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Source: *Proceedings of the National Academy of Sciences of the United States of America*, April 3, 2012, Vol. 109, No. 14 (April 3, 2012), pp. 5146-5147

Published by: National Academy of Sciences

Stable URL: https://www.jstor.org/stable/41588115

Mapping patterns of long-term settlement in Northern Mesopotamia at a large scale

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AUTHOR SUMMARY

The scale and spatial distribution of human communities in past societies are of high interest in archaeological research. The first settlements and, hence, the longest paths of development of settlement systems can be found in the Near East, on the territories of modern Iran, Iraq, Turkey, Syria, Jordan, and Israel. A characteristic property of these settlement sites is mounding, which is a result of millennia of continuing settlement activity at especially meaningful places (1). So far, however, mounding has not received much attention or even been the subject of systematic evaluation. In this study, we demonstrate the use of mounding in mapping patterns of a past human settlement. To this end, we develop a satellite remote sensing approach that identifies soils influenced by human activity, which allows us to map archaeological sites with an accuracy similar to that of intensive archaeological surveys but at a much broader geographic scale. We measure the volume of each recorded site in a digital elevation model and search systematically for factors that shaped the spatial patterns of the long-term settlement distribution we observe. We find that site volume, an underappreciated feature of ancient Near Eastern settlements, has great significance for describing generalized long-term patterns of human settlement and land use, and we illustrate its particular relevance as an indicator of past populations in spatial analysis.

Settlement mounds can be identified under ideal conditions through the multispectral signature of anthrosols, which are soils that have been heavily modified through the addition of materials from collapsed mud-brick architecture and household wastes; anthrosols are often lighter and brighter than the soils of their surroundings (1, 2). To map these sites, we employ machine learning classifiers to find areas that display a signature similar to the one observed at known nearby archaeological sites in multispectral Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images. We propose a multitemporal classification strategy—pooling information from all ASTER scenes available at a given location—which returns an anthrosol probability map that is largely free of noise from the short-term variation of the spectral signal (Fig. P1*A*). The map highlights only those locations that resemble known archaeological sites *consistently* over several years of observation. We test this classification strategy in the Upper Khabur Basin in northeastern Syria, a critical locus for the study of the origins and development of urbanism in the Near East, and obtain a 23,000-km^2 map showing the locations of anthrosols at a 10-m resolution (available from http://hdl.handle.net/1902.1/17731). A comparison of our results with the ground truth from large regional surveys shows that about 90–94% percent of the 750 sites recorded around major settlement mounds in the Basin (Tells Brak, Leilan, Hamoukar, and Beydar) can be found in the anthrosol map. In the case of Tell Brak, the largest settlement mound in Northern Mesopotamia, areas of high surface sherd density and high probability of anthropogenic soils correlate almost precisely (3) (Fig. P1 *A* and *B*).

To identify those settlement sites that were occupied over longer time spans, we use the Shuttle Radar Topography Mission digital elevation model (4). In this stage of analysis, we estimate the volume of the 14,312 sites recorded from the anthrosol map. Of these sites, 9,529 are also significantly mounded, with a total volume of 700–940 million m^3. As a comparison, the debris of a single-household mud-brick building occupied for one generation is estimated to be 20–100 m^3, providing a rough, indirect measure of the total

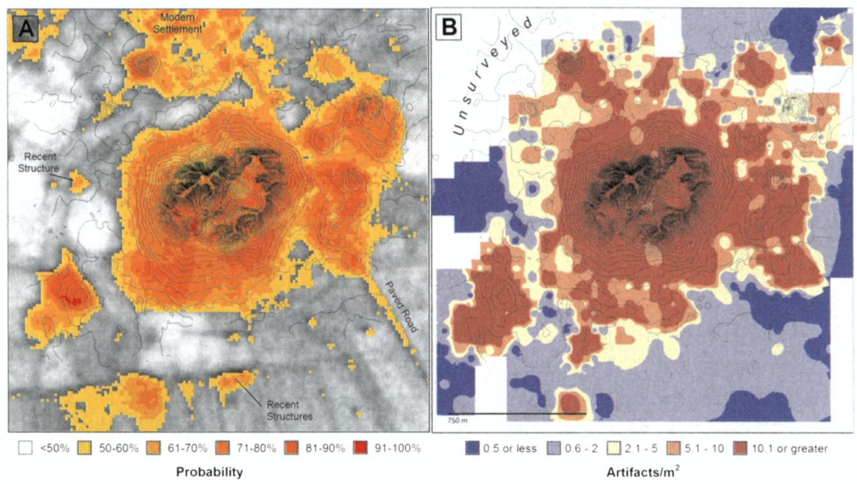

Fig. P1. Mapping anthrosols and settlement mounds. An anthrosol probability map (*A*) and results from archaeological ground survey (3) (*B*) for Tell Brak, the largest settlement mound in Northern Mesopotamia. The mound is visible in the center from the isolines indicating height. Areas of high anthrosol probability nearly correlate with areas of high sherd density at pixel level.

Author contributions: B.H.M. and J.A.U. designed research; B.H.M. and J.A.U. performed research; B.H.M. contributed new reagents/analytic tools; B.H.M. and J.A.U. analyzed data; and B.H.M. and J.A.U. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Data deposition: Anthrosol map and derived data products can be downloaded from the Harvard Institute for Quantitative Social Sciences data repository via http://hdl.handle.net/1902.1/17731.

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See full research article on page E778 of www.pnas.org.

Cite this Author Summary as: PNAS 10.1073/pnas.1115472109.

premodern sedentary population in the Basin, which would amount to 10–40 million households.

The accumulated anthropogenic debris represents the aggregate of approximately 8,000 y of sedentary agricultural populations. Settlements evolved initially during the Neolithic period (*ca.* 7000 B.C.) and developed into the "landscape of tells" (1) we now find in the Upper Khabur Basin. Using volume as a proxy for continued occupation, we consider the factors that might have been significant in shaping the observed spatial patterns of this past population.

We correlate the integral settlement volume per area—as a proxy for the total population over time—with soil types, current precipitation, and the catchment size of the largest runoff next to a settlement (as a measure for the long-term availability of surface water). Local water availability and volume, or long-term attractiveness of a site, are exponentially related. A strong relationship also exists between site volume and nodal location within a basin-wide exchange network that can be inferred from third millennium B.C. "hollow ways" (that is, broad and shallow linear depressions believed to be formed by the continual passage of human beings and animals); these landscape features have been visible on the ground until modern times and have been recorded in a previous study (5). Surprisingly, a site's absolute size, not its geographic centrality, determines the average number of visits the site receives from travelers between sites. This result suggests that interaction in the recorded settlement network had a stabilizing effect for those settlements whose growth exceeded the limit expected from local resources, helping to sustain such sites over centuries or millennia. From a wider perspective, this correlation of past routes and past populations also suggests that patterns of movement would have been as stable as the patterns of settlement recorded in this study.

In sum, we present a remote sensing approach that systematically maps anthrosols accumulated over eight millennia, and establish the largest archaeological remote sensing record for a landscape in Mesopotamia. A critical element of our approach, the proposed multitemporal classification strategy, can be easily generalized for other detection tasks in archaeological remote sensing.

Our results can be used in the integration of published findings, planning of surveys, and heritage management at an international scale. Moreover, we show that, by measuring site volume at a large scale, it may be possible to uncover long-term trends in human settlement activity and to reveal further environmental factors that influence long-term trends and sustainable settlement in the Near East.

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