APPENDIX O

GEOMORPHIC, STRATIGRAPHIC & GEOLOGIC EOLIAN EVALUATION REPORT

Geomorphic and stratigraphic evaluation of the stable early to mid-Holocene eolian (wind-blown) dune systems for proposed Desert Quartzite Solar Project, eastern Chuckwalla Valley and Palo Verde Mesa area, Riverside County, California

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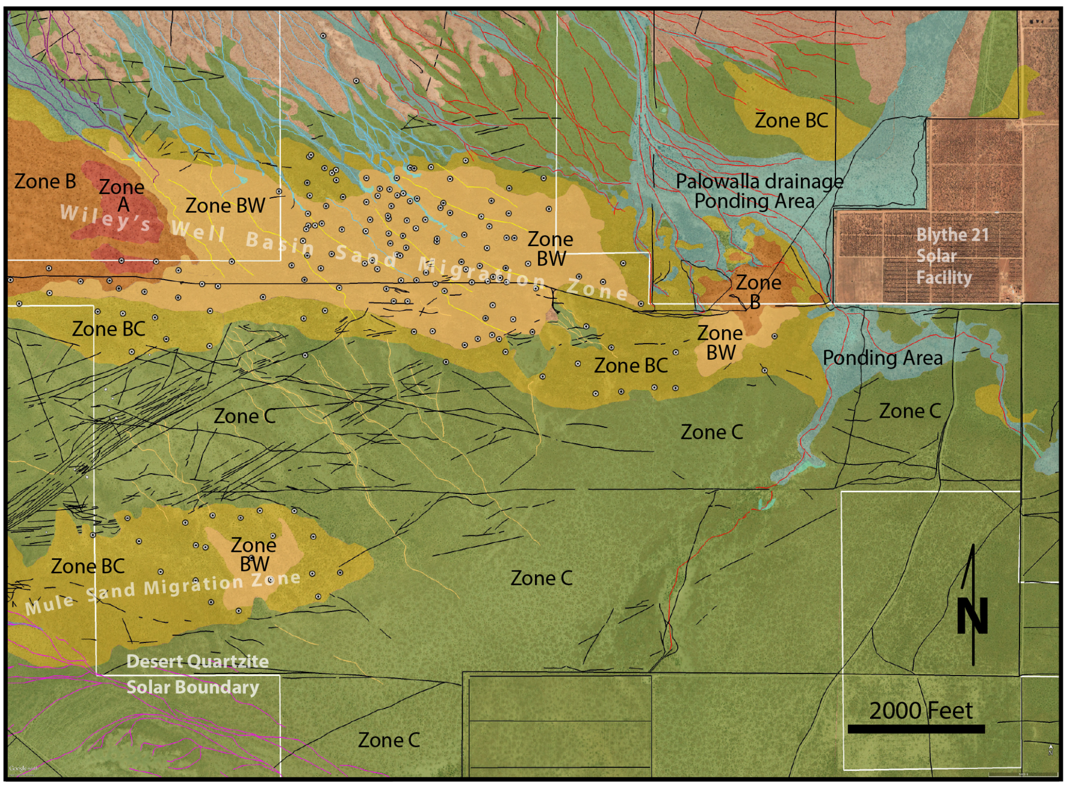

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Report Title:

Geomorphic and stratigraphic evaluation of the stable early to mid-Holocene eolian (wind-blown) dune systems for the proposed Desert Quartzite Solar Project, eastern Chuckwalla Valley and Palo Verde Mesa area, Riverside County, California

Dear Mr. Cook:

Kenney GeoScience (KGS) is pleased to provide you this geomorphic and stratigraphic evaluation regarding eolian (wind blown) systems in the region of the proposed Desert Quartzite Solar Project (DQSP) located west of Blythe California and south of Interstate Highway 10 on the Palo Verde Mesa. From our understanding, the primary motivation for this study is to determine the value of the dune system(s) habitat in the vicinity of the DQSP to support analysis of the project impacts under the National Environmental Policy Act ("NEPA) and the California Environmental Quality Act ("CEQA"). This exercise is important because the dune deposits provide habitat for the Mojave fringe-toad lizard (MFTL).

To address these questions, KGS has evaluated the geologic history near DQSP since the early Pliocene, eolian sand sources (many of which are newly proposed), eolian sand pathways, proposed regional sand migration corridors throughout southeastern California, eolian sand source changes since the Latest Pleistocene associated with variations in climate, and hydrologic systems that provide stabilizing moisture and eolian sand sources. KGS further evaluated potential impacts to the dunes from anthropogenic activities such as global climate change and diversion of flood waters from construction activities.

This study contributes not just to the understanding of the DQSP site, but also to other dune systems throughout southeastern California. Few regional studies of dune systems exist for this region, however there is much literature regarding aspects of individual dune systems and sand migration corridors. Before now, these studies had not been evaluated comprehensively. The findings of this report are also consistent with previous KGS dune studies supporting the strong importance of evaluating surface water hydrology as it plays a critical role regarding eolian sand sources and dune stability over time. These findings greatly assist in the evaluation of local dune systems whether they are similar or substantially dissimilar to regional dune systems across the southeastern California region.

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EXECUTIVE SUMMARY

This study provides an evaluation of the processes, geologic history and current characteristics of wind-blown (eolian) sand transport and deposition in the eastern Chuckwalla Valley. The study was conducted to provide a site-specific assessment of existing dune systems in the vicinity of the proposed Desert Quartzite Solar Project (DQSP), a proposed 450 MW photovoltaic solar power plant to be located on federal and private land in southeastern California. The proposed DQSP is located on the Palo Verde Mesa, east of the east end of the approximately 50-mile long, east-west trending Chuckwalla Valley (Figure ES-1).

ES 1.0 STUDY PURPOSE

The purpose of this study is to provide a more refined and site specific understanding of sand transport and dune systems in the DQSP area for use in evaluating current and potential future characteristics of the sand transport and dune systems as they relate to proposed DQSP development and biological resource habitats in the DQSP vicinity. To achieve this, the study evaluates existing dune systems within and near the proposed DQSP site to define the current aerial extent of the dune deposits and characterize the dynamic nature of the current dune system (i.e. active, stable, eroding), as well as how the dune system may evolve in the future. In addition, this study evaluates regional dune systems to evaluate whether typical eolian conditions occur at the site or if something unusual may be occurring.

ES 2.0 STUDY ELEMENTS

Evaluation of the dune systems was accomplished using the following study elements: 1) a literature review of pertinent published geologic studies; 2) geologic mapping comprised of geologic and geomorphic parameters, soil stratigraphy (age) and topographic components; 3) development of geomorphic, soil pedon and sand migration zone designations to assist in evaluating eolian geomorphology, age of geologic events, and eolian activity; 4) analysis of eolian systems to identify parameters and their importance in understanding the development of eolian systems; and 5) consideration of anthropogenic effects on dune systems including infrastructure development and climate change.

ES 3.0 STUDY KEY FINDINGS

The study evaluated numerous issues (parameters) related to dune formation, sand migration rates and dune stability in the DQSP vicinity. A more detailed discussion of the study results is provided in Section ES.4; however, the key findings most relevant to characterization of the dune systems at the DQSP site are briefly presented below.

- *Sand migration zones are local not regional*

  The DSQP site is located on the Palo Verde Mesa, just beyond the eastern terminus of the Chuckwalla Valley. The study findings indicate that the dune systems within the DSQP area are dominantly derived from and influenced by local eolian sand sources and the topographic sill that exists to the west of the DSQP site. The primary source of eolian sand deposits in the DQSP area are the Wiley's Well Basin and the Mule Mountains. These sources supply three of the four sand migration zones (SMZs) identified in the DQSP vicinity including: the Wiley's Well SMZ, the Mule SMZ and the Power Line SMZ, as shown in Figure ES-1. There is also relatively minor sand contribution from the McCoy Mountains to the north, supplying sand to the small Palowalla SMZ at the north end of the DQSP site and to the western end of the Wiley's Well SMZ due to flow into northern portion of the Wiley's Well Basin. This local sand source finding is contrary to the concept that regional sand migration corridors represent a continuous zone of sand movement where sand can travel from sources many miles upwind.

- *Regional and local dunes are stable and degrading*

  Soil profiles indicate that most of the eolian deposits in terms of total volume in the eastern Wiley's Well and Mule SMZs, including portions of the DQSP site, were deposited in the early- to mid-Holocene (12 to 4 kya, kya = thousands of years ago) until about 5 to 3 kya at which time sand migration rates decreased markedly. Since that time, the dunes in this area have been dominantly stable and in places, degrading. This geologic history for the local DQSP dune systems is very similar to the history of dunes across the southeastern California region. The dunes reached their maximum aerial extend sometime between 5 to 3 kya (i.e. limits of sand migration Zone BC).

  During historical times (~100 to 150 years past), the dune systems in the DQSP have experienced relatively minor changes other than a continuation of dune degradation typical of the late Holocene. However, some subtle changes in isolated areas of limited aerial extent have occurred associated with both an increase and decrease in stream flow to various areas which led to a relatively minor increase in eolian sand source and degradation of dunes, respectively.

  The density of vegetation in dune deposit areas can be an important parameter in terms of dune stability and sand migration rates. Other studies have found that a 10% aerial coverage of plants that are less than one foot tall decreases eolian sand migration rates by 90%, indicating that minor vegetation densities essentially decrease eolian sand migration rates exponentially. The dunes immediately north of the north boundary of the DQSP site exhibit vegetation densities at a minimum of 10 to 15% and that is during times of essentially no Sahara Mustard plant presence. During Sahara Mustard bloom years and for the following year or two once the plants have died, vegetation density across dune deposit areas are visually nearly 100%.

- *Future dune activity not to expected to change existing mapping for at least a thousand years*

  <u>Factors affecting dune systems</u> - Dune systems appear to experience aggradation (increase in dune deposit mass) during times when pluvial and playa lakes are drying up and/or experiencing repeated lake fluctuations, when alluvial fans are experiencing aggradational events (abundant fan deposition), when monsoonal storms are more frequent and with higher intensity and/or when older exposed sand bearing deposits upslope such as alluvial fans, lacustrine, or older river deposits are eroded into which results in washes transporting a larger volume of eolian size grains per flow and more frequently than typical washes emanating from bedrock regions of most regional mountain ranges. Dunes can experience variations in activity based on the additive nature of the parameter wavelengths when they collectively "add up" (aggradational events) or cancel each other out (times of stability).

Climate change - The arid-semi arid climate conditions since the mid-Holocene across southeastern California have resulted in a geomorphic condition where slight changes in regional climate (i.e., monsoonal storm activity) is sufficient to result in local re-activation of dune systems, but not sufficient to produce a robust eolian system where sand migration corridors are continuous. Global climate affecting Pacific Storm strength and frequency and local monsoonal strength, frequency and magnitude can be reflected in changes in dune behavior on a cyclic scale. There is a strong correlation from prehistoric times with increased monsoonal extreme storm frequency and magnitude with increased alluvial fan and eolian activity (aggradational events) and/or with periods of time exhibiting a warmer global climate. Dune systems appear to react to this type of climate change on the order of less than 1000 years.

If the frequency and magnitude of cool winter Pacific storms decrease (decreases vegetation density) and warm summer monsoonal storms increase (extreme events causing erosion and abundant wash sand transport), then this can lead to an increase in eolian sand generation in the valley axis area. Based on the rate of past dune aggradational events indicated in the soil record for the SMZs in the DQSP area, it is likely that if dune parameter conditions changed that encouraged dune growth (i.e., a future dune aggradational event), the existing mapped areas of dunes would be able to "absorb" the additional dune sands for at least a thousand years prior to expanding beyond the current mapped footprint (outer boundary of Zone BC). Moreover, if current vegetative conditions persist, such as the presence of invasive Sahara Mustard, this could stabilize the dunes and even further hinder dune expansion in the future.

ES 4.0 DISCUSSION OF STUDY APPROACH AND RESULTS

The key elements of the study were implemented to develop a better understanding of the extent, nature and mechanisms controlling sand migration and dune systems in the DQSP vicinity. Important aspects of the study results that provide the basis for the above key findings are discussed below.

ES 4.1 Findings and Limitations of Previous Dune Studies

Previous regional dune studies in southeastern California have proposed the existence of numerous Sand Migration Corridors occurring in valley axes and crossing over some mountain passes. Zimbelman et al. (1995) was the first to propose the possible existence of regional sand migration corridors in southeastern California, implying that eolian sand essentially migrated tens of miles from west to east, southeast down valley axis and over some mountain passes (sand ramps). Lancaster and Tchakerian (1996) evaluated numerous eolian sand ramps occurring where wind-blown sand was deposited in obstructing mountain passes or leeward side of mountains and assumed the existence of the regional sand migration corridors proposed by Zimbelman et al. (1995). Muhs et al. (2003), the most referenced scientific publication evaluating proposed regional sand migration corridors, perpetuated these beliefs, and since that time, the existence of the regional sand migration corridors has been assumed to exist, and in a sense, to have remained active throughout the Holocene.

Missing from the literature, however, was an evaluation that more accurately mapped the local sand migration corridors, local eolian source contributions, and that further took into account a wide field of studies to determine the current state and past activity and/or stability of the regional sand migration corridors. Indeed, the California Geological Survey (CSG) February 5, 2015 comments on the DRECP (see Short and Lancaster, 2015) observed that prior to the previous "Eolian System Mapping Report" prepared by CGS (Aug. 4, 2014, see Lancaster, 2014), it was "a misstatement to call [wide swaths of the desert] 'Sand Transport Corridors.' Using this term implies that the mapping describes where the sand is coming from and where it is moving to (or source areas, zones of transport and zones of deposition)." The prior mapping efforts did not have enough specific detail to define how sand was moving within these corridors nor whether eolian sand sources were dominantly from tens of miles upwind or derived from more local sources along the length of the mapped sand migration corridors. The Lancaster (2014) report did not provide sufficient information from the findings of many existing publications regarding the inactivity and lack of connectivity of eolian systems within the proposed regional sand migration zones during the late Holocene.

To address the shortcomings of previous dune studies, the analysis provided by this study considers whether local sources of eolian sand (from alluvial washes and fans) have created local deposits during current times and the past. In addition, this study included a regional evaluation that more accurately mapped the proposed regional sand migration corridors and compiled published data to determine the current state of activity and/or stability of the regional sand migration corridors.

ES 4.2 Study Approach

This study utilized a multi-disciplinary approach to evaluate the various factors that affect dune formation, stability and migration, including a thorough review of existing literature, evaluation of regional dune systems, geomorphic mapping, evaluation of the effect of long-term geologic processes and surface water flow on dune system dynamics, erosion of older sedimentary deposits as a source for dune aggradation and the potential effect of natural and anthropogenic changes on dune systems.

During the research phase of this project (and other eolian investigations by the author), it became clear that many fundamentally important aspects of the development of dune systems have not been sufficiently studied regionally to enable site-specific dunes studies. This report attempts to address these aspects of dune systems to better understand the dune dynamics in the DQSP vicinity.

An early step in this study was to complete an evaluation of regional dune systems throughout southeastern California to compare to the local dune development characteristics. Regional dune systems outside of Chuckwalla Valley were evaluated utilizing existing scientific publications referenced in Appendix A, and via mapping in Google Earth Pro, using current and historic imagery. This type of mapping was also conducted in Chuckwalla Valley in addition to utilizing the data and findings obtained during past studies (Plate ES-1 and ES-2).

This analysis provided a framework in which to compare regional verses local sand systems according to characteristics including, but not limited to, general trends of the regional dunes in terms of when they developed, had aggradational events, their relative eolian sand sources, their connectivity along the path of the proposed sand migration zones, and when they became stabilized. This analysis also provided supportive evidence regarding the relative importance of various eolian sand sources and identified some new eolian sand sources. The evaluation of regional dune systems also identified some dunes areas that had not been previously mapped based on the literature reviewed in this study (one example includes the east Pinto Valley dune system). A regional analysis of eolian dune systems was essential to understanding how typical or unique a local dune system is, due to local variations in dune parameters.

Geomorphic mapping was conducted of the local and regional eolian dune systems utilizing a series of relative sand migration rate zone designations. These designations sequentially describe progressively decreasing dune activity, which is suggested to correlate with relative eolian sand migration rates (Figure ES-2). Hence, this system provides a method for mapping a dune region showing variations in both dune geomorphology and relative migration of wind-blown sand.

Long-term geologic processes that impact the dynamic nature, development and sustainability of eolian dune systems were evaluated. Pluvial and playa lakes are considered a primary source for eolian sands where they occur. Eolian sands emanate from pluvial and playa lakes soon after they desiccate or experience repeated lake level fluctuations (intermittent lake levels) allowing for sand bearing wind abrasion to erode the lake surfaces and provide pathways for sand transport. This study evaluated the timing of pluvial and playa lake filling and receding periods in the southeastern California region to look for correlations with eolian dune aggradational and stability events.

The timing of alluvial fan aggradational events and fan-trenching (down cutting) are identified as periods of time when eolian dune systems undergo aggradational events. Washes are relatively one of the largest contributors of eolian sands in desert landscapes. This study also evaluated the relative importance of extreme storm events (monsoonal type climate), and the analysis shows that alluvial fans and eolian systems both experience aggradational events during periods of relatively more frequent and strong extreme monsoonal storm events causing erosion and relatively large magnitudes of sand transport to valley axis, and relatively weaker Pacific Storms that result in long duration precipitation leading to increased vegetation densities.

The effect of water on dune systems was evaluated because maintaining dune internal moisture is critical for their stability. Although dunes may be considered "dry" systems, in fact, it is the moisture regime in the area that plays a very critical role in their development. This is the case not only for eolian sand sources, but also dune stability. Sand dunes often develop in areas not only because there is a sufficient eolian sand source, but also because there is sufficient infiltrating moisture to allow for the internal core of the dunes to remain moist which greatly decreases the potential for sand bearing wind abrasion (Kenney, 2012; Schaaf and Kenney, 2016). In addition, dunes that remain moist also have a higher likelihood of becoming stabilized via vegetation. A drainage and watershed analysis was conducted because washes are the primary mode of sand transport from upslope to the valley axis where most dune systems exist (areas of strongest prevailing winds). The drainage and watershed analysis provides critical information because washes with larger watershed aerial extent flow more frequently and more often to the valley axis. The wash analysis also mapped the areas exhibiting distributary vs tributary drainage networks as it was discovered that braided wash systems common on alluvial fans do not result in significant eolian sand production in the valley axis, whereas tributary drainages that have collected flow from abundant washes upslope flow relatively frequently and sufficiently strong to reach the valley axis than braided systems.

This study also considered potential future changes on existing dune systems associated with climate change. An assessment of the effect of the decrease in magnitude and frequency of cool-moist Pacific Storms and an increase in warm-moist monsoonal storms on regional dune development since the latest Pleistocene that led to preferable conditions for dune systems, provides insights regarding potential changes in dune systems associated with global warming in the decades to come. However, an understanding regarding whether monsoonal storm systems (North American Monsoon system) will increase or decrease in the future is currently very poorly understood (Garfin et al., 2012). The southwestern United States is believed to become drier throughout this century which would lead to drier soil conditions (Garfin et al., 2012).

Historical anthropogenic factors associated with changes to the surface of the earth (i.e., flood control berms, borrow pits, etc.) that potentially could affect local dune systems were also evaluated. This analysis is important primarily due to the understanding of the importance of surface water flow for eolian sand sources and stabilizing moisture.

This comprehensive, multi-disciplinary approach led to many new insights regarding the history of dune systems across southeastern California since the late Pleistocene, the relative importance of local versus far field eolian sand sources, the identification of new eolian sand sources, the importance of dune hydrology to dune stability, the timing of dune aggradational events, the nature of the proposed regional sand migration zones, the long-term behavior of dune systems and whether dramatic changes to the dune system may occur in the future.

ES 4.3 Discussion of Study Results

ES 4.3.1 Age of Alluvial and Eolian Sand Deposits

It is important to understand the geologic history not only of the dune system itself, but also of the area bounding the dunes. A study of the geologic history allows for the understanding of what occurred in the area prior to the development of the dunes, which leads to understanding when the dunes began to be deposited in the area. For example, in the study area, the evaluation of the alluvial fan stratigraphy utilizing soil profiles that bound the DQSP dune system, allowed for the correlation of some of these deposits occurring beneath the dunes, which indicates that the local dunes must have begun their development after deposition of the underlying alluvial deposits. Hence, the creation of the local soil stratigraphic section with estimated minimum soil ages allows for an age estimate of the time in which the dunes encroached into the area.

Local mapping of older formational units such as those associated with the ancient Colorado River system when it had encroached (inundated) into Chuckwalla Valley and across the Palo Verde Mesa area provides insights regarding the age and rates of geologic processes in the area. Ancient Colorado River deposits estimated to be early Pliocene in age occur either at the surface or within 1 to 6 feet of the surface across most of the DQSP area. This indicates that geologic depositional rates have been remarkably slow for well over 3 million years and that the area is geomorphically stable.

Soil profiles develop when deposits are exposed to the surface of the earth and secondary soil processes occur such as development of soil horizons (A, B and C). Hence, designated soil profiles (i.e., S1, S2, S3a, etc. – Plate ES-3) developed in whatever sediments were exposed on the surface of the earth, whether it was alluvial or eolian.

It is important to determine what the parent material is during stratigraphic mapping of an area because it allows for the evaluation regarding where older eolian verses alluvial deposits occur. For example, if a S1 surface soil estimated to have a minimum age of 5 to 3 thousand years old (age of the surface) developed in eolian deposits and adjacent alluvial deposits, then this indicates that the alluvial and dune depositional contact has been stable for the past 5 to 3 kya (kya = 1,000 years) in that area. In other words, it shows strong evidence that approximately 5 to 3 kya that active eolian sands were depositing adjacent to active alluvial systems but that this system became dominantly inactive since that time (stable). This is exactly what has been identified in the DQSP area (Plate ES-3).

It can be important to evaluate the source of the parent material in alluvial deposits. For example, on the Palo Verde Mesa region, certain sediments exhibited a pinkish red color. The source of this coloration is the pinkish red parent soil sediments identified as the ancient Colorado River deposits Bullhead Alluvium that had eroded along the flanks of the local mountain ranges (McCoy and Mule mountains). The reddish hue parent sediments initially suggest that soil profiles may be older than they actually are because soils over time typically exhibit an increase in reddening over time. However, because the original sediments that deposited prior to soil development exhibited a reddish hue, this could lead to over estimating the soils age. Hence, other soil parameters were primarily utilized to estimate the age of soils younger than Soil S4. The erosion of the local exposures of the Bullhead Alluvium is proposed to be a very significant source of eolian sand for three of the four Sand Migration Zones in the DQSP area (Wiley's Well Basin SMZ, Mule SMZ and Power Line SMZ).

Soil stratigraphy designations and estimated soil ages are shown in Figure ES-3. The eolian sands in the eastern Wiley's Well Basin sand migration zone (Figure ES-1) are typically deposited upon alluvial soil unit S4 (35 to 70 kya) and only rarely on top of poorly developed soils of unit S3a (5 to 8 kya). This infers that when the sediments associated with soil units S3a and S3b were deposited, eolian sands were depositing in the eastern Wiley's Well Basin sand migration within the DQSP. The eolian deposits in the eastern Wiley's Well Basin sand migration zone exhibit S2 soils indicating that these eolian sands had deposited until about 5 to 3 kya. Hence, the eolian dune deposits in the eastern Wiley's Well Basin sand migration zone along the Gen-tie corridor and northern DQSP encroached into the area from the west and migrated eastward, and were relatively robust during the early Holocene. It also indicates that sand migration rates (and net dune deposition) decreased markedly by 5 to 3 kya, which marks the end of the early to mid-Holocene aggradational event. Since that time, the dunes in this area have been dominantly stable and in places, particularly in areas mapped as Zone BW, degrading.

The Mule sand migration zone (Figure ES-1) has a similar geologic history as that of the Wiley's Well Basin sand migration described above. The only exception is that the eastern region of the Mule sand migration zone took longer to migrate into the DQSP site area. The existing data suggests that the eolian deposits associated with the eastern Mule sand migration zone may not have encroached into the DQSP until the mid-Holocene (8 to 4 kya), and again, sand migration rates decreased markedly by 5 to 3 kya.

During much of the latter part of the late Holocene, the region of the DQSP was stable with minor alluvial or eolian deposition and the dune systems retracted and degraded. Hence, the dune systems stabilized and eastern areas of the dunes began to degrade in the area mapped as Zone BW (Plate ES-5).

During Historical times (~100 to 150 years), the dune systems in the DQSP have experienced relatively minor changes due to both an increase and decrease in stream flow to various areas which led to a relatively minor increase in eolian sand source and degradation of dunes respectively.

ES 4.3.2 Sand Corridor Continuity

The proposal of regional sand migration corridors, which can easily be mapped on small scale maps covering relatively large regions, provides a simple model to conceptualize wind-blown sand migration in southeastern California. However, when the regional sand migration corridors are mapped as a continuous zone extending for tens of miles, it has the potential to imply that sand grains may have the ability to migrate along the entire mapped length of the regional sand migration corridor not only during current times, but continuously since its time of development. This subsequently may lead to the assumption that eolian sand sources along the regional sand migration corridor may be many miles upwind and not local. This is clearly not the case for most of the proposed regional sand migration corridors.

Pease and Tchakerian (2003), based on a geochemistry analysis of sand grains along the path of the proposed sand migration corridors in southeastern California, suggest that the corridors do not represent a continuous "river of sand." This finding is consistent with the conclusions in this report. Plate ES-1 is a map of Sand Migration Zones (SMZs) and Plate ES-2 is a geomorphic map of various dune deposits and stability (relative migration rates), along the Chuckwalla Valley, as identified by this study. As explained in more detail below, the conditions in southeastern California are more accurately described as a collection of SMZs.

Regional mapping of the Dale Lake to eastern Chuckwalla Valley for this study identified areas where the sand migration pathway is essentially shut down. Specifically, historical Google Earth Pro imagery of the region of Dale Lake to the Eagle CoxComb Pass shows that this area is essentially shut down for through going eolian sand transport (Plate ES-4). In addition, this section exhibits very weak dune geomorphology in an area dominated by alluvial systems indicating it may not have ever been a significant eolian sand pathway (Plate ES-2). Instead, this report concludes that the Dale Lake sand system for the most part terminates near the Clarks Pass sand ramp (Figure ES-2) and that the abundant eolian sands occurring at the eastern end of the Pinto Basin (herein named the Pinto Basin Dunes) are derived primarily from the west to east flowing drainage system within the basin.

It appears based on review of all the data and research conducted by the author that during periods of strong eolian activity (dune aggradational events), eolian sands travel large distances when the regional sand migration corridors provide a more continuous pathway, and that these sands would be able to mix with the continuously provided local eolian sources. These conditions occur when vegetation densities are low at lower elevations, more readily allowing for sand movement, and relatively frequent monsoonal storms occur during dry periods of the year, providing for increased alluvial and dune aggradation. During times of dune stability, the regional sand migration corridors become discontinuous and local sources primarily associated with playa lake beds and alluvial systems dominate. In addition, during periods of dune stability when the older dunes become relict, they begin to cannibalize the older dunes associated with wind abrasion (eolian deposits re-working) and this provides an additional source for active eolian sands (Lancaster, 1995). This is the current condition throughout much of Chuckwalla Valley. Within the DQSP and many other areas in the Chuckwalla Valley, erosion of older relict dune deposits are a primary source for the minimal active eolian sands occurring within dune systems poorly fed by a playa lake (or ponding area) and alluvial systems (Kenney, 2010a, 2010b and 2010e). The findings of this report indicate that a period of dune stabilization and associated dune abrasion (cannibalization) has been occurring in many dune systems in the Chuckwalla Valley during the late Holocene. Some small localized dune areas have remained relatively more active as a result of increased eolian sand source due to water diversions (Palowalla SMZ), and/or a relatively strong eolian source remains such as the near Wiley's Well Basin (Plate ES-5).

Consistent with earlier work by Kenney (2010a and 2011) identifying local independent sand migration zones (SMZ) in the Chuckwalla Valley (i.e., Palen Valley SMZ and Mule SMZ on Plate ES-1), the more detailed mapping conducted during this study led to the identification of numerous semi-local and local independent sand migration zones in the area (Plate ES-1). One criteria for a dune system to be designated as an independent sand migration zone is that a dune system receives a significant source of sand from a local source that is independent from sources upwind associated with the regional valley axis sand migration corridor.

ES 4.3.3 Dune System Stability

The map shows that regions of Qe-a exhibiting the most active eolian areas are isolated, only occurring in the Palen Dry Lake and eastern most Chuckwalla Valley areas (Plate ES-2). Areas exhibiting significant erosion in areas dominated by relict dunes (unit Qs-de) occur at numerous localities along the regional Chuckwalla Valley sand migration corridor suggesting that sand migration rates along the system have significantly decreased since the older more robust dune forms were originally deposited. Regions where older "more robust" relict dunes no longer receive sufficient sand to maintain their form and instead are dominated by active sand sheets with minor internal erosion (unit Qe-ds) also occur at numerous locations in the valley. These geomorphic observations provide strong evidence of a decrease in sand migration rates since the deposition of the original more robust relict dunes were deposited. However, regions mapped as Qe-ds do allow for eolian sand transport through the system.

ES 4.3.4 Factors Affecting Dune Activity

Dune systems appear to experience aggradation (increase in size and magnitude of eolian sand production and movement) during times when pluvial and playa lakes are drying up and/or experiencing repeated lake fluctuations, when alluvial fans are experiencing aggradational events (abundant fan deposition), when monsoonal storms are more frequent and with higher intensity, and/or when older sedimentary deposits bearing considerable amounts of sand grains are eroded into (downcutting, fan trenching). It turns out that during the Holocene it is common that one of these parameters allowing for dunes to be more active is occurring at any particular time. Hence, dune system aggradational events do not appear to correlate to a single geologic parameter consistently throughout the Holocene, but instead, responding to numerous parameters each of which vary over time. Dunes can experience variations in activity based on the additive nature of the parameter wavelengths when they collectively "add up" (aggradational events) or cancel each other out (times of stability).

The combination of a decrease in vegetation density at lower elevations associated with a decrease in cold/wet winter pacific storms intensity and frequency, an increase in monsoonal storms with relatively higher frequency and strength (extreme storm events), abundant available sediment in the mountains and its transport to distal fan areas (see Wells and Dohrenwend, 1985; Nichols et al., 2007), and pluvial and playa lakes experiencing fluctuating levels, all contributed to a regional strong dune aggradational event between 14 and 8 kya. In addition, periods of relatively strong monsoonal storm frequency and strength since the mid-Holocene have resulted in smaller scale dune aggradational and re-activation events. Dune systems appear to react to this type of climate change on the order of less than 1,000 years.

Relatively strong alluvial fan aggradational events correlate with periods of stronger and more frequent monsoonal storm strength (thunderstorm-extreme events; Reheis et al., 1996; Harvey et al., 1999; Reheis et al., 1996; McDonald et al., 2003; Miller et al., 2010). Hence, eolian system activity levels correlate well with that of alluvial fan systems. During periods of relatively intense monsoonal climate conditions, many of the playa and pluvial lakes can fill and desiccate which increases eolian sediment supply substantially. In contrast, the relatively wet period in the southwestern United States associated with the global Neo-Glacial from 4.5 to 2.5 kya that led to increased vegetation density at lower elevations assisted in stabilizing most eolian dune systems in the study region and decreasing the ability for eolian sand to migrate.

The arid-semi arid climate conditions since the mid-Holocene have resulted in a geomorphic condition where slight changes in regional climate (i.e., monsoonal storm activity) are sufficient to result in local re-activation of dune systems, but not sufficient to produce a robust eolian system where sand migration corridors are continuous. Dune systems across the study region have been relatively stable since the mid Neo-Glacial period approximately 4.0 to 3.5 kya. However, the semi-arid climate occurring in the study region for much of the Holocene is near a critical threshold condition where small changes in dune parameters such as global climate affecting Pacific Storm strength and frequency and local monsoonal strength frequency and magnitude can be reflected in changes in dune behavior on a cyclic scale of approximately 1,000 to 500 years. There is a strong correlation with increased monsoonal extreme storm frequency and magnitude with increased eolian activity (aggradational events), and/or with periods of time exhibiting a warmer global climate).

Anthropogenic activities such as those that affect surface water flow can also affect dune dynamics; however, the flood control measures for construction of Highway 10 and older roads in the DQSP area have existed for decades and have only led to subtle changes in the local dune systems.

ES 4.3.5 DQSP Area Dune Activity

There are four SMZs located in the DQSP area. These include the Wiley's Well Basin SMZ, the Mule SMZ, as well as the much smaller Palowalla and Power Line SMZs (Figure ES-1). The Palowalla SMZ occurs near the eastern limit of the Wiley's Well Basin SMZ and is designated as a separate SMZ simply due to the interpretation that it has received a slight increase in eolian sand due to man-induced water diversions and ponding.

The dune deposits in the Wiley's Well Basin SMZ are less than 5 feet thick typically, and gradually get thinner toward the east, where some areas mapped as Zone BC and Zone BW are less than 3 feet thick. In areas mapped as Zone BC, older alluvium of Soil S4 occur at depths of only a few inches within interdune depressions and the dune deposits represent relict dune mounds that vary from full connectivity to scattered connectivity. Eolian deposits are generally thinner for progressively less active geomorphic eolian sand migration zone designations. In addition, the eolian deposits associated with Zone BC, which bounds the limits of eolian dominated areas (geomorphically), gradually thin toward its contact with mapped Zone C where eolian deposits are essentially less than a few inches thick near the Zone

BC/C contact. Hence, in contrast to Lancaster (2014) eolian mapping for this project was not based on dune deposit thickness, but instead, on observed eolian geomorphology on the surface.

The Wiley's Well Basin SMZ gradually narrows from a width proportional to that of the Wiley's Well Basin (~3.5 miles), to approximately 0.5 mile within the DQSP. The dunes activity also decreases toward the east with the eastern portion of the Wiley's Well Basin SMZ receiving very little sand flux input from the west within the DQSP. The primary cause for the decrease in width of the sand migration zone is the Palo Verde Topographic Sill, which is the geographic/geomorphic boundary between the eastern Chuckwalla Valley and the Western Palo Verde Mesa (Figure ES-3). The Palo Verde Topographic Sill is located approximately in the middle region of the Wiley's Well SMZ, in the vicinity of the SCE Colorado River Substation. The Palo Verde Topographic Sill consists of rise from an elevation of ~438 feet in the Wiley's Well Basin in the west, to the sill itself at an elevation of ~488 feet (high point), and then back down to an elevation of ~400 feet near the Palowalla SMZ to the east. Hence, eolian sands migrating eastward from the Wiley's Well Basin move uphill approximately 50 feet in relief, and this rise causes eolian sands to deposit. On the downwind leeward side of the topographic sill, eolian sands are also encouraged to deposit as wind speeds decrease. The sill has likely allowed for relatively more eolian sands to be deposited on the western side, crest and immediate eastern side than would have deposited if the topographic sill did not exist. In other words, the topographic sill has created a local eolian sand sink allowing for relatively increased eolian sand deposition to the west and east of the sill. Hence, the amount of wind-blown sand reaching the eastern most area of the Wiley's Well Basin SMZ is dramatically decreased because most of the eastward migrating sand is encouraged to deposit near the topographic sill. Most of the active eolian sands in Zone BW (Plate ES-5) are produced by the erosion (cannibalization) of older relict (dormant) dune deposits.

The watershed area for the drainage system producing the eolian sands for the Mule SMZ is relatively small and believed to be too small to be able to produce the magnitude of eolian sands identified in the zone if this drainage system was a typical wash system emanating from a local Mojave Desert mountain range. However, the washes of watershed have eroded into exposures of the ancient Colorado River deposits (unit Tmm, Bullhead Alluvium, Soil S7a; Plate ES-6) indicating that the washes carry a larger bedload of eolian size grains during flood events compared to typical desert washes emanating from bedrock regions and through typical alluvial fan terrains. In addition, the relatively wide tributary wash system that feeds the Mule SMZ assists in eolian sand production as it flows parallel to prevailing winds, and all the precipitation in the small watershed is focused essentially into this one wash system allowing it to more frequently flow to lower elevations. In fact, it is proposed that the Mule SMZ may not even exist if it were not for the robust sand transport of the local washes carrying eroded older sediments from unit Tmm and positive wash parameters.

The most robust dune form in the Mule SMZ is active sand sheets in a small region on the leeward (downwind) side of a topographic high associated with remnants of an ancient shoreline berm of the receding Colorado River in Pliocene (unit Tmw, Soil S7, Plate ES-6). Most of the Mule SMZ exhibits relict dune mounds with active eolian sands representing sand sheets and small coppice.

The Powerline SMZ is a small and weak eolian system that developed naturally, but may be slightly affected by minor water diversions and surface disturbances along the graded (dirt) powerline road to the southwest (Plate ES-1). The dune system receives eolian sands from wash flow in the west and ponding areas to the northwest and southeast. The area exhibits thin, relict and subdued dune mounds with active eolian sands consisting of scattered sand sheets and small coppice. The eolian deposits are less than one foot thick.

The Palowalla SMZ is a small system that occurs at the eastern end of the Wiley's Well SMZ and is designated as a separate zone based on anthropogenic factors. These include water flow diversions associated with the construction of Highway 10 to the north and creation of ponding areas due to construction of the Blythe 21 Solar Facility cut off water flow in a wash that historically ran through the facility site resulting in creation of, or increase in, ponding adjacent to the facility (Plate ES-3). This region has experienced an increase in drainage flow due to diversion of water flow associated with the construction of Interstate 10.

The eastern Wiley's Well Basin SMZ experienced essentially one dune aggradational event, likely occurring in the early to end of the mid-Holocene, and then by the late mid-Holocene began to retract. Since the cessation of the dune aggradational event, the dune areas exhibiting S2 dune soils (Plate ES-3) have degraded. Based on the rate of past dune aggradation indicated in the soil record for the Wiley's Well Basin and Mule SMZ, it is likely that if dune parameter conditions changed that encouraged dune growth (i.e., a future dune aggradational event) that the existing mapped areas of dunes would be able to accommodate the additional dune sands for at least a thousand years prior to expanding beyond its current mapped footprint. This finding assumes that current drainage flows acknowledging current anthropogenic diversions, remain relatively constant to provide critical stabilizing moisture to the dunes.

The Mule SMZ in the southwestern region of the DQSP experienced a similar history in the sense that the dune deposits are primarily relict dunes that experienced a dune aggradational event during the early Holocene and then became stable by the late mid-Holocene. Therefore, this region also experienced a decrease in relative sand migration rates during near the end of the mid-Holocene. Eolian activity in the DQSP site is therefore consistent with other dune systems across southeastern California in that they experienced strong eolian deposition in the early to mid-Holocene, which has decreased substantially since that time.

ES 4.3.6 Affects of Vegetation

The density of vegetation in dune deposit areas is a very important parameter in terms of dune stability and sand migration rates. Lancaster et al. (1998) conducted a significant, well controlled study evaluating the relationship between plant aerial coverage density and sand migration rates on a playa lake bed. Their results indicate that just a 10% aerial coverage of plants that are less than one foot tall decreases eolian sand migration rates by 90%. This result is quite astounding and indicates that minor vegetation densities essentially decrease eolian sand migration rates exponentially.

The dunes immediately north of the north boundary of the DQSP exhibit vegetation densities at minimum of 10 to 15%, during years of essentially no growth of the invasive species "Sahara Mustard" (Brassica tournefortii). This normal vegetation alone could impede sand migration by 90% or more, and the amount of non-native and invasive Sahara Mustard coverage can increase to well over 50% in a single season following a year of strong growth. Field mapping in December of 2010 indicated that a Sahara Mustard bloom had recently occurred, and mapping in April 2011 revealed that abundant dead Sahara Mustard plants remained across the dune fields still vertically in the place they had grown. Hence, once the Sahara Mustard plant dies, it remains "planted" in the ground and this was observed to remain the case for many months to possibly over a year from when the plant died. The dead plant stems break free and blow in the wind piling up on nearby dunes and coppice dunes, which means the plant continues to impede eolian sand transport after it has died and been uprooted. Hence, once there is a Sahara Mustard bloom, eolian sand migration rates are greatly diminished not only for the year of the bloom, but for a minimum of the next year, and most likely into a third year.

Dense populations of Sahara Mustard plants were identified extending within the dune system east of Wiley Well Road to DQSP. During strong Sahara Mustard growth, eolian sand migration and internal dune erosion, is nearly completely shut down.

ES 4.3.7 Potential Future Impacts

The dune systems in the area and within the DQSP have been stable for a minimum of several thousand years since the end of their mid-Holocene aggradational event. Flow within the watershed of the Wiley's Well Wash has not been altered significantly in Historical times and should result in similar eolian sand production as it did in pre-Historical times if climate remains similar. The watershed and drainage system feeding the Mule sand migration zone has not been altered in Historical times and is evaluated to remain stable. The Mule sand migration zone has been stable for at least several thousand years, similar to the Wiley's Well Basin sand migration zone to the north.

Dune parameters that could lead to changes in the dune system in the future include a continuation of surface water flow diversions that has led some areas, particularly along the northern portion of the Wiley's Well Basin dune system, to be dryer and wetter. This has already led to an increase in eolian sand source in areas receiving more water, and drying out of dunes in areas receiving less water that has led to minor dune degradation and increased sand transport rates locally. The flood control measures for construction of Highway 10 and older roads in this area have existed for decades and have also resulted in subtle changes in the local dune systems. But especially with the advent of the invasion of Sahara Mustard, which has dramatically slowed down sand migration rates from their eolian sources, the slight increase in eolian sand generation in the wetter source area associated with the Palowalla Ditch-Wash will likely continue to deposit in the area mapped as sand migration Zone B, Zone BW and Zone BC (Plate ES-5).

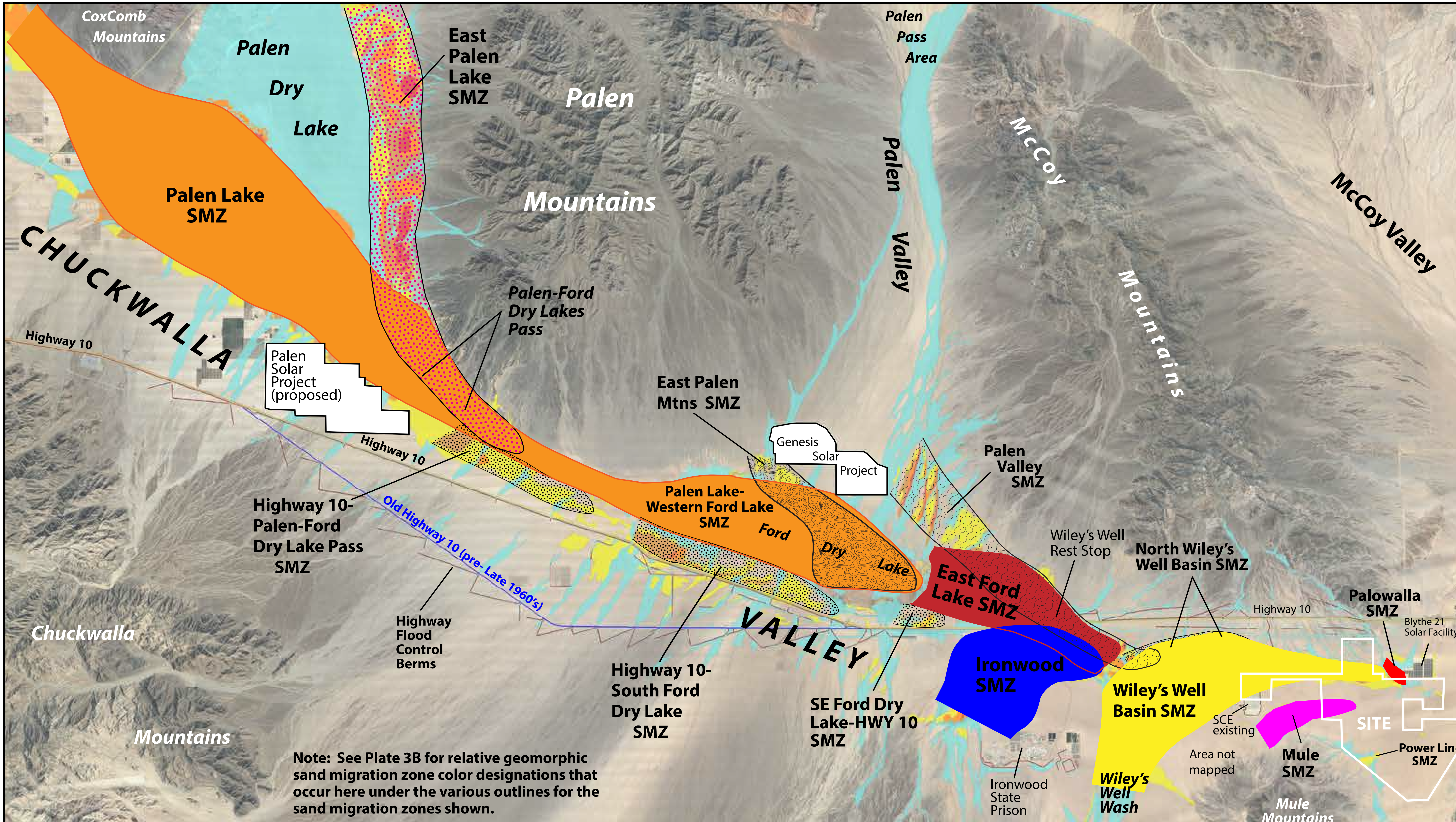
If the frequency of magnitude of cool winter Pacific storms decrease and warm summer monsoonal storms increase, this could lead to an increase in eolian sand generation and migration in the valley axis area. However, consistent with the observations noted above, the existing dune systems in the DQSP are degrading (internally eroding mostly) and thus can "absorb" newly derived eolian sands for at least a thousand years without expanding outside of the mapped dune areas, based on past dune aggradation rates.

ES 5.0 CONCLUSIONS

Global and local climatic conditions and their secondary effects during the Holocene has been beneficial for dune growth at various periods of time and near a geomorphic threshold condition where relatively subtle changes in climate can lead to dune re-activation. However, dune systems across the southeastern California region have been dominantly stable since the mid-Holocene and the sand migration corridors have essentially shut down since that time. Eolian sand sources during times of dune aggradational events since mid-Holocene have primarily been local sources.

Similarly, dune systems in the area of the DQSP site have received most of their eolian sands from local sources throughout the Holocene. The dunes encroached into the DQSP during the late-early Holocene and continued to grow until the later mid-Holocene. Since the later mid-Holocene, existing dune systems across the southeastern California region have been degrading, as they rely on the erosion of older dune deposits for new eolian sands. This is certainly the case for the dune areas in and around the DQSP. Additionally, sand migration into the DQSP from the east has been impeded by a topographic sill east of the DQSP.

If there is an increase in eolian sand production due to climate change via a decrease in Pacific storms and increase in monsoonal storms frequency and magnitude, then these newly derived sands will be deposited for at least a thousand years within the existing mapped dune system area. The incursion of the invasive Sahara Mustard plant that blooms relatively frequently (possibly 2 to 3 times per decade) has decreased sand migration rates by over an order of magnitude where it occurs. This will also cause newly derived eolian sands to deposit closer to their sources and within mapped eolian dune systems. Although their dune forms and thickness will be altered, these features are not expected to expand significantly.



N

~ 2 Miles

Kenney GeoScience

CLIENT:
FIRST SOLAR ENERGY

PROJECT (SITE):
DESERT QUARTZITE SOLAR

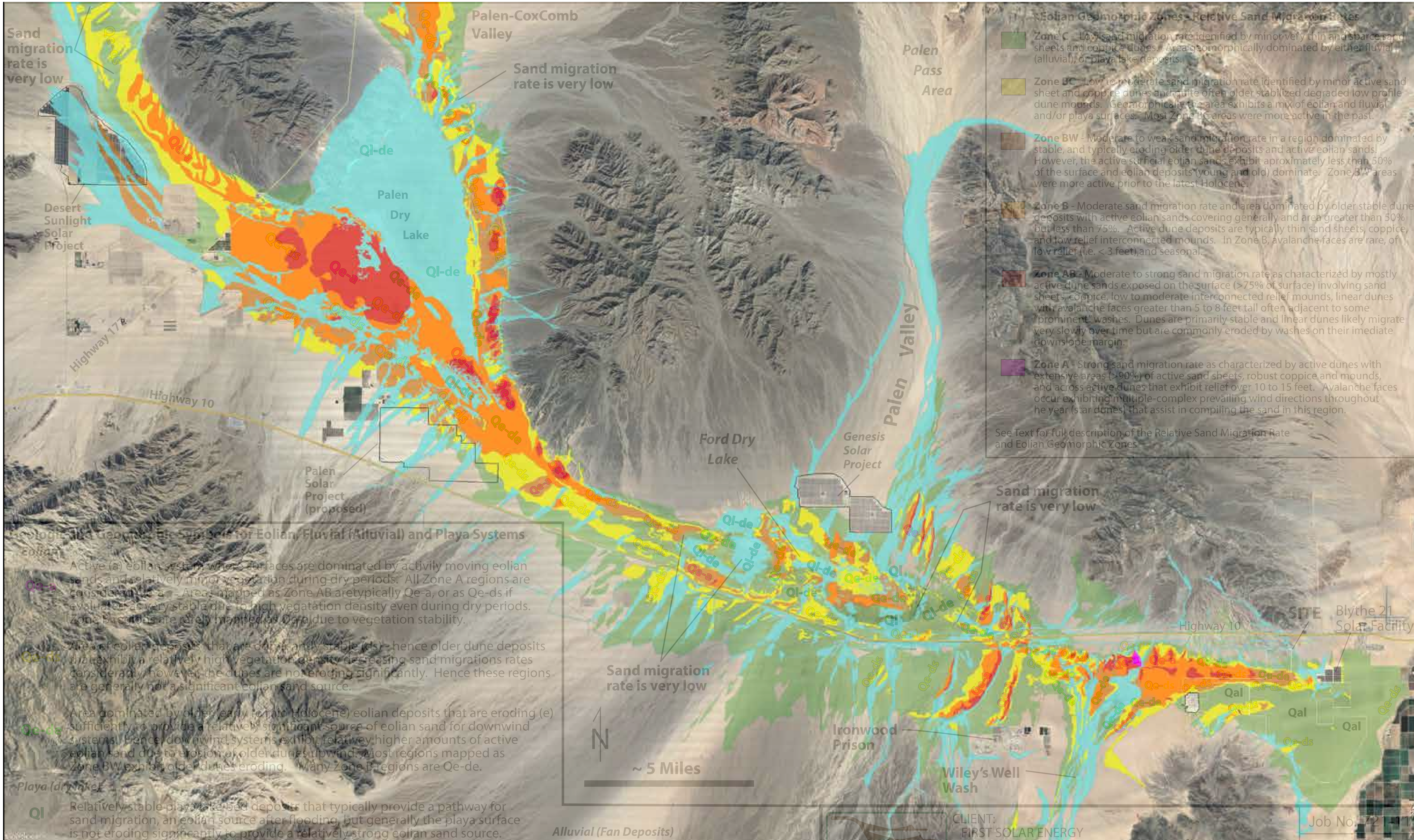
Local Geomorphic Eolian Sand Migration Zones along the Chuckwalla Valley Eolian System

Job No. 721-11

Date: September, 2017

Drafted by: MDK

PLATE ES-1



Ql-de Playa lake bed deposits that are evaluated as eroding; hence, providing a source for eolian sand deposits for downwind (toward the southeast) dune systems. These surfaces also provide eolian sands after flooding.

Qal Regions dominated by alluvial deposits shown only within the proposed Desert Quartzite Solar Project

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CLIENT: FIRST SOLAR ENERGY

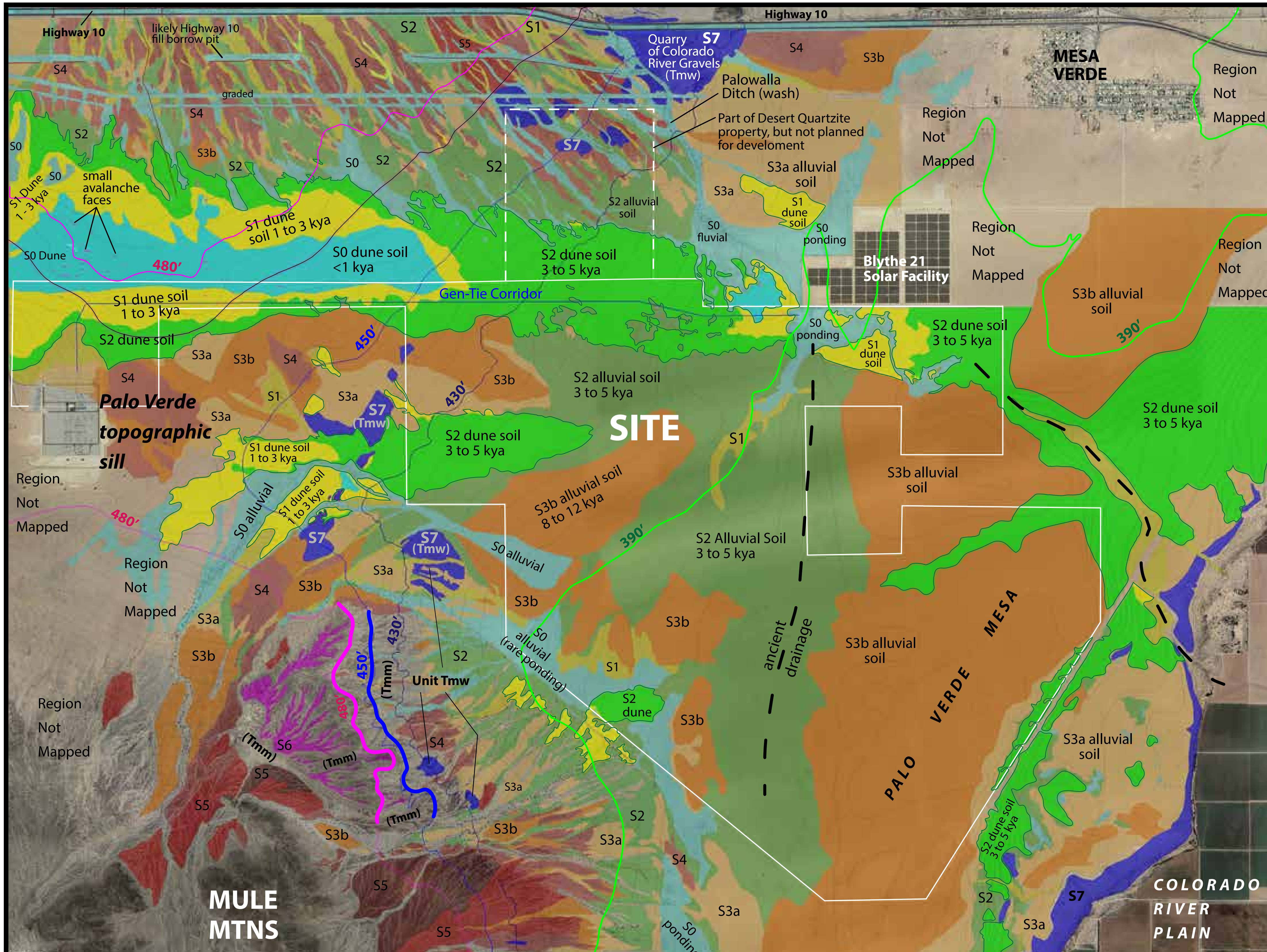
Geomorphic map showing variations in dune deposit activity and stability along the Chuckwalla Valley eolian sand system

Job No.: 721-11

Date: September, 2017

Drafted by: MDK

PLATE ES-2



Soil (Pedon) Stratigraphy

Alluvial (fluvial) Parent Material (minimum ages)

- **S0** - < 1000 years old (fluvial and ponding areas)
- **S1**- 1 to 3 kya (late Holocene)
- **S2** - 3 to 5 kya (mid to late Holocene)
- **S3a** - 5 to 8 kya (early to mid Holocene)
- **S3b** - 8 to 12 kya (latest Pleistocene to early Holocene)
- **S4** - 35 to 65 kya (late Pleistocene)
- **S5a** - > 100 kya (early Pleistocene)
- **S5b** - > 100 kya (early Pleistocene)
- **S6** - < 3.5 Ma Early Pleistocene or possibly late Pliocene Older alluvium with strongly developed soil profile resting unconformably on top of Bullhead Alluvium Colorado River deposits.
- **S7** - 3.5 to 4.5 Ma (early Pliocene). Bullhead Alluvium - Colorado River Gravels - exotic rounded cobbles with channel cross bedding (Unit Tmw) and the older member deposited to elevations of >1000 ft. throughout Chuckwalla Valley (Unit Tmm)

Eolian (Dune) Parent Material (minimum ages)

- **S0** - < 1000 years old
- **S1**- 1 to 3 kya (late Holocene)
- **S2** - 3 to 5 kya (mid to late Holocene)

Note Regarding Soil Ages: All soil ages are considered minimum values, indicating that these surfaces are likley not younger than the ages provided.

Geologic Contact - Dune Soil to Alluvial Soil Contacts

Geologic contact between eolian dune soils and alluvial soils. Contacts are gradations within eolian systems.

Topographic Contours - Colorado River Pliocene Levels

480′ — Topographic escarpment in Pliocene Bullhead Alluvium along the flanks of the northeastern Mule Mountains at approximate elevation 480 feet above sea level. Highest water elevation in the Pliocene associated with the Colorado River based on regional mapping was likely over 1,100 feet.

450′ — Topographic escarpment in the Pliocene Bullhead Alluvium along the flanks of the northeastern Mule Mountains at approximate elevation 450 feet above sea level. This escarpment is not as pronounced as the 480-foot elevation contour escarpment.

Topographic contours are from the USGS, 5-foot contour interval

Mapping conducted by M. Kenney via Google Earth Pro utilizing various years of their Hisorical Imagery. Image created with Google Earth Pro (10.2016).

N

~4000 Feet

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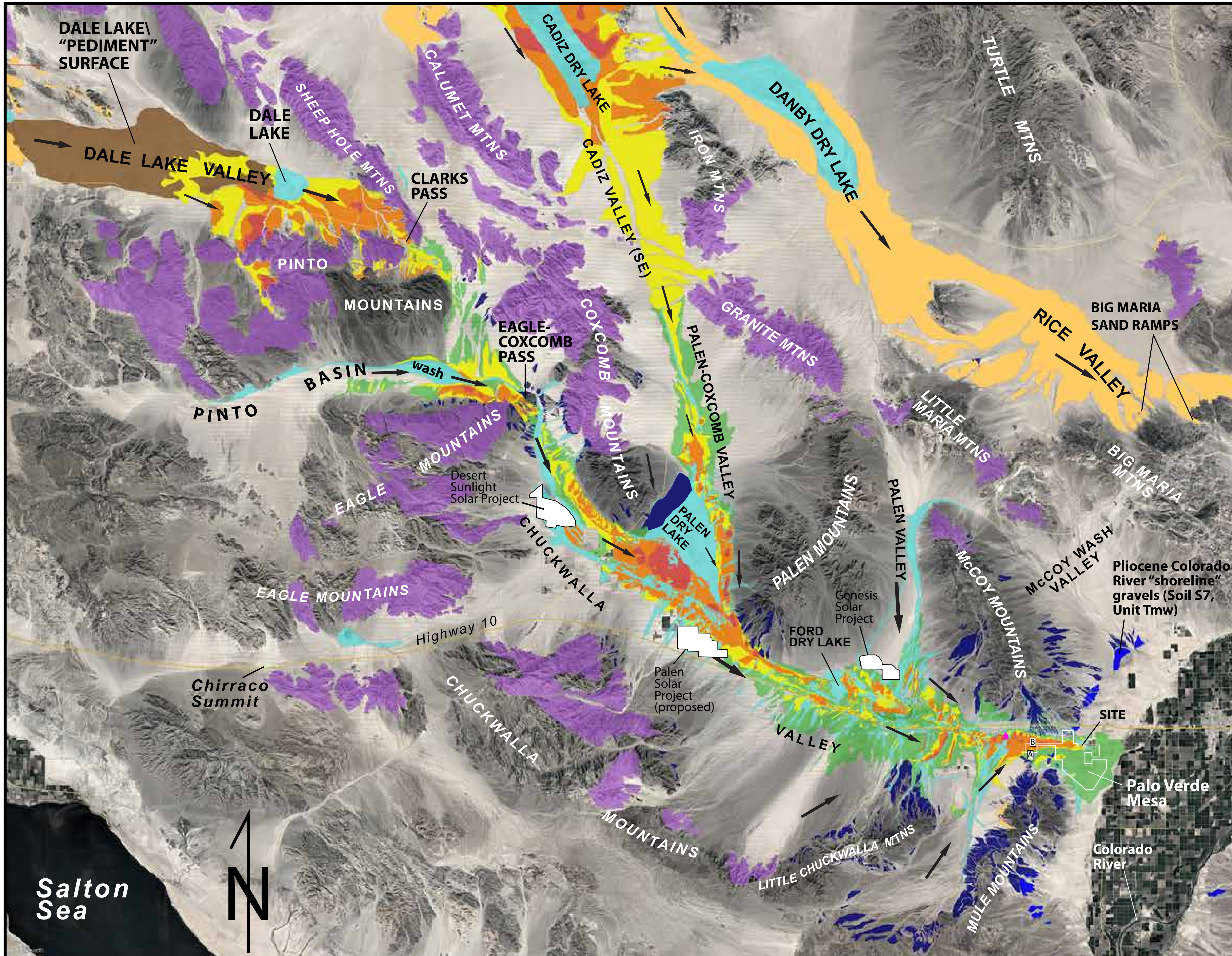
Soil (Pedon) Stratigraphy Map of Alluvial vs Eolian Soil Parent Deposits, Desert Quartzite Proposed Solar Project area

Job No. 721-11

Date: September, 2017
Drafted by: MDK

PLATE ES-3



Eolian Geomorphic Zones Dominated by Dune Geomorphology

- *Zone A and Zone AB*
- *Zone B and Zone BW (weak)*

Eolian Geomorphic Zones Exhibiting Mixed Eolian and Fluvial Geomorphology

- *Zone BC*
- *Zone C (fluvially dominated)*

Generalized Eolian Deposits (where not mapped via Eolian Zones below)

- Eolian deposits mapped in regions outside of the Dale Lake-Palo Verde Mesa, and Cadiz Dry Lake to Rice Valley sand migration zones

Eolian Sand Sources

- Generalized unit representing active playa lake surfaces (Lacustrine), active washes, and ponding areas. These areas are important for eolian systems as a sand source, sand transport and stabilizing moisture.
- Fluvial, ancient playa-lake, and Colorado River Deposits that produce relatively abundant eolian sands upon erosion. Unit primarily correlates with the Bullhead Alluvium of Howard et al. (2015), unit QTmm of Stone (2006), possibly some Bouse Formation of Spencer (2008), and Unit B of Metzger et al.(1973). Mapped as unit Tmm (Soil S7) in this study.
- Granitic rocks in the region mapped by CGS (1964 & 1967). Identified as regional and local eolian sand source upon erosion and trasonport via local washes by Muhs et al. (2003).

General Prevailing Wind Direction

- Generalized direction of "prevailing" winds most of which are altered by local valley-mountain topography

B A Location of the existing Sothern California Edison substation [A] and initially proposed Southern California Edison substaion [B] (Kenney, 2010d and 2010e).

Job No. 721-11

Mapping conducted by M. Kenney via Google Earth Pro utilzing various years of their Hisorical Imagery.Image created with Google Earth Pro (10.2016).

