Simulating Coastal Migration in New World Colonization

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The MV-II component of the Monte Verde site in southern Chile dates between 12,300 and 12,800 radiocarbon years B.P., but best estimates by Dillehay and Pino (1997: 45–49) place the occupation at approximately 12,570 radiocarbon years B.P., thus predating the Clovis complex (11,200 to 10,800 radiocarbon years B.P.) by approximately 1,000–1,200 calendar years (Batt and Pollard 1996; Fiedel 1999; Taylor, Haynes, and Stuiver 1996). A number of additional sites from South America have produced radiocarbon dates contemporaneous with or slightly predating Clovis (Borrero 1999; Bryan et al. 1978; Correal Urrego 1986; Dillehay et al. 1992; Dillehay 1999, 2000; Kipnis 1998; Mengoni Gonalons 1986). If the initial entry into the New World occurred via the Bering land bridge and migration proceeded from north to south, how were prehistoric humans able to migrate to southern Chile while leaving very few if any traces along the way? Some would argue that there is already sufficient evidence documenting the presence of a pre-Clovis occupation in North America (e.g., Adovasio and Pedler 1997, Adovasio et al. 1999, Bryan and Tuohy 1999), but it is not my intention to join this debate (for comprehensive reviews see Bonnichsen and Turnmire 1999; Dincauze 1984; Dillehay 2000; Dixon 1999; Fiedel 2000; Meltzer 1993, 1995; Owen 1984; Rogers, Rogers, and Martin 1991; Waters 1985). There are at least four possible explanations for the spatio-temporal discrepancy between the early archaeological records of North and South America: [1] The age, artifacts, or stratigraphic integrity of many early South American archaeological sites are problematic. [2] Humans entered South America before they entered North America. [Obviously, this would have required a transoceanic migration.] [3] Earlier sites...
exist in North America but we have not yet discovered them or accepted their antiquity. (4) The initial migration into the New World occurred rapidly from north to south via a coastal route the traces of which have been inundated by rising late Pleistocene and early Holocene sea levels. The final hypothesis requires the assumption that early hunter-gatherers first expanded inland into South America and that migration into continental North America was significantly delayed. Of course, these hypotheses are not mutually exclusive.

In this report, I examine the feasibility of the coastal-migration hypothesis as the sole explanation for the existence of early South American sites using a computer simulation of migration along the American Pacific Rim based on coastal colonization models proposed by Gruhn (1994) and Dixon (1993, 1999). Simulating prehistoric migrations allows us to place limits on the past. By distilling complex migratory processes down to a few key parameters it becomes possible to identify what conditions must be assumed for human arrival at Monte Verde to have predated inland migration into North America. Model parameters are constrained by data from human demography and hunter-gatherer ecology. Put simply, although any value can be plugged into a simulation variable, these values can be realistically limited using independent data from human biology and ecology.

This research is based on a simple premise: If it must be assumed that migration occurred under conditions in which hunter-gatherers could not have lived, coastal migration by itself becomes an unlikely explanation of the observed patterning in the archaeological record. Although simulation cannot empirically falsify a hypothesis, it can demonstrate flaws in the theoretical or logical construction of a hypothesis by showing that its empirical predictions cannot occur under realistic conditions. It can also point to new avenues for addressing current colonization models. This study follows in a long tradition of using computer simulation and mathematical modeling to investigate the plausibility of hypotheses concerning New World colonization (e.g., Alroy 2001; Anderson and Gillam 2000; Martin 1973; Mithen 1993; Mosimann and Martin 1975; Steele, Adams, and Sluckin 1998; Surovell 2000).

