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# Geological perspectives on the Monte Verde archeological site in Chile and pre-Clovis coastal migration in the Americas

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ABSTRACT

Discovery of the Monte Verde archeological site in Chile overturned the previous consensus that the first Americans into the New World from Asia were the makers of Clovis projectile points, and rejuvenated the hypothesis that migration through the Americas occurred largely on portions of the Pacific continental shelf exposed by Pleistocene drawdown in eustatic sea level. The postulate of travel along a paleoshoreline now hidden underwater is an attractive means to posit pre-Clovis human movement southward from Beringia to Chile without leaving traces of migration onshore. Geologic analyses of the Pleistocene paleoenvironment at Monte Verde and of the morphology of the potential migration route along the continental shelf raise questions that have not been fully addressed. The periglacial setting of Monte Verde may call its antiquity into question and the narrowness of the Pacific continental shelf of the Americas makes it unlikely that people could travel the length of the Americas without impacting ground still onshore and no farther inland than Monte Verde itself. Geological perspectives on Monte Verde and coastal migration jointly suggest that the Clovis-first hypothesis for peopling the New World may have been abandoned prematurely.



## Introduction

Understanding when humans first arrived in the New World has long been an underlying theme for American archeology. A few decades ago, broad consensus had been reached that the first Americans were people who made fluted Clovis projectile points beginning ~13,500 cal yr BP (Fig. 1) after transit through an ice-free corridor (Fig. 2) that had opened on the Canadian plains by separation of the Cordilleran and Laurentide ice sheets during deglaciation (Haynes, 1964, 1969; Martin, 1973). In recent years that Clovis-first consensus has dissipated (e.g., Bonnichsen and Lepper, 2005). A key impetus for the change in thinking was wide acceptance of evidence for pre-Clovis occupation at ~14,500 cal yr BP (Fig. 1) of Monte Verde in southern Chile (Dillehay and Collins, 1988; Pino Quivira and Dillehay, 1988). Fragmentary evidence for a human presence at Monte Verde ~20,000 yr earlier (Dillehay, 1989b) has subsequently received scant attention, and is not discussed further here.

Although many other probable or possible pre-Clovis sites are known (Goebel et al., 2008; Meltzer, 2009), Monte Verde remains the "linchpin" for interpretations of pre-Clovis migration into the Americas (Flannery, 2009). Many authors have cited Monte Verde as incontrovertible evidence for a pre-Clovis presence in the New World (e.g., Adovasio and Pedler, 1997; Meltzer, 1997; Meltzer et al., 1997; Grayson, 1998; Miracle, 1999), and Monte Verde remains the prime example of a site interpreted as pre-Clovis in age (Goebel et al., 2008). Acceptance of Monte Verde as definitively pre-Clovis has in turn spawned speculation about human migration along a late Pleistocene paleoshoreline now drowned and thus hidden from view along the Pacific continental shelf (e.g., Dixon, 2001; Mandryk et al., 2001; Fiedel, 2002; Hetherington et al., 2003). The ice-free corridor in the interior was not open until ~13,750 cal yr BP (Fig. 1), hence people could not have taken an interior route into the New World any earlier (e.g., Hoffecker and Elias, 2007; Goebel et al., 2008; Meltzer, 2009) unless migration from the Old World to the New occurred before the last-glacial maximum (Madsen, 2004).

Geological analysis confirms a periglacial paleoenvironment for Monte Verde at the time inferred for its occupation, and challenges the viability of a hidden migration route along the narrow Pacific continental shelf for the length of the Americas. If reconsideration of the Monte Verde paleoenvironment and reappraisal of the coastal migration route raise doubts about pre-Clovis migration into the Americas, perhaps the Clovis-first hypothesis should be retained in the spirit of multiple working hypotheses (Chamberlin, 1897).

## Radiocarbon chronology

For chronological comparisons of age contrasts for different archeological sites, calibration of radiocarbon ages is essential because of the variable rate of $^{14}C$ production in the atmosphere over time. Apparent ages in conventional radiocarbon years ($^{14}C$ yr BP) accordingly embrace different age spans of calendric years for different intervals of time. For example, the 250 conventional

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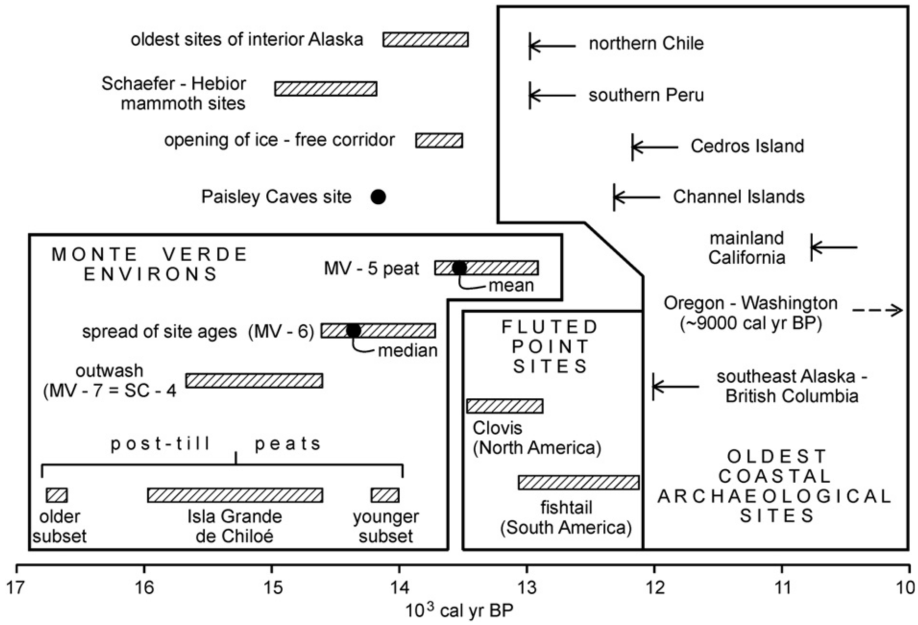


**Figure 1.** Comparative ages of key archeological sites and related geological features. See Table 1 for designation of stratal layers (MV-) at Monte Verde. Ranges of reported $^{14}$C ages calibrated to the nearest 50 cal yr BP (see text for discussion) by the curves of Reimer et al. (2004), Hughen et al. (2004), or Reimer et al. (2009).

radiocarbon years BP from 12,600 to 12,350 ($^{14}$C yr BP) include 700 calendric years (15,000–14,300 cal yr BP), whereas the 250 conventional radiocarbon years BP from 10,950 to 10,700 ($^{14}$C yr BP) include only 100 calendric years (12,900–12,800 cal yr BP).

