THE LIMITS OF REGOLITH: A PLANETARY SCALE PERSPECTIVE

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WHAT IS REGOLITH?

Definitions of regolith have proliferated in the 106 years since the work of Merill (1897). He wrote of the incoherent mass of material covering underlying rocks:

> "In places this covering is made up of material originating through weathering in-situ. In other instances it is of fragmental and more or less decomposed material drifted by wind, water or ice from other sources. This entire mantle of unconsolidated material, whatever its nature or origin, it is proposed to call the regolith from the Greek words ρεγοσ (rehgos), meaning blanket, and λιφοσ (lithos), a stone."

Subsequently other definitions came into vogue. One widely accessible example is that of Gary *et al.* (1972):

> "The entire layer or mantle of fragmental and loose, incoherent, or unconsolidated rock material, of whatever origin (residual or transported) and of very varied character, that nearly everywhere forms the surface of the land and overlies or covers the more coherent bedrock. It includes rock debris (weathered in place) of all kinds, volcanic ash, glacial drift, alluvium, loess and eolian deposits, vegetal accumulations, and soils."

This definition introduced the term to the geological community and captured the essential nature of regolith, that it formed the cover to bedrock. The term was used sporadically until the 1960s but gained currency with the development of astrogeology. The space program, both robotic and crewed, revealed the presence of fragmental materials mantling the surfaces of the Moon, Mars, Venus, Mercury, and the asteroids. "Regolith" was a generic term tailor-made for this material, and subsequently reapplied with increasing frequency to terrestrial situations. Australia has been at the forefront of terrestrial regolith studies, with probably more papers published about the regolith concept (as distinct to papers on elements of the regolith such as landforms or surficial materials) on this continent than on any other.

Consequently it is not surprising more recent definitions have had an Australian context. Eggleton (2001) described (at length) regolith as:

> "The entire unconsolidated or secondarily recemented cover that overlies more coherent bedrock, that has been formed by weathering, erosion, transport, and/or deposition of the older material. The regolith thus includes fractured and weathered basement rocks, saprolites, soils, organic accumulations, volcanic material, glacial deposits, soils, organic accumulations, volcanic material, glacial deposits, colluvium, alluvium, evaporitic sediments, aeolian deposits, and groundwater."

This new definition included secondarily cemented material, for example duricrusts, as regolith, along with organic accumulations and groundwater. This was a major advance, although not universally accepted. Many geologists unfamiliar with regolith still have problems with indurated material being regolith, even though silcrete is clearly a product of regolith processes, while being one of the most tenacious rocks known.

Dictionary definitions are inevitably somewhat wordy and pedantic. More poetic descriptions are available. For example, Twidale (1990) wrote:

> "The regolith is a mass of weathered material soaked in groundwater that is charged with salts and biota… it is a suppurating mass that gradually consumes any blocks within it, and is gradually gnawing away at… the bedrock."

An important aspect of this definition is the inclusion of living biota, not just organic remains in the regolith. It also recognises the dynamic nature of regolith, it is not just a passive blanket, but a process.

Less gothic and downright pithy definitions include "Everything between fresh rock and fresh air" (Eggleton 2001), and "The membrane of the continental crust" (Arculus *pers. comm.* 2001). The second of these recognises that the regolith is an interface between the crust and the atmosphere, hydrosphere and biosphere.

These definitions are widely used and generally useful in the regions that have seen the bulk of Australian regolith studies, chiefly the Tasman Fold Belt (e.g., Carey & Hughes 2002) and the Yilgarn (Butt *et al.* 1998) and Gawler (Craig *et al.*1999, McQueen *et al.* 1999) Cratons. However, regolith studies have moved beyond these limited areas. Techniques developed in these areas are now proving useful in the study of regions of partial and extensive sedimentary cover, such as the Western Australian palaeovalleys (Butt *et al.* 2001) and the Murray Basin (Gibson 2003). Nor should the extraterrestrial dimension be ignored. Regolith geology may have been conceived on earth, but was raised on the surface of the Moon and Mars. Given this broader application of the regolith concept and regolith study methodology, it is time the nature and extent of regolith, especially of terrestrial regolith, were re-examined.

THE LIMITS OF REGOLITH

While most definitions include unconsolidated surficial sediments, weathered rock, and soils as regolith, what about cemented sediments, duricrusts, lavas, or marine deposits? How about tectonic disturbance? These questions are being continually asked by regolith geoscientists has they move away from the same, known fields of deeply weathered terrain and soil science and into areas dominated by partial or complete cover. The questions on the nature and extent of regolith will become even more important as areas of deep basinal or platform cover, volcanic provinces, and the coastal fringe come under study. They will be asked in a different contexts as Australian developed regolith geoscience is exported overseas to alien environments such as North America, South East Asia, the South American Cordillera, or Antarctica.

The limits of regolith can be considered by asking which of the examples of supracrustal geological material in Table 1 can be called regolith and which can not. Discussion of these limits, what defines regolith and what does not, is the goal of this talk.

Table 1: Are these regolith?

