CHAPTER 3

A Land Impacted? The Younger Dryas Boundary Event in California

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One of the most intense debates in the paleosciences in recent years has focused on the question of whether or not a cosmic impact (comet) approximately 12,900 years ago caused both the Younger Dryas climatic oscillation and the disappearance of Pleistocene megafauna in North America. Since it was first advanced in print by Firestone et al. (2007), the Younger Dryas Boundary (YDB) impact hypothesis has received an array of challenges from archaeologists and paleoenvironmental scientists (e.g., Buchanan et al. 2008; Collard et al. 2008; Daulton et al. 2010; Fiedel 2009; Gill et al. 2009; Gillespie 2009; Hamilton and Buchanan 2009; Haynes 2008; Meltzer and Holliday 2010; Paquay et al. 2009; Pinter and Ishman 2008; Surovell et al. 2009; see also Kerr 2010), while at the same time, empirical evidence supporting the event has continued to accumulate (Anderson 2010; Anderson et al. 2008; Anderson et al. 2011; Andonikov et al. 2011; Bunch et al. 2010; Fayek et al. 2012; Firestone 2009; Firestone et al. 2010; Ge et al. 2009; Haynes et al. 2010; Israde-Alcántara et al. in press; Kennett et al. 2009a, 2009b; Kennett, Kennett, West, et al. 2008; Kurbatov et al. 2010; Mahaney, Kalm, Krinsley, et al. 2010; Mahaney, Krinsley, and Kalm 2010; Mahaney et al. 2011; Marshall et al. 2011; Napier 2010; Schroeder 2009; Steele 2010; Tian et al. 2011; Van Hoesel et al. 2011), including a large impact crater found off the east coast of Canada dated to about 12,900 years ago (Higgins et al. 2011).

The YDB event is argued to have had dramatic effects over much of North America if not all of the northern hemisphere, and the case for its effects on prehistoric human populations has been focused on the entire continent, with no particular emphasis on California. In most parts of North America, the late Pleistocene archaeological record (referred to commonly

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and vaguely as "Paleoindian") is relatively weak in terms of reliable radiocarbon dates and clearly associated artifact and faunal materials. Only by combining all of the evidence on a continent-wide level has it been possible to develop any kind of compelling case, although some regions have better records than others. California mostly has been only a minor contributor to the continental database, especially in regard to the timing and adaptation of late Pleistocene humans, because California's earliest archaeological record is somewhat faint. Nonetheless, some findings from California, including compelling paleoclimatic evidence from the northern Channel Islands, have figured prominently in the debate (Kennett, Kennett, West, et al. 2008). California's Paleoindian archaeological record, which we discuss here relative to the YDB impact hypothesis, has also been brought to bear, but with less compelling results. California's late Pleistocene archaeology is not yet substantial enough to provide unequivocal support for the impact hypothesis, but the available data are consistent and there is no substantive evidence to refute it. As discussed here, the hypothesis remains viable in California and merits continued evaluation.

New Perceptions of the Late Pleistocene

The impact hypothesis relies on a very precise climatic chronology that in some parts of North America can be meaningfully compared with substantive, well-dated archaeological records.

Chronological, Climatic, and Cultural Parameters

Research in the last 10 years related to the YDB hypothesis and the Clovis culture has established firmer chronologies for climate change and human presence during the late Pleistocene in North America. With respect to the latter, the Paisley Caves site in central Oregon demonstrates that humans were present just outside of what is now California at 14,000 years calibrated before present (cal BP; Gilbert et al. 2008). Furthermore, new research indicates that the Clovis culture is restricted to a more limited time range (11,300–10,900 years cal BP) than previously thought (Waters and Stafford 2007). No fluted points were associated with the oldest human occupation at Paisley Caves, so it is assumed that the cave's earliest inhabitants were not affiliated with Clovis. The cometary impact event is argued to have occurred roughly 1,100 years after the first settlement of North America and was synchronous with the demise of Clovis at the boundary between the relatively warm Ållerød interstadial (14,000–12,900 years cal BP) and the Younger Dryas (12,900–11,600 years cal BP). The latter is marked by the sudden onset of cold climate. The YDB impact hypothesis invokes that the transition from Ållerød to Younger Dryas was caused by the cosmic impact at 12,900 years cal BP,

which also brought about the end of Clovis. Later fluted point cultures such as Folsom emerged only after a possible gap in human occupation following the impact event, and only in some parts of North America.

California Paleoindian

In California, even in recent years, the term "Paleoindian" has been applied simply to the period predating 10,000 years cal BP because tool assemblages and cultures have long been ill-defined and poorly dated. A number of facts are salient concerning the Paleoindian in California.