~ 5 Miles

Kenney GeoScience

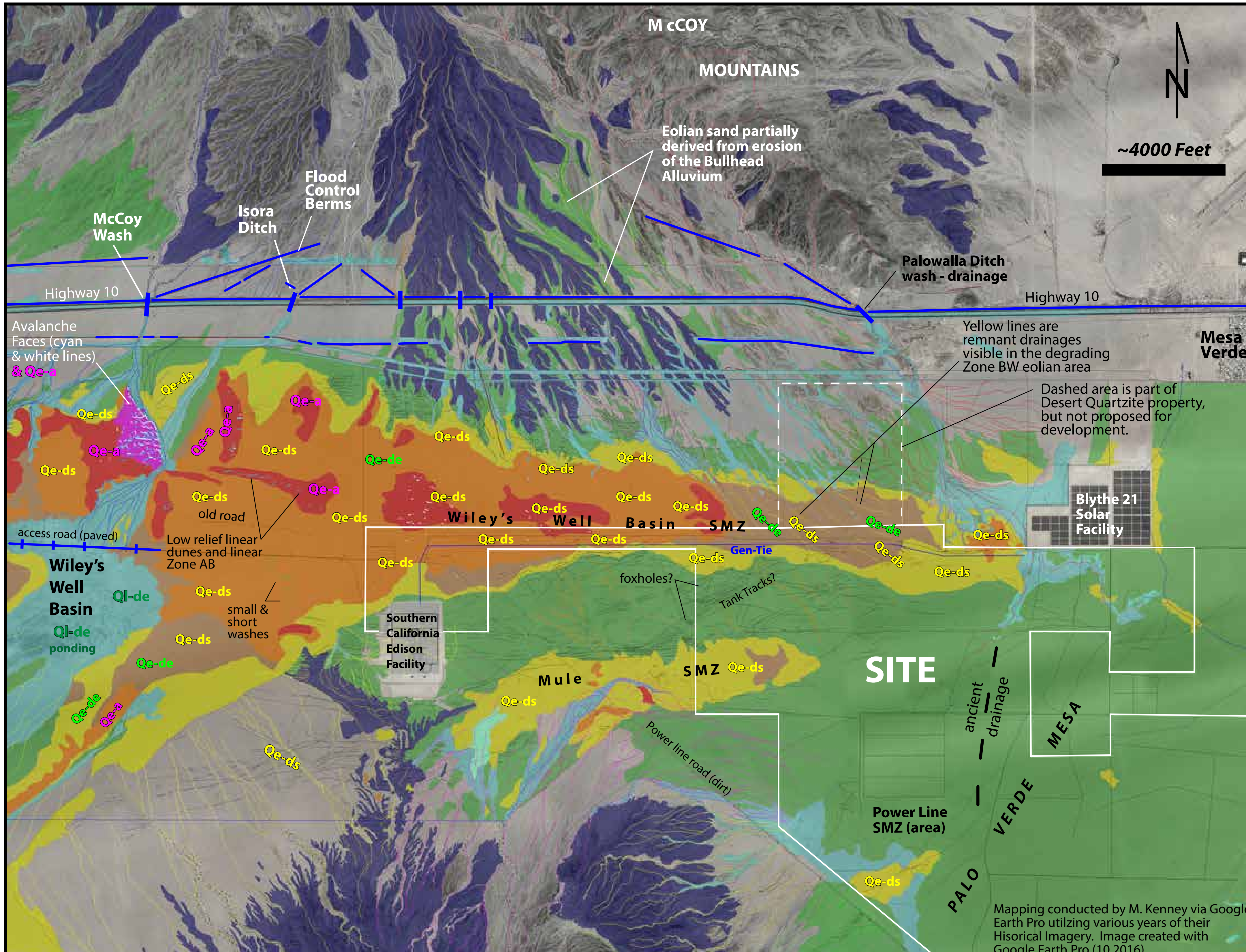
CLIENT:
FIRST SOLAR ENERGY

PROJECT:
DESERT QUARTZITE SOLAR PROJECT, NEAR BLYTHE, CA

Eolian geomorphic, dune & sand source map in Southeastern California

Date: September, 2017
Drafted by: MDK

PLATE ES-4



Eolian Geomorphic - Relative Sand Migration Zones

Zone C - Low sand migration rate and area dominated either by fluvial (alluvial), or alluvial ponding areas

Zone BC - Low to moderate sand migration rate, and geomorphically the area exhibits a mix of eolian and fluvial and/or playa surfaces. Dune deposits are also generally a mix of older stable, some eroding dunes, and active surficial loose eolian sands (sand sheets).

Zone BW - Moderate to weak sand migration rate, and area dominated by stable (vegetated), and typically eroding older dune deposits (geomorphology). Active eolian sands cover generally less than 50% of the surface area. Ponding (gravel lag surfaces) interdune depressions common.

Zone B - Moderate sand migration rate and area dominated by older stable dune deposits with active eolian sands covering generally greater than 50% of the area. Active eolian sands are typically sand sheets, coppice, and low reliefmounds. Avalanche faces are very rare and only seasonal in Zone B.

Zone AB - Moderate to strong sand migration rate and area characterized by mostly active dune sands exposed on the surface involving sand sheets, coppice, low relief mounds, and linear dunes with occassional seasonal avalanche faces.

Zone A - Strong sand migration rate and area characterized by extensive areas of active sand sheets across active dunes that exhibit relief over 10 to 15 feet. Avalanche faces occur exhibiting multiple-complex prevailing wind directions throughout the year leading to the development of star dunes. Zone A only occurs in one map area location near the termination of the Wiley's Well Wash in the herein named Wiley's Well Basin.

Eolian Source Geologic Deposits - Formations

Generalized unit representing ponding areas at the termination area of drainages and active washes. These areas are critically important for eolian systems as a sand source and stabilizing moisture for dune systems.

Sediments associated with the Colorado River when it inundated this region to an upper elevation of possibly 1,200 feet 4.3 to 3.5 Ma. These sediments produce a strong eolian sand source upon erosion. Unit correlates with the Bullhead Alluvium of Howard et al. (2015) estimated to be deposited between 4.5 to 3.5 Ma (Pliocene) and unit Tmm of this report (Soil 7).

Geologic and Geomorphic Symbols for Eolian and Playa Systems (see Plate 3A for full legend details)

Eolian

Qe-a Active dune area, however, dunes are not migrating

Qe-ds Strongly stabilized dune area

Qe-de Strongly stabilized dune area that is eroding producing eolian sand source for downwind systems

Playa (dry lake) and other smaller Ponding areas

Ql-de Ponding area that floods frequently providing an eolian sand source for downwind (toward the east and northeast) dune systems

Subdrains and flood control berms. Thin blue lines are flood control berms and thicker orthogonal lines are subdrains allow flow to pass.

Mapped dirt roads. Many of the dirt roads in close proximity and within the Site are surmised to have been produced during General Pattons tank war excersises in the early 1940's. These roads provide evidence supporting eolian geomorphic zones stability on a decadal scale, particularly for Zone BC, and Zone C, and lesser extent Zone BW, where many of these roads remain partitially preserved on the landscape.

Kenney GeoScience

CLIENT: FIRST SOLAR ENERGY

PROJECT: DESERT QUARTZITE SOLAR

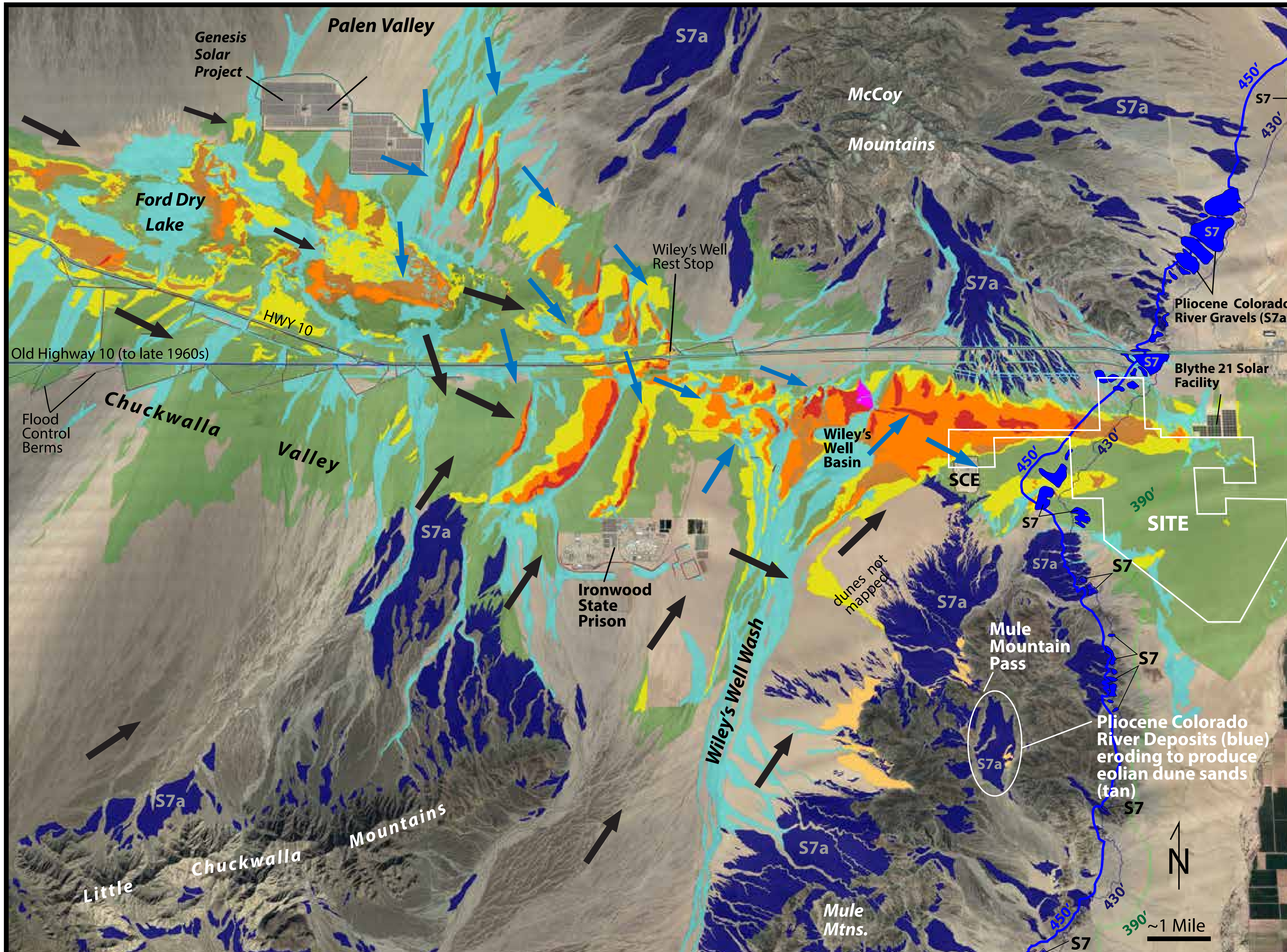
Eolian Geomorphic Zone Map and Drainage Map of the Wiley's Well Basin and Mule Sand Migrations Zones (SMZ), Desert Quartzite Proposed Solar Project area

Job No. 721-11

Date: September, 2017

Drafted by: MDK

PLATE ES-5



Eolian Geomorphic - Relative Sand Migration Zones

Zone C - Low sand migration rate idenified by minor very thin and sparce sand sheets and coppice dunes. Area geomorphically dominated by either fluvial (alluvial), or playa lake deposits.

Zone BC - Low to moderate sand migration rate identified by minor active sand sheet and coppice dunes and quite often older stabilized degraded low profile dune mounds. Geomorphically the area exhibits a mix of eolian and fluvial

Zone BW - Moderate to weak sand migration rate in a region dominated by stable, and typically eroding older dune deposits and active eolian sands. However, the active surficial eolian sands exhibit aproximately less than 50% of the surface and eolian deposits (young and old) dominate. Zone BW areas were more active prior to the latest Holocene.

Zone B - Moderate sand migration rate and area dominated by older stable dunedeposits with active eolian sands covering generally and area greater than 50% but less than 75%. Active dune deposits are typically thin sand sheets, coppice, and low relief interconnected mounds. In Zone B, avalanche faces are rare, of low relief (i.e. < 3 feet), and seasonal.

Zone AB - Moderate to strong sand migration rate as characterized by mostly active dune sands exposed on the surface (>75% of surface) involving sand sheets, coppice, low to moderate interconnected relief mounds, linear dunes with avalanche faces greater than 5 to 8 feet tall often adjacent to some "prominent" washes. Dunes are primarily stable and linear dunes likely migrate very slowly over time but are commonly eroded by washes on their imediate downslope margin.

Zone A - Strong sand migration rate as characterized by active dunes with extensive areas (>90%) of active sand sheets, robust coppice and mounds, and across active dunes that exhibit relief over 10 to 15 feet. Avalanche faces occur exhibiting multiple-complex prevailing wind directions throughout the year (star dunes) that assist in compiling the sand in this region.

Eolian Source Geologic Deposits - Formations

Generalized unit representing active playa lake surfaces (Lacustrine), active washes, and ponding areas. These areas are important for eolian systems as a sand source, sand transport and stabilizing moisture.

S7 Tmw Fluvial Colorado River Gravels associated with an ancient "shoreline-river edge) near elevation 430 to 450 feet above sea level (msl, blue lines). This unit is correlated stratigraphically to unit QTmw of Stone (2006), Unit B (Quarry Gravels) of Metzger et al. (1973), and member of the **Bullhead Alluvium** of Howard et al. (2015). Units are early Pliocene in age (Bullhead Alluvium - 4.5 to 3.5 Ma; Howard et al., 2015).

S7a Tmm Fluvial, ancient playa-lake, and Colorado River Deposits that producerelatively abundant eolian sands upon erosion. Unit primarily correlates with the **Bullhead Alluvium** of Howard et al. (2015), unit QTmm of Stone (2006), possibly some Bouse Formation of Spencer (2008), and Unit B of Metzger et al.(1973). Units are early Pliocene in age (Bullhead Alluvium - 4.5 to 3.5 Ma; Howard et al., 2015). Petrified wood bearing uper slope member extending to elevations over 850 feet.

Eolian Deposits - General in Mule Mountains

Generalized area of dune deposits typically exhibiting Zones A, AB and B (see above) along the flanks, and within upper valleys of the Mule Mountains.

Mapping conducted by M. Kenney via Google Earth Pro utlizing various years of their Hisorical Imagery.Image created with Google Earth Pro (2016). Sand migration rates varied considerably across Ford Dry Lake and near the site due to large magnitude changes in vegetation density (wet vs dry years). Mapping was conducted where possible that exhibited the strongest sand migration rates that corresponded to relatively low vegetation densities.

"Prevailing" Wind Directions Influencing Eolian Systems

Generalized direction of pertinent "prevailing" wind directions resulting in eolian sand movement as observed in the field during strong wind events and eolian dune structures. These wind directions are controlled by local valley-mountain topography and seasonal storm track dominant movement directions. These occur from the SW along Wiley's Well Wash, from the west (W) down the Chuckwalla Valley, and from the NNW down Palen Valley. The SW to NE winds have commonly been observed to flow over the Chuckwalla Mountains. Blue arrows were observed and measured and the field, gray arrows are generalized based on field experience and dune forms.

Kenney GeoScience

CLIENT:
FIRST SOLAR ENERGY

PROJECT:
DESERT QUARTZITE SOLAR PROJECT, NEAR BLYTHE, CA

Job No. 721-11

Date: September, 2017

Drafted by: MDK

Geomorphic Eolian Zone Map & Geologic Map of the Eastern Chuckwalla Valley

PLATE ES-6

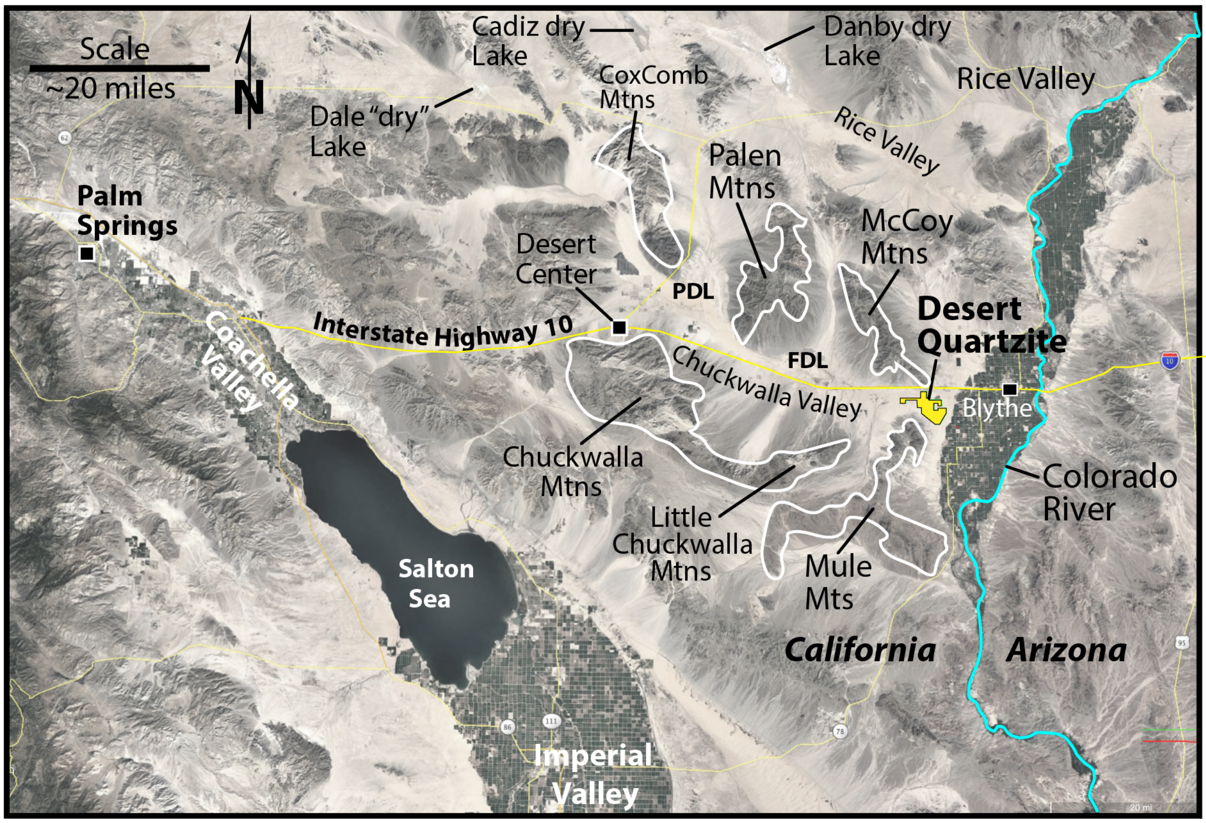
REPORT

1.0 SITE LOCATION, PROPOSED DEVELOPMENT AND TOPOGRAPHIC RELIEF

1.1 Site Location of the Desert Quartzite Solar Project

The Desert Quartzite Solar Project (DQSP) located in eastern California at the east end of the approximately 50-mile long, east-west trending Chuckwalla Valley, in southeastern California (Figure 1 and Figure 2). Palen Dry Lake (PDL) and Ford Dry Lake (FDL) occur at the western and eastern central areas respectively within the valley axis of the Chuckwalla Valley. Pertinent mountain ranges occur to the north and south of the Chuckwalla Valley that include the Palen and McCoy Mountains to the north, and the Chuckwalla, Little Chuckwalla and Mule Mountains to the south.

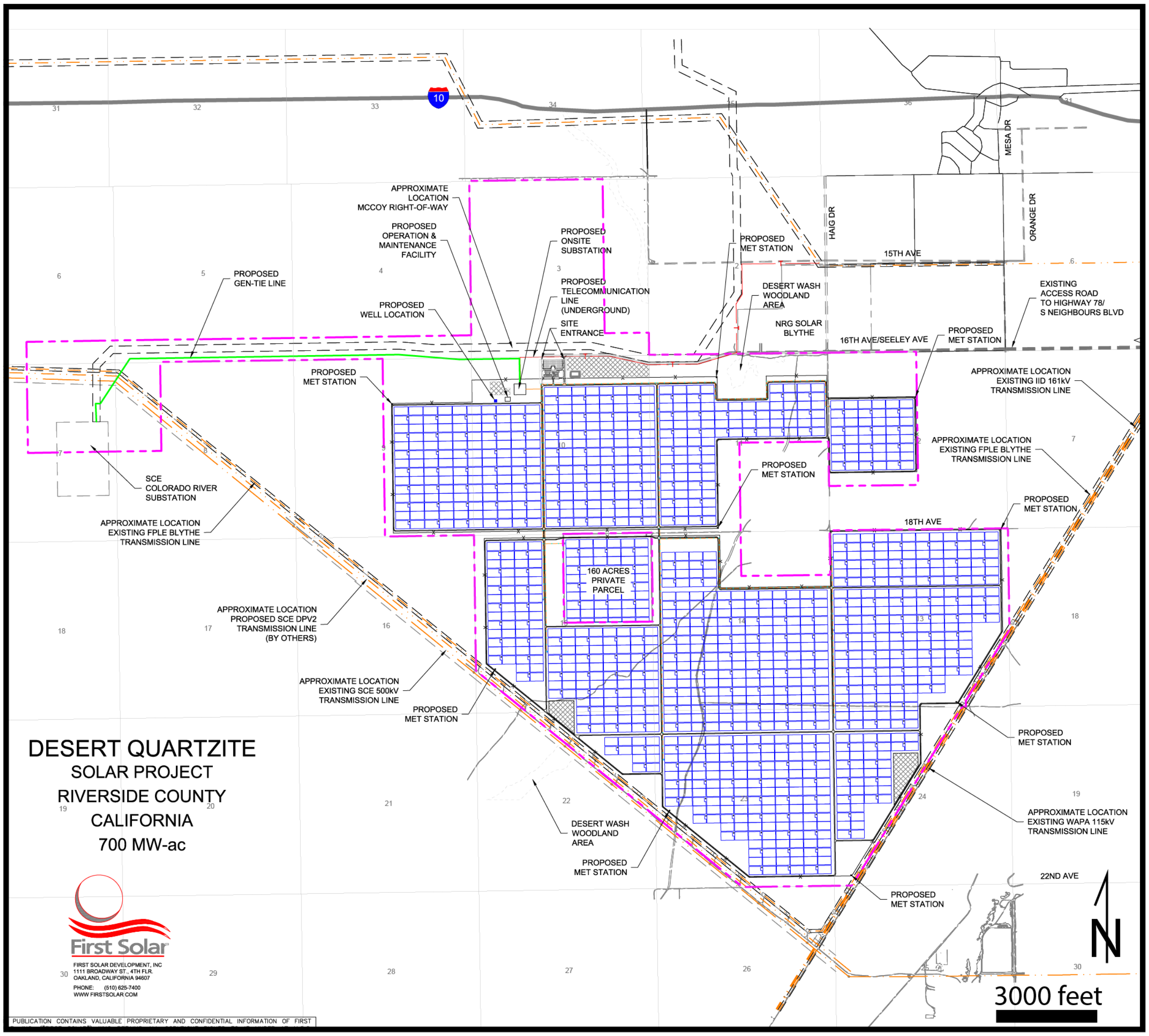
Figure 1: Regional Desert Quartzite Solar Project site location and Geographic map. PDL is Palen Dry Lake, and FDL is Ford Dry Lake.



1.2 Proposed Development

The application area for DQSP is approximately 8.2 square miles; however, an approximately 1.7 square mile northern portion of DQSP located toward the west along the Gen-Tie Corridor, and a northern parcel of the property, are not proposed for development. Hence, these regions are not part of the solar field array constructional footprint (Figure 2).

Figure 2: Site map showing general siting of proposed Desert Quartzite Solar Project development. The red dashed line delineates the boundary of the property. Blue cross hatched regions delineate the proposed footprint of the solar array.



1.3 Site topographic relief

Elevations across the region of the proposed solar field footprint range from approximately 450 foot above mean sea level (msl) in the northwest corner, to approximately 375 foot above msl in the southeastern corner. This represents an approximate total relief of 75 feet.

2.0 GEOLOGIC TIME SCALE (PERTINENT TO INVESTIGATION)

The age of most geologic events discussed in this report occurred during the Neogene and Quaternary Periods. The Neogene Period is subdivided into the Pliocene and Miocene Epochs and the Quaternary Period is subdivided into the Holocene and Pleistocene Epochs. The name and associated time interval designations utilized in this report include (kya = thousand years ago; Ma = million years ago).

PERIOD	EPOCH	TIME PERIOD
QUATERNARY	HOLOCENE	TIME PERIOD
	Latest Holocene (Historical)	~past 200 to 150 years
	Late Holocene	4 kya to 200 years ago
	Mid- Holocene	8 to 4 kya
	Early Holocene	12 to 8 kya
	PLEISTOCENE	
	Latest Pleistocene	~15 to 12 kya
	Late Pleistocene	125 to 20 kya
	Middle Pleistocene	670 to 125 kya
	Early Pleistocene	~2.6 Ma to 670 kya
NEOGENE	PLIOCENE	
	Late Pliocene	3.6 to 2.6 Ma
	Early Pliocene	5.3 to 3.6 Ma
	MIOCENE	
	Late Miocene	11.6 to 5.3 Ma
	Middle Miocene	16 to 11.6 Ma
	Early Miocene	23 to 16 Ma

Although not of critical importance to this study, it should be pointed out that the time of the boundary between the Pliocene and Pleistocene varies considerably in the literature. This dilemma has resulted from the definition of the boundary of the Pliocene/Pleistocene, which is supposed to coincide with the onset of the first northern hemisphere glaciation. The Pleistocene is the Epoch characterized as the "ice age", hence experiencing period of major glaciations and interglacial periods of time. The date of the beginning of the Pleistocene has changed as new studies refine the age of the initiation of the beginning of the ice ages and disagreements within the scientific community. Age ranges "accepted" for the beginning of the Pleistocene (and Quaternary) vary from 2.6 to 1.6 Ma. There is also disagreement regarding the end of the Pleistocene as it was a gradual transition from about 12 to 10 kya. However, the California Geological Survey utilizing primarily findings from Walker et. al (2009) adopted 11.7 kya as the "official" definition of the Holocene based on a proposal to the International Stratigraphic Commission reflecting a change in Oxygen isotopic ($O^{18/16}$) composition of an ice core from Greenland. For the purposes of this study, the end of the Pleistocene is simply rounded to 12 kya.

The Holocene Epoch is subdivided into four time intervals in this report that are not based on an internationally accepted time periods, but instead defined within this report to assist in presenting the findings. However, unintentionally, the Holocene Epoch time period subdivisions created for this report based on variations of geomorphic processes are strikingly similar to those of Bull (1991).

3.0 PURPOSE OF STUDY

The primary purpose for this study is to geologically evaluate existing dune systems within and near the proposed DQSP to understand the current aerial extent of the dune deposits, and the potential regarding how dynamic or non-dynamic the current dune system is (i.e. active, stable, eroding). This exercise has been undertaken to supplement a report prepared by the California Geological Survey, which evaluated wind-blown (eolian) resources that serve as habitat for desert species within the Desert Renewable Energy Conservation Plan ("DRECP") area, including, without limitation, the Mojave fringe-toed lizard (Uma scoparia) and North American warm desert dunes and sand flats. The author is not a professional Biologist, however, the results of this study can be utilized by Biologists to evaluate potential direct impacts on MFTL habitat associated with DQSP. Moreover, the analysis is warranted in its own right, as the CGS report, although comprehensive, was not detailed or specific to the project site. It recognized that "Study area maps, developed at an interpretive scale of 1 inch equals 24,000 inches, are regional in nature and should not be used as a substitute for detailed studies in any specific area."

During the research phase of this project (and other recent eolian investigations by the author), it became clear that many fundamentally important aspects of the development of dune systems have not been sufficiently studied regionally to enable site-specific dunes studies. These aspects include:

- Variations in dune behavior over the course of thousands of years;
- Variety in local and regional sources of eolian sands;
- Relationship of dunes to the local geology, including alluvial fans and playa lakes;
- Several aspects of local hydrology, including availability of stabilizing moisture, watershed sizes, orientation of washes to prevailing winds, water flow diversions, and regions of ponding;
- When/whether upstream erosion of older sedimentary units results in some washes transporting increased volumes of eolian sands
- Correlation of global and local variations in climate since the late Pleistocene
- Soil stratigraphy data of near surface fluvial and eolian deposits that provide evidence of the geologic history of the dune systems (When did the dunes develop? Have the dunes advanced, stayed in the same region, or retracted during the Holocene?)

- The geologic history of the area with a focus on when the dunes may have developed.
- The continuation by Kenney GeoScience to create geomorphic unit designations that provide criteria for subtle but significant variations in dunes geomorphology and for relative sand migration rates.

4.0 APPROACH OF STUDY – FROM REGIONAL TO LOCAL

Over the course of two years, the author took several steps to ensure that this resulting report would be the premier authority regarding eolian geology and geomorphology within and around DQSP. These steps include:

- Review of previous studies that include mapping:
    - Utilization of the eolian geomorphic data, analysis and findings from numerous other eolian and playa lake studies conducted by the author in Chuckwalla Valley. These include, from west to east, the Starlight, Palen, and Genesis solar projects, Southern California Edison transfer station, and 2011 work at the Desert Quartzite Solar Project.
    - Evaluation of scientific publications on many relevant topics, particularly the timing and magnitude of regional dune aggradational events, global and regional climatic variations, and periods of dune stability across southwestern north America, timing of alluvial fan deposition and trenching, among others. Appendix A lists the references read and analyzed for this report.
- Project specific mapping including the following elements:
    - Local geologic and geomorphic mapping involving the evaluation and documentation of 320 geomorphic sites conducted since 2011. Work included geomorphic description, visual estimate of aerial vegetation density, taking photographs, excavation and evaluation of soil pits at some sites, and applying a geologic description designations and relative sand migration zone designation at every site.
    - Utilization and evaluation of 1-foot topographic contours of most of the project area in addition to evaluation of 5-foot contours of eastern Chuckwalla Valley.
    - The first detailed evaluation of the proposed Dale Lake to eastern Chuckwalla Valley Sand Migration Corridor including the region of the Ford Dry Lake to Palo Verde section. Other regional proposed sand migration corridors in southeastern California were also mapped in detail via Historical Imagery on Google Earth Pro, and scientific publications.
    - Evaluation of the local soil stratigraphy and associated minimum ages of the local dunes and alluvial deposits, which provides an understanding of the geologic development of the current landscape since the late Pleistocene.
    - Compiling field mapping data into Google Earth Pro for analysis.

- Producing relative Sand Migration Rate Zone and Soil Stratigraphy maps in Google Earth Pro.
- Analysis of regional dune systems and proposed regional sand migration zones (corridors) across southeastern California to compare to local dune systems. Regionally, much of this mapping was conducted utilizing various years of Historical imagery in Google Earth Pro and scientific publications. Mapping of some dune systems previously not mapped on acquired geologic maps and literature. The evaluation of local geologic history of the area extending back to the early Pliocene. This assists in placing the geologic history of the dune systems identified at the surface into context over geologic time.

- Continued evolution of new geomorphic designations to assist in evaluating eolian geomorphology including sand migration rates. This is brand new work. To the knowledge of the author and a noted expert in the field (personal communication, N. Lancaster), no formal or published recommendations exist regarding how to map desert geomorphology, particularly eolian systems. The method devised in this report builds on numerous eolian reports in the southwestern United States and develops geomorphic criteria designations for three categories:
  - **Relative Sand Migration Zones**

    (Zone A, Zone AB, Zone B, Zone BW, Zone BC and Zone C)
  - **Relative soil profile (horizon) development** minimum ages for near surface soils

    (S0, S1, S2, S3a, S3b, S4, S5, S6 and S7)
  - **Geologic unit designations** for eolian vs fluvially dominated geomorphic areas.

    (Qe units vs. Qal units)

- Analyses of eolian systems, to identify parameters and their relative importance in understanding eolian systems, focused on evaluation of:
  - Eolian sand sources of the regional and local dune systems, which revealed the relative importance of various eolian sand sources currently and over time.
  - Alluvial fan aggradational events, areas of deposition, and timing of alluvial fan-head trenching.
  - Herein newly proposed eolian sand sources such as eroded older dissected fluvial-alluvial deposits (fan head trenching), erosion of Pliocene Colorado River deposits, and erosion of exposed older valley fill deposits.
  - The relative magnitude of eolian sand production from washes depending on the width and inset depth (local relief – bar and swale) of the wash system, orientation of the wash relative to local prevailing winds, and whether the wash may carry relatively more eolian size sand grains depending on what sediments/deposits the wash has eroded during flow upstream.
  - Watershed regions and mapping of areas of distributary and tributary drainages systems. These parameters are important regarding their potential to generate eolian sands for local

dune systems and whether these local drainages may in fact result in creating their own "mini" sand migration zones.

- Previously proposed eolian sand sources such as playa lake surfaces, granitic rock exposures in the local mountains, and washes.
- Erosional surfaces exposed across valley floors (some are pediment surfaces) exposing older sediments rich in eolian size grains. Where these sediments erode, they provide another source for eolian sand for downwind dune systems.
- Various proposed sand migration corridors in southeastern California, their sand sources, timing of development and whether the sand corridors continue to remain continuous sand migration corridors since the mid-Holocene.
- Variations in timing and magnitude, and the relative importance of Pacific "northwestern" winter storm events (global climate variations) verses monsoonal extreme storm events (regional climatic variations) in the development of not only alluvial fans, but also their newly proposed contribution to the development of eolian dune systems in the region.
- Vegetation density at the site that provide insights on sand migration rates and dune stability. Includes discussion regarding the invasive Sahara Mustard plant that has and will, unless mitigated, greatly decrease sand migration rates in existing dune systems.

- Consideration of anthropogenic effects on dune systems:
    - Evaluate potential impacts human activity such as water diversions associated with road/highway construction involving water flow diversions from the highway itself, flood control berms upslope from the highway and soil burrow pits may affect existing dune systems.
    - Evaluate how susceptible dune systems may be to climatic in the future, which involved evaluating climate data for the southwestern United States since the latest Pleistocene.
    - Discussion regarding sand migration rates and stability associated with the invasion of the invasive Sahara Mustard plant.

This comprehensive, multi-disciplinary approach provided many new insights regarding the history of dune systems across southeastern California since the late Pleistocene, the relative importance of local versus far field eolian sand sources, the identification of new eolian sand sources, the importance of dune hydrology to dune stability, timing of dune aggradational events, the nature of the proposed regional sand migration zones, the long-term behavior of dune systems, and potential changes to the dune system in the future due to natural (climate change) or anthropogenic influences.

A regional analysis of eolian dune systems was essential to understanding how typical or unique a local dune system is, due to local variations in dune parameters. These aspects are discussed in more detail in the following sections. In addition, this study provides its results primarily via a series of Plates that comprise maps and tables (Plates 1 through 8C).

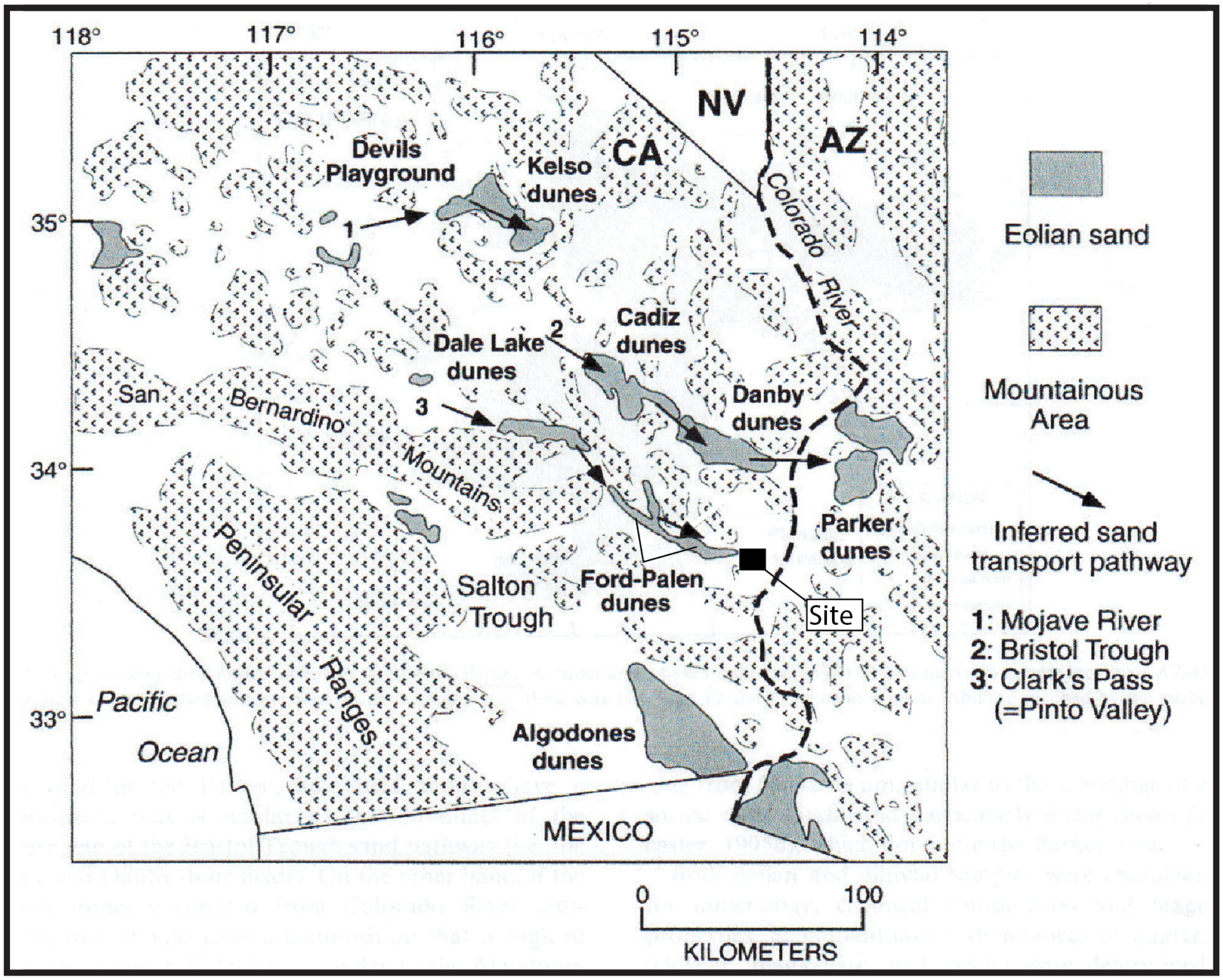
4.1 Regional dune systems and proposed regional sand migration corridors via mapping in Google earth and scientific literature

This study began with an evaluation of regional dune systems throughout southeastern California, allowing comparison to the local dunes to determine if some aspect of dune development and stability may have occurred locally that could be considered "out of the ordinary", or if the local dunes near and within the project should be considered "normal". Regional dune systems were evaluated utilizing existing scientific publications referenced in Appendix A, and via mapping in Google Earth Pro (utilizing the "historical imagery" in the region).

Previous regional dune studies in southeastern California have proposed the existence of numerous Sand Migration Corridors occurring in valley axes and crossing over some mountain passes. Zimbelman et al. (1995) was the first to propose the possible existence of through going regional sand migration corridors in southeastern California, implying that eolian sand essentially migrated to tens of kilometers from west to east, southeast down valley axis and over some mountain passes (sand ramps). Lancaster and Tchakerian (1996) evaluated numerous eolian sand ramps occurring where wind-blown sand was deposited in obstructing mountain passes or leeward side of mountains and assumed the existence of the regional sand migration corridors proposed by Zimbelman et al. (1995). Muhs et al. (2003), the most referenced scientific publication evaluating proposed regional sand migration corridors (Figure 3), perpetuated these beliefs, and since that time, the existence of the regional sand migration corridors has been assumed to exist, and in a sense, to have remained active throughout the Holocene.

Missing from the literature, however, was an evaluation that more accurately mapped the local sand migration corridors, local eolian source contributions, and that further took into account a wide field of studies to determine the current state and past activity and/or stability of the regional sand migration corridors. Indeed, the CGS February 5, 2015 comments on the DRECP (see Short and Lancaster, 2015) observed that prior to the aforementioned "Eolian System Mapping Report prepared by CGS (Aug. 4, 2014, see Lancaster, 2014), it was "a misstatement to call [wide swaths of the desert] 'Sand Transport Corridors.' Using this term implies that the mapping describes where the sand is coming from and where it is moving to (or source areas, zones of transport, and zones of deposition)." The prior mapping efforts did not have this granular level of detail to draw this conclusion. The Lancaster (2014) report did not provide sufficient information from the findings of many existing publications regarding the inactivity and lack of connectivity of eolian systems within the proposed regional sand migration zones during the late Holocene. The analysis in this report, however, considers whether local sources of eolian sand (from alluvial washes and fans) have created local deposits during current times and the past. In addition, this study performed a regional evaluation that more accurately mapped the proposed regional sand migration corridors, compiled published data from a wide field of studies to determine the current state of activity and/or stability of the regional sand migration corridors.

Figure 3: Proposed regional sand migration corridors in the southeastern California region by Muhs et al. (2003). Note that this map implies that eolian sands are migrating great distances along the proposed sand migration corridors suggesting that local eolian sand sources along their mapped lengths contribute relatively minor eolian sands.



4.2 Current and past geologic conditions of local dune system via an onsite geomorphic, geologic, and soil stratigraphic field investigation (mapping)

Geomorphic mapping, which is the evaluation of types of processes and deposits that occur at the surface, and the evaluation of relative ages of the near surface sediments via soil profile stratigraphy was conducted during this study. Geomorphic and soil stratigraphic mapping included the evaluation and documentation of 320 "geomorphic sites" where the local geomorphology and stratigraphy was evaluated and documented and including a GPS latitude and longitude location via a Garmin GPSmap 60Cx. The 320 geomorphic sites include 149 for the KGS Southern California Edison facility eolian report (Kenney, 2010d) located west to southwest of the DQSP, and 171 from this study. These geomorphic sites occur within and outside of the

DQSP project boundary, extending westward to near Wiley's Well Road. Geomorphic field sites qualitatively documenting current geomorphic and vegetation densities were conducted from 2010 to 2016 and at various times of the year. Field work was conducted during or soon after strong wind storms exhibiting variations in local prevailing winds, soon after a bloom of invasive Sahara Mustard, after prolonged cool Pacific storm rains, and after summer monsoonal storm flooding events that infiltrated the dunes.

In addition, geomorphic and geologic data was also utilized for this report from numerous other KGS eolian projects in the Chuckwalla Valley that include the Genesis (Kenney, 2010a and 2013), Palen (Kenney, 2010b) and Desert Sunlight (Kenney, 2010c) solar projects, and the Southern California Edison – Colorado River Substation (Kenney, 2010d and 2010e; Plate 2 and Plate 3A).

4.3 Geologic history of the project area since the Early Pliocene

Review of existing scientific literature including published geologic and eolian maps (i.e. Stone, 2006; Lancaster, 2014), and geologic mapping during the project allowed for an assessment of the geologic history of the site since the early Pliocene (i.e. ~4.5 million years ago). Regional stratigraphic reports for older formational units (Pliocene) exposed in the study area were utilized that described and regionally mapped Pliocene age sediments associated with the ancient Colorado River in the Chuckwalla Valley (Metzger et al., 1973; House et al., 2008; Spencer et al., 2008, Fenton and Pelletier, 2013, and Howard et al., 2015).

The analysis of these studies and their incorporation into the mapping and evaluation for this study assisted in understanding both the long term geologic history of the study area, and potential sediment sources for the local dune and alluvial systems. In addition, some of the publications provided stratigraphic-formational numerical ages for some of the ancient Colorado River deposits in the Chuckwalla Valley that clearly occurred prior to the development of the local dune systems.

4.4 Long-term behavior of desert geologic processes – pluvial and playa lakes, alluvial fans, eolian systems, climate changes via scientific publications

The dynamic nature, development and sustainability of eolian dune systems is closely associated with many geologic and climatic processes occurring both locally and regionally. Hence, dune development and long term behavior is directly connected to many parameters occurring outside their actual areas of deposition.

Pluvial and playa lakes are considered a primary source for eolian sands worldwide, and many reports provided in the references (Appendix A) substantiate this. Eolian sands emanate from pluvial and playa lakes soon after the desiccate allowing for sand bearing wind abrasion to erode the lake surfaces and provide pathways for sand transport. This study evaluated publications regarding the timing of pluvial and playa lake filling and receding periods in the southeastern California region to look for correlations with eolian dune aggradational and stability events.

Numerous secondary factors also effect dune development as well. Some of these include the timing of alluvial fan aggradational events and fan-trenching (down cutting) that are considered periods of time herein when eolian dune systems also undergo aggradational events. During times of alluvial fan aggradational events, washes typically flow with increased relative frequency and magnitude. It is evident that washes are one of the largest contributors of eolian sands in desert landscapes. In turn, these analyses led to the evaluation of the relative importance of periods of time of increased frequency and magnitude of cool and moist Pacific Northwest storms, and warm and moist monsoonal storms that represent local extreme storm events. The analysis shows that alluvial fans and eolian systems both experience aggradational events during periods of relatively more frequent and strong extreme monsoonal storm events and relatively weaker longer duration Pacific Storms. This has been the general case for the southeastern California region during the Holocene, but the data also indicates that the climate is near a critical geomorphic threshold point where a slight variation in the relative strength and frequency of Pacific verses monsoonal storm events can trigger increased or decreased alluvial and eolian activity.

4.5 Drainage surface waters flow analysis – Eolian sand sources and dune stability

Not only does surface flow water, from washes and into basins (pluvial lakes, playa lakes, and ponding areas), provide surface instabilities that lead to increased eolian sand supply, but surface flow waters also provide critical stabilizing moisture to dune systems. Sand dunes often develop in areas not only because there is a sufficient eolian sand source, but also because there is sufficient infiltrating moisture to allow for the internal core of the dunes to remain moist which greatly decreases the potential for sand bearing wind abrasion (Kenney, 2012). In addition, dunes that remain moist also have a higher likelihood of becoming stabilized via vegetation.

The evaluation of surface water flow is also critically important regarding the size of the watersheds for local wash systems. Larger water shed drainage systems have a higher probability of experiencing sufficient flow strength to reach valley axis regions. This report provides evidence showing that there is a general correlation with the size of the local watershed and the amount of eolian sands that emanate from that wash at the local base level area.

Hence, although dune systems may be considered "dry" systems, in fact, it is the moisture regime in the area that plays a very critical role in their development. This is the case not only for eolian sand sources, but also dune stability. This was shown to be the case for the Keeler Dunes in the eastern Owens Lake region where water flow across a medial to distal portion of the alluvial fan was diverted by flood control berms for over 50 years away from the downslope playa edge dune system causing the dunes to deeply abrade by sand bearing winds (Kenney, 2012).

The drainage analysis is also very important because as identified in this report, typical distributary drainage systems developing on active alluvial fans flow infrequently in distal fan areas, and therefore do not provide significant eolian sand to valley axis systems. However, it is proposed herein that tributary drainages systems that represent additive flow from many upslope contributing drainages tend to flow more frequently and stronger in addition to typically providing a relatively wide braided flow area downslope, contributing significantly more eolian sands than their distributary counterparts.

4.6 Comparison of local and regional dune systems

Regional dune systems across southeastern California were evaluated both via existing publications and extensive aerial mapping via Historical imagery provided on Google Earth Pro. Some areas in the Chuckwalla Valley had previously been mapped by the author for other projects. This analysis provided a framework in which to compare regional verses local sand systems, such as general trends of the regional dunes in terms of when they developed, had aggradational events, their relative eolian sand sources, and when they became stabilized, among others characteristics. This analysis also provided supportive evidence regarding the relative importance of various eolian sand sources and identified some previously undocumented eolian sand sources. The evaluation of regional dune systems also identified some dunes areas that had not been previously mapped based on the literature reviewed in this study (i.e. the East Pinto Basin Dunes; Plate 2; Appendix A). The regional mapping of dune systems across southeastern California provided supportive evidence that the proposed regional sand migration corridors are essentially shut down during the late Holocene and were more active-robust during the early to mid-Holocene. In addition, it provided evidence that local eolian sand sources for the proposed regional sand migration corridors are the dominant eolian sand source for portions of the sand migration corridors that are relatively more active in the late Holocene than other areas.

4.7 Potential impacts and future changes to the local dune system associated with the proposed development, climate change and historical anthropogenic activities

The geomorphic and soil stratigraphic mapping conducted in this study provide data to assist in evaluating potential impacts to existing dune systems associated with the footprint of the proposed development. However, with future climate change, the question arises regarding how the dunes may change over time and if the dunes may grow beyond their current aerial extent. However, the development of dune systems as a function of climate had to this time not been fully evaluated and is poorly understood. Dune systems across the study region of southeastern California did experience a growth period at the end of the last ice age when pluvial and playa lakes desiccated, but this does not explain intermittent dune development in the region extending through the mid-Holocene.

The review of climate related publications allowed for a better understanding of the relationship of what leads to dune system activity and stability. Namely, this review allowed for an assessment of the effect of the increase in magnitude and frequency of cool-moist Pacific Storms and warm-moist monsoonal storms on regional dune development since the latest Pleistocene. This question is addressed in this report and provides insights regarding potential changes in dune systems associated with global warming in the decades to come.

Historical anthropogenic factors associated with changes to the surface of the earth (i.e. flood control berms, borrow pits, etc.) that potentially could affect local dune systems were also evaluated. This analysis is important primarily due to the understanding of the importance of surface water flow for eolian sand sources and stabilizing moisture.

5.0 DUNE DEVELOPMENT AND STABILITY PARAMETERS

5.1 Prevailing wind directions

The prevailing wind direction is considered the direction in which wind has sufficient energy to cause both soil erosion and sand transport. One method to analyze annual wind data to determine potential sand entrainment and migration direction is the evaluation of the Resultant Drift Potential (RDD). Tsoar, (2004) indicates that a better index for wind erosion is the drift potential (DP) of the wind.

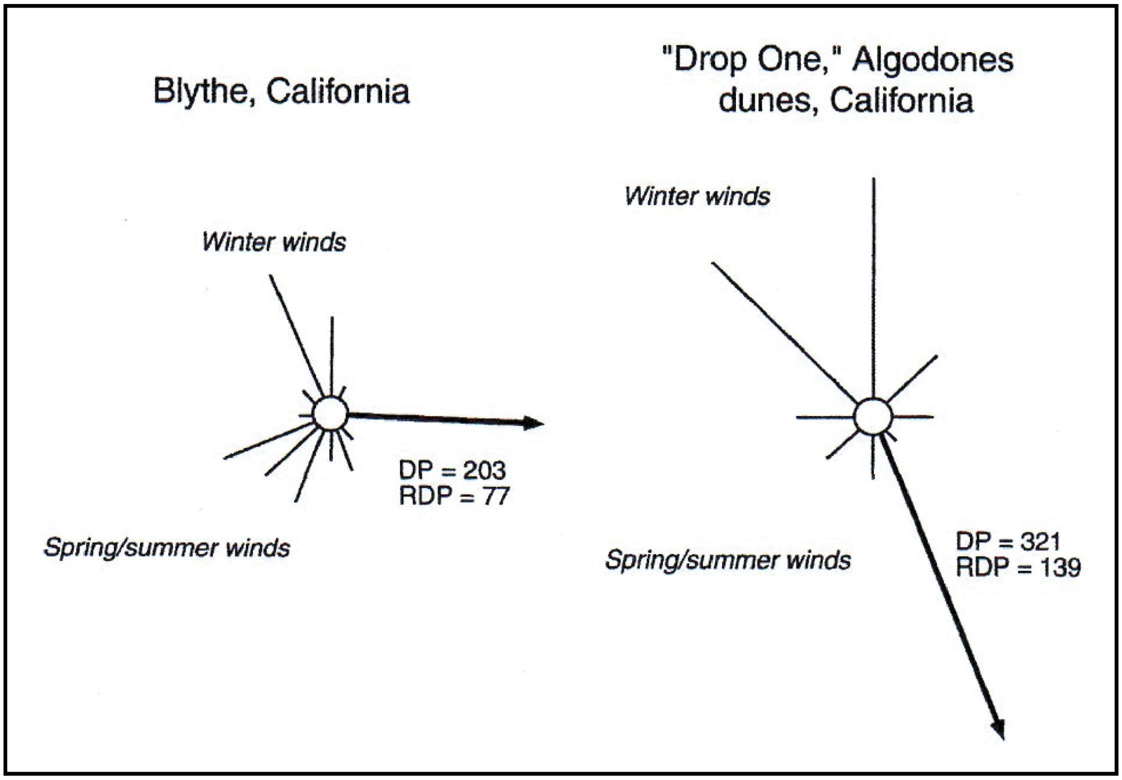
The Drift Potential (DP) = $\sum \boldsymbol{q} = \mathbf{U}^2(\mathbf{U}-\mathbf{U_t})/100 * \mathbf{t}$

U is the wind velocity (in knots), measured at a height of 10 m, $\mathbf{U_t}$ is the threshold wind velocity (=12 knots), and **t** is equal to the degree of "windiness" expressed as the annual percentage of days experiencing winds above the threshold velocity for sand movement. Essentially, **t** is the time the wind blew above the threshold velocity in percent. Dividing from 100 is for reducing the result to a smaller number (Tsoar, 2004).

q is calculated separately for each wind direction which is experiencing wind above the threshold velocity ($\mathbf{U_t}$) and its value is know as a vector unit. All vector units from all the wind directions form a sand rose diagram. DP, the total annual q for all wind directions, is a parameter of the potential maximum amount of sand that could be eroded by the wind during a year for all wind directions. Hence, DP is a measure of the potential wind power in a sandy area (Tsoar, 2004). The vector units from different directions can be resolved into a single resultant known as the resultant drift potential (RDP; Tsoar, 2004).

This method requires temporal velocity wind data from throughout the year measuring how fast the wind moved and for how long. To determine the RDD, the Drift Potential (DP) vector for each wind that occurred during the year exceeding the threshold wind velocity (~12 knots or ~14 mph) is evaluated; the DP vector is proportional to the length of time the wind blew greater than the threshold wind velocity (Tsoar, 2004). Thus, an individual DP value and vector is determined for each wind direction that blew greater than the wind threshold velocity. The DP values are proportional to how much stronger it was relative to the threshold wind velocity and how long it blew at those speeds. Adding all the DP vector unit values provides a resulting vector called the Resultant Drift Potential (RDP). The RDP vector provides a measure of the primary direction of sand transport if there is one. Adding up all the DP values provides a parameter of the potential maximum amount of sand that could be eroded by the wind during a year for all wind directions (Tsoar, 2004).

Figure 4: Resultant Drift Potential (RDP) Data from Blythe and the Algodones regions from Muhs et al. (2003). The Algodones dune field is located at the south end of the Salton Trough. These data indicate that the Pacific Cell winter weather fronts in combination with topographic (mountains and valleys) dominate the orientation of the RDP.



Annual and seasonal wind rose diagrams data from Blythe (ASOS data), which is located approximately 35 miles east of the Project site at the eastern most end of the Chuckwalla Valley near Blythe (Plate 1), indicate two dominant wind directions during typical years. During the Spring and Summer months, the strongest winds are from the south associated with monsoonal storm events. During the Fall and Winter, the strongest winds are from the north-north west associated with Pacific Ocean derived weather fronts. Determining the primary wind direction responsible for sand migration can be evaluated by geomorphic mapping of dune types, orientations, and locations, which is described later in the report, and by determining the RDP from appropriate wind data (Toar, 2004).

Muhs, et. al. (1995) determined the RDP for the Chuckwalla Valley to Blythe region for wind data collected at the Blythe Airport. Muhs, et. al., (1995) determined a RDP for the Blythe Airport that points nearly due east, parallel to the Chuckwalla Valley (left diagram) and for the Algondones dunes in the Imperial Valley region (Salton Trough) of southern California (Figure 4).

It can be seen in Figure 4 that the RDP, and thus the primary direction of migrating sand, is from the west for the Blythe area. This indicates that the Pacific Cell winter storms provide the dominant wind systems in terms of long term sand migration in the region. In addition, the nearly due east resultant vector RDP for the

Blythe airport located near the eastern outlet of the Chuckwalla Valley (Palo Verde Mesa) is very consistent with geomorphic field mapping data in the region regarding the dominant direction of migrating sand (including long term field indicators such as ventifacts and dune alignment) in the Chuckwalla Valley axis corridor. However, it is also evident based on seasonal switching of avalanche face directions, and complex dune forms observed in the region in both Winter and early Fall, that the southwesterly winds play an important role on local dune morphology. This was also observed to be the case in the dune field within Palen Dry Lake during KGS mapping in October 9, 2010

Although wind data for areas of the region indicate that strong summer monsoonal winds from the south occur, they apparently do not play a large role in terms of large long term sand transport in the region of the Project. This is also the case for other dune systems throughout southern California including the Mojave Desert (Muhs, et al., 2003; Lancaster and Tchakerian, 2003). Geomorphic evidence for this is provided by the form of the dunes. For example, well developed transverse dunes (some of which are barchan) within Palen Dry Lake clearly indicate that the dominant wind transporting directions responsible for the majority of eolian sand transport ranges from the north-northwest to northwest within the Chuckwalla Valley. In addition, a discussion with Cal-Trans workers responsible for removing sand from the Wiley Well rest area (Plate 4) near the east end of Ford Dry Lake indicated that without question the vast majority of sand moved from the north down the Palen Pass associated with winter and early spring wind events and not from the south. One of the two Cal-Trans employees had been performing the sand clean up at Wiley Well rest area for over ten years.

Additional evidence that two prevailing wind directions (SW and W) are significant in the Chuckwalla Valley is provided by work conducted by Tsoar (2004). His work indicates that vegetation densities on dunes increase when the area experiences competing prevailing wind directions. Tsoar (2004) identified that vegetated dunes and unvegetated dune occurrences could be explained via the relationship of dividing the resultant drift potential by the drift potential (RDP/DP). The RDP/DP provides a measure of the variability of the wind where values close to one indicate a narrow unidirectional drift potential, and values close to zero indicate a wide multidirectional drift potential. Tsoar (2004) indicates based on utilizing data from 43 sand dunes sites from all over the world, that unvegetated dunes exhibit a high RDP/DP (they may nearly equal each other) due to most wind power being exerted on the same dune faces, and vegetated dunes exhibit low RDP/DP (RDP << DP) exhibit wind power exerted on multiple dune faces allowing the vegetation a better opportunity to grow.

In other words, when there are competing prevailing winds, vegetation has a higher likelihood of establishment on the dunes, thus causing them to become more stabilized. Dune systems in the Chuckwalla Valley support this finding. In the central Palen Dry Lake area exhibiting mobile barchan dunes, a dominantly west prevailing wind is evident based on field mapping in the area at various times of the year. However, the dunes in the eastern Palen Lake area are much more stabilized and this region exhibits "prevailing winds" from both the west and from the north-northwest where the East Palen Lake and Palen Lake sand migration zones merge. In the eastern Chuckwalla Valley near and within the DQSP site, the linear dunes are very stabilized via vegetation where there is clear geomorphic evidence from field mapping of competing prevailing winds that also support the development of linear dunes.

5.2 Geologic history – Placing dune development in context

It is important to understand the geologic history not only of the dune system itself, but also of the area bounding the dunes. Understanding the geologic history allows for the understanding of what occurred in the area prior to the development of the dunes which leads to understanding when the dunes began to be deposited in the area. For example, in the study area, the evaluation of the alluvial fan stratigraphy utilizing soil profiles (i.e. S0 through S7) that bound the DQSP dune system allowed for the correlation of some of these deposits occurring beneath the dunes, which indicates that the local dunes must have begun their development after deposition of the underlying alluvial deposits. Hence, the creation of the local soil stratigraphic section with estimated minimum soil ages allows for an age estimate of the time in which the dunes encroached into the area (see next section).

Local mapping of older formational units such as those associated with the ancient Colorado River system when it had encroached (inundated) into Chuckwalla Valley and across the Palo Verde Mesa area provides insights regarding the age and rates of geologic processes in the area. For example, ancient Colorado River deposits estimated to be early Pliocene in age occur either at the surface or within 1 to 6 feet of the surface across most of the DQSP area. This indicates that geologic depositional rates have been remarkably slow for well over 3 million years and that the area is Geomorphically stable. Knowledge of the exposure area of these units as well provides insights regarding their contribution to eolian dune and alluvial systems as a sediment source.

5.3 Surface and near surface soil and sedimentary stratigraphic evaluation

An "area specific" stratigraphic section needs to be developed for dune studies of the dune and alluvial deposits to provide a temporal and special context for the local deposits. This can be conducted by the construction of a soil profile stratigraphic section that consists of various soil profiles and their associated age of development, in addition to identifying the parent materials of the sediments prior to the development of the soil profile.

5.3.1 Local Formational stratigraphic section

Designated Formational depositional units typically comprise those that are named and described in published geologic maps and reports which extend over a regional area. Hence, the formational units typically occur not only within the study area, but also regionally which is generally the criteria to justify the formal "formational" name. For dune studies, the identification of formations such as the early Pliocene, Bullhead Alluvium, is important as it provides a structural-stratigraphic marker where exposed across the eastern Chuckwalla Valley, but also because it provided a relatively strong eolian sand source upon erosion along the flanks of the local mountain ranges.

Formational units identified in the study area have been assigned various names although some are the same geologic depositional unit. In addition, mapping during this study identified new exposures of some regionally mapped formational units which assists in understanding the local geologic history.

5.3.2 Subdivide Quaternary Alluvium (Qal) and Quaternary Older Alluvium (Qoaf) utilizing surface and near surface (buried) soil profile stratigraphy

On most published geologic maps, alluvium is quite often simply subdivided into younger versus older alluvial units of Quaternary age (i.e. past 2.6 million years). Consequently, a few members of the relatively younger Quaternary Alluvium (Qal) and relatively older Quaternary Older Alluvium Fan (Qoaf) are identified, which are too poorly defined to be useful for eolian dune studies. Hence, a local alluvial stratigraphic section typically needs to be constructed specifically for a project such as the DQSP. Because many dune studies are most interested in the relatively recent geologic past (Holocene), it is prudent to identify numerous alluvial soil stratigraphic members that developed since the latest Pleistocene. This is important to understand when the dune encroached into the region, which is accomplished by evaluating minimum soil ages for the various alluvial deposits. This can usually be accomplished because alluvial fans have been depositing somewhat consistently since the latest Pleistocene across southeastern California, and particularly in distal fan areas. This is not the case necessarily for older alluvial deposits where a hiatus of alluvial fan deposition occurs between approximately 45 kya to the latest Pleistocene across much of southeastern California. This hiatus of deposition is observed at the site by examining the estimated minimum soil ages of Soil S4 of >35 kya and the next younger Soil S3b estimated to be ~12 to 8 kya (Figure 7A).

Alluvial deposits can be subdivided in most cases based on the evaluation of alluvial terraces that exhibit particular soil profiles (soil horizons). In this way, a stratigraphic section of alluvial deposits can be developed based on the age of the soil and its stratigraphic position. The characteristics of each designated soil profile (i.e. S1, S2, S3a, S3b, S4, etc) are described in places where that soil occurs at the surface and has not been buried. In this way it maximizes the development of that soil. However, during the study, these designated soil profiles are typically identified buried beneath younger soils. This is a powerful tool for the evaluation of alluvial fans and dune systems.

5.3.3 Alluvial vs. eolian soil parent materials (Original depositional environment)

Soil profiles develop when deposits are exposed to the surface of the earth and secondary soil processes occur such as development of soil horizons (A, B and C). Hence, designated soil profiles (i.e. S1, S2, S3a, etc.) developed in whatever sediments were exposed on the surface of the earth whether it was alluvial or eolian. The origin of the original sediments in which a soil profile develops is referred to as the “parent materials”. It is important to determine what the parent material is during stratigraphic mapping of an area because it allows for the evaluation regarding where older eolian verses alluvial deposits occur. For example, if a S1 surface soil estimated to have a minimum age of 5,000 to 3,000 years old (age of the surface) developed in eolian deposits and adjacent alluvial deposits, then this indicates that the alluvial and dune depositional contact has been stable for the past 5 to 3 kya (kya = 1000 years) in that area. In other words, it shows strong evidence that approximately 5 to 3 thousand years ago that active eolian sands were depositing adjacent to active alluvial systems but that this system became dominantly inactive since that time (stable). As discussed in later sections, this is exactly what has been identified in the DQSP area.

5.3.4 Sediment source evaluation

It can be important to evaluate the source of the parent material in alluvial deposits as well. For example, on the Palo Verde Mesa region, the soil profiles (secondary soil properties) were relatively juvenile (young) relative to the ubiquitous pinkish red color that the sediments exhibited. Typically, soils exhibiting pinkish reddish colors are generally interpreted as being older as the reddish hues are assumed to develop over time. However, it is likely that the near surface alluvial deposits across the Palo Verde Mesa area exhibited a reddish hue at the time of their deposition because the parent sediments themselves were slightly reddish in color. The source for the pinkish red parent soil sediments was identified as the Bullhead Alluvium that had eroded along the flanks of the local mountain ranges (McCoy and Mule mountains).

