May 23, 2018

Planning Commission for San Bernardino County
c/o Ms. Linda Mawby
County of San Bernardino Government Center
385 North Arrowhead Avenue
San Bernardino, California 92415
Sent by email: Linda.Mawby@lus.sbcounty.gov

COMMENT: Draft Renewable Energy and Conservation Element

FOR THE ADOPTION OF THE ORIGINAL POLICY 4.10 AND ITS SUBPOLICIES

As stated in our comment dated August 8, 2017: Since 2009, the Scenic 247 Committee of the Homestead Valley Community Council has commented on every proposal for any renewable energy project that affected the communities and landscape through which State Route 247 travels.

We opposed every one.

As Land Use Services staff well knows:

S.R.247 is eligible for State Scenic Highway status.

Civic, recreational and environmental organizations, as well as tourism destinations, have signed on as sponsors of the Scenic 247 campaign.

Please see this link to the California Department of Transportation website:

http://www.dot.ca.gov/ser/vol1/sec3/community/ch27via/chap27via.htm#scenic

Under Chapter 27 - Visual & Aesthetics Review, we find two clear statements:

"The intent of the State Scenic Highway Program is to protect and enhance California's natural scenic beauty."

"If a highway is listed as eligible for official designation, it is also part of the Scenic Highway System and care must be taken to preserve its eligible status."

But the Renewable Energy and Conservation Element approved by the Board of Supervisors last August did not include Policy 4.10 as written, which would have had a beneficial effect on eligibility.

We respectfully submit for your review some language in the **Homestead Valley Community Plan** adopted in 2007.

The "alternative" Policy 4.10 recently composed by Land Use Services to be submitted to the Planning Commission on Thursday, May 24, ignores these clearly stated objectives and policies, and would erase all the time and money spent drafting them. Nothing in the recent Countywide effort negated the concerns of 2007:

Endorsed by:

Homestead Valley Community Council
www.hvccsite.org

Morongo Basin Historical Society
www.mbhs.org

Flamingo Heights
Community Association
www.fhca.com

Johnson Valley
Improvement Association
see www.johnsonvalley.com

Hammerking Productions
dave@kingofthehammers.com

Landers Association

Yucca Mesa
Improvement Association
www.yuccamesa.org

Western American Railroad Museum
www.barstowrailmuseum.org

Lucerne Valley
Chamber of Commerce

Lucerne Valley
Economic Development Association

Lucerne Valley Market & Hardware

Lucerne Valley Museum

Route 66 Mother Road Museum
www.route66museum.org

Joshua Tree
Gateway Communities
Tourism Committee
www.joshuatreegatewaycommunities.com

Points of Interest Promotions
Lucerne Valley
billlembright@thenewlight.net

Rockhound Field Trip Fanatics!
http://rockhound-field-trips.ning.com

Morongo Basin
Conservation Association
www.mbconservation.org

Lucerne Valley-Johnson Valley
Municipal Advisory Council

Barstow Chamber of Commerce
www.barstowchamber.com

Morongo Basin
Municipal Advisory Council

Julie Hackbarth-McIntyre
Mayor. City of Barstow

Excerpts from the Homestead Valley Community Plan adopted 2007 *Emphasis added*

1 INTRODUCTION (Page 7)

HV1.1 PURPOSE OF THE COMMUNITY PLAN

The primary purpose of the Homestead Valley Community Plan is to guide the future use and development of land within the Homestead Valley Community Plan area ***in a manner that preserves the character and independent identity of the community...***

HV1.3 COMMUNITY CHARACTER (Page 11)

HV1.3.1 UNIQUE CHARACTERISTICS

Homestead Valley is a rural community characterized by its ***scenic beauty, wide open spaces,*** and small town atmosphere.

HV2.1 LAND USE - INTRODUCTION (Page 13)

The purpose of the land use element is to provide goals and policies that address the unique land use issues of the Community Plan area that are not included in the County-wide General Plan. Land use, and the policies that govern it, contribute fundamentally to the character and form of a community. With the continuing growth in many of the County's rural areas, ***the importance of protecting valuable natural resources and preserving open space*** has become increasingly important to community residents.

HV2.2 GOALS AND POLICIES (Page 20)

Goal
HV/LU 1. Re***tain the existing rural desert character of the community.***

Policies
HV/LU 1.4 Limit future industrial development to those uses which are compatible with the Community Industrial District or zone, are necessary to meet the service, employment and support needs of the Homestead Valley area, ***do not have excessive water requirements, and do not adversely impact the desert environment***

3 CIRCULATION AND INFRASTRUCTURE (Page 23)

HV3.2 CIRCULATION - INTRODUCTION (Page 24)

Residents expressed concerns regarding traffic congestion, particularly traffic congestion on SR-247,but at the same time emphasized their primary concern, ***to maintain the rural character of the community.*** Improvements to the circulation system within the community will need to be ***compatible with the community's goal of maintaining the area's rural character and scenic and natural resources.*** Residents do not want to see urban improvements throughout the community such as sidewalks, excessive street lighting, etc.

C. Scenic Routes (Page 28)

Homestead Valley has some very outstanding desert scenery. Scenic Routes play an important role in the preservation and protection of environmental assets. Scenic Route designations recognize the value of protecting scenic resources for future generations and place restrictions on adjacent development including specific sign standards regarding sign placement and dimensions, utility placement, architectural design, grading, landscaping characteristics and vegetation removal.

SCENIC CALIFORNIA 247

Excerpts from the Homestead Valley Community Plan adopted 2007 (continued) *Emphasis added*

Homestead Valley contains one County Scenic Route, Old Woman Springs Road (SR 247).

Policies (Page 28)

HV/CI 1.4 ***Preserve the status of Old Woman Springs Road (SR-247) as a County Scenic Route and ensure protection of the views*** through the following methods:

A. Require compliance with the provisions of the Open Space Overlay.

B. Support hillside preservation regulations that include standards for hillside development to control densities, allowable cut and fill heights, soil and slope stability, grading and blending of contours, structural relationships and building foundations.

HV5.2 GOALS AND POLICIES

It is important to note that some of the key issues and concerns identified under Section 7.1 are also addressed in other elements of the community plan.

Goal

HV/CO 1. ***Preserve the unique environmental features of Homestead Valley,including native wildlife, vegetation, and scenic vistas.***

Policies

HV/CO 1.1 ***Encourage the greater retention of existing native vegetation for new development projects to help conserve water, retain soil in place and reduce air pollutants.***

HV/CO 1.2 ***Require future land development practices to be compatible with the existing topography,vegetation and scenic vistas.***

9 ECONOMIC DEVELOPMENT (Page 57)

HV 9.1 INTRODUCTION

As has been repeated throughout the various elements included within this community plan, one of the most important goals of the Homestead Valley community is to protect their rural desert character. ***It will be important to ensure that future development protects and enhances the natural resources, scenic beauty and character*** in order to continue to appeal to residents.

The process that drafted the “alternative” RECE Policy 4.10 never consulted the residents burdened with industrial renewable energy projects. We live in the desert. We have never seen it as “unused land” to be destroyed in the service of urban areas or absentee renewable energy investors. Please consider the words quoted above, the legacy of many people who loved this countryside as much as we do now. They inspired our campaign for Scenic Highway 247 to benefit our disadvantaged communities. Let’s not throw away a unique regional asset in favor of a major blight. ***Keep the original Policy 4.10 as written.***

Betty Munson
Chair

SCENIC 247 COMMITTEE • 51720 Hacienda Rd.#247, Johnson Valley, CA 92285 • www.scenichighway247.com
A committee of the Homestead Valley Community Council

May 22, 2018

(Sent by email: Linda.Mawby@lus.sbcounty.gov)
Planning Commission for
San Bernardino County
c/o Ms. Linda Mawby
County of San Bernardino Government Center
Covington Chambers- First Floor
385 North Arrowhead Ave.
San Bernardino, Calif. 92415

Re: Policy 4.10 of the RECE

Dear Members of the Planning Commission,

I am a member of The Alliance for Desert Preservation, Morongo Basin Conservation, Sierra Club, Friends of Juniper Flats and San Bernardino Chapter of Audubon Society. I was also a Stakeholder in the SPARC and REVEAL portions of the RECE. I am writing as an individual and not as a member of the above organizations.

I have read the 88 page comment letter dated May 21, 2018 from the coalition of community groups, businesses, agencies and individuals, and I subscribe and adopt all of the comments therein.

Sincerely,

Neil B. Nadler

8697 High Road

Lucerne Valley, Ca 92356

WPTF
Western Power Trading Forum

Submitted Via Electronic Mail to Terri.Rahhal@lus.sbcounty.gov

Tuesday, May 22, 2018

Ms. Terri Rahhal
Planning Director
San Bernardino County Government Center
385 N Arrowhead Avenue, First Floor
San Bernardino, CA 92415-0187

Dear Ms. Rahhal,

The Western Power Trading Forum (WPTF) appreciates the opportunity to offer comments on the San Bernardino County (County) Renewable Energy and Conservation Plan (RECE). WPTF is a broad-based membership organization dedicated to reducing the long-run cost of electricity to consumers throughout the region, and maintaining the current high level of system reliability at competitive prices. WPTF member companies have invested over 16 Billion in California.

As you are aware, the RECE has conducted an extensive process with engagement from multiple stakeholders. The WPTF and its members appreciate the efforts that have been put forth to ensure the County and its community members have the ability to make informed decisions regarding renewable energy development opportunities. Renewable energy projects have the ability to provide economic and community benefits that should be considered by the County decisions makers for each project.

WPTF would like to recommend that additional clarifications be made to the RECE. Specifically, please consider the following:

Adopted Community Plans Consistency Determinations: Policy 4.10.1 suggests that projects will need to be consistent with the adopted community plan in which a project is located:

> *"If the project site is located within the boundaries of an adopted community plan, include an analysis of consistency with community values and aspirations outlined in the community plan".*

WPTF urges that this policy be revised to remove the requirement that a project needs to be consistent with the local community plan. The purpose of the community compatibility report is to identify what community benefits would be included in the proposed development to make an informed decision. Consistency determinations with the applicable adopted community plan policies is a land use policy decision, which is not appropriate for evaluation in the community compatibility report. Accordingly, we urge the following change be made to Policy 4.10.1 be revised as follows:

Western Power Trading Forum
1121 L Street, Suite 700
Sacramento, California 95814

"~~If the project site is located within the boundaries of an adopted community plan,~~ Include ~~an~~ <u>summary</u> ~~analysis~~ of consistency with community values and aspirations ~~outlined in the community plan~~".

<u>Projects Deemed Completed To Date</u>: Please ensure as previously proposed in Section 3 of the resolution 2017-167, applications for development that the County has already deemed complete be processed in compliance with the policies and regulations in effect at the time the application was accepted as complete in accordance California Government Code Section 65943.

<u>Policy 5.9</u>: The Staff Report dated May 24, 2018 includes a new policy based on discussions between County Staff and the California Energy Commission (CEC). Based on those discussions Staff recommended additional RECE Policy 5.9 to increase collaboration with CEC and BLM to encourage siting energy development projects on public lands in order to relieve the pressure from siting projects on private lands. Extensive planning efforts led by the CEC via the Desert Renewable Energy and Conservation Plan (DRECP) process has identified public lands suitable for renewable energy development on public lands.

Policy 5.9 should be clarified to state County Staff will implement this Policy and it is not a responsibility of the project applicant. It also should be further clarified that potential outcomes of these efforts will not impact the merits of a given project and rather each project located on private lands is subject to applicable County ordinances. Accordingly, WPTF urges that Policy 5.9 be revised as follows:

> *RE Policy 5.9: <u>County Staff will</u> collaborate with utilities, the California Energy Commission (CEC) and the Bureau of Land Management (BLM) to plan for RE generation facilities to be located on public lands, apart from existing unincorporated communities.*

WPTF and its member companies appreciate the efforts put forward by County Staff to ensure future renewable energy generation within the County is completed in an environmentally responsible manner, while providing economic benefits to the communities within the County.

Sincerely,

Jesús Arredondo
Western Power Trading Forum

May 23, 2018

Linda.Mawby@lus.sbcounty.gov

From: Pat Flanagan

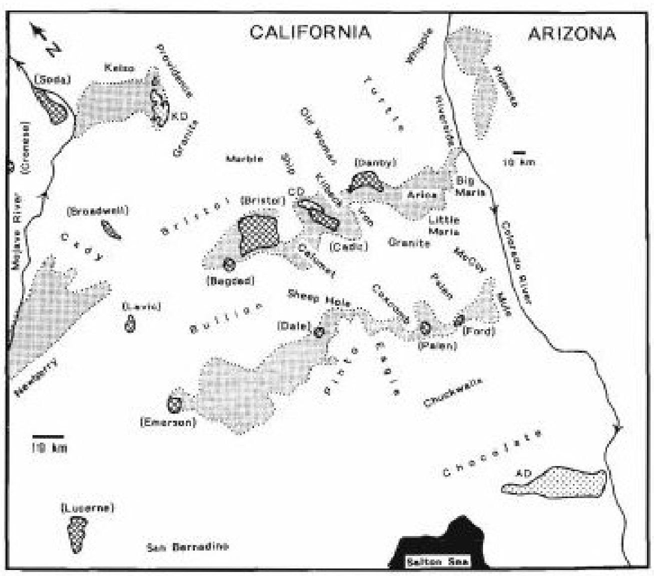
Re: Policy 4.10

To: Planning Commission

In 1983 I was the biologist on site at the experimental Solar One Power Tower facility in Daggett California. My job was to walk the field of solar panels and survey the adjacent cooling ponds for birds - living and dead. During my time there I noticed the dust rising from agricultural fields swirling around the Barstow-Daggett Airport. That was my introduction to the soils of this area.

I moved to 29 Palms in 2002 and since the installation of the Cascade Solar in Joshua Tree and 3 facilities in 29 Palms in 2013 have become very familiar with problem of blowing dust. Turns our I live on what is called a Sand Transport Path and continuing research shows that there are several such areas in the East Mojave Desert. The study that I find most informative is the study Sand Transport Paths in the Mojave Desert by Zimbelman et. al. (attached) because their map shows not only the active paths but also the areas stabilized by vegetation. See below.

Figure 1. (b) Simplified sketch map of the area shown in Figure 1a. Selected playas (gridded pattern, names in parentheses), mountains (names listed at appropriate location), and rivers (arrows show direction of flow) are labeled for reference. Sand deposits are shown in dotted patterns; the open pattern represents active (relatively unvegetated) dunes (KD = Kelso Dunes, CD = Cadiz Dunes, AD = Algodones Dunes) and the dense pattern represents inactive (stabilized by vegetation) deposits. Note that foreshortening due to the oblique viewing geometry causes horizontal scale variations across the area.



