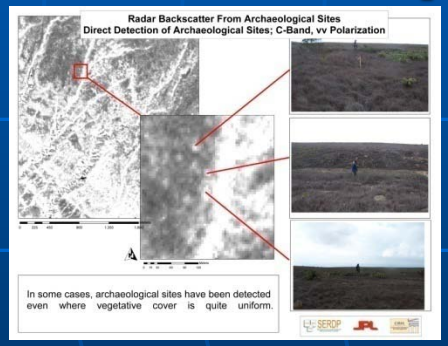
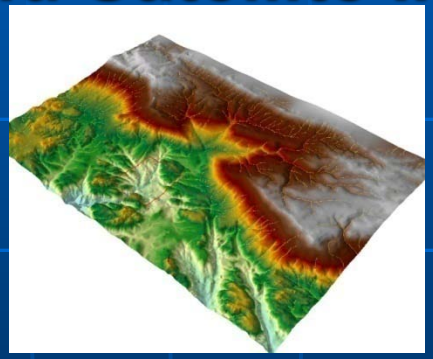
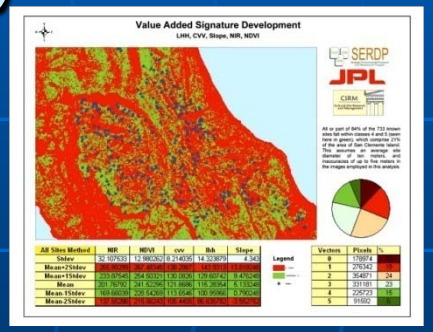
DOD Legacy Grant Overview

Institutionalizing Protocols for Wide-Area Inventory of Archaeological Sites by the Analysis of Aerial and Satellite Imagery







Cultural Site Research and Management

Douglas C. Comer, (USA)

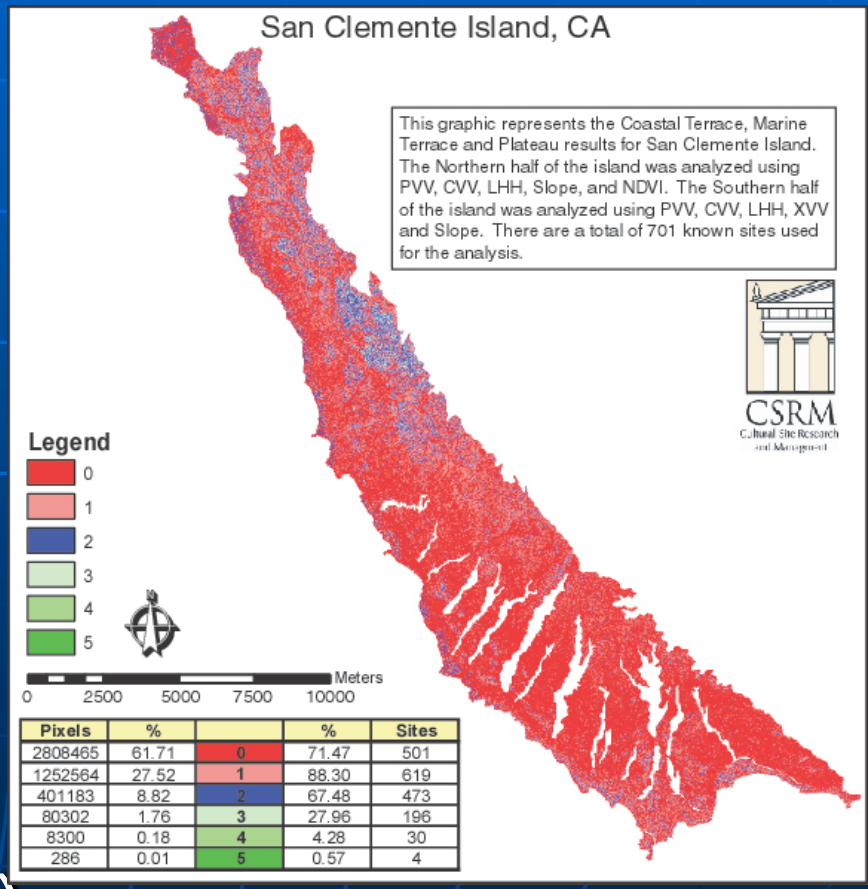
20 October 2011
Desert Managers Group Meeting
Twentynine Palms, CA

National Historic Preservation Act, Section 110

- Requires federal agencies to locate, inventory and nominate properties (including archaeological) to the National Register
  - Great amounts of money spent each year
  - Great numbers of artifacts now require storage forever
- Aerial and Satellite remote sensing can be used to determine where sites ARE NOT

Project Goals and Objectives

- Use remote sensing to inventory archaeological sites
- Identify areas where sites are not likely to be located
  - Inventory quickly and inexpensively
  - Free from restrictions
  - Negotiate sampling elsewhere (list of steps)



Pixels	%		%	Sites
2808465	61.71	0	71.47	501
1252564	27.52	1	88.30	619
401183	8.82	2	67.48	473
80302	1.76	3	27.96	196
8300	0.18	4	4.28	30
286	0.01	5	0.57	4

Approach

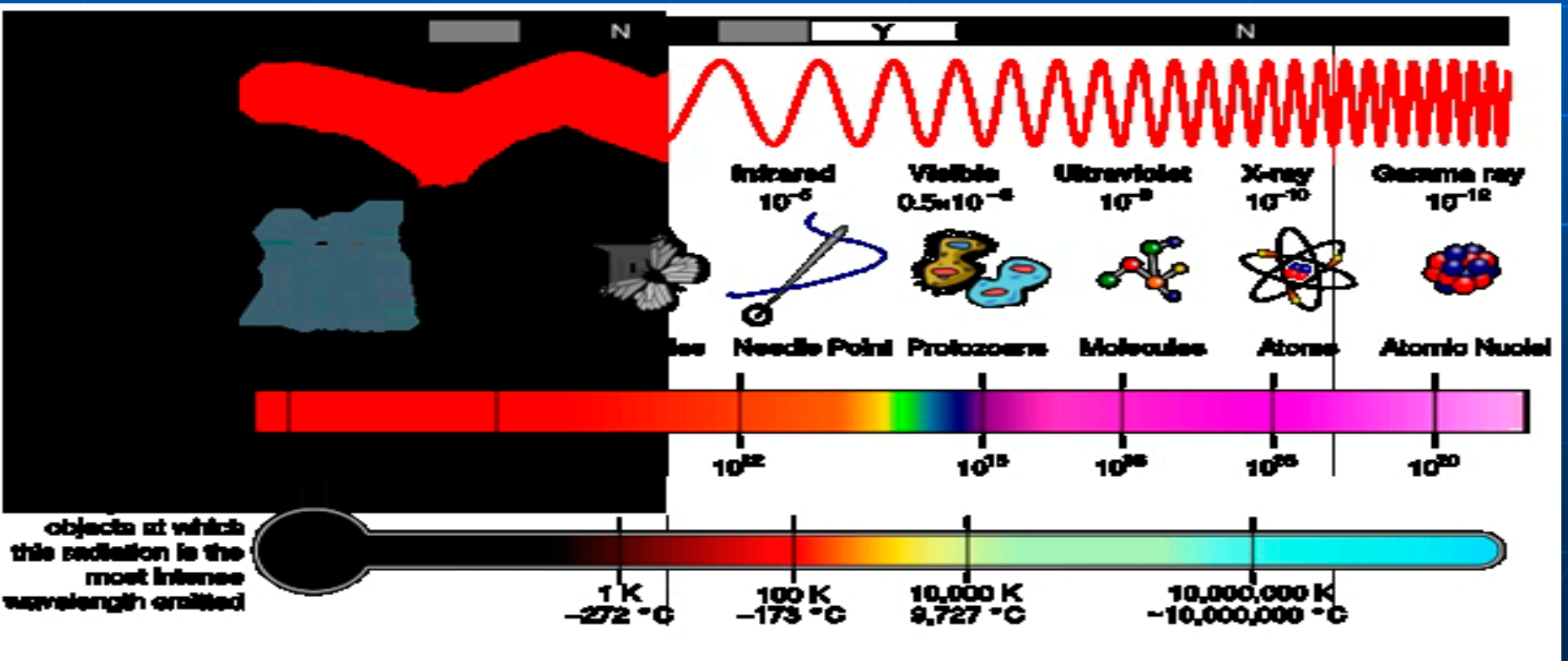
- Utilize protocols and software developed by CSRM for the detection of archaeological sites through the analysis of aerial and satellite imagery
  - multispectral
  - hyperspectral
  - synthetic aperture radar (SAR), and
  - Lidar

$$\mu_1 - \mu_2 < \mathrm{T}_{95}\sqrt{\sigma_1^2/n + \sigma_2^2/n}$$

$$dof = \frac{\left(\frac{\sigma_1^2}{n} + \frac{\sigma_2^2}{n}\right)^2}{\frac{\left(\frac{\sigma_1^2}{n}\right)^2}{(n-1)} + \frac{\left(\frac{\sigma_2^2}{n}\right)^2}{(n-1)}} = (n-1)\frac{\left(\sigma_1^2 + \sigma_2^2\right)^2}{\left(\sigma_1^2\right)^2 + \left(\sigma_2^2\right)^2}$$

All Technologies Use Portions of threElectromagnetic Spectrum

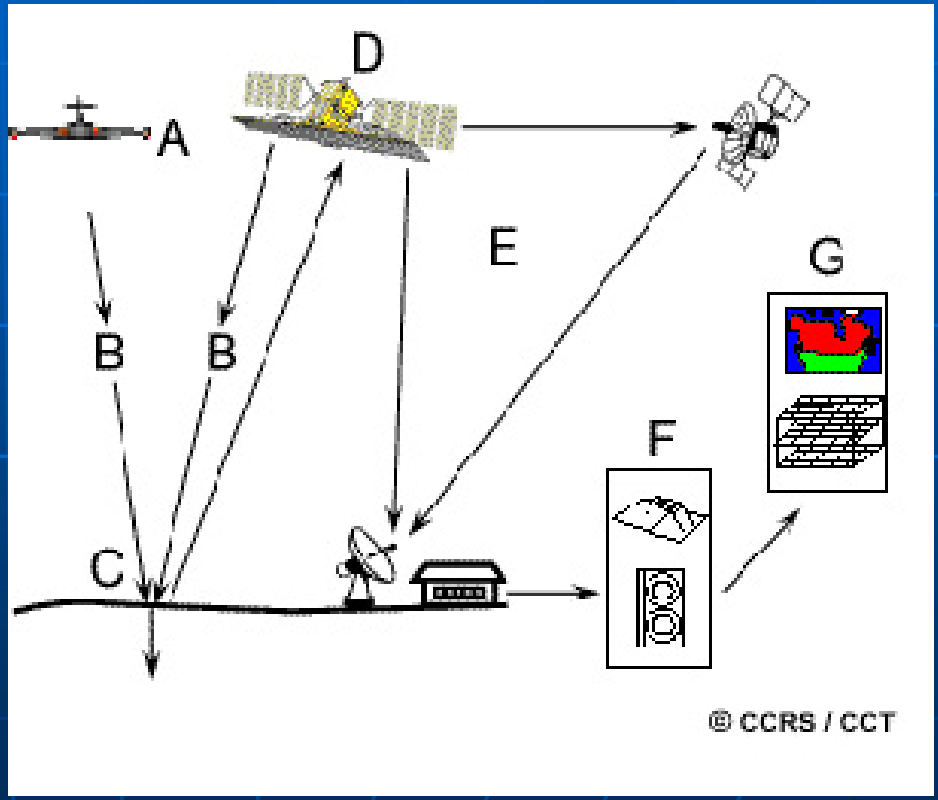
- “Blue” is 400 to 500 nanometers
- L-Band radar 15 to 30cm centimeters



