FORUM

GRAND CHALLENGES FOR ARCHAEOLOGY

Keith W. Kintigh, Jeffrey H. Altschul, Mary C. Beaudry, Robert D. Drennan, Ann P. Kinzig, Timothy A. Kohler, W. Fredrick Limp, Herbert D. G. Maschner, William K. Michener, Timothy R. Pauketat, Peter Peregrine, Jeremy A. Sabloff, Tony J. Wilkinson, Henry T. Wright, and Melinda A. Zeder

This article represents a systematic effort to answer the question, What are archaeology's most important scientific challenges? Starting with a crowd-sourced query directed broadly to the professional community of archaeologists, the authors augmented, prioritized, and refined the responses during a two-day workshop focused specifically on this question. The resulting 25 "grand challenges" focus on dynamic cultural processes and the operation of coupled human and natural systems. We organize these challenges into five topics: (1) emergence, communities, and complexity; (2) resilience, persistence, transformation, and collapse; (3) movement, mobility, and migration; (4) cognition, behavior, and identity; and (5) human-environment interactions. A discussion and a brief list of references accompany each question. An important goal in identifying these challenges is to inform decisions on infrastructure investments for archaeology. Our premise is that the highest priority investments should enable us to address the most important questions. Addressing many of these challenges will require both sophisticated modeling and large-scale synthetic research that are only now becoming possible. Although new archaeological fieldwork will be essential, the greatest payoff will derive from investments that provide sophisticated research access to the explosion in systematically collected archaeological data that has occurred over the last several decades.

Keith W. Kintigh ■ School of Human Evolution and Social Change, P.O. Box 872402, Arizona State University, Tempe, AZ 85287-2402 (kintigh@asu.edu)
Jeffrey H. Altschul ■ Statistical Research, Inc., P.O. Box 31865, Tucson, AZ 85751 (jhaltschul@sricrm.com)
Mary C. Beaudry ■ Department of Archaeology, 675 Commonwealth Avenue, Boston University, Boston, MA 02215-1406 (beaudry@bu.edu)
Robert D. Drennan ■ Center for Comparative Archaeology, Department of Anthropology, University of Pittsburgh, Pittsburgh, PA 15260 (drennan@pitt.edu)
Ann P. Kinzig ■ School of Life Sciences, P.O. Box 874501, Arizona State University, Tempe, AZ 85287-4501 (Ann.Kinzig@asu.edu)
Timothy A. Kohler ■ Department of Anthropology, P.O. Box 644910, Washington State University, Pullman, WA 99164-4910 and Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501 (tako@wsu.edu)
W. Fredrick Limp ■ Department of Geosciences, 304 JB Hunt, University of Arkansas, Fayetteville, AR 72701 (flimp@uark.edu)
Herbert D.G. Maschner ■ Idaho Museum of Natural History, 921 S. 8th Avenue, Stop 8096, Idaho State University, Pocatello, ID 83209 (maschner@isu.edu)
William K. Michener ■ University Libraries, 1312 Basehart Drive SE, MSC04 2815, The University of New Mexico, Albuquerque, NM 87131-0001 (wmichene@unm.edu)
Timothy R. Pauketat ■ Department of Anthropology, 109 Davenport Hall, MC-148, University of Illinois, Urbana, IL 61801 (pauketat@illinois.edu)
Peter Peregrine ■ Department of Anthropology, 711 East Boldt Way, Lawrence University, Appleton, WI 54911 and Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501 (peter.n.peregrine@lawrence.edu)
Jeremy A. Sabloff ■ Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501 (jsabloff@santafe.edu)
Tony J. Wilkinson ■ Department of Archaeology, South Road, Durham University, Durham, DH1 3LE, United Kingdom (t.j.wilkinson@durham.ac.uk)
Henry T. Wright ■ Museum of Anthropology, Ruthven Museums Building, 1109 Geddes Avenue, Ann Arbor, MI 48109 and Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501 (hwright@umich.edu)
Melinda A. Zeder ■ National Museum of Natural History, P.O. Box 37012, Smithsonian Institution, Washington, D.C. 20013-7012 (zederm@si.edu)

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Este artículo representa un esfuerzo sistemático para responder a la pregunta: ¿Cuáles son los retos científicos más importantes de la arqueología? A partir de una consulta masiva dirigida ampliamente a la comunidad profesional de arqueólogos, los autores aumentaron, priorizaron y refinaron las respuestas que surgieron de esta encuesta, durante un taller de dos días el cual se centró específicamente en esta cuestión. Los 25 grandes retos que emergen, se centran en los procesos culturales dinámicos y en el funcionamiento de los sistemas humanos y naturales en su conjunto. Para presentarlos aquí, organizamos estos desafíos en cinco temas: (1) surgimiento, comunidades y complejidad; (2) resiliencia, persistencia, transformación y colapso; (3) movimiento, movilidad y migración; (4) conocimiento, comportamiento e identidad; e (5) interacciones humano-medioambiente. Cada pregunta va acompañada de una discusión y una breve lista de referencias. Un objetivo importante en la identificación de estos retos es el de informar las decisiones sobre las inversiones en infraestructura para la arqueología. Nuestra premisa es que las mayores inversiones prioritarias deben ser aquellas que nos permitan abordar las cuestiones más importantes. Responder a muchos de estos desafíos requerirá adoptar tanto la elaboración de modelos sofisticados, como investigaciones a gran escala sintetizadoras que apenas ahora están siendo posibles. Aunque será fundamental llevar a cabo nuevos trabajos de campo arqueológicos, la mayor recompensa se derivará de las inversiones que proporcionen a las investigaciones sofisticadas acceso a la multitud de los datos arqueológicos recolectados sistemáticamente que se ha producido en las últimas décadas.

Archaeologists are increasingly fond of arguing that knowledge of the long-term trajectories of past societies can provide unique insights into contemporary problems and their potential solutions (Redman 2005; van der Leeuw and Redman 2002). Indeed, archaeological data and interpretations have entered political and public, as well as scholarly, debates on such topics as human responses to climate change, the eradication of poverty, and the effects of urbanization and globalization on humanity.

Adding this concern for the present to archaeology's traditional focus on the past has fostered research on coupled social and ecological systems and has led to an increasing focus on the *processes underlying* cultural transformation and change, building on the field's reconstructionist history. At the same time, archaeology as practiced in North American universities is arguably transforming itself from a subdiscipline of anthropology to a largely independent social science with strong intellectual ties to several natural and social sciences, including anthropology.

