 2019). In depositional regimes, lateritic residuum may be buried beneath transported cover which can be sampled, however this may not be present in all environments. In these situations, interface sampling can be successfully employed. The boundary between the in-situ and transported cover is an interface (unconformity) along which physical dispersion may occur before the deposition of the cover and/or represents a boundary along which geochemical dispersion is possible. Interface sampling presents a method to sample the regolith in areas of deeper transported cover that does not require drilling down to fresh rock and has the potential to increase the anomaly size compared to fresh rock. When it is possible to locate the boundary to the nearest meter, the meter interval crossing the interface is the ideal choice, but closer spacing would be preferred. Geophysics, specifically airborne electromagnetics (AEM), can be used to help define cover thickness and plan exploration campaigns targeting interfaces for geochemical sampling (Gonzalez-Alvarez 2016). In depositional regimes, Au can be enriched in the carbonate horizon of a soil profile and may give rise to, or enhance, a near- surface expression of concealed primary or secondary mineralization (Lintern, 2015). Vegetation and termite mound sampling have also proven effective in defining anomalies over mineralization (Anand et al. 2007; Hill et al 2008; Fabris at al 2008; Stewart and Anand, 2012; Anand et al., 2014) and has been successful in regions were soil sampling is ineffective. There are however important variations in how different plants accumulate elements that need to be understood before sampling can take place.

An integral part of the regolith material assessment, geochemical studies and exploration in regolith dominated terrains is regolith landform mapping. Commonly there is a strong correlation between landform and regolith type and hence these can be mapped together (Pain et al 1991). A regolith landform unit is classified as an area on a map that has a specific association with regolith materials, landforms and possibly bedrock geology. Firstly a factual map with no genetic bias is produced and subsequently a derivative map based on genetic grouping of the regolith and associated geomorphological features can be drawn. The derivative map may display some aspects of weathering and erosional history, for example by grouping the regolith landforms into three major regimes i.e., relict erosional and depositional (Anand et al. 1989, 1993a). Regolith mapping efforts usually combined field work and analyses of remote sensing data, including in particular topography and radiometric data (surface concentrations of K, Th, and U). Recently, machine-learning techniques have been explored to assist in regolith mapping (Metelka et al., 2018). Despite conceptual limitations, this simplified scheme can assist in identifying probable dispersion models and the most appropriate exploration methods, including sample selection and procedures, sample interval analysis and interpretation. Models can apply across many deeply weathered terrains in South America, Australia and West Africa and can be used to assist in planning geochemical sampling programs.