High-Resolution Imagery and the Recovery of Surface Architectural Patterns

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This article provides a broad overview of how high-resolution imagery obtained from the Digital Globe Corporation may be used to explore the structure of ancient southern Mesopotamian settlements. Although its focus is on data from Iraq, the methods described should be equally effective in similarly salinized geographic areas, such as the Egyptian Delta and the Indus Valley (Läuchli and Lüttge 2002:8), where both ancient construction methods and modern environmental conditions make subsurface architecture visible in high-altitude imagery.

Southern Mesopotamia has been exceptionally well imaged. The U.S. invasion of Iraq was the first major international event following the launch of the QuickBird satellite in early 2002 and it was tasked in February 2003 to obtain full coverage of southern Iraq—the area through which the impending invasion would take place, and coincidentally the heartland of ancient Mesopotamia. Imagery has continued to be acquired since that time, and there now are at least five images for even the most remote sites.

RECORDING SITE LOOTING

In 1994, there was a conference in Baghdad on site looting, which until the First Gulf War had been a relatively minor problem affecting only a few isolated sites, such as Umm al-Hafritat, "the Mother of Excavations" (Gibson 1996). In the aftermath of the conflict it increased dramatically, and the Department of Antiquities requested international help. There was, however, little that foreign archaeologists could do beyond explaining as publically as possible the link between the market in illegally exported antiquities and destruction of archaeological sites. After the 2003 invasion, while the news media were preoccupied with the looting of the Iraq museum, it became clear that site looting was moving to a new level. In conjunction with other efforts to aid the Department of Antiquities in that year, I began using high-resolution imagery to gage the scope of the looting and learn something of its character. Were the looters being

ABSTRACT

In large arid floodplains, like that of southern Iraq, the rise of the water table associated with irrigation can result in surface salt concentrations over the remains of subsurface architecture. These traces are visible only from the air but are sometimes captured by commercially available submeter pixel imagery. This article describes the methods used and some of the results of a project using QuickBird, WorldView-1, and WorldView-2 imagery to investigate settlement systems in southern Mesopotamia dating between the fourth and first millennia B.C. Following a discussion of methods used to better predict which images of which sites will produce the desired results, a brief exploration of key anthropological questions that these data allow us now to ask will be presented.

En las grandes llanuras de inundación áridas, como que en el sur de Irak, el ascenso de la capa freática asociada con riego puede dar lugar a concentraciones de sal de la superficie sobre los restos de la arquitectura bajo la superficie. Estos rastros son sólo visibles desde el aire, pero a veces son capturados por las imágenes disponibles en el mercado de píxeles inferior a un metro. Este artículo describe los dos métodos utilizados y algunos de los resultados de un proyecto usando QuickBird, WorldView-1 y -2 Cosmovisión imaginería para investigar los sistemas de liquidación en el sur de Mesopotamia que datan entre el cuarto y el primer milenio antes de Cristo. Después de una discusión de los métodos que se utilizan para predecir mejor qué imágenes de los sitios que van a producir los resultados deseados, se presentará una breve exploración de cuestiones antropológicas fundamentales que estos datos nos permiten ahora a preguntar.

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selective or indiscriminate in their choice of sites to pilfer? My first study was based on QuickBird imagery taken both before and after the invasion (although only a few images dated to after the end of 2003) for all of the Uruk (Adams and Nissen 1972), Eridu (Wright 1981), and Nippur survey areas (Adams 1981) and was made possible by generous funding from a wide range of sources.[1] In these images every looting hole was visible, and when images taken at different times were compared, new damage was readily apparent (Stone 2008).

In the course of this project, I realized that in some images of some sites with minor or no looting, traces of the underlying surface architecture were visible. This led to a new project, supported by a grant from the National Science Foundation, to both test methods of identifying which images of which sites were likely to preserve these surface traces, and to use the protocol so developed to purchase imagery of as wide a variety of site sizes and dates as possible. The aim was to obtain a sample of settlement data that could be used to assess long-term changes in Mesopotamian settlement and society. In addition to acquiring new images for the better-preserved sites from the southern surveys, this project also sampled sites identified in the Akkad (Adams 1972) and Diyala (Adams 1965) surveys. The anastomosing nature of the rivers in southern Mesopotamia means that areas now irrigated bear no relationship to those watered in the past. Because modern, not ancient, cultivation practices result in the preservation of surface traces, visible architecture comes as close to a random sample as we are likely to achieve.

REMOTE SENSING AND MESOPOTAMIAN ARCHAEOLOGY

Remote sensing has long played an important role in Near Eastern archaeology, although much of the earliest uses took place in areas neighboring Mesopotamia (e.g., Schmidt 1940). Adams (Adams and Nissen 1972:4) used aerial photographs in his early surveys; when these became less accessible (Adams 1981:33), he experimented with early Landsat MSS images for his Nippur survey, although he noted that their low resolution (80 m) meant that only the largest features were clearly visible. In preparation for our fieldwork at Mashkan-shapir in 1986 we obtained a 10-m resolution panchromatic SPOT image, which enabled the delineation of the ancient river and canal systems associated with the site (Stone 2003). We also digitized and georeferenced photographs taken using kite as an aerial platform as a means of providing high-resolution imagery of the site as a whole (Stone and Zimansky 2004).

Remote sensing in the area reached a new level with the declassification of Corona imagery in 1995. Jennifer Pournelle (2003, 2007) made pioneering use of these data to transform our understanding of the landscape of southern Mesopotamia at the time of the first settlements in the area. Since that time, Corona imagery has been fundamental for surveys conducted in the rain fed zone of the Middle East, from the Levant (Casana and Wilkinson 2005) through Syria (Ur 2003) to Iran (Casana 2013a) with similar hollow ways identified in most areas. Today, the Corona Atlas of the Near East established by Casana and Cothren (2013) at the University of Tennessee makes these images readily available to all. But for imagery with the resolution to resolve architecture, it was necessary to examine submeter resolution imagery and for quite some time the only real choice has been QuickBird imagery. These data however, were and are much more expensive than lower-resolution alternatives, and have therefore seen primary use as a source of good images of individual sites under excavation, rather than for broader surveys. The project described here may well be the only exception, and was only made possible by using the results an investigation into those features of the modern landscape likely to preserve architectural traces to select sites and images for purchase.

CAPTURING SURFACE ARCHITECTURAL PATTERNS: SELECTING IMAGERY

Three types of surface traces of architecture can be observed on Iraqi sites. First, where baked brick was used, the walls themselves may survive on the surface; this tends to be more common at less-ancient sites. Unbaked mud-brick, the most extensively used material in ancient Iraq, becomes visible after a rain as the water remains on the surface of the denser mud-brick walls and drains rapidly within room fills and streets, leaving the walls as dark stains on the surface (Figure 1). These traces are, however, fleeting, and it is only rarely that such traces are recorded by a passing satellite. However, when coincident with a high-saline water table the concentration of water over the denser walls produces more permanent visible traces. Here, osmosis results in slightly higher concentrations of surface salts over the mud-brick walls than over the less-dense rooms. These salt concentrations are rarely dense enough to make them visible from the ground; in most instances they can be seen only from the air. Although the walls of public buildings in Iraq are generally a meter wide or more, house walls tend to be around 60 cm, the same size as the pixel resolution of the Digital Globe imagery, which puts them on the borderline of resolution. Key questions, therefore, were whether it would be possible to resolve these traces, and, if so, which images of which sites were most likely to preserve them, and how could they best be recorded.

Selecting Images

Thanks to a very generous pricing policy for the acquisition of multiple images of the same area negotiated by my reseller, Spatial Solutions, I was able to begin this project with an initial purchase of multiple images of 31 different geographic areas within the surveyed area of southern Iraq, encompassing 113 archaeological sites with short occupations. These data, together with imagery purchased for the looting project, were used to develop an understanding of which factors knowable in advance might serve as indicators that a given image would be likely to show clear surface remains. Some criteria were self-evident: large sites have more surface area and thus an increased likelihood of preserved features, and high sites are less likely to have surface damage (other than looting) from animal and vehicle tracks, plow marks, or encroaching dunes. Other important indicators were the color of the surroundings of the site, the Normalized Difference Vegetation Index (NDVI) as a proxy for the presence of irrigation in the area, and the color of site and its environs. Each criterion was scored independently for each

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FIGURE 1. Rainfall concentrations over walls at Mashkan-shapir, 1990.

image of each site (Table 1)[2] with the total an indicator of how likely architectural traces would be preserved.