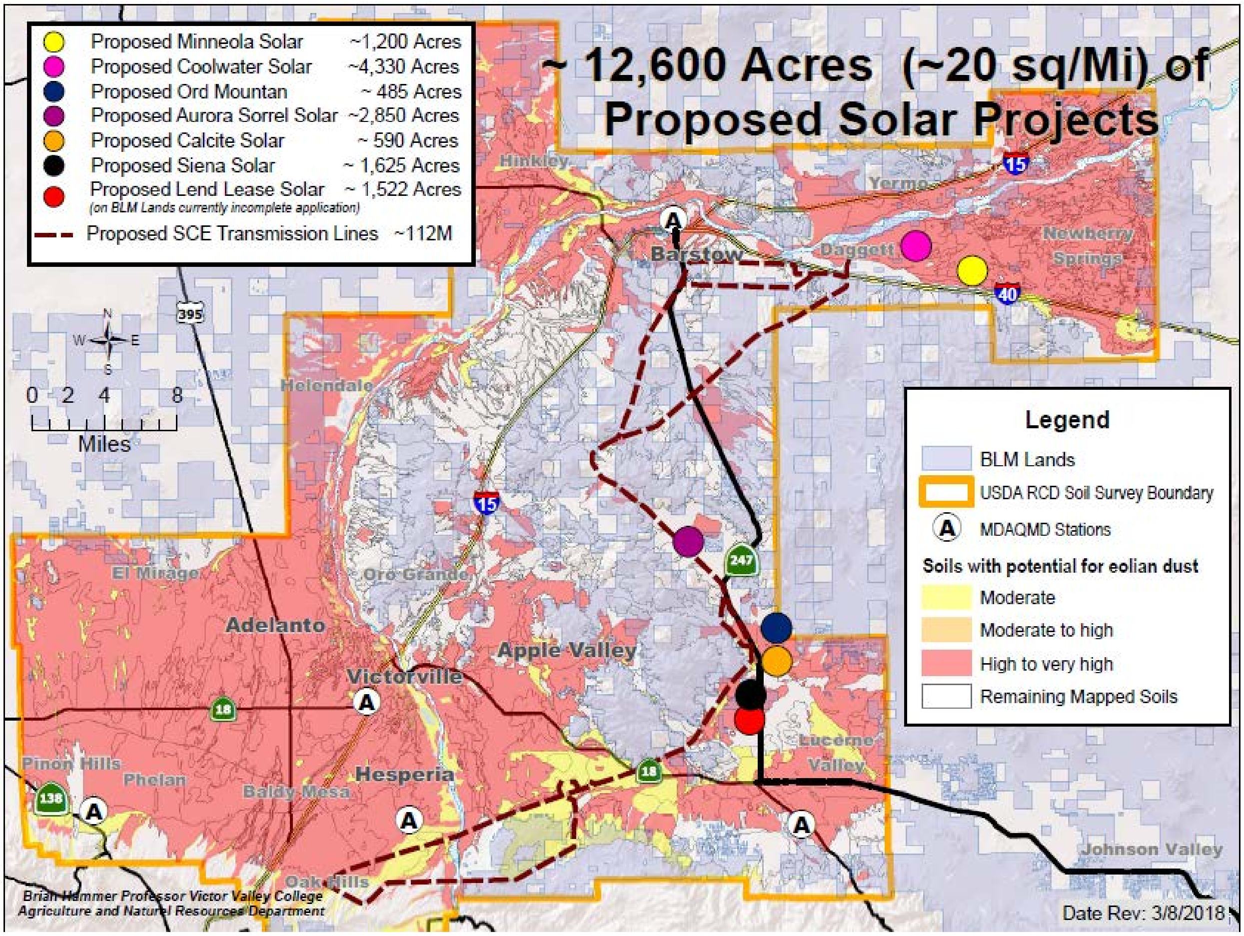
On this map from the Zimbelman study Emerson Lake is the source area for the Joshua Tree 29 Palms area and the Sand Transport Path extends nearly to the Colorado River. The Lucerne Valley dry lake area is also an active area and, including its downwind neighbor Johnson Valley, feeds dust into the Morongo Basin.

The US Geological Survey report on the geology and geography of large-footprint energy installations in the Mojave Desert, California (2012 attached). They conclude that *[about 48% the entire area is less than 5% slope, and 8.3% is less than 1% slope, the favored slope category for large footprint solar installations. For these lowest slope categories deposits underlying about 98% of the area are of either mixed eolian-alluvial origin are fine grained alluvial deposits, and are susceptible to eolian dust and sand transport, especially after disturbance.*

These favored low slope areas have been attractive for homesteading and early colonization based on agriculture and mining. These low areas are today frequently zoned Rural Living and have community plans to guide their development and economy. The low slope areas include Joshua Tree, Lucerne Valley, Daggett and Newberry Springs. These areas are mapped as sand transport paths. Unfortunately, and unlike the more urban areas of the County, these areas are not monitored for fugitive dust, also known as PM10 and PM2.5. There are, however, multiple incidents when winds exceed 15-20 mph that fugitive dust reaches levels detrimental to human health. Comment letters for this hearing provide many photos of dust events including the link to Ted Stimpfel's YouTube video.

The map below shows soils with the potential for blowing dust within the USDA Soil Survey boundary. The map includes the proposed solar projects within Lucerne Valley, Daggett, and Newberry Springs. At this time the MDAQMD's Fugitive Dust Rule 403.2, adopted in 1996, which is applicable to urban development, does not apply. It is up for revision in 2018. This means that dust mitigation for these projects is not assured, if even possible.

There is every reason, for the health of community citizens, the environment, and the economy to Prevent Utility-Scale Solar Development, which will scrape thousands of acres of land releasing sand and dust, from being built in these unincorporated areas.



Proposed Minneola Solar ~1,200 Acres
Proposed Coolwater Solar ~4,330 Acres
Proposed Ord Mountan ~ 485 Acres
Proposed Aurora Sorrel Solar ~2,850 Acres
Proposed Calcite Solar ~ 590 Acres
Proposed Siena Solar ~ 1,625 Acres
Proposed Lend Lease Solar ~ 1,522 Acres
(on BLM Lands currently incomplete application)
Proposed SCE Transmission Lines ~112M
~ 12,600 Acres (~20 sq/Mi) of Proposed Solar Projects
Legend
BLM Lands
USDA RCD Soil Survey Boundary
MDAQMD Stations
Soils with potential for eolian dust
Moderate
Moderate to high
High to very high
Remaining Mapped Soils
0 2 4 8
Miles
Hinkley
Yermo
Barstow
Daggett
Newberry Springs
Helendale
El Mirage
Oro Grande
Adelanto
Apple Valley
Victorville
Lucerne Valley
Pinon Hills
Phelan
Baldy Mesa
Hesperia
Oak Hills
Johnson Valley
Brian Hammer Professor Victor Valley College Agriculture and Natural Resources Department
Date Rev: 3/8/2018

Assessing the geology and geography of large-footprint energy installations in the Mojave Desert, California and Nevada

David R Bedford and David M Miller
U.S. Geological Survey, 345 Middlefield Road, MS-973, Menlo Park, CA 94025

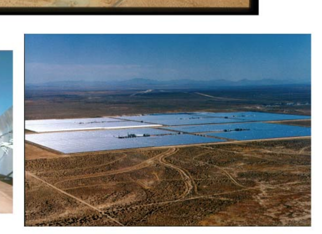
Abstract

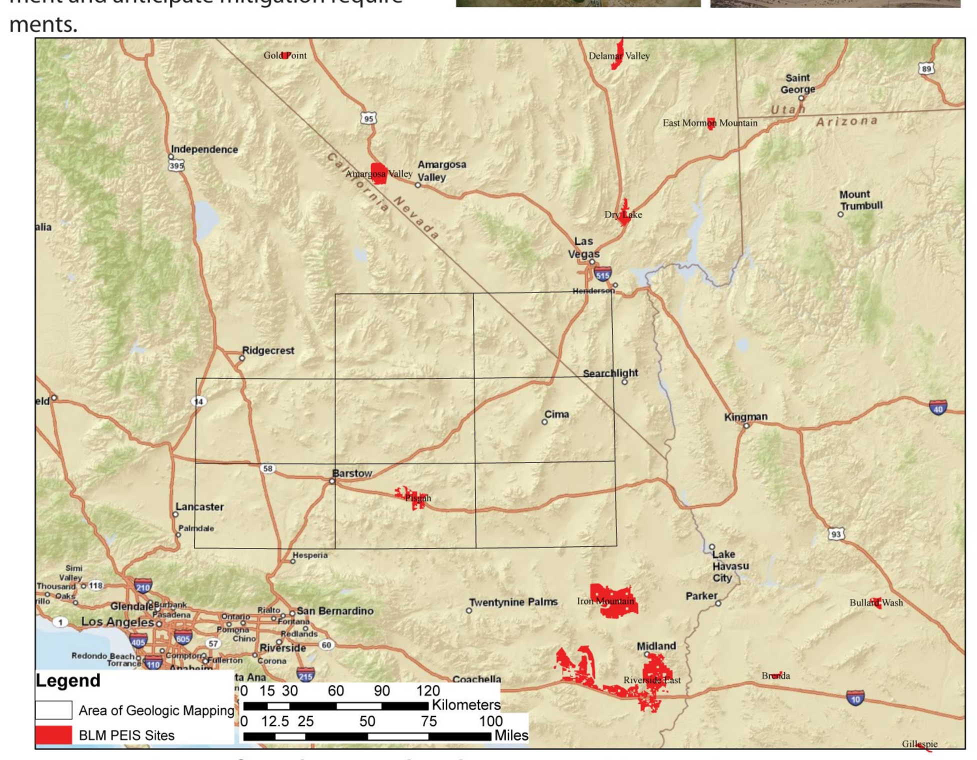
Large-footprint energy installations such as solar and wind farms are proposed for wide areas of drylands that are publicly owned. These installations impact areas of 400 to 2000 hectares each, requiring land-use assessments that are novel compared to past decisions for relatively small installations such as mine sites and roadways. Solar installations require low-gradient smooth topography, areas for which we have several data sets that can help with evaluations.
We use topography (30 m DEMs) and surficial geology (1:100,000 scale) for an area of 40,400 km2 stretching from Lancaster and Mojave on the west to Jean, NV, and Goffs, CA, on the east to evaluate potential lands for solar energy installations. The geology was mapped using uniform methods across the northern Mojave Desert so that a consistent database is available for analytical purposes. We use slope categories, surficial geology attributes, and land ownership to describe this area in a series of maps.
About 48% of the entire area is less than 5% slope, and 8.3% is less than 1% slope, the favored slope category. For this lowest-slope category, deposits underlying about 98% of the area are either mixed eolian-alluvial origin or are fine-grained alluvial deposits, and thus are susceptible to eolian dust and sand transport, especially after disturbance. In addition, in this low-slope category, 89% of the area is susceptible to flooding, based on the age and geomorphology of alluvial deposits. These maps are examples of several we present for decision-making with respect to hazards and ecological attributes in the face of climate change.

Overview

The Mojave Desert have been identified as an area with ample space and many of the resources needed for alternative energy development. Responding to recent interests in alternative energy, the BLM has received thousands of applications for large, utility-scale alternative energy developments. To assess the impacts of alternative (predominately solar and wind power) energy, the BLM has established Programmatic Environmental Impact Statement (PEIS) study sites. These sites will be used to develop management plans for the currently identified areas as well as other areas that may be potentially permitted for large energy developments.

These facilities typically require flat to very gently sloping topography and have a large footprint of disturbance. The goal of this poster is to identify how surficial geologic information can help guide site placement and anticipate mitigation requirements.



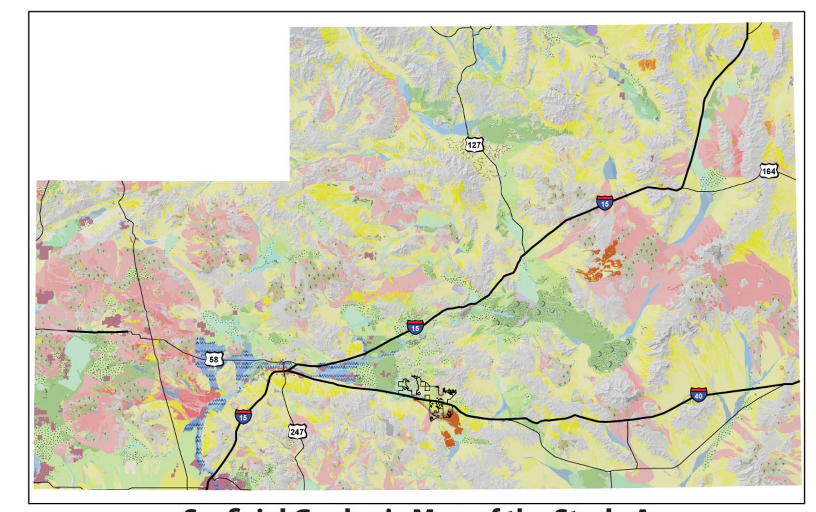


Area of analysis in the three-state Mojave Desert region.
BLM-designated PEIS sites are also shown

Geologic Mapping

USGS collected and organized surficial geology data for the 8-quadrangle area we analyzed. The database was collected at scales more detailed than 1:100,000, and generalized to that scale. This scale roughly corresponds to the 30-m DEM and Landsat resolution. The effort was organized so that resulting 8 databases are uniform and robust, resulting in a geospatial database covering a broad tract of the Mojave Desert Ecoregion. An example of a published data base is Bedford et al. (2010). Surficial geology attributes include parent material, thickness, grain size, soil development, age, and geomorphic process of deposition (or erosion). These attributes allow the database to be used for many applications such as soil hydrology, susceptibility to erosion, estimations of plant cover and plant species composition, and susceptibility to flooding (Miller et al., 2009). The database also includes point measurements of a number of soil and geomorphic properties that were not used in this study.

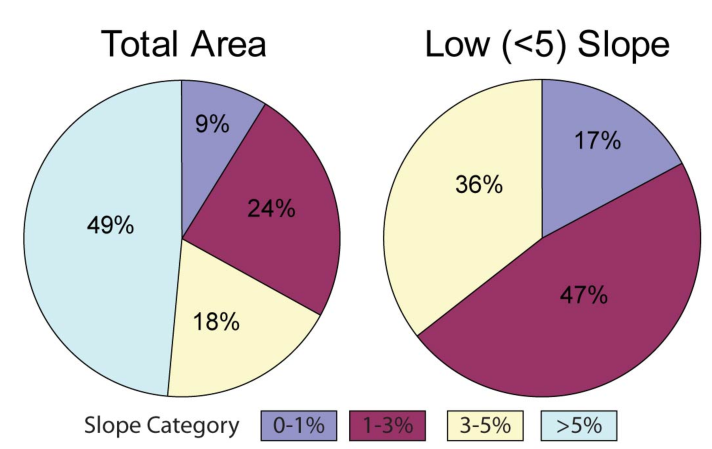
This database contains information similar to the detailed NRCS soil maps, but in addition carries geomorphic process information. The process information is powerful for applying the database to several uses. For instance, the knowledge that a polygon is typified by active alluvial fan channels carries information about recency and frequency of flooding and when combined with topography, defines "downstream" directions that will be modified if the channels are disturbed by construction.

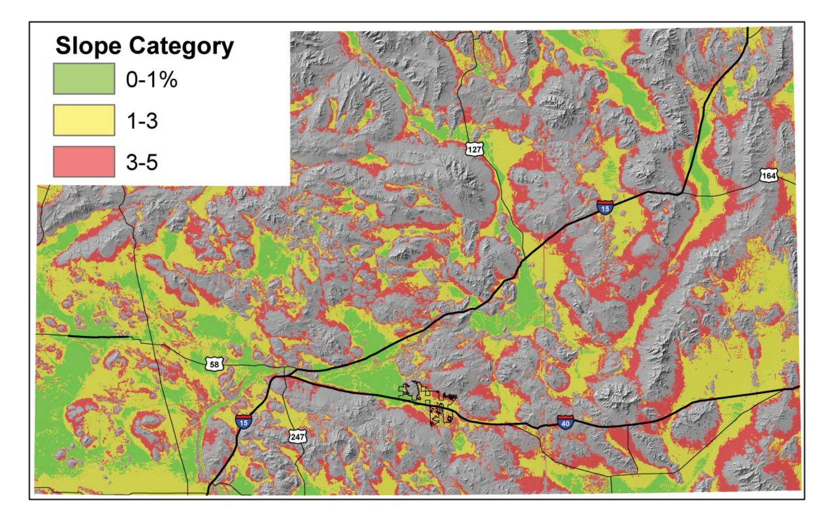


Surficial Geologic Map of the Study Area

Slope Analysis

We analyzed a 30-meter Digital Elevation Model (DEM) for areas of suitable slope. Solar energy facilities need to be sited on less than 5% slopes. To capture broad areas of similar slope, we smoothed the slope map calculated from the DEM using a 9x9 moving window. We then broke the slope map into 3 categories where facilities could be sited (0-1%, 1-3%, 3-5%) and a single category for unsuitable slopes larger than 5%.





Findings:

- About half the area is <5% slope, but only 9% is <1% slope, the favored category for installations.
- Of the <5% low-slope fraction, about half is 1-3% slope and one-third is 3-5%.
- The 0-1% slope area mainly occurs in and near playas and in the Mojave River plain.
- The 3-5% slope category tends to occur in upper piedmonts near their junctions with mountains; these areas are broader in the east than the west.

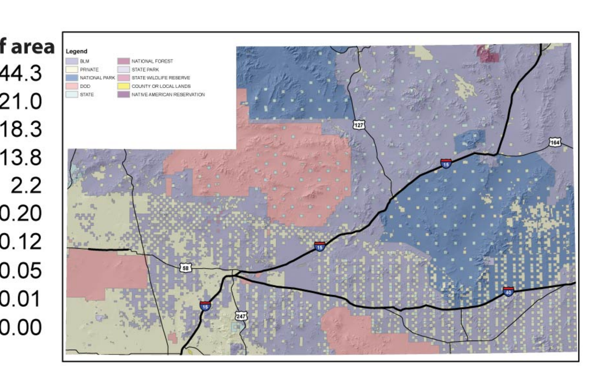
Land Ownership

We then wanted to know who owned the land across the study area. It is well known that much of the land is "off limits" for energy development (e.g. National Parks). We intersected an ownership map with the slope categories.

