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 ± 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 use10,900 ± 50 B.P. for the beginning of the Younger Dryas and 9,800 ± 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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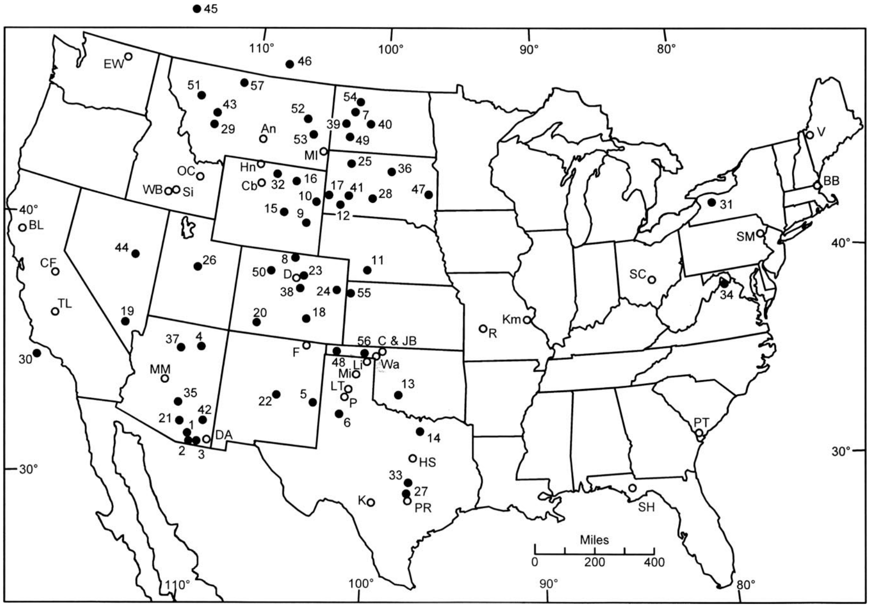

Fig. 1. Map of the United States showing 57 locations listed in SI Table 2 where one or more sites with black mats of Younger Dryas age occur (filled circles). Open circles are 27 localities with Pleistocene-Holocene transitional sediments but no black mats (SI Table 3).

ence of lignite and older humic acids derived from older carbonaceous sediments (9, 10).

From SI Table 2 (and see Fig. 5) it is apparent that the quality of YD black mat radiocarbon dating needs improvement especially near the upper and lower boundaries. Johnson and Willey (11) settled on an age range from 9,000 B.P. to 10,500 B.P. for Brady soil development after evaluating 18 ^{14}C ages at the tops and bottoms of the Brady paleosol that range from 7,940 ± 70 B.P. to 11,800 ± 110 B.P. SI Table 2 lists a rating of the quality of black mat ages from A to F (see the table caption for an explanation). Clearly, better accuracy is required for ages of the tops and bottoms of many of the layers in this study considered to represent the black mat and to better assess their correlation to the YD event. Nevertheless, all of the black mats in SI Table 2 clearly span the YD, and as discussed later, the end of the Pleistocene megafauna, the Rancholabrean termination, immediately preceded the onset of deposition of the black mat and YD cooling.

Stratigraphic Chronology

The following observations are based on geological and archaeological investigations conducted over the past 50 years for at least 97 latest Pleistocene sites or localities in North America (SI Table 2 and SI Table 3). The stratigraphy at many sites, away from glaciated areas, can be reduced to a generalized sequence (Fig. 2) that assists with correlation. The geochronology at these sites reveals a consistent pattern of inferred geological and hydrological processes (12, 13) that can be reasonably interpreted in terms of global climate change (Fig. 3).