THE COASTAL-MIGRATION HYPOTHESIS

As an alternative to the ice-free corridor, many writers have suggested that prehistoric humans may have entered the North American mainland by flanking Cordilleran ice, migrating along a chain of sea-level glacial refugia on the Northwest Coast. The first person to raise the possibility of a coastal entry was C. T. Hurst (1943: 230) in an article about the Linger Folsom site in the San Luis Valley of Colorado. Numerous others have discussed the coastal route (Chard 1963, Easton 1992, Heusser 1960, Laughlin 1988, MacGowan and Hester 1962, Mandryk et al. 2001, Rogers, Rogers, and Martin 1992), although the idea is generally attributed to Fladmark (1978, 1979, 1983), perhaps its most vocal proponent. In recent years, however, the hypothesis has taken on a new role. Gruhn (1994:254), for example, has asked:

How could the [colonizing] population expand down into South America so long ago without leaving obvious traces in North America? ... A littoral-adapted population would expand linearly down along a virgin coastline, with population growth and migration limited to a very narrow spatial front. One would expect that the front of population expansion moved fairly rapidly down along the western coastline of North America, and human groups passed through the Isthmus of Panama to reach southern-central Chile and northeastern Brazil long before settlement of the continental interior of North America.

Gruhn (1988, 1991, 1994; see also Bryan 1991) has argued that this process can explain the presence of supposed Middle Wisconsin-aged sites in South America and the absence of such sites in North America. Dixon (1993, 1999, 2001) has made a similar argument with reference to the age of Monte Verde in light of North American evidence.

Archaeological evidence supporting the coastal-migration hypothesis has been difficult to find. Sites predating 10,000 radiocarbon years B.P. in western Canada and the northwestern United States are rare, possibly because of extensive sedimentation, deep burial, and low archaeological visibility in that region (Carlson 1996, Driver 1998). Detailed sea-level reconstructions of the Hecate Strait between the Queen Charlotte Islands and mainland British Columbia suggest that modern sea levels were not attained until approximately 9,400 radiocarbon years B.P., when they may have submerged earlier coastal sites (Josenhans et al. 1997). The recent discovery of a single flake in the Hecate Strait at a depth of 53 m, associated with a shoreline dating to 10,200 radiocarbon years B.P., is a tantalizing suggestion for early occupation of the Northwest Coast (Fedje and Christensen 1999: 647), but the find is too young to provide direct support for the coastal-migration hypothesis. The Manis mastodon site on the Olympic Peninsula of Washington may provide the best evidence for an early occupation of the Northwest (Gustafson, Gilbow, and Daugherty 1979). At this site, a mastodon was discovered in association with a single flake and what appears to be a bone projectile point puncturing one of its ribs. Radiocarbon dates on associated seeds, wood, and “micro-organisms” suggest an age of approximately 11,800–12,000 radiocarbon years B.P. (Gustafson, Gilbow, and Daugherty 1979:158), but bone from this mastodon has yet to be dated directly.

In regions outside of the Pacific Northwest, other sites indicate early coastal occupations. Dates from maritime sites in California, Peru, and Chile suggest that humans may have inhabited coastal areas as early as 11,000 radiocarbon years B.P. (Erlandson et al. 1996, Keefer et al. 1998, Llagostera Martinez 1979, Sandweiss et al. 1998). These sites do not, however, predate Monte Verde or Clovis, with the possible exception of a date of 15,780
† 120 radiocarbon years B.P. from Daisy Cave on San Miguel Island near Santa Barbara, California [Erlandson et al. 1996]. Also, the presence of early sites in coastal areas may indicate that people were exploiting coastal ecosystems at that time but says nothing about the route by which they arrived.

Spatio-temporal patterning in the earliest North American sites could lend support to a Pacific coastal migration. Interestingly, fluted-point sites in eastern North America tend to be younger than those of the west (Haynes et al. 1984), suggesting an eastward vector of colonization, but these data cannot be used to distinguish between initial coastal and ice-free-corridor entries because relatively few fluted-point sites have been dated west of the continental divide. Not helping the case, a number of sites in eastern North America have been proposed as pre-Clovis candidates, possibly exceeding 12,000 years in age (Adovasio et al. 1999, Goodyear 1999, McAvoy and McAvoy 1997, Overstreet and Stafford 1997). The paucity of empirical evidence regarding coastal migration highlights the utility of simulation for evaluating the hypothesis.

