ABSTRACT

I will analyze cosmogenic ^{10}Be and ^{26}Al nuclide activities in three grain-sizes in a 2m-deep soil pit located on the Kofa Mountain Piedmont to establish the timing of deposition on a stable desert piedmont at Yuma Proving Grounds (YPG) in Yuma, AZ. I will use the resulting data to reconstruct the surface history, deposition rates, and periods of surface stability of the Kofa Mountain Piedmont. Presently, the piedmont surface is stable (neither grading nor eroding) as indicated by the presence of varnished interlocking desert pavements above an Av (vesicular) soil horizon. By deciphering the timing of deposition and surface stability, we will better understand piedmont process in relation to climate change.

INTRODUCTION

Alluvial, aeolian, hillslope, and biogenic processes dominate sediment transport in arid climates (Wells et al. 1995). Alluvial processes refer to erosion and deposition of sediment by water processes. Though scarce in the Sonoran Desert, water forms ephemeral channels that fill during rainstorms and move considerable amounts of sediment. Aeolian sediments that are fine-grained can travel great distances (cm to km) in the wind. Hillslope processes are responsible for generating sediment from mountain bedrock. Finally, biogenic processes refer to the flora trapping airborne sediments and fauna that mix and move sediment. By considering these processes in concert one can understand better the sediment transport in arid regions.

Although sediment transport depends on many individual processes, sediment on piedmonts is dominated by alluvial processes. My study focuses on the rate and timing of alluvial processes modifying the Kofa Mountain Piedmont in the Sonoran Desert located in the arid southwestern United States (Figure 1). Much of the southwestern United States consists of mountain ranges separated by extensive drainage basins.

Piedmonts, the low-sloping features that extend from the base of mountains, can be landforms characterized by sediment deposition and/or landforms where sediment is transported across the surface. My study will provide new insight into the long-term processes that have made the Kofa Mountain Piedmont.

Setting:

I am conducting my research on the Yuma Proving Grounds (YPG) in Yuma, AZ (Figure 1). The YPG is a U.S. Army installation that specializes in artillery and munitions testing. Located in southwestern Arizona, YPG contains the Kofa Mountain Range in the Sonoran Desert. Extreme temperatures (from 12 °C in the winter to 51°C in the summer), sparse vegetation (predominately consisting of Creosote Bush, White Bursage, Saguaro, Ocotillo, Thorny-Fruit Cacti, and Galleto Grasses) and low annual precipitation (approximately 91mmyr^{-1}) characterize the area (Lashlee et al. 1999).

The Kofa Mountain Piedmont, extending from the base of Kofa Mountain, is located in the southern Basin and Range, which consists of mountains separated by broad and gently sloping piedmonts (Lashlee et al. 1999). Sediment eroded from Kofa Mountain is transported in ephemeral channels that incise a higher stable piedmont surface. Such ephemeral channels at YPG remain dry for the majority of the year and only transport sediment during infrequent rains that cause flash floods, which entrain sediments of all sizes before depositing these same sediments simultaneously (Laronne and Reid, 1993). In order to quantify the history of one portion of the Kofa Mountain Piedmont, I collected sediment samples from a 2m-deep soil pit (Figures 2A, 2B). I am using cosmogenic ^{10}Be and ^{26}Al analyses and numeric models to determine deposition rates and periods of surface stability.

The Kofa Mountain Piedmont exhibits several indications of surface stability. The accumulation of aeolian fines (clay and silt) results in the formation of an Av (vesicular) soil horizon and rock varnish (Liu and Broecker, 2000). Vesicles within the soil layer, formed by escaping gases after aeolian deposition, characterize Av horizons (Figure 3) (McFadden et al. 1987). Such Av horizons suggest stability because sediment transport or erosion would easily destroy this fragile soil layer. Rock varnish, a surface coating of FeO and MnO that forms on clasts exposed to aeolian clay sediments, cover surface clasts making up the desert pavement (Figure 4). Rock varnish takes at least several hundred to several thousand years to form (Liu and Broecker, 2000). The combination of varnished clasts and the formation of an Av soil horizon suggest prolonged stability of the Kofa Mountain Piedmont. Varnished clasts at my soil pit reside as part of an extensive desert pavement.