These changing research directions are clearly illustrated by the intellectual problems that we have identified as "grand challenges" for contemporary archaeological research and scholarship. The need to identify such challenges emerged from a National Science Foundation-funded effort to identify the investments in information technology infrastructure (i.e., cyberinfrastructure) that would best enhance the abilities of archaeologists—and other researchers who use archeological data—to answer the most compelling and important scientific questions. Our premise is that the highest priority investments should enable us to address the most important questions.

What are the grand challenges facing archaeology in the next 25 years? Of course, it depends on whom you ask. Our approach was to ask as many archaeologists as possible through a crowdsourcing effort. The responses were then refined to 25 major challenges through a workshop attended by the authors of this article. We first discuss the process through which the challenges were developed and then offer 25 challenges, organized into five topics, followed by a brief conclusion.

Identifying the Grand Challenges

Crowd Sourcing

Crowd sourcing uses the power of many to provide a better answer than one gained by asking just a few. Inspired by the National Science Foundation's (2011) SBE2020 initiative, our crowd sourcing was accomplished through email requests and listserv postings by the major North American and European professional associations.[1] We asked our colleagues to identify problems of broad scientific and social interest that could drive cutting-edge research in archaeology for the next decade and beyond. We received input through a Web survey that asked for a concise statement of a grand challenge problem or question and, optionally, for justification of the importance of the problem, as well as optional demographic information from the respondent.

Between April 1, 2012 and June 30, 2012, we received 181 responses identifying 190 challenges, many of which were duplicative. The Web survey defined grand challenges to be fundamental problems in science and explicitly excluded "disciplinary challenges with respect to the practice of ar-

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chaeology, such as changes in financial and legal frameworks." Nonetheless, about 40 percent (77) of the responses related to this excluded class that was not responsive to the question posed. Responses that did identify fundamental problems in science fell into two groups. One group, on which we focus here, targeted scientific questions. The second group identified methodological issues and needs, with a notable number (25) targeting inadequate access to data and the need for more comparative and synthetic research. Of the responses relating to the practice of archaeology, the most common had to do with deficiencies in training or the need for more public education.

Most respondents (79 percent of the 177 supplying demographic information) were from the US; Europe, at 12 percent, was the only other geographical area with substantial representation. Respondents were split mainly across academic (45 percent), consulting (32 percent), and government (14 percent) employment sectors.[2] Older professionals were much more likely to respond than younger ones, with over twice as many responses from those 50 or older (66 percent) as from those ages 30–49 (32 percent). The main demographic disappointment was the sparse response from younger archaeologists and students (2 percent).[3] We have no explanation for the low response; this age group was simply not as likely to respond to the request. Males constituted 62 percent of the respondents.[4] A report including the survey instrument and all the verbatim responses (including those we did not consider further) is available through the Digital Archaeological Record (Kintigh 2013).

Grand Challenge Workshop

The project steering committee[5] designed a workshop to augment, prioritize, and refine the survey's suggested grand challenges. The workshop was held on July 31 and August 1, 2012, at the Santa Fe Institute in New Mexico. The steering committee selected the participants, the authors of this paper, for their concern with "big picture" issues and to broadly represent areas of the world, diverse theoretical perspectives, and the range of social complexity. William Michener, who has led a similar effort in ecology, facilitated the workshop. Participants were first asked, individually, to suggest abstract criteria that grand challenges should satisfy. The group then compiled and prioritized the participants' lists to arrive at a consensus set of criteria. There was a strong sentiment in the workshop (also evident in crowd-sourced responses) that the grand challenge problems should not only apply to domains outside archaeology but also be relevant to contemporary society. The problems should have global significance, though they may address processes operating at spatial scales from households to empires and at a broad range of temporal scales. We excluded questions highly specific to place and time, but privileged questions that required us to represent dynamic cultural processes. The grand challenge questions had to be, in principle, susceptible to a solution supported by data. It was agreed that addressing these problems should stretch our current methods and data and will often require multi-, inter-, or transdisciplinary collaboration.

Once we developed the criteria the grand challenges should satisfy, workshop participants individually proposed grand challenges, which the group then winnowed and prioritized. After that, the participants considered, refined, and culled the challenges proposed in the crowd-sourcing effort and integrated them with a refashioned participants' list. This ensured that key topics were not missed and allowed us to take advantage of the questions and arguments proposed by the "crowd." The result is detailed below. After the workshop, the authors prepared concise summaries and identified illustrative references for each challenge.

The Grand Challenges

The 25 grand challenges presented here focus on cultural processes and the operation of coupled human and natural systems—not on particular events of the past. While this will not surprise archaeologists, to a nonspecialist there is a notable lack of concern with the earliest, the largest, and the otherwise unique. This focus on the dynamics of culture indicates no lack of regard for prehistory; the facts of the past provide the evidence that is essential for us to confront all of the problems presented here. While we stipulated that the grand challenges had, in principle, to be solvable, or at least *addressable* with empirical evidence, participants were encouraged to consider problems that have not previously been tackled due to a lack of

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evidence or the analytical or synthetic machinery needed to make the effort practical.

The emphasis here is on understanding the dynamics of cultural processes, recognizing that humans, mediated by culture, both affect and are affected by their natural environments. The authors have no illusions about the difficulties of addressing the classes of problems proposed. We share a conviction, however, that this is the domain in which the most important problems reside. Finally, these questions are notable for their greater relevance to the contemporary world than would have been evident in a set of challenges composed several years ago.

Acknowledging that some challenges fit comfortably into more than one category, we organize the 25 grand challenges into five topics for presentation: (1) Emergence, Communities, and Complexity; (2) Resilience, Persistence, and Collapse; (3) Movement, Mobility, and Migration; (4) Cognition, Behavior, and Identity; and (5) Human-Environment Interactions. Each question is accompanied by a short discussion and a brief list of references for readers who wish to pursue the issue. There is a noticeable overlap in the questions both within and to a lesser extent between these topics. This overlap is, of course, due to the highly interrelated nature of the key factors for understanding and modeling past social dynamics.

A. Emergence, Communities, and Complexity

A1: How do leaders emerge, maintain themselves, and transform society? The origins of leaders and their long-term transformative effects are among the central questions of the social sciences. Archaeologists from multiple theoretical vantage points (materialist, sociobiological, historical) have considered this question. They have also examined the emergent organizational, political, and managerial properties of societies and their leaders. Recent archaeological and sociological studies of memory and agency further suggest that some networks have greater emergent leadership potential than others and that leadership should be analyzed as distributed throughout a network of relationships between people and their environs. However, archaeologically apparent leadership roles of some individuals may have emerged only after the fact, owing to the ways in which they were memorialized.

