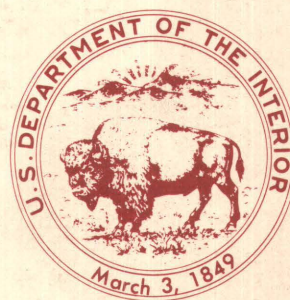


Geology and Paleoecology of the
Cottonwood Creek Delta in the
Eocene Tipton Tongue of the
Green River Formation and a
Mammalian Fauna from the
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By HENRY W. ROEHLER, J. H. HANLEY,
and J. G. HONEY

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DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary



U. S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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- (C) A Mammalian Fauna from the Base of the Eocene Cathedral Bluffs Tongue of the Wasatch Formation, Cottonwood Creek Area, Southeast Washakie Basin, Wyoming, by J. G. Honey.

Chapter A

Geology of the Cottonwood Creek Delta in the Eocene Tipton Tongue of the Green River Formation, Southeast Washakie Basin, Wyoming

By HENRY W. ROEHLER

Description of a freshwater lacustrine sandstone fan
delta in Lake Gosiute

GEOLOGICAL SURVEY BULLETIN 1669

GEOLOGY AND PALEOECOLOGY OF THE COTTONWOOD CREEK DELTA IN THE
EOCENE TIPTON TONGUE OF THE GREEN RIVER FORMATION AND A
MAMMALIAN FAUNA FROM THE EOCENE CATHEDRAL BLUFFS TONGUE OF THE
WASATCH FORMATION, SOUTHEAST WASHAKIE BASIN, WYOMING

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Geology of the Cottonwood Creek Delta in the Eocene Tipton Tongue of the Green River Formation, Southeast Washakie Basin, Wyoming

By Henry W. Roehler

Abstract

The Cottonwood Creek delta comprises a local clastic lithofacies in the Tipton Tongue of the Green River Formation in the southeast part of the Washakie basin, 4 mi north of Baggs, Wyo. The delta is lenticular in cross section and is approximately 2 mi long and 80 ft thick. It is composed primarily of quartzose sandstone that formed a freshwater fan delta within oil shale beds on the east shores of Eocene Lake Gosiute. Sandstones in the study area exhibit six distinct types of primary sedimentary structures that define specific delta and shoreline lithofacies. The stratigraphic positions and areal distribution of the primary sedimentary structures and lithofacies are illustrated by cross sections and paleogeographic maps. The delta and shorelines of the lake contain abundant mollusk, ostracode, and fish fossils. Flood-plain deposits overlying and underlying the delta locally contain vertebrate fossils that indicate that the delta is of late early Eocene age.

INTRODUCTION

Location and Accessibility

The study area occupies 7.3 mi² of Tps. 13–14 N., Rgs. 91–92 W. in the southeast part of the Washakie Basin in south-central Wyoming. It is located 4 mi north of Baggs, Wyo., and 6.5 mi north of the Wyoming-Colorado stateline. The study area is accessible by Wyoming Highway 789 (fig. 1). A well-traveled county road branches westward from Highway 789, 7 mi north of Baggs. This road parallels the south slopes of Cottonwood Creek for more than 1 mi before climbing a dugway road cut where it turns south and follows a bench formed along the east slopes of a dry tributary of Cottonwood Creek. Near the head of this dry tributary the road turns west and continues 1 mi to where it crosses Streckfus Draw near the southwest corner of the study area. A road passable by four-wheel-drive vehicles branches from Highway 789 and parallels the north edge of Cottonwood Creek across the northern part of the study area.

Field Work and Previous Investigations

The Cottonwood Creek area was investigated during field work undertaken to map the geology and assess the mineral resources of the Washakie basin. Interest in the Cottonwood Creek delta (a name introduced here) stems from the fact that the Tipton Tongue of the Green River Formation along the east margin of the Washakie basin is generally composed of lacustrine oil shale, but in the vicinity of Cottonwood Creek a thick sandstone lens (the delta) locally replaces the oil shale. The presence of the sandstone lens was first reported by Bradley (1945); he briefly explained its origin and location as “the locus of a stream that entered the ancient Green River lake basin (Lake Gosiute) from the east or southeast.” During the field investigations along Cottonwood Creek, the author realized that the delta was an important but inadequately described feature of Lake Gosiute. Consequently, detailed studies of the delta were undertaken in July 1982, and the results of those studies are presented here.

The Cottonwood Creek delta is fan shaped. It does not occupy the lakeward margin of an alluvial fan (AGI Glossary of Geology, 1973), and it is not located in close proximity to source areas. The type sedimentation may be analogous to Holocene Lake Ontario (Csanady, 1978; Sly, 1978), but it is not analogous to that described by Gilbert (1885) for Pleistocene Lake Bonneville.

Geographic Setting of the Study Area on Cottonwood Creek

Cottonwood Creek flows intermittently eastward across a desert terrane in the study area. In several places the creek intersects deeply incised dry washes that form tributaries. There are a number of springs and reservoirs along the main creek bed. These provide moisture to support native grasses and a few cottonwood trees. The slopes adjacent the creek are mostly sage covered, but cedar trees are present along the ridges that border the creek at higher elevations.

