Rapid communication

Early retreat of the Alaska Peninsula Glacier Complex and the implications for coastal migrations of First Americans

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ABSTRACT

The debate over a coastal migration route for the First Americans revolves around two major points: seafaring technology, and a viable landscape and resource base. Three lake cores from Sanak Island in the western Gulf of Alaska yield the first radiocarbon ages from the continental shelf of the Northeast Pacific and record deglaciation nearly 17 ka BP (thousands of calendar years ago), much earlier than previous estimates based on extrapolated data from other sites outside the coastal corridor in the Gulf of Alaska. Pollen data suggest an arid, terrestrial ecosystem by 16.3 ka BP. Therefore glaciers would not have hindered the movement of humans along the southern edge of the Bering Land Bridge for two millennia before the first well-recognized "New World" archaeological sites were inhabited.

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1. Introduction

The timing and entry route of the first people to inhabit the Americas has been a controversial topic for decades. The debate as it pertains to a coastal migration route revolves around two major points: maritime adaptations/lack of archaeological sites along the coasts, and a viable landscape and resource base. The discussion about a viable landscape for migration includes the timing of access via a possible coastal route along the Aleutian Archipelago and Alaska Peninsula (controlled by retreat of the Alaska Peninsula Glacier Complex (APGC) along the Northeast Pacific margin) versus timing via a more terrestrial interior route known as the "ice-free corridor" and the dates of the earliest accepted archaeological sites in the Americas. Age models based on 22 radiocarbon dates from three lake sediment cores on Sanak Island in the western Gulf of Alaska (Fig. 1), located directly within the proposed coastal

migration corridor, yield lake inception dates that place deglaciation ∼17 ka BP. These new dates are one to two millennia earlier than previous deglaciation estimates for the region (Mann and Peteet, 1994; Dickinson, 2011). Therefore glaciers would not have hindered the movement of humans along the southern edge of the Bering land bridge for two millennia before the first well-recognized archaeological sites in the Americas were inhabited (Mandryk et al., 2001; Erlandson et al., 2008; Waters et al., 2011).

Scholars have had difficulty determining the timing and nature of early coastal adaptations in North America, due to both post-glacial sea level rise and erosion of coastal margins (Gruhn, 1994; Dixon, 2001). Intensive archaeological survey on Sanak Island, for example, has documented more than 120 archaeological sites spanning the last 7000 years, but did not result in any finds of terminal Pleistocene human activity. However, evidence shows that early peoples living along the coasts of the Americas relied heavily upon marine resources. Seaweed recovered from the Monte Verde site, Chile dates to ∼14 ka BP (Dillehay et al., 2008). Evidence from Huaca Prieta, Peru shows a reliance on maritime resources starting at 14.2 ka BP (Dillehay et al., 2012) and at Quebrada Jaguay, Peru, there is a predominance of marine resources ∼13 ka BP (Keefer et al., 1998; Sandweiss et al., 1998). Sites in the California Channel
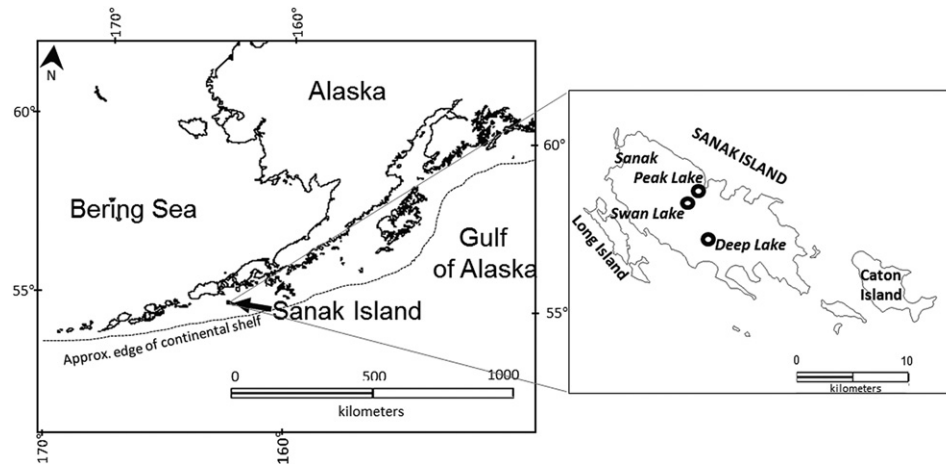
Fig. 1. Map of Sanak Island, the Aleutian archipelago and the Alaska Peninsula. Names of lakes on Sanak Island were colloquially established in the field.