SIMULATING COASTAL MIGRATION

The simulation treats the coast as a series of 77 cells arranged linearly, each 200 km in length. Each cell contains the number of people inhabiting that portion of the coast. The simulation begins with a population of 50 individuals in the first cell at 47.5° north latitude, the approximate maximum southern limit of Cordilleran ice (Dyke and Prest 1987, Porter and Swanson 1998). In each iteration, time is incremented one year, populations grow, and migration occurs if conditions are favorable. Migration proceeds by individual and group decision making based on the goal of maximizing per capita overall return rates. Thus, migration does not occur unless it leads to increased caloric return rates over present conditions. Individuals can move between occupied and unoccupied cells and, under certain conditions, between occupied cells. Return rates are modeled as a function of population density, and therefore migration is ultimately fueled by demic expansion.

The simulation requires five parameters for operation: cell width, maximum population growth rate, leapfrog distance, and two functions relating population density to return rates for coastal and inland ecosystems, respectively. The length of cells has no impact on the results of the simulation. Cell width is the width of the coastal corridor. Maximum population growth rate is the annual percentage population increase under optimal return-rate conditions, and leapfrog distance is the greatest distance coastal populations can travel in moving around occupied coastal territory to reach uninhabited coast. Figure 1, a, represents the structure of the simulation. Coastal and inland return rates are modeled as truncated third- or fourth-order polynomial functions of population density, adapted from Smith’s [1991:289–301] model of optimal group size for hunter-gatherers. Population growth rates vary from 0 to the maximum population growth rate as a linear function of return rates.4 It is assumed that for any given population density, coastal returns exceed those of inland biomes, providing an incentive for populations to migrate along the coast in preference to moving inland.

Migration into unoccupied areas of coast occurs when an individual or individuals can increase overall return rates by moving to unoccupied territory. Emigration never occurs if the population density of a cell is suboptimal; in that case, the best strategy is to stay in place until population growth and/or immigration brings population density up to optimal levels. Once optimal density is reached, however, further population growth results in reduced return rates that foster emigration in the form of fission. A subpopulation will move to unoccupied coastline when the potential return rate for the excess number of individuals above the optimum exceeds that of the parent population.4 When a population migrates to unoccupied coast, it moves to the closest available cell. If immediately adjacent cells are occupied, a population may migrate to more distant cells within the designated leapfrog distance. Migration between occupied cells occurs when it will increase returns for all parties involved and the distance to the destination population does not exceed the leapfrog distance. A given cell will permit immigration if population density is less than optimal because recruiting migrants will result in greater return rates (fig. 1, b). Once population growth has pushed return rates below maximum inland returns, a subpopulation will migrate inland5 (fig. 1, a).

The simulation tracks the relative timing of three events: first inland migration, arrival in South America, and arrival on the coast at the latitude of Monte Verde. The location and age of Monte Verde are used as benchmarks for comparison, since it is the oldest and best-dated early South American site and among the most distant. Conservative estimates of distance place South America 7,600 km and Monte Verde 13,400 km from the entry point (fig. 2). First inland migration always occurs at the northernmost cells because population pressure is always greatest in the cell first occupied. For inland migration in South America to precede inland migration in North America requires an additional assumption—that inland return rates in South America exceed or approach coastal returns, resulting in a strong incentive to move into the continental interior. A key output variable is coastal distance, the distance traveled along the coast prior to first inland migration into North America. If

3. This assumption follows the work of Winterhalder et al. [1988] and is based on the premise that greater numbers of offspring can be supported per capita at higher rates of food acquisition.
4. Fission occurs when (dcoast−dcoast) > (dcoast), where dcoast is the coastal population density at time t, dcoast is the optimal coastal population density, (dcoast−dcoast) is the potential return rate of the migrant subpopulation at time t, and (dcoast) is the return rate of the parent population at time t.
5. Inland migration occurs when (dcoast) > (dcoast), where (dcoast) is the maximum inland return rate and (dcoast) is the coastal return rate at time t. The maximum inland return rate is used because there are generally sufficient numbers of individuals above the optimal coastal number to maximize inland returns.
Fig. 1. a, The structure of the simulation. Coastal migration into unoccupied cells occurs when the number of individuals exceeding the optimum can improve their return rates by moving into unoccupied territory. Inland migration occurs when coastal returns fall below maximum inland returns. b, Population density versus status accepting or rejecting immigrants. Coastal migration between occupied cells occurs when an individual can improve returns by joining another population and that population can improve return rates by having an individual join, a condition met only when population densities for the destination cells are below the optimum. c, The “base model” structure and parameter settings. Coastal curve $r = (d + 0.2) \times (d-2) \times (d-2)/1.579$; inland curve $r = (d + 0.1) \times (d-1) \times (d-1) \times 2.7$.