Regardless of perspective, answers to questions concerning the origins and degree of inequality, power, and social complexity, and the emergence of macroscale cultural identities and the state, are contingent on how and why leadership was consolidated or institutionalized and the extent to which it assumed causal effects on society. Out of what sorts of relationships or circumstances do leaders of different sorts emerge? Do some diplomatic, administrative, religious, or political leaders effect more or less change in certain societal spheres? How is leadership incorporated into governments and what are the bases of a leader's power? Why does leadership fail? Studies analyzing the relationships of economic differentiation in the context of consensus, agency, memory, and legacy to institutions, community, and governance using temporally and spatially rich archaeological datasets can evaluate cause and effect in ways that will produce ultimate explanations of long-term and large-scale change. These will, in turn, support contextual modern understanding of how leadership qualities are related to societal attributes and historical trends.

References: Clark and Blake (1994); Clark and Colman (2008); Earle (1997); Ingold (2000); Vaughn et al. (2009).

A2: Why and how do social inequalities emerge, grow, persist, and diminish, and with what consequences? Huge individual differences in personal wealth, power, and access to and consumption of resources commonly exist within and between societies. In contemporary societies, these social inequalities also fluctuate significantly over surprisingly short intervals. However, contemporary and ancient foraging societies apparently did not tolerate more than minor differences in wealth or power, despite individual differences in strength, intelligence, ability, and, of course, age and sex.

By combining archaeological case studies with astute use of the ethnographic record, archaeologists have pieced together coherent accounts of the transformation from egalitarian to enduring hierarchical relations in several areas of the world. These changes seem remarkable in light of evidence from experimental economics for a widespread degree of aversion to inequality. However, recent research in the evolution of social cognition

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helps reconcile these findings by focusing on how human cognition may facilitate or constrain a variety of institutional outcomes.

Abundant evidence links degree of inequality to distributions of health and happiness at the individual level and social and political stability at the level of sociopolitical groups. Archaeologists need to pursue comparative work aggressively. Inequality can be systematically inferred through studies of landscapes, monuments, residences, and mortuary remains. Those studies, in turn, will permit mapping the relationship of inequality to other dimensions of individual and social experience in prehistory. Quantitative dynamic modeling to emplace general models of sociopolitical change in specific prehistoric and historical settings is now in its infancy but will be critical to our success.

References: Boehm (1999); Dubreuil (2010); Flannery and Marcus (2012); Hayden (2011); Henrich et al. (2005); Kohler et al. (2012); Smith (2012).

A3: Why do market systems emerge, persist, evolve and, on occasion, fail? Different kinds of economies developed in different cultural traditions. Market economies—in which buyers compete for sellers and sellers compete for buyers, mediated by the mechanism of "price"— are not universal, but comprise only one of a number of differently constituted economic systems. Nonmarket economies have been formally modeled, but the construction and testing of such economic models have required the long-term perspective and long-term data of archaeologists. Archaeological evaluation of exchange models through studies of the spatial distribution of sourced materials has a long history.

Examining the emergence, persistence, and dynamics of market systems will require direct archaeological study of short-term fluctuations in production, procurement, value (and indirectly "price"), and consumption in micro-chronological contexts. If market systems are emergent phenomena, rather than a universal, then we are asking a question fundamental to the diversification of states and the emergence of the modern world system. If we fail to understand (and control) market competition, we will be unable to address a central force shaping today's world.

References: Earle and Ericson (1976); Feinman and Garraty (2010); Leone and Potter (1999); Polanyi et al. (1957); Renfrew (1969); Sahlins (1972); Smith (2004).

A4: How does the organization of human communities at varying scales emerge from and constrain the actions of their members? Human communities range in size from mobile bands with a handful of members to cities with populations in the tens of millions. They can transcend single localities to become regional, supraregional, and, with modern communication, even global in scale. Many different kinds of interactions—social, political, economic, and cultural—connect members to one another. The organization of social relationships exists in the nature of these interactions and in the ways in which they are structured. In this sense, patterns of organization are the cumulative result of innumerable individual actions. At the same time, these individual actions take place in the already-structured matrices of human interaction that define communities at varying scales.

Over the course of human history, ever-larger human communities have emerged as both products and drivers of new ways to organize more complicated patterns of interaction among more diverse sets of members. Archaeologically informed investigations of the interplay between structures of interaction and the actions that can change those structures will offer deeper understandings of the dynamics of human organizational change. Such understandings are not just of academic interest. They can be vital in a world of communities with greatly varying spatial and demographic scales and tremendously diverse organizational forms, in which both patterns of organization and the actions of individuals are matters of conscious policy making.

References: Barrett (2012); Bicchieri (2005).

A5: How and why do small-scale human communities grow into spatially and demographically larger and politically more complex entities? Today, almost everyone in the world lives in large states alongside millions of mostly unrelated people. Yet, only ten thousand years ago, communities of hundreds would have seemed large. Humans are the only species capable of forming extremely large and relatively persistent groups of unrelated individuals. How and why have we accomplished this?

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The answer lies, in part, in large increases in local carrying capacity due to the domestication of plants and animals and subsequent improvements in technology and in our ability to harness new forms of energy. But while these developments help explain growth in population, increases in social group size must have additional causes and possible consequences for the distribution of access to productive resources and well-being.

Why did larger groups appear and what innovations in cognition, culture, and social and political organization allowed them to prevail historically? Understanding variability in the long-term success of various strategies for political organization around the world, and the consequences of these strategies for inequality, health, and well-being, not only addresses classic problems in social philosophy and political economy, but also provides an empirical foundation from which debates can proceed regarding the longer-term consequences of reorganizations resulting from present-day political upheavals.

References: Bocquet-Appel (2002); Bowles and Gintis (2011); Boyd and Richerson (2005); Redmond and Spencer (2012); Smil (1994).

A6: How can systematic investigations of prehistoric and historic urban landscapes shed new light on the social and demographic processes that drive urbanism and its consequences? The emergence and nature of cities are central themes for archaeologists who study complex societies and for geographers and historians who investigate long-term urban developments. Archaeological research is uniquely positioned to address questions with contemporary relevance. What conditions stimulate or discourage large-scale aggregation? What are urban successes, and why do some cities succeed over long periods while others fail? What roles do network effects and innovation (both economic and artistic) play in a city's development and success? How do we measure and evaluate persistence without overlooking change as a constant factor of urban life?