Out of a possible imagery score between 0 and 34, the images of the sites investigated ranged from 2 to 32. Sites with higher scoring images were therefore selected for this project, with the choice of images for purchase based on the highest score of the targeted site, with some additional consideration to the scores of other sites located within the 25 km^2 minimum size. Three purchases were made (Table 2). We began by ordering imagery for the sites with the highest scores. Next was a largely failed attempt to acquire imagery with preserved architectural traces on fourth millennium B.C. sites, those dating to the very beginning of Mesopotamian civilization, in spite of their generally low scores. Finally, all remaining funds were expended on those sites with high-scoring images that had not yet been explored. Few sites with high scores remained. Data was acquired in five stages: that bought for the site looting project,[3] the initial purchase for this project, and the three tests of the scoring system.

Assessing Architecture

For each image purchased an assessment of the presence of traces of houses or public buildings was made. We used a scale of between 0, meaning that no architecture was visible, and 10, where virtually the entire plan of the site was visible. Images with scores of 4 exhibited sufficient architectural traces in one area of the site to be worth digitizing (and sometimes multiple images of the same site with similar scores could be used to generate broader maps). Scores of 5 and better had increasingly good and extensive traces (Table 2). By the end of the project there were few sites with high-scoring images that had not been sampled. Of the sites dating between the fifth and first millennia B.C. and varying considerably in size, 97 have sufficient traces to be worth the time-consuming process of digitization (see below).

Predicting Rainfall

A less-fruitful exercise was an attempt to use Modus imagery—Cloud Optical Thickness and Cloud Top Temperature data—to predict when it rained where in Iraq. The problem was that the period covered by our imagery was a time of drought, and southern Iraq experienced only a handful of major storms—each of which was indeed well recorded in the Modus imagery. Thus, when rain-gauge data collected at the U.S. occupied air bases at Talil and Baghdad were compared with Modus imagery, although there was a clear coincidence between the more extreme MODUS data and significant rain events, these only occurred a couple of times over the eight years of potential data available. The weather conditions conducive to hit-and-miss thunderstorms were also recorded by the MODIS imagery, but they don't establish that any significant rainfall actually occurred at any particular place. Although disappointing for the particular conditions in southern Iraq, MODUS imagery should be successful in predicting rainfall in areas such as northern Mesopotamia

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TABLE 1. Coding of Images

Time of Year			Height		Area		NDVI	
Month	Cult. Code	Desert Code	Meters	Code	Hect.	Code	Value	Code
			.1–1.0	0	< 1.9	0	1–1000	0
Jan-Feb	0	2	1.1–2	3	2–2.9	1	1001–1200	1
Mar	1	2	2.1–3	4	3–5	2	1201–2000	3
Apr	3	1	> 3	6	5.1–20	3	2001–3000	4
May-Aug	3	0			20.1–50	5	> 3000	6
Sept	1	0			> 50	6		
Oct	1	1						
Nov	1	2						
Dec	0	2						

Environment Color*		Site Color*		Site color relative to Color of the Surrounding Area*	
Color	Code	Color	Code	Color	Code
Light to Medium & Urban	0	Dark & Dark-varied	1	Light-Light, Medium-Light, Dark-Light, Dark-Medium	0
Light to Lightish irrigated, Dark & Dark irrigated	3	Light to Darkish	3	Medium-Medium, Dark-Dark	1
Darkish, Medium to Darkish Irrigated, Flooded	4	Medium-Darkish Varied	4	Light-Dark, Medium-Dark	2
		Light-Lightish Varied	6	Light-Medium	3

*These data were obtained from the 2m resolution imagery available on the Digital Globe Web Site.

and eastern Syria, where dry farming is possible as a result of large weather systems. Indeed, it is not unlikely that similar architectural details might be recovered from satellite imagery for sites within the rain-fed agricultural areas of northern Mesopotamia. Were MODUS imagery used to identify storms in these areas, and imagery taken a day or so afterward investigated, I suspect that similar architectural patterns would be visible as the result of differential drying between walls and room fill.

TABLE 2. Statistics on the Effectiveness of the Methods Used to Increase the Probability of Acquiring Useful Imagery

	Purchased for Site Looting Project	Initial Purchase for Architectural Project	First Purchase Using Architectural Score	Purchase for 4th Millennium Sites	Second Purchase Using Architectural Score	
Purchases	1	2	3	4	5	All
Number of Sites	221	106	74	101	71	573
Number of Images	393	930	338	194	274	2129
Mean # Images/site	1.78	8.77	4.57	1.92	3.86	3.72
Mean imagery Score	11.89	14.56	16.20	15.28	18.49	14.88
Mean Architectural score	1.19	1.99	2.49	1.41	2.25	1.90
% Architectural score 4–10	14.25	24.73	33.43	16.49	27.37	23.78
% Architectural score 5–10	6.36	13.76	20.41	6.18	13.86	14.88
Mean size (ha.)	15.32	13.63	6.99	15.16	4.16	11.81

Note: Some sites were targeted in more than one purchase round. 1 = Purchased for site looting project; 2 = First purchase for this project; 3 = Purchase of imagery of best sites based on image scores; 4 = Purchase attempting to obtain good imagery of fourth millennium B.C. sites in spite of generally low imagery scores; 5 = Last purchase of the best remaining imagery.

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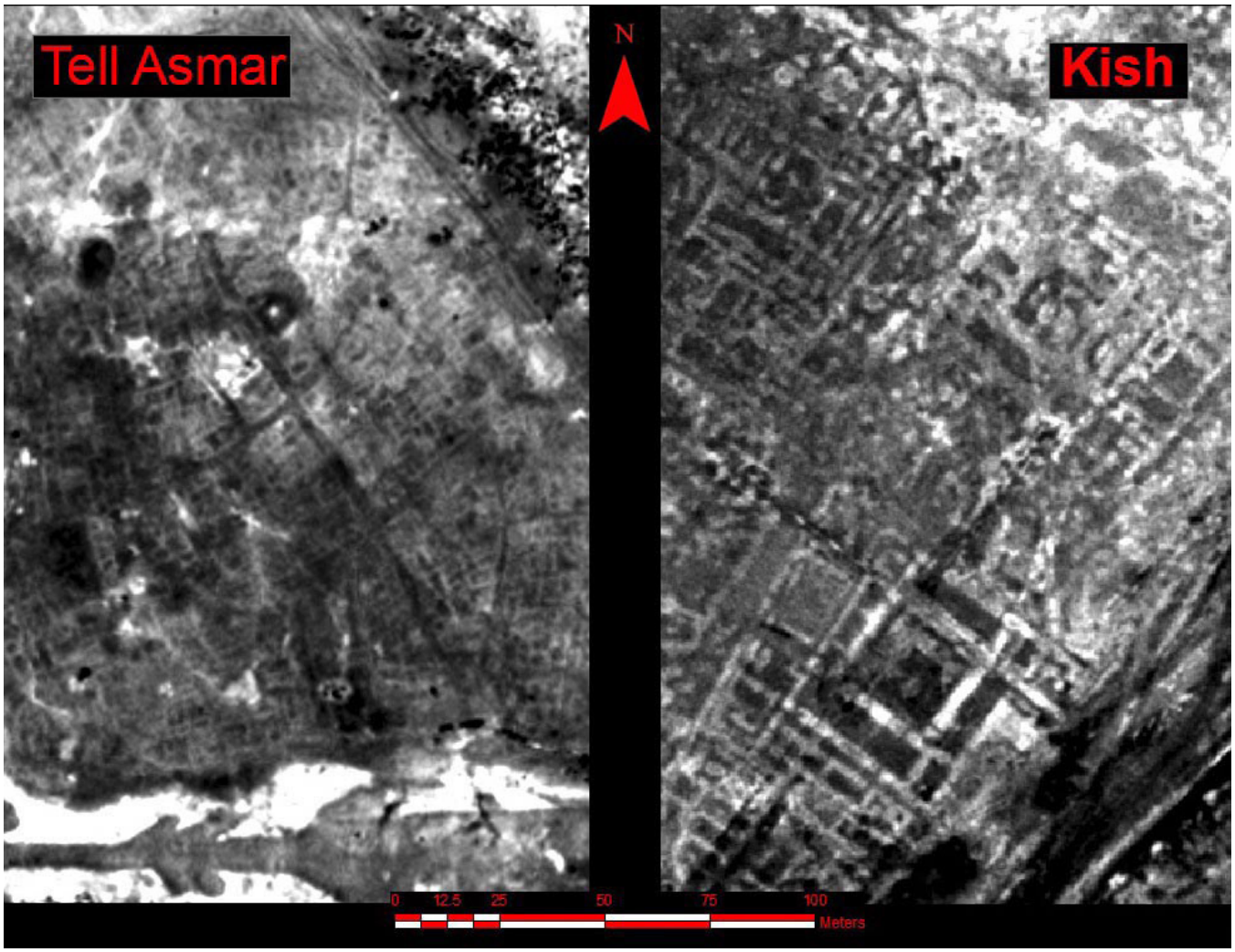


FIGURE 2. Traces of Old Babylonian domestic architecture at Tell Asmar and early palaces at Kish (imagery reproduced courtesy the Digital Globe Corporation).