Sensing Devices Work in Similar Ways

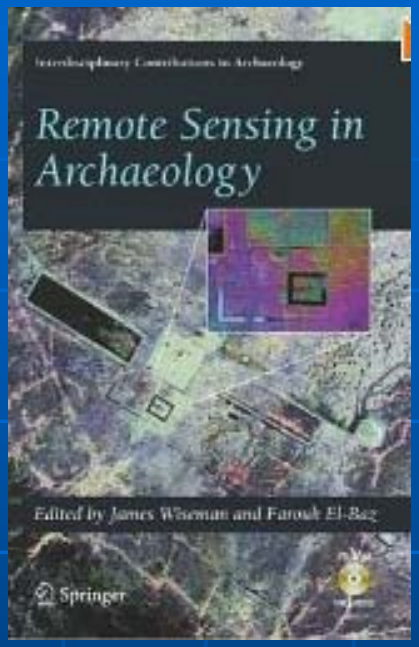
- **(A)** - the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.

- For passive systems, the sun
- For active systems like synthetic aperture radar (SAR) and LIDAR, platforms, which might be aircraft or satellites
- Angle affects image geometry

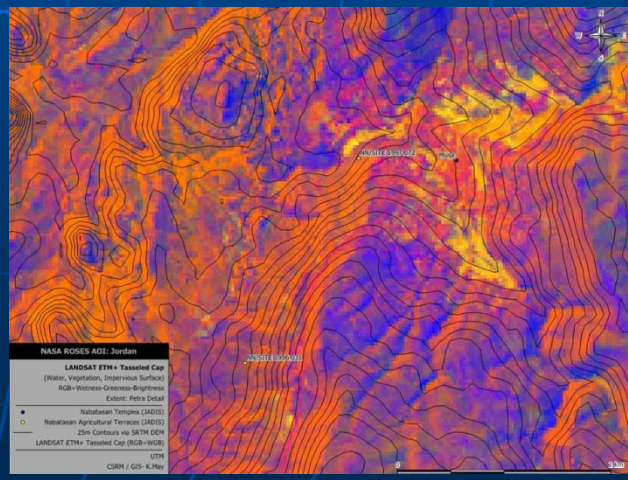


Developed by Previous Research

- Sponsored by SERDP, NASA, NSF, NCPTT, Kaplan Fund



San Clemente Island, Santa Catalina Island, Petra and other places in Jordan, Ireland, Guatemala, Costa Rica, Hawaii

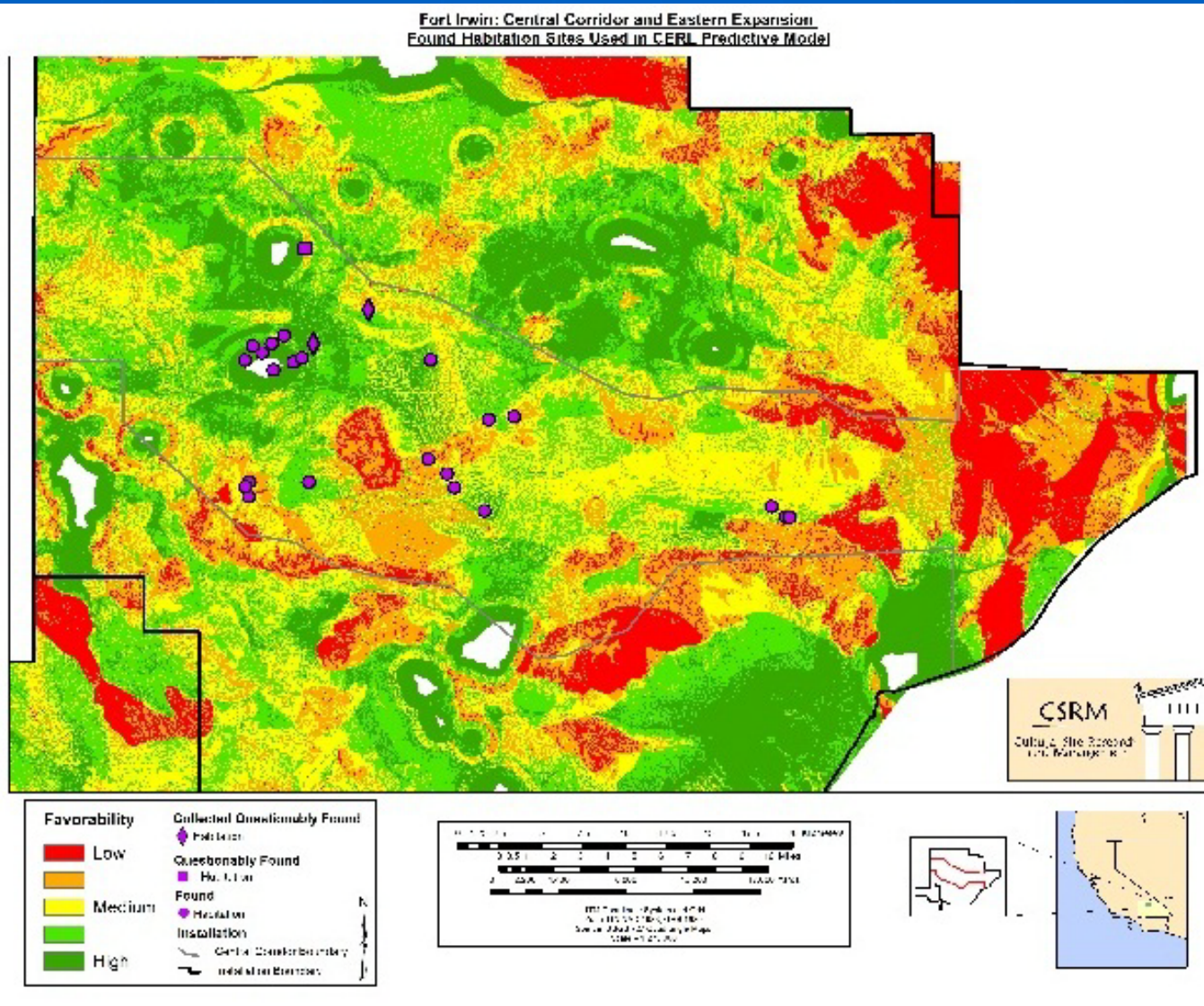


Not a Traditional Archaeological Predictive Model

Predicted regions for habitation sites, existing Fort Irwin APM

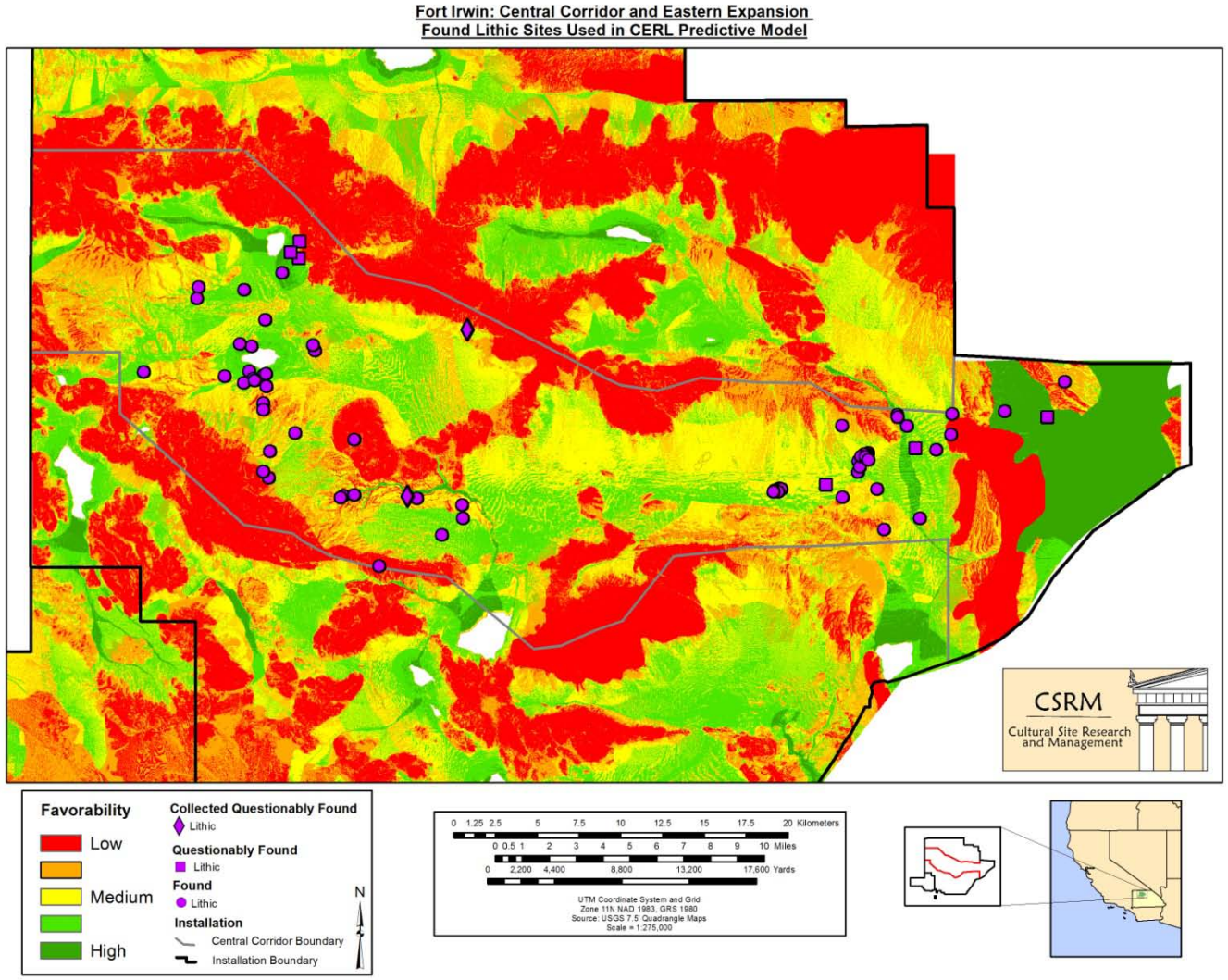
Based on historical associations:

- Distance to spring or lake
- Soil surface texture
- Soil water content
- Depth to bedrock
- Landform type
- Elevation
- Slope
- Direction of slope (aspect)



