Chapter 2

PHYSICAL SETTINGS OF THE NELLIS DUNES RECREATION AREA

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1. Location

The Nellis Dunes Recreation Area (NDRA) is located about 8 km from the northeastern margin of the conurbation Las Vegas - North Las Vegas - Henderson, in the northeastern portion of the Las Vegas Valley referred to as the Nellis Basin (Beard et al., 2007) (Fig. 1). It lies west of the Gale Hills at the southern end of the Dry Lake Range and has a more or less triangular shape with N-S, W-E and SW-NE sides of 8.0, 7.8 and 9.0 km respectively, and a small additional rectangle 2.4 km x 1.6 km in the SE. It encompasses an area of approximately 37 km^2.

2. Physical settings: an overview

2.1 Topography

The Las Vegas Valley is located in the Great Basin region of the Basin and Range physiographic province of the USA. It is an intermountain valley, surrounded by generally N-S-trending mountain ranges between 450 and 2100 m above the valley floor in the N and E, and up to 3000 m above the valley floor in the west. Nellis Dunes Recreation Area is located on the eastern side of the valley, in between the Sheep Range

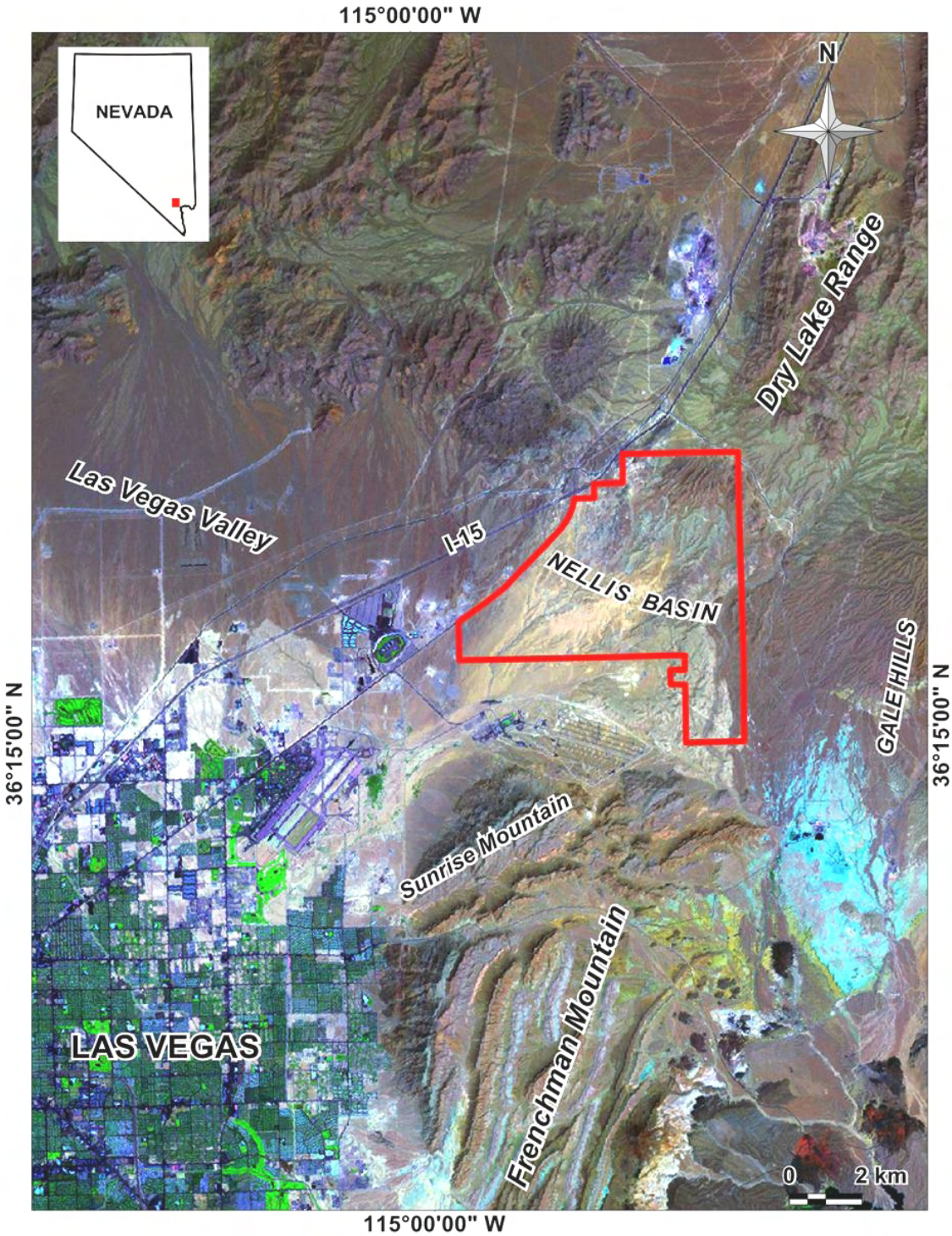

Fig. 1: Landsat band combination 7, 4, 1 showing the location of the study area relative to geographic features in the northeastern part of the Las Vegas Valley. The Nellis Dunes Recreation Area is outlined in red and occupies the Nellis Basin.

(to the N) and the Sunrise and Frenchmen Mountains (to the S), on a surface generally tilting from the NE to the SW. A detailed topographic map of the area is shown in Fig. 2. The southwestern and southeastern parts of the area are generally flat, tilting slightly to the SW. The central part shows a more complex topography, with various SW-NE-oriented valleys separated by elongated ridges and (especially in the NW) plateaus. The incision of these valleys is more prominent in the south (25-35 m) than in the north (usually about 15-20 m). In the northeastern corner the area becomes slightly mountainous, with several SW-NE ridges separating narrow valleys up to 50 m deep (Fig. 2). These ridges culminate at about 60-80 m above the surrounding landscape. Their altitude is around 850 m a.s.l., whereas the lowermost parts of Nellis Dunes Recreation Area (SW and SE corners) are situated at about 605 m a.s.l.

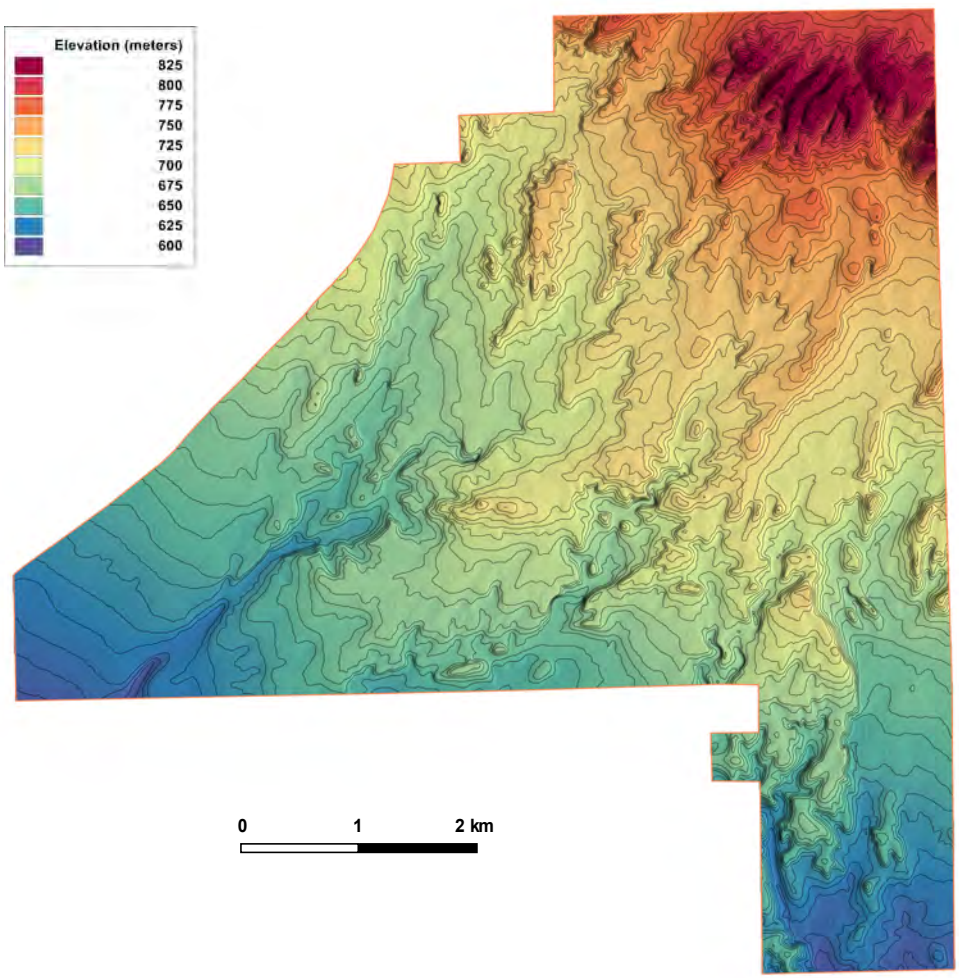

Fig. 2: Topographic map of the Nellis Dunes Recreation Area.

2.2 Geology

Nellis Dunes Recreation Area is mainly composed of incised fan remnants and exposed late Tertiary and Quaternary sediments (Fig. 3). The oldest rock units in the NDRA occur in the mountains in the northeast. They belong to the faulted and folded Ordovician Pogonip Formation, Eureka Quartzite, and Ely Springs Dolomite (Beard et al., 2007). The

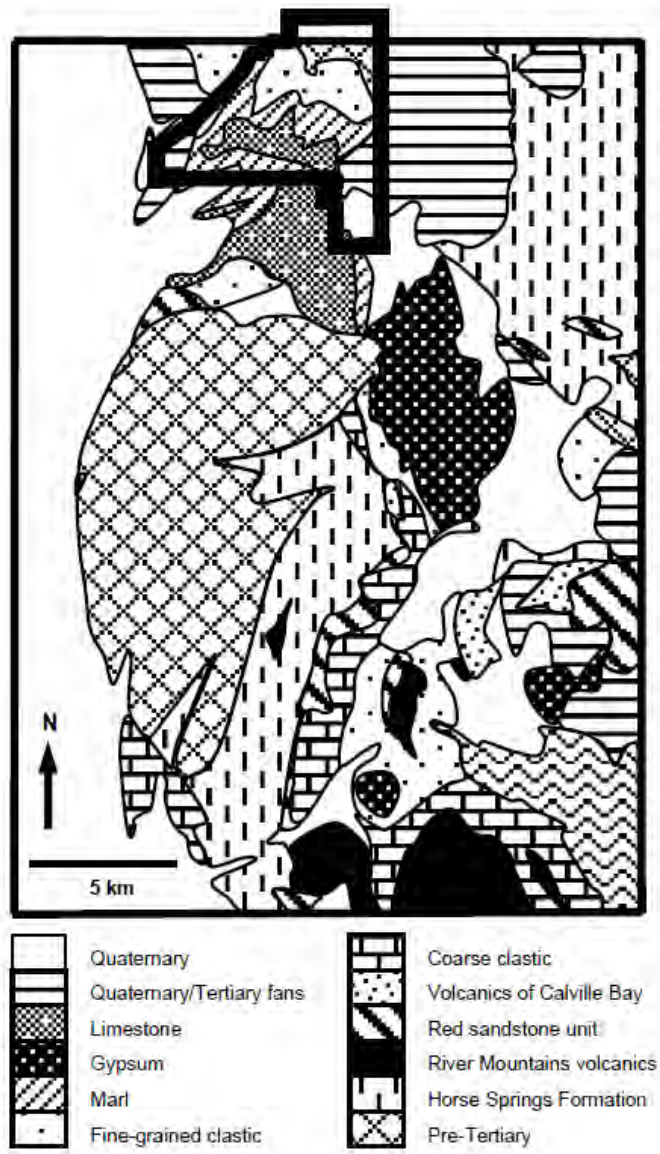

Fig. 3: Simplified geologic map of the area east of Las Vegas. NDRA is indicated by the black contour in the north. (Modified from Castor and Faulds, 2001)