5.4 Geomorphic evaluation during field mapping (Surface mapping)

A Geomorphic evaluation is one that involves identifying geologic features on the surface of the Earth that indicate the genesis of that environment and for dune deposits, the relative activity-stability of the dune areas.

5.4.1 Fluvial vs. eolian Geomorphology (qualitative)

Mapping for an eolian dune study requires identifying specific areas that are dominated by fluvial or eolian geomorphic features. This can simply be done qualitatively by estimating in the field or aerial photographs if a region exhibits predominantly fluvial or eolian characteristics. For example, bar and swale topography indicates that washes (fluvial processes) dominant an area. In contrast, a hummocky, non-draining region exhibiting internal basins (interdune basins) indicate that the landscape is dominated by eolian processes and/or older dune deposits. These data provide important criteria for mapping the contacts between eolian vs. alluvial depositional areas (i.e. the extent of dune deposits). Hence, dune systems are quite complex and bounding areas of relatively thicker dune deposits typically exhibit a gradual change from an eolian dominated area to a fluvial dominated area. To add to the complexities, in some areas of relatively “active” and robust dune systems, surface hydrology such as on occasional ponding in playa lakes and ponding areas in addition to infiltrating washes occur that are critical in providing eolian sand source and stabilizing moisture.

5.4.2 Evaluation of the extent and type of active vs. eroding-stabilized dunes (qualitative)

Within dune systems, an assessment (either quantitative or qualitative) of the relative activity of the dunes needs to be determined. For example, are older dune sands eroding and providing an internal eolian sand source for downwind dunes? What is the type of active eolian sands migrating within the system – new eolian deposits compared to possibly older dune forms that once were active and are now eroding? Answers to these questions provide very important information regarding the current “health” of the dunes and about the history of the dunes. For example, if the only active eolian sands (migrating via the wind) are sand sheets and small coppice dunes, and relatively larger dune mounds or linear dunes are eroding away and degrading, then this indicates that the dune system was more robust in the past than it is today. This is the case for most dune systems across the southeastern California region. These criteria are described later in this report utilizing the Geomorphic Unit Designations. In this study, a qualitative assessment of the extent and type of active vs. eroding-stabilized dunes was conducted.

5.4.3 Relative sand migration zone rates (qualitative)

In dune systems, sand migration rates vary considerably. This is evident by the types of active eolian sands (i.e. sand sheets, coppice, dune mounds, linear dunes, transverse dunes, etc.) that occur in an area, and of course, sand migration rates decrease remarkably near the edges of the dune system. Evaluating dunes systems utilizing relative sand migration zone rate designations based on dune geomorphology and types of active dune forms is very useful in that it provides data that can be mapped allowing for a relatively quick assessment within a dune system regarding where the fastest and slowest sand migration zones occur. Combining the relative sand migration rate zones with the Geomorphic Unit Designations indicating which areas are active, stable or eroding provides a system where once mapped, the geomorphology of an area can be more readily interpreted and assessed.

5.4.4 Local topography across eolian dune systems

An evaluation of the local topography and even subtle variations in topographic relief results in variations in wind speed which leads to areas of relatively increased or decreased eolian deposition and/or erosion of older dune deposits (abrasion). For example, if the wind is forced to rise as it encounters an upward slope, it can increase in velocity which increases its potential to carry more eolian sand and its ability to erode previously deposited “relict” dunes; however, as the wind moves over the topographic high, the wind speed will lower, which decreases its ability to transport eolian sands leading potentially to an increase in eolian deposition on the leeward site. As shown in this study at the topographic sill associated with the eastern termination of Chuckwalla Valley and the western boundary of the Palo Verde Mesa, a subtle topographic rise has affected the depositional areas and lateral extent of the relatively weak eolian dune systems.

5.5 Eolian sand sources

The evaluation of eolian sand sources was a large component to this study. Sand dunes have had a sense of mystery about them regarding why they occur in some places, and not in others, or why some dune systems appear to be more robust than would likely seem to be the case. Some of this mystery however is answered by more fully investigating eolian sand sources and combining that with established (documented) eolian sand sources. In terms of “dune mitigation and conservation”, it is critical to understand the origin of the eolian sands and particularly whether the sand was derived from near-field source (local) or far-field sources (regional). Over the course of the Holocene, it is likely that eolian sands within a dune system are both from near-field and potential relative far-field sources. Indeed, Pease and Tchakerian (2003) indicate that eolian sand sources can vary between fluvial and playa sources, but also suggest that these sources were “local”. Ramsey et al. (1999) evaluating the Kelso Dunes indicate that eolian sands derived from local and far-field sources fluctuated over time and both played an important role during the development of the large Kelso Dune system. Based on the findings of this report, it is likely that most newly generated eolian sands (late Holocene) across most of southeastern California are dominantly generated from local sources and particularly in the DQSP.

5.5.1 Washes

Washes that flow from the desert mountains to local base level along the valley axis provide a significant source for eolian sands. Numerous publications indicate that washes are a very important if not dominant source of eolian sands in the southeastern California region (Lancaster, 1997; Muhs et al., 2003; Pease and Tchakerian, 2003). Washes are also important as they transport sand to pluvial, playa lakes and ponding areas. Blackwelder (1931) indicated that playa lake beds in the southwestern United States are a strong eolian sand source due to his observation of deep abrasion across their surfaces.

Drainage system flow transports eroded eolian size sand grains to a region where the sands can be picked up by the topographically controlled prevailing winds commonly occurring within the valley axis. It is easily observed in the field, that fresh eolian sands emanate from a wash soon after it flows once a sufficiently strong wind is available to mobilize the sand. This is observed not only for relatively large washes that are hundreds of feet across but also washes as small as 3 feet across and less than one foot bar and swale (or terrace) relief. Within hours to a couple of days of strong winds occurring after a flow, a surface capping layer of gravel size clasts develop on the surface. Once the capping protective layer forms, eolian sand production from the wash via entrainment by the wind dramatically decreases. Hence, washes that flow more often will produce more eolian sands, and washes associated with larger drainage areas (watershed aerial extent) tend to flow more frequently to the valley axis than smaller ones. In contrast to washes that primarily produce eolian sand soon after flow, pluvial and playa lake beds can continue to abrade resulting in ongoing eolian sand production for years once dry, or the abrasion continues until moist sediments are exposed.

There are numerous parameters regarding how much eolian sand washes will produce. Important eolian sand generating parameters to consider regarding drainage systems is their local relief (bar and swale), its style of flow (tributary vs. distributary), size of their water shed, its orientation to prevailing winds, and volume of eolian size grains being transported due to upstream erosion of older sandy deposits (i.e. older alluvium, ancient Colorado River or older fan deposits). Relatively low bar and swale relief between the wash and channel wall elevation allows stream wash derived eolian sands to migrate outside of the wash system.

Distributary drainage systems associated with active alluvial fan areas generally do not result in relatively strong eolian sand generation. In addition, distributary drainage systems occurring in the distal portion of the fan do not flow frequently as the channel flow continues to decrease as the channels bifurcate. Tributary drainage systems where flow is progressively concentrated downslope from the merging of upslope washes (either from tributary or distributary systems) can produce relatively large volumes of sediment that can produce eolian sand, particularly when they reach the valley axis. Tributary drainages systems due to concentrating flow from a large area flow more frequently and with larger water volumes. This allows these robust washes the ability to reach the valley axis more often resulting in more abundant eolian sand production. In addition, if the tributary flow near the valley axis consists of a braided wash system with relatively low bar and swale relief, it results in relatively strong eolian sand generation. The orientation of washes is also important. Wash systems that flow sub-parallel to the prevailing wind direction and/or in the region of the valley axis are observed to produce more eolian sands than washes that flow perpendicular to the prevailing wind.

5.5.2 Granitic rocks in the mountains

Granitic rocks erode mechanically to "decomposed granite" which are predominantly sand size grains. Hence, when granitic rocks erode, they generally produce a relatively large component of eolian size sand grains to be potentially transported by local washes. Numerous publications indicate or suggest the importance of granitic rocks as a source for eolian sands in southeastern California (Ramsey et al., 1999; Zimbelman and Williams, 2002; Pease and Tchakerian, 2003). It is observed that dune systems across southeastern California that occur downstream from abundant granitic rocks are generally more robust than would be the case if the granitic rocks did not occur. Granitic rocks are exposed throughout the study area and typically, relatively robust eolian systems do occur in valleys and sand ramps (passes) adjacent to mountains exhibiting large exposures of granitic rocks (Plate 1 and Plate 2). The granitic rocks shown on Plates 1 and 2 are considered relatively significant local sources for eolian sands for valley dune systems.

5.5.3 Playa and pluvial lakes

Playa and pluvial lakes are lacustrine areas considered to possibly be the most important source of eolian sands for dune systems across southeastern California, or it may be that strong eolian aggradational events or re-activation periods simply correlate with when pluvial lakes dry up and their contribution to eolian systems may be approximately equal with that of washes. Pluvial lakes are those that filled with water and remain relatively full for thousands of years during the major glaciation events. Playa lakes, or also referred to as "dry lakes" are basins that are believed to have not filled up for thousands of years during glaciation periods but did fill and recede regularly during those times. Pluvial lakes provide eolian sands during the relatively warmer inter-glacial periods when they have dried up but oddly, also result in robust eolian production during times of intermittent fluctuating lake levels as discussed later. Numerous publications indicate that lacustrine surfaces are an important source of eolian sands or simply surfaces that can erode by abrasion suggesting an eolian source via the production of dust storms (Blackwelder, 1909; Ward and Greeley, 1984; Tchakerian, 1991; Gill and Cahill, 1992; Zimbelman, et al., 1995; Cahill, et al., 1996; Gill, 1996; Lancaster, 1997; Lancaster and Tchakerian, 1996; Rendell and Sheffer, 1996; Pease and Tchakerian, 2003; Orme, 2004; Reynolds et al., 2009; Whitney et al., 2015). The studies provide very strong evidence that lacustrine environments (playas and pluvial lake beds) provide large magnitudes of eolian sand for dune systems on the lake beds and downwind.

Many moderate to major dune systems in southeastern California emanate from relatively large lake basins exhibiting pluvial and playa lake areas. These include Lake Manix (pluvial lake for Coyote, Troy and Afton basins/lakes), Lake Mojave (pluvial lake Soda and Silver lake basins), Salt, Bristal, Cadiz, Danby, Dale, Palen and Ford dry lakes (Plate 1). Bristal, Cadiz and Danby lakes (basins) may have experienced lake levels for sufficiently long enough periods of time during glacial maximums to be considered pluvial lakes (Enzel et al., 2003). Lake Manix is interesting in that it was a "pluvial lake" up until approximately 19 kya (Miller, 2005) when it may have drained relatively quickly through Afton Canyon, but did fill to lower levels periodically as sub-lakes (including Soda Lake) up to about 13 kya. However, Enzel et al. (2003) and Wells et al. (2003) believe that Afton Canyon eroded via time transgressive incision lasting over a few thousands of years, but indicate that this is also a geologically rapid event. Lake Manix was part of a pluvial lake system including Silver Lake and Soda Lake appears to have dried up by approximately 13 kya (Plate 1).

Lake Manix is believed to have fed the Silver and Soda lake basins sufficiently to result in the development of the pluvial Lake Mojave (Enzel et al, 2003; Wells et al., 2003). The data indicates periods of intermittent lake levels where Lake Mojave filled and receded numerous times for more than several thousand years and periods of time where the lake remained relatively full. These are important data for the evaluation of eolian systems because as discussed in Kenney (2012) and Schaaf and Kenney (2016), dune systems immediately just outside the playa area receive a "pulse" of new eolian sands soon after lake levels recede, such as in the case of Keeler Dunes at Owens Lake, California. This is because soon after lake levels drop, the lake bed is fully exposed allowing for high wind-blown sand mobility (low vegetation) and the recent lacustrine deposits are also easily mobilized. In addition, washes flowing over the newly exposed lacustrine deposits produce more eolian sands compared to them flowing on a lake surface that had been exposed for longer periods of time. Eolian systems adjacent and downwind from playa and pluvial lakes receive an order of magnitude more eolian sand during times when the lakes are "intermittent" with multiple rising and falling water levels compared to more stable lake level. For example, it is proposed that this is the case for Kelso Dune aggradational events that correlate temporally with the intermittent lake levels documented for Lake Mojave by Enzel et al, (2003; Plate 8A, Plate 8B and Plate 8C).

Playa lake beds, like pluvial lake beds, as a source of eolian sand are complex as some are considered wet, and others dry, which plays a role in the type and magnitude of eolian sands emanating from their surfaces (see Reynolds et al., 2007). Dune systems can form downwind from salt-pan surfaces associated with "wet" playa and pluvial lakes that result in the development of clay and lunette dunes as described by Bowler (1973) and Thomas et al. (1993) respectively. Groundwater levels across the lakebed surface is also a critical factor. Sand bearing wind abrasion of lakebed sediments will occur rapidly but will decrease in rate exponentially once the abrasion depth reaches moist sediments. Other factors include the composition of the lakebed sediments, for example, their relative factions of clay, silt and sand and of course, variations of wind speeds across the lake bed surfaces.

It is important to point out that two playa lakes (Ford and Palen) and ponding areas (Wiley's Well Basin and the Palowalla ponding area) occur in the Chuckwalla Valley that produce their own eolian sand source locally when they fill and dry periodically. These areas also receive new eolian sand-sized sediment from local washes in the sense that more eolian sand is generated in regions of the playas where wash systems flow onto the playa that both transport new sand to the playa and the washes themselves generate fluvially derived eolian sands. These are Palen and Ford dry lakes in the western and eastern Chuckwalla Valley respectively. As a side note, it has been observed by the author in the Chuckwalla Valley, that relatively heavy rain landing on playa surfaces are sufficient to cause minor wash flow on the subtle drainage system on the lakes and result in the production of new eolian sands once sufficiently strong winds occur. For cool Pacific storms, strong but dry prevailing winds commonly occur within a week after the passing of the storm. Heavier flooding and associated erosion from warmer dry-season summer monsoonal storms disturb playa surfaces and erode into existing playa lake bed dunes providing new eolian sands to be mobilized during the next prevailing wind.

5.5.4 Ponding areas

Ponding areas and playa lakes described above are similar in that they are areas that flood and dry out relatively frequently. The only difference and defined herein, is that "ponding areas" are not sufficiently large enough to be mapped as a playa lake bed. The term "ponding areas" is utilized herein because these smaller scale "lake beds" are locally significant for dune systems but can be overlooked as an area behaving as a playa surface. For example, most of the eolian sands in the eastern Chuckwalla Valley and Palo Verde Mesa are derived from local ponding areas and their associated washes. These include the Wiley's Well Basin west of the site (Plate 4), the Palowalla Wash ponding area immediately west of the Blythe 21 solar facility (Figure 12), and a ponding area in the southwestern region of the site.

5.5.5 Washes and Alluvial fan aggradational events

Based on the review of alluvial fan aggradational events in southeastern California since the late Pleistocene (discussed later in the report), it is evident that eolian systems receive more eolian sand during relatively strong alluvial fan aggradational events. Hence, there is a positive correlation with alluvial fan and eolian dune system deposition (See Plate 8A, Plate 8B and Plate 8C). Publications such as Harvey et al. (1999) and Miller et al. (2010) indicate that alluvial fan aggradational events occurred during periods of time when cool/wet Pacific storm systems subsided and warm Monsoonal (thunderstorm) storm frequency of events increased across the southwestern United States. Leeder et al. (1998) identified that alluvial fans in the southwestern United States received reduced sediment supply, despite increased runoff (i.e. precipitation) evident from local lake (lacustrine) levels. They indicate that these periods of times occurred during glacial maximum climates and were characterized by higher effective moisture (presumably from Pacific storm systems) and the spread of woods and forests to lower elevations. Hence, the findings by Leeder et al. (1998) indicate that alluvial fans likely did not undergo aggradational events during times of stronger Pacific Storm systems. Therefore, alluvial fans likely aggraded under different climatic conditions, which occurred during periods of increased monsoonal storm activity.

It is proposed that similar conditions for alluvial fan aggradational events proposed by Harvey et al. (1999) and Miller et al. (2010) also lead to eolian aggradational and re-activation events.

5.5.6 Alluvial fan trenching (down-cutting)

Lancaster (1997) observed that eolian systems may be closely tied to geomorphic instability and channel cutting. This led to the evaluation of the timing of alluvial fan trenching in the upper reaches of alluvial fans across southeastern California and that may correlate with eolian aggradational or re-activation events due to an increase in eolian sand generation. The results of this analysis are consistent with that of Lancaster (1997) indicating that channel cutting (alluvial fan trenching) is an important parameter in re-activation and/or small dune aggradational events since the end of the early Holocene (i.e. past ~8,000 years). It is evident that if washes are eroding into older alluvial fan deposits that contain a relatively high concentration of eolian size sand grains, that those washes would contribute more eolian sands than if the washes simply flowed from the mountains to base level without erosion of the older fan deposits.

Miller et al. (2010) indicate that cool-season (winter) Pacific frontal storms cause river flow, ephemeral lakes, and alluvial fan incision, whereas periods of intense warm-season storms (monsoonal) cause hillslope erosion and alluvial fan aggradation. These conclusions indicate that washes even during periods of increased cool Pacific storm systems (i.e. frequency and magnitude at latitudes of the study region) likely transport a significant amount of eolian sands that potentially could increase eolian source. This potential increase in eolian sand generation during this type of climate could occur during times of decreased monsoonal storm frequency and strength. However, the increase in vegetation density at lower elevations where dune systems reside may inhibit eolian sand migration, and it is possible that during periods of more intense Pacific storm systems and associated fan-trenching that eolian sands are stored up near fluvial base levels. These sediments could then re-mobilized to contribute to eolian systems when Pacific storms subside and monsoonal storm systems increase spatially and temporally.

5.5.7 Exposed and eroding older sedimentary units

In the Chuckwalla Valley, and other valleys as well across southeastern California, older relatively fine grained sediments are exposed within the valleys and flanks of the mountain ranges that can erode easily by sand bearing wind abrasion and channel down cutting. Hence, where exposed and eroded, these older sediments can provide a strong source of eolian sands. This significant source of eolian sands was identified during this study by observing increased and sometimes isolated areas of eolian sands in regions of exposed Bullhead Alluvium along the edges of the Chuckwalla Valley. For example, exposures of Bullhead Alluvium which deposited during the early Pliocene when the Colorado River engulfed the Chuckwalla Valley, occurs along the flanks and within the valleys of the Mule Mountains. It is evident that where this formation is exposed and eroding, that it produces significant volumes of locally derived eolian sands. In some places, older and abandoned pluvial and playa lake deposits also produce abundant eolian sands. An example of this is west of Dale Lake (Plate 1). The same process of the erosion of sandy older sediments contributing significant eolian sand to local dunes occurs east of the Colorado River in the Parker Dunes (Plate 1). In this area, older Colorado River system deposits are exposed and commonly occur along the flanks and beneath the dune deposits which are eroding resulting in the production of eolian sands.

5.5.8 Alluvial fan depositional areas

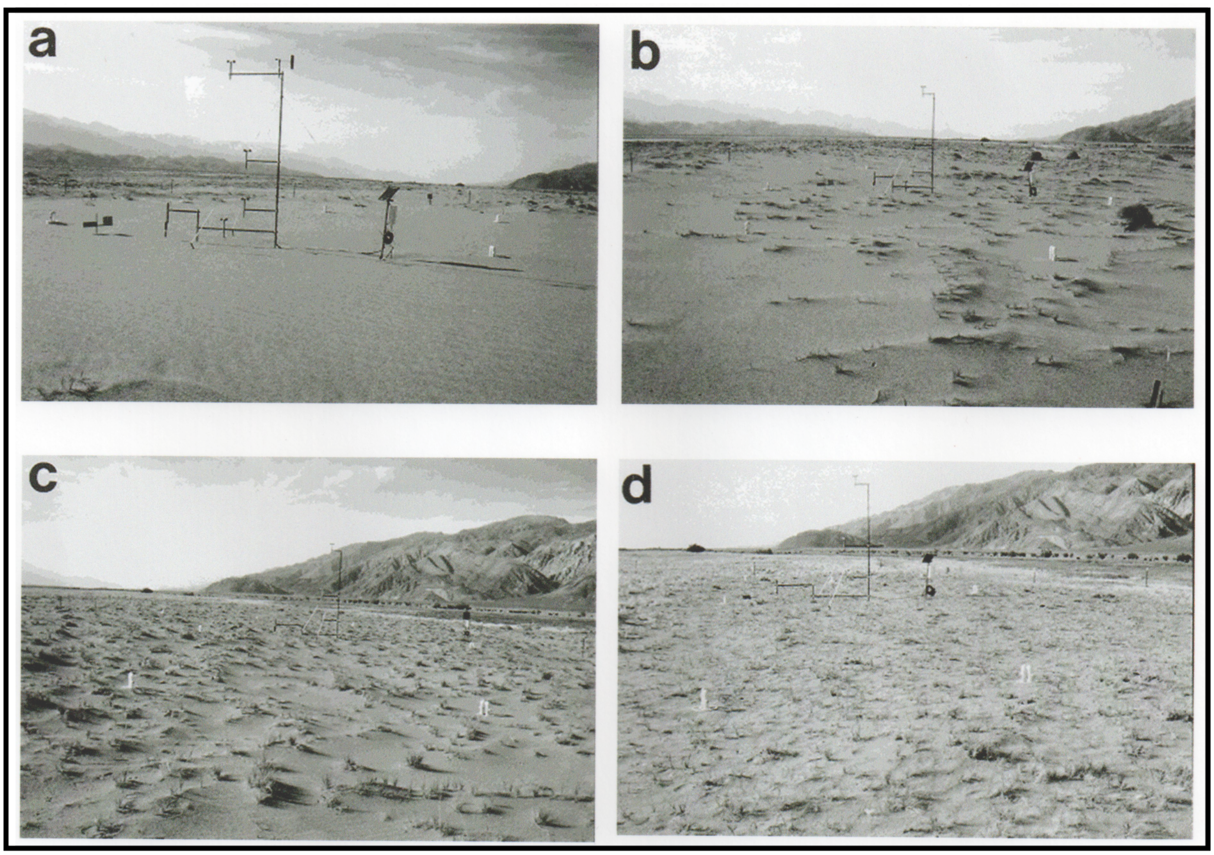
Alluvial fan processes likely contribute relatively more eolian sand to valley axis dune systems if the alluvial fans are aggrading in the distal fan portion of the fan system which typically occurs near the valley axis. During these times, sediment transport by the washes carries the sediment all the way to the valley axis where the sand is then deposited. Wells and Dohrenwend (1985) indicate that it was during the latest Pleistocene to mid Holocene that alluvial fans in the southwestern United States region primarily deposited in the distal portions of the fan and not near the mountain front as they had done previously (periods of glaciation). This is an important aspect of fan deposition in terms of eolian systems because most dune systems exhibited aggradational events during the same time period that Wells and Dohrenwend (1985) indicated that alluvial fans were also aggrading near the valley axis. This time period from the late Pleistocene to early Holocene also coincides with sporadic alluvial fan head trenching (proximal area of the fan) which is proposed to result in washes transporting relatively more sand size grains to the valley axis region. These processes lead to an increase in eolian sand production.

5.6 Dune vegetation - Dune stabilization and sand migration rates

The density of vegetation in dune deposit areas is a very important parameter in terms of dune stability and sand migration rates. Lancaster et al. (1998) conducted a significant well controlled study evaluating the relationship between plant aerial coverage density and sand migration rates on a playa lake bed (Figure 5). Their results indicate that just a 10% aerial coverage of plants that are less than one foot tall decreases eolian sand migration rates by 90%. This result is quite astounding and indicates that minor vegetation densities essentially decrease eolian sand migration rates exponentially.

The dunes immediately north of the north boundary of the DQSP exhibit vegetation densities a minimum of 10 to 15%, during years of essentially no growth of the invasive species "Sahara Mustard" (*Brassica tournefortii)*, but can increase to well over 50% during a season and following year of strong Sahara Mustard growth. Field mapping in December of 2010 and April 2011 identified a dense population of non-native and invasive Sahara Mustard (*Brassica tournefortii)* extending within the dune system east of Wiley Well Road to DQSP. During strong Sahara Mustard growth, eolian sand migration, and internal dune erosion, is nearly completely shut down.

Figure 5: Images from Lancaster et al. (1998) evaluating the relationship of vegetation densities and eolian sand migration rates on Owens Lake, California.



5.7 Types of dune forms (Sand Sheets, Coppice, Mounds, Linear, Transverse, Star Dunes - Complex)

Various types of eolian dune deposits occur in the Chuckwalla Valley and each provides evidence regarding prevailing wind directions and relative sand migration rates. Sand sheets are active sand moving across relatively planar surfaces. Ripple marks are quite common on active sand sheet deposits. If the amount of active eolian sands present are very low, sand sheets will be the only active type of active dune deposits identified.

Coppice dunes form at the base of a single plant and can be a few inches tall to over 4 feet. If moderate amounts of eolian sand are migrating through the system, active dune sands will be in the form of sand sheets and small coppice dunes. Dune mounds can be large coppice dunes but at the base of multiple plants, or simply a relatively wide mound of dune sands that do not exhibit any avalanche faces. They appear to form in areas of relatively dense vegetation where the active sand sheets are attempting to navigate through the system.

Linear dunes develop at moderate angles to the prevailing wind and in areas with competing prevailing winds. Linear dunes occur along the Gen-Tie corridor north of the Colorado River Substation and the eastern Chuckwalla Valley-western Palo Verde topographic sill (Plate 5). It is believed that the linear dunes west of the DQSP result from the competing southwesterly and westerly prevailing winds. The high vegetation density of the dunes and star dunes (described below) in the area support this conclusion. Linear dunes when robust typically migrate via extending in the direction of the prevailing wind and parallel to sub-parallel to their dune axis. However, the linear dunes in the Wiley's Well Basin dune system are strongly stabilized and only exhibit seasonal, scattered, and less than 2 feet tall avalanche faces.

Transverse dunes form at high angles to the prevailing winds and generally exhibit avalanche faces when active. They can be as small as just a foot tall, but in some places in the study area are over 8 feet tall (i.e. west of Wiley's Well Road).

Star dunes form locally when competing prevailing winds occur in the area and there is a relatively robust amount of eolian sand in the system. For this reason, star dunes are also sometimes called complex dunes. These types of dunes occur in the northeastern region of the herein named Wiley's Well Basin where the basin itself is a ponding area providing a relatively robust amount of eolian sand locally.

In many places in the study area, and observed across southeastern California, dune types that require relatively more eolian sands migrating through the system (i.e. star dunes, transverse, linear, mounds, and even coppice in some places) are eroding away, and the only active eolian sands are associated with sand sheets. This indicates that most eolian dune systems across southeastern California were more robust in terms of the magnitude of eolian sand migration than they have been during the latest Holocene.

5.8 Surface water hydrology – Eolian sand source and dune stability

The evaluation of surface water hydrology in terms of the location of drainages, types of drainage systems, drainage system watersheds aerial extent, and potential erosion into older sedimentary units greatly assists in understanding local sources of eolian sand for local dune systems. Hence, this analysis provides evidence and an avenue to recognize "micro" sand migration zones.

5.8.1 Drainage Analysis

A drainage analysis consisting of mapping individual drainages from its base level to its head waters provides valuable information regarding dune development, eolian sand sources, and dune stability. Washes transport at one time most of the eolian sand that ends up within dune systems whether to playa, pluvial or ponding areas, or from eolian sands being entrained directly from the wash itself. Drainages are evaluated to determine areas dominated by distributary or tributary systems. Wash systems that display an overall tributary flow system to the valley axis are identified as resulting in an increase of eolian sand production. In other words, tributary drainage systems near the valley axis that provide flow from nearly the entire watershed area will flow more frequently, stronger, and will more often flow to the valley axis (base level) which leads to production of more eolian sand to dune systems in this area. Regional and local mapping of wash and dune systems across the study region (southeastern California) shows strong evidence that the terminal tributary wash systems that drain most of the watershed area provide relatively abundant eolian sands compared to distributary drainage systems across active alluvial fan surfaces. It is interesting to note that mapping by the author has observed that "blue line" ephemeral drainages shown on USGS topographic maps in the region of dune systems across southeastern California quite often are sufficient to provide a significant source of eolian sand to the local dunes.

A drainage analysis will allow for an understanding of relative magnitudes of sand the drainages are transporting. For example, mapping can identify drainages eroding into older sediments (i.e. alluvial fan trenching or erosion into local Pliocene sediments) consisting of abundant eolian size grains to be transported to dune systems downslope.

5.8.2 Local watershed areas

Evaluation of the watershed area for various local drainage systems in this study indicates that there is a correlation between the size of the water shed, and the relative amount of sediment produced by that drainage system and hence the volume of eolian sand that can be produced from these sediments. Hence, identifying the aerial extent of the watershed to relatively major terminal drainage systems provides supportive evidence regarding the eolian sand contribution that wash system can provide to valley axis dune systems. Cloud bursts from thunderstorms quite often downpour heavy rains in relatively small areas. Hence, if the watershed is larger, the likelihood of that drainage system experiencing heavy flow sufficient to reach the valley axis (base level) increases accordingly.

5.8.3 Bar and swale relief – braided vs. channelized

Field work indicates that eolian sand is transported out of a wash area to enter eolian systems if the topographic relief of the washes (bar and swale relief) is relatively low. If the channel walls are over 3 to 4 feet tall, eolian sands are often produced in the wash between storms, but quite often these eolian sands remain within the drainage system and are unable to escape to enter an eolian system beyond its banks. Bar and swale relief generally decreases downslope to coincide with area near the valley axis where prevailing winds are strongest.

5.8.4 Ponding areas

Ponding areas are where surface flow waters stop flowing and pond within a relatively small basin, but not large enough to be considered or previously mapped as a playa lake. Some ponding areas are natural which locally include the Wiley's Well Basin in the eastern Chuckwalla Valley and along the southwestern region of the DQSP (Plate 3A). However, some ponding areas are man-made which include numerous borrow pits associated with the construction of Interstate Highway 10, portions of the north side of Highway 10, and a ponding area west and south of the Blythe 21 Solar Facility. Ponding areas, and particularly those associated with flow from numerous and/or large watershed drainage systems are an important source for eolian sands. This is because they are frequently flooded and this dynamic nature of its surface (disturbed frequently) allows for eolian sands to be blown out of the ponding area. Ponding areas are mapped as Soil S0 as well as the washes in this report.

5.8.5 Extent to which water infiltrates (reaches) dunes – Anthropogenic effects

A local drainage analysis evaluating drainages from their headwaters (entire watershed) to the base level typically near the valley axis where most dunes and ponding areas occur is an important parameter to evaluate during dune studies. This evaluation allows for not only providing insights regarding a qualitative assessment of how significant a wash and ponding area may be in terms of providing as a source of eolian sand for dune systems (discussed earlier), but also in terms of providing stabilizing moisture to the dunes. For many dune systems across southeastern California, overland wash flow reaches the dunes and ponds up either along the edge of the dune depositional area, or flow slowly through the dune system to pond within interdune depressions. This allows for infiltration of the water into the dune systems and increase their stability.

Dune systems, which may be naively assumed to develop in "dry environments" and thought to not require moisture for their stability, do in fact require moisture for their long-term stability. Wind abrasion within dune systems can erode older dune deposits quite rapidly if the dune sediments are dry, but the rate of erosion decreases exponentially to very low rates once the abrasion encounters moist dune sands. In addition, the dune systems vegetation which increases dune stability have also developed over time due to receiving moisture from natural drainage flow. Dune systems can react quickly (decadal scale) to a decrease in moisture allowing for older dune deposits to erode. This was proposed by Kenney (2012; also see Shaaf and Kenney, 2016) that documented abrasion rates into older relict dunes was initiated and continued to increase over the course of over three decades in the Keeler Dunes of eastern Owens Lake associated with water flow diversion berms constructed upslope in the 1940s and associated drying the dunes. Hence, dune systems can adjust relatively quickly (i.e. faster than alluvial fan systems) to variations in moisture either due to anthropogenic or climate variations. Changes in the overland flow waters received or not received by a dune system can thus lead to relatively fast changes in dune stability and dynamics.

6.0 DESIGNATIONS FOR RELATIVE SAND MIGRATION RATE ZONES, SOIL STRATIGRAPHY, AND GEOLOGIC UNITS FOR EOLIAN SYSTEMS

The approach of this study is consistent with previous geomorphic and stratigraphic evaluations of eolian systems written by the author that define various relative sand migration zone designations and soil profile stratigraphy designations (Kenney, 2010a, 2010b, 2010c, 2010d, 2010e, and 2011). The approach of establishing a series of geomorphic and soil stratigraphic designation greatly assists in the ability to map areas utilizing the designations, and processing the vast data into coherent maps that can be relatively easy to interpret. Hence, they assist in the ability to map and characterize variations in the alluvial and dune geomorphology, activity and age. In addition, new Geologic unit designations are utilized to allow for communication of the geomorphic eolian activity and/or stability of various regions. Hence, the sand migration zone designations provide an understanding of the general eolian activity level, the soil profile stratigraphy provides information on the sediments age, history, and parent material, and the Geologic unit designations indicate if a region is dominated by eolian vs. fluvial systems, and if the eolian dominated area is stable or exhibiting net erosion.

6.1 Relative Sand Migration Rate Zones designations

Geomorphic mapping was conducted of the local and regional eolian dune systems utilizing a series of relative sand migration rate zone designations that sequentially describe progressively decreasing dune activity which is suggested to correlate with relative eolian sand migration rates. Hence, this system provides a method for mapping a dune region showing variations in both dune geomorphology and relative sand migration of wind-blown sand. The method also allows for mapping areas dominated by fluvial verses eolian geomorphology. For example, Zones A, AB, B, and BW are dominated by eolian geomorphology. Zone BC typically exhibits a mixture of fluvial and eolian geomorphology but in most instances, exhibits over 50% in aerial extent eolian geomorphology. Areas mapped as Zone C are dominated by fluvial geomorphology however, minor eolian sands do migrate in these areas but not sufficiently strong to allow for significant eolian deposits.

One advantage to this method of mapping compared to Lancaster (2014) is that even regions where the eolian deposits may be less than 1-foot thick, if the area exhibits actively moving sands, and the area is dominated by eolian geomorphology, the region will likely be mapped as a dune deposit area. Lancaster (2014) defines actives dunes a being at least 1.5 meters thick. It has been observed that even in areas dominated by relict (dormant) eolian deposits that no longer receive sufficient eolian sands to maintain the older more “robust” dune forms, will be mapped in this system as a dune area because even within older dune systems, there is nearly always some active sand sheet and coppice dunes. The definitions of the various zones also reflect the very common occurrence of the older more robust dune system that is no longer “active” and instead is overprinted by eolian deposits and activity that require considerably less migrating sand.

Photographs of the various relative sand migration rate zones within the DQSP are provided in Appendix C.

Figure 6A: Descriptions of Relative Sand Migration Rate Zones from the strongest to weakest – Zone A, Zone AB and Zone B.

RELATIVE SAND MIGRATION RATE ZONES GEOMORPHIC DESCRIPTIONS

ZONE A - Relative Strong Sand Migration Rate (SMR)
Zone A is the most robust eolian dune system areas mapped for this study. The region is dominated by dune geomorphology with the majority of exposed surfaces exhibiting active moble eolian sands. Zone A exhibits active stabilized and non-stabilized sand dunes ranging from 2 to over 15-feet tall. A Zone A is very limited in the study area but one area occurs 3 miles west of the study nestled within the robust eolian sand source associated with wash and ponding areas of the Wiley's Well Basin. Avalanche faces occur as well as active sand sheets, coppice and possibly dune mounds. Avalanche face directions vary seasonally due to seasonal variations in prevailing wind directions. Hence, the dunes in Zone A are typically complex (Star Dunes) characteristic of multi-prevailing wind regimes. Region dominated by active eolian dune sand deposits, interdune depressions, and a paucity of fluvial drainages other than infiltrating drainages bounded by eolian sands.

ZONE AB - Moderately Strong SMR
Exhibits dune geomorphology indicating relatively moderately strong eolian sand transport compared to Zones B and BC. Dune types and geomporpholgy of Zone AB varies along Chuckwalla Valley and could be separated into two separate zones but was not for simplicity and no Zone AB occurs in the Site. Two distinct types of dune geomorphology occur in Zone AB. One on Palen Dry Lake, and the other in the eastern Chuckwalla Valley. The dune geomorphology varies likely due to whether two "prevailing winds" may occur in a particular region of a single much more dominant single prevailing wind occurs. For example, Zone AB dunes on Palen Lake exhibit migratory transverse barchan dunes that due to a pronounced relatively strong west to east valley axis prevailing wind regime exhibit strong dune forms and less vegetation. In contrast, in the eastern Chuckwalla Valley west of the Site, Zone AB areas are generally dominated by active sand sheets (loose sand-ripple deposits), dune mounds, coppice dunes, and weak, low relief, highly stabilized linear dunes trending approximatley east-west. The increased vegetation and linear nature of the dunes west of the Site are believed to occur due to two relatively dominent prevailing wind regimes. Namely, from the south-southwest and west. West of the site, Zone AB exhibits scattered small 2 to 4 foot tall avalanche faces (dunes) that likely only occur during seasonal strong windy periods. Zone AB is dominated by eolian dune sand deposits, interdune depressions, and a paucity of fluvial drainages west of the Site. Active and connected network of dune mounds generally occur with taller more ancient dune mounds eroding within the system suggesting the dune area was more robust in the past (early to mid Holocene).

ZONE B - Moderate SMR
Area dominanted by dune geomorphology (paucity of stream washes) which in most cases clearly exhibited a higher sand migration rate in the past (early to mid-Holocene) than in Historical times. Zone B generally consists small active coppice dunes and tails, and sand sheets. Older, inactive and relatively taller dune mounds and relatively taller coppice dunes often occur that are generally eroding which provides an internal and downwind eolian source for active sand sheets and small coppice. Vegetation density is qaulatatively generally greater than 10 to 30% in Zone B at all times, and varies depending on recent precipitation and whether a Sahara Mustard bloom occurs which if it does, increases vegetation aerial densities to over 90% for upwards of 2 to 3 years following the bloom. Region exhibits a paucity of tributary drainages if any, and the aerial extent of interdune depressions with gravel lag is greater than in Zones A and AB. Gernerally, the aerial extent of interdune lag surfaces varies but in places can be over 30%. In many locations, alluvial deposits exhibiting S2 to S4 soils (3,000 to over 35,000 years old) often occur at depths of less than 1 foot within the interdune depresions. In addition, dune deposit-interdune depression relief is generally 3 to 6 feet. These observations indicate that the eolian deposits within the majority of Zone B are only 3 to 6 feet thick and were dominantly deposited during the Holocene. Loose - active eolian sand are generally sand sheet sediments and are typically less than 1 to 3 inches thick with older stabilized eolian deposits of approximately late Holocene age occuring imediately below the active sand sheets. Avalanche faces are rare, scattered and seasonal, and typically 1 to 3 feet tall. Dunes mounds and coppice dunes are strongly stabilized.

Figure 6B: Descriptions of Relative Sand Migration Rate Zones from the strongest to weakest – Zone BW, Zone BC, Zone C, and Zone D. Note that Zone D is not mapped on the plates and figures within this report is for the most part assumed to occur outside of the mapped regions of the other relative sand migration rate zones.

RELATIVE SAND MIGRATION RATE ZONE GEOMORPHIC DESCRIPTIONS - CONTINUED

ZONE BW - Moderate to Weak SMR
Area dominanted by dune geomorphology (paucity of stream washes) however evidence of remnant washes often occur. Zone BW is characterized by relatively dense vegetation (stabilized coppice and dune mounds), interdune basins with gravel lag surfaces, and relatively thin active eolian sands in the form of sand sheets overlying older dune deposits. Zone BW exhibits an older dune system that was once more robust than it has been during the late Holocene, and coppice dunes and relatively taller dune mounds are eroding by wind abrassion to produce active eolian sands for downwind areas. No avalanch faces occur in Zone BW. Zone BW represents regions inwhich more active robust dunes have receded from during mid to late Holocene.

ZONE BC - Weak with some areas exhibiting Moderate SMR
Region exhibits characteristics of dune and fluvial-fan geomorphology suggesting relatively weak to moderate eolian sand migration rates. Most of the exposed eolian deposits are older and inactive eolian sands (Qe-ds) and active eolian deposits are domianlty in the form of sand sheets, and seasonal small dune tails. Active eolian sands are generally only 1 to 2 inch thick sand sheets overlying relatively firm older eolian sands. Older and relatively taller coppice dunes and occossional mounds often occur in small areas indicating relatively stronger sand migration rates in the past (i.e. early to mid Holocene) and the eroding older dune sands provide a local minor source for downwind dune systems.

ZONE C - Weak to Very Weak SMR
Exhibits weak dune geomporphology indicating weak to very weak eolian sand migration rates. Active dune sands occur as scattered and disconnected active sand sheets and small coppice; in general however, most plants do not exhibit active coppice dunes. Typically, Zone C is generally dominated by fluvial geomorphology with bar (fan-terraces) and swales relief. Zone C is generally dominated by gravel lag surfaces. Some active eolian sands occur within some washes and tens of feet downwind resulting from the wash itself providing the local eolian sand source. In some cases these washes are fairly minor only exhibiting an active wash approximately 10 to 20 feet wide with a bar and swale relief of 6 inches to 2 feet.

ZONE D - Very Weak with minor areas near active washes exhbiting Weak to Moderate SMR
Exhibits nearl geomorphology and geology dominated by fluvial processes and non-eolian processes. Active loose sand coppice dunes typically do not exist, and if they do are degrading. However, similar to Zone C, some minor areas of active eolian sands do occur within washes where the eolian sands are derived from the local wash itself. Most areas mapped as Zone D do not exhibit ancient dune deposits suggesting that these regions were never dominated by eolian processes.

6.2 Soil stratigraphy

A soil stratigraphic evaluation of an area is the identification of various members in terms of relative and numerical ages. Minimum numerical ages for the alluvial fan and eolian deposits are estimated based on the soil development of surficially exposed portions of each unit on an abandoned fan terrace and within near surface eolian deposits respectively. Relative ages of the stratigraphic units are determined by observing older units buried by younger units.

Soil profiles develop in sediments (or even rocks) when they are exposed to mechanical and chemical weathering processes, and wind-blown dust accumulates in surficial deposits. Over time, soil profiles exhibiting a more yellowish brown to reddish color develops, and increases in secondary silt, clay and carbonate. Soil profiles, and particularly their B horizons tend to get denser with secondary minerals such as silt, clay and carbonate in addition to exhibiting a blocky structure. On the surface, desert pavement, desert varnish, and rubification (reddening under clasts) all generally increase over time if the surface is not disturbed. In desert environments, the A horizon is commonly a vesicular Av horizon that if not disturbed can locally attain thicknesses of a little over an inch for the older soils (i.e. Soil S3b and older, Figure 7a). In many local soil profiles, due to the location of the project within a valley axis that exhibits dune systems, the relative amount of wind-blown dust and even sand in alluvial soils is higher than in other environments.

A very important aspect to the soil stratigraphic evaluation herein was identifying the type of parent materials that the soils developed in. This was critical because it allowed for more detailed mapping of contacts between older alluvium and eolian deposits in the study area. In other words, it allowed for the construction of soil maps that also delineate areas of eolian vs alluvial deposits. However, because the eolian dune systems are youthful in the study area (mid-Holocene), the lateral limits of eolian deposits mapped via soil stratigraphy (parent material) are similar with the those of relative geomorphic sand migration Zone BC, which is essentially the edge of mapped dune deposits in this study.

For alluvial deposits, the best soil descriptions for each soil unit are those obtained in test pits on the preserved fan terraces where that designated soil has remained exposed to surficial dynamic soil forming processes for the longest time. For example, from the time of cessation of deposition to current times. These exposures are considered the “type location and description” for each designated soil. The soil descriptions provided in Figure 7A and Figure 7B are from type location descriptions. However, once type location descriptions are obtained, the same soils units are also identified as buried soils where younger sediments have deposited over them. This assists in further developing the relative soil stratigraphy and cumulative ages for the various units. For example, older alluvium members are generally exposed on preserved, elevated and abandoned fan terraces progressively further up the fan, but become buried by younger alluvial deposits at progressively lower reaches of the fan. This relationship of older vs younger alluvial fan units is referred to as their morphostratigraphic relationship.

Eolian depositional areas are more complex typically compared to alluvial fan systems due to the dynamic nature of dunes in terms of not necessarily being deposited in horizontal layers, hummocky terrain with interdune basins, and that abrasion and deposition within dune systems is common (re-mobilization of dune sands over time). However, mapping in the dune system clearly identified in most areas, older soil profiles developed in eolian deposits, located within less than 6 inches to a foot of the surface if not exposed on the surface, representing a hiatus in deposition between the older alluvium and the younger eolian deposits.

Figure 7A: Designated soils for the region of the project S0, S1, S2, S3a, and S3b.

SOIL STRATIGRAPHY DESIGNATIONS (HOLOCENE) ESTIMATED AGE, AND DESCRIPTION

S0	**S0 <1000 years (1 kya)** Essentially no to very weak readily apparent secondary soil properties. Very week secondary carbonate (CaCO3). S0 soils are assumed to occur (hen
S1	**S1 1 to 3 kya** No desert varnish on clasts, weak chemical and wind abrasion weathing of surficial gravel lag clasts, weak surface gravel packing. Essentially no rubification under gravel lag clasts, very weak secondary carbonate under clasts. Secondary soil properties include an ~1/8" Av horizon but quite often does not exist, a weak Cambic Bw horizon commonly to a depth of ~3" depth identified by "yellowing" (strong brown 7.5 YR 5.6 dry common) and weak cementation (firmer) than underlying C Horizon parent material. Very weak blocky structure and moderate carbonate fizz occurs in relatively strong S1 soils. In these instances the B horizon is more readily identifiable as a firmer, darker color zone that is commonly 1 to 3 inches thick.
S2	**S2 3 to 5 kya** No to very weak desert varnish with weak chemincal and wind abrasion weathering of surficial gravel lag clasts. Slightly perceptible rubification and ~1/16" thick carbonate rings along beneathgravel lag clasts. Av horizons occur in places that when maximized exhibit 1/4" to1/2" thick gray to light yellowish brown (10YR 6/4 dry) vesicular layer. Cambic Bw horizons (3 to 4 inches) occur below the Av horizon exhibiting minor secondary fines (silts and clays), penetrative carbonate (moderate acid fizz, Stage I) and slight hardening of B horizon (very weak blocky structure) relative to underlying C horizon parent material. Well developed S2 soils exhibit weak horizontal secondary silt-clay carbonate lamelae.
S3a	**S3a 5 to 8 kya** Weak to moderately developed desert pavement and varnish, faint but clearly visible rubification, carbonate coating along clast-surface contact, softening of exposed clast surfaces from wind abrasion. Av horizon is more common in S3a soils than younger soils and and is generally ~1/4"thick, clearly vesicular, and pink (7.5YR7/3 dry). The B horizon is generaly Reddish Brown (5YR 7/3 dry) when developed in parent sandy silt deposits to light yellowish brown (10YR 6/4 dry) to light brown (7.5YR 6/4 dry) in gravelly sand parent material, medium dense, blocky, iron oxide staining along vertical joints (moderate blocky structure),Bwk horizon within 8" to 10" of surface, visible stage I- to I carbonate stringers-concentrations and/or carbonate 1/8" to 1/4" blebs (concretions). Moderately developed secondary silt-clay-carbonate horizontal lamelae can occur. Note that in the southern Palo Verde Mesa region, the parent material likely originallyexhibited a pale reddish color due to the source of this material from the erosion of the pale reddish brown Bullhead Alluvium (Soil S7) along the northern flanks of the Mule Mountains.
S3b	**S3b 8 -12 kya** Moderate developed desert pavement and desert varnish on gravel lag clasts. Thin carbonate coatings are visible underlying gravel lag clasts and some clasts exhibit moderate rubification that is stronger than for S3a soils. Chemical and wind abrasiion erosion of surface gravel lag clasts is stronger than for S3a soils. Av horizons are common and are generally 1/4" pink (5YR 7/3 dry). B horizons when undisturbed are generally 6 +/-3 inches thick, redish yellow (5YR 5/6 dry) to reddish brown (5YR 6/4 dry to damp) with with secondary translocated clays and silt exhibiting a moderate to strong blocky structure and vertical fractures extending through the B horizon. Btk horizon members occur with stage I to stage II carbonate stringers, and horizontal Bk horizons. Horizontal, very thin clay-silt-carbonate lamelae are common. Carbonate acid reaction fizz is typically violent in the B and underlying C horizons. Cabonate 1/8" concretion blebs are also common in the C horizon extending to depths of over 2 feet. Note that in the southern Palo Verde Mesa region, the parent material likely originallyexhibited a pale reddish color due to the source of this material from the erosion of the pale reddish brown Bullhead Alluvium (Soil S7) along the northern flanks of the Mule Mountains.

Figure 7B: Designated soils for the region of the project S4, S5, S6, and S7.

SOIL STRATIGRAPHY DESIGNATIONS (PLEISTOCENE AND PLIOCENE) ESTIMATED AGE, AND DESCRIPTION

Note: There are no identified soils with an age less than 35 kya (S4) and 8 to 12 kya (S3b), suggesting that minor deposition occured during the late Pleistocene in the area. This is similar to soil stratigraphy in the southeastern California region.

S4

S4 > 35 kya (likely 35 to 70 kya, Late Pleistocene)
Moderate to well developed desert varnish and pavement. Av horizon is common and typically ¼ to 1 ½ inch thick, pink (5YR 7/3 dry). Bt horizon is commonly 4 to 8 inches thick, yellowish red (5YR 5/6 dry), but often overlies a buried Bt horizong of soil S5 that is also reddish in color. Bt horizon is medium dense to dense, exhibits pinhole porosity, abundant carbonate (moderate to violent acid fizz), secondary clay, clay ped bridging with blocky structure from 8 to 13 inches depth. Numerous vertical joints filled with Av material spaced at 3 to 8 inches and extending 3 to 6 inches deep occur. Btk horizons occur and vary depending on the parent material. 1/8 inch in diameter carbonate concretions in fine grained parent materials and crude parallel to surface carbonate lamellae in coarse grained parent materials. Carbonate coatings on the underneath side of clasts, are common. S4 soils identified are typically very dense. S4 parent sediments likely deposited during the 55 kya regional alluvial fan aggradiational event (Bull, 2000). The S4 soil is widespread across the eastern Chuckwalla Valley and underlies all dune deposits indicating the local dune systems were deposited after soil S4. The late Pliestocene S4 soil is easily distinguished from Holocene age soils (S0 through S3b) due to its deep red color and density.

S5

S5 > 100 kya. Likely Early to Mid Pleistocene
Well developed desert pavement and varnish. Relatively strong rubification underlying clasts. Bt horizon is yellowish red (2.5 - 7.5YR 5/6 dry, 4/6 moist), very dense, blocky, abundant secondary translocated silts and clays. Btk horizons occure exhibiting stage II carbonate, 1/4 to 1/2 inch diameter carbonate concretions. Soil profile is a minimum of 2 ft thick, but nowhere was the entire profile examined. S5 soils commonly occur in the Chuckwalla Valley immediately below S4 soils with unconformity; however, S5 terrace surfaces upslope occur at relatively higher relief (vertically) above S4 terraces.

S6

S6 < 3.5 mya (million years ago) Early Pleistocene or possibly Late Pliocene
Older alluvium deposits shed from the Mule Mountains with strongly developed soil profile resting unconformably on top of the Bullhead Alluvium Colorado River deposits (Soil S7 below) extending to upper elevations at a minimum of 850 feet. This soil was not examined in detail but was mapped in the field in several locations. The preserved terrace surfaces of soil S6 exhibits very strong desert pavement and desert varnish. Well developed Stage II to III carbonate and a well developed B horizon occurs.

S7

S7 ~ 4.3 mya Early Pliocene
Colorado River Gravels of the Bullhead Alluvium identified in the area of the from elevatons 430 t 450 ft. Unit correlates with unit QTmw of Stone (2006; herein designated as Tmw as the unit is likely early Pliocene). Soil development consists of minimum Stage IV carbonate that fills the cobble matrix nearly 100%. The gravels are exotic, mostly well rounded indicating thawleg river tansport, however, many cobbles are also weakly oblate indicating some "beach" type back and forth erosion occured possibly associated with an ancient Colorado River edge beach bar envirnment. Evidence to support this is the tear drop cross-sectional shape of the S7 cobble deposits identified along the edge of the Palo Verde Mesa across the eastern Chuckwalla Valley.

The soil stratigraphy developed during this study was conducted for the purposes of evaluating the Holocene and latest Pleistocene in more detail than the early to late Pleistocene and the Pliocene. This is because the eolian dune deposits exposed at the surface clearly overlie late Pleistocene older alluvial deposits (Soil S4) that are widespread across the Chuckwalla Valley, and across the southeastern California region. It is acknowledged that a detailed stratigraphic study of the early to mid-Pleistocene alluvial deposits would generate many more soil units. For example, on Plate 6B, two Soil S5 surfaces (deposits) were identified which likely reside somewhere in the age range of early to mid-Pleistocene. However, a distinctive capping cut-terrace locally derived alluvial deposit that overlies the Bullhead Alluvium on the northeastern flanks of the Mule Mountains was assigned Soil S6 and is clearly stratigraphically older than Soil S5. Soil S6 was likely during recession of the ancient Colorado River from Chuckwalla Valley as it appears to be cut-off at lower slopes along Colorado River shorelines (wave cut benches; Plate 6B). Designated Soil S7 was assigned to all ancient Colorado River deposits in the study area as this simple designation proves useful in geologic discussion. The units of the ancient Colorado River deposits assigned to Soil S7 are discussed in the next section.

Example photographs of the various designated soils exhibiting both alluvial and eolian parent materials are provided in Appendix D.

6.3 Geomorphic-Geologic eolian unit designations for eolian systems

Performing a Geomorphic and Geologic evaluation of an area, and particularly regions as dynamic as eolian and active wash systems, led to the development of terms that describe both the geologic unit, and its geomorphology. That is the motivation for the Geomorphic-Geologic terms provided in Figure 8A and Figure 8B. The root terms of Qe and Qal describe whether an area is dominated by eolian processes, or alluvial-fluvial processes respectively. These terms are then modified to describe various geomorphic parameters. For example, the following terms are used to describe eolian areas (Figure 8A): “-a” for active eolian area, “-d” for dormant, “-ds” for stable dormant eolian sands, “-de” for dormant eolian sands that are eroding, and “-df” for an area dominated by older dormant eolian sands with a component of fluvial geomorphology. A similar approach was taken for alluvial depositional areas shown in Figure 8B.

Figure 8A: Geomorphic-Geologic eolian unit designations to assist in described not only the type of geologic units are exposed at the surface, but also about the geomorphic dynamics as well.

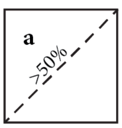
GEOMORPHIC-GEOLOGIC EOLIAN UNIT DESIGNATIONS

EOLIAN GEOMORPHICALLY DOMINATED AREAS

Areas qualitatively field assessed to exhibit >50% eolian surficial deposits (geomorphology) are designated as Qe- (eolian depositional area), and regions exhibiting >50% fluvial deposits(geomorphology) are designated as Qal (fluvial depositional area)

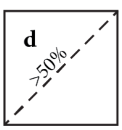
Eolian Dune Deposits (e)

Qe Mapped areas via qualtitative field assessment that are dominated by eolian deposits-geomorphology (>50%) vs. fluvial deposits. Areas dominanted by interdune depressions, ripples, coppice, mounds, and/or dunes.



Active Dune Areas (a):

Qe-a Aeolian sand areas exhibit >50% active sands. Areas generally exhibit active sand sheets (ripples), coppice, and possibly mounds and/or dunes. If dune deposit areas exhibit <50% active sand, then the area is designated as a Dormant Dune Area (below). Qe-a regions may still have recieved more aeolian sand input in the past than has been the case in the late Holocene (i.e. degrading older dune deposits are permissable).



Dormant-Dune Areas (d):

Qe-d Eolian sand areas exhibit>50% "dormant" eolian deposits that is currently stable (not eroding (Qe-de) or exhibit significant erosion of older dune deposits to provide a source for downwind dune systems (Qe-de). Qe-d areas once recieved more eolian sand in the past than during the late Holocene. These area generally coincide with Sand Migration Zone C but can occur locally within stronger sand migration zones.

Qe-ds Area dominated by "dormant" eolian deposits that is currently stable (s) and not exhibiting significant erosion (i.e. providing a current source for eolian deposits (downwind).

Qe-de Area exhibiting significant abrasion (erosion - e) of older "dormant" dune deposits resulting in a source of "new" eolian sands for downwhin dune system.

Qe-df Area dominated by dormant (d) eolian sand deposits (Qe-d) in the near surface but active fluvial (f) features have begun to develop during the late Holocene. Hence, an older dune system that had received sufficient eolian sand flux to support a dune dominated system in the past (i.e. latest Pleistocene to mid Holocene), but due to a decrease in sand migration rates, fluvial processes have become the dominant active geomorphic process in the area.

Figure 8B: Geomorphic-Geologic alluvial unit designations to assist in described not only the type of geologic units are exposed at the surface, but also about the geomorphic dynamics as well.

GEOMORPHIC-GEOLOGIC ALLUVIAL UNIT DESIGNATIONS

ALLUVIAL - FLUVIAL GEOMORPHICALLY DOMINATED AREAS

Surface Geomorphology dominated by alluvial-alluvial depositional and erosional processes (>50%,)
For example: Qualitatively fluvial (i.e. drainages, bar and swale, fan -terraces >50% aerial extent) geomorpholgy vs. eolian (dune deposits, interdune depressions, etc areas <50% aerial extent).

Qal Quaternary alluvial deposits (Holocene age, < 10 to 12 kya) Area is dominated geomorphically and geologically by fluvial processes (~ >50% of surface area). Hence ~ > 50% of area qualitatively exhibits drainages, washes, bar and swale, fan-terrace surfaces, and/or gravel lag surfaces. Coincides with Soil Designations S0 through S3b.

Qal-a Active alluvial wash and a source for new eolian sands. These areas are mapped as S0 soils on the Sand Migration Zone and Soil Stratigraphy.

Qal-eda Subordinate minor active eolian deposits typically in the form of very thin not contiguous active sand sheets and/or coppice dunes. In Qal-eda mapped regions, the active eolian sands areas are >50% of the total eolian depositional areas and indicate an area of moderate active eolian sand transport (these regions generally coincide with San Migration Zones BC or C.

Qal-eds Subordinate stable (dormant) eolian deposits in the area that are stable and generally not abrading (erode). Hence, Qal-eds areas are a poor (weak) source of new eolian sands if at all. These areas indicate that the area once recieved more eolian sand than they do during recent times. Hence, that the eolian system is less robust-active than it once was during the Holocene. Qal-eds regions generally coincide with either relative Sand Migration Zones C or D.

Qal-ede Subordinate minor eolian sands that are eroding resulting in the area producing an eolian sand source for down wind dune systems. Qal-ede regions also indicate that the eolian system is less robust-active than it once was during the Holocene. Qal-ede typically coincides with relative sand migration zone C.

Quaternary Older Alluvial Fan deposits (Qoaf) represent alluvial sediments that were deposited primarily during the Pleistocene (Figure 8C). These deposits represent soil units S4, S5 and S6 described in Figure 7B. Two older units designated as Tmw and Tmm (derived from Stone, et al., 2006 units QTmw and QTmm, Figure 9) are also utilized in this report. These formations are described in more detail in report section 8.1 below, but are important for this study because understanding their age of late Miocene to early Pliocene indicates that most geologic actively in the study area has been quite minimal since their deposition, and because the erosion of these units provided an important source for eolian sands and alluvial deposits locally.

Figure 8C: Geologic unit descriptions for Qoaf and Tmw (Soil S7).

GEOLOGIC UNITS

Qoaf Quaternary older alluvium-fan deposits (late Pleistocene age; ie. >12 kya). Where exposed at the surface, area is dominated geomorphically and geologically by fluvial processes. In most instances this unit is shown exposed at the surface as abandoned terraces. Coincides with Soil Designations S4, S5, and S6.

Tmw (S7) Tmw represents ancient Colorado River shoreline berm (beach) deposits and are shown as soil S7 on many plates and figures. Tmw consists of rounded, and oblate exotic cobbles generally range in size of 2 to 4 inches. Similar age sediments likely occur along the ancient river cutbank located along the eastern margin of the Palo Verde Mesa as mapped as Unit B of Metzger et al. (1973). Tmw provide stratigraphic evidence associated with a receding ancient Colorado River and associated lake basins from the Chuckwalla Valley and PaloVerde Mesa. The unit outcrops in the range between elevations of ~400 to 450 foot elevation from the northeastern Mule Mountains, across Chuckwalla Valley, and east of the southeastern McCoy Mountains. Relatively prominent outcrops of Tmw immediately above the 430 foot elevation exhibit tear drop cross-sectional profiles that resemble beach “shoreline” berms (lake subbasins). Stratigraphically, Tmw (soil S7) occurs at lower elevations than the ancient Colorado River derived unit Tmm described below.

Tmw occurs at relatively shallow depths (less than 1 to 5 feet in many areas) across the Palo Verde Mesa. This indicates that Palo Verde Mesa has remained a very stable Geologic and Geomorphic region for well over 2 million years having only recieved relative thin alluvial and subsequent very thin eolian deposits since that time (less than 5 feet in many areas). Tmw herein to correlates with map unit QTmw of Stone (2006), however in this study, Tmw is likely Pliocene in age and not Quaternary. Tmw correlates with the Bullhead Alluvium of Fenton and Pelletier (2013) and Howard et al. (2014), and Unit B of Metzger et al. (1973). Tmw is mapped in this report as the younger member soil S7 in interpreted herein to have deposited soon after the dominant aggredational event of the Bullhead Alluvium (unit Tmm below) in the early Pliocene estimated to have occured between 4.5 to 3.5 million years ago by Howard et al., (2015).

Figure 8D: Geologic unit description for Tmm (Soil S7).

GEOLOGIC UNITS (CONTINUED)

Tmm (S7a) Tmm represents ancient Colorado River "sub-basin lake" sediments and are shown as soil S7 in many plates and figures in this report. Tmm sediments were deposited when the acient Colorado River essentially engulfed the Coachella Valley during the early Pliocene (4.5 to 3.5 million years ago, Howard et al., 2014). During this time period the ancient Colorado River encroached and essentially completely filled Chuckwalla Valley to a minimum highest elevation of 850 feet(Howard et al., 2014). However, based on aerial imagery mapping in this study of similar sediments, the ancient Colorado River basin "lake" levels may have achieved an upper elevation of approximatley 1200 feet or lake shoreline effected sediments (terrestrial near shore) of the same time periode may occur that were mapped collectively with Tmm (soil S7 on plates and figures).

Tmm is utilized herein to correlates with map unit QTmm of Stone (2006), however as described herein, Tmm is likely Pliocene in age. Tmm correlates with the Bullhead Alluvium of Fenton and Pelletier (2013) and Howard et al. (2014), and likely Unit B of Metzger et al. (1973). Howard et al. (2014) indicate that the Bullhead Alluvium (unit Tmm) was deposited during a strong aggredational event between 4.5 and 3.5 million years ago (early Pliocene) when the Colorado River reached water level highstands. Tmm correlates as well in this report with soil S7 and was aerially mapped in detail in the Coachella Valley region due to its proposed importance as a strong eolian sand source when these sediments erode.

