Paleogene "rim gravel" of Arizona: Establishing the age of the Music Mountain Formation

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Geological Society of America's Geosphere Supplemental File doi:10.1130/GES00971.1.

INTRODUCTION TO THE FAUNA OF DUFF BROWN TANK, ARIZONA

Students of Eugene Shoemaker (Squires and Abrams, 1975) initially reported the discovery of fossiliferous limestone beds in arkosic sediments near Long Point, northwest of Flagstaff, Coconino County, Arizona. Incomplete shell fragments noted in the exposed beds were incorrectly assumed to be bivalves. Young (1982, 1987) collected specimens from the limestone beds during the 1980s, while examining exposures over a lateral distance of 20 km, and began a lengthy correspondence with J. Hartman concerning their environmental and temporal significance. The goal being to date part of the "rim gravel" section, subsequently referred to as the Music Mountain Formation.

The isolated Duff Brown Tank locality contains a relatively well preserved, relatively diverse assemblage of freshwater gastropod mollusks in thin limestone beds within the arkosic Music Mountain Formation (SF-Figs. 1, 2, 3; Young and Hartman, 2011). The lacustrine mollusk assemblage illustrated and interpreted here as Duff Brown Tank (Locality L4371) is found only at the single locality, although many similar thin limestone beds crop out in the vicinity of Long Point. The Duff Brown Tank gastropod fauna consists of ten taxa: Two species of viviparids, two pleurocerids, four hydrobiioids, a depressed planorbid, a physid, and an ellobiid species (SF-Table 1; SF-Figs. 1–3) that together suggest an early Eocene age, although a late Paleocene age cannot be ruled out. The identifications and interpretations that follow are based on specimens that are generally undeformed or only mildly distorted, and preserve good surfaces and sculpture on replaced external shells.

Documenting the age of Duff Brown Tank local fauna is not straightforward given the few modern diagnostic studies on Paleogene continental mollusks from the Western Interior of North America, and, also some limited work on the continental mollusks in the Four Corners area. The fossils and enclosing sediments were assumed to be Miocene in age by Squires and Abrams (1975). The fossils have since been proposed to be late Paleocene(?)–early Eocene (Young et al., 2007) or early Eocene (Young and Hartman, 2011) based on a similar assemblage described below. In support of this age determination, diagnosing the fossils from Duff Brown Tank requires: 1) assessing the age of the individual faunal elements in the context of known taxa nearest to the Duff Brown Tank location, and 2) reviewing the basis for age assessment of these taxa and their occurrences that are used as a standard of reference. The following sections help place the Duff Brown Tank identifications within the context of our current understanding of Paleogene continental molluscan records of the American southwest and the Western Interior in general.

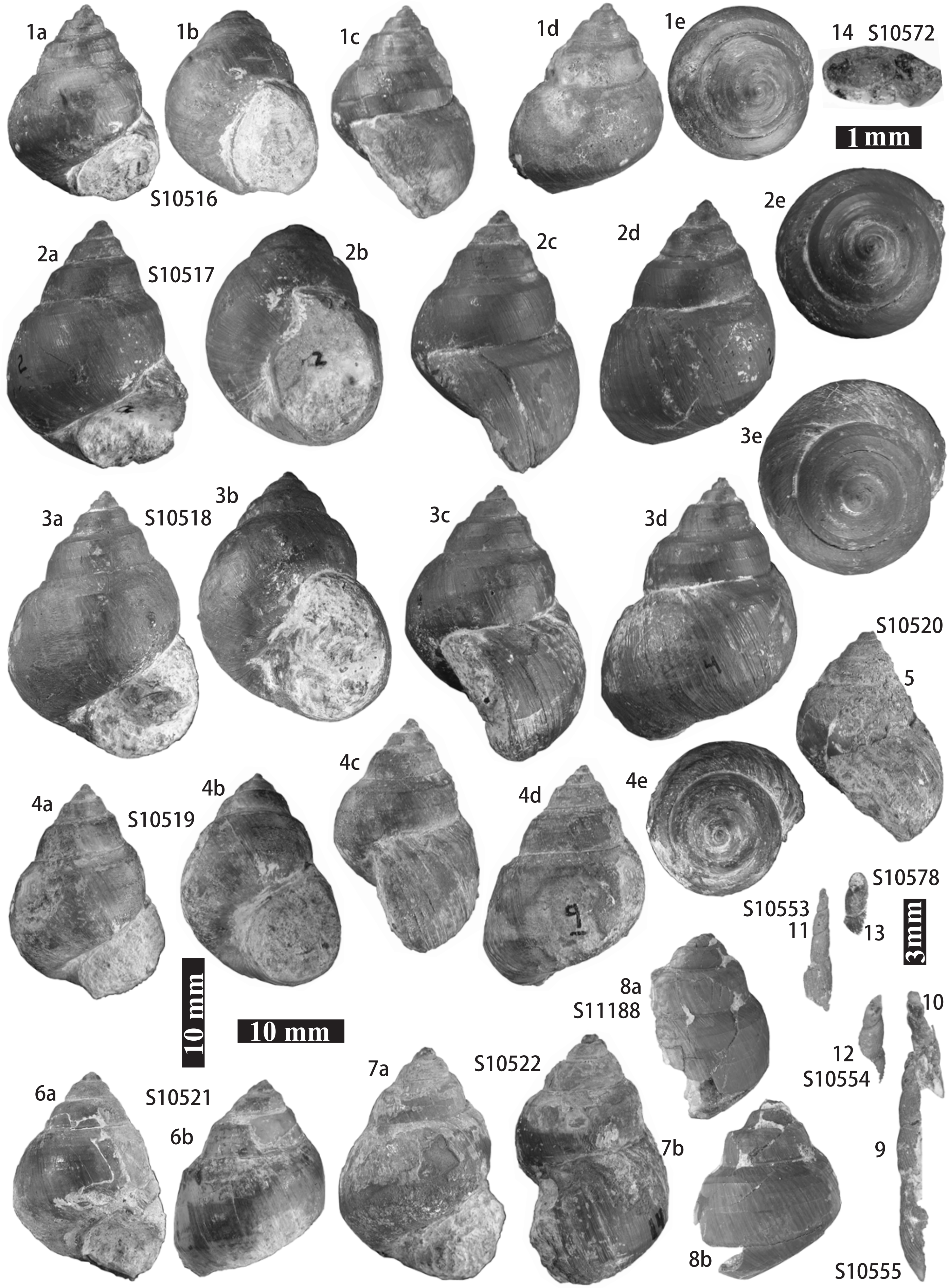
Early Faunal Comparisons and Correlations

The Duff Brown Tank locality fossils exist in relative geographic isolation and cannot be directly correlated with any closely adjacent strata that contain a similar molluscan assemblage. Thus the Duff Brown Tank taxa must be morphologically compared to taxa from other formations of known identity and established age located elsewhere in order to place the local fauna into a taxonomic and biochronologic context. This standard paleontological inference produced the identifications given in SF-Table 1, representing a mix of comparisons to late Paleocene

SF-Table 1. Duff Brown Tank Locality Local Fauna

Viviparus (Viviparidae)
V. cf. *V. meeki* Wenz
V. aff. *V. calamodontis* (Cockerell)
*Lioplacodes** Meek, 1864 (Pleuroceridae)
L. cf. *L. mariana* Yen
L. sp. *L.* form a
"Hydrobia" (Hydrobiidae)
H. aff. *H. anthonyi* (Meek and Hayden)
H. aff. *H. warrenana* (Meek and Hayden)
H. cf. *H*. sp. form b
H. cf. *H*. sp. form t
"Gyraulus" (Planorbidae)
"G." aff. *G. militaris* (White)
Physa (Physidae)
P. cf. *P. longiuscula* Meek and Hayden
P. undet.
*Pleurolimnaea** Conrad, 1866 (Ellobiidae)
P. aff. *P. tenuicosta* (Meek and Hayden)

* Extinct genus.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4b
4c
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S10553
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10 mm
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12
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6b
7a
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7b
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8b
S10555

SF-Figure 1. *Viviparus* cf. *V. meeki, Pleurolimaea* aff. *P. tenuicosta*, and *Gyraulus* cf. *G. militaris* specimen explanations, Music Mountain Formation, Duff Brown Tank, Coconino County, Arizona. Images 1–8. *Viviparus* cf. *V. meeki* Wenz (with 10-mm bar scale).
Image 1–UND-JHH S10516: 1a. Apertural; 1b. Apertural flush; 1c. Right lateral; 1d. Abapertural; and 1e. Apical.
Image 2–UND-JHH S10517: 2a. Apertural; 2b. Apertural flush; 2c. Right lateral; 2d. Abapertural; and 2e. Apical.
Image 3–UND-JHH S10518: 3a. Apertural; 3b. Apertural flush; 3c. Right lateral; 3d. Abapertural; and 3e. Apical.
Image 4–UND-JHH S10519: 4a. Apertural; 4b. Apertural flush; 4c. Right lateral; 4d. Abapertural; and 4e. Apical.
Image 5–UND-JHH S10520: Right lateral.
Image 6–UND-JHH S10521: 6a. Apertural; and 6b. Abapertural.
Image 7–UND-JHH S10522: 7a. Apertural; and 7b. Right lateral.
Image 8–UND-JHH S11188: 8a. Right lateral; and 8b. Abapertural.
Images 9–13. *Pleurolimnaea* aff. *P. tenuicosta* (Meek and Hayden) (with 3-mm bar scale).
Images 9, 10–UND-JHH S10555a: Right lateral; 10, UND-JHH S10555b: ~Abapertural.
Image 11–UND-JHH S10553: Abapertural. Image 12–S10554: ~Abapertural. Image 13–UND-JHH S10578: ~Abapertural.
Image 14. *Gyraulus* cf. *G. militaris* (White)–UND-JHH S10572 (with 1-mm bar scale).

and early Eocene species. The following is a summary of the historical analysis of these taxa to show the strengths and weakness of an early Eocene assignment for the Duff Brown Tank local fauna.

Hall, Meek, and Hayden Set the Stage

Western pioneer paleontologists faced a challenging responsibility in their studies of both marine and continental strata. They had to interpret both age and environment in a geological landscape relatively unfamiliar to scholars of the day. Geologic maps and stratigraphic columns were based on intensive, although reconnaissance in nature, studies over vast areas. Fossils played a critical role. Continental molluscan studies served as benchmarks in relative dating of formations; to this day many of the fossils collected and named, have not been restudied.