Desert pavements consist of interlocking varnished gravels forming on top of Av soil horizons (Figure 5A). One model for the formation of desert pavements involves the clasts ascending through soil overburden during a “shrink-swell” process (McFadden et al. 1987, Wells et al. 1995). An alternate model suggests that aeolian sediment accumulates beneath the interlocking clasts, thus elevating the pavement gravels above the Av horizon (McFadden et al. 1987). Such a process is referred to as “born at the surface” (Wells et al. 1995). The desert pavements at my soil pit location are one clast thick with an ~8 cm thick Av horizon. There are no large clasts within the 8 cm Av horizon (Figure 5B). Thus, it is more plausible that the pavement clasts were elevated from the influx of aeolian fines (being “born at the surface) rather than rising through the soil profile. Incised ephemeral channels on the piedmont deposited the sediments that would inevitably become the “born at the surface” pavement around my soil pit. Thus, incised channels play an important role in the depositional history and eventual formation of desert pavement of the Kofa Mountain Piedmont. By better quantifying the timing of deposition and stability of the subsurface, one can better quantify the rate of pavement formation.

Cosmogenic Nuclides:

Cosmogenic nuclide analysis is a relatively new and increasingly valuable technique used in geomorphology. Aside from soil pits, cosmogenic nuclides have been measured in order to date marine terraces (Perg, 2001), landscape stability (Bierman, 1994), and upland erosion (Beirman and Steig, 1996, Clapp et al., 2001). Cosmogenic ^{10}Be and ^{26}Al nuclides are produced from secondary cosmic rays (particularly high-energy neutrons) that enter our atmosphere and interact with oxygen and silicon respectively. Therefore, quartz is an ideal target material. Production (within quartz grains) of these nuclides decreases exponentially with depth (Lal and Arnold 1985) and have minimal production at depths >3m from the Earth’s surface (Figure 6). At the surface of the Earth, ^{26}Al and ^{10}Be nuclides are produced at a ratio of 6:1 respectively. ^{26}Al nuclides have a half-life of 7.0×10^5 years and ^{10}Be nuclides have a half-life of 1.5×10^6 years. Since production is minimal at depths >3 m, decay of the nuclides is faster than production. Given sufficient time (>100,000 yrs.) the activity of ^{26}Al will be less (due to a shorter half-life) than the activity of ^{10}Be for deeply buried sediments and the ^{26}Al/^{10}Be ratios will deviate from 6/1. Therefore, by measuring both nuclides, ^{26}Al/^{10}Be in quartz grains can yield the near-surface history of the quartz-bearing soils.

The implication of different nuclide activities in varying grain sizes and surface processes is subject to debate. For example, denudation rates in tropical Puerto Rico show that ^{10}Be activity of sand-sized grains was higher than the activity of gravel sized grains (Brown et al. 1995) suggesting that different processes deliver different size particles. In particular, Brown et al. (1995) suspect low-dosed large grains are derived from landslides while highly dosed small grains are delivered by different slope processes. In contrast, ^{10}Be and ^{26}Al activities of sand and gravel grain sizes are constant in arid basins in the American Southwest (Clapp et al. 2000, 2002) suggesting that nuclide activity is independent of sediment delivery processes.

JUSTIFICATION

Much of the southwestern United States consists of expansive deserts. Understanding the processes shaping these vast areas is valuable to the study of landscape evolution. In the Sonoran Desert (at YPG), I plan to focus on the piedmont processes (deposition and stability) and the formation of desert pavements. It has been found that there is no nuclide variability in confined desert drainage basins (Clapp et al. 2000, 2002) but we do not know if this grain size relationship holds for unconfined piedmont surfaces. By measuring ^{10}Be and ^{26}Al in multiple grain sizes from the upper 2m of a piedmont surface I will provide new insight into long-term piedmont processes including deposition rates, periods of stability, and desert pavement formation.