RESULTS

In spite of the lack of rainfall in southern Mesopotamia, 97 sites were identified (Figure 2) with sufficient surface traces of architecture to provide a good to excellent understanding of their internal organization (Figure 3). The temporal distribution is, however, variable. Although one Neolithic Ubaid site, dating to the fifth millennium B.C., has good traces (shown in Figure 4), little evidence is preserved of site surfaces dating to the fourth millennium because most are located in desert areas lacking the high-saline water table necessary for making subsurface architecture visible.

For later sites, we have three periods with good coverage and one that is not as good. Sites with surfaces dating to the mid-third millennium B.C. are not particularly common, yet two urban sites and three smaller sites have extensive traces recoverable from imagery. Old Babylonian sites, dating to the early second millennium,[4] are by far most common, whereas only a few of the somewhat later Kassite sites have preserved architecture. The last time period represented in the imagery is seen at sites like Babylon, which date to the Neo-Babylonian and Achaemenid period during the first millennium B.C.

THE ARCHITECTURAL DATA SET

The architectural patterns derived from the satellite imagery are very different from those obtained from excavation. Whereas only 8 percent of published architecture was excavated at sites less than 40 hectares in size, 50 percent of the walls visible in the satellite imagery comes from these smaller sites, providing key data on the changing organization of settlement in the countryside over time. Moreover, excavators have prioritized the recovery of large public buildings, with domestic quarters making up less than 12 percent of the excavated area, yet 83 percent of the architecture seen in the satellite imagery is domestic.

What remains problematic is the dating of the surfaces. The survey notes provide a brief description of the dated ceramics obtained from the surface, but only occasionally indicate

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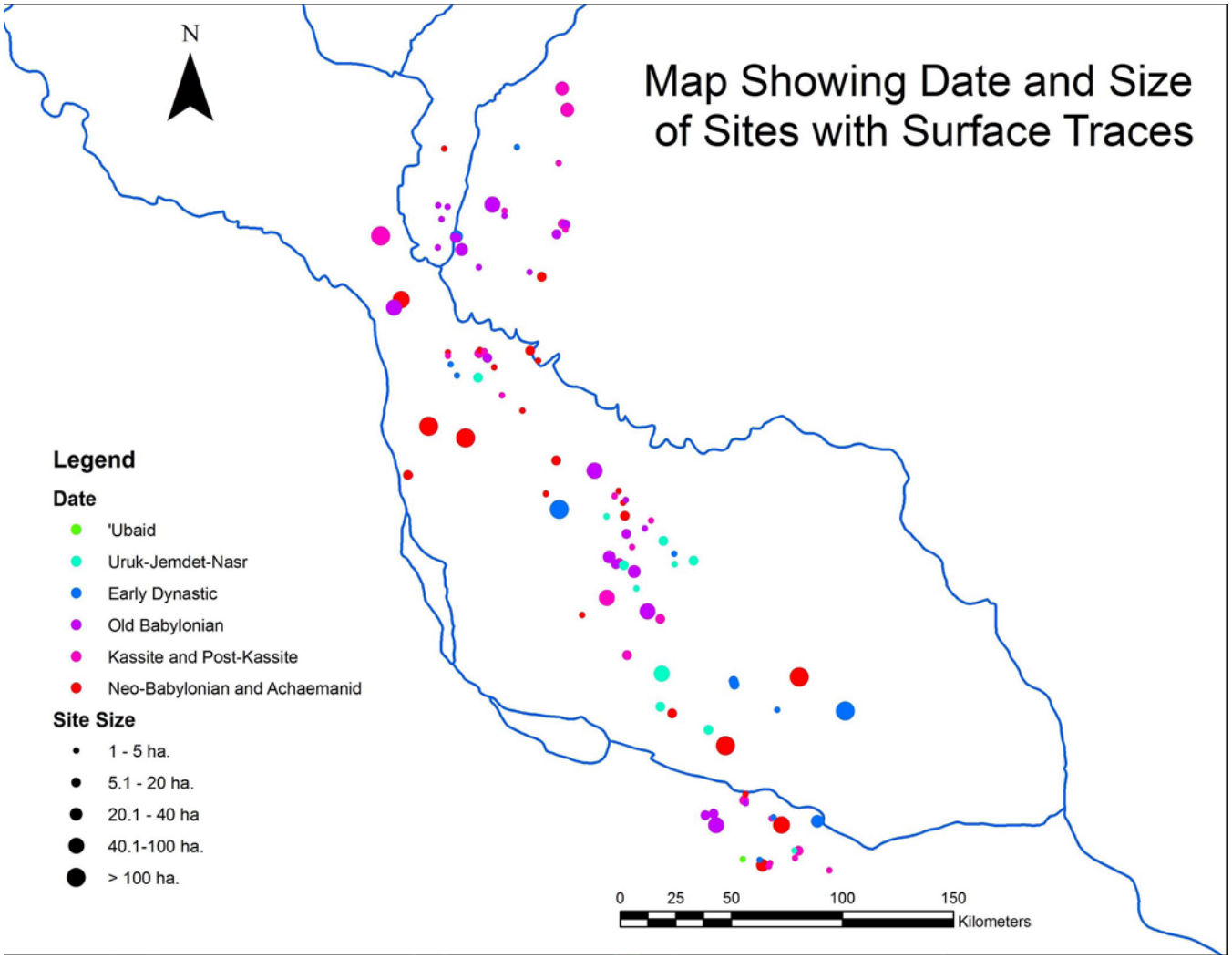


FIGURE 3. Size and date of sites with surface traces.

whether these were clustered in one part of the site or broadly distributed. For this reason, the only long-lived sites included in our sample are those where archaeological excavation has provided additional chronological detail. Otherwise, no site in our sample was occupied for more than three successive time periods. The validity of this approach is demonstrated through the consistency of patterning between sites thought to be contemporary. Indeed, in the one instance where the published terminal date of a site conflicted with the architectural pattern observed, a check with the field notes housed at the Oriental Institute in Chicago demonstrated that the later occupation period was based on a single sherd, whereas the earlier, more likely occupation yielded many.[5]

Digitizing Architectural Traces

Not surprisingly, the majority of the architectural traces preserved in these images are of domestic architecture where, as indicated above, wall traces are little more than one pixel in width. Because the key to differentiating walls from room fill are matters of light and dark, rather than color, and given that QuickBird's high-resolution data are confined to the panchromatic band, all new imagery was purchased as panchromatic, and imagery already on hand was converted to greyscale.

At ca. 60 cm, the width of house walls are only one pixel wide, making the architecture difficult to resolve. To compensate, the pixel size of all images was reduced by a factor of 5, resulting in QuickBird imagery with .12-m pixels and WorldView images with .1-m pixels. A 5-×-5 low-pass filter was then applied to smooth the results (Figure 5).[6] Contrast stretches (see below) were key to clarifying the details preserved in the imagery, but filtering reduced the clarity of the less-obvious features and was avoided.