For consistency, all radiocarbon ages cited or tabulated in this paper are calibrated from reported conventional radiocarbon ages ($^{14}$C yr BP) to the nearest 50 cal yr BP by a uniform methodology using the curves of Reimer et al. (2009) for >12,000 cal yr BP, or of Reimer et al. (2004) and Hughen et al. (2004) for <12,000 cal yr BP. Reimer et al. (2009) did not adjust any radiocarbon calibrations of Reimer et al. (2004) and Hughen et al. (2004) for ages more recent than ~12,000 cal yr BP. Because age differences of less than several

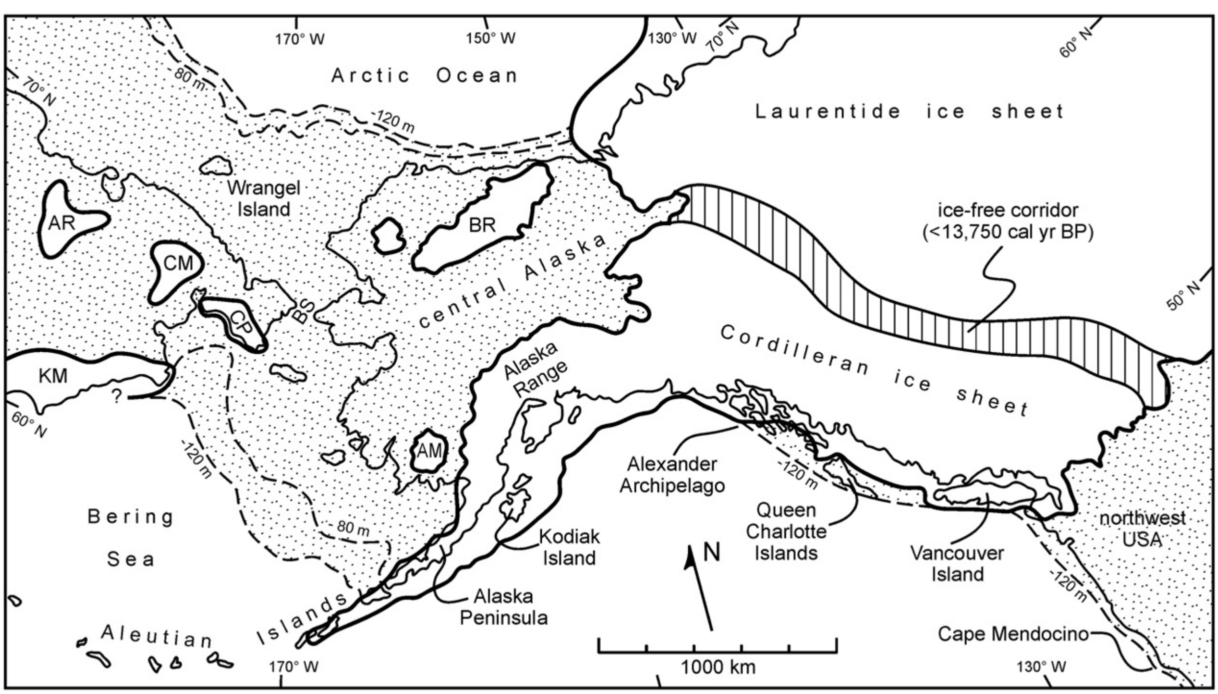


**Figure 2.** Geographic relations of the ice-free corridor on the Canadian plains and the potential coastal migration path along the Alaskan–Canadian shelf with respect to Beringia, conjoined easternmost Asia and central Alaska when the Bering Strait (BS) was dryland during synglacial drawdown in eustatic sea level. Heavy lines denote the ice limit and stippling denotes ice-free ground at the time of the last glacial maximum (dashed lines are bathymetric contours at −80 m and −120 m to show the configuration and width of continental shelf exposed during synglacial drawdown in sea level). Isolated ice caps occupying elevated tracts of Beringia: AM, Ahklun Mountains; AR, Anyui Range; BR, Brooks Range; CM, Chukotskiy Mountains; CP, Chukotka Peninsula; KM, Koryatskiy Mountains. The base map is a Mercator projection with pole at 25° N–15° E (Dickinson et al., 1986) for which all distances are consistent within the area depicted.
Adapted after Warner et al. (1982), Clague (1983), Hamilton and Thorson (1983), McCulloch (1989a), Heaton et al. (1996), West (1996), Barrie and Conway (1999), Brigham-Grette et al. (2004), Clague et al. (2004), Reed et al. (2005), and Carrara et al. (2007).

centuries are not significant for any arguments made, only best estimates or means of conventional radiocarbon ages ($^{14}$C yr BP) are converted (to cal yr BP) without regard to standard deviations of radiocarbon measurement or calibration. No differential calibration was attempted for northern and southern hemisphere ages (North and South America) because hemispheric age differentials are still uncertain for times before 11,000 cal yr BP (McCormac et al., 2004), and in general do not exceed 50 yr.

## Monte Verde setting

Monte Verde is located ~25 km west of Puerto Montt in southern Chile and <10 km from the last-glacial ice front of the Patagonian icefield, which extended for 675 km to the north and 1500 km to the south of Monte Verde (Fig. 3A). The Monte Verde site lies athwart the banks of Chinchihuapi Creek, a southern tributary of the Rio Maullín, which drains to a marine estuary from Lago Llanquihue (Fig. 4), a postglacial lake dammed by the terminal-moraine complex of a prominent ice lobe on the flank of the Patagonian icefield (Porter, 1981). Monte Verde lies only 6 km from the front of the terminal-moraine complex of the Chilotan piedmont glacier, which filled Seno Reloncaví Bay and the Golfo de Ancud (Fig. 4) during the last glaciation (Heusser, 1990).

At Monte Verde, Chinchihuapi Creek is incised <5 m into the surface of the Chilotan outwash plain composed of sediment referred to the Salto Chico Formation, which is overlain unconformably at the site by 0.8–1.2 m of postglacial sediment referred to the Monte Verde Formation. The thin veneer of Monte Verde Formation was deposited only within a shallow swale, 400 m by 180 m in extent, inset into the outwash plain and traversed longitudinally by Chinchihuapi Creek (Pino, 1989). Past descriptions of the Monte Verde site have not addressed some aspects of its periglacial setting, nor has the internal site stratigraphy been placed within the framework of the surrounding morainal and outwash geomorphology documented long after the site excavations by Andersen et al. (1999) and Denton et al. (1999)

## Monte Verde stratigraphy

The cultural horizon at Monte Verde is interpreted as a sheet midden covering the surfaces of stream banks, beaches, and point bars of ancestral Chinchihuapi Creek, and is only ~5 cm thick within an excavated habitational area occupying ~3000 m$^2$ (Dillehay and Pino, 1997a). Table 1 is a summary of the site stratigraphy of the Monte

