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INVESTIGATION OF DIFFERENT TEMPROAL AND SPATIAL SCALES OF SEDIMENT APRON BEHAVIOR IN THE MOJAVE DESERT: A COSMOGENIC APPROACH

A Proposal Presented

By

Kyle K. Nichols

To

The Faculty of the Geology Department

Of

The University of Vermont

March 15, 1998

Accepted by the Faculty of the Geology Department, the University of Vermont, in partial fulfillment of the requirements for the degree of Master of Science specializing in Geology.

The following members of the Thesis Committee have read and approved this document before it was circulated to the faculty:

______________________________ Advisor
Paul R. Bierman, Ph. D.

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1.0 Abstract

I will study Mojave Desert sediment aprons at different temporal and spatial scales. I will use the abundance of cosmogenic ^{10}Be and ^{26}Al in sediment to constrain long-term transport rates down the sediment apron surface and to determine the behavior of such surfaces in the vertical direction. I am using cosmogenic isotopes because they are an effective integrator of long-term sediment transport processes.

In order to interpret the cosmogenic nuclide measurements, I will study the small-scale geomorphology of the sediment apron. In particular, I will quantify channel depths as a proxy for the "active depth" of channel stirring. I will also determine the "active depth" using soil pit data. If field time permits, I will map the small-scale impact on the geomorphology due to military training from 1942-1944. I will use standard statistical methods to determine significant changes between control plots and impacted plots.

2.0 Introduction

Large "sediment aprons", extending from mountain ranges in the Mojave Desert, are termed *bajadas, alluvial fans, piedmonts,* and *pediments.* Each of these terms implies a specific formation process, even though little is known about what actually controls the behavior of these "sediment aprons". In fact, the literature terms alluvial fans and pediment surfaces as "problems" (Lecce, 1990 and Oberlander, 1974); in particular, it has been difficult to establish general models of landform development. In order to establish such models, the rates and the distribution of germane surface processes must be determined. My research will investigate temporal and spatial scales of sediment apron development in the Mojave Desert.

I will use cosmogenic ^{10}Be and ^{26}Al to analyze the long-term rates of sediment transport down the sediment apron and the mixing of soils in the vertical direction (Figure 1). As sediment

Figure 1	**Long-term timescale**	**Short-term timescale**
Large-scale	***4 km cosmogenic isotope transects***- shows long-term, large-scale apron behavior	*N/A*
Small-scale	***1.5 m cosmogenic isotope pit profiles***- shows long-term behavior of upper sediment surface	***Topographic map analysis***- statistical comparisons of control and experimental plots

is exposed at and near the surface, the influx of cosmic rays produces cosmogenic ^{10}Be and ^{26}Al. With increasing exposure time at the surface, additional atoms of ^{10}Be and ^{26}Al are produced in the sediments. Therefore, by measuring the abundance of ^{10}Be and ^{26}Al, in transects down a sediment apron surface and by estimating the active layer thickness where physical natural processes stir the sediment (by surveying plots at high resolution and by using soil pit data), I can constrain the minimum surface exposure time to infer the long-term behavior of the sediment apron. This technique is effective for determining sediment apron behavior on the 10^3 to 10^5 year timescale.

Desert surfaces are sensitive and may reflect changes in climate, tectonics, or human activity (Cooke and Warren, 1973 and Sheridan, 1979). One such stress occurred between 1942 and 1944 when General George S. Patton established the Desert Training Center to prepare American troops for war in North Africa. Over one million troops, 1000's of tanks and numerous other vehicles traversed sediment aprons in the Mojave Desert stirring soil and changing drainage networks (Prose, 1985). I will produce detailed maps of eighteen, 2,500 m^2 plots in both disturbed and adjacent, undisturbed areas. I will compare these maps to determine effects of human impact, and to characterize the short-term/small-scale response of sediment apron (Figure 1). I will use the maps to determine the distribution of soil stirring depths.

