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The Crazy Hollow Formation (Eocene) of Central Utah

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ABSTRACT

The Late Eocene Crazy Hollow Formation is a fluviatile and lacustrine unit that was deposited locally in the southwest arm of Lake Uinta during and after the last stages of the lake that deposited the Green River Formation. Most exposures of the Crazy Hollow are located in Sanpete and Sevier Counties. The unit is characterized by a large variety of rock types, rapid facies changes within fairly short distances, and different lithofacies in the several areas where outcrops of the remnants of the formation are concentrated. Mudstone is dominant, volumetrically, but siltstone, shale, sandstone, conglomerate and several varieties of limestone are also present. The fine-grained rocks are mostly highly colored, especially in shades of yellow, orange and red. Sand grains, pebbles and small cobbles of well-rounded black chert are widespread, and "salt-and-pepper sandstone" is the conspicuous characteristic of the Crazy Hollow. The salt-and-pepper sandstone consists of grains of black chert, white chert, quartz and minor feldspar. The limestone beds and lenses are paludal and lacustrine in origin; some are fossiliferous, and contain the same fauna found in the Green River Formation.

With trivial exceptions, the Crazy Hollow Formation lies on the upper, limestone member of the Green River Formation, and the beds of the two units are always accordant in attitude. The nature of the contact differs locally: at some sites there is gradation from the Green River to the Crazy Hollow; at others, rocks typical of the two units intertongue; elsewhere there is a disconformity between the two. A variety of bedrock units overlie the Crazy Hollow at different sites. In the southeasternmost districts it is overlain by the late Eocene formation of Aurora; in western Sevier County it is overlain by the Miocene-Pliocene Sevier River Formation; in northernmost Sanpete County it is overlain by the Oligocene volcanics of the Moroni Formation. At many sites bordering Sanpete and Sevier Valleys the Crazy Hollow beds dip beneath Quaternary sediments that fill the two valleys.

The Crazy Hollow Formation ranges from 0 to 1,307 feet (0–398 m) thick in the region, but is usually much thinner than the maximum value. At most outcrops it is only a few scores of feet (12–50 m) thick. Its age is middle Eocene, for it is only a little younger than the underlying Green River Formation. The unit developed by the washing of detritus into the basin of the southwest arm of Lake Uinta from the various source rocks in the highlands surrounding the basin. The limestone beds and lenses formed in ponds and small lakes that developed in the basin from time to time during and following the draining and evaporation of Lake Uinta.

The qualities of the Crazy Hollow Formation are descibed in detail for 10 different areas of outcrops in the Sanpete and Sevier Valleys and vicinity.

INTRODUCTION

It is now more than 50 years since the upper Eocene Crazy Hollow Formation was first proposed and described by Spieker (1949), at a time when its regional extent was not known. In the years since, the mapping, lithology, age and sedimentary history of the formation have been much advanced. This paper brings together what has been learned over the half century and presents, for the first time, a regional picture of the Crazy Hollow and its significance.

The Crazy Hollow Formation was named by Spieker (1949) for the "red and orange sandstone, siltstone, and shale, white sandstone, and pepper-and-salt sandstone that overlies the Green River Formation and underlies [mixed sedimentary and pyroclastic beds]" near Salina, Sevier County, Utah. The type locality is in a still-unnamed steep gulch that extends headward (southward) from the south wall of Salina Canyon (Fig. 1) into the middle of section 5, T. 22 S., R. 1 E., Salt Lake Base Line and Meridian (all grid designations cited refer to this same baseline and meridian). Spieker dubbed the gulch "Crazy Hollow" because of the much-faulted and complex stratigraphy in that drainage. He measured no type section. The mouth of Crazy Hollow is about one half mile (0.8 km) west of the mouth of Soldier Canyon, which is named on the topographic and geologic maps of the Salina quadrangle (Willis, 1986) and is served by a good road.

Spieker noted that the formation is widely exposed in nearby areas both north and south of Salina Canyon. It is widespread in the highlands south of Crazy Hollow to about 6 miles (9.6 km) from Salina Canyon, and from the upper reaches of Soldier Creek into T. 23 and T. 24 S., R. 1 E., the Lost and Gooseberry Creek drainages (McGookey, 1960). It extends about 6 miles (9.6 km) north from Crazy Hollow (Willis, 1986; Witkind et al., 1987). Spieker (1949) considered that the Crazy Hollow lies disconformably on the limestone beds of the upper Green River Formation and that it is overlain disconformably by pyroclastic beds in the Salina area, the only place then known to him where superjacent bedrock lies on the formation. He called those mixed sedimentary and pyroclastic beds [now the formation of Aurora] by a provisional name—Gray Gulch—that never achieved currency. He said that the Crazy Hollow is also recognizable in Sanpete Valley as far north as Spring City, and elsewhere (Spieker, 1949). It is now known to crop out, in patches, at many places in Sevier and Sanpete Counties; very small parts of the unit are also present in the southeast corner of Juab County and in southeastern Millard County (Fig. 1). We also now know that limestone and conglomerate are present in the Crazy Hollow at many places.

The Crazy Hollow is present as large patches in a number of places, (Areas 1 to 10 in Fig. 1), but in many of those places the areas of outcrop are themselves patchy, as shown in some of the numbered areas in Figure 1. The formation contains a wide variety of lithofacies, and the several patches of outcrop (Areas 1 to 10) locally have different lithofacies. Erosion, overlying Quaternary deposits, and faulting make numerous smaller patches of Crazy Hollow outcrop within each area; Areas 1 and 3 show this especially. This part of central Utah was the basin of the southwest arm of Lake Uinta, in which the Green River Formation of Utah was deposited. The mostly fluviatile Crazy Hollow sediments apparently spread only locally over the upper surface of the Green River beds as the southwest arm of Lake Uinta drained and dried. The perimeter around the remaining Crazy Hollow beds contains an area of about 1,500 square miles. There is little likelihood that the formation once completely covered the more extensive Green River Formation, although the existing areas of Crazy Hollow outcrop were doubtless larger before the effects of post-Eocene tectonics and erosion. There are no regionally extensive thick deposits of subaerial sediments covering the Green River Formation in central Utah, as there are in the Uinta Basin of northeastern Utah, once a more central part of Lake Uinta. Quite different and more active tectonics produced thick middle Tertiary deposits over the Green River Formation there—to as much as 8,000 feet (2,438 m) thick (Hintze, 1988).

Most of the existing outcrops of the Crazy Hollow Formation on the west (Fig. 1) lie on the lower flanks of the Pavant Range and the southern Valley Mountains and the southern Gunnison Plateau (San Pitch Mountains). On the east they lie on the lower reaches of the Fish Lake and Wasatch Plateaus. Most outcrops in Sanpete Valley, between Sterling and Fairview, are low on the dip slope of the Wasatch monocline. It is reasonable to suppose that the Crazy Hollow Formation may be more extensive in the subsurface, but published subsurface works do not distinguish it. A water well drilled just northeast of Ephraim in the late 1960s or early 1970s showed coarse salt-and-pepper sand above the Green River beds (G. E. Moore. Jr., personal communication, 2000), but there are no nearby outcrops of Crazy Hollow beds.

LITHOLOGY

Although mudstone is volumetrically the most abundant rock in the Crazy Hollow Formation, the "signature" rock types—salt-and-pepper sandstone and conglomerate—will be described first. Mineralogical details in this section are from Norton (1986; see also Weiss, 1982).

Salt-and-pepper sandstone and conglomerate

These rocks are so named because of the conspicuous speckled or dusky appearance afforded by the mixture of white, light gray and black grains. Fresh sandstone ranges

from very pale orange to light olive gray. The rock is light colored because "salt" grains prevail over "pepper." Norton (1986) found that the black grains are about 15 percent of the rock in northern areas (central Sanpete County) and as much as 20 percent in southern areas (Sevier County). Light grains are quartz, chert and feldspar, and the black grains and pebbles are very dark gray or black chert (Fig. 2). There is less black chert in the formation in far northern Sanpete County (Fograsher, 1956). The typical composition of salt-and-pepper sandstone is 50 percent quartz (90 percent of which is monocrystalline), 45 percent lithic fragments and 5 percent feldspar (albite and K-spar). The salt-and-pepper sandstone is a chert litharenite or feldspathic litharenite, and most lithic fragments are chert—both light gray and black. Collophane has been observed in some pebbles (T. F. Lawton, written communication, 2000). Quartz and white or light-gray chert are common in many of the Paleozoic, Mesozoic and Tertiary bedrock units of the region, but the black chert probably came from dark, cherty carbonates in the Mississippian Deseret Limestone or the Permian Park City Formation in the upper plate of the Sevier overthrust belt.

Such units are still exposed in some of the eastern ranges of the Basin and Range province, not far west of Sevier and Sanpete Counties. Biek (1991) reported well-rounded pebbles of quartzite and black chert in the Triassic Ankareh Formation near Nephi, at the south end of the Wasatch Range (Mount Nebo). The Ankareh, of course, extends far northward into the main Wasatch Range. It seems reasonable that black chert pebbles in the Ankareh may have come from the older rocks to the west to reside in the Nebo allochthon; from there some may have contributed to the Crazy Hollow Formation during a second cycle. Outcrops of the Ankareh Formation also are known from the west side of Juab Valley, across from Mount Nebo, in the West Hills (Meibos, 1983) and Long Ridge (Muessig, 1951).

Some quartz grains have characteristics of metamorphic origin, and heavy-mineral separations show small amounts of igneous minerals (zircon, tourmaline) in the sandstone (Norton, 1986). Plagioclase feldspars with albite twinning make up 40 percent of the feldspars. Most feldspar is not twinned and microcline is rare. The igneous grains and feldspars may have been reworked from sandstone in the Colton Formation, or possibly were late imports from the southeast (cf. Stanley and Collinson, 1979; Dickinson et al., 1986).

The salt-and-pepper sandstone is weakly cemented by calcite and has little strength. The finer the grain size, the better the cementation, usually; some fine-grained examples show cavernous or honeycomb weathering. Many sandstone beds exhibit weakly developed trough and tabular cross-bedding in thin to medium beds.

Oddly, the large grains "pebbles and small cobbles" are virtually all of black chert (Fig. 2). Conglomerate is not abundant in the Crazy Hollow, except in northern Sanpete County, and most conglomerate beds are thin. Pebble-supported fabric is the exception rather than the rule. Many sandstone beds have pebble bands or floating pebbles and small cobbles of black chert. Black chert pebbles are locally common in well-cemented mudstone or siltstone, like raisins in cake.

WHITE OR "CLEAN" SANDSTONE

Beds of pale-yellowish-gray or very light gray sandstone are present in many areas and are the principal deposit of the formation locally, as on the south end of the high top of the Gunnison Plateau (Fig. 1: Area 7A), in the southwest quarter of the Manti quadrangle.[1] The "clean" sandstone is mineralogically and structurally quite like that of the salt-and-pepper sandstone, except for the fewer and smaller grains of black chert. These are also litharenites or feldspathic litharenites, but without conspicuous black chert, and are the main sandstones in northern Sanpete County (Fograsher, 1956). Norton (1986) noted that most white sandstone beds in the southern districts are lensatic and many in the northern districts are broad blankets. Curiously, pebbles and larger grains of quartz or white and light-gray chert are uncommon, so that there are no white or "clean" conglomerates.

