1-1-2005

Geochronology of Merrell Locality Strata and Regional Paleoenvironmental Contexts

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This document was originally published in *The Merrell Locality (24BE1659) & Centennial Valley, Southwest Montana: Pleistocene Geology, Paleontology, & Prehistoric Archaeology*.

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Chronologic Interpretations

An assessment of the age of the deposits and the fossils incorporated within them at the Merrell Locality is based on radiocarbon measurements from bone and tusk collagen and organic sediments (Table 3 and Figures 75-76), and luminescence measurements on sediments (Feathers, this report). Nine radiocarbon dates are available from the site; seven are finite and two are infinite. The finite dates range from ca. 49,000 to 19,000 ^{14}C yr B.P. (Figure 75).

The oldest finite date of ca. 49,350 ^{14}C yr B.P. is based on measurements of collagen derived from mammoth remains from a deposit which is possibly a facies of stratum A (Hill 1999). Feathers (this report) provides two luminescence ages from deposits that are facies of stratum A. At one standard deviation, these measurements range in age from about 50,000 to about 76,000 OSL years (= calendar yr B.P.) (Figure 75). Thus, there are some indications that the sediments and vertebrate remains within stratum A can be correlated with a long interval perhaps spanning the end of isotope stage 5, all of stage 4, and the beginning of isotope stage 3. The deposits could be associated with the late Sangamon Episode (sensu lato, e.g., Karrow, Dreimanis, and Barnett 2000) and the early and middle Wisconsin (Figure 77). Fragments of tusk and teeth of *Mammuthus* were recovered from the stratum A sediments.

The radiocarbon dates from stratum B range in age from >44,000 to 32,000 ^{14}C yr B.P., or ca. 35,000 years ago (calendar yr B.P., cf. Van Andel 1997) (Figure 75). The stratum B deposits are dominantly from swamp, plaudal, and small lake environments. Fossils were typically found at the boundary of strata A and B and within the lower, more organic-rich deposits of stratum B (Figures 76 and 78). These deposits may contain fossils which

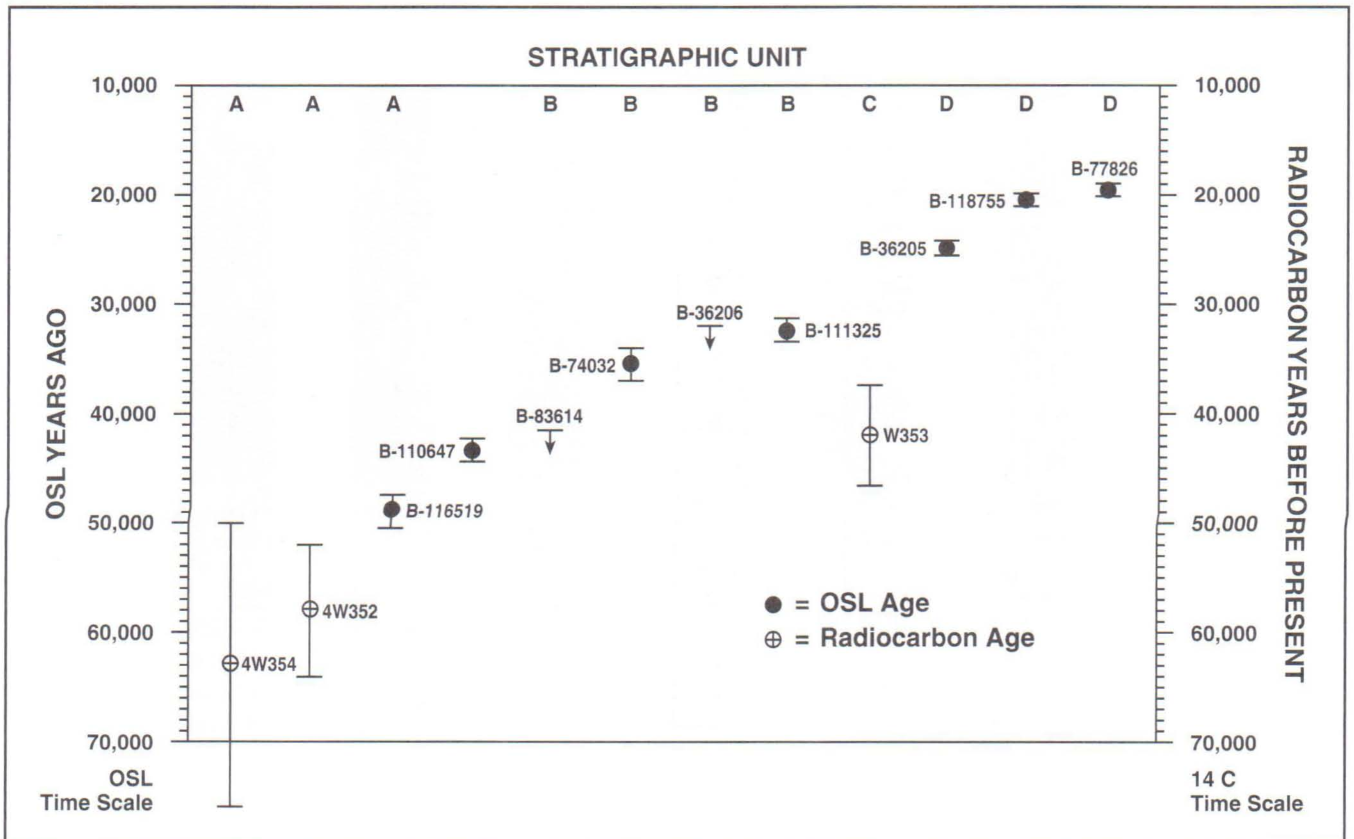

Figure 75. OSL and radiocarbon ages for samples from Merrell Locality, Centennial Valley.