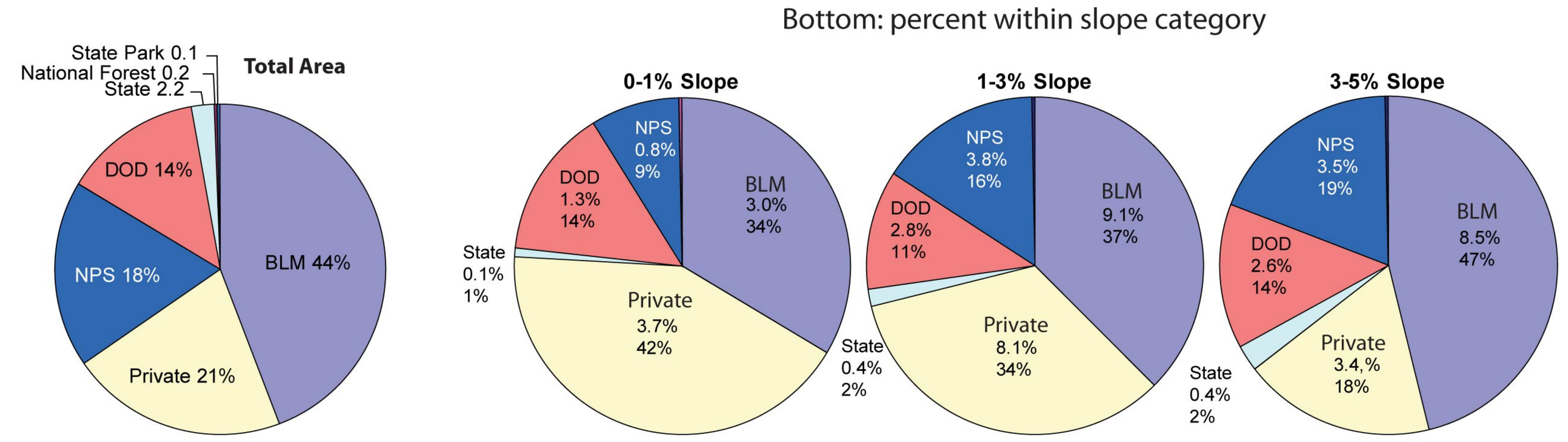
Assuming that only BLM and Privately held lands may be developed we can determine how much of the desert could be developed. Most of the area studied is managed or owned by the BLM and private landowners, respectively. Within the most suitable areas, determined by slope, this relation holds.

Example conclusion: The most suitable areas determined by slope (0-1%) make up only 9 percent of the study area. Within that area, 76% of the area could potentially be developed based on ownership.

Owner	Percent of area
BLM	44.3
Private	21.0
National Park	18.3
DOD	13.8
State	2.2
National Forest	0.20
State Park	0.12
State Wildlife Reserve	0.05
County or Local	0.01
Native Am. Res.	0.00



Ownership by slope category
Top number: percent of total area
Bottom: percent within slope category

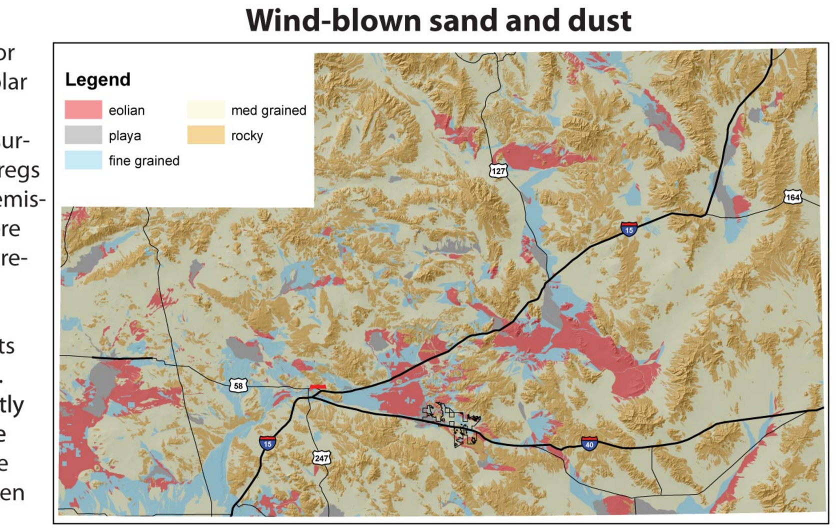


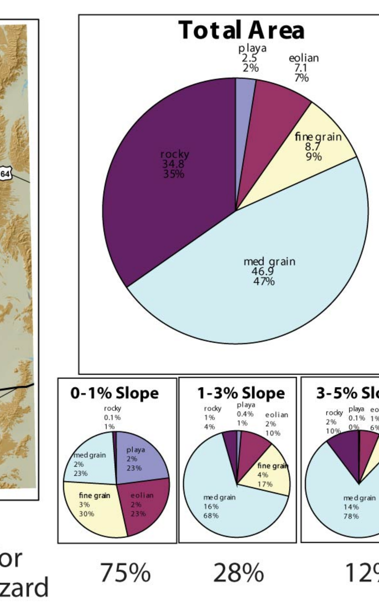
Geologic Influence on Energy Installations

We reclassified our geologic map into a few broad categories that are likely to be important to assess the impacts and functioning of alternative energy facilities.

Wind-blown sand and dust

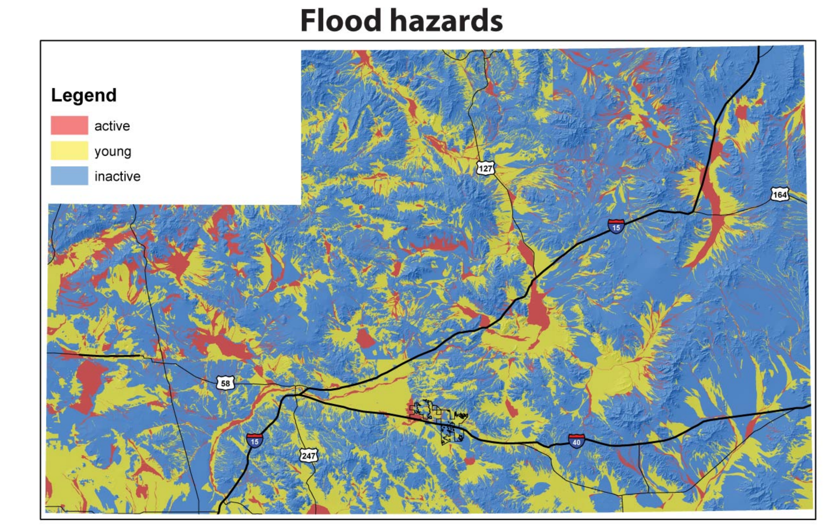
Wind-blown (eolian) sand and dust is a major hazard in arid regions and interferes with solar energy production and can greatly increase water (for cleaning) needs. Disturbance of surface biocrusts and plants, as well as pebble regs and pavements, exacerbate dust and sand emissions during storms; siting installations where eolian emissions are minimized should be preferred.
Our "eolian" category represents areas with modern or past eolian sand in the deposit; its disturbance can rapidly destabilize the soils. Playas are very fine grained and intermittently flooded, resulting in chemical crusts that are easily disrupted. Fine-grained deposits have potential for emissions of dust and sand when disturbed; lesser potential is probable for medium and rocky categories.





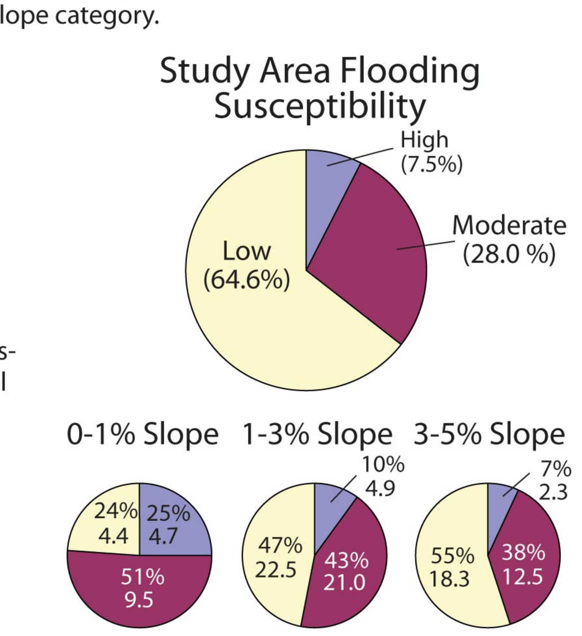
Susceptibility for **High** Eolian hazard

Flood hazards



Flood hazards on alluvial fans can be estimated with a knowledge of age of deposit, channel characteristics, and topography (House, 2005; Robins et al., 2008). Areas with active channels and deposits are intermittently active, whereas those with young deposits flood less frequently, during only the most extreme precipitation events or if channel hydrology is disturbed.

Results:
- Much of the area we identified as having favorable ownership and slopes have rocky to medium grained soils, which have low susceptibility to eolian hazard.
- A large proportion of the 0-1% slope category is composed of active and former eolian deposits, playa deposits, and fine-grained deposits. These three substrate types are the most susceptible to eolian emissions that affect the installations and downwind locations.
- The 1-3% slope category has much lower susceptibility to eolian hazards than the lowest slope category.



Results:
- Surficial geology with high flooding potential makes up only 6% of the total area with <5% slopes
- High flooding potential characterizes 25% of the area with 0-1% slope.
- High flooding potential characterizes 10% of the area with 1-3% slope.

Integration of Geologic Analyses

We investigated the geology of the areas with highest susceptibility for hazards. Spatial correspondence of flood hazard and eolian hazards in the lowest slope categories is striking result. These areas correspond with two main landforms: 1) valley bottoms, and 2) big-river flood plains. Valley bottoms are sites of playas, playa-fringe deposits of mixed origins, eolian sand deposits, and distal alluvial fan deposits. These deposits have in common a fine grain size and lack of rocky cover; as a result they are among the most unstable landforms in arid regions. Big-river flood plains are broad, generally fine-grained flats that may be rocky in a few places. Floodplains typically are valued for a wide variety of commercial and residential uses.

High hazard values (both eolian and flooding) are evident for large proportions of the lowest slope category. In contrast, the high hazard values for the 1-3% slope category applies to much less of the area: 28% is high eolian hazard and 10% high flood hazard. Similar decreases in the proportion of the steepest slope category that is susceptible to hazards are evident.

Implications for Climate Change

Increased mean temperature, extreme temperatures, and climate variability are forecast for this region. Uncertainty for forecasts of summer (monsoon) precipitation and total precipitation remain. Higher temperatures will reduce soil moisture and increase aridity, which along with increased extreme conditions, will increase emissions during extreme wind events. As vegetation responds to climate shifts there also is a likelihood for more sediment to become destabilized and made available to wind and water transport. If monsoon conditions increase in frequency and intensity due to warmer Gulf of California, increased flooding may result (Miller et al., 2010). These scenarios indicate that current assessments of the vulnerability to erosion from wind and water may need to be re-evaluated and that more of the Mojave Desert may be susceptible to these impacts. Species adapted to playa-margin environments may be especially vulnerable to climate change.

Conclusions

Although very low slope (0-1%) areas, the favored sites for solar installations, constitute less than 10% of the Mojave Desert region, they represent a disproportionately large percentage of substrate that is susceptible to flooding and to eolian sand and dust emissions. Private ownership of these low-slope lands exceeds BLM ownership; with greater road access and other features of private ownership, these lands may warrant more consideration for development. Steeper slopes (1-3%) characterize more of the desert (24%); these lands have less susceptibility to flood and eolian hazards. These steeper lands deserve greater consideration in efforts to tradeoff less suitable building land with decreased susceptibility for hazards. Future studies will add plants and animals to this study of geology and topography. Such a study could strengthen conclusions and permit forecasts in the face of climate change. Geomorphology and surficial geology allow some aspects of energy installation to be described and used for decision-making.

5 SAND TRANSPORT PATHS IN THE MOJAVE DESERT, SOUTHWESTERN UNITED STATES

James R. Zimbelman,[1] Steven H. Williams,[2] and Vatche. P. Tchakerian[3]
[1]*Center for Earth and Planetary Studies, Smithsonian Institute*
[2]*Department of Space Studies, University of North Dakota*
[3]*Department of Geography, Texas A&M University*

ABSTRACT

Remote sensing and field evidence are used to describe sand deposits found in associated pathways of emplacement in the eastern Mojave Desert. Two separate pathways are identified here: one extending eastward from the Bristol Playa through the Cadiz and Danby Playas and Rice Valley to the Colorado River, and a second parallel path extending eastward from Dale Playa through the Palen and Ford Playas to the Mule Mountains near the Colorado River. The preferential location of sand ramps on the west slopes of mountains along each path suggests that the eastward moving, wind-driven sand was not confined by topographic divides between separate drainage basins around the individual playas and valleys. Sediment analysis of selected samples shows that there are discreet associations of sand characteristics along the sand pathways, with an inferred similarity between the stabilized (vegetated) sands in Rice Valley, west of the Colorado River, and stabilized sand dunes on Cactus Plain and La Posa Plain in Arizona, east of the Colorado River. Sand transport along the paths appears to have been episodic, based on multiple paleosols present in several dissected sand ramps. Future testing of the sand transport path hypothesis will require additional sediment analyses, spectral studies of remote sensing data, and obtaining dates for selected soil horizons along the sand paths.

INTRODUCTION

Wind has long been recognized as a powerful agent for sediment transport in arid environments. Sand transport in the hyper-arid Sahara Desert in northern Africa can be traced for thousands of kilometers, providing physical evidence of the wind patterns prevalent throughout the region (Wilson 1971, El-Baz et al. 1979, El-Baz and Maxwell 1982). However, significant aeolian transport is not restricted to hyper-arid deserts. Semi-arid regions also can preserve evidence of substantial deposits of aeolian sand, but many of these deposits may be stabilized at present by a variety of desert flora adapted to the intermittent rainfall.

The advent of airborne and satellite-based remote sensing data allow both the surface materials and their associated flora to be examined in a regional context. In particular, spacecraft images have been used to identify aeolian deposits throughout the Earth (Breed and Grow 1979), as well as on Mars (Sagan et al. 1972, Greeley and Iversen 1985) and Venus (Greeley et al. 1992).

Desert Aeolian Processes. Edited by Vatche P. Tchakerian. Published in 1995 by Chapman & Hall, London.
ISBN 0 412 04241 X

Conclusions derived from remote sensing data must be corroborated by "ground truth" investigations at key localities. The present study combines preliminary field observations with satellite remote sensing data to document aeolian deposits along hypothesized sand transport pathways in the eastern Mojave Desert of California. While a considerable amount of field work remains to be carried out, our intent here is to describe the primary features which suggest that an association exists between various sand deposits. Integrated pathways of sand transport would imply that aeolian processes have regional significance well beyond the confines of individual drainage basins. The time scale of this aeolian activity is not well constrained at present, but exposures described here suggest that the dissected sand ramps in the eastern Mojave Desert contain climatic information which predates the Holocene activity evidenced by the present isolated accumulations of active dunes.

BACKGROUND

The Mojave Desert is located in southern California at the southern end of the Basin and Range physiographic province. It is an important field geology study area because it contains numerous, accessible, well-exposed examples of a variety of geologic features (Dohrenwend 1987). The Garlock and San Andreas faults define sharp boundaries to the western margin of the Mojave Desert, while the eastern boundary with the arid region surrounding the Colorado River is more gradational. The sand transport paths described in this study lie in the eastern part of the Mojave Desert, possibly including sand deposits east of the Colorado River (Figure 1). A synopsis of the geology of the study region can be found in Jahns (1954) and in Bassett and Kupfer (1964).