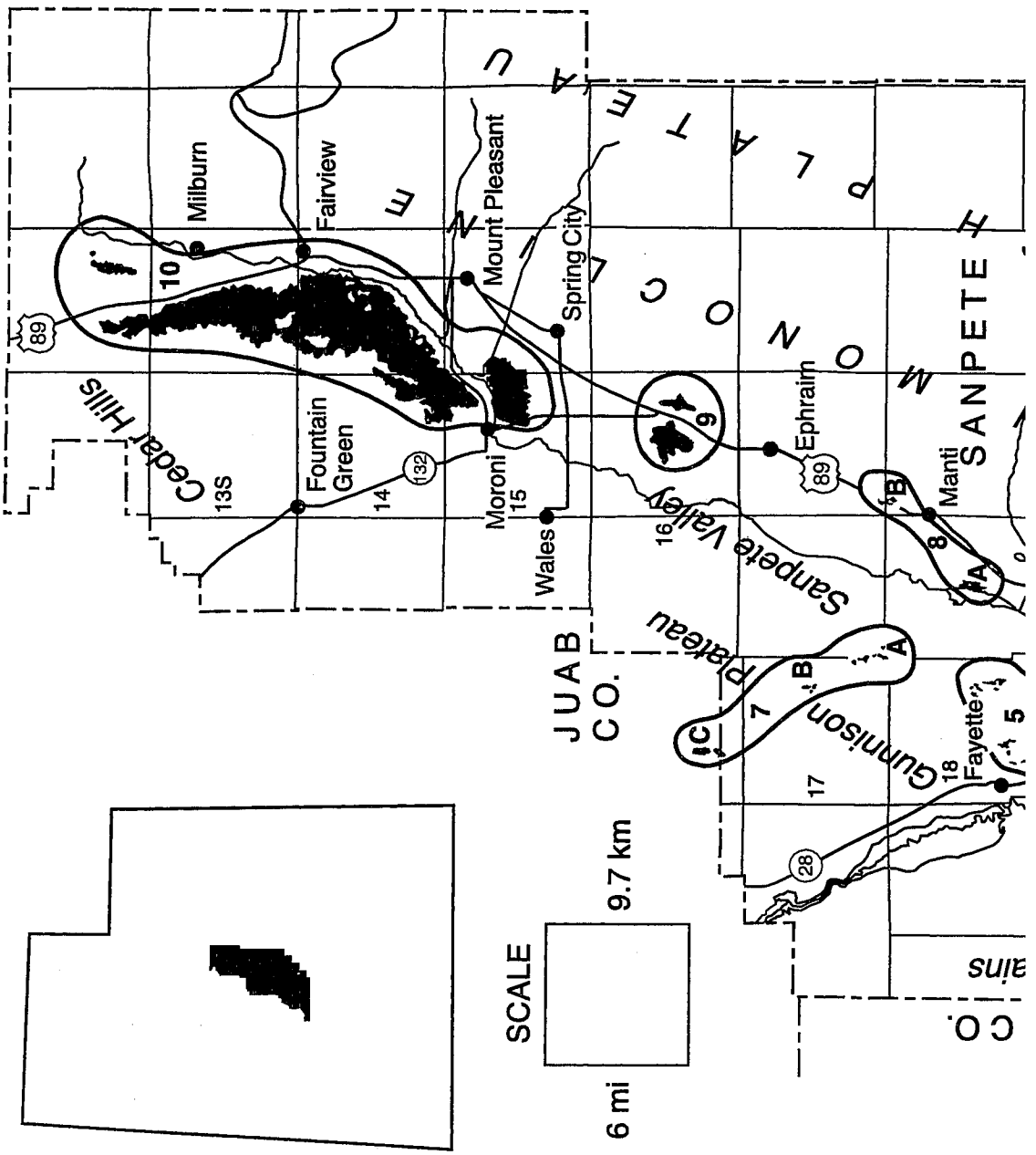
QUARTZITE CONGLOMERATE

In far northern Sanpete County, north and northwest of Fairview city, on the southeast flank of the Cedar Hills, the Crazy Hollow Formation contains medium to thick beds of coarse quartzite pebble and cobble conglomerate (Fograsher, 1956). The well-rounded clasts, from several Proterozoic quartzite formations, are reworked from Cretaceous conglomerates in Hop Creek Ridge in the central Cedar Hills, not far west of the area.

MUDSTONE AND SILTSTONE

Mudstone and siltstone of various colors make up the bulk (80–85 percent) of the Crazy Hollow Formation in most of the numbered areas and lettered subareas (Fig. 1), (Norton, 1986), except in northern Sanpete County (Area 10), where it is about half of the formation (Fograsher, 1956). Locally however, particularly where the formation is thin, there is little or no mudstone or siltstone, as in Subareas 7A, 7B, and Area 9. All of the mudrocks are sandy

[1]All quadrangles named are 7.5-minute quadrangles unless otherwise specified.


SANPETE
SEVIER
PIUTE
JUAB CO.
Milburn
Fairview
Mount Pleasant
Spring City
Ephraim
Manti
Fountain Green
Moroni
Wales
Sanpete Valley
Gunnison Plateau
Fayette
Cedar Hills
10
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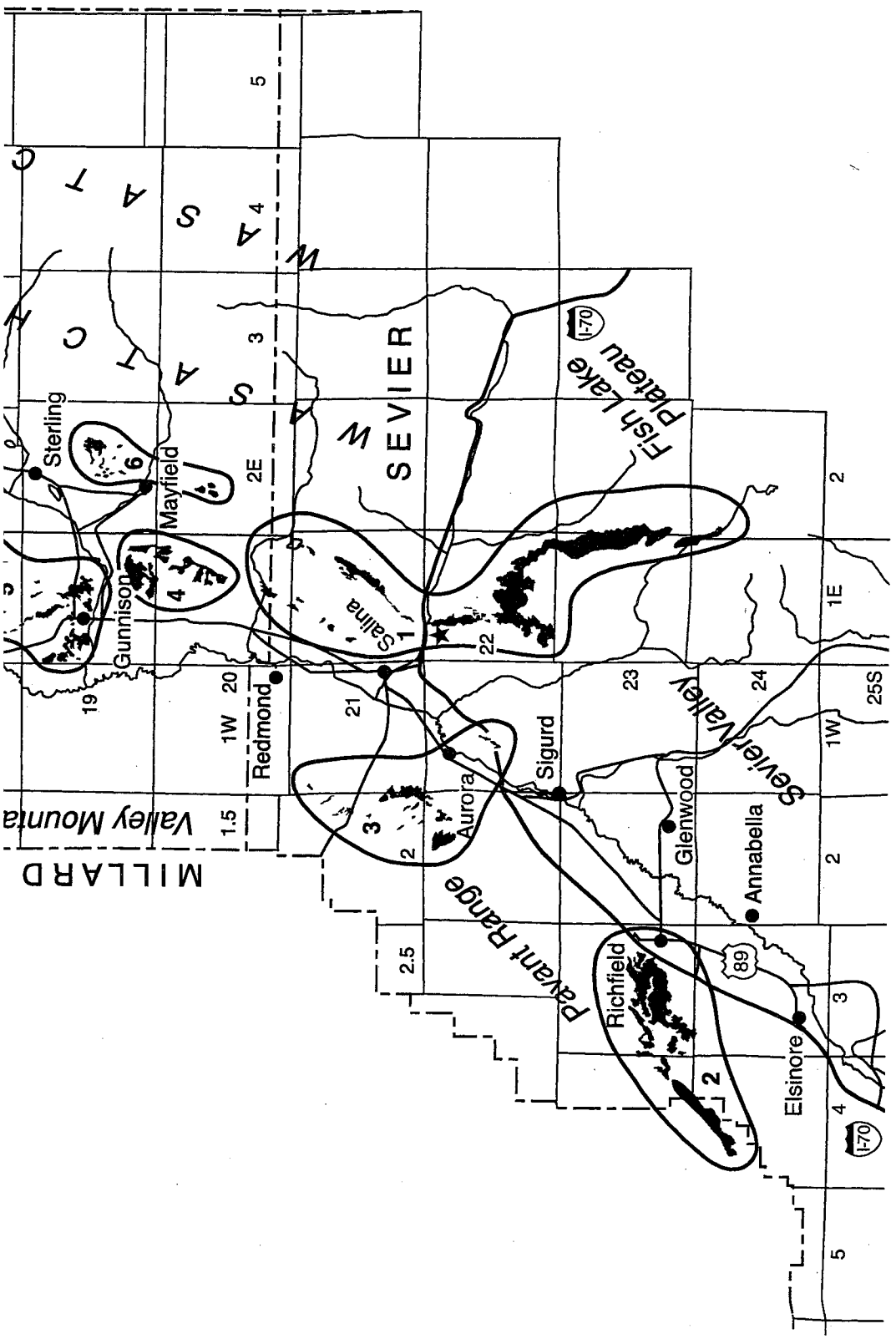

Figure 1. Map of Sanpete County and part of Sevier County, Utah, with the geologic map of the Crazy Hollow Formation represented by solid black areas. Coherent areas of outcrop patches of the formation are outlined and numbered 1 through 10. Crazy Hollow—the type area—is marked by a star in Area 1. The patches within the numbered areas closely approximate the shapes of outcrops of the Crazy Hollow Formation mapped on the many geologic maps, both published and in various theses and dissertations, from which this map was compiled. Very small outcrops are exaggerated slightly so they may show at the small scale of the map. The base of the map is adapted from the 1:500,000 map of Utah.

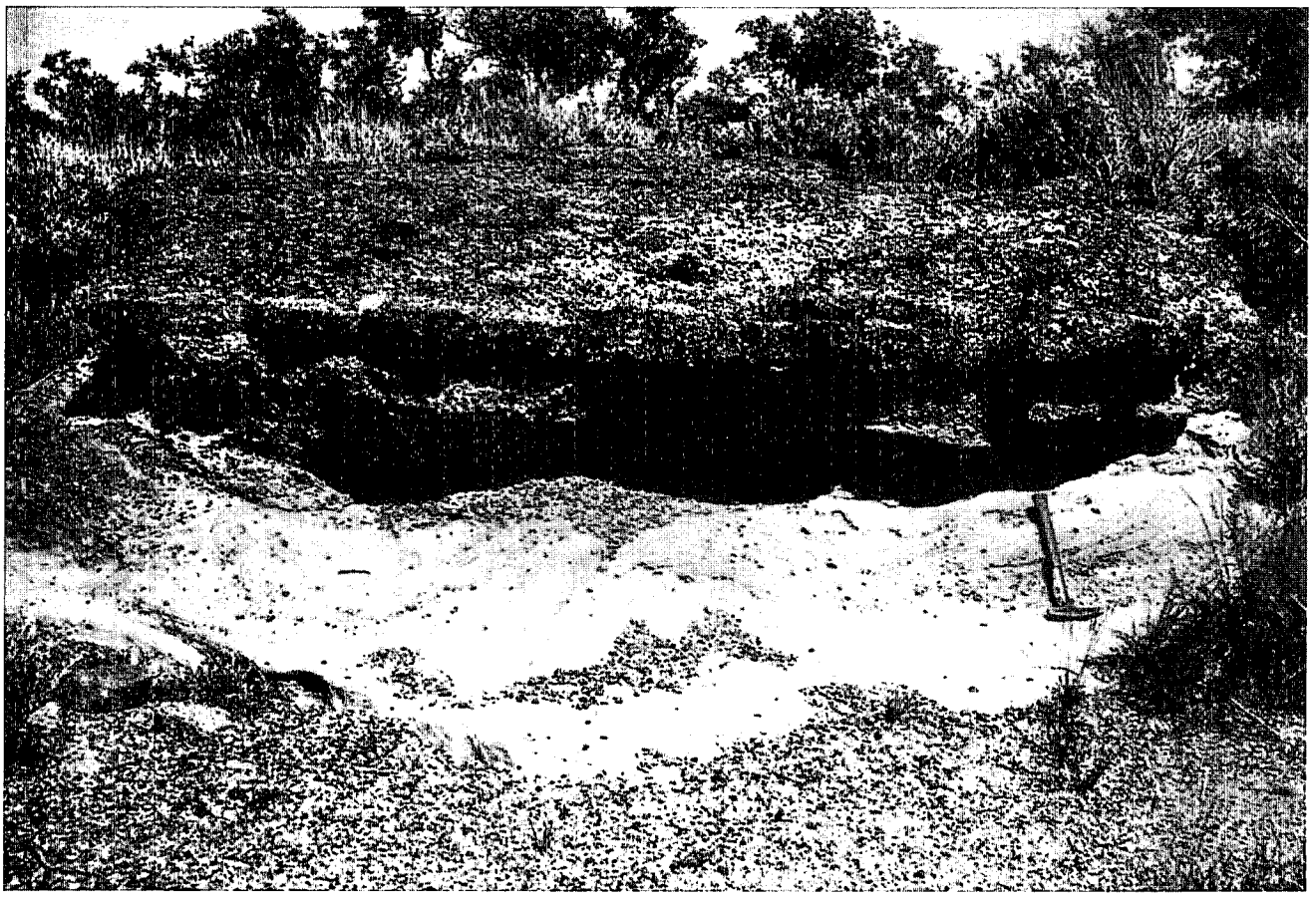

Figure 2. Outcrop of salt-and-pepper sandstone and pebble conglomerate in Subarea 7A (Fig. 1). The small black spots in the foreground are pebbles of black chert lying on the sandstone slope and the soil below it. This is part of the largest of the five outcrops in Subarea 7A, and is in the S1/2SE1/4 section 14, T. 17 S., R. 1 E. Photo by S. R. Mattox.

