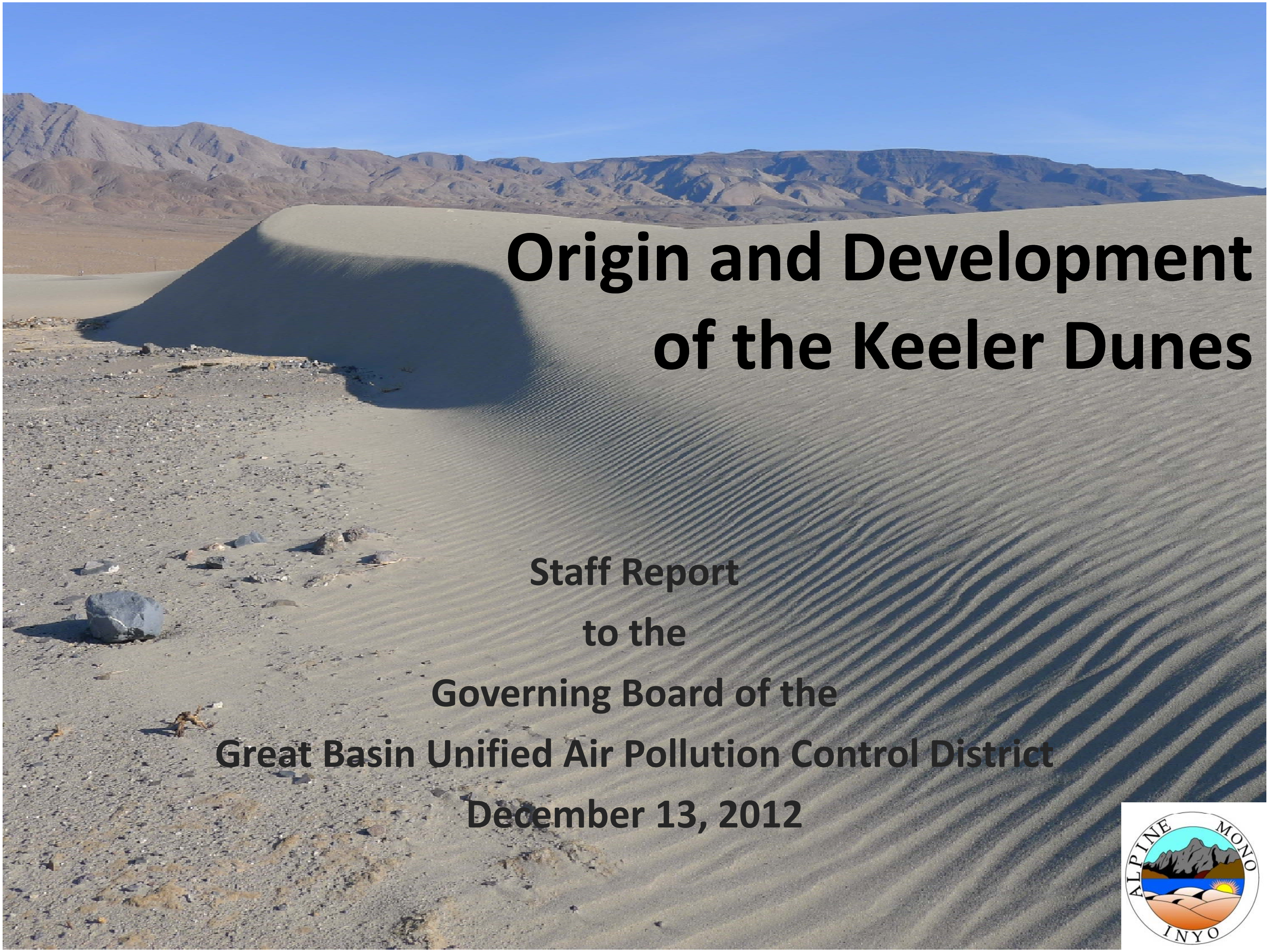


Origin and Development of the Keeler Dunes

Staff Report

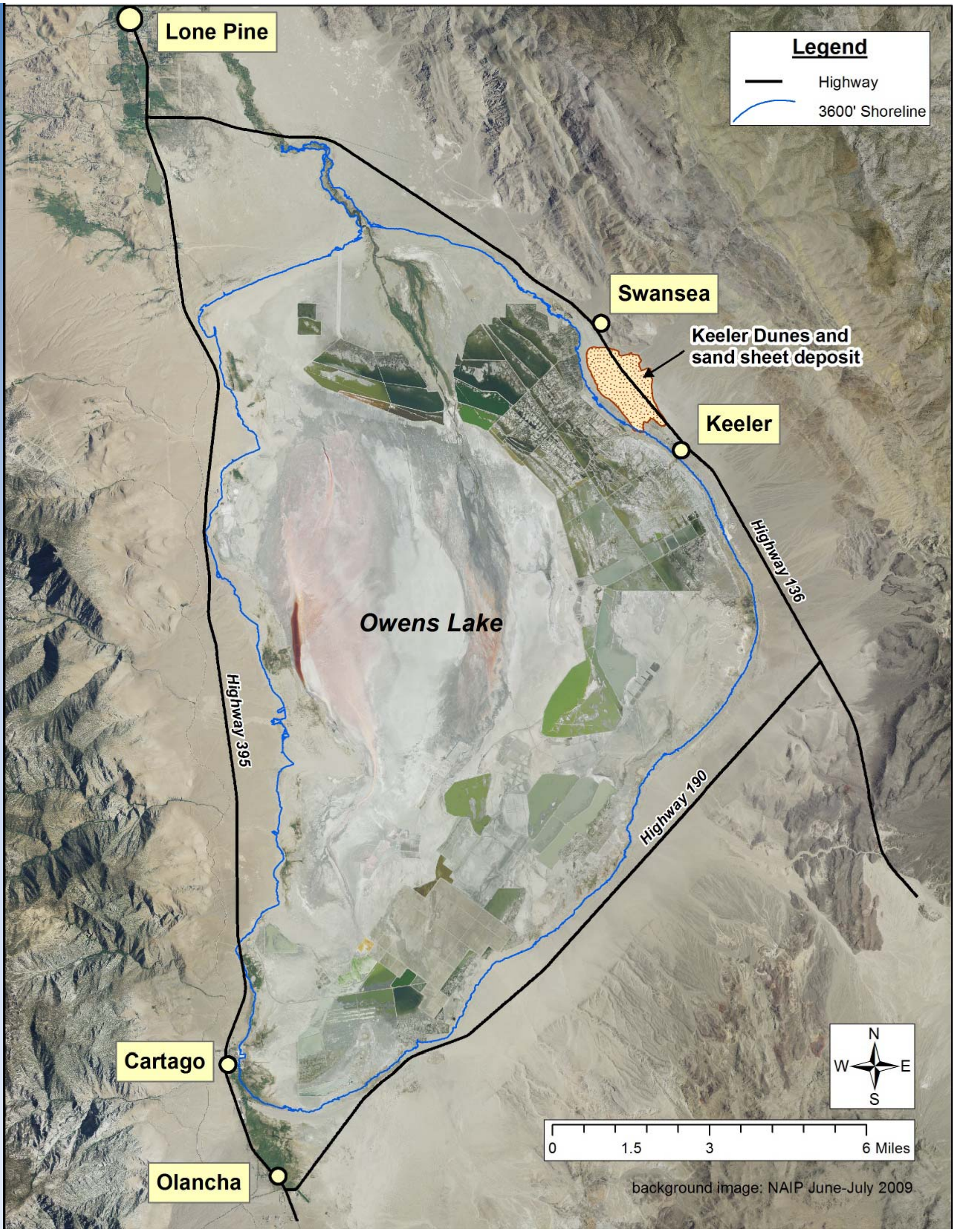
to the

Governing Board of the

Great Basin Unified Air Pollution Control District

December 13, 2012

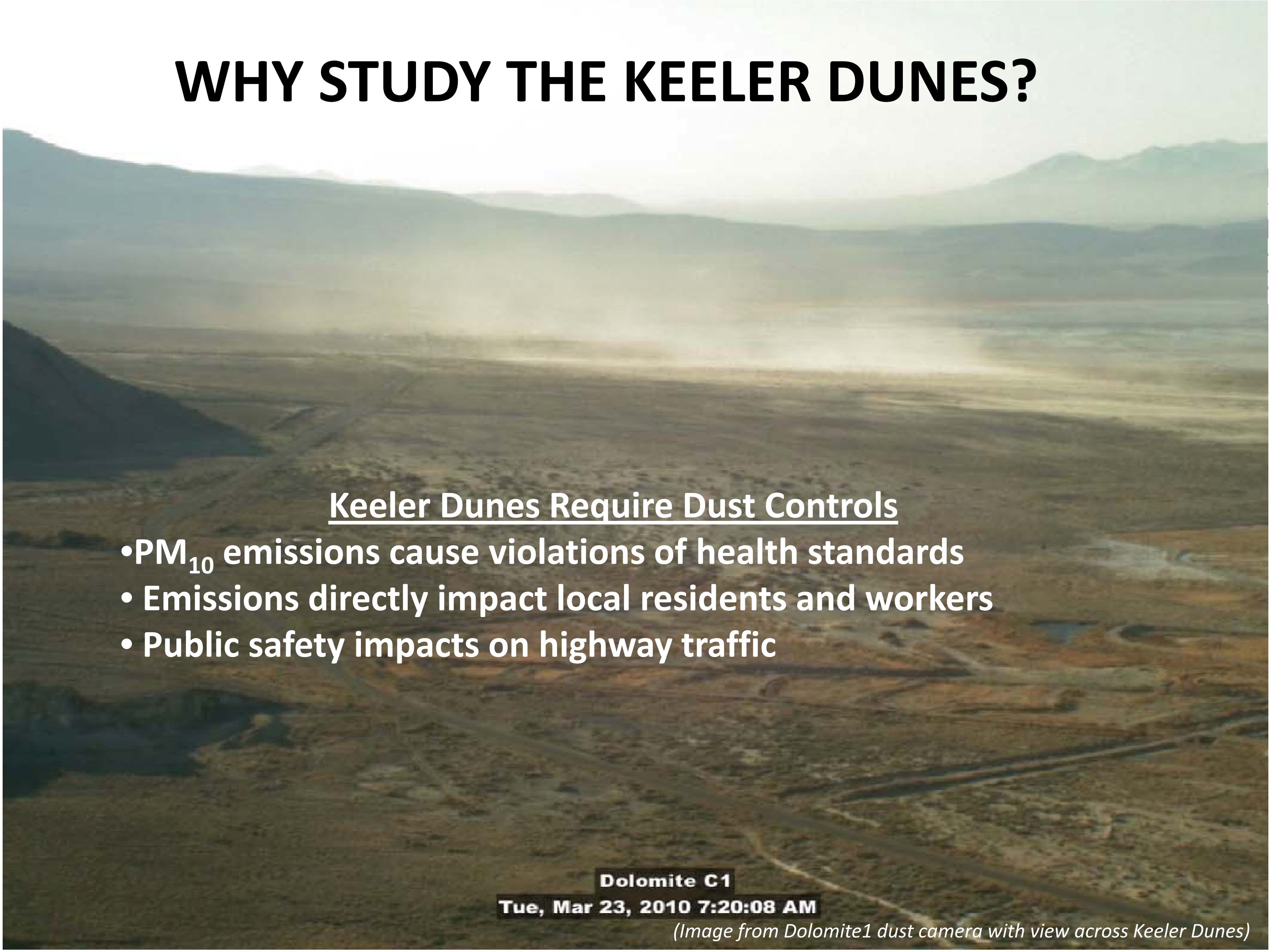
Location of Modern Keeler Dunes



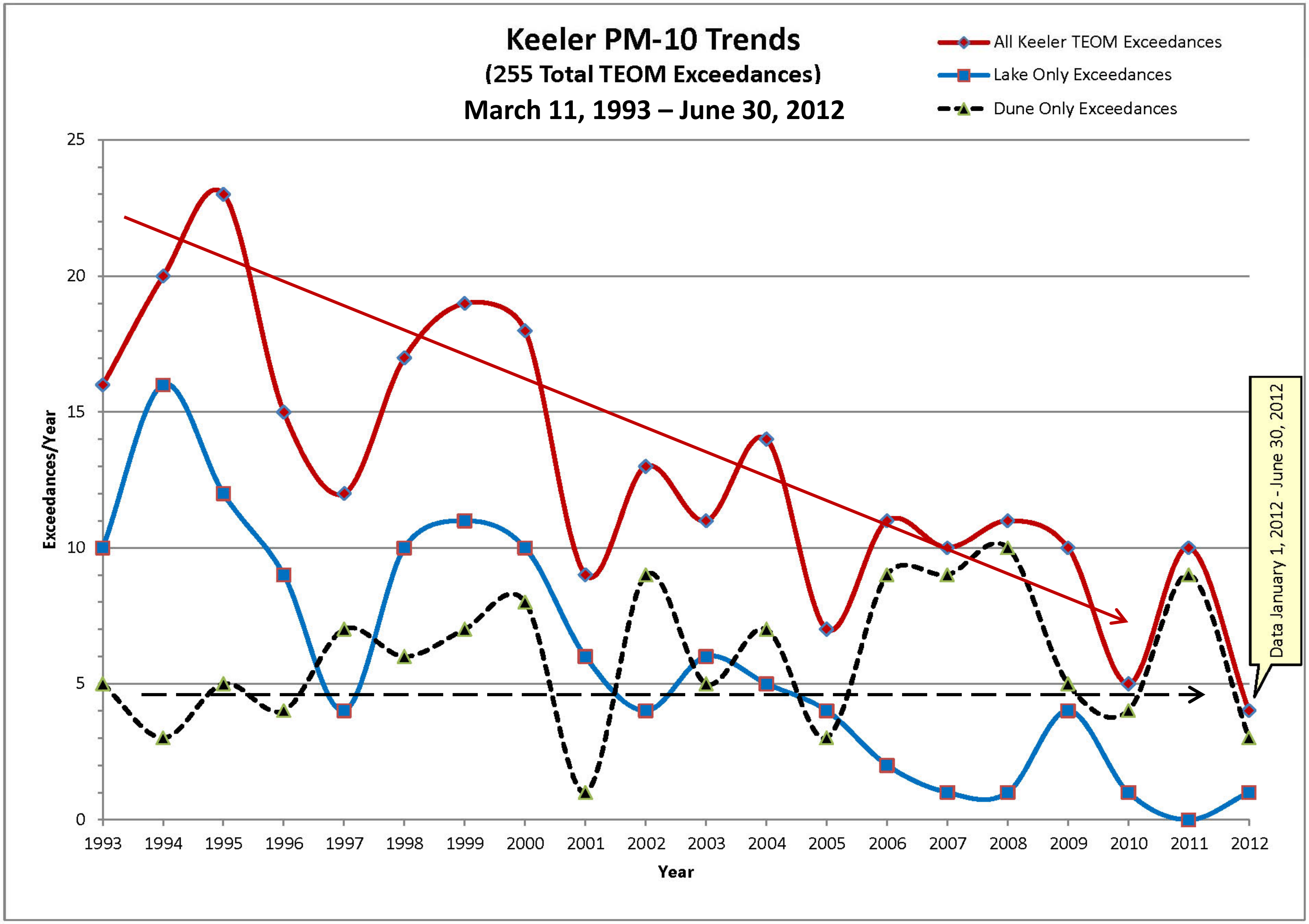
WHY STUDY THE KEELER DUNES?

<u>Keeler Dunes Require Dust Controls</u>

- PM_{10} emissions cause violations of health standards
- Emissions directly impact local residents and workers
- Public safety impacts on highway traffic



(Image from Dolomite1 dust camera with view across Keeler Dunes)


Keeler PM-10 Trends
(255 Total TEOM Exceedances)
March 11, 1993 – June 30, 2012
All Keeler TEOM Exceedances
Lake Only Exceedances
Dune Only Exceedances
Exceedances/Year
0
5
10
15
20
25
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Data January 1, 2012 - June 30, 2012

Background

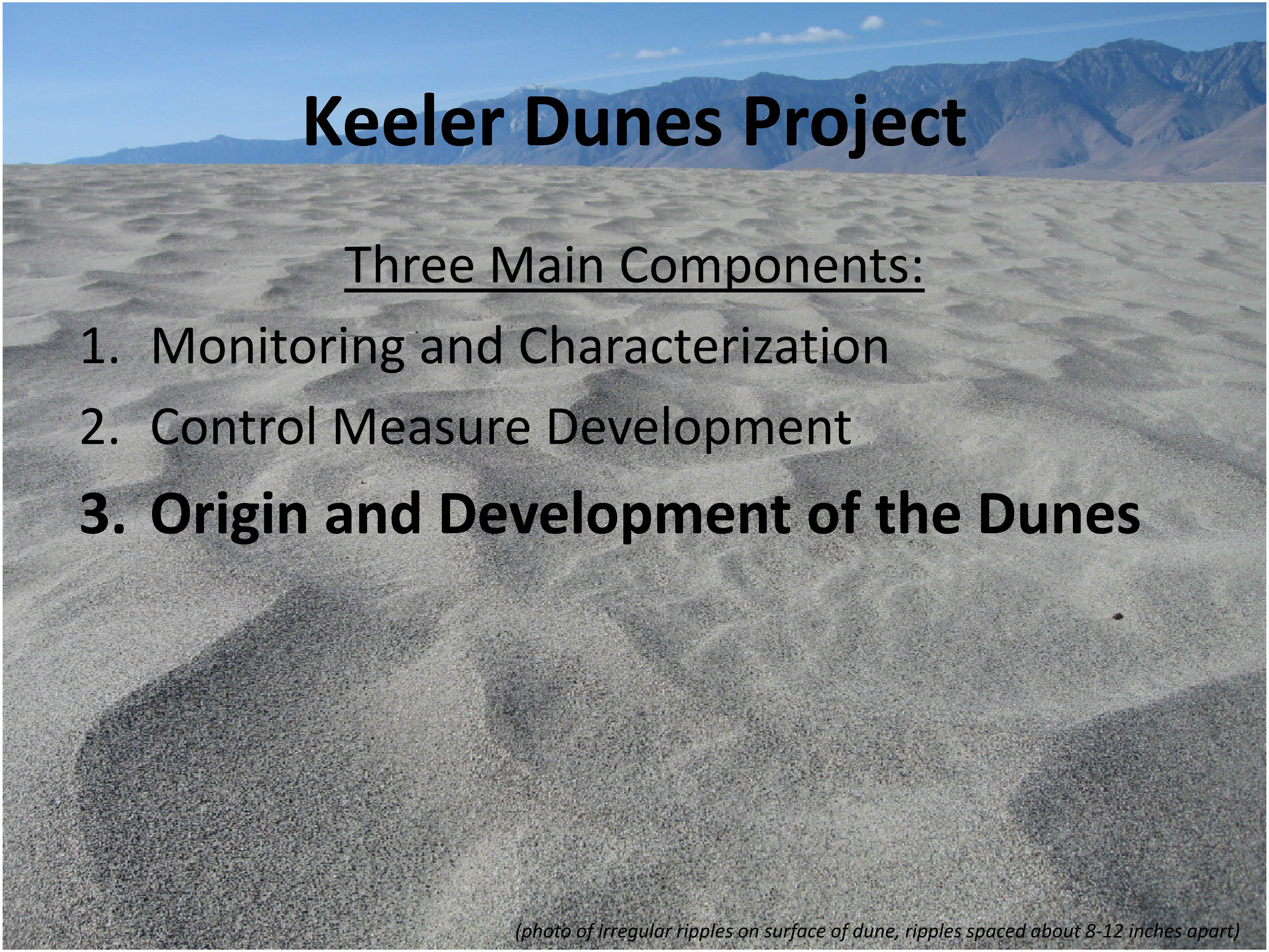
- 2003 and 2008 SIPs require controls in Keeler Dunes to meet PM_{10} attainment in OVPA
- Controls are required by 2014 to meet 2017 deadline
- 2006 Settlement Agreement has provision for District and LADWP to work together on Keeler Dunes

(surface ripples on dune)

Keeler Dunes Project

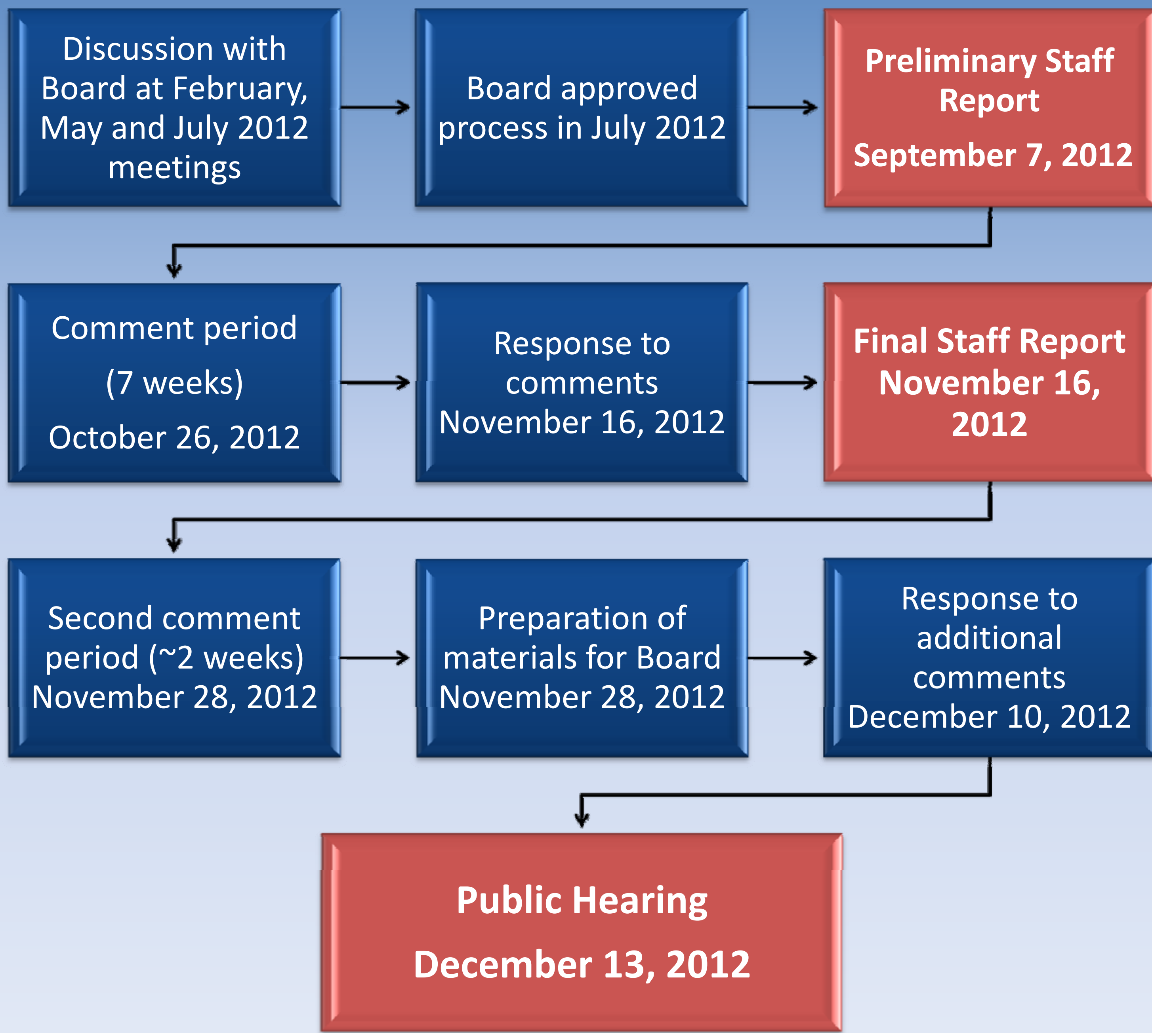
<u>Three Main Components:</u>

1. Monitoring and Characterization
2. Control Measure Development
3. **Origin and Development of the Dunes**



(photo of irregular ripples on surface of dune, ripples spaced about 8-12 inches apart)