Archaeologists face the challenge of using material evidence to identify and define urban processes associated with descriptors such as ethnic diversity and inequality. Urban landscape studies require techniques for incorporating data that reveal the details of everyday life, as well as data at nested scales (neighborhoods, precincts, and the city as a whole). Historical cities provide especially rich data, both archaeological and archival, on the social and demographic processes that resulted in the layout, organization, and affordances of urban life. Archaeological data on cities range from small architectural details and short-lived cities to broad patterns of heterogeneous urban textures covering many square kilometers and presenting a historical depth of millennia. Consequently, characterizing long-term urban fabrics and animating associated behaviors via computational modeling requires enormous data archives and substantial computational infrastructure.

References: Algaze (2008); Betancourt et al. (2008); Cowgill (2004); Lilley (2009); McIntosh (2005); Marcus and Sabloff (2008); A. Smith (2003); M. Smith (2010); M. Smith (2003); Storey (2006).

A7: What is the role of conflict—both internal factional violence and external warfare—in the evolution of complex cultural formations? Conflict, whether internal or external, has long been considered a fostering influence in the development of formal political leaders and centralized governments. The need to coordinate a military force (whether a small raiding party or a large standing army), provision that force, and manage it requires a governing individual or body. Conflict might also foster a formal economic supply system and might influence, and be influenced by, social and ideological systems. Post-conflict responses are also important to consider. Thus, conflict has the potential to impact all areas of culture and can be seen as playing a key role in the evolution of complex cultural formations.

Exploring the dialectical relationship between conflict and complex cultural formations will undoubtedly foster new approaches to the archaeological record. Conflict is notoriously difficult to identify and quantify through archaeological remains. Though some methods have been developed, more systematic and large-scale analyses are certainly necessary before this question can be thoroughly explored. These methods will involve innovations in osteology and molecular anthropology, as well as advances in comparative studies of material culture and technology.

Conflict plays a major role in contemporary hu-

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man life. Understanding its impact on our ancestors will surely help us to identify both its impacts today and its implications for the future. In this way, the exploration of ancient conflict will directly inform our response to modern conflict.

References: Armit (2011); Carniero (1970); Ferguson and Whitehead (1992); Korotayev (2008); Lekson (2002); Milner (1999); Nielsen and Walker (2009); Turchin (2005).

B. Resilience, Persistence, Transformation, and Collapse

B1: What factors have allowed for differential persistence of societies? Few issues beg for urgent attention more than the possibility that the Earth cannot support continued population growth and increased use of limited natural and energy resources. But how common has been the problem of societies outgrowing the resources available to them given their technical capacities? Why do societies collapse? The long view and materialist perspective of archaeology, and its ability to incorporate and apply analyses from social and natural sciences to a broad range of societies, make these questions exceptionally relevant to archaeological inquiry.

More theoretical development is needed, however. Will the most productive approaches be drawn from theories of robustness or resilience? Do societies exhibit different capacities for evolvability and, if so, why? Do we need to build new theory to incorporate understandings developed from the long sweep of prehistory? Whatever the case, we must continue to improve our methods for inferring and modeling population size, productivity of resources, climate, and returns to scale under various social arrangements, and we must take advantage of our strongest empirical cases (e.g., the U.S. Pueblo Southwest, Polynesia, and Western Europe) to help guide method and theory elsewhere.

References: Burger et al. (2012); Costanza et al. (2007); Holling (1973); Jen (2005); Kirch and Rallu (2007); Kohler and Varien (2012); Wagner (2011).

B2: What are the roles of social and environmental diversity and complexity in creating resilience and how do their impacts vary by social scale? Diversity is often credited with conferring resilience upon ecological systems. When considering coupled social and ecological systems more broadly, there is no simple, positive relationship between social diversity and resilience or how different dimensions of social and environmental diversity interact to affect resilience. Scholars examining sustainability often view complexity in social systems (persistent, hierarchical sociopolitical formations) as a liability. As with diversity, the relationship between complexity and resilience in socioecological systems is certainly more subtle. Indeed, substantial social complexity seems necessary for the persistence of the larger and denser social formations that dominate the planet.

Integrating insights from ecology and archaeology can contribute to contemporary understandings of the role of diversity and complexity in the resilience of socioecological systems. As societies cope with recognized vulnerabilities at particular scales and in specific domains, they must attend to vulnerabilities at other scales and in other domains that result from their responses. Enhanced awareness of the potential interactions of diversity and complexity at different scales can inform contemporary policies dealing with sustainability, particularly in the small-scale, subsistence economies in which many of the world's most ecologically vulnerable societies live and have lived over the past 5,000 years.

References: Elmqvist et al. (2003); Hegmon et al. (2008); Ives and Carpenter (2007); Nelson et al. (2011).

B3: Can we characterize social collapse or decline in a way that is applicable across cultures, and are there any warning signals that collapse or severe decline is near? The archaeological record is replete with examples of the rise and fall of communities of all scales—from hunter-gatherer groups, to towns and villages, to civilizations. With recent advances in the quantity and quality of archaeological and historical studies, we can uncover robust patterns in societal collapses over time and space. We can also pay better attention to cultural and environmental differences among cases in which societies rebound from collapse and those in which they do not, to the time between collapse and resurgence, and to cycles of rises and falls. Nevertheless, we must distinguish full societal collapse from declines

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with cultural continuities. Further, archaeologists can compare and contrast examples of collapse with those of resilience in similar and differing ecological situations.

Given the growing concern about the sustainability of our planet amid well-documented demographic and environmental trends and pressures, the causes and warning signs of collapse examined over long time periods may provide useful contexts for modern planning efforts. Further, there is the potential for comparative studies of cultural and biological systems. These efforts can build on widespread biological and ecological studies that describe major declines in plant and animal communities and that highlight warning signals (e.g., slowing return time after perturbation, higher variance, conflict) among communities at risk. Thus, there are possibilities for building both specific and general explanations for societal collapses and for constructing ever-broader theories about where and when processes implicated in collapse occur and where and when they do not.

References: Feinman and Marcus (1998); McAnany and Yoffee (2010); Scheffer et al. (2012); Schwartz and Nichols (2006); Tainter (1988); Yoffee and Cowgill (1988).