were originally within stratum A that were later redeposited into stratum B, or fossils from animals that were contemporary with the stratum B depositional contexts. Based on the luminescence and radiocarbon measurements, stratum A and possibly some stratum B deposits are older than 40,000 ^{14}C yr B.P. (Figure 79). Organic material retrieved from a bone recovered from the lower, dark facies of stratum B has been dated ca. 36,500 ^{14}C yr B.P. (or ca. 39,000 calendar yr B.P.). This would imply that some of the stratum B deposits are associated with isotope stage 3 and possibly the Early Pinedale glaciation. Tusk collagen from a specimen obtained from the lower facies of stratum B provided a date of ca. 32,470 ^{14}C yr B.P. (ca. 35,000 calendar yr B.P). This measurement would indicate that some of the fossils incorporated into stratum B are associated with the younger part of isotope stage 3 (Figure 77). They could thus be roughly contemporary with the Farmdale phase in the midcontinent (cf. Karrow et al. 2000). However, a date of roughly 35,000 B.P. would also correspond to the end of the Early Pinedale glaciation on the nearby Yellowstone Plateau, dated between 47,000 and 34,000 calendar yr B.P., which was followed by an interstadial lasting from ca. 34,000 to 30,000 years ago (Sturchio et al. 1994).

Based on stratigraphic relationships and radiocarbon measurements available from stratum B and from stratum D, the fluvial sediments of stratum C would seem to be associated with the end of isotope stage 3 or the transition to isotope stage 2. The luminescence age is approximately 42,000 calendar yr B.P. (multi-aliquot method) or 38,500 calendar yr B.P. (SAR method, with a fairly large standard deviation) (Feathers, this report). This would indicate that the sediments in stratum C were deposited during the early or middle part of isotope stage 3 (Figure 77). The luminescence date implies that the stratum C sediments were deposited during some part of the Early Pinedale advance on the Yellowstone Plateau (Sturchio et al. 1994), while the stratigraphic relationship with stratum B would seem to indicate possible contemporaneity with either the interstadial documented on the Yellowstone Plateau (ca. 34,000 to 30,000 calendar yr B.P.) or the major Pinedale advance (ca. 30,000 to 22,500 calendar yr B.P.).

Stratum D consists of a debris-flow with bones of *Equus*, *Bison*, and *Mammuthus* (Figures 62-66 and 80). It is a localized set of deposits found along the north side of the Merrell Site, in the North Block or Excavation Area I. The deposits of stratum D seem to rest on eroded surfaces