Populations reach a coastal distance of 13,400 km southward 1,000 years prior to inland migration into North America, then the prerequisite condition for the coastal-migration hypothesis has been met. A base model was created to test the effects of varying each parameter while holding the other four parameters constant [fig. 1, c]. In the base model, cell width is set to 1 km, such that the coast is essentially modeled as a one-dimensional space. Assuming a very narrow occupation of the coast speeds coastal migration and limits the potential for the creation of inland archaeological sites until intentional inland migration occurs. Maximum population growth rate is set to 3% per year, well within the range of intrinsic rates of increase for human populations [Keyfitz and Flieger 1968]. Leapfrog distance is set to 500 km. Maximum coastal returns are roughly twice those of inland ecosystems. Return rates are standardized to the maximum coastal return rate such that they vary from 0 to 1. To determine the rate of population growth for any cell, the maximum population growth rate is multiplied by the fraction of the maximum coastal return rate. For example, if maximum population growth rate is set to 3% and population density is such that return rate is reduced to 50% of its maximum value, population growth rate is adjusted to 1.5%. What a return rate of 0 implies, however, is that populations are unable to glean any food from their environment but that they are only able to maintain constant population levels. These settings are largely arbitrary and are irrelevant to the final outcome. They are used only as a point of departure for exploring the inner workings of the simulation.

Two parameters, maximum population growth rate and cell width, have no impact on the distance that coastal migration has advanced when initial inland migration occurs at the point of origin. Adjusting these pa-
Parameters do, however, impact the timing of events. Narrower cells and higher population growth rates both result in increased rates of migration, both coastal and inland, but the timing of northern inland migration and arrival at southern destinations remain proportional, resulting in inland migration occurring after coastal migration has stretched only 1,000 km southward.

Adjusting leapfrog distance in the simulation, however, does impact coastal distance. Increasing leapfrog distance allows cells to extend the time period over which they can relieve population pressure by sending out migrants over longer distances, thus delaying inland migration. Also, it increases the number of cells that contribute to the migratory front along the coast, speeding rates of migration. If populations are allowed to leapfrog huge distances (e.g., > 2,500 km), migration rates can exceed 50 km per year. Nonetheless, it is not until leapfrog distance is pushed upwards of 4,000 km that groups reach South America before they move inland in the north (fig. 3, a). Even if leapfrog distance is increased to 5,000 km in the base model, inland migration still precedes arrival at Monte Verde. Compilations of mobility data from ethnographically studied hunter-gatherers indicate that single residential moves rarely exceed 70 km and cumulative annual distances moved seldom exceed 1,000 km for the most mobile groups [Binford 2001:table 5.01; Kelly 1995:table 4-1].

Modification of coastal and inland population-density/return-rate curves permits investigation of the effects of variation in the structure of coastal and inland ecosystems on the migration process. For example, reducing optimal coastal population densities is in effect increasing environmental predictability, since smaller groups are able to maintain high returns despite the fact that there are fewer individuals pooling information and variable foraging yields. Reducing optimal coastal population densities encourages populations to emigrate to uninhabited coast to maintain low densities. This also increases the migration rate. Figure 3, b, shows how this effect is modeled. In the base model, optimal coastal population density is set to 0.535 persons per km². As expected, migration rate increases with reduced optimal density, but the effect is minor until density drops to a value far less than 0.1 persons per km² (fig. 3, c). The distance migrated down the coast when first inland migration occurs increases dramatically as optimal density becomes very low, but to reach Monte Verde in the base model before inland migration occurs in the north, optimal density would have to be less than 0.0003 persons per km².

