the way that they are remotely perceived by the sensors of geophysical machinery and remote imagery.

In effect, remote sensing allows modern archaeologists to transcend an “archaeology by capture” approach—the only real truth is the artifact in your hand—opening the door to a more noninvasive, conservation-oriented archaeology of the future.

Geographic Information Systems

Archaeological data are inherently spatial, and archaeologists map things all the time. Maps show where things are and, more important, how they relate to each other. Archaeologists use maps to plot the results of remote sensing, artifact distributions within a site and distributions of sites across a region, a state, or even a continent.

But in their traditional form, maps are difficult to update with new information, and the resulting distributions are often unwieldy to analyze.

This all changed in the late 1980s with the advent of geographic information systems (GIS), computer programs designed to store, retrieve, analyze, and display cartographic data. GIS lets you view information—any geographically related information—visually. The most common programs in use today are ArcView and ArcInfo.

Every GIS consists of three primary components: a powerful computer graphics program used to draw a map, one or more external databases that are linked to the objects shown on the map, and a set of analytical tools that can graphically interpret or statistically analyze the stored data. Most of the United States is in the process of putting all their archaeological site records into a GIS. Clearly, GIS is a basic skill that any student contemplating a career in archaeology should learn.

In true GIS format, the earth’s various features are not depicted visually—as they would be on standard two-dimensional maps—but as digital information. Virtually every standard USGS topographic map is now available digitally (some high-end GPS units contain them already). Data stored digitally, of course, can be manipulated and displayed in numerous ways.

In GIS, a database is composed of several themes, or layers. Envision a base topographic map—that’s one theme. Now envision laying a clear sheet of plastic over that map (this is how we used to do it!). You plot on the sheet all the archaeological sites you just found in a survey. This layer is another theme. Over the first sheet, you lay another on which you draw in all the water sources; this is a third theme. On yet another sheet, you draw the distribution of different vegetation communities. On another, you plot the results of high-altitude imagery; on still another, the region’s different soils... you get the picture.

By inputting all these different data digitally into a single georeferenced database, we can call up one or more of the layers and analyze the distributions. “Georeferenced” means that data are input using a common mapping reference, such as the UTM grid system mentioned previously. Because the data are digital, we can do spatial analyses in minutes that previously might have taken weeks or longer. Each of the data points is linked to a database, which can include complete information on that point. A site record, for example, might contain information on a site’s artifacts—how many projectile points or potsherds were found there—plus other data such as its size, its slope, and the kind of architecture that was present.

We can ask myriad questions of this database. For example, we might ask, “How far away from water sources are pueblo sites found?” With a GIS database, we can quickly buffer springs and streams at some standard distance, say 1-kilometer intervals. Think of this as drawing concentric circles around the springs with radii of 1 kilometer, 2 kilometers, 3 kilometers, and so on. Likewise, we would trace out land areas within 1, 2, and 3 kilometers of rivers and streams. We could then ask the program to tell us how many pueblo sites versus other kinds of sites are in the various buffers. We could also see if sites are more frequently associated with a particular kind of vegetation community or soil type—in fact, with any data set that has a spatial dimension to it.

Landscape Archaeology

GIS, remote sensing, and surface survey open up new ways to analyze spatial data. Partly because of this new ability, archaeologists have developed a new approach called landscape archaeology. Although the word “landscape” has a colloquial meaning, Carole Crumley (University of North Carolina) defines “landscape” as “the material manifestation of the relation between humans and their environments.”

In a sense, landscape archaeology has been around since the 1940s, when Gordon Willey (1913–2002) conducted the first archaeological settlement pattern study in Peru’s Virú Valley. In this regard, landscape archaeology is similar to the settlement pattern archaeology we discussed earlier, but it adds a concern with how people use and modify their environment. The case of the “Chacoan roads” shows how GIS, combined with remote sensing and survey, can help test hypotheses about how ancient peoples used a landscape.
of prehistoric roads (diagrammed in Figure 3-16). Amazingly, Lindbergh's photographs actually showed the famous Chacoan roads—but nobody recognized them as such until 1971, when archaeologists had a clue of what to look for. (Actually, Navajos living in Chaco Canyon knew about portions of the roads more than a century ago, although they, too, were unaware of their extent.)

Aerial photography traces its origins to 1857, when photographs were taken from a balloon suspended over Paris. Not long afterward, a few archaeologists took aerial photos of their sites, primarily with cameras attached to crewless balloons.

But these photos were simply to record a site and its excavations. During World War I, airplanes developed into a reliable technology and archaeologists began to use aerial photography to find buried sites. British archaeologist O. G. S. Crawford (1886–1957) first saw the potential in aerial photography when he analyzed photographs of German military units and saw signs of buried archaeological ruins. Taken with sunlight at an oblique angle, black-and-white photographs show shadows alongside slight undulations in the ground surface that point to shallowly buried walls not discernible on the ground. Soon after World War I, Crawford used aerial photography to locate Roman settlements in Britain.

Aerial photography has come a long way from black-and-white photos taken while hanging off the side of a biplane. Archaeologists have since employed everything from balloons and airplanes to the space shuttle and satellites to detect buried remains through photography. Early photographic techniques were restricted to the visible portion of the electromagnetic spectrum, and cloud cover was a problem. But new photographic techniques capture portions of the electromagnetic spectrum that the naked eye cannot see.