largest block of exposed bedrock, representing the highest elevations, belongs to the Permian Bird Spring Formation. Overlying the Paleozoic carbonates are Neogene units (10-15 Ma) assigned to the Muddy Creek Formation (Beard et al., 2007). They consist of 2-50 m thick limestone that overlies, and is partially interbedded with, a marl sequence as much as 10 m thick. The marl locally contains rock fragments of limestone, and thin gypsite layers (Castor and Faulds, 2001). A fine-grained sandy sequence underlies the limestone and marl. In the western areas, east of the I-15 interstate highway, Muddy Creek lithologies include conglomerate, sandstone, shale, and gypsum. Quaternary to late Tertiary alluvial fan remnants and inset fans are found throughout the field area. In the northern portion of the NDRA these remnants with associated resistant petrocalcic horizons cap isolated mesas. The center of the southern portion of the NDRA is characterized by an extended zone of dune sands, which cover the Tertiary deposits. Although much of the sand is generally only a few dm thick, many highly active reversing dunes (oriented NW-SE) are present. These ridges can be up to 250 m long and are separated by areas of thin sand or silty-rocky subsoil. The belt with sand dunes covers 9% of the NDRA.

2.3 Soils

Soil development is negligible in the areas of bedrock exposure (these include the badlands of exposed Muddy Creek Formation) and active sand dunes. In these regions the surficial characteristics are controlled by the underlying geology or dune sand characteristics. In the remaining areas (primarily the fan remnants), the soils are characterized by thin (0-10 cm), platy, alkaline, A and Av (vesicular) horizons containing low amounts of organic matter. Vesicular A (Av) horizons are almost always associated with desert pavements. Well-developed soils occur primarily in the southeast and southwestern portions of the field area. They contain pedogenic accumulations of calcium carbonate at depth (~15 to >100 cm), forming calcic and petrocalcic horizons. In many areas (especially in the western portion of the NDRA) the surface horizons are eroded exposing the calcic or petrocalcic horizons at the surface. In these areas, much of the surface gravels can be composed of broken fragments of the petrocalcic horizons. Pedogenic gypsum and other salt minerals are negligible or absent. Soils in the study area are classified as Typic Haplocalcids, Calcic Petrocalcids and Typic Torriorthents.

2.4 Climate

Nellis Dunes Recreation Area is located in the northeastern part of the Mojave Desert and is thus characterized by an arid climate. Summers are hot and dry, with temperatures over 40 °C, whereas winters are mild, with an average daily maximum in January around

13.5 °C. Average annual temperature is 19.5 °C (Lazaro et al., 2004). Precipitation is low, partly because of the rain shadow created by the Sierra Nevada Range and the Spring Mountains west of Las Vegas, which protect the area from large western synoptic systems (BLM, 2004). Average annual precipitation is 105 mm, but may vary substantially between years. Monthly average precipitation ranges from 2 mm in June to 14 mm in February. Scattered thunderstorms typically occur at the end of July and the beginning of August.

Average annual wind speed (at 10 m standard height) at Nellis Air Force Base, which borders to the south of the NDRA, is 3.3 m s^{-1}, and average annual gust speed, 11.0 m s^{-1} (Goossens and Buck, 2011). Gusts can be up to 25 m s^{-1}.

More details are shown in Fig. 4. The figure displays data on wind speed recorded during the wind erosion measurements phase of the project (December 2007 - December 2008). Data refer to a height of 20 m and were measured from a wind tower erected in the southwest corner of the NDRA. Wind speed was highest in April, decreased systematically until December, and then stayed more or less constant until March. This pattern applies to both the day-time (8:00 - 20:00) and night-time (20:00 - 8:00) winds. Winds were stronger during the day hours, and the difference between day and night remained more or less constant between January and August but decreased considerably from September to December. There were nearly no differences in monthly average wind speed between day and night in November and December. In March 2008 daily wind speeds were abnormally low.

Data on wind direction are displayed in Fig. 5. There is a distinct bi-modal regime: in the late spring through early autumn, winds blow mainly from the S and SW whereas in the late autumn through early spring they blow opposite, predominantly from the NE-E. However, they can blow from any direction at any time.

The bi-modal wind regime with two nearly opposing wind directions is reflected by the NW-SE oriented reversing dunes in the NDRA, which are oriented perpendicular to the two dominant wind directions.

3. Surface units prone to dust emission

The aim of the project was to study dust emissions caused by natural processes (wind erosion) and human activities (of-road vehicular activity or ORV) in the Nellis Dunes Recreation area. Besides meteorological and human factors the occurrence and intensity of the emissions is almost exclusively determined by the type and characteristics of the surfaces on which emission takes place. Defining, mapping and analysis of the different types of surfaces that occur in the NDRA is thus the first necessary step in studying dust

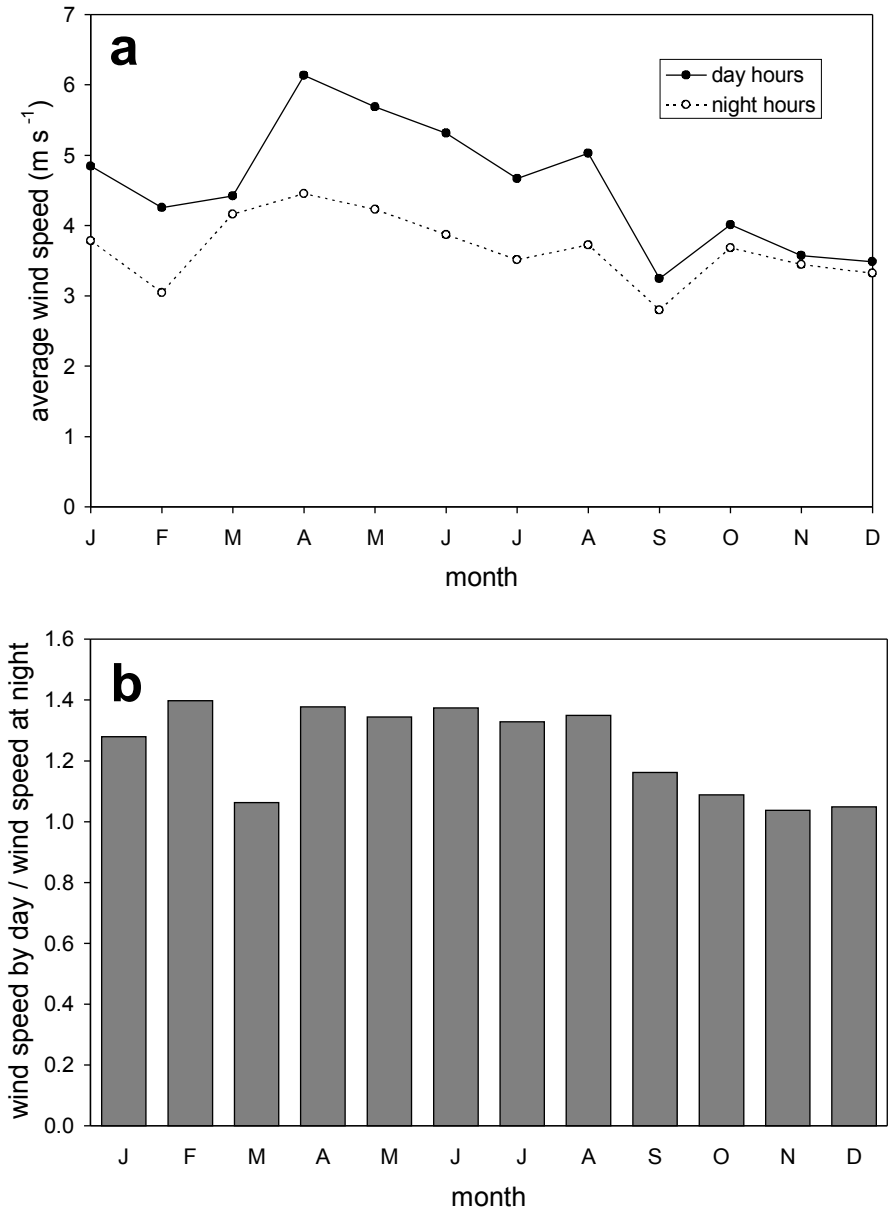

Fig. 4: Wind speed regime at NDRA. (a) average wind speed (at 20 m); (b) ratio of wind speed by day to wind speed at night.

emissions in the Nellis Dunes area. This section describes the criteria used to select the surface units, lists and describes the 17 surface units selected, and provides a detailed map of the NDRA displaying the occurrence of the surface units in the study area. A map with the ORV trails is also presented.

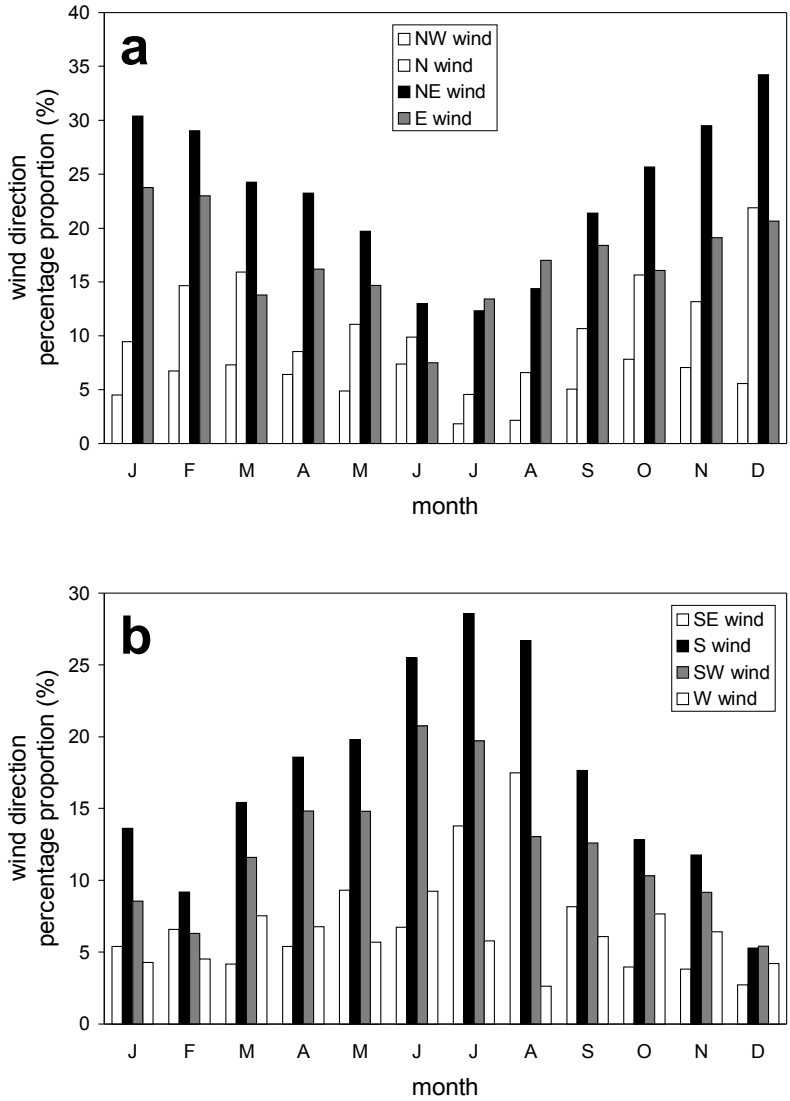

Fig. 5: Bi-seasonal regime of wind direction at NDRA. (a) N-NE sector; (b) S-SW sector. Percentages are based on 24-h data.