Hunter-gatherers rarely if ever exist at these densities [Binford 2001:table 5.01; Kelly 1995:table 6-4]. To prevent inbreeding, a minimum population of 175 persons is necessary [Wobst 1974]. In this light, if 2,000 km of annual mobility are allowed, placing 175 individuals within a 1,000-km-long strip of coast (2,000 km in round-trip mobility) results in an absolute minimum of 0.175 persons per km². This minimum value, however, is dependent upon the width of the coastal corridor. If a wider strip of land is occupied, lower population densities can be maintained because more land is available for use and greater numbers of people are supported. Order-of-magnitude increases in the width of the coastal corridor lead to order-of-magnitude decreases in minimum population densities. However, to make the coastal-migration hypothesis successful in the base model requires assuming that the coastal corridor was occupied over a width of almost 600 km. Because of the steepness of the contin-

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6. The Yahgan, Gruhn’s [1994] analogue of early coastal migrants, for example, existed at a density of 0.046 persons per km² (Kelly 1995:table 6-4), more than two orders of magnitude greater than the 0.0003 estimated minimum population density in the base model. Inland hunter-gatherers, unlike coastal groups, are not limited to a one-dimensional space, something that severely limits mating opportunities. For example, an inland band of 25 individuals at a density of 0.01 persons per km² can occupy a 50 x 50-km territory and maintain access to four neighboring groups for exchange of mates without traveling huge distances. If populations are hexagonally packed [Mandryk 1993, Wobst 1974], a single band at such densities can maintain access to six other bands or 150 other individuals without large mobility costs. For coastal groups without supplementary inland populations, a band of 25 hunter-gatherers living at a density of 0.01 persons per km² would have to travel upwards of 5,000 km per year to maintain access to 50 neighbors, assuming a 1-km width of coastal occupation.
Fig. 3. a, The effect of leapfrog distance on the distance coastal migration has proceeded (CD) when the first migrants enter inland North America. b, Modification of the coastal curve to change optimal coastal population density. c, The effect of optimal coastal population density on the distance coastal migration has proceeded (CD) when the first migrants enter inland North America.

The effect of leapfrog distance on the distance coastal migration has proceeded (CD) when the first migrants enter inland North America. A continental shelf on the west coast of the Americas, allowing any more than 50 km seems unreasonable because it would result in the creation of visible inland archaeological sites. At this setting, the minimum population density estimate is 0.0035 persons per km².

Another way to delay inland migration is to reduce inland return rates. As it becomes increasingly difficult for people to make a living inland as compared with on the coast, inland migration becomes a less attractive option. To model variation in coastal and inland return rates, the magnitude of the inland curve is systematically reduced by multiplying it by a constant (fig. 4, a). Arrival in South America does not precede northern inland migration until coastal return rates are approximately 950 times greater than inland rates (fig. 4, b). Inland migration, however, still predates arrival at Monte Verde if maximum coastal return rates are 1,000 times greater than those of inland ecosystems. Estimates based on recent foraging populations suggest that coastal return rates can at best be only 36 times greater than those of inland ecosystems.⁷

⁷ There are relatively few data available on return rates for marine resources. Smith (1991) reports overall returns for hunting of a variety of sea mammals and aquatic fowl that range from 910 Cal per hour (Canada geese in summer canoe hunts) to 8,710 Cal per hour (eiders in fall canoe hunts). Kelly (1995, table 3-3) reports a number of postencounter return rates for inland resources, ranging from just over 1,000 to over 100,000 Cal per hour, indicating that terrestrial ecosystems can produce very high returns for hunter-gatherers. Most resources, however, range from a few hundred to a few thousand kilocalories per hour. Even if an eight-hour foraging day is assumed, half of which is spent searching for food, overall returns of 250 Cal per hour should be easily obtained. In fact, this is the absolute minimum in this case because adults require approximately 2,000 Cal per day for survival. If it is assumed that coastal...
Inland migration can also be postponed by increasing coastal productivity such that high return rates are maintained at high population densities (fig. 4, c). This delays inland migration because coastal returns do not approach maximum inland returns until coastal population densities are very high. The downside of increasing coastal productivity is that high population growth rates are maintained even at high population densities. Figure 4, d shows that “stretching out” the coastal curve in this fashion has little effect on the distance that coastal migration has proceeded when groups first move inland in North America. In the best case, only 200 km are gained over the base model, with inland migration occurring when the front of coastal population expansion has proceeded only 1,200 km, approximately 100 km south of San Francisco.