B4: How does ideology structure economic, political, and ritual systems? Cosmology and ideology, a symbolized belief system about sociality and politics, have become foci of archaeological research. Recent efforts have documented past ideologies and cosmologies using such material evidence as iconography in design, architectural layouts, and the symbolization of social relations. Archaeologists now face the problem of representing, as more than verbal approximations, the ideological frames of actors that are used, revised, and selected in the course of cultural action. Specific progress has been made on a number of cases for which we have both archaeological and ethnohistoric/ethnographic/linguistic evidence, but a general formal representation of such thought systems remains a challenge.

Ideologies and related schemas *must* change if the systems of political and economic action they guide are to be transformed to address pressing problems now facing human societies. Whether we can make progress toward "grand theories" explaining major cultural transformations or whether historical contingency prevents us from constructing predictive theory, developing adequate models of the cultural schemes actually used in the negotiation of transformative change—and their success or failure—will have immediate value in predicting what will not succeed and what must be added to have any hope of success.

References: Kirch and Green (2001); Kus and Rahijaona (2000); Ortman (2012); Reilly and Garber (2007).

C. Movement, Mobility, and Migration

C1: What processes led to, and resulted from, the global dispersal of modern humans? Modern humans left Africa and dispersed across the Old World about 60,000 B.P. and by 12,000 B.P. had colonized the New World. These colonizers faced enormous challenges—new environments, new sources of raw materials and food and, in some cases, the presence of other hominin species or new predators. Exploring these challenges raises a variety of questions. For example, what were the dialectics between culture (social organization, technology, ideology) and dispersal? How did different environments facilitate and/or obstruct dispersal? What were the environmental impacts of dispersal, and how did these impacts shape cultural systems? The global dispersal of modern humans raises methodological issues as well. For instance, what is the archaeology of the submerged continental shelf, and how can we examine those deposits? What are the continuing genetic contributions from admixture between migrating and indigenous hominins? What is the relationship between modern language families and the proto-languages of migrating groups of modern humans?

These questions require innovations in methodological and theoretical approaches. Perhaps more importantly, understanding why humans moved into new regions and how they adapted to them touches on fundamental issues about human use of the environment and the potential of culture to shape, and be shaped by, the natural world. We are currently faced with enormous challenges from globalization and climate change. A better understanding of how our ancestors overcame equally great challenges as they colonized the world may help us to address and surmount the seemingly intractable problems of our present day.

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References: Abi-Rached et al. (2011); Pagel et al. 2013; Peregrine et al. (2009); F. Smith (2010); Stone et al. (2007); Wells and Stock (2007).

C2: What are the relationships among environment, population dynamics, settlement structure, and human mobility? Today's news is full of stories of drought, floods, warfare, political unrest, and religious persecution, often with attendant dislocated populations. While each event is commonly explained by one or a few proximate causes, population movements are rarely so easily explained. Some forces that lead to population dislocation occur at global or regional scales, such as changes in sea levels or persistent alterations to weather patterns. Others occur at much finer scales, such as soil depletion due to agricultural intensification or a shortened temporal interval between children. Human mobility is not simply an outcome of external factors; it can drive environmental and social change.

Archaeologists have long been interested in the causes and consequences of human mobility, and archaeological investigations continue to amass relevant data from all portions of the globe. Data alone, however, are not sufficient. Transformative progress is possible only if we frame questions in ways that can be answered. This framing entails defining and measuring essential aspects of four theoretical domains: environment, population dynamics, settlement structure, and human mobility. Each domain can range in spatial scale from small (e.g., an agricultural field) to large (e.g., a region), and differing temporal scales will need to be reconciled. Effectively characterizing these domains requires biological, environmental, sociological, historical, anthropological, and archaeological data.

Typically, archaeologists have explored human mobility through a case-study approach based on archaeological and ancillary data from small-scale research projects. However, we also see the need for regional- and continental-scale studies that match the scale of the problem to the scale of particular interactions. This synthetic research can benefit enormously from case studies, but only if their results are accessible and if modeling and simulation tools can test new theoretical relationships among variables derived from the four domains.

References: Benson et al. (2009); Fort et al. (2012); Kohler and Varien (2012); McCorriston et al. (2012).

C3: How do humans occupy extreme environments, and what cultural and biological adaptations emerge as a result? The ultimate test of our theories is their capacity to account for extreme cases. The immediate value of further research in regions with extreme environments (high altitude, high latitude, etc.) lies in the testing of theories of cultural adaptation at the limits of viability, limits at which the weaknesses of theories often become evident and new understandings must be generated.

Humans moved into hyper-arid environments at least by the last glacial maximum and into high mountain and high arctic environments a few millennia later. These are difficult and expensive places to work, and it is unsurprising that archaeologists are still developing basic culture-historical sequences in many of these areas. We have only a spotty, qualitative knowledge of peoples' early lifeways in these places. It is a tribute to the ability and sheer grit of arctic specialists that they have a more comprehensive knowledge of their cases than those in other extreme environments. However, even there, many exciting challenges remain, not least understanding how complex societies develop in such extremes. Researchers in desert Australia have advanced theory development because of the rich and well-studied ethnographic record and abundant and well-documented rock art. A similar depth of understanding is possible in the Sahara and Arabian deserts. The Tibetan plateau, a critical high-altitude case, though ethnographically and biologically well studied, is only beginning to see investigations into the archaeology of its peoples.

The hard-won lessons of survival—perhaps cultural more than technological—in these forbidding regions may well be of value in sustaining a human presence as arctic environments change and as substantial parts of our planet are growing more arid.

References: Barton et al. (2007); Beall (2007); Fitzhugh (2007); McGovern et al. (2007); Mulvaney and Kamminga (1999); Wendorf and Schild (1980).

C4: Why does migration occur and why do migrant groups maintain identities in some cir-

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cumstances and adopt new ones in others? Migration has been a widespread phenomenon since the earliest times and involves movement of individuals as well as groups to new settings. Archaeologists have long invoked migration as a cause of environmental or cultural change or as the result of such changes. Simple mechanical explanations have given way to studies of migration that are fundamentally concerned with relationships among time, objects, persons, and spaces. In addition to explaining the reasons for migrations, contemporary scholarship has highlighted the enmeshed nature of people and things. Archaeologists are confronted with the challenge of delineating how identities are forged in new settings. Recognizing that individuals produce and articulate identity continuously—through their bodies, language, and material culture—enables archaeologists to investigate identity production and reproduction.