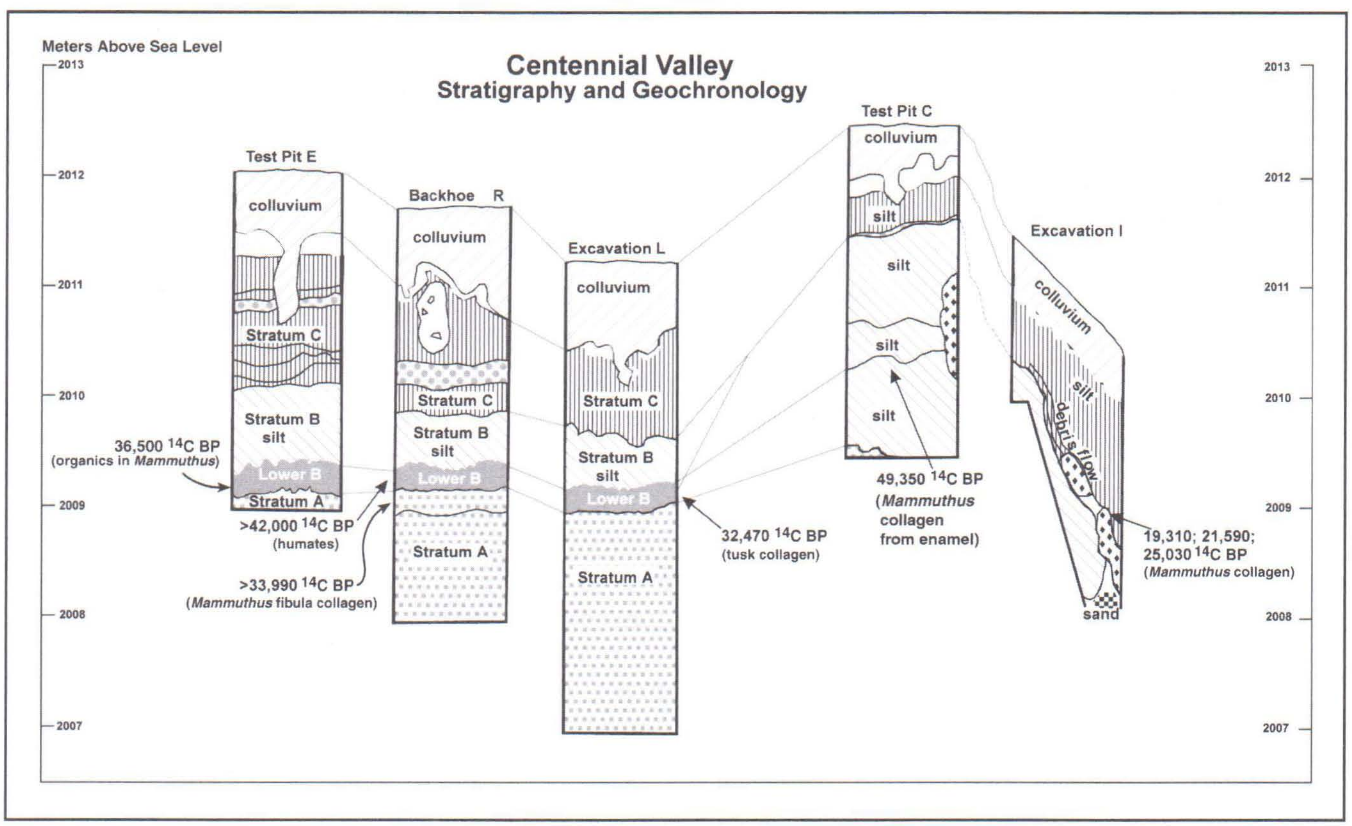

Figure 76. General stratigraphic relationships of OSL and radiocarbon samples collected from Merrell Locality, Centennial Valley (profiles by C. L. Hill).

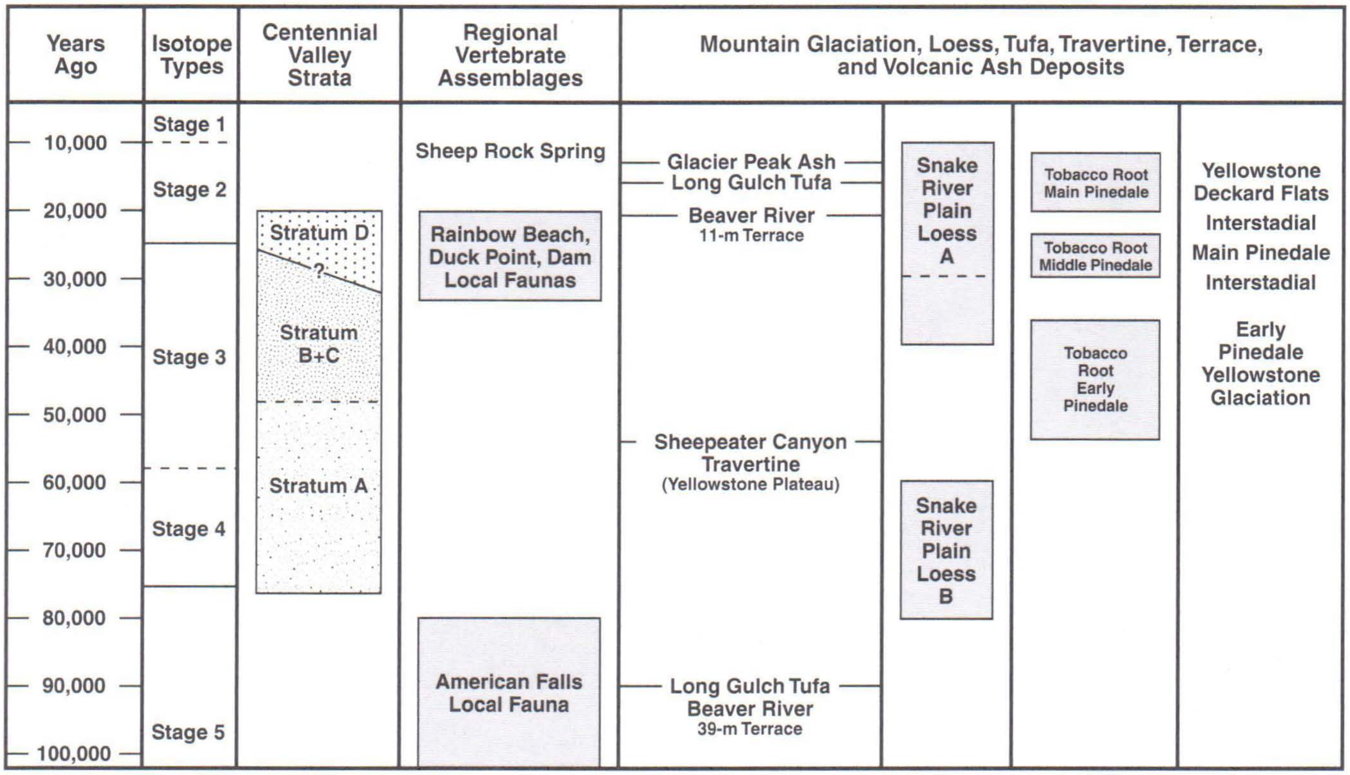

Figure 77. Late Pleistocene chronological relationships.