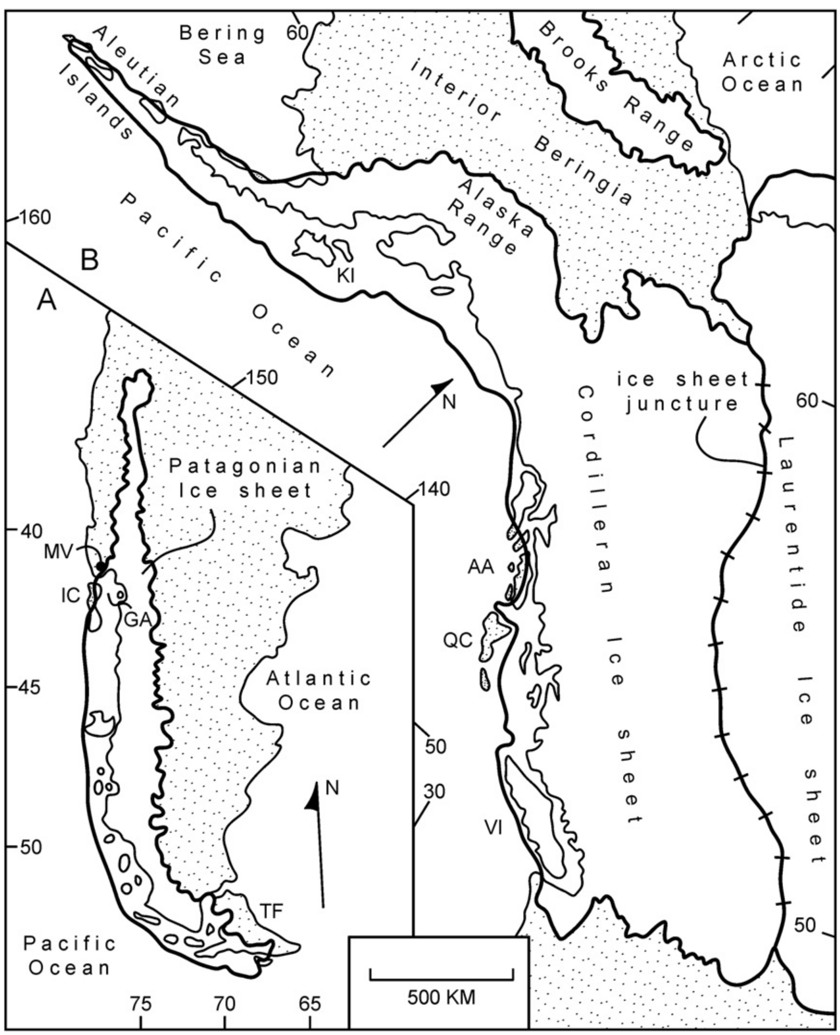


**Figure 3.** Comparison at common scale (bottom) of Patagonian (A) and Cordilleran (B) ice fields at last-glacial maximum (heavy lines denote extent of continuous icefields and stipple denotes ice-free ground). MV denotes the Monte Verde archeological site in southern Chile. Coastal ice-free refugia (North America): AA, Alexander Archipelago; QC, Queen Charlotte Islands. Other features: GA, Golfo de Ancud; IC, Isla Grande de Chiloé; KI, Kodiak Island; TF, Tierra del Fuego; VI, Vancouver Island.
Adapted after Warner et al. (1982), Clague (1983), Hamilton and Thorson (1983), Heaton et al. (1996), Barrie and Conway (1999), Hulton et al. (2002), Clague et al. (2004), Singer et al. (2004), and Carrara et al. (2007).

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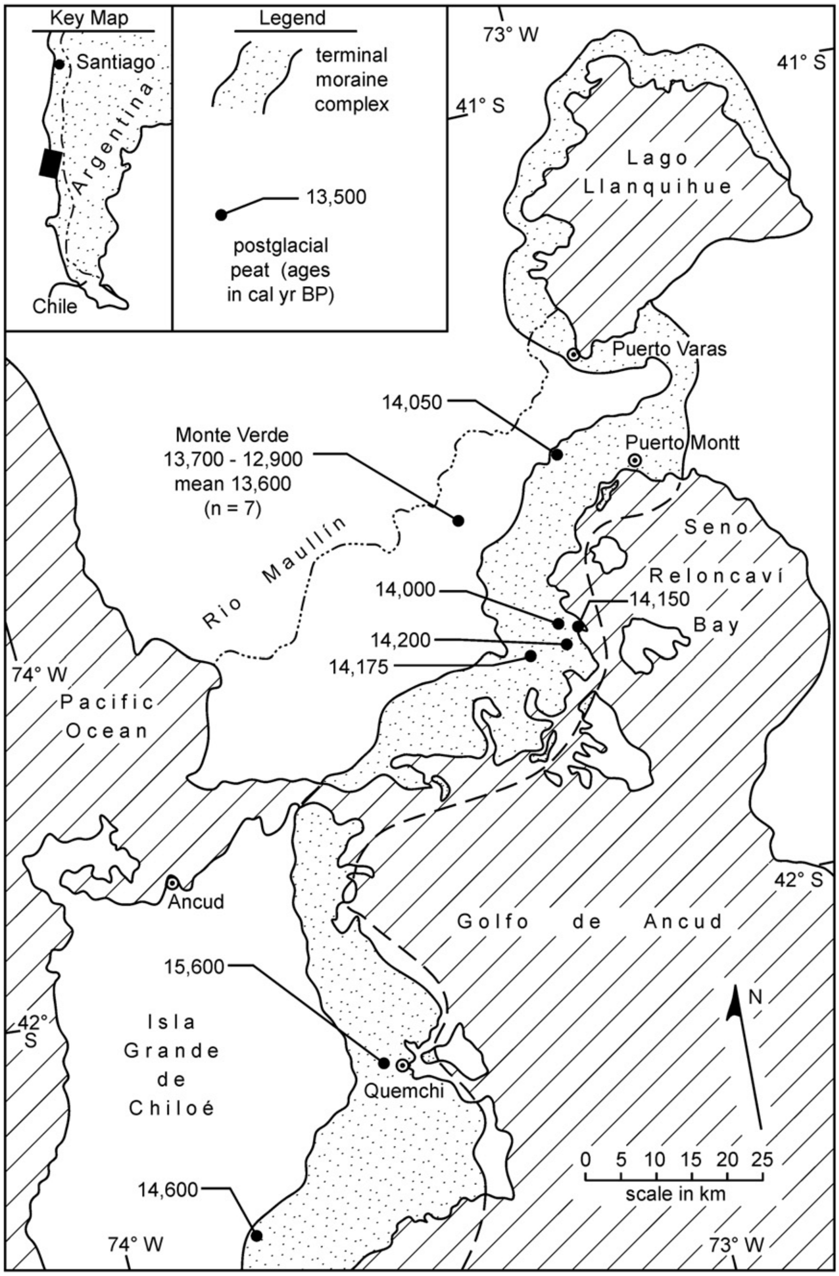


**Figure 4.** Postglacial peat ages (supra-till peats) at Monte Verde (unit MV-5) and at nearby localities in relation to the last-glacial terminal-moraine complex (stippled) of the Lago Llanquihue lobe and the Chilotan piedmont glacier (filling Seno Reloncaví Bay and Golfo de Ancud) of the Pleistocene Patagonian ice sheet.
Data from Porter (1981), Heusser (1990), Andersen et al. (1999), Denton et al. (1999), and Table 1.