Based on the evaluation of wash cut banks along the northwestern flanks of the Mule Mountains, Tmm is composed of light reddish silty sand members with occassional small gravel channel deposits. Some, but not all of the clasts are of exotic origin, suggesting that gravel clasts were derived from distances tens of kilometers away (Colorado River watershed) and local mountainranges, but further analysis is needed. Local erosion of Tmm (S7) is proposed herein to be a strong source for both local alluvial deposits in the eastern most Chuckwalla Valley, and in particular, the Palo Verde Mesa. Hence, the unusual exposure and erosion of relatively fine grained sediments along the flanks of the localmountains of Tmm locally caused washes to provide relatively more eolian sand than typical desert washes

7.0 GEOLOGY AND GEOLOGIC HISTORY SINCE THE EARLY PLIOCENE

Understanding the geologic history of an area prior to the development of the surficial eolian dune system places the development of the dunes in temporal and spatial context. For example, the findings of this report indicate that the landscape of the eastern Chuckwalla Valley and Palo Verde Mesa has experienced on average about 5 to 6 feet of alluvial deposition in many areas during the entire Quaternary (i.e. past 1.7 million years) and since the late Pliocene. Hence, most of the general topography in the study area was already in place by the end of the Pliocene, and has changed very little since that time.

The simplified Geologic History of the region of the DQSP in the eastern Chuckwalla Valley and Palo Verde Mesa area includes:

- Deposition of sedimentary deposits in Late Miocene through Early Pliocene associated with large water bodies of the ancient Colorado River up to elevations of over 1,200 feet. These deposits occur along the flanks and nestled within the local mountain ranges and at depths of several feet across the DQSP (units Tmw – Soil S7 and Tmm, Soil S7a). Note that Tmw is younger than unit Tmm and represents a recessional shoreline of the ancient Colorado River system. Soil (older alluvium) unit S6 may be contemporaneous or close in age with Soil S7 (unit Tmw).

- Deposition of coarse grained older alluvium (Soil S6) on top of unit Tmm in unconformity along the northeastern flanks of the Mule Mountains during recession of the ancient Colorado River inundation of the Chuckwalla Valley. May be close in age with the ancient Colorado River shoreline berm deposits of unit Tmw (Soil S7).

- Deposition of older alluvial unit S5 along the flanks of the local mountains during the Early to mid-Pleistocene. These units were not identified in the valley axis nor the Palo Verde Mesa and were possibly eroded away as soils S3b and S4 were observed to be deposited directly on top of the Pliocene age unit Tmw (Soil S7) in several localities on the Palo Verde Mesa area.

- Deposition of a series of older alluvial fans in the Pleistocene, the most significant member being a 65 to 35 kya deposit (Soil S4) that extended across Chuckwalla Valley and under the local dune systems.

- Deposition of a series of alluvial fan deposits in the latest Pleistocene and early Holocene that were deposited across Chuckwalla Valley and the Palo Verde Mesa region including under the local dune systems indicating that the local dune deposits had not yet encroached into the DQSP area by early Holocene. This includes primarily soil S3b which weak versions of S3b sediments were identified under the eastern most Wiley's Well Basin sand migration zone.

- Initiation of deposition of eolian deposits that migrated eastward during the late early Holocene to mid-Holocene in the region of the DQSP. Encroachment of eolian sands into the eastern most Wiley's Well Basin sand migration zone may have occurred as early as 10 to 8 kya. Alluvial fan deposits of unit S3a continued to deposit along the flanks of portions of the eolian dune sediments and many washes flowed through the dune systems. Washes continued to flow across the DQSP dune systems (not yet impeded).

- During the mid-Holocene, the dune deposits in the DQSP area were sufficiently thick and laterally extensive (>5 feet) to impede wash flow across their entire width. Hence, it was at this time that the geomorphology of the eastern Wiley's Well Basin sand migration zone was dominated by eolian processes. Washes continued to flow into the northern portions of these dunes and ponded within the dunes which increased their stability. Alluvial soil unit S3a deposits along the flanks of the dune system while the DQSP dune systems are nearing the end of their aggradational event. The most robust dune forms in the eastern Wiley's Well Basin sand migration zone (area mapped as Zone BW, Figure 11 and Figure 12) are interconnected dune mounds that developed by the growth of earlier formed coppice dunes. Dunes likely experienced this aggradational event during the warming period from 10 to 9 kya followed by the Holocene climate Optimum from 8 to 6 kya (Plate 8A). This was a period of warm and dry climate and reactivation of dunes.

- Near the mid-Holocene – Late Holocene boundary (~5 to 3 kya), alluvial soil unit S2 ceases deposition south of the DQSP solar project and soil profile S2 begins to form. The DQSP dune system is stabilizing quickly as sand migrations rates have slowed down, and the eolian soil S2 begins to develop (Figure 13 and Figure 14). Active sand sheets and coppice dunes continue to occur.

- During much of the latter part of the late Holocene, alluvial soil unit S1 deposits, and then ceases deposition to begin development of the soil we see today. The DQSP dune system has stabilized and eastern areas of the dunes begin to degrade in the area mapped as Zone BW (Figure 13 and Figure 14).

- During Historical times (~100 to 150 years), the dune systems in the DQSP have experienced relatively minor changes due to both an increase and decrease in stream flow to various areas which led to a relatively minor increase in eolian sand source and degradation of dunes respectively. The invasive Sahara Mustard plant encroached into the region at least by 2010, which has dramatically decreased sand migration rates in the DQSP dune systems. Hence, the Sahara Mustard plant has led to an increase in dune stability and decrease in dune dynamics.

The next few sections describe the geologic history of the eastern Chuckwalla Valley and Palo Verde Mesa region in more detail.

7.1 Geologic History from the Late Miocene to Early Pliocene

The oldest pertinent geologic units in the region of the DQSP are associated with relatively quiet and large water bodies that engulfed the Chuckwalla Valley during the latest Miocene to early Pliocene. The oldest of these deposits include the Late Miocene to earliest Pliocene Bouse Formation, which was deposited in quiet waters similar to lake conditions that inundated basins up to an elevation of ~1,100 to 1,800 feet along the course of the lower Colorado River (House et al., 2008). In the Chuckwalla Valley, the Bouse Formation was deposited to at least 1,130-foot elevation (House et al., 2008; Spencer at al., 2008). This water body filled the Bristol, Cadiz, Dandby, Rice, Palen, and Ford dry lakes (Plate 1; House et al., 2008; Spencer et al., 2008). It is unknown how many outcrops of the Bouse Formation may occur in the Chuckwalla Valley area as the unit is not shown on published maps, but some outcrops of this unit may be mapped via Google Earth Pro historical imagery during this study as unit Tmm (also soil S7; Plate 1).

During the early Pliocene, the Bullhead Alluvium was deposited along the lower Colorado River and represents a strong alluvial aggredational event occurring between 4.5 to 3.5 million years ago (Ma; Howard, et al., 2015). The Bullhead Alluvium was deposited on top of an erosional surface into the Bouse Formation and was deposited as part of the lower Colorado River system when it inundated Chuckwalla Valley up to elevations of 850 feet (Howard et al., 2015). The Bullhead Alluvium in many places is deposited on top of the Bouse Formation but because the Bouse Formation was deposited to elevations of 1,130 feet and the Bullhead Alluvium to an elevation of 850 feet, the Bouse Formation can occur at elevations higher than the Bullhead Alluvium. A distinctive quality of the Bullhead Alluvium is the presence of petrified wood (Howard et al., 2015), which was identified in outcrops south of the SCE Colorado River Substation (Plate 4).

The Bullhead Alluvium is mapped in this report as two members. These include unit Tmm (soil S7a) which was deposited between 4.5 to 3.5 Ma up to elevations of 850 feet if not higher, and unit Tmw (soil S7) which is proposed to represent recessional river edge bars that were likely deposited soon after 3.5 Ma (Figure 8C., Figure 8D and Plate 4). Unit Tmw occurs in the region of elevations of 430 to 450 feet and the occurrence of oblate exotic clasts indicates beach erosional processes as well as having been transported a great distance respectively.

Stone (2006) designates two units in the area that he described primarily as alluvial deposits that include QTmm and QTmw (Figure 9). Unit QTmw of Stone (2006) mapped southwest of the McCoy Mountains (Figure 9) as composed rounded gravels occurring at elevations above Palo Verde Mesa but did not indicate that these deposits were directly related to deposition associated with the ancient Colorado River. This unit is the same as the Bullhead Alluvium described by Howard et al. (2015). It is also a member of Unit B of Metzger et al. (1973) who indicates that it is exposed in the cobble rock quarry north of the Blythe 21 solar facility (Plate 5) and along the Colorado River cut bank along the eastern margin of Palo Verde Mesa (Plate 4 and Plate 6B). The findings of this report provide for the first time the identification of unit Tmw across the eastern Chuckwalla Valley along one of the lower elevation wave cut benches in the northeastern Mule Mountains near elevation 450 feet where unit Tmw cuts into unit Tmm (Plate 4 and Plate 6B). Another wave cut bench occurs at the higher elevation of 480 feet (Plate 6B). Hence, river edge cut banks occur into the older Tmm (Bullhead Alluvium), and unit Tmw (also Bullhead Alluvium) represents deposits along one of the lower elevation river cut banks in the elevation range of 420 to 450 feet (Plate 6B).

Stone (2006) mapped unit QTmm as an older alluvium unit in and along the flanks of the northern Mule Mountains (Figure 9). Based on the findings of this report and review of scientific literature, it is likely that units QTmm and QTmw of Stone (2006) correlate with the Bullhead Alluvium of Pliocene age. Because of this, within this report these units are labeled as Tmm and Tmw (also as soil S7 in this report) as they are likely not deposited during the Quaternary (i.e. Pleistocene). Additional description of these units is provided in Figure 8C and Figure 8D.

In many places, older Pleistocene age alluvium is deposited on the Bullhead Alluvium across an erosional unconformity. This is the case in the northeastern Mule Mountains where the older alluvium of soil S6 is deposited on top of the Bullhead Alluvium (Plate 6B and Figure 13). This relationship is described by Stone (2006), who mapped the unit as QTmm, and not as the Bullhead Alluvium. It is proposed that unit S6 may have deposited near the time of deposition of unit S7 (Tmw), hence, was deposited as the ancient Colorado River inundation of Chuckwalla Valley still occurred but had receded from its high stand of approximately 850 feet associated with unit Tmm (soil S7a, Bullhead Alluvium).

Geologic formational units Tmw (soil S7) and Tmm (soil S7a) are important regarding the eolian evaluation in the DQSP area. It is useful that the Bullhead Alluvium has been identified across the eastern Chuckwalla Valley and its age has been well documented to be early Pliocene. Hence, it is the oldest positively identified unit across the valley which provides essentially a beginning point for a pertinent Geologic history for the site. Unit Tmw of the Bullhead Alluvium was identified at depths of 1 to 6 feet at numerous localities in the DQSP and at the surface indicating that the total depth of Pleistocene to Holocene age alluvium across the Palo Verde Mesa is relatively thin (i.e. 1 to 6 feet). However, relatively significant erosion of Bullhead Alluvium (unit Tmm – soil S7a) occurring prior to deposition of unit Tmw cannot be ruled out in the valley axis sill and the Palo Verde Mesa (Plate 6B). Lastly, erosion of unit Tmm provided an important local source for the Quaternary alluvium and eolian systems in the region of the DQSP. In fact, the erosion of unit Tmm may have been the primary source for the eolian sands in the local dune systems.

7.2 Geologic History during the Pleistocene

The approximate time interval of the Pleistocene occurred between 2.6 Ma to 11 kya. In the Chuckwalla Valley and Palo Verde Mesa area, geologic events occurring during the Pleistocene consisted of deposition of alluvial fans along the flanks of the local mountains (proximal and medial fan areas – soils S4 and S5), but minor net deposition within the valley axis and Palo Verde Mesa area. Soil unit S4 has been identified along all alluvial fan aprons bounding the Palo Verde Mesa, but also along the edges or slightly extending into the Palo Verde Mesa. Soil S4 is estimated to have a minimum age of 35 kya, and may be as old as 65 kya. In the latest Pleistocene, soil unit S3b was deposited across most of the Palo Verde Mesa. Hence, it is the last depositional unit in the site to occur during the Pleistocene. Soil S3b is observed at the surface or very close to the surface across most of the Palo Verde Mesa, which indicates that this area has been Geomorphically stable since the early Holocene.

7.3 Geologic History in the Holocene

During the Holocene in Chuckwalla Valley, sediments were deposited via alluvial fan, playa lake, and eolian processes, and alluvial deposition dominated across Palo Verde Mesa. Near and within the site, alluvial deposition has occurred throughout the Holocene but with two periods of increased deposition (aggradation events). These occurred in the early Holocene during deposition of soil unit S3b and extending into S3a, and the second associated with deposition of soil unit S2.

The eolian sands in the eastern Wiley's Well Basin sand migration zone (Figure 1) are typically deposited upon alluvial soil unit S4 and only rarely on top of poorly developed soils of S3a age (Plate 6B, Figure 13 and Figure 14). This infers that during the early Holocene the first eolian sands migrated eastward encroaching into the DQSP, and deposited on top of older alluvial units exhibiting S4 soils and some alluvial sediments continued to be deposited within interdune areas. Over time, the amount of eolian sands and their aerial extent coverage increased by the mid-Holocene depositing on top of some early Holocene age alluvial deposits.

The eolian deposits in the eastern Wiley's Well Basin sand migration zone exhibit S2 soils indicating that these eolian sands had deposited until about 5 to 3 kya. Hence, the eolian dune deposits in the eastern Wiley's Well Basin sand migration zone along the Gen-tie corridor and northern DQSP encroached into the area and were relatively robust during the early Holocene, but then sand migration rates decreased markedly by 5 to 3 kya. Since that time, the dunes in this area have been dominantly stable and in places, particularly in areas mapped as Zone BW, degrading.

The Mule sand migration zone (Figure 11) has a similar geologic history as that of the Wiley's Well Basin sand migration described above (Plate 6b, Figure 13 and Figure 14). The only exception is that the eastern region of the Mule sand migration zone took longer to migrate into the DQSP site area as early Holocene age soils underlie the eolian deposits more extensively than identified in the eastern Wiley's Well Basin sand migration zone. Although more data is required, the existing data suggests that the eolian deposits associated with the eastern Mule sand migration zone may not have encroached into the DQSP site until the early mid-Holocene.

A Geologic map of the eastern Chuckwalla by Stone (2006) identifies scattered, non-connected eolian sand depositional areas (Qs on Figure 9). In fact, Stone (2006) shows no dune deposits between central Ford Dry Lake and just west of the Welly's Well Basin (Figure 9). Stone (2006) indicates that these deposits were mapped primarily from aerial imagery, and it may have been difficult to identify relatively weaker dune depositional areas based on the resolution of the imagery utilized.

Lancaster (2014) published an eolian geologic map that emphasized mapping of eolian dune systems (Figure 10). This map references the author of this report and much of the mapped limits of dune deposits shown in Lancaster (2014) are somewhat consistent with reports published by the author. However, the Lancaster (2014) map "active windblown deposits consisting primarily of dunes and sand sheets" in a much larger and extensive area than is likely the case. Additional eolian dune name designations would have allowed for a more detailed and accurate depiction of the level of dune stability and activity. For example, Lancaster (2014) identification of his unit Qe shows active dune and sand sheets occurring all the way across the northern section of the DQSP. This is clearly not the case based on the findings of this report.

Lancaster (2014) inconsistently mapped regions of scattered eolian deposits across the surface of ponding areas and dry lake beds that leads the reader to believe that the dune systems are more extensive, more connected, and active than is the case. This is supported by comparing Figure 10 (Lancaster, 2014) with the mapping conducted in this study (Plate 3B, Plate 4 and Plate 5). Lancaster (2014) does indicate a lack of conductivity of the eolian sand system in Ford Dry lake with the dune systems south of Highway 10 and southeast of the Wiley's Well Rest stop (Figure 10). However, Lancaster (2014) does not clearly indicate that because segments of the local sand migration zones have shut down that this implies that the more regional sand migration zones (corridors) have also shut down.

Lancaster (2014) does not indicate the timing regarding when the segments demonstrating much less eolian activity along the regional sand migration corridors occurred other than implying it took place after the end of the early Holocene dune aggredational event. Lancaster (2014) indicates that dune systems were more robust during the eolian aggredational event during the latest Pleistocene to early Holocene, but does not discuss many of the ramifications regarding weaker eolian systems consisting primarily of active sand sheets and coppice since that time occurring over eolian geomorphic landscapes exhibiting ancient-dormant more robust dune forms (large dune mounds, degraded linear and transverse dunes, etc.).

Another issue with the Lancaster (2014) report is their definition of active dune systems exhibiting a stratigraphic thickness of at least 1.5 meters (m). This is misleading for many reasons. First, active sand sheet and coppice dune dominated regions and particularly in the DQSP, are less than 1.5 m thick. This is particularly the case as well along the fringes of dunes systems where dune deposits gradually get thinner as they approach an alluvially dominated geomorphic landscape. This is one reason that in this study, geomorphic mapping criteria was done dependent on whether an area was dominated by eolian or alluvial-fluvial geomorphology regardless of the thickness of the eolian deposits. Because Kenney, M (author herein) is referenced in the Lancaster (2014) map shown in Figure 10, it should be made clear that the findings of Lancaster (2014) are not considered consistent with the findings of eolian deposits provided in this report.

The findings in this report based on the eolian geomorphic and soil stratigraphic analysis conducted herein indicate that the eolian dune deposits associated with the Wiley's Well Basin and Mule sand migration zones occurring in the DQSP were initially deposited during the early to mid-Holocene. Most of the dunes are relict eolian sediments that were deposited a minimum of 3 to 2 kya. Hence, because soil profiles provide minimum ages for their parent sediments, it is likely that the eolian deposits occurring within the DQSP were deposited prior to 3 to 2 kya. In some places, eolian deposits were identified exhibiting S3a soils, indicating that they were deposited during the mid-Holocene. Since that time, the relict but more robust dune forms have degraded and not grown. Soil stratigraphy and geomorphic mapping for this project is discussed in more detail later in the report.

Figure 9: Modified Geologic map of the study region by Stone (2006).

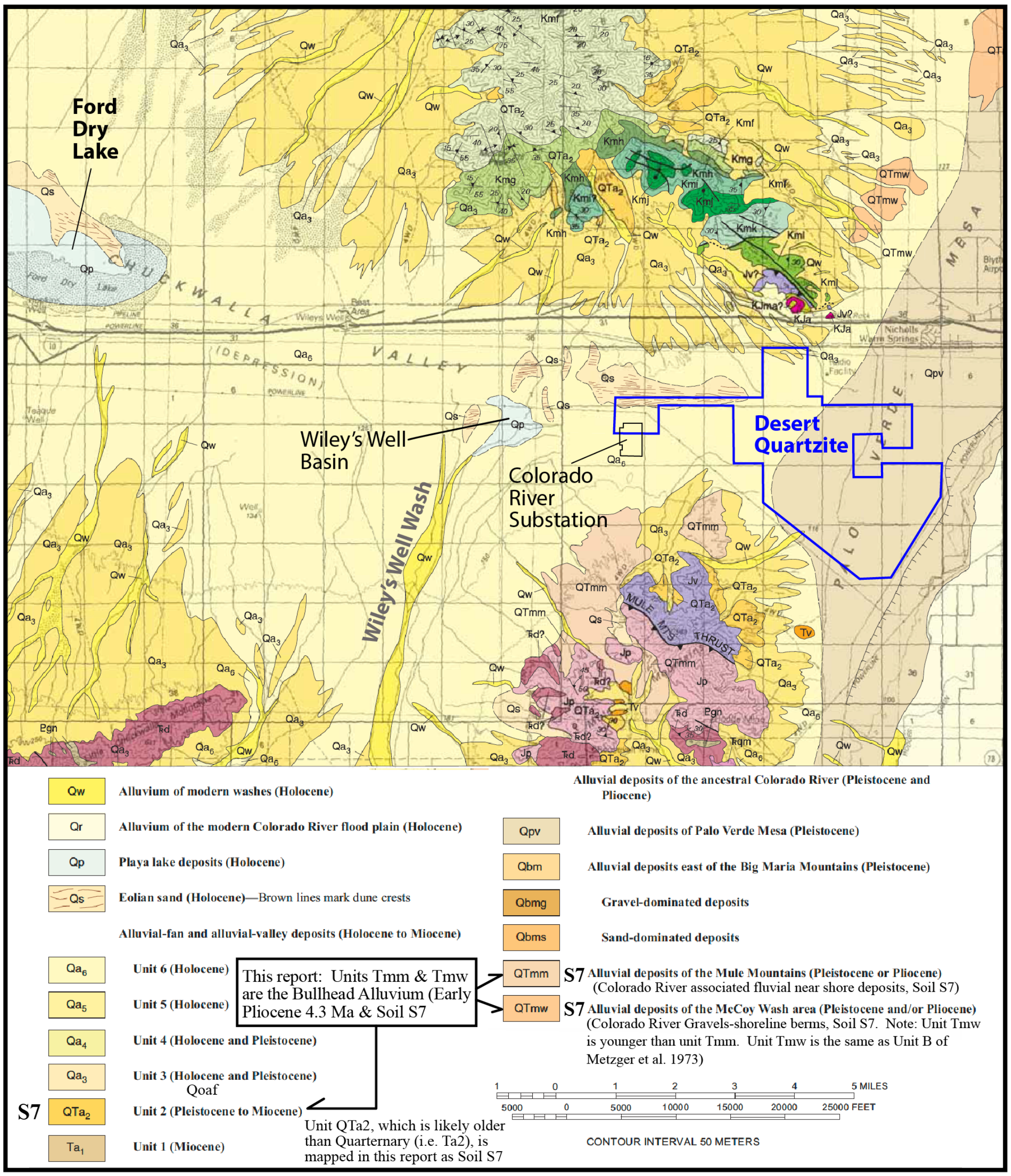
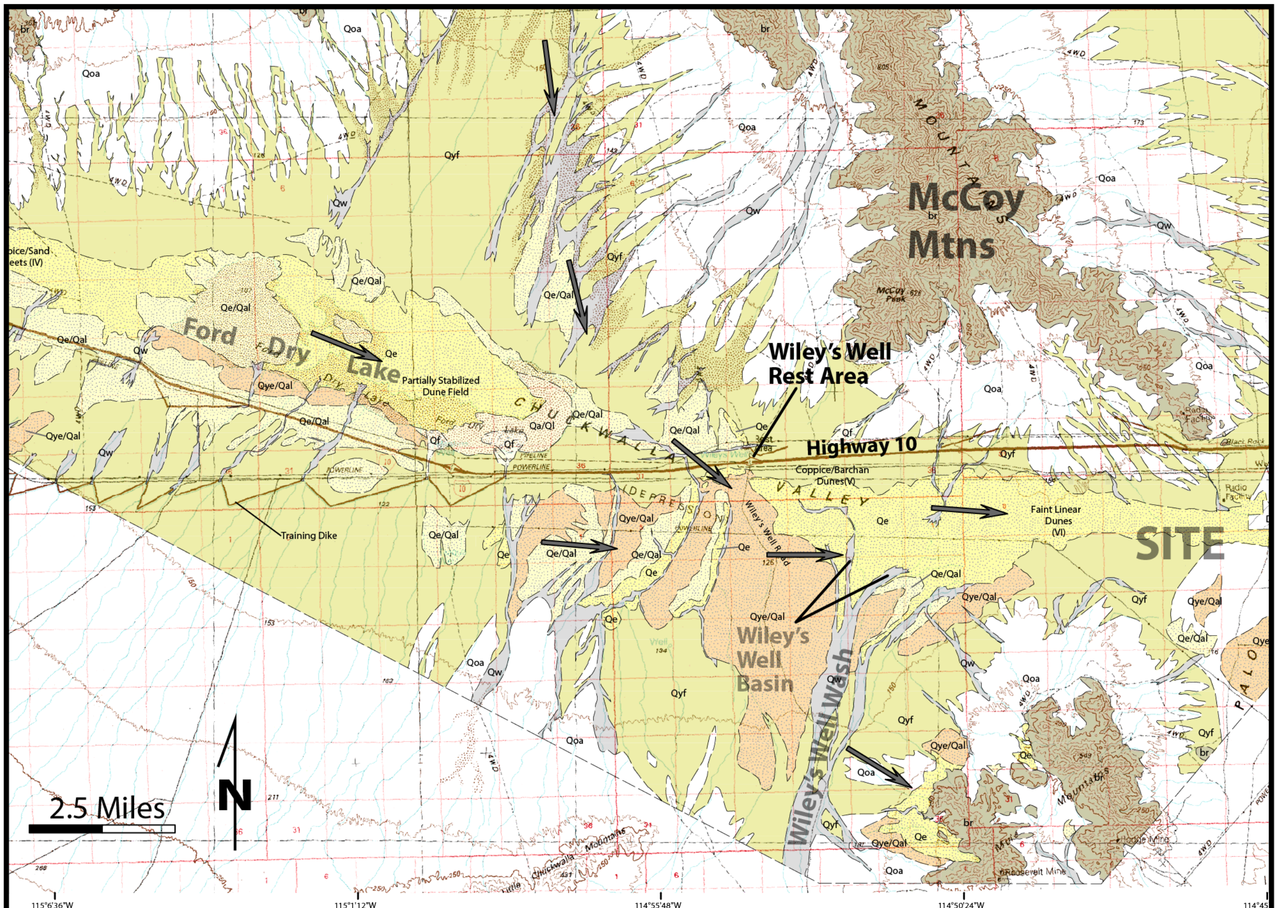


Figure 10: Eolian Geologic map by Lancaster (2014).



Active Eolian Deposits

Qe/Qal — Active windblown deposits consisting primarily of sand sheets and coppice dunes superimposed on alluvial deposits typically < 1.5 m in thickness.

Qe — Active windblown deposits consisting of dunes and sand sheets typically greater than > 1.5 m in thickness. Dunes include transverse, crescentric, parabolic, and barchan forms, as well as coppice dunes and amorphous sand hummocks.

Active Eolian Sources

Qw — Alluvial wash deposits

Qf — Alluvial fan deposits of latest Holocene age.

Qyf — Alluvial fan deposits of latest Pleistocene and Holocene age.

Qa/Ql — Alluvial valley and lacustrine deposits of late Holocene age.

Potential Eolian Sources

Qye/Qal — Stabilized windblown deposits consisting primarily of sand sheets and a small percentage of stabilized dunes superimposed on alluvial deposits. These deposits may exhibit pedogenic soil development consisting of a reddened cambic soil horizon, or carbonate filaments and coatings on pebble clasts, with carbonate morphology of Stage I to I+.

(arrow) — Predominant transport direction. Inferred from geomorphic interpretation of dune crest migration, sand sheets and streaks, and ventifacts. Active sand transport occurs between mapped source and active eolian deposits.

7.4 Geologic History in Historical Times

The primary variation in the local geology during Historical times of approximately the past 100 to 150 years is related to the effects on the dunes from human activity. Namely, the diversion of surface water flow via construction activities and the invasive Sahara Mustard plant. Changes in surface water flow has caused some dune and alluvial areas to receive either an increase or decrease in water flow compared to pre-Historical times. Most of these changes are associated with the construction of Interstate Highway 10 and older major roadways in the same general location since the mid-20th Century. The water flow diversions have allowed for additional water to reach some dune areas, and a bit less in others. This is discussed in more detail later in the report, but the net result within the DQSP is that changes associated with anthropogenic water diversions are quite minimal.

Likely the largest impact to dune systems in the study area and possibly regionally, during Historical times and likely into the future is the invasion of the non-indigenous Sahara Mustard plant. This species experiences dense bloom episodes across eolian dominated depositional areas that may occur approximately every 4 to 7 years based on limited field work data by the author. If this plant persists, it will slow down sand migration rates likely more than an order of magnitude and lead to dune sands depositing closer to their sources.

8.0 REGIONAL EOLIAN SAND MIGRATION CORRIDORS IN SOUTHEASTERN CALIFORNIA

Regional sand migration corridors (sand pathways) have been proposed in southeastern California (Zimbelman et al., 1995). These sand migration corridors are proposed to allow eolian sands to migrate east to southeastward within valleys, and even navigating over mountain passes associated with sand ramps in some instances. The proposed regional sand migration pathways occur in regions where the wind-blown sand is transported over various geomorphic landscapes including playa lakes, alluvial fans, and mountain terrains. However, based on mapping provided in this report, the proposed sand migration corridors consist of a series of individual eolian systems that align via connectivity associated with topographically controlled prevailing winds. In terms of sand source, alluvial fans (washes), playa lakes, and migrating wind-blown sand are concurrently active geologic processes which impart their respective geomorphology to the landscape and occur along the length of the proposed sand migration corridors. Lacustrine (playa and pluvial lake beds) and alluvial fan processes are believed to provide the largest source of eolian sand systems. Hence, sand migration corridors receive substantial eolian sands from local sources along their mapped lengths and the proposed regional sand migration corridors were likely originally mapped as such due to connecting a series of relatively distinct dune systems.

The proposal of regional sand migration corridors, which can easily be mapped on small scale maps covering relatively large regions provide a simple model to conceptualize wind-blown sand migration in southeastern California. However, when the regional sand migration corridors are mapped as a continuous zone extending for tens of miles, it has the potential to imply that sand grains may have the ability to migrate along the entire mapped length of the regional sand migration corridor not only during current times, but continuously since its time of development. This subsequently may lead to the assumption that eolian sand sources along the regional sand migration corridor may be many miles upwind and not local. This possible assumption therefore infers that each proposed sand migration corridor has a “Lake Victoria to the Nile River” (source of the Nile River) type source at the northwestern beginning of the regional sand transport zone. This is clearly not the case for most of the proposed regional sand migration corridors.

Since the proposal by Zimbelman et al. (1995) of the regional sand migration corridors in southeastern California, considerable research has been conducted to better understand when the regional eolian systems essentially began to develop, dune activity variations over time, and what are the primary eolian sand sources. However, to the author’s knowledge, there is not a publication that attempts to integrate these publications collectively.

8.1 Published work regarding regional sand migration corridors (transport pathways)

Numerous geologic, geomorphic and stratigraphic studies have adopted the existence of regional sand transport pathways (sand migration zones) throughout southeastern California (Figure 1, Plate 1 and Plate 2). The initial eolian research in southeastern California that may have provided the concept of regional sand migration corridors was the Sharp (1966) study of the Kelso Dunes. His findings indicate that sand grains migrated 35 miles from their source at Afton Canyon (Lake Manix; Plate 1) toward the east to the Kelso Basin that is bounded by obstructing mountains to the east. Sharp (1966) indicated that the westerly winds transporting the dune sands were topographically controlled by connectivity of local valleys and adjacent mountain ranges.

Based on regional mapping of dune systems in southeastern California, Zimbelman et al. (1995) expanded the findings by Sharp (1966) for the Lake Manix-Afton Canyon to Kelso Dune sand transport zone, that two other regional sand transport pathways occur in southeastern California (Mojave Desert). These include one extending from Bristol Playa through the Cadiz and Danby playa lakes and Rice Valley to the Colorado River, and the other from Dale Lake, across the eastern Pinto Basin, and then continuously down Chuckwalla Valley (Palen and Ford playa lakes) to terminate near the Mule Mountains west of the Colorado River (Plate 1 and Plate 2). Zimbelman et al. (1995) proposed that previously identified eolian dune depositional areas in their proposed regional sand migration pathways are interconnected via a series of wind-blown sand migration zones and intermittent eolian sand source areas.

Lancaster and Tchakerian (1996) evaluated the geomorphology and sediments of sand ramps that occur along the flanks of mountains and mountain passes in the region and indicate that they occur next to regional and local sand transport corridors. These findings indicate that sand ramps, which in a sense exhibit a topographic obstruction to eolian sand migration did allow for continuous connectivity of their respective sand transport pathway.

Muhs et al. (2003) adopted the regional eolian sand transport pathways proposed by Zimbelman et al. (1995) and evaluated whether the eolian sands from the eastern end of these sand transport corridors crossed over the Colorado River in northwestern Arizona as proposed by Zimbelman et al. (1995). Their findings indicate that eolian sands from the eastern end Bristol Lake to eastern Rice Valley sand migration zone were unable to migrate across the Colorado River. Zimbelman and Williams (2002) indicate that the eolian sands east of the Colorado River in the Parker Dunes are chemically indistinguishable from the Colorado River Sands.

This provides strong evidence that eolian sands from the eastern Rice Valley have not been able to migrate across the Colorado River system.

Pease and Tchakerian (2003), based on a geochemistry analysis of sand grains along the path of the proposed sand migration corridors in southeastern California, suggest that the corridors do not represent a continuous "river of sand". Hence, suggesting that eolian sands are likely unable to migrate the entire lengths of the proposed regional sand corridors at any time, but particularly not since the mid-Holocene.

Lancaster (2014) conducted eolian mapping of some of these dune systems and adopted the proposed regional sand migration pathways (corridors). Work conducted by the author (Kenney, 2010a, 2010b and 2010c) for solar energy projects adopted the regional sand migration transport corridors showing a continuous transport pathway along eastern Chuckwalla Valley. Mapping by Lancaster (2015) adopted the regional sand migration corridor model associated with his geomorphic mapping of dune systems in Chuckwalla Valley.

The hypothesis of the regional sand migration corridors in southeastern California by Zimbelman et al. (1995) appears to have provided the benefit of conceptualizing all the dune systems collectively suggesting that they all likely have many commonalities in terms of age, sand sources, relationships with alluvial fan and playa lake activity, and climate variations. Some local parameters have been studied, and they include the clear importance of playa lakes as a source of eolian sands once the playa lakes desiccate, which in turn indicates a correlation of dune activity and climate. Another is the correlation of increased eolian sand production associated with erosion of granitic rocks in the local mountains. However, few detailed geomorphic studies have been conducted to the authors knowledge that evaluate the potential effect on dune systems of local parameters that may result in variations of eolian behavior along particular sections of the regional sand migration corridors. This study attempted to do this by mapping the regional sand migration corridors in sufficient detail such that subtle variations in the dune systems could be identified with the hope that a cause for the variation could be identified that presumably would also be local. This is very important for geomorphic eolian studies for proposed developments due to their "local" scale.

8.2 Latest Pleistocene to present activity of regional sand migration corridors

Numerous published papers provide evidence regarding the timing of dune development and activity since the late Pleistocene in southeastern California. Most dunes systems are dynamic and typically re-cycle older dune deposits via erosion and re-mobilization, and therefore do not provide a continuous stratigraphic record of their geologic history to evaluate long term behavior. Lancaster and Tchakerian (1996), point out that sand ramps however, located along some of the sand migration corridors provided a relatively complete stratigraphic record alternating between eolian and fluvial dominated periods. As they point out, this relatively complete stratigraphic record occurs because the sand ramps deposit upwards (vertically) over time which minimizes erosion of older dunes.

The findings of Bateman et al. (2012) suggest that the palaeoenvironmental information provided by several southeastern California sand ramps may be more complex and less complete than first believed. Based on their review of existing regional sand ramp data and a focus of the Soldier Mountain sand ramp (Plate 1) near Lake Manix, they determined that these eolian deposits accumulated quickly (< 5ky), probably in a single phase before becoming relict (dormant). They indicate that the dune deposits at Soldier Mountain appear strongly controlled by a "window of opportunity" when the plentiful sand is available and cease to develop when this sediment supply diminishes and/or the accommodation space is filled with the confines of the sand ramp depositional area. Their findings are consistent with those of this report indicating that most of the mass of the DQSP site dune systems were primarily deposited during the early to mid-Holocene and are primarily relict geomorphic terrains since that time.

Age data from numerous sand ramps in southeastern California (i.e. Solder Mountain near Lake Manix, Clark Pass, Iron Mountain, and Big Maria Mountains) indicate that a regional strong eolian aggredational event occurred from the latest Pleistocene till near the end of the early Holocene (i.e. 8 to 7 kya; see Plate 8A, 8B and 8C; Lancaster and Tchakerian, 1996; Rendell and Sheffer, 1996; Pease and Tchakerian, 2001; McDonald et al., 2003; Bateman et al., 2012). Eolian deposit age data across southeastern California also indicate that a regional dune aggredational event (strong sand flux and migration rates) occurred from the latest Pleistocene to about 8 kya (Lancaster, 1997l; Lancaster and Tchakerian, 1991).

Lancaster (1994) provides a summary of eolian systems in arid regions that indicates that many dune fields have accumulated episodically, with changes in sediment supply and dune mobility occurring throughout time and likely driven by climatic change. His findings regarding dune fields around the world indicate that there is abundant evidence that eolian activity has been both more extensive and/or intense than it is at present (latest Holocene). Lancaster (1994) indicates that evidence to support a significant decrease in eolian activity during the later Holocene include dormant and relict dunes and sand sheets that are stabilized by vegetation and soil development among others processes. Pease and Tchakerian (2002) indicate, along with numerous other studies of eolian dune systems across southeastern California (see Plate 8A, Plate 8B and Plate 8C), that the regional sand migration corridors have dramatically slowed down since the mid-Holocene.

Regional mapping of the Dale Lake to eastern Chuckwalla Valley for this study identified areas where the sand migration pathway is essentially shut down. The region of Dale Lake to the Eagle CoxComb Pass was mapped via historical Google Earth Pro imagery and this section appears essentially shut down for through going eolian sand transport (red dashed line on Plate 1). In addition, this section exhibits very weak dune geomorphology in an area dominated by alluvial systems indicating it may not have ever been a significant eolian sand pathway (Plate 1 and Plate 2). Instead, it is proposed that the Dale Lake sand system for the most part terminates near the Clarks Pass sand ramp (Plate 1) and that the abundant eolian sands occurring at the eastern end of the Pinto Basin (herein named the Pinto Basin Dunes) were derived primarily from the west to east flowing drainage system within the basin. Hence, the Pinto Basin Dunes are proposed to have developed not by west to east sand migration from the Dale Lake areas, but instead by the local robust Pinto Basin wash system. This wash produces more eolian sands than typical washes due to numerous factors. The wash occurs in the valley axis and flows parallel to the topographically controlled prevailing winds. The water shed (not mapped) for the Pinto Basin wash is relatively large and extends beyond the limits of the basin and local bounding mountain ranges. The large watershed causes this wash to flow more frequently than washes associated with smaller water sheds. The occurrence of abundant granitic rocks as well in the local mountains also assists the washes to produce a relatively larger magnitude of eolian sand than washes emanating from other types of bedrock.

Aerial image mapping also indicates a fluvial dominated system and that eolian sand migration is hindered over Eagle CoxComb Pass causing the eolian sand migration rate to be relatively slow to the southeast in the eastern Chuckwalla Valley (red dashed line on Plate 1). A series of active dunes along the west flank of the CoxComb Mountains (Plate 2) likely receive abundant eolian sands from the local wash that is proposed to carry more eolian size sand grains than typical desert washes. This wash may carry an order of magnitude more eolian sand size bedload than typical washes emanating from bedrock dominated mountain ranges because it is the eastern extent of the Pinto Basin wash system. Hence, this wash has flowed through the eastern Pinto Basin dune system and entrained abundant eolian sand that had deposited within the wash. In addition, this wash is also provided higher than usual eolian size sand grains due to erosion of older (Pliocene) fluvial sediments (dark blue units on Plate 2) and granitic rocks exposed in the local mountains. The wash then flows to Palen Dry lake and provides eolian sand to that system due to its orientation down the valley axis parallel to prevailing winds and its wide braided drainages with subtle bar and swale geomorphology. Hence, the Pinto Basin wash system has essentially resulted in a series of eolian dunes that connect the Pinto Basin Dunes with those of the northwestern Palen Dry Lake dune system. In this model, sand transport from the Pinto Basin to the northwestern Palen Dry Lake likely includes episodes of fluvial and eolian transport. Episodic forms of transport of eolian size sand grains may very well be the case on playa lake beds.

Eolian Geomorphic mapping via field work and analysis of historical Google Earth Pro imagery between Palen and Ford dry lake bed areas, and in the eastern Ford Dry Lake area indicate that sand migration rates are very low and that older relict dune systems are eroding. Hence, these areas represent eolian sand migration “breaks” essentially along the Chuckwalla Valley sand corridor system. As discussed in other portions of this report, numerous local sources of eolian sand occur in the Ford Dry Lake area.

8.3 Published eolian sand sources for regional sand migration corridors

The southern eolian dune systems collectively occur within a relict landscape that developed during Basin and Range extensional tectonics of the late Miocene through possibly early Pliocene. The extensional tectonics pulled the crust apart resulting in a series of exposed mountain ranges and adjacent valleys. This region is referred to as the Basin and Range geomorphic province due to this phase of deformation and that the valleys are in fact internal continental basins with flow from local and most regional drainages terminating within local valleys. This is important because most of the eolian sands in the regional dune systems originally are created by erosion of the local mountain ranges. The mountain derived eolian sands then migrate downslope, primarily associated with alluvial processes, although some grains are picked up by the wind to become available for the local eolian system.

However, evaluating specific eolian sand sources is complex due to the relatively common mineral composition of most of the rocks exposed in the local mountain ranges. Granitic rocks, which are common in the region (Plate 1 and Plate 2), easily erode to produce a relatively large magnitude of eolian size sand grains compared to other rock types, suggesting that washes emanating from granitic rock exposures may be a relatively larger source of eolian sands than other mountain ranges. This was found to be the case by mapping during this project where a good example of a primarily granitic eolian sand source was identified in the Pinto Mountains (Plate 1).

Many research articles have indicated that the primary source for eolian sand is from playa lake surfaces and alluvial processes (Sharp, 1966; Zimbelman et al., 1995; Lancaster and Tchakerian, 1996; Lancaster, 1997; Ramsey et al., 1999; Pease and Tchakerian, 2002; Zimbelman and Williams, 2002; Pease and Tchakerian, 2003; Muhs et al., 2003) Playa lake beds result in the production of relatively high volumes of eolian sands once they desiccate, providing not only a pathway for eolian sand but also a sand source from sand baring wind abrasion. Alluvial processes (fluvial) produce eolian sands quite readily soon after a wash flows and experiences wind speeds sufficient to pick up sand and transport it. This process assists in the supply of new eolian sands to an eolian system outside of the wash where the bar and swale relief of the wash is sufficiently small to allow the eolian sand grains to exit the fluvial system. This is typically the case in the distal portion of fans or where washes flow along valley axis.

Playa lakes occur sporadically, and alluvial washes occur essentially along the entire length of the regional sand migration corridors (Plate 1 and Plate 2). This suggests that local eolian sources are a very important sources, if not the most important source, of eolian sands along the regional sand migration corridors and this is proposed by numerous regional eolian studies referenced previously. For example, Pease and Tchakerian (2003) agree with other work that the local sources along the corridor system provide the primary source of eolian sands (Zimbelman and Williams, 2002; Muhs et al., 2003). Hence, the regional sand migration corridors clearly receive eolian sands along their path with strong influxes near and downwind from playa lakes and by washes that occur in most valley regions. These findings are consistent with those of this report based on regional eolian mapping shown on Plate 1 and Plate 2. But as explained in more detail below, these conditions are not present in and around the DQSP site.

Ramsey et al. (1999) evaluating the Kelso Dunes provide evidence not only of eolian sands having migrated from the Mojave River-Lake Manix source areas 35 miles to the west, but also from local mountain ranges (alluvial processes) bounding the Kelso Dune themselves. However, the proposed Lake Mojave that occurs only 20 miles to the west and the final flow destination for the Mojave River-Lake Manix hydrologic system (Enzel et al., 2003 and Wells et al., 2003; Plate 1) also provides substantial eolian sands to the Kelso Dune system.

It appears based on review of all the data and research conducted by the author that during periods of strong eolian activity (dune aggredational events), eolian sands travel large distances when the regional sand migration corridors provide a more continuous pathway, and that these sands would be able to mix with the continuously provided local eolian sources. These conditions occur when vegetation densities are at lower elevations and relatively frequent monsoonal storms occur during dry periods of the year. During times of dune stability, the regional sand migration corridors become discontinuous and local sources primarily associated with playa lake beds and alluvial systems dominate. In addition, during periods of dune stability when the older dunes become relict, they begin to cannibalize the older dunes associated with wind abrasion (eolian deposits re-working) that provides an additional source for active eolian sands (Lancaster, 1995). Within the DQSP and many other areas in the Chuckwalla Valley, erosion of older relict dune deposits are a primary source for the minimal active eolian sands occurring within dune systems poorly fed by a playa lake (or ponding area) and alluvial systems (Kenney, 2010a, 2010b, and 2010e). The findings of this report indicate that a period of dune stabilization and associated dune abrasion (cannibalization) has been occurring in many dune systems in the Chuckwalla Valley during the late Holocene. As discussed earlier in the report and in the next section, some localized dune areas remain relatively active due to continuous input of new eolian sands from local sources that generally occur near playa lake beds, ponding areas, and strong alluvial systems.

8.4 New hypotheses regarding eolian sand sources along the regional sand migration corridors

As discussed above, playa lake beds and alluvial systems represent the primary sources for newly generated eolian sands. Regional eolian system mapping during this project provided on Plate 1 and Plate 2 provided insights regarding local parameters associated with playa lakes (and ponding areas) and alluvial processes that play a role in newly derived eolian sand. These concepts assist in the understanding of the relative importance of local eolian sources verses far field from upwind areas along the proposed regional sand migration corridors. Some previously unrecognized eolian sand sources have also been recognized.

Playa lakes for example are generally described as a strong eolian source primarily after they have desiccated when the climate changes from wet to drying (i.e. at the end of the last ice age). However, playa lakes in southeastern California region routinely flood to shallow depths that provide surface instabilities resulting in eolian sand production. This is the case for local Palen and Ford dry lake beds that receive significant flow from local drainages. In fact, subdued drainage systems occur across these playas allowing for relatively frequent surface disturbance that greatly increases eolian sand production. The fluids also assist in providing ongoing dune stabilizing moisture. Hence, it is not necessary for playa lakes to fill completely for extended periods of time and then finally desiccate to provide a significant eolian sand source for local dune systems. This locally observed process is likely the case for other playa lake beds in the region.

Another eolian sand source not previously identified or evaluated comes from the erosion of older sedimentary deposits. This local eolian sand source is proposed to be significant to many dune systems along the Dale Lake to eastern Chuckwalla Valley sand migration corridor. In the west, the Dale Lake dune system occurs primarily east (downwind from prevailing winds) of Dale Dry Lake, which based on aerial imagery mapping in Google Earth Pro is only approximately 3 square miles in size. In addition, eolian deposits are identified upwind from Dale Dry Lake across a surface of eroding older sedimentary deposits via a series of tributaries and wind abrasion (brown areas on Plate 1 and Plate 2). The fluvial networks erode into the older sedimentary units that are exposed across a large surface area (i.e. piedmont) resulting in fluvial erosion where the drainages produce loose sediment bearing large quantities of eolian size sand grains that can then be transported by the wind once flow ceases. In addition, sand bearing wind across the sedimentary piedmont surface induces additional erosion of the exposed older sedimentary deposits resulting in the production of additional eolian sands which can be easily transported toward the east to become part of the Dale Dry Lake dune system.

Within the Chuckwalla Valley, erosion of exposures of the mostly Pliocene fluvial and quiet water deposits associated with the Colorado River engulfment of the valley provide a significant source of eolian sands. These deposits are dominantly unit Tmm of this report (also referred to as Soil S7, unit QTmm of Stone, 2006) and are clearly a source of eolian sand based on their isolated exposure in the Mule Mountains where erosion of this unit appears to be the only reasonable source of eolian sands for the local dune system (Plate 4). Erosion of this and other similar units essentially cause local washes eroding into them to provide a larger source of eolian sands than due typical washes emanating from bedrock mountain ranges and across typical alluvial fans. For example, most of the dune systems in the eastern Chuckwalla Valley have received much more eolian sand due to the erosion of the older sedimentary deposits (Tmm) than would typically have been the case for typical Mojave Desert washes which has been an important factor in the development of Ironwood and Wiley Well Basin sand migration zones (Plate 3A). In fact, it is proposed that the Mule sand migration zone in the southeast corner of the DQSP may not even exist if it were not for the robust sand transport of the local washes carrying eroded older sediments from unit Tmm. An important parameter in the evaluation of the significance of eolian sand source from the erosion of older sedimentary units is the size of the drainage water shed, characteristics of the wash system in terms such its orientation, braided geomorphology, and termination conditions (ponding area, playa surface, etc.).

Although alluvial processes are considered a major source of eolian sands for regional dune systems, they have not been evaluated in detail regarding how they may play a role other than as a conduit for wash transport. The observation that erosion of unit Tmm, which is not alluvial fan deposits, was clearly a significant eolian sand source led to the hypothesis that periods of erosion into older alluvial fan deposits (fan trenching) would likely also result in significant increase in eolian sand. This led to the evaluation of the timing and cause of alluvial fan aggredational events, and timing of alluvial fan trenching (down cutting, Plate 8C). This idea was apparently conceptualized by Lancaster (1997) that provides insightful concepts by indicating that eolian deposits are a product of climatic changes that increase sediment supply from fluvial and lacustrine (playa and pluvial lake beds) sources and may, therefore, be closely tied to period of channel cutting and geomorphic instability. This idea is discussed later in the report, but in summary, it was determined that eolian systems across southeastern California exhibited much higher magnitudes of activity (aggredational events) during times of alluvial fan aggredational events, and during times of alluvial fan trenching (Plate 8A, Plate 8B and Plate 8C). The process of alluvial fan trenching may be one parameter that allowed dune systems to be more sporadic over time than alluvial fan aggredational events as the two processes can occur independent of the other. The evaluation also indicates that eolian dunes across southeastern California experienced dune aggredational events during periods of relatively stronger and more frequent monsoonal storms (cloud burst, isolated thunder storms) but colder Pacific storms systems were occurring less frequently. This climate condition occurred during the early Holocene and mid to late Holocene and correlates with periods of time of increased eolian activity (Plate 8B). Increased monsoonal storm activity and decreased Pacific storm activity most strongly occurred in southeastern California, and are recently being discovered to be the driving agent for regional alluvial fan aggredational events.

9.0 CHUCKWALLA VALLEY DUNE SYSTEMS - SAND MIGRATION ZONES AND STABILITY

Detailed geomorphic eolian mapping via field work and aerial imagery (Google Earth Pro) in the Chuckwalla Valley was conducted utilizing the designated relative geomorphic sand migration zones (Appendix C; Plate 2) that have evolved as a method of eolian mapping by the author (2010b, 2010d, 2010e, 2011) In addition, general mapping was conducted for this region utilizing the geologic-geomorphic designations (Report Section 7.3) that have also evolved over time by the author in an attempt to construct terms that describe geomorphic variations within dune systems that to the author's knowledge had not been done previously. For example, the use of eolian map units Qsa, Qsad and Qsr to designate regions dominated by active, active and stable mix, and stable eolian sediments exposed on the surface was new (2010a, 2010b, 2010d, and 2011). The results of this mapping are provided below.

9.1 Identified local sand migration zones

One criteria for a dune system to be designated as an independent sand migration zone is that a dune system receives a significant source of sand from a local source that is independent from sources upwind associated with the regional valley axis sand migration corridor. Consistent with earlier work by Kenney (2010a and 2011) identifying local independent sand migration zones (SMZ) in the Chuckwalla Valley (i.e. Palen Valley SMZ and Mule SMZ on Plate 3A), the more detailed mapping conducted during this study led to the identification of numerous semi-local and local independent sand migration zones in the area of the DQSP. Some of these zones are natural, and others result from anthropogenic activities that are historical in age. More specifically, the sand migration zones are shown on Plate 3A, and include:

9.1.1 *Palen Lake Sand Migration Zone*

The Palen Lake SMZ occurs along the southwestern region of the Palen Dry Lake, more specifically along the alluvial fan and playa lake bed contact (Kenney, 2010b). Hence, most of the dune deposits associated with the Palen Lake SMZ occur on top of playa lake bed deposits (Kenney, 2010b).

Eolian sands migration over time in the Palen Lake SMZ is dominantly from NWW to SWW along the southern portion of Palen Dry Lake in a region, however, each year strong prevailing winds emanating down the Palen-CoxComb Valley from the NNW west causing eolian sands to migrate toward the SSE, which assists in concentrating the Palen Lake SMZ eolian deposits along the southwestern portion of the playa.

The primary source of eolian sands for the Palen Lake SMZ is from the northwest associated with the sand migration system along the western flank of the CoxComb Mountains, but also the wash that flows along the western margin of that dune system. This wash system is connected to Pinto Basin and represents a very large watershed area. Southeast moving water flows along the wash into the southwestern region of the Palen Lake SMZ dune system (Plate 3A and Plate 3B). Most alluvial washes flowing northward from the Chuckwalla Mountains flow through the dunes to reach the playa lake bed and these washes may reach the playa area more frequently compared to historical times due to flood control berms associated with Highway 10 that concentrate and increase channel flow. There is clear evidence of relatively frequent flooding on Palen Dry Lake, indicating that the lake bed itself is a significant eolian sand source. In addition, flood waters are able to penetrate vast areas of the Palen Lake dune system which provides critical stabilizing moisture allowing the dunes to resist sand bearing wind abrasion.

Most of the eolian sands of the Palen Lake SMZ exhibit a distinctive pale orange color and particularly along the southwestern two-thirds of the SMZ (Plate 3A). This is in contrast with the light grayish color of the East Palen Lake SMZ that intersects the Palen Lake SMZ to the southeast. Some of the dunes along the northeastern region of the Palen Lake SMZ exhibit colors that are not distinctly orange nor light gray. This suggests that some eolian sands enter the northeastern region of the Palen Lake SMZ from the north from the erosion of lakebed sediments and/or across the entire exposed playa surface.

The Palen Lake SMZ is the most robust dune system in Chuckwalla Valley and represents an interconnected network of transverse dunes exhibiting seasonal avalanche faces. These areas are mapped as Zone AB on

Plate 3B. Active barchan dunes over 10 feet tall that exhibit avalanche faces occur in this area, indicating a prevailing wind from the NWW to SSE. In some areas the barchan dunes, which develop in areas of relatively low eolian sand input flux, commonly occur in the central Palen Lake area as independent dunes separated by playa lake surfaces. As observed on various years of historical imagery, dune activity levels and stability vary significantly depending on precipitation.

9.1.2 *East Palen Lake Sand Migration Zone*

The East Palen Lake SMZ transports sand southward down the Palen-CoxComb Valley axis and then along the eastern edge of Palen Dry Lake along the contact between the lake bed surface to the west, and alluvial fan deposits to the east. Portions of the East Palen Lake SMZ are deposited on older alluvial fan surfaces and alluvial washes flow through and within the dune system providing additional eolian sand source, dune stabilizing moisture, and destabilization as it reworks eolian sands. The most robust dune form in the area are weak transverse dunes generally less than 5 feet tall that exhibit avalanche faces indicating a north to south prevailing wind.

The East Palen Lake SMZ merges with the Palen Lake SMZ in the easternmost area of the Palen Lake playa lake beds. The East Palen Lake SMZ dunes exhibit light grayish hues similar with the Palen Lake playa surface to the west suggesting that the playa lake beds are a significant eolian sand source. This is supported by the identification of a braided wash system flowing southward across the entire length of the playa west of the East Palen Lake dune system and seasonally variable amounts of migrating eolian sands identified on the lakebed. Toward the north, the primary eolian sand source for the East Palen Lake dune system is from the north associated with eolian deposits along the Palen-CoxComb Valley wash system north of Palen Lake (Plate 2).

9.1.3 Palen Lake-Western Ford Lake Sand Migration Zone

The Palen Lake-Western Ford Lake SMZ occurs in the western region of Ford Dry Lake and receives eolian sands from the Palen Lake and Eastern Palen Lake SMZ's to the west, erosion of Ford Dry Lake, and erosion of relict dunes. The dune system is very weak and non-continuous, stabilized, and in many areas degrading. The most robust dunes in the area are converging relict strongly stabilized mounds exhibiting active sand sheets. The dune deposits are less than 5 feet thick.

Aerial mapping of various years indicates that many upwind relict dune deposits in the eastern portion of the dune system are eroding via sand bearing wind transported over the lakebed in the west. Numerous low bar and swale washes occur on the Ford Dry lake bed which in terms of aerial coverage represents well over 50% of the region of the Palen Lake-Western Ford Lake SMZ. Ponding also occurs in the central region of the Palen Lake-Western Ford Lake SMZ immediately west of a stabilized, relict, and degrading dune system. These areas are observed on Plate 3B where the ponding area is shown as unit Ql-de (playa erosional area) to the west of unit Qe-ds (stabilized dunes). Hence, in terms of the regional sand migration corridor extending down the Chuckwalla Valley, the exposed playa lake bed in western Ford Dry Lake represents a section where sand migration rates have not been sufficient certainly during the late Holocene, but possibly during the entire Holocene, to allow for the development of a dune depositional area that could geomorphically overcome playa processes. In the central and eastern Ford Dry Lake area the dune and playa processes compete geomorphically in more equal proportions.

9.1.4 East Palen Mountains Sand Migration Zone

The East Palen Mountains SMZ receives eolian sand from a drainage system emanating from the southeastern Palen Mountains west of the Genesis Solar Project (Plate 3A). Eolian sands produced by this wash system immediately north of the playa surface of Ford Dry Lake migrates southeastward to merge with eolian sands migrating eastward in the Palen Lake-Western Ford Lake SMZ (Plate 3A). A region of exposed playa surface that frequently floods occurs between the Palen Lake-Western Ford Lake and East Palen Mountains SMZ. This playa area provides a source for new eolian sands for the southeastern portion of the East Palen Mountains SMZ. The most robust dunes in the area are seasonally active interconnected and non-migrating dune mounds. In many areas activity levels of the dunes decreases outward toward the edges of the system where the relict dune mounds erode providing an internal source of eolian sands.

9.1.5 East Ford Lake Sand Migration Zone

The East Ford Lake SMZ receives eolian sands from the East Palen Mountains SMZ to the west, a ponding and water flow drainage system that flows to the north just west of the western mapped boundary of the East Ford Lake SMZ, and erosion of older relict dune deposits (Plate 3A and Plate 3B). The dune system is stable and in many areas degrading which provides an internal source of eolian sands. The dune system consists of an interconnected dune mound system generally less than 5 feet thick exhibiting a network of ponding areas within interdune depressions many of which are interconnected themselves. The interdune depressions are filled with water relatively frequently allowing for the infiltration of stabilizing moisture for the dune system. In addition, these flooding events, as observed by the author in the field, are sufficient to fill the interdune depression such that they breach from one depression to another which then can develop into internal flood-flow events as one basin drains into another in a cascade fashion. These flood events remobilize relict eolian sand deposits which provide a new eolian sand source.

Eolian sands within the East Ford Lake SMZ migrate ESE (see Windrose Direction in the Glossary, Appendix B) to where it merge with eolian sands migrating toward the SE within the Palen Valley SMZ (Plate 3A). However, sand migration rates in the central portion of the East Ford Lake SMZ are very low (Zone C) and the region primarily consists of exposed playa lake beds as shown on Plate 3B. This indicates that the East Ford Lake SMZ likely contributes minor eolian sand to the Palen Valley SMZ since the mid-Holocene.

9.1.6 Palen Valley Sand Migration Zone

The Palen Valley SMZ occurs on the southeastern region of Palen Valley and receives its eolian sand from a braided channel system that flows from north to south in Palen Valley (Kenney, 2010a). The Palen Valley wash system flows relatively frequently to terminate in Ford Dry Lake. The most robust dune type in the zone are linear dunes that exhibit avalanche faces that are in places over 5 feet tall. Two areas exhibiting linear dunes occur with one in the northern region, fed by eolian sands from the Palen Valley wash system, and the other in the southeast, fed by the combination of the merging of the Palen Valley and East Ford Lake SMZ's. In the two linear dune areas, they are commonly bounded by washes, particularly along their eastern side, and separated by zones of weak sand migration rates over alluvial fan surfaces. Between the two linear dune areas, alluvial fan washes and deposits dominate the geomorphology. These alluvial fan drainages flow toward the SSW across the Palen Valley SMZ to terminate in Ford Dry Lake. Some of these washes emanate from exposures of unit Tmm which upon erosion provide an increased eolian sand input for the Palen Valley SMZ (Plate 4).

Toward the southeast, the more robust Palen Valley SMZ merges with the weaker East Ford Lake SMZ, which as discussed previously, produced in a new set of linear dunes exhibiting avalanche faces which extend all the way to just north of the Wiley's Well Rest Stop (Plate 3A). Geomorphic and soil stratigraphic field mapping immediately south of Highway 10 within the Palen Valley SMZ indicates that sand migration rates in this area have been low for a minimum of the past 3 to 5 thousand years. However, anthropogenic activities have greatly reduced the sand migration rate in the southeastern Palen Valley SMZ. Construction of Highway 10, which consists of two elevated berms over 10 feet tall with a middle depression and associated parallel shallow fill borrow pits, has greatly diminished the ability of eolian sands to migrate to the previous natural termination at the western end of the Wiley's Well Basin dune system (Plate 3A).

9.1.7 Ironwood Sand Migration Zone

The Ironwood SMZ occurs north of the Ironwood State Prison and south of Highway 10 (Plate 3A). The primary source of eolian sand for this zone is from a series of south to north flowing washes emanating from the Little Chuckwalla Mountains (see Plate 7A). These washes transport more eolian size sand than typical Mojave Desert washes due to the erosion upstream of the Pliocene Colorado River deposits unit Tm (see Plate 4). In addition, the erosion of granitic rock exposures in the region between the eastern Chuckwalla Mountains and western Little Chuckwalla Mountains allows these washes to carry a larger magnitude of eolian size sands than typical Mojave Desert washes which also provides a source of eolian sands to the Ironwood SMZ (Plate 7A). A very minor component of eolian sands within the Ironwood SMZ emanate from the regional Chuckwalla Valley Sand Migration Corridor system. In addition, very minor eolian sands migrate east of the Ironwood SMZ to merge with the Wiley's Well Basin eolian system.

The most robust dune type in the Ironwood SMZ are transverse to the linear dunes due to variable prevailing wind regimes. The linear dunes are commonly bounded by active washes on their eastern side and eastward migration of the dunes has resulted in eastward migration of the washes. Between the more robust linear-transverse dune areas are regions dominated by alluvial geomorphology where relative sand migration rates are low.

9.1.8 *Wiley's Well Basin Sand Migration Zone*

The Wiley's Well Basin SMZ dune system occurs in the region of the Wiley's Well Basin and the northern limit of the Wiley's Well Wash in the west, and extends eastward to terminate where it merges with the Polowalla Sand Migration Zone (Plate 3A). The Wiley's Well Basin SMZ extends along the northern most portion of the DQSP site (Figure 11). It is proposed that nearly all eolian sands in the Wiley's Well Basin SMZ system were generated locally not only during the early Holocene regional eolian aggredational event, but also since the mid-Holocene. Eolian sands in the Wiley's Well Basin SMZ are generated from the wide, north flowing Wiley's Well Wash braided wash system, south flowing washes from the southern McCoy Mountains, and Wiley's Well Basin ponding area where all these wash systems terminate. The Wiley's Well Basin floods frequently from monsoonal cloud burst "thunderstorm" events that, based on mapping in the region since 2010, have occurred a minimum of two times. As discussed later in this report, the watershed drainage area for the Wiley's Well Wash is large extending over 16 miles to the south allowing for drainage of the western Mule Mountains (Plate 7A).

The Wiley's Well Basin SMZ is provided a relatively higher amount of eolian sands from the local washes due to erosion of older silty-sand sedimentary deposits of the ancient Colorado River (unit Tmm) located in the "alluvial fan" regions in the southern McCoy Mountains "embayment" (Plate 7B), and western Mule Mountains (Plate 2 and Plate 4). Erosion of unit Tmm has also provides the primary eolian sand source for dune deposits along the flanks of the Mule Mountains and within the mountain range (Plate 4).