LITERATURE REVIEW

Soil development is directly related to geomorphic processes and the geomorphic setting (Daniels and Hammer, 1992). Soil properties will alter through time and change according to climate as unique soil characteristics can commonly dictate the mechanics of a surficial system (Ritter et al., 1978). Since soil development is related to surficial processes, soils provide a context (or constraints) to produce quantitative piedmont-process models based cosmogenic nuclides.

Cosmogenic nuclide data offers many insights to landscape evolution over the 10^3 to 10^5 year time scale (Bierman, 1994). The rates at which nuclide bearing sediments are produced in drainage basins that move along desert surfaces, such as piedmonts, determines the nuclide activity within sediments upon final deposition. Most cosmogenic nuclide studies measure activities in rock to determine exposure age (Nichols et al., In prep) and bedrock erosion rates (Clapp et al., 2002). Recent studies have measured nuclide activity in sediment to determine drainage basin-wide erosion rates (Clapp et al, 2001, 2002). Applying this technique to the Kofa Mountain Piedmont includes not only the sediment generation history, but also the transportation history across the piedmont to the pit location. In drainage basins, the abundance of cosmogenic nuclides in sediment exiting a basin is inversely related to the rate at which the basin is eroding (Bierman and Steig 1996), thus high erosion rates have low nuclide activities.

Cosmogenic nuclide activity is used to create models of erosion rates along piedmonts and throughout drainage basins (Bierman and Steig, 1996, Nichols et al. 2002). As sediment exits the basins the nuclide activity in alluvial sediments increases as the sediment is transported down the piedmont and away from the mountain (Nichols et al. 2002). After deposition, continued production of nuclides creates a unique nuclide signature at depth that can be modeled to estimate the depositional history of the piedmont (Nichols et al., 2002, Phillips et al., 1998, Perg et al., 2001, Anderson et al., 1996).

At the Kofa Mountain Piedmont, grain size varies throughout the soil profile (fine silt and sand to cobble). Some units with large grain sizes might represent debris flow deposition while other layers with better-sorted grains might represent fluvial deposition. My study will test three grain sizes to see if depositional process dictates nuclide activity in a presently arid environment to obtain accurate timing for surface change. The implication of cosmogenic nuclide activity variation for different grain sizes is subject to debate. Research conducted in the Luquillo Experimental Forest in Puerto Rico concluded that ^{10}Be nuclide activity of fluvial sediments depends on the grain size tested (Brown et al. 1995) and thus the delivery process to the river. In contrast, grain size has shown not to yield different ^{10}Be activity in arid drainage basins (Clapp et al. 2001, 2002) and thus nuclide activity is independent of delivery process.

METHODS

Approximately 10 kg of soil were sampled from 11 depths of a 2m-deep pit at YPG: 0 - 8cm, 8 - 30cm, 30 - 50cm, 50 - 70cm, 70 - 100cm, 100 - 120cm, 120 - 140cm, 140 - 154cm, 154 - 167cm, 167 – 185cm, and 185 - 200cm. Each sample was dry sieved into 7 different grain sizes: > 4000 µm, 1000 - 4000 µm, 841-1000 µm, 500 - 841 µm, 250 - 500 µm, 125 - 250 µm, and < 125 µm. The grain size sample > 4000 µm for each of the 11 samples was crushed and sieved into > 841 µm, 250 – 841 µm, and < 250 µm. Samples > 4000 (250 - 841) µm, 500 – 841 µm, and < 125 µm for each of the 11 sample depths are being prepared at the University of Vermont for cosmogenic nuclide analysis. To eliminate any meteoric inheritance of ^{10}Be, samples will be etched in HF and the quartz present in the soil will be isolated. Sample targets will be analyzed by Accelerated

Mass Spectrometry (AMS) to measure the ^{26}Al/^{10}Be ratios. These data will be used to construct a numerical model to quantify piedmont history at YPG.

EXPECTED OUTCOMES

I do not know if the analysis of different grain sizes will result in different nuclide activities. Analyzing various grain sizes for each soil section, however, will provide more information about sediment transport and deposition processes of desert piedmonts. By understanding the depositional processes and the surface stability of the Kofa Mountain Piedmont I will be able to constrain the formation and timing of desert pavements.