Verde Formation and immediately underlying strata of the Salto Chico Formation (note that MV-7 and SCH-4 are alternate designations for the same stratal unit). The cultural horizon is in the top of unit MV-6, or atop unit MV-7 where unit MV-6 is absent. The MV-5 peat layer postdates the cultural horizon, which it covers and seals. Only the basal 15–25 cm of the Monte Verde Formation including the MV-5 peat layer predate 12,000 cal yr BP. Most of the Monte Verde Formation is composed of overlying Holocene fluvial and associated stream-valley sediment above an unconformity marking a depositional hiatus of ~3500 yr.

Unit MV-4 (~9000 cal yr BP) is a basal channel lag of the Holocene fluvial system that deposited unit MV-3, an aggradational fluvial succession which oversteps unit MV-4 and tapers laterally to a compact clayey paleosol overlying unit MV-7 (equivalent to unit SCH-4 forming the synglacial outwash plain). Lenticular unit MV-6, capped by the cultural horizon, was formed as a complex of paleochannel and closely associated point-bar deposits, and has a concave-downward base, occupying the thalweg of ancestral Chinchihuapi Creek and overlying an unconformable surface incised into unit MV-7 (= SCH-4). The cultural horizon passes laterally from the surface of unit MV-6 to the surface of unit MV-7 beyond the extent of unit MV-6. The lateral transition is interpreted to mean that the occupation surface extended laterally from stream-flank beaches and point bars (MV-6) to eroded stream banks composed of synglacial outwash sediment (MV-7 = SCH-4). The peat of sealing unit MV-5 (13,700-12,900 cal yr BP) was deposited as a gallery bog formed along ancestral Chinchihuapi Creek, and locally intertongues with fluvial unit MV-6 (14,600–13,700 cal yr BP).

The wide span of radiocarbon ages (15,650–13,700 cal yr BP) for the cultural horizon at Monte Verde (Table 1) is thought to reflect

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**Table 1**
Monte Verde site stratigraphy[a].

| Stratum | cm | Description | Age (n = number of radiocarbon dates) |
|---|---|---|---|
| MV-1 | 8–10 | Soil or sod | Modern |
| MV-2 | 10–30 | Fine to medium friable sand with 2 cm black peat (and ironstone) | Holocene (no radiocarbon dates available) |
| MV-3 | 25–50 | Volcaniclastic gravel containing brown peat and white clay lenses and freshwater mollusks | 9300–5550 cal yr BP (n = 4 on wood) |
| MV-4 | 10–15 | Lenticular fine to medium gravel | 9000 cal yr BP. (n = 1 on wood) |
| MV-5 | 8–12 | Yellow-red to chocolate brown peat of gallery bog; locally intertongues with MV-6 | 13,700–12,900 cal yr BP (n = 6 on wood) |
| MV-6[b] | 8–12 | Discontinuous channel sand and gravel incised into MV-7 (cultural horizon is in top 5 cm of MV-6 or in MV-7 where MV-6 is absent) | 14,550–13,700 cal yr BP (n = 4 on wood)<br>13,850 cal yr BP (n = 1 on ivory)<br>14,150 cal yr BP (n = 2 on seaweed)[c]<br>14,600 cal yr BP (n = 1 on mastodon bone) |
| MV-7 | – | Compact sand (outwash plain) of unit SC-4 (Salto Chico Formation) | 15,650–14,600 cal yr BP (n = 4 on wood from upper layer including log hut foundations of the cultural horizon) |

Unconformity (hiatus ~ 3500 yr): MV-3 rests locally on MV-4, MV-5, MV-6, and MV-7 (= SC-4).

[a] Data from Dillehay (1989a, 1989b), Dillehay and Pino (1989, 1997a, 1997b), Dillehay et al. (2008), George et al. (2005), Haynes (1999), Pino (1989, 1997), and Pino Quivira and Dillehay (1988).

[b] Outlier age of 16,800 cal yr BP on charcoal regarded as spurious (Dillehay and Pino, 1997b) and omitted from table.

[c] Terrestrial calibration; marine calibration with ΔR = 0 would be 13,750 cal yr BP.

uncertainties of radiocarbon dating, rather than duration of occupation, which is judged to have been brief (Dillehay and Pino, 1989, 1997b). The dates for materials interpreted as culturally related are systematically older (15,650–14,600 cal yr BP) for the sheet midden where it overlies glacial outwash sediment of unit MV-7 than for the sheet midden where it overlies post-glacial stream deposits of unit MV-6 (14,600–13,700 cal yr BP). The overall mean of dates (n = 12) for the cultural layer is 14, 440 cal yr (median age 14,350 cal yr BP), and the mean age (n = 8) for dates from the top of unit MV-6 alone is 14,105 cal yr BP (median age 14,100 cal yr BP). An overall median age of 14,350 cal yr BP is adopted here for the Monte Verde site (Fig. 1), and lies within the age range (15,050–14,150 cal yr BP) suggested originally for the site (Dillehay and Pino, 1997a), but is 250 yr younger than the age of 14,600 cal yr BP more recently preferred for the site (Dillehay et al., 2008). Erlandson et al. (2008) suggested that AMS dates for seaweed (14,150 cal yr BP) may provide the most reliable age for the cultural horizon, but an AMS date on mastodon bone thought to be an artifact has yielded an age of 14,600 cal yr BP (George et al., 2005). The AMS dates for seaweed and bone almost exactly bracket the site age of 14,350 cal yr BP assumed here. The non-overlapping subsets of wood ages from unit MV-7 (15,650–14,600 cal yr BP) and unit MV-6 (14,550–13,700 cal yr BP) may reflect the different ages of wood buried in synglacial outwash sediment (unit MV-7) and postglacial stream sediment (unit MV-6).