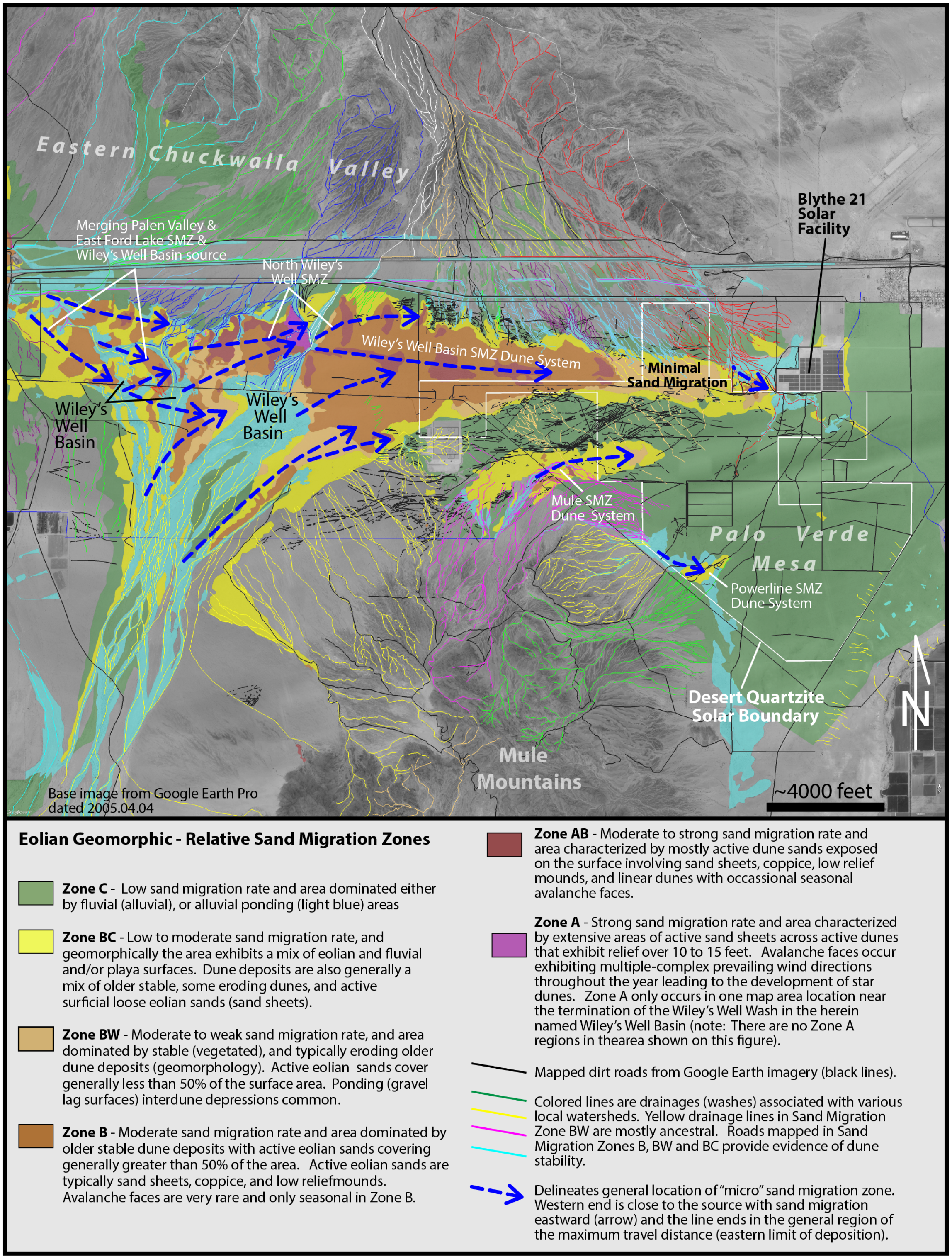
The most robust dune form in the Wiley's Well Basin SMZ are complex-star dunes that are over 15 to 20 feet tall and exhibit seasonal avalanche faces (Zone A on Plate 4). These features are also mapped as within the North Wiley's Well Basin SMZ that is discussed later (see Plate 3A). The Zone A area is bounded on the eastern side by washes emanating from the southern McCoy Mountain embayment area (Plate 7B). Over time, the wash along the eastern side of Zone A has migrated eastward likely tens of feet as the dunes migrated. The wash continues to flow southward to pond in the Wiley's Well Basin, hence, to mix with waters from the Wiley's Well Wash system.

Toward the east of Zone A in the Wiley's Well Basin SMZ and its corresponding east bounding wash, the Wiley's Well Basin SMZ, the most robust eolian dunes are stabilized linear dunes that are typically less than 3 feet tall and only occasionally exhibit seasonal and alternating direction avalanche faces. These occur in areas mapped as Zone AB on Plate 5. These dunes are likely relatively more vegetated due to competing prevailing winds from the west and southwest than would be the case if there was a strongly dominant prevailing wind. Some very weak and not fully developed transverse dunes occur in the northern most region of the Wiley's Well Basin SMZ, however, this area is delineated as the North Wiley's Well Basin SMZ discussed separately later.

The dune deposits in the Wiley's Well Basin SMZ are less than 5 feet thick typically, and gradually get thinner toward the east where in some areas mapped as Zone BC and Zone BW are less than 3 feet. In areas mapped as Zone BC, older alluvium of Soil S4 occur at depths of only a few inches within interdune depressions and the dune deposits represent relict dune mounds that vary from full connectivity to scattered connectivity. Eolian deposits are generally thinner for progressively less active geomorphic eolian sand migration zone designations. In addition, the eolian deposits associated with Zone BC which bounds the limits of an eolian dominated area, gradually thin toward its contact with mapped Zone C. Hence, in contrast to Lancaster (2014) eolian mapping for this project was not based on dune deposit thickness, but instead, on observed eolian geomorphology on the surface.

The Wiley's Well Basin SMZ gradually narrows from a width proportional to that of the Wiley's Well Basin (~3.5 miles), to approximately 0.5 mile within the DQSP (Plate 5). The dunes activity also decreases toward the east with the eastern portion of the Wiley's Well Basin SMZ receiving very little sand flux input from the west within the DQSP (Zone BW on Plate 4 and Plate 5). The primary cause for the decrease in width of the sand migration zone is the Palo Verde Topographic Sill, which is the geographic/geomorphic boundary between the eastern Chuckwalla Valley and the Western Palo Verde Mesa (Plate 5). The Palo Verde Topographic Sill, is located approximately in the middle region of the Wiley's Well SMZ (Plate 5). The Palo Verde Topographic Sill consists of rise from an elevation of ~438 feet in the Wiley's Well Basin in the west, to the sill itself at an elevation of ~488 feet (high point), and then back down to an elevation of ~400 feet near the Palowalla SMZ. Hence, eolian sands migrating eastward from the Wiley's Well Basin move uphill approximately 50 feet in relief, and this rise causes eolian sands to deposit. On the downwind leeward side of the topographic sill, eolian sands are also encouraged to deposit as wind speeds decrease. The sill has likely allowed for relatively more eolian sands to be deposited on the western side, crest and immediate eastern side than would have deposited if the topographic sill did not exist. In addition, the amount of wind-blown sand reaching the eastern most area of the Wiley's Well Basin SMZ is dramatically decreased because most of the transporting sand is encouraged to deposit on the to the west associated with the topographic sill (see area Zone BW on Plate 5). Most of the active eolian sands in Zone BW (Plate 5) are produced by the erosion (cannibalization) of older relict (dormant) dune deposits.

Figure 11: Eolian Geomorphic & Relative Sand Migration Zone map of the eastern Chuckwalla Valley and Palo Verde Mesa area.



9.1.9 North Wiley's Well Basin Sand Migration Zone (anthropogenic)

The North Wiley's Well Basin SMZ occurs within the Wiley's Well Sand Migration Zone and is designated as a separate system based on the interpretation that this dune area has been affected by anthropogenic activities related to water flow diversions. Most drainages from the southern McCoy Mountain embayment are diverted since construction of Highway 10, as shown on Plate 7B. This has caused some of the northern areas of the Wiley's Well Basin dune system to receive more and less drainage flow (Plate 7B). The water flow diversions have resulted in more water entering the western region of the North Wiley's Well Basin SMZ leading to an increase in eolian sand generation, and relatively dryer conditions in the eastern portion of the North Wiley's Well Basin SMZ leading to a region exhibiting less vegetation density where eolian sands can migrate further distances than would be the case naturally (Plate 7B). These conditions have led to a historical increase in sand migration from the southward flowing wash along the eastern side of Zone A in northern Wiley's Well Basin area (Plate 4), toward the ENE within the North Wiley's Well Basin SMZ. A series of low relief, active, poorly vegetated transverse dunes occur in this area (Zone A areas on Plate 5), that may have resulted from ablation erosion of older more pronounced linear dunes due to a decrease in internal dune stabilizing moisture. This area receives less moisture in historical times due to water flow diversions (Plate 7B). Alternatively, these weak linear dune forms may have developed during historical times due to the increase in eolian sand production downwind and increase in the ability for sand to migrate in the area due to a decrease in vegetation.

9.1.10 Palowalla Sand Migration Zone (Anthropogenic)

The Palowalla SMZ occurs at the eastern end of the Wiley's Well SMZ and is designated as a separate zone based on anthropogenic water flow diversions associated with the construction of Highway 10 to the north. Construction of the Blythe 21 Solar Facility cut off water flow in a wash that historically ran through the facility site resulting in creation of, or increase in, ponding adjacent to the facility (Plate 3A and Plate 7B). This region has experienced an increase in drainage flow due to diversion of watershed area K1 and a portion of K, which since construction, is completely diverted to flow through the Palowalla Ditch (flow under Highway 10, Plate 7B). In addition, a north-south trending flood control berm extending from Palowalla Ditch at Highway 10 to just northwest of the Blythe 21 Solar Facility has also focused flow that would have spread out over the alluvial surface to the western area of the existing solar plant. Un-natural ponding of these flood waters occurs along the western and southwestern areas just outside of the facility due to elevated berms bounding the site (Figure 12).

It is proposed that the water diversions from upper fan areas and the ponding during recent historical times has led to an increased flux of eolian sand to this local area of the Wiley's Well Basin SMZ. The increase in eolian sand flux has resulted in an isolated area that was likely a Zone BC, consistent with regions to the west, to Zone B and Zone BW with respect to geomorphic relative sand migration rate areas (Figure 12). Note that the geomorphic relative sand migration zone rate mapping in this area shown on Figure 12 is a better depiction than the mapping on Plate 5 and Plate 6A.

9.1.11 Mule Sand Migration Zone

The Mule SMZ was originally mapped by Kenney (2011) during a preliminary eolian study for the DQSP identifying the sand transport zone as emanating from a drainage system from the northern Mule Mountains

(Figure 11, Plate 3A and Plate 6A). The watershed area for the drainage system producing the eolian sands for the Mule SMZ is relatively small (Plate 7A – Watershed P) and believed to be too small to be able to produce the magnitude of eolian sands identified in the zone if this drainage system was a typical wash system emanating from a local Mojave Desert mountain range. However, the washes of watershed P have eroded into exposures of the ancient Colorado River deposits (unit Tmm, Plate 6A) indicating that the washes carry a larger bedload of eolian size grains during flood events compared to typical desert washes emanating from bedrock regions and through typical alluvial fan terrains. The generation of eolian sands from the upwind source wash area is assisted by the orientation of the prevailing winds trending in a similar direction as the wash system, low bar and swale relief, and that the drainages system is wide and braided.

The most robust dune form in the Mule SMZ are active sand sheets in a small region on the leeward (downwind) side of a topographic high associated with remnants of an ancient shoreline berm of the receding Colorado River in Pliocene (unit Tmw, Soil S7, Plate 5). This area is mapped as Zone AB and comprises an area of only ~3.5 acres. Most of the Mule SMZ exhibits relict dune mounds with active eolian sands representing sand sheets and small coppice.

9.1.12 *Highway 10 Sand Migration Zones (Anthropogenic)*

Several relatively small areas were identified north of the modern Highway 10 where eolian sand generation has increased associated with construction of the old and modern Highway 10. These include the Highway 10-Palen-Ford Dry Lake Pass, Highway 10-South Ford Dry Lake, and SE Ford Dry Lake SMZ's (Plate 3A). These regions receive newly generated eolian sands from washes that flow toward the north from the Chuckwalla and Little Chuckwalla Mountains (Plate 3A). This region is part of the regional Chuckwalla Valley sand migration corridor; however, it has received additional eolian sand input since construction activities of the modern and old Highway 10 (Plate 3A). In Pre-historical times, the drainages flowing northward from the Chuckwalla Mountains would have gradually fanned out into a dense braided network of progressively weaker flowing drainages. In this condition, flow would have reached the valley axis much less frequently resulting in a smaller magnitude of eolian sand generation in the valley axis dune system.

Since highway construction, water flow has been diverted by flood control berms for both the older and newer Highway 10 and this has increased flow rates at specific points (i.e. subdrains) along both freeway systems (Plate 3A). The increased flow rates have allowed water to more frequently reach the valley axis and have increased channel erosion. These processes transport more alluvial sand to the valley axis area where prevailing winds are the strongest. The sand is subsequently mobilized by the wind to produce eolian sands. The increased flow of these drainages may also cause portions of the Ford Dry Lake bed to inundate, which would result in an additional, but slight, increase in eolian sand generation.

9.1.13 Powerline Sand Migration Zone

The Powerline SMZ is a small and weak eolian system that has developed naturally, but may be slightly affected by minor water diversions and surface disturbances along the graded (dirt) powerline road to the southwest (Figure 11 and Plate 3A). The dune system receives eolian sands from wash flow in the southwest and ponding areas to the northwest and southeast (Plate 5). The area exhibits thin, relict and subdued dune mounds with active eolian sands consisting of scattered sand sheets and small coppice. The eolian deposits are less than 1 foot thick.

9.2 Mid to Late Holocene dune connectivity of local sand migration zone

Mapping of eolian systems is complex due to many factors. Some of these include lateral gradational changes in dune forms and activity, variations in dune activity over time that results in relict dune forms that are no longer active, and degree of internal erosion of relict dunes. However, these are important criteria when evaluating dune activity and stability. The eolian geomorphic relative sand migration zones provide a method for showing various degrees of dune form and activity, but various degrees of internal dune erosion or dune migration are not indicated sufficiently. The Geologic and Geomorphic symbols for eolian, fluvial and playa systems discussed in Section 7.3 assist in the communication regarding variations of ground surface stability. For example, simply indicating that a dune system is stable does not provide information whether internal erosion of older relict dunes is a significant source of eolian sands. For playa lake surfaces, it is beneficial to be able to characterize whether the playa lake surface is primarily just a pathway for eolian sands (i.e. unit Ql), or if the playa lake surface is eroding resulting in a source of eolian sands as well (i.e. unit Ql-de).

General regions of the dune systems in Chuckwalla Valley were mapped utilizing the Geologic and Geomorphic eolian, fluvial (alluvial) and playa designations in combination with the relative sand migration zone designations (Plate 3B). Due to their importance as regions of eolian sand production, areas of frequent water disturbance are also shown (soil S0, washes and lakebeds, Plate 6B).

The map shows that regions of Qe-a exhibiting the most active eolian areas are isolated, only occurring in the Palen Dry Lake and eastern most Chuckwalla Valley areas (Plate 3B). Areas exhibiting significant erosion in areas dominated by relict dunes (unit Qs-de) occur at numerous localities along the regional Chuckwalla Valley sand migration corridor suggesting that sand migration rates along the system have significantly decreased since the older more robust dune forms were originally deposited. Regions where older more robust relict dunes no longer receive sufficient sand to maintain their form and instead are dominated by active sand sheets with minor internal erosion (unit Qe-ds) also occur at numerous locations in the valley. This also indicates a decrease in sand migration rates since the original more robust relict dunes were deposited. However, regions mapped as Qe-ds do allow for eolian sand transport through the system.

Review of the entire map shown on Plate 3B indicates that the Ford Dry Lake eolian system represents a significant obstacle for through going eolian sand transport. In addition, it is more likely that throughout the Holocene, Ford Dry Lake eolian systems have received most of their sand from local sources as discussed in the previous section.

9.3 Correlation of watershed size and drainage flow type (tributary vs. distributary) with sand migration zones

Water flow within washes and in ponding regions is the most important source of eolian sand generation in addition to providing stabilizing moisture for dune systems. It seems reasonable that the size of the watershed (drainage system aerial extent) of a wash system would be an important parameter in terms of the wash systems ability to generate eolian sands. Larger watershed areas capture more precipitation that leads to stronger water flow. Drainage systems that remain primarily tributary systems where water flow merges downstream also allow for increased flow rates downstream which increases the probability that water flow to the valley axis will occur leading to production of eolian sands. One characteristic that many of the wash systems have that lead to the production of sufficient eolian sands to produce a local sand migration zone is that they flow primarily as a braided tributary system where the flow has accumulated from wash flow over an extensive aerial extent within their watersheds. This is the case for essentially all identified local sand migration zones in the Chuckwalla Valley and across southeastern California. For example, drainage areas A, C, B, R1, Q, and P (Plates 7A and 7B) all focus their overland water flow into a relatively narrow zone close to the valley axis.

In areas of alluvial fan distributary drainage systems, much less eolian sand is produced in the valley axis as flow from these wash systems much less frequently reaches the strength required to reach the valley axis and most have deposited their sand bedload prior to reaching the valley axis. This is the case along the northern Chuckwalla Mountains where flow across a very wide and dense distributary system across the alluvial fan (bajada) has not led to significant eolian sand production (Plate 7A).

There is also a correlation of the relative sand migration zone (SMZ) magnitude and the size of its associated watershed (Plate 7A). For example, comparing the relative strength of the Ironwood and the Wiley's Well Basin sand migration zones with their watershed areas S+R1 and Q respectively, which are relatively robust eolian systems, with the North Ford Dry Lake SMZ (Cz) resulting from flow in watershed area C shows a correlation of sand migration zone robustness and watershed size (Plate 7A). These watersheds appear to be of sufficient size to generate enough sand to supply the respective SMZ's, indicating that this may be the sole source of sand for the SMZ's. Another example is the relatively weak Mule SMZ (area Pz on Plate 7A) and its relatively small watershed P (Plate 7A).

9.4 Prevailing winds and effects on sand migration zones

Prevailing winds are those that are sufficient to transport eolian sands. In Chuckwalla Valley and western Palo Verde Mesa, the prevailing winds vary locally due to the type of storms producing the winds and from local topography. Within the valley axis, prevailing winds, are from the west and southwest which generally coincide with storms generated in the Pacific during the winter (westerly prevailing winds) and summer monsoonal storms (southwesterly prevailing winds). However, the north-south trend of the Palen and McCoy Mountains results in strong north to south prevailing winds in the Palen Valley causing sands within the Palen Sand Migration Zone (SMZ) to migrate south-southeastward in the northern area and curved toward the southeast as the zone enters the Chuckwalla Valley axis (Plate 7B).

Prevailing winds from the west and southwest play a very important role for the Wiley's Well Basin dune system as it has caused the formation of complex-star dunes in the northern Wiley's Well Basin area, and stabilized small linear dunes down the axis of the dune system. The linear dunes occur in the western and central areas mapped as Zone A on Plate 7B within the Wiley's Well Basin Dune System.

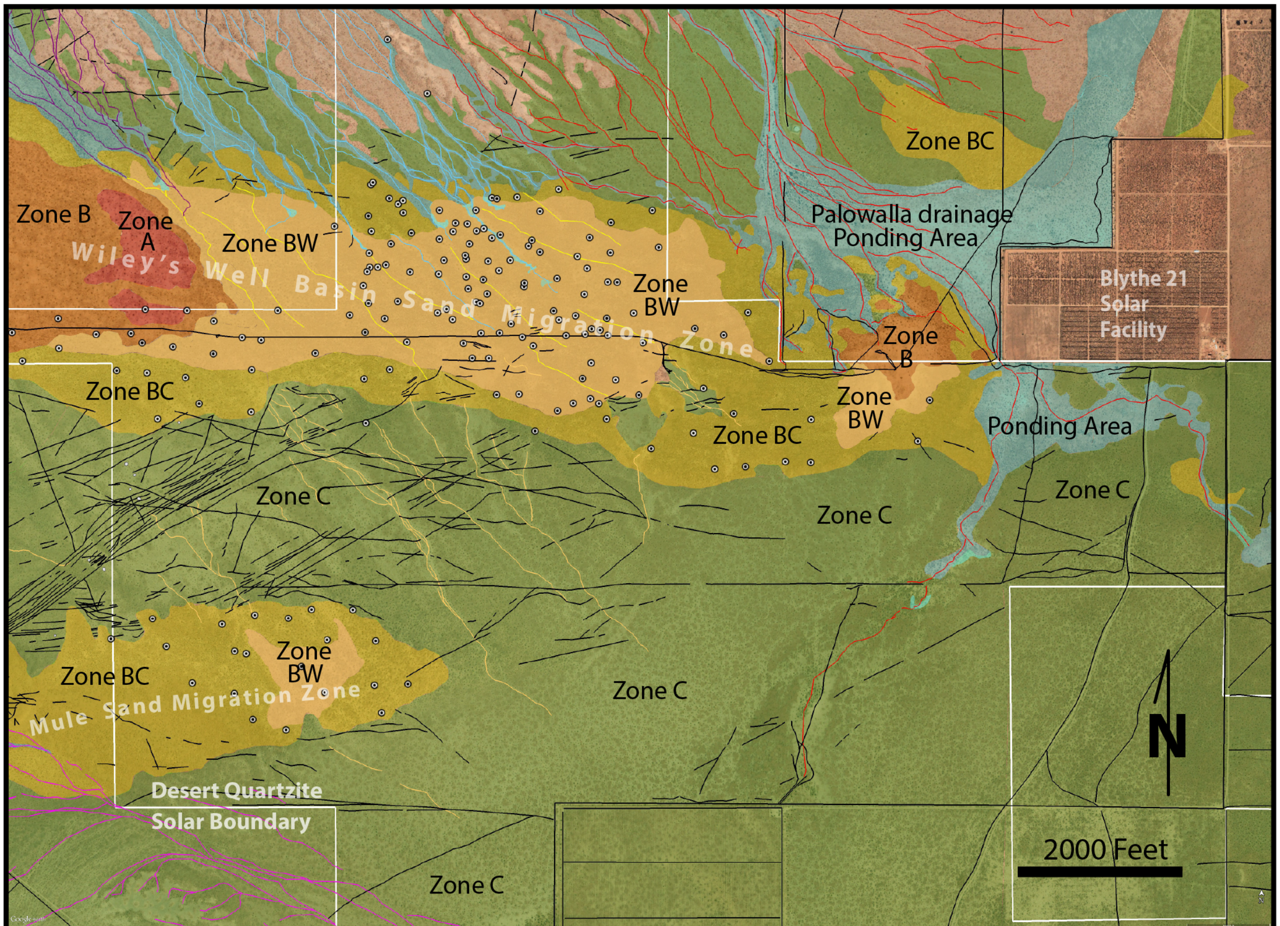
10 AGE OF DUNE SYSTEMS IN THE EASTERN CHUCKWALLA VALLEY AND PALO VERDE MESA AREA

S3a soil profiles in the eastern Wiley's Well Basin dune system that are estimated to be 8 to 5 kya show a mixed parent material of eolian and alluvial sediments suggesting that wind-blown sediments (sands) had begun to reach the area in the early mid-Holocene. The identification of widespread S2 soils in eolian parent sediments that are estimated to be a minimum of 5 to 3 kya indicates that a relatively robust period of dune deposition occurred in the eastern Wiley's Well Basin SMZ during the early to mid-Holocene. S2 soils developed in alluvial deposits (parent material) occur to the north and the south of the region mapped as S2 eolian parent soils (Figure 13 and Figure 14). This indicates that fluvial washes flowed across the region of the dune system likely prior to the dunes migrating to this region and growing to such an extent to be able to block water flow (Figure 14). The soil profile ages are estimates, and are not accurate enough to determine the exact timing of the migration of the dunes eastward, but the data provided indicates that the local dune aggradational event in the eastern Wiley's Well Basin SMZ occurred relatively quickly and possibly over the course of one to two thousand years during the late-early to early mid-Holocene.

To the west, older alluvial soils of early Holocene age occur south of the Wiley's Well Basin SMZ (soils S3b estimated to be a minimum of 12 to 8 kya, Figure 14). This indicates that the S3b Alluvial Soil area was essentially abandoned as an active alluvial fan once the obstructing eolian dune deposits to the north were deposited. These data are also interpreted to indicate that eolian dune sands in this area were deposited prior to the dunes to the east. In addition, it indicates that the dune deposits in the Wiley's Well Basin SMZ migrated eastward over time gradually and deposited over an active alluvial fan surface and then cut off alluvial processes from upslope once the dunes reached sufficient thickness to obstruct overland flow. Additional evidence to support this claim was the identification of alluvial sediments of late to earliest Holocene age under the eolian deposits where S2 Eolian Soils are shown on Figure 14.

The eastern Wiley's Well Basin SMZ experienced essentially one dune aggredational event, likely occurring in the early Holocene, and then by the mid to late Holocene retracted. Since the cessation of the dune aggradational event, the dune areas exhibiting S2 Dune Soils (Figure 14) have degraded. Based on the rate of past dune aggregation indicated in the soil record for the Wiley's Well Basin and Mule SMZ, it is likely that if dune parameter conditions changed that encouraged dune growth (i.e. a future dune aggredational event) that the existing mapped areas of dunes would be able to accommodate the additional dune sands for at least a thousand years prior to expanding beyond its current mapped footprint. This finding assumes that current drainage flows, acknowledging current anthropogenic diversions, remain relatively constant to provide critical stabilizing moisture to the dunes. The Mule SMZ in the southwestern region of the DQSP experienced a similar history in the sense that the dune deposits are primarily relict dunes that experienced a dune aggredational event during the early Holocene and then became stable by the mid-Holocene. Therefore, this region experienced a decrease in relative sand migration rates during the mid-Holocene. Eolian activity in the DQSP site is therefore consistent with other dune systems across southeastern California in that they experienced strong eolian deposition in the early Holocene which has decreased substantially since the mid-Holocene.

Figure 12: Relative Geomorphic sand migration zone map of the eastern Wiley's Well Basin and Mule Sand Migration Zones in the DQSP. Locations of identified Mojave fringe-toad lizard from an AECOM biological report for the DQSP (circles with enclosed black dot) are shown which correlate well with the mapped limits of Sand Migration Zones A, B, BW and BC.



Note: See text, Plate 3B and Figure 11 for descriptions of the designated Sand Migration Zones designations

Base image from Google Earth Pro dated 2005.04.04

Mapped dirt roads from Google Earth imagery (black lines).

Colored lines are drainages (washes) associated with various local watersheds. Yellow drainage lines in Sand Migration Zone BW are mostly ancestral. Roads mapped in Sand Migration Zones B, BW and BC provide evidence of dune stability.

⊙ Approximate location of identified Mojave fringe-toad lizard (AECOM)

Figure 13: Soil stratigraphic map of the Desert Quartzite Solar Project (DQSP) indicating the soil designations, estimated minimum ages of the surface, and parent sediments to surface soils that indicate what type of deposits (alluvial vs. eolian) the soils developed in.

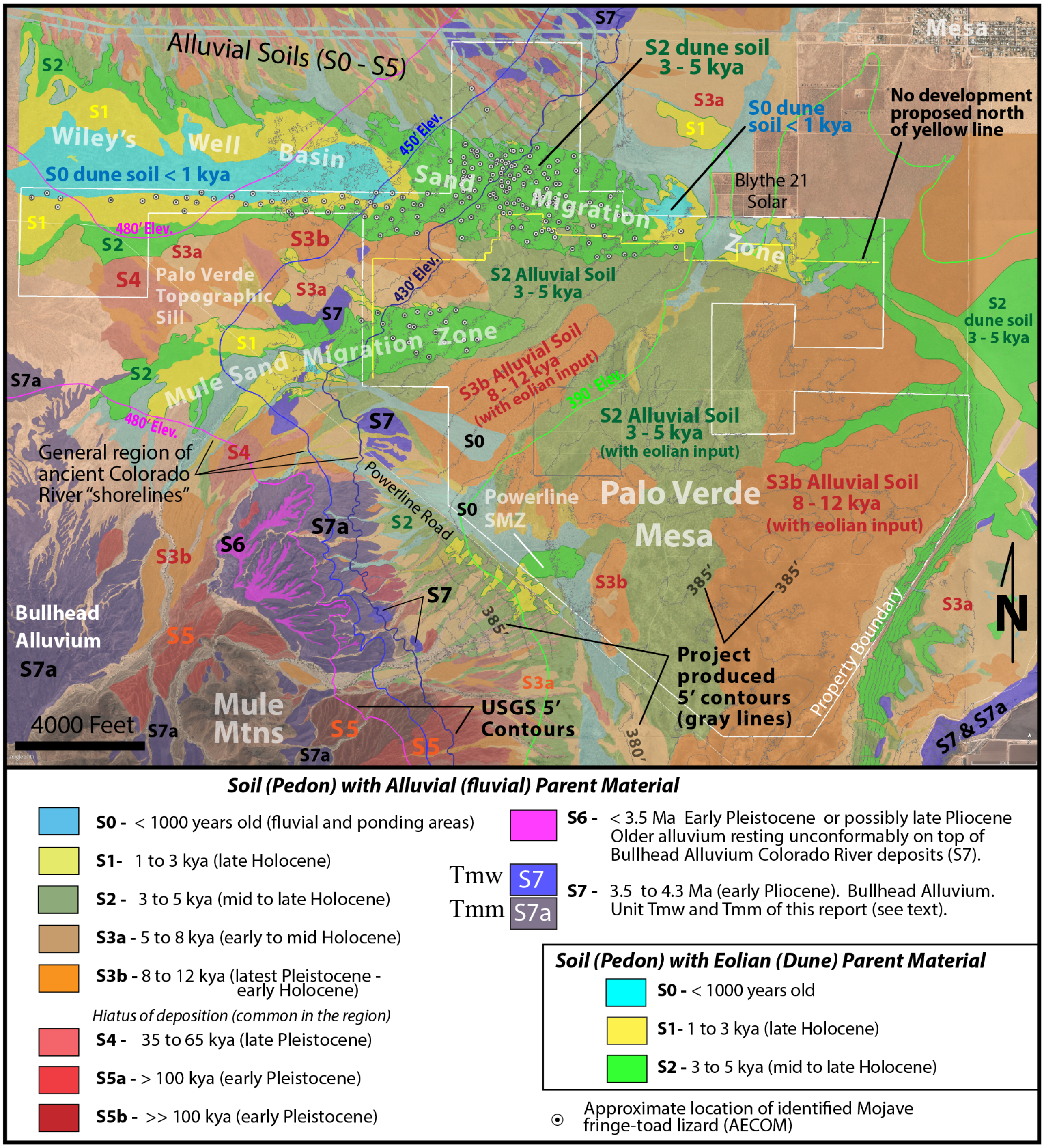


Figure 14: Soil stratigraphic map of the Desert Quartzite Solar Project (DQSP) focusing on site dune systems that indicate soil designations, estimated minimum ages of the surface, and parent sediments to surface soils that indicate what type of deposits (alluvial vs. eolian) the soils developed in.

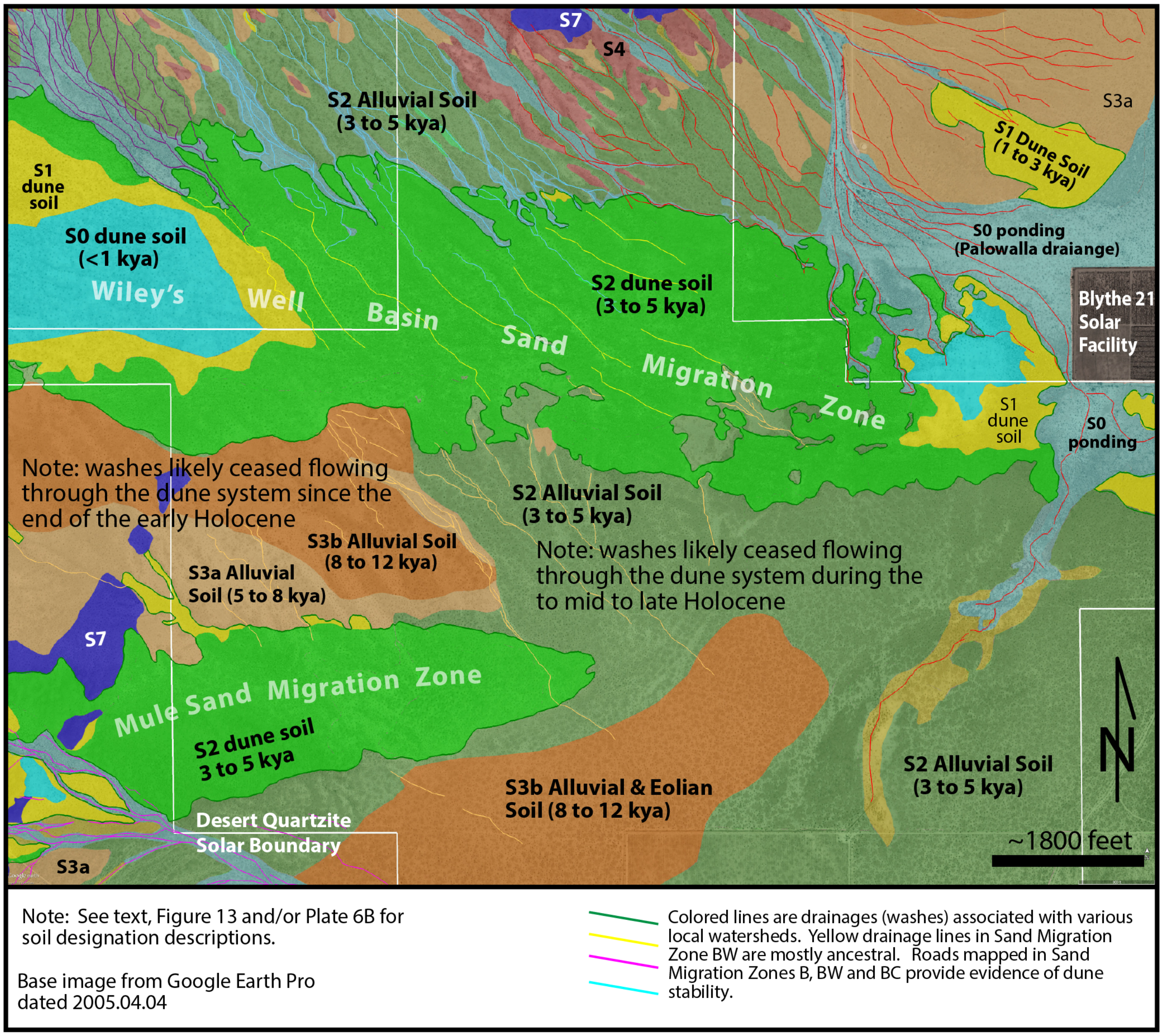
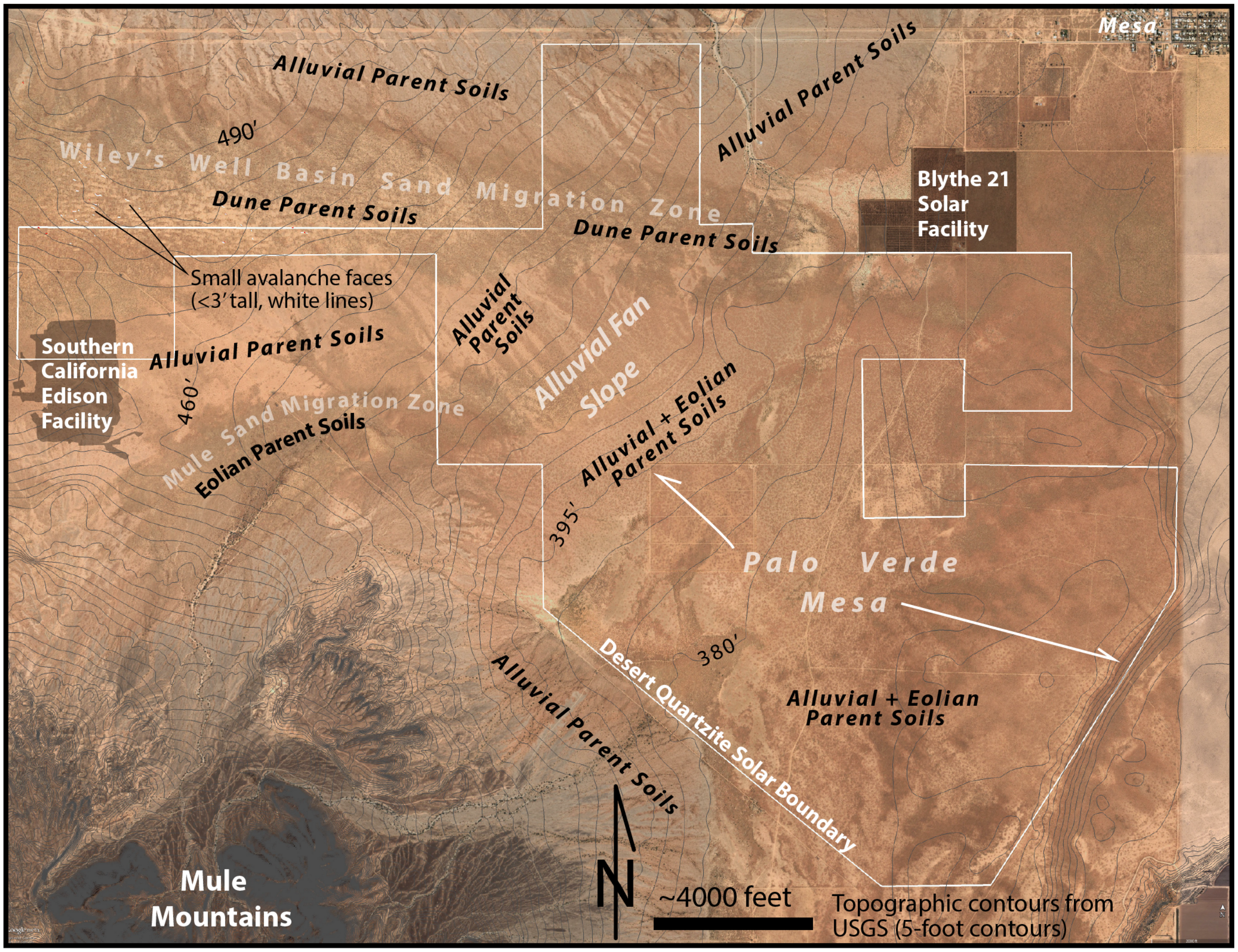


Figure 15: Aerial image map obtained from Google Earth Pro with a date of 2005.04.04 showing generalized regions where the surficial sediments are either eolian or alluvial. Pedogenic soils developed in these sediments and the mapping of these soils with their corresponding age and parent sediments are shown on Figure 13 and Figure 14.



11 LOCAL VEGETATION DENSITY AND SAND MIGRATION RATES

Vegetation density is a very important eolian parameter in that vegetation provides stability for the dunes and as discussed earlier in the report, just 10% vegetation aerial coverage decreases sand migration rates by 90% (Lancaster et al. 1998). Estimates of aerial vegetation densities in the dune areas is problematic due to order of magnitude variations from relatively low values when no Sahara Mustard exists (dead or alive) compared to times when Sahara Mustard plants occur either dead or alive.

Vegetation densities across the DSQP dune systems, which have been observed in the field during many times of the year since 2010 by the author, have exhibited a visual aerial coverage of 5 to 10% for species other than Sahara Mustard. An example of average vegetation densities dominated by native species (very minor to no Sahara Mustard) across the site is shown on Figure 16 that provides a Google Earth Pro historical aerial image of mostly sand migration Zone BW (see Figure 17a). The vegetation is evenly spaced across the dune area and provides a strong inhibitor to sand transport. A pixel capture evaluation of the aerial image in the southern picture of Figure 16 indicates a vegetation density of 6%, however, it was visually evident that this image processing technique had not captured all vegetation. Therefore, vegetation densities on the site, at 6 to 10%, are sufficient to decrease sand migration rates up to 90%. Note that to the west of the green box close-up area shown in the lower image of Figure 16 that vegetation densities are very similar in sand migration Zone B (refer also to Figure 17a). Additional field photographs are provided in Appendix C (designated sand migration zone photographs) and Appendix D (soil stratigraphy photographs).

Based on field mapping by the author, the DSQP dune systems have experienced a minimum of 1, but likely 2 Sahara Mustard blooms since 2010. When the invasive Sahara Mustard blooms in the area it results in essentially 100% vegetation aerial density as observed in Figure 17b. The plant grows to heights of over a foot and is so thick that it binds on legs inhibiting walking. As shown in Figure 17b, once the Sahara Mustard plant dies, it remains "planted" in the ground and this was observed to remain the case for many months to possibly a year from when the plant died. The dead plant stems break free and blow in the wind piling up on nearby dunes and coppice dunes, which still impedes eolian sand transport. Hence, once there is a Sahara Mustard bloom, eolian sand migration rates are greatly diminished not only for the year of the bloom, but for a minimum of the next year, and most likely into a third year.

The influence of the invasive Sahara Mustard on dunes systems where they have encroached will change the dunes long term behavior dramatically. It is anticipated that eolian sands will likely continue to be created at their sources, but will have much more difficulty transporting as far within the dune system away from their source. This model suggests that due to the invasive Sahara Mustard, new eolian sands will primarily deposit near their source causing near source aggredational events (increased sand near the source, compared to the past), and downwind dune systems will receive less eolian sands than they had in the past.

Figure 16: Aerial images from Google Earth Pro from 10/25/2012. The upper image shows the northern portion of the DQSP. The green inset box in the upper image is the enlarged area shown in the lower image. The vegetation density shown in the lower image is typical of Zone BW in the site during a typical year not experiencing higher vegetation densities associated with a have precipitation year or a Sahara Mustard bloom. The minimum vegetation density is 5 to 6% based on a crude photoshop pixel evaluation, but is likely at least 10 percent.

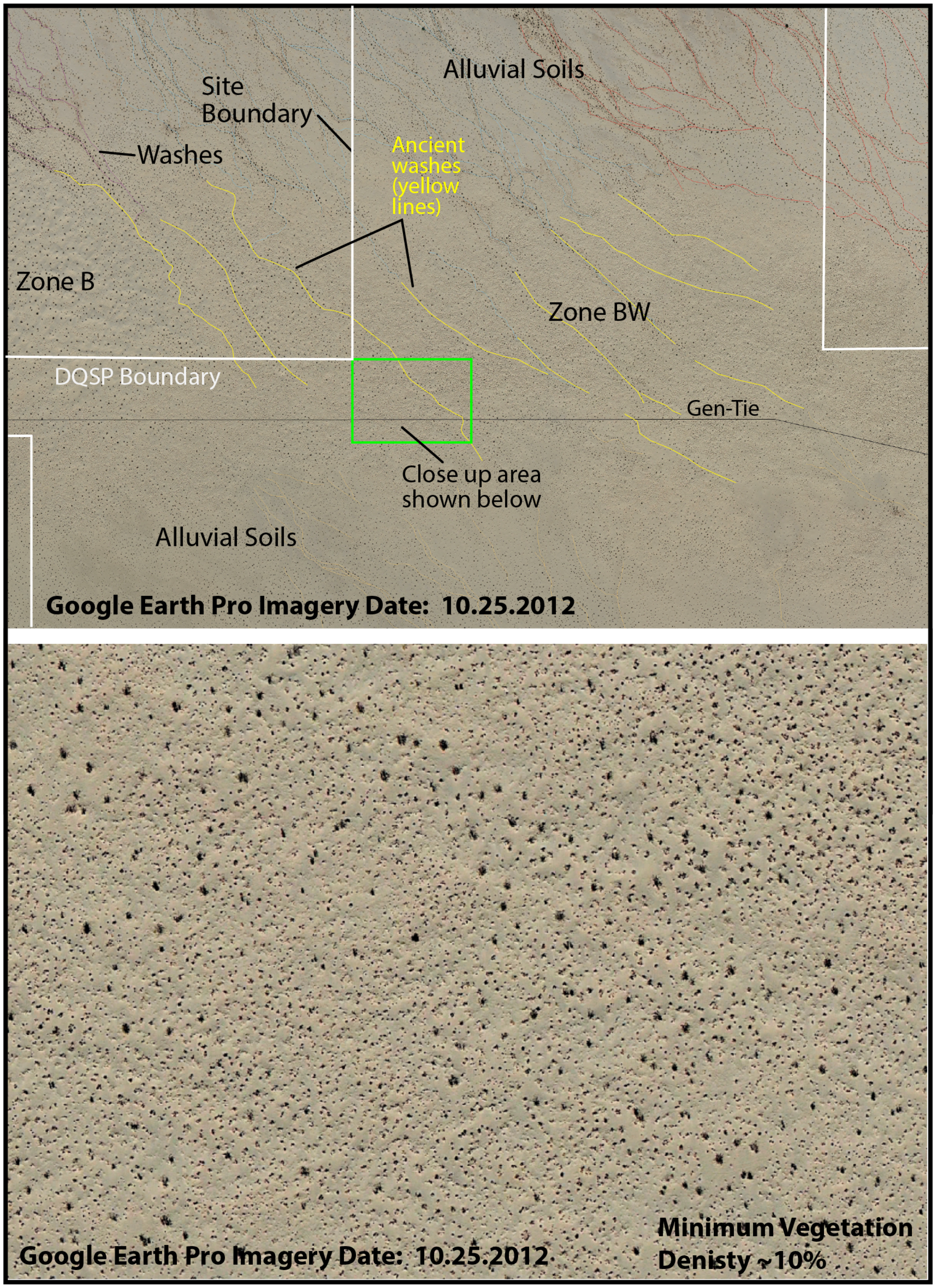


Figure 17a: Geomorphic relative sand migration zone map of the northern DQSP. The location of the vegetation pictures shown in Figure 16 identified as the green rectangular box. The site of field photograph at geomorphic site 53 shown in Figure 17b is also identified.

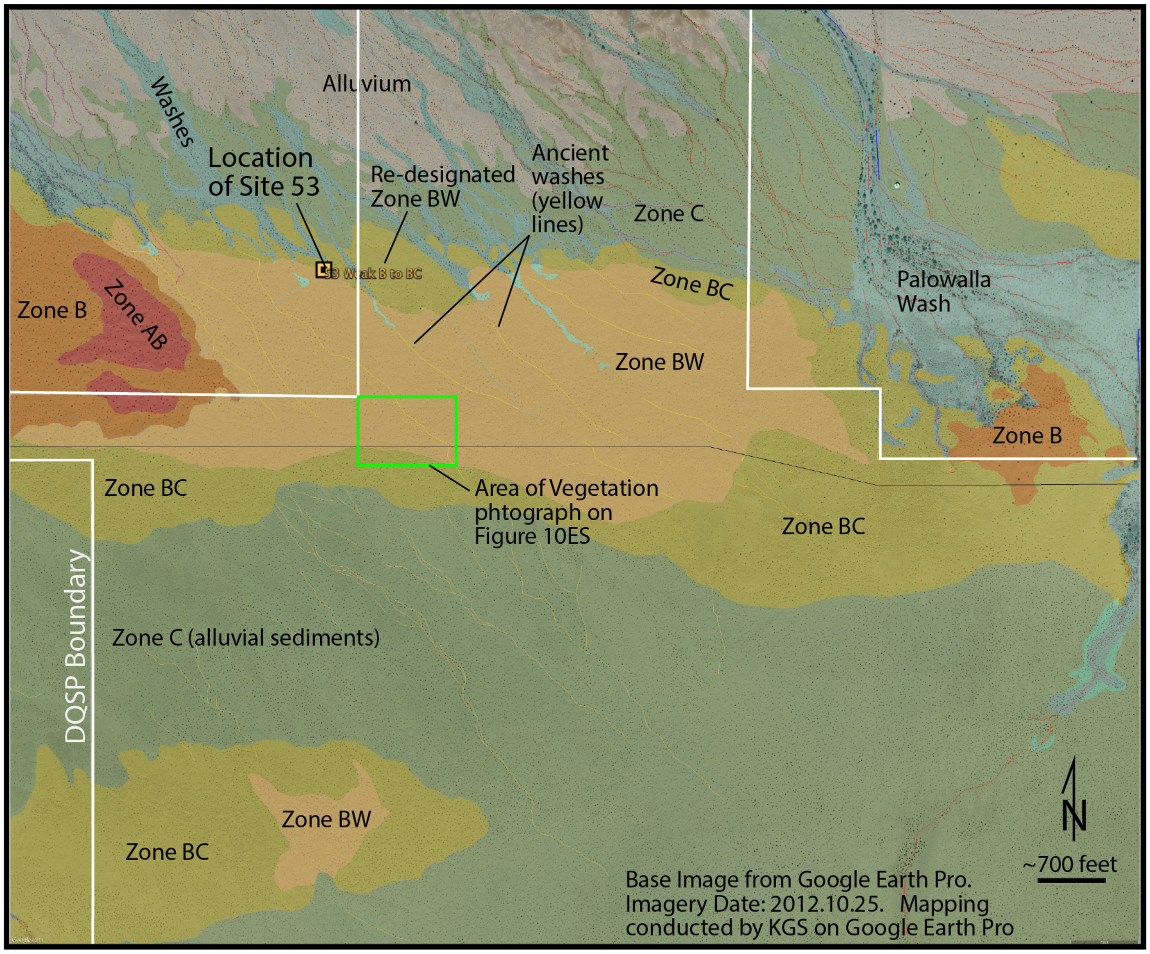
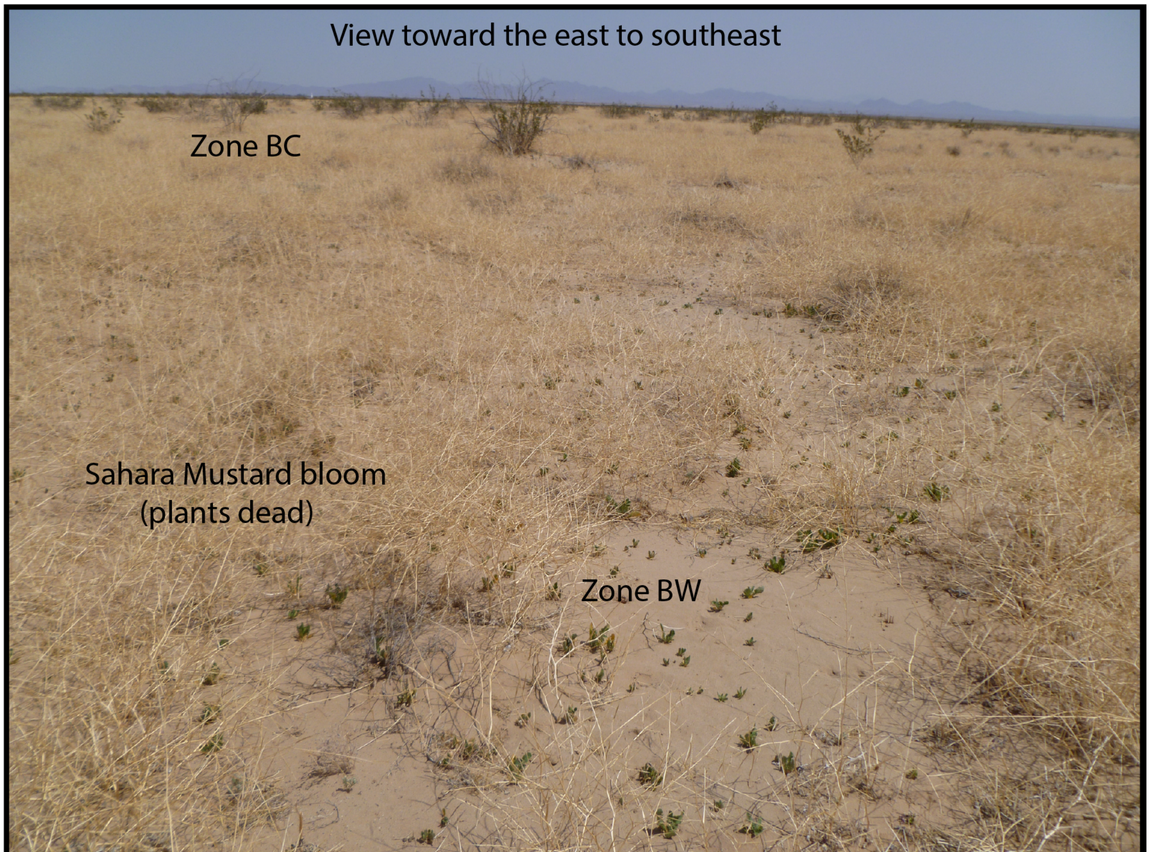


Figure 17b: Field photograph of geomorphic field Site 53 (map location shown on Figure 17a). The photograph was taken on April 4th, 2011 and several months after a Sahara Mustard bloom. In this image, the Sahara Mustard plants, have died but remain emplaced in the ground. During and for many months to over a year of a Sahara Mustard bloom, the vegetation density increases to nearly 100% which essentially shuts down sand migration.



Site 53 Latitude 33 35.622
Longitude 114 46.813

Date of photograph: 2011.04.04

Geomorphic Eolian Sand Migration Zone is Zone BW in foreground, turns to Zone BC in the background.

12 LOCAL HISTORIC VS. PRE-HISTORIC SURFACE WATER FLOW

As discussed throughout this report, one key dune parameter is local water flow both in terms of natural flow, and Historic flow if construction activities have occurred. Water flow is critical for the generation of new eolian sands and infiltrating waters for dune stability (Kenney, 2012, Schaaf and Kenney, 2016). The findings of the surface water flow analysis conducted in this report in terms of waters reaching the dune areas in the eastern Chuckwalla Valley and western Palo Verde Mesa are provided on Plate 7B. Generalized areas that may be receiving more and less water flow than in the past are identified with blue stipple dots and red stipple dots respectively.

Water diversions from north flowing drainages emanating from the Little Chuckwalla Mountains and Mule Mountains have not experienced water diversions significant enough to affect the Wiley's Well Basin dune system (Plate 7A and Plate 7B). The only possibly significant water diversion with north flowing drainages is the construction of an east west trending paved access road which was constructed sometime during the past 5 to 6 years (Plate 7B). The road transects the important Wiley's Well Basin ponding area that is considered the primary source for eolian sands for the Wiley's Well Basin dune system. Portions of this road are constructed on a man-made berm with a series of sub-drains allowing for water to continue flowing north of the road to the northern portion of the Wiley's Well Basin. However, it is not known if the sub-drains impede northward water flow compared to natural conditions prior to the road being constructed. Regardless, increased water flow to the northern portion of the Wiley's Well Basin has been occurring from south flowing drainages emanating from the southern McCoy Mountains since construction of water diversions associated Highway 10 (Plate 7A and Plate 7B).

Diversion of water flow associated with watershed E (Plate 7B) has caused less water flow to a region northwest-west of the Wiley's Well Basin area. Some relict dune areas in this "dry area" are abrading and vegetation densities on the relict dunes may have decreased. It is possible based on this limited research that older eolian sands are being re-mobilized in this area and able to travel greater distances due to a decrease in historical moisture.

Water flow diversion of washes from watershed F and G (Plate 7A and Plate 7B) are concentrated to the northern central portion of the Wiley's Well Basin which is interpreted as increasing moisture to this area. The most prominent dunes in the Wiley's Well Basin dune system occur in this area and it is possible that these dunes have grown due to increased eolian sand source and stabilizing moisture during historic times. Water flow diversions of watersheds F and H (Plate 7B) have been diverted from a dune area in the north-central region of the Wiley's Well Basin dune system. This area is shown as a red "dryer" region on Plate 7B. Although more research would need to be conducted to resolve the matter, the dunes in this area appear more "dried out", and less vegetated than other dune areas and active dune areas may be encroaching into areas where pre-Historical dunes had not occurred or the sand migration rate has increased during Historical times.

Water flow diversions of watershed K1 along the north side of Highway 10 to the Palowalla Ditch has caused less water flow to watersheds M and L south of Highway 10 (Plate 7B). The region of the dunes that is receiving less water is shown as a dry area on Plate 7B occurring along the northern portion of the Wiley's Well Basin dune system at the southern limits of watersheds M and L. Although the drainage analysis of the area had not been completed prior to field mapping, review of field data including notes and photographs does not suggest that the dunes are being negatively impacted by the water diversions. In the western portion of the dry area flow within watershed M is concentrated by Highway 10 borrow pits allowing for more regular flow to the dune system near the Zone AB-Zone B to the west and Zone BW to the east contact. The area of increased flow is shown as light blue Soil S0 in the southern portion of Watershed M (Plate 7B).

In the eastern most Wiley's Well Basin dune system, an increase in water flow has occurred in Historic times associated with water diversions of watersheds K and K1 under Highway 10 via the Palowalla Ditch (Plate 7B). In addition, un-natural water ponding occurs along the western and southwestern region of the Blythe Solar Facility due to construction of the facility intersecting and diverting flow from a drainage that previously flowed through the footprint of the facility. The increase water flow to this area and ponding has increase eolian sand production leading to an increase in sand migration in the eastern most portion of the Wiley's Well Basin dune system.

Based on the Historic water flow analysis, most of the Wiley's Well Basin dune system continues to receive water flow that allows the dunes to remain stable.

13 EOLIAN RESPONSE TO GLOBAL AND LOCAL CLIMATE

Eolian dune systems across southeastern California (the regional study area) have clearly not experienced a steady and consistent growth rate since the latest Pleistocene (Lancaster, 1995). Instead, eolian systems have experienced dramatic variations in development since the Last Glacial Maximum (LGM). The LGM is defined as the time when the continental ice sheets reached their maximum positions, which is believed to have occurred about 33 to 26.5 kya and that these magnitudes of ice were maintained to 19 to 20 kya (Clark et al., 2009). Eolian systems across the southeastern California region experienced a strong aggradational event that began approximately 15 kya, which coincides with the timing of many of the playa and particularly pluvial glacial lakes desiccating across the southwestern United States (Plate 8A, Plate 8B and Plate 8C). Hence, there is a correlation between eolian dune development and climate (Tchakerian, 1991; Lancaster, 1992; Lancaster, 1994, Lancaster, 1995; Zimbelman et al., 1995; Lancaster and Tchakerian, 1996; Lancaster, 1997, Lancaster and Helm; 2000; Lancaster et al., 2003; Pease and Tchakerian, 2003; Tsoar, 2004; Bateman et al., 2012).

Strong eolian aggredational events correlate with periods of time when relatively abundant eolian sand is generated and the sands can migrate and deposit within dune systems away from their source. This is clearly the case on a large regional scale soon after pluvial and playa lakes desiccate providing both an eolian sand source from playa erosion and pathways for the sand to migrate. However, review of dune ages, times of dune re-activation, aggredational events and periods of dune stability since the late Pleistocene indicate a complex story suggesting that numerous climatic factors and their related secondary effects play a role in dune activity (Plate 8A, Plate 8B and Plate 8C).

Numerous possible parameters were evaluated during this study including Global Climate variations, regional climate variations, pluvial lake levels, alluvial fan depositional periods, areas of alluvial fan deposition, upper fan trenching (down-cutting), vegetation variations, monsoonal vs. Pacific Storm frequencies and magnitude variations, dune aggredational and re-activation periods (Plate 8A, Plate 8B and

Plate 8C). These data suggest that dune systems react to both global and local changes in climate and the secondary effects of climate such as vegetation density, and alluvial fan behavior. Dune systems experienced aggredational events once pluvial lakes and playa lakes desiccated after the last global glaciation period ending during the Latest Pleistocene (~15 kya). For the most part, the Holocene has been a period of time allowing for the development of dune systems to both aggrade by re-activation and then to become stable. This is likely due to the Holocene climate across the study region that has been semi-arid but close to the hyper-arid climate. Annual precipitation criteria for semi-arid and hyper-arid is ~4 inches/year, which is the amount of average rainfall that the desert regions of southeastern California have received in historical times (Figure 18A and Plate 1). Zimbelman et al. (1995) indicates that semi-arid regions can preserve evidence of substantial eolian deposits via vegetation stabilization as a variety of desert flora are adapted to the intermittent rainfall. However, it seems reasonable that if rainfall decreased slightly to cause the region to experience hyper-arid conditions, that it may be sufficient to cause stabilizing vegetation to die off allowing for an increase in dune instability (increase active sand transport), increase the ability for sand transport and increase eolian sand production. If the decrease in annual precipitation were associated primarily with a decrease in cool-wet Pacific storms (Figure 18B) then the vegetation die off particularly at lower elevations may be more dramatic causing a greater increase in eolian activity. And finally, if all that were to occur but at the same time the magnitude and frequency of extreme but highly intermittent monsoonal storms increased in the region causing increased alluvial fan (washes) activity and fluctuating water levels on playa surfaces, then eolian systems would likely experience re-activation. This eolian re-activation model suggesting relatively small climatic changes can lead to an eolian aggredational event from a "dormant period" may support findings by Bateman et al. (2012) that indicate that eolian systems can accumulate quickly (<5 kya) in a single-phase event before becoming relict.

The Holocene climate across the southeastern California region is therefore close to a critical geomorphic threshold where subtle changes in climate over the course of millennia can lead to either dune re-activation or stability. The combination of the global warming event of the Bølling-Allerød interstadial from 15 to 13 kya that decreased cooler Pacific Storm events in the study area (Plate 8A) with the onset of more frequent and intense gulf Monsoonal storm events in the study region (Plate 8B) led to a robust regional dune aggradational event. Similar conditions occurred again beginning with a global warming period from 10 to 8 kya decreasing Pacific Storm strength in the study region aligning with either continued or increased monsoonal storm frequency and magnitude compared to recent times. These conditions or close approximation continued to about 4 kya which allowed for relatively robust eolian activity from about 10 to 4 kya across southeastern California. The cooler conditions associated with the global Neo-Glacial period from 4.5 to 2.5 that increased cool Pacific Storm and coincides with a decrease in monsoonal storm magnitude and frequency led to a period of dune stability across the study region including all the regional sand migration corridors.

However, southeastern California region (southwestern United States) has experienced local climate variations that do not correlate exactly with changes in global climate. For example, regional dry-warm periods occurring in the southwestern United States encroach into the global cooling New-Glacial period occurring from 4.5 to 2.5 kya. Dune re-activation and some continued dune aggradational behavior continued in southeastern California during the Neo-Glacial likely due to local climate exhibiting drier-warmer conditions and higher monsoonal storm strength and frequency (Plate 8B). Note that alluvial fan deposition across the study region also increased from about 6 to 2 kya (Plate 8A).

Figure 18a: Average annual precipitation in the southwestern United States. The area of the site (DQSP) and the regional sand migration corridors correlate well with low elevation regions experiencing <4 inches/years, which are areas that receive the least amount of rain in the southeastern California region. The bounding mountain areas are experiencing between 4 to 8 inches/year.