to some degree; any with more than 50 percent sand are regarded as sandstone. Although Spieker (1949) and several of his students used the term "shale," few of the mudrocks of the Crazy Hollow have the fissility expected of true shales. These beds are colored by traces of iron in various states; most are moderate reddish-brown to very pale orange, but gray, lavender, purple and green also are present. Most of the mudrocks are weakly calcareous and very readily eroded; fresh rock of this sort is covered at most places by regolith and soil having the color of the fresh bedrock beneath it.

CARBONATE ROCKS

Carbonate rocks make up only about 10 percent of the Crazy Hollow Formation regionally, but they are quite varied in appearance and composition. Limestone and dolomitic limestone prevail, but some is limy dolomite. Norton (1986) found that there is very little dolomite in the northern districts, but that in the southern districts the fraction of dolomite in hand samples ranges from 0 to 80 percent. Most limestone and dolomitic limestone beds are yellowish gray, but pale-red and medium-gray limestones are also present locally. Most of the carbonate beds are micrite or intraclastic, with some mud or sand. Norton (1986) referred to some as sandy limestones, but the average carbonate fraction in all types is 85 percent. A few beds contain nodules of light-colored chert, but this is not common. Thicknesses differ widely; most units in measured sections range from less than 2 feet (0.5 m) to 12–14 feet (3.6–4.3 m), but one unit in Norton's measured section near Willow Creek (section 33, T. 20 S., R. 1 E.) is 137 feet (42 m) thick (Norton, 1986).

Except in far northern Sanpete County, most limestone beds contain few macrofossils. A few thin beds of medium-gray or brown biomicrite do contain macrofossils, including gastropods and charophytes (as near Sterling—Fig. 1: Subarea 8A). La Rocque (1956) reported a few clams and snails from the Crazy Hollow Formation; how-

ever, his samples were collected and brought to him by student geologists, so the localities of his fossiliferous Crazy Hollow samples cannot now be known. La Rocque did show that the fauna is the same as that of the Green River Formation, so that no age difference can be presumed from the fossils. Although sparse vertebrate remains are known from the upper Green River Formation (Nelson et al., 1980), none have been observed or reported from the Crazy Hollow Formation.

Thin and medium limestone beds—brown or light gray—in northern Sanpete County are fossiliferous at many outcrops (Fograsher, 1956). They contain principally gastropods and bivalves, but also ostracodes, "plant remains" [probably leaves], and rare "fish remains." Jensen (1988) reported the same suite of biota in the Fairview quadrangle from his upper member of the Green River Formation, which includes what is here called Crazy Hollow beds. Even so, limestone is no more abundant, relatively, there than elsewhere in the region.

RELATIONS OF THE CRAZY HOLLOW TO OTHER FORMATIONS

Spieker (1949) said that the Crazy Hollow Formation lies disconformably on the limestones of the upper member of the Green River Formation. He also believed that overlying bedrock—the so-called Gray Gulch mixed sedimentary and pyroclastic rocks in the Salina-Gooseberry Creek area (Fig. 1: Area 1)—was disconformable on the Crazy Hollow. At the time he knew of only that one superjacent unit. Fograsher (1956) found that the volcanic deposits of the Moroni Formation lie disconformably on the Crazy Hollow Formation on the southeast flank of the Cedar Hills, in the far north of Sanpete County (Area 10). Work by other Ohio State University students found additional outcrops of the Crazy Hollow, mostly in Sanpete and Sevier Valleys, and they all endorsed Spieker's view that the formation is disconformable on the Green River Formation. The beds that Spieker called Gray Gulch in 1949 have been renamed [formation of Aurora (Willis, 1987, 1988)], and the nomenclature of the units lying on the Crazy Hollow along the west side of Sevier Valley (Areas 2 and 3) has also been revised. We will deal first with the base of the Crazy Hollow.

SUBJACENT FORMATIONS

That the Crazy Hollow lies disconformably on the upper limy member of the Green River Formation is now established for many outcrops in Sanpete and Sevier Counties. The contact is not exposed in northern Sanpete County, but Fograsher (1956) interpreted clasts of cherty limestone like that in the Green River Formation as evidence of at least local erosion and disconformity.

Norton (1986) pointed out that there are many examples regionally of the close relationship between the two formations. For example, Willis (1986) found interfingering of the Green River and Crazy Hollow Formations locally in the Salina quadrangle. Farther west, on the west flanks of the Gunnison Plateau, the prevailing condition is structural accordance of the two units, but scour and small-scale intertonguing of the two formations are also present (Fig. 3). Local sharp contacts that suggest scour are common (Weiss, 1982; Mattox and Weiss, 1989; Mattox, 1992).

It is clear that the lithofacies of the upper, limestone member of the Green River Formation changes westward across the Gunnison Plateau, toward the margin of Lake Uinta and the more clastic lake-marginal sediments (Mattox, 1987; Weiss et al., 2000). These western lithofacies of the Green River are more clastic than those typical of the formation in Sanpete Valley, which lies approximately where the deepest part of the southwest arm of Lake Uinta was. The westward changes in the upper Green River makes it more like the Crazy Hollow beds, which led to the similarity between the two at many localities (Weiss, 1982; Norton, 1986; Weiss et al., 2001).

At a few localities the Crazy Hollow Formation lies on or against rock units older than the Green River Formation, as at Big Hollow, southwest of Richfield (sections 3 and 4, T. 24 S., R. 4 W., in Area 2 of Fig. 1), where it lies on coarse conglomerate of the upper Flagstaff Limestone (Schneider, 1964; Norton, 1986; Steven et al., 1990). The Crazy Hollow is faulted down against the upper member of the Jurassic Arapien Shale 2.6 miles (4 km) north of the village of Sterling (Subarea 8A). Nearby it lies disconformably on exposures of the Green River, but local diapirism of the Jurassic Arapien Shale has distorted the area (Subarea 8A), cut out the Green River beds locally, and raised the Arapien against dipping Crazy Hollow beds (Weiss, 1994). The Crazy Hollow lies unconformably on the Arapien Shale northeast of Salina (Area 1). Local diapirism by the Arapien Shale has disturbed Green River and Crazy Hollow beds severely at Rocky Point, just west of the city of Gunnison (Area 5), but the Arapien is not in contact with either bedrock unit (Mattox, 1992).

SUPERJACENT DEPOSITS

No estimate is possible of the amount of Crazy Hollow rock that may have been stripped from sites along the western and eastern margins of Sanpete and Sevier Valleys during later Tertiary and Quaternary times. The formation—of original or lesser thickness—is buried by Quaternary alluvial and valley-fill deposits at many sites in these same areas. Different bedrock units cover the Crazy Hollow Formation in four different areas. One is of sedimentary rocks with only reworked volcanic fractions, but

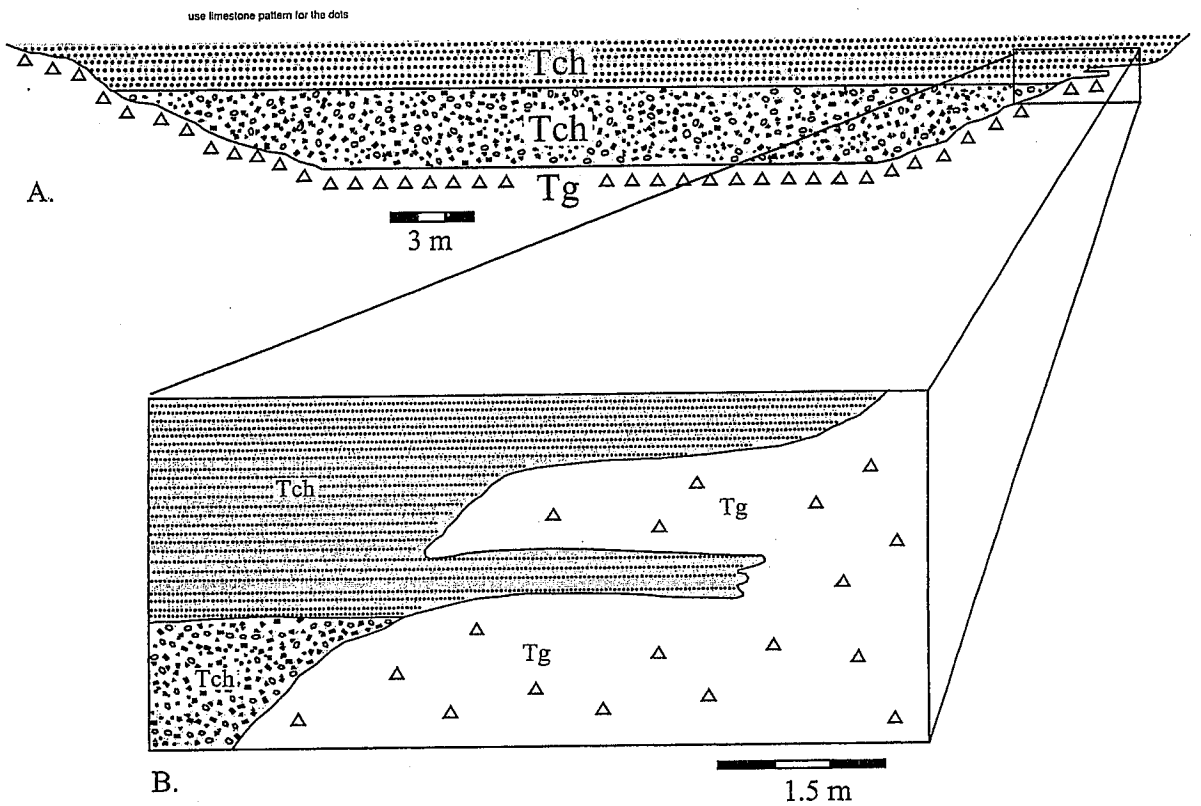

Figure 3. Diagrammatic cross section of the interfingered contact of the Green River and Crazy Hollow Formations in SE1/4SE1/4 of section 5 and NE 1/4NE 1/4 of section 8, T. 19 S., R. 1 E., near the middle of the Gunnison 7.5-minute quadrangle in Area 5 (revised by Mattox from Mattox and Weiss, 1989, and Mattox, 1992, Fig. 2). The beds of the two formations are parallel in that area.

The depression in the Green River limy mud may have been bottom topography or a shallow channel, similar to that described from Area 9. The depression was filled first by sand mixed with black chert pebbles, and then by salt-and-pepper sand that intertongued with the coincidentally deposited limy mud. Both stratigraphic units have hardened subsequently, and cherty blebs and nodules have formed in the Green River limestone.

the other three are of mixed sedimentary and pyroclastic deposits.