## Monte Verde deglaciation

Five post-till peats overlying the last-glacial terminal-moraine complex of the Chilotan piedmont glacier at localities within ~20 km of Monte Verde (sites 36, 80, 82, 84, 91 of Denton et al., 1999) date to 14,200–14,000 cal yr BP (Fig. 4). The postglacial peats were collected <25 cm from the base of mire deposited in wetlands of waterlogged depressions between moraine crests following the retreat of ice from the moraine front, and provide a minimum date (~14,100 cal yr BP) for local deglaciation Three older peats deposited atop the terminal-moraine complex during the interval 16,750–16,600 cal yr BP (sites 79, 89, 90 of Denton et al., 1999) are viewed here as peats deposited during progressive deglaciation. Post-till peats (n = 3) overlying morainal till to the southwest on Isla Grande de Chiloé (Heusser, 1990) date to the intermediate age span of 15,950–14,600 cal yr BP (Fig. 1). Intertill peats of the moraine complex formed during the last glaciation date from 18,000–17,000 cal yr BP backward through the interval 22–44 ka (Denton et al., 1999).

The peat of unit MV-5 at Monte Verde (Table 1) has a mean age of ~13,600 cal yr BP (Fig. 1), hence was deposited ~500 yr after post-till peats had first begun to accumulate over the Chilotan terminal moraine complex southeast of Monte Verde (Fig. 4). The gallery bog of unit MV-5 was not deposited, however, until Chinchihuapi Creek had been incised several meters into the Chilotan outwash plain. The ages of the basal horizons of post-till peats (Fig. 4) fall within the latter part of the age range inferred for the Monte Verde cultural horizon (Table 1). This relationship underscores the conclusion that the inferred time of Monte Verde occupation was contemporaneous with terminal deglaciation (Dillehay, 1997). A periglacial setting for the only widely accepted pre-Clovis site near the Pacific coast of the Americas is provocative, given that 12,000 km of coastline to the north do not lie close to any nearby ice margins. Yet the only alternative to a periglacial occupation of Monte Verde is to heed the doubts of skeptics that the provenience of Monte Verde artifacts may not be adequately tied to Monte Verde stratigraphy (Fiedel, 1999; Haynes, 1999; Roosevelt, 2000), and thereby to reconsider the antiquity of the human occupation at Monte Verde.

## Monte Verde paleoshoreline

Pino (1989) concluded that "the coastline of the late Pleistocene period probably did not differ fundamentally from the modern one" near Monte Verde. Given the impacts of global glacio-eustasy and local glacio-isostatic effects near the Pleistocene ice limit, this statement cannot be strictly valid. Subsequent work (Dillehay et al., 2008) has addressed the probable effects of eustatic fluctuation in sea level near Monte Verde, but isostatic effects of nearby ice loads on site history remain unexplored.

The drawdown of 60 m in global sea level inferred by Dillehay et al. (2008) at the time of Monte Verde occupation is valid for 12,000 cal yr BP. For hindcasting paleoshorelines near Monte Verde at the time of its inferred occupation (~14, 350 cal yr BP), drawdown of sea level by 80 m at 14,000 cal yr BP is a better estimate (Bard et al., 1996; Fleming et al., 1998; Siddall et al., 2003). Reconstructed paleoshorelines would accordingly shift somewhat farther seaward than depicted by Dillehay et al. (2008), who placed the Pacific shoreline now at the mouth of the Rio Maullín, only 40 km downstream from Monte Verde (Fig. 4), at a position 90 km from Monte Verde during site occupation. For a eustatic drawdown of −80 m instead of −60 m, Monte Verde would have lain >100 km inland from a paleoshoreline directly to the west of the present mouth of the Rio Maullín, and at an elevation of ~140 m above ambient sea level. The paleoshoreline off the steep coast of Seno Reloncaví Bay to the east of Monte Verde (Fig. 4) would not shift more than 10 km for either −60 m or −80 m postulated drawdowns in sea level, although small offshore islands may have been linked to the mainland and the narrow passage between the mainland and Isla Grande de Chiloé was closed (Dillehay et al., 2008).

Glacio-isostatic effects near the Patagonian ice front had as yet undetermined effects on relative sea level on both the shores of Seno Reloncaví Bay and the Pacific coast at the mouth of the Rio Maullín (Fig. 4). The physical impetus for isostatic subsidence (S) of the substratum beneath an ice load is given by the expression $S = \rho_i/\rho_m \cdot h_i$, where $\rho_i$ is the density of ice, $\rho_m$ is the density of mantle rock, and $h_i$ is ice thickness ($\rho_i/\rho m$ ~ 0.3). The full potential subsidence S is not

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experienced below the edge of an ice load because the lithosphere has finite flexural rigidity, and the impetus for subsidence is spread laterally over a broader region. Subsidence is less beneath the ice margin than calculated by the expression for S, an isostatic moat is depressed in front of the ice load, and a compensatory flexural upwarp ("forebulge") is raised beyond the depressed moat.

Near Monte Verde, the thickness of late-glacial ice filling Lago Llanquihue was 1000–1200 m (Porter, 1981), and a comparable thickness is assumed here for ice of the Chilotan piedmont glacier filling Seno Reloncaví Bay with its center ~35 km from Monte Verde (Fig. 4). In coastal British Columbia and adjacent Puget Sound, observed postglacial rebound indicates that subsidence of the substratum beneath 1000 m of glacial ice was 125–175 m (Thorson, 1980; Clague et al., 1982), or approximately half that expected (300 m) from the expression for S given above. The depression of the Monte Verde site within the flexural moat in front of the ice load could not have exceeded 180 m, else the underlying outwash plain in front of a terminal moraine could not have remained subaerial during eustatic drawdown in synglacial sea level by ~120 m (Bard et al., 1996; Fleming et al., 1998; Siddall et al., 2003). Off British Columbia, the crest of the uplifted flexural forebulge beyond the isostatic moat lay ~75 km from the last-glacial ice margin (Clague, 1983; Hetherington et al., 2003). A similar flexural geometry near Monte Verde would place the crest of the forebulge on the continental shelf beyond the present coastline off the mouth of the Rio Maullín and Isla Grande de Chiloé (Fig. 4), and may have caused retreat of the synglacial shoreline farther offshore than inferred from consideration of global eustasy alone.

Postglacial isostatic rebound in British Columbia was rapid (Clague, 1983), and two-thirds complete within 1000 yr after deglaciation. Concomitant collapse of the uplifted forebulge on the shelf was comparably rapid (Josenhans et al., 1997; Carrara et al., 2007). If synglacial subsidence of Monte Verde was 75–150 m, isostatic rebound by two-thirds of that amount within 1000 yr would imply an emergence rate of 50–100 mm/yr for the land surface near Monte Verde. As the rate of postglacial eustatic rise in sea level was only ~10 mm/yr, marine flooding of Monte Verde during any stage of site history is precluded.

