

Younger Dryas “black mats” and the Rancholabrean termination in North America

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Of the 97 geoarchaeological sites of this study that bridge the Pleistocene-Holocene transition (last deglaciation), approximately two thirds have a black organic-rich layer or “black mat” in the form of mollic paleosols, aquolls, diatomites, or algal mats with radiocarbon ages suggesting they are stratigraphic manifestations of the Younger Dryas cooling episode 10,900 B.P. to 9,800 B.P. (radiocarbon years). This layer or mat covers the Clovis-age landscape or surface on which the last remnants of the terminal Pleistocene megafauna are recorded. Stratigraphically and chronologically the extinction appears to have been catastrophic, seemingly too sudden and extensive for either human predation or climate change to have been the primary cause. This sudden Rancholabrean termination at $10,900 \pm 50$ B.P. appears to have coincided with the sudden climatic switch from Allerød warming to Younger Dryas cooling. Recent evidence for extraterrestrial impact, although not yet compelling, needs further testing because a remarkable major perturbation occurred at 10,900 B.P. that needs to be explained.

climate change | extinction | radio carbon | stratigraphy | archeology

Near the end of late Pleistocene, the climate of the Northern Hemisphere, which had become generally warmer, causing glacial retreat (deglaciation), suddenly reverted back toward near-glacial cold conditions for approximately a millennium for reasons that are still debated (1). First recognized in pollen profiles from deposits in northern Europe, this cold reversal was named the Younger Dryas after fossil pollen of the dryas plant (*Dryas octopetala*), signifying a tundra flora found in fossil pollen assemblages (2, 3). Radiocarbon ages for the Younger Dryas period vary depending on the interpretation of the investigators and perhaps geographically (4). Here, I use $10,900 \pm 50$ B.P. for the beginning of the Younger Dryas and $9,800 \pm 50$ B.P. for the end, essentially as shown in figure 11 of Stuiver *et al.* (5). (All ^{14}C ages are given in uncalibrated years before 1950.)

Younger Dryas “Black Mat” Characteristics

Most Younger Dryas (YD) age black layers or “black mats” are dark gray to black because of increased organic carbon (0.05–8%) compared with strata above and below (6, 7). Although these layers are not all alike, they all represent relatively moist conditions unlike immediately before or after their time of deposition as a result of higher water tables. In most cases higher water tables, some perched, are indicated by the presence of mollisols and wet-meadow soils (aquolls), algal mats, or pond sediments, including dark gray to black diatomites, at >70 localities in the United States (Fig. 1 and supporting information (SI) Table 2). Therefore, black mat is a general term that includes all such deposits, and some YD marls and diatomites are actually white. These latter cases are included in the nearly 30 localities containing strata representing the Pleistocene-Holocene transition (Allerød-Younger Dryas-Holocene) that do not exhibit a black layer because of little or no interaction with ground water or are represented by white to gray diatomaceous strata of YD age (Fig. 1 and SI Table 3 and SI Fig. 6). There are both younger and older black layers, but they do not appear to be widely distributed over the continent like the YD black mat,

nor are they known to be associated with any major climatic perturbation as was the case with YD cooling.

Stratigraphy and Climate Change

Stratigraphic sequences can reflect climate change in that lacustrine or paludal sediments such as marls or diatomites indicate ponding or emergent water tables and some mollisols or aquolls indicate shallow water tables with capillary fringes approaching or reaching the surface. Such conditions support plant growth and thereby increase the organic content of wetland or cienega soils collectively referred to as black mats. Many of the black mats discussed here occur in eolian silt or fine sand (loess) where the black organic horizons reflect more mesic conditions than either before or after. Strata above and below the black mat reflect drier conditions with lowered water tables, and buried features such as wells dug by humans or animals and dry spring conduits indicate fallen water tables and drier conditions. Fallen water tables commonly result from a relatively warm, dry climate, whereas black mats, as used here, may have accumulated under conditions of increased precipitation and/or colder climate when rainfall is more effective in recharging water tables because of reduced evapotranspiration.

Radiocarbon Chronology

From SI Table 2 it is clear that the ^{14}C age of the tops of many black mats is younger than the sudden *ca.* 10,000 B.P. end of the YD. This can be caused by contamination as well as by a time lag between the abrupt end of YD cooling and the end of black mat formation.