In the Aurora-Redmond Canyon area (Fig. 1: northern part of Area 3) the Crazy Hollow is overlain unconformably by the Sevier River Formation of mixed clastics, some limestone and reworked volcanic clasts (Willis, 1987, 1988, 1991). The Sevier River Formation in this area was formerly called the Bald Knoll Formation of presumed early Tertiary age (Gilliland, 1951). This was the type locality of the Bald Knoll, but it was demonstrated to be the Sevier River Formation of Miocene-Pliocene age (Willis, 1986, 1988). Willis (1988) showed further that the rocks that had been called Bald Knoll *elsewhere* in the Sevier Valley-Salina Canyon area were *not* equivalent to the type Bald Knoll; he named *them* "the formation of Aurora" (Willis 1987, 1988).

The superjacent beds in the Salina area (Area 1) were called Gray Gulch by Spieker (1949), but that provisional name never achieved formal usage. Gilliland (1949) had proposed the name Bald Knoll for a sequence of very light-colored claystones, siltstones, sandstones, tuffs and some limestones that lies on the Crazy Hollow 5 miles (8 km) due west of Redmond, Sevier County (Gilliland, 1951). The name Bald Knoll then had priority as a formal term, so McGookey (1960) carried it eastward across Sevier Valley (from Area 3 to Area 1) and applied it to the mixed sedimentary and bentonitic unit lying on the Crazy Hollow near and southeast of Salina. Williams and Hackman (1971) followed McGookey's usage. But these beds are *not* correlative with Gilliland's type Bald Knoll, now known to be Miocene-Pliocene in age; they are late Eocene in age (Willis, 1986, 1987, 1988). Willis substituted the formation of Aurora for them, suppressed the name Bald Knoll, and substituted Sevier River Formation for the type Bald Knoll of Gilliland (1949, 1951). Upper Eocene beds formerly mapped as Bald Knoll (Lautenschlager, 1952; McGookey,

1960; Williams and Hackman, 1971) were renamed formation of Aurora (Willis, 1987). Steven et al., (1990) also used Bald Knoll in the old sense; doubtless the interval between their work and its publication was long. The upper Eocene beds consist of mudstone, bentonitic shale, sandstone and limestone, and they—the formation of Aurora—overlie the Crazy Hollow disconformably not only in its type area (Area 1), but also in Area 2 and the southern part of Area 3 on the west side of Sevier Valley (Norton, 1986; Willis, 1986, 1988, 1991).

In far northern Sanpete County, the Crazy Hollow Formation is overlain disconformably by the upper Eocene to middle Oligocene Moroni Formation, a unit of tuff, volcanic breccia and conglomerate, and waterlain sandstone (Schoff, 1951; Witkind and Marvin, 1989). The eroded edge of the Moroni Formation lies disconformably on the Crazy Hollow; at some sections only thin sheets of disaggregated Moroni cobbles crop out over the Crazy Hollow top (Fograsher, 1956). Schoff (1951) mapped the Crazy Hollow beds as part of the Green River Formation.[2] The Green River-Crazy Hollow contact is not exposed in this area, but can be closely estimated (Fograsher, 1956). Jensen (1988) denied that the Crazy Hollow exists in this area, but we believe that he was mistaken, as explained below.

THICKNESS

The thickest sections of the Crazy Hollow lie on the Green River in Area 4, on the dip slopes of the hogbacks along the east edge of Sevier Valley, between Salina and Mayfield, where Gilliland (1951) found 1,000 feet (305 m) of Crazy Hollow. Norton (1986) measured 1,307 feet (398.4 m) of the unit in this region, in sections 33 and 34 of T. 20 S., R. 1 E. Spieker (1949) cited "about 600 feet [183 m]" for the thickness of the Crazy Hollow in the type area, about 8 miles (13 km) farther south. McGookey (1960) measured a complete section not far south of the type locality as 997 feet (304 m), but Willis (1986) found no unfaulted sections in the area, and estimated the true thickness to be between 600 and 800 feet (183–244 m). Fograsher (1956) estimated that the unit is "at least 210 feet [64 m] thick" in northern Sanpete County, at the edge of the Cedar Hills.

Regionally, then, the Crazy Hollow can be said to range from 0 to 1,307 feet (0–398 m) in thickness. At many outcrops it is much closer to the minimum than the maximum thickness, being only a few scores of feet (12–50 m) thick.

[2]Although published in 1951, two years after the Crazy Hollow Formation was named, Schoff's map was completed in 1936.

AGE OF THE CRAZY HOLLOW FORMATION

Spieker suggested that the age of the Crazy Hollow "is probably Eocene, and may be late Eocene," based solely on physical criteria. Gilliland (1951) considered the issue and concluded that it is "likely late Eocene." The limited fossil suite studied by La Rocque (1956) shows that the Crazy Hollow fauna is about the same as that of the Green River Formation, but he settled on "Eocene?" for its age. Fograsher (1956) apparently took no advantage of the fossils he found, and did not hazard a suggestion of the age of the Crazy Hollow. Weiss (1982) considered evidence of the age of the Green River adduced by both vertebrate paleontologists and geochronologists, and concluded that the Crazy Hollow was Oligocene in age. Norton (1986) reviewed several works of the early 1980s and said that the Crazy Hollow is late Eocene in age. Willis (1986) showed that the Green River and Crazy Hollow Formations interfinger locally in the Salina area, as Weiss (1982) and Mattox and Weiss (1989) had shown elsewhere. Sheliga (1980) obtained ages of about 43 million years for the lower member of the Green River near Ephraim, by $^{40}Ar/^{39}Ar$ analysis. Bryant and others (1989) obtained ages of 45 to 42 million years by fission-track dating of tuffs in the Green River at the north end of the Wasatch Plateau. Based partly on such reports, workers in recent years have considered the Crazy Hollow to be late Eocene in age and only slightly younger than the top of the Green River. According to Cande and Kent (1992), however, such radiometric ages as are mentioned above are in the middle of the middle Eocene (upper Lutetian). Thus a middle Eocene age is adopted for this report.

LITHOFACIES BY AREAS

The principal rock types have been described and the high variability of lithofacies across central Utah has been emphasized. In this section the main characteristics of the Crazy Hollow Formation in each of several areas and subareas (Fig. 1) will be summarized,

1–THE SALINA-GOOSEBERRY CREEK AREA

This includes the type area (the star in Fig. 1) of the Crazy Hollow Formation and exposures southeast and northeast of the city of Salina, all in the Salina quadrangle (Spieker, 1949; Willis, 1986), and the southeastward extension of the formation up the north slope of the Fish Lake Plateau into the Rex Reservoir quadrangle and the Gooseberry country (McGookey, 1960; Williams and Hackman, 1971). A section measured by McGookey (1960) about 1.5 miles (2.4 km) up Crazy Hollow from Salina Canyon totaled 997 feet (304 m) and consisted of salt-and-pepper sandstone (6.5 percent), sandstone (15 percent), sandstone with

lenses of salt-and-pepper sand (29.2 percent) and mudstone (49.3 percent). Norton (1986) measured a section about one mile (1.6 km) upstream from McGookey's; it totaled 948 feet (289 m) and included salt-and-pepper sandstone (1.4 percent), sandstone (13.6 percent), siltstone (8 percent) and mudstone (77.1 percent). The mudstones are highly varied in color, including red to orange, reddish brown, purplish red, yellow to orange, pinkish gray and green (McGookey, 1960; Norton, 1986).

Although the two sections are closely comparable in thickness, both may be somewhat too thick, for Willis (1986) found no unfaulted sections of the Crazy Hollow in that vicinity. Older published works assert a disconformity between the Green River and the Crazy Hollow, but more recent studies consider the contact generally gradational (Willis, 1986). McGookey (1960) named the superjacent beds Bald Knoll—now the formation of Aurora (Willis 1986, 1988).

2–THE RICHFIELD AREA

The southwestern-most extent of existing Crazy Hollow beds is just west and southwest of the city of Richfield, Sevier County (Steven et al., 1990). The exposures are on the southeast flank of the dip slope of the Pavant Range, in an area close to the southern limit of Lake Uinta. The Green River Formation pinches out southward in the vicinity (Lautenschlager, 1952), so that the Crazy Hollow lies on the Green River toward the north, but on the Flagstaff Limestone (the Colton Formation is also absent there) south of the pinchout (Steven et al., 1990). Schneider (1964) denied that the Green River pinches out, but his map is ambiguous on the point and he gives no evidence for his prediction that the Green River will be found in the adjacent Sevier quadrangle, next to the south. Steven et al. (1990) adopted Lautenschlager's (1952) view of the matter. Schneider (1964) and Steven et al. (1990) mapped the beds lying on the Crazy Hollow as the Bald Knoll Formation, following Gilliland (1951), but Norton (1986), following the work-in-progress of Willis (1986, 1988), used formation of Aurora. The Crazy Hollow beds continue northeast from this area into the southwest corner of the Aurora quadrangle—Area 3—(Willis, 1988).

Schneider (1964) reported that the Crazy Hollow Formation is 260 feet (79 m) thick "just west of Richfield," and Lautenschlager (1952) gave 366 feet (112 m) in the same general area. Norton (1986) measured a section 1,030 feet (314 m) thick in Big Hollow, in the southwesternmost outcrop of the Crazy Hollow, about 8 miles (10.3 km) west-southwest of the center of Richfield. The Crazy Hollow there rests on the quartzite and black limestone cobbles of the conglomerate that lies near the top of the Flagstaff Limestone (Schneider, 1964). She reported the bulk composition of the unit as salt-and-pepper sandstone (0.8 percent), sandstone (13.1 percent), quartzite and black chert conglomerate (1.9 percent), mudstone (14.3 percent), sandy limestone (2.2 percent) and a covered interval of 60.7 percent with pebbles and chunks of limestone in the soil (Norton, 1986). The sandstone beds are reddish gray to yellow, orange and light gray. The mudstones are red and brown, and the sandy limestone beds pale red (Norton, 1986).

3–THE AURORA AREA

This area contains numerous exposures in the Aurora quadrangle (Willis, 1988) and one at the extreme southern edge of the Redmond Canyon quadrangle (Willis, 1991). The Crazy Hollow Formation here continues the trend of the Richfield area, northeastward along the lower slopes of the Pavant Range. It is sandwiched between the Green River Formation and formation of Aurora, as it was in the northern part of the Richfield area. Beds on those slopes are cut by numerous northwest-trending faults that chop them into many blocky outcrops, except close to the village of Aurora. Three tiny outcrops of Crazy Hollow beds are exposed across Sevier Valley in the southeast quadrant of the Aurora quadrangle (Willis, 1988), in the SE1/4 section 16 and the NW1/4 section 21, T. 22 S., R. 1 W. There the Crazy Hollow lies on the Green River beds but has no bedrock cover.

The beds succeeding the Crazy Hollow Formation are different in the far north of the Aurora quadrangle. The few Crazy Hollow outcrops there, both south and north of Denmark Wash, are small fault slices, plus one such slice just across the northern quadrangle boundary, in the Redmond Canyon quadrangle (Willis, 1988, 1991). Only some of those outcrops show Green River beds below the Crazy Hollow, but the succeeding beds are not the late Eocene formation of Aurora. The covering formation, disconformable on the Crazy Hollow, is the Sevier River Formation of Miocene-Pliocene age—previously called the Bald Knoll Formation and formerly thought to be late Eocene in age (Willis, 1988, 1991).