## Migration pathways

The first humans to enter the New World came across the Beringia land bridge when synglacial drawdown in sea level united Siberia and North America into a contiguous landmass spanning the present Bering Strait (Goebel et al., 2008). At the last glacial maximum (−120 m sea level), the land bridge was 1500 km wide (Fig. 2), and was still 1000 km wide as late as 14 ka (−80 m sea level). Drowned subaerial peats indicate directly that the Beringia land bridge persisted until at least 13,250–12,000 cal yr BP (Elias et al., 1992, 1996). The Bering Strait did not finally open to block land passage until sea level rose to −50 m (Mann and Hamilton, 1995) during the interval 11.5–10.5 ka (Bard et al., 1996; Fleming et al., 1998; Siddall et al., 2003), late enough to allow the ancestors of either Clovis or Monte Verde migrants to access Alaska by land travel.

The crucial step in peopling the Americas was not, however, passage from Eurasia into central Alaska within Beringia, for Asian and American segments of Beringia are geologically and were paleogeographically integral parts of the same continental block (Hoffecker et al., 1993; Fiedel, 2000). The crucial step was passage southward from central Alaska, a geographic cul-de-sac until deglaciation opened pathways through or around the ice barriers that blocked transit from Beringia to the rest of the New World during the last glaciation (Fig. 2).

As recapitulated by Erlandson (2002), Fladmark (1979) noted the only two feasible routes for late Pleistocene travel southward from Beringia. An inland route along the Canadian plains formed as a narrow ice-free corridor (Fig. 2) between continental glaciers when deglaciation parted the previously amalgamated Cordilleran and Laurentide ice sheets (Fig. 3B). A coastal route formed along the exposed continental shelf once piedmont glaciers had retreated from the shelf (Figs. 2 and 3). Although migrants from Asia could have reached unglaciated central Alaska during the last glaciation as soon as evolving paleoclimates and paleoenvironments allowed survival, the earliest documented ages for multiple archeological sites (n = 8) in central Alaska (Fig. 2) date to the time interval of 14,200–13,450 cal yr BP immediately preceding Clovis dispersal through the Americas (Powers and Hoffecker, 1989; Kunz and Reanier, 1994; Holmes, 1996, 2001; Holmes et al., 1996; Hoffecker, 2001; Bever, 2006; Hoffecker and Elias, 2007).

Confident evaluation of either of the two routes of travel southward from Alaska into the Americas is frustrated by the lack to date of any evidence for a human presence within the ice-free corridor at the time of presumed Clovis migration or along the submerged shelf at the time of postulated pre-Clovis migration. Yet one or the other, or both, of the two routes of travel was presumably used at the appropriate time. It is worthy of note that multiple Clovis-age sites are known within a few hundred kilometers of the southern end of the ice-free corridor (Grayson and Meltzer, 2002; Stanford et al., 2005), whereas Monte Verde is the only widely accepted near-coastal pre-Clovis site and is located ~12,000 km to the south of an equivalent latitude on the shelf off western Canada (Figs. 2, 5).

## Coastal migration

The postulate of coastal migration along the continental shelf is attractive because it offers a means for people to travel south toward Monte Verde without leaving any pre-Clovis record on ground that is still dry land. Expectations of evidence for pre-Clovis coastal migration that arose after the discovery of Monte Verde have as yet met, however, with no confirmation from direct supporting data, and the postulate of pre-Clovis coastal migration remains speculative.

To facilitate geologic appraisal of the coastal migration route from Beringia to Monte Verde, Figure 5 shows the western margin of the Americas on a special Mercator projection (also used for Fig. 2) for which relative distances are the same for the length of the Pacific margin of the Americas, and spatial configurations of landmasses near the Pacific coast are correctly shown because the equator of the projection lies subparallel to the length of the American Cordilleras. On standard Mercator projections with the rotational geographic pole as the pole of projection, distances are distorted from tropical to polar regions, and the Pacific margin is shown incorrectly as recurving in a broad arc from its trend along the western flank of the Americas to a different trend along the eastern flank of Asia. In reality, however, the trend of the circum-Pacific margin approximates a linear great circle on the globe from the southern cone of South America to Japan and Taiwan (Dickinson, 2008). There is no regional curvature in the trend of the continental margin leading from the North American Cordillera across the Bering Sea to the Kamchatka Peninsula (Fig. 5).

For evaluating the likelihood of travel along the drained continental shelf without impacting ground now exposed onshore, it is important to appreciate that the continental shelf off the tectonically active Pacific coasts of the Americas is narrower than in many parts of the world. During the interval 16,000–11,000 cal yr BP, when eustatic sea level rose from −100 m to −50 m (Bard et al., 1996; Fleming et al., 1998; Siddall et al., 2003), the subaerially exposed shelf south of Vancouver Island (Fig. 3) was nowhere >50 km wide, was ≤25 km wide along most segments, and off steep coasts was <10 km wide for long distances (de Almeida, 1978; Reed et al., 2005). By comparison, the Monte Verde site then lay >100 km from the contemporary paleoshoreline on the exposed offshore shelf. Monte Verde is not a coastal site, and movement inland from the shelf pathway as far as Monte Verde is located would have taken migrants to

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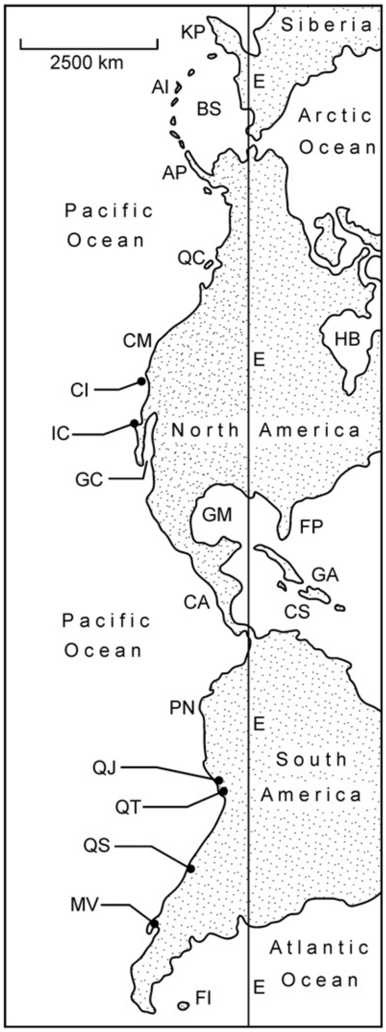


**Figure 5.** Western margin of the Americas shown on a Mercator projection with pole of projection at 25° N–15° E (Dickinson et al., 1986). Vertical line (E) is the great-circle equator of the projection; MV denotes the Monte Verde archeological site in South America. Other locales: AI, Aleutian Islands; AP, Alaska Peninsula; BS, Bering Sea; CA, Central America; CI, Channel Islands (off southern California); CM, Cape Mendocino; CS, Caribbean Sea; FI, Falkland Islands; FP, Florida Peninsula; GA, Greater Antilles; GC, Gulf of California; GM, Gulf of Mexico; HB, Hudson Bay; IC, Isla de Cedros; KP, Kamchatka Peninsula; PN, Punta Negra; QC, Queen Charlotte Islands; QJ, Quebrada Jaguay; QS, Quebrada Santa Julia; QT, Quebrada Tacahuay.

settings well inland from the present Pacific shoreline at any stage along a coastal route of travel from Vancouver Island to Monte Verde.