Process Leading Up to Public Hearing



Investigations into the Origin and Development of the Keeler Dunes

1. Historical documents research
2. Historical photo analysis
3. Air photo and satellite imagery analysis
4. Geomorphic mapping and analysis
5. Geology – Stratigraphy and Chronology
6. Sand transport analysis – surface change evaluation
7. Dune transect and movement investigation

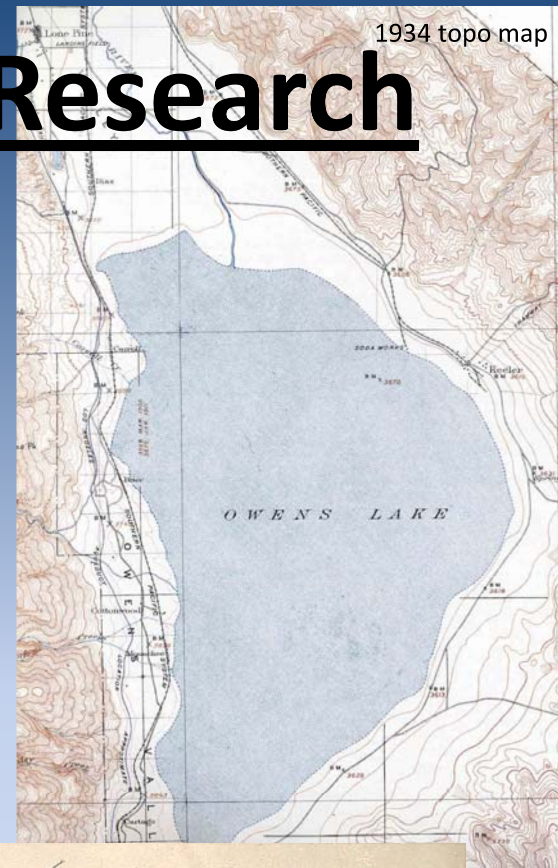
(Background: layering and ripples on dune surface, February 8, 2011)

Project Team

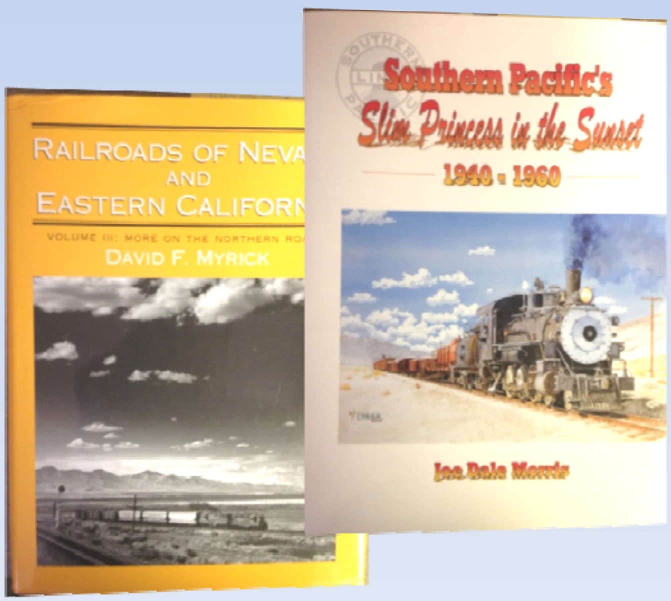
- District Staff
- Scientific Experts
  - Desert Research Institute (DRI)
  - Dr. Scott Stine
  - Sapphos Environmental Inc.
  - HydroBio ARS

1. Historical Document Research

- Historical document search
  (train records, local mining, newspapers etc.)
- Historical photos
- Historical maps

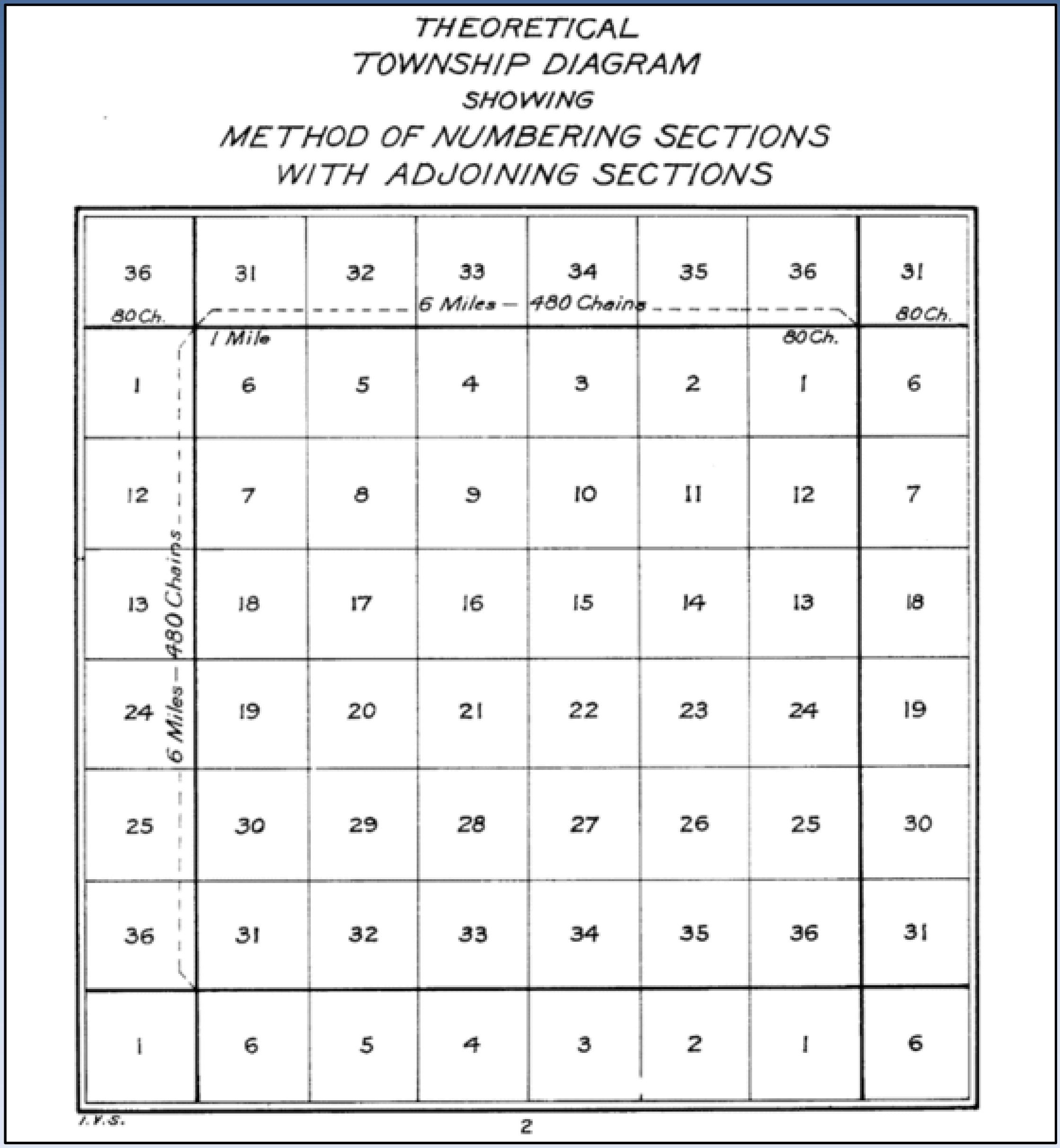


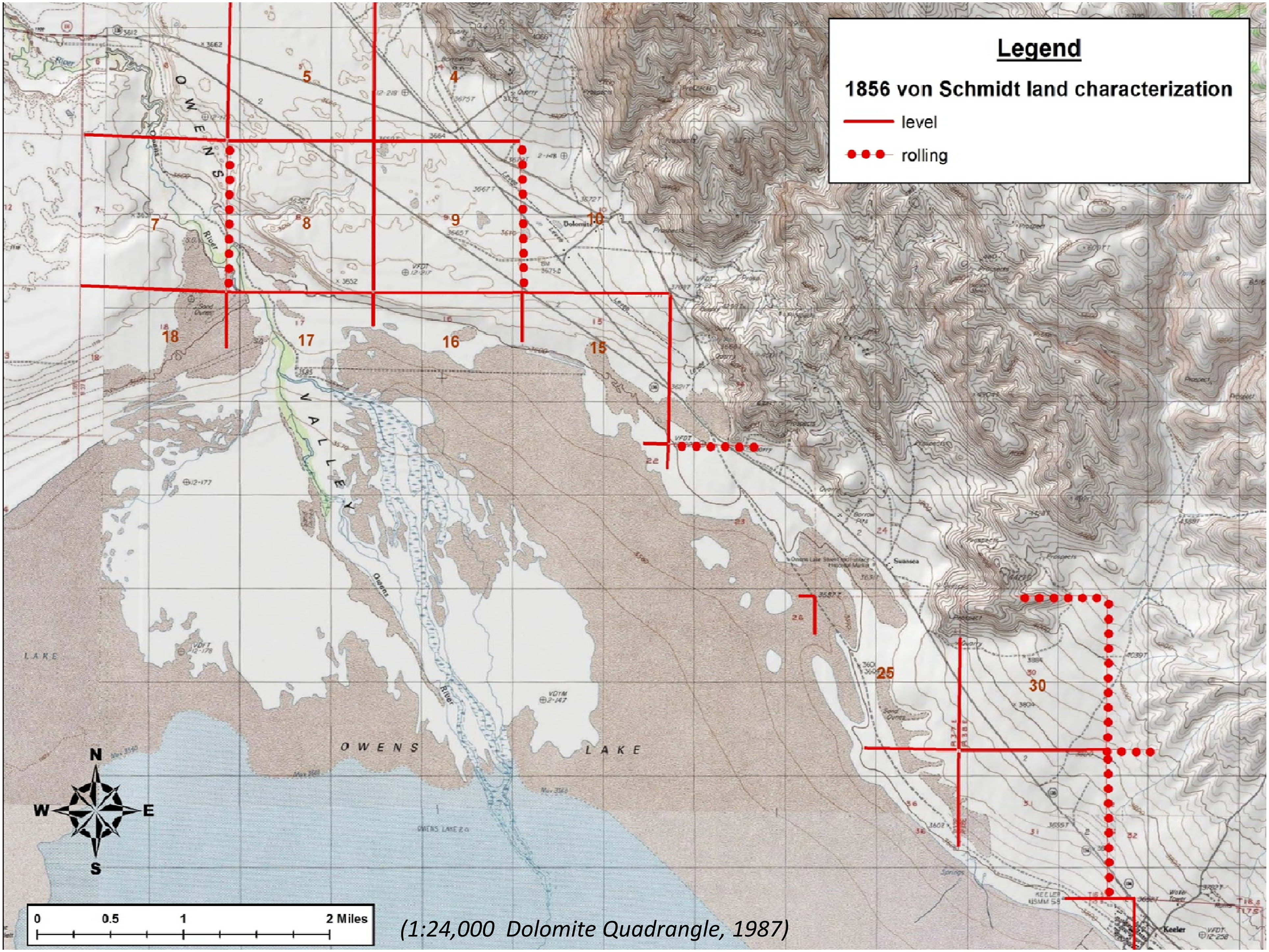
1934 topo map



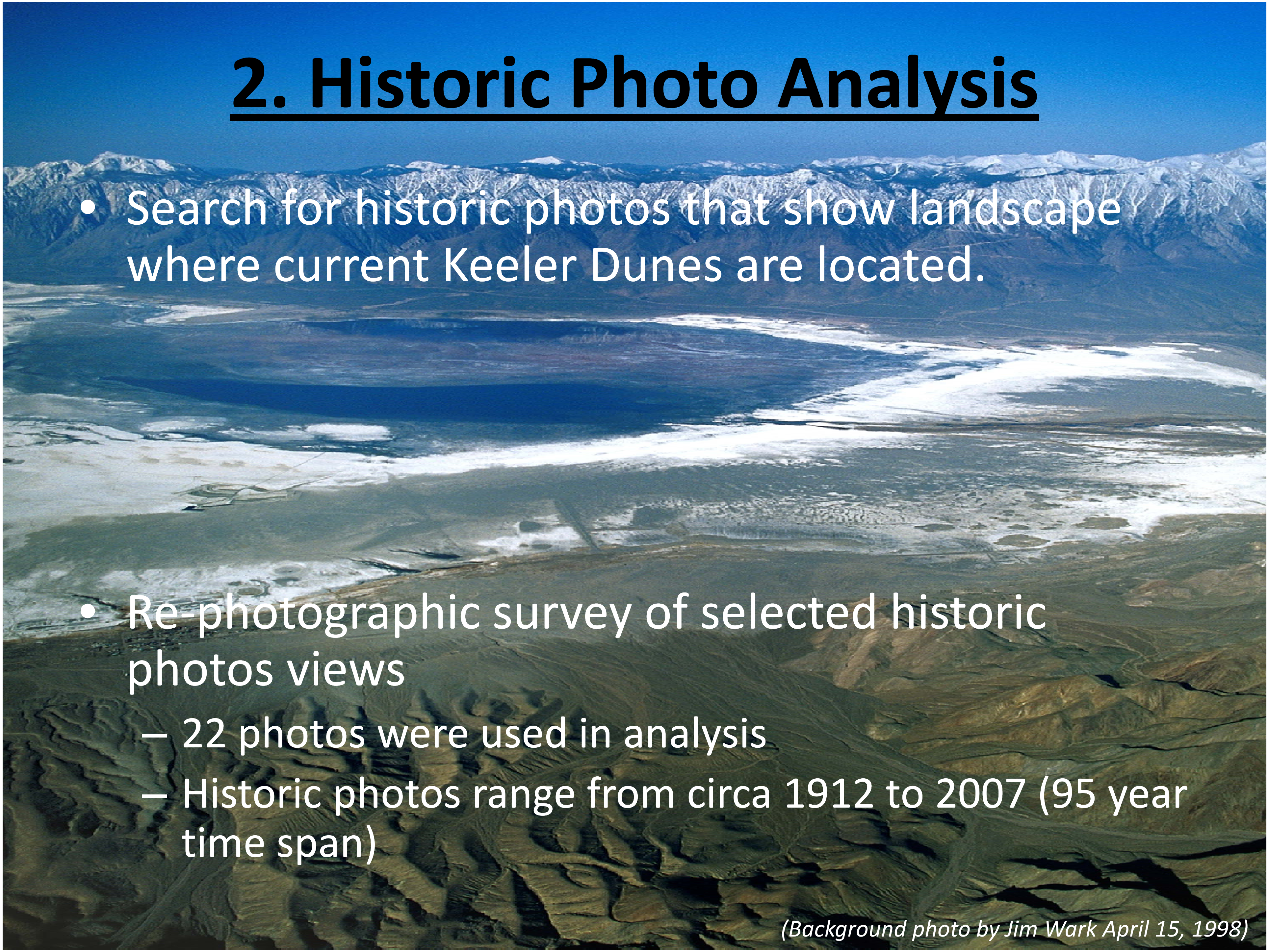
Von Schmidt Public Land Survey

- Public Lands survey following statehood in 1850
- 1855-1857 survey of lands in Owens Valley and Mono Basin
- Land characterization conducted along Township and section lines
- Land survey followed strict protocol
- Land character rated based on agricultural suitability and topography





(1:24,000 Dolomite Quadrangle, 1987)



2. Historic Photo Analysis

- Search for historic photos that show landscape where current Keeler Dunes are located.

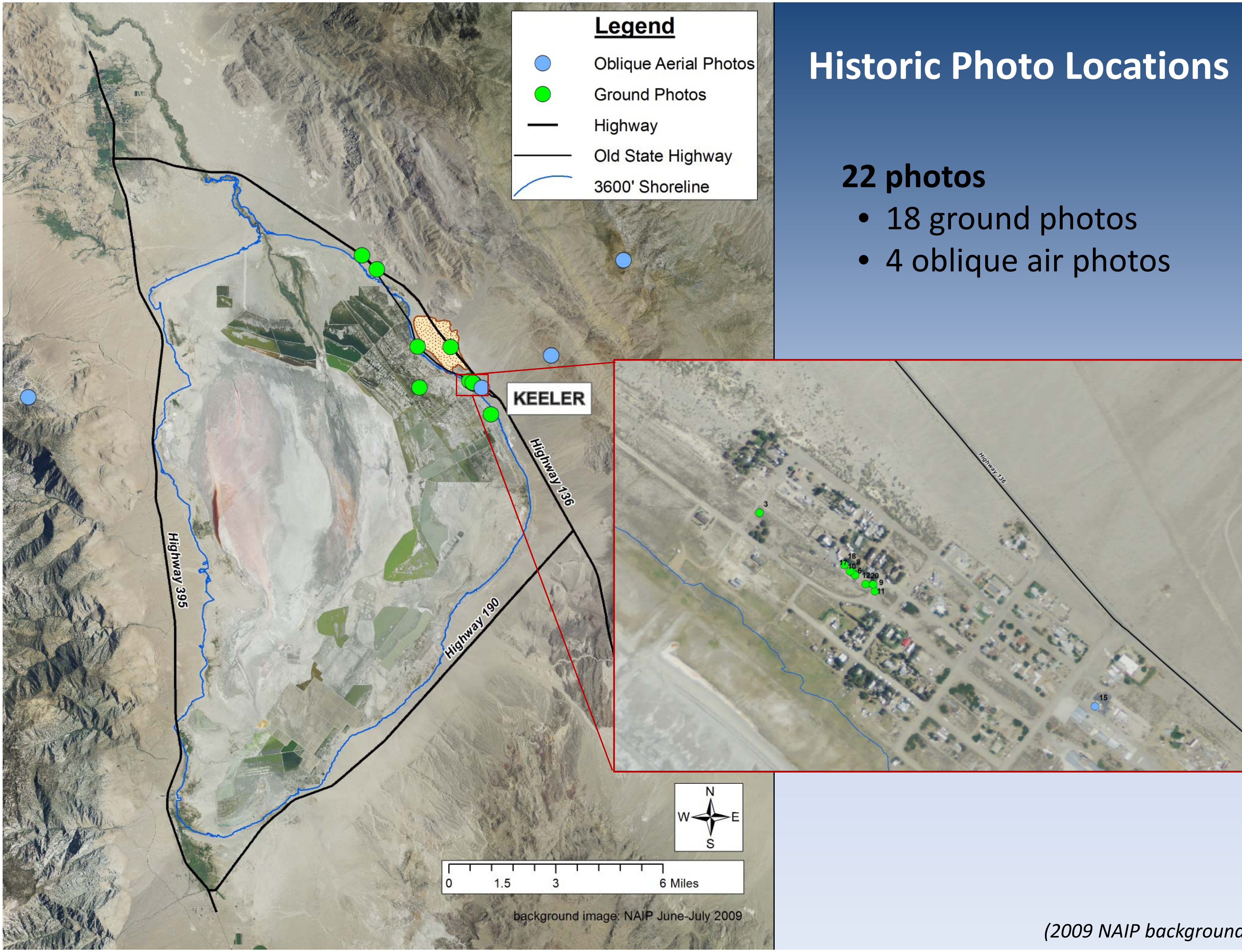
- Re-photographic survey of selected historic photos views
  - 22 photos were used in analysis
  - Historic photos range from circa 1912 to 2007 (95 year time span)

(Background photo by Jim Wark April 15, 1998)

Historic Photo Locations

22 photos

- 18 ground photos
- 4 oblique air photos



(2009 NAIP background)

1936 Aerial Photo of Keeler

Old Wooden Pipeline Monument

(photo with view to east from Shallow Flooding DCM, December 2012)

Inyo Development Company
c. 1920 vs 2012

View From Keeler to Northwest
1940 - 2012

Train into Keeler, 1953 - 2012

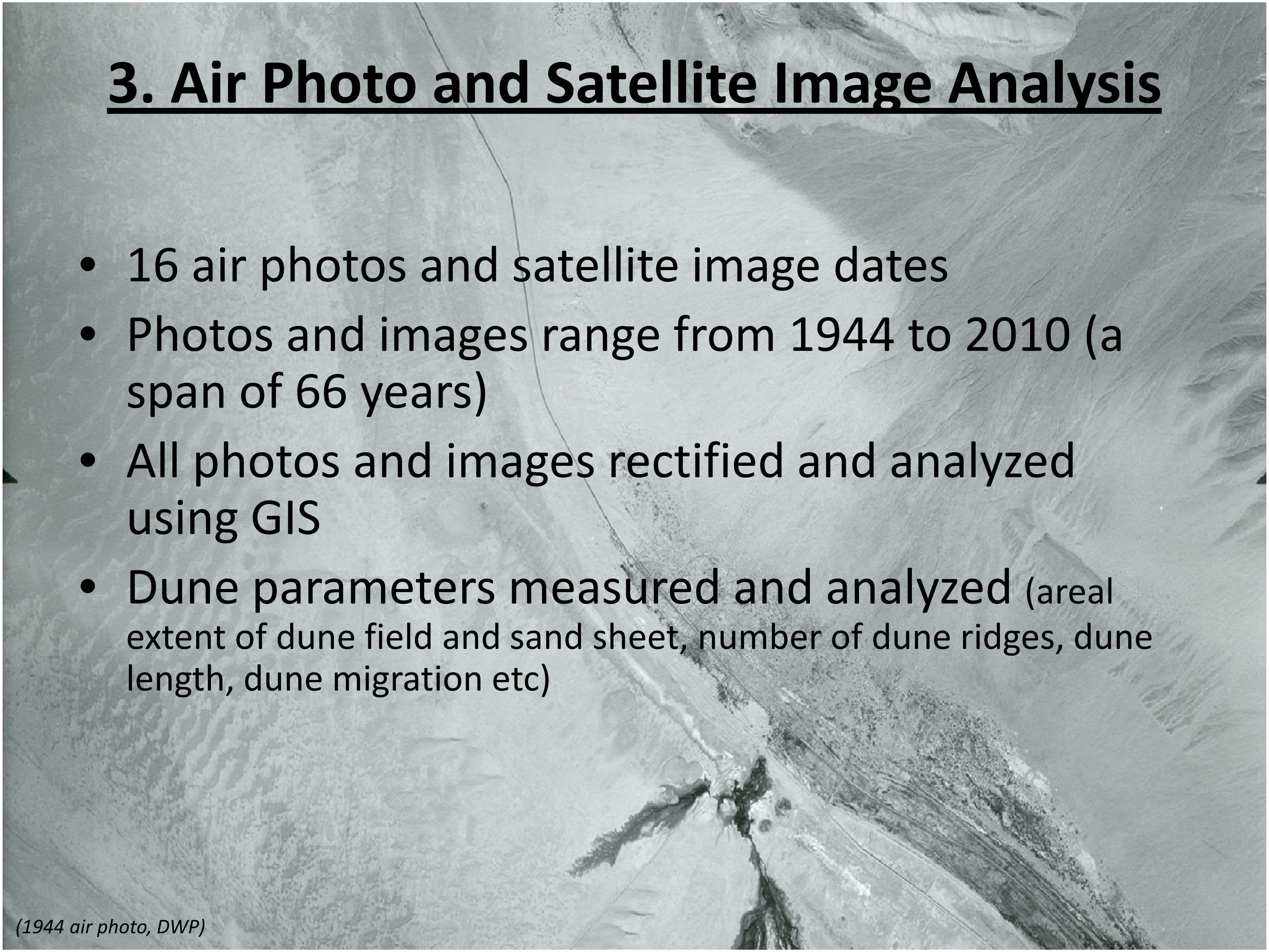
Summary of Historical Photo-Rephoto Analysis

1. Condition of the landscape changed dramatically over historical time
2. Landscape over much of the area has changed from vegetated with little or no loose surface sands to relatively unvegetated with deep aeolian sand deposits
3. Current conditions and extent of much of the Keeler Dunes developed after 1960 but before 1998
4. Overall movement of Keeler dune sand deposit to the south-southeast towards Keeler.