TIMELINE

- December 15-16, 2002: samples collected from McDonald pit YPG Yuma, AZ
- January 28 – February 5, 2003: 11 samples (22 bags, ~1 gal) dry sieved into 7 grain sizes (> 4000 µm, 1000 – 4000 µm, 841-1000 µm, 500 – 841 µm, 250 - 500 µm, 125 – 250 µm, and < 125 µm)
- February 6 – April 4, 2003: >4000µm from each of 11 samples crushed and then sieved into 3 new grain sizes (> 841 µm, 250 – 841 µm, and < 250 µm)
- April 6, 2003: Samples > 4000 (250 - 841) µm, 500 – 841 µm, and < 125 µm for each of the 11 sample sections were submitted to UVM laboratories for HCl etching and cosmogenic ^{10}Be and ^{26}Al isotope analysis (by AMS)
- Summer 2003: continue reading on piedmont process and desert pavement development
- January – April 2004: model the data from analyzed soil samples
- May 2004: present my findings and final report to the Skidmore College Geology Department

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FIGURE CAPTIONS

Figure 1. Yuma Proving Grounds (YPG) is located in southwestern Arizona in the Basin and Range YPG is the horseshoe-shaped outline. My soil pit is located in the area marked with the small circle inside the Kofa Range.

Figure 2A. Two meter-deep soil pit located on the Kofa Mountain piedmont. The soil pit is situated within a broad, varnished desert pavement. The presence of an incised channel in the background indicates occasional erosion down the piedmont.

Figure 2B. Close-up of the soil pit showing sample locations from the 11 depth sections.

Figure 3. An example of an Av (vesicular) soil horizon. Vesicles are above the white line drawn on the sample.

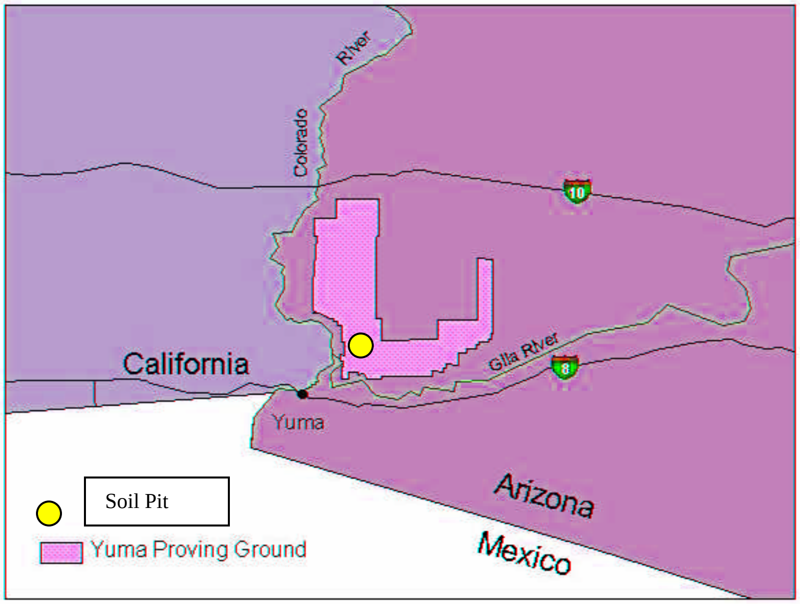
Figure 4. The rock varnish present on the desert pavement at YPG. Varnish is the result of clay-rich aeolian sediments interacting with exposed surface clasts. Note the dark color represents top of clast exposed sub-aerially.

Figure 5A. A top-down view of the desert pavement present on the Kofa Mountain piedmont. Note the darkly varnished interlocking clasts.