## Shelf morphology

North of Vancouver Island, a shelf region dotted locally by multiple offshore islands is broader than farther south, and was exposed to a width of 100–125 km off Canada and southern Alaska during late Pleistocene time. The key to its viability as a coastal pathway is to gage when the glaciated Alaskan shelf (Mann and Hamilton, 1995), which blocked passage for 1500 km during the last glaciation (Fig. 2), was free enough of ice to permit human transit, either on foot (Meltzer, 2009) or by watercraft (Dixon, 2001; Goebel et al., 2008). Only high elevations on Kodiak Island (Figs. 2 and 3) projected as isolated nunataks above the regional surface of piedmont glaciers that covered the rest of the Alaskan shelf until 19,200 cal yr BP (Mann and Peteet, 1994). Travel along the Alaskan shelf may have been feasible at any later time, although the oldest post-glacial fossil plants on the coast of the Alaska Peninsula date to 13,800 cal yr BP and the oldest known post-till peats to 12,800 cal yr BP (Jordan and Maschner, 2000; Jordan, 2001).

South of the Gulf of Alaska, ice-age refugia for large native mammals (Warner et al., 1982; Heaton et al., 1996; Fedje et al., 2004; Carrara et al., 2007) were present even at the peak of the last glaciation on islands near the shelf edge along the Pacific flanks of both the Alexander Archipelago and the Queen Charlotte Islands (Figs. 2 and 3). Those coastal ice-free refugia were separated, however, from interior Beringia by 1000 km of mountain ice, and from the shelf edge of western Beringia by 2000 km of glaciated shelf lying south of the Alaska Peninsula and the Alaska Range (Figs. 2 and 3). Deglaciation of the remainder of the Canadian shelf did not begin until after 18,800 cal yr BP, though before 18,000 cal yr BP (Blaise et al., 1990; Barrie and Conway, 1999), and was not complete until near 16,750 cal yr BP (Josenhans et al., 1995; Barrie and Conway, 1999). Travel southward from the Alexander Archipelago to the Queen Charlotte Islands on emergent shelf was possible, however, at any time after 16,700 cal yr BP (Barrie and Conway, 1999; Hetherington et al., 2003), and terrestrial plants dating to the interval 16,950–16,200 cal yr BP have been recovered from the seafloor beneath Hecate Strait between the Queen Charlotte Islands and the mainland of British Columbia (Barrie et al., 1993). By 15,200 cal yr BP, the floor of Hecate Strait had evolved on the proglacial forebulge into a complex of coastal fluviodeltaic plains and offshore islets separated by shallow marine passages (Fedje and Josenhans, 2000; Hetherington et al., 2003).

Despite paleoenvironmental reconstructions allowing for the possibility of late Pleistocene human migration along the Alaskan and Canadian continental shelves, there is as yet no positive evidence for a Pleistocene human presence in coastal Alaska or British Columbia (Fig. 1). Oldest ages reported from onshore coastal archeological sites in the Alexander Archipelago and Queen Charlotte Islands, and on the adjacent mainland of British Columbia and the Alaska Peninsula, fall within the post-Clovis age range of 12,000–10,200 cal yr BP (Josenhans et al., 1995, 1997; Heaton et al., 1996; Driver, 1998; Fedje and Christensen, 1999; Fedje and Josenhans, 2000; Mandryk et al., 2001; Erlandson, 2002; Fiedel, 2002; Bever, 2006), and submerged sites investigated to date are no older than 10,500 cal yr BP (Josenhans et al., 1997; Carrara et al., 2007). If there was a pre-Monte Verde coastal migration along the Alaskan and Canadian continental shelves, pre-Clovis migrants evidently clung to a hidden paleoshoreline now submerged offshore without leaving any record yet discovered on land.

The continental shelf narrows markedly south of Vancouver Island and Puget Sound (Fig. 2). The oldest known North American coastal sites south of Canada are in the Channel Islands of southern California (Fig. 5), although a site farther south on Isla de Cedros (Fig. 4) off Baja California is nearly as ancient. The archeological record on San Miguel and Santa Rosa Islands extends back to 12,300 cal yr BP (Erlandson, 2002; Fiedel, 2002; Rick et al., 2005), and on Isla de Cedros to 12,150 cal yr BP (Des Lauriers, 2006). Those ages are post-Clovis (Fig. 1), but inland California sites at Clear Lake (13,150 cal yr BP) and Tule Lake (13,350 cal yr BP) are a millennium older (Erlandson, 1994), within the Clovis age span. For sea level at 12,000 cal yr BP (−60 m), access to then-conjoined San Miguel and Santa Rosa Islands from the narrow continental shelf near Point Conception on the California coast required a water passage of 30–35 km (McCulloch, 1989b), nearly as lengthy as required today (35–40 km), but Isla de Cedros was almost conjoined with Punta Vizcaino on the Baja California mainland (Des Lauriers, 2006). The oldest known coastal archeological site on the mainland of southern California is located 10 km inland from the modern shoreline, and dates to 10,750–10,150 cal yr BP (Jones et al., 2002).

Traveling along the continental shelf from Point Conception in southern California to Monte Verde would entail a detour of >1500 km around the head of the Gulf of California (Fig. 5), or a crossing of 125 km of open ocean between exposed shelf near the tip of Baja California and exposed shelf off the Mexican mainland (Reed et al., 2005). The

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Colorado River has built a shallow subaqueous delta into the head of the Gulf of California, but water depths farther south along the axis of the gulf exceed 200 m for a distance of >750 km. Multiple local embayments would also have slowed travel on foot along the coasts of both Americas, and long segments of surf-swept coast would have posed a challenge to travel using watercraft. Erlandson et al. (2007) suggested that the high organic productivity of offshore kelp forests may have encouraged coastal migration, but there is currently a gap of 4000 km between kelp habitats of the northern and southern hemispheres within which coastal mangrove thickets and fringing coral reefs are dominant instead. Postulating that kelp forests helped sustain people along the full distance of a coastal migration path requires assuming that offshore kelp was continuous through the tropics during the waning phases of the last glaciation.

Maritime-adapted cultures dating to near the Pleistocene–Holocene boundary have been documented at several locales along the coasts of northern Chile and southern Peru within 1200–2800 km of Monte Verde (Fig. 5): Quebrada Santa Julia at 12,950–11,100 cal yr BP (Jackson et al., 2007), Quebrada Tacahuay at 12,650–10,900 cal yr BP (Keefer et al., 1998), and Quebrada Jaguay at 12,950–11,200 cal yr BP (Sandweiss et al., 1998). The site ages overlap broadly with the ages associated with Clovis-related fishtail points farther inland but are not pre-Clovis (Fig. 1).