Aeolian activity has formed sand sheets at several locations in the Mojave Desert. Sand ramps over 100 m thick occur in places where topography has impeded local sand migration (H.T.U. Smith 1967, R.S.U. Smith 1982). These sand ramp deposits include soil layers and other features that contain paleoclimatic information (Tchakerian 1991). The deposition of each layer presumably followed the desiccation of pluvial lakes lying upwind, with soil formation occurring between pulses of aeolian activity (Smith 1982, McFadden et al. 1987, Wells et al. 1987, Chadwick and Davis 1990, Tchakerian 1991). Some sand ramps are so large that they surmount the windward side of the topographic obstacle responsible for their formation. This study presents a hypothesis of regional aeolian transport that provides a unifying framework in which to interpret the results obtained from widely distributed sand ramps in the Mojave region.

A synoptic view of the Mojave Desert is best obtained from remote sensing data. Several recent remote sensing and field studies have focused on aeolian processes in the Mojave region (e.g., Blount et al. 1990, Paisley et al. 1991, Lancaster et al. 1992, Laity 1987, 1992, Zimbelman and Williams, in preparation). These efforts revealed that active sand can be distinguished from sand

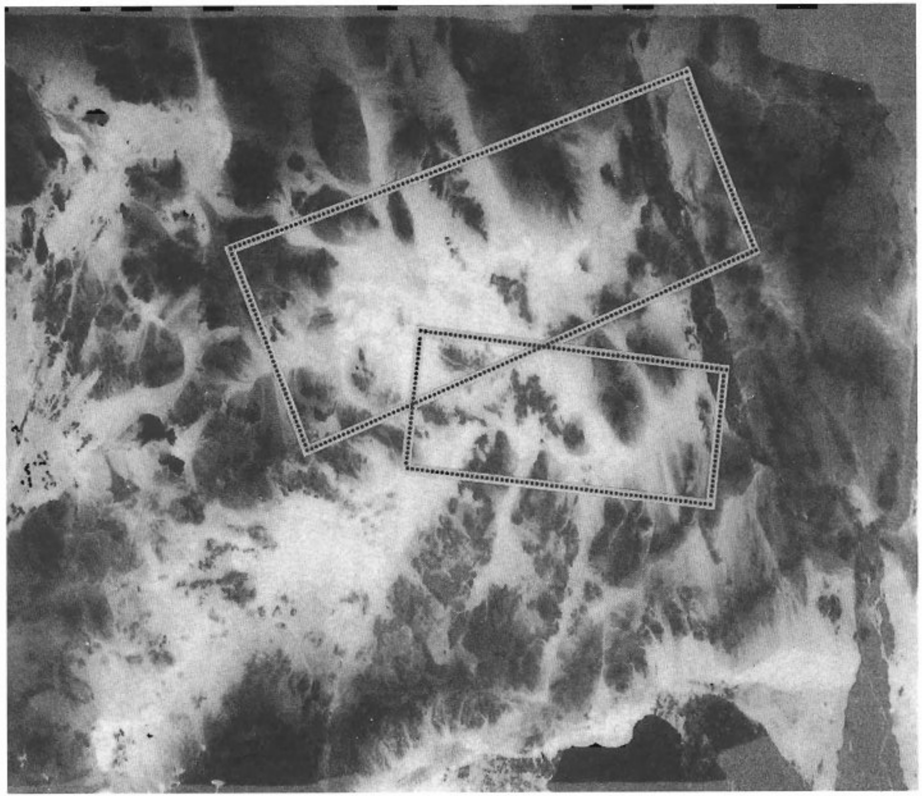


Figure 1. (a) Oblique view of the eastern Mojave Desert, taken with the Linhof camera on board the Space Shuttle. This view shows the Mojave Desert area from the outwash plains of the Mojave River (near Barstow, California) at left, to the agricultural fields along the Colorado River at right. The line of sight is nearly coincident with the paths of sand transport described in the text. Dotted lines show the locations of Figures 2 (top) and 7 (bottom). See Figure 1b for selected feature names near the pathways. Portion of frame 51B-146-111, obtained during Shuttle flight STS 51B, between April 26 and May 6, 1985.

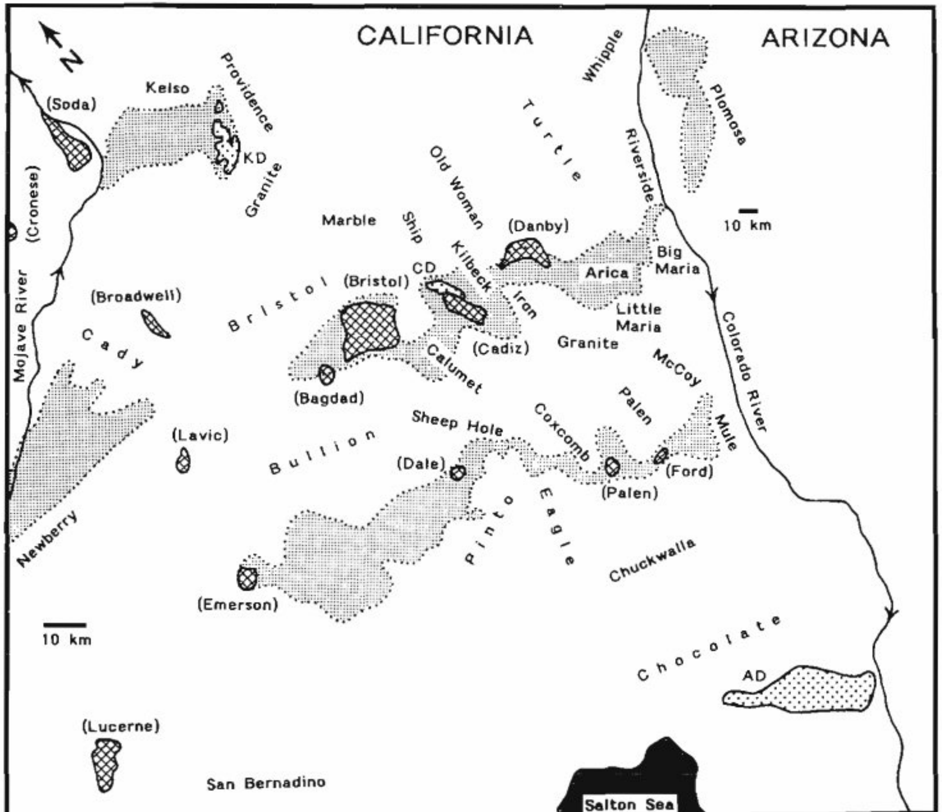


Figure 1. (b) Simplified sketch map of the area shown in Figure 1a. Selected playas (gridded pattern, names in parentheses), mountains (names listed at appropriate location), and rivers (arrows show direction of flow) are labeled for reference. Sand deposits are shown in dotted patterns; the open pattern represents active (relatively unvegetated) dunes (KD = Kelso Dunes, CD = Cadiz Dunes, AD = Algodones Dunes) and the dense pattern represents inactive (stabilized by vegetation) deposits. Note that foreshortening due to the oblique viewing geometry causes horizontal scale variations across the area.

stabilized by vegetation through subtle but consistent differences in reflectance properties between the Landsat Thematic Mapper spectral bands. Similar spectral differences exist in the Landsat data used in the present study, although the differing plant populations appear to play a significant role in the reflectance properties of aeolian deposits in the Mojave region (Zimbelman and Williams, in preparation). Consequently, seasonal variations may prove to be critical to the spectral response of certain Mojave sand deposits. These relationships are still under active investigation, so the results presented here will be based primarily on morphology as observed in a single spectral band.

SAND TRANSPORT PATHS

Three principal locations of aeolian deposits in the eastern Mojave Desert are described here: the Bristol Trough (which includes the Bristol, Cadiz, and Danby playas), Clark's Pass (which includes the Dale, Palen, and Ford playas), and the Cactus and La Posa Plains in Arizona (Figure 1). Both the active and stabilized (vegetated to the point of nonmobility) sand deposits observed at these locations are hypothesized here to be part of regional sand transportation paths which cross the Mojave Desert southeast to the Colorado River, and possibly beyond the river. These locations are all south and east of the Kelso Dunes (Figure 1), the most prominent and intensively studied dune field in the Mojave Desert (Sharp 1966, 1978, Paisley et al. 1991, Lancaster et al. 1992, Lancaster 1993). The sand in the Kelso Dunes originated in broad outwash plains associated with the Mojave River, was transported to the southeast by the prevailing winds, and collected at the base of the >1800-m Providence and Granite Mountains, which formed an insurmountable barrier to the windblown sediments (Sharp 1978). The sands associated with the Bristol Trough and Clark's Pass also are oriented along the prevailing northwest-to-southeast wind direction (Greeley and Iversen 1985), but these sand deposits have traversed several distinct drainage basins on their way to the Colorado River. Sand from the Bristol Trough may have even contributed to a third major sand deposit, a field of stabilized dunes on the Cactus Plain and La Posa Plain east of the Colorado River. Each of the three sand localities is described in greater detail in the following sections.

Bristol Trough

The most prominent association of sand deposits begins at the Bristol Playa near the head of a broad topographic low called the Bristol Trough (Thompson 1929). Sand occurs continuously over a distance of almost 150 km, eventually terminating at the Colorado River (Figure 2). The sand deposits concentrate around three large playas (Bristol, Cadiz, and Danby), and consist of both active dunes and vegetation-stabilized sand sheets and linear dunes (Figure 2). The relation of the sand deposits to the mountains they traverse indicates that the sand movement was toward the east-southeast, with prominent sand ramps present on the west side of several mountain ranges along the pathway.

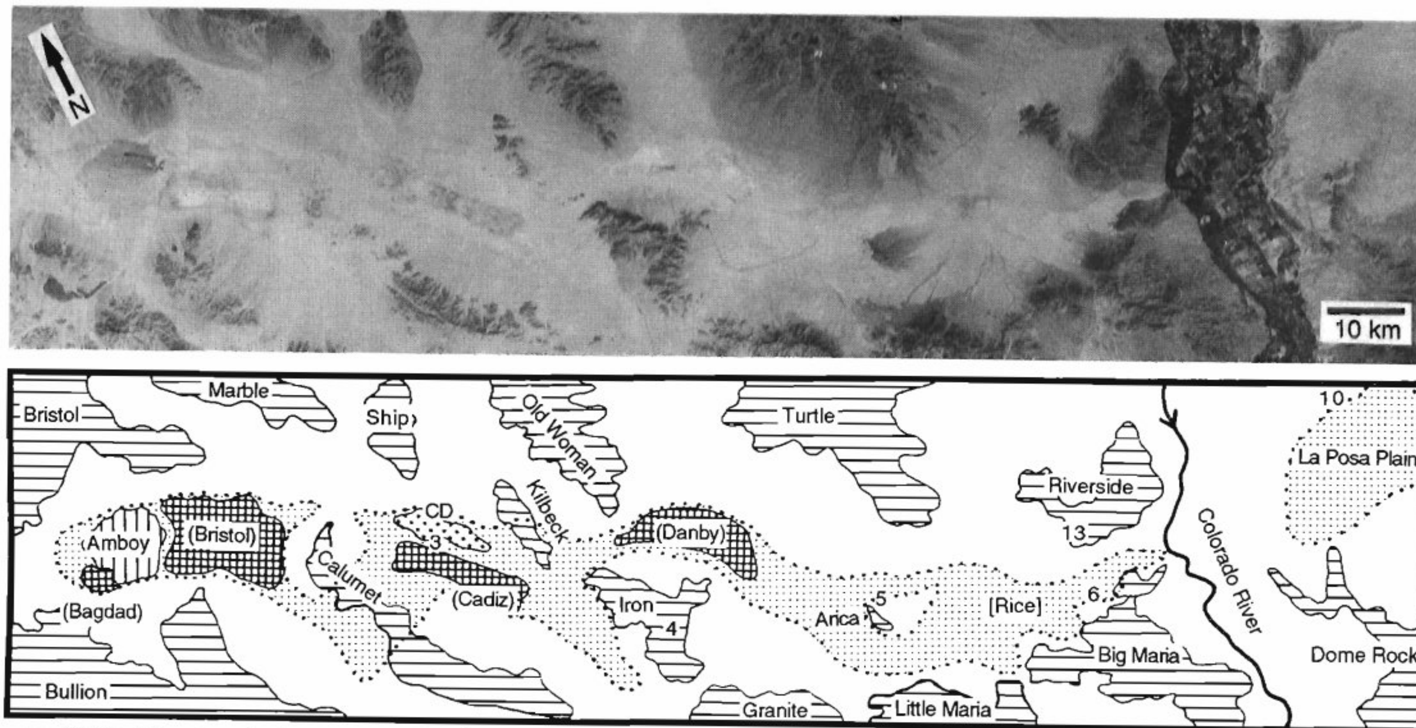


Figure 2. Bristol Trough sand path, seen on a portion of a Large Format Camera photograph, frame 2063, taken during the STS 41-G Space Shuttle flight between October 5 and 13, 1984. The sketch map below the photograph labels mountains (horizontal lined pattern), playas (gridded pattern), and sand deposits (dotted pattern). The active Cadiz Dunes (CD) are shown in a large dotted pattern. Rice Valley is identified by the name within square brackets. The Amboy lava flow (vertical lined pattern) is a Holocene basaltic eruption that covered the western portion of Bristol Playa. Numbers indicate the approximate centers of the orbital views shown in the corresponding figures.

Sand accumulations first become discernible west of the Bristol Playa, in the broad valley between the Bristol and Bullion Mountains (Figure 2). The Holocene basalt flow associated with the Amboy cinder cone covered the western portion of the Bristol Playa, leaving the small Bagdad Playa west of the Amboy flow as a remnant of the ancestral Bristol Playa (Bassett and Kupfer 1964). Sand derived from Bristol Mountains alluvium traverses the Amboy lava flow from WNW to ESE (Greeley and Iversen 1985), consistent with the annual wind flow in the region during the Holocene (Laity 1992). A prominent low-albedo wind streak is present downwind from the Amboy cinder cone (Figure 2). Sand transport across the flow is obstructed by the cinder cone, and enhanced turbulent wind scour in the lee of the cone aids in inhibiting sand migration into the wind streak (Greeley and Iversen 1978, 1985). There is no evidence, either in remote sensing data or on the ground, that sand from the Mojave River has traversed the Cady Mountains to enter the Bristol Playa basin from the west (Figure 1); the Bristol area is interpreted here to represent the beginning of the aeolian sand deposits that extend east to the Colorado River (Figure 2).

Sand is abundant southeast of the Bristol Playa, where it has built large ramps against the western slopes of the Calumet Mountains (Figure 2). The sand ramps provide shallow slopes for saltating sand to climb the western flanks of the mountains, as well as shallow slopes along which the sand moves

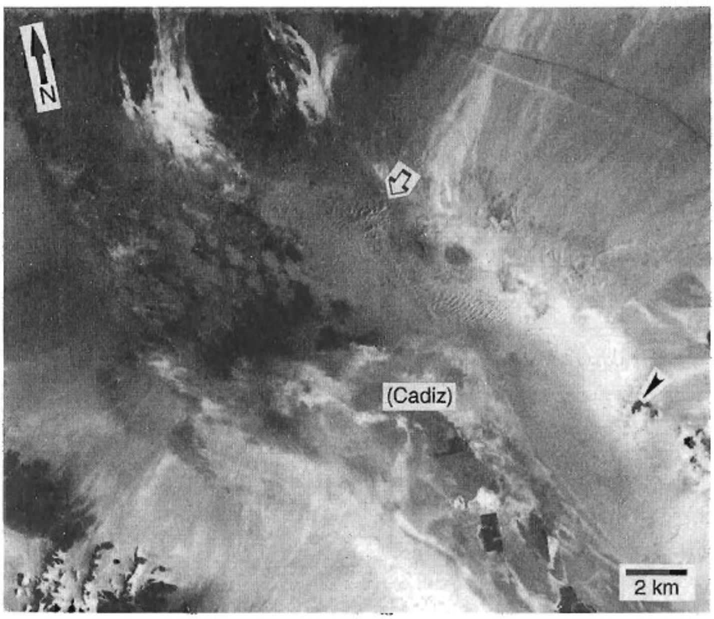


Figure 3. (a) Portion of a Landsat Thematic Mapper image showing the northern end of Cadiz Playa and the Cadiz Dunes north of the playa. The largest dunes (open arrow) have 30 m of relief. Transverse dunes are present along the northern margin of the playa; the dark arrow shows the location and orientation of Figure 3b. Landsat TM band 5, obtained on September 26, 1986.