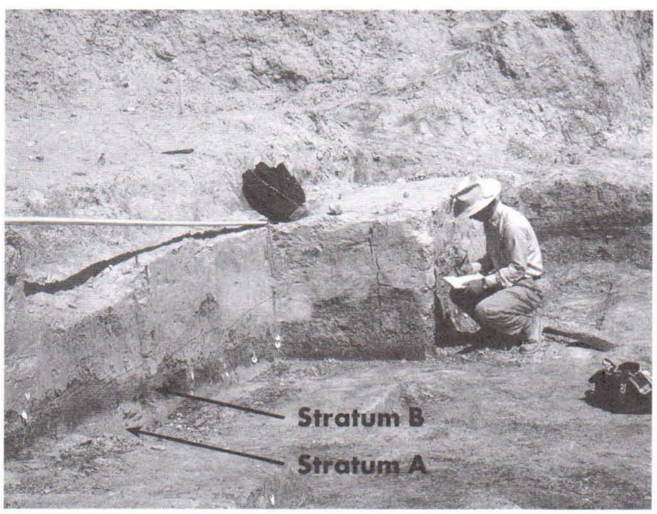

Figure 78. Strata A and B, South Block, Merrell Locality, looking generally toward grid north (C. L. Hill photo).

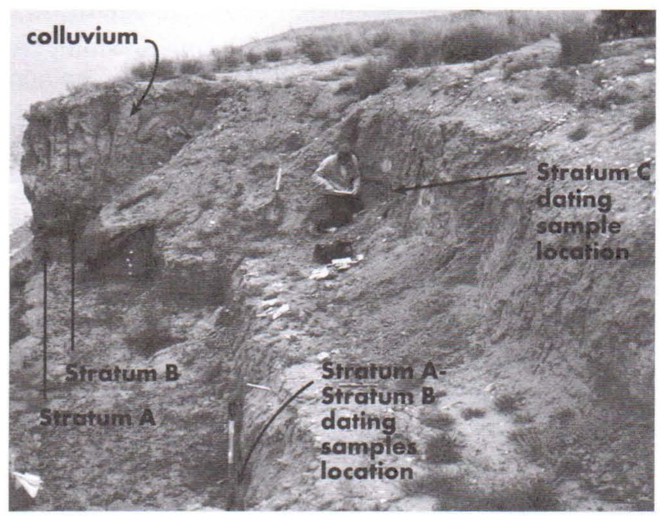

Figure 79. Collection of OSL samples from South Block, Merrell Locality (C. L. Hill photo).

of strata A-C. Thus, there is the potential that stratum D may contain fossil remains younger than stratum C as well as, potentially, fossils originally in strata A-C. The stratum D fossil assemblage definitely appears to be in secondary position and seems to have incorporated bones of several ages. The youngest date of ca. 19,000 ^{14}C yr B.P. or about 22,000 years ago (Table 3, Figure 77) was obtained from collagen in mammoth bone. This provides a maximum age for the deposit. It implies that some of the fossils in the debris flow are slightly older than the Last Glacial Maximum (isotope stage 2). Another date of ca. 25,000 ^{14}C yr B.P. or ca. 28,000 years ago (Table 7, Figure 75) is also from bone incorporated into this deposit (Dundas 1992). This date indicates that some of the assemblage may be associated with the transition connected with isotope stages 2 and 3. There is also the possibility that older fossils origi-

