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Windows of opportunity for the peopling of the Americas

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For decades, the route and timing of human dispersal to the Americas have been the focus of a lively debate in the scientific community (1). From this debate, two primary models for the peopling of the Americas have emerged. The first, and older, model posits that the first inhabitants of North America expanded southwards from Beringia by traversing an inland "ice-free corridor" between the retreating Cordilleran and Laurentide ice sheets (2). In recent years, an alternative model has gained traction: That humans first reached the Americas by sailing along the Pacific coastline from Northeast Asia (the "coastal migration theory", ref. 3). In PNAS, Praetorius et al. (4) use marine sediment records and climate model simulations to reconstruct oceanographic conditions in the Northeast Pacific from the Last Glacial Maximum (LGM) to the Holocene and, in doing so, identify environmentally favorable time intervals for human migration to the Americas using the Pacific coastal route.

Recent geological research on the peopling of the Americas has focused on identifying the presence or absence of ice-free conditions and/or ecological viability along the interior (5–7) and coastal routes to the Americas (8–12). These studies have revealed that parts of the coastal route were available for migration earlier than the interior route and, importantly, that the coastal route may have been open and ecologically viable during one or more of the pulses of human migration inferred from paleogenetics (13). Although not without controversy (e.g., ref. 14), a growing number of cultural sites south of the ice sheets that reportedly predate the opening of the ice-free corridor (15, 16) provide additional support for the coastal migration theory.

While many archeologists now believe that the Pacific coast was the main entry point to the Americas during the late Pleistocene (17), few studies have examined the potential impact of Pacific Ocean conditions on coastal migration. Royer and Finney (18) proposed that meltwater-driven variations in the velocity of the Alaska Coastal Current, which flows counterclockwise along the Gulf of Alaska continental shelf today (Fig. 1), may have helped or hindered human travel on the Northeast Pacific coast. Relying on assumptions about the relationship between modern Alaskan glacier melt and Cordilleran Ice Sheet contribution to global sea-level change, they suggested that variations in freshwater flux to the North Pacific Ocean during deglaciation resulted in a reduction in the strength of the Alaska Coastal Current prior to 16 ka, followed by an acceleration in current strength from the Bølling–Allerød (~14.65 ka) to the start of the Younger Dryas (~12.8 ka). Based on these inferences, they argued that coastal migration may have been more feasible before the Bølling–Allerød. However, this hypothesis—and the validity of its underlying assumptions about the timing of maximum freshwater discharge to the Northeast Pacific Ocean—has not been thoroughly tested. Praetorius et al. carry out several model experiments to assess this hypothesis and use new and previously published marine sediment records to reconstruct paleoenvironmental conditions along the Pacific coastal route to the Americas.

Simulating Coastal Current Velocity

To evaluate the influence of ice sheet melt, climate, and sea-level change on coastal current strength, Praetorius et al. ran several general circulation model simulations of the Northeast Pacific Ocean under conditions that approximate the LGM, Bølling–Allerød, and modern. In the first experiment, they lowered the sea level to 120 m below present and ran the model with LGM atmospheric boundary conditions. Their Bølling–Allerød simulation used modern atmospheric boundary conditions and a sea level of 75 m below present. The authors also simulated the impact of sudden, large-volume freshwater discharge from the Columbia River to the Northeast Pacific over 1 y (in the style of the Missoula Megafloods) under LGM model conditions. To assess the impact of sustained freshwater input to the Pacific Ocean from multiple sources—which more closely approximates the delivery of meltwater to the Northeast Pacific from a disintegrating Cordilleran Ice Sheet—the authors ran hosing simulations on a lower-resolution model.

In these simulations, the Alaska Current more than doubled in velocity during the LGM relative to modern. The authors suggest that the Alaska Current intensified due to lower sea levels funneling the two major Gulf of Alaska currents into a single stream as well as stronger winds during the LGM. During intervals with enhanced freshwater flux to the Pacific, such as Siku Event 1 (~18.5 to 16 ka; refs. 21 and 22), both models also simulate an increase in Alaska Current speed (Fig. 1). On the other hand, the Alaska Current decreased in strength during their Bølling–Allerød simulation when sea levels were set to an intermediate position between the LGM lowstand and modern (Fig. 1).