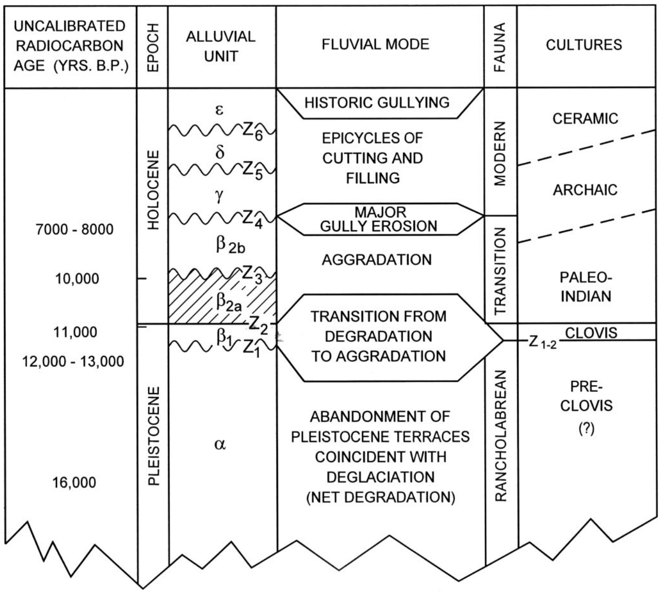

Fig. 2. Generalized late Pleistocene-Holocene stratigraphy correlated with fluvial processes and archaeological cultures (modified after ref. 6).

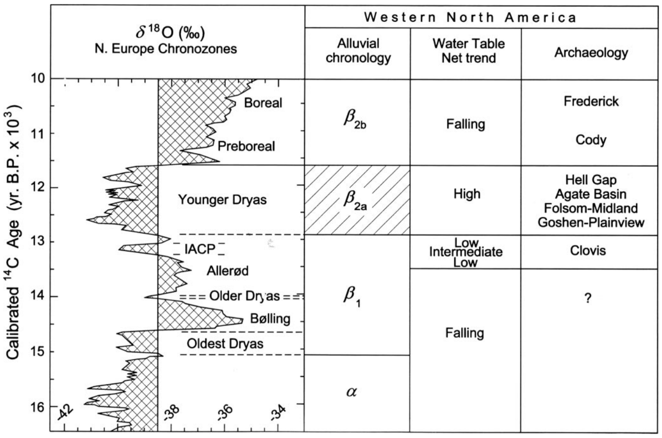

Fig. 3. Chronological chart correlating the generalized alluvial chronology to the northern European climatic chronozones (modified after ref. 5), water table fluctuations, and archaeological technocomplexes of the American Southwest. See *Stratigraphy and Climate Change* in the text for the interpretation of water table trends. Archaeological technocomplexes are arranged chronologically with the realization that the age of Goshen-Plainview with respect to Folsom-Midland has yet to be adequately determined.

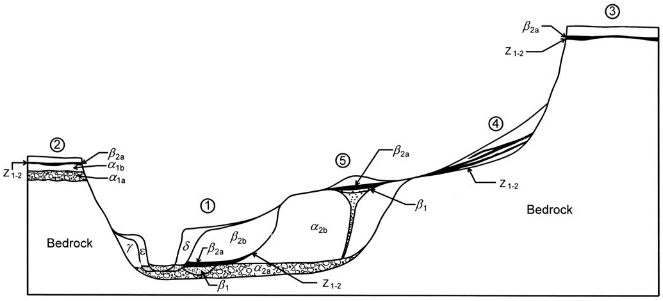

Fig. 4. Generalized stratigraphic profile of an idealized cross-section to show five geomorphic positions of the Younger Dryas black mat (β2a). Position 1 is typical of late Pleistocene-early Holocene alluvial terraces or alluvial fans inset against older Pleistocene deposits (α2). Position 2 is typical of strath terraces where β2a is a cumulic mollic paleosol on loess or fine-grained alluvium overlying strath gravels. Position 3 is typical of uplands where β2a black mat is a wet-meadow paleosol caused by poor drainage or a perched aquifer. Position 4 is found in colluvium or eolian deposits against bedrock uplands with spring seeps where mollic epipedon development is interrupted by either eolian or colluvial deposition. Similar stratigraphy can derive from redeposition of black mat sediments. Position 5 is typical of spring-fed ponds and wetlands where diatomites or marls formed during the YD. In other cases, as spring discharge waned, dark brown to black peaty deposits formed at position 5 during the YD. Position 6, not shown in Fig. 4, represents YD black mats associated with pond or lake shore sediments. Also not shown is position 7 representing cave deposits of YD age.

Stratum α. Stratum α usually consists of late Pleistocene lake beds, spring deposits, eolian deposits, or alluvial terraces older than 13,000 B.P. associated with Rancholabrean fauna and only tenuous archaeological (human) evidence. Away from glaciated areas, by 13,000 B.P. water tables had fallen to their lowest levels in at least 20 kys as indicated by streams that had become grossly underfit compared with their full-glacial age valleys (Fig. 4, β1 vs. α2a). Uplands became stable during deglaciation or developed cumulic mollisols, but many valley sides were eroded during Bølling-Allerød (B-A) time to form the Z1 contact (Fig. 2).