One technique used at Chaco in the 1980s was thermal infrared multispectral scanning, or TIMS. TIMS measures infrared thermal radiation given off by the ground; it is sensitive to differences as small as 0.1° centigrade. Although we’ve had the ability to make infrared photographs for some time—the Landsat satellite did it in the 1970s—TIMS produced photographs of higher quality.

**Figure 3-15** Pueblo Bonito, one of several large pueblos in Chaco Canyon, in northwestern New Mexico; many smaller sites were revealed by surface survey, and a road system by remote sensing.

**The Chacoan Roads: Discovery**

Chaco Canyon was the center of a vast social and political network between 950 and 850 years ago, when two distinct kinds of sites appeared in the region. Throughout the Four Corners area, numerous smaller pueblo sites dotted the landscape. But huge sites—the Great Houses such as Pueblo Bonito (Figure 3-15)—appeared in Chaco Canyon and a few other places on the Colorado Plateau. The Great Houses were centrally located amid a cluster of smaller sites, defining a “community.” By 900 years ago, the Great Houses had developed into large, formal ancestral Pueblo towns.

In 1970 and 1971, archaeologist R. Gwinn Vivian (Arizona State Museum) was mapping what he thought was a series of ancient canals in Chaco Canyon. As he began excavating, Vivian realized that the linear features were like no canals he’d ever seen. Instead of having a U-shaped cross-section, the Chaco “canal” appeared to be a deliberately flattened and carefully engineered roadway.

Vivian described his curious find to Thomas Lyons, a geologist hired to experiment with remote sensing possibilities in Chaco Canyon. Together, Vivian and Lyons started looking at the available aerial photographs of the area. Some of these photographs dated to the 1960s, but Charles Lindbergh (1902–1974), the famous American aviator-explorer, had taken others in the 1930s, before grazing was permitted at Chaco.

Looking carefully at these black-and-white photos, Vivian and Lyons saw unmistakable traces of a prehistoric road network. They commissioned new flights, and road segments were field-checked against the aerial photographs. By 1973, Gwinn and Lyons had identified more than 300 kilometers
TIMS images require a very complex kind of camera, and the data—the sensed infrared radiation—are transformed via a computer program into so-called false-color images. False-color images map the ground in terms of infrared radiation—rendering terrain in garish colors such as red, blue, and purple.

Because the Chacoan roads are more compacted than the surrounding matrix (even if their compacted surface is buried), they reflect more radiation than the surrounding sand. In false-color images, the roads appear as clear, tan lines against a backdrop of red sand. The Chaco experiment proved that TIMS can detect features such as buried road systems, even if they are invisible to an archaeologist standing on top of them.

The Chacoan roads are very subtle topographic features, often only 5 to 10 centimeters deep, yet sometimes 7 to 10 meters wide. TIMS data could find them, but only indirectly because this technique detects radiation due to compaction. A better way would be to map the land surface at a scale that could pick up fine-grained, 5- to 10-centimeter changes. Today, we have just such a technique in lidar, which stands for “light detection and ranging” (a combination of “light” and “radar”).

Lidar is capable of mapping all kinds of phenomena, from slight bumps on the ground to the density of water vapor in clouds. Simply put, lidar maps things by bouncing a laser off them and tracking how much time it takes the light to bounce back. With the instrument located by very sensitive GPS, it can create a map of any surface—at a scale of centimeters rather than meters. For regional mapping, the instruments are often carried in satellites or in low-flying aircraft. The instrument’s settings can vary in terms of the wavelength of light emitted, the form of reflection, the detection method of the reflected light, and the pulse method. A trained technician decides what settings to use depending on the phenomena to be sensed and the conditions. With the right settings, lidar can even penetrate a forest canopy, and map structures or the ground surface beneath it. Arlen and Diane Chase (University of Central Florida) used lidar to map the huge Maya site of Caracol in Belize, discovering new stone structures, causeways, and agricultural terraces over 200 square kilometers. And with the right settings, lidar can detect even the most subtle undulations in the ground surface. Anna Sofaer and Richard Friedman
This elaborate road system may have covered some 250,000 square kilometers; yet these ancestors of modern Pueblo peoples had no wheeled vehicles or even beasts of burden. Why did the people of Chaco build these roads across the desert?

**The Chacoan Roads: Interpretation**

One hypothesis is that the Chacoan roads facilitated movement of food and other goods across the landscape. Many roads radiate outward from Chaco Canyon, so perhaps they were a way to provision the inhabitants of the canyon’s Great Houses with maize, timber, and other supplies.

But landscapes carry symbolic meanings as well as economic potential. Perhaps the roads were not economic at all, but instead served some ceremonial function. In fact, because the roads tend to cut straight across hills, rather than skirt around their bases, and make inexplicable sharp turns, many archaeologists favor a noneconomic interpretation. To hypothesize what this purpose might be, we can look to the descendants of Chaco.

Among those people are the Keres, the Puebloan peoples who live along the northern Rio Grande in New Mexico in the pueblos of Cochiti, San Felipe, Santa Ana, Santo Domingo, and Zia. In traditional Pueblo theology, the world consists of several nested layers, surrounded at the edges by four sacred mountains. As James Snead (California State University, Northridge) and Robert Preucel (Brown University) describe...