Not a Traditional Archaeological Predictive Model

Predicted regions for lithic sites, existing Fort Irwin APM



Is Not Based Upon Image Interpretation

Open Ritual Sites at Lemon Tank Seen in Near-Infrared Imagery

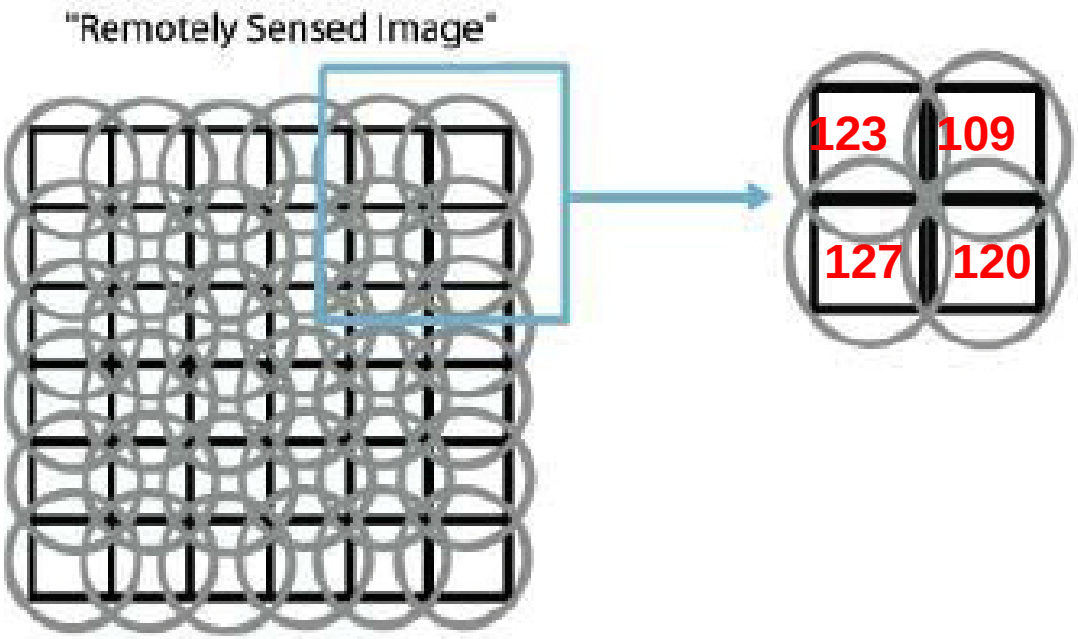
IKONOS False Color IR

Near Infrared
Red
Green

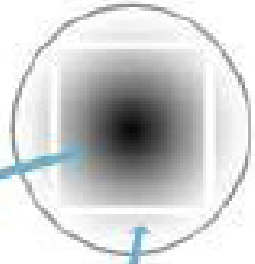
CSRM
Cultural Site Research and Management

0 62.5 125 250 375 500 Meters

Based on Numbers Binned in Pixels



The grid represents a remotely sensed image composed of pixels (represented by squares). The circles around each square (pixel) in the grid indicate the area within the field-of-view of individual detectors in a sensor. Roughly 50% of this area falls outside of the pixel boundary.

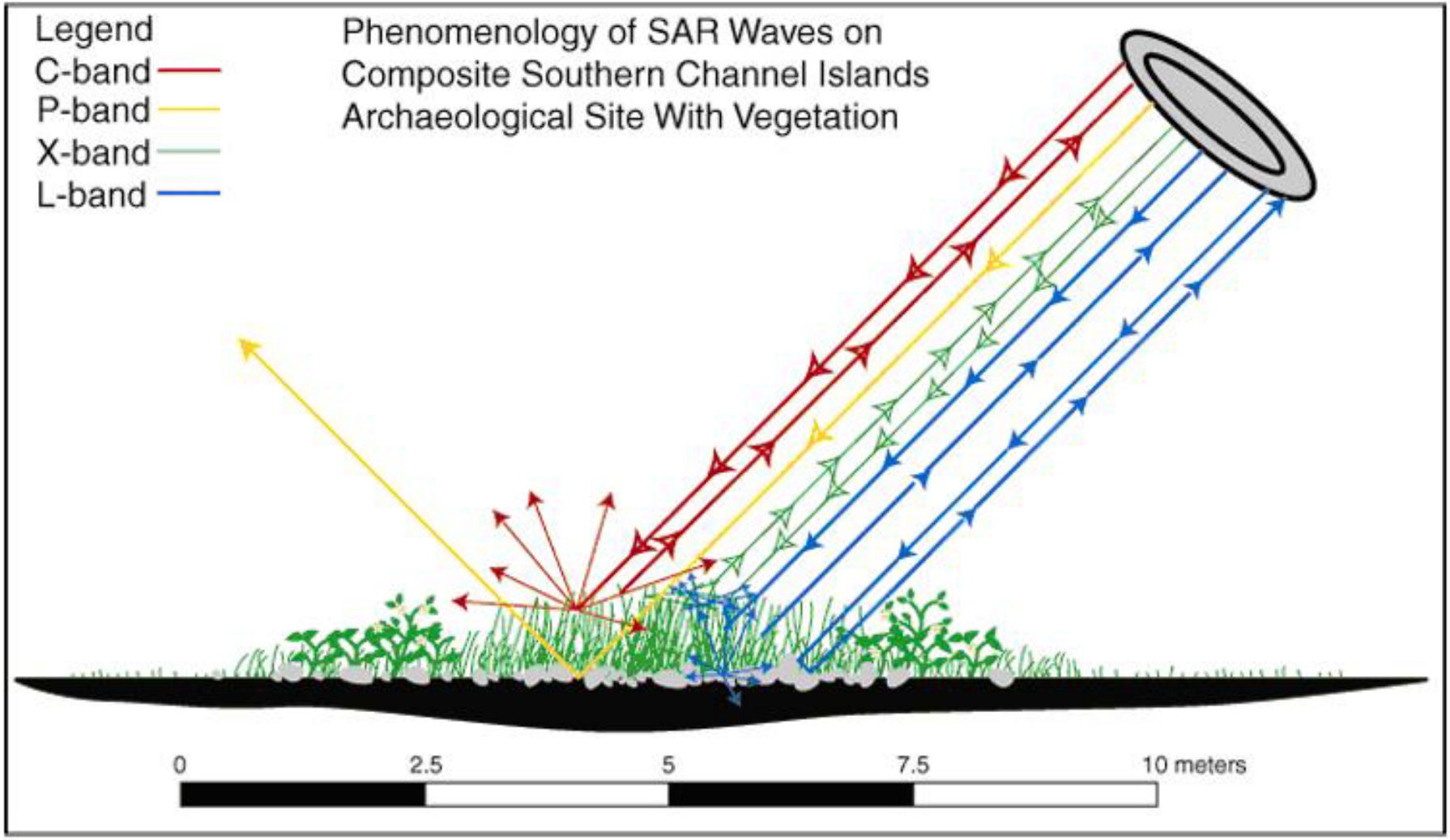


The dark center denotes the most sensitive part of the detector.

The white square represents a pixel.

The detector is most sensitive at the center of the circle and this sensitivity tapers off toward the edge. In other words the light coming from the center of the detector's field-of-view has a greater influence on the pixel value than the edge.

Where the Numbers Come From



Team

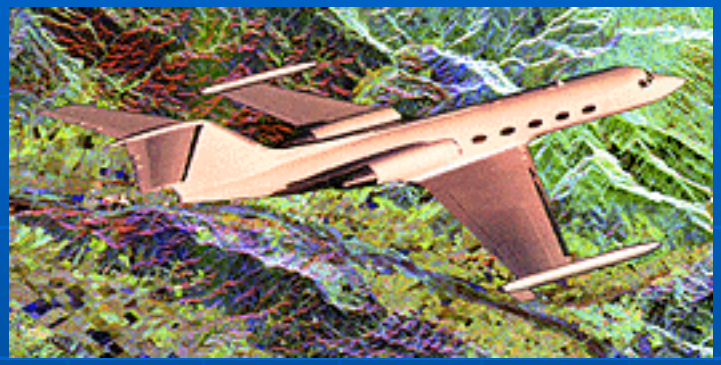
- Dr. Douglas Comer, CSRM
- Prof. Carey Preibe, Johns Hopkins University, Mathematics and Imaging
- Dr. James G. Tilton, NASA Goddard, Electrical Engineer, software expert
- Dr. Ronald Blom, JPL/NASA, Solid Earth Science Lead
- Dr. Bruce Chapman, JPL/NASA, Radar Lead

Team, Key Students

- Daniel Sussman, Ph.D. candidate, Johns Hopkins University Mathematics and Imaging
- Miles Wimbrow, Senior, Johns Hopkins University, Archaeology
- Will Magarry, Post-doc next year at Johns Hopkins University (University College, Dublin)

Features

- Features can be a set of values from a band of data or a set of value generated by algorithms used on other data sets.
- Original features were X-band SAR and IKONOS four band (R,G,B, NIR)imagery



Example: These Features Generated Others

- 1 X-band synthetic aperture radar (SAR) image
- 2 Red
- 3 Green
- 4 Blue
- 5 Near infrared
- 6 Slope
- 7 Normalized difference vegetation index (NDVI)
- 8 Wetness
- 9 Greeness
- 10 Brightness
- 11 Unnamed

Red and Near Infrared generated 7: NDVI
(NIR — Red)/(NIR + Red)

8,9,10, and 11 generated by Tassled Cap Transformation using the blue, green, red, and nir bands

Statistical Framework

Image

- Pre-processing
- Radiance correction
- Quantization
- Set of locations
- Prepare for *Training*

Image Processor

- Quantitative representation of a location; defined as function

$$f : \{1, 2, \ldots, w\} \times \{1, 2, \ldots, h\} \times (\mathbb{R}^{w \times h})^B \mapsto \mathbb{R}^{d'}$$

- *NOT enhancement, training*

Feature Extractor

- Reduces dimensionality of the imaged processed representation. PCA)

$$g : \mathbb{R}^{d'} \mapsto \mathbb{R}^{d}, \quad d \ll d'$$

- Needed to avoid "curse of dimensionality"