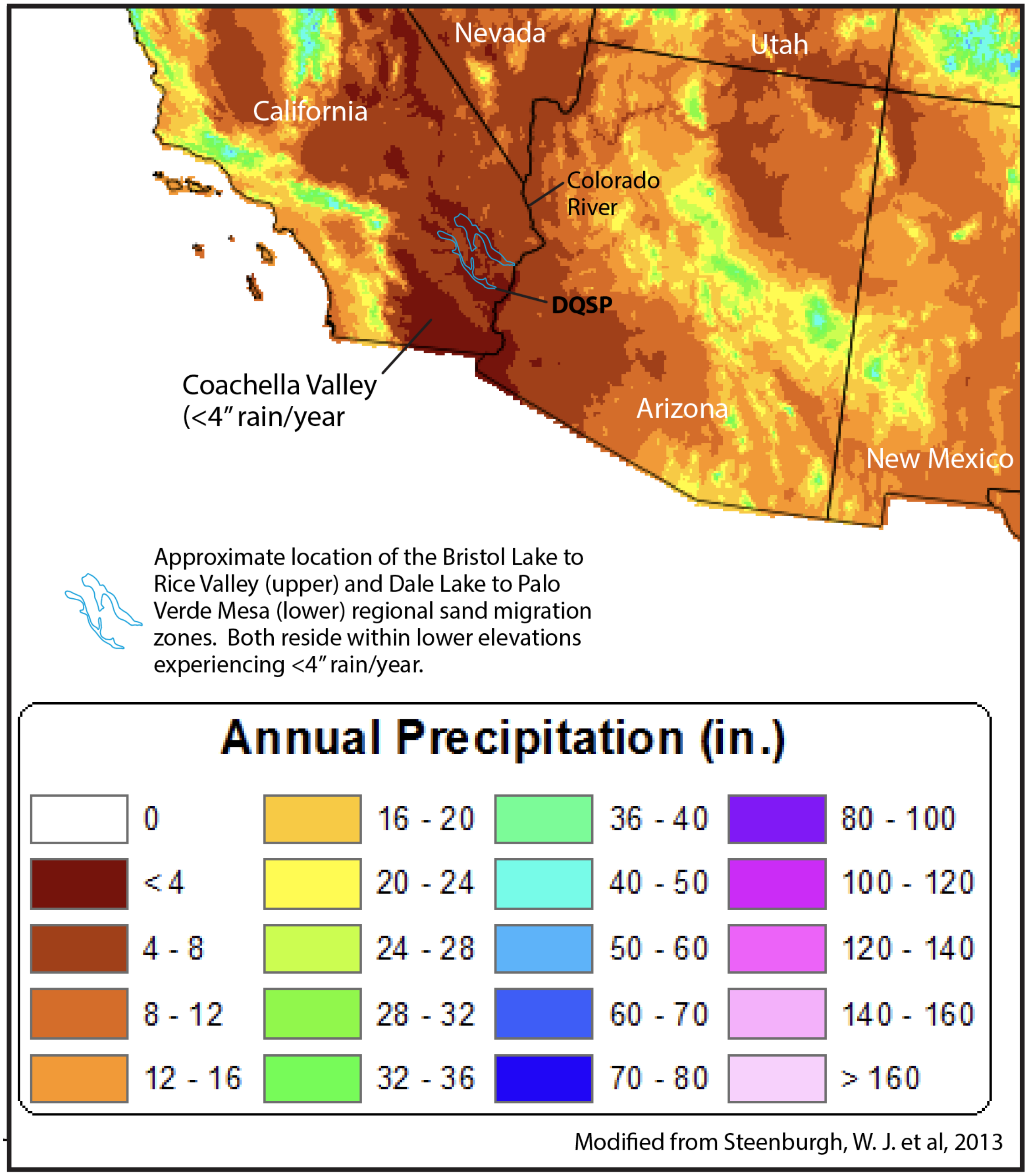
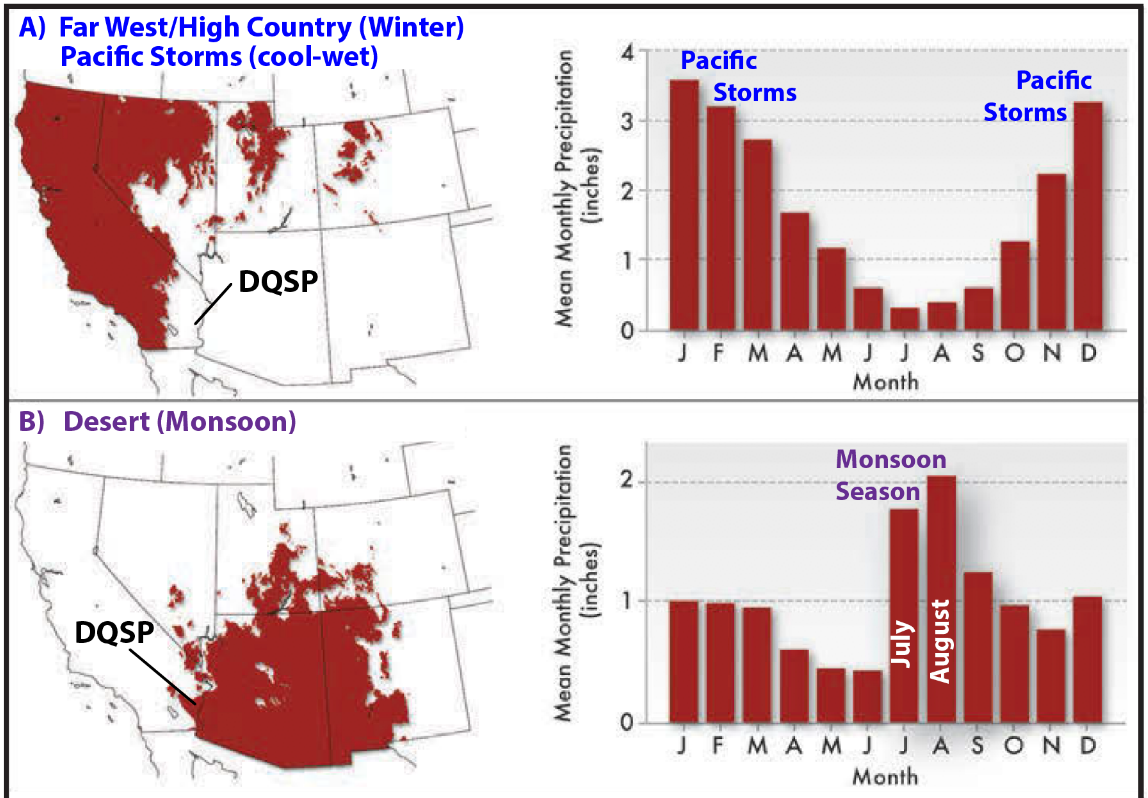


Figure 18b: Regional climate data for the southwestern United States showing: A) Upper-Figure – areas receiving significant "far west/high country" winter Pacific storm precipitation and the mean monthly precipitation per month; B) Middle-Figure – areas receiving significant desert monsoonal "thunderstorm" precipitation and the mean monthly precipitation per month; and C) Lower-Figure – average wind speed for various times of the year measured in Blythe, California located approximately 20 miles east of the project site.



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C) Average Wind Speed in Miles Per Hour (MPH) at Blythe, California

January	**6.5**	**Winter - Strong Pacific Storms (low winds & wet)**
April	8.9	Spring - (strong winds, mostly dry)
July	**9.4**	**Summer - Strong Monsoon (strong winds & dry)**
August	**8.8**	**Summer - Strong Monsoon (strong winds & dry)**
October	6.7	Fall - (low winds)

https://pubs.usgs.gov/of/2004/1007/weather.html

Dune systems appear to experience aggradational (increase in size and magnitude of eolian sand production and movement) during times when pluvial and playa lakes are drying up and/or experiencing repeated lake fluctuations, when alluvial fans are experiencing aggradational events (abundant fan deposition), when monsoonal storms are more frequent and with higher intensity, and when alluvial fans that had been deposited earlier are eroded into (fan trenching) or eroding into even older non-fan sediments with abundant eolian size grains. It turns out that during the Holocene it is common that one of these parameters allowing for dunes to be more active is occurring at any particular time. Hence, dune system aggradational events do not appear to correlate to a single geologic parameter consistently throughout the Holocene, but instead, responding to numerous parameters each of which vary over time. Dunes can experience variations in activity based on the additive nature of the parameter wavelengths when they collectively "add up" (aggradational events), or cancel each other out (times of stability).

The combination of decrease in vegetation density at lower elevations associated with a decrease in cold/wet winter pacific storms intensity and frequency, increase in monsoonal storms with relatively higher frequency and strength (extreme storm events), abundant available sediment in the mountains and its transport to distal fan areas (see Wells and Dohrenwend, 1985; Nichols et al., 2007), and pluvial and playa lakes experiencing fluctuating levels, all contributed to a regional strong dune aggradational event between 14 and 8 kya. In addition, periods of relatively strong monsoonal storm frequency and strength (Figure 18B) since the mid-Holocene have resulted in dune aggradational and re-activation events (Plate 8B). Dune systems appear to react to this type of climate change on the order of less than 1000 years. Geomorphic response times of dune systems are likely faster than that of other desert processes and may provide the "canary in the coal mine" process indicating that desert systems are changing relatively significantly.

Relatively strong alluvial fan aggradational events correlate with periods of stronger and more frequent monsoonal storm strength (thunderstorm-extreme events; Reheis et al., 1996; Harvey et al., 1999; Reheis et al., 1996; McDonald et al., 2003; Miller et al., 2010). Hence, eolian systems activity level correlates well with that of alluvial fan systems. It is important to point out that during periods of relatively intense monsoonal climate across that many of the playa and pluvial lakes can fill and desiccate which increases eolian sediment supply substantially (Plate 8). In contrast, the relatively wet period in the southwestern United States associated with the global Neo-Glacial from 4.5 to 2.5 kya that led to increased vegetation density at lower elevations assisted in stabilizing most eolian dune systems in the study region (Plate 8A).

Harvey et al. (1999) provide a strong case for alluvial fan aggredational events across the southwestern United States during periods of time of strong monsoonal (extreme storm events) climate in terms of increased frequency and magnitude. The observation that torrential rains in the deserts play a critical role to increased erosion and flow to playa regions was also suggested by Tolman (1909). Eolian dune systems experience aggredational events when relatively strong monsoonal storm periods correlate with periods of relatively weaker Pacific Storms that provide long duration rains leading to increased lake filling (Miller et al., 2010) and higher vegetation density at lower valley axis elevations. These processes lead to dune stability. Monsoonal storms are extreme events that allow for strong flow carrying abundant sediment and moisture to the valley axis (playas and distal fan areas), but soon dry up to not allow for more dense vegetation to occupy the landscape. Therefore, the most productive climate for dune development (growth) is the combination of relatively strong monsoonal extreme storm frequency and magnitude in combination with relatively weaker but longer duration cold/wet Pacific Storm events.

The findings of Harvey et al. (1999) indicate that the southwestern most region of the United States experienced relatively stronger monsoonal storm strength and frequency compared to regions to the northwest, north and northeast. In fact, the region they show as experiencing stronger and more frequent monsoonal storms and relatively weaker cold/wet Pacific Storms correlates very well with the region of the numerous regional sand migration corridors shown on Plate 1 and Plate 2. This indicates that one of the principle reasons that the southeastern California region, in addition to western Arizona, have resulted in extensive dune systems is that these regions have experienced strong monsoonal storm strength and frequency during the Holocene. Other factors include the difficulty of Pacific storms to reach southeastern California due to rain shadow effects, and the local topography in southeastern California exhibiting Basin and Range extensional tectonic mountain ranges and valleys that provide strong and controlled prevailing winds. It is likely that even a small decrease in the strength and frequency of cool winter Pacific storm systems hitting the southern California coast may lead to a substantial drop in precipitation in southeastern California due to the difficulty of these storms maintaining moisture over a series of mountain ranges to the west.

Monsoonal storms, in addition to their ability to create flows that carry sediment to the valley axis allowing for the distal fan regions to grow, also have a much larger ability to cause erosion upstream and carry more sediment, as first described by Tolman (1909). This indicates that extreme flood events have an ability to generate much more eolian sand than long duration Pacific Storm events. It has been observed that during the Holocene, alluvial fan deposition has primarily occurred in the distal regions of the fan (Wells and Dohrenwend, 1985; Nichols et al., 2007), and this observation is consistent with increased monsoonal storm frequency and strength relative to Pacific Storms in the southwestern United States. Monsoonal storms have the added benefit for eolian sand generation in that extreme monsoonal storm events also exhibit much more erosion capabilities than long duration Pacific Storms. Hence, periods of strong monsoonal storm frequency and strength will erode more deeply into the upper fan regions (fan trenching) and into older non-fan sediments. This proposal for increased eolian sand production associated with monsoonal storm periods is supported by work on alluvial fan deposition by McFadden and McAuliffe (1997). They identified a correlation between alluvial fan depositional-aggredational events with the lithology of the materials that the alluvial fan washes eroded into. This observation regarding alluvial fan depositional rates increasing due to the washes carrying additional sediment from the erosion of older sediments is consistent with the hypothesis proposed herein for heavily sand laden washes emanating from eroding fan-trench areas and/or older non-fan sediments increasing eolian sand source to dune systems. Alluvial fan-trenching in the proximal and mid-fan portions of the fan increased from approximately 14 kya and extending to the mid-Holocene (~6 to 7 kya, Plate 8C). Hence, washes during this time carried a relatively large abundance of eolian size sand grains assisting in eolian dune development.

The arid-semi arid climate conditions since the mid-Holocene has resulted in a geomorphic condition where slight changes in regional climate (i.e. monsoonal storm activity) is sufficient to result in local re-activation of dune systems, but not sufficient to produce a robust eolian system where sand migration corridors are continuous. Dune systems across the study region have been relatively stable since the mid Neo-Glacial period approximately 4.0 to 3.5 kya. However, the semi-arid climate occurring in the study region for much of the Holocene is near a critical threshold condition where small changes in dune parameters such as global climate affecting Pacific Storm strength and frequency and local monsoonal strength frequency and magnitude can be reflected in changes in dune behavior on a cyclic scale of approximately 1000 to 500 years. There is a strong correlation with increased monsoonal extreme storm frequency and magnitude with increased eolian activity (aggredational events), and/or with periods of time exhibiting a warmer global climate (Plate 8B). However, Garfin et al. (2012) indicate that forecasting variations in monsoonal behavior in the southwestern United States (i.e. the North American monsoon - NAM) is fraught with difficulties and essentially not possible at present. Therefore, it is unknown whether NAM will increase or decrease in the future. Garfin et al. (2012) do forecast that the southwestern United States will likely get drier and hotter in the coming century which will lead to soils moisture decreasing.

14 POTENTIAL FUTURE IMPACTS

The dune systems in the area and within the DQSP have been stable for a minimum of several thousand years since the end of the mid-Holocene aggredational event. Dune parameters that could lead to changes in the dune system in the future include a continuation of surface water flow diversions that has led to some areas particularly along the northern portion of the Wiley's Well Basin dune system to be dryer and wetter (Plate 7B). As discussed in this report, this has led to an increase in eolian sand source in areas receiving more water (i.e. sand source for sand migration zones Qz1 and Kz on Plate 7A), and drying out of dunes in areas receiving less water that has led to minor dune degradation and increased sand transport rates locally (pathway of sand migration zone Qz1 on Plate 7A). The flood control measures for construction of Highway 10 and older roads in this area have existed for decades and have only led to subtle changes in the local dune systems. With the advent of the invasion of Sahara Mustard which has dramatically slowed down sand migration rates from their eolian sources, the slight increase in eolian sand generation in the wetter source area associated with the Palowalla Ditch-Wash (Plate 7A) will likely continue to deposit in the area mapped as sand migration Zone B, Zone BW and Zone BC (Figure 12, Plate 5 and Plate 6A) for many decades.

Flow within the watershed of the Wileys Well Wash (watershed Q on Plate 7A) has not been altered significantly in Historical times and should result in similar eolian sand production as it did in pre-Historical times if climate remains similar. Numerous subdrains located under the Southern California Edison Facility appear to allow for substantial Wiley's Well Wash flow to migrate north of the access road (Plate 7B).

The watershed and drainage system feeding the Mule SMZ (watershed P feeding sand migration zone Pz on Plate 7A) has not been altered in Historical times and therefore continues to provide sufficient flow for dune moisture stability and generation of eolian sands to feed the system. The Mule sand migration zone has been stable for at least several thousand years like the Wiley's Well Basin sand migration zone to the north.

If the frequency and magnitude of cool winter Pacific storms decrease and warm summer monsoonal storms increase, then this is proposed to lead to an increase in eolian sand generation in the valley axis area. The existing dune systems in the DQSP have been degrading (internally eroding mostly) for several thousand years, and thus can "absorb" newly derived eolian sands for hundreds of years or more without expanding outside of the mapped dune areas where the dunes had originally expanded to in the mid-Holocene (i.e.

beyond the contact of sand migration Zones BC/Zone C). However, the invasion of Sahara Mustard has greatly diminished the ability for sand to migrate from their sources. Hence, if Sahara mustard persisted, it is proposed that it would primarily lead to thicker and more robust dune systems near their sources during the next century.

15 CONCLUSIONS

Global and local climatic conditions and their secondary effects during the Holocene has been beneficial for dune growth at various periods of time and near a geomorphic threshold condition where relatively subtle changes in climate can lead to dune re-activation. However, dune systems across the southeastern California region have been dominantly stable since the mid-Holocene and the sand migration corridors have essentially shut down since that time. Eolian sand sources during times of dune aggredational events similar to that of the early Holocene and during times of dune stability have primarily been from local sources with the possible exception of the Kelso dune system that was likely provided relatively large magnitudes of eolian sands during the early Holocene when dune parameter conditions greatly favored eolian sand production and migration.

Dune systems in the area of the DQSP have received most of their eolian sands from local sources throughout the Holocene. The dunes encroached into the DQSP during the late-early Holocene and continued to grow until the later mid-Holocene. Since the mid-Holocene, existing dune systems across the southeastern California region are degrading and relying in large degree on the erosion of older dune deposits for new eolian sands. This is certainly the case for the dune areas in the DQSP. If there is an increase in eolian sand production due to climate change via a decrease Pacific storms and increase in monsoonal storms frequency and magnitude, then these newly derived sands will be deposited for likely a minimum of a hundred years within the existing mapped dune system area (i.e. areas of sand migration zones A through BC, which are not impacted by the proposed development). The reach of the deposits is likely to be furthermore constrained by the incursion of the invasive Sahara Mustard plant, which blooms relatively frequently (estimated to be 2 to 3 times per decade) and has decreased sand migration rates by over an order of magnitude where it occurs. These blooms will cause newly derived eolian sands to deposit closer to their sources and within mapped eolian dune systems, altering only the dune forms and increase in localized eolian sediment mass.

The findings of this report are that eolian sand sources remain intact near and within the DQSP, and that for decades to come, the area of dune deposition will not expand beyond the mapped region of sand migration Zone BC.

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REPORT END

APPENDIX A

REFERENCES

APPENDIX A

REFERENCES

Note: This is a partial reference list of publications available to the author during preparation of this report; however, not all the references provided below were formally referenced in the report.

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APPENDIX B

GLOSSARY OF TERMS

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ABRASION: Erosion of a surface when coarser sediments move across the surface in a saltation process. For example, when the wind transports sand grains and the sand grains dislodge bits of the ground surface, that is abrasion.

ACTIVE AEOLIAN (EOLIAN) LANDFORMS: Active eolian landforms are features on which contemporary surface sand and, locally, avalanche faces at the angle of repose. Primary sedimentary structures are preserved. Depending on their morphological type, active dunes may be migrating in the net transport direction (e.g. concentric or transverse dunes), extending (e.g. linear dunes), or vertically accreting (e.g. star dunes-complex dunes). The degree of aeolian activity may vary seasonally, annually or decadally in response to changes in sand supply, wind velocity, vegetation cover and moisture contents. Definition from Lancaster, 1992. Also see Dormant and Relict dune definitions below from Lancaster, 1992. Note however, that this definition does not take into account where active sands requiring nominal active eolian sands (i.e. sand sheets, small coppice, weak dune mounds) are currently occurring in an ancient dune system representing an ancient more robust eolian system in the past.

AEOLIAN/EOLIAN: Alternate spelling of eolian. See Eolian.

AGGRADATION: Aggradation (or alluviation) is the term used in geology for the increase in land elevation, typically in a river system, due to the deposition of sediment. Aggradation occurs in areas in which the supply of sediment is greater than the amount of material that the system is able to transport. The mass balance between sediment being transported and sediment in the bed is described by the Exner equation. The term *aggradational event* is used by eolian scientists to describe a period of time when a dune systems increases its mass of eolian sands indicating that the eolian sand sources are producing sufficient sand to allow for dune deposition. Hence, a perio9d of time when the wind supplies more sand than leaves the dunes system. In alluvial environments, when washes and streams deposit sediments it is referred to as *alluviation*.

ALLUVIAL/ALLUVIAL DEPOSITS: Sediments deposited by flowing water.

ALLUVIATION: Another name for aggradation but specific to alluvial processes (washes, channels, streams, stream terrace, etc).

ANGLE OF REPOSE: The angle, from 0 to 90 degrees, of a slope that marks the last stable slope angle. If the angle gets any steeper, material on the slope will move downhill.

BAJADA: An alluvial plain that forms along the flanks of a mountain where fan-shaped alluvial deposits overlap. Often, numerous alluvial fans from an individual valley within a mountain range merge to form a relatively smooth surface referred to as a bajada. A Bajada is a type of Piedmont Surface.

BARCHAN DUNES: A **barchan** or **barkhan dune**, (from Kazakh бархан [bɑɾˈ.χɑn]), is a crescent-shaped dune. The term was introduced in 1881 by Russian naturalist Alexander von Middendorf,[1] for crescent-shaped sand dunes in Turkestan and other inland desert regions. Barchans face the wind, appearing convex and are produced by wind action predominately from one direction. They are a very common landform in sandy deserts all over the world and are arc-shaped, markedly asymmetrical in cross section, with a gentle slope facing toward the wind sand ridge, comprising well-sorted sand. This type of dune possesses two "horns" that face downwind, with the steeper slope known as the slip face, facing away from the wind, downwind, at the angle of repose of sand, approximately 30–35 degrees for medium-fine dry sand.[2] The upwind side is packed by the wind, and stands at about 15 degrees. Barchans may be 9–30 m (30–98 ft) high and 370 m (1,210 ft) wide at the base measured perpendicular to the wind. Simple barchan dunes may appear as larger, compound barchan or megabarchan dunes, which can gradually migrate with the wind as a result of erosion on the windward side and deposition on the leeward side, at a rate of migration ranging from about a meter to a hundred metres per year. Barchans usually occur as groups of isolated dunes and may form chains that extend across a plain in the direction of the prevailing wind. Barchans and megabarchans may coalesce into ridges that extend for hundreds of kilometers. Dune collisions and changes in wind direction that spawn new barchans from the horns of the old govern the size distribution in a given field.[3] As barchan dunes migrate, smaller dunes outpace larger dunes, catching-up the rear of the larger dune and eventually appear to punch through the large dune to appear on the other side. The process appears superficially similar to waves of light, sound, or water that pass directly through each other, but the detailed mechanism is very different. The dunes emulate soliton behavior, but unlike solitons, which flow through a medium leaving it undisturbed (think of waves through water), the sand particles themselves are moved. When the smaller dune catches up the larger dune, the winds begin to deposit sand on the rear dune while blowing sand off the front dune without replenishing it. Eventually, the rear dune has assumed dimensions similar to the former front dune which has now become a smaller, faster moving dune that pulls away with the wind.[4]

BASIN AND RANGE PROVINCE: A vast region that covers much of the inland Western United States and northwestern Mexico. It is defined by unique topography: abrupt changes in elevation that alternate between narrow faulted mountain chains and flat arid valleys or basins.

BATHYMETRIC: Related to bathymetry.

BATHYMETRY: The features of land when it lies underwater. Underwater equivalent of topography.

CAMBIC HORIZON (Bw Horizon): A weakly developed mineral layer in the middle part (B horizon) of a soil profiles. The Bw horizon can be recognized by minor chemical weathering (a yellowish stain due to oxidation), and minor secondary flux of wind-blown dust. In desert regions such as the Mojave Desert, southeastern California, Bw horizons generally require a couple of thousand years to develop, but are typically less than several thousand years old.

COPPICE DUNES: Vegetated sand mounds that are often scattered throughout sand sheets in semi-arid regions where shrubs and blowing sand are abundant. Any shrub sticking up into the airborne stream of sand impedes the flow. The resulting turbulence and lost speed cause sand grains to settle on the downwind side of the shrub and around its base. Coppice dunes range from about 1.5 – 9 feet high and 3 – 45 feet wide. Within any given field of coppice dunes, however, the dune size tends to be uniform. Because the sand accumulates in piles around the plants and is swept from the surfaces between the plants, a hummocky, rough topography develops that is very different from sand sheets without vegetation (which are typically smooth, flat, and gently undulatory). Under certain conditions, individual or clusters of coppice dunes become very large and are then called vegetation mounds. Coppice dunes are commonly associated with parabolic dune fields.

COPPICE TAIL: On the leeward (downwind) side of the coppice mound, at the base of the plant, is a triangular tail; the wide end attaches to the mound and points (narrows) downwind. The coppice tails are generally 3 inches to 3 feet long and provide excellent wind vector data for the past 1 to 10 years. A lack of active coppice tails (or degraded and/or vegetated coppice mounds) is an excellent indicator that sand is not currently migrating within that area. Most active coppice dunes in the Chuckwalla Valley region do exhibit coppice tails.

CORRIDOR SYSTEM, EOLIAN: Proposed eolian sand pathways that may allow wind-blown sand to travel for tens of miles and involve numerous sub-basins and possibly sand ramps. A corridor system allows wind-blown sand to travel tens of miles via topographic valleys and playa lake basins. It is clear that the proposed sand migration corridors in southeastern California are provided significant amounts of local sands.

TEMPORAL AND SPATIAL SCALE - CYCLIC: A way to measure the evolution of large dune field areas over time (Lancaster, 1995). A cyclic temporal scale spans periods of 1 thousand to 10 thousand years and its spatial scale corresponds to that of large dune field areas. These large dune field areas developed over thousands of years during major aggradational events of the latest Pleistocene to mid Holocene. Cyclic scale covers the formation of most of the larger dunes within the Chuckwalla eolian system.

TEMPORAL AND SPATIAL SCALE - GRADED: A way to measure the dynamics and morphology of dunes, including the migration of individual dunes within a dune system. Graded temporal scale spans time periods of 1 to 100 years. During those time frames, dunes tend to be in full or partial equilibrium with the rates and directions of sand movements generated by surface winds (Lancaster, 1995). In the Mojave Desert, graded time structures include small active dunes and medium to larger active coppice dunes and their respective tails.

TEMPORAL AND SPATIAL SCALE - INSTANTANEOUS: Instantaneous temporal and spatial scale involves very short periods of time and small areas. Eolian structures that form within instantaneous scale include the formation of sand ripples – which can develop in a few minutes - and very small coppice dune tails behind shrubs.

DEFLATION: A process in which wind picks up loose, fine particles, such as whitish, powdery mineral salts, and the particles then move suspended in the airstream. Deflation is common on "wet" playa surfaces where the groundwater is within 15 feet of the surface and routinely produces new salt crusts on the surface.

DISTRIBUTARY DRAINAGE SYSTEM: A **distributary**, or a **distributary channel**, is a stream that branches off and flows away from a main stream channel. They are a common feature of river deltas. The phenomenon is known as river bifurcation. The opposite of a distributary is a tributary. Distributaries usually occur as a stream nears a lake or an ocean, but they can occur inland as well, such as on alluvial fans or when a tributary stream bifurcates as it nears its confluence with a larger stream. In some cases, a minor distributary can divert so much water from the main channel that it can become the main route.

DORMANT AEOLIAN (EOLIAN) LANDFORMS: Dormant aeolian landforms are those on which surface sand transport and deposition are currently absent or at low level, yet are capable of reverting to an active condition as a result of minor climate changes (e.g. prolonged regional drought). Wind rippled surfaces are rare or absent, as are avalanche faces at the angle of repose. The former avalanche slope may be degraded, so that lee face slope angles of 20 degrees or less are common on crescentic dunes. Primary sedimentary structures are still present, but may be partially destroyed by bioturbation. Vegetation cover is usually well developed and includes a high percentage of perennial plants, including shrubs. The sand surface may be stabilized with biogenic crusts. Sand mobility may be reduced by a low=energy wind regime, lack of sand supply, and/or presence of a well-developed vegetation cover. Dormant dunes may revert to active features as a result of minor cyclic or secular environmental changes. A wide variety of degrees of dune dormancy can occur, but this class of aeolian landforms implies that they have not experienced active sand transport on time-scales of decades or greater. This definition is from Lancaster, 1992. Within Kenney GeoScience reports, the term "dormant dunes" and "relict dunes" is utilized to represent an eolian system that exhibits older dunes that are no longer receiving sufficient eolian sands to maintain those dune forms. In these areas, active sand in the form of sand sheets and coppice dunes that require minor magnitudes of eolian sand are transported over the older dune system. In addition, areas mapped by Kenney GeoScience as dormant or relict dunes also exhibit internal abrasion providing an internal source of eolian sand.

EOLIAN/(AEOLIAN): Wind blown. Eolian refers to processes associated with the wind, such as ventifacts, abrasion, wind-blown sand transport, and dune deposition. Aeolus was ruler of the winds in Greek mythology.

EOLIAN DEPOSITS: Sediments transported and subsequently deposited by moving air. Sand dunes form by eolian deposits.

EROSION: In earth science, erosion is the action of surface processes (such as water flow or wind) that remove soil, rock, or dissolved material from one location on the Earth's crust, then transport it away to another location.[1] The particulate breakdown of rock or soil into clastic sediment is referred to as physical or mechanical erosion; this contrasts with chemical erosion, where soil or rock material is removed from an area by its dissolving into a solvent (typically water), followed by the flow away of that solution. Eroded sediment or solutes may be transported just a few millimeters, or for thousands of kilometers.

GEOLOGIC TIMESCALE: A way to measure time and compare ages over millions of years. Geologists often need to compare the ages of rocks or landscapes, or discuss how long before the present something occurred. The geologic timescale provides a standardized reference. Thus, for example, when someone says a formation developed in "Late Pliocene", everyone else knows it developed between 12,000 and 126,000 years ago. In the geologic timescale, the longest divisions of time are the three eras, (from oldest to youngest) the Paleozoic, Mesozoic, and Cenozoic. Each era is divided into periods, and the periods are divided into epochs.

GEOMORPHIC: Related to geomorphology.

GEOMORPHIC PROVINCE: An area with common geologic or geomorphic attributes. A province may include a single dominant structural feature.

GEOMORPHOLOGIST: Scientists who seek to understand why landscapes look the way they do, to identify landform history and dynamics, and to predict future landscape changes through a combination of field observations, physical experiments, and numerical modeling. Geomorphologists work within a broad base of disciplines, including physical geography, geology, geodesy, engineering geology, archaeology and geotechnical engineering – which contributes to varied research styles and interests.

GEOMORPHOLOGY: The scientific study of landscapes – how they form and change, what their topographic and bathymetric features say about physical, chemical, and biological processes operating at or near the Earth's surface.

HOLOCENE: A measure of geologic time. In the geologic timescale, the Holocene is the current epoch, which began about 11,700 years ago (10,000 ^{14}C years ago).

HORIZON, SOIL: A layer generally parallel to the soil crust, whose physical characteristics differ from the layers above and beneath. Typically, soil horizons develop once a surface becomes stable, and thus affected by near-surface and surficial processes. Each soil type usually has three or four horizons defined by color, texture, or other obvious physical features. Typical soil horizons, from shallowest to deepest, are called: A, B, and C horizons. In many cases, particularly for buried soils, only the B and C horizons remain. Soil horizons change over time due to chemical and mechanical weathering, percolating water, plant and animal activity, wind-blown influx of material, and more. The soil changes occur over predictable time intervals, which allows soil scientists to estimate ages of the surfaces. Also see Soil Profile.

INTERDUNE AREAS: Desert floor between dunes in dune fields. Closed interdune areas may be poorly drained, contain playas, and are typically flat. Where dry and floored by sandy sediment, interdune areas have many of the same characteristics as sand sheets. With near-surface moisture, interdune areas may contain grasses, shrubs, trees, or even settlements. Interdune areas range in size from a few to tens of square miles. In any given locality, the sizes and shapes of the interdune areas are similar, as are those of the intervening dunes.

Kya: Abbreviation for "thousand years ago". Sometimes shown as ka or KYA.

LACUSTRINE: Lacustrine deposits are sedimentary rock formations which formed in the bottom of ancient lakes.[1] A common characteristic of lacustrine deposits is that a river or stream channel has carried sediment into the basin. Lacustrine deposits form in all lake types including rift graben lakes, oxbow lakes, glacial lakes, and crater lakes. Lacustrine environments, like seas, are large bodies of water. They share similar sedimentary deposits which are mainly composed of low-energy particle sizes. Lacustrine deposits are typically very well sorted with highly laminated beds of silts, clays, and occasionally carbonates.[2] In regards to geologic time, lakes are temporary and once they no longer receive water, they dry up and leave a formation. In desert environments, lacustrine environments include both playa and pluvial lakes.

LAST GLACIAL MAXIMUM: The Last Glacial Maximum (LGM) was the last period in the Earth's climate history during the last glacial period when ice sheets were at their greatest extension. Growth of the ice sheets reached their maximum positions in about 24,500 BCE. Deglaciation commenced in the Northern Hemisphere between approximately 18,000 to 17,000 BCE and in Antarctica approximately 12,500 BCE, which is consistent with evidence that it was the primary source for an abrupt rise in the sea level in about 12,500 BCE.[1] Vast ice sheets covered much of North America, northern Europe, and Asia. The ice sheets profoundly affected Earth's climate by causing drought, desertification, and a dramatic drop in sea levels.[2] It was followed by the Late Glacial.

LARGE SCALE MAPS: Large scale maps show a smaller amount of area with a greater amount of detail. The geographic extent shown on a large scale map is small. A large scaled map expressed as a representative scale would have a smaller number to the right of the ratio. Also see small scale map.

LEE(WARD) SIDE OF A DUNE : Leeward is downwind from the dominant wind direction that is primarily responsible for a dune's form. The lee side of a dune exists between the crest and the base of the avalanche face. Many active dunes (geologic unit Qsa), exhibit a free avalanche face where sand sediment is deposited near the angle of repose. (Lee side is opposite of stoss side, which is upwind)

LINEAR DUNES: One of the most common dune types, linear dunes are straight to irregularly sinuous, elongate, ridges of loose, well-sorted, very fine to medium sand. The straight varieties are often called *sand ridges*, and the sinuous varieties are often called *seifs*. Sinuosity and alternate slip faces develop because crosswinds change direction and shepherd the sand to one side then the other of the dune axes. The length of a linear dune, can range from several feet to many miles and is much greater than its width. The long axes of the linear dunes align within 15° of the prevailing wind or with the drift direction of the local winds. Linear dunes form in at least two environmental settings: where winds of bimodal direction blow across loose sand, and where single-direction winds blow over sediment that is locally stabilized (through vegetation, sediment cohesion, or topographic shelter from the winds). Linear dunes do exist in areas with varied wind speeds and directions. Most are probably "fossil" dunes formed during the Pleistocene, which had similar wind directions but more vigorous winds. Where linear dunes are active today, they are becoming more complex, with secondary dunes. Long standing opinion is that linear dunes migrate parallel to and along the downwind axis of the dune. However, new evidence indicates that linear dunes move about 15° oblique to the dune axis.

Ma: Abbreviation for "million years ago".

MINERALOGY: A field of geology specializing in the chemistry, crystal structure, and physical (including optical) properties of minerals and mineralized artifacts. Mineralogy studies classification of minerals, the processes of mineral origin and formation, their geographical distribution, and their utilization.

PARABOLIC DUNES: In plan view, these are U- or V-shaped mounds of well-sorted, very fine to medium sand with elongated arms that extend upwind (opposite of Barchan dunes). Slip faces occur on the outer (convex) side of the nose of the dune and on the outside slopes of its elongated arms. Parabolic dunes are always associated with vegetation--grasses, shrubs, and occasional trees anchor the trailing arms. Most parabolic dunes do not grow taller than tens of feet except at their forward portions. There, vegetation halts or slows the sand and it piles up. In inland deserts, parabolic dunes extend downwind from blowouts in sand sheets that are only partly anchored by vegetation. They can also originate from beach sands and on shores of large lakes. Parabolic dunes, like crescentic dunes (i.e. barchan), are characteristic of areas where winds were strong and unidirectional during their growth and migration.

PALEOSOL: (*palaeosol* in Great Britain and Australia) A former or "fossil" soil, preserved by burial underneath sediments or volcanic deposits, which may have lithified into rock.

PENETROMETER: An instrument for determining the consistency or hardness of a substance by measuring the depth or rate of penetration when a rod or needle is driven into the substance by a known force.

PIEDMONT SLOPE: An "apron" of sediment debris that lies between a mountain and a valley floor. A piedmont slope characteristically slopes away from the mountains, and flow directions are transverse to flow directions in the valley floor, so a piedmont slope indicates where the mountain and valley were at the time of the slope's formation. The piedmont slope is subdivided into five types based on morphology and relative age. Each of the five types forms by similar processes. Three of the types are relevant to this study: debris flows (fluidized slurries that flow downslope following intense downpours), grain flow (gravity-driven grain-to-grain downslope movement of sediment), and traction currents (sediments entrained by streams or sheet flows).

PLAN VIEW: Also known as map view. Looking at a feature or area from directly above it.

PLAYA LAKE – DRY LAKES: A playa lake is formed when water from rain or other sources, like intersection with a water table, flows into a dry depression in the landscape, creating a pond or lake. If the total annual evaporation rate exceeds the total annual inflow, the depression will eventually become dry again, forming a playa. Salts originally dissolved in the water precipitate out and are left behind, gradually building up over time. A playa appears as a flat bed of clay, generally encrusted with precipitated salts. These evaporite minerals are a concentration of weathering products such as sodium carbonate, borax, and other salts. In deserts, a playa may be found in an area ringed by bajadas. Dry lakes are typically formed in semi-arid to arid regions of the world. The largest concentration of dry lakes (nearly 22,000) is in the southern High Plains of Texas and eastern New Mexico. Most dry lakes are small. However, Salar de Uyuni in Bolivia, near Potosí, the largest salt flat in the world, comprises 4,085 square miles (10,582 square km).[2] Also see Pluvial Lakes.

PLIOCENE: A measure of geologic time. In the geologic timescale, the Pliocene epoch extends from 5.3 to 2.58 Ma. It is the second and youngest epoch of the Neogene period in the Cenozoic Era. From youngest to oldest, the epochs in the Cenozoic Era are Holocene, Pleistocene, Pliocene, Miocene, Oligocene, Eocene, Paleocene. In the Mojave Desert, most formations are Pliocene or younger.

PLEISTOCENE: A measure of geologic time. In the geologic timescale, the Pleistocene epoch extends from 2.58 million to ~12,000 years before present. The Pleistocene includes the world's most recent period of repeated glaciations and is subdivided into *Early* (2.6 million to 781k years ago), *Middle* (781k to 126k years ago) and *Late* (126k to 12k years ago. This report refers to *Latest* Pleistocene, which began 50k to 60k years ago.

PLUVIAL LAKES: A **pluvial lake** is a landlocked basin (endorheic basin) that fills with rainwater during times of glaciation, when precipitation is higher.[1] Pluvial lakes that have since evaporated and dried out may also be referred to as paleolakes.[2]

QUATERNARY: A measure of geologic time. The present day is part of the Quaternary period of the Cenozoic Era. The Quaternary began about 2.588 million years ago (Ma) and is divided into two epochs: the Pleistocene and the Holocene. The end of the Pleistocene is considered to occur at 11.7 Ma. The Quaternary continues to this day.

RELICT AEOLIAN (EOLIAN) LANDFORMS: Relict aeolian landforms are those that are clearly a product of past climatic regimes or depositional environments and have been stabilitzed for a period of at least 1000 years. They include dunes and sand sheets that are stabilized by soil development (including calcic horizons, early stages of diagenesis (partial cementation), deflation lag surfaces, colluvial cover, and woodland vegetation. Relict features may revert to an active state only as a result of major environmental changes. This definition is from Lancaster, 1992. Within Kenney GeoScience reports, the term “relict dunes” is utilized to represent an eolian system that exhibits older dunes that during their development required more eolian sand migration than is currently taking place. In these areas, active sand in the form of sand sheets and coppice dunes that require minor magnitudes of eolian sand are transported over the older dune system. In addition, areas mapped by Kenney GeoScience as dormant or relict dunes also exhibit internal abrasion providing an internal source of eolian sand. The Lancaster, 1992 relict dune definition is reasonable for dunes that developed during interglacial period prior to the Holocene interglacial as it takes tens of thousands of years for well developed calcic soil horizons to developed. However, it is a useful definition for quite ancient relict dune systems.

RUBIFICATION: Rubification refers to a substance becoming more reddish in color. For the purposes of eolian geomorphic and stratigraphic reports, the term rubification is utized as a soil profile term where reddening under surficial clasts increase over time which assists in estimating a surficial soils minimum age.

SAND SHEETS (SAND PLAINS): Flat, or gently undulatory, broad floors of windblown sand deposits that lie in thin layers that are gently inclined or horizontal. Sand sheets have fine grained material separated by layers – only one grain thick! - of coarser, “wind lag” particles. The latter are the coarsest particles that can be shifted by the wind. In any one place, the sizes of the wind lag particles are remarkably uniform, and may be so closely packed that the layer forms a miniature desert pavement. Sand sheets give information about the strength of the winds. Inactive sand sheet deposits provide evidence of past wind sand migration corridors.

SALTATION: The movement of loose, hard particles in a turbulent flow of wind or water over an uneven surface. Examples include pebbles in rivers, sand drift over deserts, and soil blowing over prairies.

SAND RIDGE: see Linear Dunes.

SEDIMENT: **Sediment** is a naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and/or by the force of gravity acting on the particles. For example, sand and silt can be carried in suspension in river water and on reaching the sea be deposited by sedimentation and if buried this may eventually become sandstone and siltstone, (sedimentary rocks). Sediments are most often transported by water (fluvial processes), but also wind (aeolian processes) and glaciers. Beach sands and river channel deposits are examples of fluvial transport and deposition, though sediment also often settles out of slow-moving or standing water in lakes and oceans. Desert sand dunes and loess are examples of aeolian transport and deposition. Glacialmoraine deposits and till are ice-transported sediments.

SEIF: see Linear Dunes.

SMALL SCALE MAP: Small scale maps show a larger amount of area with less amount of detail. The geographic extent shown on small scale maps is relatively larger than for large scale maps. A small scaled map expressed as a representative scale would have a larger number to the right of the ratio compared to large scale maps. Also see large scale map.

SOIL PROFILE: The **soil profile** is a vertical section of the **soil** that depicts all of its horizons**.** A **soil** horizon makes up a distinct layer of **soil**. The horizon runs roughly parallel to the **soil** surface and has different properties and characteristics than the adjacent layers above and below.

STABILIZED DUNES: Sand dunes that are unable to migrate due to vegetation growth on the dune. Stabilized dunes often develop due to limited eolian sand input. However, some dunes evaluated by the author appear to be stabilized not by vegetation, but by moisture. (The moisture may come from underlying springs, precipitation on the dunes that penetrates into the dune, or storm runoff that seeps into the dune mass. This process is poorly studied, although critical to the stability of dunes.) Within this study, stabilized dunes dominate dune areas mapped as Qsad and Qsr. Also referred to as vegetated dunes.

STOSS SIDE OF A DUNE: The stoss side of a dune points in the direction of the dominant wind, responsible for the primary dune form. The stoss side lies between the toe and the crest of the dune, on the upwind side (opposite of the lee side, which is downwind).

TOPOGRAHIC: relating to topography.

TOPOGRAPHY: The arrangement of the physical features of an area. For example, the location and elevations of valleys and mountains are part of an area's topography.

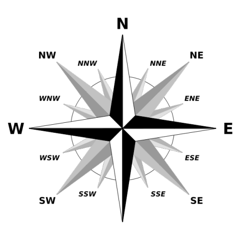
TRIBUTARY DRAINAGE SYSTEM: A **tributary**[1] or **affluent**[2] is a stream or river that flows into a larger stream or main stem (or parent) river or a lake.[3] A tributary does not flow directly into a sea or ocean.[4] Tributaries and the main stem river drain the surrounding drainage basin of its surface water and groundwater, leading the water out into an ocean. A confluence, where two or more bodies of water meet together, usually refers to the joining of tributaries. The opposite to a tributary is a distributary, a river or stream that branches off from and flows away from the main stream.[5] Distributaries are most often found in river deltas.

VEGETATION MOUND: A large Coppice Dune.

VENTIFACTS: Rocks that have been abraded, pitted, etched, grooved, or polished by wind-driven sand. Ventifacts typically occur on gravel-size rocks exposed to sand-bearing wind. Ventifacts are identified by rounded edges and a soft feel on the gravel side exposed to the atmosphere. Ventifacts provide information regarding the prevailing wind direction.

WIND DIRECTIONS: Meteorologists always define the wind direction as the direction the wind is coming from. If you stand so that the wind is blowing directly into your face, the direction you are facing names the wind.

WINDROSE DIRECTIONS FOR WIND AND SAND MIGRATION DIRECTIONS: The windrose figure below provides the direction nomenclature for the direction wind is moving, and within this report, the direction eolian sands are migrating. The wind direction is described by the direction the wind is coming from, and for eolian sand migration, it's the direction that the sand is toward. Hence, for sand migration moving ESE, the sand is moving from the WNW toward the ESE.



APPENDIX C

SAND MIGRATION ZONE DESIGNATION PHOTOGRAPHS

APPENDIX C

SAND MIGRATION ZONE DESIGNATION PHOTOGRAPHS

Photograph of geomorphic sites across the site to provide documentation of the geomorphic characteristics of the various sand migration zones within the property, but also to document the dune conditions at a particular time. The photographs also provide evidence of a Sahara Mustard bloom exhibiting abundant dead plants months after they had grown and died.

Figure AC-1: Location map for selected Geomorphic Sites in which photographs of the test pits with soil stratigraphy evaluated.

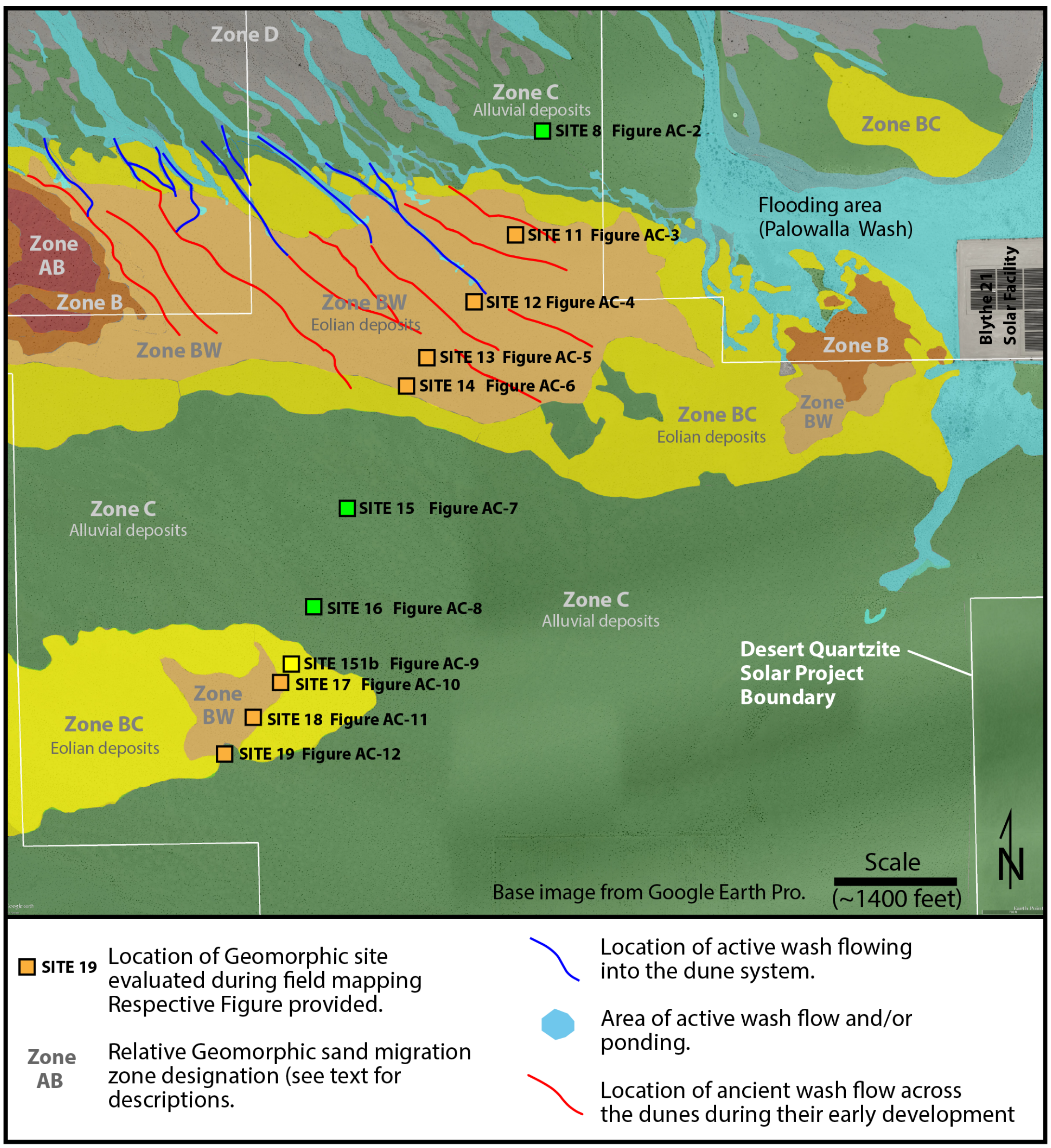


Figure AC-2: Geomorphic Site 8 Geomorphic Relative Sand Migration **Zone C**

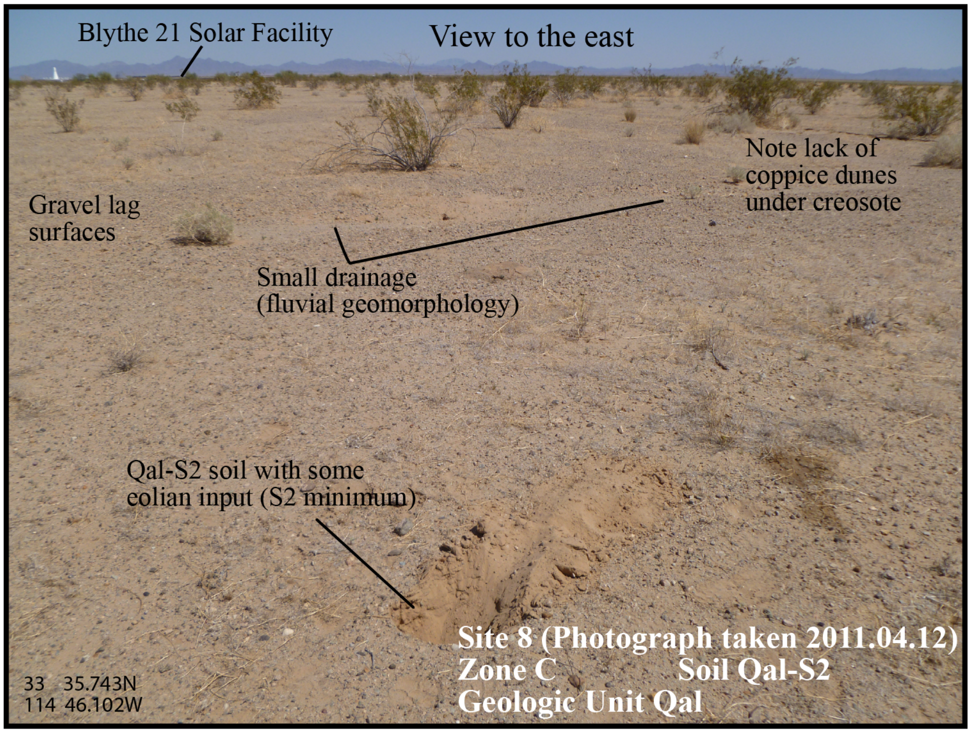


Figure AC-3: Geomorphic Site 11 Geomorphic Relative Sand Migration **Zone BW**

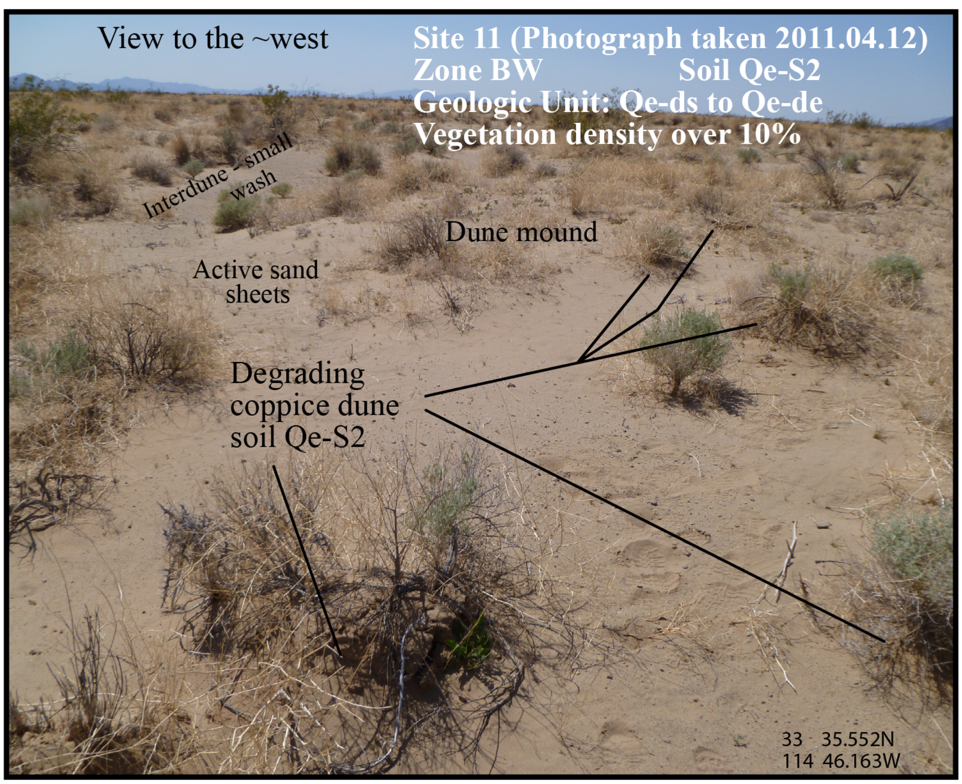


Figure AC-4: Geomorphic Site 12 Geomorphic Relative Sand Migration **Zone BW**

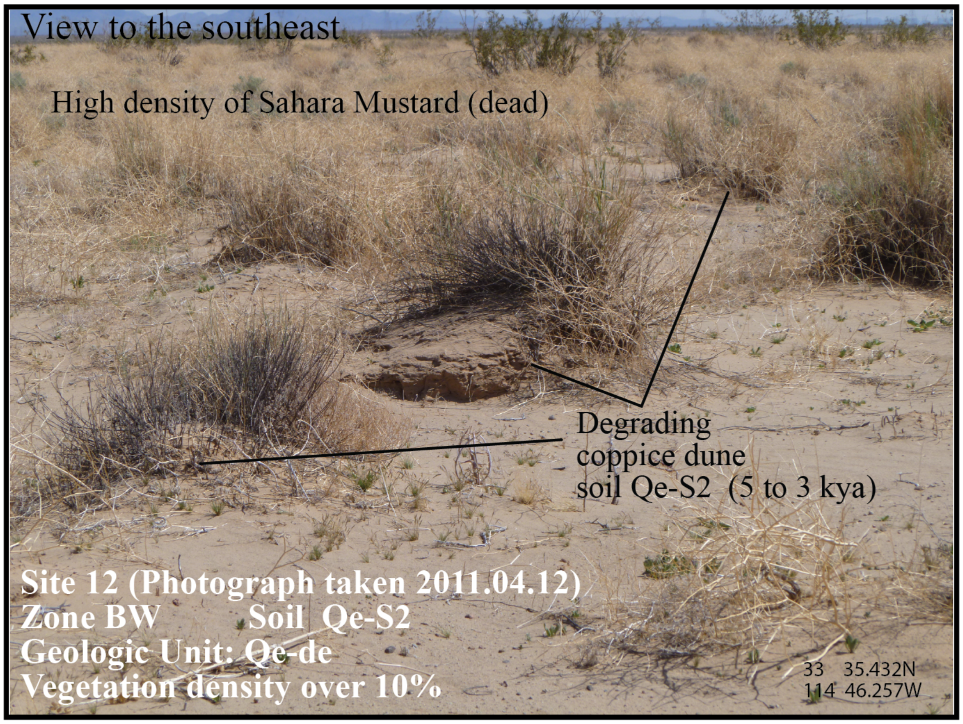


Figure AC-5: Geomorphic Site 13 Geomorphic Relative Sand Migration **Zone BW**

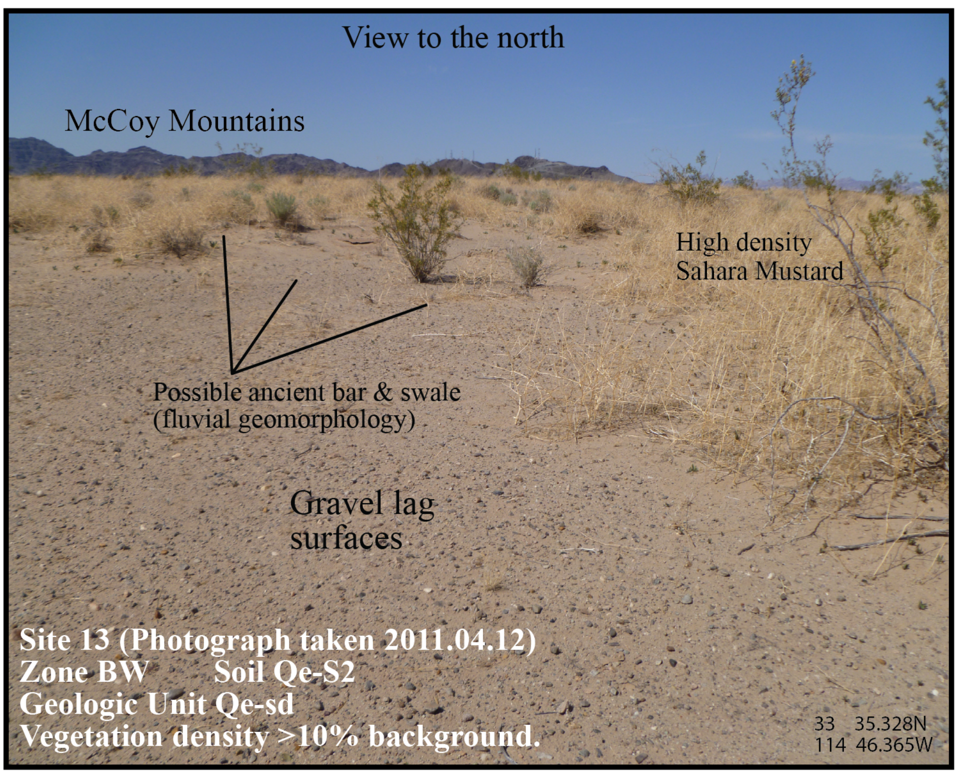


Figure AC-6: Geomorphic Site 14 Geomorphic Relative Sand Migration **Zone BW**

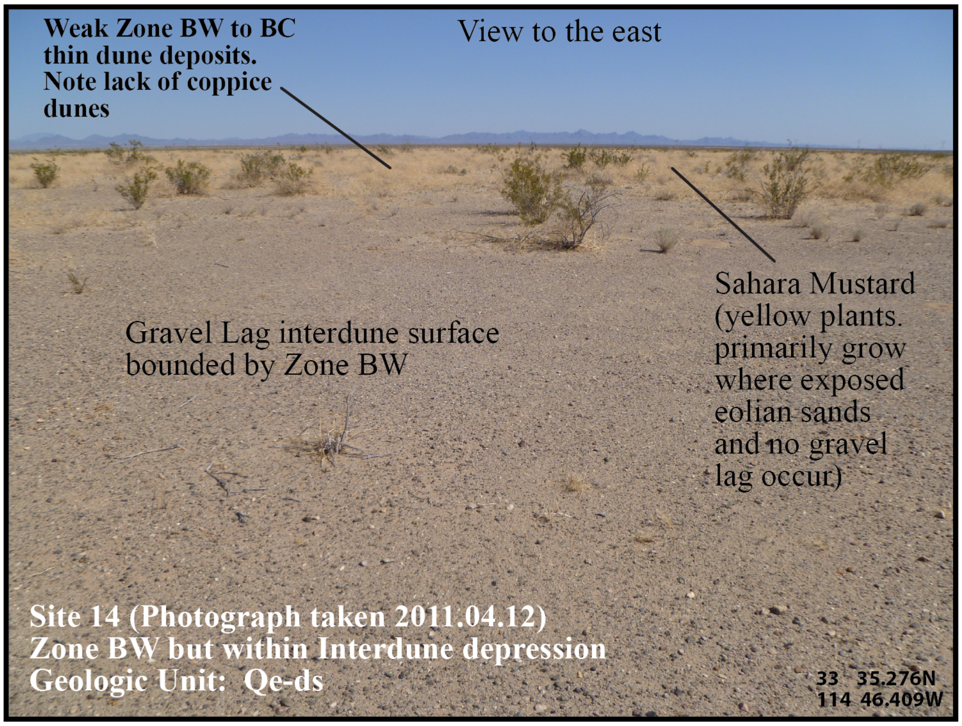


Figure AC-7: Geomorphic Site 15 Geomorphic Relative Sand Migration **Zone C**

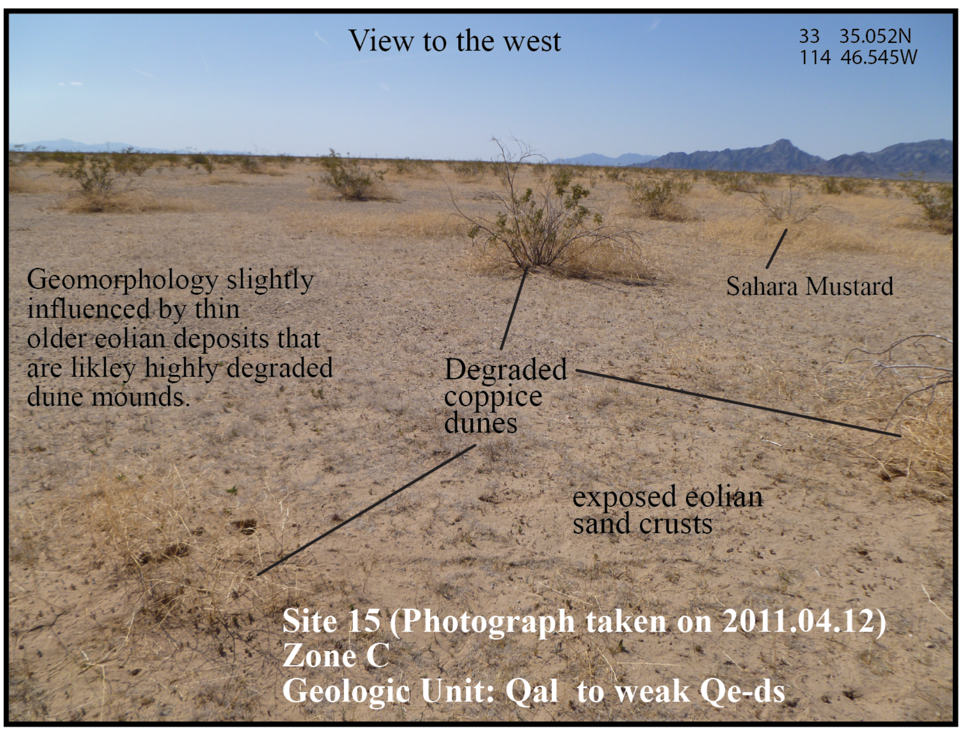


Figure AC-8: Geomorphic Site 16 Geomorphic Relative Sand Migration **Zone C**

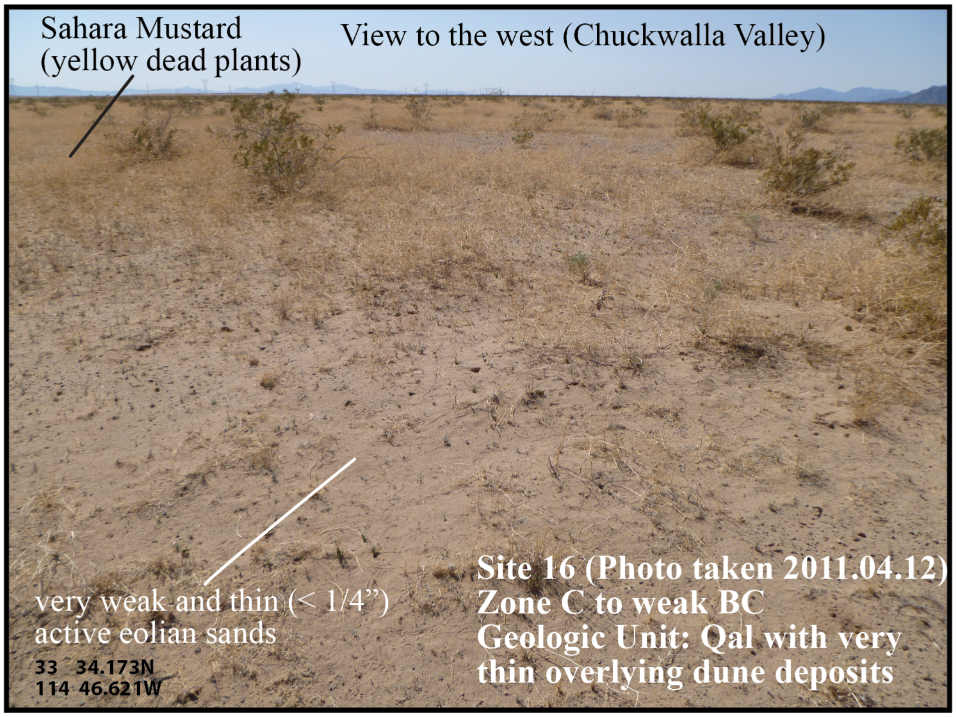


Figure AC-9: Geomorphic Site 151b Geomorphic Relative Sand Migration **Zone BC**

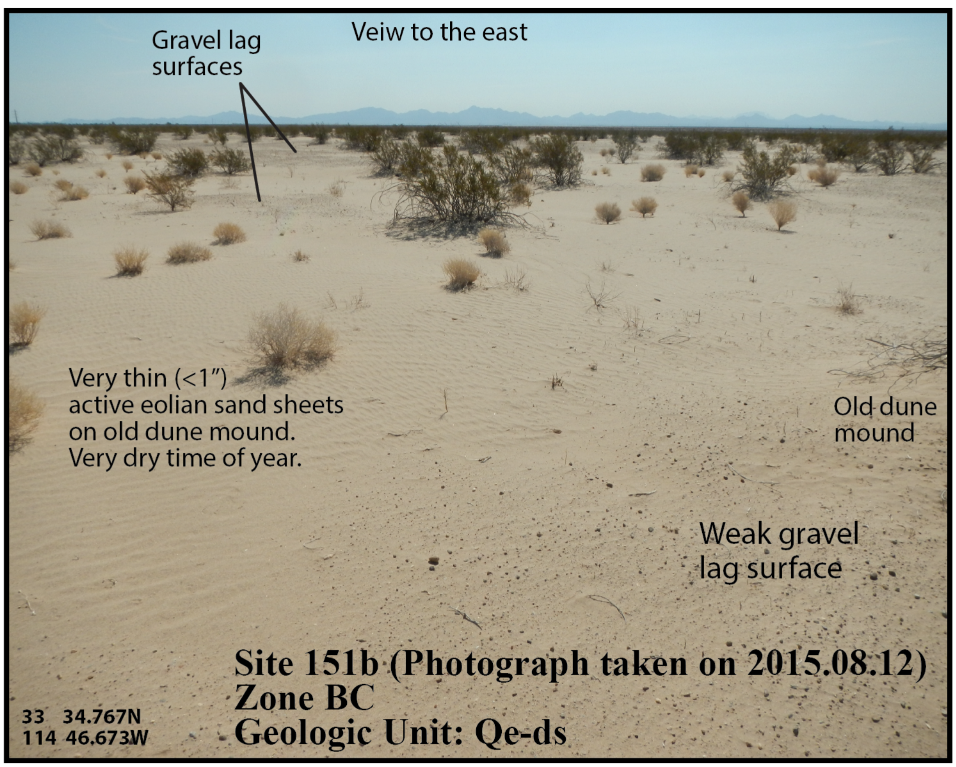


Figure AC-10: Geomorphic Site 17 Geomorphic Relative Sand Migration **Zone BC to BW**