First, there is not a single site in California where Clovis has been dated. No sites in California were used in Waters and Staffords' important (2007) redefinition of the age range of the Clovis culture. In the absence of chronometric data from within the state, the only reasonable estimate for the age of Clovis in California is the same as is now established elsewhere: 13,300 to 12,900 years cal BP.

Second, there are no sites in California where Clovis or other fluted points have been recovered in direct association with the remains of megafauna. Remains of megafauna are not uncommon (many elements have been found at La Brea, the northern Channel Islands [Agenbroad 2002] and Tulare Lake [Fenenga 1992], but the classic association between fluted points and remains of mammoths, for example, has never been confirmed in California). This is partially a product of poor preservation since bone does not preserve well in California away from the coast or at any appreciable elevation. Without this confirming evidence, the assumption remains that Clovis people in California pursued large game as they did elsewhere in North America.

Third, many fluted projectile points have been recovered from California, but very few have been from stratified sites; the overwhelming majority are simply isolated surface finds (Dillon 2002; Rondeau et al. 2007). Those locations that have produced more than isolated examples (e.g., Borax Lake, Komodo) have not provided contexts or samples suitable for chronometric dating other than obsidian hydration, which is not accurate enough to provide credible age estimates. Also, fluted point typologies are poorly developed in California; some examples match classic Clovis in size and style, but others do not. Because of the absence of well-dated fluted point components, it is not possible to determine if any of the fluted point variants represent regional Paleoindian variants that postdate Clovis (akin to Folsom). Thus, a working assumption remains that California fluted points represent a regional, coeval expression of Clovis, despite a range of stylistic variation.

Fourth, there are no archaeological sites on the mainland of California that have produced unequivocally cultural radiocarbon dates—older than ca. 11,000 years cal BP—with the exception of the Tule Lake site

in northeastern California that produced a date of ca. 13,500 years cal BP on a large piece of wood charcoal. Even this date is in serious need of corroboration due to problems associated with dating old wood (Kennett et al. 2002) since it was recovered from only a modest test excavation that has never been fully reported.

Fifth, in recent years it has also become apparent that a number of relatively old sites exist on the California coast that are generally referred to under the rubric of Paleo-Coastal (Erlandson, this volume; Erlandson et al. 2008, 2011; Moratto 1984). The term "Paleo-Coastal" was originally coined to distinguish relatively old coastal occupations from interior big-game hunters under the assumption that these early coastal occupations marked lifeways that were distinct from interior-based big-game hunting, possibly as a reflection of a coastal migration corridor into the New World. An underlying assumption for the Paleo-Coastal Tradition was that it was potentially coeval with Clovis, yet technologically and culturally distinct. Early on, however, it was used in some cases to refer to sites dating only as old as 10,000 to 9,000 years cal BP on the California mainland. None of these mainland sites is in fact old enough to match the age estimate for Clovis or to be directly relevant to the YDB impact hypothesis. However, a number of sites on the northern Channel Islands are now known to predate 11,000 years cal BP. One site, the Arlington Man skeleton, dates to 13,100 to 12,900 years cal BP, and is contemporary with Clovis (Johnson et al. 2002; Kennett, Kennett, West, et al. 2008), whereas at least four others on San Miguel and Santa Rosa islands date between 12,300 and 11,500 years cal BP, the tail end of the Younger Dryas (Erlandson et al. 2007, 2011). This is followed by a large increase in the site visibility on these islands in the early Holocene (Erlandson et al. 2008; Kennett, Kennett, West, et al. 2008). Importantly, the most recently reported Paleo-Coastal sites show tool assemblages dominated by small, stemmed projectile points and are decidedly distinct from Clovis (Erlandson et al. 2011), confirming long-held suspicions.

California and the YDB

Paleoenvironmental Contributions from the Santa Barbara Channel

With the growing evidence for human presence on the northern Channel Islands at a significant time depth, it is perhaps not surprising that much of the case for the YDB impact in California comes from the Santa Barbara Channel area. Research into the paleoenvironment of this area has a long history, so a fairly substantial suite of paleoenvironmental information exists. Site preservation and visibility are also

exceptionally good on the islands: far superior to most of mainland California. Support for the YDB impact comes from (1) high-resolution paleoclimatic reconstructions from offshore sediment cores and from exposed profiles; (2) the chronology of megafaunal extinction on the islands; and (3) evidence for wildfire and abrupt ecosystem disruption.