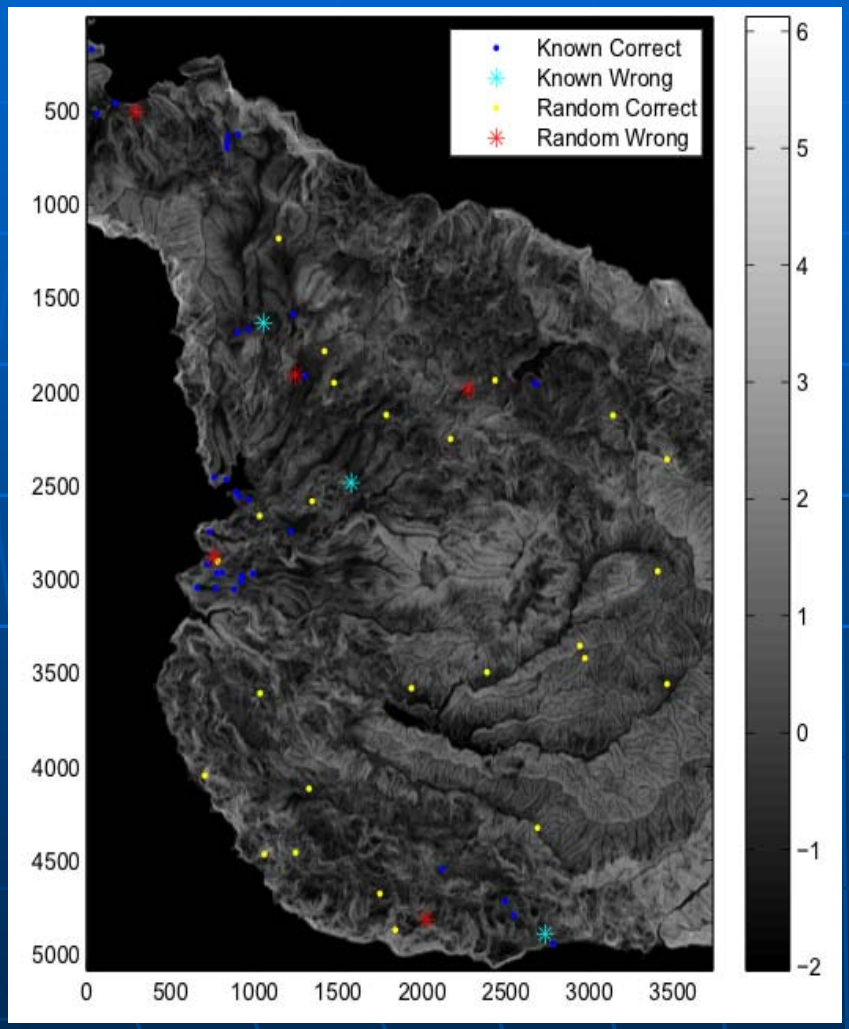
Classifier

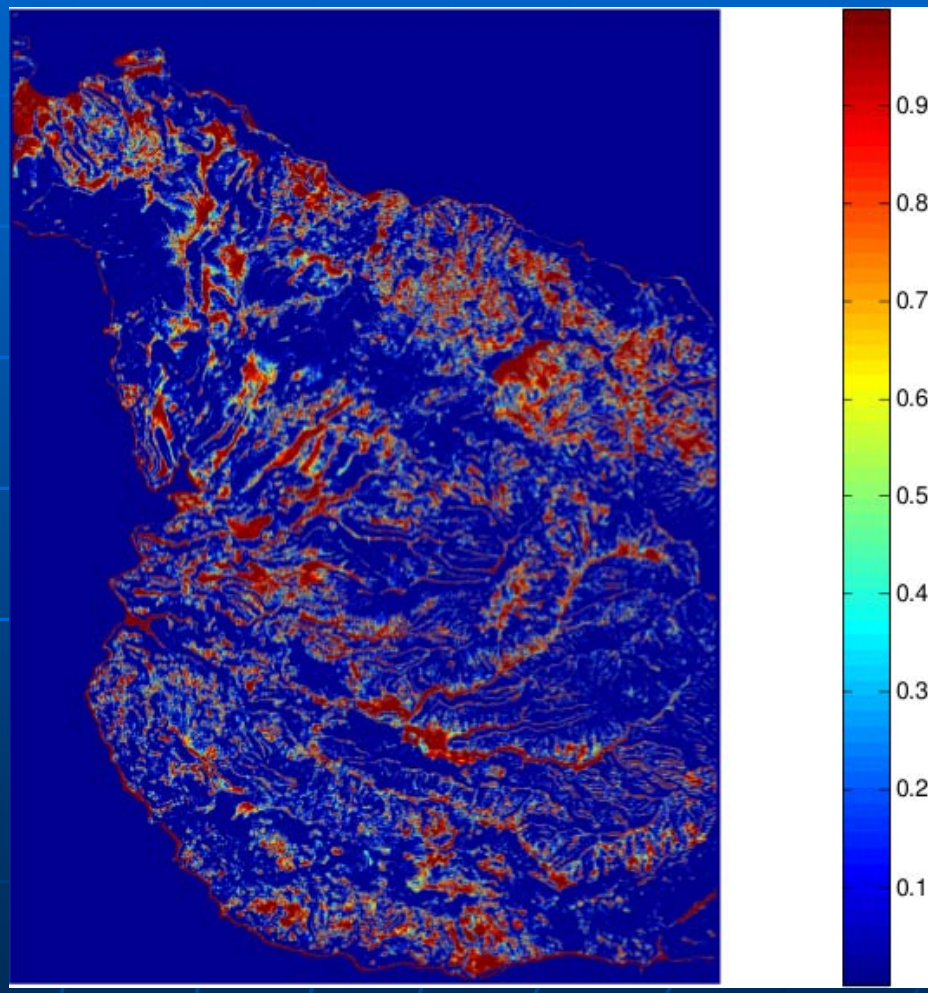
- Assigns a class label (0 or 1) to feature extracted vector.

$$h : \mathbb{R}^{d} \mapsto \{0, 1\}$$

- 0 - No Arch. Significance
- 1 - Arch. Significance

Site Error and Posterior Maps





Concentration and Gain

Number and percentage (of total land area) of potential habitation site pixels detected and Known Site Detection Rate utilizing 192 level RHSeg based quantization plus Proposed Concentration and Gain Factors.

Number of detections	Number of pixels	% detection (out of 12873517 pixels)	Known Site % Detection	Concen-tration Factor*	Concentration relative to one or more detectons	Gain†
nine or more	691	0.0054%	2.78%	517.51	26.45	99.81%
eight or more	7,304	0.057%	8.33%	146.88	13.27	99.32%
seven or more	31,663	0.25%	19.44%	79.06	7.14	98.74%
six of more	79,499	0.62%	36.11%	58.48	5.28	98.29%
five or more	153,967	1.20%	52.78%	44.13	3.99	97.73%
four or more	260,199	2.02%	66.67%	32.98	2.98	96.97%
three or more	410,799	3.19%	88.89%	27.86	2.52	96.41%
two or more	639,730	4.97%	97.22%	19.56	1.77	94.89%
one or more	1,162,841	9.03%	100.00%	11.07	1.00	90.97%

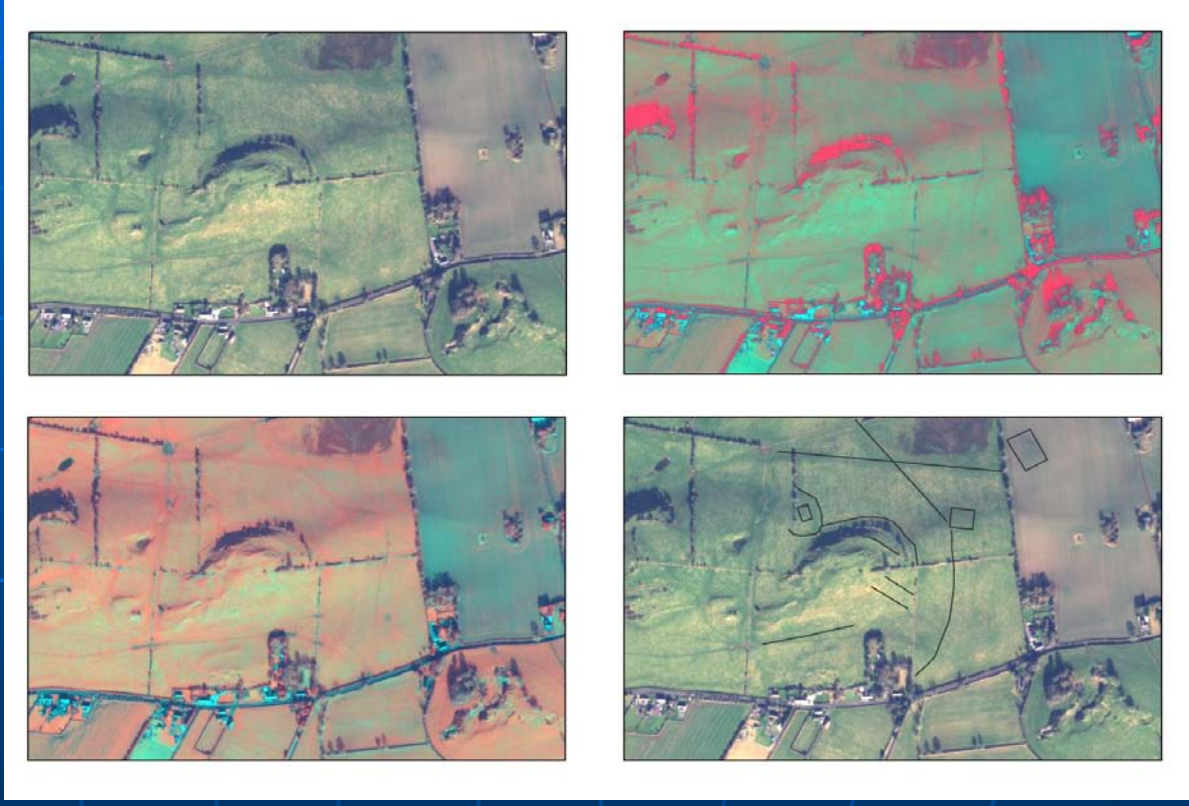
* Concentration Factor = Known Site % Detection/% detection.

† Gain = 1 – (% detection / Known Site % Detection)