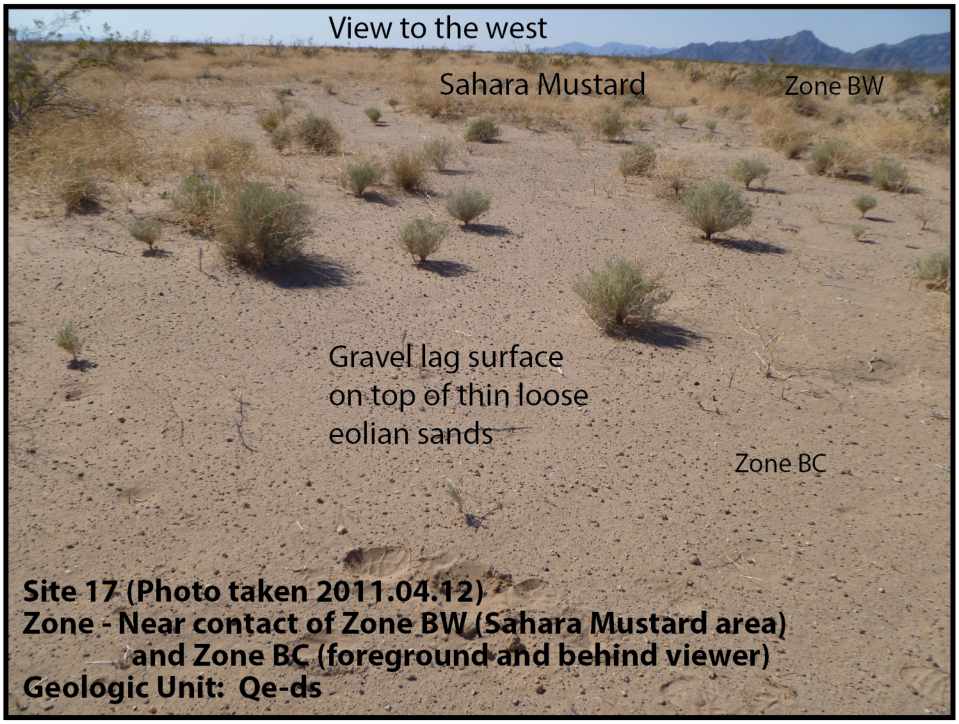


Figure AC-11: Geomorphic Site 18 Geomorphic Relative Sand Migration **Zone BW**

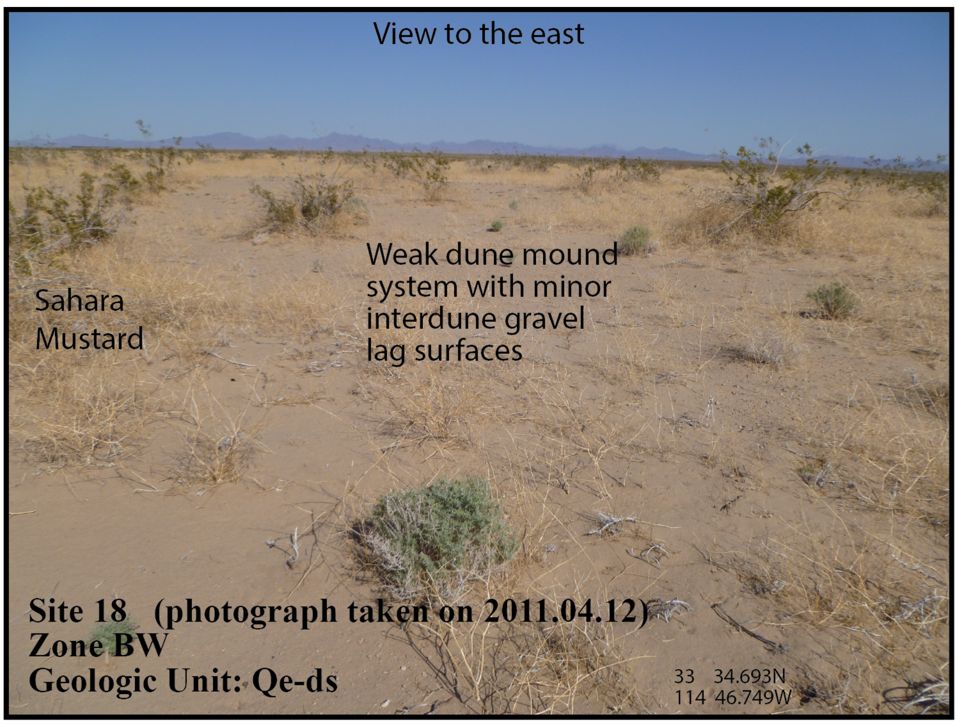
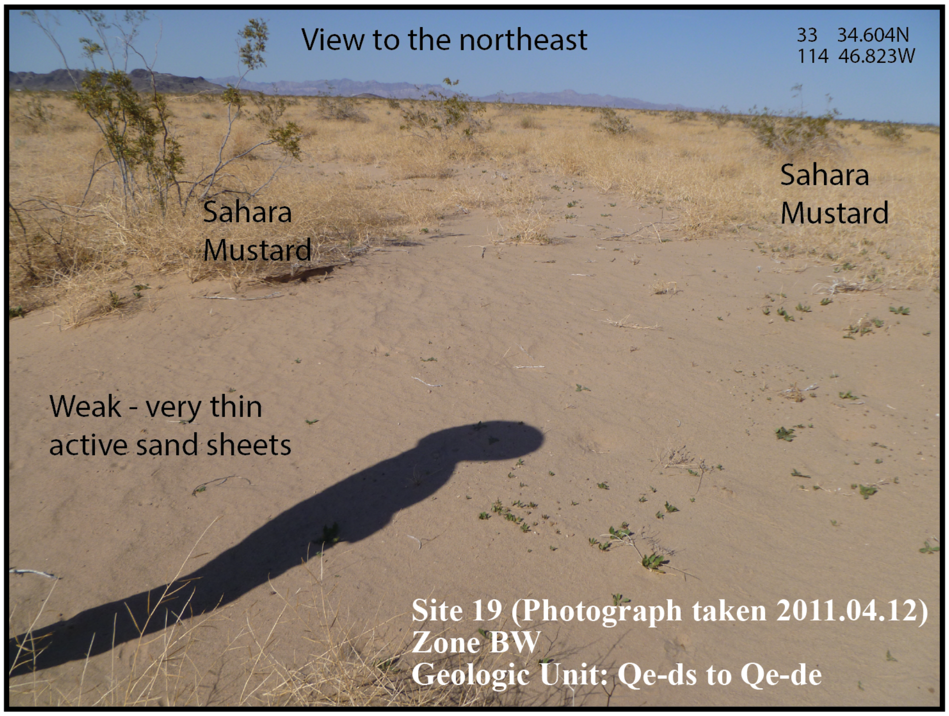


Figure AC-12: Geomorphic Site 19 Geomorphic Relative Sand Migration **Zone BW**



APPENDIX D

SOIL STRATIGRAPHIC DESIGNATION PHOTOGRAPHS

APPENDIX D
SOIL DESIGNATION PHOTOGRAPHS

Photographs of various soils of the designated soil stratigraphy utilized in this study. The photographs are organized by providing eolian parent material soils first, then alluvial parent soils second and in increasing age.

Soil stratigraphy nomenclature example: Qe-S2/Qal-S3a/Qoaf-S4 describes a surface soil with eolian parent material of S2 development (age of 5 to 3 kya), overlying a soil with alluvial parent material soil of S3a development (8 to 5 kya), that overlies the deepest soil with older alluvium parent material of S4 development (age of ~35 to 65 kya).

Figure AD-1: Location map for selected Geomorphic Sites in which photographs of the test pits with soil stratigraphy evaluated.

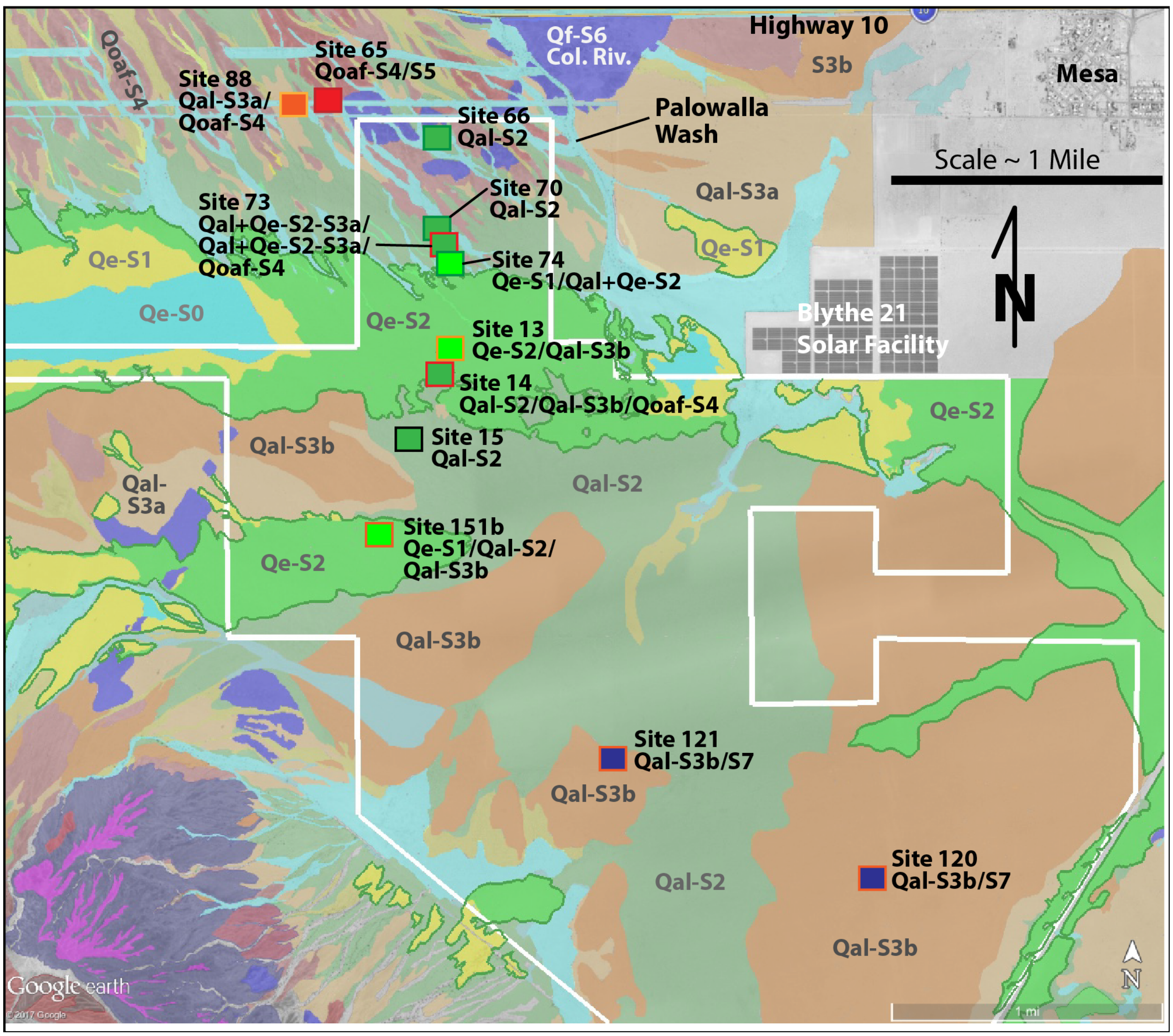


Figure AD-2: Geomorphic Site 74 Soil Stratigraphy: Qe-S1/Qal+Qe-S1 to S2

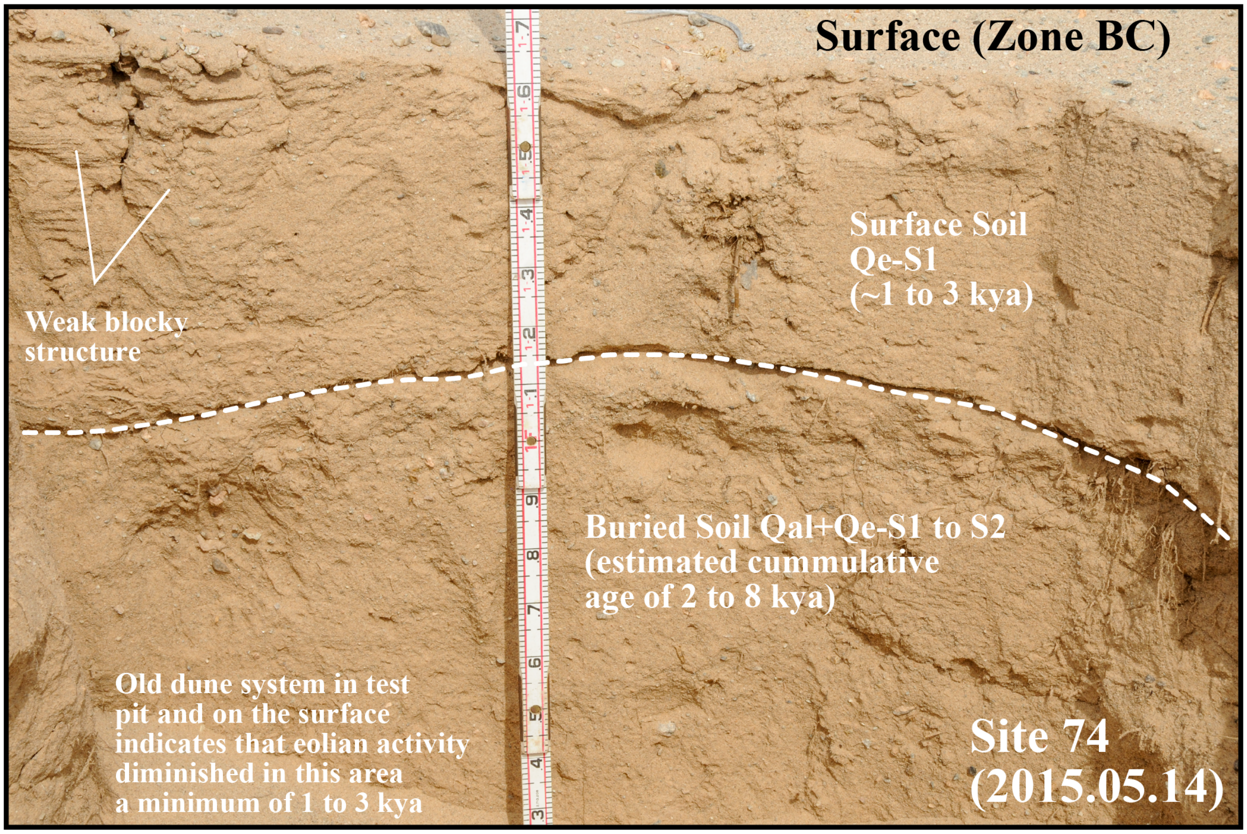


Figure AD-3: Geomorphic Site 151b Soil Stratigraphy: Qe-S1/Qal-S3b/Qoaf-S4

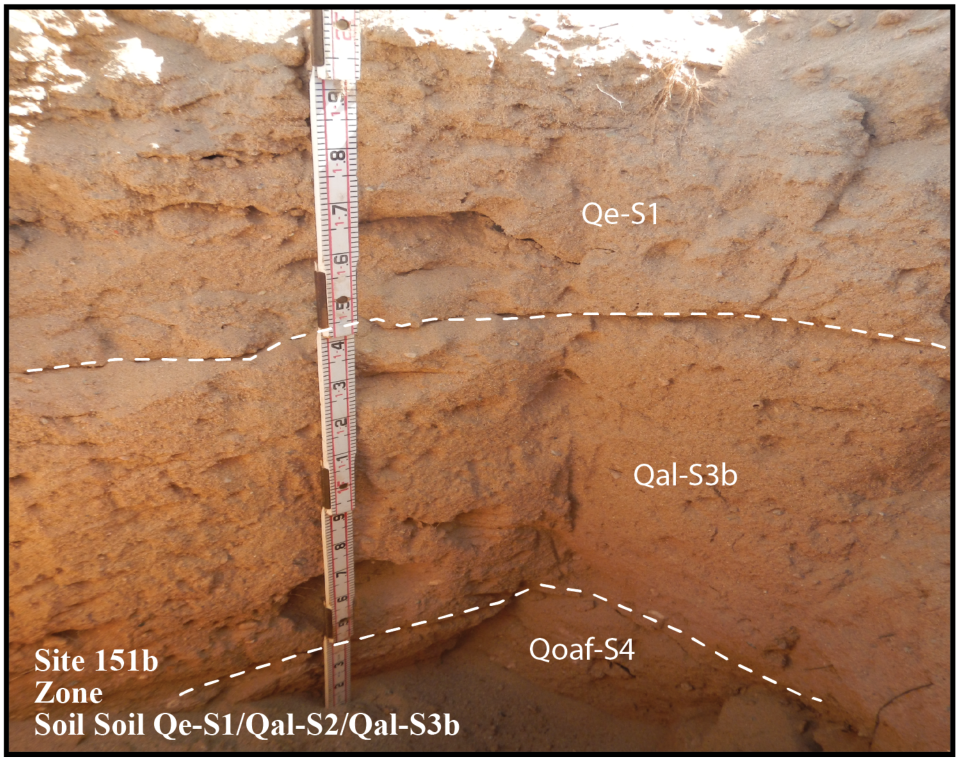


Figure AD-4: Geomorphic Site 13 Soil Stratigraphy: Qe-S2/Qal-S3b to possibly Qoaf-S4

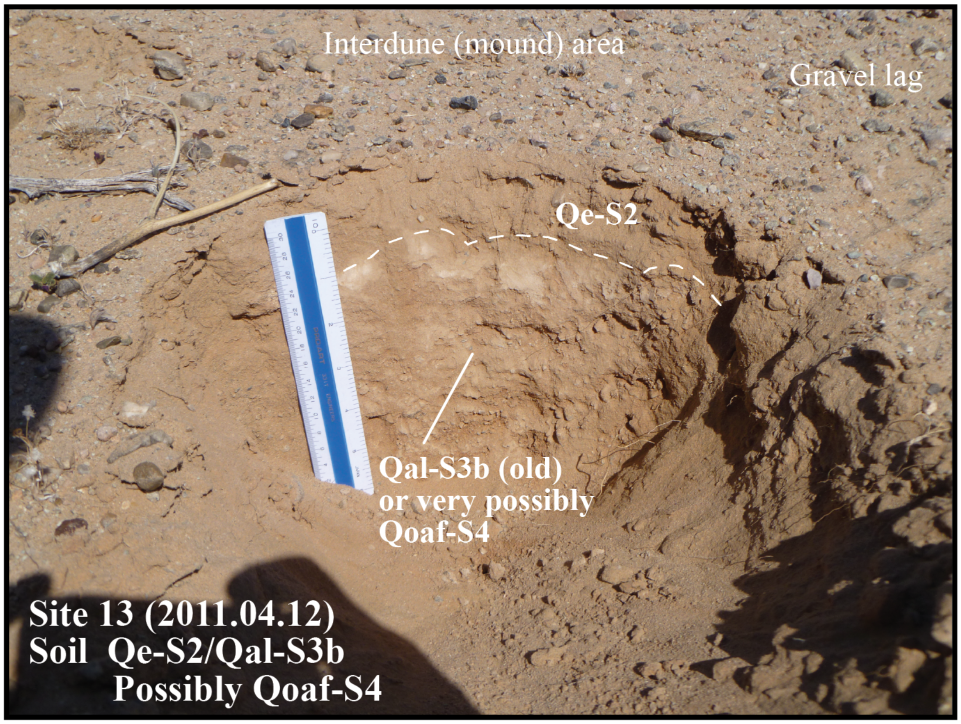


Figure AD-5: Geomorphic Site 14 Soil Stratigraphy: Qe-S2/Qal-S3b/Qoaf-S4

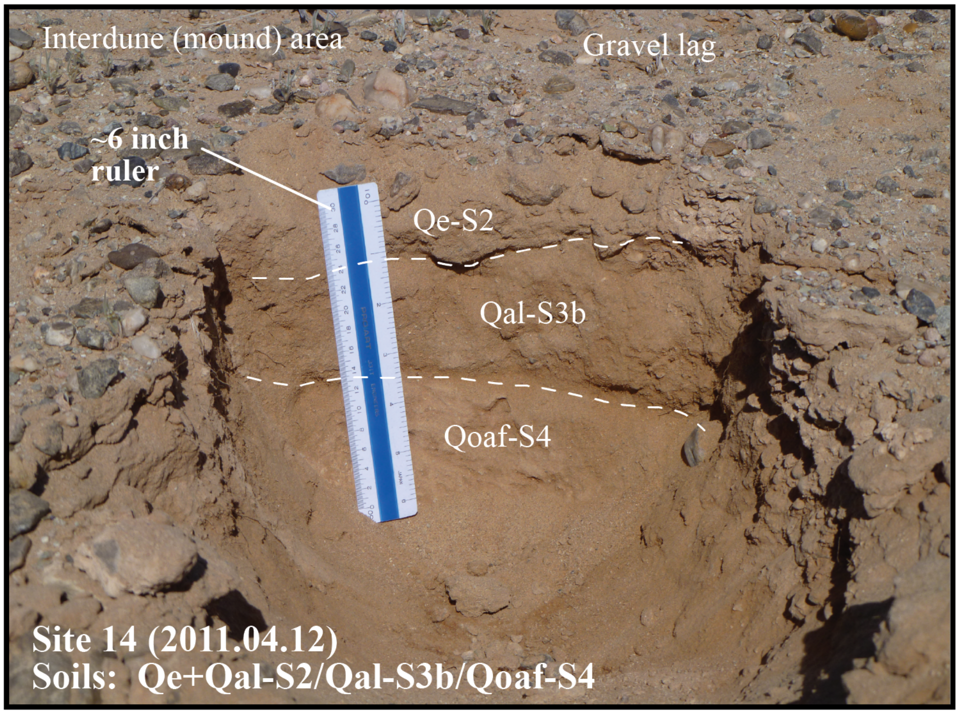


Figure AD-6: Geomorphic Site 70 Soil Stratigraphy: Qal-S2 (mature) approaching Qal-S3a

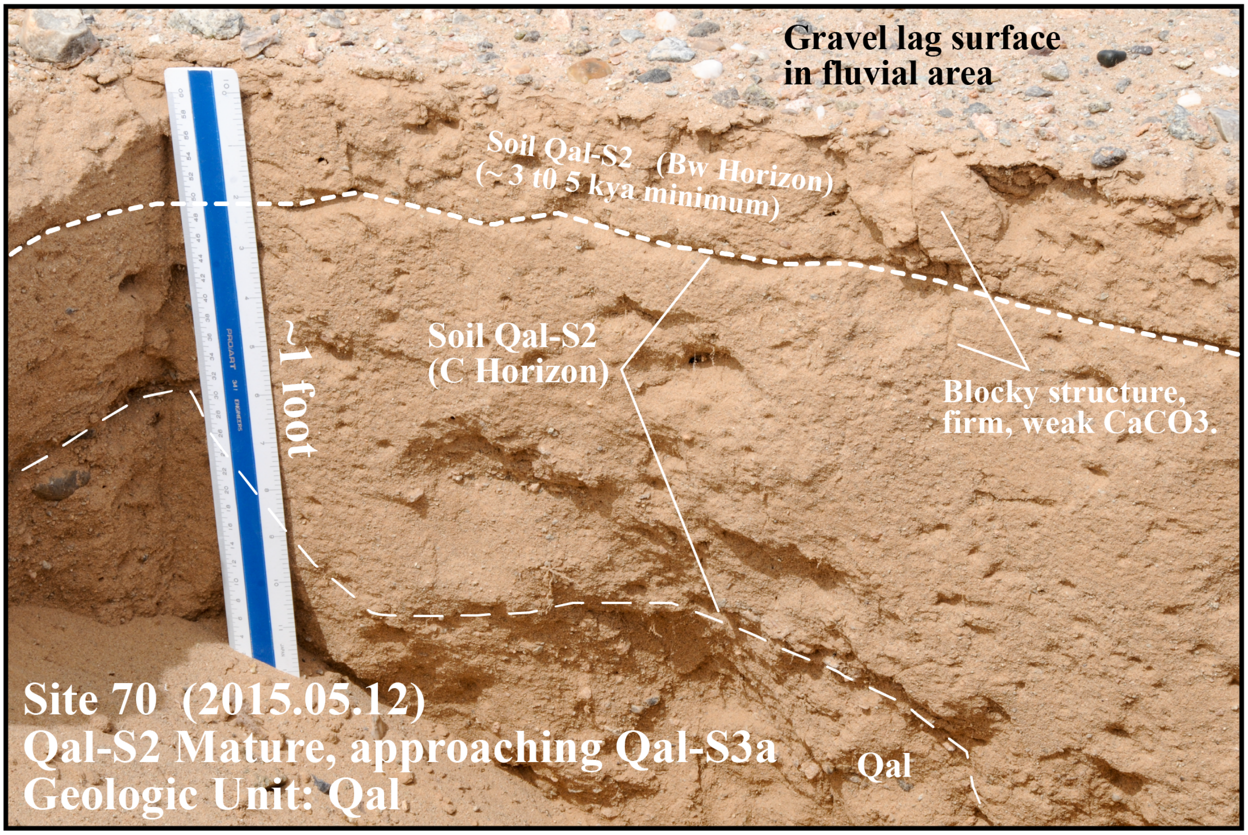


Figure AD-7: Geomorphic Site 66 Soil Stratigraphy: Qal-S2/Qal-S2 buried-1/Qal-S2 buried-2

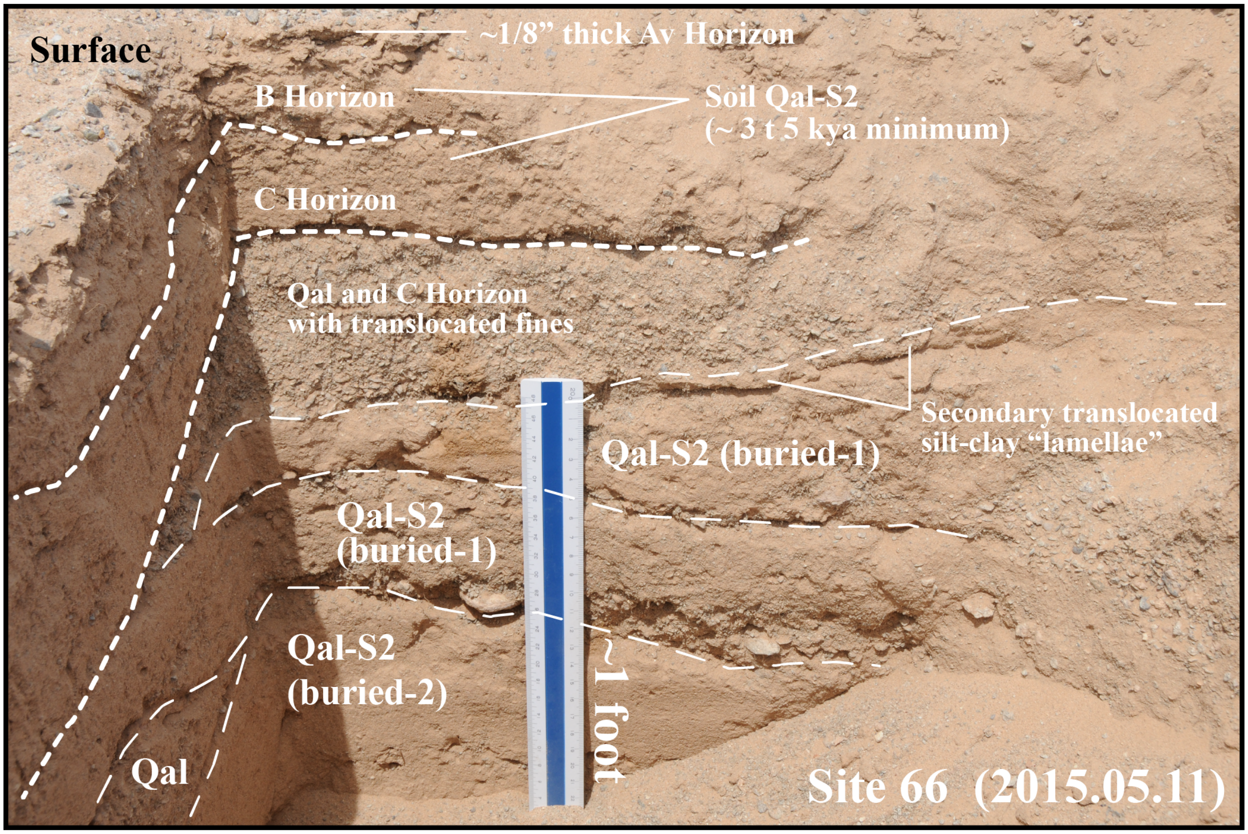


Figure AD-8: Geomorphic Site 15 Soil Stratigraphy: Qal-S2

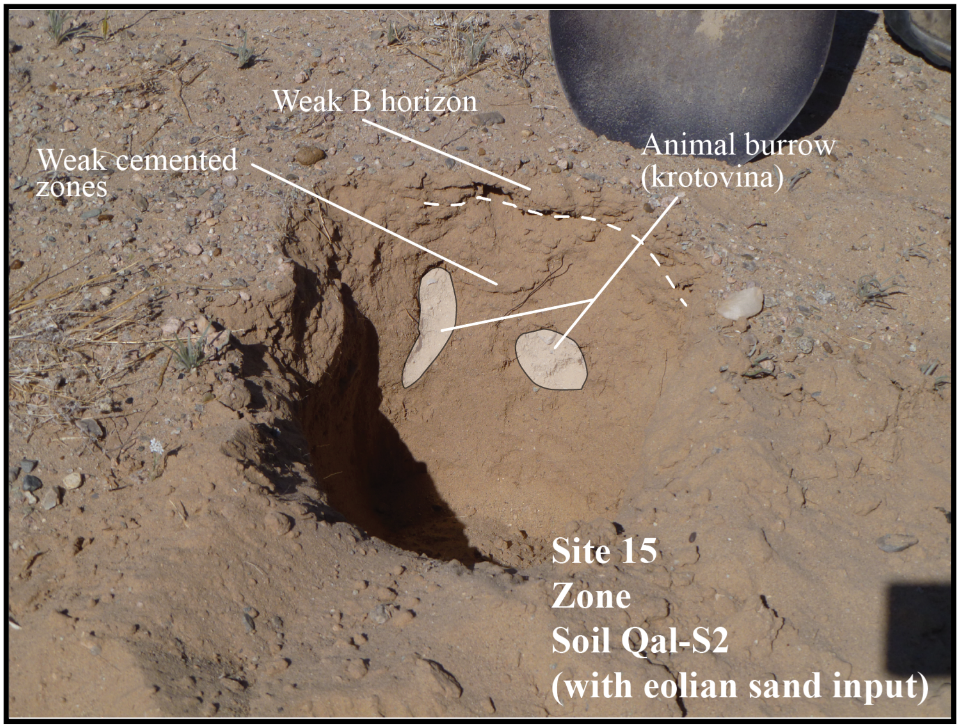


Figure AD-9: Geomorphic Site 73 Soil Stratigraphy: Qal+Qe-S2 to weak S3a/Qal-S2-S3a/Qoaf-S4

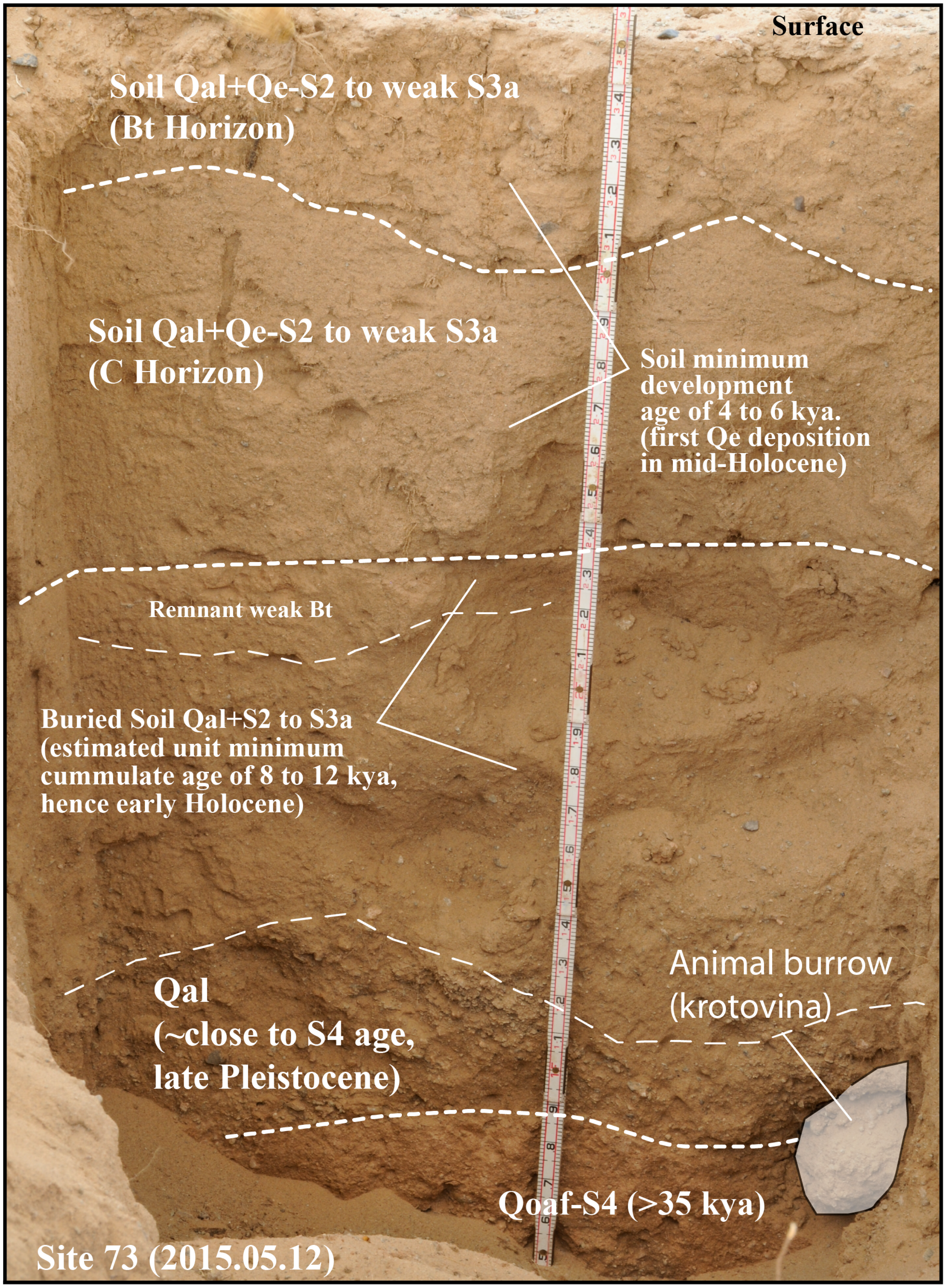


Figure AD-10: Geomorphic Site 88 Soil Stratigraphy: Qal-S3a/Qoaf-S4

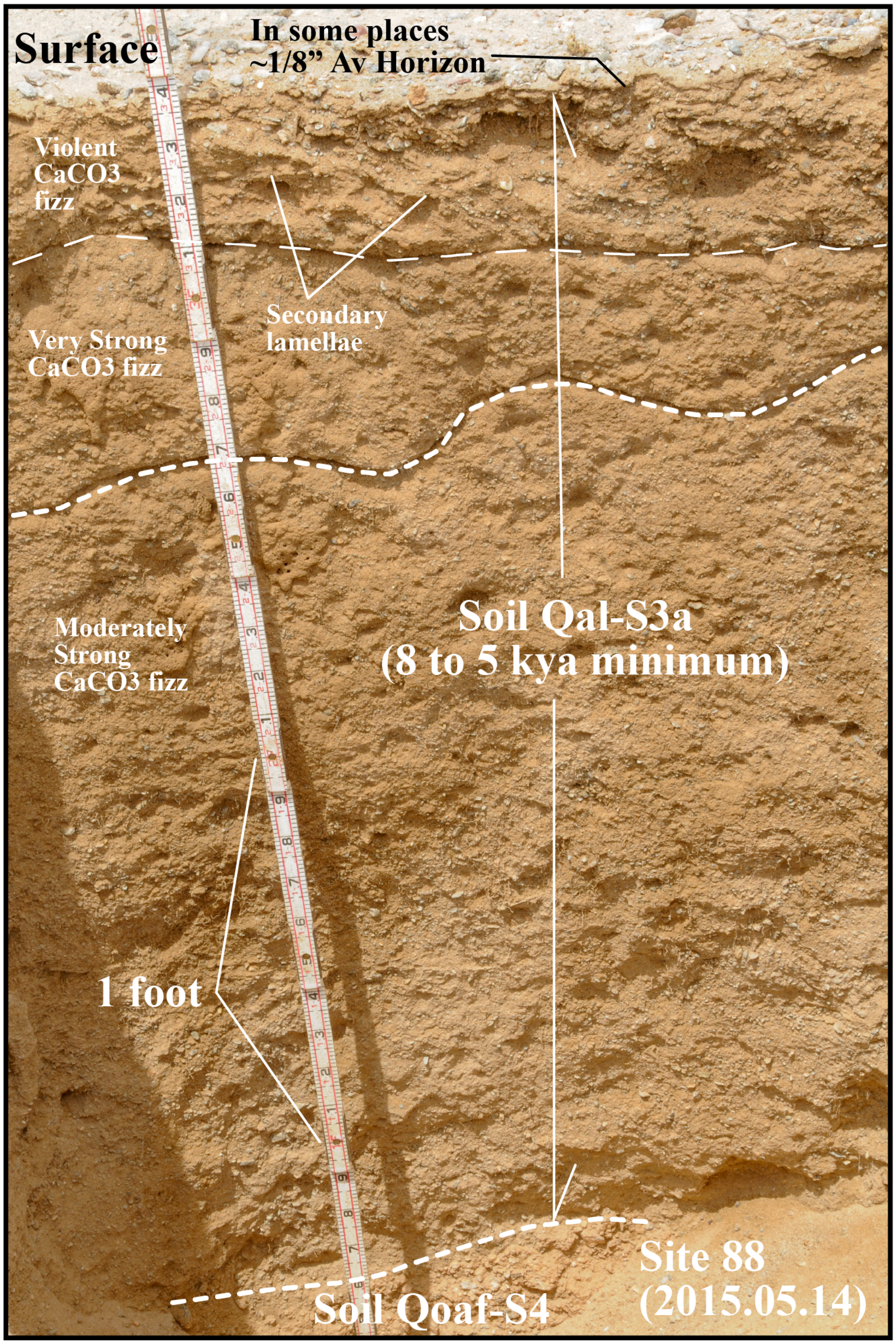


Figure AD-11: Geomorphic Site 120 Soil Stratigraphy: Qal-S3b/S7 Bullhead Alluvium (Tmw)

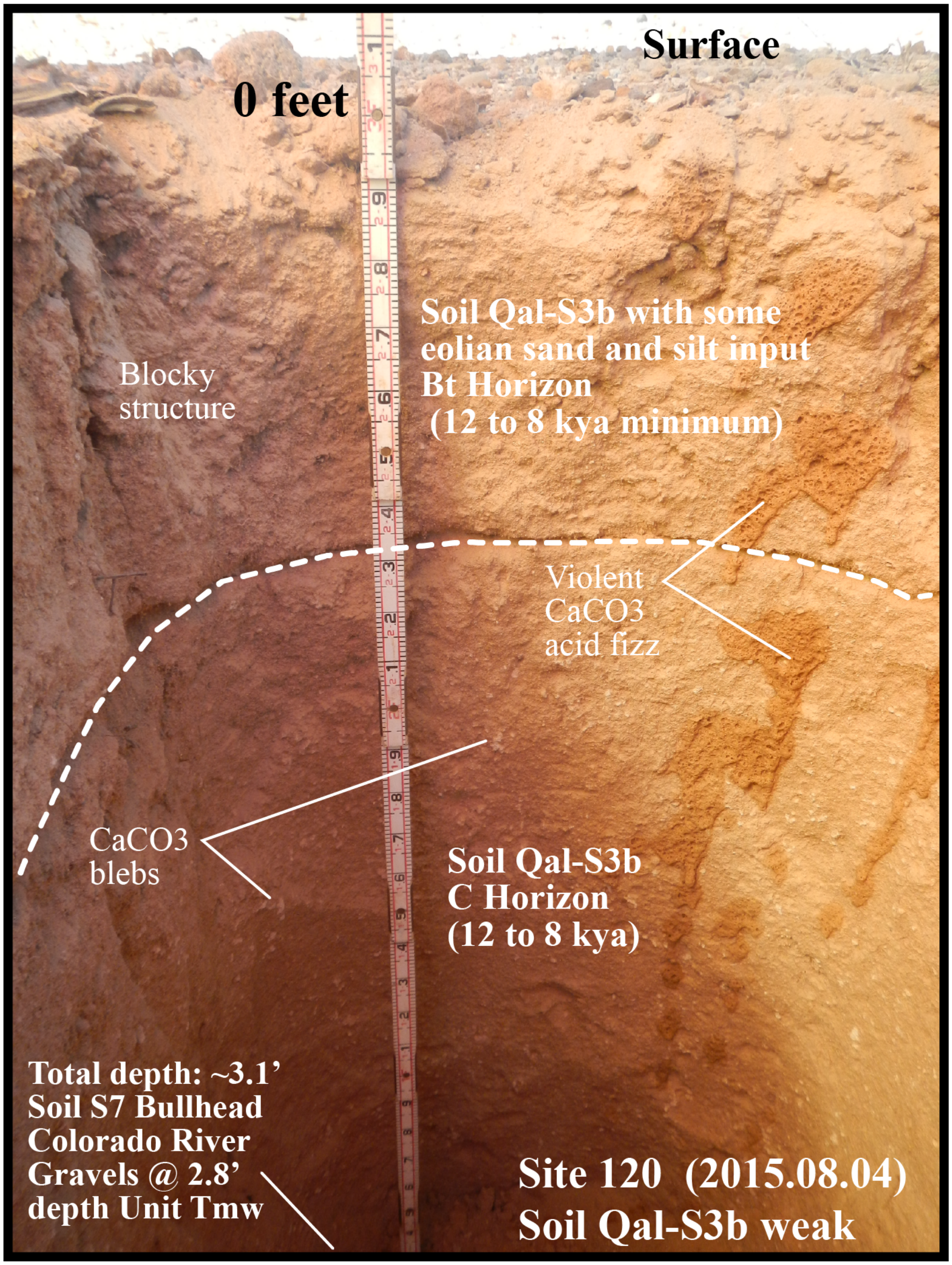


Figure AD-12: Geomorphic Site 121 Soil Stratigraphy: Qal-S3b/S7 Bullhead Alluvium (Tmw)

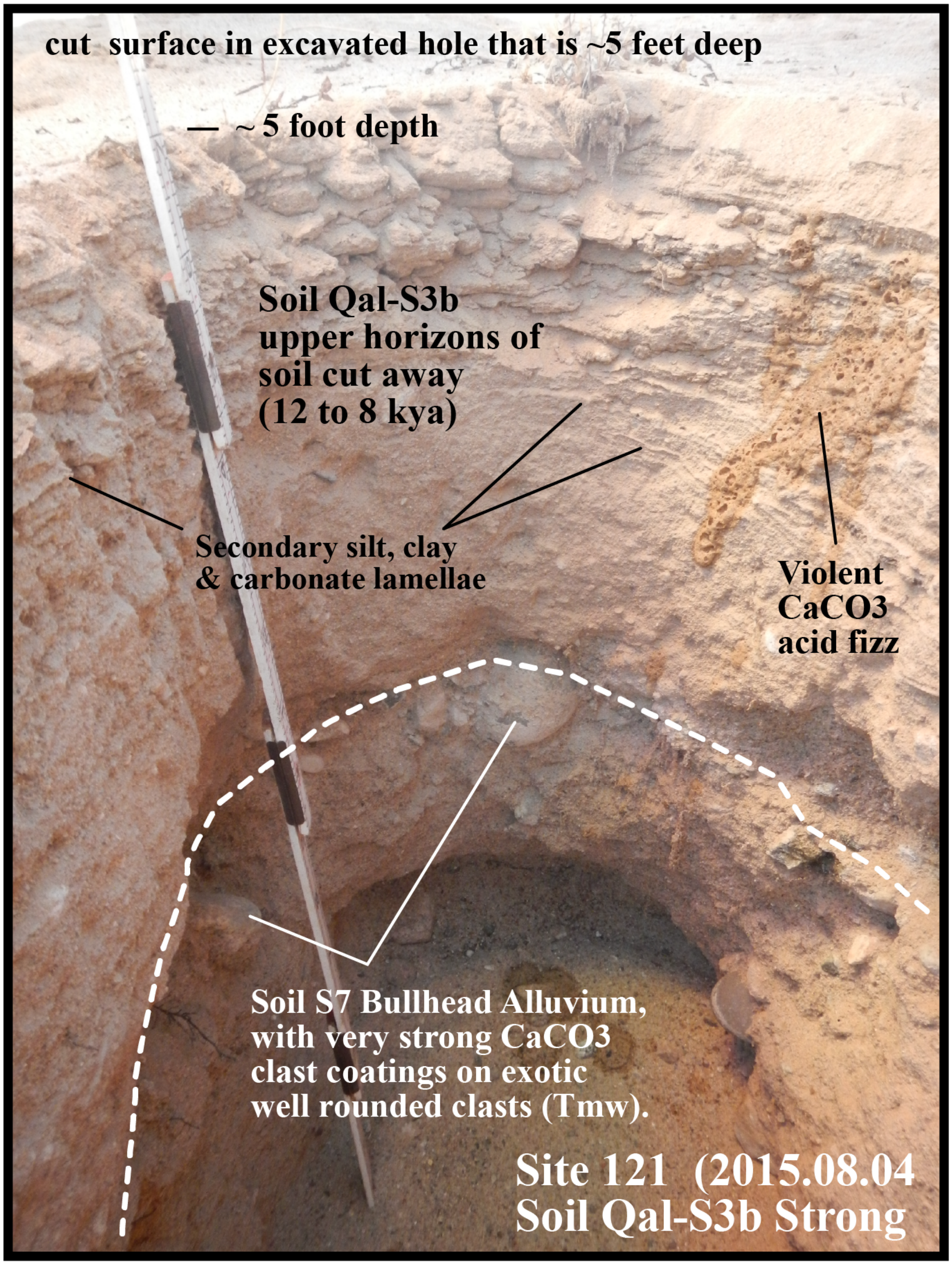
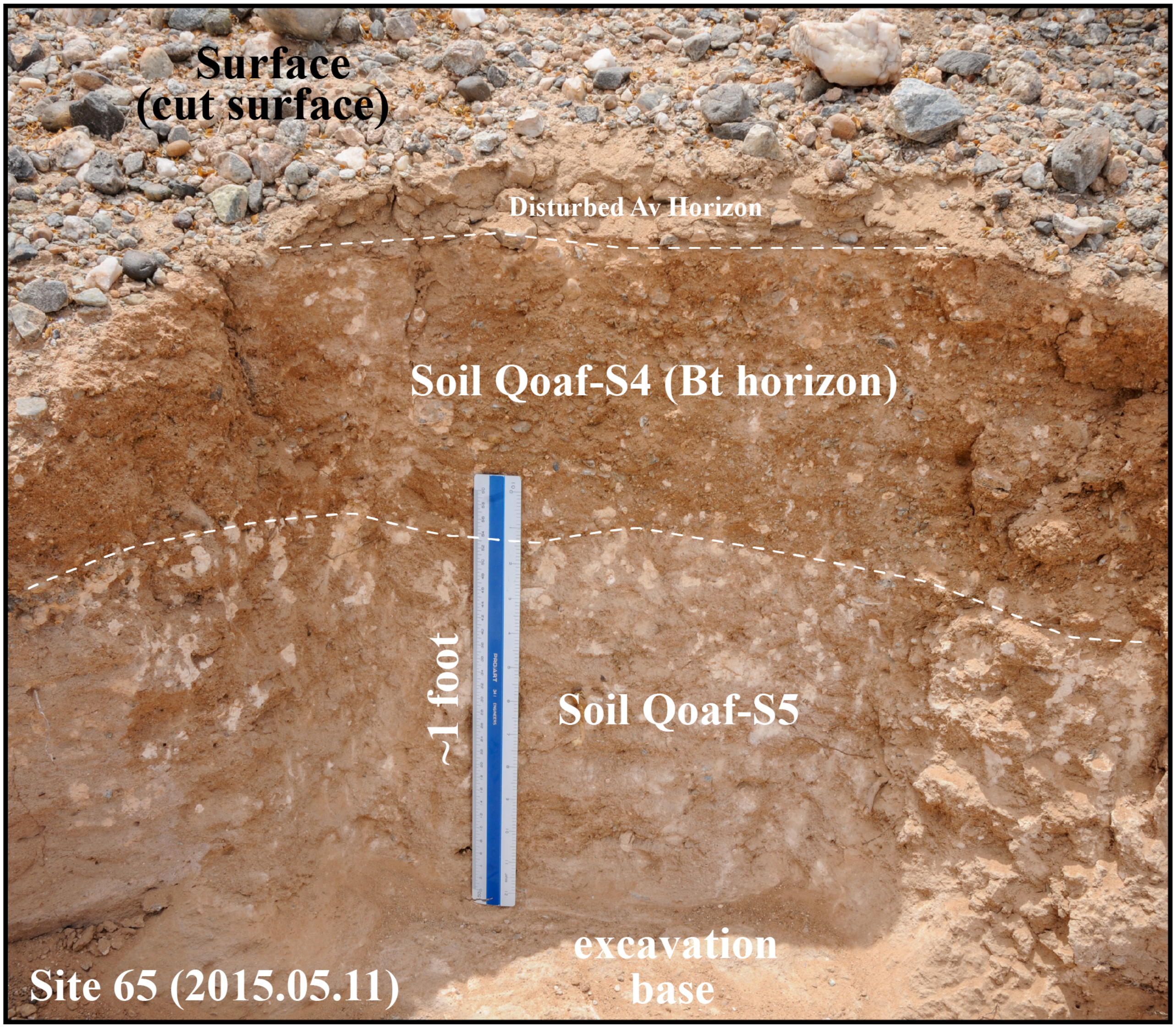


Figure AD-13: Geomorphic Site 65 Soil Stratigraphy: Qoaf-S4/Qoaf-S5



APPENDIX E

REPORT PLATES

RELATIVE GEOMORPHIC EOLIAN (DUNE) SAND MIGRATION ZONES

Generalized Eolian Deposits (where not mapped via Eolian Zones below)

- Eolian deposits mapped in regions outside of the Dale Lake-Palo Verde Mesa, and Cadiz Dry Lake to Rice Valley sand migration zones

Eolian Zones Dominated by Dune Geomorphology

- Zone AB
- Zone B and Zone BW (weak B)

Eolian Zones Exhibiting Mixed Eolian and Fluvial Geomorphology

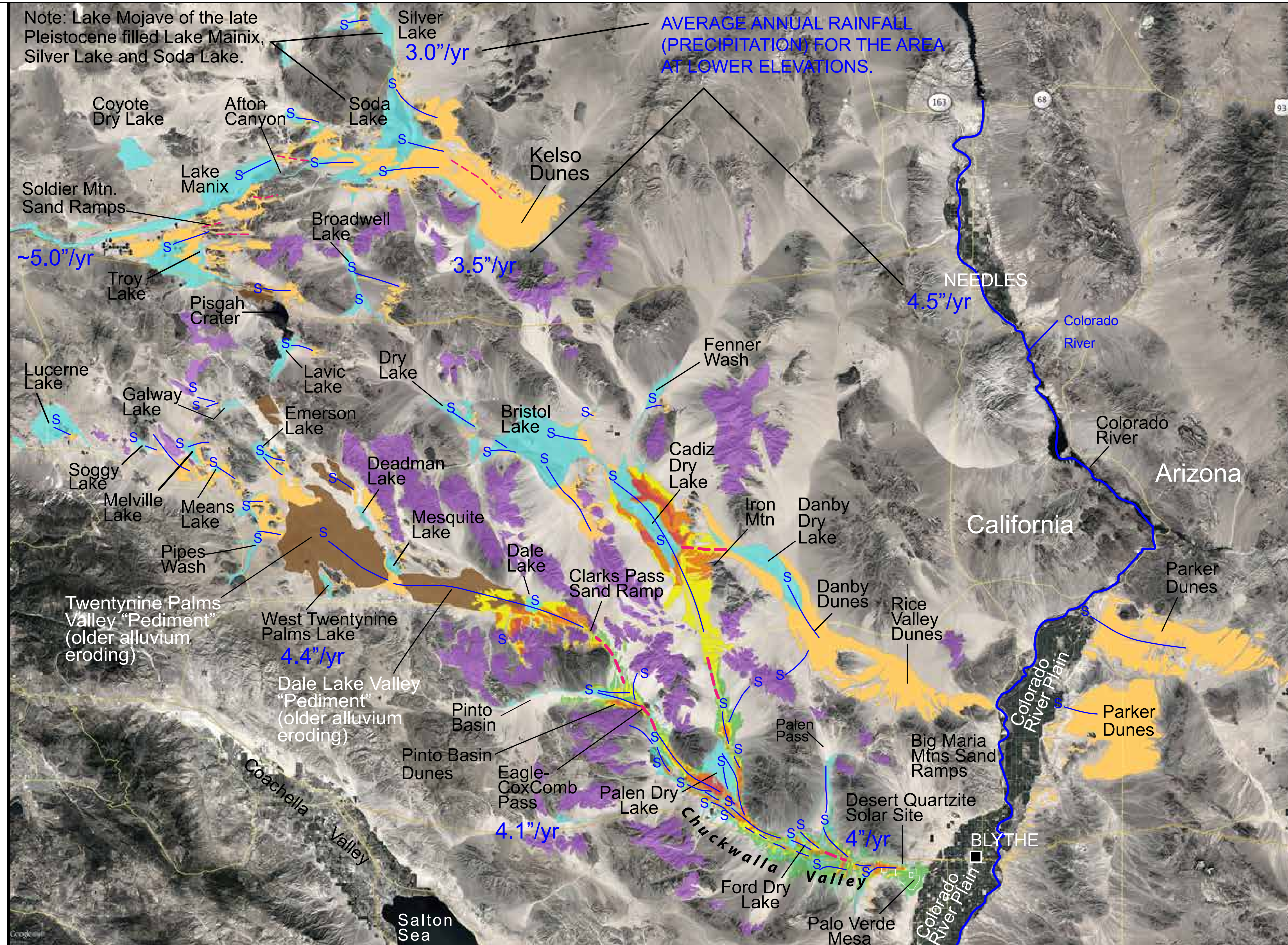
- Zone BC
- Zone C (fluvially dominated)

Eolian Sand Sources

- Generalized unit representing active playa lake surfaces (Lacustrine), active washes, and ponding areas. These areas are important for eolian systems as a sand source and transport. Hence, new sand is generated in these areas and is transported from and/or across these areas.
- Valley fill sedimentary units eroding and providing an eolian sand source
- Granitic rocks in the region mapped by CGS (1964 & 1967). Identified as regional and local eolian sand source upon erosion and transport via local washes by Muhs et al. (2003).

Eolian Sand Migration Zones & Sources

- S — Approximate locations of "micro" localized eolian sand migration zones along the paths of some proposed regional and continuous sand migration zone; however these zones have not been continuous paths for sand migration since the early Holocene (~8 kya). "S" placed near eolian sand source.
- Portions of the proposed regional sand migration zones that are essentially shut down to eolian sand transport.



N

~ 20 Miles

Mapping conducted by M. Kenney via Google Earth Pro utilizing various years of their Historical Imagery. Image created with Google Earth Pro (10.2016).

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CLIENT:
FIRST SOLAR ENERGY

PROJECT:
DESERT QUARTZITE SOLAR PROJECT, NEAR BLYTHE, CA

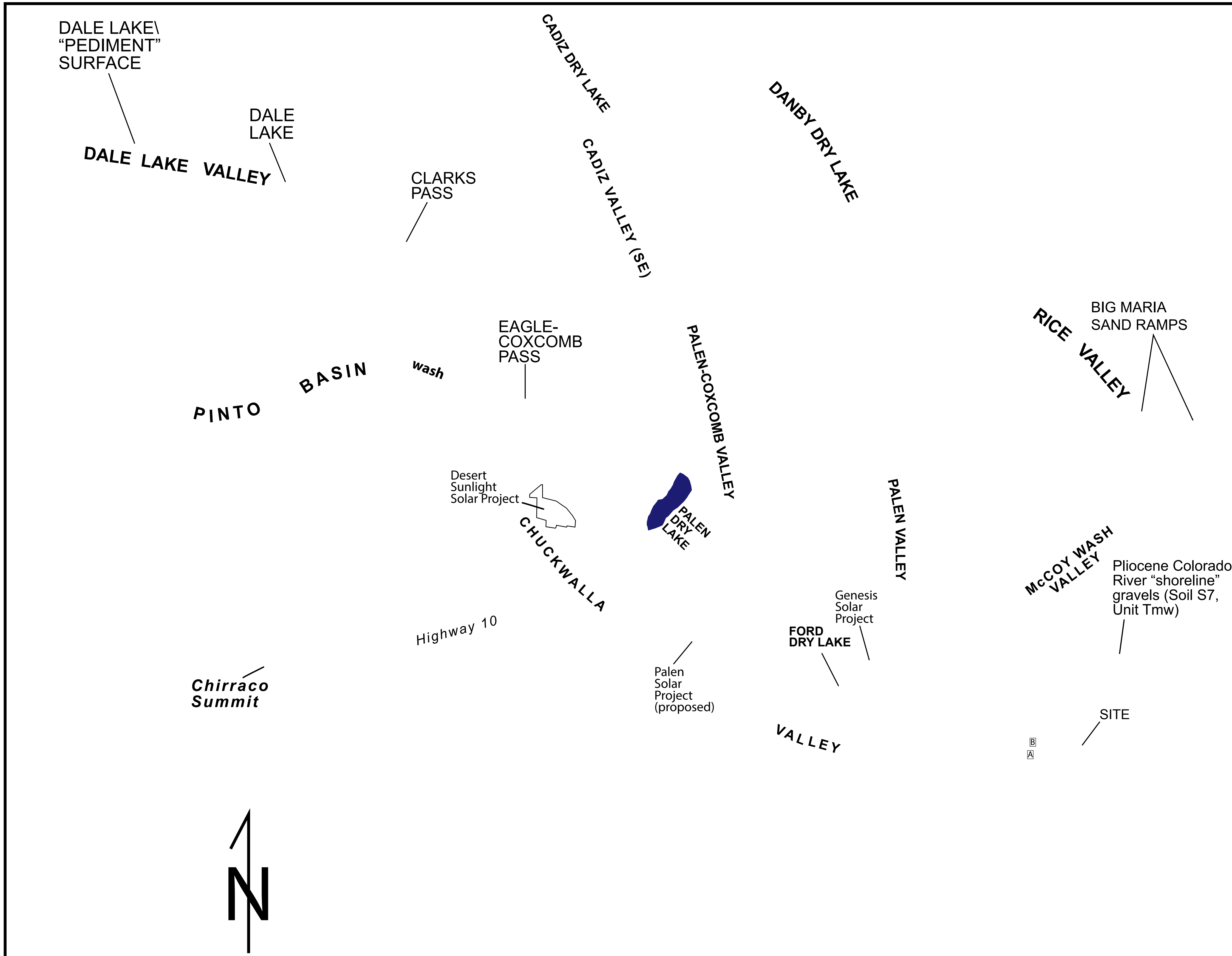
Eolian dune & sand source map, in Southeastern California

Job No. 721-11

Date: September, 2017

Drafted by: MDK

PLATE 1



Eolian Geomorphic Zones Dominated by Dune Geomorphology

Zone A and Zone AB

Zone B and Zone BW (weak)

Eolian Geomorphic Zones Exhibiting Mixed Eolian and Fluvial Geomorphology

Zone BC

Zone C (fluvially dominated)

Generalized Eolian Deposits (where not mapped via Eolian Zones below)

Eolian deposits mapped in regions outside of the Dale Lake-Palo Verde Mesa, and Cadiz Dry Lake to Rice Valley sand migration zones

Eolian Sand Sources

Generalized unit representing active playa lake surfaces (Lacustrine), active washes, and ponding areas. These areas are important for eolian systems as a sand source, sand transport and stabilizing moisture.

Fluvial, ancient playa-lake, and Colorado River Deposits that produce relatively abundant eolian sands upon erosion. Unit primarily correlates with the Bullhead Alluvium of Howard et al. (2015), unit QTmm of Stone (2006), possibly some Bouse Formation of Spencer (2008), and Unit B of Metzger et al.(1973). Mapped as unit Tmm (Soil S7) in this study.

Granitic rocks in the region mapped by CGS (1964 & 1967). Identified as regional and local eolian sand source upon erosion and trasonport via local washes by Muhs et al. (2003).

General Prevailing Wind Direction

Generalized direction of "prevailing" winds most of which are altered by local valley-mountain topography

B A Location of the existing Southern California Edison substation [A] and initially proposed Southern California Edison substaion [B] (Kenney, 2010d and 2010e).

Job No. 721-11

Mapping conducted by M. Kenney via Google Earth Pro utilzing various years of their Hisorical Imagery.Image created with Google Earth Pro (10.2016).