3.0 Field Area

The southern Mojave Desert is a good location to study temporal and spatial scales of sediment apron behavior. There is no recent tectonic activity, the bedrock is quartz rich and the area is remote. The only significant human impact was military training in the 1940's.

3.1 Geography and Geology

I will study two adjacent sediment aprons, one extending from the Iron Mountains and the other from the Granite Mountains (Plate 1). The Iron and Granite Mountains have a relief of about 400 m and are composed of granitic rock. The sediment aprons are 4 to 6 km long and the gradients are approximately 0.03-0.04. The aprons are composed of equant mineral grains (~2 mm) disaggragated from the bedrock. The two sediment aprons converge with a third sediment apron to form a closed basin.

3.2 Climate

The Iron Mountain and Granite Mountain sediment aprons receive an average of 10 cm of precipitation a year, based on the Blythe gauging station located about 80 miles to the southeast of the field area. Late summer and mid-winter are the wettest seasons.

3.3 Desert Training Center (DTC)

In April of 1942, General George S. Patton, Jr. established the Desert Training Center to prepare the American troops for war in North Africa. At peak occupation, 200,000 troops lived in 12 camps spread throughout the southeastern part of California, the western part of Arizona and the southern part of Nevada. Two of these camps, Camp Iron Mountain and Camp Granite, are located on the sediment apron surfaces extending from the Iron and Granite Mountains, respectively (Plate 1). The camps contained roads, walkways, living quarters, administration quarters, motor pools and parking areas. Many of the tents, roads and walkways were outlined with rocks from the local area. Many rock alignments, although in various states of deterioration, are still visible in the camps. Due to the remoteness of the area, Camp Iron Mountain and Camp Granite have received minimal amounts of impact from private off road vehicle (ORV) use since decommissioning. A fence was constructed around Camp Iron Mountain in 1973 to prohibit further ORV use. (Bureau of Land Management 1984).

4.0 Previous Research

4.1 Sediment aprons

Sediment apron research is extensive and mostly focuses on alluvial fans (Nilsen and Moore, 1984). Much of this research uses present-day processes and rates to infer long-term processes (Bull, 1964, Beaty, 1970, Beaty, 1974, and Hooke, 1967). Research by Hooke and

Rohrer (1979) used laboratory models of alluvial fan development explicitly stating that the scaling relationships to large fans are unknown.

Much of the alluvial fan literature examines depositional processes. Many alluvial fans studied in the literature provide evidence for debris flows (Beaty, 1974, Blissenbach, 1952, Wells and Harvey, 1987, Harvey, 1984, Hooke 1967 and Whipple and Dunne, 1994). Others point out that source area sediments and slopes determine the emplacement mechanisms. Wasson (1977) and Blair (1987) state that sheetflow can play a major role in fan development.

Terminology, process speculations and classification problems related to pediment development dominate the pediment literature. Confusion in pediment terminology prompted Whitaker (1979) to write a paper on the definition of a "pediment". Oberlander (1974) concluded that pediment formation in the Mojave Desert probably occurred in the Tertiary. Oberlander did not include any of his own data and his paper is quite speculative. Denny (1967) compares alluvial fans and pediments describing the main distinction as the depositional nature of fans and erosional nature of pediments. Doehering (1970) reports that it is possible to distinguish between alluvial fans and pediments by solely using a statistical analysis of topographic maps.

4.2 Cosmogenic Isotopes

Cosmic rays penetrate the Earth's atmosphere and bombard rock and sediment producing cosmogenic ^{10}Be and ^{26}Al. Differences in the latitude, the altitude and the depth of samples, affect the production rates of cosmogenic isotopes (Lal, 1991). As sediment moves down the apron surface, it is dosed by cosmic radiation producing ^{26}Al and ^{10}Be. As sediment is buried during transport, cosmic rays will continue to produce isotopes at depth, although production rates fall off exponentially below the surface (Figure 2).