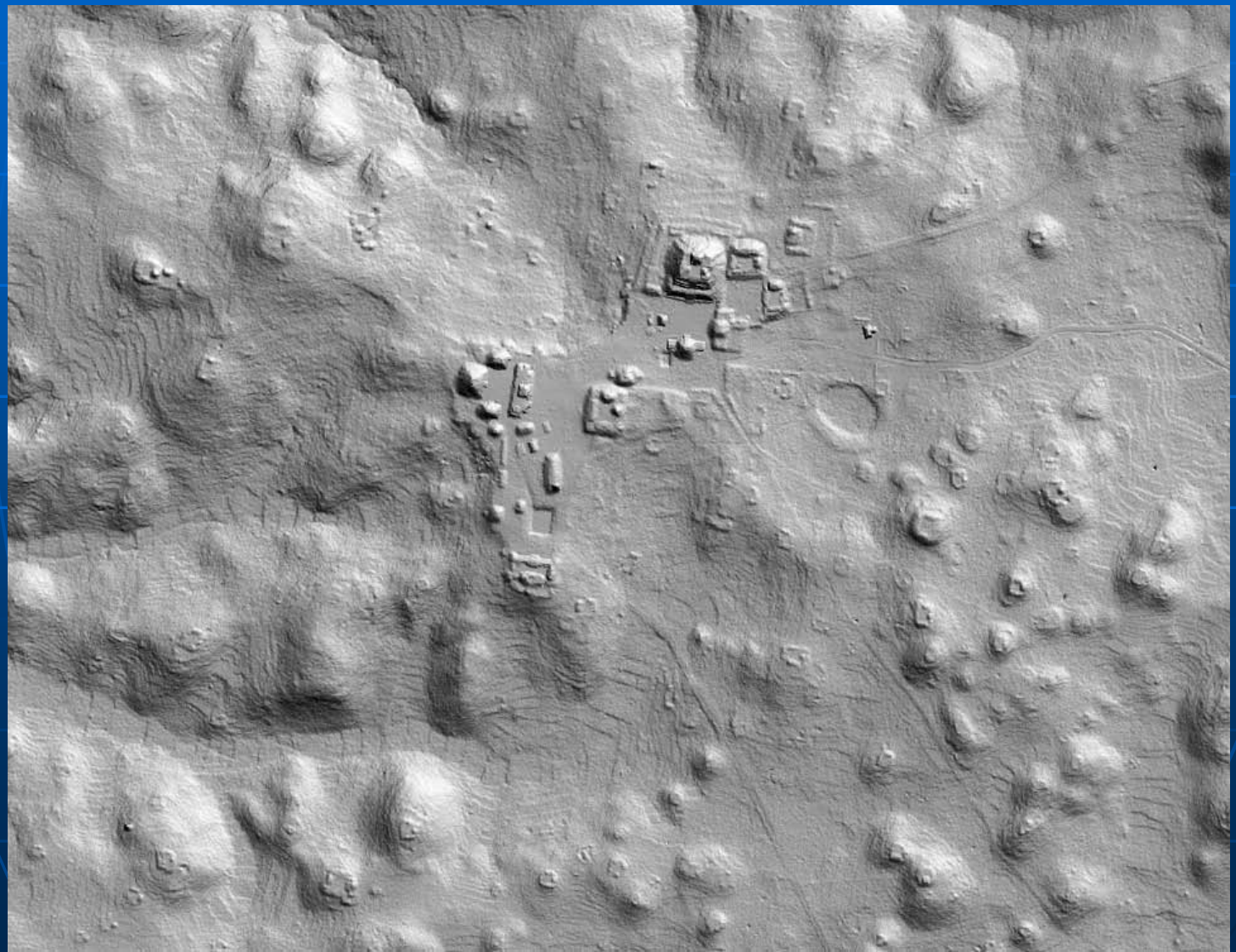
A gain statistic approaching 1 would be perfect. APMs developed by Minnesota are regarded as exemplary and at best have gain statistics of 0.73 to 0.78 for high probability areas

Multispectral WorldView-2

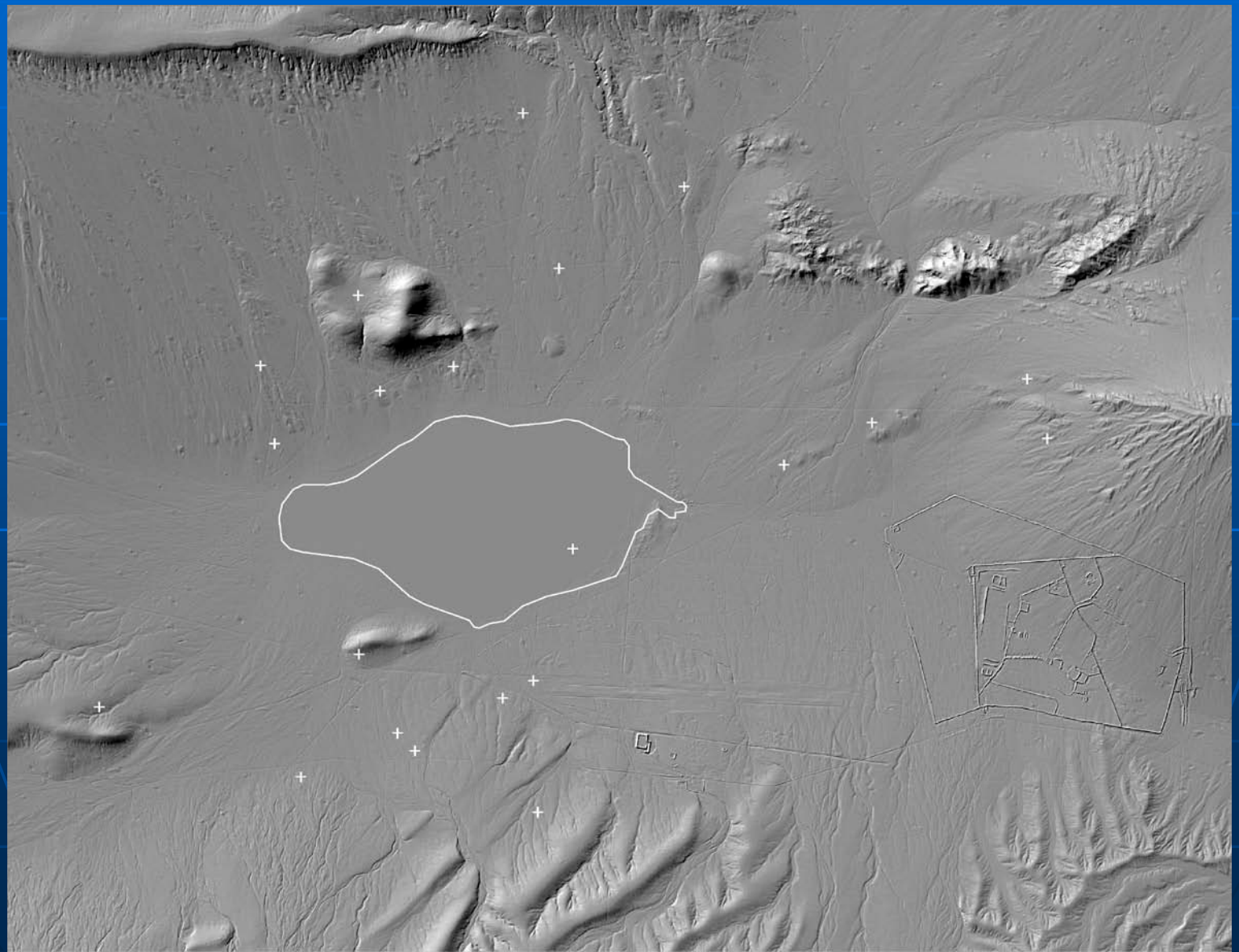
- Panchromatic: 450 - 800 nm
- 8 Multispectral:
- Coastal: 400 - 450 nm
- Red: 630 - 690 nm
- Blue: 450 - 510 nm
- Green: 510 - 580 nm
- Yellow: 585 - 625 nm
- Red Edge: 705 - 745 nm
- Near-IR1: 770 - 895 nm
- Near-IR2: 860 - 1040 nm
- Pan 50cm pixels
- Multispectral 2m pixels