The most successful digitization of architectural traces generally requires multiple images taken after different temporally spaced rainstorms as both different parts of the site and individual walls vary in clarity between images (Figure 6). Moreover, although stock imagery from Digital Globe is georeferenced, this is not exact, so the first step is the exact alignment of all of the images, which can contribute to the final plan of a particular site. A single point that could be associated with a feature that is

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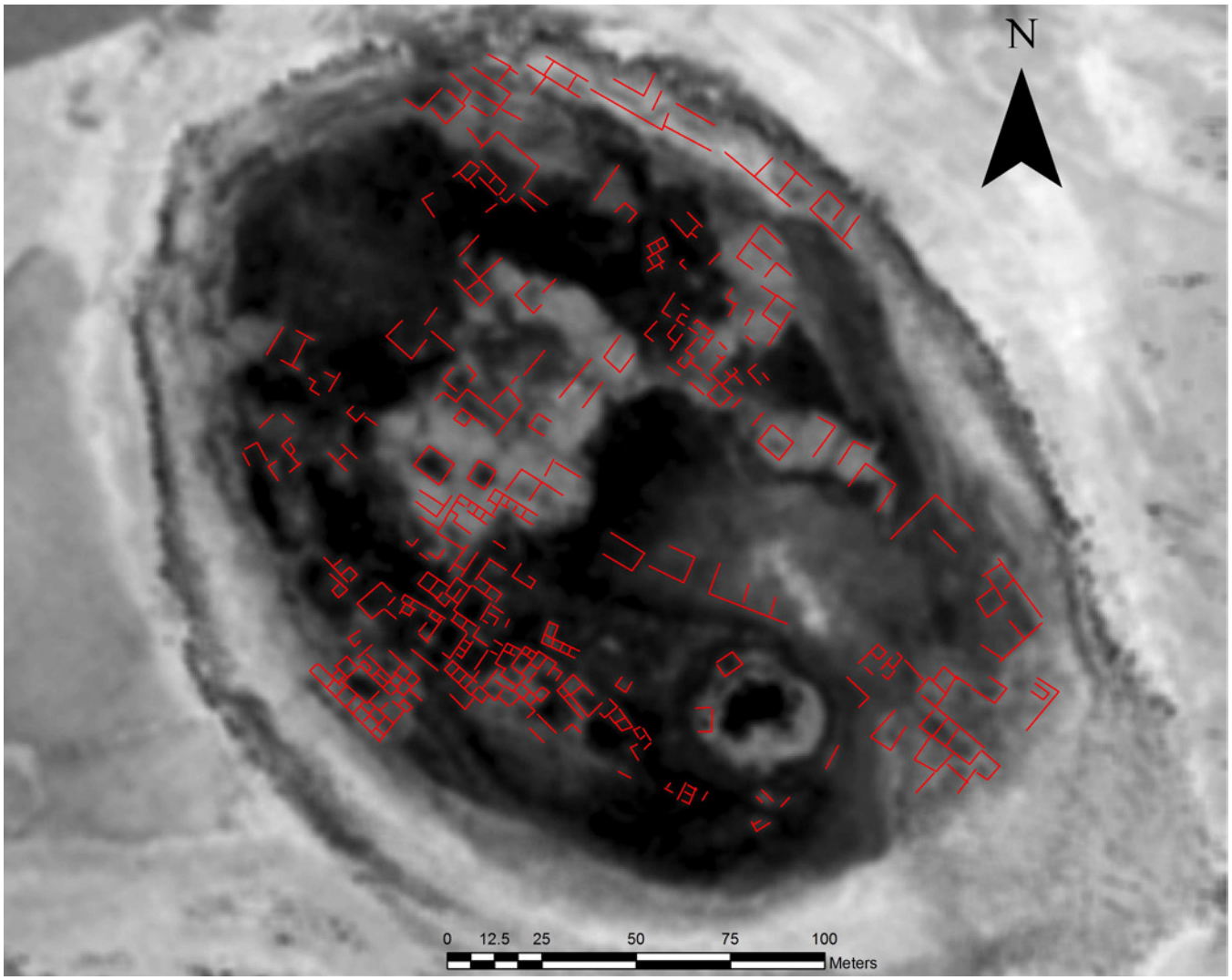


FIGURE 4. Eridu Survey Site 104 (imagery reproduced courtesy the Digital Globe Corporation).

clear in each image would be identified and the images shifted until exactly aligned. For larger sites, this needs to be repeated multiple times for different parts of the site because there are also slight variations in the geometry of each image.

Once aligned, those processed images with useful architectural traces were opened in Arcmap using contrast stretches based on the standard deviations of the imagery in the display extent (Figure 6). Digitization needs to be done by hand and is a very iterative process as each useful image is checked. By using the display extent for the contrast stretch, the process of digitization automatically increases the contrast of the top image in the area digitized, which often further clarifies the underlying pattern. When this automatic increase in contrast becomes excessive, a little panning reverts the image to its original state. This is a slow and challenging process that is not easily delegated, and so far I have been able to digitize only a handful of sites fully, although preliminary work has been conducted on many others.

KEY QUESTIONS IN MESOPOTAMIAN ARCHAEOLOGY

As indicated above, high-resolution satellite imagery provides a random sample of Mesopotamian architecture because the modern irrigation that makes these visible is the end product of millennia of shifting water courses, such that there is no relationship between the locations of modern watercourses with those of the past. These architectural traces nearly triple the total area of known architectural data for Mesopotamian sites. They have more than doubled our knowledge of the layout of public architecture, the focus of research by early archaeologists, and expanded the area of domestic architecture fivefold, including on many of the small sites only rarely explored through excavation. The remainder of this article highlights three key questions that these data can help to resolve and that are of significance not only to our understanding of ancient Mesopotamian settlement in particular, but also to our understanding of early complex society in general. The first concerns the loca-

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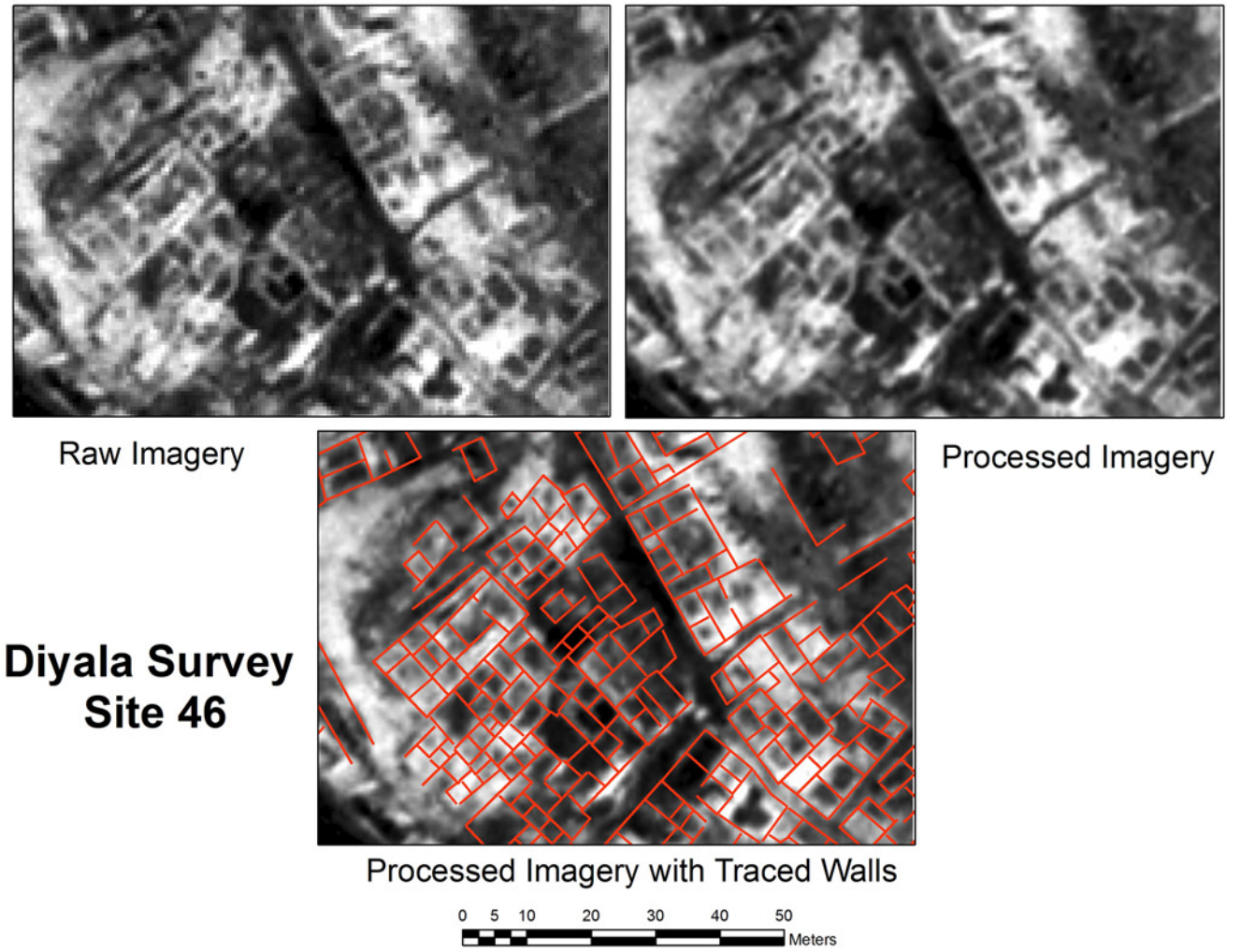


FIGURE 5. Diyala Survey Site 46: Raw imagery, processed imagery and with traced Walls Kish (imagery reproduced courtesy the Digital Globe Corporation).

tion of public buildings whose centrality is often understood as symbolic of the central control of the state. The second focuses on domestic areas, where the variable scale of housing within and between neighborhoods can be considered indicators of the social differentiation of their inhabitants. The third focuses on the role played by small settlements, the types of sites only rarely investigated through excavation.