3.1 Criteria

The identification of the surface units is primarily based on their potential to emit dust. Therefore, dust emission units do not necessarily need to correspond with geologic, geomorphic, or pedologic units, although direct or indirect relationships with such units usually exist. The type of surface, combined with the composition of the subsoil, usually determines the vulnerability of a unit to emit dust. The criteria for selecting emission

units are thus mainly based on the following observations: presence and amount of rock fragments, presence and amount of crusts, presence and amount of vegetation, textural composition of the top layer (sand, silt, and clay), and sometimes, though not always, topographic position and geomorphic setting. These characteristics are relatively stable over time, making them useful tools for selecting and defining surface units for the purpose of studying dust emission. Other factors such as rainfall and, at the local scale, disturbance caused by animal activity, also affect the emission of dust but are more variable in time and space and thus less recommended as selection tools. In NDRA there is no grazing and animal disturbance of the top layer is very small to negligible. Furthermore NDRA is quite small (37 km^2), and rainfall is distributed nearly homogeneously over the area. Rainfall and animal disturbance are thus not relevant criteria to define dust-emission surface units in NDRA. However, NDRA is extensively used for ORV recreation, and therefore areas that are highly disturbed due to human activity are included in the mapping criteria.

3.2 The 17 surface units selected for this study

Seventeen surface types were identified in the Nellis Dunes Recreation Area based on textural composition, surface crusts, rock cover, and vegetation. They can be grouped into four major classes:

(1) *Sands and sand-affected areas:* active or stabilized sands, with or without rock fragments and/or vegetation;

(2) *Silt and clay areas:* loose and slightly stabilized silt and clay deposits, with or without rock fragments;

(3) *Rock-covered areas:* stabilized silty or sandy silt deposits with rock fragments on top, desert pavements over a silty sublayer (Av horizon), bedrock, and/or petrocalcic horizons;

(4) *Drainage areas:* active drainages in sand and silt areas, and gravelly drainages.

In this study, sand is defined as the fraction 63–2000 μm, silt as the fraction 2–63 μm, and clay as the fraction <2 μm.

The distribution of the surface units as a proportion of the total area of the NDRA is illustrated in Figure 6. A detailed description of each unit is given below, and a summary, for quick reference purposes, is provided in Table 1. Quantitative information for each unit is shown in Table 2. Photographs of the units, grouped by class are shown in Figures 7–10.

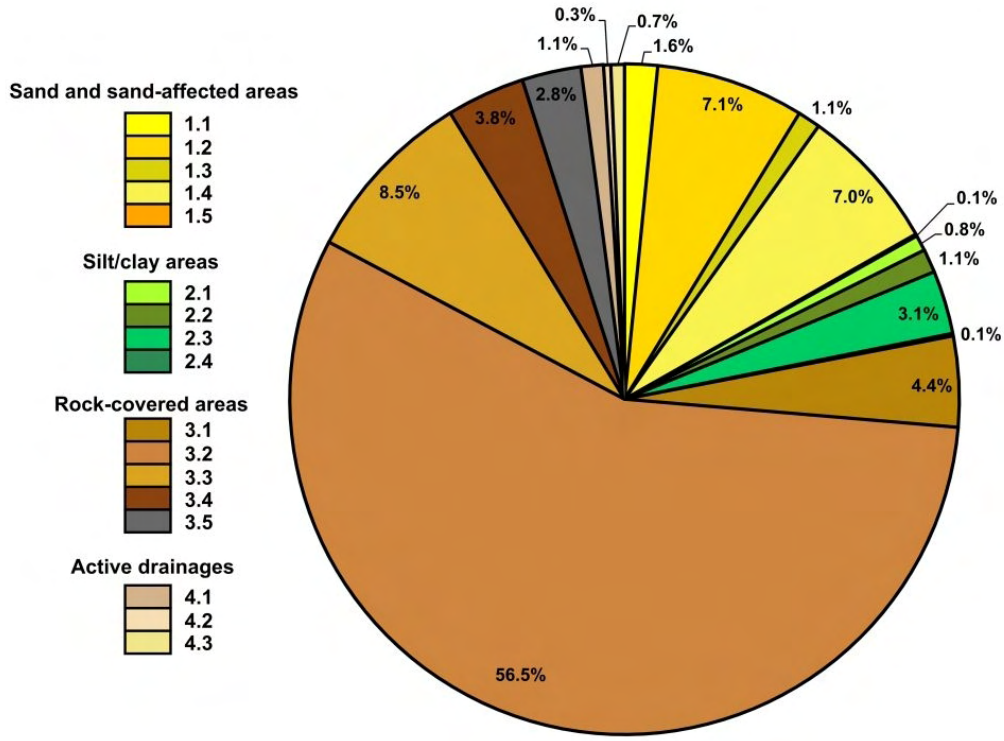

Fig. 6: Chart illustrating the areal proportions of the 17 surface types within the Nellis Dunes Recreation Area.

3.2.1 Sand and sand-affected areas

Surface Unit 1.1: Dunes with no vegetation. Active sand dunes and sand sheets with no vegetation occur mostly, though not exclusively, as prominent ridges. The depth of the active sand layer varies from a few decimeters to several meters. Sparse rock fragments and underlying petrocalcic horizons may locally outcrop where the sand layer is thin. Surface crusts are absent.

Surface Unit 1.2: Dunes with vegetation. Dune sands with sparse shrubs. The sand is active and there is no surface crust. Small coppice dunes may be present. Rock fragments may occur on the surface, but rock cover is low (<5%) and does not affect the deflation.

Surface Unit 1.3: Disturbed sand surfaces. Mixture of loose and active sand, rock fragments and underlying bedrock. This unit typically occurs in areas where shallow (<2-3 cm) sands cover a substratum of petrocalcic horizons and/or bedrock and disturbance by human activity is high.

Table 1: Overview and characteristics of the 17 surface units in the Nellis Dunes Recreation Area

Map unit	Description	Rock fragments	Surface crust	Vegetation
Sand and sand-affected areas				
1.1	Active dunes without vegetation. Decimeter to several meters thick.	Sparse; may have exposed petrocalcic horizons	Absent	Absent
1.2	Active dunes with vegetation. Coppice dunes <50 cm may be present.	Sparse; <5% rock cover	Absent	Isolated shrubs
1.3	Anthropogenic disturbed sand surfaces. Typically <2-3 cm thick loosse sands overlying petrocalcic horizons or bedrock.	Common, mixed with 2-3 cm thick loose sand overlying bedrock	Absent	Absent
1.4	Patchy, shallow (1-3 cm thick), loose sand overlying silty/rocky subsoil	Common, not interlocking, rocks in subsoil are exposed at surface	Absent	Isolated shrubs
1.5	Very fine sand and coarse silt outcrops. Commonly badlands.	Absent	Physical	Mostly absent
Silt/clay areas				
2.1	Silt/clay outcrops with biological crust	Sparse, <3-4% rock cover	Biologic	Isolated shrubs
2.2	Silt/clay outcrops with gravel	Common, <15%, not interlocking	Physical	Usually absent
2.3	Aggregated silt deposits, commonly badlands, aggregates <5 mm diameter	Absent	Physical, patchy distribution	Absent
2.4	Anthropogenic disturbed silt surfaces	Variable, not interlocking	Absent	Absent
Rock-covered areas				
3.1	Well-developed desert pavements with underlying silty Av horizon	Abundant: tightly interlocking rock fragments, nearly 100% surface cover	Physical between rock fragments	Rare, isolated shrubs
3.2	Rock-covered surface with silt/clay	Many: 60-80%, poorly interlocking	Physical and biological between rock fragments	Common, shrubs (10-15%)
3.3	Rock-covered surface with sandy loam	Many: 60-80%, poorly interlocking	Physical and biological between rock fragments	Common, shrubs (10-15%)
3.4	Rock-covered with encrusted sand and biological crusts	Common: 20-30%, poorly interlocking	Biological, continuous	Common, shrubs (10%)
3.5	Bedrock and/or exposed petrocalcic horizons	Continuous rock outcrop	Absent	Rare shrubs
Active drainages				
4.1	Gravelly drainages, without fine sediment	Abundant: 90-100%, non-interlocking gravel clasts	Absent	Absent
4.2	Gravel and sand drainages	Abundant: 70-80% with sand mixture	Absent	Absent
4.3	Gravel and silt/clay drainages	Common: 30-60%, poorly interlocking, with silt mixture	Physical	Common, shrubs (10-30%)

Surface Unit 1.4: Patchy layers of sand over silty or rocky subsoil. These surfaces constitute a thin layer of loose sand (1-3 cm) covering the subsoil. Many underlying clasts are exposed at the surface. There is no surface crust; the sand is active, and small dunes may locally occur.

Surface Unit 1.5: Outcrops of a mixture of very fine sand and coarse silt. These outcrops may occur in badlands and on steep slopes, but also on plateaus. In NDRA, they typically have a yellow color. These surfaces are almost free of vegetation and are usually stabilized by a silty sandy crust.