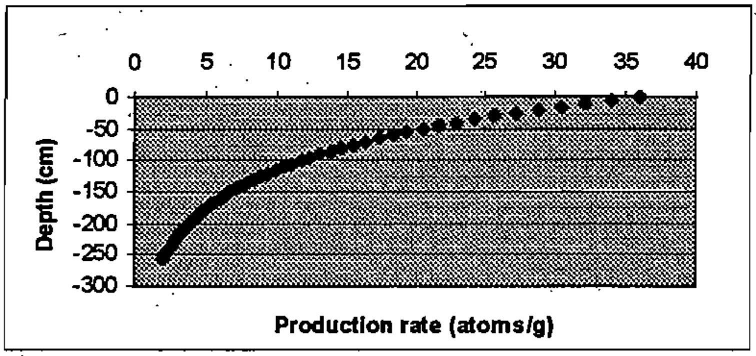

Figure 2: Production rate as a function of depth using a standard ^{26}Al production rate (36 atoms/g) and sediment density (1.8 g/cm^3)

Although, the majority of the cosmogenic isotope literature involves bedrock surface exposure ages and bedrock erosion rates (e.g. Bierman, 1994, Kurz et al., 1990, Stone et al., 1996, and Nishiizumi et al., 1991), researchers recently have used cosmogenic ^{10}Be and ^{26}Al in sediment to determine basin erosion rates and sediment deposition histories (Bierman and Steig, 1996, Granger et al., 1996, Granger et al., 1997 and Anderson et al., 1996). Presently, Clapp (pers. comm.) is using ^{10}Be and ^{26}Al to constrain basin scale sediment generation rates and sediment residence times on hillslopes and alluvial fans. Nishiizumi (1992) has published an abstract on exposure histories of desert sands using ^{10}Be and ^{26}Al.

4.3 Previous research at Study Area

Camp Iron Mountain and Camp Granite have been the focus of ecological and geomorphological research (Prose 1985, Prose and Metzger 1985, and Prose et. al. 1987). Prose (1985) determined that soil compaction due to vehicle and tank traffic on-camps is significant compared to off-camp measurements. Prose (1985) also determined that single tank passes visually disturbed the soil 25 cm in depth and up to 50 cm laterally, encouraging accelerated soil erosion. Prose and Metzger (1985) concluded that military use of the lands altered drainage networks and altered plant succession. The aforementioned results demonstrate that military use has had some short term (decades) effect on geomorphology and plant communities.

5.0 Research Plan

5.1 Cosmogenic Isotope Transect Sampling

I will use both the Granite Mountain and the Iron Mountain sediment aprons to determine the long-term exposure history of surface sediment as function of distance away from the range front. Each sample will consist of sediment amalgamated from 20 locations on four-kilometer-long transects (Plate 1). Amalgamating the sediment from multiple sites will effectively average the isotope abundances along each transect. I will walk five transects on each sediment apron, at one-kilometer intervals successively farther from the range front (Plate 1). Two samples, collected from the mouths of two valleys at each range front, will provide the average isotope abundance of material entering the sediment apron. These mountain valley samples will allow me to estimate the erosion rate of the source basins and thus the sediment influx entering the sediment apron. I will collect seven samples form each sediment apron, making a total of 14 samples. The transects will be located so as to minimize human influences, by avoiding the Colorado River Aqueduct, powerlines, and roads.

5.2 Cosmogenic Isotope Pit Sampling

I will characterize the isotope abundance profile as a function of depth by digging two 1.5 m deep soil pits. One pit will be located above Camp Iron Mountain in order to characterize a profile free from human disturbance. The other pit will be located below Camp Iron Mountain in order to characterize a profile in a zone that may have been impacted by human disturbance. I will visually log the stratigraphy and soil development in each soil pit. I will sample each stratum, if possible. If the pits are homogeneous or there are more than eight distinctive strata I will use a 20 cm depth interval to determine sample locations. I will collect 8 samples from each soil pit, a total of 16 samples.