Islands contain remains of marine fish and mammals dating to ∼12 ka BP (Erlandson et al., 2011). The Arlington Springs site, also located in the Channel Islands and which contained human remains is dated to ∼13 ka BP (Johnson et al., 2002). Monte Verde remains the oldest well-accepted site in the Americas and was inhabited by 14.5 ka BP (Dillehay, 1997), prior to the opening of the ice-free corridor that was created when the Cordilleran and Laurentide ice sheets retreated 13.7 ka BP (Catto, 1996; Dixon, 2001; Dickinson, 2011). However, more detailed evidence shows that

the ice-free corridor was probably not habitable by humans until close to 13 ka BP (Arnold, 2002; Dickinson, 2011). Together these data lend credence to the hypothesis that the Americas could have been populated first via the Pacific coast by people with maritime adaptations rather than through an interior ice-free corridor, although it is likely that there were later movements of people through the interior.

This is not a new argument. More than 30 years ago Knut Fladmark (1979) proposed that a coastal migration route to the
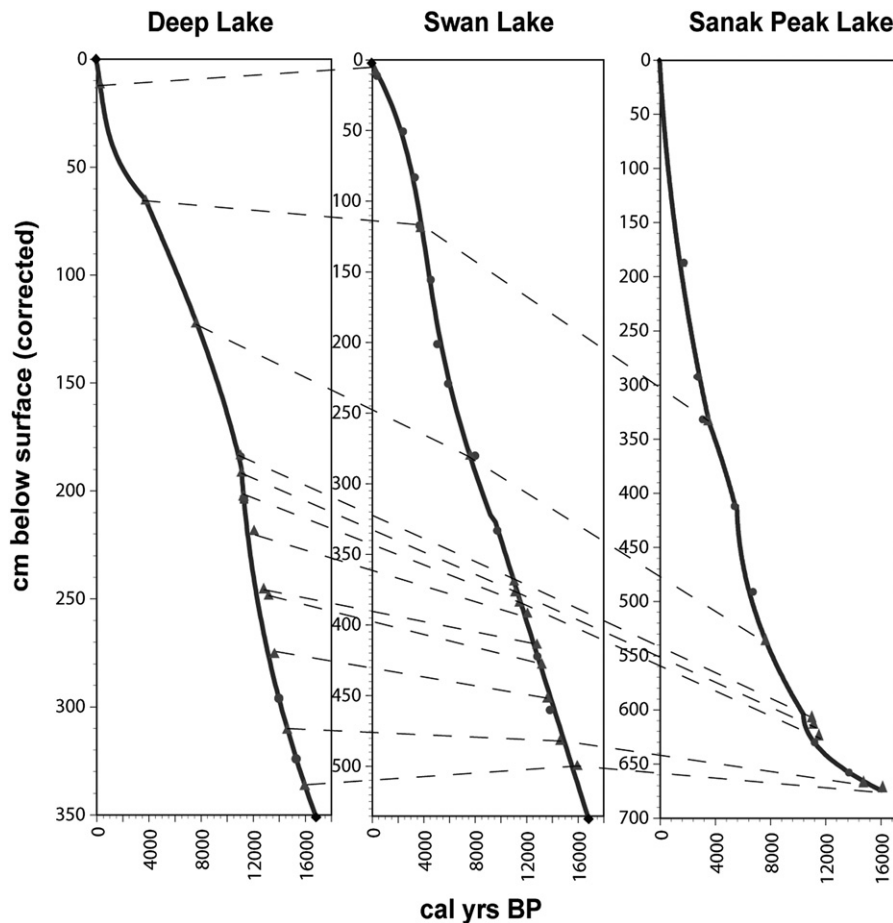

Fig. 2. Age-model representations. Depth of radiocarbon dates are shown with circles and tephra depths with triangles. Dotted lines indicate chemically correlated tephras. Ages are calibrated years before present (cal yrs BP) and depths are corrected to remove thickness associated with major tephras (see Section 2.3). The Sanak Peak Lake core terminated in the lowermost tephra, limiting the estimation of deglaciation within this particular lake to a minimum of 16 ka BP.

America's was a likely scenario. But this model was rejected by most scholars because ice sheets were assumed to have covered the North Pacific continental shelf from Puget Sound to the Aleutian Islands (Mann and Peteet, 1994; Mann and Hamilton, 1995; Dickinson, 2011). From the 1990s onward, a number of studies demonstrated clearly that parts of the Northwest Coast were likely an ice-free refugium (Heaton et al., 1996; Hetherington et al., 2003; Lacourse et al., 2005). Carrara et al. (2007) identified 8 areas from just south of Yakutat, Alaska to the southern extent of Graham Island that were potentially ice free and viable landscapes for humans to utilize on a coastal migration route. Ice retreated from the general area prior to 15.4 ka (Ager et al., 2010). Portions of Kodiak Island were also believed to have deglaciated somewhat early with radiocarbon dates at base of peat cores of 13,420 ± 20 (Beta-26607; Peteet and Mann, 1994:Table II) which using Calib 6.0 have median dates of 16.5 ka BP. The most significant remaining barrier to human coastal migration around the Northeast Pacific was the APGC, which was thought not to have disintegrated until 15–16 ka (Mann and Peteet, 1994; Mandryk et al., 2001; Goebel et al., 2008), too late to account for the early sites such as Monte Verde.