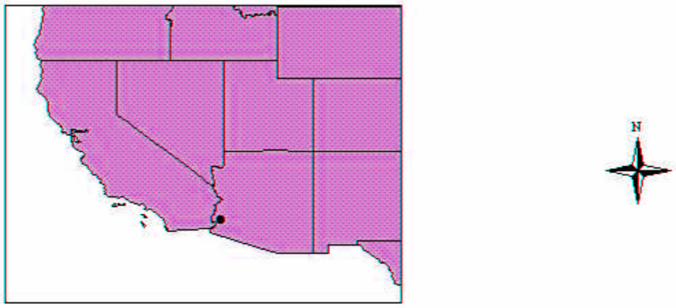
Figure 5B. Cross-Section view of the desert pavement at my soil pit. This photograph displays the 2 cm-thick pavement formed above the 8cm Av soil horizon. Also note the absence of clasts within the 8cm-thick Av section.

Figure 6. The production of cosmogenic ^{10}Be and ^{26}Al nuclides decreases exponentially with depth from the surface of the Earth.

FIGURES



a. YPG Installation Location



b. YPG Regional Location

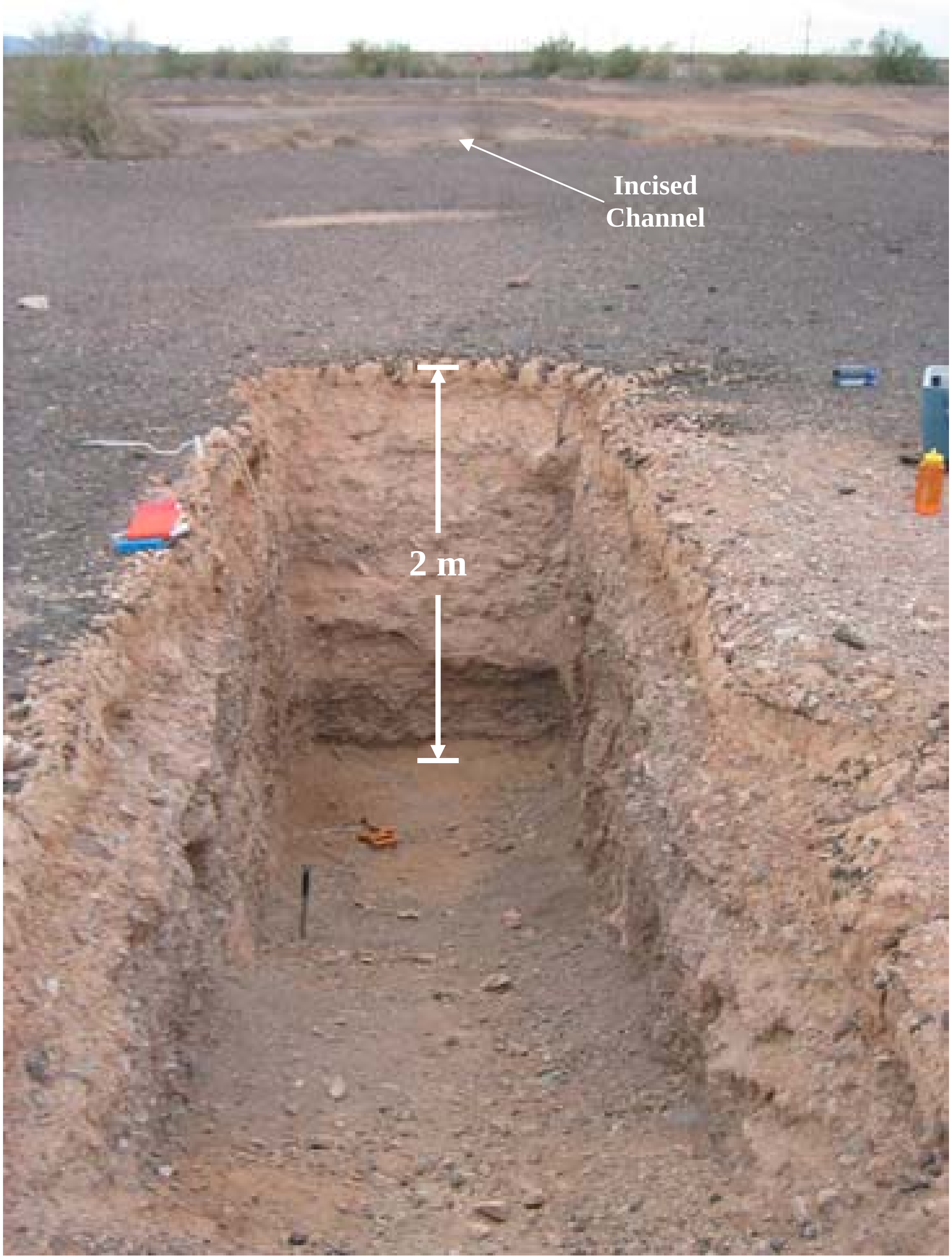


Figure 2A


0-8 cm
8-30 cm
30-50 cm
50-70 cm
70-100cm
2 m
100-120cm
120-140cm
140-154cm
154-167cm
167-185cm
185-200cm

