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Global Choke Points May Link Sea Level and Human Settlement at the Last Glacial Maximum

JEROME E. DOBSON, GIORGIO SPADA and GAIA GALASSI

ABSTRACT. Global choke points are preeminent nodes in geographic networks and geopolitical touchpoints subject to control by nations. They appear today as recurring theaters of conflict worldwide and also in archaeological investigations delving thousands of years back in time. How different were today's global choke points at the Last Glacial Maximum (LGM) ~ 20,000 years ago? For the first time, we map nine of them to visualize their conditions at LGM. The global feature aquaterra—all lands inundated and exposed repeatedly during the Late Pleistocene ice ages—initially was mapped as first approximations of sea level. Here we refine its boundaries using Glacial Isostatic Adjustment (GIA) models to account for the Earth's deformation and horizontal migrations of shorelines in response to glacial melting. We found three choke points sufficiently open to navigation, but six others presented substantially greater barriers than today. Implications include strategic insights on where to search for submerged evidence of human settlement. *Keywords: global choke points, hypsography, Last Glacial Maximum, sea-level change.*

Global Choke Points

Aquaterra is the collective name for all lands that were inundated and exposed repeatedly during the Late Pleistocene ice ages from the first appearance of modern humans through today (Dobson 1999, 2014; Davies 2016; Spada and Galassi 2017). As water is retained and released by continental ice sheets, a "vast millennial tide" causes landmasses, collectively about the size of South America, to disappear and reappear in repeating cycles. Surely such enormous shifts of landmass configurations and aggregate land areas must cause corresponding changes in geographic patterns of transport, migration, communication, trade, social interaction, defensive posture, and other forces and factors that are fundamental to the human geography of each passing age. Here, we illustrate with an example that is local and specific—sea channels and overland portages measured to a kilometer or so—yet global in its implications affecting transportation, settlement, and trade patterns across whole regions. We ask what impact changing sea levels had on regional and global patterns of transport. We answer by comparing the global choke points of today with themselves at the Last Glacial Maximum, ~ 20,000 years ago. We focus on global choke points, distinguished by their impacts on whole seas, coasts, continents, and regions.

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A choke point, informally a "bottleneck," is defined as a geographic place at which transportation routes converge in response to physical constraints such as coastlines, rivers, wetlands, and mountains. Each choke point affects surrounding regions by funneling trade through relatively narrow pathways. Thus, the place itself and all travel, transport, and trade across it are vulnerable to control by a dominant nation or coalition of nations. Choke points occur on land and sea, but here we focus on coastal lands. Maritime choke points are straits or isthmuses, viewed from a nautical perspective, meaning transport is by water and emerging land is a barrier. Conversely, from a terrestrial perspective the sea lanes themselves are barriers to travel by foot, animal, or automobile.

Choke points are crucial geopolitical features, often embroiled in conflicts around the world. They are explained in most introductory world regional geography textbooks (Bradshaw and others 2012) and featured routinely in news reports. A recent special issue of *Limes*—a monthly geopolitical magazine published in Italy—focuses on geopolitics of the sea with an entire section (IV, "The Strategic Straits") of seven separate articles on individual choke points. At present, the Strait of Hormuz gets daily news attention due to diplomatic and military actions to maintain (or alter) the balance of power over petroleum transport. Indeed, many definitions of choke point emphasize military significance. In this study, we emphasize broader aspects such as travel, transport, trade, and migration, but the specter of geopolitical force always looms as it has worldwide for thousands of years. We chose two isthmuses and seven straits that qualify as truly global choke points because they impact travel, transport, and trade worldwide.

Geographers typically list today's global choke points as: the Isthmus of Panama, the Bosporus and Dardanelles (0.75 km minimum width), the Strait of Gibraltar (15 km), the Isthmus of Suez, the Strait of Hormuz (50 km), and the Malacca Strait (2 km). The Bab al Mandab (20 km) plays a similar role at the southern end of the Red Sea but is rarely listed, perhaps because its role is overshadowed by the Suez Canal at the northern end. The Bering Strait is not considered a global choke point today because it is somewhat broader (82 km) and carries a tiny fraction of the ship traffic of most others. Prehistorically, however, it narrowed dramatically during the ice ages and closed entirely at LGM. At times it was a local and regional choke point impacting travel by Tlingit, Inuit, and other Amerind navigators. From the 1500s onward, European and later American exploration in search of a "Northwest Passage" testified to the global significance of its strategic location. Now global warming may unleash its potential. Of all choke points, it is the most discussed across the most varied disciplines. Similarly, the Strait of Sicily is broad today, but narrowed considerably during LGM. This narrowing combined with closure of its northern counterpart, the Strait of Messina, constricted traffic to the same channel width as the Strait of Hormuz today. Here we treat the straits of Sicily and Messina, the Bab al Mandab, and Bering Strait as global choke points, appearing on this map in

FIG. 1—Geographical distribution of the nine global choke points considered in this study. Aquaterra, encompassing all lands alternatingly inundated and exposed during the Late Pleistocene ice ages, is based on current bathymetry, ETOPO1-Ice Surface Data, with no adjustments for isostatic seafloor changes. Elsewhere in the text we adjust for glacial isostacy. Cartography by Jerry Whistler, Kansas Biological Survey, University of Kansas. Mollweide Equal Area Projection.

relation to the extent of aquaterra (Figure 1). Our judgment was confirmed retrospectively in that *Limes* chose the same list except the Bering Strait and the straits of Sicily and Messina (Caracciolo 2019).

For the first time ever, we map these key locations on the ocean floor based on bathymetry adjusted for isostasy. Nicholas Ray and J. M. Adams (2001, 9) issued a clear call for this advancement, "Due to the extent of the ice sheets during LGM, coastlines were dramatically changed in certain areas due to the drop of sea-level. Based on coral cores, a common accepted mean value for this drop is about 120 meters (e.g. Fairbanks 1989), even though this change was locally higher or lower, due to the glacio-hydroisostatic contributions to sea-level" (Lambeck and Chappell 2001).

The world contains innumerable maritime choke points. In principle, any sound lying between an island and a coast might qualify at some local level if the island's perimeter were large enough to encourage sailors to shortcut through the sound. Any peninsula might qualify if its length-to-width ratio were great enough to encourage overland portages by foot, animal, or vehicle. Some major straits—Magellan, Palk, and Torres, for instance—may warrant attention, but are omitted here purely due to space limitations. We will not discuss the Danish Straits because they were covered by a massive ice sheet at LGM.

To illustrate the importance of choke points in archeology, consider the eastern Mediterranean archipelago of Fourni, where underwater archeologists have discovered 53 ancient shipwrecks and expect to find more (Murray 2018).

According to investigators, the high incidence of wrecks spanning 2,500 years happened not because the surrounding sea was exceptionally dangerous, but because the site was a "maritime navigational choke point" lying "at the crossroads of ancient north-south trade routes connecting the Black Sea to Alexandria and … east-west routes to Spain and Italy." Dates range from the sixth century BCE to the twentieth century CE (Gannon 2017).

Wright (2009, 56) pointedly asks if choke points at the Last Glacial Maximum could "have influenced the movements and growth of human populations in such a way as to initiate rapid language differentiation?" His question about language alone would justify keen attention to choke points, but the context raises even broader questions about transportation, migration, trade, and navigation. We focus on transport potential, while trusting that our findings will be of use to other scholars investigating language, culture, and settlement.

Maritime Transport and Trade

Choke points evolve in prescribed ways whenever sea level rises or falls, and potential transport evolves in concert as generalized here (Figure 2). When sea level falls, straits narrow and isthmuses broaden. Given enough fall, straits become isthmuses, and isthmuses become coastal plains. Eventually, transport shifts from maritime to terrestrial transport with increasing distances of overland portions. At some point aquaterran plains become so broad that their impedence discourages portages, as in the cases of Bering, Hormuz, and Malacca. Is there

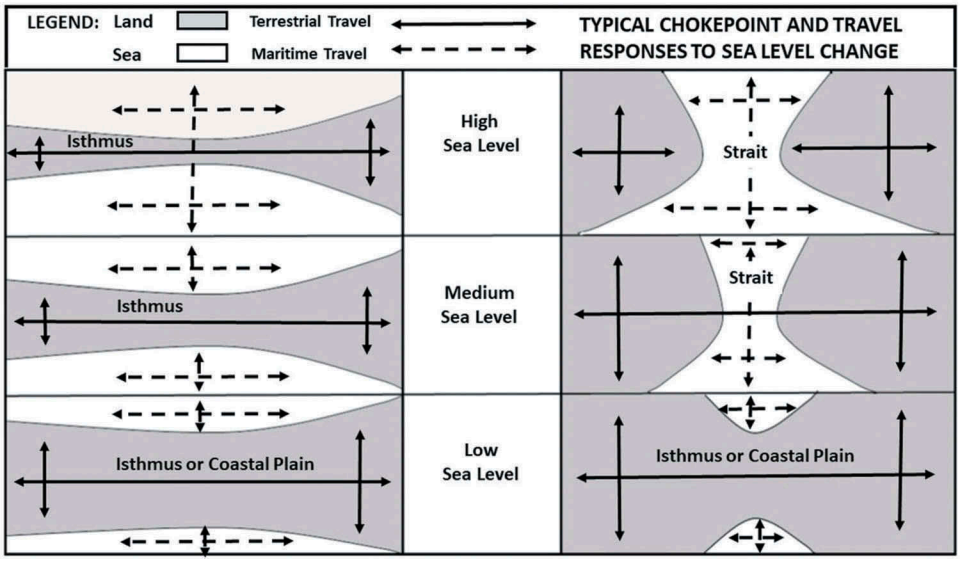

Fig. 2—Typical Changes in the Morphology of Straits and Isthmuses in Response to Sea Level Rise or Fall.

a limit? During the Middle Ages camel caravans transported goods 700 km back and forth across Sudan, and the Silk Road (not a choke point) was ten times that long across Asia.