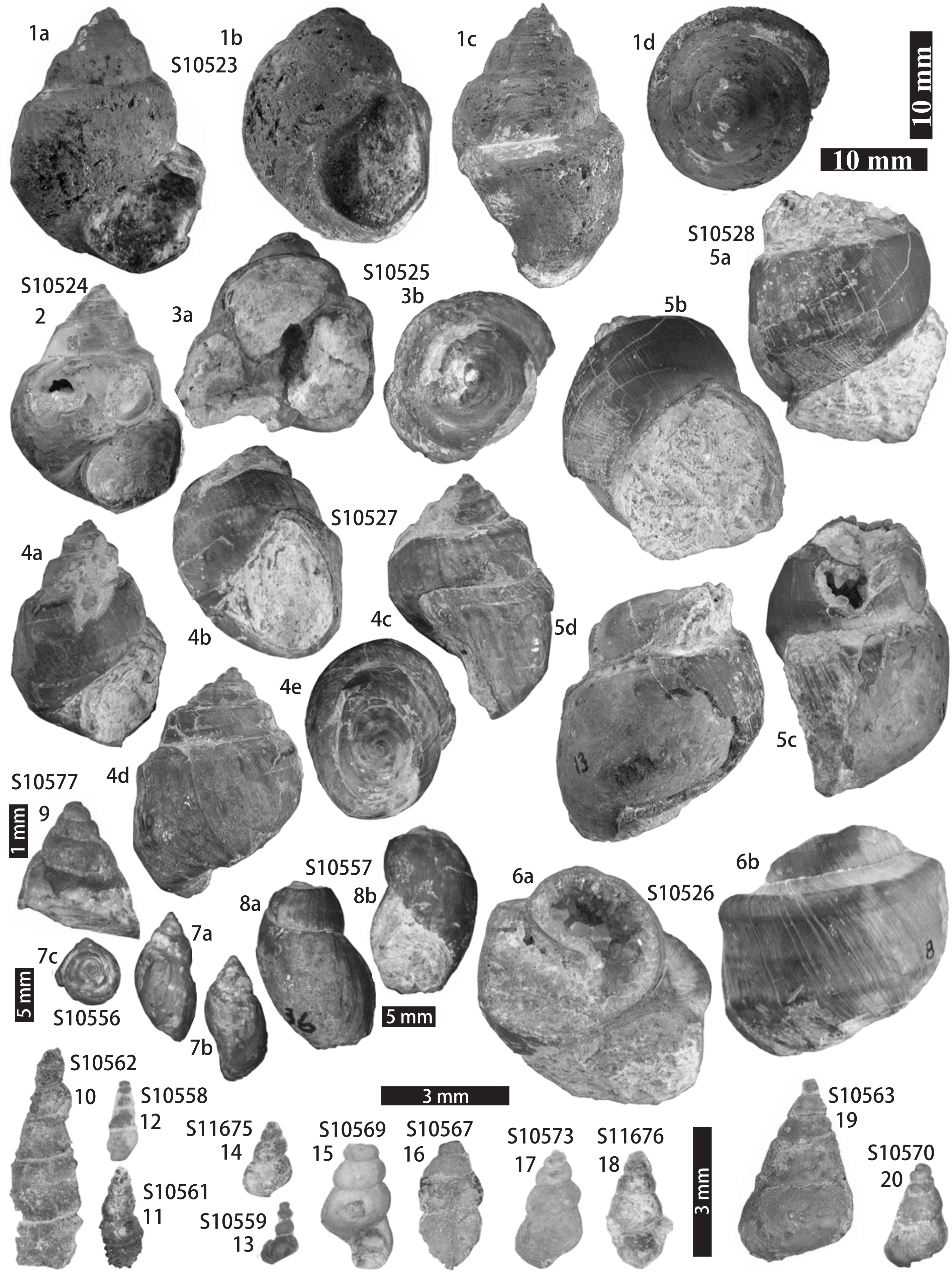
Continental molluscan studies began in the 1840s, when Hall (1845a, b) published the first paper naming new continental molluscan species of the West (e.g., Wyoming, Utah). Apparently, only Hall saw these fossils, as the type specimens were reported as unavailable (see Meek, 1876; Hartman, 2004). F.V. Hayden and his crews collected specimens in the Williston and Power River Basins of the northern Great Plains in the 1850s, while conducting independent studies coordinated with surveying missions of the topographic engineers. F.B. Meek, with Hayden, published on a large number of continental molluscan species from the Upper Cretaceous Judith River and Fort Union beds (Great Lignite Group) and identified these fossils from age-interpreted stratigraphic sections (e.g., Meek, 1876; Hartman et al., 2013).

White in the American Southwest

Although Hall, Hayden, and Meek predated C.A. White's paleontological field work in the American Southwest in the 1870s, White was the most influential in his description of many new species, including his work on the Laramie Group, and interpretation of the evolution of unionids. The "classic" Fort Union Formation continental molluscan fauna of Meek and Hayden was correlated throughout the West (Meek, 1876, available and known to White; see Hartman, 1984; Hartman and Kihm, 1992). This "classic" unit, as described along the Upper Missouri River, would much later be determined as Paleocene in age, and represents a relatively narrow band of geologic time (Hartman and Kihm, 1995). White (1883a, 1886) subsumed the Fort Union to be part of his Laramie Group when correlating faunal elements as far away as southern Utah. The Laramie time "period" included many continental molluscan assemblages ranging mostly from Late Cretaceous to Paleocene to lower Eocene in age. In the late 1800s and early 1900s, the Paleogene (Tertiary) was "sans Paleocene" and inconsistently represented as "Lower Eocene" (see Wood et al., 1941). United States geologists and paleontologists during the exploratory expeditions of 1800s generally mixed lithic and chronostratigraphic concepts, while their European counterparts were detailing methods of biostratigraphy.

U.S. Territorial Geological Surveys

With the advent of the U.S. geographical and geological territorial surveys following the Civil War, vast tracks of western North America were mapped on a preliminary basis prior to the establishment of the U.S. Geological Survey in 1879. White played an important role beyond the naming of many western continental molluscan species. He, more than most, interpreted the age relationships of the strata based on their fossil content (e.g., summary in White, 1883a). After naming over 50 Laramie-age species in 10 years, White (1886) had the opinion that mollusks, snails in particular, were highly variable. He asserted that several species from widely separated locations were equivalent, or represented "varieties," thereby broadening species concepts that spanned the Laramie interval, as then defined. As we have subsequently learned, the faunal assemblages combined at the time by White and others in continental strata across Utah, Wyoming, Colorado, and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S10573
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S11676
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3 mm
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13

SF-Figure 2. *Viviparus* aff. *V. calamodontis, Physa* cf. *P. longiuscula*, *"Hydrobia"* cf. *"H." warrenana, "H."* cf. *"H." anthonyi, "H."* sp. *"H."* form b, and *"H."* sp. *"H."* form t specimen figures. Music Mountain Formation, Duff Brown Tank, Coconino County, Arizona.
Images 1–6. *Viviparus* aff. *V. calamodontis* Cockerell (with 10-mm bar scale).
Image 1–UND-JHH S10523: 1a. Apertural; 1b. Apertural flush; 1c. Right lateral; and 1d. Apical.
Image 2–UND-JHH S10524: Apertural. Image 3–S10525: 3a. Apertural flush; and 3b. Apical.
Image 4–UND-JHH S10527: 4a. Apertural; 4b. Apertural flush; 4c. Right lateral; 4d. Abapertural; and 4e. Apical.
Image 5–UND-JHH S10528: 5a. Apertural; 5b. Apertural flush; 5c. Right lateral; and 5d. Abapertural.
Image 6–UND-JHH S10526: 6a. Apertural; and 6b. Abapertural.
Images 7–9. *Physa* cf. *P. longiuscula* (Meek and Hayden) (with 5-mm bar scale).
Image 7–UND-JHH S10556: 7a. Apertural; 7b. Abapertural; and 7c. Apical.
Image 8–UND-JHH S10557: 8a. Apertural; and 8b. Abapertural. Image 9–S10577: Apertural.
Images 10–12. *"Hydrobia"* cf. *"H." warrenana* (Meek and Hayden) (with 3-mm bar scale).
Image 10–UND-JHH S10562: Right lateral. Image 11–UND-JHH S10561: Right lateral.
Image 12–UND-JHH S10558: Right lateral.
Image 13–14. *"Hydrobia"* cf. *"H." anthonyi* (Meek and Hayden) (with 3-mm bar scale).
Image 13–UND-JHH S10559: Abapertural. Image 14–UND-JHH S11675: Abapertural.
Image 15-18. *"Hydrobia"* cf. *"H."* sp. form b (with 3-mm bar scale).
Image 15–UND-JHH S10569: Oblique apertural. Image 16–UND-JHH S10567: Right lateral.
Image 17–UND-JHH S10573: Apertural. Image 18–UND-JHH S11676: uncertain.
Images19–20. *"Hydrobia"* cf. *"H."* sp. form t (with 3 mm bar scale).
Image 19–UND-JHH S10563: Abapertural. Image 20–UND-JHH S10570: Abapertural.

North Dakota, actually spanned many millions of years on either side of the Cretaceous–Paleogene boundary.

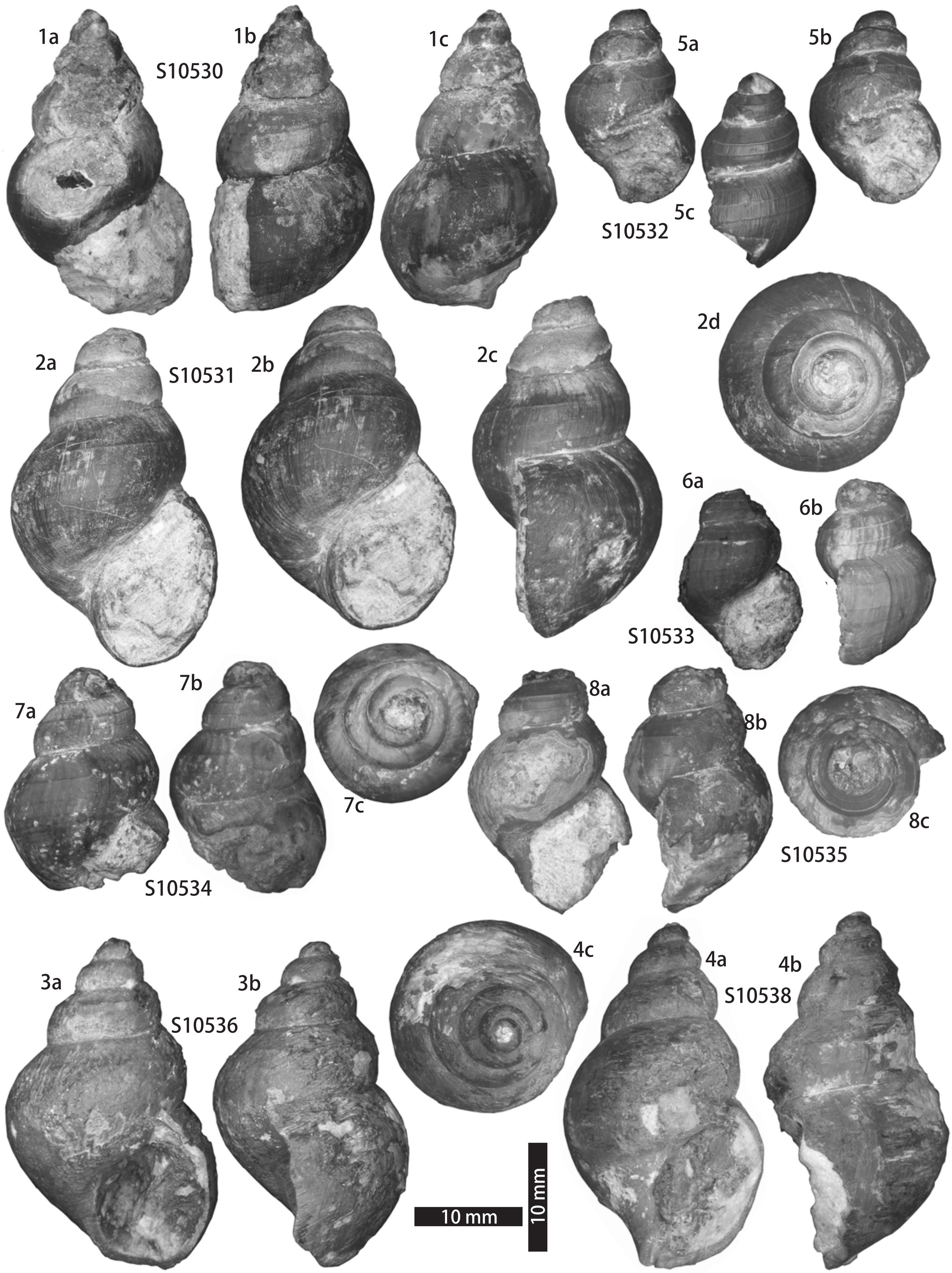
For example, White (1886, p. 17) stated that

> "it appears probable that at least the upper portion of the series of strata which are exposed in the vicinity of Fort Union, near the mouth of Yellowstone River, should be referred to the Wasatch Group [*]. That the lower portion of the series known as the Fort Union beds belongs to the Laramie Group cannot be doubted, because of the presence there of characteristic dinosaurian [no dinosaurs in Fort Union of Meek and Hayden] and other vertebrate remains; but there is evidently no break in that series of strata which should separate them into two formations. In the upper part of the series, however, only fresh water molluscan forms have been found, if we accept one species of *Corbula* [†], and this is understood to have come from a comparatively low horizon [actually Ti3 to Ti4*]. Moreover, several of the same species of mollusks which are found in the Fort Union series of Laramie strata are also found in the Wasatch strata of Utah according to White's work."
>
> * Now upper Paleocene, Ti3–Ti4 NALMA, "classic" Fort Union Formation fauna (Hartman and Kihm, 1992, 1995).
>
> † Now *Pachydon*, a freshwater corbulid from the Fort Union Formation (Hartman and Anderson, 2002; Anderson et al., 2006).