5.3 Topographic surveying

I will make precise maps (1 cm resolution) of 18 subplots (2500m^2) on the Iron Mountain sediment apron. To quantitate small-scale features of the sediment apron, I will map

- all drainages in six control plots in undisturbed areas
- all drainages in six plots influenced by human foot traffic on walkways
- all drainages in six plots influenced by vehicle traffic on roads within the camp

The data will be input to ArcView to characterize depths, orientations, and widths (a proxy for drainage area) of each channel. I will also use ArcView to calculate drainage densities and to calculate a probability density function for channel depth. The probability density function is of utmost importance as is will allow me to estimate the depth of sediment stirring caused by fluvial action on the apron surface. Statistical comparisons between the control plots and the disturbed plots will show whether human impact has changed the small-scale morphology of the sediment apron surface.

5.4 Sample Processing

I will separate pure quartz from the 30 sediment samples at the University of Vermont cosmogenic nuclide extraction laboratory as outlined in the laboratory web page (http://beluga.uvm.edu/geowww/cosmolab.html). Susan Nies, the extraction lab technician, will then extract Be and Al from the quartz. I will measure isotope ratios using the accelerator mass spectrometer at Lawrence Livermore National Laboratory (LLNL).

5.5 Data Interpretation

Sediment erodes off of the Granite and Iron Mountains and is transported across the sediment apron. There are three endmembers of sediment behavior on the sediment apron; the *steady state transport* case, where net sediment storage is equal to zero and the sediment mass flux onto the surface equals the sediment mass off the surface, the *aggradational* case, where incoming sediment flux exceeds outgoing sediment flux, and the *erosional* case, where incoming sediment flux is less than outgoing sediment flux. For illustrative purposes, I will assume steady state and examine the steady state transport case.

5.5.1 Estimates of the active layer or stirring depth

For modeling purposes, I define the active layer as the depth to which present geological processes mix the sediment. Estimating active layer thickness is crucial for determining the mass flux of sediment through the sediment apron. I will estimate active layer thickness using several independent methods. First, I will use ArcView to calculate a statistical distribution of active channel depths from my detailed control plot maps. Second, I will use the stratigraphy of the soil pits to identify the thickness of sediment that is well-stirred and exhibits the least soil development. Third, I will use the isotopic profiles from the soil pits to determine the active layer. A significant isotopic accumulation difference between the top two layers would suggest that the upper layer is the active layer; furthermore, the well-mixed active layer should have uniform isotopic abundances as a function of depth. All three methods are approximations and while they may not represent the long-term behavior of the sediment apron, each considers different time scales.

5.5.2 Sediment supply to sediment apron

The flux of material entering the sediment apron is controlled by erosion rate of the Granite and Iron Mountains. By measuring cosmogenic isotope accumulations in sediment shed from the bedrock mountains, it is possible to calculate long-term rates of erosion and sediment generation (Bierman and Steig, 1996, Granger, 1996 and Clapp, pers. comm.). I will use ^{10}Be and ^{26}Al in the four sediment samples collected at the range front of the Granite and Iron Mountains to calculate the rate at which they supply sediment to the adjacent aprons.

5.5.3 *Transport time across the sediment apron*

I will use two methods to calculate average sediment transport times across the sediment apron. First, I will consider isotope accumulation as a function of distance down apron (Figure 3). By approximating stirring depth, I can calculate cosmogenic based travel times.

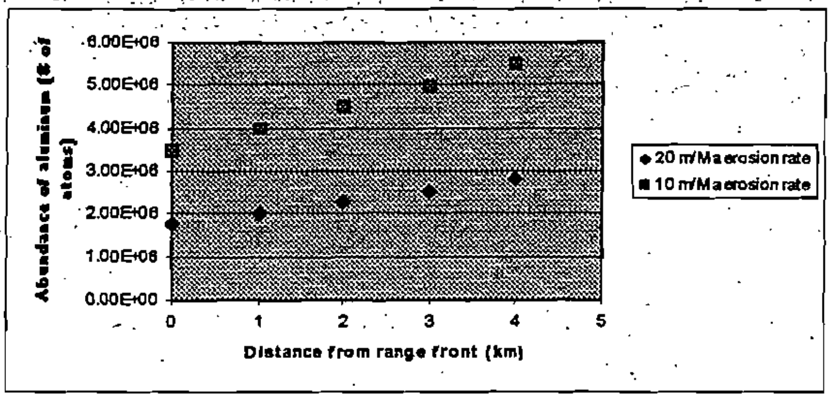

Figure 3: Isotope abundance as a function of distance from range front. Isotope abundance is a proxy for time. Graph shows two curves for different erosion rates of the source basins.