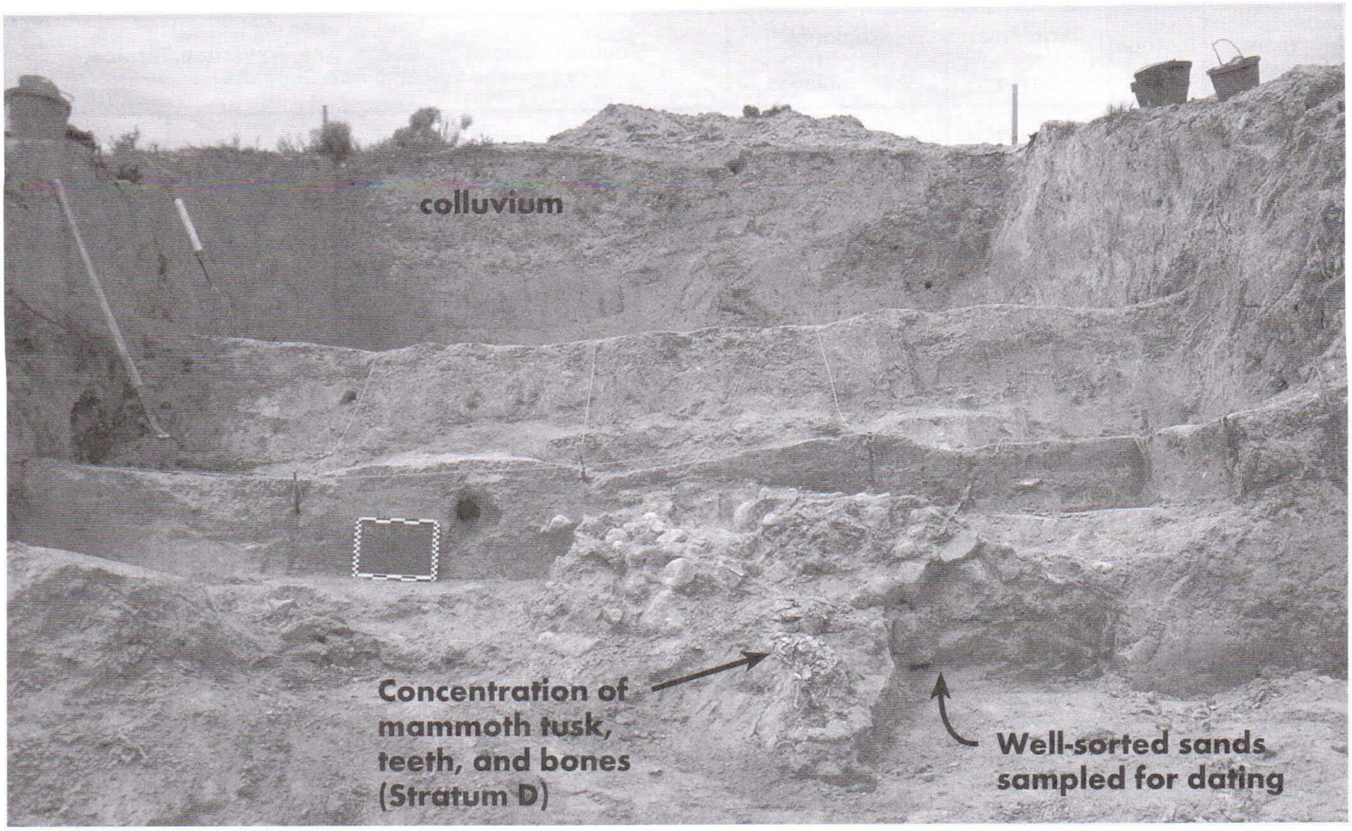

Figure 80. Location of OSL sample from stratum A below stratum D, North Block, Merrell Locality (C. L. Hill photo).

nally associated with strata A-C may be mixed within the debris flow. The date of 19,000 ^{14}C yr B.P. (ca. 22,000 years ago) appears to indicate that the youngest Pleistocene fossils from Merrell are slightly older than the Last Glacial Maximum, but are within the local "full glacial" advance on the Yellowstone Plateau (Sturchio et al. 1994). The debris flow itself could be younger.

General Discussion of Chronologic Framework

The luminescence measurements of two sedimentary facies of stratum A and the radiocarbon date of a mammoth remains from a possible facies of stratum A seem to demonstrate that stratum A is likely associated with isotope stage 4 and the early part of isotope stage 3 (Figure 75). Some of the bones incorporated into the deposits of stratum A may be too old to obtain finite radiocarbon ages. Others may be around 50,000 yr B.P.

Stratum B appears to be primarily associated with isotope stage 3 (Figure 75). There seems to be a strong possibility that the stratigraphic sequence associated with stratum B dates a local example of a changing environment associated with a marsh or pond-lake basin in the Centennial Valley. The possible presence of Pleistocene lakes within the valley is likely related to a combination of tectonic, geomorphic, and climatic processes. Organic deposits associated with bone from stratum B date ca. 36,500 ^{14}C yr B.P. or ca. 39,000 years ago, while bone collagen from mammoth dates to >34,000 ^{14}C yr B.P. Calibrated for comparison with the U-series chronology, the dates of ca. 37,000 ^{14}C yr B.P. may imply an age closer to 40,000 B.P. for the deposition of organics in stratum B. If not actually beyond the ability of radiocarbon measurement, the dates from stratum B would indicate a potential temporal association with two Pinedale alpine glacier advances and possibly the intervening interstadial. Using the glacial chronology developed for the region immediately to the east of Centennial Valley (Sturchio et al. 1994), the radiocarbon- dated organics can be correlated with the Early Pinedale glacial advance that centered ca. 40,000 calendar yr B.P. (Figure 77).

A date of 25,000 ^{14}C B.P. (Table 3) from collagen from the debris flow or channel (Dundas 1992) is estimated to be about 28,000 calendar years B.P. (Van Andel 1998). The debris flow also contains bone dated ca. 19,310 ^{14}C yr B.P., or about 22,000 calendar yr B.P., based on calibration with the U-series chronology (cf. Sturchio et al. 1994; Bartlein et al. 1995; Bard et al. 1990; Van Andel 1998).