The Location of Public Buildings

Public buildings—temples and palaces—have been the focus of the bulk of excavations at major sites (Supplemental Table 1). The location of public buildings is important. On the one hand, clusters of secular and religious structures in the center of a city symbolize the power of the political and religious elite. On the other hand, when these structures are scattered throughout the city, or are at the periphery, this reflects the presence of multiple sources of authority and less-centralized political power. Mesopotamian ziggurats, high towers with the temple of the city god at the top were clearly the most visible feature of Mesopotamian cities. Many were located toward the edges of the sites, such as those at Nippur and Ur; others are somewhat more centrally located, such as that at Uruk. Excavated palaces are rare, but the best known, the Sinkashid palace at Uruk (Lenzen and Bottéro 1966:Plate 35) and the early twin palaces at Eridu, were located on separate mounds at the far edges of these sites (Safar et al. 1981); although at very small sites, like Tell Harmal (Baqir 1959) and Haradum (Kepinski-Lecomte 1992), administrative and religious centers were found opposite one another along the main street. In general, the excavated data suggest that centralizing institutions were dispersed in Mesopotamian settlements, although the data from the small sites do give us pause. The preservation of traces of public buildings, often clear in the satellite imagery as a result of their thicker walls and larger rooms and courtyards, allow a broader exploration of this issue.

Clear evidence for the location of the earliest palaces, those dating to the late Early Dynastic Period, was provided by excavations at Eridu and satellite data at Kish and a mixture of surface observation and satellite imagery at Abu Salabikh. At Eridu, excavations uncovered a pair of more-or-less identical palaces. Their function was made clear by their plan in which each had the square courtyard leading via double doors into a

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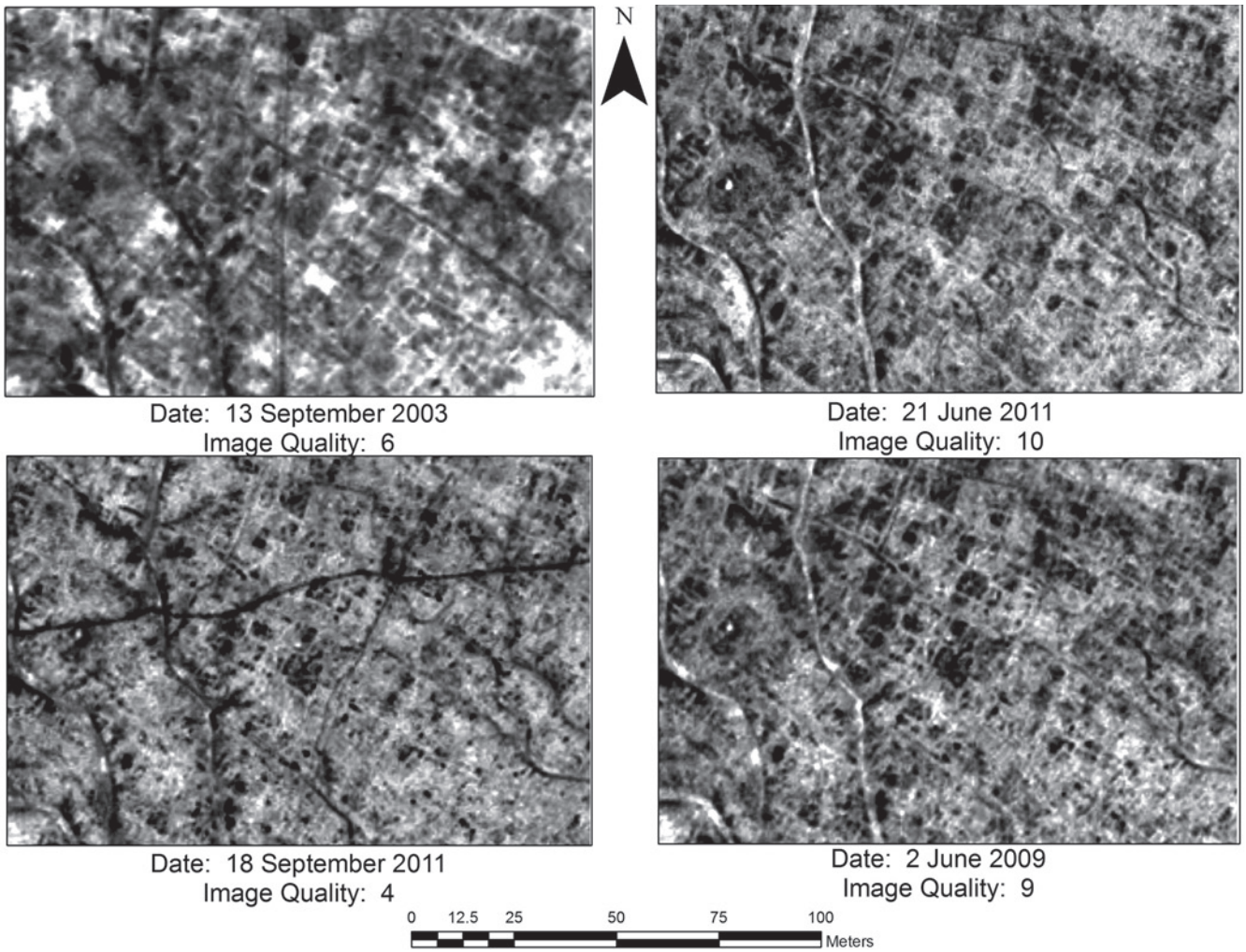


FIGURE 6. Multiple Images of part of the site of Lagash (imagery reproduced courtesy the Digital Globe Corporation).

rectangular throne room known from later palaces dating as late as the time of Nebuchadnezzar (Margueron 1982). Very similar structures, but three of them in this instance, can be seen in satellite imagery from Kish (Figure 2). Like those at Eridu, these are located a half-kilometer away from the temple, and suggest that the "Palace" A, located next to the temple and bearing no architectural similarity to any other palaces must have served some other function.

At Abu Salabikh, the excavators recorded surface traces of a small part of a building with the double walls typical of the third millennium palace at Eridu and the palaces at Kish, located on the south mound, an area separated by an ancient watercourse (Wilkinson 1990) from the main mound generally understood to have included the main temple. Satellite imagery suggests that these were associated with a large public building at least some of whose walls were double. The only complication is that we see two different orientations, perhaps indicating the traces of two, differentially eroded, periods of construction.

The images of these buildings make it clear that from the very beginning palaces were located as distant as possible from the main temple. The recovery of the palaces at Kish is especially important here, because they allow us to rethink the role of "Palace" A with its location suggesting an association with the neighboring temple.

A similar pattern can be seen at later sites. We conducted survey work at Mashkan-shapir between 1987 and 1990, which allowed us to locate a majority of the activity areas within the city—temple, manufacturing, cemetery, and so forth—but not the palace, even though it is well documented in the cuneiform literature. Mashan-shapir was a short-lived planned city, created through the expedient of building a city wall (Stone and Zimansky 2004) and therefore likely to conform to Mesopotamian ideals of urban organization. Since our work there, the surrounding desert has been replaced by irrigation agriculture that has led to the preservation of extensive architectural remains on the surface, including the traces of a 50×50-m building at the very north of the site, as far away from the temple as possible, with quite visible traces of a large square courtyard leading into a rectangular room via twin doorways—the hallmark of palace architecture.