(background photo: ripples on dune surface, Feb 8, 2011)

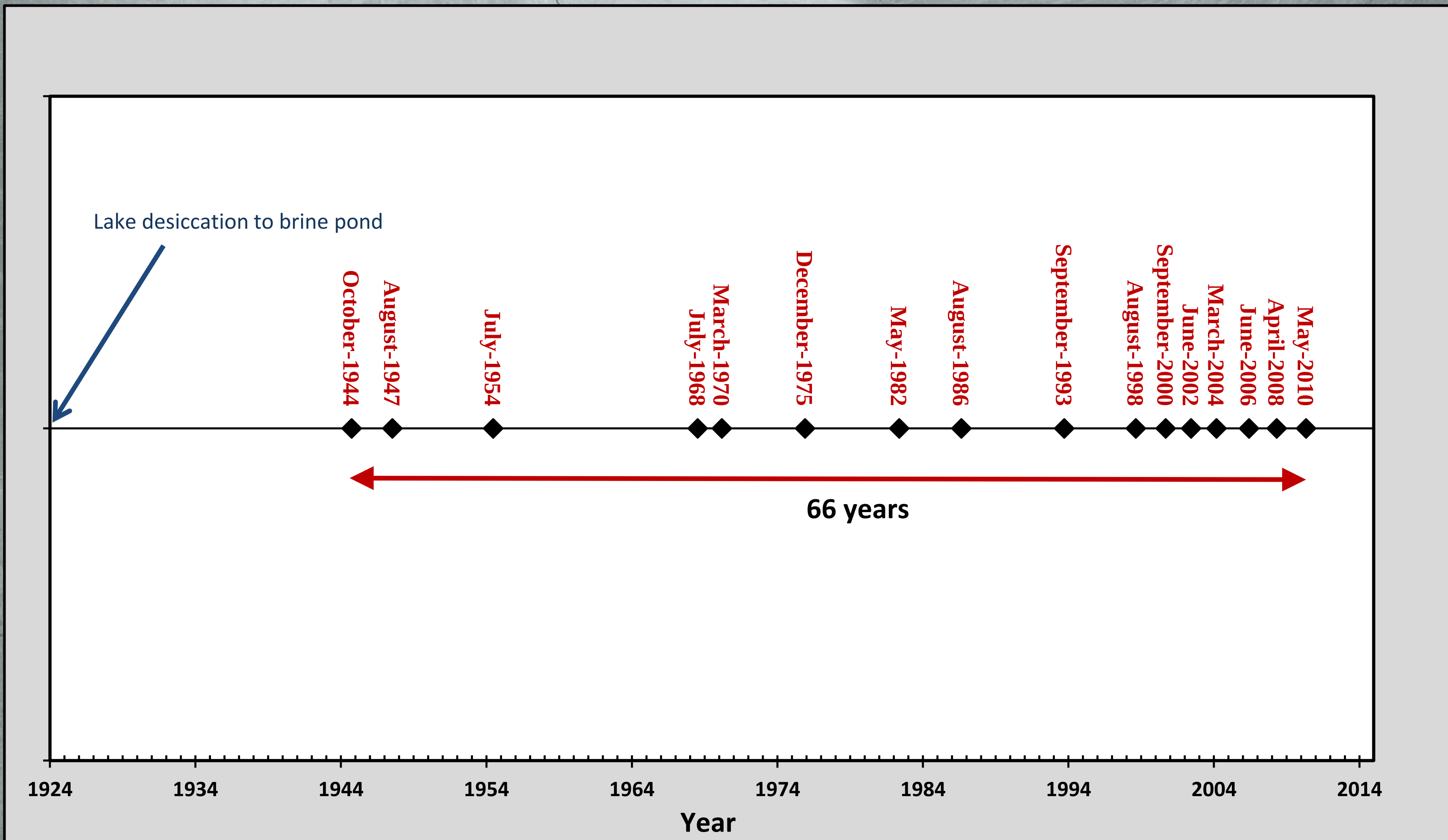
3. Air Photo and Satellite Image Analysis

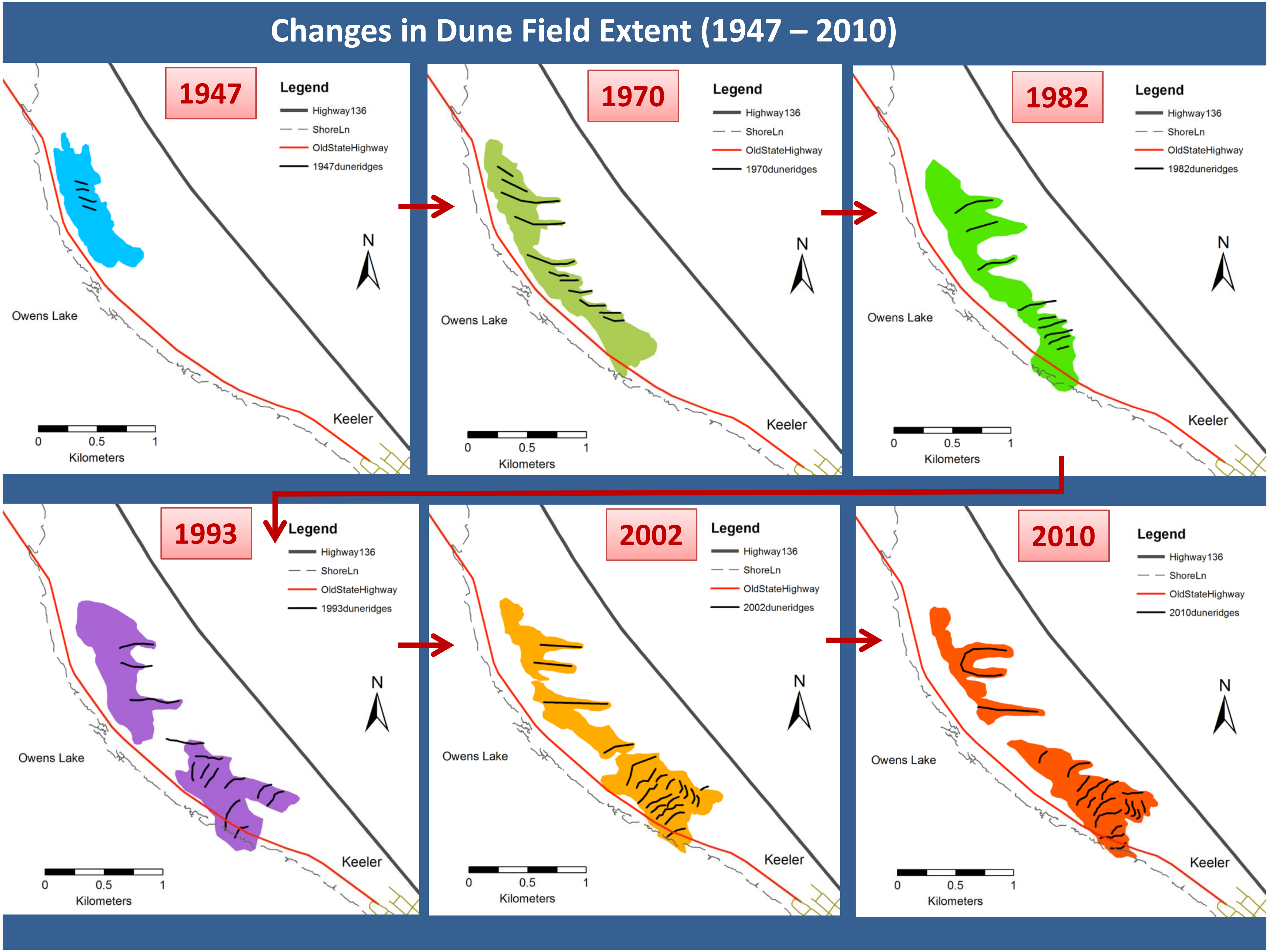
- 16 air photos and satellite image dates
- Photos and images range from 1944 to 2010 (a span of 66 years)
- All photos and images rectified and analyzed using GIS
- Dune parameters measured and analyzed (areal extent of dune field and sand sheet, number of dune ridges, dune length, dune migration etc)



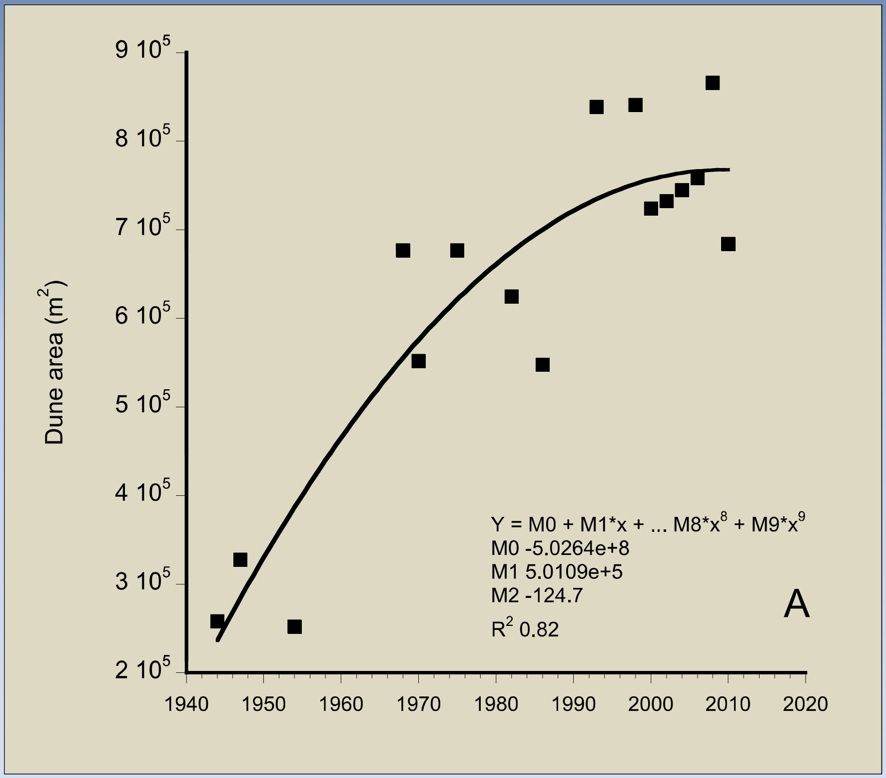
(1944 air photo, DWP)

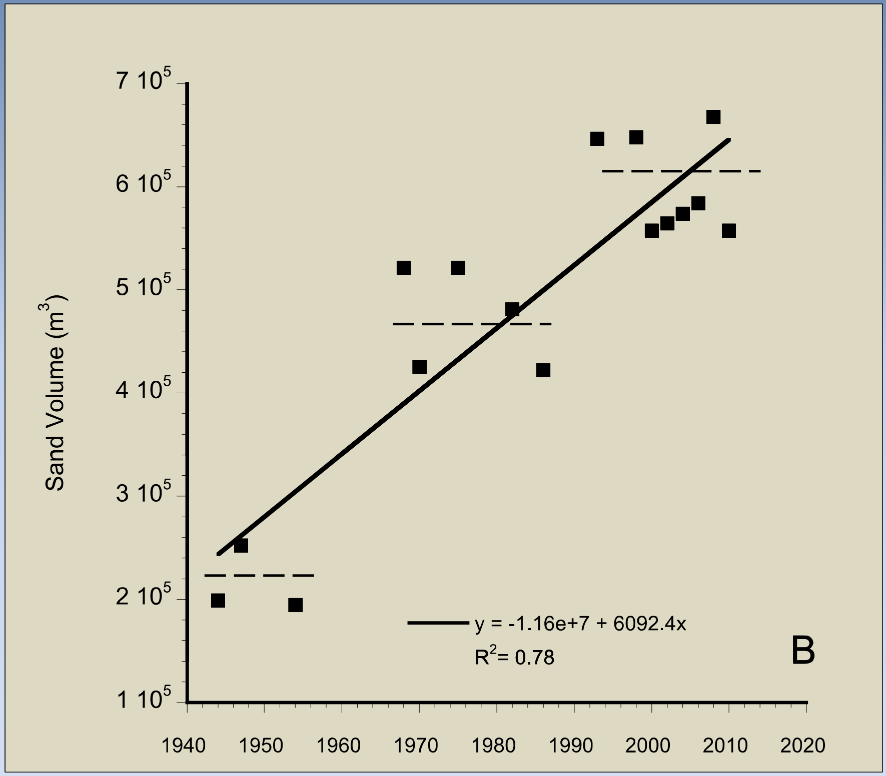
Image and Photo Timeline



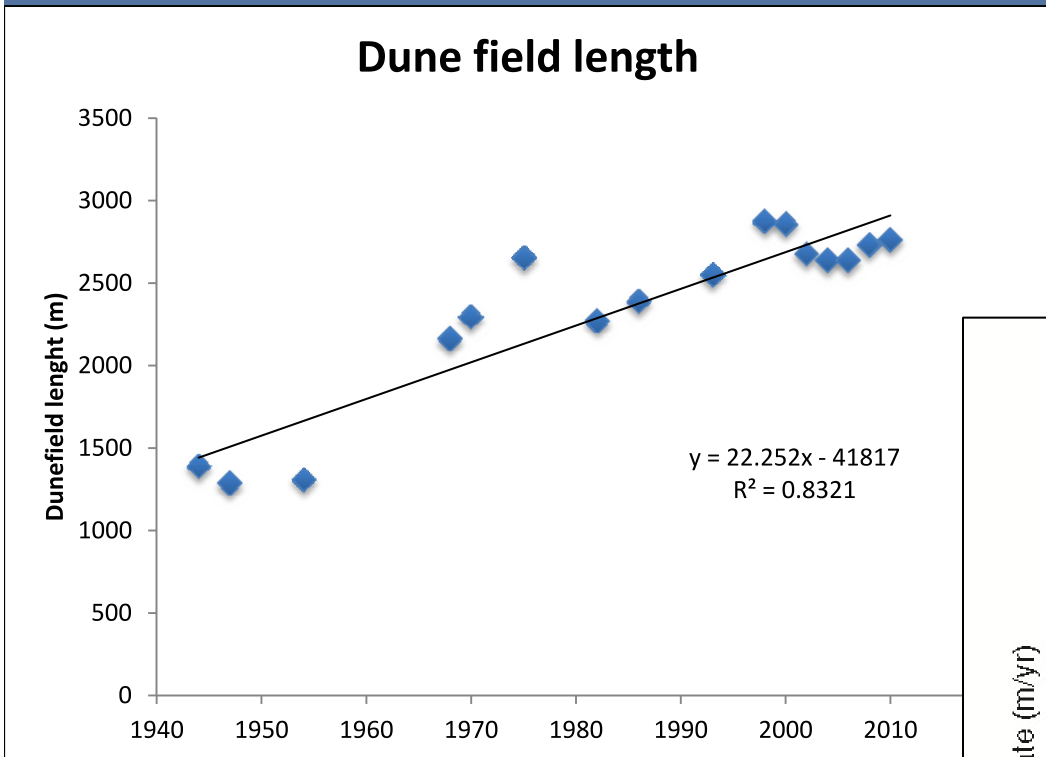

Changes in Dune Field Extent (1947 – 2010)
1947
1970
1982
1993
2002
2010
Legend
Highway136
ShoreLn
OldStateHighway
1947duneridges
1970duneridges
1982duneridges
1993duneridges
2002duneridges
2010duneridges
Owens Lake
Keeler
N
0
0.5
1
Kilometers

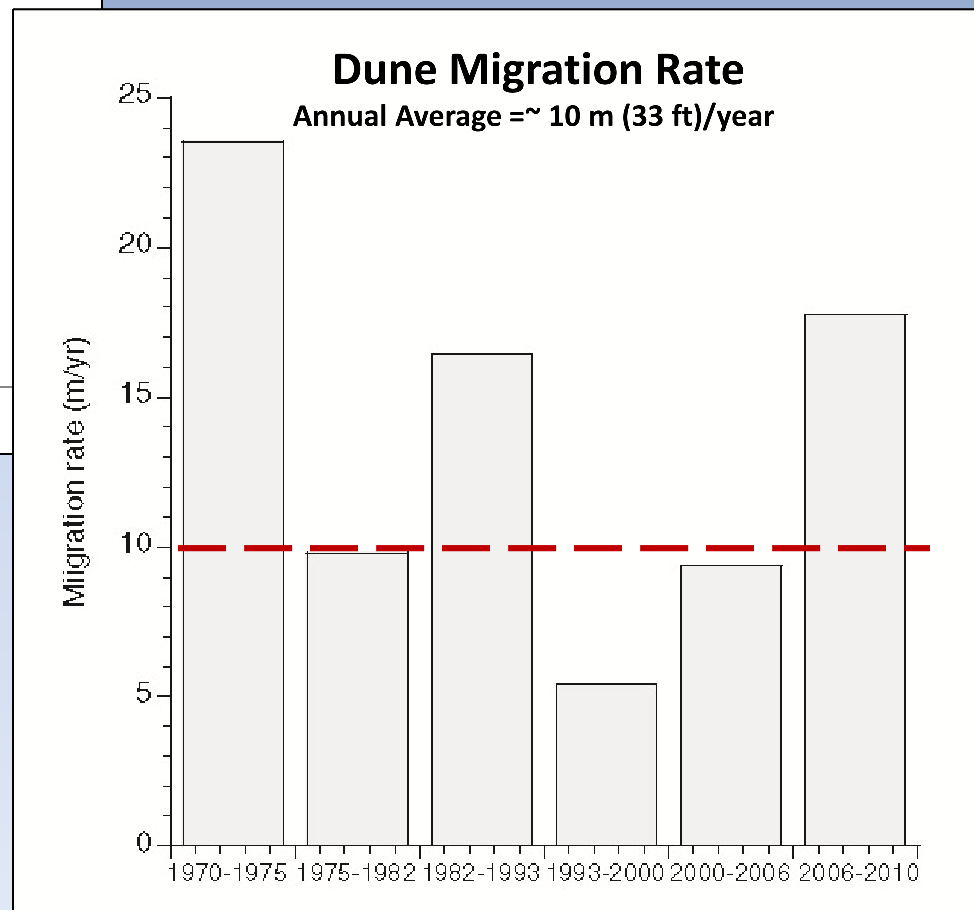
Changes in Dune Field Area and Volume (1944 – 2010)





Changes in Dune Field Length and Migration (1944 – 2010)





Dune and Sand Sheet Development Summary 1944-2010

Date	Dune Field Area km^2 (mi^2)	Sand Sheet Area km^2 (mi^2)	Dune Field Length (m)	Dune Field Volume (m^3)
1. 1944 - 1954	0.25 (0.10)	1.8 (0.70)	1,400	215,000
2. 1968 – 1982	0.68 (0.26)	4.3 (1.66)	2,300	474,000
3. 1986 – 2000	0.83 (0.32)	4.0 (1.55)	2,300	600,000
Changes observed through 2000	**3 fold increase in dune field area**	**2 fold increase in sand sheet area**	**2 fold increase in dune field length**	**3 fold increase in dune field volume**
4. 2002 - 2010	0.78 (0.30)	3.4(1.32)	2,700	600,000

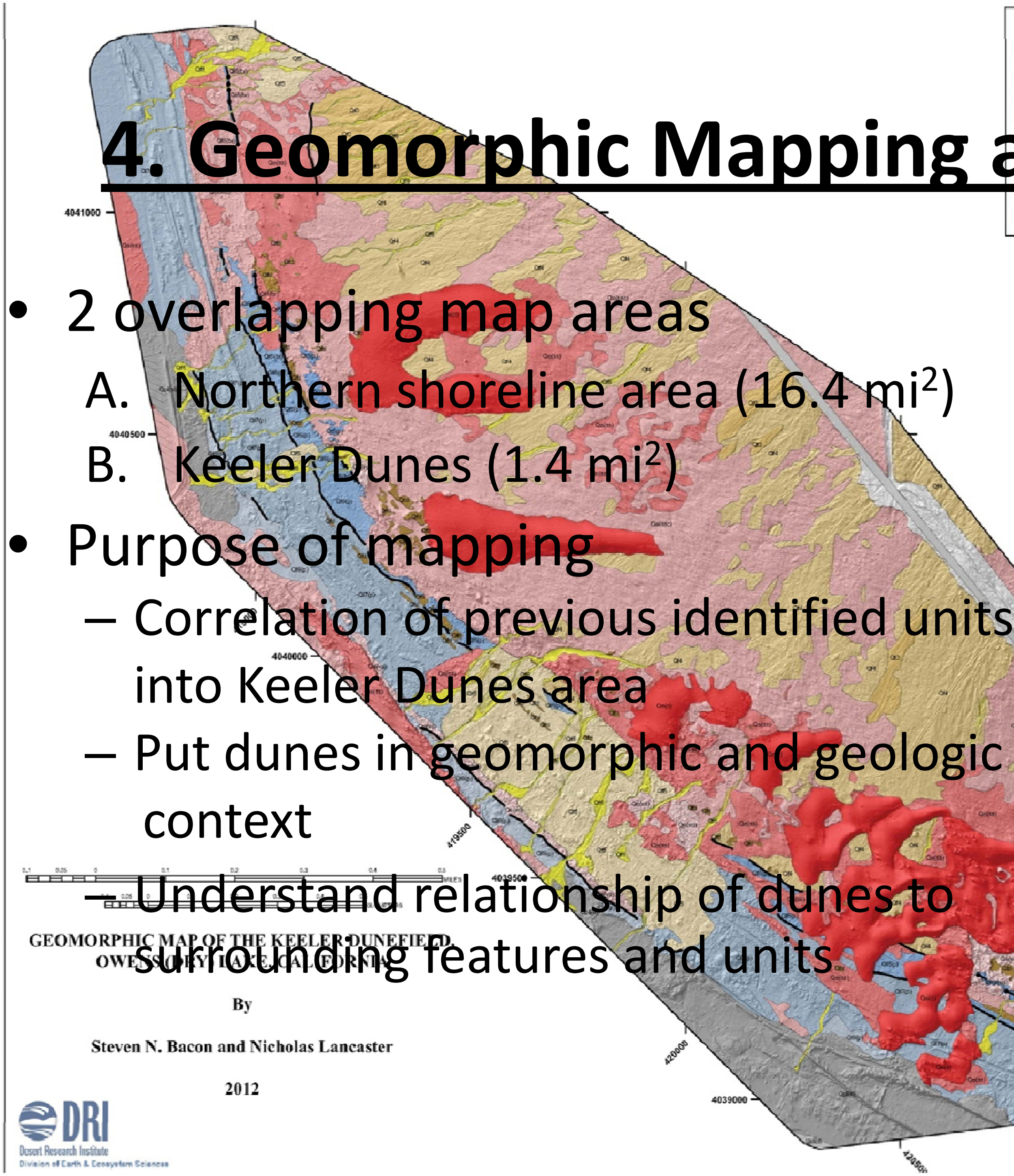
Summary of Air Photo and Satellite Image Analysis