Table 1
Mean values of grain size, sorting, and percent silt and clay for selected samples from the Mojave Desert, California

Aeolian unit	Mean (ϕ)	Standard deviation	Skewness	Kurtosis	% silt and clay
Dale Lake					
Unit 1	2.24	0.83	0.10	1.17	2.90
Unit 2	1.91	0.91	0.14	1.15	3.10
Unit 3	2.15	0.85	0.08	1.10	3.25
Unit 4	1.70	1.21	0.05	1.05	1.25
Unit 5	2.23	0.78	-.07	0.93	2.40
Calumet Mtns	2.91	0.97	0.22	1.29	4.83
Cadiz Dunes	2.35	0.29	-.03	0.89	
Iron Mtns	2.45	0.88	0.15	1.10	7.20
Rice Valley	2.95	0.75	0.20	1.25	6.25
Cactus Plain	2.87	0.87	0.25	1.35	5.98

down the eastern flanks of the mountains. Neither climbing nor falling dunes are observed on the Calumets, but Landsat spectral data indicates that stabilized sand dominates a 10-km-long reach of the central portion of the mountains, where sand ramps were evident on the ground. Alluvial fan deposits around the northern end of the Calumets lack any prominent sand accumulations, leading to the interpretation that most sand from the Bristol area crossed the central Calumets instead of going around the northern alluvial fans.

East of the Calumet Mountains, sand deposits are concentrated around the Cadiz Playa, which is in the broad valley between the Calumet Mountains and the Kilbeck Hills (Figure 2). The sand deposits attain a considerable thickness on the northern margin of the Cadiz Playa; individual dunes display 30 m of relief and are clearly resolved in Landsat Thematic Mapper data (Figure 3a). Ground investigation showed that the dunes north of Cadiz Playa are the only substantive area of active dunes observed along the Bristol Trough path. The active sand gradually thins to the east, where transverse dunes with 1-2 m of relief become the dominant aeolian landform (Figure 3b).

Stabilized sand sheets extend eastward from the Cadiz Valley across the southern end of the Kilbeck Hills into the Danby Valley (Figure 2). Extensive sand ramps are present around the southern Kilbeck Hills, and are particularly well developed on the western slopes of the Iron Mountains (Figure 4a). Where ephemeral streams dissect the Iron Mountain sand ramps, tens of meters of sand are exposed within the channels, both in the western sand ramps (some of which have active dunes on the channel crest, Figure 4b), and in stabilized sand ramps on the northern flanks (Figure 4c).

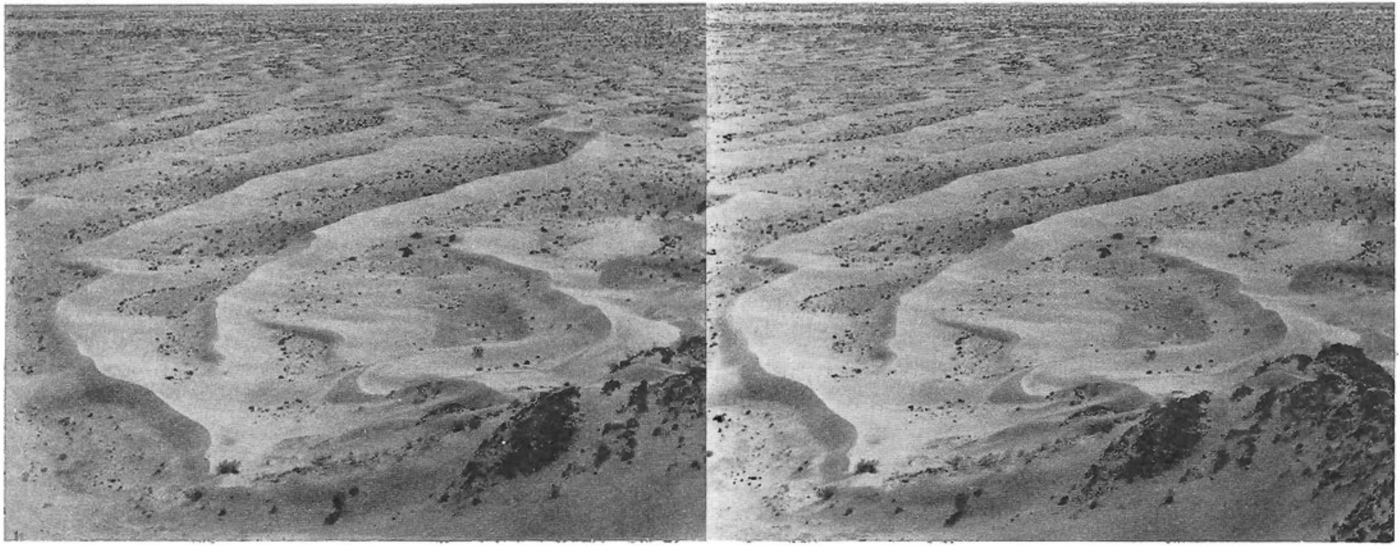


Figure 3. (b) Oblique stereo pair of transverse dunes north of the Cadiz Playa, looking southwest. Stereo view shows exaggerated topography; the dunes have 1 to 2 m of vertical relief and an average spacing of 40 m. Photographs taken on September 26, 1986, from the top of a small hill north of the playa.

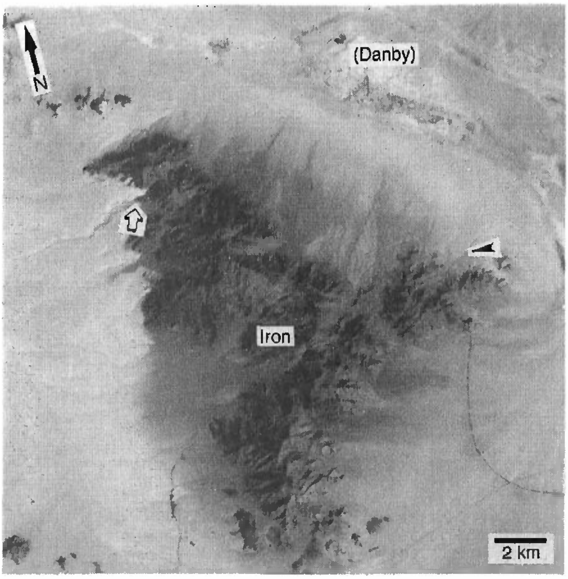


Figure 4. (a) Portion of a Landsat Thematic Mapper image showing the Iron Mountains south of Danby Playa. Prominent sand ramps are present on the western slope of the mountains; open arrow shows the location and orientation of the photograph in Figure 4b. Less active (more vegetated) sand ramp on the northern slope was sampled in 1991; the dark arrow shows location and orientation of the photograph in Figure 4c. Landsat TM band 5, obtained on September 26, 1986.

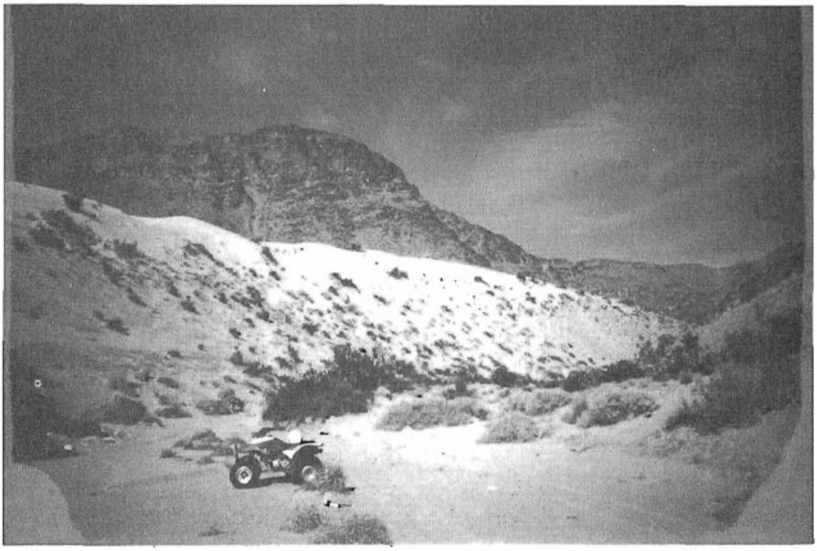


Figure 4. (b) View of entrenched sand ramp on the western slope of the Iron Mountains, taken from the channel floor. The 25-m-high channel wall has considerable vegetation cover at this locality, but the channel crests consist of active dune patches. Photograph was taken on October 9, 1993.

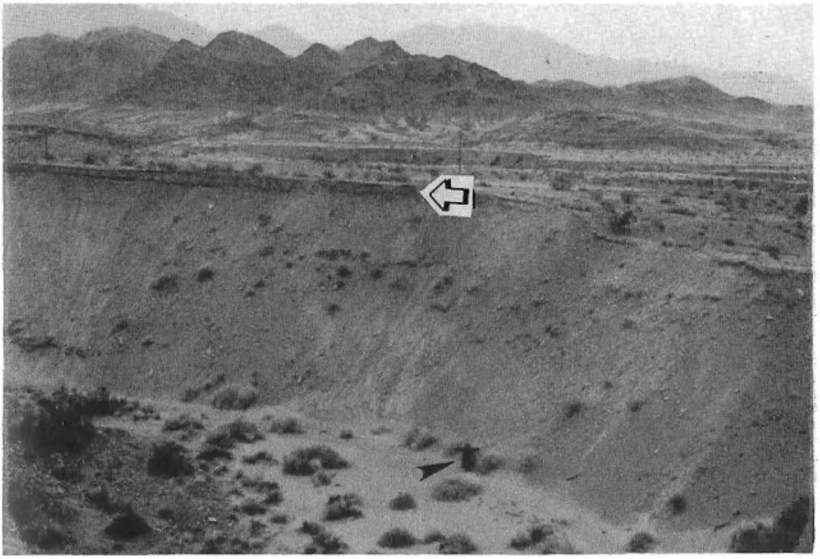


Figure 4. (c) Entrenched sand ramp on the northern slope of the Iron Mountains, with a paleosol complex (open arrow) capping the deposit. Note the outstretched arms of a 1.6 m field assistant (dark arrow) in the ephemeral wash, which exposes the sediments of the sand ramp. The top of the sand ramp is mantled with taluvium (talus and alluvium). Photograph was taken in 1992.

South of Danby Playa, the sand deposits spread to cover much of the Rice Valley with linear dunes and sand sheets, both of which are stabilized by desert vegetation (Figure 2). Sand surrounds the 500-m-high Arica Mountains (Figure 5a); a prominent sand ramp on the western slope almost reaches the top of the highest peaks, while the eastern slope is essentially sand-free (Figure 5b). Fields of stabilized linear dunes cover the southern side of the Rice Valley (Figure 6a). Sand ramps terminate at stream margins within the Big Maria Mountains, exposing up to 10 m of accumulated sand (Figure 6b). A narrow strip of sand exits the eastern end of Rice Valley, extending east to the Colorado River. Basic sedimentological characteristics of four sand deposits sampled along the pathway are listed in Table 1.

Clark's Pass

A second association of sand deposits roughly parallels the Bristol Trough path, but along a more southerly route (Figures 1 and 7). Sand ramps east of the Dale Playa at the eastern end of the Twentynine Palms Valley allowed sand to exit the valley through Clark's Pass, a narrow gap between the Sheep Hole and Pinto Mountains (Figure 8a).

The orientation of the Sheep Hole and Pinto Mountains acted like a funnel to concentrate migrating sand rather than trapping it completely, as at the Kelso Dunes. The sand ramps developed between the mountains allow wind-blown sand to climb more than 250 m from the level of Dale Playa to Clark's Pass.

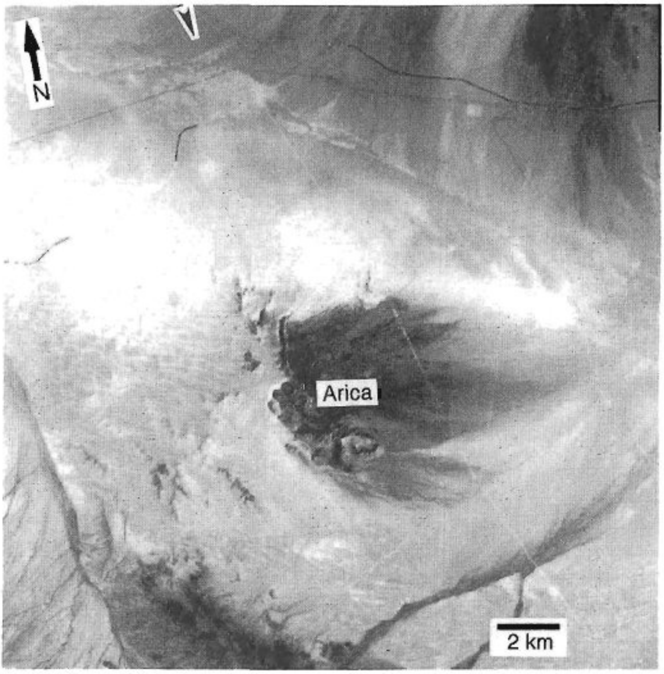


Figure 5. (a) Portion of a Landsat Thematic Mapper image showing the Arica Mountains at the west end of Rice Valley. The dark arrow at the top shows the orientation of the photograph in Figure 5b, taken from a position just off the northern edge of the image. Landsat TM band 5, obtained on September 26, 1986.

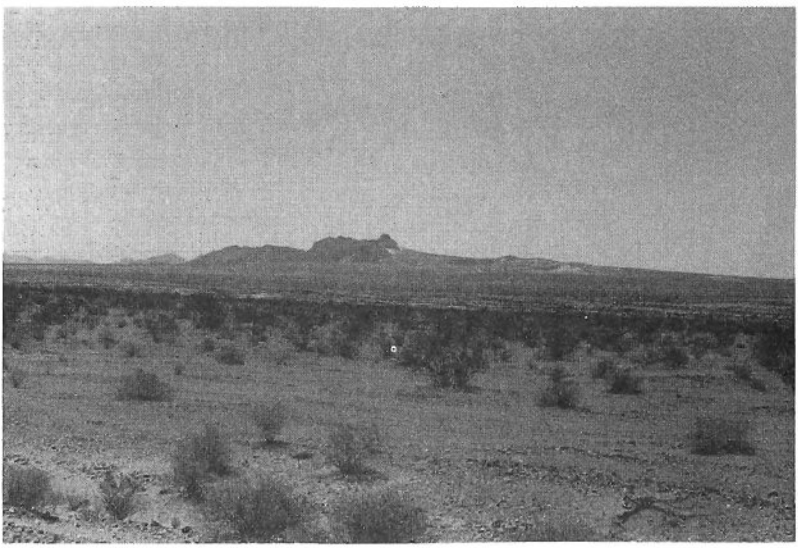


Figure 5. (b) Profile view of the Arica Mountains, looking south from a road that follows the railroad tracks north of Danby Playa. A prominent sand ramp is present on the west slope (right) while the east slope (left) is relatively sand-free, in the lee of the 500-m-high mountains. Photograph was taken in May 1991.

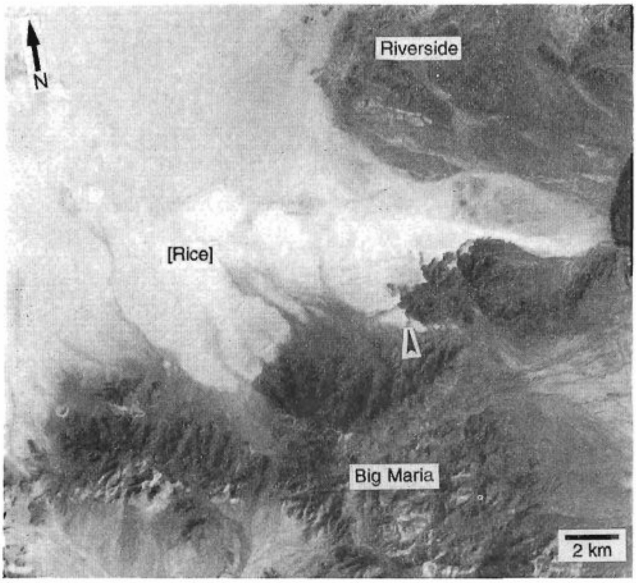


Figure 6. (a) Portion of a Landsat Thematic Mapper image showing stabilized dunes in Rice Valley. The sand deposits occur against the northern slopes of the Big Maria Mountains, and are cut by emphemeral channels from those mountains. The dark arrow shows the location and orientation of Figure 6b. Landsat TM band 5, obtained on September 26, 1986.