Second, I will assume that the sediment apron is a steady state surface of transport. I can calculate an average sediment residence time on the apron by using cosmogenically determined sediment influx rates (F_{in}), the length and width of the sediment apron, and the depth of the active layer (Figure 4).

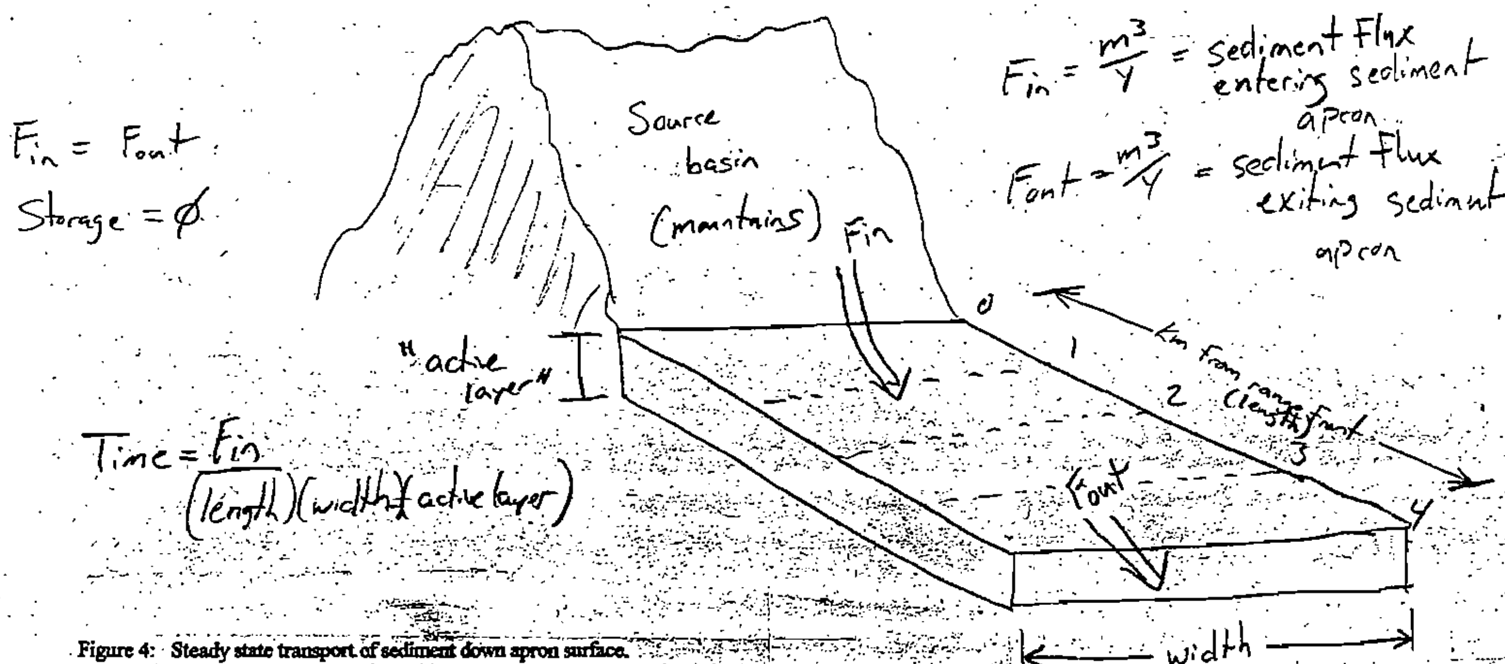

Figure 4: Steady state transport of sediment down apron surface.