The Greenland ice core record (cf. GISP II) shows apparent warm interstadial events between about 33,000 and 23,000 calendar years B.P., with "full glacial" values from around 18,000 to 15,000 calendar years B.P. (cf. Sowers and Bender 1995). However, the glaciers on the Yellowstone Plateau appear to have reached their maximum several thousands of years before the Last Glacial Maximum (cf. Pierce, Obradovich, and Friedman 1976; Sturchio et al. 1994), when the LGM is related to low global sea levels around 18,000 ^{14}C yr B.P. or about 20,000 calendar years B.P. The maximum extent of the glaciers to the south in the Wind River Range may have been contemporary with the LGM, with Pinedale assigned ages of 23,000-16,000 yr B.P. based on ^{36}Cl/^{10}Be measurements (cf. Chadwick et al. 1997; Phillips et al. 1997). On the Yellowstone Plateau, there seems to have been a major Pinedale advance resulting in full-glacial conditions between 30,000 and 22,500 calendar yr B.P., followed by a recession and a late Pinedale (Deckard Flats) advance between 19,500 and 15,500 calendar yr B.P. (Sturchio et al. 1994) (Figure 77). The youngest fossil materials incorporated into the debris flow, therefore, appear to be associated with the local major Pinedale advance ("full-glacial"), while the radiocarbon-dated materials are within the interstadial interval observed in the Greenland ice core.

The bone dated within the debris flow is redeposited; it may be older than the debris flow in which it was incorporated. Thus, while the date of ca. 19,000 ^{14}C yr B.P. (22,000 calendar yr B.P.) provides a maximum age for the deposit, it also provides some chronologic control on the age of the vertebrate remains. Taking into account the departure of radiocarbon dates from the U-series chronology, this indicates the presence of elements of a mammoth biome in Centennial Valley perhaps ca. 22,000 calendar years B.P., thus linking these faunal elements with the "full-glacial" ice advance in the region immediately to the east, ranging from 29,900 to 22,500 calendar yr B.P. (Sturchio et al. 1994). A period of ice recession was followed by the Late Pinedale (Deckard Flats) ice advance after 19,500 calendar yr B.P. (cf. Sturchio et al. 1994), but there is no chronometric evidence that any of the fossils at the Merrell Locality can be assigned to this interval. The youngest radiocarbon dated fossil dates to ca. 22,000 years ago and thus is associated with local "full-glacial" conditions.

Paleoclimatic Context

The Centennial Valley is located within a region where a variety of paleoclimatic proxy indicators can assist in the evaluation of climate model simulations. Certain models (cf. Benson and Thompson 1987; Kutzbach and Wright 1985; Spaulding 1991; Clark and Bartlein 1994) indicate that climate change in the region during the Pleistocene was a response to changes in atmospheric circulation patterns--specifically, oscillations in the jet stream--that result in increases in winter precipitation and annual cooling during glacial intervals. There is also a potential climate-tectonic connection (cf. Ruddiman 1994) since tectonic uplift of the Rocky Mountains has been implicated as a factor in precipitation changes and alteration of jet stream and storm tracks over North America (Kutzbach 1994). Tectonic activity may also have played a direct role in influencing changes in the drainage system with the valley.

A regional climate model (RCM), using general circulation model (GCM) simulations as boundary conditions, indicates that glacial maximum temperatures were cooler and that winter precipitation was substantially greater in western North America (Hostetler et al. 1994a,b). These conditions would have been conducive to both the growth of mountain glaciers and the appearance of pluvial lakes, as well as the presence of lakes fed by glacial meltwater at glacial-interglacial transitions. Dynamic fluctuations in climate, which can influence habitat variability and biotic diversity (cf. Guthrie 1990), would be expected to influence adaptive responses of plant and animal populations in the region.

Mountain glaciers respond to global climate change (cf. Sturchio et al. 1994) and, in the Centennial region, three major sets of alpine glaciation are indicated: pre-Bull Lake, Bull Lake, and Pinedale (Sonderegger et al. 1982:8). Studies of the Yellowstone Plateau east of Centennial Valley also provide a chronologic framework of glaciation and deglaciation for comparison (Pierce 1979; Pierce et al. 1976; Porter, Pierce, and Hamilton 1983; Richmond 1986a, 1986b; Sturchio et al. 1994). The framework is potentially representative of Pleistocene glacier activity in the Northern Rockies (cf. Forman et al. 1993). In Yellowstone, two diamictons indicate glacial advance during the Plio-Pleistocene, and deposits indicate glacial advances within isotope stages 40 or 36 (pre-Illinoian J or I), 34 (1,580,000-1,510,000 B.P., advance H), and 14 (562,000-512,000 B.P., advance C). Lake sediments containing volcanic ash have dated to ca. 483,000 B.P. Separate tills correlate with isotope stages 14 and 12 (Richmond 1986a,b) and there are indications of glaciation ca. 375,000 B.P. (Sturchio et al. 1994). Isolated deposits identified as pre-Bull Lake tills have been mapped on the southeast side of the Centennial Valley (Witkind 1976), although care must be taken to demonstrate that the diamictons represent till related to glacial advances and not to mass-wasting events associated with tectonic activity.