2. Methods

2.1. Lake core collection and description

Sanak Island is predominantly low-lying with a rolling topography that is broken by Sanak Peak (530 m above modern sea level [m asl]) in its northwest quadrant. The island is dotted with many small lakes, streams and bogs and vegetation consists mostly of grassy tundra with sedge marsh in low lying areas and crowberry tundra on hillsides. Sediment cores were collected in the summer of 2004 using a Livingstone piston corer from an inflatable catamaran raft. The cores were extruded in the field into rigid plastic tubes and wrapped in order to preserve stratigraphic integrity. Two of the cores span the entire post-glacial period (see Fig. 2 for individual core depths). Lakes had firm core tops allowing undisturbed recovery of the sediment–water interface and upper sediments. Cores were shipped to the University of Alaska Fairbanks where they were stored at ~4 °C. Sediments were described in terms of general lithology, and sampled continuously at 1 cm intervals along the length of each core. Each sediment sample was measured for wet and dry bulk density, water content, LOI at 500 °C and 850 °C and magnetic susceptibility. Pollen slides were prepared at the University of Alaska Fairbanks by standard methods (Faegri et al., 1989) and pollen identified under 400× and 1000× magnification. Pollen zones were delineated by visual inspections of diagrams of pollen percentages and pollen accumulation rates (as in Jordan and Krumhardt, 2003).

2.2. Age models

Radiocarbon ages for all samples were derived from terrestrial plant macrofossils found in the lake cores and analyzed at the Center for Atomic Mass Spectroscopy (CAMS), Lawrence Livermore National Laboratory. The ages were calibrated using Calib 6.0 from Queen's University Belfast's [14]Chrono Centre (Table 1; Stuiver and Reimer, 1993). Age model depths were adjusted by removing the thickness of large, single-deposit ash accumulations in order to better estimate accumulation rates of non-tephra sediments, assuming the deposition of these thicker deposits was relatively instantaneous. Basal ages were further refined to account for rapid deposition of glacial sediments at the base of some cores, as glaciers withdrew from Sanak Island. In the case of Swan and Deep lakes, basal ages were considered to be the top of glacial sediments. In Sanak Peak Lake the core ended in the lowermost tephra and it remains unclear as to whether that reflects the initiation of

Table 1
Radiocarbon dates of terrestrial plant macrofossils in lake cores from Sanak Island.

Lake	Depth (cm BS[a])	Corrected depth (cm BS[a])	CAMS Lab ID	[14]C age	Age (cal yrs BP[b])
Swan Lake	9	9	124453	265 ± 45	383–341
Swan Lake	48.5	48.5	124452	2295 ± 35	2401–2360
Swan Lake	81	81	124454	3045 ± 35	3323–3268
Swan Lake	115	115	127196	3385 ± 40	3697–3630
Swan Lake	173.5	153.5	127711	3995 ± 35	4567–4522
Swan Lake	219	199	124455	4420 ± 35	5098–5009
Swan Lake	247	227	132854	5045 ± 40	5942–5856
Swan Lake	333	278	132855	7090 ± 35	8011–7977
Swan Lake	386	331	132856	8640 ± 150	9881–9542
Swan Lake	495	420	127197	10,760 ± 110	12,918–12,750
Swan Lake	533	458	111108	11,900 ± 60	13,875–13,753
Sanak Peak Lake	188	188	111103	1755 ± 45	1778–1662
Sanak Peak Lake	292	292	111104	2400 ± 40	2522–2401
Sanak Peak Lake	332	332	111105	3025 ± 50	3325–3252
Sanak Peak Lake	424	412	132856	4690 ± 90	5530–5369
Sanak Peak Lake	504	492	111106	5840 ± 60	6792–6668
Sanak Peak Lake	777	631	111107	9690 ± 110	11,274–11,118
Sanak Peak Lake	803	657	115524	11,810 ± 70	13,817–13,647
Deep Lake	260	184	132858	9580 ± 40	11,089–10,979
Deep Lake	280	204	115525	9850 ± 60	11,342–11,255
Deep Lake	376	296	115582	12,070 ± 60	14,042–13,895
Deep Lake	408	328	115526	13,080 ± 180	15,788–15,237

[a] BS = below surface.
[b] cal yrs BP = calibrated years before present.

sedimentation within that lake or was a product of incomplete core recovery. In addition, linear fits of the bottom several AMS dates in each core yielded similar basal ages as the polynomial fits using ages from the entire core.