5.5.4 Effects of Human impact

I will compare control plots with the human-influenced plots to determine whether there are small-scale differences in morphology. I will use ArcView to calculate statistical parameters (standard deviation and mean) of the small-scale geomorphology, including channel depth, orientation, channel width, drainage density, sinuosity, and gradient. I will use standard statistical tests, such as the t-test, to determine the significance of the observed differences between the plots.

6.0 Importance of Research

Most research concerning arid-region sediment surfaces has focused on alluvial fans, with less emphasis on pediment surfaces. Many researchers have tried to address the long-term behavior of arid-region sediment surfaces using various techniques. Using cosmogenic isotopes to determine long-term sediment histories on sediment aprons is a new approach to understanding, quantitatively, the behavior of such surfaces.

This project will also address how short-term human activity affects the small-scale geomorphology. This is significant because no other research has investigated the different temporal scales and different spatial scales in regards to sediment apron behavior.

References:

Anderson, R. S., Repka, J. L. and G. S. Dick. 1996. Explicit treatment of inheritance in dating depositional surfaces using in situ ^{10}Be and ^{26}Al. *Geology,* **24**, 47-51.

Beaty, C. B. 1970. Age and estimated rate of accumulation of an alluvial fan, White Mountains, California, U.S.A. *American Journal of Science,* **268**, 50-70.

Beaty, C. B. 1974. Debris flows, alluvial fans, and a revitalized catastrophism. *Zeitschrift fur Geomorphologie Supplementband,* 21, *39-51.*

Bierman, P. R. 1994. Using in situ produced cosmogenic isotopes to estimate rates of landscape evolution: A review from the geomorphic perspective. *Journal of Geophysical Research,* **99**, 13,885-13,896.

Bierman, P. and E. J. Steig. 1996. Estimating rates of denudation using cosmogenic isotope abundances in sediment. *Earth Surface Processes and Landforms*, **21**, 125-139.

Blair, T. C. 1987. Sedimentary processes, vertical stratification sequences, and geomorphology of the Roaring River alluvial fan, Rocky Mountain National Park. *Journal of Sedimentary Petrology,* **57**, 1-18.

Blissenbach, E. 1952. Relation of surface angle to particle size distribution on alluvial fans. *Journal of Sedimentary Petrology*, **22**, 25-28.

Bull, W. B. 1964. History and causes of channel trenching in western Fresno County, California. *American Journal of Science,***262**, 249-258.

Bureau of Land Management. 1984. Iron Mountain Divisional Camp Resource Management Plan, United States Department of the Interior, 63 pp.

Cooke, R. U. and Warren, A. 1973. *Geomorphology in Deserts.* University of California Press, Berkeley, 374 pp.

Denny, C. S. 1967. Fans and pediments. *American Journal of Science,* **265**, 81-105.

Doehring, D. O. 1970. Discrimination of pediments and alluvial fans from topographic maps. *Geological Society of America Bulletin,* **81**, 3109-3115.

Granger, D. E., Kirchner, J. W., and R. Finkel. 1996. Spatially averaged long-term erosion rates measured from in situ-produced cosmogenic nuclides in alluvial sediment. *Journal of Geology,* **104**, 249-257.

Granger, D. E., Kirchner, J. W., and R. Finkel. 1997. Quaternary downcutting rate of the New River, Virginia from differential decay of cosmogenic ^{26}Al and ^{10}Be in cave-deposited alluvium. *Geology,* **25**, 107-110.

Harvey, A. M. 1984. Debris flows and fluvial deposits in Spanish Quaternary alluvial fans: Implications for fan morphology. In Koster, E. H. and Steel, R. J. (Eds.), *Gravels and Conglomerates. Canadian Society of Petroleum Geologists Memoir*, **10**, 123-132.

Henley, D.C. 1989. *"The land that God forgot..." The saga of Gen. George Patton's Desert Training Camps.* Western American History Series, United States of America, 54 pp.

Hooke, R. L. 1967. Processes on arid-region alluvial fans. *Journal of Geology*, **75**, 438-460.