Do our findings matter? One must ask, how much maritime travel, transport, and long-distance[1] trade existed ~ 20,000 years ago. Davies (2016) views aquaterra as a measure of the geographical extent of the Anthropocene, but that could be true for any level of development, however primitive. Tarlach (2019, 58) states, "A bias remains against the idea that early humans were advanced enough to use coastal resources, including traveling by boat … Many younger researchers, however, are more open-minded about early seafaring." Archaeologists, young and old, may cringe at the thought of studying transport where none is known to exist.

However, our analyses actually measure transport potential, not transport per se. The very purpose of measuring portages across isthmuses or detours around closed straits is to judge how added distance may impede travel; often that means no travel at all. Just as today's car navigation systems calculate shorter or faster paths without predicting how many cars will drive each one, our results are useful to know, regardless whether the number of travelers is 0, 100, or 1,000,000 by foot, cart, car, or boat.

We readily acknowledge that archaeological evidence does not support the existence of ports and commercial transport networks at LGM. A rigorous overview of material culture, such as Wright (2009), emphasizes stone tools as the highest proven levels of material culture and "the dates at which the earliest definable protolanguages began to differentiate" as contemporaneous developments in nonmaterial culture.

Even if transport and trade are not supported by archaeological evidence, travel by individuals on foot was likely at all nine global choke points. The number of travelers may be small, but it is not zero, and a choke point's effect is real even if only one lonely person hiked the long way around. This understanding then serves the underwater archaeologist searching for artifacts left by that lone traveler.

The current state of seafloor exploration is inadequate to rule out anything simply because it has not been found. This statement is not a disparagement of underwater archaeology or other disciplines engaged in seafloor exploration. Exactly the opposite, it is a stark recognition of how enormous the task will be and how few dollars, ships, and personnel are devoted to it. To illustrate, consider that the choke point at Fourni and its trove of 53 shipwrecks were unsupported by archaeological evidence just five years ago (Murray 2018). Plus, these submerged boats 2,500 years old at 10–60 m depth should have been far

[1] W. F. Leemans (1977, 2) distinguishes between "long-distance trade" across countries or regions and "distributive trade," which is essentially local.

easier to find than any objects 20,000 years old at 100 to 125 m depth. Our faith in archaeologists tells us there will be more discoveries to come.

Aquaterra is a physical global feature. It does not need human occupance, much less Holocene levels of development, to justify its existence. However, land masses collectively equivalent in size to South America existed in aquaterra at times when human society was rapidly advancing in lands above current sea level. It would not be surprising to find artifacts in aquaterra at any time period when they are known to have existed above. Stone structures, for example, well may lie at depths that were exposed in the eleventh century BP, since Göbekli Tepe is known to have existed then (Curry 2008). The very existence of aquaterra opens a crucial new line of questioning: did some cultural inventions exist in aquaterra significantly before they existed above? Ports, for instance, would have been firmly imbedded below current sea level, and seagoing boats would seldom have been lifted scores of meters above old sea levels. Hardly any nautical evidence from LGM and even much later times would be available to archeologists today. Hence, we do not rule out the possibility that ports existed at dates much earlier than currently known. Still, we speak subjectively in every instance when we speculate about where those ports should be.

No one knows what occurred in aquaterra at the LGM. Hard evidence for maritime transport is lost precisely because the old coast and treacherous shoals are now submerged at −125 m. The LGM itself is a daunting horizon, but our research points to later horizons of equal importance that are more attainable. Some portions of Foul Bay's basin were open to occupation as late as 7000 BP, only 2,300 years before Egyptians built their first major structure—the Pyramid of Djoser (4700 BP).

We speak speculatively about trade, transport, and human travel in aquaterra, yet with some confidence because populations did migrate into most of the Earth's habitable places at very early dates (Cavalli-Sforza and others 1993; Wright 2009; Gamble 2013). Moreover, aquatic origins of hominins have been debated since Alister Hardy (1960), with specifically coastal origins proposed by Carl Sauer (1962), yet viewed as pseudoscience by many anthropologists (Langdon 1997) despite striking indicators (subcutaneous fat; salt-wasting kidneys; nearly hairless bodies; extreme dependence on iodine—a predominantly coastal resource) that we find convincing. J. E. Dobson (1998) found that iodine availability and mutations of genes controlling the Thyroid Na+/I− Symporter (Levy and others 1997; Dobson 2002), which led to the extraordinarily efficient thyroid of modern humans, can explain morphological differences between modern humans and Neanderthals.

Many cultural inventions—red ochre, obsidian, flint, domesticated animals—spread far from their places of origin at very early dates. According to Leemans (1977), " … in most instances the diffusion of [advancing human settlement] may have coincided with trade, trade being one of the links in this diffusion. For as

a rule all contacts between peoples, tribes and clans may be accompanied by the exchange of goods, either in the first or second instance."

If maritime trade existed, where would it have been? Where would ports likely have been? How would overland trade routes have aligned to maximize efficiency of transport from resources to consumers? Here we examine the earliest evidence for watercraft, cargo, transport, trade, and structures.

Ample evidence of maritime trade exists as early as 2700 BCE (Pendleton and others 2002), but tantalizing clues suggest that craft and cargo existed much earlier. The earliest evidence of ocean travel by humans is the settling of Aborigines in Australia, long accepted as >40,000 years ago with a recent estimate of 65,000 BP (Clarkson and others 2017; Bird and others 2019; Westaway 2019). G. Irwin (1991) (a) suggested that Aborigines may have used boats to hop from island to island with a maximum distance of about 100 km in the longest hops, (b) emphasized the importance of intervisability among islands and continental shores, and (c) summarized a wide selection of literature on Pleistocene boats and navigation.

The settling of Australia required transport of individuals and necessities of survival, not trade of bulk goods, but it raises crucial questions for aquaterra. When did boat technology spread from Southeast Asia to other coasts of Asia, Europe, and Africa? Were boats continuously available to some residents of aquaterra from then on? How early did boats support trade in the submerged lands now missing from the archeological record? At a minimum, the Australian evidence suggests that boats were available in certain portions of aquaterra well before the LGM.

Subsequently, seaborne commerce existed as long ago as the Early Bronze Age evidenced by the oldest known maritime shipwreck and its cargo of early Helladic II pottery found off the island of Dokos and dated 2700–2200 BCE (Leemans 1977). The oldest shipyard, however, is dated much earlier at 8,000 BP (Daley 2019). Wooden vessels and associated facilities typically do not survive well in marine environments due to the navel shipworm *Taredo navalis*.

The Ebla tablets (c. 2500 BCE to 2250 BCE) document trade networks centered on ancient trading posts in Anatolia. By 1960 BCE, Assyrian colonial settlements—karū (plural)—were established beside indigenous cities throughout the region. The main center of trading at karum (singular) Kanesh (later called Kültepe) was in the landlocked center of Asia Minor, but the term karum, itself, can mean a quay, port, or commercial district.

The implication is that, unlike Kanesh itself, many commercial centers were seaports with quays, just as ports are built today, and trade was associated with them. That in turn implies maritime trade, which the Assyrians are known to have conducted. In that same millennium, round vessels were used extensively on all coasts of Western Europe (Leemans 1977). Then, during the Greek Dark Age (c. 1100 to 775 BCE) the Phoenicians were a notoriously dedicated maritime

trading society who developed a sophisticated trade involving maritime transport of commercial unguents (Jones 1993).

Land transport of raw materials started early in human development. In Kenya, Brooks and others (2018) found stone materials imported from 25 to 50 km away as raw materials and then processed on site during the earliest Middle Stone Age (>295,000 to ~ 320,000 ya).

In regard to maritime transport, Neanderthal seafarers appear to have transported mousterian tools to the southern Ionian Islands of Kefallinia and Zakynthos between 110,000 and 35,000 years ago (Ferentinos and others 2012). Similarly, Homo erectus seafarers appear to have brought stone tools to the island of Flores, Indonesia, via watercraft at least 750,000 years ago (Gibbons 1998; Bradshaw 2019). With such venerable precedents, the possibility of watercraft existing during the LGM cannot be dismissed.

What cargoes might have been hauled? Pottery itself dates back ~ 20,000 years, precisely to the LGM, in China (Wu and others 2012). Thus, it would not be surprising to find shards as low as −125 m off the coast of Asia. At a minimum, this evidence suggests one likely cargo that existed during the LGM. It would be remarkable but not surprising if shards were found at similar depths off the coast of Europe since the Venus of Dolni' Věstonice, Czech Republic, the first fired clay object of any kind, dates much earlier at 28,000 to 24,000 BP (Vandiver and others 1989).