Despite the separation of outcrops to both sides of Sevier Valley, and the significant change in the rock overlying the Crazy Hollow in the northwest, the formation seems to have about the same lithology in all the areas of exposure. Hills of dark mottled orange, red and yellow sandstone and mudstone are punctuated by discontinuous ledges of resistant sandstone (Willis, 1988). Norton (1986) measured a section, about one mile (1.6 km) northwest of Aurora, of 979 feet (298 m) of Crazy Hollow beds between Green River limestone and Aurora mudstone containing volcanic glass. She found that most of the formation (71 percent) is sandstone, followed by mudstone (24.6 per-

cent), muddy sandstone (3.5 percent), one bed of unfossiliferous sandy limestone (0.8 percent) and one bed of pebbly sandstone (0.07 percent).

Although about half of the sandstone beds are pale orange, yellowish orange, or pinkish gray, a rainbow of other colors is present: dark yellowish orange, very light gray, moderate orange pink and grayish orange to reddish brown (Norton, 1986). The sandstone beds are mostly fine or medium grained quartz. Dark-gray or black chert sand grains are not common; no salt-and-pepper sandstone is exposed at this section. Black chert pebbles are conspicuous in the one thin "pebbly sandstone" bed, and two beds of very pale orange sandstone (8 percent of the sandstone total) contain lenses of black chert pebbles (Norton, 1986). A few sandstone beds have the form of a channel fill, and several show both tabular- and trough-cross-bedding.

The colors of mudstone are almost as varied as those of the sandstone beds, but they run to darker shades: reddish orange and reddish brown, orange, yellowish brown and pale red (Norton, 1986). Many are somewhat shaly, and one reddish-brown bed contains numerous crystals of gypsum.

4–THE REDMOND EAST AREA

This area embraces a variety of outcrops low on the outer flank of the Wasatch monocline, all in the eastern part of the Redmond quadrangle (Witkind, 1981). The quadrangle is the southeast quarter of the Gunnison 15-minute quadrangle mapped much earlier by Gilliland (1951); Witkind's map is largely a compilation from Gilliland's work. This area contains the thickest accumulations of Crazy Hollow beds, with no overlying bedrock, although Witkind showed the Bald Knoll [formation of Aurora] over it in the subsurface of his cross section. Some of the outcrop patches that are very wide east-west suggest great thickness, but they are wide because of their low dip.

Norton (1986) measured a stratigraphic section in sections 33 and 34 of T. 20 S., R. 1 E., near the south end of this outcrop belt. The array of rock types there includes salt-and-pepper sandstone and pebbly sandstone (4.2 percent), sandstone (6.6 percent), and limy sandstone (3.4 percent), all in the lower part of the section; mudstone, some beds with lenses of salt-and-pepper sandstone (26.4 percent); limy mudstone (1.6 percent); silty mudstone (8.7 percent); sandy limestone (4.7 percent); muddy limestone (3.3 percent); limestone (11.9 percent) and a covered interval with red and gray mudstone soil (29.4 percent). The sandstone and limy sandstone are light gray, the mudstones are mostly reddish brown or reddish orange, and the limestones are pale red and weather to pale orange or yellowish gray. Her section is 1,307 feet (398 m) thick.

Gilliland (1951) reported the base of the Crazy Hollow as disconformable in the few places where it is exposed in this area. Norton found the formations accordant at the base of her measured section, but the basal pebbly sandstone over Green River limestone suggests a disconformity. Walking out beds to sites somewhat north of her section shows basal Crazy Hollow limestone lying on upper Green River limestone. Once again, the contact appears to be conformable in some places but disconformable in others.

5–THE GUNNISON AREA

Outcrops of the Crazy Hollow Formation are numerous at the southern end of the Gunnison Plateau, just north of where it plunges beneath the sediments of Sevier Valley. This area lies in the northwest quarter of the Gunnison 15-minute quadrangle, mapped by Gilliland (1951), and in the Gunnison 7.5-minute quadrangle, mapped by Mattox (1992). Their results are quite comparable, although Mattox was able to show more detail; Gilliland had the disadvantage of having no topographic maps. Most outcrop patches are all of rusty-weathering salt-and-pepper sandstone, pebbly sandstone and conglomerate with pebbles mostly of black chert. The Crazy Hollow lies on the Green River Formation in this area, and has no overlying bedrock cover. The thickest exposure north of Highway 28 is 65 feet (20 m), at the middle of the 7.5-minute quadrangle. The thickest exposure in the area, estimated by Mattox (1992) to be about 300 feet thick (91 m), is the badly faulted cap of Rocky Point, in the southwest corner of the 7.5-minute quadrangle, just west of the city of Gunnison.

Pale-orange and very light gray micritic limestone beds, each less than 10 feet (< 3 m) thick are rare in the whole area (Mattox, 1992). On the gentle slopes northeast and east of the city of Gunnison the beds are mostly light-gray and reddish mudstones. Gilliland (1951) reported a few unidentifiable bone fragments from the upper beds on Rocky Point. Platy fragments of silicified Green River limestone are present at the base of the Crazy Hollow Formation locally. Even so, the two formations are intimately related and of about the same age (Fig. 3; Mattox and Weiss, 1989; Mattox, 1992).

6–THE MAYFIELD AREA

This is a region of broad dip slopes of cuestas of Green River Formation low on the flanks of the Wasatch monocline. Small patches of the Crazy Hollow Formation lie scattered over the Green River slopes, trapped in many cases on the downthrown (east) side of one of the antithetic faults that cut the monocline. Most of the outcrops are in the south half of the Sterling quadrangle (Weiss, 1994), but a few lie on a similar great Green River cuesta south of Mayfield, in T. 20 N., R. 2 E. of the Mayfield quadrangle (Johnson, 1949). The prevalent rock type is salt-and-pepper sandstone with numerous pebbles and small cobbles of black chert. Light-gray, pink and red sandy mudstone

are interbedded with the grayish sandstone and conglomerate (Weiss, 1994). The Crazy Hollow beds are not covered, even by Quaternary deposits; the thickest outcrops in the area are 90 feet (27 m) thick, probably a mere fraction of the original thickness.

The intimate relation of the Green River and Crazy Hollow Formations is well shown in this area, for thin lenses of red mudstone and pebbly salt-and-pepper sandstone are present high in the beds of the upper, limestone member of the Green River Formation. Further, the small knoll of Crazy Hollow rock in the middle of the SE1/4 of section 22, T. 19 S., R. 2 E. is capped by 15 feet (5 m) of yellowish-brown silty limestone typical of the upper member of the Green River, although that cap is not mapped as Green River (Weiss, 1994).

7–THE TOP OF THE GUNNISON PLATEAU

Three different types of deposits of the Crazy Hollow Formation lie in three different subareas on the top of the south half of the Gunnison Plateau (Fig. 1). The three subareas are: A) the southwest quadrant of the Manti quadrangle (Weiss and Sprinkel, 2000); B) the east-central part of the Hells Kitchen Canyon SE quadrangle (Mattox, 1987); C) the southwest quadrant of the Chriss Canyon quadrangle (Weiss et al., 2001). Subareas A and B are on the crest of the Gunnison Plateau, in the Divide graben (Mattox, 1987) that dropped the upper, limestone member of the Green River Formation to form a resistant cap at the top of the plateau. Subarea C is at the upper bend of the West Gunnison monocline.

A–Manti Quadrangle: Remnants of the Crazy Hollow beds lie atop the upper, limestone member of the Green River Formation on some of the elongate fault blocks within the Divide graben (Mattox, 1987) where it swings southeastward out of the Hells Kitchen Canyon SE quadrangle into the southwest quadrant of the Manti quadrangle (Weiss and Sprinkel, 2000). The Crazy Hollow rock is all "clean" quartzose sandstone, locally cross-bedded, calcareous and weakly cemented. It is fine- to medium-grained and contains only a small population of the black chert grains that make salt-and-pepper sandstone elsewhere. The maximum thickness of Crazy Hollow in this subarea is 70 feet (21 m) (Weiss and Sprinkel, 2000). The bedding in the Green River and the Crazy Hollow is accordant, but the contact is not well exposed, so conformity or lack of it cannot be determined.

B–Hells Kitchen Canyon SE Quadrangle: Five very small patches of fine-grained red sandstone and fine- to medium-grained pebbly salt-and-pepper sandstone and conglomerate lie on top of the limestone member of the Green River Formation in the east-central part of this quadrangle (Mattox, 1987). Pebbles of black chert, white quartz arenite, and gray carbonates are present, and both grain- and matrix-supported conglomerate beds are exposed (Fig. 2). Most beds are but weakly cemented by calcite. The thickest outcrop is about 40 feet (12 m) thick (Mattox, 1987).

Thin-section petrography (T. F. Lawton, written communication, 2000) shows the framework grains are about 50 percent finely crystalline chert, much of it fossiliferous, and microcrystalline collophane. Some grains of collophane contain spherical quartz-filled microfossils that may be radiolarians derived from phosphatic Permian(?) rocks. Other mineral constituents are monocrystalline quartz (25–30 percent), potassium feldspar with both microcline and perthitic textures (5 percent), and sparry calcite (15 percent). The latter may conceal original detrital carbonate grains.

Although Mattox did not map the two members of the Green River separately, the upper, limestone member overlies the lower, shale member here as it does elsewhere in the region. The contact of the Crazy Hollow with the Green River limestone member is not well exposed, but the coarseness of the former suggests a basal conglomerate over a disconformity at these sites. The rock in each of these small patches is weakly coherent (Fig. 2), so that the weathered grains wash down the slopes from the plateau crest. They accumulate on the slumped Colton beds below the down-faulted Green River beds in the Divide graben. On the east side of the crest, particularly, black pebbles are common on soils on those slumped Colton beds in the western part of the Manti quadrangle (Weiss and Sprinkel, 2000). Their appearance there is always startling, for black chert is not present in undisturbed Colton beds.

C–Chriss Canyon Quadrangle: The West Gunnison monocline is conspicuous in the southwest quadrant of the Chriss Canyon quadrangle, and it drops the Colton, Flagstaff and Green River Formations from the top of the Gunnison Plateau down to Flat Canyon and toward Juab Valley. The monocline is cut by a number of mostly antithetic faults. In a graben between such faults in the upper bend of the monocline, near the top of the plateau, is a canoe-shaped map exposure less than two miles long (<3.2 km) of Crazy Hollow beds (Weiss et al., 2001). At its south end this body extends only 200 feet (61 m) into the Hells Kitchen Canyon SE quadrangle (Mattox, 1987).

Most of the exposure consists of bedding surfaces of a well-cemented brownish-orange calcareous silty mudstone and conglomeratic sandstone. Numerous pebbles of black chert are scattered through the mudstone, and most of the pebbles in the sandstone are also of black chert. The cross-bedding in a sandstone layer is inclined NNE, which suggests a southwesterly source (T. F. Lawton, written communication, 2000). Lawton also transmitted the

report of a thin section from this outcrop: it contains 40 percent monocrystalline quartz, some of it highly spherical, 40 percent detrital calcite grains being replaced by calcite cement, 2–3 percent of chert grains with fossil ghosts, less than one percent of K-spar and 15 percent of calcite cement. Worn overgrowths are common among the quartz grains, and relict fossils show among the grains of detrital calcite.

No stratigraphic contact with the Green River Formation is exposed. The Crazy Hollow beds are faulted down against the Colton Formation on the east and down against the lower, shale member of the Green River Formation on the west. Various Quaternary mass-wasting deposits lie over parts of the Crazy Hollow preserved in the graben. Although no thickness can be measured for this exposure, the Crazy Hollow Formation is estimated to be about 400 feet (122 m) thick in this area.