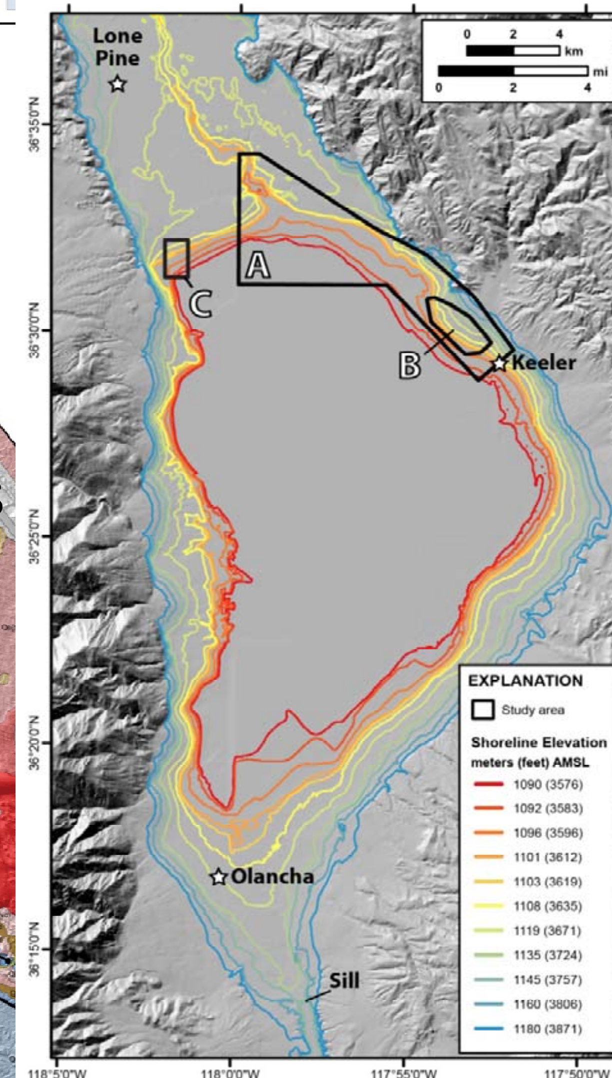
1. Modern emissive Keeler Dune field is a young immature dune field
2. Areal extent and volume of the dune field increased by a factor of 3 from 1944 to 2000
3. Northwestern portion of dune deposit has eroded and thinned since dust control implementation on lake bed
4. Overall movement of Keeler Dune deposit is to the south-southeast towards Keeler

(background photo: ripples on dune surface, Feb 8, 2011)

4. Geomorphic Mapping and Analysis

- 2 overlapping map areas
  A. Northern shoreline area (16.4 mi^2)
  B. Keeler Dunes (1.4 mi^2)
- Purpose of mapping
  - Correlation of previous identified units into Keeler Dunes area
  - Put dunes in geomorphic and geologic context
  - Understand relationship of dunes to surrounding features and units

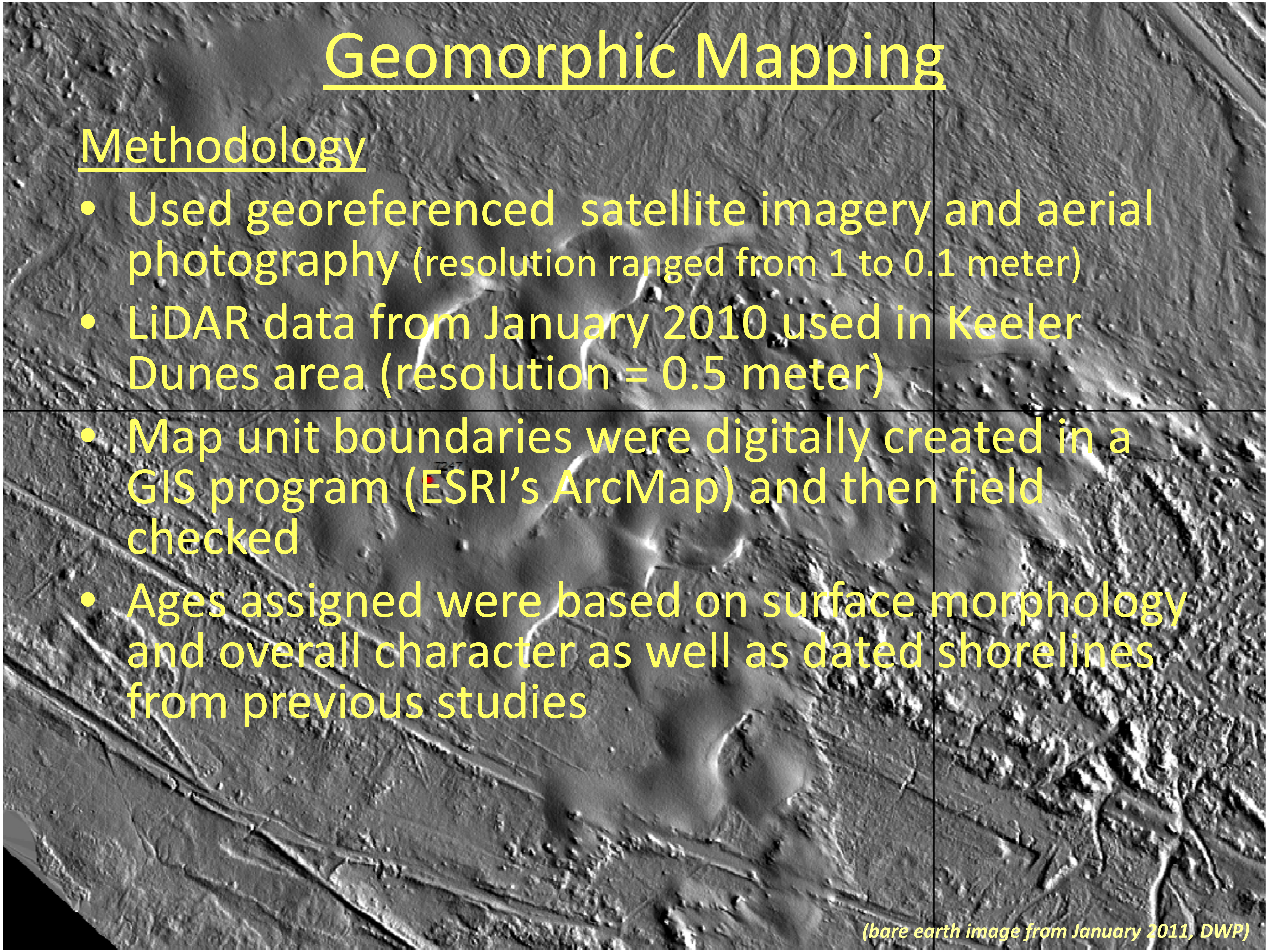




Geomorphic Mapping

Methodology

- Used georeferenced satellite imagery and aerial photography (resolution ranged from 1 to 0.1 meter)
- LiDAR data from January 2010 used in Keeler Dunes area (resolution = 0.5 meter)
- Map unit boundaries were digitally created in a GIS program (ESRI's ArcMap) and then field checked
- Ages assigned were based on surface morphology and overall character as well as dated shorelines from previous studies

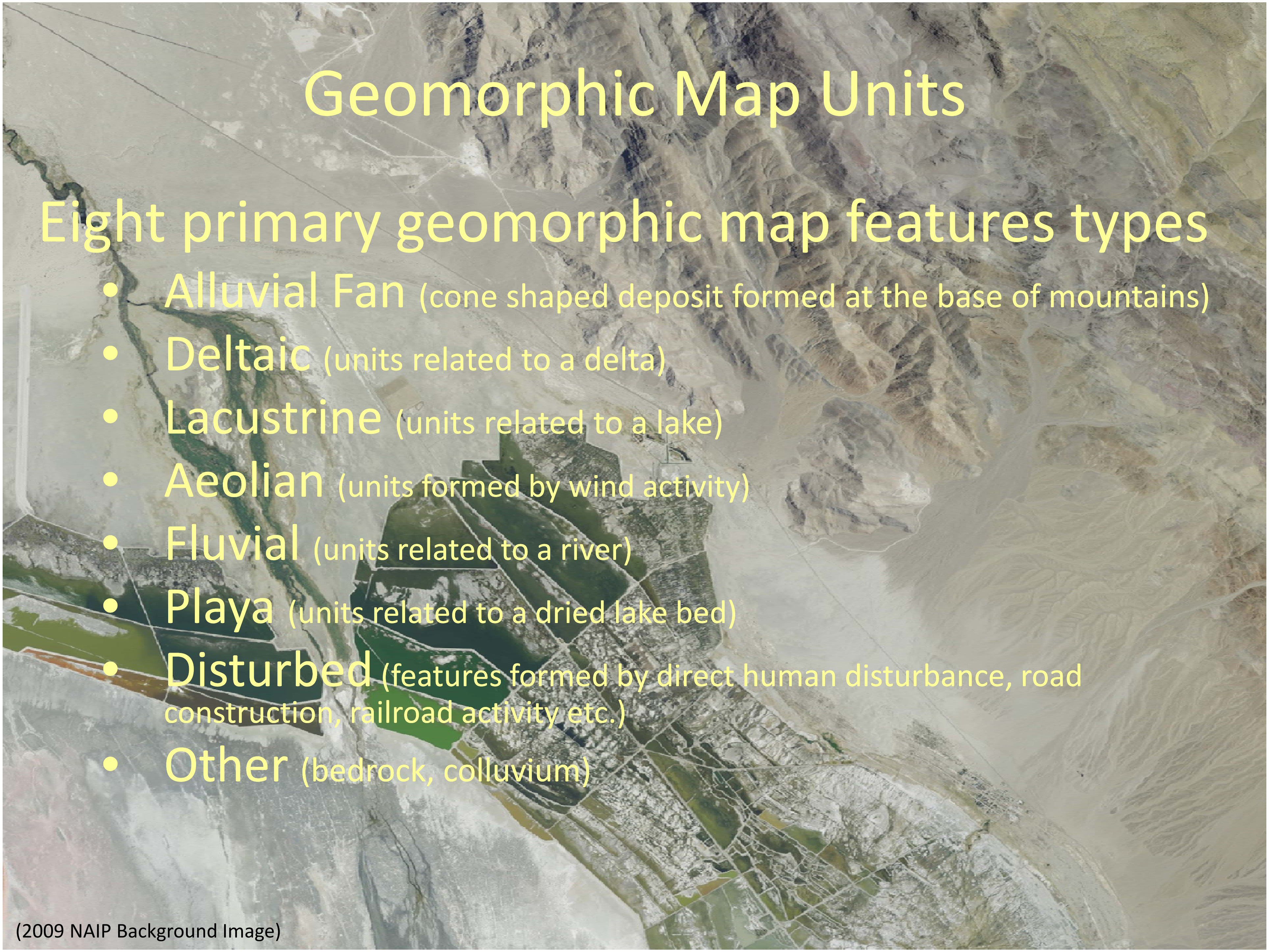


(bare earth image from January 2011, DWP)

Geomorphic Map Units

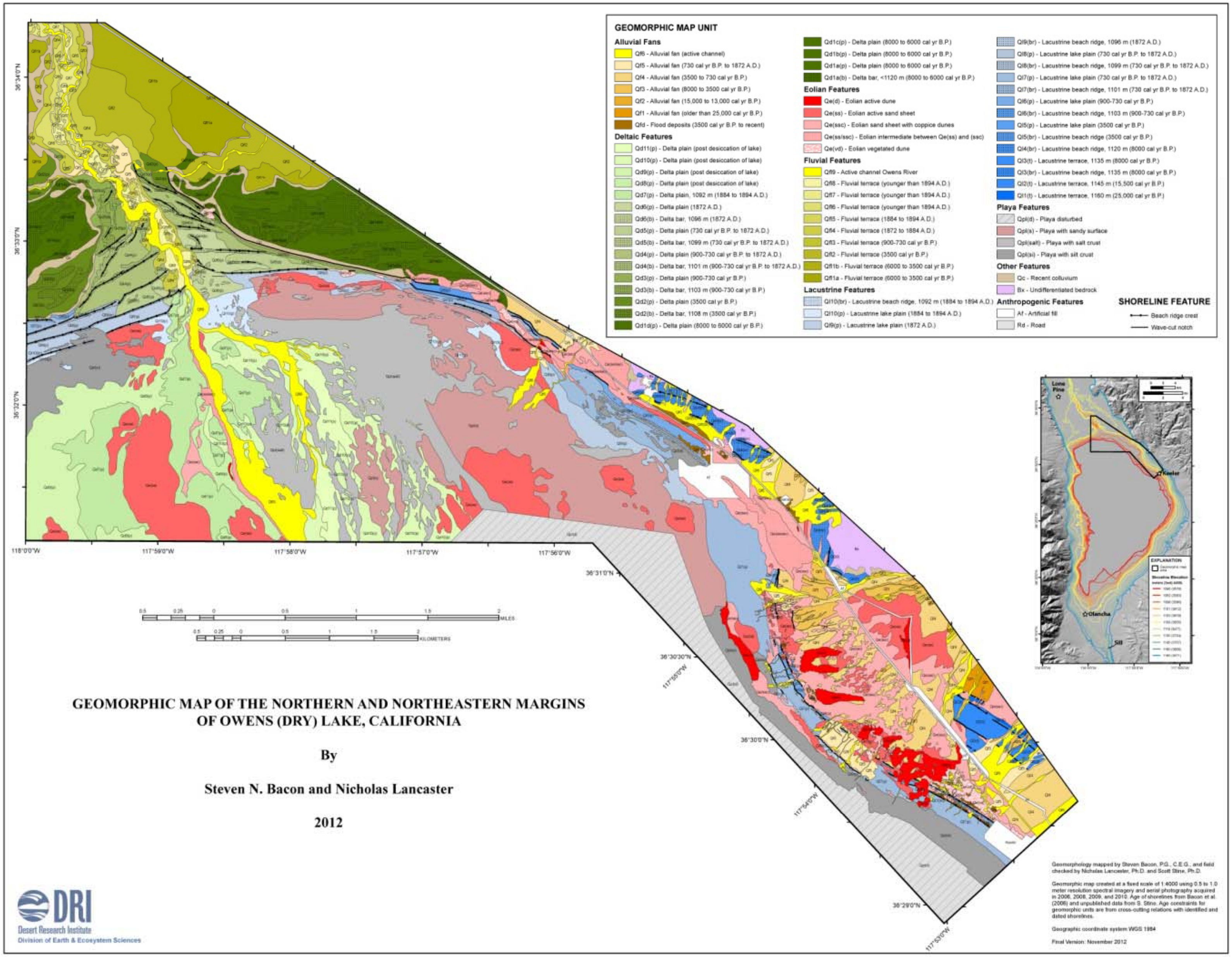
Eight primary geomorphic map features types

- Alluvial Fan (cone shaped deposit formed at the base of mountains)
- Deltaic (units related to a delta)
- Lacustrine (units related to a lake)
- Aeolian (units formed by wind activity)
- Fluvial (units related to a river)
- Playa (units related to a dried lake bed)
- Disturbed (features formed by direct human disturbance, road construction, railroad activity etc.)
- Other (bedrock, colluvium)

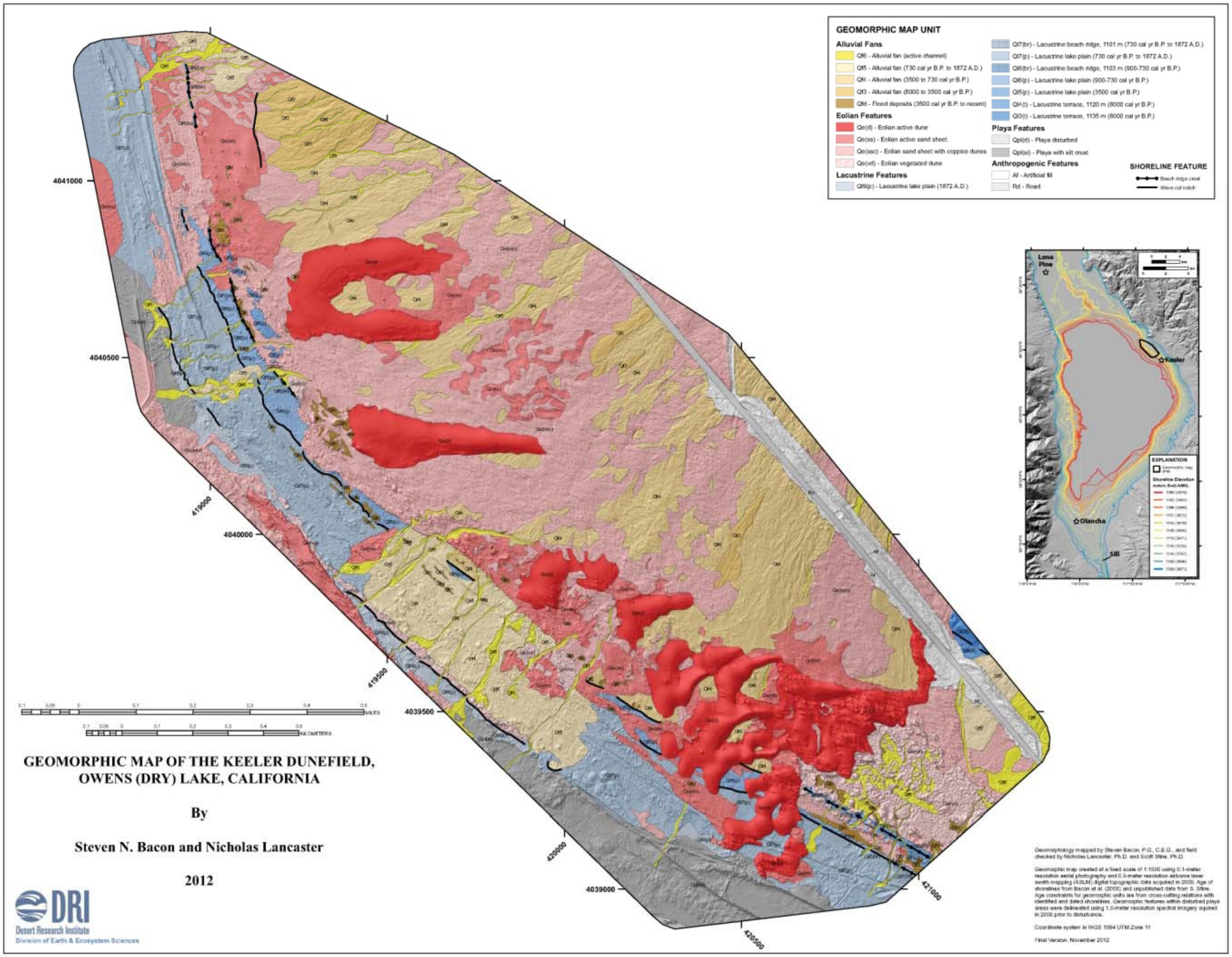


(2009 NAIP Background Image)

Geomorphic Map of Northern Shoreline

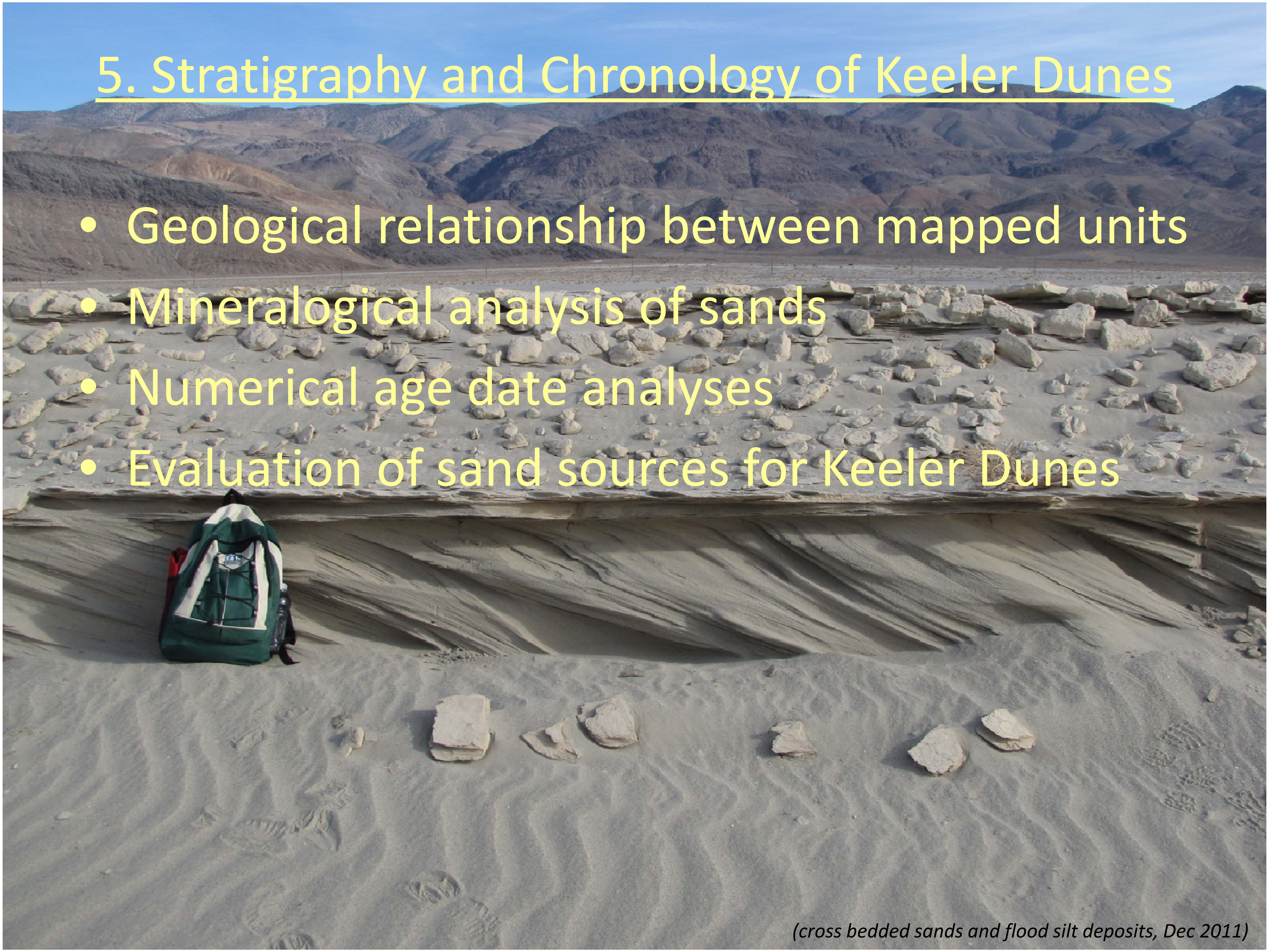


Geomorphic Map of Keeler Dunes



5. Stratigraphy and Chronology of Keeler Dunes

- Geological relationship between mapped units
- Mineralogical analysis of sands
- Numerical age date analyses
- Evaluation of sand sources for Keeler Dunes