~ 5 Miles

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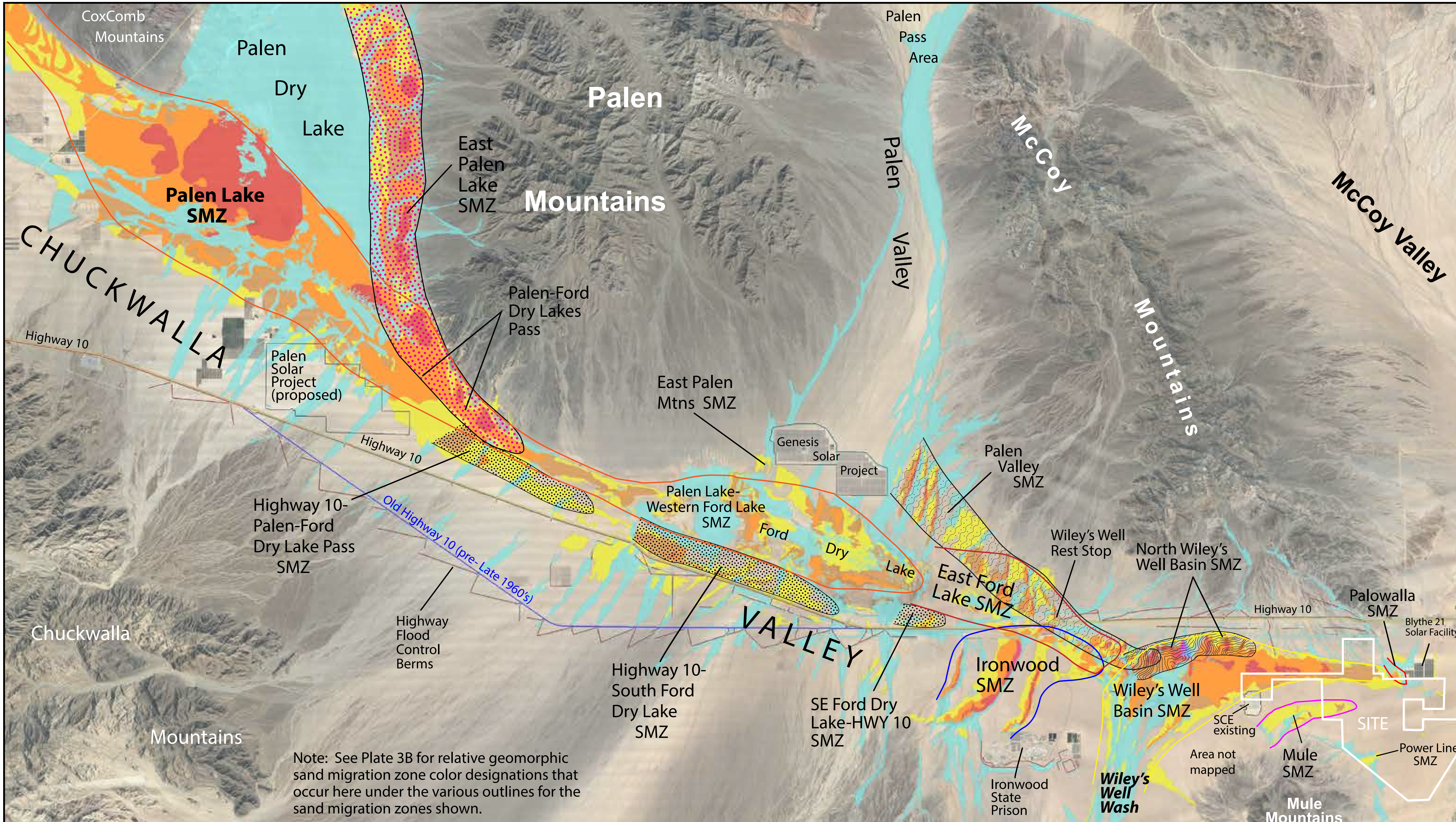
PROJECT:
DESERT QUARTZITE SOLAR PROJECT, NEAR BLYTHE, CA

Eolian geomorphic, dune & sand source map in Southeastern California

Date: September, 2017

Drafted by: MDK

PLATE 2



N

~ 2 Miles

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PROJECT (SITE): DESERT QUARTZITE SOLAR

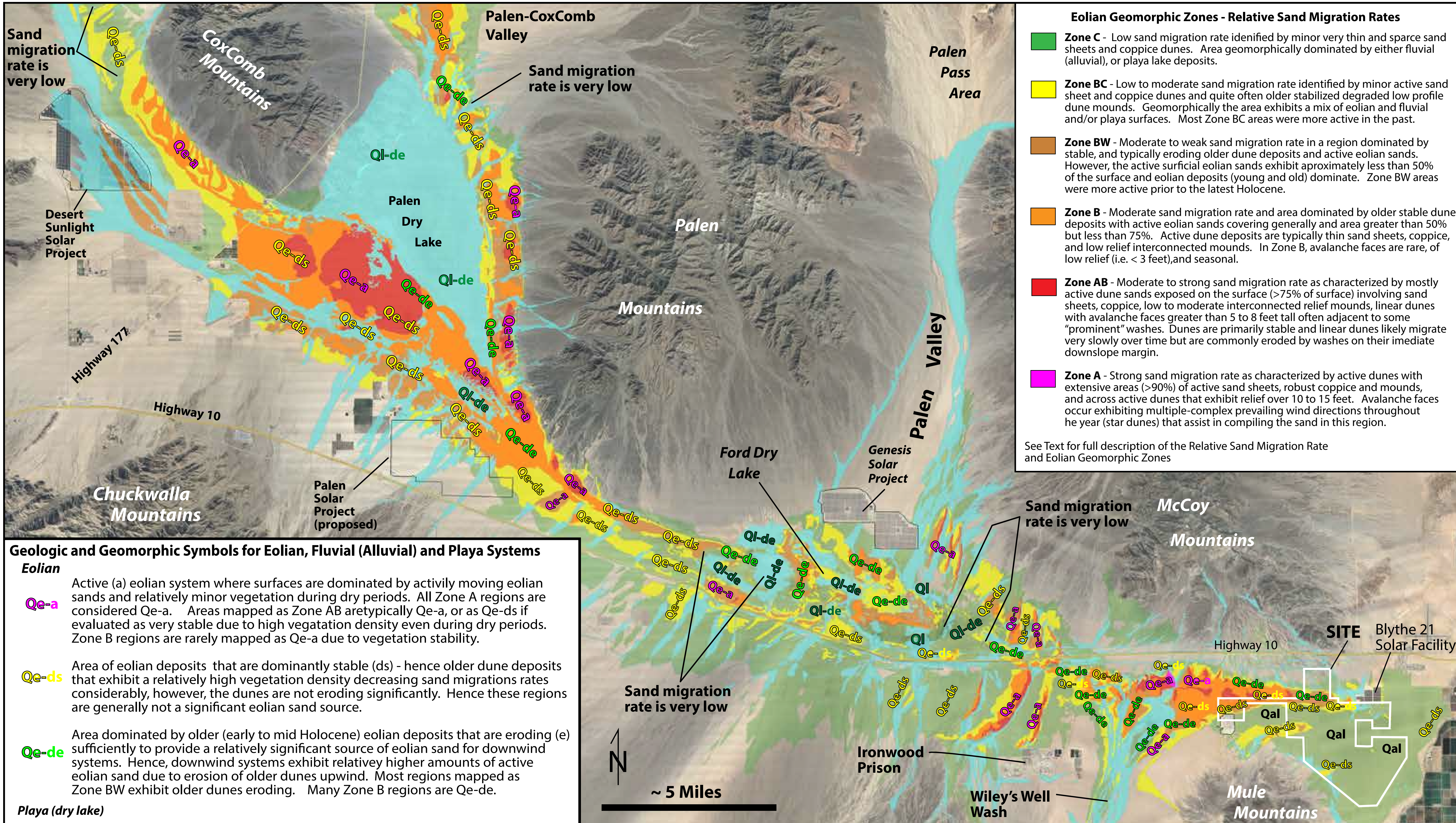
Local Geomorphic Eolian Sand Migration Zones along the Chuckwalla Valley Eolian System

Job No. 721-11

Date: September, 2017

Drafted by: MDK

PLATE 3A



Eolian Geomorphic Zones - Relative Sand Migration Rates

Zone C - Low sand migration rate idenified by minor very thin and sparce sand sheets and coppice dunes. Area geomorphically dominated by either fluvial (alluvial), or playa lake deposits.

Zone BC - Low to moderate sand migration rate identified by minor active sand sheet and coppice dunes and quite often older stabilized degraded low profile dune mounds. Geomorphically the area exhibits a mix of eolian and fluvial and/or playa surfaces. Most Zone BC areas were more active in the past.

Zone BW - Moderate to weak sand migration rate in a region dominated by stable, and typically eroding older dune deposits and active eolian sands. However, the active surficial eolian sands exhibit aproximately less than 50% of the surface and eolian deposits (young and old) dominate. Zone BW areas were more active prior to the latest Holocene.

Zone B - Moderate sand migration rate and area dominated by older stable dune deposits with active eolian sands covering generally and area greater than 50% but less than 75%. Active dune deposits are typically thin sand sheets, coppice, and low relief interconnected mounds. In Zone B, avalanche faces are rare, of low relief (i.e. < 3 feet),and seasonal.

Zone AB - Moderate to strong sand migration rate as characterized by mostly active dune sands exposed on the surface (>75% of surface) involving sand sheets, coppice, low to moderate interconnected relief mounds, linear dunes with avalanche faces greater than 5 to 8 feet tall often adjacent to some "prominent" washes. Dunes are primarily stable and linear dunes likely migrate very slowly over time but are commonly eroded by washes on their imediate downslope margin.

Zone A - Strong sand migration rate as characterized by active dunes with extensive areas (>90%) of active sand sheets, robust coppice and mounds, and across active dunes that exhibit relief over 10 to 15 feet. Avalanche faces occur exhibiting multiple-complex prevailing wind directions throughout he year (star dunes) that assist in compiling the sand in this region.

See Text for full description of the Relative Sand Migration Rate and Eolian Geomorphic Zones

Geologic and Geomorphic Symbols for Eolian, Fluvial (Alluvial) and Playa Systems

Eolian

Qe-a Active (a) eolian system where surfaces are dominated by activily moving eolian sands and relatively minor vegetation during dry periods. All Zone A regions are considered Qe-a. Areas mapped as Zone AB aretypically Qe-a, or as Qe-ds if evaluated as very stable due to high vegatation density even during dry periods. Zone B regions are rarely mapped as Qe-a due to vegetation stability.

Qe-ds Area of eolian deposits that are dominantly stable (ds) - hence older dune deposits that exhibit a relatively high vegetation density decreasing sand migrations rates considerably, however, the dunes are not eroding significantly. Hence these regions are generally not a significant eolian sand source.

Qe-de Area dominated by older (early to mid Holocene) eolian deposits that are eroding (e) sufficiently to provide a relatively significant source of eolian sand for downwind systems. Hence, downwind systems exhibit relativey higher amounts of active eolian sand due to erosion of older dunes upwind. Most regions mapped as Zone BW exhibit older dunes eroding. Many Zone B regions are Qe-de.

Playa (dry lake)

Ql Relatively stable playa lake bed deposits that typically provide a pathway for sand migration, an eolian source after flooding, but generally the playa surface is not eroding significantly to provide a relatively strong eolian sand source.

Ql-de Playa lake bed deposits that are evaluated as eroding; hence, providing a source for eolian sand deposits for downwind (toward the southeast) dune systems. These surfaces also provide eolian sands after flooding.

Alluvial (Fan Deposits)

Qal Regions dominated by alluvial deposits shown only within the proposed Desert Quartzite Solar Project

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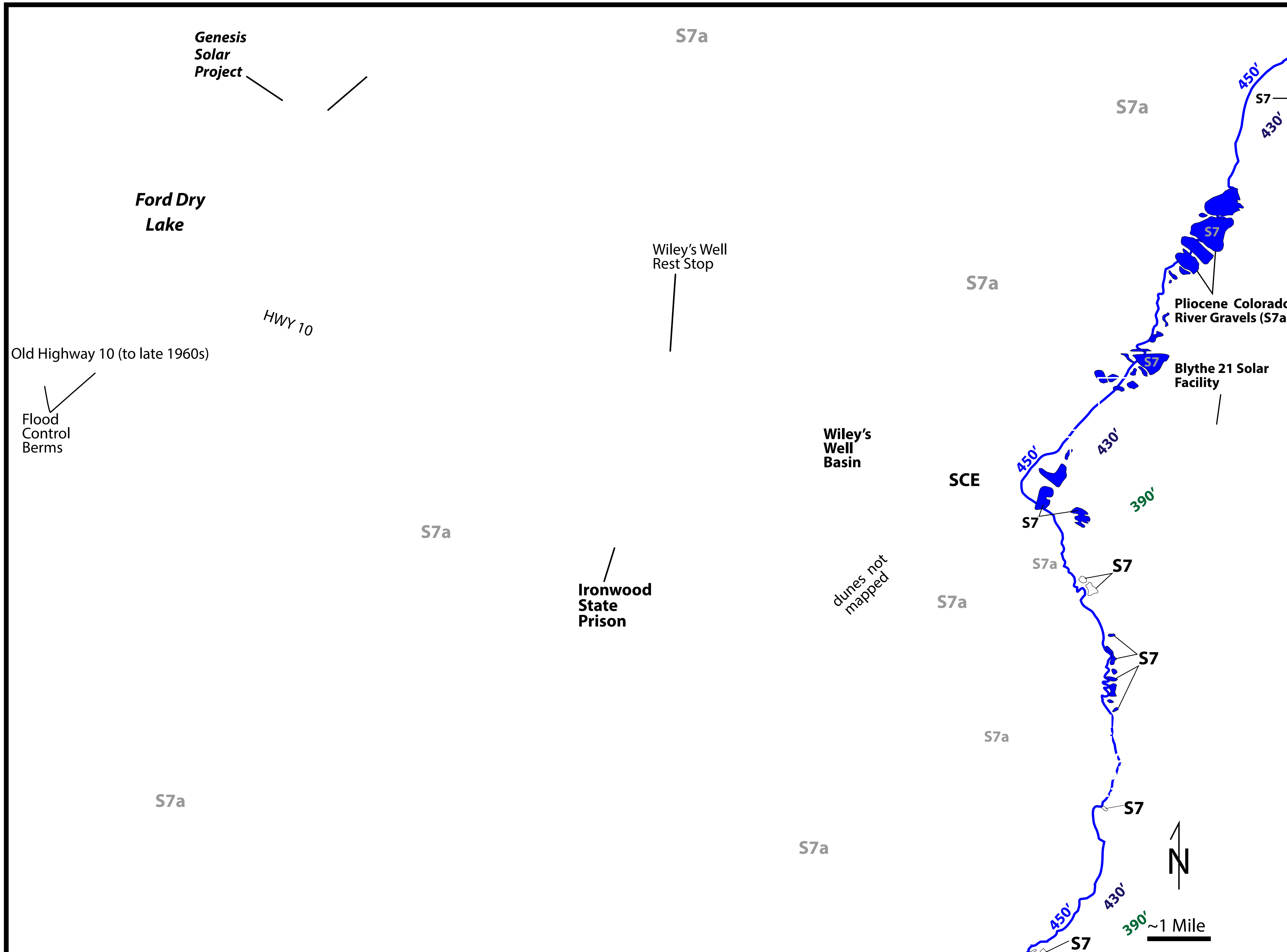
Geomorphic map showing variations in dune deposit activity and stability along the Chuckwalla Valley eolian sand system

Job No. 721-11

Date: Sept., 2017

Drafted by: MDK

PLATE 3B



Eolian Geomorphic - Relative Sand Migration Zones

Zone C - Low sand migration rate idenified by minor very thin and sparce sand sheets and coppice dunes. Area geomorphically dominated by either fluvial (alluvial), or playa lake deposits.

Zone BC - Low to moderate sand migration rate identified by minor active sand sheet and coppice dunes and quite often older stabilized degraded low profile dune mounds. Geomorphically the area exhibits a mix of eolian and fluvial

Zone BW - Moderate to weak sand migration rate in a region dominated by stable, and typically eroding older dune deposits and active eolian sands. However, the active surficial eolian sands exhibit aproximately less than 50% of the surface and eolian deposits (young and old) dominate. Zone BW areas were more active prior to the latest Holocene.

Zone B - Moderate sand migration rate and area dominated by older stable dunedeposits with active eolian sands covering generally and area greater than 50% but less than 75%. Active dune deposits are typically thin sand sheets, coppice, and low relief interconnected mounds. In Zone B, avalanche faces are rare, of low relief (i.e. < 3 feet), and seasonal.

Zone AB - Moderate to strong sand migration rate as characterized by mostly active dune sands exposed on the surface (>75% of surface) involving sand sheets, coppice, low to moderate interconnected relief mounds, linear dunes with avalanche faces greater than 5 to 8 feet tall often adjacent to some "prominent" washes. Dunes are primarily stable and linear dunes likely migrate very slowly over time but are commonly eroded by washes on their imediate downslope margin.

Zone A - Strong sand migration rate as characterized by active dunes with extensive areas (>90%) of active sand sheets, robust coppice and mounds, and across active dunes that exhibit relief over 10 to 15 feet. Avalanche faces occur exhibiting multiple-complex prevailing wind directions throughout the year (star dunes) that assist in compiling the sand in this region.

Eolian Source Geologic Deposits - Formations

Generalized unit representing active playa lake surfaces (Lacustrine), active washes, and ponding areas. These areas are important for eolian systems as a sand source, sand transport and stabilizing moisture.

S7 Tmw Fluvial Colorado River Gravels associated with an ancient "shoreline-river edge) near elevavation 430 to 450 feet above sea level (msl, blue lines). This unit is correlated stratigraphically to unit QTmw of Stone (2006), Unit B (Quarry Gravels) of Metzger et al. (1973), and member of the **Bullhead Alluvium** of Howard et al. (2015). Units are early Pliocene in age (Bullhead Alluvium - 4.5 to 3.5 Ma; Howard et al., 2015).

S7a Tmm Fluvial, ancient playa-lake, and Colorado River Deposits that producerelatively abundant eolian sands upon erosion. Unit primarily correlates with the **Bullhead Alluvium** of Howard et al. (2015), unit QTmm of Stone (2006), possibly some Bouse Formation of Spencer (2008), and Unit B of Metzger et al.(1973). Units are early Pliocene in age (Bullhead Alluvium - 4.5 to 3.5 Ma; Howard et al., 2015). Petrified wood bearing uper slope member extending to elevations over 850 feet.

Eolian Deposits - General in Mule Mountains

Generalized area of dune deposits typically exhibiting Zones A, AB and B (see above) along the flanks, and within upper valleys of the Mule Mountains.

Mapping conducted by M. Kenney via Google Earth Pro utilizing various years of their Hisorical Imagery.Image created with Google Earth Pro (2016). Sand migration rates varied considerably across Ford Dry Lake and near the site due to large magnitude changes in vegetation density (wet vs dry years). Mapping was conducted where possible that exhibited the strongest sand migration rates that corresponded to relatively low vegetation densities.

"Prevailing" Wind Directions Influencing Eolian Systems

Generalized direction of pertinent "prevailing" wind directions resulting in eolian sand movement as observed in the field during strong wind events and eolian dune structures. These wind directions are controlled by local valley-mountain topography and seasonal storm track dominant movement directions. These occur from the SW along Wiley's Well Wash, from the west (W) down the Chuckwalla Valley, and from the NNW down Palen Valley. The SW to NE winds have commonly been observed to flow over the Chuckwalla Mountains. Blue arrows were observed and measured and the field, gray arrows are generalized based on field experience and dune forms.

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PROJECT:
DESERT QUARTZITE SOLAR PROJECT, NEAR BLYTHE, CA

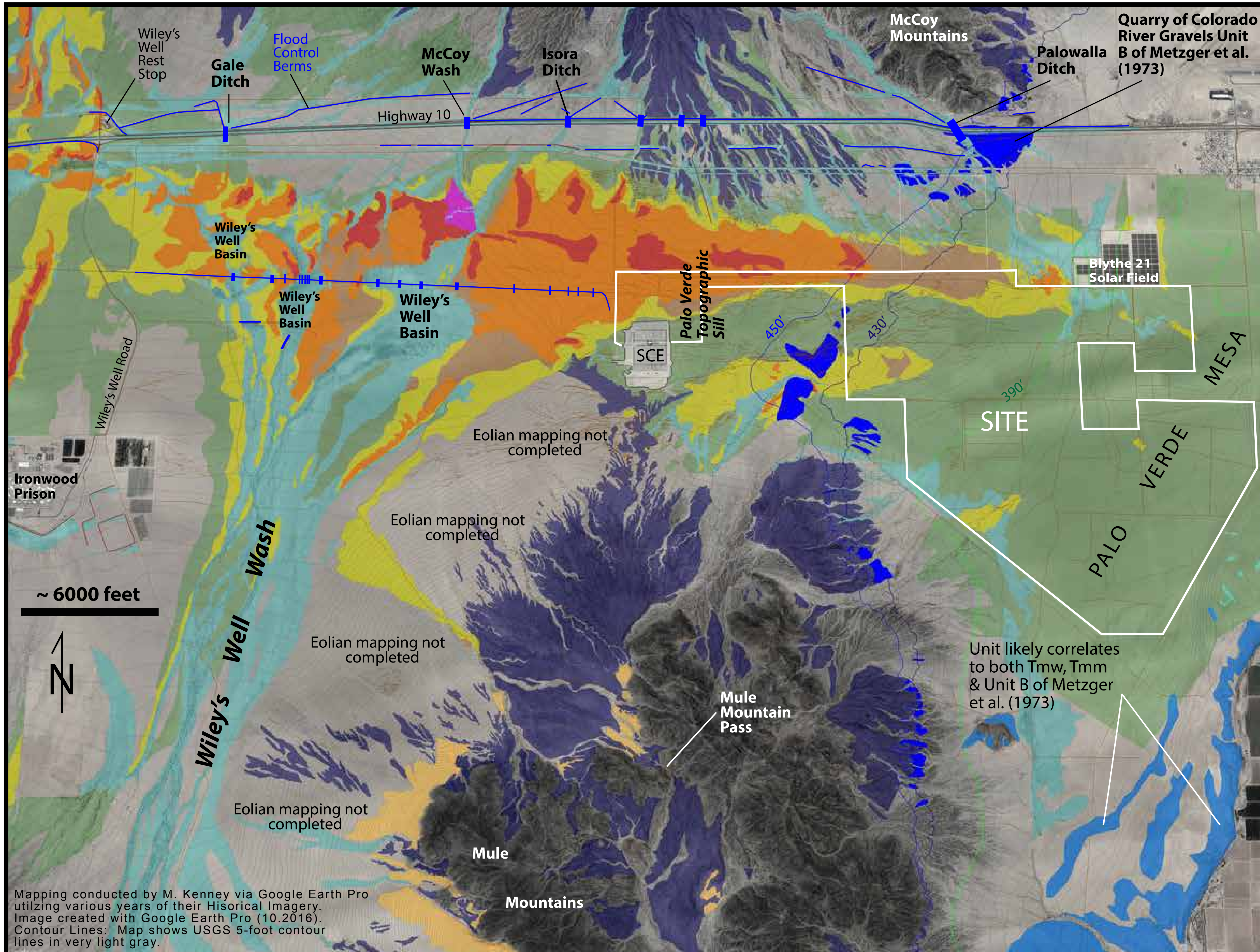
Job No. 721-11

Date: September, 2017

Drafted by: MDK

Geomorphic Eolian Zone Map & Geologic Map of the Eastern Chuckwalla Valley

PLATE 4



Eolian Geomorphic - Relative Sand Migration Zones

Zone C - Low sand migration rate and area dominated either by fluvial (alluvial), or playa lake surfaces (deposits).

Zone BC - Low to moderate sand migration rate, and geomorphically the area exhibits a mix of eolian and fluvial and/or playa surfaces. Dune deposits are also generally a mix of older stable, some eroding dunes, and active surficial loose active eolian sands (sand sheets).

Zone BW - Moderate to weak sand migration rate, and area dominated by stable (vegetated), and typically eroding older dune deposits (geomorphology). Active eolian sands cover generally less than 50% of the surface area. Ponding (gravel lag surfaces) interdune depressions common.

Zone B - Moderate sand migration rate and area dominated by older stable dune deposits with active eolian sands covering generally greater than 50% of the area. Active eolian sands are typically sand sheets, coppice, and low reliefmounds. Avalanche faces are very rare and only seasonal in Zone B.

Zone AB - Moderate to strong sand migration rate and area characterized by mostly active dune sands exposed on the surface involving sand sheets, coppice, low relief mounds, and linear dunes with occassional seasonal avalanche faces.

Zone A - Strong sand migration rate and area characterized by extensive areas of active sand sheets across active dunes that exhibit relief over 10 to 15 feet. Avalanche faces occur exhibiting multiple-complex prevailing wind directions throughout the year leading to the development of star dunes. Zone A only occurs in one map area location near the termination of the Wiley's Well Wash in the herein named Wiley's Well Basin.

Eolian Source Geologic Deposits - Formations

Generalized unit representing active playa lake surfaces (Lacustrine), active washes, and ponding areas. These areas are important for eolian systems as a sand source, sand transport and stabilizing moisture.

S7 Tmw Fluvial Colorado River Gravels associated with an ancient "shoreline-river edge) near elevavation ~420 to 450 feet above sea level (msl, blue lines). This unit is correlated stratigraphically to unit Tmw (QTmw of Stone (2006), Unit B (Quarry Gravels) of Metzger et al. (1973), and member of the Bullhead Alluvium of Howard et al. (2015). Units are early Pliocene in age (Bullhead Alluvium - 4.5 to 3.5 Ma; Howard et al., 2015). Also soil S7 in this report.

S7a Tmm Fluvial, ancient playa-lake, and Colorado River Deposits that produce relatively abundant eolian sands upon erosion. Unit primarily correlates with the Bullhead Alluvium of Howard et al. (2015), unit Tmm (QTmm of Stone (2006), possibly some Bouse Formation of Spencer (2008), and Unit B of Metzger et al.(1973). Units are early Pliocene in age (Bullhead Alluvium - 4.5 to 3.5 Ma; Howard et al., 2015). Also soil S7 of this report.

Eolian Deposits - General in Mule Mountains

Generalized area of dune deposits typically exhibiting Zones A, AB and B (see above) along the flanks, and within upper valleys of the Mule Mountains.

Subdrains and flood control berms. Thin blue lines are flood control berms and thicker orthogonal lines are subdrains allow flow to pass.

Mapped dirt roads. Many of the dirt roads in close proximity and within the Site are surmised to have been produced during General Pattons tank war excersises in the early 1940's. These roads provide evidence supporting eolian geomorphic zones stability on a decadal scale, particularly for Zone BC, and Zone C, and lesser extent Zone BW, where many of these roads remain partitially preserved on the landscape.

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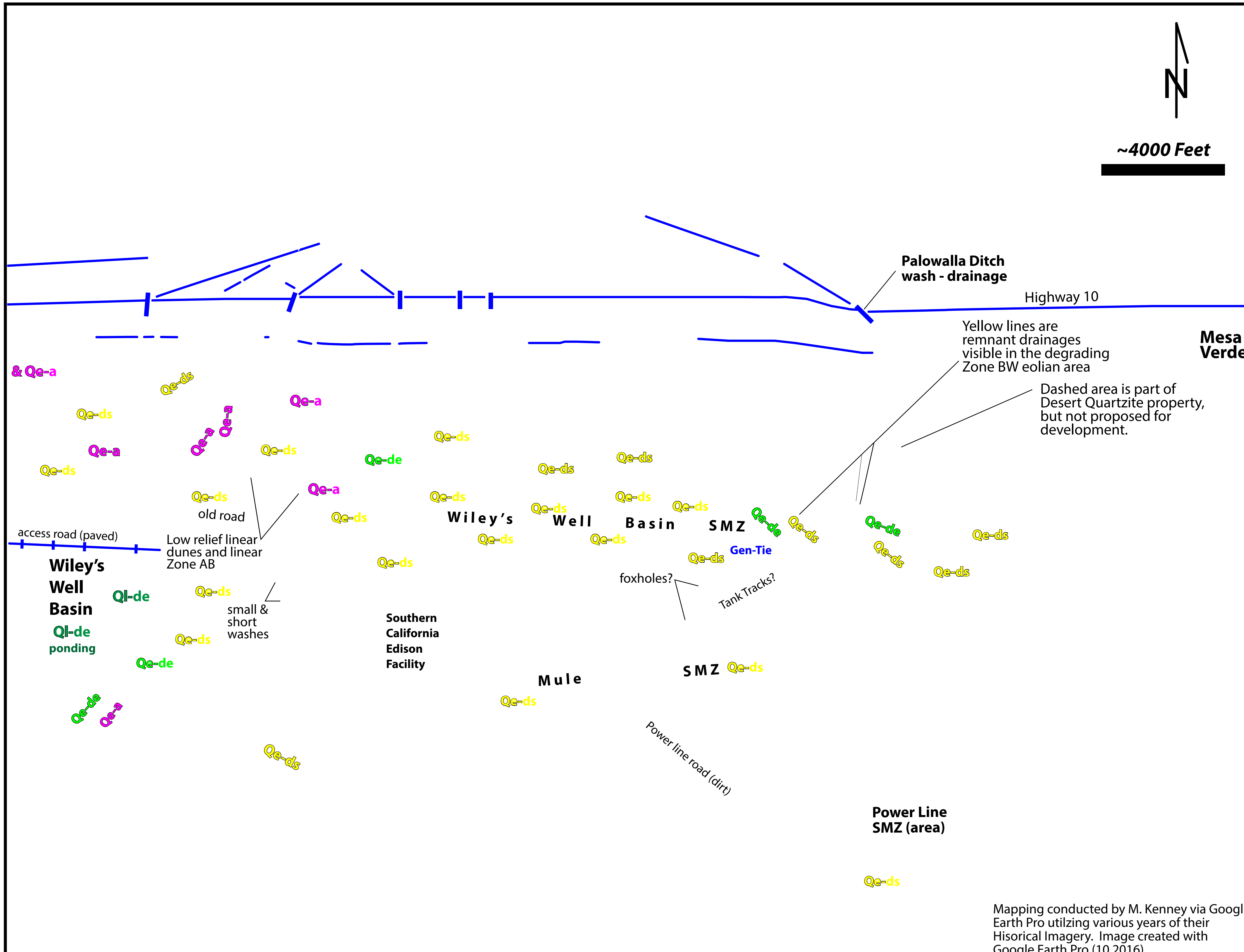
Eolian Geomorphic Zone Map in the vicinity of the Desert Quartzite Solar Project

Job No. 721-11

Date: September, 2017
Drafted by: MDK

PLATE 5



Eolian Geomorphic - Relative Sand Migration Zones

Zone C - Low sand migration rate and area dominated either by fluvial (alluvial), or alluvial ponding areas

Zone BC - Low to moderate sand migration rate, and geomorphically the area exhibits a mix of eolian and fluvial and/or playa surfaces. Dune deposits are also generally a mix of older stable, some eroding dunes, and active surficial loose eolian sands (sand sheets).

Zone BW - Moderate to weak sand migration rate, and area dominated by stable (vegetated), and typically eroding older dune deposits (geomorphology). Active eolian sands cover generally less than 50% of the surface area. Ponding (gravel lag surfaces) interdune depressions common.

Zone B - Moderate sand migration rate and area dominated by older stable dune deposits with active eolian sands covering generally greater than 50% of the area. Active eolian sands are typically sand sheets, coppice, and low reliefmounds. Avalanche faces are very rare and only seasonal in Zone B.

Zone AB - Moderate to strong sand migration rate and area characterized by mostly active dune sands exposed on the surface involving sand sheets, coppice, low relief mounds, and linear dunes with occassional seasonal avalanche faces.

Zone A - Strong sand migration rate and area characterized by extensive areas of active sand sheets across active dunes that exhibit relief over 10 to 15 feet. Avalanche faces occur exhibiting multiple-complex prevailing wind directions throughout the year leading to the development of star dunes. Zone A only occurs in one map area location near the termination of the Wiley's Well Wash in the herein named Wiley's Well Basin.

Eolian Source Geologic Deposits - Formations

Generalized unit representing ponding areas at the termination area of drainages and active washes. These areas are critically important for eolian systems as a sand source and stabilizing moisture for dune systems.

Sediments associated with the Colorado River when it inundated this region to an upper elevation of possibly 1,200 feet 4.3 to 3.5 Ma. These sediments produce a strong eolian sand source upon erosion. Unit correlates with the Bullhead Alluvium of Howard et al. (2015) estimated to be deposited between 4.5 to 3.5 Ma (Pliocene) and unit Tmm of this report (Soil 7).

Geologic and Geomorphic Symbols for Eolian and Playa Systems (see Plate 3A for full legend details)

Eolian

Qe-a Active dune area, however, dunes are not migrating

Qe-ds Strongly stabilized dune area

Qe-de Strongly stabilized dune area that is eroding producing eolian sand source for downwind systems

Playa (dry lake) and other smaller Ponding areas

Ql-de Ponding area that floods frequently providing an eolian sand source for downwind (toward the east and northeast) dune systems

Subdrains and flood control berms. Thin blue lines are flood control berms and thicker orthogonal lines are subdrains allow flow to pass.

Mapped dirt roads. Many of the dirt roads in close proximity and within the Site are surmised to have been produced during General Pattons tank war excersises in the early 1940's. These roads provide evidence supporting eolian geomorphic zones stability on a decadal scale, particularly for Zone BC, and Zone C, and lesser extent Zone BW, where many of these roads remain partitially preserved on the landscape.

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DESERT QUARTZITE SOLAR

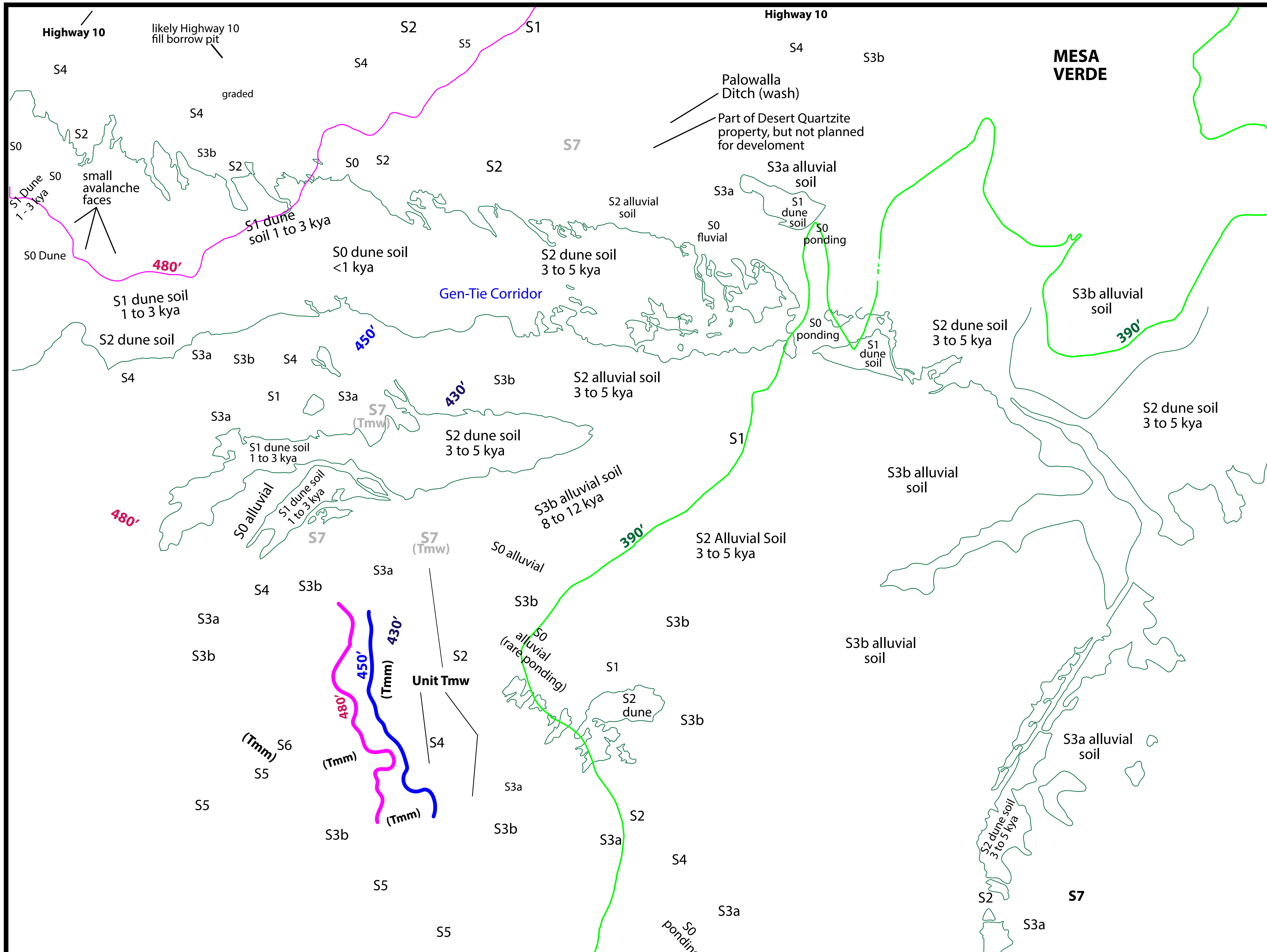
Eolian Geomorphic Zone Map and Drainage Map of the Wiley's Well Basin and Mule Sand Migrations Zones (SMZ), Desert Quartzite Proposed Solar Project area

Job No. 721-11

Date: September, 2017

Drafted by: MDK

PLATE 6A



Soil (Pedon) Stratigraphy

Alluvial (fluvial) Parent Material (minimum ages)

- **S0** - < 1000 years old (fluvial and ponding areas)
- **S1**- 1 to 3 kya (late Holocene)
- **S2** - 3 to 5 kya (mid to late Holocene)
- **S3a** - 5 to 8 kya (early to mid Holocene)
- **S3b** - 8 to 12 kya (latest Pleistocene to early Holocene)
- **S4** - 35 to 65 kya (late Pleistocene)
- **S5a** - > 100 kya (early Pleistocene)
- **S5b** - > 100 kya (early Pleistocene)
- **S6** - < 3.5 Ma Early Pleistocene or possibly late Pliocene Older alluvium with strongly developed soil profile resting unconformably on top of Bullhead Alluvium Colorado River deposits.
- **S7** - 3.5 to 4.5 Ma (early Pliocene). Bullhead Alluvium - Colorado River Gravels - exotic rounded cobbles with channel cross bedding (Unit Tmw) and the older member deposited to elevations of >1000 ft. throughout Chuckwalla Valley (Unit Tmm)

Eolian (Dune) Parent Material (minimum ages)

- **S0** - < 1000 years old
- **S1**- 1 to 3 kya (late Holocene)
- **S2** - 3 to 5 kya (mid to late Holocene)

Note Regarding Soil Ages: All soil ages are considered minimum values, indicating that these surfaces are likley not younger than the ages provided.

Geologic Contact - Dune Soil to Alluvial Soil Contacts

Geologic contact between eolian dune soils and alluvial soils. Contacts are gradations within eolian systems.

Topographic Contours - Colorado River Pliocene Levels

480' — Topographic escarpment in Pliocene Bullhead Alluvium along the flanks of the northeastern Mule Mountains at approximate elevation 480 feet above sea level. Highest water elevation in the Pliocene associated with the Colorado River based on regional mapping was likely over 1,100 feet.

450' — Topographic escarpment in the Pliocene Bullhead Alluvium along the flanks of the northeastern Mule Mountains at approximate elevation 450 feet above sea level. This escarpment is not as pronounced as the 480-foot elevation contour escarpment.

Topographic contours are from the USGS, 5-foot contour interval

Mapping conducted by M. Kenney via Google Earth Pro utlizing various years of their Hisorical Imagery. Image created with Google Earth Pro (10.2016).

N

~4000 Feet

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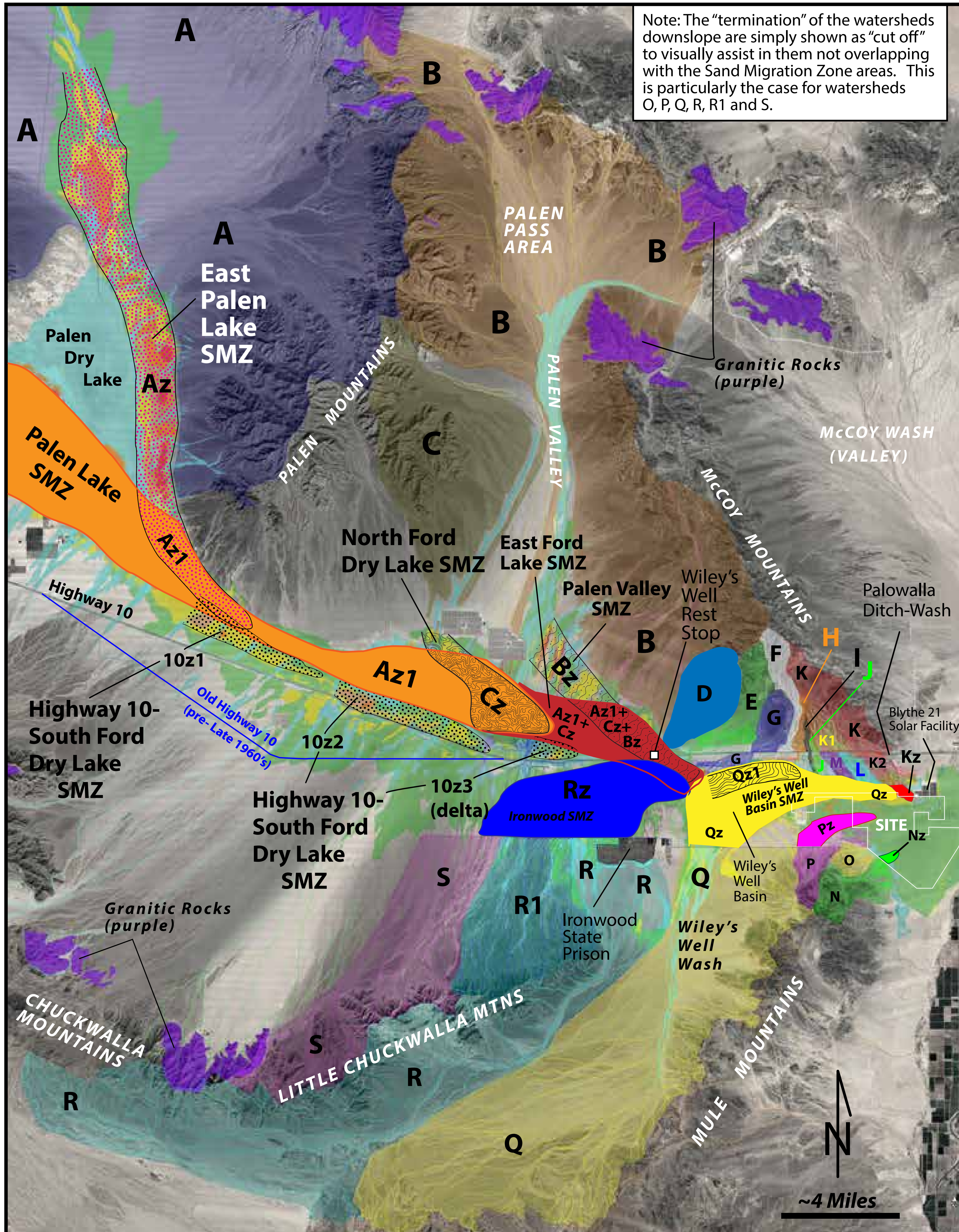
Soil (Pedon) Stratigraphy Map of Alluvial vs Eolian Soil Parent Deposits, Desert Quartzite Proposed Solar Project area

Job No. 721-11

Date: Sept., 2017
Drafted by: MDK

PLATE 6B



Water-shed	Square Miles	What Sand Migration Zone the watershed feeds	Notes Regarding Sand Migration Zones Interactions and Eolian Sand Sources
A	265	Az	**East Palen Lake SMZ** - mixes with Palen Lake SMZ to create SMZ Az1
B	127	Bz	**Palen Valley SMZ** - mixes with East Ford Lake SMZ to the souteast (Az1+Cz+Bz)
C	26	Cz	**North Ford Dry Lake SMZ** - mixes with SMZ Az1 and East Ford Lake SMZ to the east
		Az1+Cz	**East Ford Dry Lake SMZ** - mix of Az1+Cz SMZ's, and sands from erosion of playa sediments & older degrading dunes from the west
		Az1+Cz+Bz	**East Ford Dry Lake SMZ** - mix of Az1+Cz +Bz SMZ's, and sands from erosion of playa sediments & older degrading dunes from the west
D	5.4	Az1+Cz+Bz	Watershed D flow is diverted to provide sand to SMZ's Az1+Cz+Bz
E	3.7	Az1+Cz+Bz	Watershed E flow is diverted to under Highway 10 to provide sand to SMZ's Az1+Cz+Bz
F	1.9	Qz1	Watershed F flow is diverted to Wiley's Well Basin to provide sand to SMZ's Qz1 & Qz
G	2.3	Qz1	Watershed G flow is diverted to Wiley's Well Basin adding sand to SMZ's Qz1 & Qz
H	0.4	Qz1	Watershed H flow is diverted to Wiley's Well Basin adding sand to SMZ's Qz1 & Qz
I	0.3	Qz	Watershed I flows close to natural course under HWY10 to north central SMZ Qz
J	0.3	Qz	Watershed J flows close to natural course under HWY10 to north central SMZ Qz
K	4.0	Kz	**Pallowalla SMZ** - Watershed K flow diverted to Palowalla Ditch adding sand to SMZ Kz
K1	1.3	Kz	**Pallowalla SMZ** - Watershed K1 flow diverted to Palowalla Ditch adding sand to SMZ Kz
K2	1.0	Kz	**Pallowalla SMZ** - Watershed K2 flows mostly naturally adding sand to SMZ Kz
L	0.6	Qz	**Wiley's Well Basin SMZ**
M	0.5	Qz	**Wiley's Well Basin SMZ**
N	3.1	Nz	**Powerline SMZ** - Watershed N flows with slight dirt road diversion to ponding area Nz
O	1.1	Nz	**Powerline SMZ** - Watershed O flows with slight dirt road diversion to ponding area Nz
P	1.7	Pz	**Mule SMZ** - Watershed P flows without diversion (naturally) providing sand to SMZ Pz
Q	71	Qz	**Wiley's Well Basin SMZ** - Watershed Q flows naturally along Wiley's Well Wash providing abundant eolian sands to SMZ Qz
R	68	Rz	**Ironwood SMZ** - Most flow in Watershed R occurs naturally west of Ironwood Prison. Relatively minor flow diversions in Watershed R flows and ponds around Ironwood Prison. These flows, primarily on west side of R provided abundant eolian sand to SMZ Rz
R1	16.4	Rz	**Ironwood SMZ** - Watershed R1 flows naturally to the west side of SMZ Rz and provides relatively abundant eolian sand to SMZ Rz. Further downslope, flow in the western part of watershed R1 is focused by flood control berms of HWY10 providing sands to SMZ 10z3.
S	26.3	Rz	Watershed S provides flows naturally to provide minor eolian sand to the western upwind western region of the Ironwood SMZ. Downslope, watershed S is focussed by flood control berms and flows onto Ford Dry Lake providing sands to East Ford Dry Lake SMZ.
	10z1	I	Increased and focussed drainage flow associated with HWY 10 flood control berms (old and new highways) resulted in increased eolian sand production north of HWY 10 where flow rate is increased substantially leading to the creation of SMZ 10z2.
	10z2		ISame description as for SMZ 10z1.
S	10z3		Eolian sands eminating from the delta in SE Ford Dry Lake with historical drainage flow increaseed due to flood control berms associated with HWY 10

Mapping conducted by M. Kenney via Google Earth Pro utilzing various years of their Hisorical Imagery. Image created with Google Earth Pro (10.2016).

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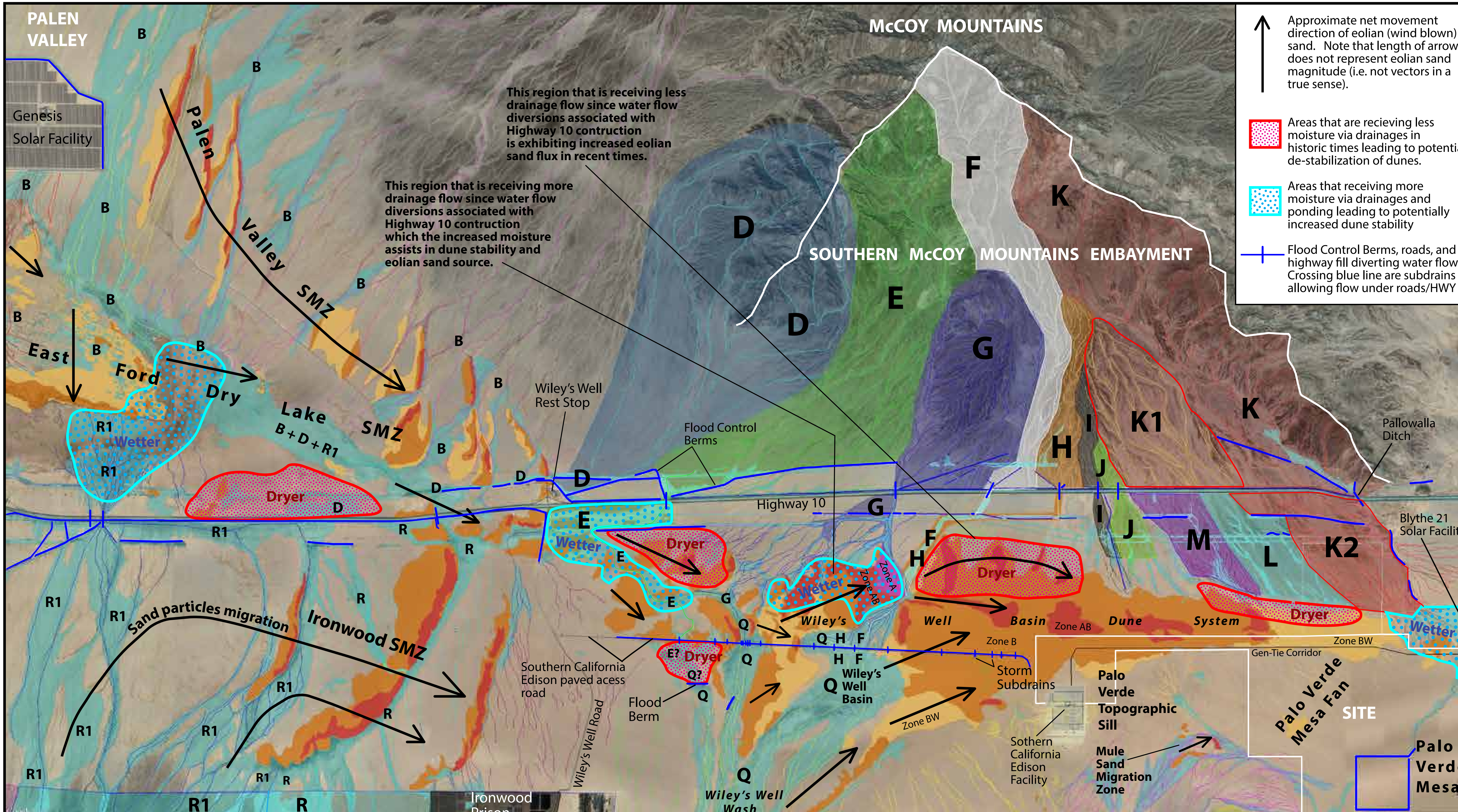
Watershed and Respective Eolian Sand Migration Zones (SMZ) of the Chuckwalla Valley Region

Job No. 721-11

Date: September, 2017

Drafted by: MDK

PLATE 7A



See text and Plate 5 for descriptions of the Eolian Geomorphic Sand Migration Zones A, AB, B, and BW, which are areas geomorphically dominated by eolian deposits.

Significant washes, ponding areas and playa lake surfaces shown as light cyan blue (Soil S0).

Watershed "drainage system" designations (**B** through **Q**) and regions are the same as shown on Plate 7A. Drainages are shown as thin lines of various colors

N

~8000 FEET

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Job No. 721-11

Local Watersheds & Historic Drainage Flow, Historic Dry and Wet Areas, Sand Migration Zones A, AB, B an BW, and Net Sand Migration Directions Over Time

Date: September, 2017

Drafted by: MDK

PLATE 7B

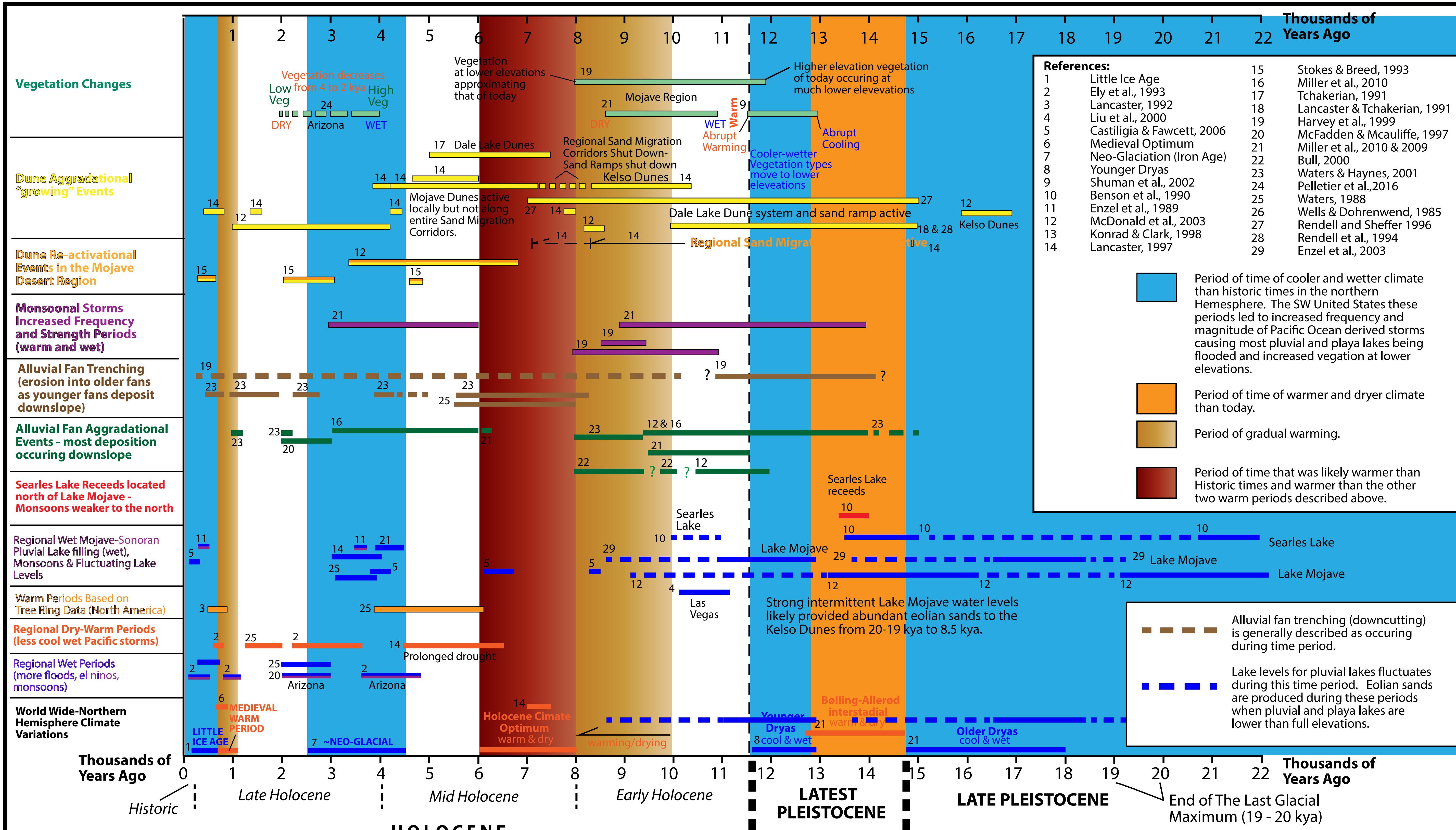

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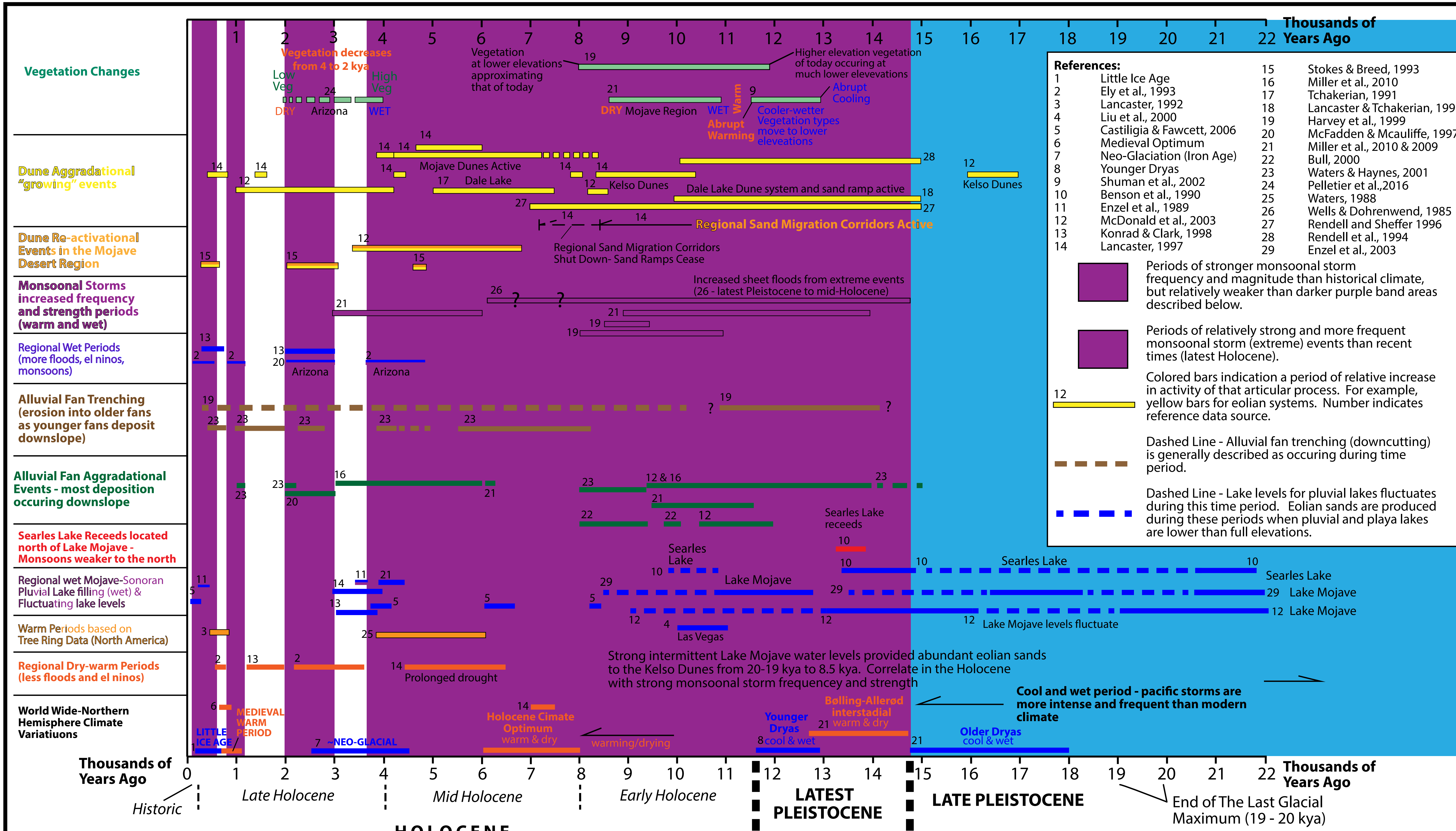
Table of Pertinent Geologic Events From the Latest Pleistocene to Late Holocene - Focus on World Climate

Job No. 721-11

Date: September, 2017

Drafted by: MDK

PLATE 8A



Kenney GeoScience

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Table of Pertinent Geologic Events From the Latest Pleistocene to Late Holocene

Job No. 721-11

Date: September, 2017

Drafted by: MDK

PLATE 8B

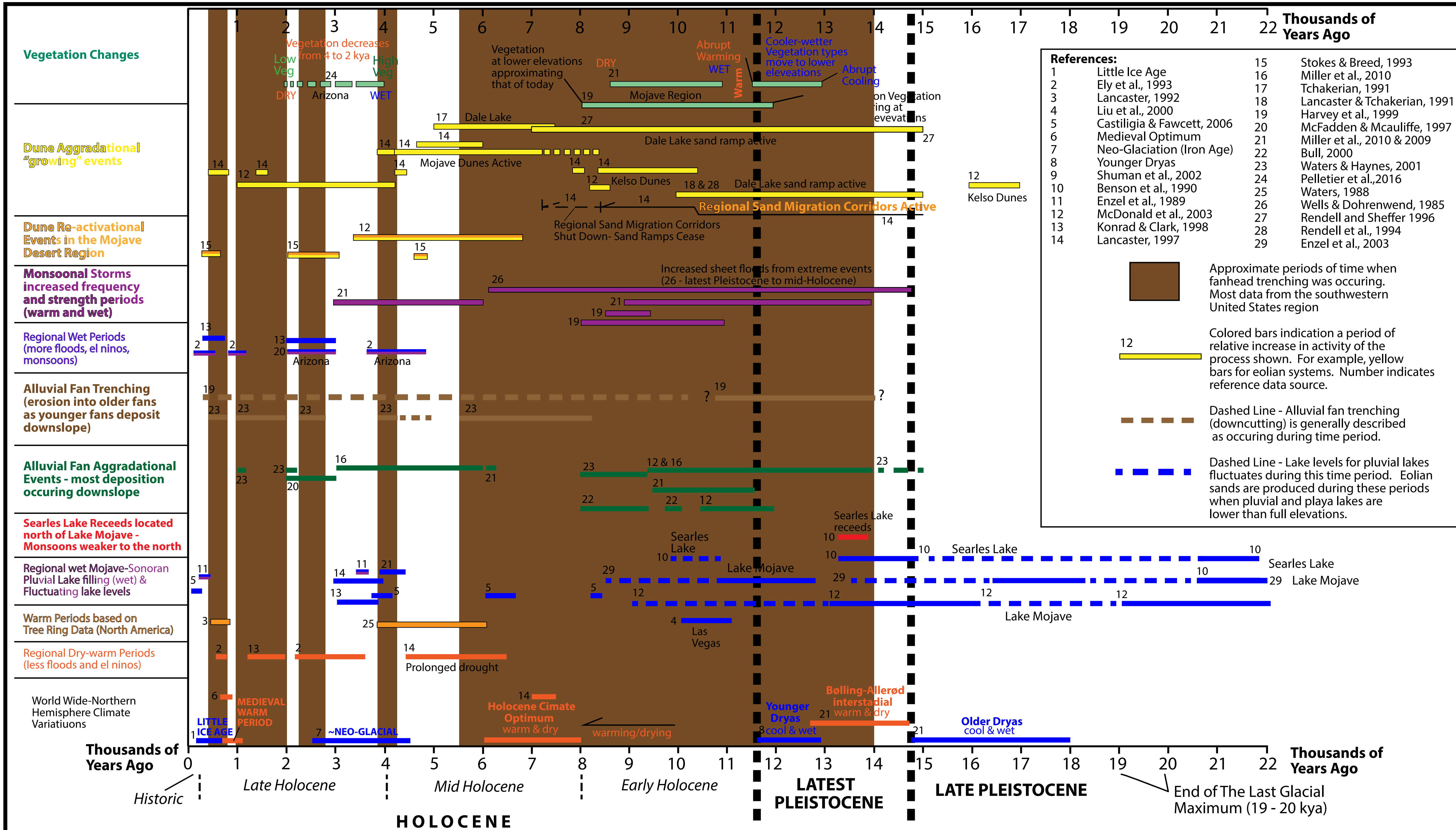

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Table of Pertinent Geologic Events From the Latest Pleistocene to Late Holocene- Focus on Fan Trenching

Job No. 721-11

Date: September, 2017

Drafted by: MDK

PLATE 8C