Hooke R. L. and Rohrer, W. L. 1979. Geometry of alluvial fans: effect of discharge and sediment size. *Earth Surface Processes,* **4**, 147-166.

Kurz, M. D., Colodner, D., Trull, T. W., Moore, R. B., and K. O'Brien. 1990. Cosmic ray exposure dating with in situ produced cosmogenic ^{3}He: results from young Hawaiian lava flows. *Earth and Planetary Science Letters*, **97**, 177-189.

Lal, D. 1991.Cosmic ray labeling of erosion surfaces, In-situ production rates and erosion models. *Earth and Planetary Science Letters*, **104**, 424-439.

Lecce, S.A. 1990. The alluvial fan problem. In Rachocki, A. H. and Church, M. (Eds.), *Alluvial Fans A Field Approach.* John Wiley & Sons, Chichester, 391pp.

Nilsen, T. H. and Moore, T. E. 1984. *Bibliography of Alluvial-Fan Deposits.* Geo Books, Norwich. 96 pp.

Nishiizumi, K. Kohl, C. P., Arnold, J. R. Klein, J. Fink, D. and R. Middleton. 1991. Cosmic ray produced ^{10}Be and ^{26}Al in Antarctic rocks: exposure and erosion history. *Earth and Planetary Science Letters*, **104**, 440-454.

Nishiizumi, K. 1992. Exposure histories of desert sands using cosmogenic nuclides. *EOS Transaction, AGU*, **73,** 185.

Oberlander, T. M. 1974. Landscape inheritance and the pediment problem in the Mojave Desert of southern California. *American Journal of Science*, **274**, 849-875.

Prose, D. V. 1985. Persisting effects of armored military maneuvers on some soils of the Mojave Desert.. *Environmental Geological Water Science*, 7, 163-170.

Prose, D. V. and Metzger, S. K. 1985. Recovery of soils and vegetation in World War II military base camps: Mojave Desert. *U.S. Geological Open-File Report*, 85-234, Reston.

Prose, D. V., Metzger, S. K. and H. G. Wilshire. 1987. Effects of substrate disturbance on secondary plant succession; Mojave Desert, California. *Journal of Applied Ecology*, **24**, 305-313.

Sheridan, D. 1979. *Off-Road Vehicles on Public Land.* U.S. Government Printing Office, 84pp.

Stone, J. Lambeck, K. Fifield, L. K., Evans, J. M. and R. G. Cresswell. 1996. A lateglacial age for the Main Rock Platform, western Scotland. *Geology*, **24**, 707-710.

Wasson, R. J. 1977. Late-glacial alluvial fan sedimentation in the lower Derwent Valley, Tasmania. *Sedimentology*, **24**, 781-799.

Wells, S. G. and Harvey, A. M. 1987. Sedimentologic and geomorphic variations in storm-generated alluvial fans, Howgill Fells, northwest England. *Geological Society of America Bulletin*, **98**, 182-198.

Whipple, K. and Dunne, T. 1992. Debris-flow fans in Owens Valley, California. *Geological Society of America Bulletin*, **104.**

Whitaker, C. R. 1979. The use of the term "pediment" and related terminology. *Zeitschrift fur Geomorphologie Supplementband*, **23**, 427-439.

Timeline to completion:

April 13, 1998-	* oral presentation of proposal
May 4-22, 1998-	* collect field data and samples from Iron Mountain and Granite Mountain sediment aprons
June-August 1998-	* prepare quartz from sediment samples * continue construction of Stella models * input topographic data in GIS * full summer salary supplied by the Army Research Office
September-November 1998-	* samples prepared by S. Nies * Complete GIS analysis of topographic data * run cosmogenic isotope samples on accelerator mass spectrometer at LLNL * prepare and present data at National GSA convention probably for a poster presentation
October 1998-	* submit written progress report * present oral progress report
November 1998- May 1999-	* write thesis document * Research assistantship supported by the Army Research Office
May 4, 1999-	* defend research