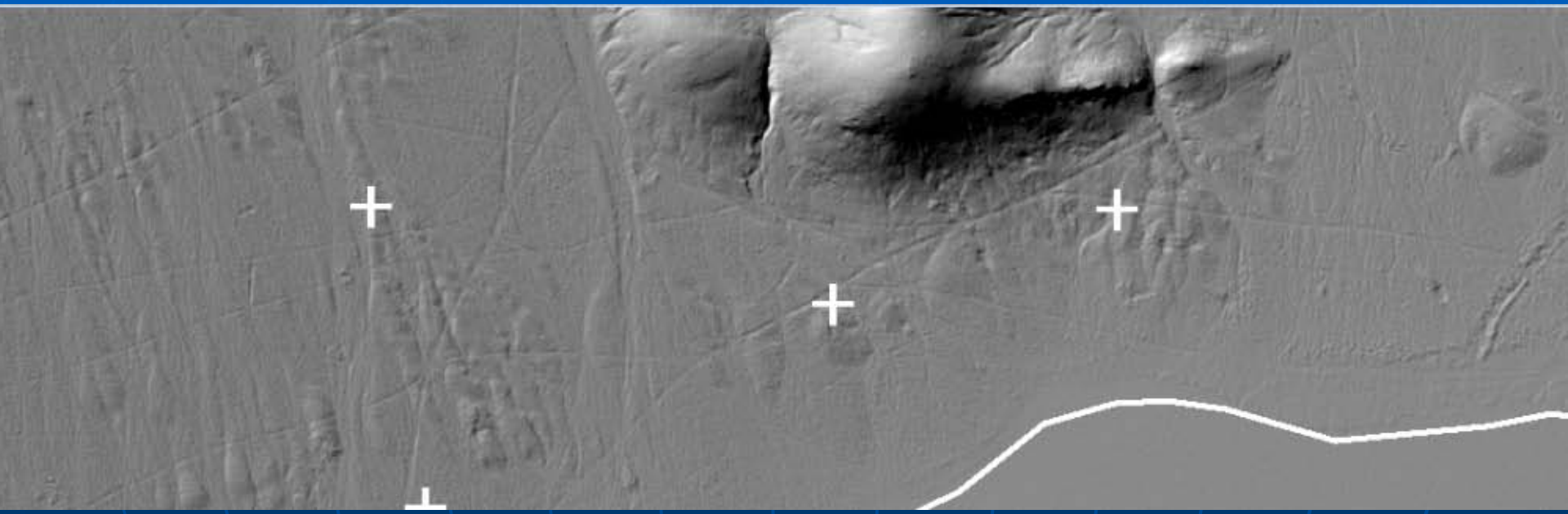
Lidar Through Jungle Canopy



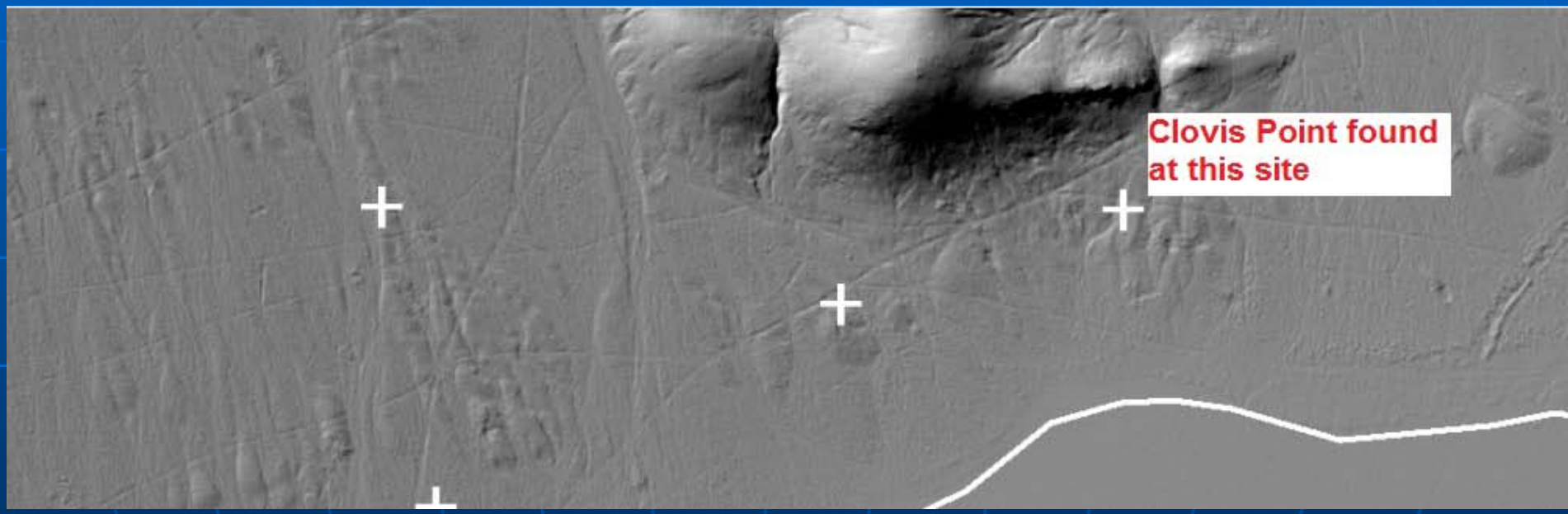
Nelson Lake, Fort Irwin



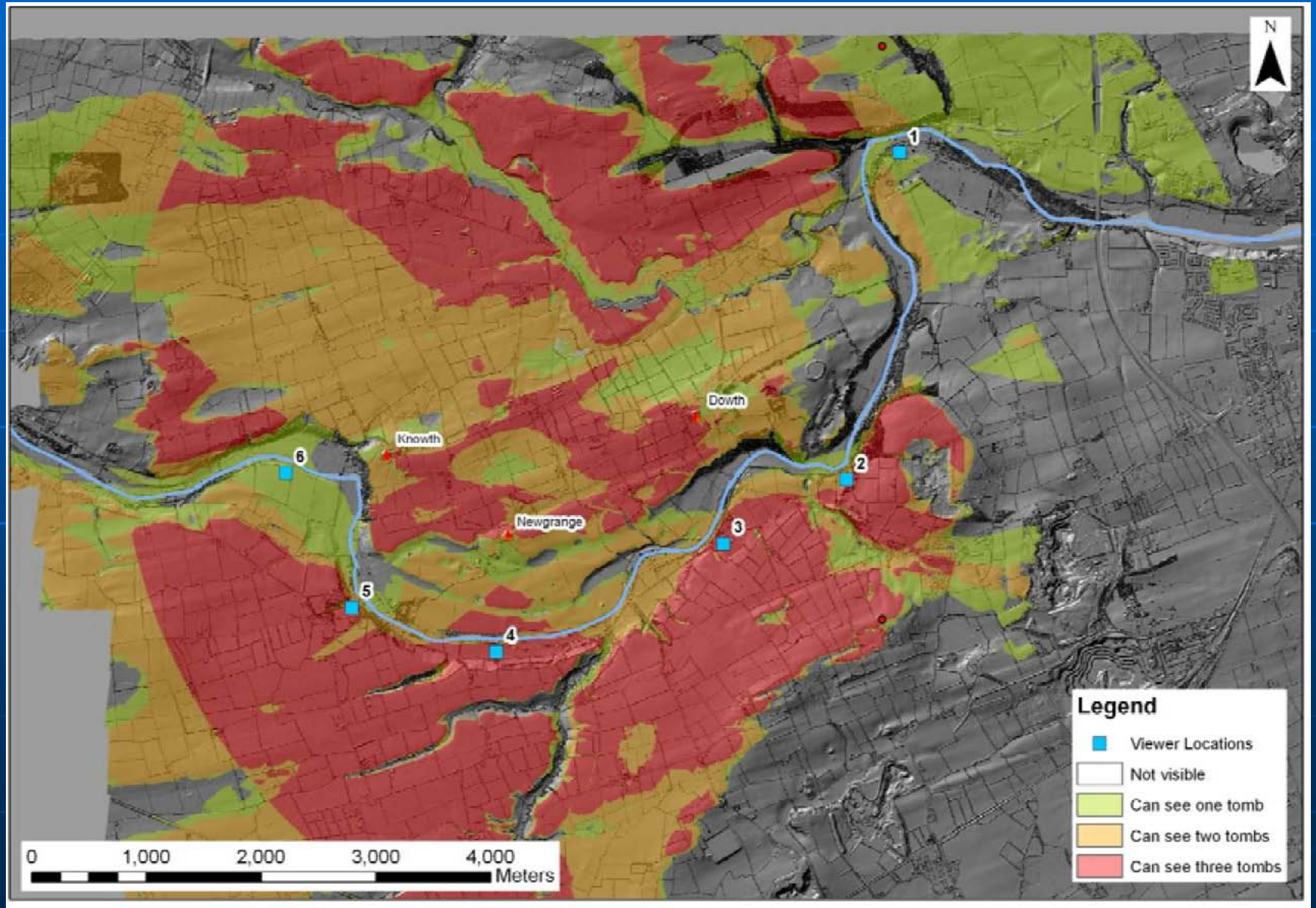
Beach Ridges



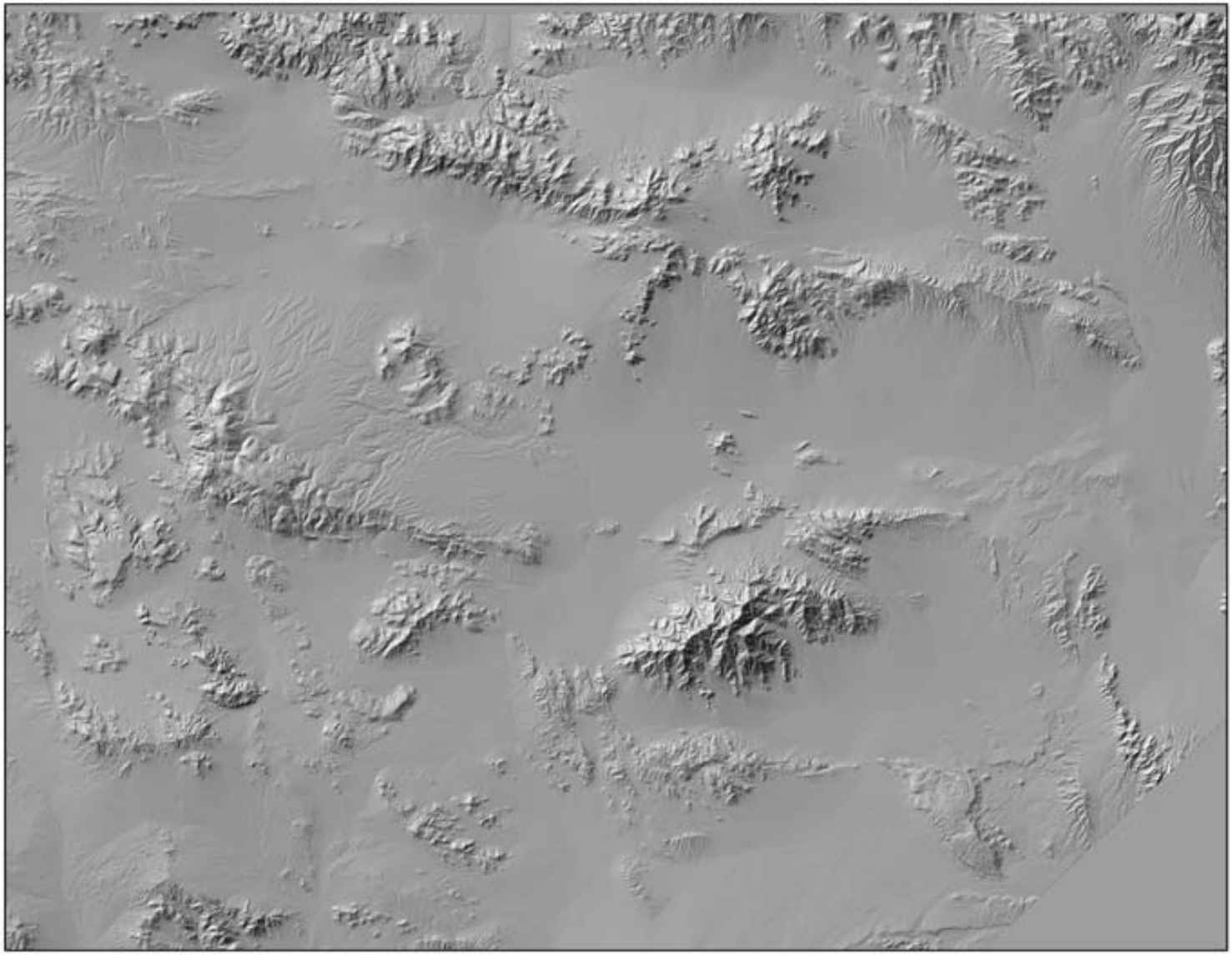
Pluvial Lake Shoreline



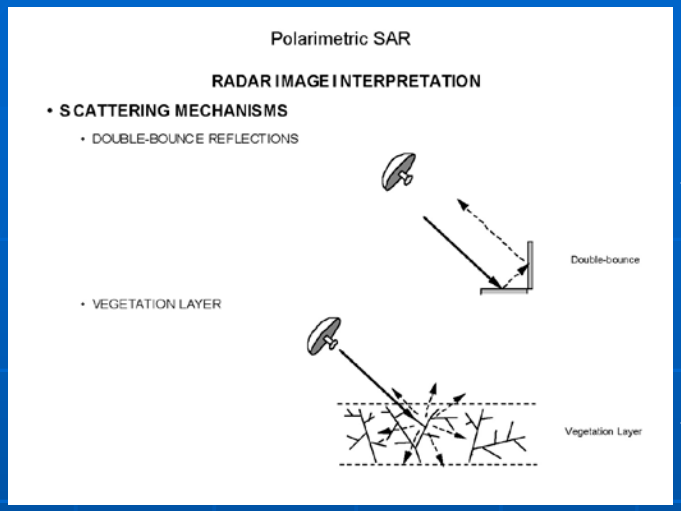
Bru na Boinne
Viewshed in Neolithic



Viewshed as Feature



Differential Scattering Phenomenology



Very Bright

Not So Bright

What Influences Return?:

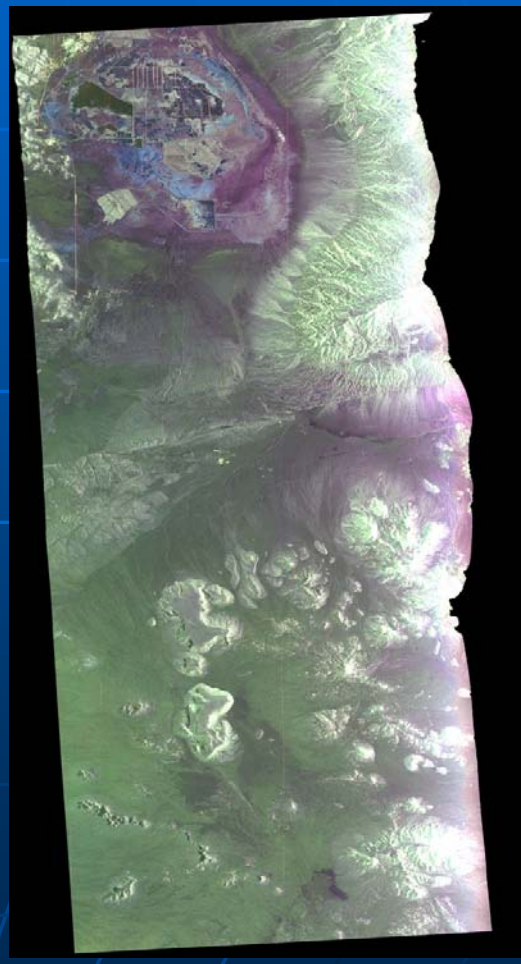
- Topography
- Structure (e.g., of vegetation, buildings, walls); especially angular, regular geometric pattern
- Surficial Roughness (e.g., ice, water, rock, rock scatters)
- Dielectric Property