It is well known that the upper, limestone member of the Green River Formation becomes more highly clastic westward in the Gunnison Plateau, toward what once was the margin of the southwest arm of Lake Uinta. This change from open lacustrine toward lake-marginal lithofacies is well displayed in the Chriss Canyon quadrangle (Zeller, 1949; Millen, 1982; Norton, 1986; Weiss et al., 2001). In fact, the rocks and the colors of the upper member of the Green River Formation show increasing similarity westward to the rocks and colors of the Crazy Hollow Formation. Zeller was the first to consider this facies change, and concluded that the brownish-yellow muddy and somewhat pebbly limestones lying on the Arapien Shale in section 6, T. 16 S., R. 1 E., and in sections 1, 12, and 13, T. 16 S., R. 1 W., belonged in the upper part of the Green River Formation (Zeller, 1949). To distinguish them he named them the "Tawny beds," a term with a checkered history in the subsequent 50 years. Some workers have called the "Tawny beds" the Crazy Hollow Formation (e.g., Norton, 1986), and others have kept them in the upper Green River Formation (e.g., Millen, 1982). The history of the usage and assignment of the "Tawny beds" is given by Weiss et al., (2001) and need not be repeated here.

If the "Tawny beds" are called Crazy Hollow, the "normal," limy, upper member of the Green River Formation would be reduced to a small fraction of its regional thickness, and most of the resulting thicker Crazy Hollow section would become a lithofacies of the upper member of the Green River. The facies change westward in the upper member of the Green River is well exposed, so it seems better to regard the calcareous clastic beds once named "Tawny beds" as the lake-marginal lithofacies of that member of the Green River Formation, following Weiss et al. (2001). The consequence for the Crazy Hollow Formation is that it remains a deposit lying mostly on the Green River, here and in regions more central to the old lake basin than Juab Valley. It may well have once overlain the top of the Green River in Juab Valley, but no evidence of that remains.

8–THE STERLING-MANTI AREA

Two small areas of Crazy Hollow Formation crop out in southern Sanpete Valley: A) between 2 and 3.5 miles (3.2–5.6 km) north of the village of Sterling and B) on Temple Hill in the northeast corner of the city of Manti (Fig. 1). Rocks in the two subareas are quite different, and each subarea exposes special features of stratigraphy and structure.

A–Sterling: A shallow syncline that is broken by several faults strikes north in the middle of the north half of the Sterling quadrangle (Weiss, 1994). Rocks of the Colton, Green River, and Crazy Hollow Formations are folded, but the Crazy Hollow beds are confined to the western limb of the syncline. A variety of rock types is exposed in different parts of the Crazy Hollow outcrop. The east-dipping slope in the NW1/4 section 27 T. 18 S., R. 2 E. is thinly covered with sandy red mudstone and sandstone. In the adjacent SW1/4 of section 22 there is much salt-and-pepper sandstone, with reddish-brown, pale-orange, yellowish-gray and pale-red sandstone and mudstone. A great ledge of pebbly salt-and-pepper sandstone by the creek in the NW1/4SW1/4 of section 22 is 33 to 36 feet (10–11 m) thick. Norton (1986) measured a section across the SW1/4 of section 22 and got a total thickness of 659 feet (201 m). As this does not include the red beds farther south in the syncline, this may be a minimum thickness for the Crazy Hollow Formation in this subarea.

The varicolored mudstone and sandstone beds in her measured section continue on the north side of the abandoned railroad grade, into the NW1/4 of section 22, but are not well exposed there (Norton, 1986). Of special interest, however, are two (locally three) thin beds of dark-brown gray-weathering fossiliferous limestone close to the line between the SW1/4 and NW1/4 of section 22. Each bed is less than one foot (~26 cm) thick, and they are grouped in an interval less than 10 feet (3 m) thick. Whole gastropod shells, species of the genera *Goniobasis* and *Physa,* some spar-filled or with partial geopetal mud fillings, are present. Shells of the bivalve genera *Elliptio* and *Sphaerium* and abundant flakes of broken shell are stacked parallel to bedding. All are aquatic species. Charophytes appear in thin sections of the limestones (Norton, 1986).

B–Temple Hill: A low cuesta of Green River and Crazy Hollow rocks—part of the Wasatch monocline—lies across the border of the Manti and Ephraim quadrangles at the north edge of the city of Manti (Weiss and Sprinkel, 2000). Most of the volume of the hill is of the upper, limestone member of the Green River Formation, on which the Manti

Temple of The Church of Jesus Christ of Latter-day Saints stands. The Temple was built of the limestone from that hill.

Both the Green River and Crazy Hollow beds are repeated in Temple Hill, for the western part of the hill is a northwest- to north-dipping cuesta of upper Green River and Crazy Hollow beds, while the higher and more easterly part of the hill is a shallow syncline of both lower and upper members of the Green River Formation and the repeated Crazy Hollow Formation (Weiss and Sprinkel, 2000). The rocks of the syncline are in "fault contact" with the north- and northwest-dipping beds in the underlying cuesta. But the syncline is believed to be a toreva block (rather than a faulted block) that rode down the dip of the monocline and came to rest on the crest of the cuesta beneath it (Weiss and Sprinkel, 2000).

The most conspicuous elements of the Crazy Hollow beds in Temple Hill are salt-and-pepper sandstone and pebble conglomerate that form cliffs. They are present both in the cuesta and in the overlying synclinal toreva block, but the cliffs are thinner and less resistant in the synclinal block. This accords with the view that those beds came from an original site both farther east of the cuesta and farther from the source of the Crazy Hollow sediments. Yellowish-gray and orange mudstone is also present beneath the gray-weathering cliffs of sandstone and conglomerate. The thickness of the Crazy Hollow in the lower outcrop (the cuesta) is 54 feet (16 m) (C. E. Corbató, personal communication, 2000). Of that, 30 to 34 feet (9–10 m) is a mudstone weathering light orange and overlain by cliffs 20 to 24 feet (6–7 m) thick of salt-and-pepper sandstone and conglomerate.

9–THE EPHRAIM-SPRING CITY AREA

Cuestas of the Green River Formation lie at the toe of the Wasatch monocline at many latitudes, but they are most conspicuous and expose the thickest sequences of beds in a chain of cuestas that reaches from Ephraim to the latitude of Spring City. Their dip slopes lie not far east of U.S. 89 in this belt, which is well displayed on the Chester quadrangle. Just south of the junction of U.S. 89 with Utah 132, a great cuesta lies to the east of 89 and a smaller one to the west of it. That to the east is upper Green River with a thin scab of Crazy Hollow sandstone on its back. That to the west, named Sand Ridge, and lying west of the abandoned railroad grade, is entirely Crazy Hollow sandstone, about 115 feet (35 m) thick. Both of those outcrops are of "clean" sandstone, being mostly of quartz and white chert and weathering to yellow or orange. Sand grains of black chert are conspicuous in fresh rock, but not so abundant as in the salt-and-pepper sands.

On the east side of U.S. 89, just south of that road junction, is a low cut, made in 1957 during a realignment of the highway, in the toe of the Green River limestone cuesta. At the south end of the cut is a lens 0 to 6 feet (0–2 m) thick of yellowish-gray-weathering sandstone with some black chert sand grains. (The south half of the lens has been cut off by the topography.) It is Crazy Hollow rock, but it is enclosed in Green River limestone beds with shale partings. It is part of the succession of beds that built the upper member of the Green River Formation and another evidence of the intimate relationship between the Green River and the Crazy Hollow Formations (Weiss, 1982). The lens may have been a distributary channel on the floor of the lake or swamp in which the Green River limestones were forming—or even a sand bar in Lake Uinta. But the rock type presaged the coming of the Crazy Hollow Formation.

10–THE FAIRVIEW-MOUNT PLEASANT AREA

The Crazy Hollow Formation was identified in this region near the northern edge of Sanpete County and mapped on aerial photos by Fograsher (1956). The beds dip very gently westward here, so that the underlying Green River Formation lies to the east and the Moroni Formation lies to the west of and in patches on the Crazy Hollow beds. The Fairview quadrangle, which contains part of the area mapped by Fograsher, was mapped on a topographic base by Jensen (1988). Jensen's map is much more detailed than Fograsher's, although it has no section lines on it. Jensen, however, believed that the Crazy Hollow is not present in the Fairview quadrangle, but that it pinches out about 2 miles southwest of the city of Fairview, in the Mount Pleasant quadrangle. Consequently, Jensen included those beds mapped by Fograsher as Crazy Hollow in the upper member of his Green River Formation. Jensen was encouraged in this direction by personal communication(s) from I.J. Witkind (Jensen, 1988). Witkind himself also omitted the Crazy Hollow from this region (including the Mount Pleasant quadrangle), despite having made use of Fograsher's work (Witkind and Weiss, 1991). Jensen (1988) also noted that Schoff (1951) did not map the Crazy Hollow Formation, but although it was published in 1951, Schoff's map was made in 1932 and 1936.

Stratigraphy: Fograsher (1956) measured 10 sections of the Crazy Hollow Formation in the Mount Pleasant-Fairview area, between T. 15 S., R. 3 E. and T. 12 S., R. 4 E. Seven of them have the Moroni Formation at the top and two of the seven expose his Zone C (the uppermost) of the Green River Formation close to the base of exposed Crazy Hollow beds. In the five of his sections that lie in or close to the Fairview quadrangle the apparent full thickness of the Crazy Hollow is from 169 to 221 feet (52–67 m) thick. Fograsher (1956) estimated that the formation in the northern part of the area was at least 210 feet (64 m) thick. Jensen said the thickness of his upper member of the

Green River Formation ranges between 1,394 and 1,968 feet (425–600 m) thick within the Fairview quadrangle (Jensen, 1988). Thus, Jensen's concept of the upper member of the Green River Formation includes Fograsher's Crazy Hollow beds and a large thickness of Fograsher's Green River beds.

It is clear from Jensen's language that he had a very limited notion of the composition of the Crazy Hollow Formation; he believed it to consist substantially of sandstone. He misunderstood the original definition of the formation (Spieker, 1949), thinking that Spieker meant it as mainly sandstone. He also took as characteristic of the formation the dominantly sandstone—with minor black chert grains—lithofacies of the Ephraim-Spring City trend, citing Bonar (1948) and Faulk (1948). The beds of the Crazy Hollow that remain in that area are indeed mostly sandstone, but are by no means typical of the whole formation regionally. Jensen apparently had no knowledge of the lateral variability of the unit, and depended on old work (Bonar, 1948) from one particular area to color his view. Not having worked his way into the Fairview area from much farther south, Jensen's view of the Crazy Hollow was too narrow, too simple, and biased as to the composition of the unit. Jensen was also influenced by the fact that Schoff (1951) had mapped only Green River beds in the Fairview area, although Schoff's map was made in 1932 and 1936, long before the Crazy Hollow Formation was defined.

Inspection of the area by the senior author in 1991 convinced him that Fograsher's stratigraphy describes the Green River and Crazy Hollow Formations in this area better than does Jensen's. What remains to be described here is the relationship between the Crazy Hollow of Fograsher (1956) and the upper member of the Green River Formation, into which Jensen (1988) put all the beds that Fograsher had mapped as Crazy Hollow. Jensen was able to publish only one measured section of the Green River; it was measured on the same cliffs on which Fograsher measured his Section No. 1, in the SE1/4 [not the SW1/4 as Jensen stated] of section 14, T. 13 S., R. 4 E., about 1.5 miles (2.5 km) southwest of Milburn. The two sections are closely comparable, but neither displays the entire thickness of the Green River Formation. Fograsher's Green River Zones A (Units 1 and 2) and B (Unit 1) are recognizable in Jensen's descriptions, but Fograsher's Zones B (Unit 2) and C are absent from Jensen's section. Thus, Jensen's published section, being all Green River beds, contains none of the beds that Fograsher included in the Crazy Hollow, and does not help us with the issue of presence or absence of the Crazy Hollow Formation.