2.3. Tephra correlations

Tephra layers were initially identified visually, through smear slides and by magnetic susceptibility. Thin section grain mounts were prepared for each unit by setting grains in a matrix of Petro-Poxy© and polishing the surface to a smoothness of <1 μm. Each sample was analyzed for major elemental compositions using grain-specific electron microprobe analysis (EPMA) on a Cameca SX-50 microprobe with four wavelength-dispersive spectrometers.

Tephra samples were then classified according to the IUGS total alkali-silica classifications of Le Bas et al. (1986). Correlations to published Holocene tephras from the Aleutian Archipelago region were made using the dataset of Carson et al. (2002). Correlation coefficients between samples were calculated using the multivariate SIMAN analysis of Borchardt (1974) (Table 2). The accuracy of the SIMAN analysis was verified using oxide variation plots. Two tephras were chemically identified as the Fisher/Funk eruption, whose maximum age has recently been dated ~11.1 ka BP (Carson et al., 2002) and the Roundtop eruption (Miller and Smith, 1987) which has yet to be well dated but is older than the Fisher/Funk eruption based on stratigraphy (Carson et al., 2002). These previously published eruption dates were used to independently verify lake core age models. The remaining tephras were dated via interpolation using bracketing AMS dates in each core. The tephra ages were then averaged across all three cores, and these dates were used to generate regression models, as well as to plot tephra ages in Fig. 2.

3. Results

These conservative age models demonstrate that lacustrine sedimentation began in all three lakes nearly 17 ka BP. A total of 12 tephras were cross-correlated between the lakes (Table 2). Dates derived from our age model of two tephras matched to Fisher/Funk and Roundtop eruption fall within previously published age ranges

Table 2
Similarity coefficients of tephras across all three lake cores.

Tephra	Corrected depth (cm BS)			Multivariate similarity coefficients	Median date (cal yrs BP)
	Swan Lake	Deep Lake	Sanak Peak Lake		
T0	5	11		95%	242
T2	116	65	333	95–96%[a]	3746
T3	277	122	532	95%[b]	7617
T4	366	183	609	95%[b,c]	11,024
T5	374	191		93%	11,111
T6	381	202	624	93–94%[a]	11,453
T7	389	218		95%[d]	12,068
T8	411	245		98%	12,803
T9	425	248		94%	13,183
T10	449	275		93%	13,616
T11	479	310	667	92–95%[a]	14,604
T12	497	336	673	94–95%[a]	15,951

[a] Range of similarity coefficients is based on comparisons between all three lakes.
[b] Similarity coefficients were derived from comparisons between Deep and Swan Lakes while lithology, which was distinct in these deposits, was used to match tephras from Sanak Peak to Swan and Deep lakes.
[c] Corresponds to the Fisher/Funk tephra referred to in text.
[d] Corresponds to the Roundtop eruption referred to in text.

of these eruptions. Furthermore, the first appearance of *Artemisia*, *Ericaceae*, *Cyperaceae*, *Salix,* and *Poaceae*, as evidenced from pollen found in Deep Lake sediments, is at 16.3 ka BP (Fig. 4), 2000 years earlier than previous evidence for plant colonization on the Alaska Peninsula (Jordan, 2001; Dickinson, 2011). These species suggest an arid terrestrial ecosystem.

Field and bathymetric data indicate that the depth and duration of ice cover across the Sanak archipelago during the last glacial maximum (LGM) was less extensive than previously estimated for the region (cf. Detterman et al., 1986; Mann and Peteet, 1994). Striations and ice-override features provide evidence that the island group was overrun by ice from a source area to the north and northeast during the LGM, but their maximum elevation indicates that ice thickness did not exceed 70 m asl. Till deposits are thin and discontinuous around the island, rarely exceeding 1 m in thickness. Bathymetry suggests that basal ice may have been deflected to the southeast along the north shore of the island, steered by a 120 to 160-m deep channel that extends from Sanak to the continental shelf (Fig. 3; GLOBE Task Team, 1999; Danielson et al., 2008), possibly contributing to a thinner ice profile on the island. An additional constraint on ice thickness is provided by regional isostatic modeling, supported by observed elevations of isostatically-uplifted shorelines, the highest of which is about 6 m asl on Sanak Island (compared to 25 m asl at the head of Cold Bay 50 km to the north) (James, 2001; Jordan, 2001). Sea surface temperature (SST) in the North Pacific was markedly rising by 16 ka BP (Sabin and Pisias, 1996), which is coeval with maximum isostatic uplift (Jordan, 2001) on the peninsula. Combined with our deglacial chronology on Sanak, this suggests that the North Pacific coastline during the late LGM was located south of the Sanak archipelago, probably near the current 100 m isobath that defines the modern shelf break (Fig. 3).