A "Sea-Ice Highway" to the Americas?

Praetorius et al. then address how ice in the marine environment may have influenced coastal migration to the

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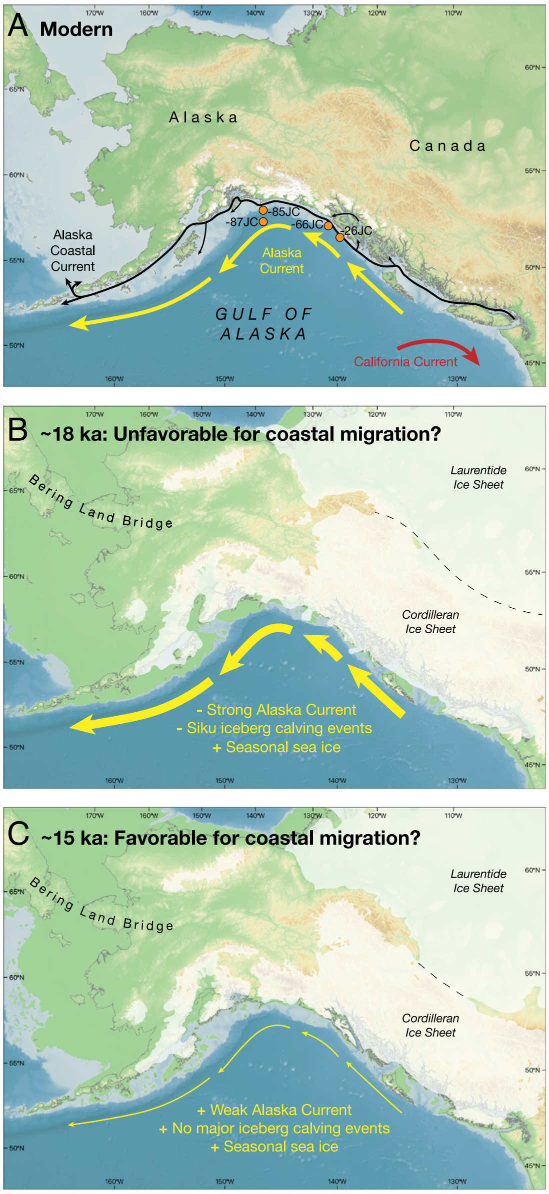

Fig. 1. Study area in the Northeast Pacific Ocean. The outline of modern shorelines is shown in all panels as a light gray line. Digital elevation model (DEM): ETOPO 2022 Bedrock (19). Green to brown colors indicate areas above sea level, and blue colors indicate areas below sea level. (*A*) Paths of modern ocean currents in the Gulf of Alaska modified from Royer and Finney (18), including the California Current (red arrow), Alaska Current (yellow arrows), and the Alaska Coastal Current (black arrows). Locations of marine sediment cores used by Praetorius et al. (4) for sea-ice reconstructions are marked by orange dots (full core names have a prefix of EW0408). Modern glacier extents are shown by white shading. (*B*) Reconstruction of the study area at ~18 ka, a time that Praetorius et al. suggest was unfavorable for coastal migration. As in Praetorius et al.'s simulations, in this reconstruction, sea levels are set to 120 m below present. (*C*) Reconstruction of the study area at ~15 ka, a time that Praetorius et al. hypothesize would be favorable for coastal migration. Sea level across the study area is shown at 75 m below modern. In panels *B* and *C*, ice sheet extents from Dalton et al. (20) are shown in white shading. The relative change in simulated velocity of the Alaska Current from Praetorius et al.'s ocean circulation modeling is indicated by the thickness of the yellow arrows. Factors that could increase (+) or decrease (−) the ease of coastal migration are listed at the bottom center of both panels.