A very bright return:

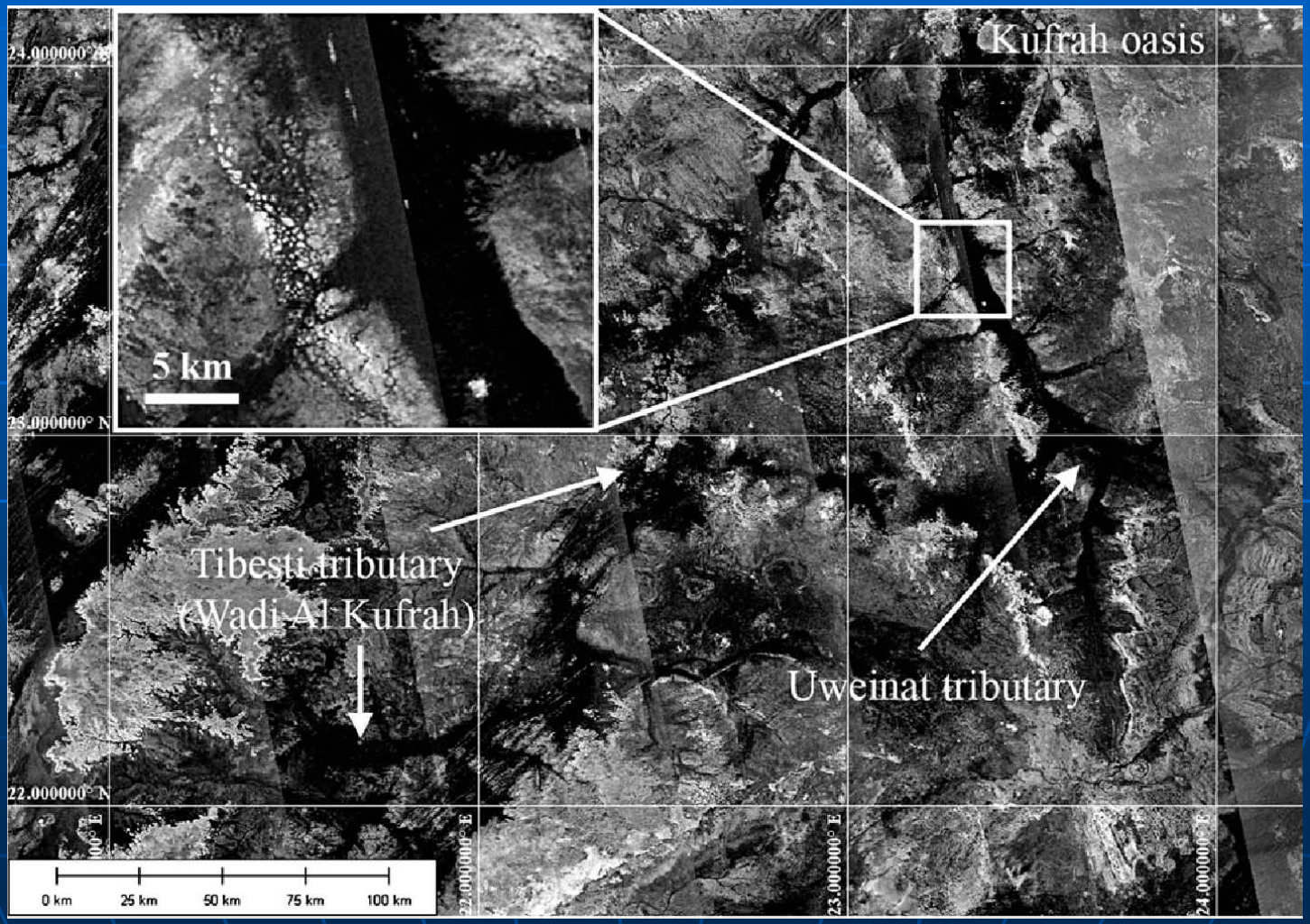
metal corner reflectors

Data from SAR Platforms

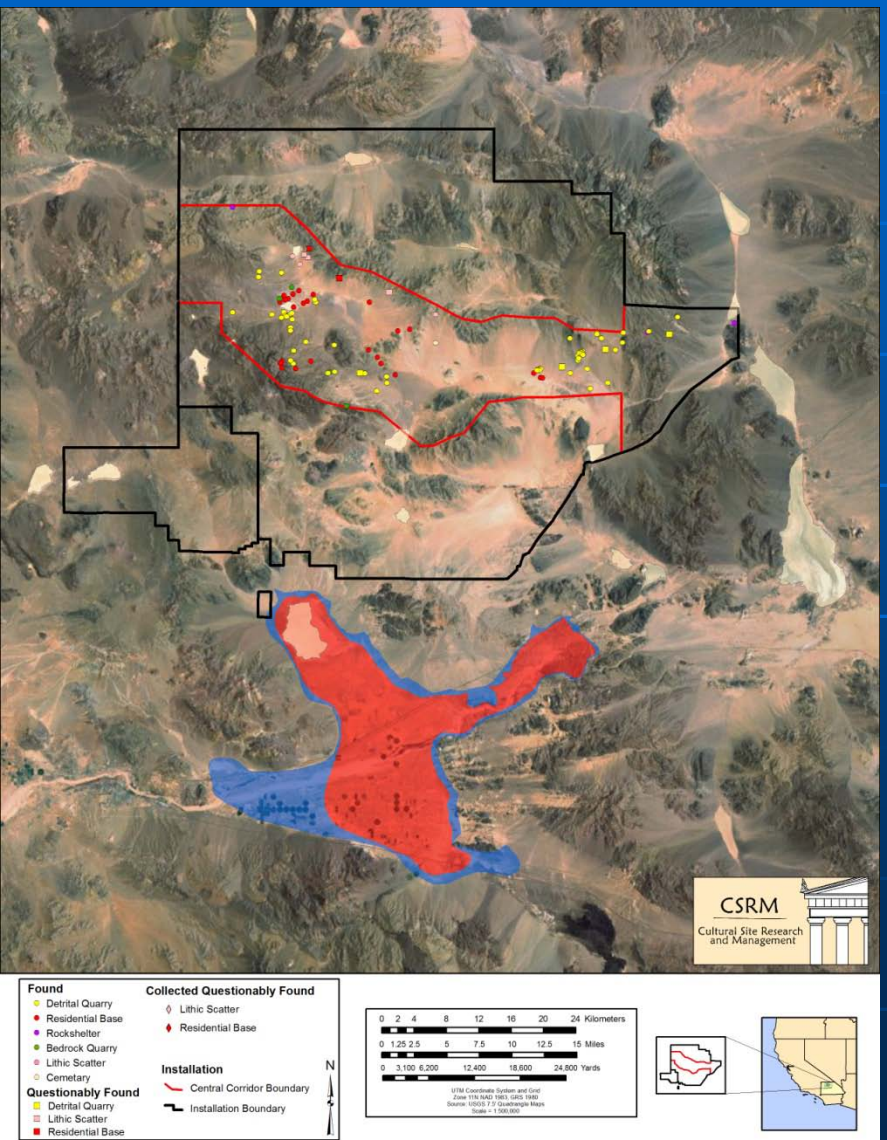
- AirSAR: Airborne, C-, L-, P-Bands polarized VV, VH, HV, VV
- GeoSAR: Airborne, X- and P-Bands Polarized HH, VV
- PALSAR, Satellite, L-Band Polarized HH, HV, VH, VV
- UVSAR, Airborne, L-Band Polarized HH, HV, VH, VV



Libya, Ancient River System



Pleistocene/Holocene Lakes



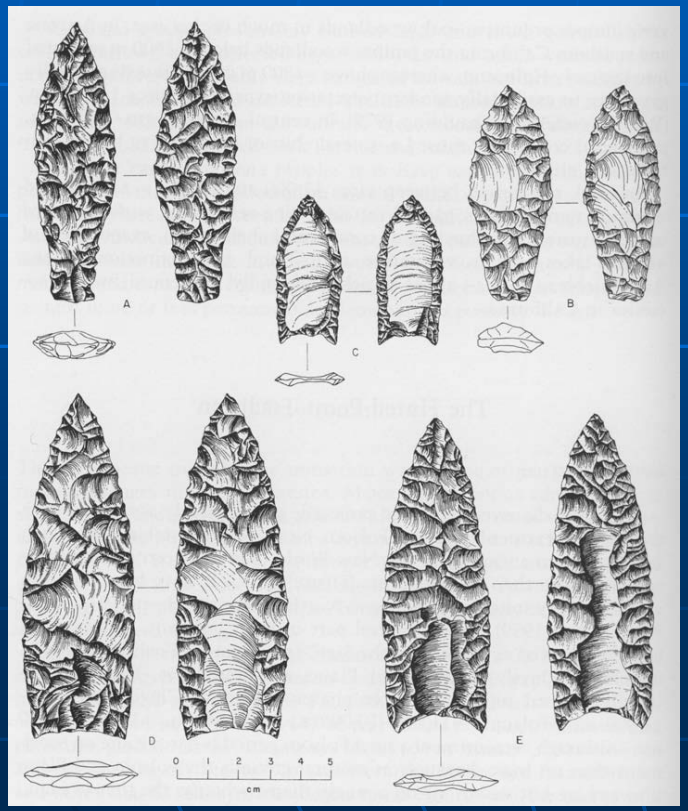
Shorelines changed over millennia

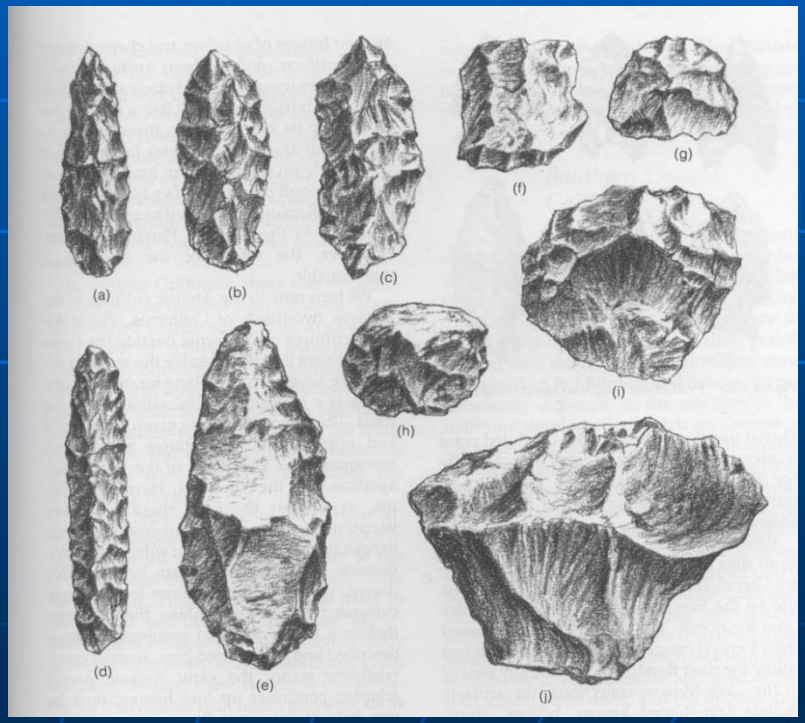
Buried shorelines might be locations of early sites