None of the five parameters in the base model explored individually can produce the condition postulated by the coastal-migration hypothesis—arrival at Monte Verde before inland migration into North America. However, the possibility remains that by combining the effects of all the simulation parameters this condition can be met. A best-case scenario was created to test this proposition (fig. 5). Cell width was set to 50 km. Leapfrog distance was set to 1,000 km. Optimal coastal population density was set to 0.0033 persons per km². Maximum coastal return rates were set to 36 times those of the inland, and population growth was slowed to 0.5% per year to “buy time” between the entrance into South America and the first instance of inland migration in the north. The values chosen for each parameter are their estimated the-
Fig. 5. The best-case model and results. Coastal curve \( r = (d + 0.73) \times (d - 1.47) \times (d - 1.47)/1.579; \) inland curve \( r = (d + 1) \times (d - 1) \times (d - 1) \times 0.14. \)

Theoretical maxima or minima, and with these rather optimistic conditions coastal migration stretches 11,600 km before groups first move inland in the north. Arrival in South America predates inland migration by 767 years. Populations first set foot in South America in year 1,500, and northern inland migration occurs in year 2,267. However, Monte Verde is not reached until almost 309 years later, in year 2,576. If the maximum population growth rate is set to 3% per year, entry into South America predates inland migration by only 129 years, a time span barely detectable by radiocarbon dating. Nonetheless, assuming that inland migration occurred shortly after entry into South America, the simulation predicts that it is possible to produce the earliest visible New World archaeological sites in South America.

Although superficially the simulation has come close to producing the desired outcome—arrival at the latitude of Monte Verde prior to northern inland migration—there are problems with this formulation. First, Monte Verde supposedly predates Clovis by at least 1,000 years. In the best-case simulation, Monte Verde would postdate Clovis by approximately 300 years—a 1,300-year discrepancy. Furthermore, this form of the simulation has some bizarre predictions. For example, because coastal cells are so large (10,000 km²) and inland return rates are so low [1/36 of maximum coastal returns], inland migration does not occur until more than 13,000 people are present in a cell, and this condition is met in the founding cell in year 2,267. Furthermore, the simulation predicts that when the wave of population advance enters South America, there will be more than 300,000. Clearly, there is no archaeological support for high population densities along the west coast of North America in the late Pleistocene or even the early Holocene.

These predictions suggest two ways in which the model may be unrealistic. First, if maximum inland return rates were higher, inland migration would occur sooner, and coastal populations could serve as a “demographic pump,” feeding inland migration and maintaining relatively low coastal population densities. Second, the curve relating population density to return rates may not be steep enough. If coastal return rates were modeled to drop very rapidly as a function of population density, coastal population growth would be slowed and high population densities would not be attained so quickly. Both modifications of the model, however, would promote early inland migration and slow coastal migration. If inland returns were greater, inland migration would occur earlier, and individuals moving inland would no longer contribute to demographic pressure driving coastal migration. If the coastal curve were modified in such a way that return rates dropped quickly as a function of population density, coastal return rates would rapidly approach maximum inland returns, causing inland migration, and coastal migration would be delayed by declining population growth rates.

**Discussion**

The coastal-migration hypothesis alone appears incapable of explaining the spatio-temporal discrepancy between Monte Verde and early North American sites. For the hypothesis to be viable requires assuming (1) that the
initial migration into the New World occurred via a coastal route, [2] that inland return rates for North America were unrealistically low relative to coastal return rates, [3] that in South America and only in South America inland return rates were either equivalent to or exceeded those of the coast, [4] that optimal coastal population densities were excessively low, [5] that populations were very mobile and leapfrog distances were very large, [6] that population growth was very slow, and [7] that the occupation of coastal lands extended considerably inland without creating a clear archaeological signature. Even assuming all of these conditions, the simulation is unable to make arrival at Monte Verde precede inland migration into North America. Additionally, many of these assumptions are very difficult to justify. For example, the coastal-migration hypothesis postulates that first inland migration occurred in South America, but there is little reason to believe that South America would have favored inland migration and the entirety of North America would not. Allowing populations to leapfrog up to 1,000 km of coast seems very extreme. Also, recent work suggests that colonizing populations would be characterized not by sluggish population growth but by rapid expansion [Steele, Adams, and Sluckin 1998, Surovell 2000]. Additionally, Late Pleistocene inland ecosystems were home to many genera of megafauna that had never experienced human predation [Berger, Swenson, and Persson 2001, Jelinek 1967, Kelly 1999, Martin 1973], and inland returns could have been quite high.