Stratum β1. The Clovis culture is the first well defined cultural technocomplex to occupy North America from 11,500 B.P. to 10,900 B.P. A recent reevaluation of the Clovis time span narrows it from 11,200 B.P. to 10,850 B.P. (14), but not without controversy (15). Most of the *in situ* Clovis sites have been found to lie on this ancient Z1 surface or in association with Stratum β1 which represents late Pleistocene channel sands, pond sediments, or spring deposits that are directly buried by β2a, the YD black mat (Fig. 4, positions 1 and 5) and that correlate with the B-A chronozones (Fig. 3). The duration of the hiatus between the base of β2a and the top of β1, contact Z2, is very short, possibly representing decades or less. This is consistent with the short ≈300-year time interval for Clovis proposed by Waters and Stafford (14). However, the duration is difficult to determine more precisely by using radiocarbon dating because of variable radiocarbon production across the Allerød-YD transition (4). At Clovis sites people interacted with the last of the Rancholabrean megafauna at spring heads, along spring-fed streams, or around ponds represented by stratum β1.

Some springs, lakes, and streams dried up as emergent water tables fell below the ground surface because of drought conditions that occurred during the Allerød (16). Termination of the Rancholabrean megafauna occurred at the end of this Clovis-age dry period, when Clovis hunters appear to have been most widespread and immediately preceding the abrupt cooling to near glacial conditions of the YD.

Stratum β2a. Stratum β2a represents YD black layers (black mats) at >70 localities (Fig. 1 and SI Table 2) and reflects more mesic conditions in the form of wet-meadow soils or a rise of water tables (6, 7, 17) to either emergence as ponds or saturation of lowland surfaces (Fig. 4, position 1). In eolian deposits on uplands, black mats take the form of cumulic mollisols (aggrading A horizons) (Fig. 4, positions 2 and 3). The Z2 contact with β1 is conformable in most areas, deflational in a few, and merges with Z1 at the edges of the β1 channel to form the Z1–2 surface (Fig. 2). This surface, covered by the YD black mats, demarks the topography of the Clovis-age landscape (SI Fig. 6). At 27 sites mammoth bones are blanketed by YD black mat deposits (Table 1). Six of these have Clovis artifacts on the same surface (Z1–2) on which the bones rest. Bioturbation across the Z1–2 contact at several sites resulted in a mixture or reversals of radiocarbon ages with ages of $>11,000$ B.P. in lower β2a and younger, 10,000+ B.P., for strata on which β2a is resting. Hell Gap and the Jim Pitts sites are examples (SI Table 2, nos. 9 and 17a) (SI Fig. 7*a* and SI Fig. 8*b*).

The β2a black mat deposits are devoid of *in situ* megafauna other than bison (*Bison bison antiquus*) but contain the earliest post-Clovis archaeological evidence represented by *in situ* Paleoindian artifacts, e.g., Folsom-Midland, Plainview-Goshen, and Agate Basin (Figs. 3 and 5), commonly in direct association with the bones of extinct bison in the Great Plains and Southwest (18). In the eastern United States post-Clovis fluted-point-making cultures dominated during the YD (19, 20), whereas the Dalton technocomplex appeared in the Southeast (21). The YD black mats blanket the Clovis-age Z1–2 surface (Fig. 4, β2a) and provide a marker horizon for exploration for Paleoindian sites. The manifest increase in cultural diversity and bison kill sites (18) following Clovis suggests a significant population increase during YD time.

Of the 70 sites in SI Table 2, 56 (80%) have skeletal elements of the Rancholabrean megafauna directly underlying the YD black mat (Table 1). Approximately 38.6% have mammoth remains, 37.1% bison, 8.6% horse, 7.1% camel, 2.9% mastodon, and 8.6% other extinct-species remains, all on the Clovis-age surface, and only bison remains appear in the overlying YD black mat.