4. Discussion

Recent evidence derived from marine sediment cores indicates three warm periods, 18.2–17.2 ka BP, 16.8–16.3 ka BP and 16.2–14.7 ka BP, during which SST were too high to support sea ice formation from spring to fall in the northwestern Pacific (Sarnthein et al., 2006); at least one warm period occurred in the eastern Bering Sea by 16.8 ka (Caissie et al., 2010). To the east, evidence from a marine core in the Gulf of Alaska, northeastern Pacific, indicates ice retreat beginning around 16.8 ka BP as well (Addison et al., 2012). This apparent warm period ~17 ka BP coincides with the deglaciation of Sanak Island, and is consistent with our
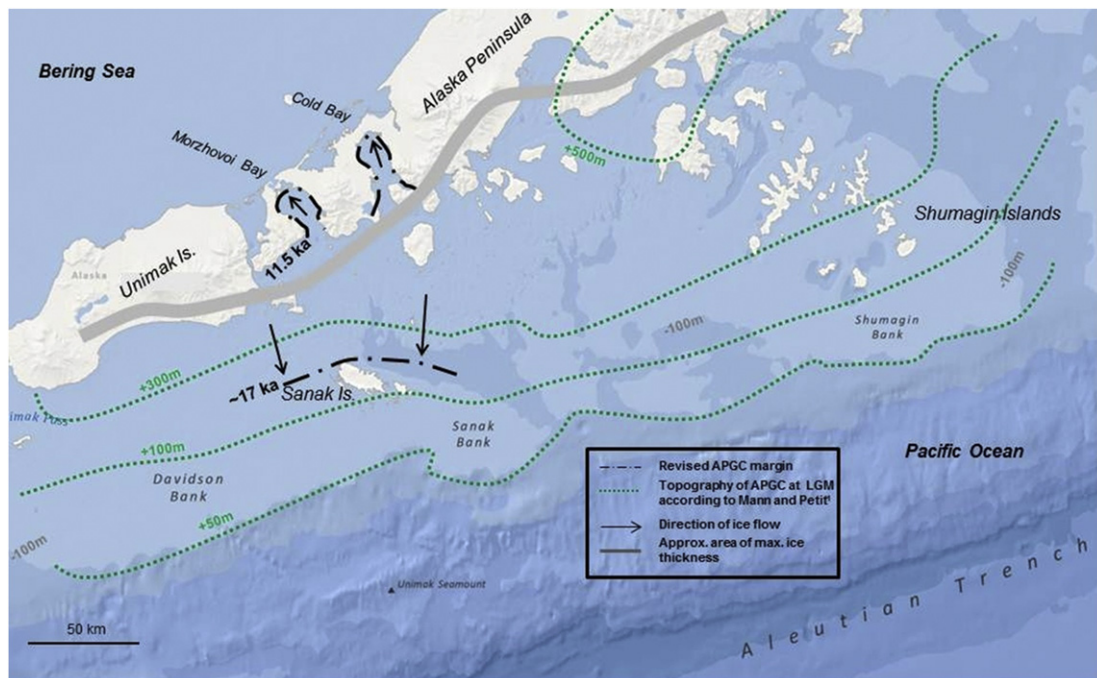