(cross bedded sands and flood silt deposits, Dec 2011)

Sample Locations

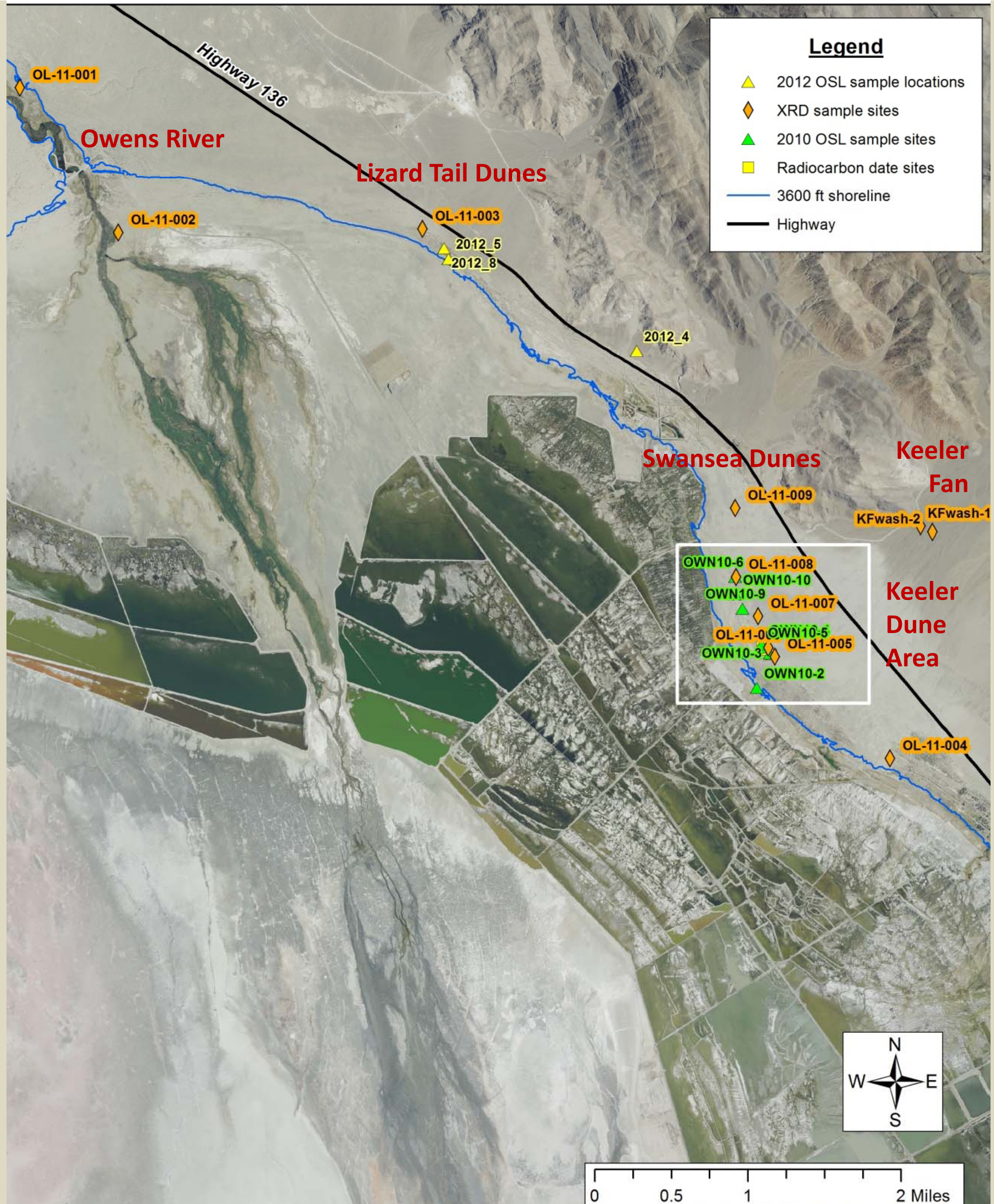
<u>Mineralogical Analyses of Sand</u>

- X-ray Diffraction (XRD) = orange
- Samples collected from:

1. Owens River
2. modern emissive Keeler Dunes
3. Paleo-dunes
4. Swansea and Lizard Tail Dunes
5. Keeler Fan

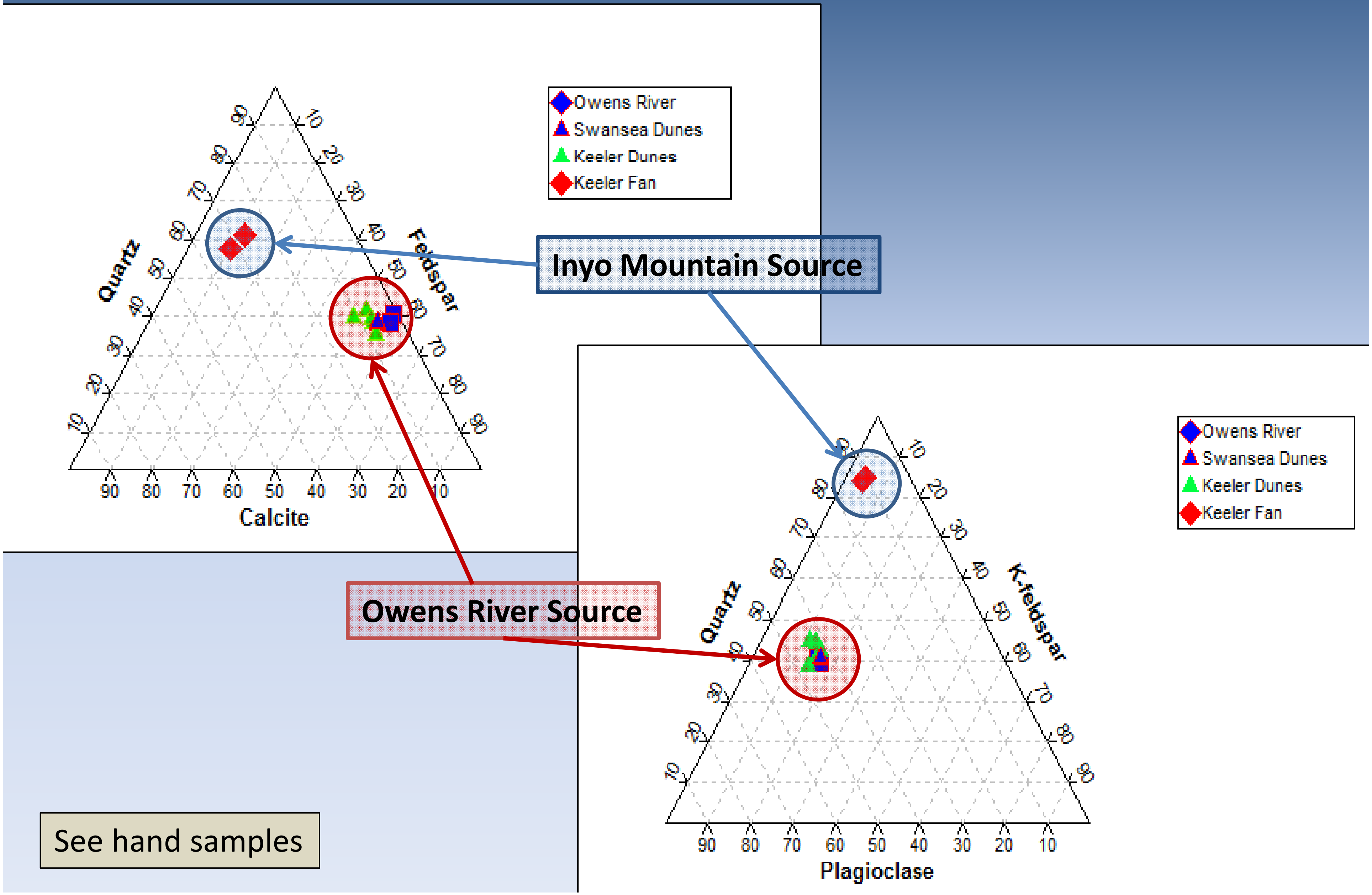
<u>Numerical Age Date Analyses</u>

- Optical Stimulated Luminescence (OSL) = yellow and green
- Radiocarbon



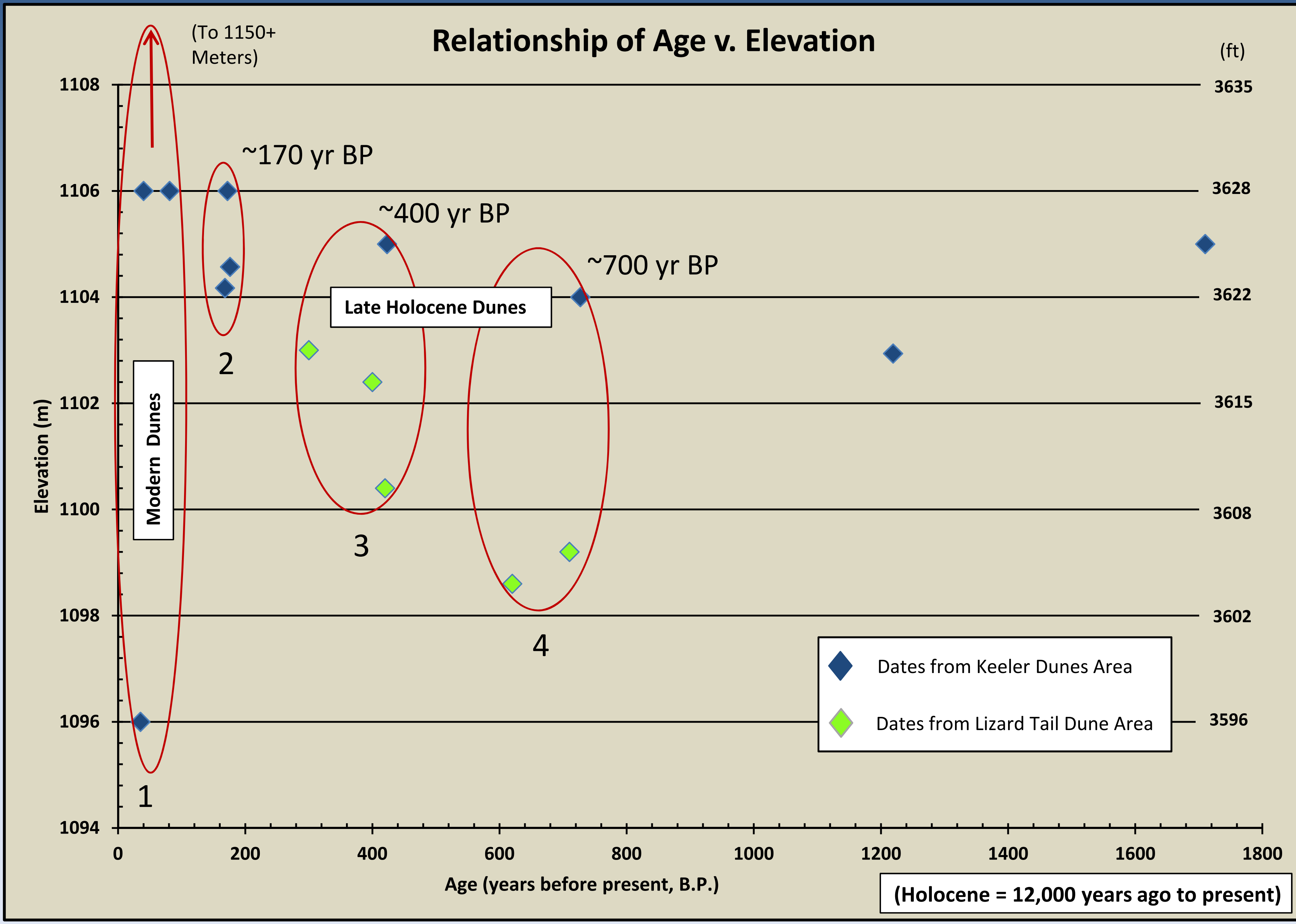
(2009 NAIP Background Image)

Mineralogical Analyses

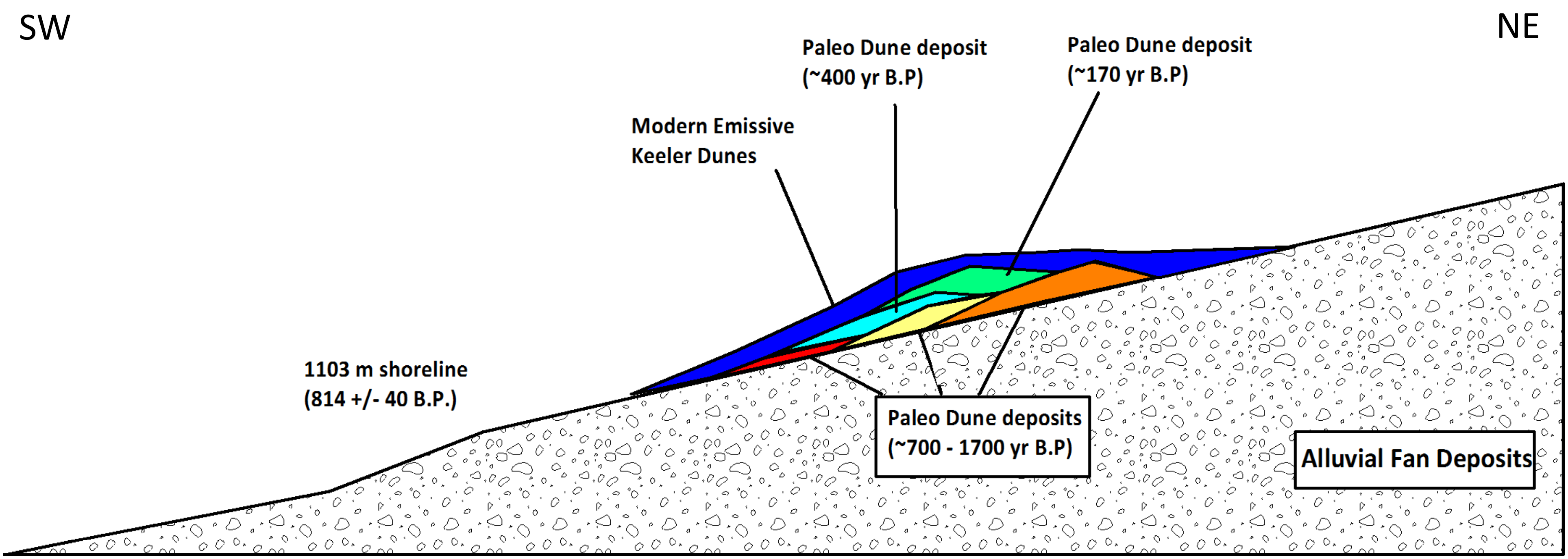


See hand samples

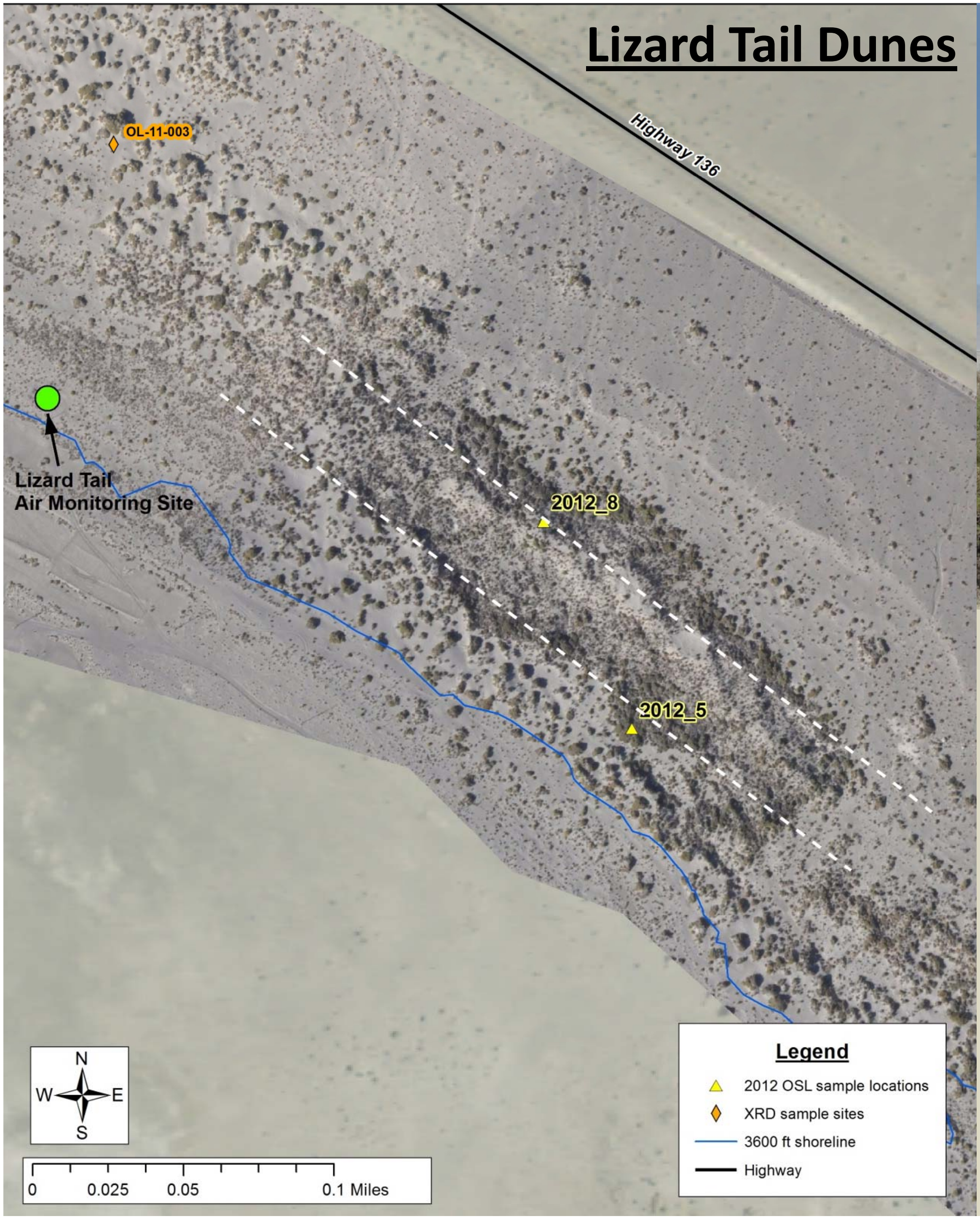
Age Date Data from Keeler and Lizard Tail Areas



Schematic Cross Section Across Keeler Dunes



- Multiple periods of Holocene dune deposition
- Internal stratigraphy of Holocene dunes is complex
- Topographic control of Holocene dunes along 1103 m (~3,618 ft) shoreline
- Modern emissive Keeler Dune bury paleo-dune deposits



(OSL sampling, June 2012)

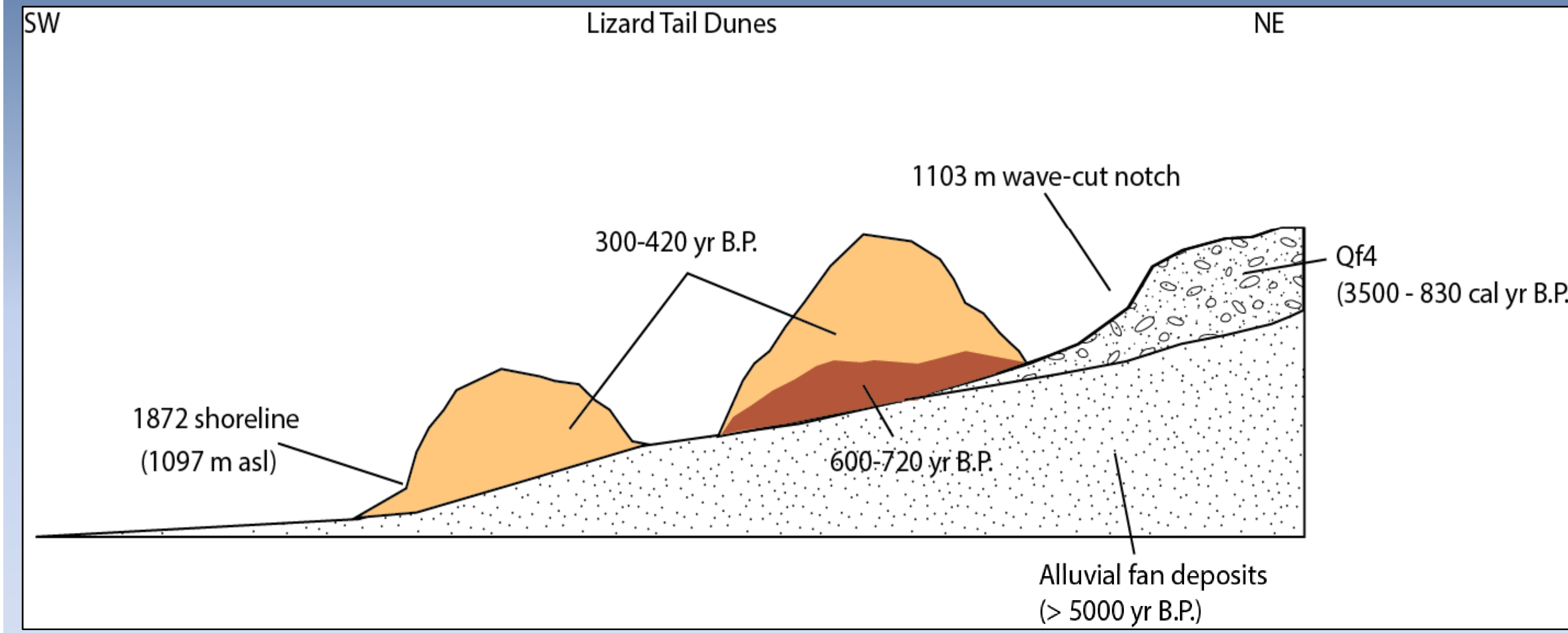
Lizard Tail Dunes

Two dune ridges present

OSL profiles taken in each dune ridge

(High resolution air photo mosaic, 2011)

Generalized Cross Section across Lizard Tail Dunes



- Two periods of Late Holocene dune development
- Formation of dunes below 1103 m (3,618 ft) erosion feature
- Historic shoreline forms erosional notch in Holocene dunes

Summary of Stratigraphic and Chronologic Work

- Geology of the area is complex with multiple periods of Holocene dune development
- Holocene dune formation appears to have topographic control along ~1103 m (3,618 ft) shoreline
- Mineralogical composition of Holocene dunes, modern Keeler Dunes, and Owens River sands are the same
- Emissive Keeler Dunes are a modern feature of the landscape

