Quantifying Desert Surface Processes Using $^{10}$Be and $^{26}$Al

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What is a desert piedmont?
Three common types of desert piedmonts

A. Erosional

B. Depositional

C. Erosion | Transport | Deposition
Why should we care about piedmonts?

• Ubiquitous landforms in the American southwest (and in all deserts worldwide)
• Easily developed (low gradient, sediment cover easy to excavate)
• Greatly studied (100+ years), but long-term process rates are poorly quantified (slow rates of change)
Need to understand long-term piedmont processes (and short-term too!)

• Quantify long-term process rates to understand the background dynamics of piedmonts

• Quantify short-term processes to determine present day behavior of piedmonts

• Compare the rates to understand human impact on desert ecosystem
Yucca Mountain
Chemehuevi Mountain
East Range Road
Cosmogenic Nuclides

The isotopes are like a suntan.
Why use $^{10}$Be and $^{26}$Al?

- Target mineral is quartz, an abundant mineral on Earth.
- Production rates are well known (Nishizumi et al., 1989; Clark et al., 1995; Bierman et al., 1996; Larsen et al., in revision).
- Latitude and altitude corrections are well known (Lal, 1991; Dunai, 2000).
- Use as dosimeters to model near surface history.
$^{10}$Be and $^{26}$Al for desert piedmonts

- Measure $^{10}$Be and $^{26}$Al in sediment to quantify
  - sediment yield from source basins at top of piedmont
  - Sediment transport across piedmonts
  - Long-term surface histories (such as deposition) on piedmont (if any)
Depth profile of $^{10}$Be production in sediment
A Incised bedrock and alluvium

B Incised alluvium

12 km
Field Methods

- Three types of samples
  - Source basin sample
  - Transect samples
  - Soil pit samples

- Provides a 4-D look into piedmont processes
Source basin samples
Transect Samples

- Ephemeral Channels
- Incised alluvium
- Bedrock
- Colluvium
Logistical nightmare
Soil pit sampling
Shallow Soil Pits
Active Transport Layer
Laboratory Methods

• Sieve sediment for 0.5 to 0.85 mm
• Separate quartz with HCl and HF/Nitric acid baths
• Dissolve quartz and extract Be and Al
• Analyze for ratios ($^{10}$Be:$^{9}$Be and $^{26}$Al:$^{27}$Al) at LLNL on AMS
Chemehuevi Transect Samples

$y = 0.29x + 1.41$

$R^2 = 0.98$

Distance from mountain front (km)

$^{10}$Be activity ($10^5$ atoms g$^{-1}$)

Ephemeral channel sediment
Chemehuevi Transect Samples

$y = 0.29x + 1.41$

$R^2 = 0.98$

$^{10}\text{Be}$ activity ($10^5$ atoms g$^{-1}$) vs. Distance from mountain front (km)

Incised alluvial sediment

$y = 0.29x + 1.41$

$R^2 = 0.98$
Chemehuevi Transect Samples

$y = 0.29x + 1.41$

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Distance from mountain front (km)

$^{10}$Be activity ($10^5$ atoms g$^{-1}$)

Bedrock and colluvium sediment
Chemehuevi Transect
Samples

$y = 0.29x + 1.41$

$R^2 = 0.98$

$10^5$ Be activity (atoms g$^{-1}$)

Distance from mountain front (km)

Sawtooth Range sediment
Deposition signature

Sediment from uplands

Depth (cm)

$^{10}\text{Be}$ activity (atoms g$^{-1}$)

Fixed location - constant $^{10}\text{Be}$ inventory

Active layer
Deposition signature

$^{10}$Be activity (atoms g$^{-1}$)

Sediment

Depth (cm)
Deposition signature

$^{10}\text{Be activity (atoms g}^{-1}\text{)}$

Sediment

Depth (cm)
Deposition signature

$^{10}\text{Be}$ activity (atoms g$^{-1}$)

Sediment

Depth (cm)
Deposition signature

$^{10}$Be activity (atoms g$^{-1}$)

Sediment

Depth (cm)
Hiatus in deposition

$^{10}\text{Be}$ activity (atoms g$^{-1}$)