The Venus of Vlakno (a 15,000 ya bone pendant) was found in a Croatian cave overlooking the Adriatic Sea where the aquaterran Great Adriatic Plain (Figure 3) served as the occupants' hunting ground during the Epigravettian

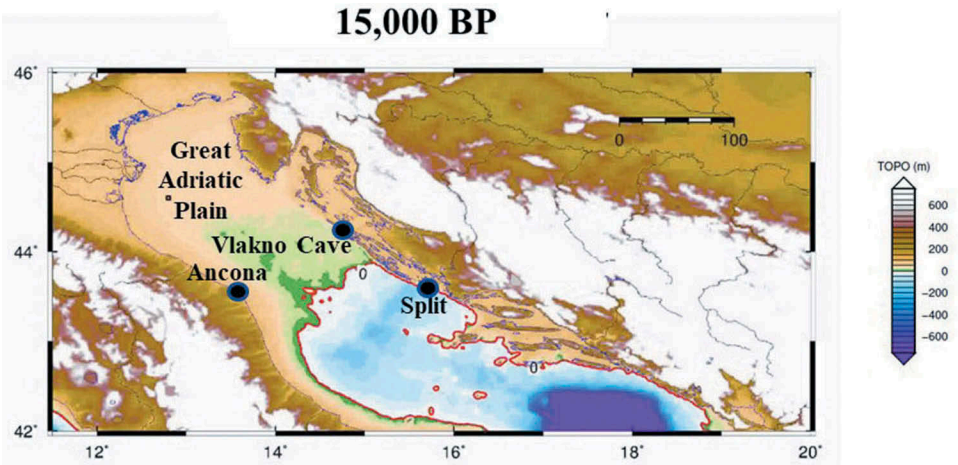

Fig. 3—Reconstruction of the Great Adriatic Plain and of the paleo-contours of the Adriatic Sea at 15, 000 BP, according to our GIA simulations, with some modern cities shown for reference. Lambert Azimuthal Equal Area Projection.

period. Terrestrial and marine mollusks, gastropods, and shells were harvested to be consumed and worn as ornaments (Cvitkušić and others 2017). At that time, according to our model, sea levels were about 80 m lower than today. Kaiser and Forenbaher (2015) found strong maritime influences in the beginnings of Neolithic agriculture there, even concluding " … the success of farmers and shepherds in the Adriatic was contingent on the prior success of navigators and mariners there" (Kaiser and Forenbaher 2015, 9).

Some marine goods originated at the coast without clear evidence of crossing open sea. For example, perforated seashells found in Cro-Magnon sites of Europe (30,000 to 32,000 BP) (Lartet 1868a, b) suggest trade of maritime goods hauled from coasts to interiors, probably carried on foot and not necessarily involving ocean transport.

If aquaterran travelers built ports, how would we recognize them today? In terrestrial settlements postholes used in building construction often are recognizable. For aquaterran settlements, archeologists must consider the deterioration that occurred above ground while the land was exposed and underwater when inundated. What remains might be difficult to recognize in the demanding conditions of underwater archaeology.

A better hope lies with stone structures, which would survive thousands of years of currents and tides, but in tropical latitudes typically would be shrouded in coral. Above ground the oldest known stone structure is the enigmatic Göbekli Tepe at nearly 11,000 years old (Curry 2008). The earliest habitation at Jericho dates to the same period, and the walled city itself dates to 8800 BP. Thus, while no habitable structures are known to have existed at LGM, some existed while Foul Bay's basin retained most of its land.

Materials and Methods

We follow Spada and Galassi (2017), who examined global sea levels at 30,000 BP to today and key intermediate dates. We employ a Glacial Isostatic Adjustment (GIA) model to account for the Earth's deformation and gravity variations in response to glacial melting and for a "gravitationally self-consistent" reconstruction of the paleotopography (Peltier 1994), using an iterative approach. In particular, the model extends the sea-level equation solver SELEN (Spada and Stocchi 2007) to any given coastline, taking into account the horizontal migration of shorelines, the transition between floating and grounded ice, and the rotational feedback on sea level (Martinec and others 2018; Spada and Melini 2019). The computations adopt the latest version of the ice sheets chronology progressively developed by Kurt Lambeck and collaborators at the Australian National University (see e.g., Lambeck and Chappell 2001; Lambeck and others 2002, 2003). The Earth is spherically layered, with a viscosity increase by a factor of 10 between the upper and lower mantle. In our GIA runs, a uniform equal-area grid (Tegmark 1996) with horizontal spatial resolution of 20 km is

employed; the total integration interval is 30,000 years, with time increments of 500 years.

Data input models and variables include: (a) present day topography constrained by the National Oceanic and Atmospheric Administration's ETOPO1 global elevation database at 1 arc–minute resolution, (b) depth-dependence of density and rheological parameters (i.e., a spherically symmetric Earth model), (c) a set of "Love numbers" (measures of spherical viscoelasticity for the Earth originally conceived by Augustus Edward Hough Love) to a given maximum harmonic degree (e.g., lmax = 256), (d) a model for the present day topography (ETOPO1) to define the present day ocean function, (e) a raster surface of the Earth on which the sea-level equation is discretized (global equal-area icosahedron-based spherical grid), and (f) information about the geometry of the ice sheets and about their time-evolution in the time window of interest (an "ice model"). Preliminary analyses employed ETOPO1 global elevation data (Amante and Eakins 2009) mapped by Dobson (2014), including cartography by Jerry Whistler (Figure 1) and a visualization developed by Zong (2015).

Other global GIA models exist, e.g. ICE-6G_C (VM5a) of Peltier and others (2005). With respect to the model adopted in this study, ICE-6G_C (VM5a) is characterised by different assumptions about the volume of the major ice sheets at the LGM, the chronology of de-glaciation, and the viscosity contrast between the upper and the lower mantle. Using SELEN, we have verified that, as long as we are concerned with the evolution of topography since the LGM, the two models provide consistent scenarios for the geometry of the choke points. This has been verified even across the Bering Strait, relatively close to the former Laurentide ice sheet, where ice distribution and volumes differ significantly in the two GIA models.

Global Choke Points At LGM

The impacts of sea-level change are conspicuous and undeniable. Over the past ~ 20,000 years, there have been extended periods during which only three of the seven straits existed, and portages were far longer than today. Both isthmuses were much longer portages as well. Here we examine each of the nine selected choke points.

1. THE BERING STRAIT

At LGM, the Bering Strait was a broad plain of exposed dry land (Figure 4). Jakobsson and others (2017) conclude that rapid flooding of Beringia began about 11,000 BP, after the Younger Dryas climate event (c. 12,900 to c. 11,700 BP). Spada and Galassi (2017) agree that flooding started about 11,000 BP, and rapid inundation ceased by 10,000 BP.

There is no widely accepted archaeological evidence of human occupancy in the Americas at LGM, but genetically based estimates suggest that an isolated

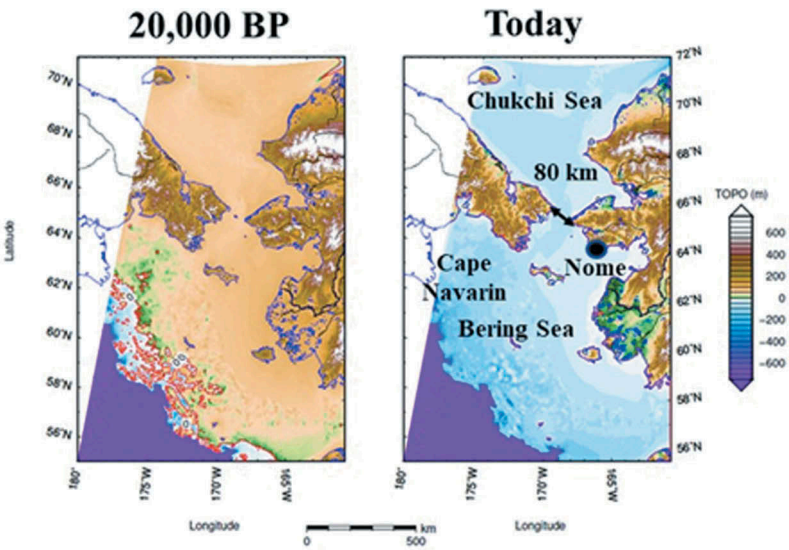

FIG. 4—Paleogeographic reconstruction of the Bering Strait at LGM (left), compared with the present topography (right) and the shortest ocean route today. Note the Bering Transitory Archipelago in the southwest at LGM. Lambert Azimuthal Equal Area Projection.

population moved south of the North American ice sheets sometime after ~19,500 BP (Llamas and others 2016; Davis and others 2019; Pinotti and others 2019). Charcoal and bone at the Cooper's Ferry site in western Idaho have been radiocarbon dated between 15,280 and 16,560 BP. Furthermore, the site's age means the migration itself "predates the opening of an ice-free corridor (≤14,800 BP)" (Davis and others 2019). Similarly, in South America there is no evidence for human occupancy at LGM, but Monte Verde II in Chile has been directly dated between 14,220 and 13,980 BP (12,310 and 12,290 carbon-14 years ago) (Dillehay and others 2008). Occupants transported seaweed, a typical source of iodine, from distant estuaries and beaches for use as food and medicine. Investigators in both studies believe their findings support the hypothesis that initial human migration into the Americas occurred via a Pacific coastal route, and both studies indicate early penetration into their respective continents, 500 km to Cooper's Ferry and 90 km to Monte Verde. Anderson and Bissett (2015) and Anderson and others (2013) offered comprehensive conceptual and empirical analyses of how sea-level changes may have influenced coastal migrations in the Southwestern, Gulf Coast, and Southeastern United States. Stanford and others (2014) investigated a possible Paleolithic site on the continental shelf near the LGM paleo-river mouth of the Susquehanna River. In addition to a mammoth skull, the site contained a rhyolite biface knife from a source in present-day Pennsylvania 320 km inland.