Problems related to radiocarbon dating of bulk black mat sediments result from potential influence of younger contaminants in the form of humic acids from more recent soils, very fine particulates derived from younger vegetation and microorganisms, and nuclear age ^{14}C taken up by modern vegetation and soil CO_2 . Whereas great care is taken in the laboratory to decontaminate sediment-soil samples, some contaminant may remain in the pretreated residue. Including wet oxidation in the pretreatment can further reduce contaminants (8) but sometimes at the expense of reducing the amount of carbon residue to be dated. Furthermore, bulk sediment soil dates represent time averages, reflecting mean residence times of organic carbon because of its translocation and bioturbation in soils.

Radiocarbon dating suggests that deposition onset for some black mats appears to have preceded the sudden onset of the YD, but these older ages likely result from mixing of organic carbon of different ages across the Z1–2 contact described later. The most extreme effects on radiocarbon age result from the pres-

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B.P. and 10,900 B.P. (31, 13). It appears, therefore, that the basal contact of the Leonard Paleosol represents the Clovis occupation surface and rests on strata of various older ages such as late Pleistocene fill, late Pleistocene alluvium, Peoria loess of late Pleistocene age, and bedrock of pre-Pleistocene age. This is the Z1–2 surface.

The radiocarbon dates in excess of 11,000 B.P. may be the result of mixing of strata across the Z1–2 contact where older carbon is derived from the old surface and/or the top of older strata as a result of bioturbation (9, 10). The initial and terminal ages of the Leonard Paleosol need further testing at such sites.

Stratum β 2b. Stratum β 2b represents eolian silts that were thickened in low areas by slope wash and redeposited as overbank alluvium in some areas. In Nebraska this is the Big Nell Loess and the Pick City Member of the Oahe Formation in the Dakotas (26). A brief episode of erosion is apparent at some sites by the Z3 contact (Fig. 2) representing a brief hiatus that occurred sometime between 9,000 and 10,000 B.P. The transition from Paleoindian to Archaic lifestyles occurred during β 2b deposition. This was followed by a period of stability before a major episode of stream entrenchment (Fig. 2, Z4) and deflation that, in the western United States, marked the Altithermal period of drought (32). This appears to have been the driest interval within the Holocene (33). Along most trunk streams most if not all of the β strata were removed during this period by channel widening (34)

Implications of YD Black Mats

No skeletal remains of horse, camel, mammoth, mastodon, dire wolf, American lion, short-faced bear, sloth, tapir, etc., or Clovis artifacts have ever been found *in situ* within the YD age black mat, and no post-Clovis Paleoindian artifacts have ever been found *in situ* stratigraphically below it. Whereas ^{14}C ages of the youngest Clovis sites overlap with those of the oldest Folsom sites at one sigma, the stratigraphic separation is clear (13). The megafaunal extinction and the Clovis-Folsom transition appear to have occurred in <100 years, perhaps much less, and are defined stratigraphically by the Z1–2 contact. This contact and the initiation of YD black mat deposition appear not to have been time transgressive (Fig. 5). This implies that extinction of the Rancholabrean megafauna was geologically instantaneous, essentially catastrophic (35). Graham and Stafford (36) report ^{14}C age data suggesting that horses and camels became extinct 200 years before mammoths and mastodons. However, excavations at the Murray Springs and Lehner Clovis sites indicate synchronous extinction of all four of these taxa in addition to dire wolves, American lions, and tapirs (37).

Deposition of the β 2a YD black mat in some places began after a period of degradation and erosion (Z1) coincident with terminal deglaciation during the Bølling-Allerød (B-A) climatic fluctuations (Fig. 3). The β 1 channel deposits (Fig. 2) of the B-A period can represent as much as 2,000 years of bedload scour and fill (dynamic equilibrium) with Clovis people arriving toward the end of this interval during the late Allerød (6).

The climate changes reflected by Allerød-age strata appear to be two brief dry intervals at the Blackwater Draw Clovis site (38, 39; but see ref. 40 for a different interpretation) separated by the InterAllerød Cold Period (IACP). The black mat at a few locations may have begun accumulating during the Allerød period (28) or perhaps the IACP, based on older radiocarbon ages. However, these ages may have been affected by contamination with older carbon. In any case the major deposition began with the onset of YD cooling. This cooling probably caused reduced evapotranspiration resulting in more effective recharge of the water tables. To account for valley aggradation in low-order drainages by gradual accumulation of slope-washed eolian sand and silt of stratum β 2b, rainfall may have been less

intense and more general (41) than after the beginning of the mid Holocene. The mid to late Holocene has been marked by more concentrated intense rains and associated epicycles of entrenchment and filling (Fig. 4, γ , δ , and ϵ) (34, 42).

