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Discovering Archeological Sites from Space

Using Space Shuttle Radar Data at Petra, Jordan

The popular image of Petra, which flourished from about the third century BCE to the third century CE, was probably established by the cameo appearance of one of its magnificent two-millennia-old Nabataean tombs in the Indiana Jones *Last Crusade* movie. Yet the sandstone canyon system in which Petra is located contains a wide variety of archeological sites from many different time periods. Among these are some of the earliest village sites anywhere, as well as Bronze Age, Edomite, Byzantine, and Crusader sites. With sites above ground and below, Petra provides an attractive proving ground at which to develop techniques for detecting archeological sites with radar data collected by satellites and space shuttles. What renders Petra nearly ideal for this purpose, however, is the extremely arid environment there. Certain radar bands can penetrate dry soils; vegetation that can complicate radar returns is sparse at Petra.

Technologies associated with space programs have produced cameras and multi-spectral sensors carried by satellites and space shuttles capable of producing highly informative imagery. Most recently, radar apparatus has been added to the payload of these space vehicles. Unlike optical and multi-spectral apparatus that passively senses portions of the electromagnetic spectrum, radar actively scans for target characteristics, and so provides unique categories of data. Radar is extremely sensitive to surface variations. Topographic features on the order of millimeters can be detected. Different radar wavelengths can differentiate among tree canopy, shrubs, and grasses on the basis of trunk, branch, and leaf dimension. Even ice caps, soils, and stone can be classified on the basis of surface texture. Also, radar is sensitive to dielectric characteristics that are often linked to the presence of water. Finally, longer radar wavelengths can penetrate a variety of substances, including clouds, vegetation, and dry soils. Polarizing radar waves to be transmitted and received at the same orientation enhance penetration.

Imagery enhancement and analysis software can be used to combine data generated by radar waves of different lengths and polarizations in the same image. For example, longer waves polarized for maximum penetration can provide indications of the presence or absence of water beneath vegetative cover, while shorter waves can produce data pertinent to identifying the covering vegetation in the same. Recent advances in software technology render it possible to combine optical imagery or imagery produced by multi-spectral sensors with radar imagery.

Aerial images produced by more established technologies are at present usually of higher resolution and larger scale than imagery produced from radar data. They also contain information of different sorts than that in radar imagery, which is often highly complementary to the radar data. A premise of our research is that non-radar imagery can provide the key to successful extraction of information about cultural resources from radar data. In research completed in 1997, conducted by the NPS Applied Archeology Center in collaboration with The Hashemite University in Jordan, we intended to test this premise. In particular, we wanted to

Al-Khazna, one of hundreds of spectacular tombs cut in the pink sandstone walls that surround Petra, appeared in The Last Crusade Photo by the author.

overcome limitations imposed by the 25 meter pixel size typical in images produced from radar data. We hoped to discover what cultural resources might be contained within the pixels themselves, and kinds of resources might be indicated by patterns of pixels.

NASA's Jet Propulsion Laboratory (NASA/JPL) provided radar data of Petra employed in the study. It was obtained in 1994 by the space shuttle *Endeavour,* which carried space imaging radar/synthetic aperture (SIR-C/X-SAR) apparatus. Instruments carried by previous SIR missions and other satellites, spacecraft, and aircraft, including commercial ones, also commonly employ the same radar bands and polarizations.

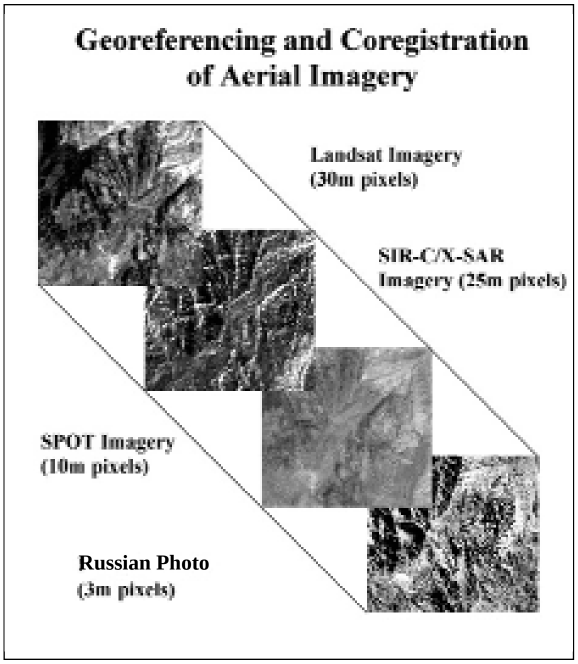
Essential steps in the enhancement and analysis were orthocorrecting (removing distortion) and georeferencing (fitting imagery to a standard coordinate system) SIR-C/X-SAR radar imagery, and coregistering this imagery with orthocorrected, georeferenced larger scale, higher resolution of other types.