The LGM map (Figure 4) reveals, for the first time, an intricately complex archipelago, running from Siberia at Cape Navarin southeastward about 1000 km. These islands, sounds, and bays would have been the active interface among ice, land, and ocean. The entire archipelago was backed on the north by a broad swath of tundra (Ray and Adams 2001), meaning the area likely would have been as habitable as the north shore of Alaska today. This previously unknown archipelago would have been an ideal staging area for LGM travelers heading east by land or water and thus today an ideal candidate area for submerged coastal settlements. The progenitors of Amerinds would have needed food, shelter, and maritime facilities such as fish traps and landings for umiak and kayak. Its very existence favors the Kelp Highway (Erlandson 2007)—a coastal maritime route from Asia to North America—for it would have been a maritime homeland in which to hone the precise skills Amerinds would need —kayaking, hunting, sheltering, and surviving—to reach and settle North American landfalls.

Based on multiple runs of the GIA model, this transitory aquaterran archipelago existed intact from at least 30,000 BP to 20,000 BP. Soon afterward, a rapid inundation of the western islands began, so that by 10,000 BP, when the Bering Strait finally opened, only three tiny islands remained west of the strait. The loss of islands after 20,000 BP matches the population movement genetically detected in North America by Llamas and others (2016), Davis and others (2019), and Pinotti and others (2019).

From 10,000 BP to 8000 BP the number (and size) of islands in the east reduced rapidly (in 500-year time steps) from fifty-seven to fifty-three to thirty-nine to seventeen then six, after which it remained steady at only a few. As these inundations occurred first in the west and then in the east, residents would have had no choice but to evacuate, however dangerously, choosing among Asia, the Aleutian Islands, and North America. The archipelago's eastern shift after 10,000 BP would have favored migrating to North America by a seaward route. We advocate searching for landfall settlements at depths of -90 m to current sea level off the coast of Alaska. We propose naming this aquaterran feature the Bering Transitory Archipelago.

2. THE ISTHMUS OF PANAMA

The Isthmus of Panama (Figure 5) was a barrier to sea travel throughout human history until the Panama Canal was completed in 1914. The portage where the canal lies today was 180 km at LGM compared to 80 km for the current transect from Colon to Panama City. The shortest portage anywhere across Central America at LGM was approximately 160 km long. All oceangoing cargoes were offloaded at one end or the other and carried by human or draft animal power across the isthmus, notably via the Rio Chagres route, named the Camino Real de Panama soon after the founding of Panama City in 1519.

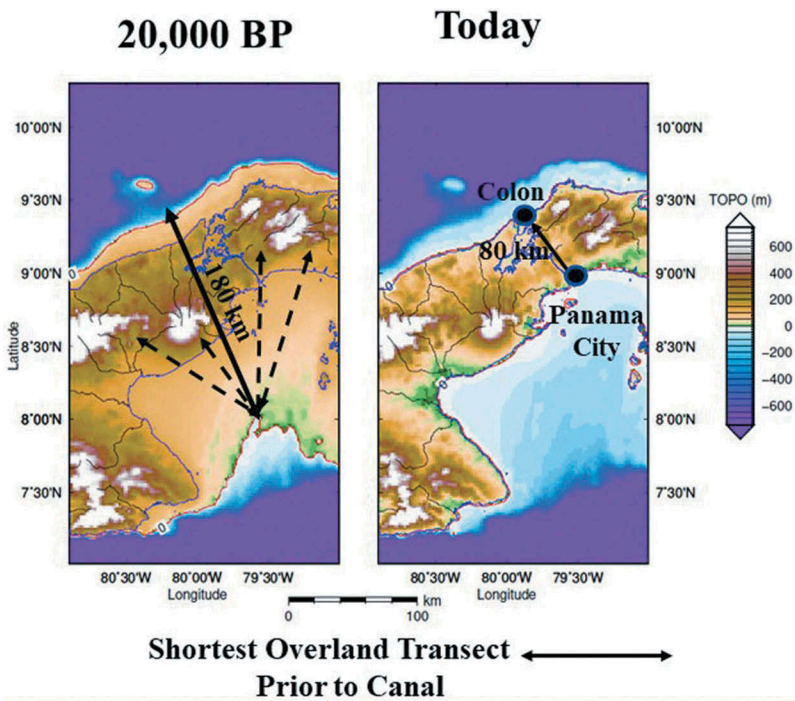

FIG. 5—Geographical reconstruction of the Isthmus of Panama at the LGM (left) and at present time (right), based upon the GIA simulations performed in this work. The shortest overland transects are also compared. Lambert Azimuthal Equal Area Projection.

It is worth noting that hypothetical penetration of 90 km, equivalent to inland penetration at Monte Verde, would be sufficient to cross today's Isthmus of Panama but not its width at LGM. Whereas, hypothetical penetration of 500 km, equivalent to inland penetration at Cooper's Ferry, would cross it with ease at LGM or now. Archaeological evidence for the earliest human occupancy on the Isthmus itself is dated between 11,500 and 9000 BP (Pearson and Cooke 2003). Examining fluted-point collections from North, Central, and South America, Pearson (2017) found technological similarities that support a Clovis demic expansion from Middle America at least as far as Venezuela. Human migration and/or technological diffusion may have spread via the Isthmus or the now submerged Atlantic coast.

The LGM map (Figure 5) shows one preeminent focal point for crossing the Isthmus. It is the southern terminus of the 180 km portage drawn on the map. A bay of the Pacific Ocean extends northward broadly into the Isthmus and then extends again at its tip to make a shorter crossing than any others available in Panama. Due to the curving arc of the shore, however, many other possible portages radiate from this same point, though all but the Rio Chagres route encounter uplands as high as 1000 m along the way. This point would appear to

be a good candidate location for a submerged settlement, possibly serving as a port or even a nascent entrepôt. In geographic terminology, an entrepôt is a principal transshipment location—city, port, or trading post—where goods are imported and exported, stored, and traded.

3. THE BOSPORUS AND DARDANELLES

The Bosporus and Dardanelles were cut off from the world ocean as sea level dropped below the Aegean mouth of the Dardanelles (Figure 6). Rather than today's saltwater channel of 300 km, there was an overland route of 350 km, one-third of which was a deep lake now submerged beneath the Sea of Marmara. The Danube River was an alternative exit to the west, albeit with no short, unimpeded access to the Mediterranean Sea.

The Black Sea lapped the Bosporus at times whenever precipitation was sufficient to fill its basin, and a river flowed freely from sea to sea. This route was about the same as today, except that its mouth in the Aegean Sea was 50 km farther southwest. At other times, rainfall was insufficient, and the Bosporus was dry. Overland travelers likely crossed over the Gallipoli Peninsula (120 m high, about 5 km across) to reach the Gulf of Saros, thereby shortening total distance by about 125 km.

Ryan and Pitman (2000) postulate a catastrophic inundation from the Bosporus into the Black Sea after dry conditions had caused the Black Sea's level to fall 80 m below the world ocean. As the ocean rose, it breached the Bosporus about 7600 BP. Others question the depth, speed, and timing of the

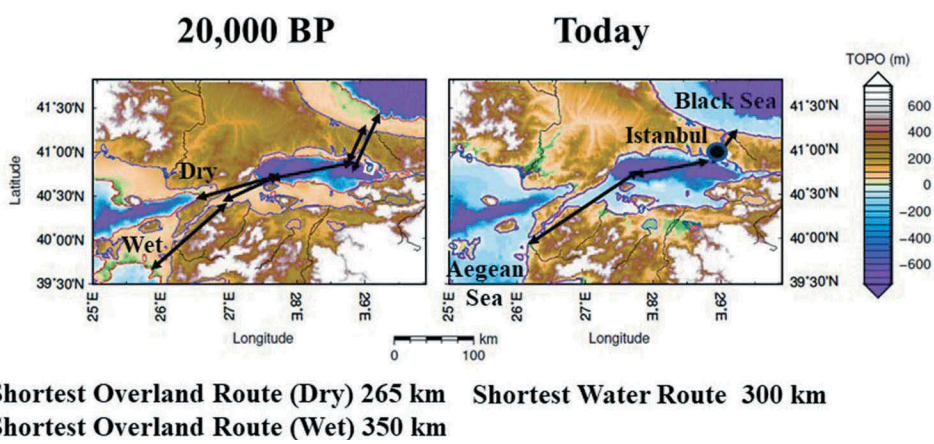

FIG. 6—The Bosporus and Dardanelles at LGM and today (left and right frames, respectively), distinguishing between long term dry conditions when precipitation was insufficient to fill the Black Sea basin and long term wet conditions when rivers overflowed the basin and replaced the Bosporus and Dardanelles. Lambert Azimuthal Equal Area Projection.

inundation. Giosan and others (2009) favor a slower rate of inundation about 9400 BP when the Black Sea was just 30 m below the world ocean.

The LGM map (Figure 6) highlights several candidate areas for submerged settlements, all of which would have depended on ocean depth and river flow. When the river was navigable, there could have been a settlement, possibly a nascent entrepôt, in the Aegean Sea 50 km west of the current mouth of the Dardanelles and a less prominent port on the Black Sea just east of the current mouth of the Bosporus. When there was no navigable river, a western terminus in the Gulf of Saros might have served as a settlement, possibly a nascent entrepôt. Its location would be near today's eastern end of the gulf, and its depth would have been considerably shallower than at LGM, say -100 to -80 m, since the dry-climate period is believed to have predated a Black Sea inundation in 9400 BP or 7600 BP. In either case, wet or dry, two lake settlements could have existed at the eastern and western ends of Lake Marmara, now submerged beneath the Sea of Marmara.

4. THE STRAIT OF GIBRALTAR

The Strait of Gibraltar (Figure 7) was about 10 km wide at LGM compared to just over 14 km today. Thus, its navigability was about the same as today, except for a likely acceleration in velocities of currents and tides.

