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New world paleoenvironments during the Last Glacial Maximum: Implications for habitable land area and human dispersal

Joanna R. Gautney

Department of Anthropology, University of North Carolina at Chapel Hill, 301 Alumni Building, CB #3115, UNC-CH, Chapel Hill, NC 27599, United States

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ABSTRACT

The movement and dispersal of human populations during the Pleistocene is a complex question, and one that has been addressed extensively in the literature. During Pleistocene glacial periods, landscapes and coastlines altered dramatically, with old routes closing and new routes opening. One of the best understood of these glacial periods, the Last Glacial Maximum (between 22 and 18 ka), is of particular interest with regards to the colonization of the New World. Despite decades of study, archaeologists still do not fully understand the timing and tempo of that process. This study contributes to this discussion by presenting an estimation of habitable land area in the New World at the LGM when sea level was 120 m lower than present day using a previously published method for mapping ancient coastlines and calculating land areas in Google Earth. Areas defined as uninhabitable include those areas covered by ice sheets, glaciers, and ice fields, and areas of extreme aridity. Combined habitable land areas of North and South America are estimated as 34,149,094.81 km^2. Added to data from the previous study, a new estimate of global habitable land area at the LGM is calculated to be 111,108,807.21 km^2. Data on paleocoastlines are then used to predict locations where archaeological traces of early human dispersals may potentially be found.

1. Introduction

The dispersal of modern humans into the Americas has been one of archaeology's most enduring and provocative questions. Until fairly recently, it was widely accepted that the earliest dispersals into the New World took place sometime around 13 ka, through the ice-free corridor that separated the Cordilleran and Laurentide Ice Sheets after the Last Glacial Maximum (LGM) (Haynes, 2002). However, a multitude of recent evidence indicates that the peopling of the Americas was a much more complex process (Erlandson et al., 2007; Erlandson, 2013; Fagundes et al., 2008; Halligan et al., 2016; Llamas et al., 2016; O'Rourke and Raff, 2010; Pitblado, 2011).

Human behavior and dispersals of the past have largely been dictated by climate, with environments changing dramatically through the many Pleistocene glacial cycles, and new migration routes appearing or disappearing as well. Behavioral modernity, regardless of how it is defined or recognized in the archaeological record, plays an important role because it allowed humans to modify their environments. As behavioral modernity arose, human behavior became increasingly flexible and gave us the ability to inhabit previously inaccessible environments, including those in the cold and inhospitable environments of the northern latitudes. Behavioral modernity allowed for novel food procurement strategies and the innovation of shelters and clothing (Gilligan, 2007, 2010).

The Last Glacial Maximum is an important period for many reasons. Geologists and paleoclimatologists have studied the LGM extensively, and because of technological advances in absolute dating techniques, climate modelling, and geochronology, much is known about this period (Clark and Mix, 2002; Clark et al., 2009; Dyke et al., 2002; Lambeck et al., 2002; Yokoyama et al., 2000). While the LGM is, with the exception of the Holocene interglacial, the most recent large manifestation of natural global climate change, it is by no means the only large-scale shift in climate that has occurred during hominin evolutionary history. Two characteristics distinguish this glacial maximum from others. First, it is by far the best preserved in the geological record, and therefore the best understood (Mix et al., 2001). Second, it likely played an integral role in the timing and tempo of the colonization of the New World by modern humans. During this period, previously inaccessible land areas were exposed due to a fall in sea level, while other routes were blocked by the presence of ice sheets.

This study explores the paleoclimate of the New World at the LGM, and the role that sea level and ice formations may have played in early human settlement and dispersal patterns. It builds on previously published studies examining habitable land area, ancient coastlines, and population density at the LGM in the Old World and the New World (Anderson and Bissett, 2015; Cartajena et al., 2014; Clark et al., 2014;

E-mail address: jgautney@email.unc.edu.

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Gautney and Holliday, 2015; Gustas and Supernant, 2017; Holliday et al., 2014). Here, habitable land area of the New World at the LGM is presented, along with revised global estimations of habitable land area, and these data are contrasted with estimations from present day. These data will then be used to examine areas of coastline where early sites may be expected to be found, and to explore the geographical contexts of known sites of early human occupation. Reconstructing ancient coastlines is important for inferring likely routes of dispersal and settlement sites, and for evaluating differing models of human dispersal into the New World. An exploration of these now-submerged coastlines of North and South America will contribute to our understanding of the timing and tempo of these early dispersals, and can be used to predict locations where archaeological traces may be found in the future.

2. Methodology

2.1. Land area estimation

Habitable land area of North and South America was calculated employing a previously published method used to calculate LGM habitable land areas in Eurasia, Africa, and Australia (Gautney and Holliday, 2015; Holliday et al., 2014). This method uses the polygon creation function in Google Earth, which calculates the area contained within a polygon. Google Earth is a virtual map and geographical information program that maps the Earth using satellite data gathered from a range of American governmental agencies such as the United States Navy, the National Geospatial-Intelligence Agency, and the National Oceanic and Atmospheric Administration. It uses elevation data primarily from the National Aeronautics and Space Administration's Shuttle Radar Topography Mission (SRTM) to produce a 3D virtual map of topography both above and below current sea level. Google Earth allows users to create their own maps and provides a suite of tools including the polygon creation function. Using this function, users can draw polygons on a map by plotting points, and information including elevation and geographical latitude and longitude are given for each point. Using these points, land area is calculated within the created polygon.