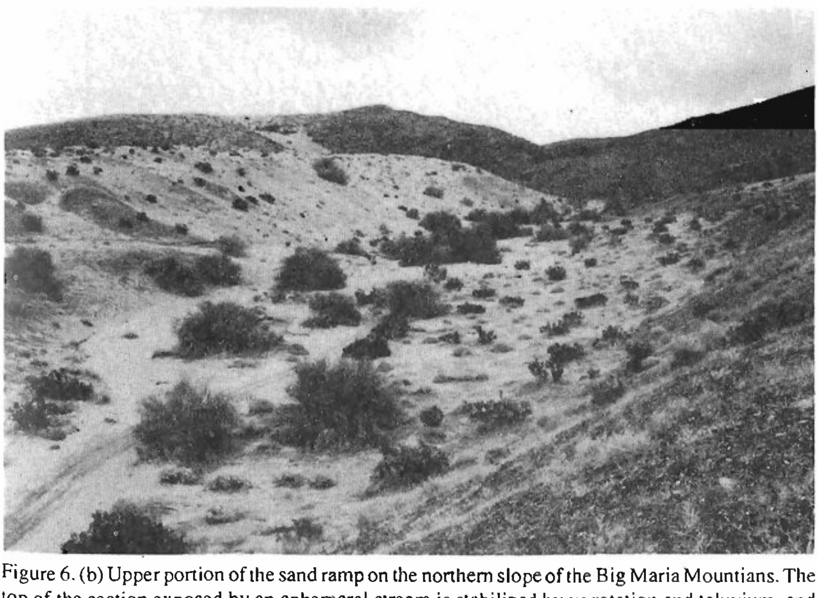


Figure 6. (b) Upper portion of the sand ramp on the northern slope of the Big Maria Mountians. The top of the section exposed by an ephemeral stream is stabilized by vegetation and taluvium, and capped by a prominent paleosol. Photograph was taken in 1991.

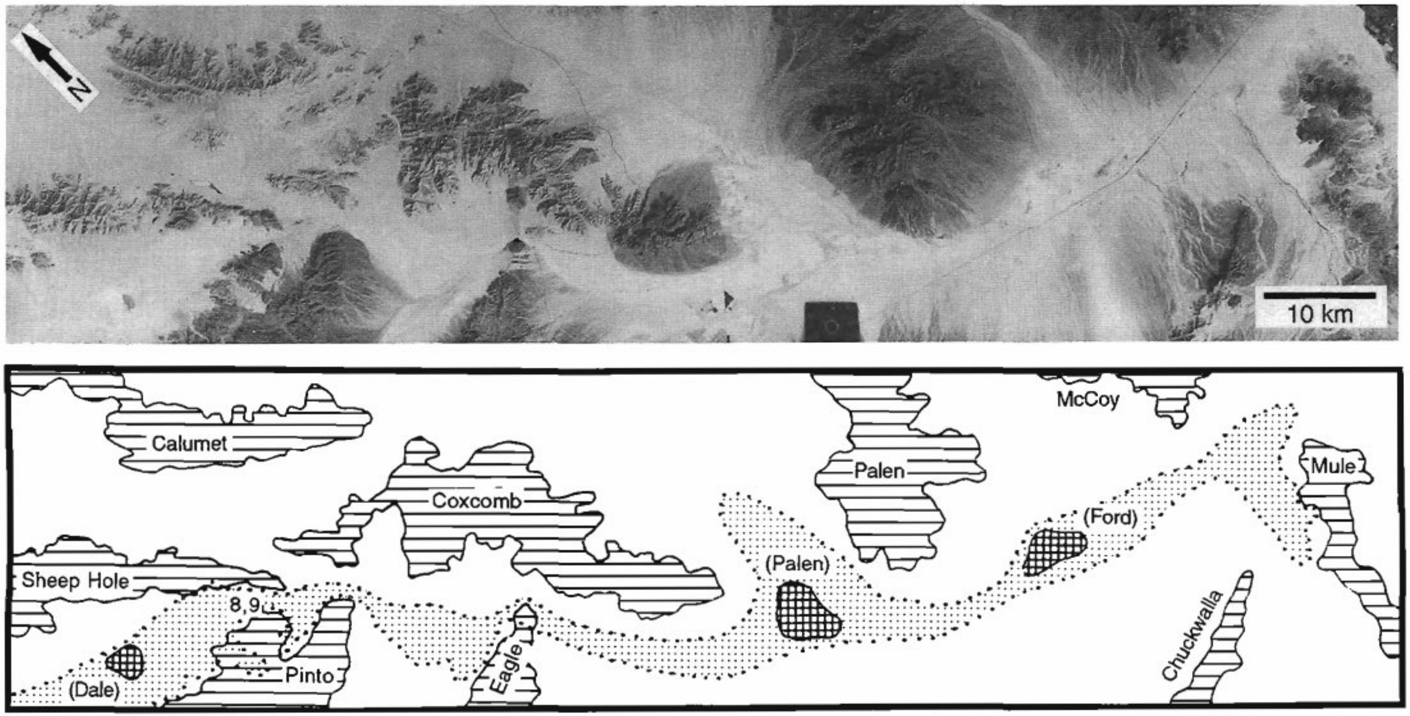


Figure 7. Clark's Pass sand path, seen on a portion of a Large Format Camera photograph, frame 2063, taken during the STS 41-G Space Shuttle flight between October 5 and 13, 1984. The sketch map below the photograph labels mountains (lined pattern), playas (gridded pattern), and sand deposits (dotted pattern).

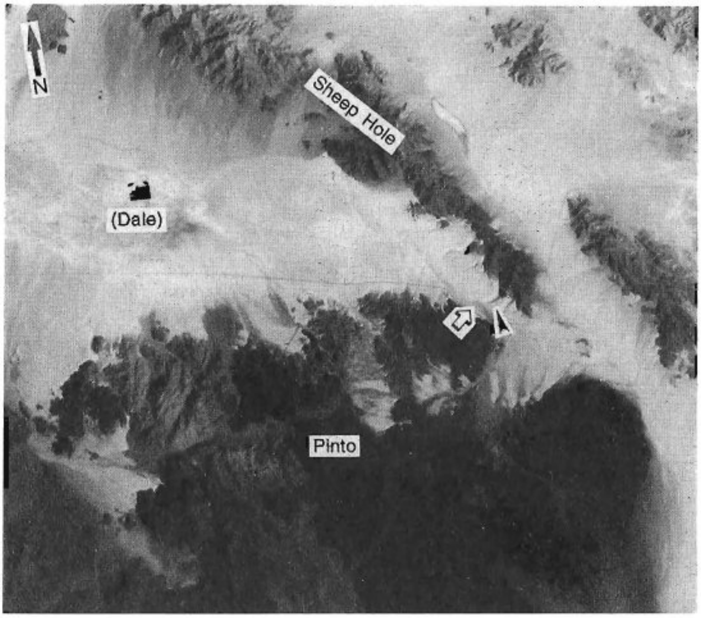


Figure 8. (a) Portion of a Landsat Thematic Mapper image showing the Clark's Pass area. Sand is ramped against the Sheep Hole (top) and Pinto (bottom) Mountains, providing an exit from the Twentynine Palms Valley, past Dale Playa, through Clark's Pass. The dark arrow shows the location and orientation of Figure 8b, and the open arrow shows the location and orientation of Figure 9a. Landsat TM band 5, obtained on September 26, 1986.

Some sand has been trapped in small valleys along the northern margin of the Pinto Mountains (Figure 8a), but the volume of sand deposits within the mountains appears to be much smaller than that of the sand ramps leading up to Clark's Pass. Ephemeral streams from the Sheep Hole Mountains cut into the sand ramps at several locations (Figure 8b), providing a cross-section through tens of meters of sand and exposing several soil horizons.

Several major stratigraphic units are identified within the Dale sand ramp (Tchakerian 1991) by the combination of geomorphic and soil-stratigraphic relations (Figure 9, Table 1). The units are predominantly aeolian in origin, with some intermixed fluvial deposits. Unit 1 contains fine to medium ($Mz = 2.24\ \phi$) moderately sorted ($\sigma = 0.83$) aeolian sands with grus and a silt/clay content of 2.9%. It is capped by a reddish yellow (5YR/6/6) paleosol with discontinuous carbonate nodules. Unit 2 comprises fine to medium ($Mz = 1.91\phi$) poorly sorted ($\sigma = 0.91$) aeolian sands and has a silt and clay content of 3.1%. It contains numerous fluvial cut and fill lenses. The unit is capped by a prominent reddish yellow (7.5YR/6/6) paleosol with calcrete disseminated throughout the matrix, and carbonate enriched root pseudomorphs. Unit 3 consists of mostly yellowish red (5YR/5/8) medium to coarse ($Mz = 2.15\phi$) moderately sorted ($\sigma = 0.85$) aeolian sands with large percentages of grus. It is capped by a poorly developed discontinuous paleosol with some calcareous

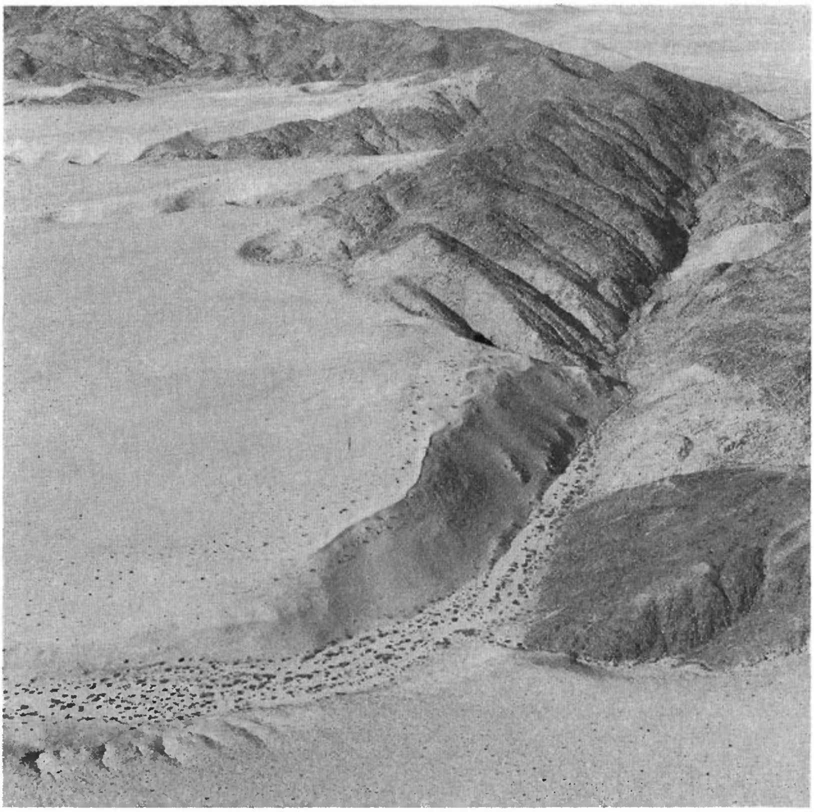


Figure 8. (b) Sand ramp on the western side of the Sheep Hole Mountains near Clark's Pass, at the east end of the Twentynine Palms Valley (Shelton et al. 1978, figure 9-21). Note the active dune along the crest of the channel. Oblique aireal photograph taken by R. Greeley.

rhizoliths. Unit 4 contains primarily fluvially redistributed dune sands, cut-and-fill structures, and coarse gravel alluvial channels. The sediments are mostly coarse sands (Mz = 1.70ϕ), and are poorly sorted (σ = 1.21).

The section is topped by weakly consolidated sand that forms the surface of the sand ramp. Unit 5 contains brownish yellow (10YR6/6) fine to medium (Mz = 2.23ϕ), moderately well sorted (σ = 0.78) aeolian sands, with a silt/clay content of 2.4%. The uppermost section of Unit 5 is obscured by loose aeolian sands. However, about 500 m to the west of this section, further aeolian depositional units have been identified which are stratigraphically equivalent to or younger than Unit 5. They consist of brownish yellow, fine to medium, moderately well sorted aeolian sands similar in composition to Unit 5. Additional units in the area are similar, with respect to grain size, sorting, percent silt/clay, and quartz grain surface micromorphologies (SEM analysis), to Unit 5, suggesting emplacement by a single aeolian episode with multiple depositional pulses (Tchakerian 1991).

After exiting through Clark's Pass, the sand traversed the northern end of the Eagle Mountains and passed the Palen and Ford Playas (Figure 7). The sand deposits around the Palen and Ford Playas are primarily in the form of broad sand sheets, with very limited development of isolated, stabilized dunes. There is no evidence at present that sand reached the Colorado River after passing the Mule Mountains (which have prominent sand ramps on their western slopes), but the lack of visible sand likely results from the extensive agricultural activity along the Colorado River in the vicinity of Blythe, California.

Cactus Plain–La Posa Plain

A third accumulation of sand deposits possibly may be related to the proposed sand transport pathways through the Mojave Desert. Large fields of stabilized linear dunes are present on the eastern bank of the Colorado River near the town of Parker, Arizona (Figure 10). These dunes are directly opposite the termination point of the Bristol Trough path at the Colorado River (Figure 1). There is no obvious source for the stabilized dunes on the Cactus Plain and the La Posa Plain (Figure 10); the adjacent mountains display typical alluvial fan development with no apparent accumulation of sand-sized materials to supply the sand to the extensive dune fields. The Colorado River could be a source for the sand, except that the Cactus Plain–La Posa Plain area is the only sand accumulation next to the river but not next to a large lake or playa (such as the Algodones Dunes near the Salton Sea; Figure 1).

The Arizona linear dunes generally have from 2 to 4 m of relief and are oriented approximately transverse to the prevailing wind direction evident within the Bristol Trough (Greeley and Iversen 1985, Laity 1992). No prominent sand ramps are evident around the dunes; the sand accumulation progressively thins leading up to the adjacent mountains. However, the silt/clay content of the Cactus Plain dunes is nearly twice as large as that of the Dale units exposed within the Clark's Pass path, but is similar to the silt/clay content of the Iron Mountain and Rice Valley sands from the eastern portion of the Bristol Trough path (Table 1). The increased silt/clay content does not appear to be pedogenic in origin; the loose sand covers the dunes but they are no longer mobile because of the desert vegetative cover. The adjacent locations and the overall similarities between the Rice Valley and Cactus Plain sands raise the possibility that the Arizona sands may be genetically related to the "apparent" termination of the Bristol Trough path at the Colorado River; this intriguing possibility is discussed in the following section.

DISCUSSION

The alignment of the Mojave sand paths is because of a combination of topography and prevailing winds. Our observations led to the hypothesis that the paths represent the aeolian part of a combined aeolian/alluvial/fluvial drainage system, as discussed below. Also described are the possibility of net sand migration across the Colorado River, and some paleoclimatic implications of the sand transport path hypothesis.

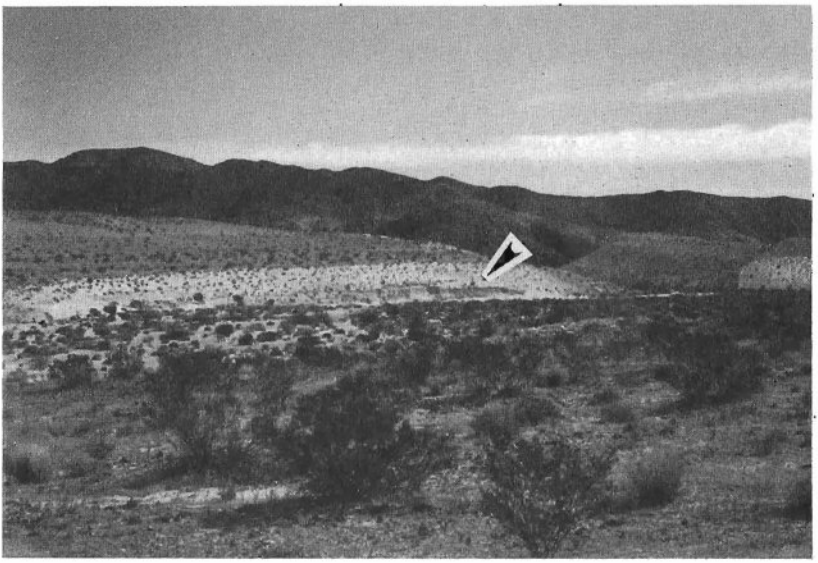


Figure 9. (a) The upper part of the Dale Lake sand ramp, with an ephemeral fluvial wash in the foreground (see also Figure 8). The Sheep Hole Mountains are in the background. The dark arrow points to the paleosols shown in Figures 9b and 9c, exposed by the streamcut in the sand ramp. Photograph taken in 1987.