The LGM map (Figure 7) shows a broader coastal plain on north and south shores, increasing to the west. Straits do not always encourage substantial settlement; still, underwater archaeological reconnaissance may be warranted on both shores. The same is true for the shallow salt water surrounding

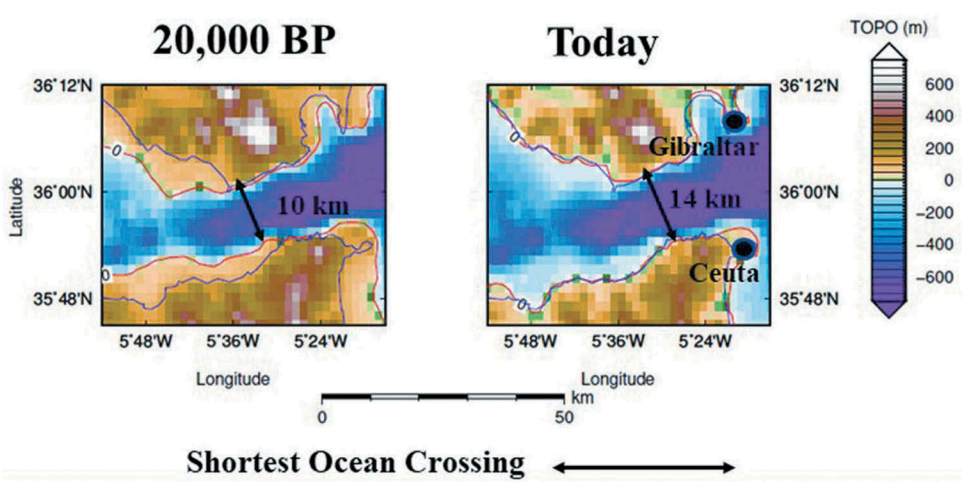

FIG. 7—Paleo-shorelines of the Strait of Gibraltar at the LGM (left) and today (right), also showing the shortest ocean crossing. Lambert Azimuthal Equal Area Projection.

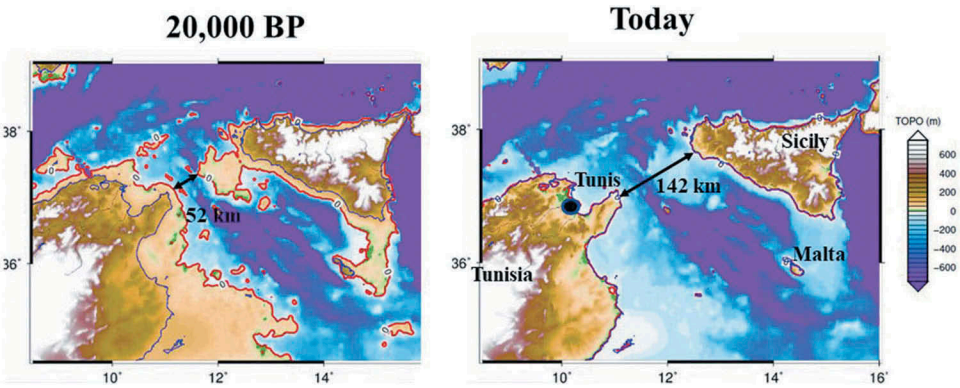

Fig. 8—Reconstruction of the paleotopography of the Straits of Sicily and Messina, at the LGM (left), compared with the present shorelines (right). Lambert Azimuthal Equal Area Projection.

Gibraltar and Ceuta, which were protected from the Atlantic Ocean then as today.

5. THE STRAITS OF SICILY AND MESSINA

The straits of Sicily and Messina (Figure 8) almost severed the Mediterranean Sea into two separate seas, divided by the Island of Sicily, the closed Strait of Messina, and the narrowed Strait of Sicily—142 km wide today but only 52 km across at LGM. Still, most of the crossing was 80 m to several hundred meters deep, and seamen could plot a course of at least 100 m depth from deep sea in the east and west. K. Roy and W. Richard Peltier (2018) recently tested an improved model ICE-7G NA (VM7), which refines the depths of regional subdivisions (# 12–15) in the channel but does not alter our conclusion.

The LGM map (Figure 8) shows additional islands and coastal plains in an area already known for early settlement. The Hal Saflieni Hypogeum of carved limestone on Malta is 6,000 years old (McKenna 2017). A 12 m long, carved monolith recently discovered at 40 m depth is taken as evidence of human occupance about 10,000 years ago (Lodolo and Ben-Avraham 2015).

6. THE ISTHMUS OF SUEZ

The Isthmus of Suez was dramatically different at LGM; the Gulf of Suez itself did not exist, and there was no canal (Figure 9). The transect of today was then a portage 520 km long. The return of the Gulf to, say, 10 m depth about 6000 BP shortened the portage to 150 km. Starting as early as c. 3850 BP, attempts were made to build a canal of about 135 km connecting the Nile Delta with Great Bitter Lake (now part of the Suez Canal). Herodotus, Aristotle, Strabo, and Pliny the Elder reported efforts by several pharaohs (Sesostris, Necho, and Ptolemy II)

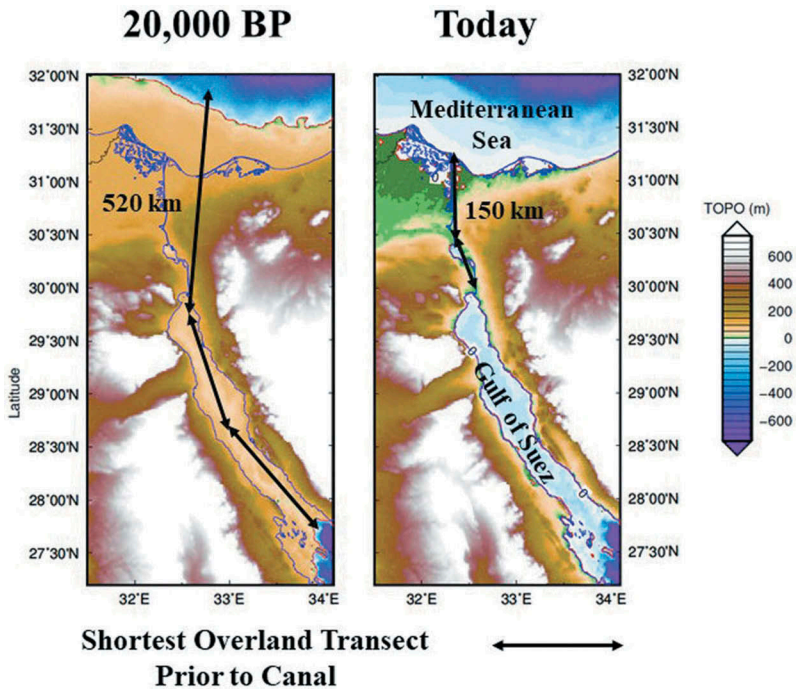

FIG. 9—Shorelines in the region of the Isthmus of Suez at LGM (left) and today (right), according to our GIA simulations. The shortest overland routes are also shown. Lambert Azimuthal Equal Area Projection.

and conquerors (Darius the Great, Trajan, and 'Amr ibn al-'As), but the record is unclear as to which efforts were successful and when the canal was navigable. The geographer and astronomer Ptolemy (c.100–c.170 CE) reported that the "River of Trajan," a Roman canal, was open in his lifetime. Completion of the Suez Canal in 1869 finally removed the barrier altogether.

After the Gulf was refilled (about 8000 BP) until 1869, traffic was split among at least five overland routes, to and from: i) Arsinoe on the Gulf of Suez northward to Pelusium on the Mediterranean Sea; ii) the Nile River (north of Cairo) eastward to the Gulf of Suez. This route was facilitated by Necho's Canal sporadically from c. 550 BCE to c. 767 CE; iii) Foul Bay (on the Red Sea straddling the present Egypt-Sudan boundary) northwestward to the Nile River at Coptos (Qift); iv) Foul Bay westward to the Nile River at Syene (Aswan); v) the Nile River upstream (south) of Wadi Halfa 700 km southeastward to Suakin, Sudan.

The preference for the Wadi Halfa to Suakin route throughout the Middle Ages is testament to how dangerous the Red Sea was. Suakin was favored over more northerly ports despite the portage's overland length (>700 m) because i) the Red Sea with its narrow width and north-south orientation was extremely

difficult to navigate before John Harrison solved the problem of longitude in 1761, and ii) reefs were numerous and treacherous along the western shore of the Red Sea. The same factors doubly ensured that aquaterran travelers favored the Foul Bay route over the Suez route.

The LGM map (Figure 9) shows termini at each end of the overland portage, one in the Gulf of Suez and another in the Mediterranean Sea. Furthermore these termini would have migrated slowly with rising seas from the extreme ends to the remaining isthmus. This hypothesized trail of lost settlements may be less dramatic than expected, however, as the crossing may have been long enough to reduce traffic volume. In a separate manuscript in preparation we will explore the alternative route though Foul Bay.

7. BAB AL MANDAB

The Bab al Mandab and Red Sea responded to global sea-level rise and fall (Figure 10). Their ultimate depth (assuming adequate precipitation in the basin) is limited by the Hanish Sill, only about 7 m deeper than actual sea level at LGM, and located 150 km north of the narrowest channel through the Bab al Mandab. The channel itself narrowed from today's 25 km to about 3–5 km at LGM but with little effect on navigability, except for a likely acceleration in velocities of currents and tides.