The interpretative process that assesses age based on the collection of more fossils and geological observations is intriguing to follow. For example, White's suggestion of

> "the intimate relation of the Laramie of the Upper Missouri River region to the fresh-water Eocene series is apparently supported by the discovery of some fresh-water beds on the top of Sentinel Butte, in that region [*]. These beds are connected with the underlying Laramie strata by direct continuity [†], I have suggested that they probably represent the Green River Group" [‡] (White, 1886, p. 17).
>
> * Actually, White River Group (see Boyer, 1981).
>
> † Actually, these beds are substantially unconformable (Murphy et al., 1993).
>
> ‡ Actually, the fish-bearing beds belong to the South Heart Member, Chadron Formation, White River Group.

White (1886, p. 399, 400) organized those thoughts in an unnumbered table. His original figure is organized taxonomically and does not permit a straightforward biostratigraphic interpretation represented by the species. A first revision of the nomenclature and reordering based on the original occurrence provides a better sense of "like" taxon ranges (not figured). However, SF-Figure 4 stratigraphically orders the taxa in a provisional first appearance datum (FAD) and last appearance (LAD) arrangement. The "typical Laramie," as used by White in this figure, includes mostly taxa that were first reported from the Fort Union Formation, the exception being *Acroloxus actinophorus*, which is likely from the Eocene part of the Flagstaff Formation. Excluding this latter taxon, this "typical Laramie" assemblage (White, 1886) is late Paleocene in age and should overlie the "Puerco Group" of New Mexico.The above discussion is meant to show that important parts of White's stratigraphic framework are wrong. Nonetheless, White (1883a, 1886) provided the basis upon which subsequent workers interpreted the temporal framework of strata in the southwestern United States and the Western Interior in general. Add to this White's concept of a highly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SF-Figure 3. *Lioplacodes* aff. *L. mariana* specimen Figures. Music Mountain Formation, as Figs. 2,3. Images 1–6. *Lioplacodes* cf. *L. mariana* Yen (with 10-mm bar scale).

Image 1–UND-JHH S10530: 1a. Apertural; 1b. Right lateral; and 1c. Abapertural.
Image 2–UND-JHH S10531: 2a. Apertural; 2b. Apertural flush; and 2c. Right lateral.
Image 3–UND-JHH S10536: 3a. Apertural; 3b. Right lateral.
Image 4–UND-JHH S10538: 4a. Apertural; 4b. Right lateral; and 4c. Apical.
Image 5–UND-JHH S10532: 5a. Apertural; 5b. Right lateral; and 5c. Apertural flush.
Image 6–UND-JHH S10533: 6a. Apertural; 6b. Right lateral.
Image 7–UND-JHH S10534: 7a. Apertural; 7b. Right lateral; and 7c. Apical.
Image 8–UND-JHH S10535: 8a. Apertural; 8b. Right lateral; and 8c. Apical.

variable species, which led later paleontologists to misidentify a number of numerous common species based on the overly broad morphological definitions or incorrectly assigned illustrated examples.

White's Taxonomic Studies of *Viviparus*

White was an assistant geologist from 1874–1876 to Wheeler's "West of the One Hundredth Meridian" survey under J. W. Powell. Powell (1876, p. VI) specifically noted that "[o]n my travels during the year 1875, Prof. C. A. White was my geological companion, and the trip was made largely for the purpose of collecting fossils at localities where they had previously been discovered, but to which sufficient time had not been given to make good collections." The product of these efforts was White's (1876 [also, December, 1874, "republished in its final form," White, 1875, p. 3; 1877]) Chapter III, "Invertebrate Paleontology of the Plateau Province," included in Powell's "Report on the Geology of the eastern portion of the Uinta Mountains," where White includes a locality register of all taxa collected by Powell and others to date. It included an unpublished locality catalog for collections made in 1874 and 1875, indicating the responsible collector, collection number(s), general location and "age" information (White, 1875u). An example of such a locality record is: "353–359, Powell [collector,] Point of Rocks Group, Sevier Cliffs, 12 miles [19.3 km] above Panguitch, Utah" for the year 1874 [Locality L3335, see SF-Table 2].

SF-Table 2. White (1875, 1876) Viviviparidae Identifications

Taxon/Lnos	Location	White's Stratigraphy
Viviparus trochiformis **(Meek and Hayden), 1856**		
L3826	Last Bluff	Tertiary
L3825	Ephraim City	Tertiary
L3827	South of Last Bluff	Tertiary
L3322	East of Joe's Valley	Tertiary
L3815	At the head of Soldier's Fork	Tertiary
L3814	"West base of Mu-si-ni-a Plateau, [sic], 1,000 feet below its summit."	Tertiary
Viviparus trochiformis **, var., fide White (1875)**		
L3827	South of [end of p. 214] Last Bluff "Associated with No. 337" [sic; should read 237]	Tertiary
Viviparus ionicus **White (n. sp.), 1875**		
L3322a	East side of Joe's Valley "Associated with the other species just described, at Wales, Utah"	Probably Tertiary
Viviparus –? **after White (1875)**		
L3333	Wales "Associated with other species just described"	Tertiary
Viviparus panguitcheiisis **White, 1876**		
L3335	Sevier Cliffs, twelve miles above Panguitch	(K) Point of Rocks Group
L3335a	Upper Kanab	(K) Point of Rocks Group
Viviparus paludinaeformis **(Hall), 1845**		
	Unknown	Bitter Creek Group (K)
	Unknown	Lower Green River Group
L4102a	Henry's Fork	Upper Green River Group
L4104	Alkali Stage Station, WY	Upper Green River Group
	Unknown	Bridger Group

Taxa of *Viviparus* are important in assessing the age of the Duff Brown Tank local fauna. White emphasized the variability of *Viviparus meeki* and reported it from several localities in Utah (see Appendix A–Locality Register). White's identifications of fossil *Viviparus* that is potentially relevant to this study are shown in SF-Table 2.

White (1874, 1875, 1877, 1886) identified *Viviparus meeki* Wenz (then *V. trochiformis*) from six localities all nominally from the Paleogene (Tertiary) in Utah (East of Joe's Valley, L3322; Wales, L3333; West base of Musinia Plateau, L3814; Head of Soldier's Fork [= Soldier Fork Creek, = Soldier Creek], L3815; Ephraim City, L3825; Last Bluff, L3826; and South of Last Bluff, L3827) (SF-Fig. 3 of White). Of these locations, White illustrated specimens from Wales, Last Bluff, and from an unknown locality (Schuchert, 1905). White (1883a) also illustrated specimens of *Viviparus* collected from the Yellowstone River on an unrelated project.

Yen's use of NALMA and Coal-bed Stratigraphy

T.-C. Yen (1948a, 1949) attempted a fuller use of continental mollusks in biochronology by correlating them to North American Land-Mammal Ages (NALMA). In 1948, Yen identified what he considered to be Eocene taxa and recognized species assignable to the Wasatchian and Bridgerian NALMA. These vertebrate fauna-based ages had just recently been organized in their modern form by the Wood et al. (1941) committee (see SF-Table 3). Yen (1948a, p. 634) accurately noted that:

"[w]ith the exception of a few records made in recent

SF-Table 3. Yen's (1948) Eocene NALMA Taxa

Taxon of Yen	Eocene Beds of Yen
Wasatchian NALMA*	
Unio mendax White	Wasatch
Unio whitei Henderson 1	Wasatch
Unio sinopae Cockerell	Gray Bull
Unio wasatchensis Cockerell	Wasatch
Unio didymictides Cockerell	Gray Bull
Viviparus ionicus White	Wasatch
Viviparus jepsoni Russell	Gray Bull
Viviparus paludinaeformis (Hall)	Wasatch
Hydrobia recta White	Wasatch
Hydrobia utahensis White	Wasatch
Goniobasis filifera White	Wasatch
Goniobasis carterii Conrad	Sand Coulee
Goniobasis nodulifera Meek	Wasatch
Bridgerian NALMA*	
Unio washakiensis Meek	Washakie
Unio grangeri Cockerell	Washakie
Unio haydeni Meek	Bridger
Unio leanus Meek	Bridger
Unio clinopisthus White	Green River
Unio shoshonensis White	Green River
Viviparus wyomingensis Meek	Bridger
Hydrobia gregorii Meek	Bridger
Goniobasis arcta Meek	Bridger
Goniobasis simpsoni Meek	Bridger
Goniobasis tenera (Hall)	Green River and Bridger
Lymnaea minuscula White	[without entry]
Physa bridgerensis Meek	Bridger
Planorbis aequalis White 2	Green River
Australorbis spectabilis (Meek)	Green River
Australorbis utahensis (Meek)	Green River
Anisus cirrus (White)	Green River

* = Stage of Yen (1948a)
1 = *Unio rectoides* White
2 = A young form of *Australorbis spectabilis* (Meek)

years, for many of the species described from the Eocene beds definite data on exact stratigraphic position are not provided [for earlier collections]. This is confusing, particularly in places where the Wasatch and the Green River beds (lower part) interdigitate. Moreover, the differentiation between the Fort Union formation, of Paleocene age, and the Wasatch formation, of lower Eocene age has been an unsettled question for the last quarter of a century, so that many species characteristic of the Fort Union have been assigned to the Wasatch."