Paleoenvironmental Records

Well-preserved stratified sediments from the Santa Barbara Basin have produced high-resolution faunal and $\delta^{18}O$ records that are consistent with global trends identified in such sequences as the Greenland ice cores (Hendy and Kennett 1999). Sediments marking the onset of the Younger Dryas show a sharp change with multiple markers at approximately 12,900 years BP indicating an abrupt transition to cool sea surface temperatures consistent with dramatic, abrupt evidence in the Greenland ice sheet (Kennett, Kennett, West, et al. 2008; Steffensen et al. 2008).

Megafauna Extinction

Mammoths (*Mammuthus columbianus*) colonized the Channel Islands at some time early in the Quaternary and by at least 47,000 years ago there evolved a pygmy variant (*M. exilis*) known from at least 140 localities on the islands (Agenbroad 2002). Despite concerted efforts over many years (see Orr 1968), there are no known cases of association between mammoth remains and tools on these islands and no evidence that they were hunted by humans. Nonetheless, the youngest radiocarbon date for the species is 12,900 years cal BP (Agenbroad 2002), indicating that its extinction was coincident with the onset of the Younger Dryas.

Wildfire and Ecosystem Disruption

Stratified sediments from sea cores from the Santa Barbara Basin and from terrestrial sediments on Santa Rosa Island show major fires on the islands at approximately 13,000 years cal BP that correspond with the last known occurrence of pygmy mammoths on the island. A stratigraphic sequence in Arlington Canyon showed black, carbon-rich strata highly similar to the black mat layers associated with the Younger Dryas onset elsewhere in North America (Haynes 2008). The charcoal stratum produced carbon spherules indicative of intense fires that Kennett, Kennett, West, et al. (2008) interpret as evidence of widespread wildfire.

Subsequently, Kennett et al. (2009a) reported an assemblage of nanodiamonds, cubic diamonds, and hexagonal diamonds from the YDB layer in the Arlington Canyon profile dating to 12,950 years cal BP. Recovered in association with other evidence for major biomass burning, hexagonal diamonds are known on Earth only in meteorites and impact craters. Kennett et al. (2009b) later reported a peak in nanodiamonds from

a series of other YDB layers in North America, suggesting that they provide strong evidence for an extraterrestrial impact at the onset of the Younger Dryas. One research group has recently challenged the identification of the nanodiamonds (Daulton et al. 2010), but another independent study (Tian et al. 2011) confirmed the identification of nanodiamonds in Northern European sediments dating to 12,900 years cal BP, with none in the layers above and below. The Daulton et al. (2010) study also does not provide adequate provenience details to verify that their samples were in fact from the YDB layers at Arlington Canyon, and the sampling protocols (resolution and extraction) used were insufficient to recover nanodiamonds if they existed in the section. Furthermore, a recent study strongly refutes the speculations of Daulton et al. (2010) and provides additional evidence for a nanodiamond datum in North America (Central Mexico; Israde-Alcátara et al. in press).

The Human Archaeological Record

In 2008, Kennett, Kennett, West, et al. suggested that the archaeological record from the Channel Islands, and to a lesser degree the mainland, were consistent with the YDB impact hypothesis. They argued that the Arlington Man skeleton demonstrates an occupation of the Channel Islands during Clovis times, but that after the demise of Clovis, there was a significant gap in occupation that they attributed to the devastating effects of the YDB impact. Only around ca. 12,200 years cal BP did human populations again show a presence on the islands.

A similar case was made for mainland California based on the prevailing but limited late Pleistocene archaeological chronology. As discussed by Kennett, Kennett, West, et al. (2008) and Jones (2008), one of the enigmatic features of the fluted point (Clovis) record in California is that it does not connect well with the Holocene archaeological record. Clovis artifacts are widespread in California, but it has been impossible to confirm their age and association with remains of large animals. Some argue (e.g., Rosenthal and Meyer 2004) that the absence of substantial late Pleistocene components is simply a problem of visibility: that Clovis sites have not been found because they are deeply buried. Certainly this is a legitimate problem, but fluted isolates are also commonly found on the surface, and it has proven easy to find early Holocene sites in locations like central and southern California, where more than 30 sites dated between 10,000 and 9,000 years cal BP have been identified in the last two decades (Porcasi 2008). However, it has proven very difficult to find sites dating older than 10,000 years cal BP. In other parts of the world, it is possible to connect Holocene occupations with earlier ones simply by sampling deeper beneath 10,000-year old materials. In California, such excavations prove fruitless because the Pleistocene and Holocene archaeological

records do not seem to connect. In the view of Kennett, Kennett, West, et al. (2008) and Jones (2008, 2009), this pattern could reflect small but widely dispersed populations of Clovis hunters and coastal colonists who were present in western North America only for a brief interval prior to the impact event. These populations would have been severely reduced by the hypothesized cosmic impact, as Firestone (2009), Firestone et al. (2007), and Kennett, Kennett, West, et al. (2008) have suggested.