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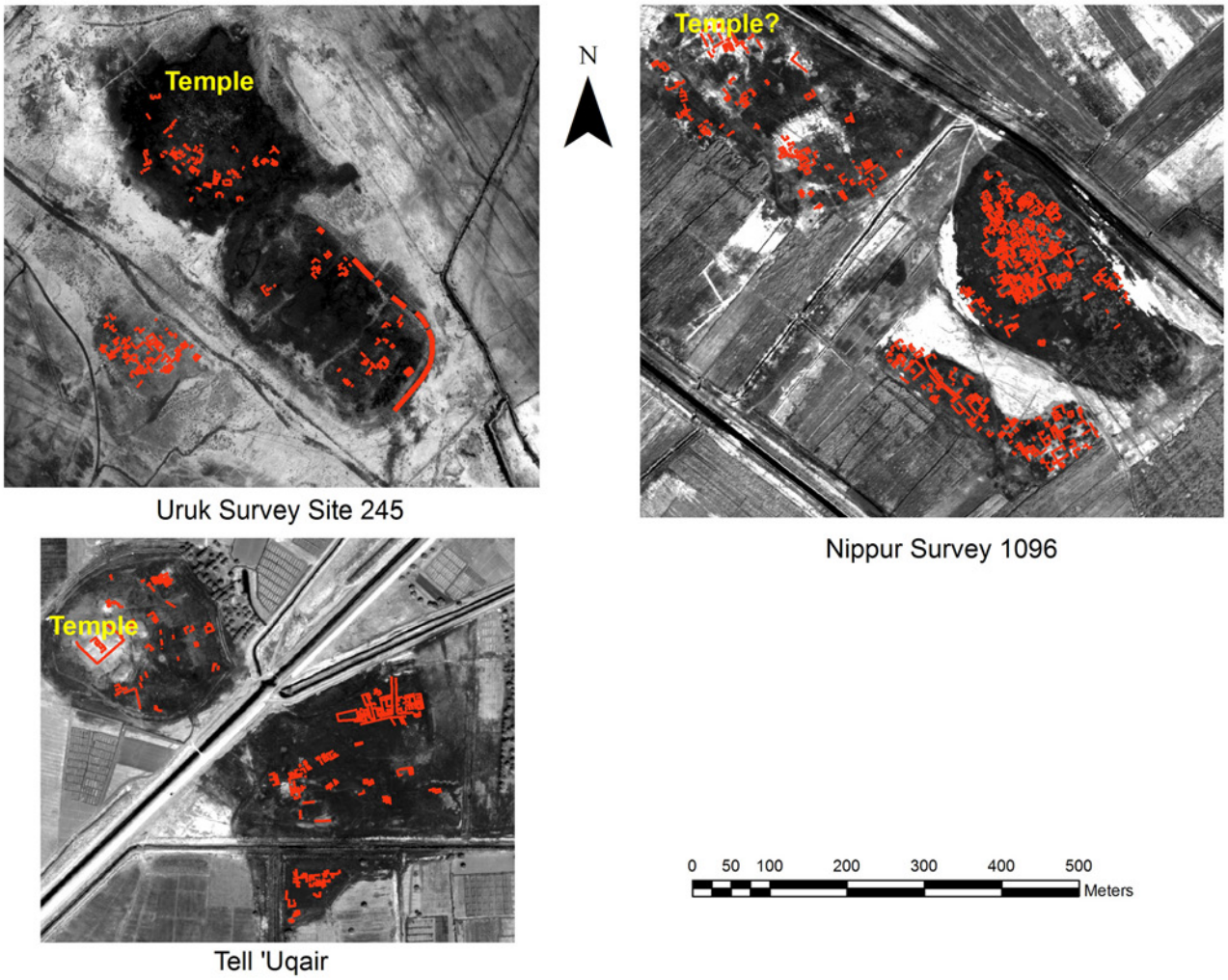


FIGURE 7. Jemdet-Nasr period site plans (imagery reproduced courtesy the Digital Globe Corporation).

When you add to these data the many instances where less-well-defined public buildings are seen toward the edges of sites large and small in the imagery, the evidence is overwhelming that Mesopotamians located their public buildings at the edges of sites, and kept their religious and secular centers as far from one another as possible.

Assessing Inequality in Domestic Architecture

There have been, and continue to be, extensive debates over the degree to which all complex societies were based on high degrees of inequality (Flannery and Marcus 2012; Trigger 1993), a debate that is reflected in the literature on Mesopotamia (Pollock 1999; Postgate 1994). These issues are difficult to resolve given the emphasis of archaeological excavation on large public buildings—the structures most closely associated with the elites. But, as is clearly evidenced in Supplemental Table 1, the imagery makes no such selection, making available an extensive sample of domestic architecture, derived from sites large and small, dating to the entire range of periods of occupation (except the Uruk). The key factor that drives the organization of domestic housing in Mesopotamia is crowding, so the mean size of domestic spaces varies widely between sites. This is, perhaps, not surprising because residence is constrained by the city walls. Often short-lived sites have larger-scale domestic architecture than long-lived ones, and smallish sites with very important temples have exceptionally cramped housing. But if we are interested in inequality, it is not differences in the mean size of housing that is of interest but, rather, the degree of differentiation in housing size within sites. Because the doorways in domestic architecture are almost always smaller than the pixel size of our imagery, we cannot resolve actual houses in the dense party-wall housing complexes. But what we can do is measure spaces and compare both mean space sizes within sites and the degree of differentiation in room sizes both within and between sites. Gini coefficients, used most often to compare income inequality between countries, were calculated for this purpose. The Gini coefficient is a measure of statistical dispersal that ranges from a low (0), where all have identical incomes, to a high (1), where one person has all of the wealth.[7] Because large excavated houses have larger spaces than small ones ($R = 0.7493$, $p = 0$, $N = 101$), high Gini coefficients reflect greater house size differentiation within neighborhoods. Where physically separated domestic

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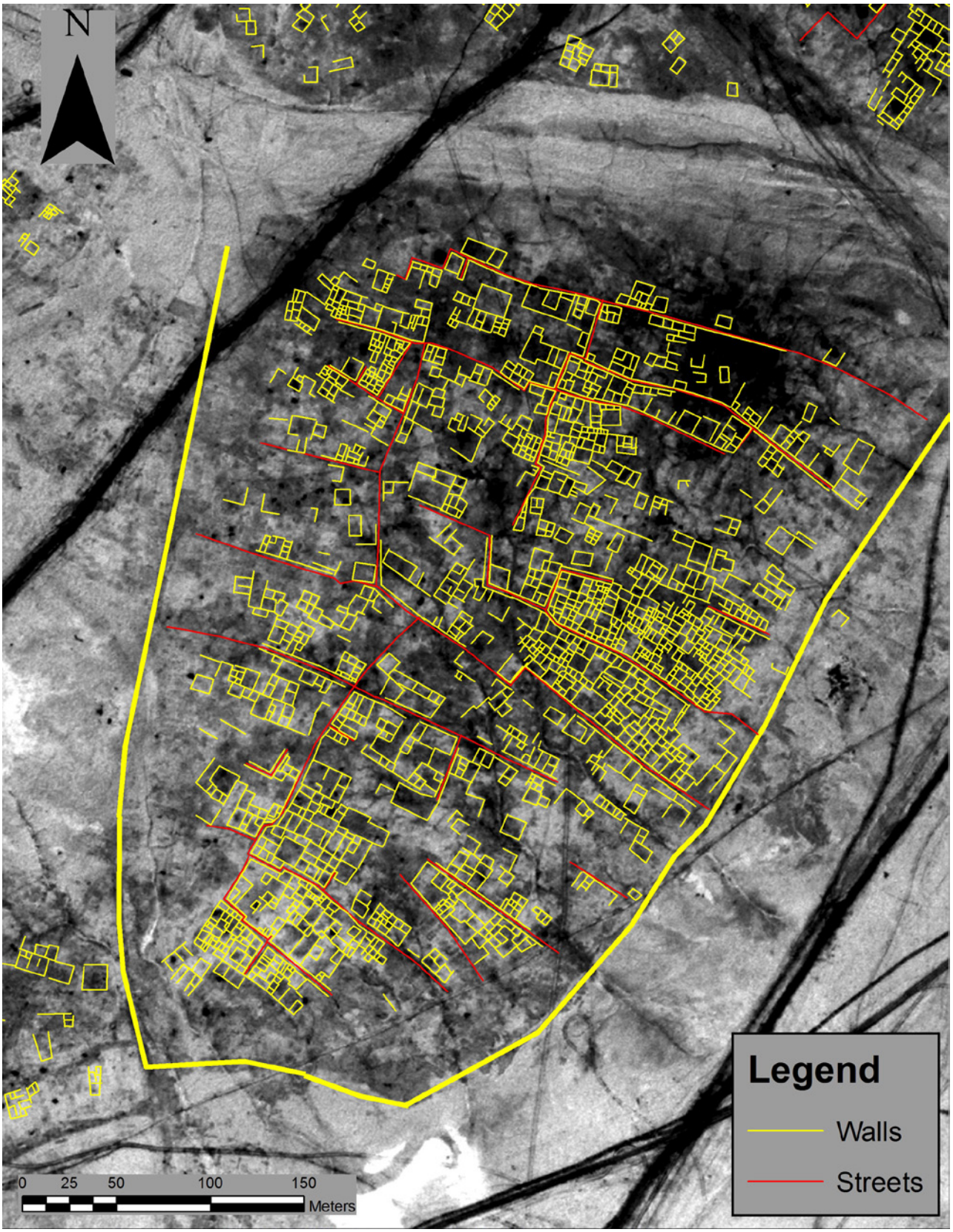


FIGURE 8. Architectural traces in the northern part of the Early Dynastic site of Lagash (imagery reproduced courtesy the Digital Globe Corporation).