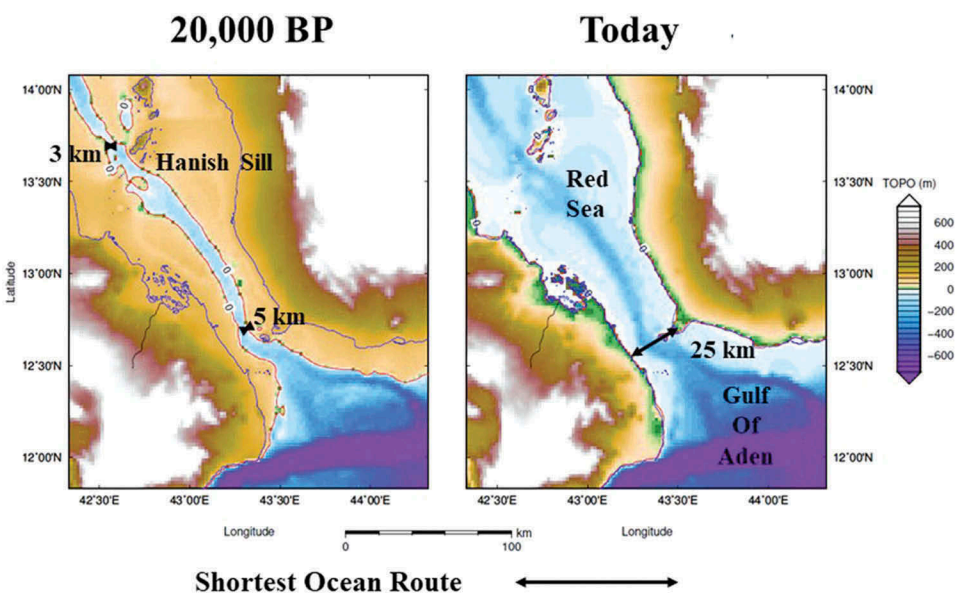

Fig. 10—Paleotopography of Bab al Mandab at LGM (left), compared to the present day topography (right). The shortest ocean routes in the two time frames are also shown. Lambert Azimuthal Equal Area Projection.

The LGM map (Figure 10) shows additional islands and coastal plains in a region already linked with early settlement in Egypt, Israel, and Sudan. Straits do not always encourage substantial settlement; still, underwater archaeological reconnaissance may be warranted on both shores.

8. THE STRAIT OF HORMUZ AND THE PERSIAN GULF

The Strait of Hormuz (Figure 11) and entire Persian Gulf (Figure 12) were exposed land. The Strait was a seacoast with the combined Tigris and

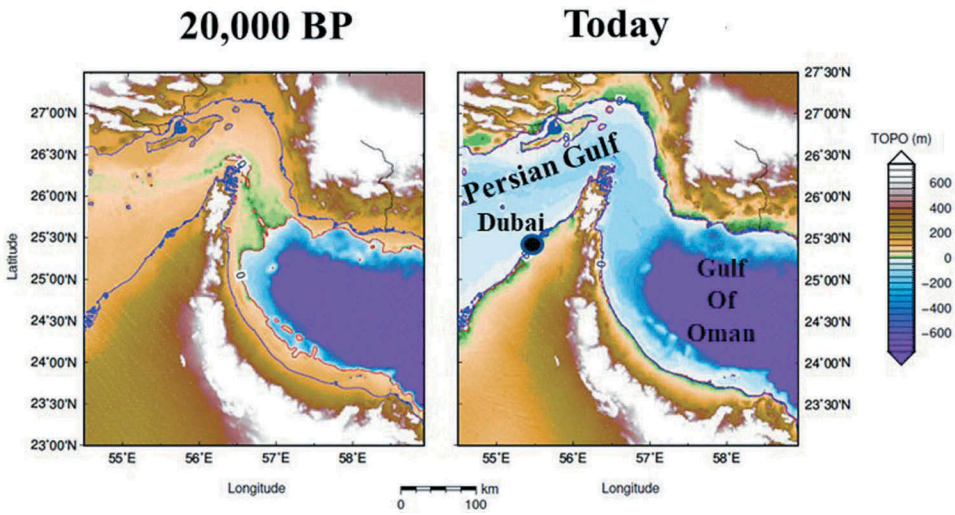

FIG. 11—Reconstruction of the topography in the Strait of Hormuz at the LGM (left) and today (right). Lambert Azimuthal Equal Area Projection.

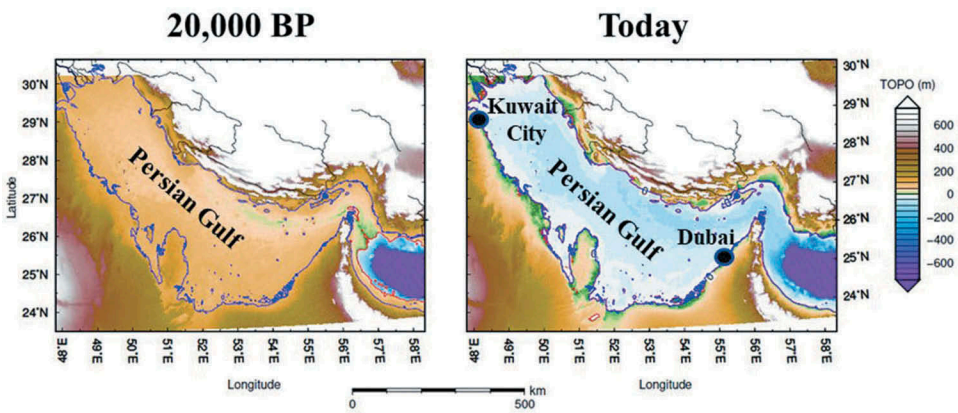

FIG. 12—Paleotopography of the Persian Gulf at LGM (left) and at present time (right). Lambert Azimuthal Equal Area Projection.

Euphrates rivers flowing through. All travel and transport to the interior were via river navigation or overland trek.

The LGM maps (Figures 11 and 12) show an entire region that was landlocked for thousands of years. The small bay remaining at the mouth of Hormuz may have served inland markets, but there would have been no high-volume traffic across to destinations on the other side. Most candidate settlements of interest to underwater archaeologists would have developed beside the river on the dry sea floor as water receded slowly across from LGM to 7,500 years ago.

9. THE STRAIT OF MALACCA

The Strait of Malacca was replaced with a 1000-km linear land barrier (Figure 13). Today's Strait is shaped like a funnel with its wide western end and narrow, island-constricted eastern end. All depths at the eastern end are less than 30 m, and many channels between islands are less than 3 m. The entire funnel was exposed for thousands of years before and after LGM. Indeed, all of aquaterra between Sumatra, Java, Borneo, and Southeast Asia was exposed. There was no alternative for seagoing vessels except to circumnavigate the entire landmass of Southeast Asia plus aquaterran Sundaland through the long passage separating Sundaland from Sahul. On a trip from Taiwan to Sri Lanka, for example, the detour increased total distance from 5700 km today to 9200 km then.

The LGM map (Figure 13) shows an entire region that was landlocked for thousands of years. The wide bay remaining at the western mouth of Malaca may have served inland markets, but there would have been no high-volume traffic across to destinations on the other side. Indeed, if distance were the only

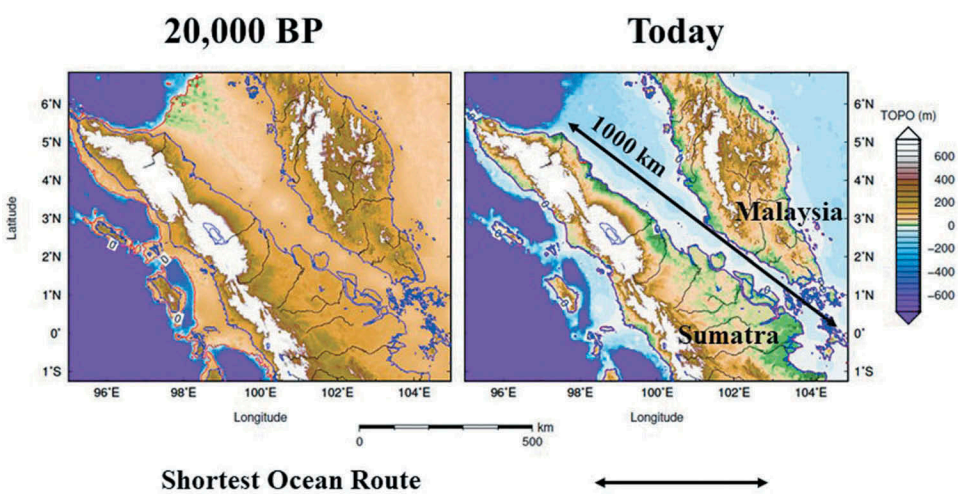

FIG. 13—The Strait of Malacca at LGM (left) and today (right), also showing the shortest ocean route today. Lambert Azimuthal Equal Area Projection.

concern, north-south routes would have held an advantage over east-west routes. Most candidate settlements of interest to underwater archaeologists would have developed on the dry sea floor as water receded slowly eastward across it from LGM to 7,500 years ago.

Conclusions

The very existence of aquaterra implies enormous shifts of aggregate land areas and evolving configurations of land masses for 120,000 years, reaching its deepest bathymetric extent at Last Glacial Maximum (LGM) ~ 20,000 years ago. We expected corresponding changes of transportation potential and found them in spades. Changing sea levels dramatically altered seven of nine global choke points and impacted regional and global transportation potentials. At LGM, maritime transport potential was impeded for much of the world, while conversely land travel extended over larger areas of exposed land and faced fewer ocean barriers. Only two global choke points were nearly unchanged—the Strait of Gibraltar and Bab al Mandab—and even they were somewhat narrower. In summary: The Strait of Gibraltar, Strait of Sicily, and Bab al Mandab were open and navigable, but the Bering Strait, Strait of Hormuz, and Strait of Malacca were dry land. The Isthmus of Panama was an arduous portage 2.25 times as long as today, and the Isthmus of Suez portage was 3.5 times as long as today.