Sediment

Depth (cm)
Deposition signature

$^{10}\text{Be}$ activity (atoms g$^{-1}$)

Sediment

Depth (cm)

$y = 0.29x + 1.41$

$R^2 = 0.98$

Distance from mountain front (km)

$^{10}\text{Be}$ activity ($10^5$ atoms g$^{-1}$)
Deposition signature

$^{10}$Be activity (atoms g$^{-1}$)

Higher $^{10}$Be activity

Sediment

Depth (cm)
Deposition signature

$^{10}\text{Be activity (atoms g}^{-1}\text{)}$

Higher $^{10}\text{Be activity}$

Sediment

Depth (cm)
Deposition signature

$^{10}\text{Be activity (atoms g}^{-1}\text{)}$

Sediment

Depth (cm)

Higher $^{10}\text{Be activity}$
Deposition signature

$^{10}\text{Be}$ activity (atoms g$^{-1}$)

Sediment

Depth (cm)

Higher $^{10}\text{Be}$ activity
CP2 - wash surface
12 km from mountain front
Rapid deposition followed by stable surface

$^{10}\text{Be}$ activity (atoms g$^{-1}$)

Depth (cm)
Rapid deposition followed by stable surface

$^{10}\text{Be}$ activity (atoms g$^{-1}$)
CP1 - proximal surface
6 km from mountain front
Soil Pit comparison

- Deposition 18 mm ky$^{-1}$ from 70 to $\sim$34 ky ago piedmont wide (both soil pits)
- Erosion of alluvial sediment $\sim$34 ky ago (CP1)
- Increased deposition rates (37 mm ky$^{-1}$) on wash surface and higher nuclide activities $\sim$34 ky ago (CP2)
- Change from sediment deposition to transport on wash surface $\sim$ 8 ky ago
Model Equation

Sediment in

Sediment in erosion

Sediment deposition

Sediment out
Chemehuevi Ephemeral Channel Samples

$y = 0.29x + 1.41$

$R^2 = 0.98$

$^{10}\text{Be}$ activity ($10^5$ atoms g$^{-1}$)

Distance from mountain front (km)
Sediment velocities

\(^{10}\text{Be} \text{ activity (10}^5 \text{ atoms g}^{-1})\)

Distance from mountain front (km)

8 cm y\(^{-1}\)

39 cm y\(^{-1}\)
Iron and Granite Mountain piedmonts
Chemehuevi vs. Iron and Granite

Normalized $^{10}$Be activity ($10^5$ atoms g$^{-1}$)

Distance from mountain front (km)

Points: CM, P, SR, IA, WS

Chemehuevi

$^{10}$Be = 0.20x + 0.96

$R^2 = 0.97$
Chemehuevi vs. Iron and Granite

1. Chemehuevi
   \[ ^{10}\text{Be} = 0.20x + 0.96 \]
   \[ R^2 = 0.97 \]

2. Granite
   \[ ^{10}\text{Be} = 0.28x + 0.80 \]
   \[ R^2 = 0.99 \]

Distance from mountain front (km)
Normalized \(^{10}\text{Be}\) activity
\((10^5 \text{ atoms g}^{-1})\)

- CM
- P
- SR
- IA
- WS
Chemehuevi vs. Iron and Granite

1. Chemehuevi
   \[ {^{10}\text{Be}} = 0.20x + 0.96 \]
   \[ R^2 = 0.97 \]

2. Granite
   \[ {^{10}\text{Be}} = 0.28x + 0.80 \]
   \[ R^2 = 0.99 \]

3. Iron
   \[ {^{10}\text{Be}} = 0.31x + 1.11 \]
   \[ R^2 = 0.98 \]

Normalized \(^{10}\text{Be}\) activity (\(10^5\) atoms g\(^{-1}\))

Distance from mountain front (km)
Iron and Granite Mountain piedmonts

- Simple surface (no incision, channels migrate similar to distal Chemehuevi Mountain piedmont)
Iron and Granite Mountain piedmonts

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- Deposition rates 17 to 37 mm ky$^{-1}$ (same as Chemehuevi Mountain piedmont)
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- Depositional hiatus at Holocene-Pleistocene climate transition (~10 ky ago)
Iron and Granite Mountain piedmonts