Figure 2B

Figure 3

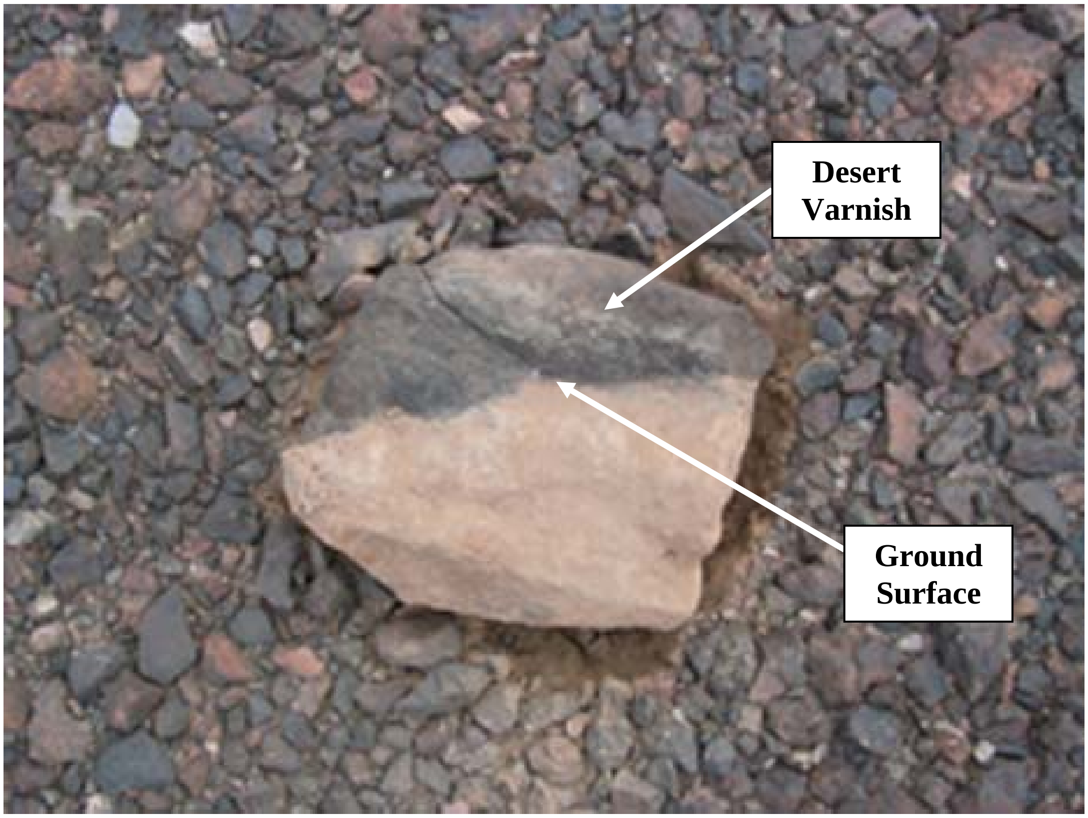


Figure 4

Figure 5A