Causes of Pleistocene Extinction

Nothing in the Quaternary stratigraphic record is more impressive than the abruptness of megafaunal extinction near the end of the Pleistocene. If all remaining elements of Rancholabrean megafauna, other than bison, terminated at the end of the Allerød chronozone, as indicated stratigraphically by the Z2 contact, the exact time of the catastrophic event is not resolvable within <100 years by radiocarbon dating, although this will improve significantly with tree-ring calibration (4). Grayson and Meltzer (43, 44) argue that Pleistocene extinction was gradual with some elements dying out long before others. This may indeed be true for a number of taxa but for many forms there are still inadequate geochronological data to accurately determine the exact age of their extinction. The fact remains that the existence of mammoths, mastodons, horses, camels, dire wolves, American lions, short-faced bears, sloths, and tapirs terminated abruptly at the Allerød-Younger Dryas boundary. This is the Rancholabrean Termination (RT). Only bison survived to the Younger Dryas, probably because they vastly outnumbered other species.

The occurrence of so many Clovis sites with stratigraphic evidence of drought (16) in the interval representing the end of the Allerød warm period, and the termination of most of the Pleistocene megafauna taxa in an instant before the YD makes possible several explanations for extinction. Martin's (45, 46) overkill hypothesis posits humans as the sole cause, but could they do it everywhere in the same instant? Lundelius and Graham (47) invoke climate change, but this, like overkill, would seem to require more time than the evidence for stratigraphic abruptness allows. MacPhee and Marx (48) believe hyper disease caused extinction of the megafauna, but natural selection would have left survivors. Perhaps the incredible coincidence of drought, rise of the Clovis population, and extinction at the onset of the glacial cold of the YD indicates multiple causes of extinction (16). In the San Pedro Valley of Arizona animals under stress gathered at dwindling water sources only to be annihilated by Clovis hunters (37). However, many relatively young, tender mammoths in the San Pedro Valley died without Clovis impact (35). Did a long-lasting deep freeze deny water to them? Considering the abruptness and magnitude of the termination, a major environmental and biotic disturbance took place at 10,900 B.P. that requires interpretation.

Should an extraterrestrial (ET) cause be considered? Brakenridge (49) and Berger (1) suggest there may be an ET explanation for YD in the form of a supernova. Brakenridge points out that supernova Vela occurred sometime between 11,300 and 8,400 years ago. Firestone *et al.* (50) proposed that a comet impact 12,900 years ago (≈ 10.9 radiocarbon years ago) caused the megafauna extinction and triggered the onset of YD cooling. They document a total of 14 proxies, in a layer (the YDB) found at the base of the black mat at many locations, indicative of an ET impact and associated major biomass burning. This includes above background peaks in magnetic spherules, magnetic grains, carbon spherules, glass-like carbon, charcoal, iridium, ^3He , and nanodiamonds at the Z1–2 contact at many Clovis-age sites.

So far, by preliminary examinations, I have found microspherules in magnetic fractions separated from microstratigraphic samples at the base of the black mat at Murray Springs. However, micrometeorites and microspherules are components of cosmic dust that is constantly falling to earth (51). Therefore, this is just the beginning of a scientific study to see if an ET event can be verified to explain the Rancholabrean termination. Further

analysis is in progress and other Clovis sites need independent study and verification of this evidence. Until then I remain skeptical of the ET impact hypothesis as the cause of the YD onset and the megafaunal extinction. However, I reiterate, something major happened at 10,900 B.P. that we have yet to understand.

Conclusions

Black mats, as described here, appear to be stratigraphic manifestations of Younger Dryas climate and indicate a rise in local water tables apparently because of more effective recharge, as a result of cooler climate. The YD black mat covers the Clovis age landscape on which the last skeletal remnants of Rancholabrean megafauna occur. This stratigraphic contact represents (i) the

end of the Allerød warm period and the abrupt beginning of the YD, (ii) the abrupt termination of Rancholabrean fauna, and (iii) the last evidence of the Clovis culture. The attribution of these events to an extraterrestrial event needs further testing.

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