Fig. 3. Previous and revised extent and height of the APGC. Inferred distal margin positions of the APGC (black dashed lines) based on lacustrine sediment core age models and radiocarbon ages on terrestrial macrofossils (Dochat, 1997; Jordan, 2001; this paper Section 2.1), field evidence, and bathymetric data (Danielson et al., 2008). Heavy line shows approximate axis of thickest ice along the western extent of the APGC at the LGM (Mann and Peteet, 1994). Arrows indicate ice flow directions interpreted from terrestrial and submarine topography. Dotted lines indicate previous estimates of ice thickness at the height of the LGM according to Mann and Peteet (1994) versus our revision to 70 m asl on Sanak Island. The +50 m line highlights previous estimates of ice extent until ~16 ka and its association with the 100 m isobath ("−100 m") and continental shelf break. Base map modified from ArcGIS (2011).
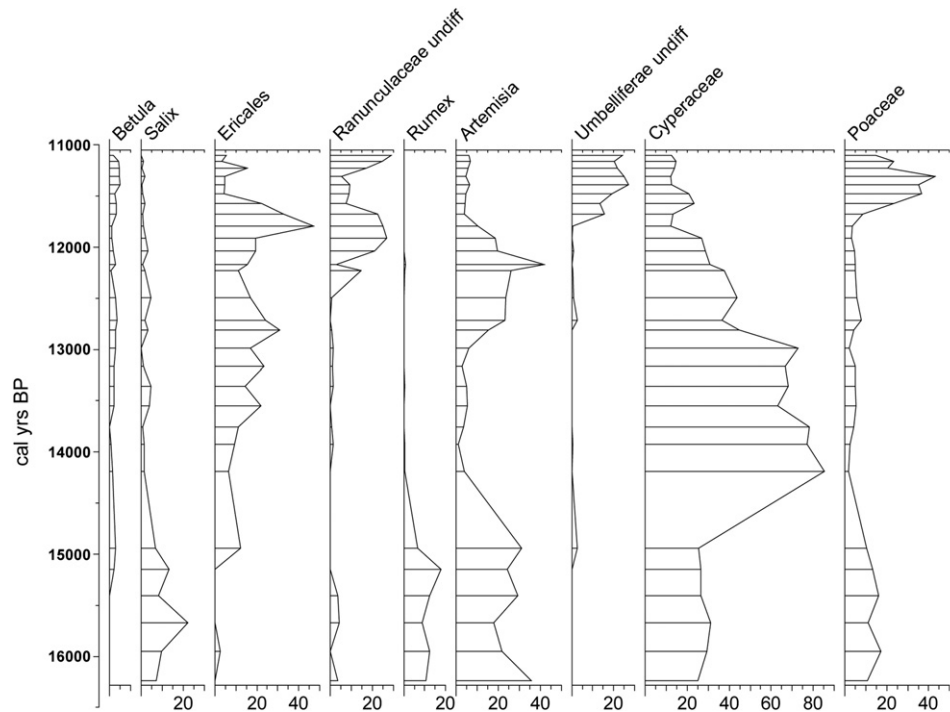
Fig. 4. Pollen diagram of the base of Deep Lake Core.

inference of regional deglaciation of the western Alaska Peninsula continental shelf at this time.

These new age models of the three lake cores record deglaciation nearly 17 ka BP (Fig. 2), and field evidence indicates a maximum glacial cover of 70 m thickness on Sanak Island (cf. Fig. 3). This suggests a much earlier retreat of a thinner and less contiguous ice mass from the continental shelf than previous estimates based on extrapolated data from other sites in the Gulf of Alaska, none of which are located in this critical area. This is significant for three reasons: [1] the absence of glaciers along the coastal plain of southern Beringia as early as 17 ka BP increases the likelihood that the coast was a viable landscape for humans to traverse before many of the less disputed, early archaeological sites were inhabited in the Americas, [2] these are the first local records of deglaciation timing from the eastern Aleutian archipelago and coastal margin of southern Beringia; previously published deglacial chronologies are derived from sites several hundred kilometers northeast of this region (Mann and Peteet, 1994); [3] our data suggest that models proposing a contiguous, south-flowing ice mass whose topographic axis was parallel to the Alaska Peninsula ca 30–40 km northeast of Sanak need to be revised.

5. Conclusion

These results collectively warrant revision of models inferring a thick and contiguous LGM ice mass that covered the continental shelf south of the axis of the Aleutian Archipelago/Alaska Peninsula until ∼15–16 ka BP and suggest that portions of the shelf were exposed and available for human coastal migration. Seasonal ice-free conditions and warm SST preceding and during the revised early period of retreat of the APGC would presumably have supported productive coastal ecosystems that could have served as a viable resource base for humans. As Dickinson (2011:207) recently stated, the key to the viability of a coastal pathway is determining when the continental shelf south of the Alaska Peninsula was deglaciated and suitable for humans to traverse. Recent evidence, cited above, of ice age refugia along the

southeastern coast of Alaska and through British Columbia, warming oceans after 18–17 ka BP, and a minimum age of deglaciation of 16.5 ka BP on western Kodiak Island warrant a new view of a traversable coastal landscape farther southeast along the proposed human migration route to the Americas. While not proving that First Americans migrated along this corridor, these latest data from Sanak Island show that human migration across this portion of the coastal landscape was unimpeded by the APGC after ∼17 ka BP, with a viable terrestrial landscape in place by ∼16.3 ka BP, well before the earliest accepted sites in the Americas were inhabited.

References

Addison, J.A., Finney, B.P., Dean, W.E., Davies, M.H., Mix, A.C., Stoner, J.S., Jaeger, J.M., 2012. Productivity and sedimentary delta N-15 variability for the last 17,000 years along the northern Gulf of Alaska continental slope. Paleoceanography 27.

Ager, T.A., Carrara, P.E., Smith, J.L., Anne, V., Johnson, J., 2010. Postglacial vegetation history of Mitkof Island, Alexander Archipelago, southeastern Alaska. Quaternary Research 73, 259–268.