For every strategic aquaterran detour, we found arguments commending submerged sites for future reconnaissance by underwater archaeologists. The most compelling are (a) a previously unknown submerged archipelago on the southwest shore of the aquaterran Bering landmass; (b) the tip of a pivotal bay on the south shore of the aquaterran Isthmus of Panama; (c) a string of potential transport nodes through the aquaterran Bosporus and Dardanelles, plus a previously unsuspected alternative portal near the eastern end of the aquaterran Gulf of Saros; and (d) a realignment of potential transport from the Gulf of Suez to Foul Bay thence via the Nile River to the Mediterranean Sea.

GIA modeling joins radar, sonar, and lidar as means of mapping and imaging three-dimensional morphology. Each distinctively renders physical surfaces in its own meaningful and revealing ways. Each excels in specific attributes that fit a particular need. Lidar, especially, has sparked recent excitement for its ability to detect overgrown and somewhat buried archaeological structures and render subterranean networks, for instance more than 60,000 Maya structures and settlements in Guatemala. GIA modeling, while spatially coarse by radar, sonar, and lidar standards, is ideally suited to the needs of our research focusing on ocean floors in past times. Conversely, lidar is primarily terrestrial; radar can sense beneath a water surface, but not very deep; and sonar can sense the ocean floor and even find ancient features, but it cannot sense or predict transitory features that no longer exist. The Bering Transitory Archipelago, for example,

which existed for at least 22,000 years but disappeared 8,000 years ago, could be detected by GIA modeling and not by other means.

The concept of aquaterra encourages strategic thought and holistic research from diverse geographic, oceanographic, and archaeological perspectives. Aquaterra now lies under tens of meters of seawater; an oceanographer's knowledge and expertise are essential to understand its complex physical systems. Repeatedly in cycles, aquaterra was dry land … ultimately with houses, roads, and buildings; a geographer's knowledge and expertise are essential to understand its complex infrastructures, networks, economies, and cultural systems. An underwater archaeologist's skills and perspectives are essential to find definitive evidence. A host of diverse fields and disciplines—geologists, biologists (especially evolutionary biologists), microbiologists, nautical engineers, spatial statisticians, and many others—will be essential to address issues ranging from detection to forensics to seafloor access. Collaboration is key. New methods, models, and databases promise breathtaking views of long-lost landscapes.

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References

Amante, C., and B. W. Eakins. 2009. *ETOPO1 1 Arc-minute Global Relief Model*. NOAA Technical Memorandum NESDIS NGDC-24. Boulder, Colo.: National Geophysical Data Center, Marine Geology and Geophysics Division.

Anderson, D. G., and T. G. Bissett. 2015. The Initial Colonization of North America: Sea Level Change, Shoreline Movement, and Great Migrations. In *Mobility and Ancient Society in Asia*

and the Americas, edited by M. D. Frachetti and R. N. Spengler III. Switzerland: Springer International Publishing. DOI: 10.1007/978-3-319-15138-0_6.

Anderson, D. G., T. G. Bissett, and S. J. Yerka. 2013. The Late-Pleistocene Human Settlement of Interior North America: The Role of Physiography and Sea-Level Change. In *PaleoAmerican Odyssey* edited by K. E. Graf, C. V. Ketron, and M. R. Waters, 235–255. College Station, Tex.: Center for the Study of the First Americans.

Bird, M. I., S. A. Condie, S. O'Connor, D. O'Grady, C. Reepmeyer, S. Ulm, M. Zega, F. Saltré, and C. J. A. Bradshaw. 2019. Early Human Settlement of Sahul Was Not an Accident. *Scientific Reports* 9 (1): 8220. DOI: 10.1038/s41598-019-42946-9.

Bradshaw, C. J. A., S. Ulm, A. N. Williams, M. I. Bird, R. G. Roberts, Z. Jacobs, F. Laviano, L. S. Weyrich, T. Friedrich, K. Norman, and F. Saltré. 2019. Minimum Founding Populations for the First Peopling of Sahul. *Nature Ecology & Evolution*. DOI: 10.1038/s41559-019-0902-6

Bradshaw, M., G. W. White, J. P. Dymond, and E. Chacko. 2012. *Contemporary World Regional Geography: Global Connections, Local Voices*. New York: McGraw-Hill.

Brooks, A. S., J. E. Yellen, R. Potts, A. K. Behrensmeyer, A. L. Deino, D. E. Leslie, S. H. Ambrose, J. R. Ferguson, F. d'Errico, A. M. Zipkin, and others. 2018. Long-distance Stone Transport and Pigment Use in the Earliest Middle Stone Age. *Science* 360 (6384): 90–94.

Caracciolo, L., ed.. 2019. The Strategic Straits. Part IV. *Limes*. Rome, Italy: Gruppo Editoriale L'Espresso.

Cavalli-Sforza, L. L., P. Menozzi, and A. Piazza. 1993. Demic Expansions and Human Evolution. *Science* 259: 639–639.

Clarkson, C., Z. Jacobs, B. Marwick, R. Fullagar, L. Wallis, M. Smith, R. G. Roberts, E. Hayes, K. Lowe, C. Carah, and others. 2017. Human Occupation of Northern Australia by 65,000 Years Ago. *Nature* 547 (7663): 306.

Curry, A. 2008. Göbekli Tepe: The World's First Temple? *Smithsonian.com* (November): http://www.smithsonianmag.com/history-archaeology/gobekli-tepe.html.

Cvitkušić, B., S. Radović, and D. Vujević. 2017. Changes in Ornamental Traditions and Subsistence Strategies during the Palaeolithic-Mesolithic Transition in Vlakno Cave. *Quaternary International* in press.

Daley, J. 2019. An 8,000-year-old Platform in Britain Could Be the Oldest Boat-building Site Ever Discovered. *SmartNews*, Smithsonian.com. https://www.smithsonianmag.com/smart-news/8000-year-old-boat-building-platform-found-coast-britain–180972989/.

Davies, J. 2016. *The Birth of the Anthropocene*. Berkeley: University of California Press.

Davis, L. G., D. B. Madsen, L. Becerra-Valdivia, T. Higham, D. A. Sisson, S. M. Skinner, D. Stueber, A. J. Nyers, A. Keen-Zebert, C. Neudorf, M. Cheyney, M. Izuho, F. Iizuka, S. R. Burns, C. W. Epps, S. C. Willis, and I. Buvit. 2019. Late Upper Paleolithic Occupation at Cooper's Ferry, Idaho, USA, ~16,000 Years Ago. *Science* 365 (6456): 891–897. DOI: 10.1126/science.aax9830

Dillehay, T. D., C. Ramírez, M. Pino, M. B. Collins, J. Rossen, and J. D. Pino-Navarro. 2008. Monte Verde: Seaweed, Food, Medicine, and the Peopling of South America. *Science* 320 (5877): 784–786. DOI: 10.1126/science.1156533

Dobson, J. E. 1998. The Iodine Factor in Health and Evolution. *Geographical Review* 88 (1): 1–28.

_____ 1999. Explore Aquaterra-Lost Land beneath the Sea. *GeoWorld* 12: 30–31.

_____ 2002. Comment in Reply: An Interdisciplinary Discourse on the Role of Iodine in Human Evolution. *Geographical Review* 92 (1): 97–103.

_____ 2014. Aquaterra *Incognita*: Lost Land beneath the Sea. *Geographical Review* 104 (2): 123–138.

Erlandson, J. M., M. H. Graham, B. J. Bourque, D. Corbett, J. A. Estes, and R. S. Steneck. 2007. The Kelp Highway Hypothesis: Marine Ecology, the Coastal Migration Theory, and the Peopling of the Americas. *Journal of Island and Coastal Archaeology* 2 (2): 161—174. DOI: 10.1080/15564890701628612

Ferentinos, G., M. Gkioni, M. Geraga, and G. Papatheodorou. 2012. Early Seafaring Activity in the Southern Ionian Islands, Mediterranean Sea. *Journal of Archaeological Science* 39 (7): 2167–2176.

Gamble, C. 2013. *Settling the Earth: The Archaeology of Deep Human History*. Cambridge, U.K.: Cambridge University Press.

Gannon, M. 2017. Divers Find 8 More Wrecks at Sunken-ship Hotspot in Greece. https://www.livescience.com/59805-divers-find-8-more-shipwrecks-greece.html.

Gibbons, A. 1998. Ancient Island Tools Suggest Homo erectus Was a Seafarer. *Science* 279 (5357): 1635–1637.

Giosan, L., F. Filip, and S. Constatinescu. 2009. Was the Black Sea Catastrophically Flooded in the Early Holocene? *Quaternary Science Reviews* 28 (1–2): 1–6.

Hardy, A. 1960. Was Man More Aquatic in the Past? *New Scientist* 7 (174): 642–45.

Irwin, G. 1991. Pleistocene Voyaging and the Settlement of Greater Australia and Its Near Oceanic Neighbours. In *Report of the Lapita Homeland Project*, edited by J. Allen and C. Gosden, 9—19. Canberra, Australia: Highland Press.

Jakobsson, M., C. Pearce, T. M. Cronin, J. Backman, L. G. Anderson, N. Barrientos, G. Björk, H. Coxall, A. De Boer, L. A. Mayer, and others. 2017. Post-glacial Flooding of the Bering Land Bridge Dated to 11 cal ka BP Based on New Geophysical and Sediment Records. *Climate of the Past* 13 (8): 991.

