Paleoindian demography and the extraterrestrial impact hypothesis

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Recently it has been suggested that one or more large extraterrestrial (ET) objects struck northern North America 12,900 ± 100 calendar years before present (calBP) [Firestone RB, et al. (2007) Proc Natl Acad Sci USA 104: 16016–16021]. This impact is claimed to have triggered the Younger Dryas major cooling event and resulted in the extinction of the North American megafauna. The impact is also claimed to have caused major cultural changes and population decline among the Paleoindians. Here, we report a study in which 1,500 radiocarbon dates from archaeological sites in Canada and the United States were used to test the hypothesis that the ET resulted in population decline among the Paleoindians. Following recent studies [e.g., Gamble C, Davies W, Pettitt P, Hazelwood L, Richards M (2005) Camb Archaeol J 15:193–223], the summed probability distribution of the calibrated dates was used to identify probable changes in human population size between 15,000 and 9,000 calBP. Subsequently, potential biases were evaluated by modeling and spatial analysis of the dated occupations. The results of the analyses were not consistent with the predictions of extraterrestrial impact hypothesis. No evidence of a population decline among the Paleoindians at 12,900 ± 100 calBP was found. Thus, minimally, the study suggests the extraterrestrial impact hypothesis should be amended.

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of the calibrated Paleoindian dates are biased by time-dependent site destruction.

**Results and Discussion**

Fig. 1 shows the summed probabilities of the calibrated radiocarbon dates for the period from 15,000 to 9,000 calBP. The shape of the summed probability distribution suggests slow population growth between 15,000 and 13,100 calBP, which is likely the period of the initial colonization of North America by humans migrating from East Asia via Beringia and an ice-free corridor between the Laurentide and Cordilleran ice sheet and/or along the coasts of Beringia and the Pacific Northwest (7–10). Thus, the slow population growth during this period may reflect small groups of initial colonists or possibly multiple failed attempts at colonization. Subsequently, there is a period of rapid population growth. Lasting from 13,100 to 13,000 calBP, this population growth coincides with the efflorescence of Clovis in North America (11, 12). Thereafter, population increases reasonably steadily until 9,000 calBP, when another period of rapid population increase occurs. Shortly before 9,000 calBP, the curve drops dramatically. This last drop is an artifact of our dataset, which does not include radiocarbon ages younger than 8,00014C BP.

Between 13,000 and 9,500 calBP, the summed probability distribution exhibits a number of troughs. One of these begins at 12,800 calBP, which is within the error range of the date for the ET impact used by Firestone et al. (1). However, the trough in question is not only short but also relatively minor in scale. It lasted only 100 years and is no more pronounced than some of the other troughs that occur in the 13,000–9,500 calBP period (e.g., the one that occurs at 11,300 calBP). As such, it is not consistent with a population bottleneck.

Although the depth and duration of the trough that begins at 12,800 calBP are inconsistent with a population bottleneck, it is possible that the trough represents a decline in population and therefore supports a weaker version of Firestone et al.’s (1) hypothesis. However, this possibility is not consistent with the results of our spatial analysis of the radiocarbon dates. Fig. 2 shows the geographic distribution of 74 radiocarbon dates from three time periods: the 300 years before the proposed ET impact (13,299–13,000 calBP), the 300 years during which the impact is hypothesized to have occurred and its direct effects are likely to have been most severe (12,999–12,700 calBP), and the subsequent 300 years (12,699–12,400 calBP). Given that the ET impact is proposed to have occurred north of the Great Lakes, if the trough represents a population decline, there should be significantly fewer Paleoindian radiocarbon dates in northern latitudes during the second time period compared with the first and third time periods. This is not the case. A χ² test revealed no statistical difference in the counts of radiocarbon dates in the six blocks of latitude and longitude between the first and second periods (χ² = 8.13, P = 0.15). Similarly, no statistical difference was found in the counts of radiocarbon dates in the six blocks of latitude and longitude between the second and third periods (χ² = 3.83, P = 0.57). Redistributing the blocks using different longitudinal boundaries (see Methods) did not alter the results of the χ² test. This result suggests that the trough in the summed probability distribution that begins at 12,800 calBP is a conse-
ments by Pinter and Ishman (13) and Haynes (14). Pinter and Ishman propose between the ET impact and the extinction of the megafauna. Haynes argues that ‘something major happened’ in North America at 12,900 calBP, but he is skeptical that an ET impact initiated the Younger Dryas and caused the megafaunal extinctions.

Clearly, if Pinter and Ishman (13) are correct, the reason we failed to find evidence of a Paleoindian population bottleneck at the time of the proposed ET impact is that there was no ET impact. However, this explanation is not the only one that is consistent with our results. There are two other potential explanations for our failure to find evidence for a decline in the size of the Paleoindian population at 12,900 ± 100 calBP. One is that a major ET impact occurred and had significant, continent-wide ecological effects, including the extinction of the megafauna, but did not devastate the Paleoindians for some reason. The other is that an ET impact occurred but was much smaller than the one proposed by Firestone et al. (1) and therefore had only local effects. Determining which of these hypotheses is correct will require further research.