Arnold, T.G., 2002. Radiocarbon dates from the ice-free corridor. Radiocarbon 44, 437–454.

Borchardt, G.A., 1974. The SIMAN coefficient for similarity analysis. Classification Society Bulletin 3, 2–8.

Caissie, B.E., Brigham-Grette, J., Lawrence, K.T., Herbert, T.D., Cook, M.S., 2010. Last Glacial Maximum to Holocene sea surface conditions at Umnak Plateau, Bering Sea, as inferred from diatom, alkenone, and stable isotope records. Paleoceanography 25.

Carrara, P.E., Ager, T.A., Baichtal, J.F., 2007. Possible refugia in the Alexander Archipelago of southeastern Alaska during the late Wisconsin glaciation. Canadian Journal of Earth Science 44, 229–244.

Carson, E.C., Fournelle, J.H., Miller, T.P., Mickelson, D.M., 2002. Holocene tephrochronology of the Cold Bay area, southwest Alaska Peninsula. Quaternary Science Reviews 21, 2213–2228.

Catto, N.R., 1996. Richardson Mountains, Yukon-Northwest Territories: the northern portal of the postulated "ice-free corridor". Quaternary International 32, 3–19.

Danielson, S., Johnson, M., Solomon, S., Perrie, W., 2008. Alaska region bathymetric DEM: 1 km gridded bathymetric dataset based on ship soundings: a research tool for the waters of eastern Russia, Alaska and Western Canada, Alaska Marine Science Symposium, Anchorage, AK.

Detterman, R.L., Reed, K.M., Thorson, R.M., 1986. Glaciation of the Alaska Peninsula. In: Hamilton, T.D. (Ed.), Glaciation in Alaska: The Geologic Record. Alaska Geological Society, pp. 151–170.

Dickinson, W.R., 2011. Geological perspectives on the Monte Verde archeological site in Chile and pre-Clovis coastal migration in the Americas. Quaternary Research 76, 201–210.

Dillehay, T.D., 1997. Monte Verde: A Late Pleistocene Site in Chile, the Archaeological Context. Smithsonian Institution Press, Washington DC.

Dillehay, T.D., Bonavia, D., Goodbred Jr., S.L., Pino, M., Vasquez, V., Tham, T.R., 2012. A late Pleistocene human presence at Huaca Prieta, Peru, and early Pacific Coastal adaptations. Quaternary Research 77, 418–423.

Dillehay, T.D., Ramirez, C., Pino, M., Collins, M.B., Rossen, J., Pino-Navarro, J.D., 2008. Monte Verde: seaweed, food, medicine and the peopling of South America. Science 320, 784–786.

Dixon, E.J., 2001. Human colonization of the Americas: timing, technology and process. Quaternary Science Reviews 20, 277–299.

Dochat, T., 1997. The Glacial History of the Lower Alaska Peninsula. Department of Geology, University of Wisconsin, Madison, Madison, WI.

Erlandson, J.M., Moss, M.L., Des Lauriers, M., 2008. Life on the edge: early maritime cultures of the Pacific Coast of North America. Quaternary Science Reviews 27, 2232–2245.

Erlandson, J.M., Torben, C.R., Braje, T.J., Casperson, M., Culleton, B., Fulfrost, B., Garcia, T., Guthrie, D., Jew, N., Kennett, D.J., Moss, M.L., Reeder, L., Skinner, C., Watts, J., Willis, L., 2011. Paleoindian seafaring, maritime technologies, and coastal foraging on California's Channel islands. Science 331, 1181–1185.

ESRI, 2011. www.arcgis.com/home/webmap/viewer.html.

Faegri, K., Kaland, P.E., Krzywinski, K., 1989. Textbook of Pollen Analysis, fourth ed. John Wiley & Sons, Inc, New York, New York.

Fladmark, K.R., 1979. Routes: alternate migration corridors for Early Man in North America. American Antiquity 44, 55–69.

GLOBE Task Team, 1999. The global land one-kilometer base elevation (GLOBE) digital elevation model, Version 1. In: Hastings, D.A., Dunbar, P.K., Elphingstone, G.M., Bootz, M., Murakami, H., Maruyama, H., Masaharu, H., Holland, P., Payne, J., Bryant, N.A., Logan, T.L., Muller, J.P., Schreier, G., MacDonald, J.S. (Eds.), National Geophysical Data Center, first ed. National Oceanic and Atmospheric Administration, Boulder, CO.

Goebel, T., Waters, M.R., O'Rourke, D.H., 2008. The Late Pleistocene dispersal of modern humans in the Americas. Science 319, 1497–1502.