The 27 sites of SI Table 3 that do not have black mats *per se* have strata that are manifestations of YD climate. Of these, 19 (70%) have Rancholabrean megafauna remains all in contact with the YD-age sediments (Table 1). Of the total, 18.5% have mammoth bones on the Clovis age surface, 11.1% have mastodon, 37% have bison, and 3.7% have horse remains on the Z1–2 contact.

Table 1. Number and percentage of megafauna species in SI Tables 2 and 3

	Mammoth		Mastodon		Bison		Horse		Camel		Other	
Total number of sites in this study	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
70 sites with YD black mats 56 (80%) with extinct fauna	27	38.6	2	2.9	24	34.3	6	8.6	5	7.1	6	8.6
27 sites with other YD sediments 19 (70%) with extinct fauna	5	18.5	3	11.1	10	37	1	1.4	0	0	0	0

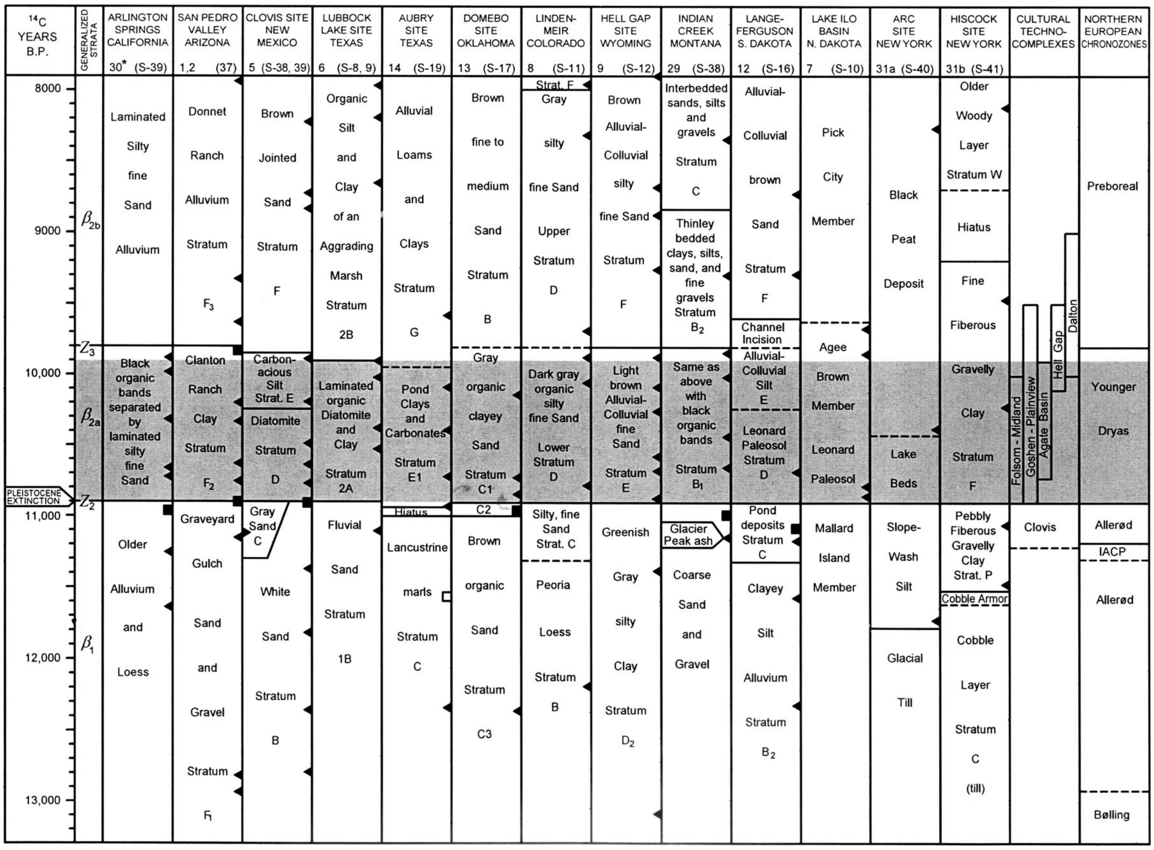

Fig. 5. Correlation chart of stratigraphic columns for 12 sites or areas that have the Younger Dryas black mat. Contacts designated Z1 and Z3 are erosional, resulting in a hiatus in some sections. Contact Z2 is the Clovis occupational surface on which the black mat was deposited. Away from channel or pond facies Z2 merges with the late glacial erosion surface Z1 to form the Z1–2 contact (see Fig. 2). (Modified after ref. 16). Black triangles are radiocarbon dates and black squares are Clovis radiocarbon ages plotted against ^{14}C scale on the left. Open square is the Aubrey site Clovis date. It plots in an anomalous stratigraphic position because it is on an erosional surface (G/A2 = Z1–2) representing a hiatus in the East Camp area (figure 3.22 SI Reference List, S19). Generalized stratum Z1 is two or three hundred years off the bottom of the chart. *Numbers refer to map numbers of Fig. 1 and SI Table 2 and SI Table 3. Reference numbers are in parentheses.

Twenty-three sites lack a documented extinct fauna. Fifteen, or 65%, have either Clovis artifacts on the Clovis-age surface and/or post-Clovis Paleoindian artifacts in the overlying YD sediments. All of the sites in SI Tables 2 and 3 have either radiocarbon ages indicating YD ages for the black mat and/or have a Clovis-age (Z1–2) contact. Therefore, the Z1–2 contact appears to be the same age everywhere, essentially isochronous, in this study (Fig. 5).

Changes in the geomorphic position of the YD black mat (upland, lowland, and intermediate slopes), are represented in some areas as facies or catenas (Fig. 4). Regional YD paleosols include the Brady Paleosol of Nebraska (22) and the Leonard Paleosol of the Dakotas, which is in the Aggie Brown Member of the Oahe Formation (23, 24). The Aggie Brown Member rests disconformably on the Mallard Island Member (25) whose surface is the Z1–2 contact. On some upland locations where the black mat is represented by cumulic mollisols in eolian sediments, the Z1–2 surface can be recognized only as a transitional zone from relatively inorganic loess to organic black soil.