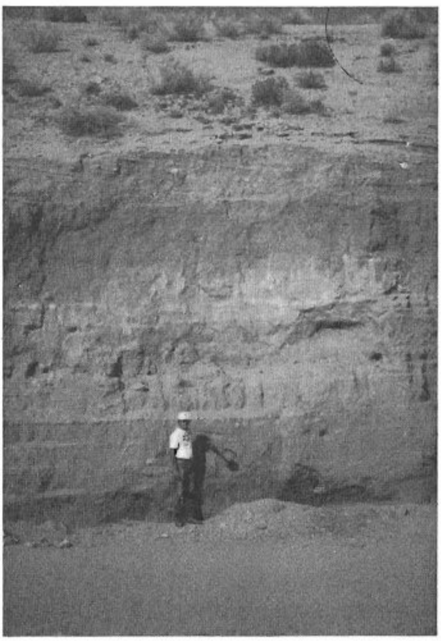


Figure 9. (b) A close up view of the middle section of the sand column exposed in the wash of the ephemeral stream described in Figure 9a. The section exposed here is about 10 m thick. Photograph taken in 1987.

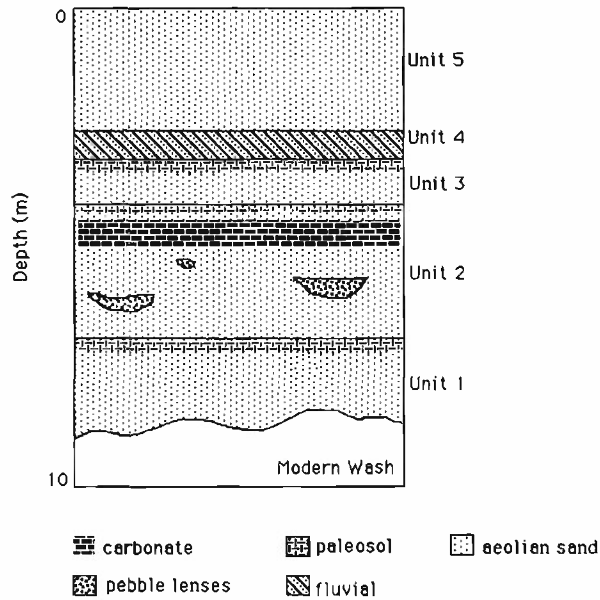


Figure 9. (c) A detailed geomorphic and soil-stratigraphic cross-section of the sand ramp exposure shown in Figure 9b.

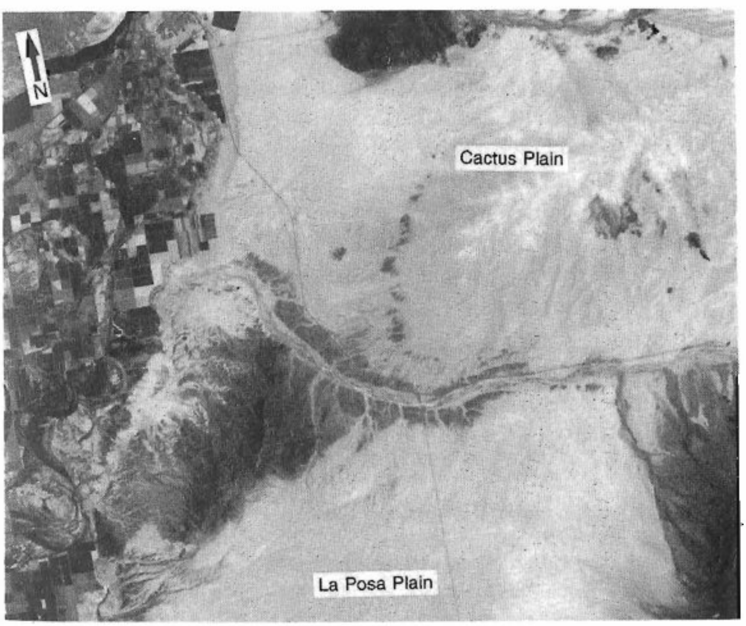


Figure 10. Portion of a Landsat Thematic Mapper image showing the stabilized dunes near Parker, Arizona. Agricultural use of the Colorado River floodplain is evident at left. The dunes are concentrated on the Cactus Plain (top) and the La Posa Plain (bottom), with no apparent source area evident in the sourrounding mountains. Landsat TM band 5, obtained on June 9, 1984.

Sand Transport Pathways As "Rivers Of Sand"

The pathways followed by the sand in transport toward the Colorado River can be compared to the path followed by a tributary stream on its way toward a higher order primary river. Both systems show sensitivity to local topography, but windblown sand is not forced always to flow down the local topographic gradient. The longitudinal profile of a river generally is concave upward, in accord with a steady downstream decrease in slope (e.g., Leopold et al. 1964, p. 248-255). In contrast to fluvial systems, aeolian sand can surmount or bypass significant topographic obstacles under favorable conditions of wind orientation and sand supply. Sand deposition on the windward side of the mountain ranges built sand ramps that facilitate continued access by saltating sand up the gentle windward slope of the ramp. Sand along the Bristol Trough path surmounts relief of up to 100 m on portions of the Calumet and Iron Mountains (Figure 11a), while the Clark's Pass path traverses 250 m of relief to provide an outlet for the sand from the Dale Playa (Figure 11b). Sufficient sand was available from the Dale Basin to build the large sand ramps that characterize the Clark's Pass path. In contrast, smaller ramps were sufficient to surmount the topography along the Bristol Trough path.

The Mojave and Colorado River systems may have been connected in earlier epochs (Blackwelder 1933, 1954, Miller 1946). Blackwelder (1954) postulated a Mojave/Colorado connection via the Bristol Trough that coincides exactly with the observed sand path (Figure 12). The hypothesized drainage connection was then disrupted by a combination of climate change, tectonic processes, and the eruption of the Pisgah volcanics. The association of the Mojave Desert sand deposits with (sometimes large) playas contributed to an assumption that the sand was locally derived, solely from the nearest paleolake. Our preliminary remote sensing analysis and field observations suggest that the present-day playas may be intermediate concentration points (at local topographic lows) for a more through-going movement of windblown sand. The tectonic trough enclosing the Bristol, Cadiz, and Danby Playas provides a preexisting trend along which the wind-blown sediments now encounter only minimum topographic obstacles, which were surmounted or bypassed through prolonged aeolian activity. In this sense, the sand transport paths might be considered "rivers of sand" that have reclaimed and actually shortened a possible drainage path from an earlier epoch. Considerable field work remains to be done to test the validity of this hypothesis, as well as much more extensive sediment analyses.

Possible Trans-Colorado River Sand Transport

Two intriguing questions are raised by the possibility of sand transport paths in the Mojave region: what is the ultimate fate of sand in transit along each path, and what is the source of the sands on the Cactus and La Posa Plains? Much of the sand entering the Colorado River is transported downstream, with much of it perhaps contributing to the Gran Desierto dune field in Mexico (Merriam 1969, Lancaster et al. 1987, Blount and Lancaster 1990). However, we

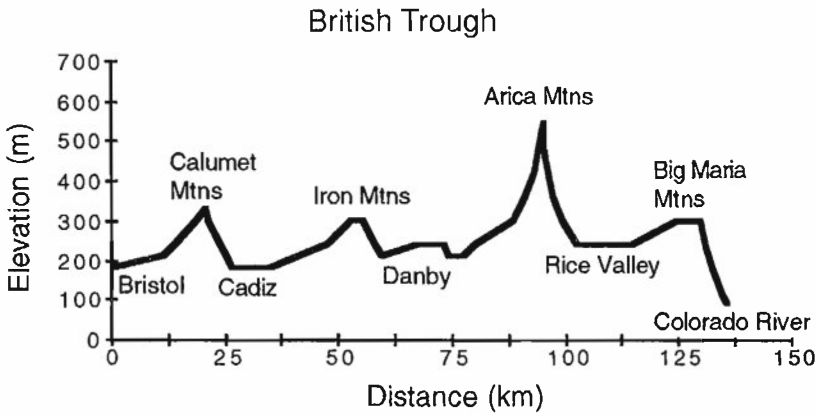


Figure 11. (a) Topographic profile along the Bristol Trough path. Vertical exaggeration is approximately 87X. The profile follows the approximate centerline of the sand path, including both active and inactive sand deposits. Mountain ranges encountered along the path are labeled above the profile; these topographic obstacles are crossed by the sand through emplacement of thick sand ramps. Playa names and Rice Valley are labeled below the profile, which ends at the Colorado River near Quien Sabe Point. Topographic data are from 1:250,000 Needles (USGS 1969a) and Salton Sea (USGS 1969b) map sheets.

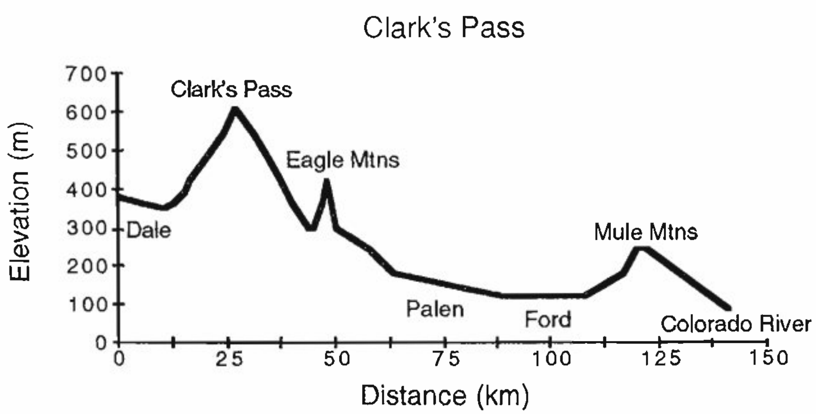


Figure 11. (b) Topographic profile along the Clark's Pass path. Vertical exaggeration is approximately 87X. The profile follows the approximate centerline of the sand path, including both active and inactive sand deposits. Mountain ranges encountered along the path are labeled above the profile; these topographic obstacles are crossed by the sand through emplacement of thick sand ramps. Playa names are labeled below the profile, which ends at the Colorado River near Blythe, California. Topographic data are from 1:250,000 Needles (USGS 1969a) and Salton Sea (USGS 1969b) map sheets.

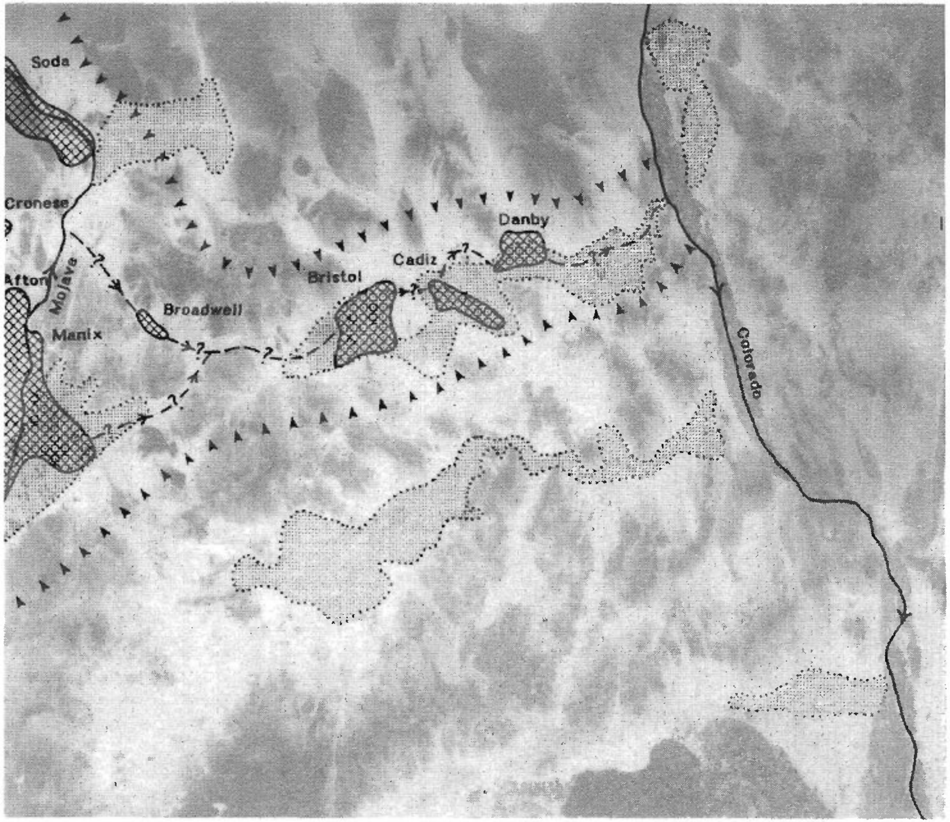


Figure 12. The paleodrainage reconstruction of Blackwelder (1954) is superposed on the oblique photograph in Figure 1a. Arrows outline the drainage into the paleolakes (gridded pattern). Dotted patterns show sand deposit locations from Figure 1b. Note the close match of the Bristol Trough sand path and the inferred drainage from the Mojave River to the Colorado River.

speculate that some of the sand transported down the pathways may have crossed the Colorado River and ended up on the Cactus and La Posa Plains (Williams et al. 1991, Tchakerian et al. 1992). The lack of other sand accumulations east of the Colorado River argues against the river itself as the primary sand source and argues for a mechanism which could bring mobile sand to this particular location. Batches of aeolian sand appear to enter the river floodplain at the western end of the sand transport paths (Figure 13). Eventually, the river may have opened a new meander channel west of aeolian sand deposits on the floodplain, which were then remobilized by the wind and exported onto the Cactus and La Posa dunefields. It is difficult to assess how effective such a process may have been prior to regulation of flow along the Colorado River. However, this mechanism could account for the presence of a large quantity of sand on the plains east of the Colorado River and is coincident with the termination of sand transport paths through the Mojave Desert.

Paleoclimatic Implications

The presence of well-developed paleosols and multiple aeolian depositional units within the sand ramps along the sand transport paths indicates that aeolian activity in the Mojave Desert has been widespread and episodic. A description of the units exposed in the Dale sand ramp was given earlier, and additional exposures of multiple soil-horizons were observed during a recent reconnaissance survey of the more remote portions of the Bristol Trough sand pathway. Such exposures within the sand pathways may be related to more extensively studied paleosols in the western Mojave Desert.

In the Silver Lake basin (part of Pleistocene Lake Mojave), an aeolian depositional period (Qe2) that took place between 12 and 8.7 ka, has been recognized by Wells et al. (1987) and Brown (1989). An older aeolian depositional episode prior to 22 ka has also been identified by Brown (1989) in sediment cores from the Silver Lake basin. The sedimentary record from Lake Mojave indicates that lake levels were low to intermediate between 13.5 and 9 ka, with final dessication around 8.7 ka (Brown 1989). It seems likely that the sand ramps observed along the sand transport pathways also witnessed increased levels of aeolian sediment input during low stands of the desert paleolakes, as sediments became available for transport from dried lake basins and their surrounding piedmont areas.