Active continental basin sediments	Snow and ice
Inactive continental and platform sediments	Permafrost
Artesian basin sediments	Soil gases
Modern continental margin sediments	Large volcanic provinces
Ancient continental margin and platform sediments	Shallow hydrothermal (epithermal) deposits and alteration.
Deep marine sediments	Fractured bedrock

DISCUSSION

If some of these supracrustal units are regolith while others are not, criteria for this decision need to be developed that can be applied in both Australia and elsewhere. These criteria may require a reassessment of conceptual models on the nature and extent of terrestrial regolith. The prime problem is consistency in application and demarcating recognisable boundaries. Several examples follow.

Marine sediments in onshore successions form part of the regolith in many localities (see Hou *et al.* 2003, Clarke *et al.* 1996). In many places, such as Bonaparte Gulf (Clarke & Ringis 2000), Pleistocene terrestrial sediments and weathering profiles underlie a thin veneer of Holocene sediment, and modern drainage features can be traced offshore by various geophysical techniques. Should then modern marine sediments be classed as regolith, if not, why?

Comparatively thin basin or platform sediments, such as those of the Eucla Basin (Clarke *et al.* 2003), are not normally considered regolith. However, in many places these sediments are continuous with lateral equivalents in palaeovalleys that are classed as regolith (c.f. Clarke *et al.* 1996, Hou *et al.* 2003). If these shallow basin sediments are not classed regolith, why should their lateral; equivalents in palaeovalleys be classed as such? If thin platformal sediments are regolith, how about thicker basin-filling successions? If they are not, where should the demarcation line be drawn?

If we accept basinal successions as being regolith, in at least some senses of the word, should we also include sediments in fold belts? It could be argued that these have been tectonised and thus have begun the process of cratonisation. However folding and faulting to some extent effects regolith in many locations, so tectonism in itself may not be sufficient criteria. If the absence of *significant* tectonism is used as a criteria, how much is too much?

A SOLAR SYSTEM PERSPECTIVE

A broader perspective may assist terrestrial geologists to place the limits of regolith in the context of planetary geology. Most terrestrial geologists would baulk at calling deeply fractured bedrock or thick volcano-sedimentary basins regolith, however this is consistent with the conventions of astrogeology. On the surface of the Moon and Mars the surficial regolith is underlain by the megaregolith, which consists of sedimentary deposits, lava flows, and primordial crust fractured by large-scale impacts (see Hartmann 2001, Russell & Head 2002). The megaregolith on these bodies locally exceeds 10 km in thickness. The term megaregolith corresponds in a general way to “supracrustal”, as used by Archaean geologists (e.g. Huston *et al.* 2000, Pidgeon & Hallberg 2000).

Similarly, while ice and snow are not normally considered regolith on earth, even though in areas of permanent cover they blanket the bedrock in a manner directly analogous to other surficial deposits. On the smaller bodies of the outer solar system the entire crust can be composed of ices, with regolith (Phillips & Chyba 2001) consisting of ice “lavas”, impact breccias, and both weathered through bombardment by cosmic radiation and micrometeorites.

However, each planetary body is unique, and Table 2 summarises some unique aspects of the Earth’s surface, as compared to the other rocky bodies of the inner solar system (Moon, Mars Venus, Mercury, and the asteroids). These features have a major impact of regolith processes, the role of an oxidising atmosphere; biosphere and active hydrosphere on surfaces processes are well understood. Plate tectonics has had a major role in resurfacing the earth and resulted in a crustal chemistry quite different to that of the other rocky bodies. The presence of a thick terrestrial atmosphere, like the even thicker atmosphere of Venus, is to protect the surface from the gardening effect of repeated impacts large and small, a process very important to regolith evolution on the airless bodies and also Mars. Some of these differences are not independent; earth has an oxidising atmosphere because of the biosphere, which is also largely responsible for the fixing of carbon dioxide in the crust as both reduced carbon and carbonate. From a planetary perspective, the question that needs to be asked from this table is: are these differences sufficient to justify a unique terrestrial concept of regolith, or should our understanding of terrestrial regolith, and its limits, be integrated within a broader solar system wide perspective?

Table 2: Unique features of the surface of planet Earth compared to other rocky bodies.

Plate tectonics	Active hydrosphere
Oxidising atmosphere	Biosphere
Thick atmosphere (Venus also)	Crustal carbon sequestration

CONCLUSIONS

The limits of terrestrial regolith is not clearly defined, unlike the situation on other planets. This is may partly be the result of the more complex surface process of the earth, dominated by plate tectonics, but may also reflect the *ad hoc* nature of our understanding of regolith and the immature character of our discipline. This contrasts with the understanding of regolith by astrogeologists, who include as regolith all supracrustal successions as well as the upper crust where fractured by impacts. Regolith geoscience is not reductionist; regolith cannot be reduced to aqueous chemistry, or mineral geochemistry, despite current fads and fashions. Terrestrial regolith geoscience is ultimately expansionist in nature, studying nothing less than the entire surface system of planet earth.

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