Table 2: Information on texture, rock cover, surface crust, surface resistance and vegetation for the 17 surface units in the Nellis Dunes Recreation Area

Surface unit	Soil texture										Rock fragments			Surface crust	Surface resistance		Vegetation
	>2000 µm (%)	1000–2000 µm (%)	710–1000 µm (%)	500–710 µm (%)	250–500 µm (%)	180–250 µm (%)	105–180 µm (%)	63–105 µm (%)	<63 µm (%)	Median grain diameter (fraction < 500 µm) (µm)	Rock cover (on surface)		Rock content (>2 mm in upper 15 mm) (%)	Presence	Normal resistance (kg* cm^{-2})	Tangential resistance (kg* cm^{-2})	Vegetation cover (%)
											total area (%)	non-vegetated area only (%)					
sands and sand-affected surfaces																	
1.1	0.01	0.01	0.01	0.03	12.03	58.77	26.97	2.12	0.07	209.98	0.0	0.0	0.01	no	0.136	0.051	0.5
1.2	13.86	0.61	0.23	0.17	4.06	21.14	48.32	10.50	0.88	181.50	4.3	4.6	13.86	no	0.143	0.134	8.7
1.3	49.74	2.76	0.99	8.75	3.01	4.10	24.25	5.15	1.08	178.45	54.6	54.9	49.74	no	0.159	0.171	0.5
1.4	40.84	0.60	0.16	0.22	0.44	2.01	45.42	8.43	1.44	153.21	23.6	28.3	40.84	no	0.149	0.244	18.3
1.5	10.77	6.70	2.14	1.70	7.58	9.03	46.69	11.77	2.35	152.20	4.3	4.3	10.77	yes	0.615	0.710	1.0
silt/clay surfaces																	
2.1	19.62	2.46	1.19	1.69	7.97	13.35	18.02	26.20	8.63	155.94	3.4	4.1	19.62	yes	0.210	0.780	16.8
2.2	24.45	5.86	3.70	3.96	9.81	7.47	15.13	15.29	10.95	52.35	11.3	11.6	24.45	yes	0.207	0.689	2.1
2.3	31.85	18.67	9.31	10.21	14.34	4.45	4.56	3.09	3.02	122.54	2.7	2.7	31.85[c]	yes	0.117	0.364	0.0
2.4	42.31	1.65	1.17	1.76	8.79	12.79	21.21	7.40	2.88	192.97	31.7	31.9	42.31	yes	1.112	1.940	0.5
rock-covered surfaces																	
3.1	74.40	1.80	1.26	0.88	2.97	2.95	8.19	5.77	1.47	117.26	94.9	97.8	74.40	no[a]	NA[a]	NA[a]	3.0
3.2	46.68	5.01	2.30	1.97	5.15	5.32	20.38	9.24	3.31	135.91	64.4	75.6	46.68	yes	1.109	1.451	14.4
3.3	32.29	1.63	0.55	0.50	1.12	2.07	41.07	18.37	2.34	139.98	32.6	40.1	32.29	yes	1.152	0.969	18.4
3.4	20.81	2.73	0.83	1.19	6.33	9.38	38.43	16.90	2.90	156.68	22.6	25.1	20.81	yes	0.218	0.560	10.1
3.5	99.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	84.79	94.3	98.5	99.99	no[b]	NA[b]	NA[b]	4.4
drainage surfaces																	
4.1	94.77	1.24	0.38	0.36	1.11	0.55	1.25	0.25	0.07	211.10	97.9	97.9	94.77	no[a]	NA[a]	NA[a]	0.0
4.2	63.93	4.50	1.24	1.10	6.43	10.02	9.82	2.17	0.56	229.08	76.0	76.0	63.93	no	0.085	0.127	0.0
4.3	60.54	6.27	2.45	2.37	11.42	9.44	5.10	1.40	0.64	202.23	35.8	47.0	60.54	yes	1.452	1.219	21.4

[a] Desert pavement.
[b] Bedrock.
[c] Particles >2 mm consist of aggregates of silt.

3.2.2 Silt and clay areas

Surface Unit 2.1: Silt and clay with crust. These surfaces usually occur near drainage channels in silt areas. The sediment is predominantly composed of silt and commonly shows a continuous cyanobacterial crust. Some vegetation (isolated shrubs) is typical. A few scattered rock fragments (<3-4%) may occur, but they remain sparse.

Surface Unit 2.2: Silt and clay with gravel. Mixture of silt and gravel, but with considerably more (>85% in weight) silt than gravel on the surface. A surface crust may be present, although many areas are not encrusted. These surfaces do not occur in drainage areas but are typically located on hill slopes and plateau escarpments.

Surface Unit 2.3: Aggregated silt deposits. Silt and clay surfaces where the particles are bound in aggregates up to 5 mm in diameter. The percentage of free particles is low. A surface crust is common, but the crust may be disturbed or even absent. These surfaces are entirely devoid of vegetation, and their erosion produces badlands-style topography.

Surface Unit 2.4: Disturbed silt surfaces. Mixture of noncrusted silt and rock fragments overlying bedrock. They occur in areas where the surface has been disturbed by human activity and are the silt equivalent of surface unit 1.3.

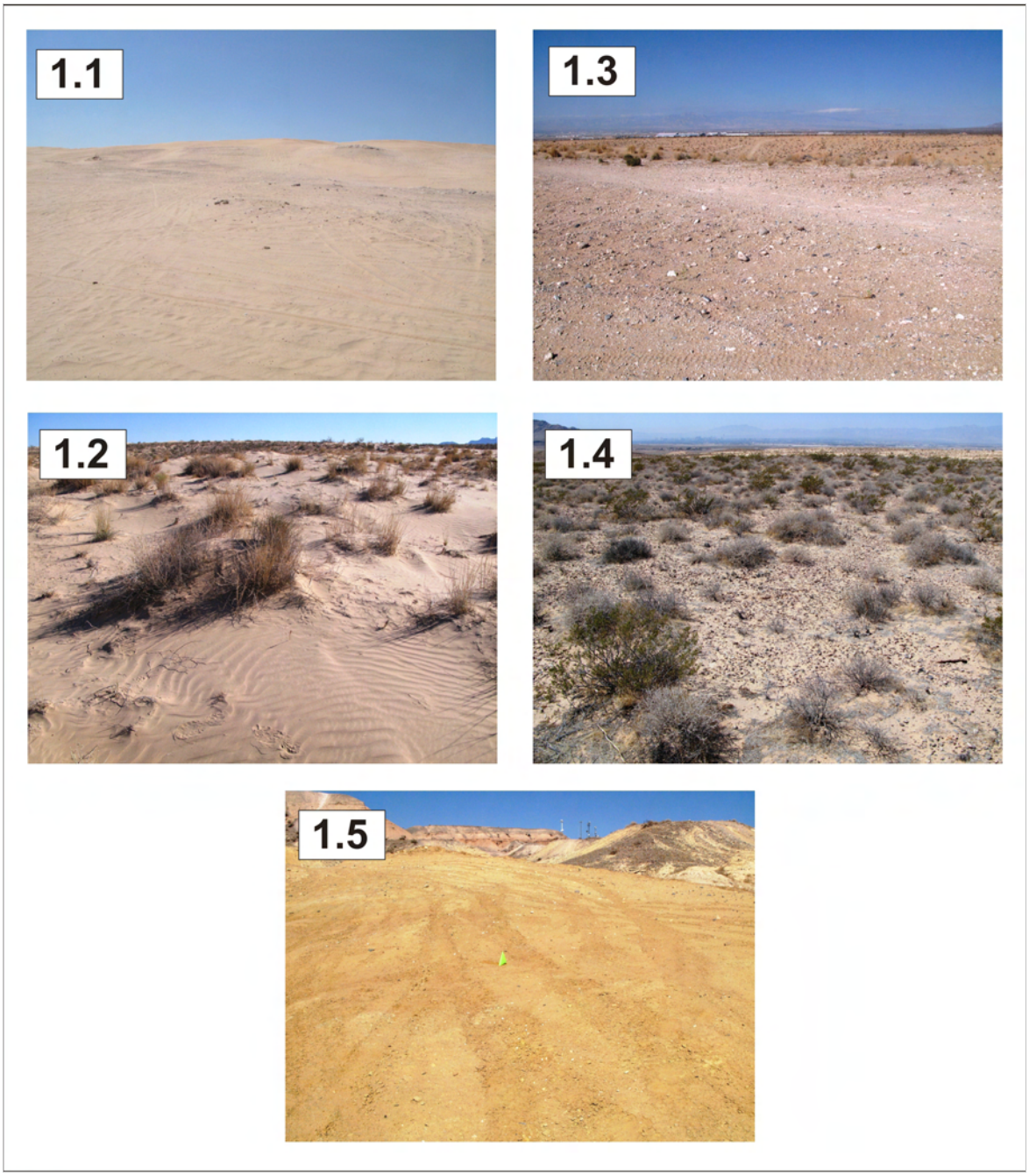

Fig. 7: Photograph of sand and sand-affected area surface units. 1.1: Dunes with no vegetation; 1.2: Dunes with vegetation; 1.3: Disturbed sand surfaces; 1.4: Patchy layers of sand over silty or rocky subsoil; 1.5: Very fine sand and coarse silt.

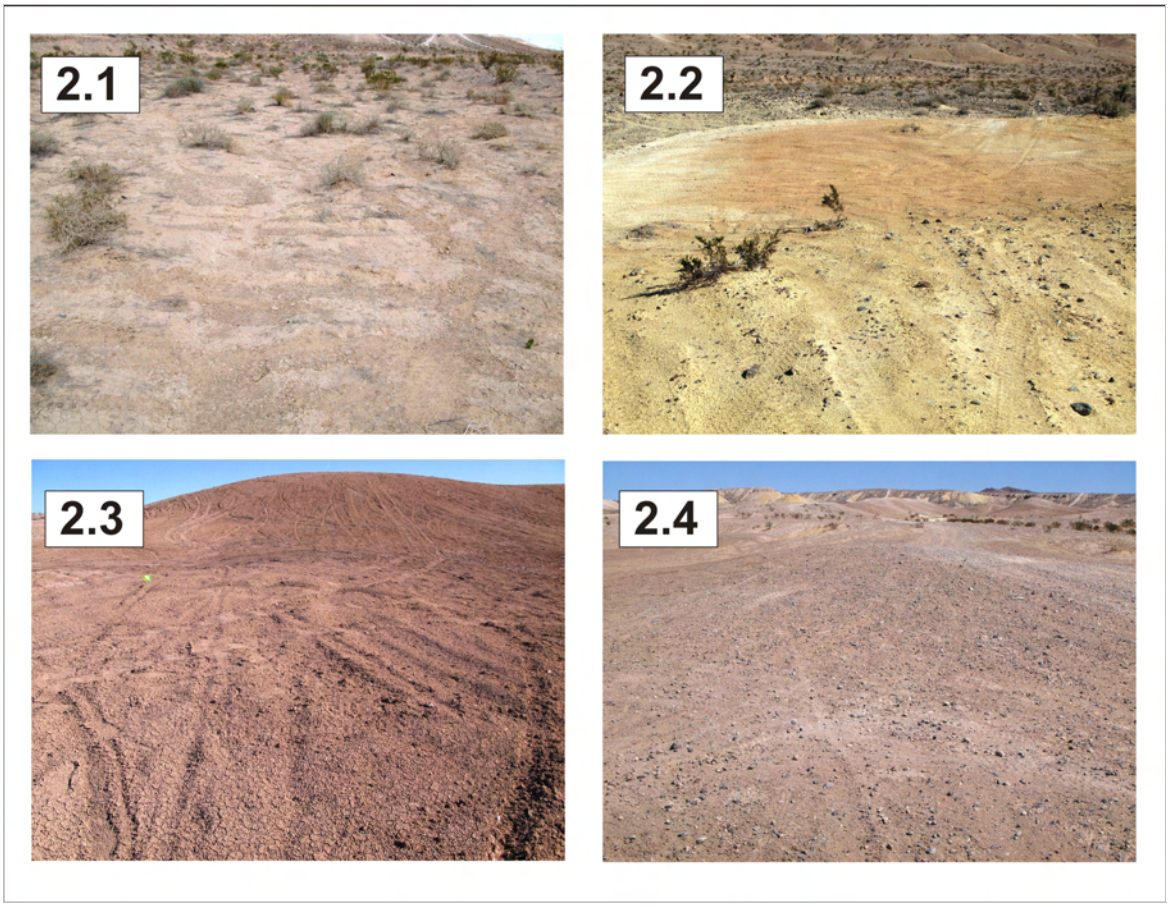

Fig. 8: Photograph of silt and clay area surface units. 2.1: Silt and clay with crust; 2.2: Silt and clay with gravel; 2.3: Aggregated silt deposits; 2.4: Disturbed silt surfaces.