Varying weak degrees of reddening observed in 10–20 cm of loess below the Leonard Paleosols in some localities appear to be Bw (color B) horizons resulting from weathering that preceded the YD. On these loess-covered uplands the cumulic mollisols are darker and thicker in swales (9, 26) and may reflect perched groundwater or poor drainage (Fig. 4, positions 2 and 3). Examples of these are the Flaming Arrow site, North Dakota (SI Table 2, no. 40a, SI Fig. 9*f*), and Sheep Mountain Table, South Dakota (SI Table 2, no. 41, SI Fig. 10*b*). In lowlands they occur deeply buried beneath floodplains (Fig. 4, position 1), a classic example being represented by Paleosol YY in the Medicine Creek area, Nebraska (27) (SI Table 2, no. 11). In some colluvial settings multiple black bands are separated by lighter colored slope wash sediments representing colluvial redeposition in some places and intermittent aggradation in others (Fig. 4, position 4). Locality 3 of the Agate Basin site, Wyoming (SI Table 2, no. 10a, SI Fig. 7*b*), is a typical example. The black mat sometimes formed in spring-fed wet meadows, elsewhere as peaty lenses over spring conduits (7) (Fig. 4, position 5). Gilcrease Spring Mound, Nevada (SI Table 2, no. 19b, SI Fig. 8*c*), is an excellent example.

At several archaeological sites in South Dakota the Leonard Paleosol thickens in low areas or depressions because of slope wash of eolian silt and fine sand and becomes thinner up slope where it commonly has younger soils welded to it, in some cases after erosion of parts of the Leonard Paleosol. Radiocarbon dates on charcoal from the basal 10 cm of this black mat range from 9,855 B.P. to 11,860 B.P. with the majority (5 of 8) being in excess of 11,000 B.P. On this basis Donohue (28) considered the age range of the Leonard Paleosol to be essentially 9,000 B.P. to 12,000 B.P. However, on the basis of archaeological evidence at stratified sites in North Dakota, as well as Chalk Rock (29) and Lange/Ferguson (30) sites in South Dakota, the Leonard Paleosol appears to overlie the Clovis occupation surface (Z1–2) and contains in its basal portion post-Clovis artifacts, i.e., Folsom-Midland, Goshen-Plainview, and Agate Basin (9, 10, 25). These cultural technocomplexes all date between ≈10,000

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 β2b. Stratum β2b 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 β2b 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 β2a 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 β1 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 β2b, 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 ($\approx$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, ^{3}He, 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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