Sites on surface degraded by many processes (erosion, desert pavement)

Opens Possibility to Model Subsurface Sites

- These can be tremendously important



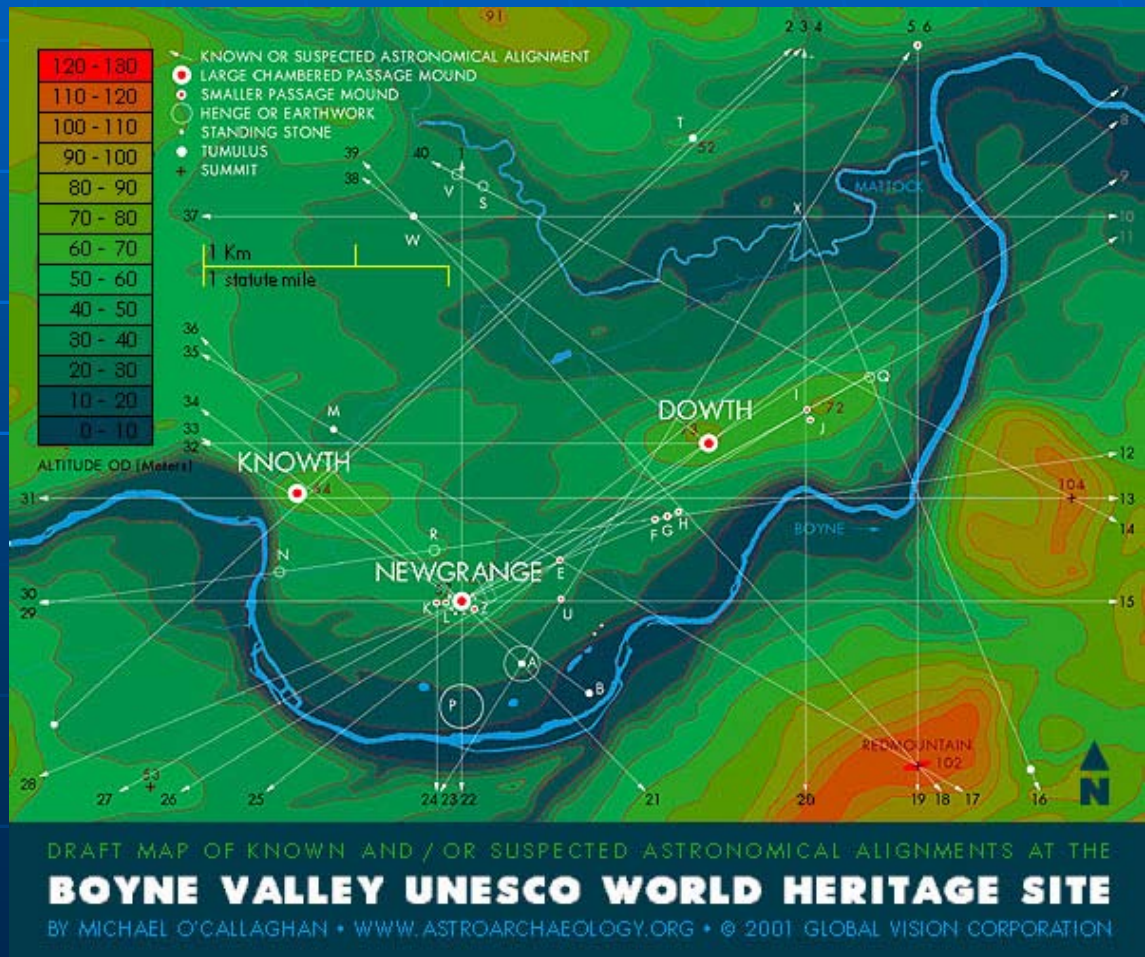


Closing Points

- We will also try merging traditional APMs and signature development results
- Made possible by rapid advancement in technology (e.g., Lidar) and computing power.
- Models and programmatic agreements now with SHPO now, inventories soon

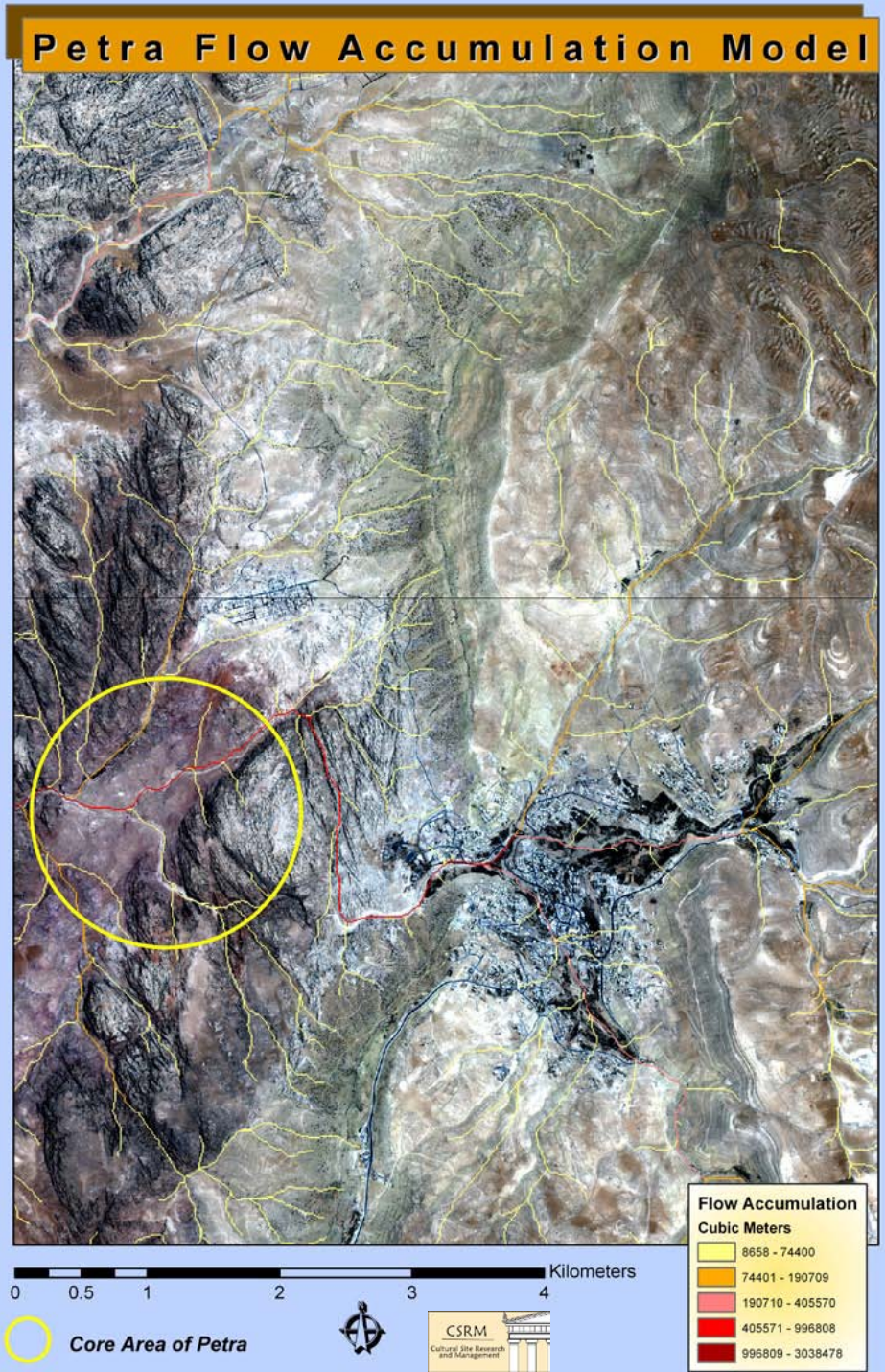
Criteria for Selection

- (i) to represent a masterpiece of human creative genius (Bru na Boinne)



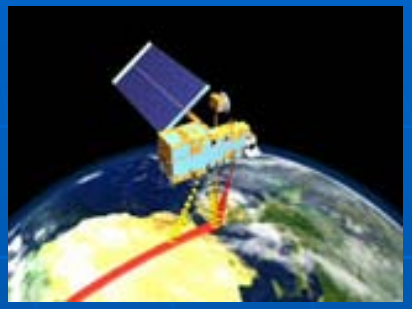
Flow Accumulation Model

- During the rain event of 12-14 January 2004, up to 3,038,478 cubic meters of water passed of the point in the Petra region that accumulated the greatest volume of rainfall
- This rain event provided 133 millimeters of rain
- The average yearly total is 205 millimeters

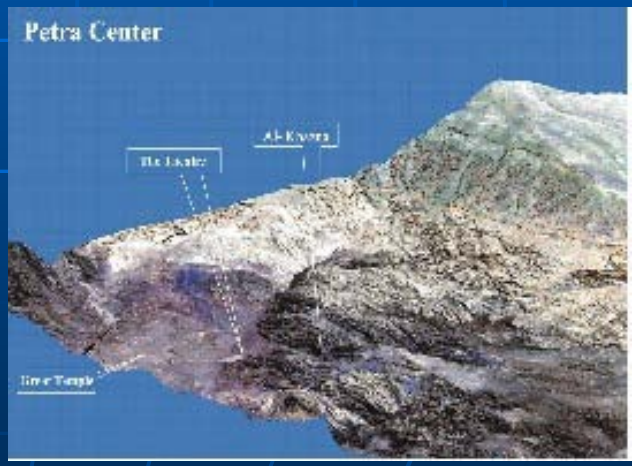


Aerial and Satellite RS

- Can provide scientific basis for zoning
  - Landscape models (hydrology, view shed)
  - Identification or predictive models of cultural and natural resource distribution
  - Even monitoring change within management zones



ASTER Satellite



University Affiliates

- A network of universities that share capacity and data
- Includes universities in host countries (where archaeological research is ongoing)
- Through
  - Serving data
  - Sharing research results
  - Regular meetings (symposia)
  - Training sessions
  - Building capacity at regional centers
- Much of this can be done through the Internet

Possible Partners

- Such a network would be complementary to the goals and program of many institutions, including:
- NASA
- The World Bank
- UNESCO
- The US State Department
- USAID
- The European Union
- Many philanthropic organizations