Americas. Using a sea-ice proxy based on abundances of the C_{37} tetra-unsaturated methyl alkenone, the authors reconstruct annual sea-ice concentrations in four Gulf of Alaska sediment cores (Fig. 1). Combining their new alkenone record with other published sea-ice reconstructions, Praetorius et al. demonstrate that extensive seasonal sea ice fringed the Gulf of Alaska from the LGM through ~14.8 ka. The inference of seasonal sea ice from the LGM to the deglacial suggests that if humans were present along the Northeast Pacific coast at this time, these populations must have not only been adapted to coastal life but also to dramatic shifts in environmental conditions throughout the year. Furthermore, the authors speculate that sea ice may have actually facilitated coastal migration by forming a "sea-ice highway" upon which humans could move and hunt during the winter months. During the warmer summer months, these groups could have traveled by boat and obtained resources along the hypothesized eastern Pacific "kelp highway" (12). The combination of a summer kelp highway and a winter sea-ice highway that ensures continuity of coastal resources is an intriguing idea, but it requires a more thorough assessment from paleoenvironmental and archeological studies (3).

Prime Times for Coastal Migration

In the final sections of the manuscript, Praetorius et al. bring together a wealth of paleoclimatic data that highlight the dynamic character of Northeast Pacific coastal environments from the LGM to the Holocene, and ultimately suggest that 24.5 to 22 and 16.4 to 14.8 ka were the most environmentally favorable times for coastal migration. Falling between Siku iceberg discharge events (21), these two intervals were characterized by seasonal sea ice, stretches of unglaciated coastal land, and weaker north- or east-flowing nearshore currents (Fig. 1). These time windows also bracket the western Cordilleran Ice Sheet maximum (10, 11), predate the opening of the "ice-free corridor" (6), and postdate the hypothesized timing of genetic divergence between East Asian and Native American populations (13). The identification of these environmentally favorable time intervals for coastal migration is broadly useful, but the ocean circulation simulations do not include factors such as tides, eddies, winds, and freshwater discharge by rivers that may have locally counteracted the regional trends in Alaska Current strength. As a result, it remains unknown whether the location and timing of "optimal" boat travel conditions varied across the Pacific coast.

Even with this uncertainty, the interpretations presented by Praetorius et al. represent a potentially important step forward in the peopling of the Americas debate and could guide future archeological research. Archeologists may consider excavating ancient shorelines whose ages fall within the two most favorable windows of opportunity for boat travel. Such targeted surveying may aid in identifying other locations with stratigraphic units that contain useful archeological records. The results presented by Praetorius et al. may also help to focus new research questions on the ways of life for founding Native American populations, particularly their adaptations (if any) to winter sea ice. These research directions will have wide implications for our understanding of human coastal dispersals in the Americas and elsewhere.

Paleoenvironmental constraints on ice sheet extent, shoreline position, coastal ecology, and oceanic conditions should all continue to play an important role in evaluating the coastal migration theory. With the rise of cosmogenic nuclide surface exposure dating techniques, we are obtaining an increasingly detailed picture of terrestrial ice sheet retreat and the post-LGM reopening of the migration routes. However, as the number of potential pre-Clovis cultural sites grows, the need to determine when LGM ice sheet advances first closed the migration routes is becoming clearer. Furthermore, it is still unknown whether there were extensive areas of unglaciated terrain along the coastal route during the local LGM. Successfully locating these elusive ice-free refugia will likely require investigations on now-submerged regions of the continental shelf, which poses its own set of logistical challenges. Alongside these reconstructions, examining the ecology of Northeast Pacific paleoshorelines and carrying out high-resolution ocean circulation simulations that can resolve near-shore currents would offer a more complete picture of the environmental context for coastal migration. Common to all of these potential threads of inquiry is the need for creative approaches that draw from multiple disciplines, such as the one employed here by Praetorius et al.

Praetorius et al. use marine sediment records and climate model simulations to reconstruct oceanographic conditions in the Northeast Pacific from the Last Glacial Maximum (LGM) to the Holocene, and in doing so, identify environmentally favorable time intervals for human migration to the Americas using the Pacific coastal route.

Of course, our understanding of the processes and timing of human expansion into the Americas must ultimately rely on the archeological record. Nonetheless, by bringing conditions in the Pacific Ocean to their rightful place at the forefront of the discussion, Praetorius et al. provide a key paleoenvironmental perspective on the coastal migration theory, and there is no doubt that the ideas presented in this paper will stimulate debate and research in the years to come.