The coastal-migration hypothesis alone holds little potential for explaining the age discrepancy between Monte Verde and early North American sites, and Gruhn's (1994) proposition that it could explain the presence of sites of Middle Wisconsin age in South America and their absence in North America seems similarly remote. It cannot be stressed enough, however, that the simulation says nothing about the route of the initial migration into the New World or the route taken to South America. Coastal migration remains possible and perhaps likely, but if it had occurred we would expect to find the earliest inland sites in the New World not in South America but in western North America. The fundamental reason the model fails to produce the desired outcome is that the coastal distances are simply too great for southward migration to outpace population growth and inland migration in parent populations left behind.

Does the model negate the possibility of humans' ever having engaged in long-distance, rapid, linear colonization events? At least two examples of such colonization events are well known: the expansions across the Arctic coasts of northern Alaska and Canada by peoples of the Arctic Small Tool Tradition and the Thule [Maxwell 1985, McGregor 1984, 1996]. The simulation, however, is not at odds with these events. The scarcity of fuel for winter fires on the treeless tundra would have tethered people to coastal areas. The peoples of the Arctic Small Tool Tradition seem to have depended in part upon driftwood for fuel, while those of the Thule tradition were reliant upon burning lipids from sea mammals [Maxwell 1985]. This “coastal tethering” is analogous to reducing inland return rates in the simulation to near-zero levels, and the simulation would predict a rapid coastal migration with little inland colonization. The inland biomes of western North and South America, with the possible exception of the South American coastal deserts, have significantly higher productivity and habitability than the barren lands of the high arctic.

According to the simulation, if the primary corridor of colonization was the western coast of the Americas, the earliest archaeological sites both above and below sea level should be found in western North America and most likely in the Pacific Northwest. From our current limited sample of sites and radiocarbon dates, no such pattern emerges. Where does this leave us? One possibility is that our current view of the archaeological record is afflicted by sampling bias. Implied in most spatio-temporal analyses of human migration is that the archaeological record should produce a sample that accurately reflects the pathway of colonization, essentially an assumption of equal visibility in all regions. Ideally, the regions that were first occupied should produce the earliest dates while those occupied later should produce later dates. As Steele, Adams, and Sluckin (1998) have noted, however, the strength of the archaeological signal of the earliest colonizers is a function not simply of the length of occupation of a region but of the cumulative occupation expressed as the number of persons occupying a region multiplied by time—essentially a measure of person-hours. In this sense, regions favoring high population growth rates and high population densities will produce stronger archaeological signals than those occupied by groups at much lower population densities. This phenomenon could seriously bias our perceptions of the directionality of colonization because regions with long cumulative occupation spans would be more likely to produce early dates than those with short cumulative occupations span even if people first arrived in the latter. It seems unlikely that this phenomenon alone could account for the age discrepancy between early North and South American sites, but it could help to explain it.

This exercise has critically evaluated one version of the coastal-migration hypothesis and shed light on the process of colonization by demonstrating how it might occur as the cumulative product of the operation of simple rules governing individual decision making. Furthermore, it has provided some insight into assumptions underlying current informal models of coastal migration. Finally, even though the simulation has failed to demonstrate that coastal migration alone could have produced the observed archaeological record, this does not rule out the possibility of further simulation’s producing that outcome or of further archaeological fieldwork’s invalidating the findings presented herein.

Formal simulations can also provide avenues for future research through their direct implications. For example, the colonization model provides insight into the likely locations of the earliest inland sites if indeed a coastal migration occurred. As discussed above, inland migration is expected to occur first in regions close to the point
of origin because of the maximum time depth for population growth. Although coastal and inland ecosystems are treated as a constant for the sake of simplicity, the functions relating return rates to population density for these biomes would likely vary considerably up and down the coast. The model developed herein suggests that inland migration would be promoted in areas in which the disparity between inland and coastal return rates is minimized or even reversed. Paleoecological data on marine productivity and the composition of terrestrial plant and animal communities could certainly be incorporated into the model to refine this prediction.