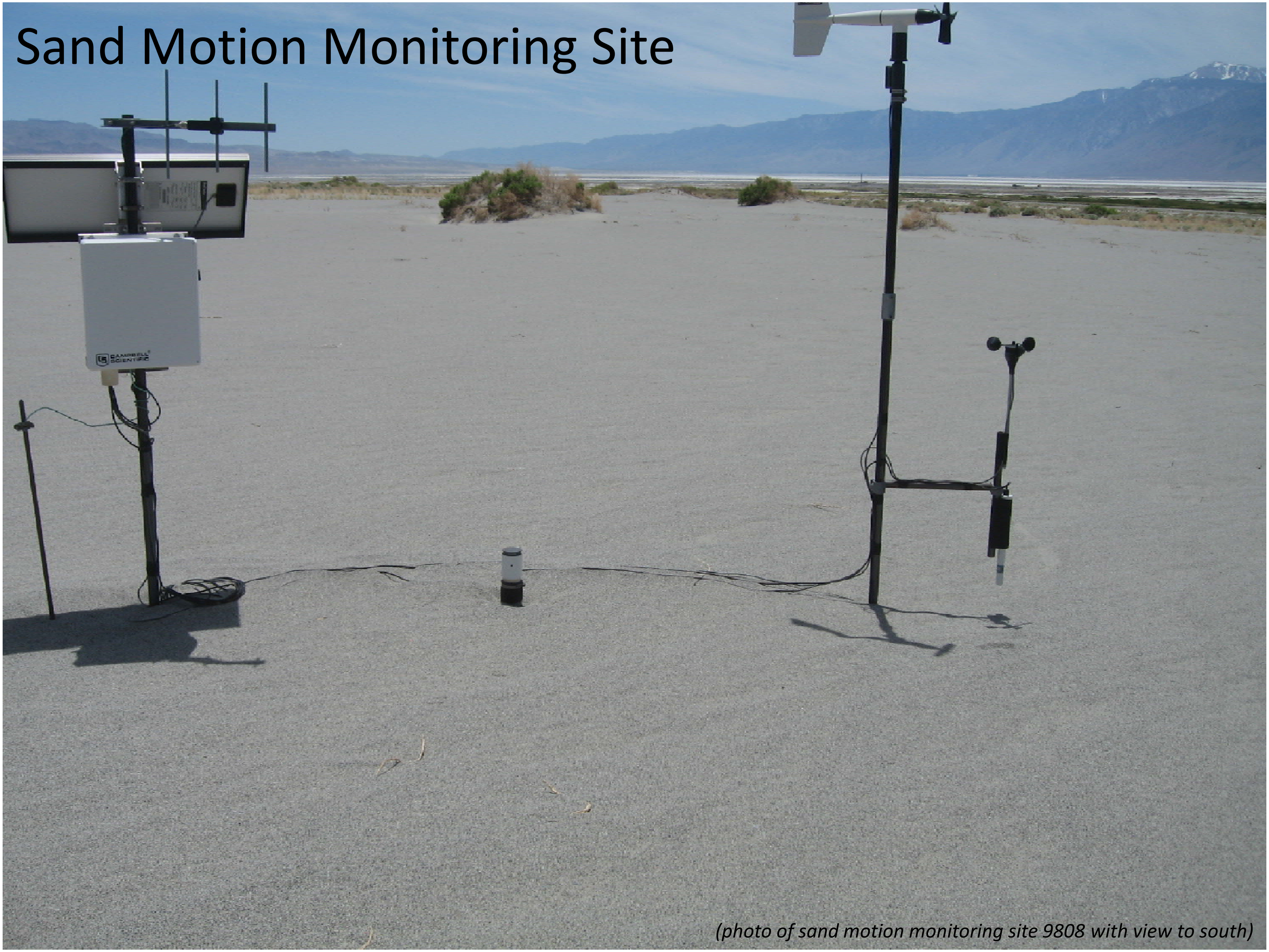
(sand in cracks of flood silt deposit)

6. Sand Transport Analysis

- Analysis of sand flux data from Dust ID program sites to estimate the amount of surface change across area
- Study included two time periods
    1. 2000-2001 (before dust controls)
    2. 2009-2012 (after expansion of KD network)

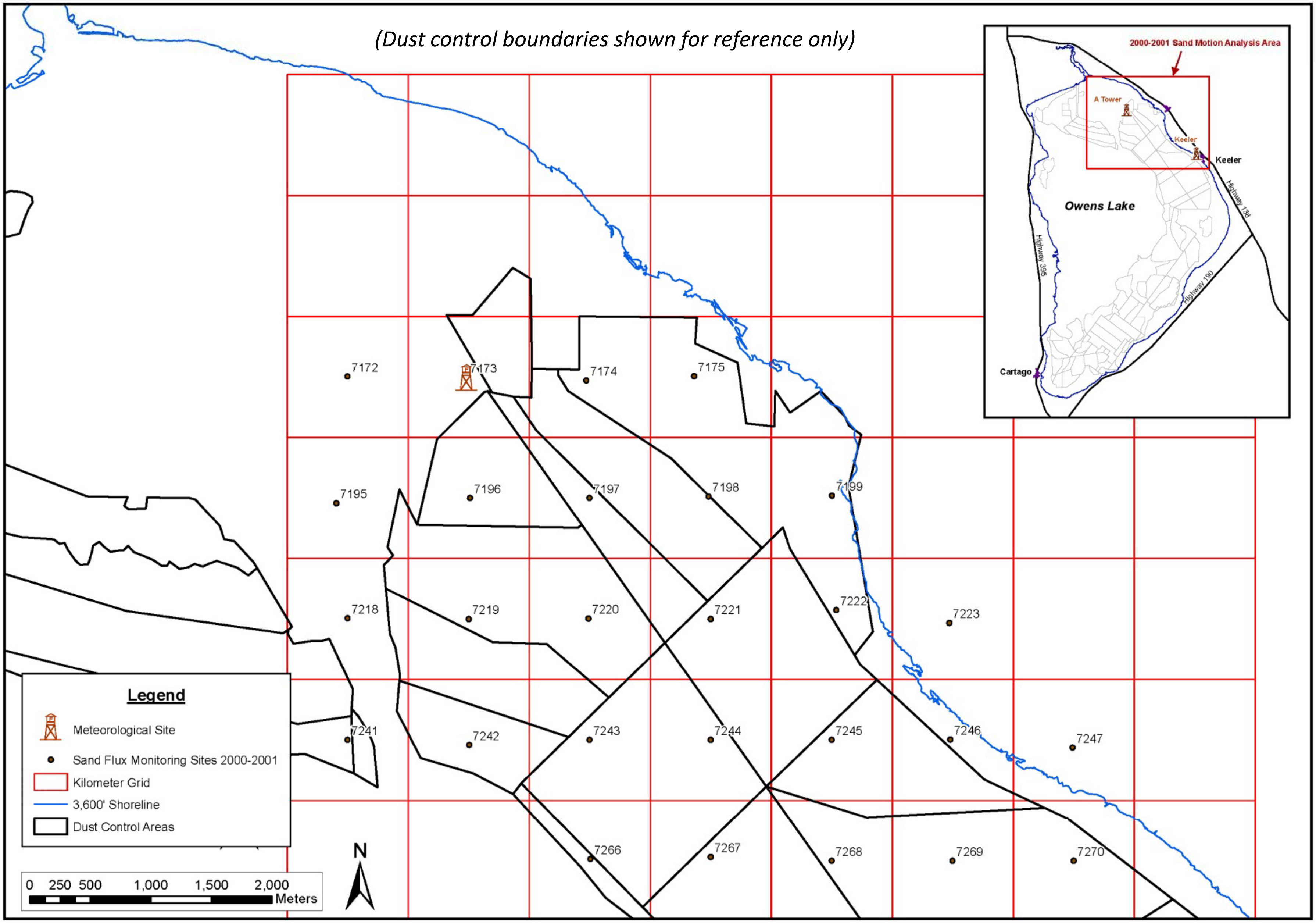
(background image: 2000 orthophoto)

Sand Motion Monitoring Site

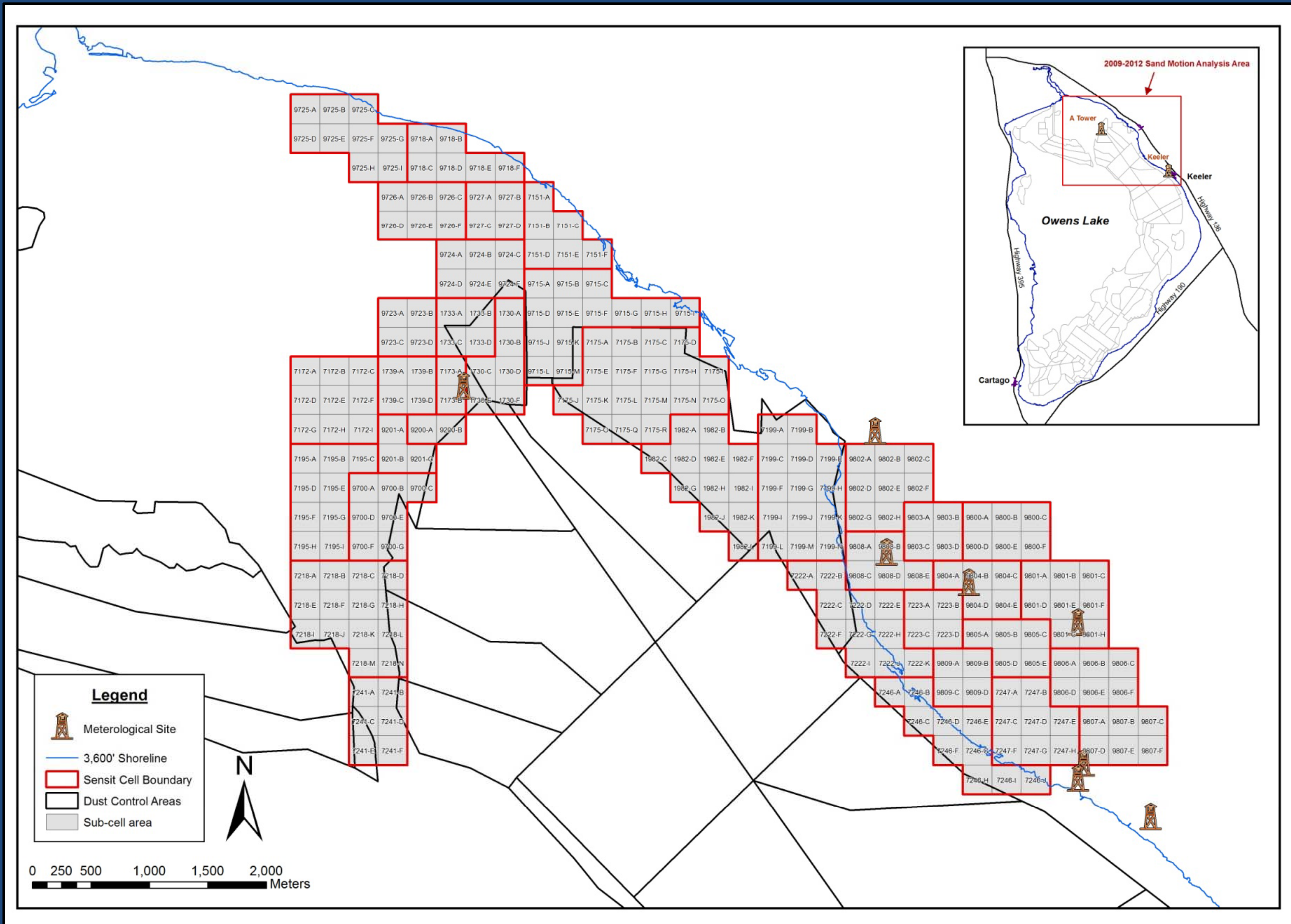


(photo of sand motion monitoring site 9808 with view to south)

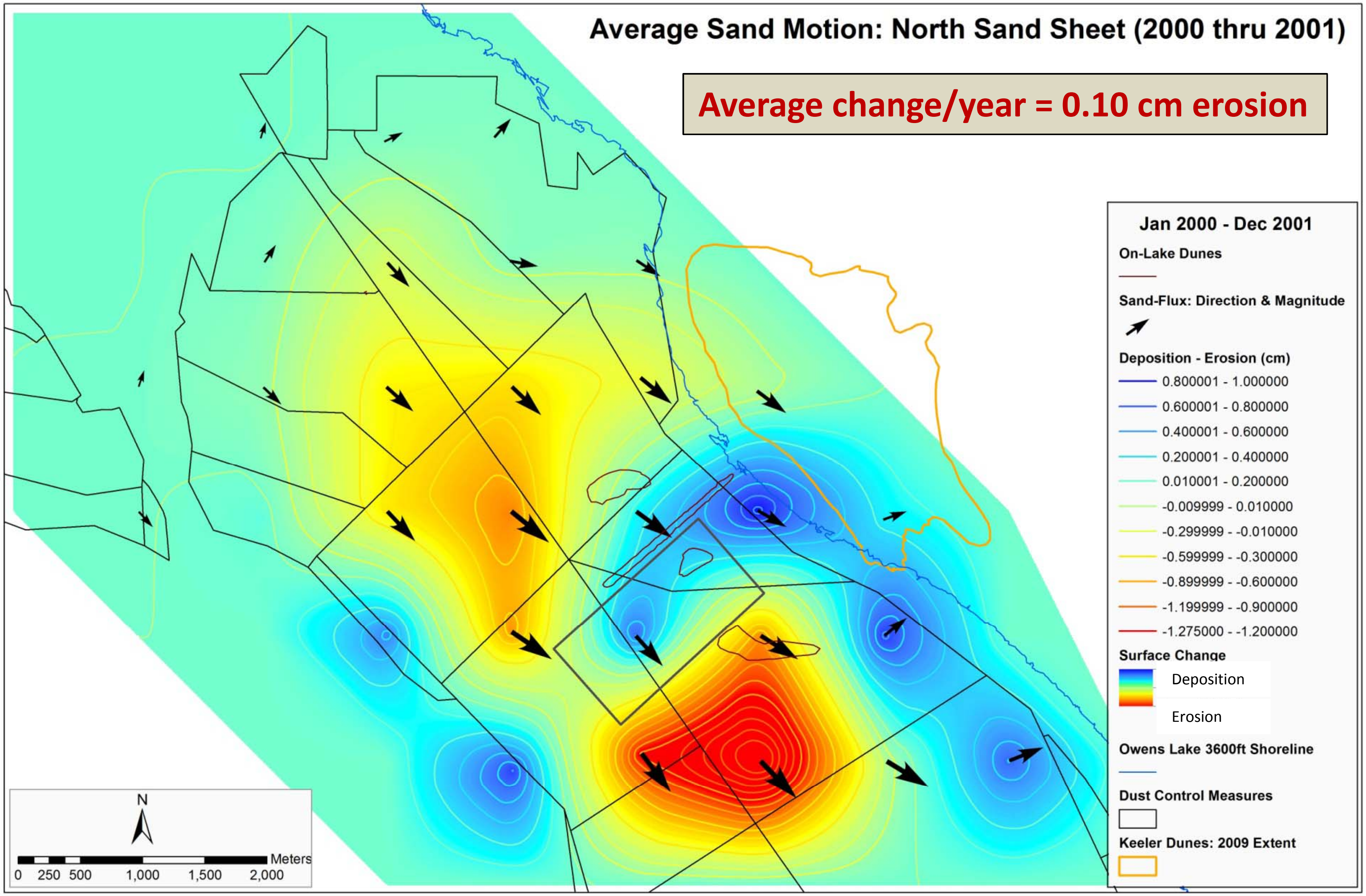
1-Kilometer Grid used in 2000-2001



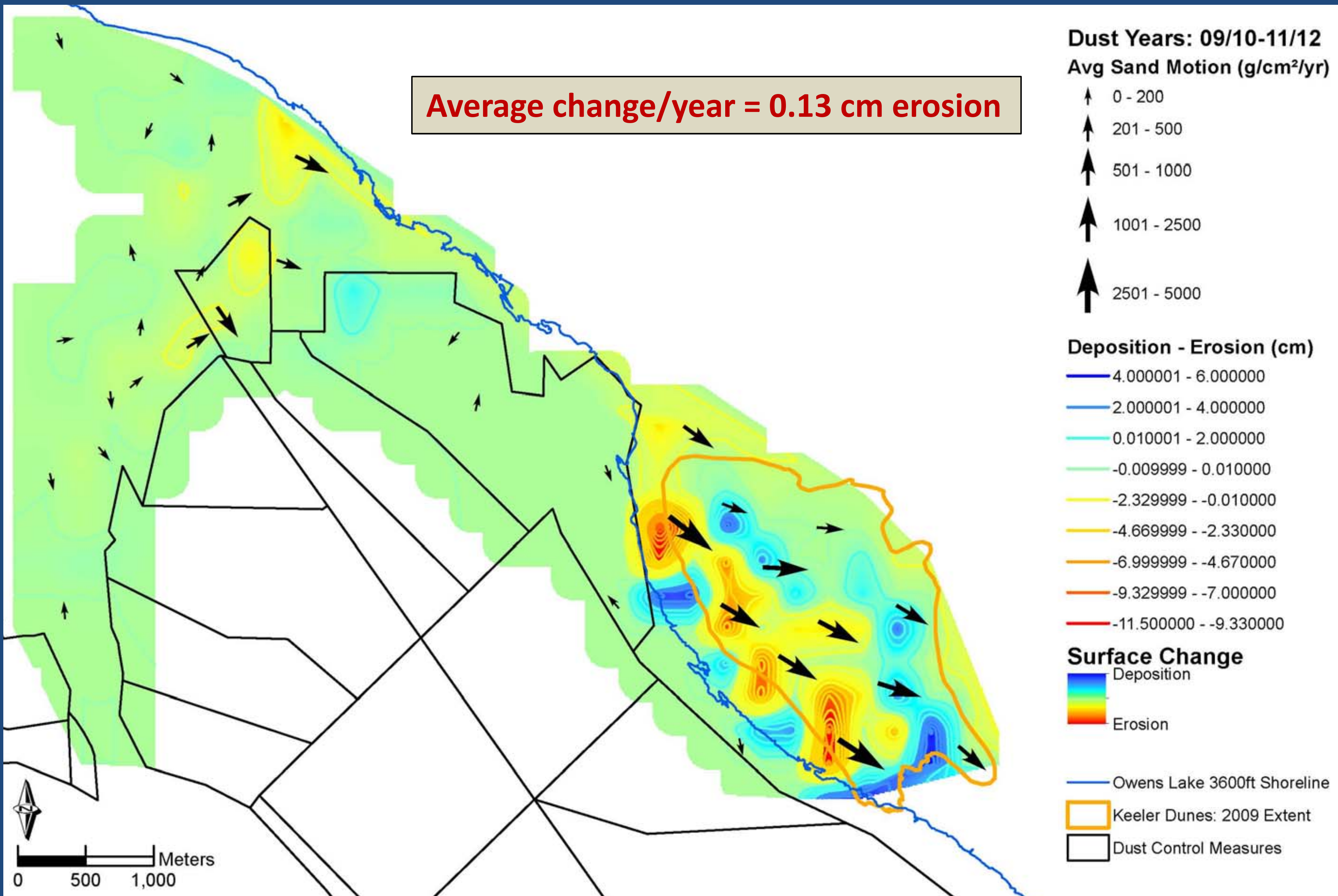
250 meter Irregular Grid used in 2009-2012

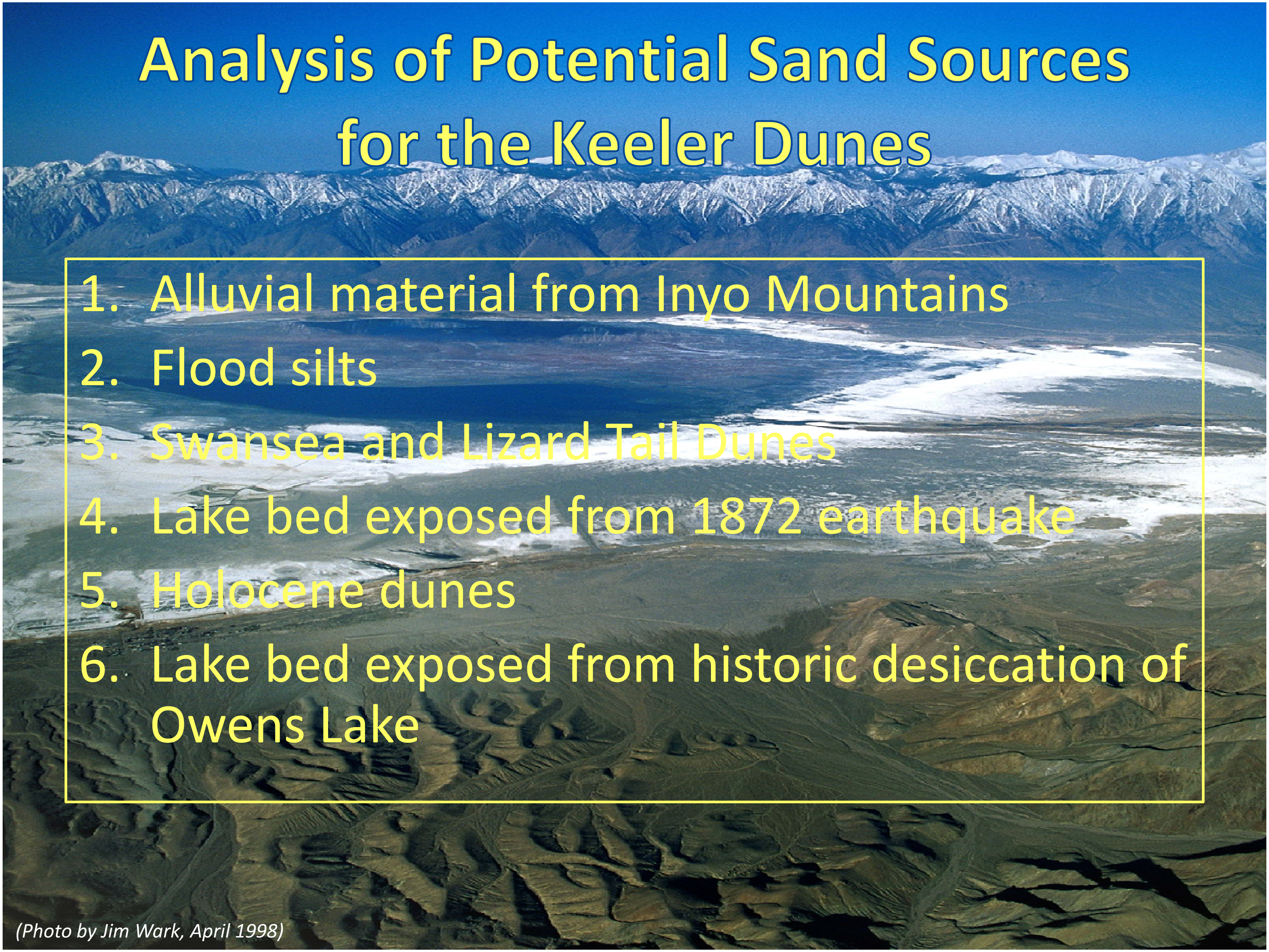


Average Surface Change: 2000-2001
(Pre-Dust Controls)