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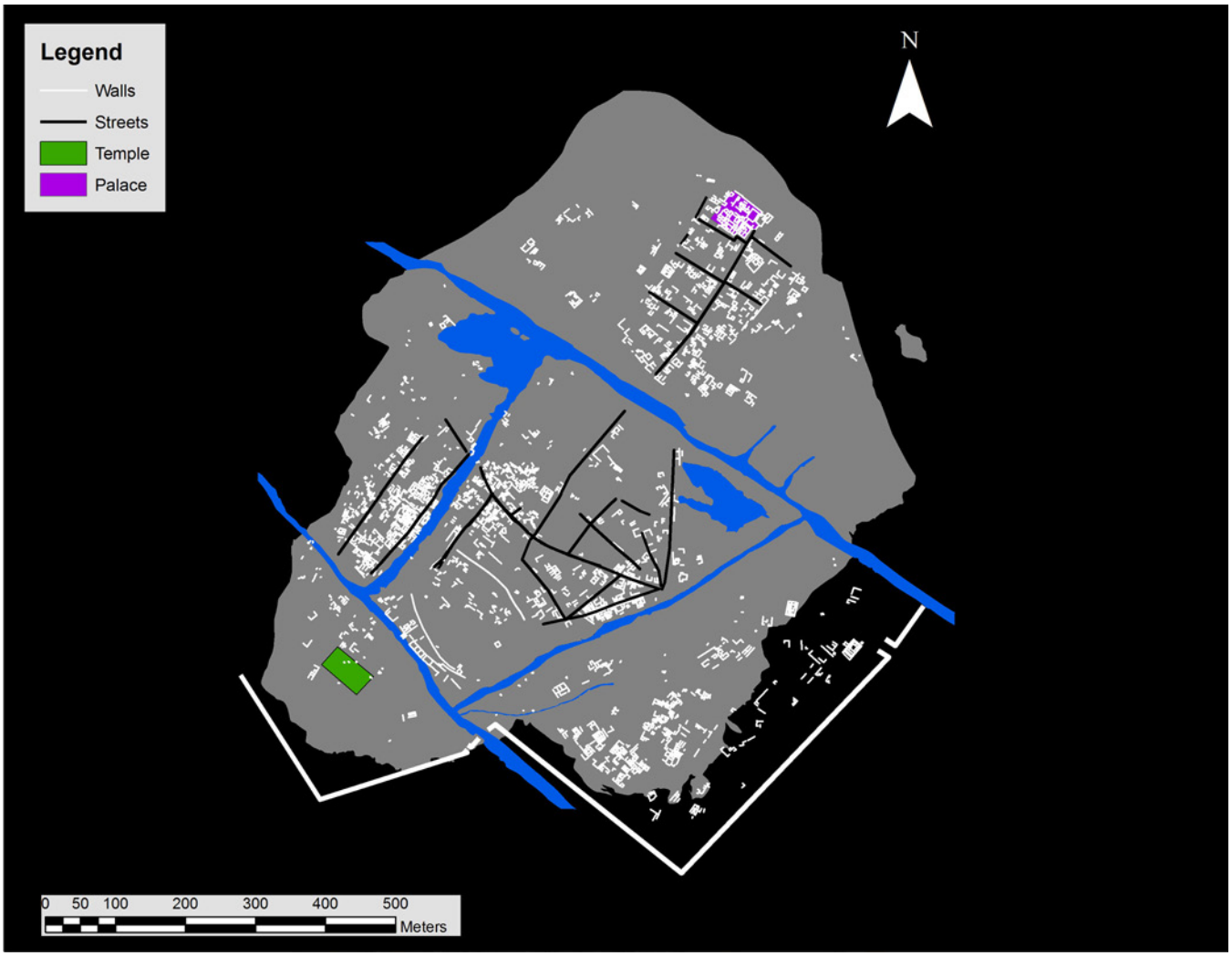


FIGURE 9. Plan of Mashkan-shapir based on both survey and satellite imagery.

architectural traces are visible within individual sites, it becomes possible to evaluate differences in both mean room size and differentiation within sites.

This approach suggests that early sites, those dating to the Uruk and Jemdet-Nasr periods were indeed quite differentiated, exhibiting significant differences in mean room size between site sectors and with quite high Gini coefficients in each area. However, these differences are erased with the shift to the dense courtyard houses and significant growth of cites in the mid third millennium. It is only after the Old Babylonian period that we seem some increase in differentiation, and even the Neo-Babylonian houses do not exhibit as high a degree of differentiation as seen in the earliest stages of Mesopotamian urbanism. These data indicate considerable dynamism in social relations over time and suggest a need to rethink how we perceive the dynamics of early civilizations (Baker 2010, 2011). But this approach would need to be applied to comparable domestic areas in other early civilizations before its broader significance can be assessed.

Assessing the Role of Small Settlements

Archaeologists have long tended to focus on large sites (where present) at the expense of small ones. The result has been to assume that small sites were little more than rural outposts, housing the farmers so necessary for the support of the larger cities. The two excavations of small sites that have been undertaken, both of which date to the Old Babylonian period (Baqir 1959; Kepinski-Lecomte 1992), have revealed settlements that differ in no way from the excavated results of the larger cities, except that their temples and administrative buildings were at a much smaller scale. Their inhabitants were equally literate, pursued the same activities, and had access to the same suite of objects as their urban counterparts.

Although the artifactual inventories that indicate similar patterns in large and small sites are invisible in the imagery, the patterns of housing are not, allowing a comparison in overall use of space between large and small sites. Of the sites in Supplemental Table 1, 43 percent are less than 5 ha in size and all time periods

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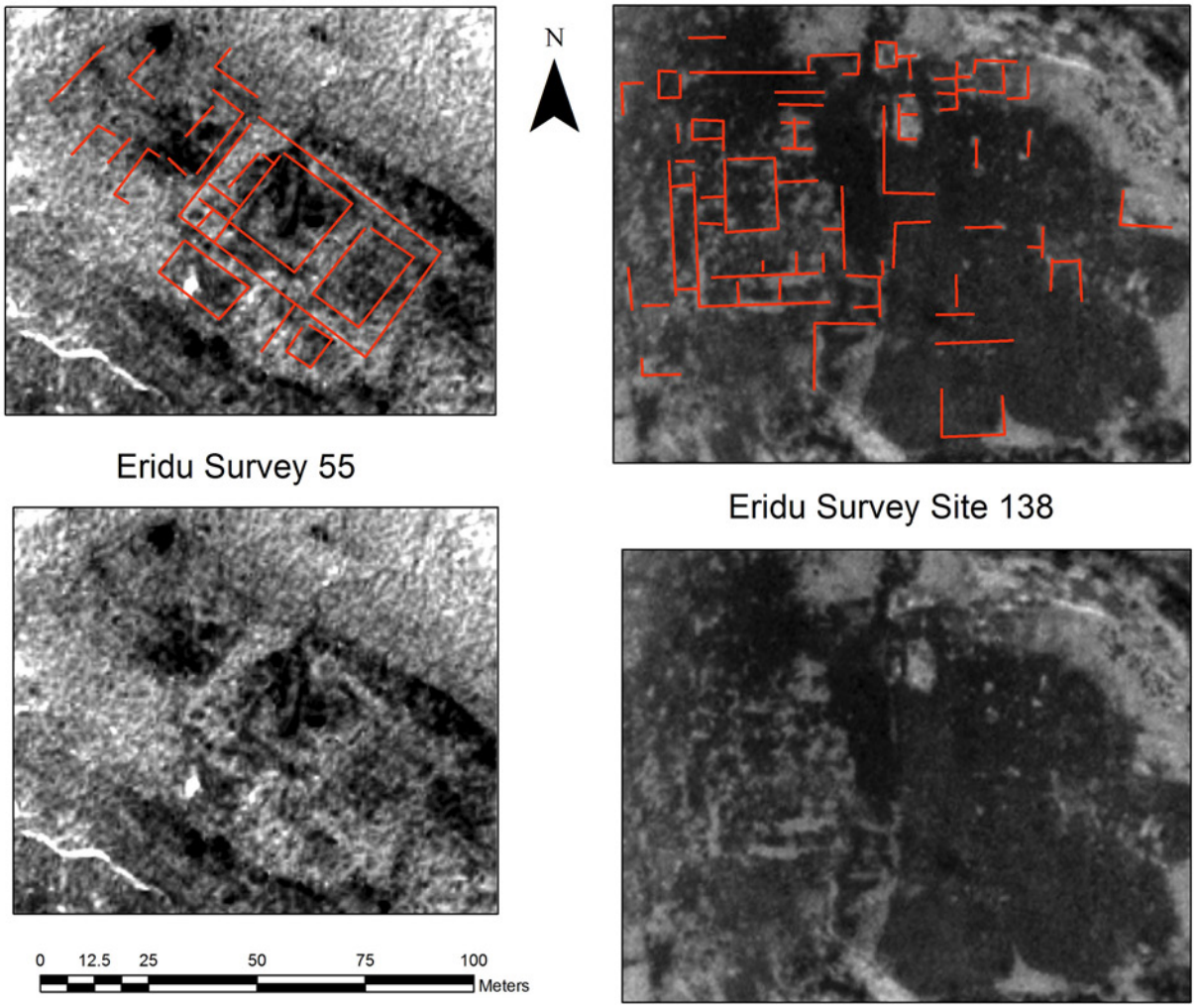