- Simple surface (no incision, channels migrate similar to distal Chemehuevi Mountain piedmont)
- Deposition rates 17 to 37 mm ky\(^{-1}\) (same as Chemehuevi Mountain piedmont)
- Depositional hiatus at Holocene-Pleistocene climate transition (~10 ky ago)
- Sediment velocities are decimeters per year
Conclusions

• Sediment velocities are not dependent on piedmont morphology (simple vs. complex)
East Range Road
Upper Surface
East Range Road
Wash Surface
Source Basin Sample
Three common types of desert piedmonts

A. Erosional

B. Depositional

C. Erosion | Transport | Deposition
Uplands supply (ERV-UB)
3.62 x 10^4 kg y^{-1} km^{-2}

Eroding piedmont (gray)
supplies (ERV-P)
1.31 x 10^4 kg y^{-1} km^{-2}

Mixed sediment from uplands
and piedmont (ERV-LB)

Distributaries on wash surface: no significant sediment input
Transect data

$^{10}\text{Be} \left(10^5 \text{ atoms g}^{-1}\right) = 0.50x + 6.1$

$R^2 = 0.94$

Distance from uplands (km)

$^{10}\text{Be}$ activity

ERV-LB
ERV-P
ERV-UB

$^{10}\text{Be} \left(10^5 \text{ atoms g}^{-1}\right) = 0.50x + 6.1$

$R^2 = 0.94$
Rapid deposition followed by stable surface

$^{10}$Be activity (atoms g$^{-1}$)
Rapid deposition followed by stable surface

$^{10}$Be activity (atoms g$^{-1}$)

Depth (cm)
$^{10}\text{Be}$ activity ($10^5$ atoms g$^{-1}$)

Depth (cm)

EP1

76 ky
No nuclide dependence with depth!
$^{10}$Be activity ($10^5$ atoms $^{-1}$)

Depth (cm)

- 7 to 10 ky
- 15 to 25 ky
- 40 – 150 mm ky$^{-1}$
- 80 – 100 mm ky$^{-1}$
- 20 ky
- 7 to 10 ky
Distance from uplands (km)

$^{10}$Be activity ($10^5$ atoms g$^{-1}$)

- $8$ cm y$^{-1}$
- $23$ cm y$^{-1}$
Conclusions

• Sediment velocities are not dependent on piedmont morphology (simple vs. complex)
• Sediment velocities are the same for undisturbed and disturbed piedmonts
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• Large-scale structural controls do not affect long term process rates
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• Sediment velocities are not dependent on piedmont morphology (simple vs. complex)
• Sediment velocities are the same for undisturbed and disturbed piedmonts
• Large-scale structural controls do not affect long term process rates
• Quantify baseline process rates on disturbed piedmonts
What effect do Army tanks have on sediment movement?
Long-term vs. Short-term

- Long-term sediment movement based on cosmogenic nuclides is 8 to 23 cm y$^{-1}$
Long-term vs. Short-term

• Long-term sediment movement based on cosmogenic nuclides is 8 to 23 cm y$^{-1}$

• Contemporary measurements suggest sediment movement is 80 cm y$^{-1}$
Long-term vs. Short-term

- Long-term sediment movement based on cosmogenic nuclides is 8 to 23 cm y\(^{-1}\)
- Contemporary measurements suggest sediment movement is 80 cm y\(^{-1}\)
- Disturbance by tanks, trucks, and troops increases sediment movement from 4 to 10 fold!
Conclusions

- Sediment velocities are not dependent on piedmont morphology (simple vs. complex)
- Sediment velocities are the same for undisturbed and disturbed piedmonts
- Quantify baseline process rates on disturbed piedmonts
- Large-scale structural controls do not affect long term process rates
- Contemporary sediment movement rates can be up to 10 fold greater than baseline rates on disturbed piedmonts
Acknowledgements

- Funding from DEPSCoR grant #DAAD199910143 and the Jonathan O. Davis and J. Hoover Mackin scholarships
- Ruth Sparks and the ITAM crew at Ft. Irwin for logistical support
- Needles BLM crew for Chemehuevi soil pits
- Missy Eppes for soils descriptions
Thanks Lyman!
Thanks Paul!