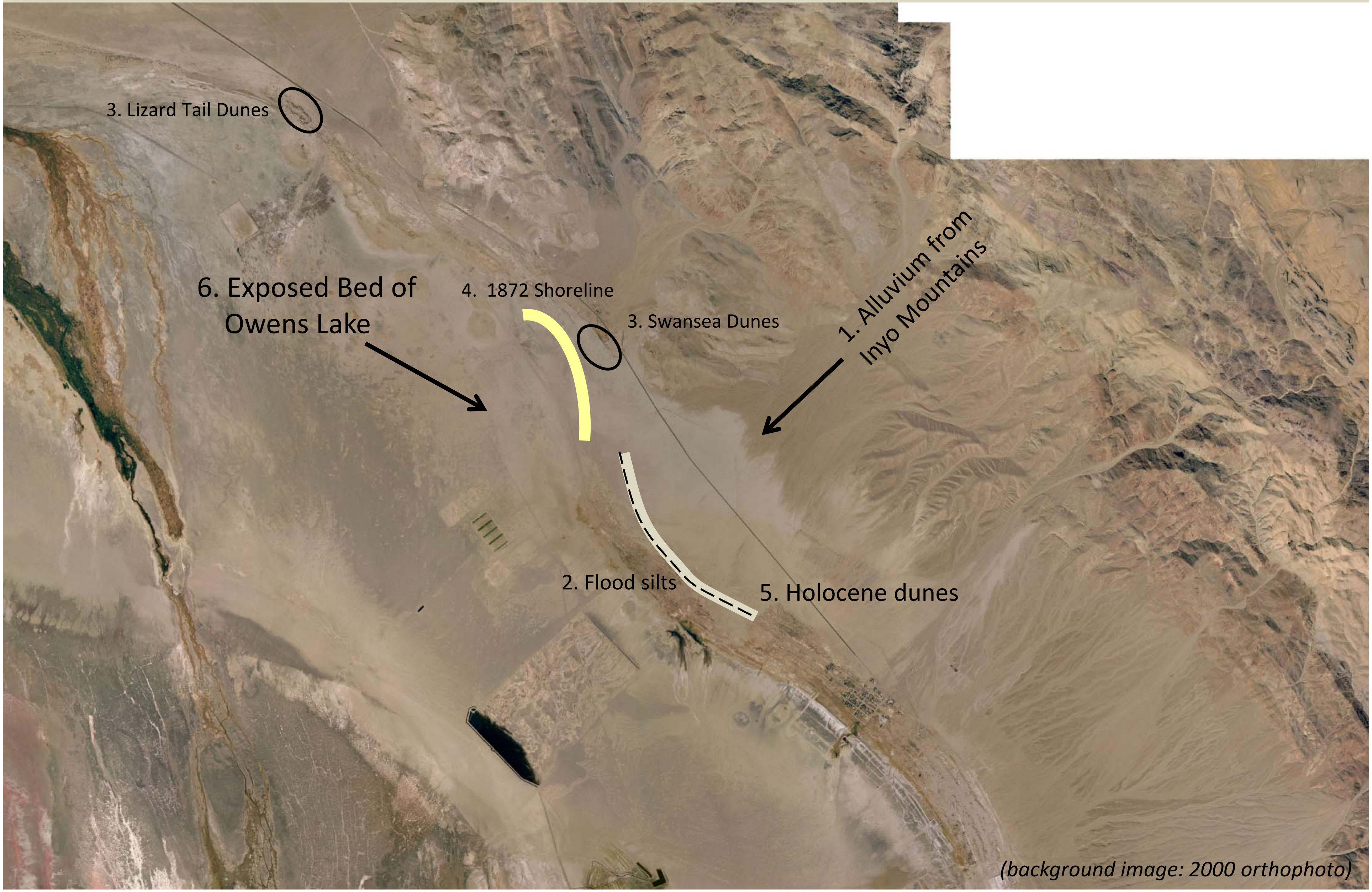
Average Surface Change: 2009-2012
(Post-Dust Controls)



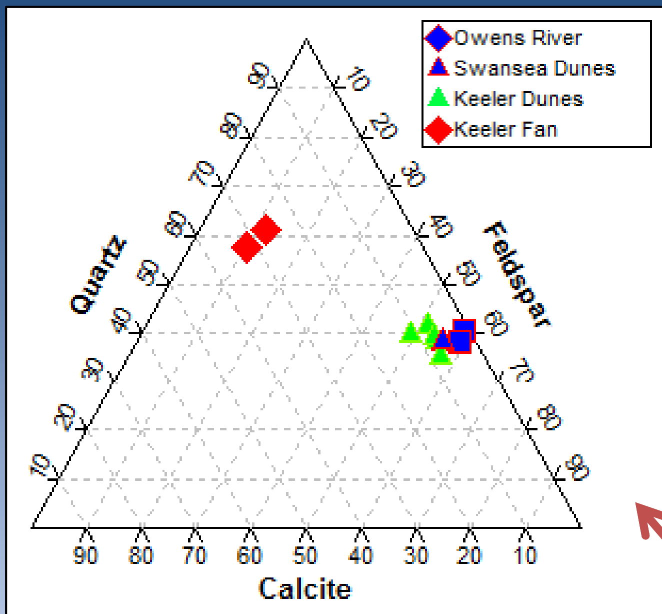


(Photo by Jim Wark, April 1998)

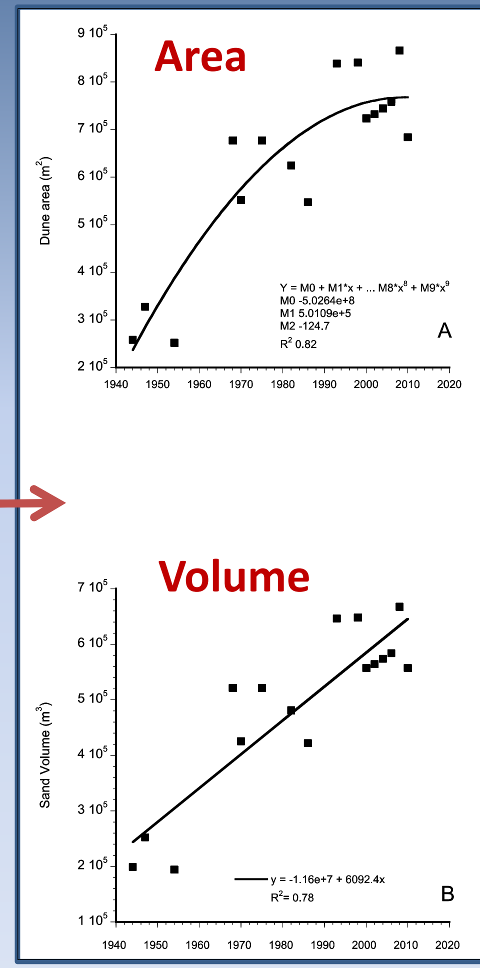
Location of Potential Sand Sources

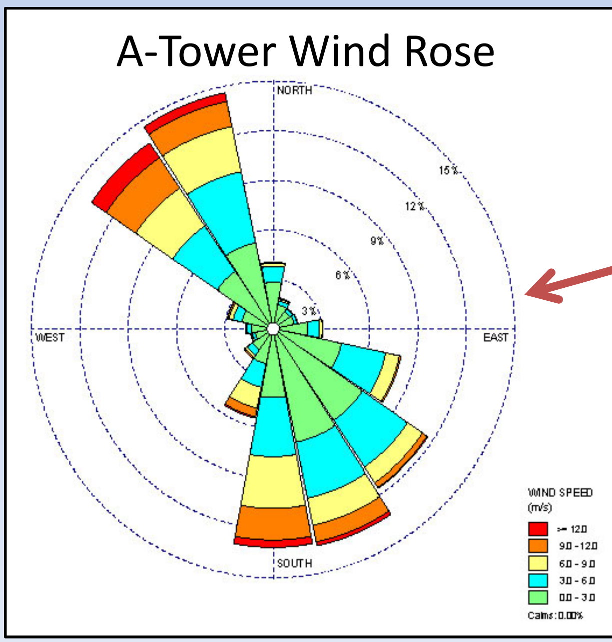


Important Considerations for Sand Source Identification



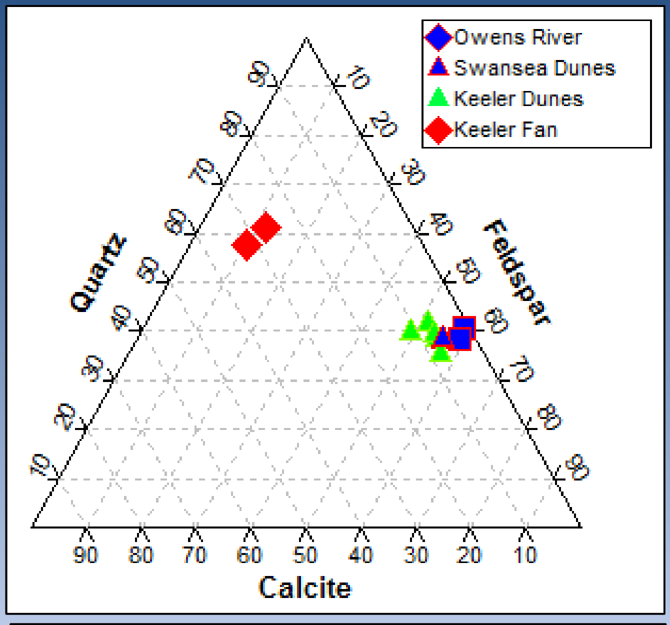
- Mineralogy
- Volume
- Particle size = sand
- Transport direction

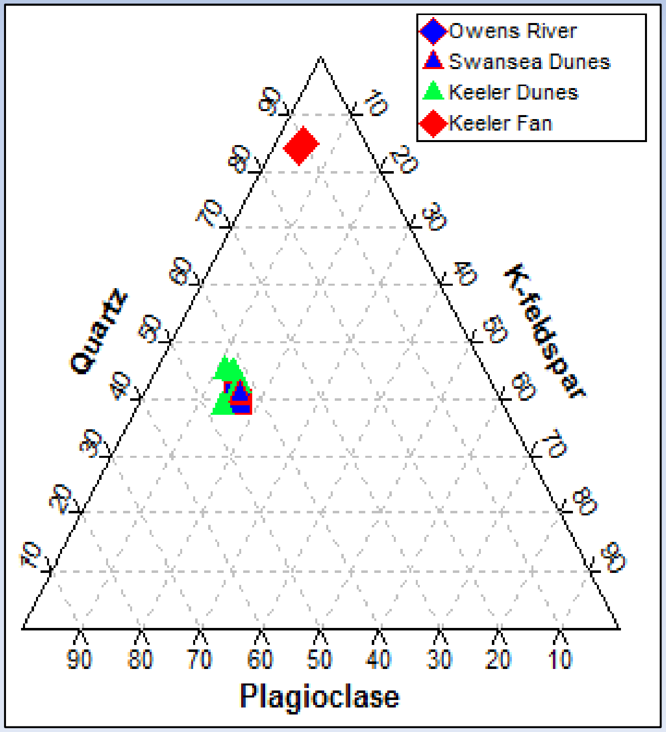




1. Alluvial Material from Inyo Mountains

- Mineral composition of alluvial material is different from Keeler Dunes
- Overall particle size of alluvium is coarse – high proportion of gravel
- Alluvial fan does not show signs of extensive erosion
- Source is located to east of dunes





2. Flood Silts

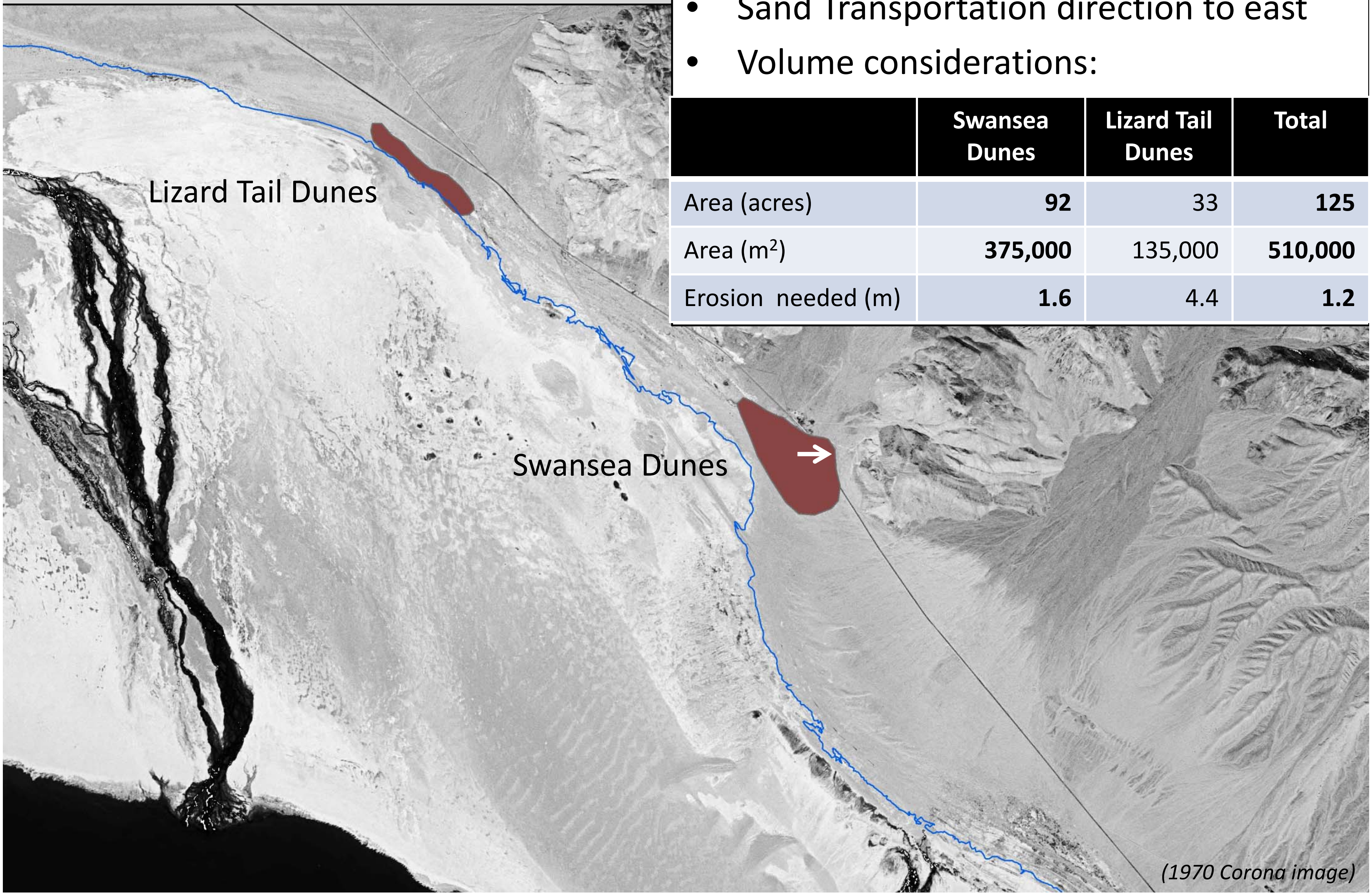
- Particle size – flood silt deposits have low sand content
- Limited aerial extent (7 acres = 30,000 m^2)
- Composition considerations – source is from Inyo Mountains
- Volume of material is insufficient (using a thickness of 10-15 cm yields a volume of ~3,000-4,500 m^3 much less than required 600,000 m^3)

(sand deposits in cracked flood silts)

3. Swansea and Lizard Tail Dunes

- Mineralogy is similar to Keeler Dunes
- Particle size = sand
- Sand Transportation direction to east
- Volume considerations:

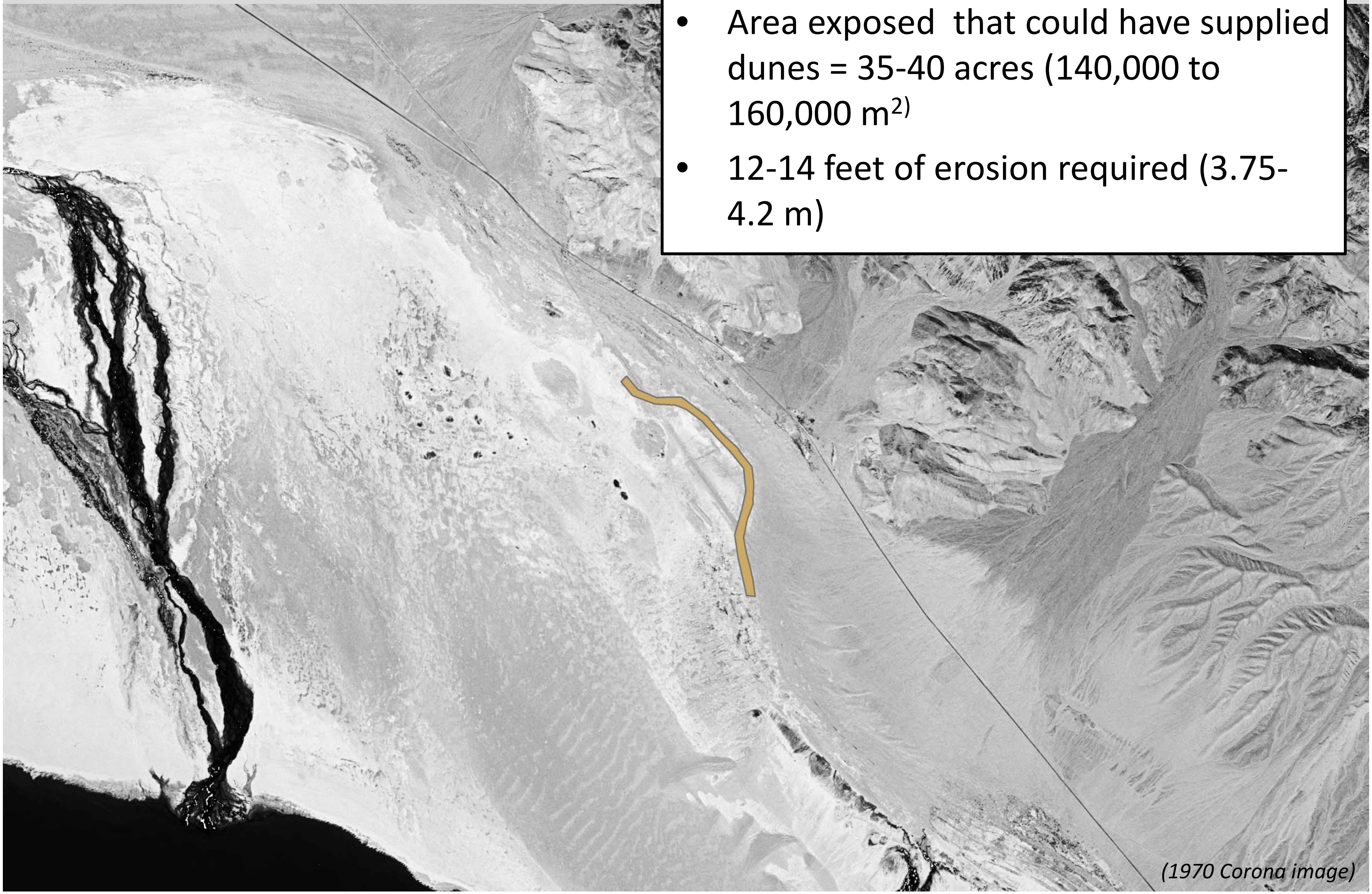
	Swansea Dunes	Lizard Tail Dunes	Total
Area (acres)	**92**	33	**125**
Area (m^2)	**375,000**	135,000	**510,000**
Erosion needed (m)	**1.6**	4.4	**1.2**



(1970 Corona image)

4. Lake bed exposed during 1872 Earthquake

- Estimate exposed lake bed = ~200 ft wide
- Area exposed that could have supplied dunes = 35-40 acres (140,000 to 160,000 m^{2})
- 12-14 feet of erosion required (3.75-4.2 m)



(1970 Corona image)

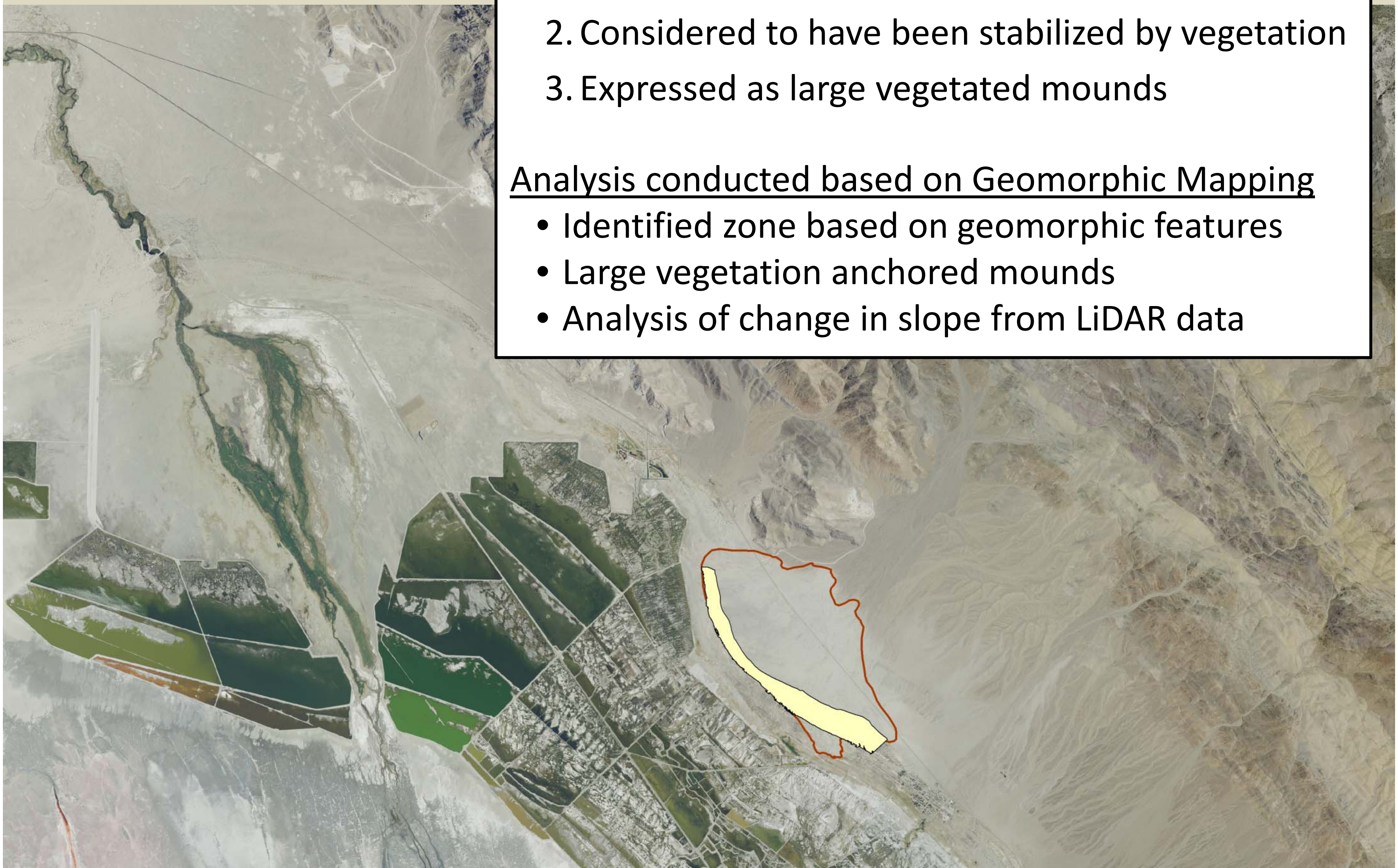
5. Holocene Dunes

<u>General Character of Known Holocene Dune Deposits</u>

1. Occur along topographically controlled elevations
2. Considered to have been stabilized by vegetation
3. Expressed as large vegetated mounds