Methods

A total of 1,509 radiocarbon dates from archaeological sites in Canada and the United States were used in the study. The dates span the period 13,000 to 8,000 14C BP. Twenty-three of these dates were obtained from Hamilton and Buchanan (11) and Waters and Stafford (12). The remaining dates were obtained from the Canadian Archaeological Radiocarbon Database (ref. 15; www.canadianarchaeology.ca/radiocarbon/card/card.html). We removed radiocarbon dates labeled as anomalous in the latter source. These are radiocarbon dates that were either too young or old in relation to the accepted target age. Following methods discussed by Shennan and Edinborough (4) we used a pooled mean date for site occupations or discrete cultural components (Shennan and Edinborough use the term “phase”; here, we use the term “occupation”) with multiple radiocarbon assays. We did this to prevent occupations with multiple dates from biasing the results. Pooled mean dates were calculated from uncalibrated dates by using the Calib 5.1 program (16). We pooled radiocarbon dates from 237 Paleoindian occupations with multiple dates. The resulting database consists of 628 radiocarbon dates [supporting information (SI) Table S1]. It should be noted that we did not independently assess the validity of individual radiocarbon dates. Undoubtedly there are dates in our sample that some investigators may consider erroneous. However, we contend that, given the large size of the sample and the removal of dates identified as anomalous, a small number of erroneous dates will not alter the broad trends in the data.

Summed Probability Distribution Analysis. The single and pooled mean uncalibrated radiocarbon dates in our sample were calibrated in CALPAL (ref. 17; www.calpal.de) by using the Intcal04.14 curve (18). The probabilities of these calibrated dates were then summed and plotted along the abscissa according to calendar age BP.

Spatial Distribution Analysis. To test for statistical differences in the spatial distribution of radiocarbon-dated occupations in the three time periods, we compared the number of occupations in each period in six blocks of latitude and longitude by using a χ2 test. We defined blocks as 10° of latitude, between 30° and 50° of latitude, and the four below 30° of latitude. It is worth noting that the southern boundary of the Laurentide ice sheet is estimated to have been at or slightly below the 50th parallel —12,900 cal BP (19). In the region of the Great Lakes it may have dipped as far south as the 45th parallel (19). Therefore, the paucity of radiocarbon-dated occupations in these areas is attributable to the lack of habitable land. To check whether the way in which the blocks were defined influenced the results of the statistical test we shifted the longitudinal boundaries from 70–130° to 60–120° to create a different set of blocks and subjected the counts to a χ2 test.

Assessing Taphonomic Bias. We used a model developed by Surovell and Brantingham (6) to assess whether time-dependent site destruction could obliterate evidence of a population bottleneck at 12,900 ± 100 calBP. Surovell and Brantingham’s model assumes a constant rate of site destruction through time. The relationship between the taphonomic rate (λ) and occupations is expressed as:

\[ n = n_0 e^{-\lambda t} \]
where \( n_t \) is the number of occupations created at time \( t \), \( \lambda \) is the constant rate of site destruction, and \( t \) is the time elapsed from initial deposition of the occupations to the present.

We simulated a period of exponential population growth for 6,000 years (15,000–9,000 calBP), the approximate duration of the Paleoindian period. At 12,900 calBP we created a population bottleneck by reducing the population to 1,000, after which we allowed for exponential population growth to proceed again in the following time periods. This bottleneck represents a 91.5% decline in the population. Population growth before, and after, the bottleneck was modeled with the following equation:

\[
\frac{dt}{K} = e^{\alpha t},
\]

where \( K \) is the number of occupations and \( \alpha \) is the population growth rate. \( \alpha \) was set at 0.00008 based on Pennington’s (20) estimate for hunter–gatherer population growth rates. Initially, the starting population size was set at 10,000. Subsequently, we used starting population sizes of 5,400 and 1,000 based on the estimations of Kitchen et al. (21), which they derived from genetic models for Paleoindian founding populations of 15,000 years ago. We began with a taphonomic rate of 1 in 100,000 sites destroyed per year (\( \lambda = 1/100,000 \)), which Surovell and Brantingham (6) suggest is extremely low. We then increased the taphonomic rate to 1 in 10,000 sites destroyed per year (\( \lambda = 1/10,000 \)). Lastly, we identified the highest plausible taphonomic rate, which was defined as the highest rate compatible with the recovery of at least one complete site in each time period. The highest plausible taphonomic rate was determined to be 1 in 1,125 sites destroyed per year (\( \lambda = 1/1,125 \)). To make the results of the simulations comparable with the results of our analysis of the summed probability distribution for the real Paleoindian dates, we converted the numbers of simulated radiocarbon-dated occupations per time period to relative frequencies.

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