3.2.3 Rock-covered areas

Surface Unit 3.1: Desert pavements. Well-developed and mature desert pavements over a (usually silty) subsoil (Av horizon). The rock fragments are partially embedded in the silt, and rock cover density is close to 100%. Vegetation (shrubs) may locally occur, but most desert pavements are devoid of any vegetation.

Surface Unit 3.2: Rock-covered surfaces with silt and clay zones. The top layer is composed of silt with some very fine sand and contains many rock fragments (cover percentage: 60-80%). Pavements are less well developed as compared to unit 3.1. The areas in between the rock fragments show a continuous and permanent surface crust.

Vegetation (shrubs) typically covers 10-15% of the surface. These surfaces occur anywhere in the landscape and are the dominant surface unit in the Nellis Dunes Recreation Area.

Surface Unit 3.3: Rock-covered surfaces with sandy loam. These surfaces resemble surface unit 3.2, but the top layer contains small amounts of sand. The sand has been blown in from nearby sand areas. In the Nellis Dunes field, they typically occur in silt areas located close to the sand dunes. Vegetation (shrubs) typically covers 10-15% of the surface.

Surface Unit 3.4: Rock-covered surfaces with encrusted sand. This type of surface is similar to the 3.2 and 3.3 surfaces but is largely composed of sand, with small amounts of silt. It is covered by a continuous cyanobacterial crust. This crust is much weaker than the silt crusts of surface units 3.2 and 3.3. Vegetation (shrubs) is common and covers approximately 10% of the surface.

Surface Unit 3.5: Bedrock and/or petrocalcic horizons. Outcrops of bedrock and exposed petrocalcic horizons. The percentage of rock cover is close to 100%. Silt may have accumulated only near a few sparse shrubs and in deep cracks. Outcropping bedrock is commonly Paleozoic and Neogene carbonates.

3.2.4 Active drainages

Surface Unit 4.1: Gravelly drainages. Active drainages with almost pure gravel. In the NDRA these surfaces typically occur in the channels of the major drainages. The gravel is almost free of sand, silt, and clay, and its cover percentage is close to 100%.

Surface Unit 4.2: Gravel and sand drainages. Active drainages with a mixture of gravel and sand. They occur in sand areas, in particular within the smaller sized valleys, and also in the upstream zone of the larger drainages where there is insufficient water to wash the sand. Vegetation is usually absent.

Surface Unit 4.3: Gravel and silt and clay drainages. Active drainages with a mixture of silt and gravel. They are the silt equivalent of surface unit 4.2 except that many of them have considerable vegetation (usually shrubs). Silt and gravel drainages without vegetation also occur, especially in first-order channels in badlands.

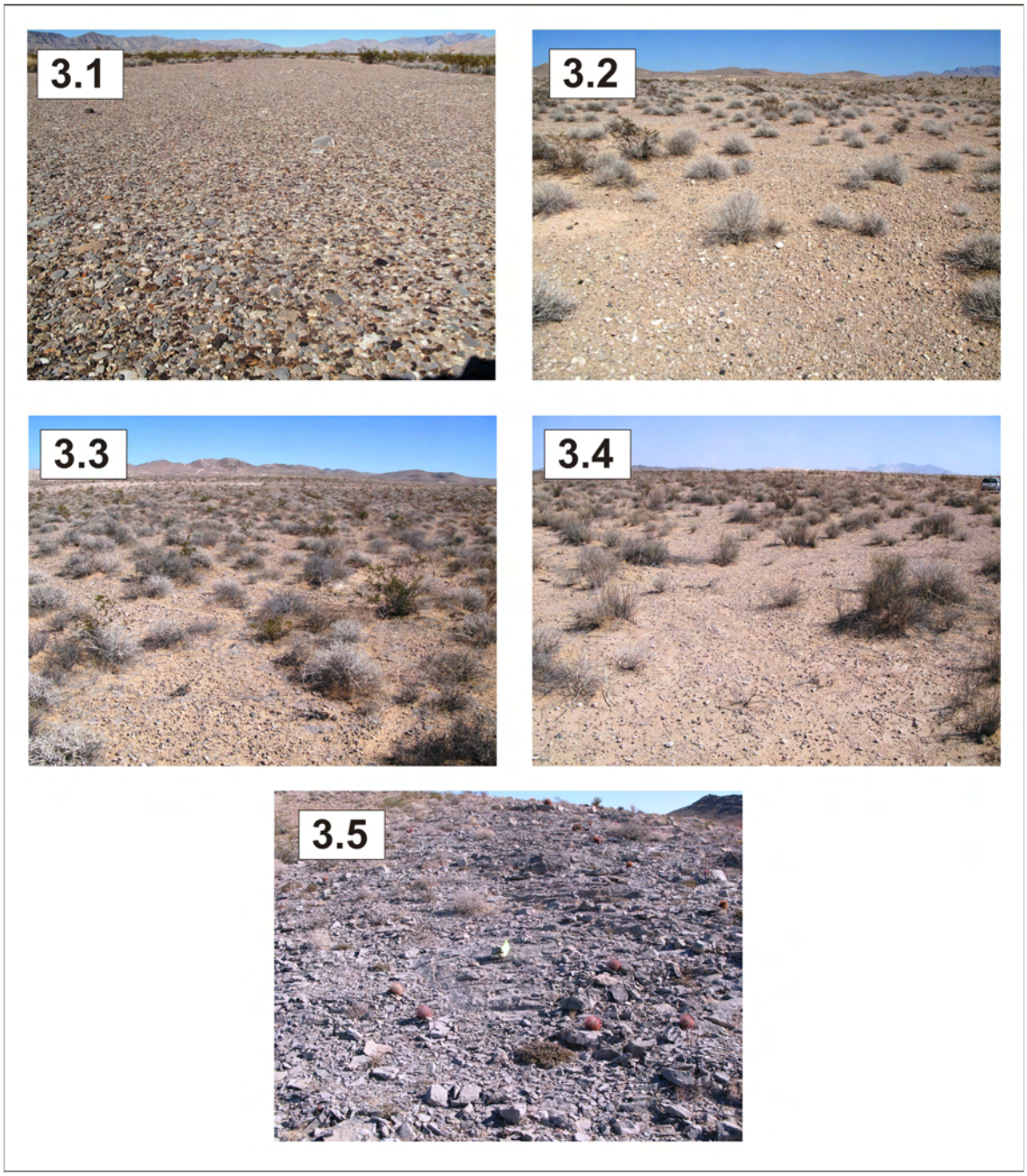

Fig. 9: Photograph of rock-covered area surface types. 3.1: Desert pavements; 3.2: Rock-covered surfaces with silt and clay zones; 3.3: Rock-covered surfaces with sandy loam; 3.4: Rock-covered surfaces with encrusted sand; 3.5: Bedrock and/or petrocalcic horizons.

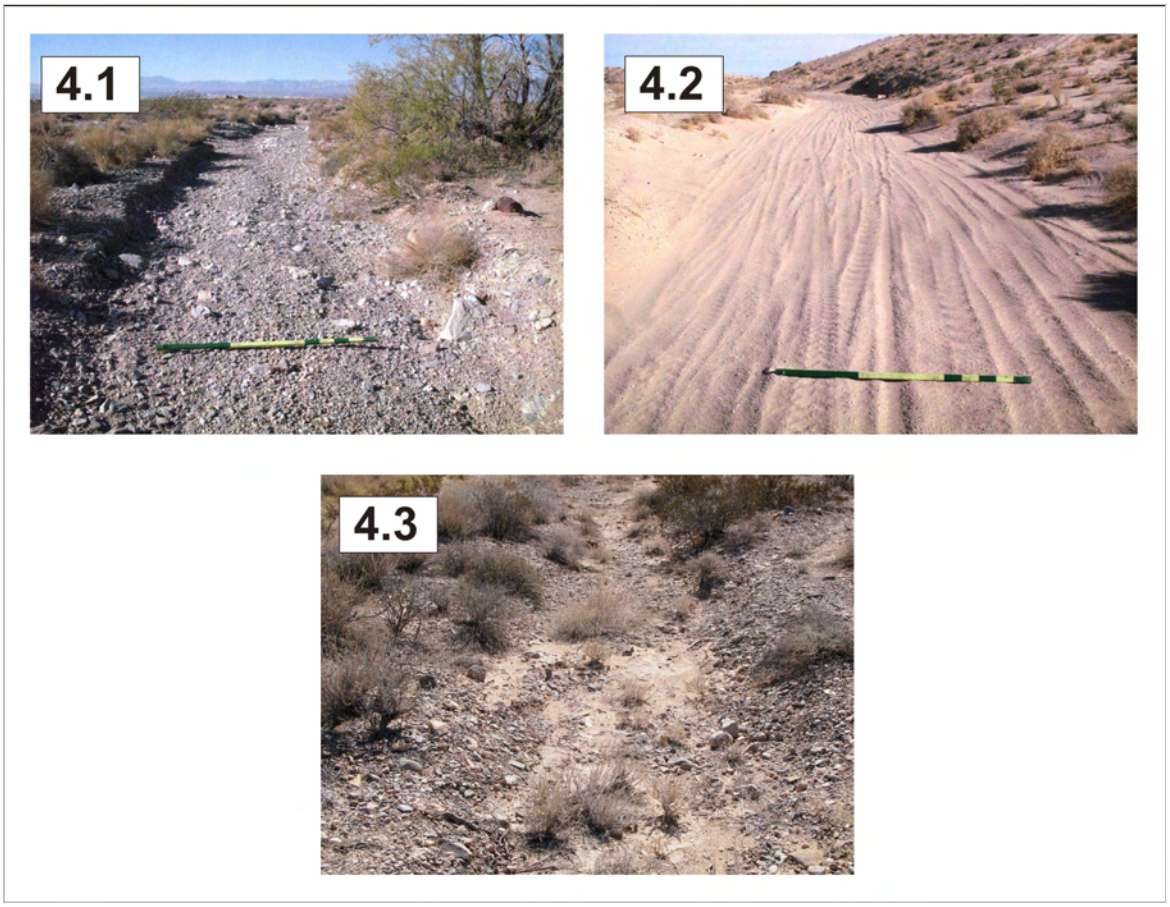

Fig. 10: Photograph of active drainage areas. 4.1: Gravelly drainages; 4.2: Gravel and sand drainages; 4.3: Gravel and silt and clay drainages.