The critical defect in Jensen's argument has to do with a thick (about 40 feet [12 m]) sandstone that is conspicuous low in the Crazy Hollow Formation in section 15, T. 14 S., R. 4 E., about 2 miles (3.2 km) southwest of Fairview, in the Mount Pleasant quadrangle. Fograsher called this the "sandstone member" of the Crazy Hollow, noted that it interfingers with shale to the south, continues only a short distance north of section 15, and has at least 25 to 35 feet (7.6–10.7 m) of brown and gray shale and mudstone between it and Zone C of his Green River Formation (Fograsher, 1956). The "sandstone member" occupies less than a square mile, and was not mapped elsewhere by Fograsher; he suggested that it may be a sandbar (Fograsher, 1956). Jensen (1988) took that sandstone, which does not crop out in the Fairview quadrangle, to *be* the Crazy Hollow Formation. The trouble with his conclusion is that an additional thickness of beds (about 100 feet [30 m]) lie *above* that sandstone and beneath the volcanic Moroni Formation. Jensen mapped those 100 feet of beds, the horizon of the sandstone, and a great thickness of beds below that horizon as his upper member of the Green River Formation (Jensen, 1988). This implies that the Crazy Hollow in the Fairview-Mount Pleasant area is a lens with thick tongues of Jensen's upper member of the Green River Formation both below and above it. The reality of small-scale intertonguing of Green River and Crazy Hollow lithofacies close to the formational contact is a major point already set forth in this paper. But no evidence has been offered from anywhere in the region that the two formations intertongue units of the order of a hundred or more feet (30 m) thick. Jensen (1988) is simply wrong about the Crazy Hollow, although his map is graphically superior to Fograsher's. The qualities ascribed to the Crazy Hollow Formation in the Fairview-Mount Pleasant area are here summarized from Fograsher (1956).

Lithology: The percentages of the thicknesses of the several rock types summed from Fograsher's 10 sections are as follows: shale and mudstone (54.3 percent), sandstone (29.1 percent), conglomerate (8.7 percent) and limestone (8 percent). One third of the thickness of all of his sections is covered intervals; it is tempting to presume that they are mostly mudstone, which would make the mudstone percentage of the whole 69.3 percent. But because the exposed thick mudstone units contain a number of thin and medium sandstone and limestone beds, those rocks would not be represented accurately; the above values from exposed beds are the better basis.

Mudrocks: The mudstone and shale beds are colored brown, yellow, green, gray, red or purple; red and purple are in the minority. Many are "blocky," as Fograsher (1956) called them; such are taken to be mudstone rather than true shale. Nearly every mudstone or shale unit is greater than a few feet (1 m) thick, a few are 10 to 20 feet (3–6 m) thick, and the thickest fully exposed is 55 feet (17 m) thick. Fograsher (1956) pointed out that shale and mudstone beds are more abundant (82 percent of the thickness

exposed in his measured sections) south of Fairview than in the northern sections (39 percent) near the north edge of the Fairview quadrangle, where conglomerate is a significant fraction of the Crazy Hollow Formation. Though the entire formation is calcareous, Fograsher (1956) reported no fossils in the mudstones and shales.

Sandstone: The sandstone beds are red, gray, buff and tan, and most are medium to coarse grained. Most are medium to thick bedded—3 to 15 feet (1–4.5 m) thick—except for the "sandstone member" of Fograsher (1956). That body has a maximum thickness of 43 feet (13 m) in the cliffs along the San Pitch River just southwest of Fairview. It is light-yellowish-gray brown-weathering medium- and coarse-grained quartz and lithic sandstone moderately well cemented with calcite, and contains traces of biotite and pyroxene. It contains a very few percent of black chert grains as well. The unit is cross-bedded, grades into mudstone southward, and terminates abruptly on the north, outside of the Fairview quadrangle (Fograsher (1956). It is probable that the same sandstone body extends northwest about 3 miles (5 km) to Fograsher's measured section No. 17 (NW1/4 section 8, T. 14 S., R. 4 E.), but that is also outside of the Fairview quadrangle, so that Jensen (1988) was accurate in stating that the "sandstone member" (i.e., the Crazy Hollow Formation to Jensen) did not crop out in the Fairview quadrangle.

Though he makes no mention of salt-and-pepper sandstone, Fograsher (1956) cites one occurrence of black chert pebbles, low in the "sandstone member." They average one inch (2.6 cm) in diameter, and are associated with small slabs of upper Green River cherty limestone. He knew that they resembled similar pebbles from much farther south, but postulated that they had been eroded from one thin (0.1 foot [3 cm]) bed of black chert in the upper member of the Green River a mile or so north of the pebbles. This is hard to credit—to erode chert from high in one formation, round it into pebbles, and deliver them into the lower part of the next younger formation a mile away. Those pebbles are more probably the same black chert brought to other regions of Crazy Hollow outcrop. Why so little black chert was delivered to the Fairview-Mount Pleasant area is not known. It may have been because a high point on the upper plate of the Sevier orogenic belt—the Charleston-Nebo thrust sheet—impeded delivery of pebbles of Paleozoic chert eastward at this latitude.

Conglomerate: The Crazy Hollow Formation contains several beds, 3 to 20 feet (1–6 m) thick, of coarse quartzite conglomerate in the districts 5 to 6 miles (8–9.5 km) north and northwest of Fairview (Fograsher, 1956). The average size of the mainly "buff to gray" clasts is 4 inches (10 cm), and the sandstone matrix is of similar color. No clasts of igneous rock are present, so these conglomerates are unrelated to the Moroni Formation. The conglomerate is 42 percent of the thickness exposed in measured sections in these areas, whereas mudrocks are only 39 percent (Fograsher, 1956). The sandstone that is interbedded with the conglomerate is more varied in color, being red, gray, or tan, and is medium to coarse grained. Jensen (1988) mapped the principal conglomerate ledges as thinning southward from the northwest corner of the Fairview quadrangle, but ignored those in the highlands 7 miles (11 km) due north of Fairview.

These conglomerate beds are a special case for the Crazy Hollow Formation, for its conglomerates elsewhere are all of the black-chert-pebble variety. Just 8 miles (13 km) northwest and 11 miles (18 km) west of this patch of conglomeratic Crazy Hollow, and beyond the volcanics of the Moroni Formation, is Hop Creek Ridge, on the northwest side of the Cedar Hills. On the ridge and to both sides are great thicknesses of Upper Cretaceous conglomerate in the Indianola Group and Price River Formation (Schoff, 1951). Banks (1991) revised the stratigraphy and mapped only units of the Indianola Group there. Regardless of the names, that area is loaded with quartzite cobbles and boulders derived from later Precambrian formations in the Basin and Range province, once the hinterland of the Sevier orogenic belt. Those quartzite clasts in the Crazy Hollow Formation in northern Sanpete Valley are merely reworked from the vicinity of Hop Creek Ridge.

Limestone: Numerous beds of white, light-gray or brownish limestone are present in the Crazy Hollow Formation, and they are more abundant and constitute a greater volume southwest of Fairview than in the north (Fograsher, 1956). Many are platy or thin bedded, and most are fossiliferous—in marked contrast to the Crazy Hollow limestones of southern Sanpete County and points south. Most of these fossils are gastropods and bivalves; ostracodes are common, plant remains uncommon, and fish remains rare (Fograsher, 1956; Jensen, 1988). Most beds of limestone (Fograsher made no attempt to determine the presence of dolomite) are thin, a few are of medium thickness, and one that is 14 feet (4 m) thick lies at the top of the Crazy Hollow, directly under the Moroni Formation, west-southwest of Fairview (Fograsher, 1956).

ENVIRONMENT OF DEPOSITION

Late in the history of the Green River Formation the sediments were mostly thin-bedded limy mud, lenses of oolitic or ostracodal sand, and some stromatolite layers. Thin tuffs, fine ash layers now altered to bentonite, and lenses of quartzose sand are interspersed with the carbonate beds in the highest 10–20 meters of the formation. Locally abundant black chert near the top of the formation presaged the coming of the Crazy Hollow sediments.

The varied mass of different kinds of sedimentary rock

in the Crazy Hollow Formation can only be of subaerial and freshwater origin. The variety of colors of the beds results from different states of oxidation—mostly of iron. The different textures reflect mostly the nature of the rocks and weathered products exposed in the source areas on the highlands surrounding the former southwestern arm of Lake Uinta. The bedding of the sandy and pebbly deposits and the lensing shapes of many suggest stream deposition in channels and on floodplains, with various parts of stream systems—such as point bars, riffles, and overbank deposits—imaginable at many sites. The abundant mudstone deposits are the distal parts of alluvial fans and the finer-grained blankets of mud that locally covered the floor of the old lake basin. All of the deposits are limy, doubtless because of the abundance of carbonates in the bedrocks of the source areas. The limestone beds accumulated in ponds and small lakes on the floodplains and the valley floor. The larger sheets of limestone may represent temporary re-expansions of Lake Uinta as it waxed and waned (in the short term) during its last stages. The strange thing about them is the relative paucity of carbonate deposits in Sevier Valley, as compared to Sanpete Valley, especially in its northern part. Perhaps this is true because Lake Uinta retreated northward, and the lacustrine and paludal environments persisted somewhat longer in northern Sanpete County than farther south in Sevier County. Finally, Basin-and-Range extension tectonics have tipped, bent, and raised the remnants of the Crazy Hollow deposits into a variety of present-day topographic sites.

PALEOGEOGRAPHY

LAKE UINTA AND THE GREEN RIVER FORMATION

The paleogeography of Lake Uinta during the late stages of the deposition of the Green River Formation is relevant to the history of the Crazy Hollow Formation. Green River lakes in Colorado, Utah, and Wyoming accumulated great thicknesses of lacustrine, paludal and lake-margin sediments that make up the Green River Formation. The Green River beds in Utah and Colorado were deposited in Lake Uinta, which occupied a large area south of the Uinta Mountains uplift, but also extended west and southwest around the north end of the Wasatch Plateau and into central Utah, about as far as Richfield (Hintze, 1988, Fig. 76). The "footprint" of this southwest arm—Sanpete Bay—of Lake Uinta was a little larger than that of the present extent of the Green River Formation in central Utah. The perimeter of the Green river outcrop in the region is somewhat greater than that of the Crazy Hollow Formation (Fig. 1).

In central Utah the Green River Formation shows lithofacies changes toward the western margin of Sanpete Bay, an increase of clastic grains and decrease of aquatic carbonate beds. Pinch-outs are present locally. These features that suggest nearness to the shore of Sanpete Bay are present in eastern Juab Valley, the Valley Mountains, and the Pavant Range, but are absent from the northwest flank of the Fish Lake Plateau and the west flank of the Wasatch Plateau. Although the outcrop of the Green River Formation lies across central Utah like a fat sausage, from Thistle to Richfield, Sanpete Bay probably had a somewhat different shape and extended somewhat farther to the east—much farther east than the present eastern limit of the Green River outcrop. Although no one knows how much farther east, it seems probable that Sanpete Bay and the main body of Lake Uinta did not join across the entire area of the Wasatch Plateau and the north half of the San Rafael Swell (Hintze, 1988, Fig. 76).

SOURCE AREAS AND MATERIALS

We know that the Sevier orogenic belt lay west of Sanpete Bay. Remnants of that highland are represented today in the Pavant Range, the Valley Mountains, the Canyon Range, the East Tintic Mountains, and part of Long Ridge. Reasonable sources of the distinctive particles in the Crazy Hollow Formation may be located in one or more of those uplands. But nothing of the sort can be said for the east shore of Sanpete Bay. It is reasonable, therefore, to suggest that the bulk of Crazy Hollow sediments came from the west and southwest.