Sediment supply from desert lake basins was drastically curtailed after 9 ka, as a result of the changing environmental conditions which caused most lakes either to dry up or to reach very low water levels (Benson et al. 1990). The sand ramps probably underwent a period of stabilization through vegetation development and soil formation because of the reduction in sediment supply. They were subsequently mantled by rock debris from the adjoining mountains and later entrenched by ephemeral streams. In the middle Holocene, from about 7 to 5 ka, the Mojave Desert experienced a drier than present climatic regime, a period referred to as the climatic optimum or the Altithermal, first recognized

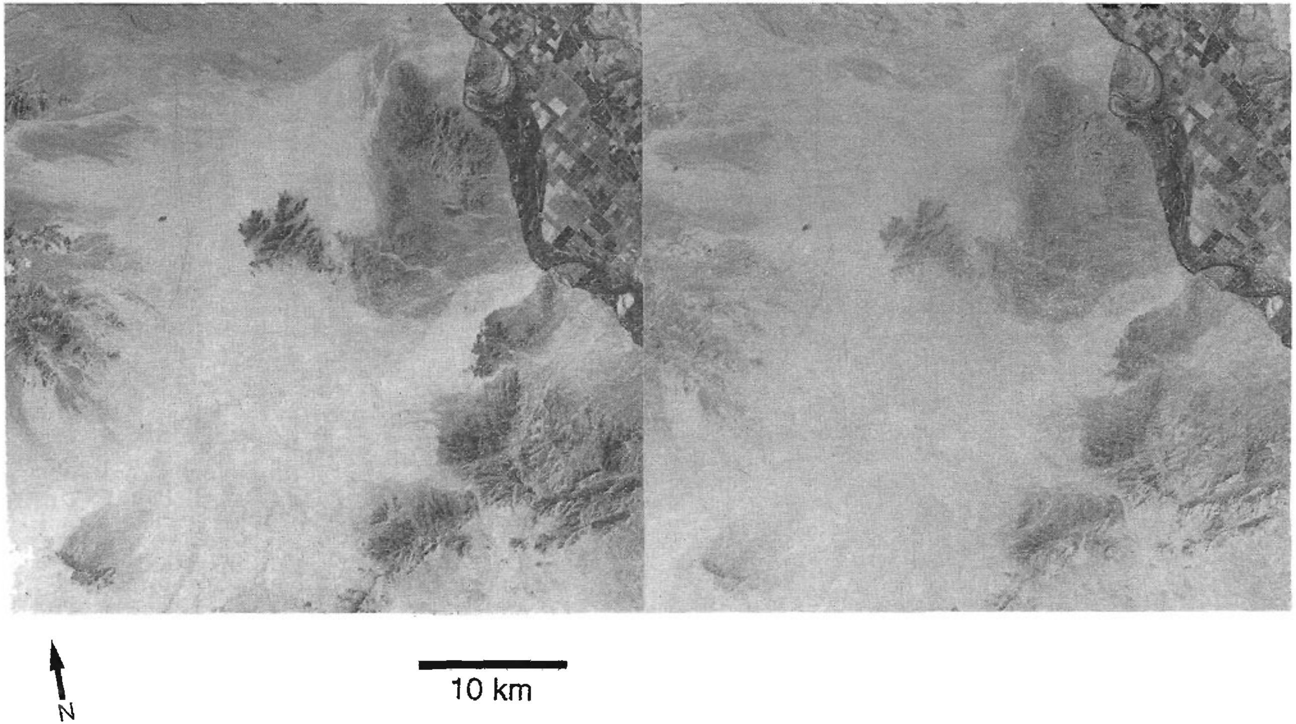


Figure 13. Stereo view of Rice Valley and the Quien Sabe Point area, from portions of Large Format Camera photographs, frames 2062 (left) and 2064 (right), taken during the STS 41-G Space Shuttle flight between October 5 and 13, 1984. The vertical relief is highly exaggerated in this stereo pair, but this view emphasizes the relation between the sand deposits, the mountains, and the Colorado River.

by Antevs (1962). According to Spaulding (1991), Middle Holocene macrofossil (packrat middens) records from the southern Mojave Desert indicate a more arid period than the present between 6800 and 5060 yr B.P. It is thus highly probable that the Middle Holocene period witnessed little aeolian activity as desert lakes were already dessicated by the time of the Altithermal, and most sand ramps fully stabilized.

Accelerator Mass Spectroscopy (AMS) ^{14}C and cation-ratio dating of varnished ventifacts on stabilized debris mantling sand ramps in the Cronese Basin in the Mojave Desert (see left margin of Figure 1b) indicate that aeolian activity ceased or was at a minimum, and that debris deposits were already stabilized, between 5.5 and 5 ka (Dorn et al. 1989). Hence (given the absence of numerical ages directly from dune deposits), most of the sand ramps were probably stable with rock talus and vegetation before the onset of more xeric conditions during the Altithermal, and aeolian activity was at a minimum or mostly restricted to those few desert basin areas that had active sediment input, such as the Mojave River Wash supplying sediments for the Kelso Dunes. Using luminescence dating measures, Lancaster et al. (1991) report a lack of ages older than 5000 yr B.P. from the main Kelso Dune fields, and suggest that the majority of the sediments have been extensively reworked prior to the mid-Holocene.

The entrenched sand ramps within the Bristol Trough and Clark's Pass sand pathways represent a valuable resource for studying paleoclimatic information preserved within the paleosols. The Dale sand ramp is presently the only locality within the sand pathways that has been thoroughly studied for sedimentological characteristics, but our field studies have identified other localities within the Bristol Trough path where entrenched sand ramps expose paleosol sequences. Comparison of the paleosol sequences, both along a given pathway and between adjacent pathways, should provide a test for the emplacement scenarios proposed here. Luminescence dating of key paleosol horizons is perhaps the most critical information required to quantify the climatic information recorded within the sand ramps.

FUTURE WORK

We have presented here the preliminary descriptions and interpretations of the sand deposits present in the eastern Mojave Desert. A considerable amount of field work remains to be carried out, particularly in terms of describing and documenting the sediment characteristics and internal stratigraphy within the thick sand ramps evident at several locations. The sand transport pathway hypothesis can be tested through additional analyses of samples already collected, particularly looking for mineralogical information which could indicate whether or not the sand at the proposed "upstream" end of the pathways could have supplied the sands observed at the termination of the pathways. Additional sedimentological studies may also help to test whether or not the sands along the pathways are consistent with transport away from the inferred source of each pathway. Obtaining samples specifically collected for luminescence dating measurements (Lancaster et al. 1991) from geographically separated soil horizons is essential to the development of a regional stratigraphic history of the eastern Mojave Desert.

The remote sensing data have been used in the present work for basic geomorphic and geographic descriptions, but spectral variations between different bands of Thematic Mapper data should be useful in refining the distribution of active and stabilized sand deposits (Blount et al. 1990). We also hope that the spectral information will be useful for estimating sand thickness throughout the region based on vegetation that is sensitive to particular sand thicknesses (Zimbelman and Williams, in preparation).

CONCLUDING REMARKS

We have presented both remote sensing and field evidence for the emplacement of aeolian sand pathways in the eastern Mojave Desert. Two pathways are described in detail: one extending eastward from the Bristol Playa past the Cadiz and Danby Playas through Rice Valley to the Colorado River, and a second path extending eastward from Clark's Pass past Palen and Ford Playas to the Mule Mountains by the Colorado River. The preferential development of sand ramps on the west slopes of mountains along each path indicates that the eastward-moving, wind-driven sand was not restricted by topographic divides between separate drainage basins around the individual playas and valleys. Preliminary sediment analysis of selected samples shows that there are discrete associations of sand characteristics along the sand pathways, with an inferred possible relationship between the stabilized sands in Rice Valley (within the Bristol Trough path) west of the Colorado River and stabilized linear dunes on the Cactus Plain and La Posa Plain east of the Colorado River. Sand transport along the paths appears to have been episodic, based on multiple soil horizons present in several dissected sand ramps.

ACKNOWLDGEMENTS

Several people assisted during the collection and processing of the data presented here: J. Heisinger and A. Johnston provided valuable image processing assistance at the Center for Earth and Planetary Studies, National Air and Space Museum, and the Large Format Camera prints are courtesy of Ron Greeley, Dan Ball, and the Arizona State University Planetary Geology group. The authors are grateful for careful reviews of an earlier version of the paper by Ron Dorn and Andrew Bach. Tchakerian acknowledges the support of the donors of the Petroleum Research Fund, administered by the American Chemical Society (ACS-PRF 26124-G2).

REFERENCES

Antevs, E. (1962) Late Quaternary climates in Arizona. *American Antiquity*, v. 28, p. 193-198.

Bassett, A. M., and Kupfer, D. H. (1964) A geologic reconnaissance in the southeastern Mojave Desert. *California Division of Mines and Geology Special Report*, v. 83.

Benson, L. V., Currey, D. R., Dorn, R. I., Lajoie, K. R., Oviatt, C. G., Robinson, S. W., Smith, G. I., and Stine, S. (1990) Chronology of expansion and contraction of four Great Basin systems during the past 35,000 years. *Paleogeography, Paleoclimatology, Paleoecology*, v. 78, p. 241-286.

Blackwelder, E. (1933) Lake Manley: An extinct lake of Death Valley. *Geographical Review*, v. 23, p. 464-471.

Blackwelder, E. (1954) Pleistocene lakes and drainage in the Mojave region, southern California. In R.H. Jahns (ed.) *Geology of Southern California*. California Division of Mines Bulletin, v. 170, p. 35-40.

Blount, H. G., and Lancaster, N. (1990) Development of the Gran Desierto sand sea. *Geology*, v. 19, p. 724-728.

Blount, H. G., Smith, M. O., Adams, J. B., Greeley, R., and Christensen, P. R. (1990) Regional aeolian dynamics and sand mixing in the Gran Desierto: Evidence from Landsat Thematic Mapper images. *Journal of Geophysical Research*, v. 95, p. 15463-15482.

Breed, C. S., and Grow, T. (1979) Morphology and distribution of dunes in sand seas observed by remote sensing. In E. D. McKee (ed.) *A Study of Global Sand Seas*, U.S. Geological Survey Professional Paper 1052, p. 253-302.

Brown, W. J. (1989). *Late Quaternary Stratigraphy, Paleohydrology, and Geomorphology of Pluvial Lake Mojave, Silver Lake and Soda Lake Basins, Southern California*. M.S. thesis, University of New Mexico.

Chadwick, O. A., and Davis, J. O. (1990) Soil forming intervals caused by eolian sediment pulses in the Lahontan Basin, northwestern Nevada. *Geology*, v. 18, p. 243-246.

Dohrenwend, J. C. (1987) Basin and range. In W. L. Graf (ed.) *Geomorphic Systems of North America*, Centennial Special, v. 2. Boulder, Colorado, Geological Society of America, p. 303-342.

Dorn, R. I., Jull, A.J.T., Donahue, D. J., Linick, T. W., and Toolin, L. J. (1989) Accelerator mass spectrometry radiocarbon dating of rock varnish. *Geological Society America Bulletin*, v. 101, p. 1363-1372.

El-Baz, F., Breed, C. S., Grolier, M. J., and McCauley, J. F. (1979) Aeolian features in the western desert of Egypt and some applications to Mars. *Journal of Geophysical Research*, v. 84, p. 8205-8221.

El-Baz, F., and Maxwell, T. A., eds. (1982) *Desert landforms of southwestern Egypt: A basis for comparison with Mars*. NASA Contractor Report CR-3611.

Greeley, R., and Iversen, J. D. (1978) Field guide to the Amboy lava field, San Bernadino County, California. In R. Greeley et al. (eds.) *Eolian Features of Southern California: A Comparative Planetary Geology Guidebook*. Arizona State University p. 24-52.

Greeley, R., and Iversen, J. D. (1985) *Wind as a Geologic Process*. New York, Cambridge University Press.

Greeley, R., Arvidson, R. E., Elachi, C., Geringer, M. A., Plaut, J. J., Saunders, R. S., Schubert, G., Stofan, E. R., Thouvenot, E.J.P., Wall, S. D., and Weitz, C. M. (1992) Aeolian features on Venus: Preliminary Magellan results. *Journal of Geophysical Research*, v. 97, p. 13319-13345.

Jahns, R. H., ed. (1954) *Geology of Southern California*. California Division of Mines, Bulletin 170.

Laity, J. E. (1987) Topographic effects on ventifact formation, Mojave Desert, California. *Physical Geography*, v. 8, p. 113-132.

Laity, J. E. (1992) Ventifact evidence for Holocene wind patterns in the east-central Mojave Desert. *Zeitschrift für Geomporhologie*, v. 84, p. 73-88.

Lancaster, N. (1993) Kelso Dunes. *National Geographic Research and Exploration*, v. 9, p. 444-459.

Lancaster, N., Greeley, R., and Christensen, P. R. (1987) Dunes of the Gran Desierto sand-sea, Sonora, Mexico. *Earth Surface Processes and Landforms*, v. 12, p. 277-288.

Lancaster, N., Wintle, A. G., Edwards, S. R., Duller, G., and Tchakerian, V. P. (1991) Chronology of aeolian activity at Kelso Dunes: evidence from luminescence dating of dune sediments. *Geological Society of America Abstracts with Programs*, v. 23, p. 355.

Lancaster, N., Gaddis, L., and Greeley, R. (1992) New airborne imaging radar observations of sand dunes: Kelso Dunes, California. *Remote Sensing of the Environment*, v. 39, p. 233-238.

Leopold, L. B., Wolman, M. G., and Miller, J. P. (1964) *Fluvial Processes in Geomorphology*. W.H. Freeman & Co., San Francisco.

McFadden, L. D., Wells, S.G., and Jercinovich, M. J. (1987) Influences of eolian and pedogenic processes on the origin and evolution of desert pavements. *Geology*, v. 15, p. 504-508.

Merriam, R. (1969) Source of sand dunes of southeastern California and northwestern Sonora, Mexico. *Geological Society of America Bulletin*, v. 80, p. 531-534.

Miller, R. R. (1946) Correlation between fish distributions and Pleistocene hydrography in eastern California and southwestern Nevada, with a map of the Pleistocene waters. *Journal of Geology*, v. 54, p. 43-53.

Paisley, E.C.I., Lancaster, N., Gaddis, L. R., and Greeley, R. (1991) Discrimination of active and inactive sand from remote sensing: Kelso Dunes, Mojave Desert, California. *Remote Sensing of the Environment*, v. 37, p. 153-166.

Sagan, C., Veverka, J., Fox, P., Dubisch, R., Lederberg, J., Levinthal, E., Quam, L., Tucker, R., Pollack, J. B., and Smith, B. A. (1972) Variable features on Mars: Perliminary Mariner 9 television results. *Icarus*, v. 17, p. 346-372.

Sharp, R. P. (1966) Kelso dunes, Mojave Desert, California. *Geological Society of America Bulletin*, v. 77, p. 1045-1074.

Sharp, R. P. (1978) The Kelso Dune complex. In R. Greeley et al. (eds.). *Eolian Features of Southern California:* A Comparative Planetary Geology Guidebook. Arizona State University, p. 53-63.

Shelton, J. S., Papson, R. P., and Womer, M. (1978) Aerial guide to geological features of southern California. In R. Greeley et al. (eds.) *Eolian Features of Southern California: A Comparative Planetary Geology Guidebook*. Arizona State University, p. 216-249.

Smith, H.T.U. (1967) *Past versus present wind action in the Mojave Desert region, California*. U.S. Air Force Cambridge Laboratory Report AFCRL-67-0683.

Smith, R.S.U. (1982) Sand dunes in the North American Desert. In G.L. Bender (ed.) *Reference Handbook on the Deserts of North America*. Greenwood Press, Westport, Connecticut, p. 481-554.

Spaulding, W. G. (1991) A middle Holocene vegetation record from the Mojave Desert of North America and its paleoclimatic significance. *Quaternary Research*, v. 35, p. 427-437.

Tchakerian, V. P. (1991) Late Quaternary aeolian geomorphology of the Dale Lake sand sheet, southern Mojave Desert, California. *Physical Geography*, v. 12, p. 347-369.

Tchakerian, V. P., Zimbelman, J. R., and Williams, S. H. (1992) Transport of aeolian sediments across desert basins, California and Arizona. *Association of American Geographers Abstracts*, 88th Annual Meeting, p. 235.

Thompson, D. G. (1929) *The Mojave Desert Region, California: A Geographic, Geologic, and Hydrologic Reconnaissance*. U.S. Geological Survey Water-Supply Paper 578.

U.S. Geological Survey (1969a) Topographic map of the Needles area, California. Map NI 11-6, scale 1:250,000, Denver, CO.

U.S. Geological Survey (1969b) Topographic map of the Salton Sea area, California. Map NI 11-9, scale 1:250,000, Denver, CO.

Wells, S. G., McFadden, L. D., and Dohrenwend, J. C. (1987) Influence of late Quaternary climatic changes on geomorphic and pedogenic processes on a desert piedmont, eastern Mojave Desert, California. *Quaternary Research*, v. 27, p. 130-146.

Williams, S. H., Zimbelman, J. R., and Tchakerian, V. P. (1991) Evidence of aeolian sand transport across the Colorado River. *EOS, Transactions of the American Geophysical Union*, v. 72, p. 214.

Wilson, I. G. (1971) Desert sandflow basins and a model for the development of ergs. *Geographical Journal*, v. 137, p. 180-199.

Zimbelman, J. R., and Williams, S. H. (in preparation) Aeolian wind streaks: Geological and botanical effects on surface albedo contrasts.