In the Wind River Range, the three youngest Bull Lake glaciations could date between 130,000 and 95,000 yr B.P., while the Pinedale glaciations range from 23,000 to 16,000 yr B.P. (Chadwick et al. 1997; Phillips et al. 1997). On the Yellowstone Plateau, a Bull Lake glacial advance seems to have occurred prior to ca. 134,000 calendar yr B.P., perhaps about 150-140,000 calendar yr B.P. (cf. Pierce, Obradovich, and Friedman 1976; Porter, Pierce, and Hamilton 1983; Forman et al. 1993; Sturchio et al. 1994). This glaciation has been associated with stage 6 (ca. 150,000 B.P., Late Illinoian, Richmond 1986b; Richmond and Fullerton 1986). Glacial pulses are also associated with isotope substages 5d (ca. 117,000 B.P.) and 5b (ca. 90,000 B.P.), and possibly with stage 4 (79,000-65,000 B.P., Richmond and Fullerton 1986). Tufas dated to ca. 90,000 yr B.P. indicate that the 39-m (128-ft) terrace of the Beaverhead River northwest of Centennial Valley could be Sangamon or late Bull Lake (Bartholomew et al. 1999) (Figure 77). Isotope stage 5b has been correlated with a Late Bull Lake advance (Richmond 1986).

It has been proposed that there was no glacial advance during for the Middle Wisconsin, isotope stage 3 (ca. 65,000-35,000 yr B.P.), in the Rocky Mountains and Yellowstone (Richmond and Fullerton 1986). However, the Sheepeater Canyon travertine on the Yellowstone Plateau has a U-series age of ca. 55,000 calendar yr B.P. and is mantled by Pinedale till (Sturchio et al. 1994). The Early Pinedale advance on the Yellowestone Plateau may have begun by ca. 47,000 yr B.P. and continued until ca. 34,000 yr B.P. (Sturchio et al. 1994) (Figure 77). The nearby Lemhi Range contains evidence of three glacial advances estimated to date ca. 150,000, 60,000, and 25,000 yr B.P. (Butler et al. 1983). Within the Three Rivers Basin (Hill 2001a), two major Pinedale advances were recognized in the Tobacco Root Mountains (Roy and Hall 1981). The "early Pinedale" interval may have been initiated by 50,000-45,000 yr B.P. and continued beyond 35,000 yr B.P., while the "middle Pinedale" advance may date to ca. 22,400 yr B.P. (Roy and Hall 1981; Hall and Heiny 1983; Hall and Michaud 1988) (Figure 77).

Another indicator of glacial conditions in the region has been provided by the chronologic framework associated with loess deposition on the eastern Snake River Plain, south of the Centennial Valley (Foreman et al. 1993). There appear to be two intervals of loess deposition (Figure 77). The older loess sequence, deposited between 80,000 and 60,000 B.P., is considered to have probably been coincident with an "early Wisconsinan" glacial episode (Foreman et al. 1993). The younger loesss sequence is thought to have started forming between 40,000 and 30,000 yr B.P., with deposition continuing until ca. 10,000 yr B.P.; it also seems to have been associated with a regional glacial cycle (Foreman et al. 1993). The middle of the younger loess has luminescence age estimates of ca. 28,000 and 25,000 yr B.P., while a radiocarbon age of ca. 11,980 ^{14}C yr B.P. (ca. 14,000 years ago) provides an approximate date for the top of the sequence (Foreman et al. 1993; Bartlein et al. 1995).

Summary of Pleistocene Geologic Events

Tectonic activity and volcanism influenced the last 2.5 million years of prehistory in the Centennial Valley. The Centennial Mountains were lower in the Late Tertiary-Early Quaternary, which influenced glaciation and habitat settings. Just tectonic displacement at a specific locality would have effected a habitat change, regardless of fluctuations in the paleoclimate. For instance, some results of uplift--vegetation change, stream incision and erosion, and diamictons from mass-wasting--may also be indicators of climate change (cf. Ruddiman 1994).

Throughout the Quaternary, there has been tectonic displacement in the valley. The Huckleberry Tuff, derived from the Yellowstone Caldera and dated to 2 million years ago, appears to have diverted the ancestral Plio-Pleistocene Madison River which had flowed southward into the Centennial Valley (Mannick 1980). Displacement on the order of 5,000-6,000 ft (>1,500 m) has occurred in the upper (east side) Centennial Valley since deposition of the Huckleberry Tuff (Mannick 1980). On the east side of the valley, there has been greater than an inch of movement per year since the last glaciation; Post-Pinedale displacement has been estimated at 1.2 in (5.1 cm) per year (Mannick 1980). The Centennial Fault has a scarp on the west side of the valley, closer to the Merrell Locality, which shows a displacement of about one-fifth that in the eastern end (Sonderegger et al. 1982). Faults are also present north of the Lima Reservoir and close to the valley-dam constriction area (Stickney, Bartholomew, and Wilde 1987; Stickney and Bartholomew 1987; Myers and Hamilton 1964).

During the Late Pliocene-Early Pleistocene, the Centennial Valley was occupied by a large lake, indicated partially by the deposition of freshwater limestone (Mannick 1980). It has been proposed that glacial meltwater had accumulated in the Centennial Valley, forming a large lake (Sonderegger et al. 1982).