One possible implication is that significant inland migration would be discouraged by coastal ranges in the Pacific Northwest, California, and Central and South America, where return rates would rapidly decline with eastward movement. Where corridors of habitable land exist between coastal ranges and the Pacific Ocean, however, early archaeological sites would be expected. More important, these ranges do not constitute an impenetrable barrier to the interior. Where large rivers empty into the Pacific Ocean, perforating coastal mountain chains, inland ecosystems would have appeared very attractive to prehistoric populations, since continental waterways serve as linear ecotones where many terrestrial and aquatic resources are available. The Columbia River, less than 200 km from the point of entry used in this study, is an obvious corridor into continental North America (see Bryan and Tuohy 1999). Other possible North American entry corridors include the San Francisco Bay, leading to the Central Valley of California, and the Colorado River. Such predictions may provide a relatively straightforward means of verifying coastal migration through intensive archaeological survey and excavation in the regions of these potential conduits to the interior.

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Excavations at the Palaeolithic Site of Attirampakkam, South India: Preliminary Findings

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India occupies a crucial place in the study of the Lower Palaeolithic, particularly in relation to questions of hominid dispersals across Asia and regional adaptations to a diversity of natural habitats (Petraglia 1998). This potential has often been overlooked, predominantly because of a paucity of published reports and a preconceived notion of the rarity of well-preserved sites that are fossiliferous and have potential for being dated. In this context, our ongoing excavations at Attirampakkam near Chennai (South India), which are aimed at investigating early hominid behaviour in a new ecological context in India and at providing an age for the Acheulian in this region, are significant.

This report focuses on preliminary results of the first season’s excavations at a well-preserved multicultural Palaeolithic site, Attirampakkam (13°13’50”N lat., 79°53’20”E long., 37.75 m above sea level), in the Kortallayar River basin of South India. Investigated for more than a century, the site has been regarded as a type site for the Lower Palaeolithic Madras Handaxe Tradition. Discrepancies noted in the stratigraphic and cultural sequences proposed by previous scholars (Banerjee 1964–65, Foote 1866, Krishnaswami 1938) led to a re-examination of the archaeology of the Kortallayar River basin (Pappu 1996, 1999, 2001a, b), and Attirampakkam was subsequently selected as the first in a series of excavations to be conducted at several well-preserved Palaeolithic sites in the region. Preliminary excavations at this site in 1999 revealed an Acheulian occupation in and on the surface of a 4-m-thick deposit of laminated clay indicative of a palaeofloodplain situation. This constitutes a previously unreported ecological habitat for the Indian Palaeolithic. The discovery of fossil teeth at the site was of great significance considering the extreme paucity of faunal remains at Indian Lower Palaeolithic sites. Subsequent excavations in 2000 led to the discovery of an Acheulian living floor with cores, tools, anddebitage in association with a set of animal footprints.

Despite more than a century of prehistoric archaeology in India, we know little about its Lower and Middle Palaeolithic in comparison with those of Africa or Eurasia. Although active research on the Indian Lower Palaeolithic spans more than three decades, few systematic long-term regional studies coupled with excavations of well-preserved sites have been initiated. Notable among these are multidisciplinary projects in various parts of India (Allchin, Goudie, and Hegde 1978, Corvinus 1983, Misra and Rajaguru 1989, Paddayya 1982, Paddayya and Petragni 1995, Sharma and Clark 1983, Petragni, Laporta, and Paddayya 1999), which have focused on the environmental history of sites in their regional contexts and on the interpretation of site functions. In recent years, efforts have been made to model site formation processes (Pappu 1999, Paddayya and Petragni 1993, 1995) and to obtain dates for the Acheulian (Misra 1995). Excavations at open-air Lower Palaeolithic sites have yielded assemblages in a wide range of sedimentary contexts. Artefacts occur [1] at Chirki-on-Pravara in gravel and a cobble-rubble horizon [Corvinus 1983], [2] at Didwana 16 R in a stabilized sand dune [Misra 1995], [3] in the Hunsgi-Baichhal complex [Paddayya 1982, Pad-