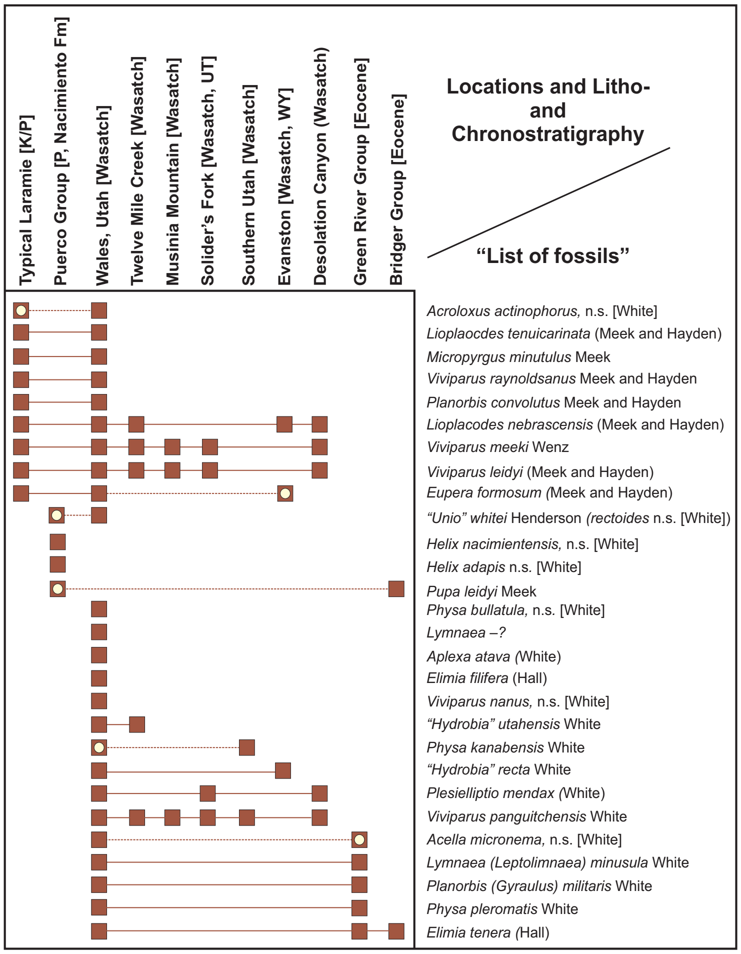
Succinctly put, interpretation of continental molluscan ages is confounded by generalized morphological species concepts and lack of reasonably detailed understanding of biostratigraphic relationships among taxa. As discussed here, resolving these issues is an ongoing effort.

Yen's (1948a, table 1) (revised as SF-Fig. 5) showed the "previous records" of his determination of Wasatchian and Bridgerian taxa (SF-Table 3). Additional taxa were chosen from the ongoing work of Tourtelot (1946, then unpublished, but later Tourtelot, 1953; see also Tourtelot and Nace, 1946). Yen's table 1 arranged the species taxonomically, but did not indicate whether the taxa were temporally arranged by numbered localities (e.g., W1, W2; B1, B2 . . .). The inference is that they were not, but in fact the localities are more or less time ordered (see Yen's table 1 and SF-Fig. 5). SF-Figure 5 includes updates to the ages of Yen's (1948a) localities, but is not intended as a revision of early and medial Eocene continental molluscan biochronology. One can conclude from Yen's organization of Wasatchian and Bridgerian identifications that certain taxa are indicative of these NALMA.

Yen (1948b, unnumbered figure, p. 36) further attempted to organize continental mollusks into a more refined stratigraphic context by recognizing taxon occurrence within coal-bed intervals (SF-Fig. 6). Yen (1948b) recognized the Paleocene–Eocene boundary at the Tongue River–Wasatch unit contact (top of the Roland coal bed). Yen noted that there was no particularly good temporal reason for this placement. Although fossil mammal localities are not plentiful in the Powder River Basin, subsequent work has identified the Paleocene–Eocene boundary (Paleocene–Eocene Thermal Maximum, PETM; Wa0 NALMA) by Wing et al., 2003) at exposures near Chalk Butte south of Powder River (USGS Sussex Quadrangle, 1:24,000), Johnson County, Wyoming (T. 43 N., R. 79 W.). Studies by Peter Robinson (University of Colorado-Boulder, written communications, 2013) placed the Wa0 horizon about 175 m above the base of the Wasatch Formation. Hartman's (1984, 1990) Powder River Basin molluscan studies indicated a Paleocene–Eocene boundary well above the Arvada and below the Felix coal beds (between 113 to 183 m above the Roland coal bed, based on data available). A relatively distinct and abundant viviparid molluscan assemblage was indicated (Hartman, 1984) and subsequent work has indicated that Clarkforkian (uppermost Paleocene) and Wasatchian (lowest Eocene) continental molluscan assemblages are present and diverse (Hartman and Roth, 1998, 1997; Hartman, 1990).

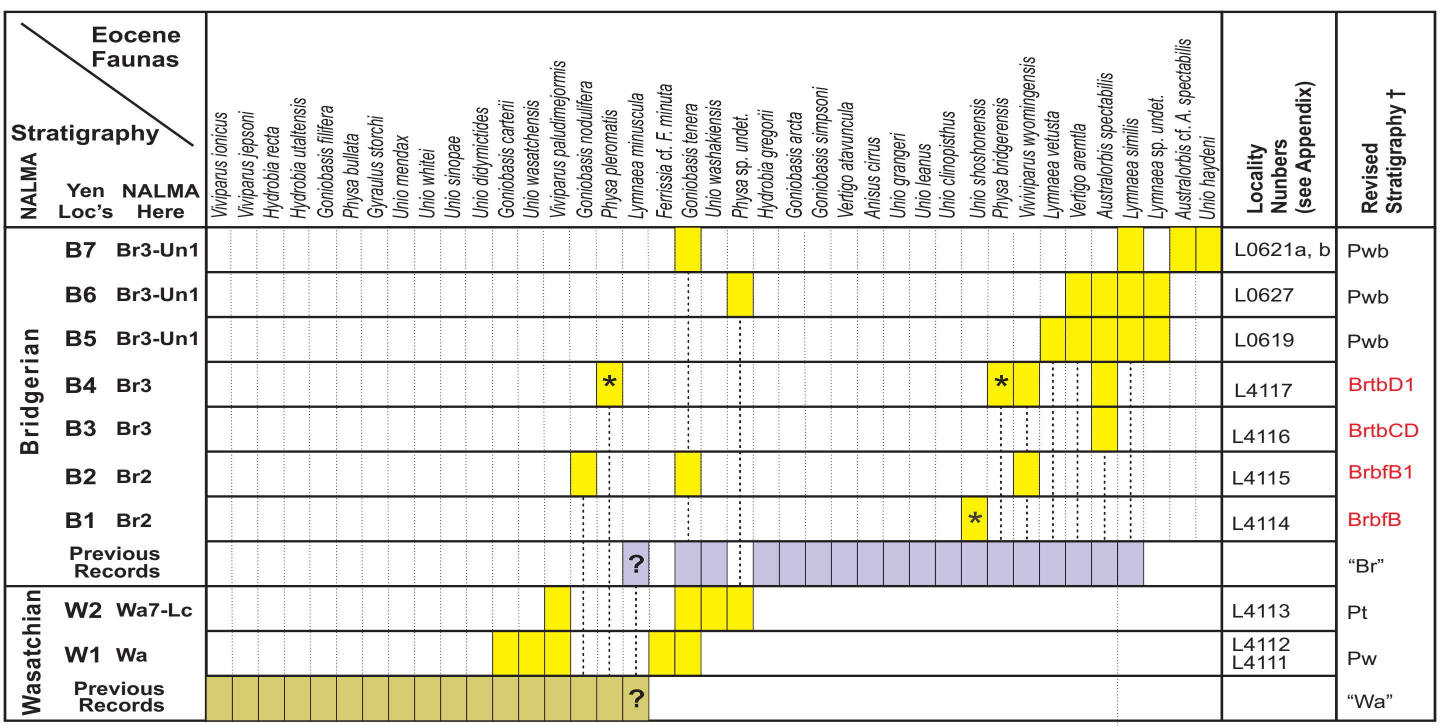
La Rocque's Study in Utah

La Rocque (1960) provided a basis for discrimination of Paleocene–Eocene beds of the Flagstaff Formation (SF-Fig. 7) in central Utah by analyzing continental mollusks (SF-Fig. 8). La Rocque (1960, table 3; see SF-Fig. 8) recognized a Paleocene lower unit (Unit 1) and an Eocene upper unit (Unit 3), with a middle unit (Unit 2) containing few fossils of undetermined age. La Rocque (1960, p. 73–76) provided diagnoses (SF-Table 4) for Paleocene and Eocene continental mollusks from Units 1 and 3 of the Flagstaff Formation. He stated that the fauna of Unit 1 was very



SF-Figure 4. White (1886) in this and other publications attempted to sort out the age relations of strata encountered in explorations of the territorial surveys in the context of Meek and Hayden's founding observations in the Upper Missouri River Country. Similarity (convergence) of fossil morphologies at different times in the fossil record (Upper Cretaceous vs. Paleogene) and how marine and freshwater taxa should be treated through time (i.e., if the fossil is marine, the strata are Cretaceous in age, in regard to the Laramie section) resulted in taxonomic and thus chronostratigraphic confusion.

SF-Figure 5. Early use of mammals to organize continental mollusks in biochronologic order. This chart reorders and adds data from Yen (1948a), Tourtelot (1946, 1953), and Tourtelot and Nace (1946) into approximate temporal order based on NALMA using Gunnell et al. (2009) and Gregg Gunnell (Duke University, written communication, 2013). The "previous records" section of Yen (1948a) is, unfortunately, rather ambiguous. * = Related taxon. Abbreviations: P = Paleogene; PtLc = e.g., Paleogene Tatman Formation Lostcabinian. Pw = Wasatch Formation. Pb = Bridger Formation; PbB1 = Bridger (Bridgerian 1); and PbD-lower = Bridger D-lower part Pwb-U1-B2 = Wagon Bed Formation (Bridgerian 2 to Unintan 1). BrtbD1= Bridger Formation, Twin Buttes Member (Upper Bridger) Unit D, lower unit (Lonetree limestone); BrtbCD = Bridger Formation, Twin Buttes Member (Upper Bridger), Unit C or D, (white beds in Unit D); and BrbfBl = Bridger Formation, Black Forks Member (Lower Bridger), Unit B, lower unit (Lyman limestone). Br3 = upper Bridgerian (see Gunnell et al. (2009; written communication, 2013); B2 Br2 = middle Bridgerian, Br1b = early Bridgerian (see Gunnell et al., 2009; written comm., 2013); Br3-Un1 using dates from Gunnell, but Br2 is possible (49-45 Ma).



* = Related taxon. Abbreviations: P = Paleogene; PtLc = e.g., Paleogene Tatman Formation Lostcabinian. Pw = Wasatch Formation. Pb = Bridger Formation; PbB1 = Bridger (Bridgerian 1); and PbD-lower = Bridger D-lower part; Pwb-U1-B2 = Wagon Bed Formation (Bridgerian 2 to Unintan 1).

BrtbD1= Bridger Formation, Twin Buttes Member (Upper Bridger) Unit D, lower unit (Lonetree limestone); BrtbCD= Bridger Formation, Twin Buttes Member (Upper Bridger), Unit C or D, (white beds in Unit D); and BrbfBl= Bridger Formation, Black Forks Member (Lower Bridger), Unit B, lower unit (Lyman limestone) (matches color abbreviations above).