3.3 Creation of a surface units map

3.3.1 Methodology

Mapping of the NDRA began with the designation of the 17 surface units described above. Apart from the grain-size characteristics, mineralogical composition and distribution of the surface mineralogy was also examined using the shortwave infrared (SWIR) and the thermal infrared (TIR) bands of the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) instrument. This imagery was acquired on 6 July 2000 and obtained from Land Processes Distributed Active Archive Center

(https://lpdaac.usgs.gov/) supported by NASA (National Aeronautics and Space Administration) and the U.S. Geological Survey. The SWIR component of ASTER has a 30-m spatial resolution that covers the spectral range of 1.6 to 2.4 μm over six bands. The TIR component covers the spectral range of 8.1 to 11.7 μm over five bands with a spatial resolution of 90 m. Analysis of the study area using the ASTER imagery focused on using the SWIR and TIR bands to isolate the occurrence of individual minerals and their relationship to mapped surface units. Calculation of a quartz (Rockwell and Hofstra, 2008) and carbonate index (Ninomiya et al., 2005) using bands 10-13 and bands 13-14, respectively, created images that defined the occurrences of these types of minerals. ASTER bands 8, 6, and 4 were combined to produce a SWIR image that was then further processed using a decorrelation stretch to enhance the differences between the individual bands (Mather, 2004).

The quartz and carbonate indices derived from the ASTER imagery are useful for characterization of surface mineralogy over large areas, but they do not provide the needed spatial detail for constructing a dust emission potential map at the scales involved. Thus, construction of the surface units map involved the use of high-resolution, Quickbird satellite imagery and field reconnaissance. The Quickbird imagery consists of two products. The first is a 0.6-m resolution panchromatic band and the second is a 2.4-m resolution multispectral product consisting of three visible bands and a near-infrared (0.45-0.90 μm) band. Field mapping, using the Quickbird imagery as a base, was accomplished through use of a ruggedized field computer with a global positioning system (GPS) attachment. This setup allowed field locations and unit contacts to be mapped with a high degree of accuracy. The contacts were then compiled using the Manifold GIS mapping package to produce the final surface units map. Developing the map in GIS allows creation of a georeferenced product that can be combined with other types of geographic information such as topography or aerial photography.

3.3.2 Distribution of the surface units over the NDRA

3.3.2.1 Remote sensing data

ASTER multispectral satellite imagery using band combinations 8-6-4 from the SWIR and the quartz and carbonate indices from the TIR bands were examined for the study area. The quartz index indicates quartz sand in the central and western parts of the study area (bright areas in Fig. 11a). The carbonate index (bright areas in Fig. 11b) shows that the concentration of carbonates is confined to the eastern parts of the study area. The ASTER band combination that provides the best surface unit determination is the 8-6-4 SWIR combination (Fig. 12). Here, the sandy areas underlain by units 1.1, 1.2, and 1.4 are shown in yellow (Fig. 12; area A), denoting the quartz composition of the sands. The main belt of dune sands is well defined, stretching from the southwest into the central

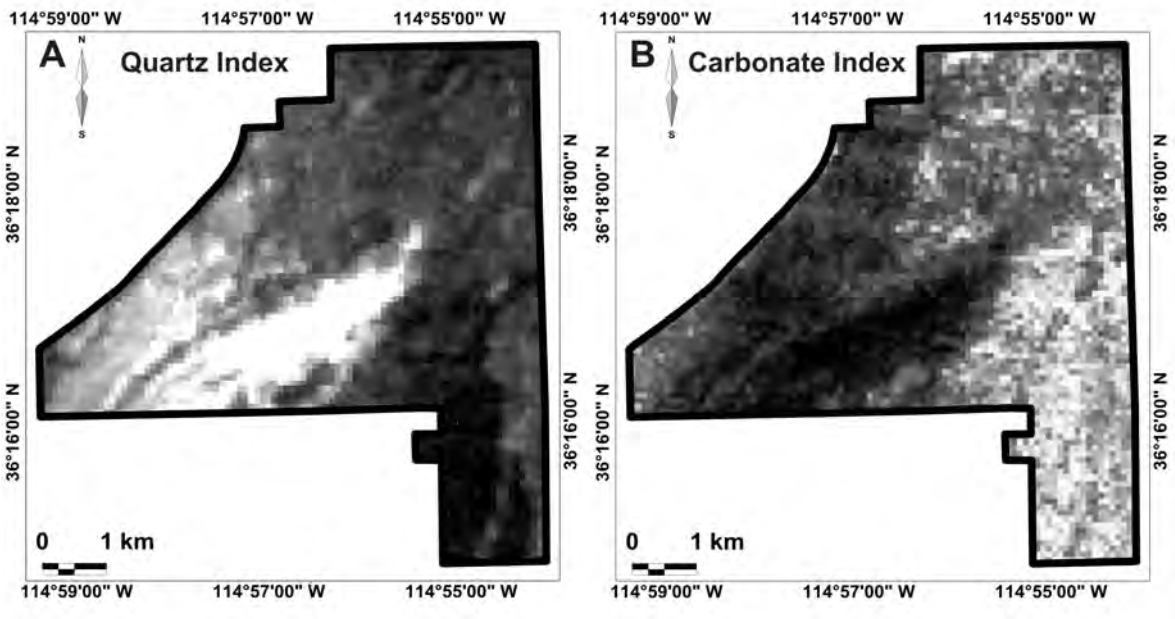

Fig. 11: Results of band mathematics calculations and ratios using ASTER (Advanced Spaceborne Thermal Emission Reflection Radiometer) thermal infrared bands. (a) Quartz index with brighter areas showing the occurrence of quartz. The bright areas in the center of the image denote the location of the main dune field. (b) Carbonate index with brighter areas indicate the occurrence of carbonates. The carbonate signature in the southeast portion of the study area reflects outcropping of limestone units within the Muddy Creek Formation.

portion of the map areas. Sandy areas also lie to the west (Fig. 12; area B), where they are separated from the main belt by a deeply incised wash (Fig. 12; area C). The sandy zones are more sparse and isolated in area B compared to those in area A. Silty units, such as 2.3, are the light purple areas (Fig. 12; area D) that occur primarily in the northwest. These units are capped by thin gypsum layers that are shown in darker purple (Fig. 12; area E). Paleozoic carbonates of the Bird Spring Formation occur in the northern part of the NDRA (Fig.12; area F), whereas the better expressed carbonate signature derived from limestone clasts of the Muddy Creek Formation (Beard et al., 2007) occur in the south and eastern part of the NDRA (Fig. 12; area G).

3.3.2.2 The surface units map

Detailed mapping of surface units using a Quickbird imagery base indicates that the overall distribution of surficial units in the NDRA follows a northeast-southwest trend (Fig. 13). This orientation is particularly evident in the western part of the study area, where a rough zonation of rock-covered surfaces (3.x units) progresses from silty clay

zones (3.2) to sand-encrusted areas (3.4). The sandy dune areas (1.1 and 1.2) are often rimmed by a thin layer of patchy sand (1.4). This type of zonation is most evident in those areas where there is significant sand present.

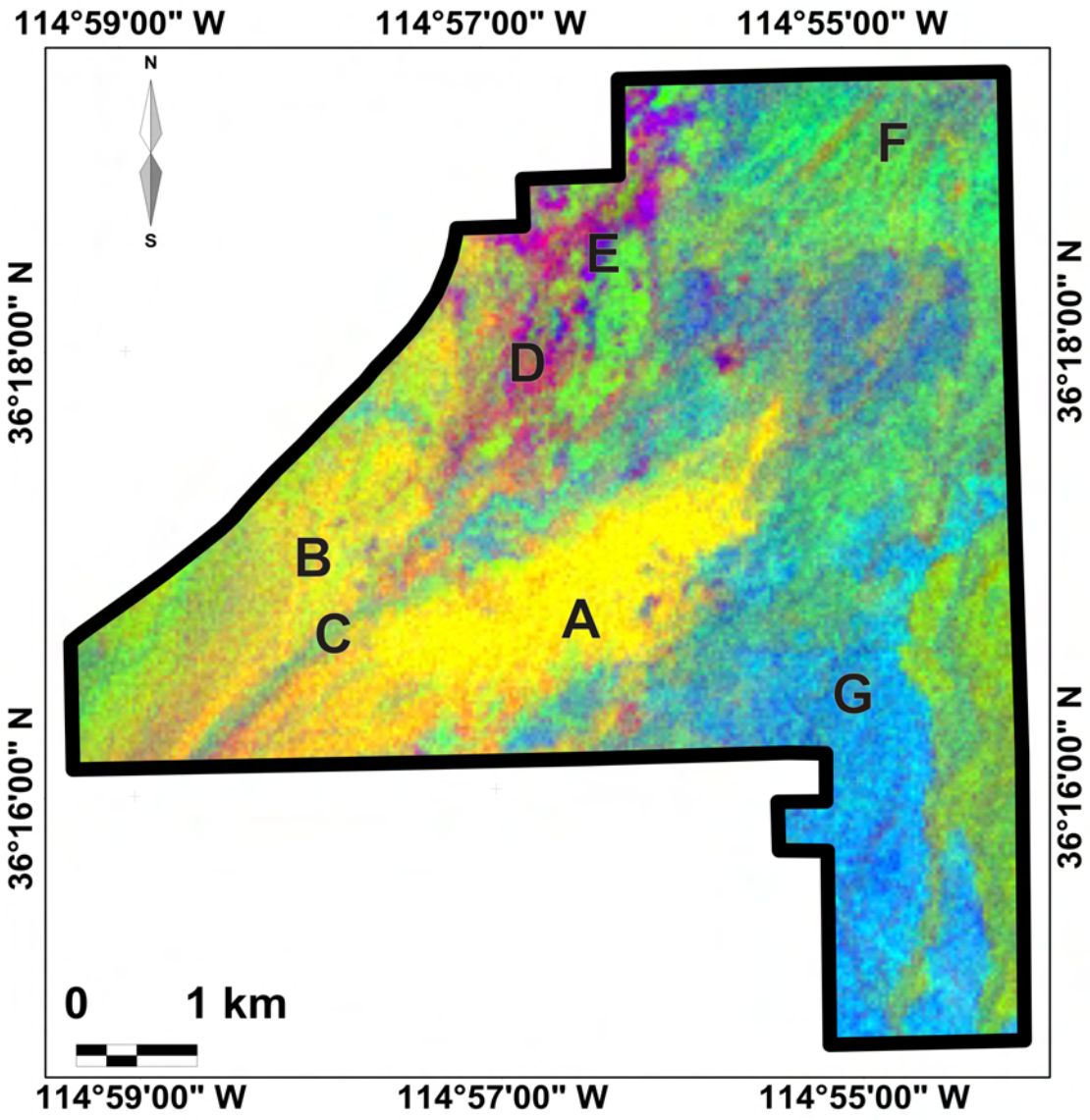

Fig. 12: Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) shortwave infrared image of bands 8-6-4 with a decorrelation stretch applied. A and B: Quartz-rich sandy areas; C: Wash separating sandy areas; D: Muddy deposits representing unit 2.3; E: Gypsum layers capping ridge tops; F: Paleozoic carbonates of the Bird Spring Formation; G: Carbonate of the lower Muddy Creek Formation.