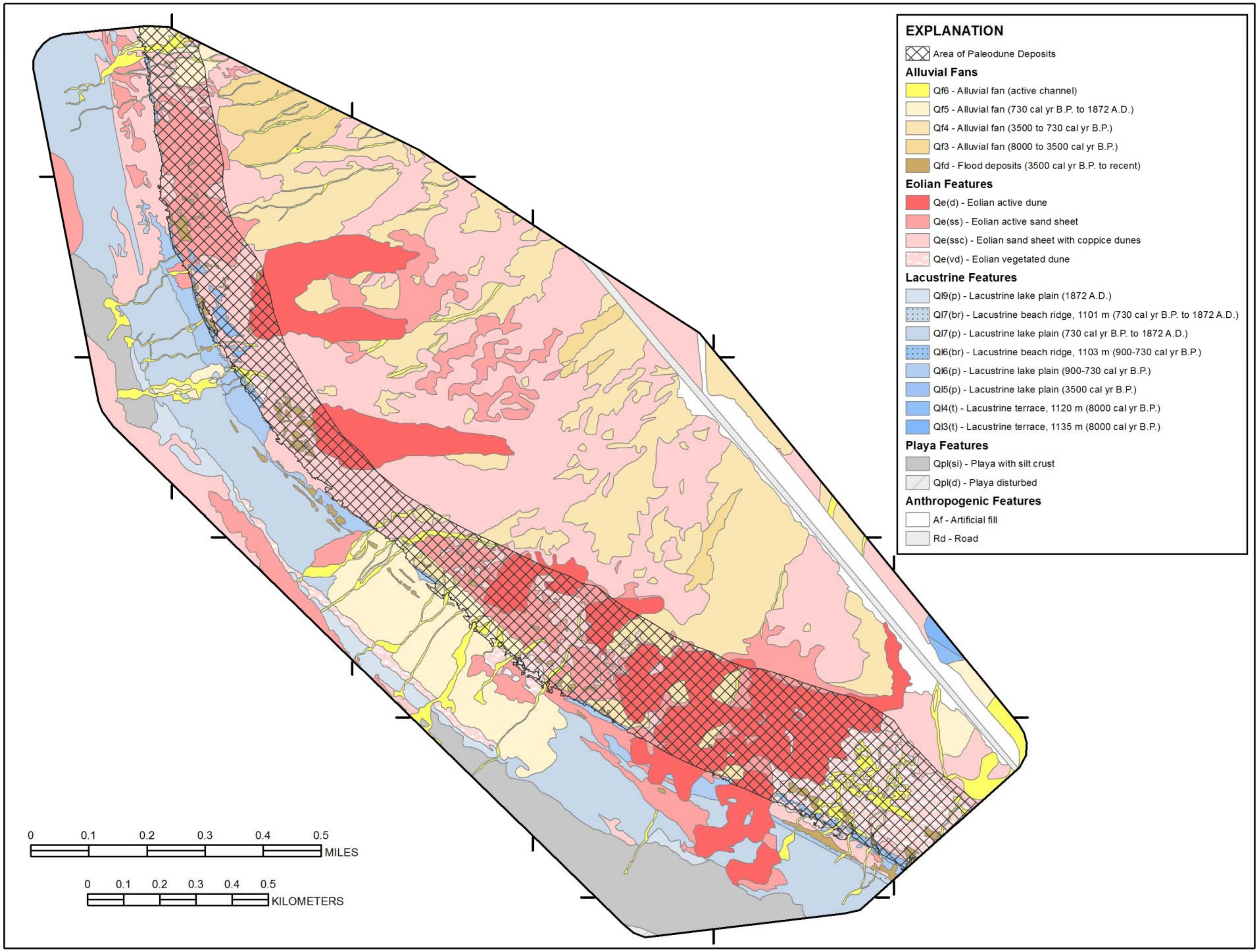
<u>Analysis conducted based on Geomorphic Mapping</u>

- Identified zone based on geomorphic features
- Large vegetation anchored mounds
- Analysis of change in slope from LiDAR data



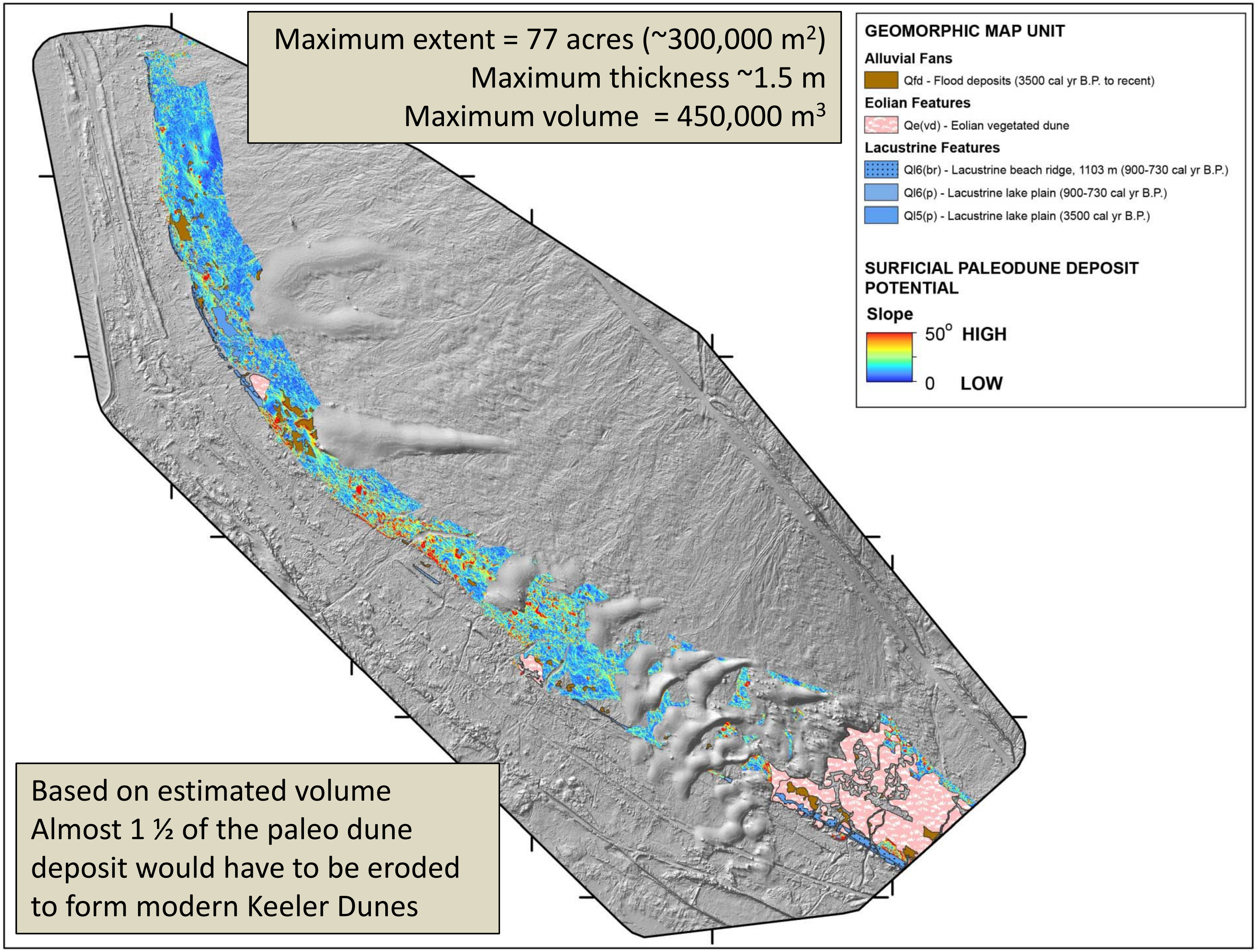
(2009 NAIP background)

Area with Potential Holocene Dunes on Geomorphic Map



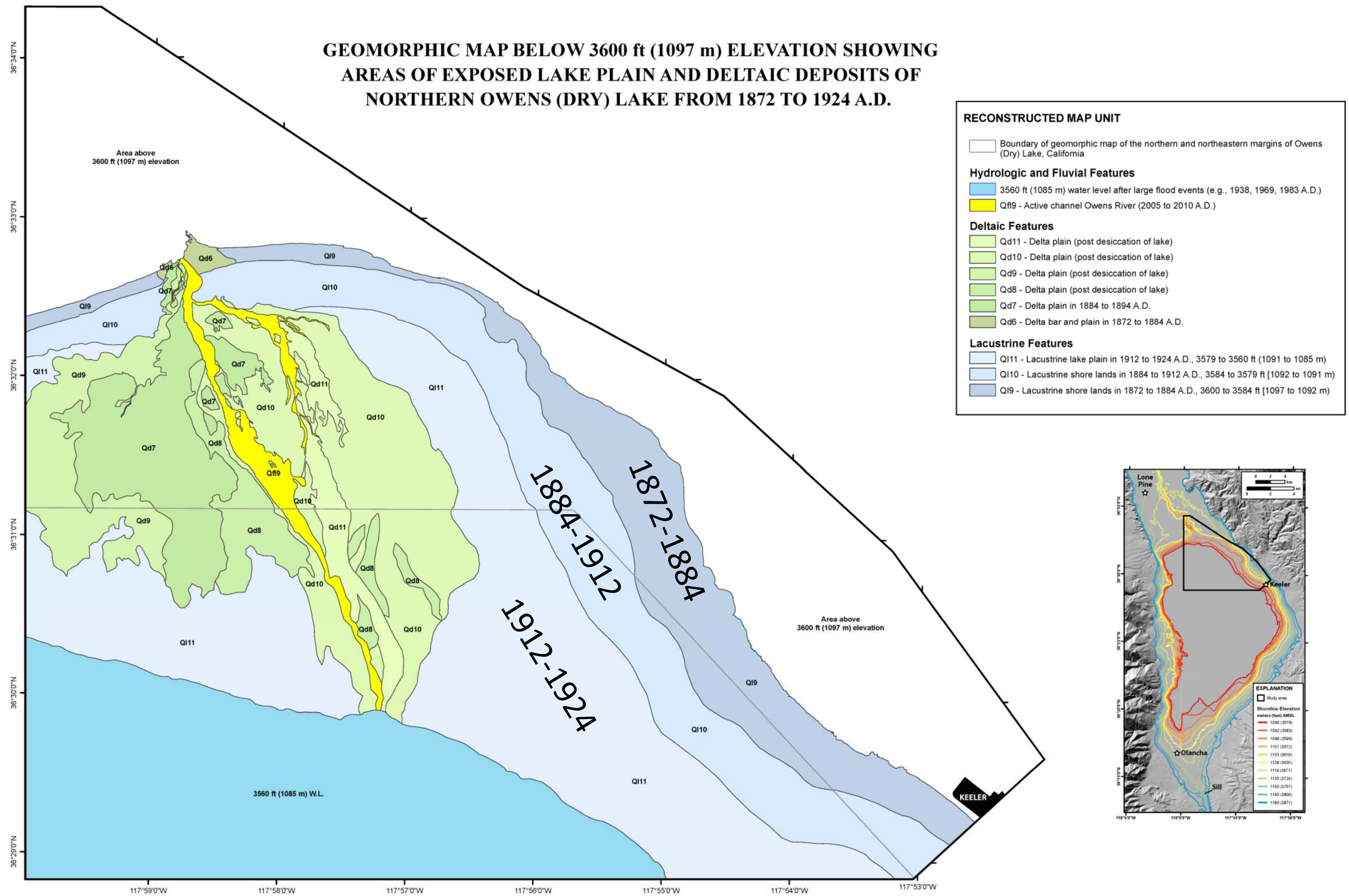
Area with Potential Holocene Dunes with Bare Earth DEM

Maximum extent = 77 acres (~300,000 m^2)
Maximum thickness ~1.5 m
Maximum volume = 450,000 m^3

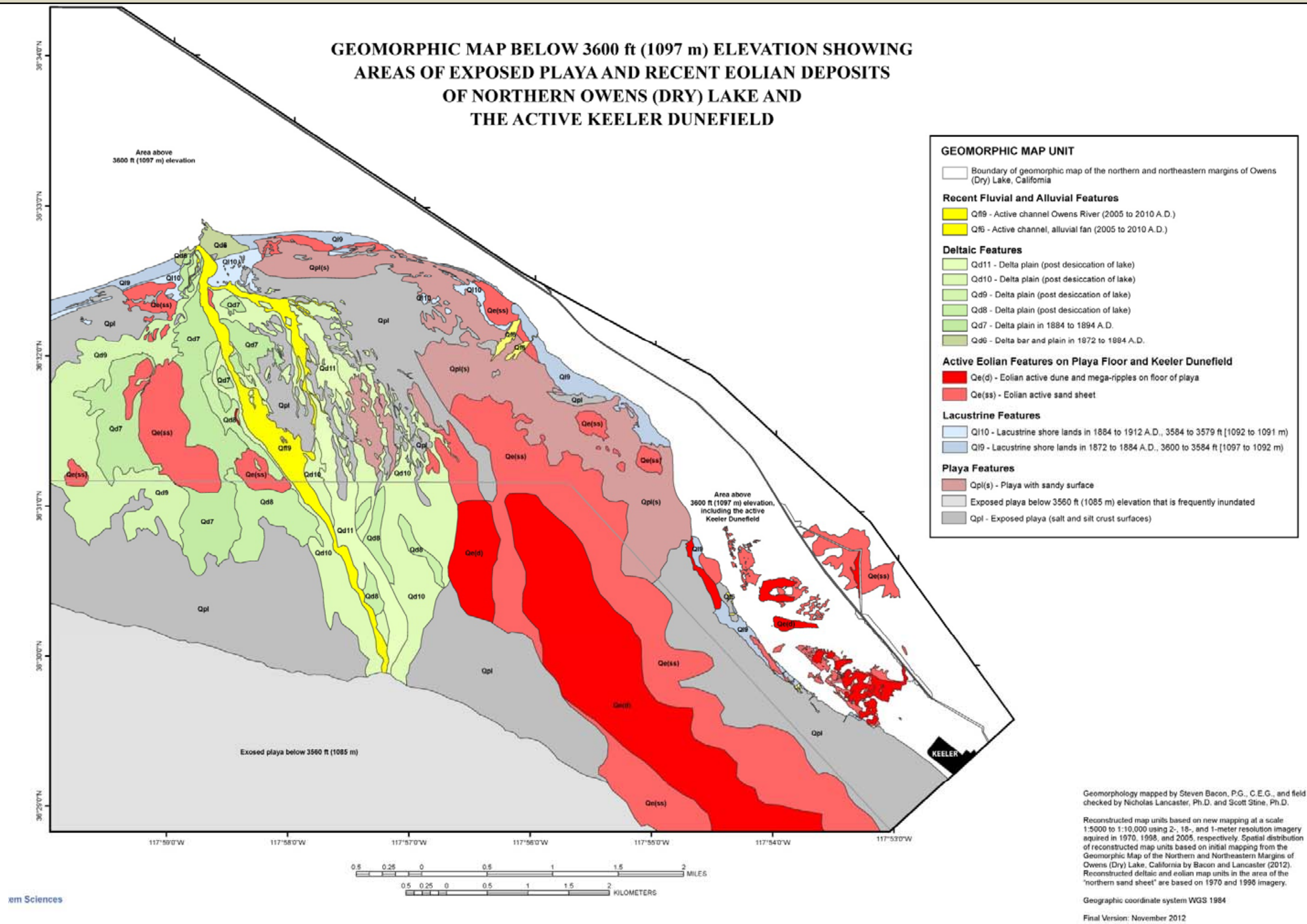


Based on estimated volume Almost 1 ½ of the paleo dune deposit would have to be eroded to form modern Keeler Dunes

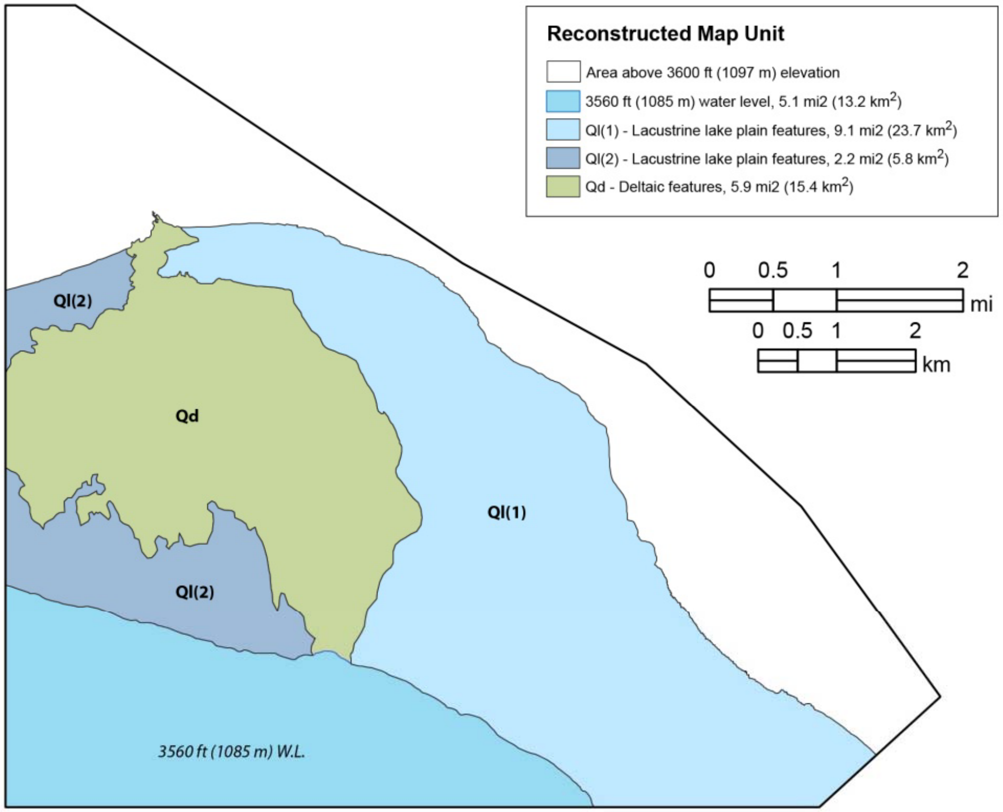
6. Exposed Lake Bed from Historic Desiccation



6. Exposed Lake Bed from Historic Desiccation



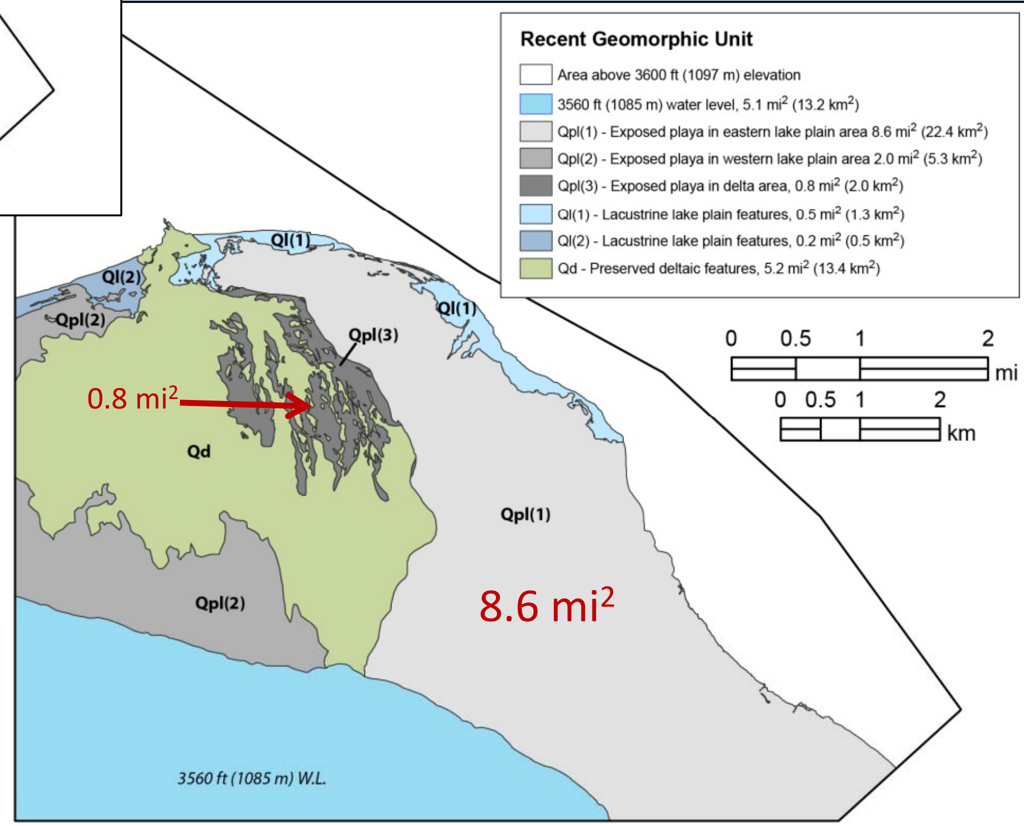
Eroded Lake Bed Area



Eroded Lake Bed (Total = 9.4 mi²)

8.6 mi² (in eastern lake plain)

0.8 mi² (in eastern delta)



6. Exposed Lake Bed from Historic Desiccation

- Mineral composition is correct
- Transport direction is correct (geometry)
- Evidence of erosion on over 6,016 acres (= 9.4 mi^2 or 24.4 km^2)
- Average erosion of 2.5 cm erosion needed to get 600,000 m^3 volume required

- Average erosion rate ~0.10 -0.13 cm calculated from sand flux data
- 77 year erosion period (1924-2001) x erosion rate = 7.7 to 10.0 cm erosion on lake bed.
- Only 1/3 to 1/4 of this is needed to be transported into dunes

(1998 Space Shuttle image)

Summary of Main Results

1. Historic documents do not identify current Keeler Dunes until 1987
2. Analysis of public lands survey data suggests that modern and emissive Keeler Dunes were not present in 1850's
3. Historic photo/rephoto analysis indicates that modern emissive Keeler Dunes are a recent feature of the landscape
4. Air photo and satellite image analysis shows that modern Keeler Dunes are a young immature dune field that grew by a factor of three from 1944 to 2000
5. Geomorphic mapping shows that Keeler Dunes are one of the youngest features in the area and that they bury older dune deposits
6. Age dating indicates that were multiple dune building episodes in the Late Holocene and that paleo-dunes are located along former shoreline features
7. Sand transport analysis indicated that there is a net movement of sand off of the exposed lake bed and that the lake bed has eroded about 0.10 to 0.13 cm/yr.
8. Sand source study indicates that main source of sand for modern Keeler Dunes came from dried bed of Owens Lake

(photo rippled dune surface)

Staff Summary and Conclusions

District conducted 7 separate research investigations.

The landscape within the Keeler Dunes has changed dramatically over the last century.

Current Keeler Dunes are a modern feature of the landscape and formed after the historic desiccation of Owens Lake.

Geomorphic mapping and geological analysis show that there were older stable vegetated dunes associated with Late Holocene stands of ancient Owens Lake.

The Late Holocene dune deposits are different in character and extent than current active and emissive modern Keeler Dunes.

Modern active and emissive Keeler Dunes formed from sands moving off of the historically exposed bed of Owens Lake that was dried as a result of water diversions of inflowing waters.

Material from the eroded lake bed moved onto the existing vegetated Keeler Fan changing the landscape and creating a mobile and emissive sand deposit that is a public health and safety threat.

Modern active and emissive Keeler Dunes are anthropogenic.

(skeleton of greasewood in Southern Dune complex)

(photo of abandoned power line running under one of the Keeler Dunes, Feb 23. 2012)