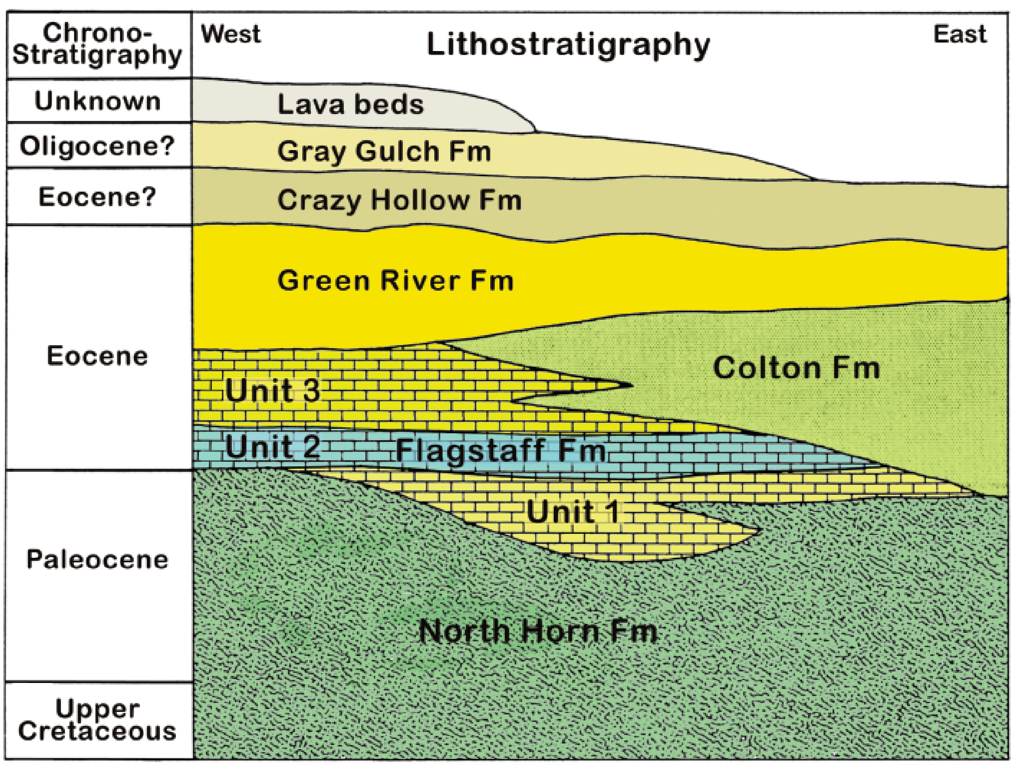
Br3 = upper Bridgerian (see Gunnell et al. (2009; written communication, 2013); B2 Br2 = middle Bridgerian, Br1b = early Bridgerian (see Gunnell et al., 2009; written comm., 2013); Br3-Un1 using dates from Gunnell, but Br2 is possible (49-45 Ma).

Powder River Basin continental molluscan biostratigraphy c. 1948. Taxa reorganized by first and last appearance datums.	Generalized coal and interbed sequence after Baker (1929)	Coal bed thickness/ interbed thickness (ft / m)	*Lioplacodes nebrascensis*	*Lioplacodes nebrascensis producta*	*Campeloma nebrascense*	*Eupera* cf. *E. formosa*	*"Lioplacodes" limneaformis*	*Viviparus retusus*	*Plesielliptio silberlingi*	*Plesielliptio priscus*	*Viviparus raynoldsanus*	*Lioplacodes mariana*	*Lioplacodes tenuicarinata*	*Viviparus meeki*	*Acroloxus minuta*	*Palaeancylus radiatus*	*Pleurolimnaea tenuicosta*	*Reesidella nana*	*Physa* cf. *P. bdgerensis*	*Physa* cf. *P. longiuscula*	*Gyraulus militaris*	*Clenchiella* n. sp.	*"Hydrobia" warrenanum*	*"Clenchiella" planospiralis*	*"Unio"* sp. undet.
Wasatch Formation	Badger coal bed/interval	0-7.0/180 0-2.1/ 55																							
Wasatch Formation	Local coal bed/interval	0-5.0/180 0-1.5/ 55					5		1	4		9	4	5								1	7	6	1
Fort Union Formation Tongue River Member	Roland coal bed/interval	0-13/195 0- 4/ 59					3		1	1	1	7	1	7							2	2	1	1	
Fort Union Formation Tongue River Member	Smith coal bed/interval	0-20.0/ 70 0- 6.1/ 21				1	6			2	3	7	7	2	1	1	1	1	1	1	1	3			
Fort Union Formation Tongue River Member	Powers coal bed/interval	0-10/ 60 0- 3/ 18					1					1		1											
Fort Union Formation Tongue River Member	Anderson coal bed/interval	10-27.0/ 65 3- 8.3/ 20					2				1	1	2												
Fort Union Formation Tongue River Member	Dietz No. 1 coal bed/interval	0-16.0/200 0- 4.9/ 61									1	1	1												
Fort Union Formation Tongue River Member	Canyon coal bed/interval	6.0-24.0/180-230 1.8- 7.3/ 55- 70					1			2	2	2	1												
Fort Union Formation Tongue River Member	Wall coal bed/interval	6.0-32.0/236 1.8- 9.8/ 72		1	2		2	1	1	1	1	1													
Fort Union Formation Tongue River Member	Brewster-Arnold coal bed/interval	10-17.0/170 3- 5.2/ 52	1	1	1	1	1																		
Fort Union Formation Tongue River Member	Knoblock coal bed/interval	20.0/396 6.1/121																							

Yen (1948b) identifications with taxonomic updates

Numbers indicate number of localities-bearing respective taxon.

SF-Figure 6. Coalbed interval distribution of Paleocene–Eocene continental mollusks in the Powder River Basin. Coalbed nomenclature as used by Yen (1948b), but similar to that subsequently used by USGS authors studying continental mollusks (Taylor, 1975, and references therein). Most localities were reported from Montana, but a few were located in adjacent areas in Wyoming. The range in coalbed thickness is given in feet and meters (e.g., Roland, 0 to 13 feet, 0 to 4 m thick) along with the interbed thickness (e.g., Smith and Roland coalbeds (195 ft, 55 m).



SF-Figure 7. Chronostratigraphy of the Flagstaff Formation of central Utah (enhanced after La Rocque, 1960). The carbonate units of the Flagstaff Formation are divided into Units 1, 2 and 3. Unit 2 is largely unfossiliferous.

Flagstaff Taxa Reordered La Rocque Chart	PgPf Unit 1	PgP-Ef Unit 2	PgEf Unit 3
Albertanella minuta	×		
Carinulorbis utahensis	×		
Carychium cf. *C. exile*	×		
Elliptio mormonum	×		
Ferrissia? sp. A	×		
Ferrissia? sp. B	×		
Gastrocopta? sp.	×		
Goniobasis tenera form A	×		
Goniobasis tenera form D	×		
Hydrobia cf. *H. recta*	×		
Hydrobia utahensis	×		
Lioplacodes limnaeiformis	×		
Lioplacodes mariana	×		
Lioplacodes tenuicarinata	×		
Micropyrgus minutulus	×		
Physa bridgerensis	×		
Physa cf. *P. longiuscula*	×		
Physa cf. *P. rhomboidea*	×		
Pisidium sp. undet.	×		
Pluerolimnaea tenuicosta	×		
Viviparus trochiformis	×		
Discus cf. *D. ralstonensis*	×		×
Gyraulus militaris	×		×
Physa sp. undet.	×		×
Sphaerium cf. *S. formosum*	×		×
"Helix" riparia	×	×	×
Holospira cf. *H. leidyi*		×	×
Bulimulus? sp.			×
Elliptio mendax			×
Ferrissia actinophora			×
Goniobasis tenera form B			×
Gyraulus aequalis			×
Hydrobia ephraimensis			×
Lampsilis spiekeri			×
Oreohelix sp.			×
Physa pleromatis			×
Viviparus paludinaeformis			×

SF-Figure 8. Differentiating Paleocene and Eocene units of the Flagstaff Formation of central Utah on the basis of continental mollusks (modified from La Rocque, 1960). The taxa identified by La Rocque (original identifications are reordered to indicate distinctiveness of assemblages. Although certain identifications were revised by Taylor (1975) and Hartman (1984), and more taxonomic work is necessary, Paleocene and Eocene molluscan assemblages can be readily distinguished. Blue highlights note morphologies thought similar to the Duff Brown Tank Locality (see SF-Table 4 for revised nomenclature).

similar in composition to several others reported from the Paleocene, notably citing the Tongue River Member of the Fort Union Formation. As noted earlier, this specific correlation of Paleocene faunas to taxa of the Fort Union Formation resulted from an earlier generalization on "Paleocene" ("Lower Eocene") and Eocene stratigraphy and commingling of apparently closely related morphologies. Thus Yen (1948b) and La Rocque (1960) found representative viviparid, pleurocerid, and sphaeriid species that were hard to distinguish empirically from Meek and Hayden's "classic" Paleocene fauna (Hartman and Kihm, 1992). La Rocques's (1960) mollusk identifications for Unit 1 of the Flagstaff Formation are in harmony with fossils found in the intercalated Paleocene and Eocene beds in the North Horn and Colton Formations, respectively (SF-Fig. 7). Taylor (1975) reidentified the molluscan assemblages from the Flagstaff Formation reported by La Rocque (1960), obtaining a similar result despite a number of reassignments (SF-Fig. 9, SF-Table 4).

Taylor's Contribution and Geological Time

Like Yen, Dwight Taylor was trained in malacology and added a sophisticated taxonomic dimension to the study of Western Interior continental mollusks. He also coordinated some of his activities with vertebrate paleontologists and correlated continental molluscan faunules with the developing North American Land-Mammal Age system (e.g., McKenna et al., 1962). Taylor commented extensively on Paleocene and Eocene molluscan nomenclature in areas relevant to the NALMA study. Most of these observations were published in the work of others. Ultimately, his ideas that were summarized in an unusual format in a USGS Open-File Report (Taylor, 1975) were made available by John Hanley (edited without final involvement of the author).

Although many generic assignments are not accepted (e.g., Hartman, 1984, 1998; Hartman and Roth, 1998; and herein), Taylor (1975) clearly indicated the need for revision of Paleogene continental molluscan identifications by earlier workers (e.g., SF-Fig. 9). Taylor's placement of the Paleocene–Eocene boundary at the Anderson coal bed was without mammalian control (SF-Fig. 10) and thus did not correlate with international or national interpretations of the boundary placement. His criterion was largely based on an independent line of reasoning that this horizon showed the greatest change in the molluscan record in the Powder River Basin section. An increase in continental molluscan diversification is noted elsewhere at about this time in the end-Paleocene faunal assemblages of the Clarkforkian in the Bighorn Basin (Hartman and Roth, 1998), but it is not coincident with recognized criteria for the P/E boundary.

SF-Table 4. Delimiting Paleocene from Eocene continental mollusks in the Flagstaff Formation.*

Diagnosis of the Eocene Flagstaff Formation (Unit 3) (after La Rocque, 1960)

1) Occurrence in Unit 3 and not in Unit 1 of the Eocene species:

Gyraulus aequalis (White) [*Biomphalaria aequalis* after Taylor, 1975]

Physa pleromatis White

2) Absence in Unit 3 of undoubted Paleocene units:

Viviparus trochiformis (Meek and Hayden) [*Viviparus meeki* Wenz]

Lioplacodes limnaeiformis (Meek and Hayden) [*L. limneaformis* (Meek and Hayden)]

Lioplacodes mariana Yen [not *Cleopatra multistriata* (Meek and Hayden) after Taylor, 1975]

Diagnosis of the Paleocene Flagstaff Formation (Unit 1) (after La Rocque, 1960)

1) Occurrence of *Pleurolimnaea tenuicosta* (Meek and Hayden) and *Albertanella minuta* Russell.

Both recorded so far only from the Paleocene.