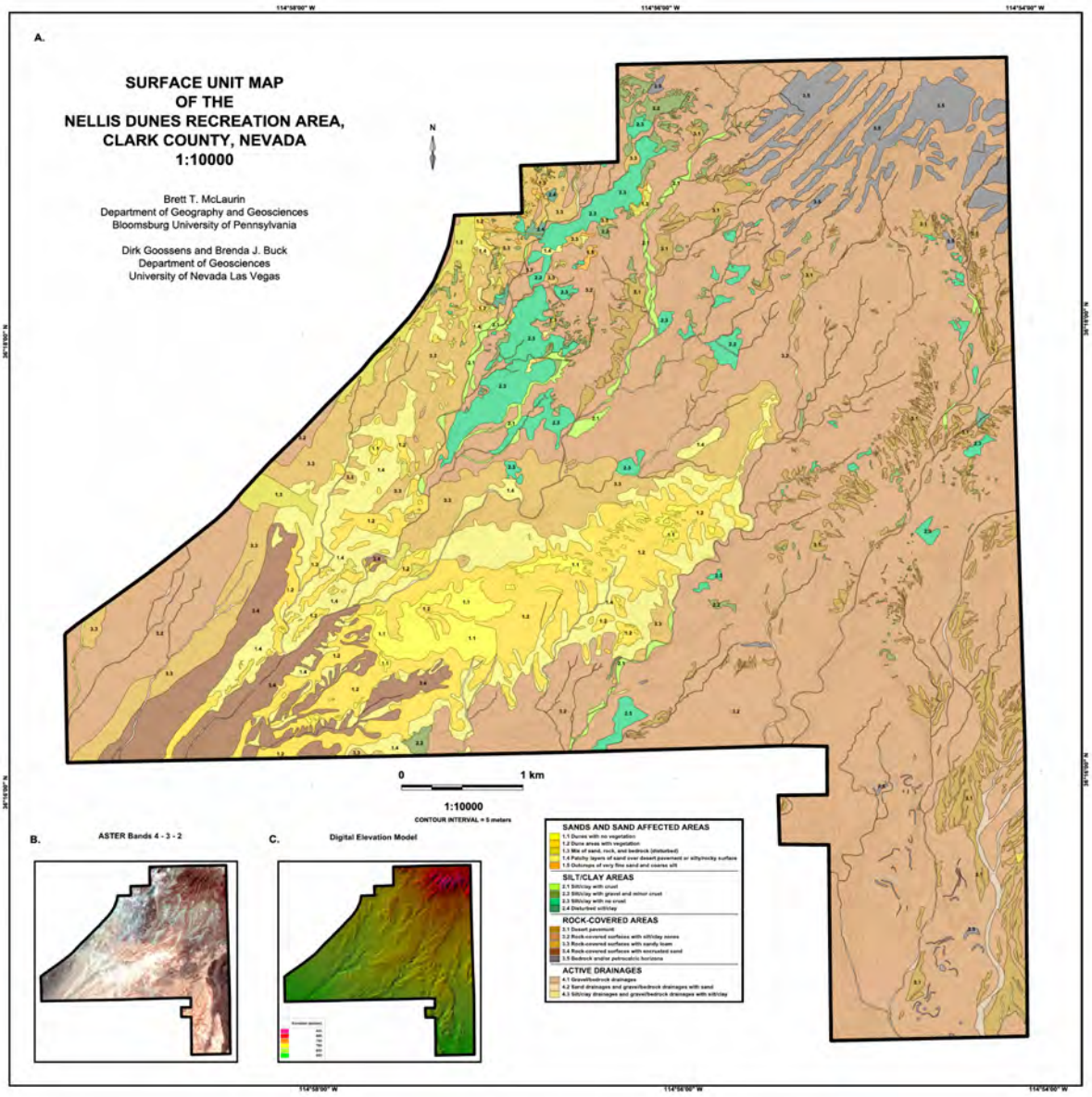

Fig. 13: (a) Surface unit map of the Nellis Dunes Recreation Area; (b) Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) composite image with band combination 4-3-2; (c) Digital elevation model compiled from the U.S. Geological Survey 10-m resolution digital elevation models of the Apex and Frenchman Mountain quadrangles.

The central part of the sand dune area is characterized by slightly meandering, NW-SE-oriented ridges of reversing dunes indicating that sand transport alternates from two opposing directions (NE and SW). Smaller, more amorphous sand accumulations occur in the areas in between the reversing dunes. Their morphology changes through time reflecting the most recent direction of sand transport. The abrupt changes from sand-dominated units to rock-covered surfaces with silt and clay zones (3.2) are often partitioned by deeply incised drainages such as those that mark the eastern edge of the dune field in the south-central portion of the study area. Sand that is transported from the west becomes trapped within the drainages, which prevent much of the sand from entering the areas to the east.

The surficial units in the northwestern part of the NDRA are primarily controlled by the lithologies of the underlying Muddy Creek Formation. Although some sand is present (3.3 and 1.5), the most significant unit is the aggregated silt deposit (2.3). This unit contains no vegetation and is characterized by badland-style topography. These areas contain some of the highest density of vehicular trackways. The northeast-southwest orientation of this unit follows underlying mudstone of the Muddy Creek Formation from which this surface unit is derived. West and east of the main belt of unit 2.3, yellow sand units (1.5) occur stratigraphically above the 2.3 units. These are, in turn, overlain by the more resistant Muddy Creek limestone and gypsum or more commonly, petrocalcic horizons that cap isolated mesas and are preserved as topographic highs.

East of these areas where there are significant sand and silt units, the landscape is dominated by relict and inset alluvial fan geomorphic surfaces (e.g., Peterson, 1981; Bull, 1991); especially common are the rock-covered surfaces with silt and clay (3.2). These large expanses are occasionally interrupted by finer grained silt units (2.2 and 2.3) and well-developed desert pavements (3.1) along the flanks of drainages. The desert pavements are easily identifiable from the Quickbird imagery and appear as elongated areas that are darker in color and have a smoother surface texture with little vegetation. The desert pavement surfaces occur in areas east of the main silt occurrences.

Bedrock and/or petrocalcic units (3.5) occur as three outcropping types. They are (1) petrocalcic horizons, (2) Paleozoic limestone, and (3) Neogene limestone of the Muddy Creek Formation. Petrocalcic horizons exposed at the surface are often of limited lateral extent and represent areas of soil erosion. These occur along the tops and sides of all of the highest, and oldest, geomorphic surfaces. Many of these zones occur in the western part of the study area, but most of them are below the resolution of mapping. Paleozoic limestone of the Permian Bird Spring Formation forms hills in the northern part of the NDRA. South of this area isolated outcrops occur where the surficial material is thin. Limestone layers in the south-central and southeastern parts of the NDRA are different from the gray-black limestone, characteristic of the Paleozoic strata in the north. These units are relatively flat-lying and consist of white to grayish, laminated limestone and are part of the Muddy Creek Formation. The outcrop occurs as thin ledges that are separated by zones of map unit 3.2 (rock-covered surfaces with silt and clay).

Some of the map units correspond well with specific geomorphic surfaces or to bedrock formations, while others do not. Units that correspond to exposed bedrock are 1.5, 2.2, 2.3, and 3.5. The active drainages (4.1, 4.2, and 4.3), correspond to Q4 surfaces of Bull (1991). In most Quaternary maps, only unit 1.1 would be defined as an active, aeolian geomorphic surface (e.g., Qe of House et al., 2010) because of the dune forms and thickness of the aeolian sand. The other units in this study with active but thin, aeolian sands (1.2, 1.4, and 3.4) overlie a wide variety of inset or relict alluvial fan surfaces that correspond to Q1-Q3 of Bull (1991) or Qea of House et al. (2010). Unit 3.1 is defined by well-developed desert pavements and is found on early Holocene-latest Pleistocene inset fans, corresponding to Q3 surfaces of Bull (1991) and Qay1 of House et al. (2010). The remaining units cross a broad spectrum of geomorphic surfaces. The most extensive unit, 3.2, is found on a wide variety of geomorphic landforms that have poorly developed desert pavements, reflecting a combination of processes including young surfaces where desert pavements have not fully developed, to very old surfaces where they have degraded (House et al., 2010). These include Pliocene ballenas with exposed and fragmented stage 6 petrocalcic horizons (Gile et al., 1966; Peterson, 1981; House et al., 2010), middle-early Pleistocene fan remnants, early Holocene-latest Pleistocene and late-middle Holocene inset fans, and colluvial slopes of bedrock outcrops (Peterson, 1981; House et al., 2010). Although unit 3.3 is mostly present on middle to early Pleistocene fan remnants, its distribution is primarily controlled by proximity to local sand sources and not geomorphic position. Unit 2.1 occurs on latest and middle Holocene inset fans and inside active drainages along bars, where biological soil crust formation is favored (Williams et al., 2010). Disturbed surfaces (1.3 and 2.4) can occur on any geomorphic surface.

3.4 The ORV trails in the Nellis Dunes Recreation Area

3.4.1 Mapping methodology

Since the goal of the project involved, among other issues, addressing the impact of off-road vehicles on the various surface types, it was important to determine the location, width, and length of the unpaved tracks that exist throughout the NDRA. Trackway depth was not recorded because the extreme variability and density of the tracks made collecting those data impractical. Using the highest resolution Quickbird imagery (0.6 m), track centerlines were digitized and the widths measured. A structured query language (SQL) statement using a geospatial buffer extension was executed that converted the centerlines into polygons of the appropriate width. These polygons were then intersected with the surface units map to determine the area of surface units covered by ORV tracks.