Questions to consider include: How did the new setting differ from the old? Was migration temporary or permanent, was it voluntary or not, and what were the ease and frequency of contact with, or return to, the old setting? Were migrants expected to assimilate into a new society or coexist within it—whether purposely or through exclusion? The answers to these questions all affect the degree to which migrants can maintain traditional patterns of behavior made manifest through material culture. Recently, archaeologists have acknowledged that nostalgia for the home place, or homesickness, influences migrant attempts to replicate "home" through religious practices, foodways, furnishings, clothing, architecture, and landscape.

References: Brettell and Hollifield (2000); Burmeister (2000); Cabana and Clark (2011); Chapman and Hamerow (1997); Colburn and Hughes (2010); Hakenbeck (2008); van Tilburg and Vingerhoets (2005).

D. Cognition, Behavior, and Identity

D1: What are the biophysical, sociocultural, and environmental interactions out of which modern human behavior emerged? Anatomically modern humans emerged in the period 150,000 to 200,000 B.P. in Africa. There is also firm evidence that behaviorally modern humans (with art and complex tools) were present throughout the Old World by 40,000 B.P. Archaeologists debate the sequence of events between 150,000 and 40,000 B.P. Were anatomically modern humans behaviorally modern as well? Was there a single point of origin or multiple sources? Investigations in southern Africa present compelling evidence for early developments characteristic of behaviorally modern humans, such as abstract art, complex technology, substantial trade or transport of materials, and perhaps even plant management, but there are great lacunae in the record until around 40,000 B.P.

Thus, we need to know, how did humanity arise? What complex interactions formed the basis for the emergence of modern human behavior? To some researchers, these changes resulted from a sudden change in the cognitive capabilities of the populations—perhaps due to a neurological mutation; other researchers point to pressures from external processes, such as sharp changes in climate; yet others suggest that it is the inevitable outcome of a critical demographic mass of the anatomically modern humans. Archaeological evidence and analysis of a massive body of emerging data are critical to resolving this question—one essential to understanding the fundamental nature of humanity.

References: Henshilwood et al. (2011); Mace (2009); Mellars (2006); Powell et al. (2009); Schwartz and Tattersal (2010).

D2: How do people form identities, and what are the aggregate long-term and large-scale effects of these processes? The identities that humans ascribe to themselves and to others undergird the cultural practices, decision-making strategies, and worldviews of all societies in ways that impact long-term and large-scale organizational, religious, political, ethnic, national, and international developments. Identity formation is a continuous cultural process that happens simultaneously at personal, community, regional, and transregional scales, as well as at the interface of society and biology. But how are the various processes and the scales at which they operate connected to long-term and large-scale historical and evolutionary developments? What explains why certain relationships or associations, but not others, are linked to identity? Critical to future efforts is distinguishing how human identities (vs. the modes of affiliation among other species) form with respect

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to biological and emotional bonds. Are there specific intersocietal or intrasocietal contexts (e.g., feasts, pilgrimages, migrations) or modes of experience (e.g., theatrical, ritual, religious) that produce different identities?

Identity construction happens in spaces and engages material things and what people do with them. Thus, the process is measureable through the remains of domestic and nondomestic practices and performances. Extensive datasets of archaeological materials provide evidence on innumerable contexts of human identity formation at multiple scales and with great time depth. Human violence or peacemaking and political stability or change often hinge on issues of identity. Indeed, understanding these processes may allow us to address contemporary geopolitical problems more effectively.

References: Canuto and Yaeger (2000); Dietler and Herbich (1988); Fowler (2004); Inomata and Coben (2006); Jones (1996); Nielsen and Walker (2009).

D3: How do spatial and material reconfigurations of landscapes and experiential fields affect societal development? To the extent that inhabiting a landscape or engaging some field of things configures cultural beliefs and society, reconfigurations of the people, places, and things of those landscapes or fields are tantamount to practical, political, or religious change. Space and matter are fundamental dimensions of human experience; they shape and constrain the direction of cognitive development, social change, and biological evolution. From technologies and houses to landscapes and cyberspace, the processes of making, doing, sensing, inhabiting, and relating to things and beings are intimately connected to human neurological development, cultural values, identity formation, social structure, and political change.

Studies addressing how spatial and material (and practical and political) reconfigurations of landscapes and experiential fields affect societal development will transform scientific understandings of the long-term relationships between nature and culture, evolution and history. They will allow us to answer a suite of key questions about human evolution and hunter-gatherer adaptations: What explains the expansion of *Homo sapiens*? Why do communal values pervade bands and tribes? How does plant and animal tending transform social relations? What are the causal relationships among monumentality, inequality, and identity?

This overarching question folds seemingly disparate disciplines and schools of thought into a scientific archaeology of cultural process with profound implications for today's world. Tracking and evaluating localized arrangements and reconfigurations, of course, necessitates extensive investments in digital spatial datasets that incorporate LiDAR, geophysical, and other three-dimensional data that allow virtual exploration and analysis.

References: Bradley (2000); Dobres (1999); Ingold (2000); Parker-Pearson et al. (2006); Robb (2007); Robb and Pauketat (2013).

E. Human-Environment Interactions

E1: How have human activities shaped Earth's biological and physical systems, and when did humans become dominant drivers of these systems? The role of humans in altering Earth's climate and transforming its ecosystems is a central concern of twenty-first-century scientific inquiry and public policy. Recently, earth scientists have proposed that the Earth has moved into a new epoch, the "Anthropocene," in which humans have become the major force shaping Earth's ecosystems, atmosphere, and landforms. Much of the debate about the Anthropocene has focused on identifying its atmospheric or geological signatures. Researchers in other fields have variously traced its onset to the Industrial Revolution at A.D. 1800, to the spread of wet rice farming and cattle pastoralism at 8000 B.P., or to as long ago as 14,000 B.P., with the extinction of Pleistocene megafauna.

Despite producing key data, archaeologists have largely been left out of this discussion. This is a major limitation, since archaeology, drawing on cross-disciplinary tools capable of tracking the increasingly dominant role of humans in Earth systems, brings a deep-time perspective that stands to make significant contributions to understanding how humans have shaped the Earth. The challenge is to join disparate efforts into a broad-based initiative that can integrate existing and new sets of archaeobiological, geomorphological, paleoenvironmental, demographic, and other relevant data to model human/environmental interactions through time. By bringing archaeology's strengths

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to bear on this debate, the discipline situates itself at the center of fundamental questions that cut across the social, biological, and physical sciences and that are the focus of important international policy debate. Archaeology is well positioned both to identify the onset of the Anthropocene and to provide a unique perspective on how humans came to assume this dominant transformative role in shaping our planet.