2) Affinities of the fauna with that of the North Horn Formation, in that both contain:

Viviparus trochiformis (Meek and Hayden) [= *V. meeki* Wenz; *Bellamya* of Taylor, 1975, not recognized]

Hydrobia cf. *H. recta* White ["*Hydrobia* "]

3) Presence in Unit 1 (Paleocene) and absence in Unit 3 (Eocene) of the following species here and elsewhere:

Viviparus trochiformis (Meek and Hayden) [*Viviparus meeki* Wenz]

Lioplacodes limnaeiformis (Meek and Hayden) [*L. limneaformis* (Meek and Hayden)]

Lioplacodes mariana Yen [not *Cleopatra multistriata* (Meek and Hayden) after Taylor, 1975]

Lioplacodes tenuicarinata (Meek and Hayden) [*Cleopatra* of Taylor, 1975, not recognized]

4) Occurrence in Unit 1 and not in Unit 3 of additional species of Paleocene aspect:

Elliptio mendax (White) [*Plesielliptio*]

Hydrobia utahensis White [*"Hydrobia "*]

Micropyrgus minutulus (Meek and Hayden)

Carinulorbis utahensis La Rocque [*Valvata bicincta* Whiteaves after Taylor, 1975)

Other taxon name updates

Sphaerium cf. *S. formosum* to *Eupera formosa* (Meek and Hayden) after Taylor (1975)

Ferrissia actinophorus to *Acroloxus actinophorus* White after Talor (1975), but not = *A. ratiatulus*

Gyraulus militaris White to *Biomphalaria storchi* (Russell) fide Taylor (1975)

* Includes comments about Taylor (1975); nomenclatural updates to La Rocque (1960).

Hanley Extends White, Yen, and La Rocque

Geologists and paleontologists continued studying areas formerly only briefly visited by territorial surveys or mapped by coal and mineral geologists of the USGS. Fossils were frequently recovered and given to USGS paleontologists for identification. How species were identified and new species applied in any given area depended on what had already been published, but the authors necessarily relied on the compendia of line drawings dating back to the territorial monographs and bulletins and early USGS publications. Subsequently, more modern contemporary studies like that of La Rocque (1960) in Utah became widely used because of their focus, updated approach on ecology, and slightly more modern taxonomy. Significant rethinking of taxonomy, except for Russell (1964; includes many name changes) and Taylor (1975, unknown to most workers) had not been attempted even though major changes in the approach to the taxonomy of modern continental mollusks had been underway for decades (Ortmann, 1912). Questions on biogeography, biostratigraphy, and paleoecology were addressed, but no concerns were raised by La Rocque (as was true of previous workers) about the consequences and evolutionary implications of distributing these faunas across the Western Interior of North America. The Paleocene fauna of central Utah, as identified by La Rocque (1960), is a “classic” Fort Union Formation association largely transplanted 1100 km. The morphological variability through time and space of a species as used by White (1886) was not reconsidered and thus long-ranged biostratigraphic ranges were perpetuated even though the understanding of formation definitions and chronostratigraphic correlation were becoming more refined. Early interpretations of species variability (e.g., White, 1886) unnaturally extended species stratigraphic ranges and/or paleobiogeographic distributions across alluvial and deltaic systems of the Western Interior of North America (Laramidia and with closure of the Cannonball Seaway).

Important contributions of Hall and Cockerell

As noted, Hall (1845a, b) reported the first new species of continental mollusks from the western United States (not yet a territory) from specimens collected in 1844 by J.C. Frémont of the U.S. Army Corps of Topographical Engineers. Hall, under the mistaken impression that Frémont's fossils were collected from marine strata, assigned them all to marine genera. He subsequently recognized his error (blaming Frémont) in an addendum to his report. Unfortunately, the fossils described and illustrated by Hall were never seen again (Hartman, 2004). One of the taxa described by Hall (1845a, p. 298, 308, pl. 3, figs. 4, 4a; Frémont collection number 21) was *Pleurotomaria uniangulata* Hall = *Viviparus uniangulatus* (Hall) (SF-Fig. 11). This taxon has been interpreted as from Utah County, Utah, from an escarpment in Spanish Fork Canyon along Soldier Creek (L3370), a few kilometers west of Soldier Summit (see Hartman, 2004; Taylor, 1975). The tentatively identified taxa suggests it is a mixed collection not solely derived from the latitude and longitude or locality description reported by Frémont (Hall, 1845a). The occurrence is interpreted as probably Green River Formation (Flagstaff Member?).

T.D.A. Cockerell (1915) introduced *Campeloma calamodontis* from the San Jose Formation ("Wasatch [Eocene], at Ojo San José, New Mexico" of Cockerell, p. 120) on the basis of specimens collected by William Stein in 1912 (Hartman, 1981) (SF-Fig. 11). The location (L3823) of this taxon in Sandoval County north of Cuba, New Mexico, is also poorly known. Like *V. uniangulatus*, a topotypic collection either has not been made or has not been recognized from existing specimens that would help better understand its morphology. Although one would like better geographic and stratigraphic documentation for both taxa, there seems little doubt that they can be assigned to the lower Eocene of their respective units—Hall's *Viviparus uniangulatus* to the Green River Formation (Flagstaff Member?); Hanley's misidentified taxon to the Green River and Wasatch Formations (see below); and Cockerell's *V. calamodontis* to the San Jose Formation. The Duff Brown Tank locality specimens are more closely comparable (see SF-Fig. 11 and SF-Figs. 1-3) to these lots than they are to either Paleocene or lower Eocene viviparid morphologies.

Hanley's Eocene Study–Assessing Duff Brown Tank Identifications

The preceding review highlights the problems commonly associated with identifying species based on literature resources. John Hanley (1974, 1976) identified continental mollusks in Wyoming and Colorado and effectively ignored the Utah and New Mexico records of Hall (1845a, b) and Cockerell (1915) as they pertained to species not subsequently identified since their naming. Hanley comprehensively examined the stratigraphy, taphonomy, paleoecology, and taxonomy of continental mollusks of the Wasatch and Green River Formations in his study area, but followed nomenclatural practices and habits that resulted in misidentification of certain taxa (e.g., taxa associated with the "Laramie problem," *Viviparus meeki*; see Clemens and Hartman, 2014; Hartman and others, 2014).

Hanley (1974, 1976) illustrated four specimens as *Viviparus trochiformis* (= now *V. meeki* Wenz) three of which are given in SF-Figure 11 (Images 3–5). None of Hanley's specimens are assignable to *V. meeki*. The specimens are too strongly shouldered (like *V. calamodontis* and *V. uniangulatus*, if the line drawing is accurate), giving the shells a less trochiform appearance. The Hanley specimens also have a different revolving sculpture pattern; the raised paired of low revolving ridges in *V. meeki* is a consistent feature not seen in the Hanley material.

The species identity of *Viviparus* present in Hanley's collection cannot be confirmed at this time. Although similar to *V. calamodontis*, this taxon's somewhat poor surface preservation makes direct feature comparison inconclusive. There may be good reason to compare Hanley's material to *V. uniangulatus*, but the lithograph drawings of Hall are of low quality. Comparison to near topotypic material is necessary (and should be possible). In any case, the *Viviparus* taxon to which the Duff Brown Tank *Viviparus* species is being compared is lower Eocene (of Hall, Cockerell, or Hanley; note, one Laney Member occurrence is middle Eocene) (SF-Fig. 2).

Hanley (1974, 1976) further identified *Pleurolimnaea tenuicosta* (Meek and Hayden) from the main body of the Wasatch Formation in Sweetwater County, Wyoming (L3923). Hanley also made questionable comparisons to this species from the Luman Member of the Green River Formation (L3833) and the problematic lacustrine facies of the Wasatch Formation (L3929). Like *V. meeki,* Meek and Hayden's *P. tenuicosta* was described from the upper part of the Fort Union Formation (L0429), and can be interpreted as upper Paleocene in age (Hartman and Kihm, 1995). Henderson (1935, p. 242) wrote: "I am suspicious of the Utah and Canada records, but have included them [in his catalog]. Hanley is correct in his assignment of his specimen to *Pleurolimnaea*; it may also be comparable to the specimen reported by White (1880) from the upper

Flagstaff Formation			Lithostratigraphy
Lower	Middle	Upper	Taylor (1975) taxon identifications
×			*Plesielliptio* aff. *P. priscus*
×			*Pisidium*
×			*Valvata bicincta*
×			*Bellamya* n.sp. B
×			New Gen. A *limneaformis*
×			*Cleopatra multistriata*
×			*Cleopatra tenuicarinata*
×			*Elimia? tenera* form A
×			*Elimia? tenera* form D
×			*Hydrobia utahensis*
×			*Hydrobia* cf. *H. recta*
×			*Pleurolimnaea tenuicosta*
×			*Carychium* cf. *C. exile*
×			*Bulinus (Pyrgophysa)*
×			*Physa bridgerensis*
×			*P* .cf. *P. longiuscula*
×			*Physa* cf. *P. rhomboidea*
×			*Gastrocopta?*
×	----	×	*Sphaerium*
×	----	×	*Valvata*
×	----	×	*Acroloxus radiatulus*
×	----	×	*Discus* cf. *D. ralstonensis*
×	----	×	*Holospira* cf. *H. leidyi*
×	×	×	*Helix riparia*
		×	*Elliptio mormonum*
		×	*Lampsilis spiekeri*
		×	*Bellamya paludinaeformis*
		×	*Elimia? tenera*
		×	*Hydrobia ephraimensis*
		×	*Biomphalaria storchi*
		×	*Physa pleromatis*
		×	*Bulimulus?*
		×	*Oreohelix*

SF-Figure 9. Occurrence of fossil mollusks in the Flagstaff Formation, Wasatch Plateau, Utah (after Taylor, 1975).* SF-Table 4 includes suggested nomenclatural updates for both La Rocque (1960) and Taylor (1975). Taylor's revisions indicate more taxa in common between Paleocene and Eocene strata, but only a few of these are based on well-established species.

Wasatch or Green River Formation a few kilometers east of Table Rock, Wyoming (L4442).

No detailed comparison of these frequently well preserved ellobiids with their disjunct distribution has been undertaken. Specimens ranging from the Williston Basin to the southwestern United States appear, however, to differ in length, spire attenuation, and strength of axial sculpture. La Rocque (1960, p. 36) considered that the records from the upper Paleocene Flagstaff Formation (lower part) may be sufficiently distinct ("consistently smaller, more fusoid, and not as shouldered") to "merit varietal rank." Hanley's single good specimen is smaller (USNM-Pal 210114) then any of La Rocque's specimens, but this may be in proportion to the fewer number of whorls (the last whorl accounting for much of the specimen's length).

The Duff Brown Tank ellobiid specimens appear especially elongate (SF-Fig. 1) and possess distinctive, if not coarse, sculpture. Hanley's sample size is too small to make an adequate comparison, but the Duff Brown Tank specimens are more directly comparable to upper Paleocene to lower Eocene *P. tenuicosta*-like specimens from the southwest than to species from the Fort Union Formation.