Alluvial fans had formed before and during the presence of a glacial lake, while younger fans were deposited after the lake had drained; a topographic break along the edges of some fans seems to indicate that parts of some alluvial fans were deposited underwater in delta-like conditions. This break may be the result of currents in a former lake. Lacustrine deposits, including several beach deposits, mark former shorelines of a dwindling glacial lake (Witkind 1976). Younger streams have trenched and segmented the lacustrine deposits. Lake deposits reach elevations of 6,717 fasl (2,047 masl) north of Lower Red Rock Lake, and are above 6,800 fasl (2,073 masl) northeast of Upper Red Rock Lake. Some of the valley lakes may have been fed by warm spring activity, and are related to geothermal heat sources (Mannick 1980:67). The present lakes (and perhaps the Pleistocene lakes) are warmed by waters circulating along the Cligg Lake Fault and other faults. Travertine deposited along the eastern shore of Elk Lake reflects the past existence of thermal springs within the valley (Mannick 1980: 68).

A date of 36,500 ^{14}C yr B.P. (calibrated to ca. 40,000 B.P. in the U-series chronology, cf. Van Andel 1997) indicates that organics within sediment at the Merrell Locality in the Centennial Valley could have been deposited before or during an ice advance associated with isotope stage 3 (Early Pinedale). This dark organic deposit (stratum B, LL2, equivalent to level 3 [or III] of Bump 1989) seems to reflect a habitat setting related to the margins of a Pleistocene marsh.

Isotope stage 2 (ca. 35,000-13,000 yr B.P.) appears to have been associated with a major global glacial event. Pinedale till has been reported along the north face of the eastern Centennial Mountains (Witkind 1976). Pinedale moraines advanced beyond the valley mouths and coalesced on the east side of the valley. Within the interval from 34,000 to 29,000 B.P., the ice margin on the Yellowstone Plateau receded, indicating an interstadial event. Fossils dated ca. 25,000 ^{14}C yr B.P. (ca. 28,000 calendar yr B.P.) at Merrell would indicate the continued presence of a mammoth biome around the early part of this advance. Northwest of Centennial Valley, the 11-m terrace above the Beaverhead River is covered by a tufa dated to ca. 15,000 calendar yr B.P., implying an age of ca. 26,000 calendar yr B.P. and a possible association with the major Pinedale advance (Bartholomew et al. 1999) for the terrace deposits (Figure 77). It seems feasible that the youngest fossils recovered from stratum D in Centennial Valley are associated with the major Pinedale "full-glacial" advance or perhaps the transitional interval after ca. 22,500 yr B.P.

A major "full-glacial" advance, which appears to have occurred between ca. 30,000 and 22,500 yr B.P. (Sturchio et al. 1994), is associated with the youngest radiocarbon date from stratum D at the Merrell Site. The calibration curve indicates that the Last Glacial Maximum of ca. 18,000 ^{14}C yr B.P. probably occurred 22,000-21,000 B.P. (Tushingham and Peltier 1993). A major melting back of the ice margin between 22,500 and 19,500 yr B.P. was followed by a minor advance between 19,500 and 15,500 yr B.P. (centered on ca. 18,000 yr B.P., Sturchio et al. 1994) on the Yellowstone Plateau. A Late Pinedale readvance or standstill in the ice margin position seems to have occurred before 14,500 yr B.P. (ca. 13,000 ^{14}C yr B.P., cf. Porter, Pierce, and Hamilton 1983; Richmond 1986b).

Loess deposition in the region to the south of Centennial Valley between 40,000-30,000 yr B.P. and 10,000 yr B.P. has been correlated with the Pinedale glaciation (Foreman et al. 1993). Pluvial lake expansion from ca. 32,000 to 10,000 B.P. yr is also associated with regional Pinedale glaciation, with high stands contemporaneous with deglaciation events (cf. Currey and Oviatt 1985; Benson and Thompson 1987; Benson et al. 1990). A lake (or lakes) may have filled most of the Centennial Valley ca. 12,000-10,000 B.P. at the end of the last glacial period (Sonderegger et al. 1982:15).

Conclusions: Lithostratigraphic and Biostratigraphic Context

The stratigraphy of the Centennial Valley contains lithologic and biostratigraphic information that can be used to infer the paleoenvironmental and paleoclimatic context of the Upper Pleistocene of southwestern Montana. Several stratigraphic units contain Pleistocene vertebrate remains (strata A-D). Based on a calibration with the U-series chronology, the radiocarbon dates indicate the presence of a generalized mammoth biome within the Centennial Valley around or before 50,000 to perhaps ca. 22,000 years ago. The luminescence ages reported by Feathers (this report) seem to demonstrate that deposition of stratum A occurred prior to ca. 50,000 years ago. Vertebrate remains are found within and on the top of stratum A and the marsh deposits of stratum B, estimated to date to ca. 40,000 B.P., or earlier. The vertebrate remains found in the North Block (Excavation I) seem to have been incorporated into a debris flow (stratum D). The remains indicate the presence of mammoth biome-related fauna in the valley, perhaps associated with full-glacial conditions. The faunal assemblages from the Centennial Valley appear to be younger than the American Falls Local Fauna from Idaho (Figure 77). Younger Idaho fossil vertebrate assemblages (Rainbow Beach, Duck Point, and Dam Local Faunas) may be approximately contemporary with some fossils recovered from strata B-D (Figure 77).