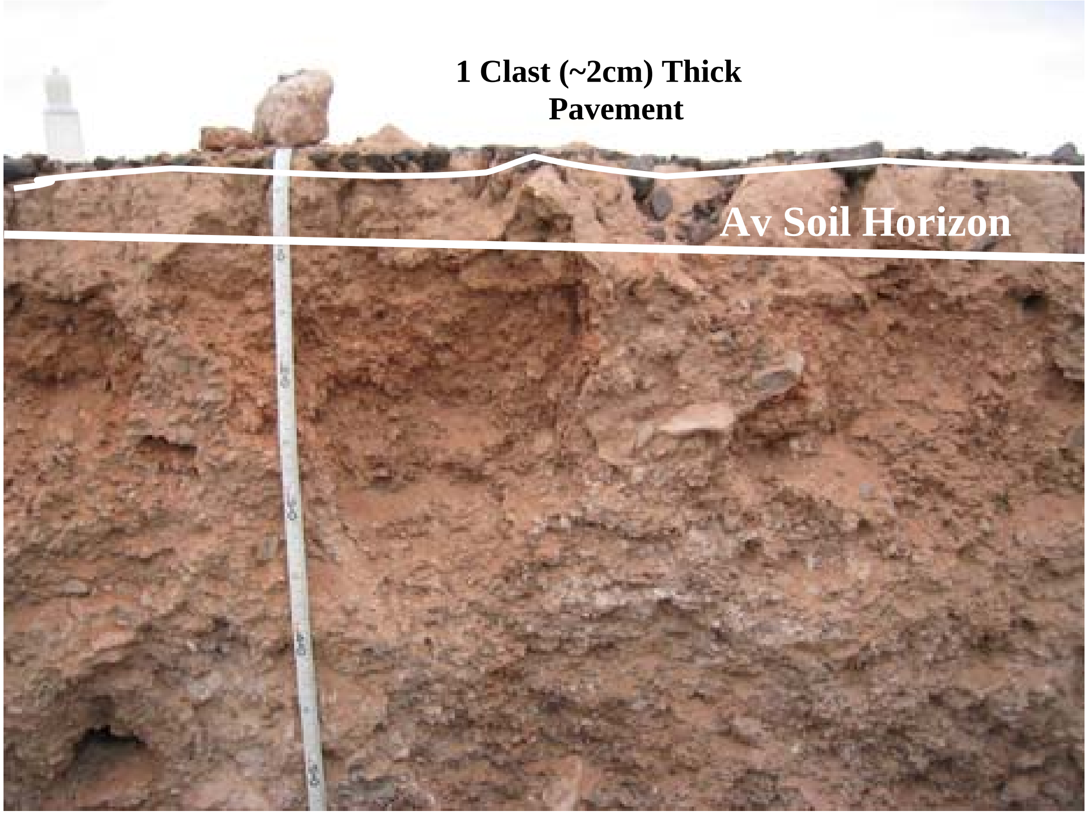


Figure 5B

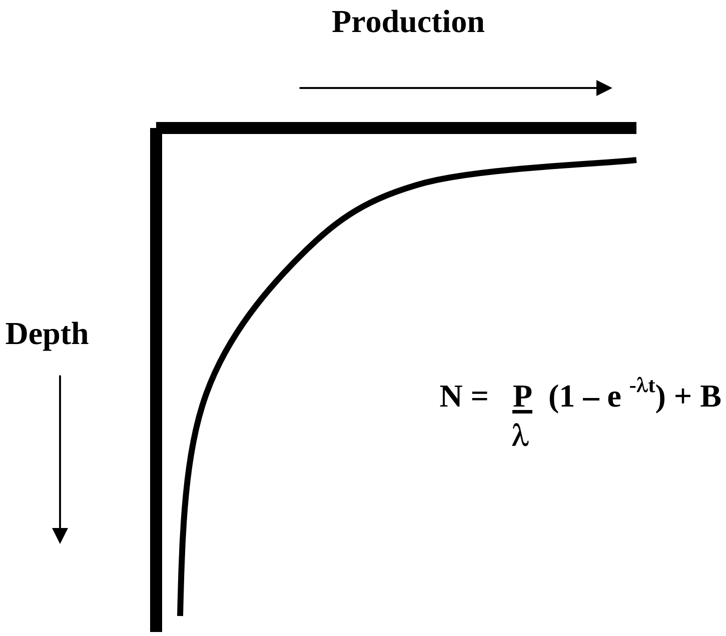


Figure 6