Gruhn, R., 1994. The Pacific Coast route of initial entry: an overview. In: Bonnichsen, R., Steele, D.G. (Eds.), Method and Theory for Investigating the Peopling of the Americas. Center for the Study of the First Americans, Corvallis, OR.

Heaton, T.H., Talbot, S.L., Shields, G.F., 1996. An Ice Age refugium for large mammals in the Alexander Archipelago, southeastern Alaska. Quaternary Research 46, 186–192.

Hetherington, R., Barrie, J.V., Reid, R.G.B., MacLeod, R., Smith, D.J., James, T.S., Kung, R., 2003. Late Pleistocene coastal paleogeography of the Queen Charlotte Islands, British Columbia, Canada, and its implications for terrestrial biogeography and early postglacial human occupation. Canadian Journal of Earth Sciences 40, 1755–1766.

James, T.S., 2001. Postglacial rebound analysis for better determination of earthquake-related deformation and rheology at subduction zones. Technical Abstract. USGS.

Johnson, J.R., Stafford, T.W., Ajie, H.O., Morris, D.P., 2002. Arlington springs revisited. In: Brown, D., Mitchell, K.C., Chaney, H.W. (Eds.), Proceedings of the Fifth California Islands Symposium. Santa Barbara Museum of Natural History, Santa Barbara, CA, pp. 541–545.

Jordan, J.W., 2001. Late Quaternary sea-level change in southern Beringia: postglacial emergence of the western Alaska Peninsula. Quaternary Science Reviews 20, 509–523.

Jordan, J.W., Krumhardt, A., 2003. Postglacial climate and vegetation history of the western Alaska Peninsula. Alaska Journal of Anthropology 1, 16–33.

Keefer, D.K., deFrance, S.D., Moseley, M.E., Richardson, J.B., Satterlee, D.R., Day-Lewis, A., 1998. Early maritime economy and El Nino events at Quebrada Tacahuay, Peru. Science 281, 1833–1835.

Lacourse, T., Mathewes, R.W., Fedje, D.W., 2005. Late-glacial vegetation dynamics of the Queen Charlotte Islands and adjacent continental shelf, British Columbia, Canada. Paleogeography, Paleoclimatology, Paleoecology 226, 36–57.

Le Bas, M.J., Lemaitre, R.W., Streckeisen, A., Zanettin, B., 1986. A chemical classification of volcanic rocks based on the total alkali silica diagram. Journal of Petrology 27, 745–750.

Mandryk, C.A.S., Josenhans, H., Fedje, D.W., Mathewes, R.W., 2001. Late Quaternary paleoenvironments of northwestern North America: implications for inland versus coastal migrations routes. Quaternary Science Reviews 20, 301–314.

Mann, D.H., Hamilton, T.D., 1995. Late Pleistocene and Holocene paleoenvironments of the North Pacific coast. Quaternary Science Reviews 14, 449–471.

Mann, D.H., Peteet, D.M., 1994. Extent and timing of the Last Glacial Maximum in Southwestern Alaska. Quaternary Research 42, 136–148.

Miller, T.P., Smith, R.L., 1987. Late Quaternary caldera-forming eruptions in the eastern Aleutian arc, Alaska. Geology 15, 434–438.

Peteet, D.M., Mann, D.H., 1994. Late-glacial vegetational, tephra and climatic history of southwestern Kodiak Island, Alaska. Ecoscience 1, 255–267.

Sabin, A.L., Pisias, N.G., 1996. Sea surface temperature changes in the northeastern Pacific Ocean during the past 20,000 years and their relationship to climate change in northwestern North America. Quaternary Research 46, 48–61.

Sandweiss, D.H., McInnis, H., Burger, R.L., Cano, A., Ojeda, B., Paredes, R., Sandweiss, M., Gascock, M.D., 1998. Quebrada Jaguay: early South American maritime adaptations. Science 281, 1830–1832.

Sarnthein, M., Kiefer, T., Grootes, P.M., Elderfield, H., Erlenkeuser, H., 2006. Warmings in the far northwestern Pacific promoted pre-Clovis immigration to America during Heinrich Event 1. Geology 34, 141–144.

Stuiver, M., Reimer, P.J., 1993. Extended 14C data base and revised CALIB 3.0 14C age calibration program. Radiocarbon 35, 215–230.

Waters, M.R., Forman, S.L., Jennings, T.A., Nordt, L.C., Driese, S.G., Feinberg, J.M., Keene, J.L., Halligan, J., Lindquist, A., Pierson, J., Hallmark, C.T., Collins, M.B., Widerhold, J.E., 2011. The Buttermilk Creek Complex and the origins of Clovis at the Debra L. Friedkin site, Texas. Science 331, 1599–1603.