References: Crutzen (2002); Doughtry et al. (2010); Fuller et al. (2011); Rick and Erlandson (2008); Zalasiewics et al. (2008); Zeder et al. (2006).

E2: What factors drive or constrain population growth in prehistory and history? Demography and population growth have been at the center of global policy debates since at least the first publication of Malthus in 1798. Subsequent discussions have often continued his pessimistic tone. Although archaeological data on ancient populations remain patchy, it is essential to develop more precise estimates of population size and growth rates and the intensity of human impacts on the environment.

It is essential to go beyond simple description, such as the familiar logistic curves of population growth. Demography is properly situated between "choice and constraint" within a web of disciplines that consider human behavior and agency, as well as biological, environmental, socioeconomic, and political factors. Archaeology is well suited to participate in the debates that surround population growth because it can, over the very long term, estimate population levels, evaluate human impacts on the environment, and contribute to understanding the drivers of, and constraints on, growth.

Resource availability, human fertility and physiology, agricultural production, health, technological developments, political economy, and socioeconomic and historical processes all serve to both drive and constrain population growth. Because technology and socioeconomic and political processes can all raise the ceiling for population growth, the concept of ever-relaxed constraints on population growth helps explain modern dilemmas such as overpopulation and rapid urban expansion. The observation that urban centers often experience higher death rates even as they increase in population through immigration needs to be investigated over millennia, not just over the last few centuries.

Bioarchaeological, historical, and regional survey datasets have been used to estimate ancient populations, but more robust estimates are possible only if we integrate these data sources at local, regional, and global scales. Although modern population levels are well above those of the ancient past, an understanding of how human communities responded when they approached demographic ceilings can be generated from archaeological data and can contribute fundamentally to policy debates. But ancient demographic research requires multidisciplinary collaborations and comparative research over wide geographical areas.

References: Bocquet-Appel and Bar-Yosef (2008); Chamberlain (2006); Costanza et al. (2011); Livi-Bacci (1992); McAnany and Yoffee (2010); Meadows et al. (2004); Roberts and Buikstra (2003).

E3: What factors drive health and well-being in prehistory and history? The world today likely includes some of the healthiest and longest-lived people ever to inhabit the Earth, even though the advantages of contemporary medicine and nutritious diet are far from universally available. Archaeologists now combine studies of ancient and modern DNA and bioarchaeological analyses of human remains with contextual information from the archaeological record and from documents, where available. In this way, it has been possible to document major shifts in health and nutrition for the Neolithic demographic transition, for urbanization, and for the recent epidemiological (demographic) transition.

Current information suggests that complicated interactions on various timescales, rather than simple one-way causal chains, gave rise to or accompanied these shifts. For example, infectious-disease loads, including those due to zoonoses, resulted in increasing human mortality with the formation of villages and cities, but eventually promoted increased disease resistance through natural selection. Moreover, individuals in egalitarian societies exhibited similar patterns of morbidity, whereas these patterns strongly diverged in state-level societies, sorted by class and wealth.

Archaeologists must continue to deepen research collaborations with specialists in other

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fields to determine the impacts of climate change, emergence of inequality, population/resource balances, diet, and microbiomes on health and well-being—as indicated by stature, osteologically manifest pathologies, and demographic rates—and the distributions of impacts across populations. These topics galvanize public interest to such an extent (e.g., the vast literature on the "Paleolithic Diet") that accuracy in our reconstructions and arguments concerning causal relationships should be an important part of our public responsibility.

References: Barnes et al. (2011); Barrett et al. (1998); Danforth (1999); Gage (2005); Steckel and Rose (2002).

E4: Why do foragers engage in plant and animal management, and under what circumstances does management of a plant or animal lead to its domestication? Foragers, past and present, manage plant and animal communities to increase resource predictability and human carrying capacity of the territories they exploit. This deliberate management of resources is fundamental to domestication. The human capacity for spontaneous invention of new behaviors, and our ability to pass on these behaviors to others through social learning, elevates the scope and impact of human niche-construction activities far beyond that found in other animals. This, of course, has resulted in major expansion of managed plant and animal species in human modified ecosystems.

Twenty-first-century archaeology is uniquely poised to address unresolved questions about the factors that shape human-resource management and are implicated in plant and animal domestication: What are the circumstances that lead to the diversification and intensification of human niche-construction behaviors? Why do certain forager groups focus on specific territories and resources within those territories? Why and how do these activities result in domestication of certain plant and animal species and not others? What are the long-term environmental and cultural consequences of these activities?

Addressing these questions requires that we integrate information on the resource strategies of both modern and ancient foragers, assimilate information on forager responses to climate and environmental change from the deep past to the present, and identify signatures of human management in the DNA of managed plants and animals. It requires analyses at different geographic scales to isolate both commonalities and differences in the contexts, courses, and outcomes of human resource management and domestication. It also requires grappling with alternative theoretical stances that see forager adaptations as driven by principles of optimization, risk reduction, community, or belief systems. Marshaling archaeological tools and data sets, researchers can illuminate how and why people have transformed much of the Earth into an anthropogenically managed landscape that is dominated by domesticated and other species dependent on humans for their survival.

References: Kelly (1995); Kennett and Winterhalder (2006); Laland and O'Brien (2010); Smith (2011); Zeder (2012).

E5: Why do agricultural economies emerge, spread, and intensify, and what are the relationships among productive capacity, population, and innovation? How and why people around the world developed and adopted subsistence economies based on domesticates remains a central problem in archaeological inquiry. Identifying the dynamic processes that led to agricultural economies emerging, spreading, and intensifying is a challenge of enormous scope. Agricultural economies encompass a diverse array of domestic plant and animal species that have different ecological requirements and are grown under a wide variety of production strategies. They span a broad range of social and political systems—from small-scale societies with minimal socioeconomic differentiation and little or no centralized leadership to empires that encompass vast regions fueled by highly specialized economies and structured around rigid socioeconomic and political hierarchies.

Three closely related factors are critical to understanding how agricultural economies arose, proliferated, and, in some cases, collapsed: (1) productive capacity—the caloric output of various crops and livestock under different production regimes and environmental circumstances; (2) population—the size and distribution of producers and consumers across the landscape; and (3) innovation—developments in technology and practice and in the institutions that mediate relationships between productive capacity and pop-

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ulation. Structuring studies around these factors leads to questions about population size and density and their impact on agricultural emergence and spread, the ways in which hierarchical control structures mediate risk and enhance (or constrain) productivity, and the levels of cultural complexity possible without agriculture.