As with modern Pleuroceridae, the simple and complex morphologies of this family have resulted in many species names, varieties, synonymies, and misidentifications. *Lioplacodes* and *Elimia* are the two main fossil genera to which species have been assigned, with the former common in the Paleocene and the latter common in the Eocene of the Western Interior. The Duff Brown Tank locality contains one species (SF-Fig. 3) compared here to Lioplacodes mariana Yen. The type locality from which Yen (1946) described the taxon is from the upper Paleocene (Clarkforkian) "Wasatch" Formation of the Powder River Basin, Sheridan County, Wyoming (Hartman, 1984, L2053). Yen noted its similarity to *Lioplacodes nebrascensis* (Meek and Hayden) (L0435, L0422). Taylor (1975) synonymized *L. mariana* with *Cleopatra multistriata* (Meek and Hayden), a comparison not considered valid here. La Rocque (1960) identified *L. mariana* from the lower part of the Flagstaff Formation in central Utah and noted that it is relatively abundant

Powder River Basin

Chronostratigraphy: North American Land-Mammal Stages († this report)	Early Eocene / Paleocene (* after Taylor (1975))	†	Gray Bull (* after Taylor (1975))	Lithostratigraphy (Coalbed intervals) after Taylor (1975)	
Lower Eocene	Early Eocene (Wasatchian)	Wa / Cf-Wa0	Gray Bull (latest & post-)	Wasatch Formation	Above Arvada coalbed
Upper Paleocene	Early Eocene (Wasatchian)	Cf	Gray Bull (except latest Gray Bull)	Fort Union Formation Tongue River Member	Arvada bed to Roland bed
Upper Paleocene	Early Eocene (Wasatchian)	Ti-Cf / latest Tiffanian	Gray Bull (except latest Gray Bull)	Fort Union Formation Tongue River Member	Roland bed to Smith bed
Upper Paleocene	Early Eocene (Wasatchian)	latest Tiffanian	Gray Bull (except latest Gray Bull)	Fort Union Formation Tongue River Member	Smith bed to Anderson
Upper Paleocene	Paleocene	latest Tiffanian / Ti4	Tiffanian (Ti)	Fort Union Formation Tongue River Member	Anderson bed to Wall bed
Middle	Paleocene	To	Torrejonian (To)	Fort Union Formation Tongue River Member	Below Wall bed

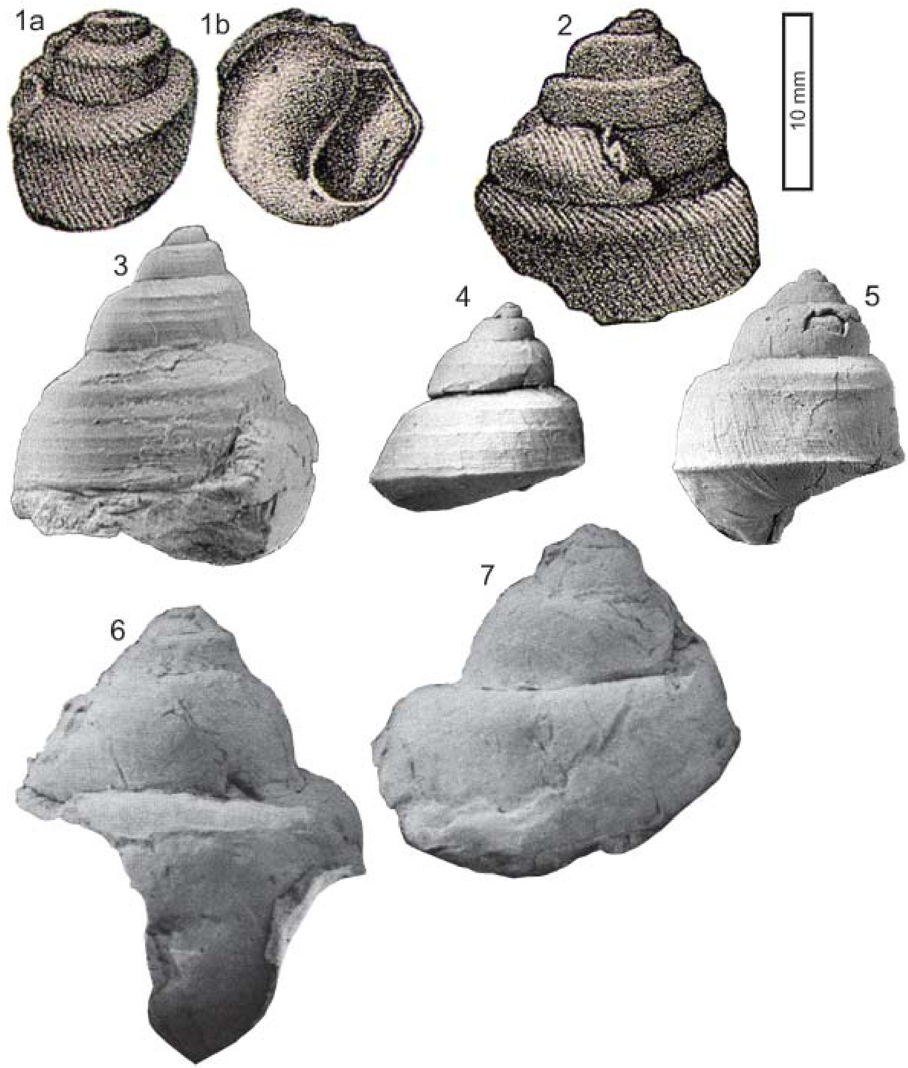
Taxon Identifications after Taylor (1975)	Above Arvada coalbed	Arvada bed to Roland bed	Roland bed to Smith bed	Smith bed to Anderson	Anderson bed to Wall bed	Below Wall bed
Bellamya retusa						x
Campeloma nebrascense						x
Campeloma cf. *C. vetulum*						x
Cleopatra nebrascensis producta						x
Sphaerium cf. *S. heskethense*				x		x
Pisidium cf. *P. insigne*		x	x	x		x
Plesielliptio priscus		x	x	x	x	x
N. Gen. A *limneaformis*‡		x	x	x	x	x
Bellamya n. sp. A					x	
Plesielliptio silberingi		x	x	x	x	
Cleopatra multistriata		x	x	x	x	
Cleopatra tenuicarinata		x	x	x	x	
Valvata bicincta				x		
Bellamya cf . *B. raynoldsana*				x		
Hydrobia anthonyi				x		
Reesidella nana			x	x		
Hydrobia cf. *H. recta*			x	x		
Acroloxus radiatulus			x	x		
Clenchiella planospiralis		x	x	x		
Clenchiella n. sp. A		x	x	x		
Eupera formosa	?		x	x		
N. Gen. A *minutum*	x	x	x	x		
Pleurolimnaea tenuicosta	?	x	x	x		
Physa cf. *P. bridgerensis*	x			x		
Bellamya aff. *B. retusa*	x		x			
Bellamya raynoldsana		x	x			
Hydrobia eulimoides		x	x			
Biomphalaria storchi		x	x			
Micropyrgus minutulus		x				
Plesielliptio haydeni	x					
Sphaerium aff. *S. occidentale*	x					
Valvata aff. *V. lewisi*	x					
Valvata aff. *V. bicarinata*	x					
Bellamya paludinaeformis	x					
Bellamya wyomingensis	x					
Micromelaniidae?	x					
Elimia? aff. *E.? nodulifera*	x					
Acroloxus n. sp. A	x					
Planorbis	x					
Omalodiscus	x					
Physa cf. *P. plermatis*	x					

‡ of Lioplacinae

SF-Figure 10. Powder River Basin upper Paleocene and lower Eocene continental molluscan identifications placed in coalbed intervals (after Taylor, 1975). Taylor's work, in part, revises Yen (1948b), but also introduces new taxonomic issues to be resolved. A clear faunal distinction exists between Paleocene and Eocene strata regardless of nomenclatural interpretations. Taylor's correlation to mammalian ages was based more on molluscan turnover (at the Anderson bed) than on any control based on mammals.

where it occurs and more abundant than the other identified species of the genus. Following Yen (1948b), he also reported that it was known from the lowest Eocene of Montana. These "Wasatch" localities, however, are not Eocene in age, as previously noted, and can be assigned to the Clarkforkian. The morphology was not recognized in the Green River or Wasatch Formation of Hanley's study (1974, 1976), but a similar form was identified as *Lioplacodes nebrascensis* from the late Tiffanian of the Bighorn Basin (Hartman and Roth, 1998). Thus the Duff Brown Tank specimens are a close relative of late to latest Paleocene *Lioplacodes*.

A single specimen from Duff Brown Tank (SF-Fig. 1, Image 14) is comparable to *"Gyraulus" militaris* (White). Like any small, only fairly well preserved specimen of its kind, a positive identification is difficult. Its size, whorl shape, and depressed spire compare with other assignments to this taxon (La Rocque, 1960). White (1880, p. 160; 1883b) described this species from the "head of Soldiers' Fork, Utah" (L3815). It was thought at the time to be from "the upper portion of the Laramie or the lower portion of the Wahsatch Group." The type locality of *"G." militaris* cannot be precisely relocated, but could be from the North Horn, Colton, or Flagstaff Formations that crop out in this area of Soldier Creek in Utah County. The studies of Fouch et al. (1987) from nearby Price Canyon did not shed light on the biostratigraphy of this taxon, even with their extensive fossil collecting. Their focus on the North Horn Formation section, however, suggests slightly younger rocks (e.g., Colton and Flagstaff) might contain comparable material. Hanley (1974, 1976) reported, but did not illustrate, *Gyraulus militaris* from a few localities in the main body and Niland Tongue of the Wasatch Formation of the Washakie Basin



SF-Figure 11. Specimens of *Viviparus* species from lower Eocene strata of Utah, Wyoming, and New Mexico with comparable morphologies found at Duff Brown Tank. Images 1a, b, and 2: *V. uniangulatus* (Hall) (from Hall, 1845; matrix removed from Image 2; see also Hartman, 2004); Images 3–5, *V. trochiformis* (Meek and Hayden) (= *meeki* Wenz) as identified by Hanley (1974, 1976); and Images 6 and 7, *V. calamodontis* (Cockerell) (from Hartman, 1981; matrix removed from figures).

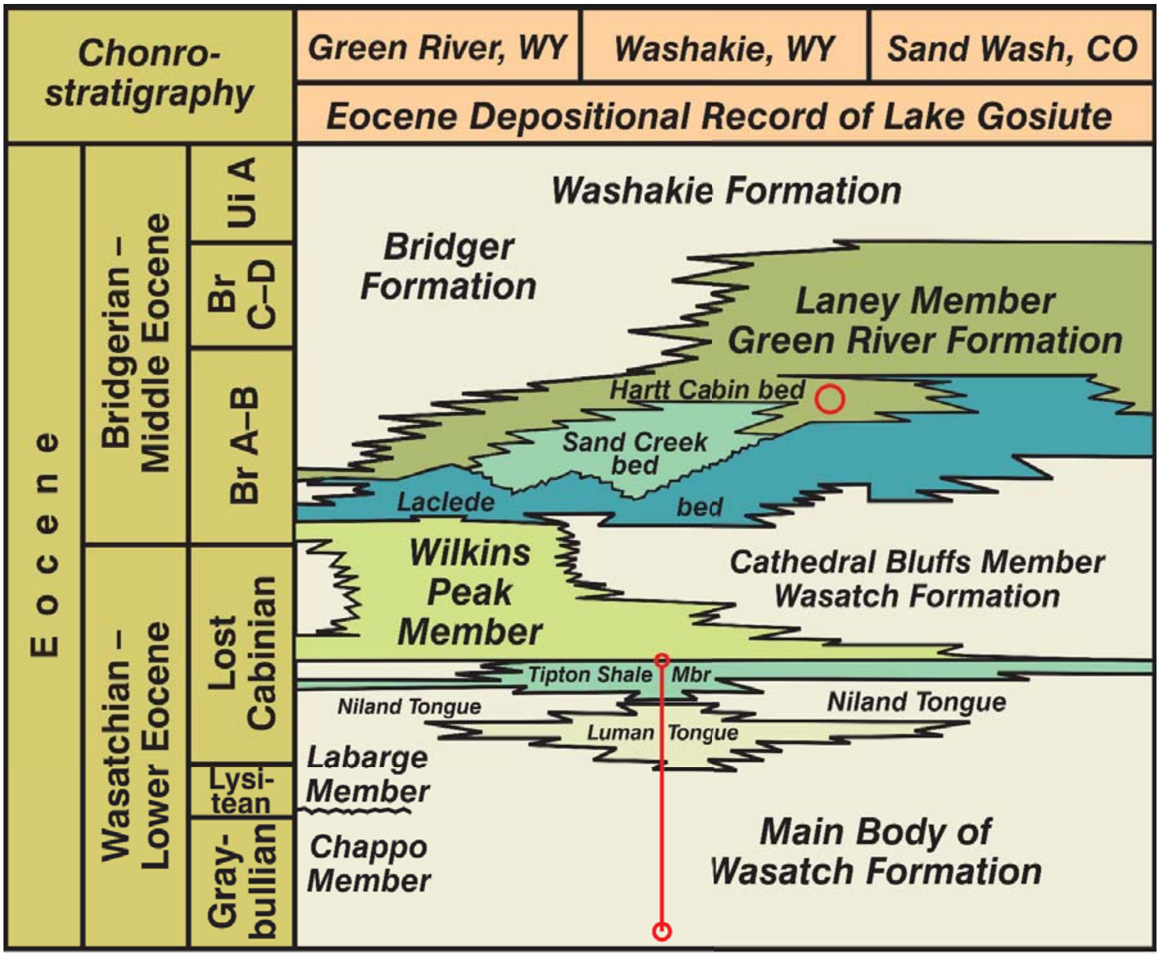
and the Luman Tongue and Douglas Creek Member Green River Formation of the Piceance Basin.