Jones, D. W. 1993. Phoenician Unguent Factories in Dark Age Greece: Social Approaches to Evaluating the Archaeological Evidence. *Oxford Journal of Archaeology* 12 (3): 293–303.

Kaiser, T., and S. Forenbaher. 2015. Navigating the Neolithic Adriatic. In *Fresh Fields and Pastures New: Papers in Honor of Andrew M.T. Moore*, edited by K. T. Lillios and M. Chazan, 145–164. Leiden, Netherlands: Sidestone Press.

Lambeck, K., and J. Chappell. 2001. Sea Level Change through the Last Glacial Cycle. *Science* 292 (5517): 679–686.

Lambeck, K., A. Purcell, P. Johnston, M. Nakada, and Y. Yokoyama. 2003. Water-load Definition in the Glacio-hydro-isostatic Sea-level Equation. *Quaternary Science Reviews* 22 (2): 309–318.

Lambeck, K., Y. Yokoyama, and T. Purcell. 2002. Into and Out of the Last Glacial Maximum: Sea-level Change during Oxygen Isotope Stages 3 and 2. *Quaternary Science Reviews* 21 (1–3): 343–360.

Langdon, J. H. 1997 Umbrella Hypotheses and Parsimony in Human Evolution: A Critique of the Aquatic Ape Hypothesis. *Journal of Human Evolution* 33 (4): 479–494. DOI:10.1006/jhev.1997.0146. PMID 9361254.

Lartet, L. 1868a. Mémoire sur une Sépulture des Anciens Troglodytes du Périgord. *Zoologie et Paléontologie* 5 (10): 133–145.

_____ 1868b. Une Sépulture des Troglodytes du Périgord (crânes des Eyzies). *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 3 (1): 335–349.

Leemans, W. F. 1977. The Importance of Trade. *Iraq* 39 (1): 1–10. URL http://www.jstor.org/stable/4200042.

Levy, O., G. Dai, C. Riedel, C. S. Ginter, E. M. Paul, A. N. Lebowitz, and N. Carrasco. 1997. Characterization of the Thyroid Na +/I - Symporter with an Anti-COOH Terminus Antibody. *Proceedings of the National Academy of Sciences of the United States of America* 94 (11): 5568–5573. Stable URL: http://links.jstor.org/sici?sici=00278424%2819970527%2994%3A11%3C5568%3ACOTTNS%3E2.0.CO%3B2-0.

Llamas, B., L. Fehren-Schmitz, G. Valverde, J. Soubrier, S. Mallick, N. Rohland, S. Nordenfelt, C. Valdiosera, S. M. Richards, A. Rohrlach, M. I. B. Romero, I. F. Espinoza, E. T. Cagigao, L. W. Jiménez, K. Makowski, I. S. L. Reyna, J. M. Lory, J. A. B. Torrez, M. A. Rivera, R. L. Burger, M. C. Ceruti, J. Reinhard, R. S. Wells, G. Politis, C. M. Santoro, V. G. Standen, C. Smith, D. Reich, S. Y. W. Ho, A. Cooper, and W. Haak. 2016. Ancient Mitochondrial DNA Provides High-resolution Time Scale of the Peopling of the Americas. *Science Advances* 2 (4): 1–10. DOI:10.1126/sciadv.1501385pmid:27051878.

Lodolo, E., and Z. Ben-Avraham. 2015. A Submerged Monolith in the Sicilian Channel (Central Mediterranean Sea): Evidence for Mesolithic Human Activity. *Journal of Archaeological Science: Reports* 3: 398–407.

Martinec, Z., V. Klemann, W. van der Wal, R. Riva, G. Spada, Y. Sun, D. Melini, S. Kachuck, V. Barletta, K. Simon, and others. 2018. A Benchmark Study of Numerical Implementations of the Sea Level Equation in GIA Modelling. *Geophysical Journal International* 215 (1): 389–414.

McKenna, S. 2017. Malta's Hypogeum, One of the World's Best Preserved Prehistoric Sites, Reopens to the Public. *Smithsonian.com*. https://www.smithsonianmag.com/travel/maltas-hypogeum-one-worlds-best-preserved-prehistoric-sites-reopens-public-180963397/.

Murray, L. 2018. The Underwater Archaeology of Fourni, Greece's Shipwreck Capital of the World. Stevenage, Hertfordshire: The Institution of Engineering and Technology. https://eandt.theiet.org/content/articles/2018/07/the-underwater-archaeology-of-fourni-greece-s-shipwreck-capital-of-the-world/.

Pearson, G. A. 2017. Bridging the Gap: An Updated Overview of Clovis across Middle America and Its Techno-Cultural Relation with Fluted Point Assemblages from South America. *PaleoAmerica* 3: 1–28. DOI: 10.1080/20555563.2017.1328953.

Pearson, G. A., and R. G. Cooke 2003. The Role of the Panamanian Land Bridge during the Initial Colonization of the Americas. *Antiquity* 76 (294): 931–932.

Peltier, W. R. 1994. Ice Age Paleotopography. *Science* 265 (5169): 195–201.

Peltier, W. R., D. F. Argus, and R. Drummond. 2015. Space Geodesy Constrains Ice Age Terminal Deglaciation: The Global ICE-6G_C (VM5a) Model. *Journal of Geophysical Research: Solid Earth* 120 (1): 450–487.

Pendleton, M., T. Stephens, A. Ellis, and G. Fox. 2002. The Characteristics of Early Helladic II Period Wood Recovered from an Underwater Shipwreck Site near Dokos, Greece. *Microscopy and Microanalysis* 8 (S02): 1070–1071.

Pinotti, T., A. Bergström, M. Geppert, M. Bawn, D. Ohasi, W. Shi, D. R. Lacerda, A. Solli, J. Norstedt, K. Reed, K. Dawtry, F. González-Andrade, C. Paz-Y-Miño, S. Revollo, C. Cuellar, M. S. Jota, J. E. Santos Jr.., Q. Ayub, T. Kivisild, J. R. Sandoval, R. Fujita, Y. Xue, L. Roewer, F. R. Santos, and C. Tyler-Smith. 2019. Y Chromosome Sequences Reveal a Short Beringian Standstill, Rapid Expansion, and Early Population Structure of Native American Founders. *Current Biology* 29: 149–157. DOI:10.1016/j.cub.2018.11.029pmid:30581024.

Ray, N., and J. Adams. 2001. A GIS-based Vegetation Map of the World at the Last Glacial Maximum (25,000-15,000 BP). *Internet Archaeology* 11, 5 pages with geographic database and map.

Roy, K., and W. Peltier. 2018. Relative Sea Level in the Western Mediterranean Basin: A Regional Test of the ICE-7G NA (VM7) Model and a Constraint on Late Holocene Antarctic Deglaciation. *Quaternary Science Reviews* 183: 76–87.

Ryan, W., and W. Pitman. 2000. *Noah's Flood: The New Scientific Discoveries about the Event that Changed History*. New York: Simon and Schuster.

Sauer, C. O. 1962. Seashore–Primitive Home of Man. *Proceedings of the American Philosophical Society* 106 (1): 41–47.

Spada, G., and D. Melini. 2019. A Fortran Program for Solving the Gravitationally and Topographically Self-consistent Sea Level Equation in Glacial Isostatic Adjustment Modeling. *Geoscientific Model Development Discussions 2019*: 1–37. DOI: 10.5194/gmd-2019-183. https://www.geosci-model-dev-discuss.net/gmd-2019-183/

Spada, G., and G. Galassi. 2017. Extent and Dynamic Evolution of the Lost Land Aquaterra Since the Last Glacial Maximum. *Comptes Rendus Geoscience* 349 (4): 151–158.

Spada, G., and P. Stocchi. 2007. SELEN: A Fortran 90 Program for Solving the "Sea Level Equation." *Computers and Geosciences* 33 (4): 538–562.

Stanford, D. J., D. L. Lowery, M. Jodry, B. A. Bradley, M. Kay, T. W. Stafford, Jr., and R. J. Speakman. 2014. New Evidence for a Possible Paleolithic Occupation of the Eastern North American Continental Shelf at the Last Glacial Maximum. In *Prehistoric Archaeology on the Continental Shelf*, edited by A. Evans, J. Flatman, and N. Flemming, 73–92. New York: Springer.

Tarlach, G. 2019. Return to Aquaterra. *Discover*, June, 54–61.

Tegmark, M. 1996. An Icosahedron-based Method for Pixelizing the Celestial Sphere. *The Astrophysical Journal* 470: L81.

Vandiver, P. B., O. Soffer, B. Klima, and J. Svoboda. 1989. The Origins of Ceramic Technology at Dolnì Věstonice, Czechoslovakia. *Science* 246 (4933): 1002–1008.

Wessel, P., and W. H. F. Smith. 1998. New, Improved Version of Generic Mapping Tools Released. *Eos Transactions American Geophysical Union* 79 (47): 579.

Westaway, M. C. 2019. The First Hominin Fleet. *Nature Ecology & Evolution*. DOI: 10.1038/s41559-019-0928-9.

Wright, H. T. 2009 Humanity at the Last Glacial Maximum. In *Ancient Human Migrations: A Multidisciplinary Approach*, edited by P. Peregrine, I. Peiros and M. Feldman, 55–73. Salt Lake City: University of Utah Press.

Wu, X., C. Zhang, P. Goldberg, D. Cohen, Y. Pan, T. Arpin, and O. Bar-Yosef. 2012. Early Pottery at 20,000 Years Ago in Xianrendong Cave, China. *Science* 336 (6089): 1696–1700.

Zong, C. 2015. *Late Pleistocene Sea Levels and Resulting Changes in Global Land Distributions*. Master's thesis, University of Kansas.