Exploring how these relationships have shaped agricultural economies over time requires diverse datasets and advanced computational and modeling capacities. Analyses of integrated data—on crop and livestock species, agricultural practices, environmental parameters, settlement size and distributions, social structures that impact agricultural capacities, and symbolic systems that shape the identity of agriculturalists—will reveal the relationships that have structured agricultural economies. These relationships will inform understandings of current-day interactions of innovation and capacity as agricultural economies struggle to feed a growing world population now exceeding seven billion.

References: Johnston (2003); Killion (1992); Morrison (1996); Smith (2007), Wills (2012).

E6: How do humans respond to abrupt environmental change? On December 26, 2004, a massive earthquake-caused tsunami swept across the Indian Ocean, killing more than 250,000 people. Indigenous peoples participating in small-scale foraging economies, horticulturalists, and commercial fishermen were severely impacted by this event, but some foragers, such as those in the Andaman Islands, appear to have been spared major disruptions. An immediate worldwide response to this event was to increase scientific funding to better predict and monitor tsunami, but almost no funding was directed to investigating the impacts on peoples' lives, the effects on regional social dynamics, or traditional settlement and subsistence responses to these events.

Abrupt environmental changes, including tsunami, earthquakes, volcanic eruptions, short-term weather events, and wildfires are often, but not necessarily, catastrophic, and they may have both negative and positive consequences for particular societies. Investigating the social and political responses and adaptations to these external agents of change is key to understanding the critical roles they play in social change, migration, economy, and demography. Detecting and assessing the intensity and frequency of abrupt and short-term environmental perturbations in the archaeological record will require the integration of data from settlement archaeology, zooarchaeology, paleoecology, sedimentology, seismology, geomorphology, and allied disciplines.

References: Cooper and Sheets (2012); Grattan and Torrence (2007); Maschner and Jordan (2008); Sandweiss and Kelly (2012); Sintubin (2011); Torrence (2002).

E7: How do humans perceive and react to changes in climate and the natural environment over short- and long-terms? Studying the effects of environmental change on human societies has long been a dominant theme of archaeological research. While some regard the relationship as one sided, with the environment determining or greatly constraining cultural responses, most recent explorations see a more dynamic relationship, with the environment shaping and being shaped by human societies.

People constantly monitor aspects of the environment and respond to perceived change by integrating their observations with their goals, their knowledge, and their life experiences. While considered responses will often improve outcomes in a given year, such decisions can result in alterations of the environment that are highly detrimental in the long term. Furthermore, it appears quite difficult to respond appropriately to environmental changes that are sufficiently slow that they cannot be perceived in a single lifetime—such as shifts in the Earth's temperature, sea levels, stream flows, and soil chemistry—even in complex societies that maintain permanent records of environmental observations.

Archaeologists are reasonably successful in documenting societal reactions to short- and long-term environmental change. Most interpretations are, however, post hoc, functional explanations of why a particular culture made the choices that it did. Case by case, these interpretations may seem compelling, but they have proven extremely difficult to generalize. Even theoretical models have been limited in geographic scope due to technological and computing limitations. The challenge is to move from case or regional studies to larger-scale comparative research, and to learn how to

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make generalizable statements about how people make choices that draw on universal biases in cognition (and in fact to study the evolution of those biases). These efforts will require making data from relatively small field projects widely accessible and increasing current technological capabilities to allow for studies of human-environment interaction to increase in scope and complexity.

References: Garrison and Dunning (2009); Gigerenzer et al. (2011); Ingold (2011); Kelly et al. (2013); Sandweiss and Kelly (2012); Shepard et al. 2012; Turner and Sabloff (2012).

Concluding Observations

Many of the cultural processes implicated in these challenges undoubtedly involve complex, nonlinear relationships in which cause and effect are not readily distinguished. Further complicating our task, short-term human responses to problems often have unintended consequences, in both the short and long terms. As a result, addressing many of these challenges will require both sophisticated modeling and large-scale synthetic research that are only now becoming possible (Kintigh 2006).

Although new archaeological fieldwork will be needed, the greatest payoff will derive from investments that allow us to exploit the explosion in systematically collected archaeological data that has occurred since the middle of the twentieth century. Unfortunately, at present these data are, overwhelmingly, difficult or impossible to find and access. Both the modeling and the synthetic research will require far more comprehensive online access to thoroughly documented primary research data and to unpublished reports and other documents detailing the contextual information essential for the comparative analyses. This need for online access was also emphatically noted in the crowd-sourced responses to our grand challenge survey.

In addition to the imposing intellectual challenges, we face the unfortunate fact that the archaeological record is diminishing—quite rapidly in many parts of the world—with differential impacts for different aspects of the record. Archaeological research has been, and will continue to be, of concern to descendant communities. In some cases, that concern will translate into serious impediments to our scientific work. However, our experience over the last two decades suggests that the respectful engagement of these communities can greatly enhance our search for systematic knowledge about past events and processes. Finally, addressing many of these problems will require intensive, cross-disciplinary collaborations. Although those collaborations will be demanding and time consuming, they have the potential to yield transformative results with cascading impacts far beyond archaeology.

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Notes

1. These organizations agreed to disseminate the request: American Cultural Resources Association, Archaeological Institute of America, Institute for Archaeologists (UK), Canadian Archaeological Association, European Archaeological Association, Paleoanthropology Society, Register of Professional Archaeologists, Society for American Archaeology, Society for Historical Archaeology, and World Archaeological Congress.

2. The Society for American Archaeology Member Needs Assessment (2010) has 36 percent academic, 19 percent consulting, and 13 percent government (n = 3,054).

3. Society for American Archaeology (2010) lists 23 percent younger than 35, 41 percent 35–54, and 37 percent 55 and older (n = 3,043). Zeder (1997) had 7 percent, 81 percent, and 11 percent of her sample of 250 professional archaeologists in the < 30, 30–49, and 50 + age groups, respectively.

4. Society for American Archaeology (2010) shows 56 percent male, 44 percent female (n = 3,051).

5. The steering committee was comprised of three academic archaeologists, Kintigh, Limp, and Sabloff; one consulting archaeologist, Altschul; an ecologist, Kinzig; and an information scientist, Michener.

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