In the previous study, habitable land area was estimated for the Pleistocene Old World using this method (Gautney and Holliday, 2015). For the reasons to be discussed below, polygons for most of the New World were drawn at elevations 120 m lower than present-day sea level, with one landmark plotted approximately every mile along all coastlines. The same method was employed here for North and South America. Areas deemed uninhabitable during the LGM due to the presence of ice or areas of extreme desert were mapped using the same method, then subtracted from the total areas to determine habitable land area.

2.2. LGM landscapes

The Last Glacial Maximum has been defined as the interval between 23,000 and 19,000 cal-yr BP in which global ice volumes reached their maximum (Clark et al., 2009; Mix et al., 2001; Yokoyama et al., 2000). During this 4000 year window, climate was reasonably close to an equilibrium state, being relatively free from short-term oscillations (Mix et al., 2001), and ice volumes remained constant. After 19,000 years ago, global temperatures began to increase, sea level began to rise, and climate shifted dramatically worldwide.

Global climate was drastically different during the LGM than the present-day, generally trending cooler and drier. In the Old World, deserts such as the Sahara and Arabian desert expanded, while forested areas in Africa shrank, considerably changing large portions of the landscape (Goudie, 1992; Jolly et al., 1998; Ray and Adams, 2001). Likewise, the interior areas of the Sahulland landmass were substantially more arid, and these arid zones of the continent were also considerably larger than they are at present (Smith, 1989). Due to sea level changes, large portions of land that are today submerged were exposed, most notably the Sunda Shelf (Gautney and Holliday, 2015). North and South America were drastically different in many locations during the LGM as well, for the most part due to the presence of large ice sheets and other forms of permanent ice. These differences will be discussed in greater detail below.

2.2.1. Sea level

Estimations of sea level at periods in the past is not always a straight-forward endeavor. Uranium-thorium dating of corals and records of shallow-water sediment facies have provided a great deal of valuable information on sea levels during the LGM and other periods (Clark and Mix, 2002; Fairbanks, 1989; Yokoyama et al., 2000). However, other factors such as glacial isostatic adjustment can serve to complicate estimations of sea level change. Glacial isostatic adjustment is a physical process caused by Pleistocene glacial cycles and comprises several processes including post-glacial rebound and isostatic depression. These processes are essentially the compression and rebound of land under ice sheets during and after glacial and interglacial periods, respectively (Peltier, 2001). Any calculation of Pleistocene ice volume or sea level change without accounting for these processes is incomplete. This problem has been approached by several scholars, with most sea level estimations adjusted to account for glacial isostatic adjustment ranging between 120 m to 130 m globally (Lambeck et al., 2002; Milne et al., 2002; Shennan et al., 2002). For the purposes of this study, sea levels were plotted at 120 m lower than present day for most New World coastlines with the exception of coastlines along southern Beringia and stretches of North America's Pacific Coast.

While global estimations of sea level at the LGM average −120 m, deformational and gravitational effects of the Cordilleran and Laurentide Ice Sheets led to regional departures from that eustatic average (Clark et al., 2014). Because sea level was especially variable along the coastline stretching from southern Beringia to Washington-Oregon, and because the region is of particular importance in the modelling of early dispersal patterns into the New World, coastlines were drawn according to regional modelling reported in Clark et al. (2014). Sea level along the southern Beringian coast is been estimated to have been −80 m lower than present-day sea level. In contrast, along the western margin of the Cordilleran Ice Sheet, LGM sea level has been estimated to have been 50–80 m higher than present day, owing to combined gravitational and isostatic effects of the ice sheet. Coastlines along the western margin of the ice sheet were drawn at an elevation of 65 m above present day sea level. South of the western margin of the Cordilleran Ice Sheet, sea level gradually re-approaches something close to the eustatic average, with sea levels along the California coast being estimated at about −110 m relative to modern coastlines (Clark et al., 2014).

2.3. North America

The most drastic difference between LGM and current day environments in North America is the presence of the Laurentide and Cordillarian ice sheets covering major northern portions of the continent. The extent and thickness of Pleistocene ice sheets, as well as their internal ice dynamics, have been the subject of much debate (Briner et al., 2003). Some reconstructions have indicated that ice sheets were relatively thin and unstable (Alley and MacAyeal, 1994; Clark, 1994), while other models most widely accepted today have indicated ice sheets as relatively thick and stable (Kleman and Hättestrand, 1999). Geophysical modelling, along with dating of glaciated landscapes and field-based mapping, have been used to reconstruct former ice sheets globally (Denton, 1981; Dyke et al., 2002; Hughes, 1998; Peltier, 1994). In North America, three ice sheets covered a large portion of the continent: the Laurentide, the Cordilleran, and the Innuitian ice sheets (Dyke et al., 2002). The extent of these three ice sheets is fairly well understood.