FIGURE 10. Small Kassite sites with large buildings (imagery reproduced courtesy the Digital Globe Corporation).

are represented. These data make clear that Tell Harmel and Hardum were indeed typical of their time and can be matched in density by these many other small contemporary sites. But this was not the case for the Kassite and Post-Kassite periods. Instead, many small sites have only traces of public buildings, although these are generally not very large. Only one has traces of what appears to be domestic architecture, and that is not particularly well preserved. Domestic architecture similar to that seen in urban centers is once again typical of the smaller Neo-Babylonian settlements.

It is the combination of the random nature and sheer volume of the architectural traces that makes possible the exploration of many of the questions regarding patterns of settlement that are key to understanding early complex societies. Were similar research carried out in other geographic areas, some of the disputes among scholars investigating early complex societies might be resolved.

CONCLUSION

The high resolution of today's commercially available imagery may well revolutionize our understanding of the archaeological record of complex societies. Most archaeologists have used imagery to understand broad patterns of settlement over time and space, while the internal details of those settlements have remained largely unknown. The excavated record of Mesopotamia, and indeed of most early complex societies, is dominated by information on public buildings at large sites, leaving our understanding of the underlying social structure largely uninvestigated. Moreover, although cuneiform tablets provide key written data, in most instances their archaeological findspots are unknown, either because they were never recorded, or, too often, because they were recovered through looting. As a result there have been long-standing disputes among archaeologists as to whether complex societies in general were fundamentally unequal (e.g., Flannery and Marcus 2012) or quite variable (e.g.,

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Bruce Trigger 1993, 2003). A similar divide exists between the two main textbooks in Mesopotamian archaeology (Pollock 1999; Postgate 1994) and similar arguments exist between those working on other complex societies.

Satellite imagery has long played a moderating role in these discussions by focusing attention on broad settlement patterns rather than on the details of public buildings or royal graves. Much of the early survey work in Iraq used aerial photographs to identify and locate sites (Adams 1965:24, 1981:28-33; Adams and Nissen 1972:4-5; Wilkinson and Tucker 1995:25), but the process of developing photo mosaics was a slow and arduous process. The first major breakthrough here was the declassification of Corona imagery, which required no permission from local governments. At least for the Near East, the use of Corona imagery has allowed the detailed reconstruction of both sites and the communication systems that linked them with their hinterlands and each other over a much broader area than would have been possible otherwise. Yet even as these have made a very important contribution to our understanding of the interaction spheres of those living at all levels within the larger landscape, they cannot reveal information on social relations between and within sites, the vast majority of which remain otherwise uninvestigated except through surface survey and dating.

In the same way that Corona imagery has revolutionized our understanding of broad settlement patterns (e.g., Ur 2003), so can high-resolution imagery open our eyes to the internal organization of these settlements. Because similar conditions of salinization exist in the Egyptian Delta and the Indus Valley, a similar approach, following the same decision-making processes used here to select images, should work well. MODUS imagery's ability to predict consistent rainfall is limited in the desert areas of southern Iraq during a decade of drought. The impact of the few sustained rains that occurred was clear enough in these data, but they were simply too rare to be useful. In areas where there is sufficient rainfall to sustain agriculture, however, MODUS imagery could be used to identify narrow time spans when differential drying of mud-brick walls and room fills might be visible following significant rainfall events, allowing efficient exploitation of available high-resolution imagery.

This article ended with a discussion of changes in settlement patterns over time in southern Mesopotamia, which need not be recapitulated here. What is important, though, is the degree to which archaeologists, myself among them, tend to assume that the best preserved period within a long sequence can be understood as typical of the society as a whole. Unless early complex societies collapse like the Maya, archaeologists tend to depict them as quite static once fully established. The Mesopotamian data presented above, however, suggest the existence of multiple, quite dramatic, changes in organization. The earliest cities appear quite differentiated, with each mound having a different character. Sites dating to the best-known time periods, the late Early Dynastic and Old Babylonian periods, exhibit a high degree of consistency and it seems likely that the intervening Akkadian and Ur III periods were similar. The shift toward very rural settlement in the Kassite period, suggested also by the written documentation, is clearly shown in the satellite data, because domestic housing is almost invisible in the current record. The resurgence of urban life, based on a new social contract, can be seen in the sites dating to the first millennium B.C.

This broad-brush view of the trajectory of Mesopotamian settlement can only be drawn through the combination of the limited and often selective excavated data and the random sample of architecture recovered from the high-resolution satellite imagery. Although we generally consider high-resolution imagery too expensive to be used in so broad a fashion, applying the methods used in this project to select imagery to similar environments might well give an equally broad view of settlement at the cost of little more than one major field season.

Data Availability Statement

All imagery used for this project is copyrighted data licensed from DigitalGlobe and permission for use is limited to those who contribute directly to this project. The digitized plans derived from satellite images are currently a work in progress, with the exception of those included in this volume. Final plans will be published in a summary of project activities in a separate stand-alone volume.

Supplemental Materials

Supplemental materials are accessible via the SAA member login at http://saa.org/home/tabid/

Supplemental Table 1. Excavated and Satellite Derived Architecture in Mesopotamia

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NOTES

1. The site looting project was supported by grants from the National Endowment of the Humanities, the U.S. State Department Cultural Division, the National Geographic Society, the Joukowsky Foundation, the National Science Foundation, and private donors.
2. Note that the values used are pertinent to the situation in southern Iraq and cannot be expected to be the same in other places.
3. These sites were all within the Uruk, Nippur, and Eridu survey areas, which encompass a larger proportion of desert than is present in Akkad and the Diyala.
4. There are some issues with the chronology of sites in the south. The earliest surveys were conducted in the north, in the Diyala and Akkad regions, where a quite clear sequence of occupation from Ur III to Old Babylonian to Kassite is known from the excavated examples. Since the time of the surveys, we have realized that much of the south was largely abandoned for most of the Old Babylonian period (Stone 1977). But the surveys distinguished between dates in the late third to early second millennium (Ur III/Isin-Larsa) and those of the somewhat later second millennium (Old Babylonian), which probably do not exist. Because many of the abandoned sites were never reoccupied, it seems likely that most of the surfaces given either of these designations date to the early second millennium, although some might be a little earlier.
5. This is Diyala Site 46, illustrated in Figure 5.
6. Note that the image shown in Figure 5 is one of the two best examples of preservation of domestic architecture in the imagery.
7. The Gini Coefficient is based on the Lorenze curve and is most often used to evaluate income inequality.

   The Lorenz curve plots the cumulative share of income held by the cumulative tenths of households ranked from the poorest to the most affluent. If each successive 10 percent of households held 10 percent of total income, then the curve would be a diagonal line at 45 degrees. The greater the income disparity between tenths of households, the greater the bowing of the curve away from the diagonal line and the higher the Gini coefficient. The Gini coefficient ranges theoretically from 0.0 (perfect equality) to 1.0 (perfect inequality). [Kahn et al. 2000]

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