Jones (2009) pointed out that the apparent disruption in the archaeological record contrasts with the expectations of adaptationist models that have been prevalent in California since the 1970s (e.g., Chartkoff and Chartkoff 1984). These models suggest that western North America was initially settled by highly mobile, specialized big-game hunters who, after wiping out the megafauna, gradually shifted to more generalized economies as the climate warmed and their populations increased. The archaeological predictions from these models include evidence for gradual in situ adaptive shifts and incrementally growing populations. Archaeological visibility should slowly increase as well, but the record, as it has been revealed, seems more consistent with abrupt rather than gradual change.

Collard et al. (2008) disputed the interpretations of Kennett, Kennett, West, et al. (2008) and Jones (2008) and suggest that summed probability distribution of the 73 oldest radiocarbon dates from California indicate continuity in occupation from Clovis through the Holocene, with no significant disruption. This study followed the protocols of an earlier and larger statistical analysis of 1,500 radiocarbon dates that failed to show evidence of a population decline during the Younger Dryas (Buchanan et al. 2008). Anderson et al. (2008), however, showed that the radiocarbon database used by Buchanan et al. was highly incomplete, and that the more complete record available to them was in fact consistent with the predictions of the YDB impact hypothesis. Kennett, Stafford, and Southon (2008) and Culleton (2008) questioned the legitimacy of the database used by Buchanan et al. and their statistical methods. The California dataset used by Collard et al. (2008) was not published in detail, so it is impossible to evaluate these claims, but the pattern is inconsistent with the datasets that have been published in recent years.

Overkill in California

One of the key aspects of the impact hypothesis is that it offers a viable alternative to Paul Martin's (1967) overkill hypothesis. When it was first proposed, overkill seemed to provide a compelling explanation for the rapid peopling of the Americas by Clovis peoples, and the disappearance of megafauna at the end of the Pleistocene, but time has not been kind to this hypothesis. As Grayson and Meltzer (2003) and Meltzer (2009) pointed out, research in the last 40 years has simply failed to produce

further compelling evidence that allow for the late Pleistocene extinctions to be confidently attributed to human overhunting. In this regard, the situation in California, where no association between megafauna and cultural materials has ever been established, is not unusual. Very few of the 35 genera of animals that went extinct at the end of the Pleistocene have been recovered from archaeological sites anywhere in North America. Although some ecologists still feel that the extinction pattern on the continent is consistent with a human cause (Barnosky et al. 2004), the archaeological record has not yielded additional meaningful support for this view.

The cosmic impact hypothesis has been introduced into North American archaeology at a time when the failings of the overkill model have been acknowledged by many (see discussion by Meltzer 2009), protestations by the theory's advocates notwithstanding (Fiedel and Haynes 2004). A cosmic impact provides an alternative explanation for the extinction of 35 genera of animals, and Kennett and West (2008) suggest that the biostratigraphic evidence from across the continent shows that populations of large animals did not persist across the YDB, and that for many, the extinction was at or close to the onset of the Younger Dryas (also see Haynes 2008). Most of the animals that went extinct were large ones (the Aztec rabbit and some birds were exceptions). Larger animals would have been most stressed by the catastrophic environmental events associated with the impact, whereas the smaller animals would have survived differentially relative to large ones. As others have noted, this is similar to the extinctions that resulted from the Cretaceous-Tertiary (K-T) boundary impact event (Ruban 2009) although the K-T impact was considerably larger and brought much more widespread effects than the YDB impact event. A recent study by Gill et al. (2009) suggests that the demise of the megafauna began at least 1,000 years before the YDB event, at least in some localities, but the study was limited to one poorly dated lake core and ignores a wide range of biostratigraphic data indicating an abrupt extinction event close to 12,900 years cal BP. Faith and Surovell (2009), though not supporters of the impact hypothesis, reevaluated chronological evidence for megafaunal extinctions and concluded that the best explanation has to involve a mechanism capable of wiping out up to 35 genera of mammals in a geologic instant.

Summary

The YDB impact hypothesis provides one of the first reasonable alternative explanations for certain aspects of the Paleoindian archaeological record in California with the caveat that the latter remains chronologically and culturally imprecise. The impact event itself is supported with empirical evidence (e.g., nanodiamonds), including substantial paleoenvironmental findings from the Santa Barbara Channel; however, additional work is needed

throughout California. The poor chronological resolution of the archaeological record before 10,000 years cal BP in California (and indeed much of the North American continent) suggests the need for further research.

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