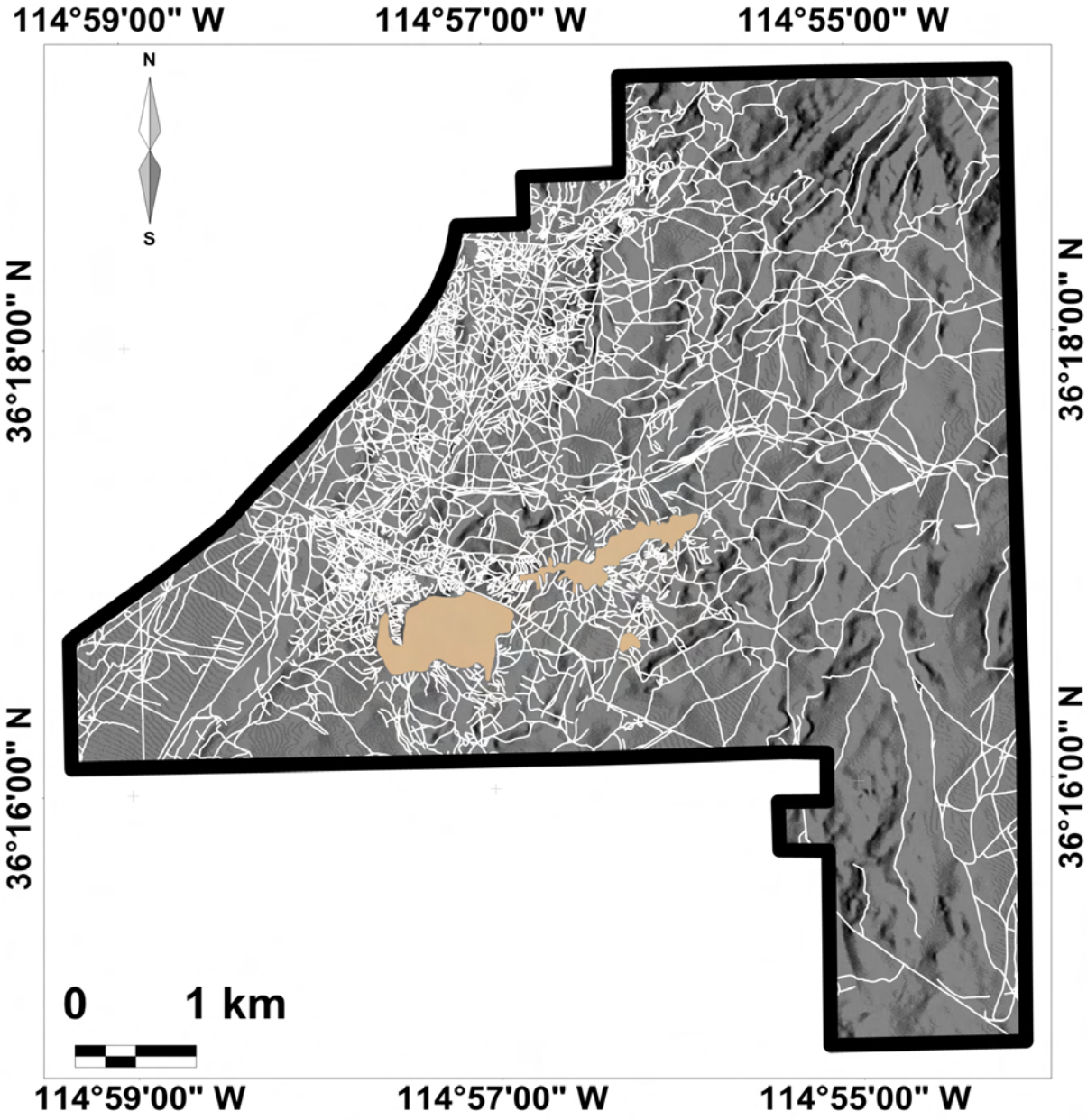

Fig. 14: Location of the tracks in the Nellis Dunes Recreation Area. Areas underlain by sandy units often show abrupt termination of tracks, especially within the more active dunes (unit 1.1 and, to a lesser extent, unit 1.2). The movement of windblown sand buries any trackways generated from off-road driving. These areas are delineated by the brown shading.

3.4.2 Distribution and density

The density of tracks can be expressed either as the total length of tracks within each mapping unit or by using a metric that calculates the length of trackway (km) within a particular surface unit to the total surface area of that unit (km^2). This metric is a derivation of the road density, as described by Forman et al. (2003), which is frequently used as a method to assess the impact of roads on environments. The definition of road density is the length of road (km) divided by the total area (km^2) and is expressed as km/km^2. However, for this study, we are concerned with the trackway density within each surface unit. Thus, we utilize the length of track within each surface unit and divide it by the surface area of each surface unit to calculate the trackway density (km/km^2).

The locations of the various tracks in the Nellis Dunes Recreation Area are shown in Fig. 14. It should be noted that track locations are particularly variable in those areas underlain by the sandy units 1.1 and 1.2 due to their temporary nature. Windblown sand in these active dune areas often covers tracks; hence many trackways appear to abruptly terminate within these sandy zones. In Figure 14, these areas are delineated by brown shading.

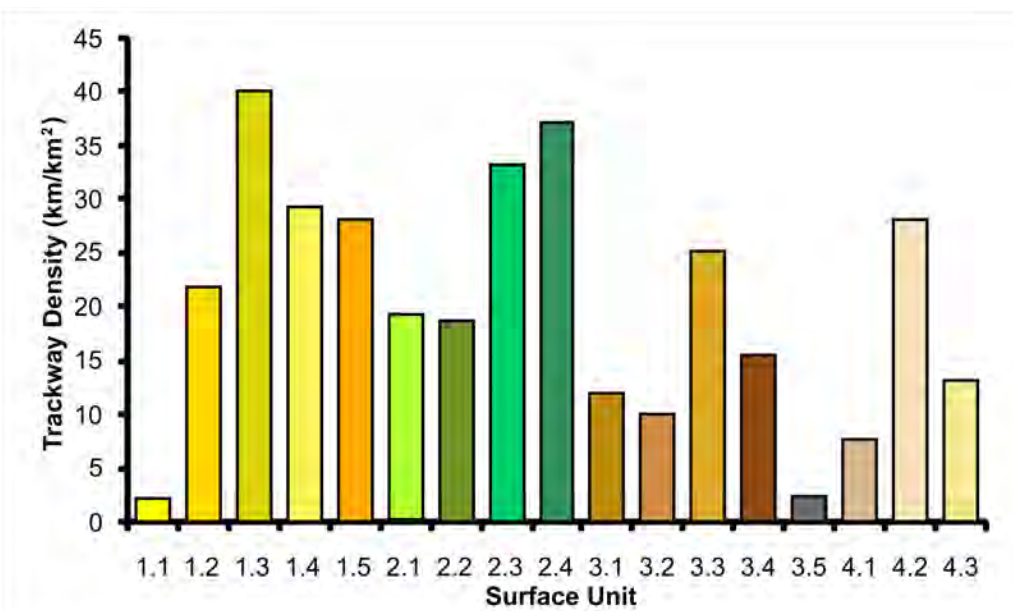

Fig. 15: Graph illustrating the trackway density for each surface unit, which reflects the density of permanent trackway within each unit. The trackway density (km/km2) is calculated by dividing the length of track with each unit (km) by the total surface area covered by the unit (km2). Most trackways generated in unit 1.1 (active dunes with no vegetation) are only temporary due to their rapid burial with windblown sand and are thus not well represented by this figure.

The trackway density in all 17 units is shown in Figure 15. The units with the lowest trackway density are 1.1 (2.2 km/km^2) and 3.5 (2.3 km/km^2). The sand dunes of unit 1.1, as stated previously, do not preserve trackways very well due to being quickly covered by windblown sand. Thus, the actual trackway density and utilization of this unit for ORV activity is certainly higher. Bedrock and outcropping petrocalcic horizons (unit 3.5) have low values for track density, since it is difficult for ORV activity to leave trackways in this type of material. However, tracks can occasionally be traced across these areas where a thin layer of sediment covers the rock surface. The highest trackway density units are 1.3 (40.2 km/km^2) and 2.4 (36.9 km/km^2), which is expected because surface disturbance is part of their definition (see section 3.2). The units with the next highest density of trackways are 2.3 (33.1 km/km^2) and 1.4 (29.4 km/km^2). The 2.3 unit is silty and devoid of any vegetation and rocks and thus very easy to drive; hence it is used by all drivers (including the less experienced ones), which explains the high density of trackways. The 1.4 unit is sandier and often borders areas adjacent to the sand dune units of 1.1 and 1.2. The high trackway density of 28.1 km/km^2 for unit 4.2 (gravelly and sandy drainages) reflects the popularity of these washes as trackways, particularly in those areas close to the main dune field.

References

Beard, L.S., Anderson, R.E., Block, D.L., Bohannon, R.G., Brady, R.J., Castor, S.B., Duebendorfer, E.M., Faulds, J.E., Felger, T.J., Howard, K.A., Kuntz, M.A., Williams, V.S., 2007. Preliminary geologic map of the Lake Mead 30′ × 60′ quadrangle, Clark County, Nevada, and Mohave County, Arizona. U.S. Geological Survey Open-File Report 2007-1010, scale 1:100,000, 3 sheets.

BLM, 2004. Las Vegas Valley Disposal Boundary, Final Environmental Impact Statement and Record of Decision, Chapter 3: Affected Environment. Las Vegas Bureau of Land Management, Las Vegas, Nevada.

Bull, W.B., 1991. Geomorphic Response to Climate Change. Oxford University Press, New York.

Castor, S.B., Faulds, J.E., 2001. Post-6 Ma limestone along the southeastern part of the Las Vegas Valley shear zone, southern Nevada. In: Young, A., Spamer, E.E. (Eds.), Colorado River. Origin and Evolution. Grand Canyon Association, Grand Canyon, Arizona, 77-79.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T., Winter, T.C., 2003. Road ecology: Science and Solutions. Island Press, Washington.

Gile, L.H., Peterson, F.F., Grossman, R.B., 1966. Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Science 101, 347–360.

Goossens, D., Buck, B., 2011. Effects of wind erosion, off-road vehicular activity, atmospheric conditions and the proximity of a metropolitan area on PM10 characteristics in a recreational site. Atmospheric Environment 45, 94-107.

House, P.K., Buck, B.J., Ramelli, A.R., 2010. Geologic assessment of piedmont and playa flood hazards in the Ivanpah Valley area, Clark County, Nevada. Nevada Bureau of Mines and Geology, Report 53. http://www.nbmg.unr.edu/Pubs/r/r53/index.html. (online only)

Lazaro, M.A., Chang, Y-S., Kuiper, J.A., Kotamarti, V.R., James, D.E., Brazao, R., Pulugurtha, S., 2004. Cumulative Las Vegas Valley Air Quality Modeling Assessment of ongoing Bureau of Land Management (BLM) Federal Land Disposition Actions within the BLM Disposal Boundary. Report prepared for the Bureau of Land Management (BLM), University of Chicago and University of Nevada Las Vegas.

Mather, P.M., 2004. Computer processing of remotely-sensed images: An introduction (third edition). Wiley, Chichester.

Ninomiya, Y., Fu, B., Cudahy, T.J., 2005. Detecting lithology with Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) multispectral thermal infrared "radiance-at-sensor" data. Remote Sensing of Environment 99, 127–139.

Peterson, F.F., 1981. Landforms of the Basin and Range Province defined for soil survey. Nevada Agricultural Experiment Station Technical Bulletin 28. University of Nevada, Reno.

Rockwell, B.W., Hofstra, A.H., 2008. Identification of quartz and carbonate minerals across northern Nevada using ASTER thermal infrared emissivity data - Implications for geologic mapping and mineral resource investigations in well-studied and frontier areas. Geosphere 4, 218–246.

Williams, A., Buck, B., Soukup, D., Merkler, D., 2010. Geomorphic controls of biological soil crust distribution, Mojave Desert (USA). Proceedings 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1-6 August 2010, Brisbane, Australia. Published on CD-ROM.