First, ground control points were established at features visible in radar imagery, and visible in other imagery to be georeferenced, including: Russian satellite photographs (with pixels of three meters); SPOT multi-spectral imagery; LANDSAT multi-spectral imagery; B/W photographic stereo pairs of 1:10,000, 1:25,000, and 1:30,000 scale; and tethered balloon photographs of about 1:500 to 1:1,000 scale.

Establishing real world coordinates for points visible in all aerial imagery with a global positioning system (GPS). Photo by the author.

Control points were established to less than half-meter accuracy by use of a global positioning system (GPS). These points provided the information required by computer software to reduce image distortion; that is, to orthocorrect imagery. Recorded as real world coordinates and therefore common to all images, the points could be used to georeference and then coregister all images. Images were in this way "stacked" one atop the other, so that a given point in one image corresponded to the same point in another. Images were entered as themes into a geographical information system (GIS). Computer-enhanced radar, LANDSAT, and SPOT were entered into the GIS as themes, as were the GPS locations of archeological sites and features observed in the field and recorded by other researchers. Imagery could be stacked and viewed; numerous areas of potential interest were observed. Some of these examined on the ground proved to be:

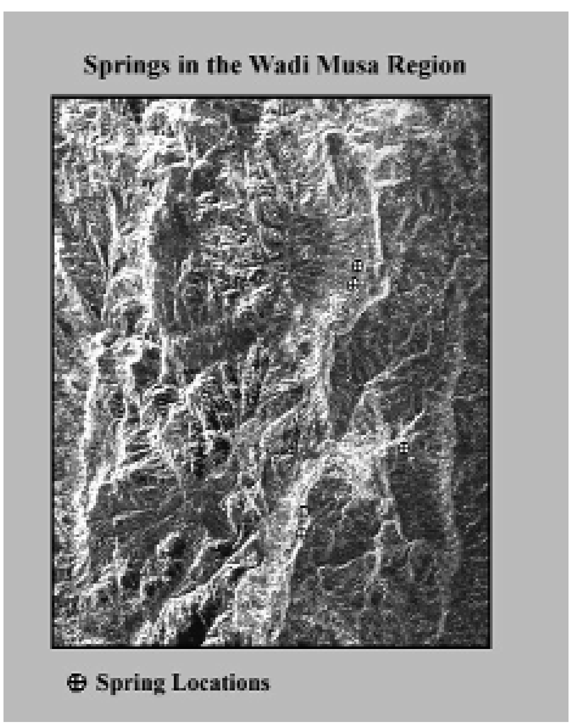
- **Natural landforms of relevance to archeological sites and features:** A bright band that runs from north to south through the radar imagery of the Petra area was at first attributed to a road. It was later observed—in other sorts of aerial imagery and on the ground—that a line of major springs occurred along this band, which may represent a geological fault. The line of springs no doubt influenced the location of human occupation sites in the region. A circa 6,500 BCE village site, Beidha, is found near the band, which also is at an elevation at which wild emmer wheat grows. Beidha is among the sites where cereal crops were first cultivated. Radar images highlight other aspects of the topography that made specific locations suitable for ancient constructions. Flat areas in the sandstone canyon system that contained the ancient trading city of Petra were at a premium, and were used for agriculture or as building sites.
- **Landforms altered by human occupation:** Among those found at Petra were an apparent Byzantine structural complex built alongside the flattened top of a high hill. An ancient pathway could be seen in radar imagery running from the eastern edge of the canyon system to the center of Petra. Locations where dams were constructed in steep-sided streambeds ("wadis") could also be ascertained in some imagery.
- **Archeological sites and features themselves:** One site identified in merged radar and optical imagery was located just outside the famous "Siq" (narrow sandstone canyon) that was the primary entrance to the city of Petra. The terrain and configuration of walls at the site suggest a stopping place for caravans prior to



"Stacking," or coregistering, aerial images that have been georeferenced and orthocorrected. A given location can thereby be found in each image. Digital image by K. Joly.

their entry to the city. Of particular note were distinctive pixels which were observed on the ground to be associated with a certain sort of archeological feature. These features were variously blocks of rooms, water management devices (especially dams across narrow wadis), or cisterns, but in all cases could be described as open subterranean chambers, generally angular in plan.

In the coming year, we plan to test the statistical association of specific feature characteristics with the coloration of pixels in imagery created by assigning primary colors to three different radar band polarizations. Correlations will also be sought with measures of the strength of received radar waves of different lengths and polarizations.



Aerial radar image of the research area. The bright vertical band near the center corresponds to a line of springs, and is probably a geological fault. Viewed at different scales, areas, patterns, and even individual image pixels of certain colors denote landforms of archeological interest and archeological features and sites themselves. Digital image by K. Joly.

Such correlations, if found, will enable direct detection of small archeological sites and features with radar data. Many, perhaps most, such sites and features are in remote areas or hidden by vegetation or soil. It is probable that only aerial radar, or another, yet undiscovered, means by which to probe large areas at a time, can be used to find them before they come to light through development, looting, or erosion.

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