There is thus no conclusive evidence for a pre-Clovis human presence along the Pacific coast of the Americas north of Monte Verde (Erlandson, 2002). The aggregate length of narrow shelf (≤50 km) from Vancouver Island to Monte Verde was ~12,000 km (Fig. 5), even without allowing for a detour around the head of the Gulf of California. Positing southward travel confined to the continental shelf, leaving no discernible record of passage inland from the present shoreline, requires assuming that people never strayed inland from the paleoshoreline as far as Monte Verde is located for that whole distance, or else dropped no identifiable artifacts or manuports if they did. Except for the apparent antiquity of Monte Verde, there would be no compelling reason to seek evidence for pre-Clovis coastal migration (Fiedel, 2002).

## Corridor migration

Over the decades during which positive evidence for pre-Clovis travel along a coastal migration path has failed to emerge, evidence for the coincidence in the timing of Clovis dispersal with the opening of the ice-free corridor has strengthened, even though evidence for a Clovis presence within the corridor itself is still lacking. Sites that have yielded Clovis points in North America lie within the age range of 13,450–12,850 cal yr BP (Taylor et al., 1996), or 13,050–12,800 cal yr BP using more stringent chronometric criteria (Waters and Stafford, 2007). Sites yielding Clovis-related fishtail points (Morrow and Morrow, 1999) in the Pampas and Patagonia east of the Andes span the younger but overlapping age range of 13,050–12,100 cal yr BP (Borrero et al., 1998). Clovis points are known as yet only from undated sites in Central America (Dillehay, 2009), but their presence there confirms the bicontinental distribution of Clovis-related cultures.

The Clovis time span closely followed, within just a few hundred years, opening of the ice-free corridor (Fiedel, 2002). Dyke and Prest (1986, 1987a, 1987b) showed that the corridor had begun to open on both the north and the south by 17,000 cal yr BP, but was still closed by ice along nearly 1000 km of its central segment at 15,500 cal yr BP. A continuous though narrow ice-free corridor had opened by 13,850–13,750 cal yr BP (Dyke and Prest, 1987b; Levson and Rutter, 1996; Dyke, 2004). Open sedge flats within the corridor were subsequently invaded by grass, willow, and poplar (aspen) to form open woodlands by 13,500 cal yr BP (White et al., 1985; Beaudoin et al., 1996), and big-game animals were present within the corridor by 13,450 cal yr BP (Burns, 1996). Habitats favorable for human occupancy were probably not present within the corridor until 13,150–12,850 cal yr BP (Jackson and Duk-Rodkin, 1996; Arnold, 2002), and the oldest habitation sites within the corridor date to 12,600–12,500 cal yr BP (Fedje et al., 2004). Human occupation of the corridor at more than temporary night camps was not required, however, for transit through the corridor by people moving south (Haynes, 2005). The opening of a vegetated ice-free corridor by 13,750–13,500 cal yr BP was closely coordinate with postulated Clovis travel through the corridor beginning shortly after 13,500 cal yr BP (Fig. 1).

Most have argued that no areal gradient of rapid Clovis dispersal (Fiedel, 2005) can be discerned (Waters and Stafford, 2007). A recent statistical analysis of Clovis site ages in North America argues, however, that Clovis dispersal from the north toward the south and east, as required by entry through the ice-free corridor, is the most likely interpretation of the age pattern (Hamilton and Buchanan, 2007), although an opposed viewpoint has been taken by others (Beck and Jones, 2007). The spread of Clovis culture across a landscape occupied at least locally by small populations of pre-Clovis peoples is conceivable, but Clovis dispersal unimpeded by territorial opposition or competition is a more attractive scenario (Jelinek, 1992; Fiedel, 2000; Meltzer, 2002).

## Problematical sites

Of uncertain significance are ages for human feces recovered from the Paisley Caves near Summer Lake in south-central Oregon (Gilbert et al., 2008). The three oldest ages (all AMS) average 14,150 cal yr BP, distinctly older than Clovis dates but overlapping available ages for the cultural horizon at Monte Verde. The Paisley Caves lie 300 km inland from the Oregon coastline across topographically rugged and heavily forested coastal mountains plus the entire width of the Cascade Range topped by snow-capped volcanic cones. Localities at a comparable distance from the Pacific coast at the latitude of Monte Verde lie across the crest of the Andes in eastern foothills of Argentina. Perhaps it is easier to envision derivation of the Paisley Cave inhabitants from early migrants through an incipient ice-free corridor than from the Oregon-Washington coast where the oldest known archeological sites do not predate ~9000 cal yr BP (Erlandson, 2002).

Even more problematical are the Schaefer and Hebior mammoth sites in Wisconsin within intermorainal troughs of the end-moraine complex of the Laurentide ice sheet ~2500 km east of the Pacific coast (Fig. 1). At each site, a single disarticulated mammoth skeleton of bones interpreted to bear signs of butchering is associated with non-diagnostic stone artifacts (Goebel et al., 2008). Overlapping ages of 14,950–14,750 cal yr BP (Hebior) and 14,850–14,150 cal yr BP (Schaefer) for the sites predate the opening of the inland ice-free corridor (Joyce, 2006), although the age of the Schaefer site has been questioned (Grayson and Meltzer, 2002). Postulating travel eastward to Wisconsin from a migration route down the Pacific coast would spoil the rubric that coastal migration allowed pre-Clovis access to Monte Verde without leaving a discernible onshore record of passage southward. Perhaps the evidence for human butchering, which is contested (Goebel et al., 2008), will prove to be inconclusive.

## Summary perspective

In the two decades since the announcement of the presumed antiquity of Monte Verde, which fortified notions of pre-Clovis coastal migration, not a single positive trace of pre-Clovis peoples has been discovered anywhere else along the coastal fringe of the Americas. Over the same time span, however, evidence for the coincidence of Clovis dispersal with the opening of an interior ice-free corridor has been strengthened, although any direct evidence for a human presence within the corridor itself at Clovis time is still lacking. Given the absence of robust evidence for pre-Clovis migration along the coast and paleoenvironmental questions bearing on the antiquity of Monte Verde, the Clovis-first model perhaps deserves retention as one working hypothesis. Genetic studies suggest that Native Americans first spread from Beringia to the rest of the Americas between 16.6 ka and 11.2 ka (Goebel et al., 2008). Genetic simulation further suggests that the split occurred earlier rather than later during that interval of time, but genetic modeling is unlikely to be precise enough at the millennial scale to distinguish between Clovis and pre-Clovis (Monte Verde) migrations. Only further archeological research can resolve the longstanding conundrum, but the geological constraints that are highlighted here for pre-Clovis interpretations deserve more attention than they have received to date.

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