1. T. J. Braje, T. D. Dillehay, J. M. Erlandson, R. G. Klein, T. C. Rick, Finding the first Americans. *Science* **358**, 592–594 (2017).
2. B. A. Potter *et al.*, Early colonization of Beringia and Northern North America: Chronology, routes, and adaptive strategies. *Quat. Int.* **444**, 36–55 (2017).
3. L. G. Davis, D. B. Madsen, The coastal migration theory: Formulation and testable hypotheses. *Quat. Sci. Rev.* **249**, 106605 (2020).
4. S. Praetorius *et al.*, Ice and ocean constraints on early human migrations into North America along the Pacific coast. *Proc. Natl Acad. Sci. U.S.A.* **120**, e2208738120 (2023).
5. M. W. Pedersen *et al.*, Postglacial viability and colonization in North America's ice-free corridor. *Nature* **537**, 45–49 (2016).
6. J. Clark *et al.*, The age of the opening of the ice-free corridor and implications for the peopling of the Americas. *Proc. Natl. Acad. Sci. U.S.A.* **119**, e2118558119 (2022).
7. P. D. Heintzman *et al.*, Bison phylogeography constrains dispersal and viability of the ice free corridor in western Canada. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 8057–8063 (2016).
8. C. M. Darvill, B. Menounos, B. M. Goehring, O. B. Lian, M. W. Caffee, Retreat of the western Cordilleran Ice Sheet margin during the last deglaciation. *Geophys. Res. Lett.* **45**, 9710–9720 (2018).
9. C. F. G. Hebda *et al.*, Late Pleistocene palaeoenvironments and a possible glacial refugium on northern Vancouver Island, Canada: Evidence for the viability of early human settlement on the northwest coast of North America. *Quat. Sci. Rev.* **279**, 107388 (2022).
10. C. K. Walcott, J. P. Briner, J. F. Baichtal, A. J. Lesnek, J. M. Licciardi, Cosmogenic ages indicate no MIS 2 refugia in the Alexander Archipelago, Alaska. *Geochronology* **4**, 191–211 (2022).
11. A. J. Lesnek, J. P. Briner, C. Lindqvist, J. F. Baichtal, T. H. Heaton, Deglaciation of the Pacific coastal corridor directly preceded the human colonization of the Americas. *Sci. Adv.* **4**, eaar5040 (2018).
12. J. M. Erlandson *et al.*, The kelp highway hypothesis: Marine ecology, the coastal migration theory, and the peopling of the Americas. *J. Isl. Coast. Archaeol.* **2**, 161–174 (2007).
13. J. V. Moreno-Mayar, Terminal Pleistocene Alaskan genome reveals first founding population of Native Americans. *Nature* **553**, 203–207 (2018).
14. B. A. Potter *et al.*, Arrival routes of first Americans uncertain. *Science* **359**, 1224–1225 (2018).
15. L. G. Davis *et al.*, Late Upper Paleolithic occupation at Cooper's Ferry, Idaho, USA, ~16,000 years ago. *Science* **365**, 891–897 (2019).
16. M. R. Bennett *et al.*, Evidence of humans in North America during the Last Glacial Maximum. *Science* **373**, 1528–1531 (2021).
17. T. J. Braje *et al.*, Fladmark+ 40: What have we learned about a potential Pacific Coast peopling of the Americas? *Am. Antiq.* **85**, 1–21 (2020).
18. T. C. Royer, B. Finney, An oceanographic perspective on early human migrations to the Americas. *Oceanography* **33**, 32–41 (2020).
19. NOAA National Centers for Environmental Information. *ETOPO 2022 15 Arc-Second Global Relief Model* (NOAA National Centers for Environmental Information, 2023).
20. A. S. Dalton *et al.*, An updated radiocarbon-based ice margin chronology for the last deglaciation of the North American Ice Sheet Complex. *Quat. Sci. Rev.* **234**, 106223 (2020).
21. M. H. Walczak *et al.*, Phasing of millennial-scale climate variability in the Pacific and Atlantic Oceans. *Science* **370**, 716–720 (2020).
22. E. Maier *et al.*, North Pacific freshwater events linked to changes in glacial ocean circulation. *Nature* **559**, 241 (2018).