The abundant black chert in the Crazy Hollow Formation can have come from Mississippian or Permian formations, exposures of which still crop out in the highlands west of the area of Sanpete Bay. The black chert also may prove to be phosphatic generally, as suggested by one sample from Subarea 7C. Black chert may have come from cherty members of the Mississippian Deseret Limestone or the Permian Park City Formation. Highly spherical quartz grains probably came from Jurassic eolianites. Mono-crystalline quartz and the sparse grains of other basement-rock minerals may have been reworked from Paleozoic or Mesozoic sandstone units. The same is true of the feldspars, but some may also have been reworked from exposed edges of the Colton Formation, which lies under the Green River Formation. The concept of feldspar grains having come from far to the southeast of the region (Stanley and Collinson, 1979; Dickinson et al., 1986) was used to explain the significant feldspar content of the Colton Formation (Weiss, 1994; Weiss and Sprinkel, 2000; Weiss et al., 2001). This seems unnecessary for the Crazy Hollow Formation, for occasional grains of feldspar from the Sevier orogenic belt and, especially, from exposed edges of the Colton Formation could have provided the small feldspar fractions in the Crazy Hollow Formation.

DRAINING OF SANPETE BAY

Lake Uinta probably disappeared as a consequence of more rapid drainage and a dryer climate. The greater abundance of carbonate beds in the Crazy Hollow Formation in the northern districts argues that water withdrew northward from Sanpete Bay. The local occurrence of carbonate beds in the Crazy Hollow shows that the water did not sweep out of the bay in a single northward flood. The lake floor was uneven, so that ponds and lakes remained locally on the old lake floor—for years in the cases of the thicker and more extensive bodies of carbonate rocks.

As the lake lowered and the margins of its basin were exposed, clastic sediments spilled into the basin and across the newly exposed lake floor. One set of cross-beds in Subarea 7C (Fig. 1) suggests delivery from the southwest. Regrettably, cross-bedding is not common in the Crazy Hollow Formation, and most is poorly developed. The regional differences seen in the ten different areas of outcrop described earlier arose from differences in the regolith and bedrock upstream from a variety of delivery points.

T. F. Lawton writes (personal communication, 2000) ". . . the source for these rocks consisted of nearby Paleozoic and Mesozoic strata and more distant basement rocks lying generally to the south. I envision a post-Sevier thrust belt, but perhaps pre-Basin and Range, world that ramped gradually toward Phoenix, Arizona and San Bernardino, California. There was no Grand Canyon in the way to intercept basement grains coming from the Mogollon Rim of central Arizona, which had not yet collapsed during extension. I would also judge that much of the salt-and-pepper appearance is the consequence of detrital collophane . . . from phosphatic strata."

No quality of the Crazy Hollow Formation suggests the elevation of the region during Crazy Hollow time. The present wide range of elevations of outcrops of the Crazy Hollow is a result of Laramide movements and Basin-and-Range extension. The failure of the system to accumulate the great thicknesses of post-Green River sediment that lie in the Uinta basin argues that the highlands west (and south?) of Sanpete Bay were lower, had a lesser gradient, and trapped less moisture than did the south flank of the Uinta Mountains.

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[3]Corbató and Moore are Profs. Emeritus of The Ohio State University, and Moore was thesis advisor to A. C. Fograsher.

REFERENCES CITED

Banks, R.L., 1991, Provisional geologic map of the Fountain Green North quadrangle, Sanpete and Juab Counties, Utah. Utah Geological Survey Map 134, 19 p., 2 pls., scale 1:24,000.

Biek, R.F., 1991, Provisional geologic map of the Nephi quadrangle, Juab County, Utah. Utah Geological Survey Map 137, 21 p., 2 pls., scale 1:24,000.

Bonar, C.M., 1948, Geology of the Ephraim area, Utah. Columbus, The Ohio State University, M.S. thesis, 115 p.

Bryant, B., Naeser, C.W., Marvin, R.F., and Mehnert, H.H., 1989, Upper Cretaceous and Paleogene sedimentary rocks and isotopic ages of Paleogene tuffs, Uinta Basin, Utah. U.S. Geological Survey Bulletin 1787-J, 22 p.

Cande, S.C., and Kent, D.V., 1992, A new geomagnetic polarity time scale for the Late Cretaceous and Cenozic. Journal of Geophysical Research, 97(B10):13,917–13,951.

Dickinson, W.R., Lawton, T.F., and Inman, K.F., 1986, Sandstone detrital modes, central Utah foreland: Stratigraphic record of Cretaceous-Paleogene tectonic evolution. Journal of Sedimentary Petrology, 56: 276–293.

Faulk, N.R., 1948, The Green River Formation in the Manti-Spring City area of central Utah. Columbus, The Ohio State University, M.S. thesis, 84 p.

Fograsher, A.C., 1956, The stratigraphy of the Green River and Crazy Hollow Formations of part of the Cedar Hills, central Utah. Columbus, The Ohio State University, M.S. thesis, 88 p. [map scale 1:63,360]

Gilliland, W.N., 1949, Geology of the Gunnison [15-minute] quadrangle, Utah (Abstract). Abstracts of Doctoral Dissertations, No. 57, The Ohio State University Press, p. 69–75.

_____, 1951, Geology of the Gunnison [15-minute] quadrangle, Utah. University of Nebraska Studies, New Series, No. 8, 101 p.

Hintze, L.F., 1988, Geologic history of Utah. Brigham Young University Geology Studies, Special Publication 7, 202 p.

Jensen, N.R., 1988, Geology of the Fairview 7 1/2′ quadrangle, Sanpete County, Utah. Brigham Young University Geology Studies, 35:101–121. [map scale 1:80,000]

Johnson, M.S., 1949, Geology of the Twelvemile Canyon area, central Utah. Columbus, The Ohio State University, M.S. thesis, 91 p.

La Rocque, Aurèle, 1956, Tertiary mollusks of central Utah. *In* Peterson, J.A. (ed.), Intermountain Association of Petroleum Geologists, Seventh Annual Field Conference, p. 140–145.

Lautenschlager, H.K., 1952, The geology of the central part of the Pavant Range, Utah. Columbus, The Ohio State University, Ph.D. dissertation, 188 p.

Mattox, S.R., 1987, Provisional geologic map of the Hells Kitchen Canyon SE quadrangle, Sanpete County, Utah. Utah Geological Survey Map 98, 17 p., 2 pls., scale 1:24,000.

_____, 1992, Provisional geologic map of the Gunnison [7.5-minute] quadrangle, Sanpete County, Utah. Utah Geological Survey Map 139, 11 p., 2 pls., scale 1:24,000.

Mattox, S.R., and Weiss, M.P., 1989, Stratigraphic relations of the Eocene Green River and Crazy Hollow Formations, central Utah (Abstract). Geological Society of America Abstracts with Programs, v. 21(5):113.

McGookey, D.P., 1960, Early Tertiary stratigraphy of part of central Utah. American Association of Petroleum Geologists Bulletin, 44:589–615.

Meibos, L.C., 1983, Structure and stratigraphy of the Nephi NW 7 1/2 Minute quadrangle, Juab County, Utah. Brigham Young University Geology Studies, 30:37–58.

Millen, T.M., 1982, Stratigraphy and petrology of the Green River Formation (Eocene), Gunnison Plateau, central Utah. De Kalb, Northern Illinois University, M.S. thesis, 220 p.

Muessig, S.J., 1951, Geology of a part of Long Ridge, Utah. Columbus, The Ohio State University, Ph.D. dissertation, 213 p.

Nelson, M.E., Madsen, J.H., Jr., and Stokes, W.L., 1980, A titanothere from the Green River Formation, central Utah: *Teleodus uintensis* (Perissodactyla: Brontotheriidae). University of Wyoming Contributions to Geology, 18(2):127–134.

Norton, K.L., 1986, The lithofacies and paleogeography of the Crazy Hollow Formation, central Utah. De Kalb, Northern Illinois University, M.S. thesis, 183 p.

Schneider, M.C., 1964, Geology of the Pavant Mountains west of Richfield, Sevier County, Utah. Brigham Young University Geology Studies, 11:129–139, scale 1:36,200.

Schoff, S.L., 1951, Geology of the Cedar Hills, Utah. Geological Society of America Bulletin, 62:619–645, scale 1:125,000.

Sheliga, C.M., 1980, Sedimentology of the Eocene Green River Formation in Sevier and Sanpete Counties, central Utah. Columbus, The Ohio State University, M.S. thesis, 166 p.

Spieker, E.M., 1949, The transition between the Colorado Plateau and the Great Basin in central Utah. Salt Lake City, Utah Geological Society Guidebook to the Geology of Utah, No. 4, 106 p.

Stanley, K.O., and Collinson, J.W., 1979, Depositional history of Paleocene-Lower Eocene Flagstaff Limestone and coeval rocks, central Utah. American Association of Petroleum Geologists Bulletin, 63: 311–323.

Steven, T.A., Morris, H.T., and Rowley, P.D., 1990, Geologic map of the Richfield 1° x 2° quadrangle, west-central Utah. U.S. Geological Survey Map I-1901, scale 1:250,000.

Weiss, M.P., 1982, Relation of the Crazy Hollow Formation to the Green River Formation, central Utah. *In* Nielson, D.L. (ed.), Overthrust belt of Utah: 1982 Symposium and Field Conference. Utah Geological Association Publication 10, p. 285–289.

_____, 1994, Geologic map of the Sterling quadrangle, Sanpete County, Utah. Utah Geological Survey Map 159, 26 p., 2 pls., scale 1:24,000.

Weiss, M.P., and Sprinkel, D.A., 2000, Geologic map of the Manti quadrangle, Sanpete County, Utah. Utah Geological Survey Open-File Report No. 372, 37 p., 3 pls., scale 1:24,000.

Weiss, M.P., McDermott, J.G., Sprinkel, D.A., Banks, R.L., and Biek, R.F., 2001, Geologic map of the Chriss Canyon 7.5′ Quadrangle, Juab and Sanpete Counties, Utah. Utah Geological Survey Open-File Report No. 383, 67 p., 1 pl., scale 1:24,000.

Williams, P.L., and Hackman, R.J., 1971, Geology, structure, and uranium deposits of the Salina [1° x 2°] quadrangle. U.S. Geological Survey Map I-591, scale 1:250,000.

Willis, G.C., 1986, Geologic map of the Salina quadrangle, Sevier County, Utah. Utah Geological and Mineral Survey Map 83, 20 p., 2 pls., scale 1:24,000.

_____, 1987, The late Eocene formation of Aurora, a replacement for the abandoned Bald Knoll Formation in the Sevier Valley area, central Utah (Abstract). Geological Society of America Abstracts with Programs, 19(5)343.

_____, 1988, Geologic map of the Aurora quadrangle, Sevier County, Utah. Utah Geological and Mineral Survey Map 112, 21 p. 2 pls., scale 1:24,000.

_____, 1991, Geologic map of the Redmond Canyon quadrangle, Sanpete and Sevier Counties, Utah. Utah Geological Survey Map 138, 17 p., 2 pls., scale 1:24,000.

Witkind, I.J., 1981, Reconnaissance geologic map of the Redmond quadrangle, Sanpete and Sevier Counties, Utah. U.S. Geological Survey Map I-1304-A, scale 1:24,000.

Witkind, I.J., Weiss, M.P., and Brown, T.L., 1987, Geologic map of the Manti 30′ x 60′ quadrangle, Carbon, Emery, Juab, Sanpete, and Sevier counties, Utah. U.S. Geological Survey Map I-1631, scale 1:100,000.

Witkind, I.J., and Marvin, R.F., 1989, Significance of new potassium-argon ages from the Goldens Ranch and Moroni Formations, Sanpete-Sevier Valley area, central Utah. Geological Society of America Bulletin, 101:534–548.

Witkind, I.J., and Weiss, M.P., 1991, Geologic map of the Nephi 30′ x 60′ quadrangle, Carbon, Emery, Juab, Sanpete, Utah, and Wasatch counties, Utah. U.S. Geological Survey Map I-1937, scale 1:100,000.

Zeller, H.D., 1949, The geology of the west-central portion of the Gunnison Plateau. Columbus, The Ohio State University, M.S. thesis, 83 p.