Of all of the relatively common taxa, species of Physidae are difficult to identify with confidence in late Paleocene or early Eocene strata. The Duff Brown Tank locality (SF-Fig. 2) has a fairly well preserved taxon that compares well with La Rocque's (1960) *Physa* cf. *P. longiuscula* Meek and Hayden. The Fort Union Formation species (Hartman, 1984, L0429) in its type area is late Paleocene in age (Ti3 to Ti4) (Hartman and Kihm, 1996, 1995, 1992). Hanley (1974, 1976) tentatively identified this taxon in both the Wasatch (main body, problematic lacustrine facies) and Green River Formations (Luman Tongue and Douglas Creek Member) (see SF-Fig. 12). Today's species of *Physa* can have a wide distribution. Their self-fertilizing method of reproduction, rapid dispersal, and environmentally sensitive morphology leads to difficulty with fossil taxonomy. A not so subtle problem is the condition in which the specimens are rendered to us through taphonomic processes. La Rocque's specimens are internal molds with some shell, the Duff Brown Tank specimens are variably preserved external molds, whereas type specimens are nearly original shell material, although crushed.

The species of Hydrobiidae from Duff Brown Tank (SF-Fig. 2) are small freshwater snails in need of much study. Assignment to *Hydrobia* in the North American Cretaceous and Paleogene fossil record is invalid, a holdover of a generalized taxonomy from the 19th century. A potentially closely related, or at least morphologically similar, group of *"Hydrobia"*-like snails occur in Upper Cretaceous to middle Eocene strata of Western Interior of North America. Varying greatly in abundance and diversity, these taxa existed on Laramidia, the prograding deltas during the final closure of the Western Interior Seaway (Cannonball Sea), and during post-inland sea, Laramide deposition. Abundance and diversity at Duff Brown Tank suggest quiet water conditions. Preliminary comparisons can be made to *"H." utahensis* White, but the specimens are incomplete. La Rocque (1960) compared this species and other specimens from Unit 1 of the Flagstaff Formation to *"H."* cf. *"H." recta* White. This high-spired form has some similarity to Image 10 of SF-Figure 2, but the Duff Brown Tank specimen does not likely attain a sufficient number of whorls to be assigned to that species. Another small hydrobiioid with few whorls is shown in Images 13 and 14 of SF-Figure 2. The remaining hydrobiioids are referred to forms–*"H."* sp. form b, and *"H."* sp. form t and are under further study (Images 15–18 and 19 and 20, respectively). *"H." anthonyi* (Meek and Hayden). *H. utahensis* and *"H." anthonyi* were described from the Flagstaff Formation of Utah (L3814; White, 1876) and Fort Union Formation (L0433; Meek and Hayden, 1856), respectively. They are known with confidence from upper Paleocene strata.

AGE OF THE DUFF BROWN TANK LOCAL FAUNA

Considering the number of issues that complicate species identification and age determination, diagnosing



SF-Figure 12. This chronostratigraphic correlation diagram documents the range of Hanley's (1974, 1976) identification of *Viviparus* cf. *V. calamodontis* Cockerell (was *trochiformis* [Meek and Hayden] of Hanley, = *V. meeki* Wenz) in the Green River Formation (colored units) and bounding lithic units in southwestern Wyoming and northwestern Colorado. The red line and circle indicate multiple and single records of Hanley's taxon, respectively (enhanced and slightly modified from Hanley, derived originally from Roehler, 1972).

the precise age of the Duff Brown Tank gastropod local fauna means some uncertainty exists until additional supportive fossil data become available. Logically this would include controlled chronostratigraphic data and additional mollusks or molluscan studies. However, the significance of the gastropod fossil age determination provided here is that no other more precise data exist on the age of any part of the Music Mountain Formation.

Only late Paleocene or early Eocene species comparisons are made to the Duff Brown Tank local fauna. The fauna is characteristic of the late Paleocene, with dominant occurrences of caenogastropods (viviparids, pleurocerids, and hydrobiioids) and aquatic pulmonates (physids) being typical assemblage in both shallow-river and lacustrine settings. The ellobiid is less ubiquitous, but nonetheless common enough to be considered a possible, if not regular, faunal element. A comparison to Unit 1 of the Flagstaff Formation of La Rocque (1960) is appropriate except for the greater snail diversity seen in most Flagstaff assemblages and the presence of mussels. The suggestion that the Duff Brown Tank local fauna is early Eocene in age (Wasatchian) is based on a lack of direct comparability to Paleocene taxa and greater similarity to the Eocene *V. calamodontis* or *V. uniangulatus*. However, the absence of Elimia and the presence of *Lioplacodes* indicate a fauna with a Paleocene appearance. Despite these uncertainties, the Duff Brown Tank locality limestone beds of the Music Mountain Formation should not be considered younger than early Eocene in age, based on molluscan evidence. The limestone beds represent an episode of local drainage impoundment associated with Laramide deformation and a moister climate than the upper Eocene(?)-Oligocene Buck and Doe Conglomerate that caps the Music Mountain outcrops 70 km to the west.

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APPENDIX A–LOCALITY REGISTER

L-numbers (e.g., L0422) refer to a Hartman locality numbering system for mostly continental mollusks in North America. The following localities were mentioned in this report and are briefly identified here.

L0422. Mercer Co., ND, "Fort Clark." Tongue River Member, Fort Union Formation (Hartman, 1984, 1992).

L0429. McKenzie Co., ND, "three miles [4.8 km] below Fort Union." Fort Union Formation (Hartman, 1984, 1992).

L0433. Richland Co., MT, "Yellowstone River, thirty miles [48 km] above the mouth." Fort Union Formation (Hartman, 1984, 1992).

L0435. Probably McKenzie Co., ND, "mouth of Yellowstone River." Tongue River Member?, Fort Union Formation (Hartman, 1984, 1992).

L0619. Natrona Co., WY. Locality B5 (Yen, 1948a). Wagon Bed Formation (49 to 45 Ma, about Bridgerian 2 to Uintan1 NALMA) (Tourtelot, 1953; as interpreted, and Gunnell, Duke University, written communication 2013).

L0621. Natrona Co., WY. Locality 19 (Tourtelot, 1946), Locality B7 (Yen, 1948a), Badwater area. Wagon Bed Formation (49 to 45 Ma, about Bridgerian 2 to Uintan1 NALMA) (Tourtelot, 1953; as interpreted, and Gunnell, Duke University, written communication 2013).

L0627. Fremont Co., WY. Locality B6 (Yen (1948a). Wagon Bed Formation (49 to 45 Ma, about Bridgerian 2 to Uintan1 NALMA). (Tourtelot, 1953; as interpreted, and Gunnell, Duke University, writtien communication 2013).)

L2053. Sheridan Co., WY, sec. 6, T. 54 N., R. 76 W., T.C. Prettyman farm; "Wasatch" Formation, just below the Arvada coal bed; Roland–Arvada coal bed interval (Yen, 1946, Taylor, 1975; Hartman, 1984).

L3322. Emery Co., UT, "east side of Joe's Valley," "About twenty miles to the east of Joe's Valley"; Howell (1875), White (1877a).

L3333. Sanpete Co., UT, "Wales," "near Wales"; Wasatch given, possible Flagstaff Formation (White, 1877a, 1886b).

L3814. Sanpete Co., UT, Musinia Mountain (various spellings) (Mary's Nipple), but interpreted by La Rocque (1960) as Musinia Plateau; Flagstaff Formation (White, 1877a, 1886bl see La Rocque, 1960).

L3815. Utah Co., UT, "At the head of Soldier's Fork" (now Soldier Creek); Colton or Flagstaff Formations (White, 1877a, 1880, 1886b).

L3825. Sanpete Co., UT. Ephraim City (White, 1877a). Interpreted as likely from the Colton Formation.

L3826. Last Bluff now Table Cliff, Strata of Tertiary age (Howell, 1875; White, 1877a). Interpreted as Claron Formation, pink limestone member.

L3827. Garfield Co., UT. South of Last Bluff (Howell, 1875; White, 1877a). Interpreted as Kaiparowits Formation, but uncertain.

L3833. Sweetwater Co., WY. Locality GR 10-69 (Hanley, 1974). Luman Tongue, Green River Formation.

L3929. Sweetwater Co., WY. Locality GR 3-71 (Hanley, 1974). Main body of Wasatch Formation.

L4111. Sweetwater Co., WY. Locality W1, "From Sec . 36, T. 14 N., R. 102 W. (Yen 1948a). Wasatch Formation, near contact with Luman Tongue of Green River Formation (interpreted).

L4112. Sweetwater Co., WY. Locality W1, "in a bed about 100 feet [61 m] above the preceding [L4111] exposure" (Yen, 1948, p. 636). Wasatch Formation, near contact with Luman Tongue of Green River Formation (interpreted).

L4113. Hot Springs Co., WY. Eargle Locality W2 = Locality W2 (Yen, 1948a). Tatman Formation (Hartman, 1984).

L4114. Sweetwater Co., WY. Locality B1 [Bridger 1] (Yen, 1948a). Bridger Formation, Blacks Fork Member (uncertain mapping of area), possibly Twin Buttes Member, Unit C (interpreted; Gunnell, Duke University, written communication, 2013).

L4115. Sweetwater Co., WY. Locality B2 [Bridger 2] (Yen, 1948a). Bridger Formation, Blacks Fork Member, Unit B, lower unit (Lyman limestone) (near contact with underlying map unit TbA) after Murphey et al. (2011).

L4116. Sweetwater Co., WY. Locality B3 [Bridger 3] (Yen, 1948a). Bridger Formation, Twin Buttes Member, Unit C or D, main white beds in Unit D ("near prominent white layer of Twin Buttes"; Yen, 1948a) (using Murphey and Evanoff, 2006, 2007).

L4117. Sweetwater Co., WY. Locality B4 [Bridger 4] (Yen, 1948a). Locality plots in map unit TbDl, Bridger Formation, Twin Buttes Member, Unit D, Lonetree Limestone (lower unit) (using Murphey and Evanoff, 2006, 2007).

L4371. Coconino County, AZ. Duff Brown Tank Locality. As reported herein.

L4442. Sweetwater Co., WY. "About three miles east of Table Rock Station [4.8 km]"; "from debatable strata" (White, 1879, p. 251; White, 1883b, Wahsatch or Green River Groups). Wasatch Formation.