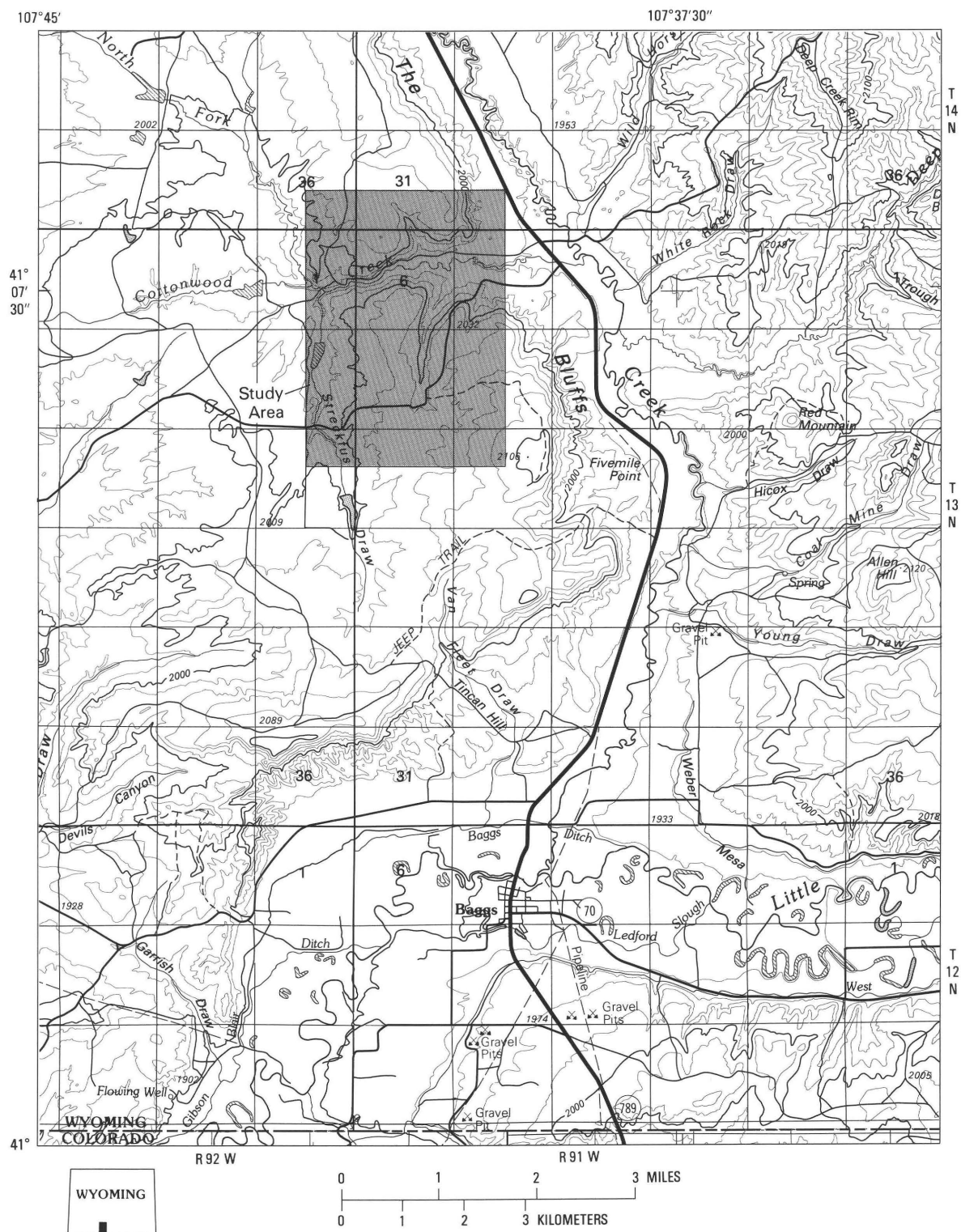


Figure 1. Index map of the study area along Cottonwood Creek north of Baggs, Wyo. (Base from USGS Baggs, WY-CO 1° quadrangle; scale 1:100,000)

Sandstones that compose the delta dip gently westward and crop out as a series of drab gray, tan, or brown ledges that rise in step-fashion upward from talus

and alluvium-covered slopes that are present near creek level (fig. 2). The delta sandstones are well exposed, except in the western and southern parts of the study area,

where they thin and are obscured by talus and slope wash composed mostly of variegated mudstone and sandstone derived from the overlying Cathedral Bluffs Tongue of the Wasatch Formation.

Regional Paleogeographic Setting

Lake Gosiute occupied nearly 15,000 mi² of the ancestral greater Green River basin in what is now southwest Wyoming and adjacent parts of Colorado and Utah during the period of deposition of the Tipton Tongue. During this period the lake extended from the Thrust Belt on the west to near the Sierra Madre and Rawlins uplift on the east and from the Uinta Mountains on the south to near the Wind River Mountains on the north. The surface of the lake was probably less than 1,000 ft above sea level, but the surrounding mountains rose a few hundred feet higher (Bradley, 1929). Comparisons by Bradley (1929) of Eocene Lake Gosiute with Holocene lakes and studies of lower Eocene floras by Leopold and MacGinitie (1972) suggested that the average annual temperature along Lake Gosiute during Tipton deposition probably ranged between 72°F and 82°F. The annual precipitation was between 38 and 50 inches. MacGinitie (written commun., 1972) believed that the climate was "humid, warm temperate, with little or no frost." Shoreline areas were undoubtedly forested. A generalized paleogeographic map of Lake Gosiute during the period of Tipton deposition is shown in figure 3.

STRATIGRAPHY

Nomenclature, Lithologies, and Depositional Environments

Eocene rocks in the Washakie basin are more than 12,000 ft thick (Roehler, 1972) and are divided into the Wasatch Formation of fluvial origin, the Green River Formation of lacustrine origin, and the Washakie Formation of fluvial origin. The Green River Formation intertongues extensively with the underlying Wasatch Formation and the overlying Washakie Formation (fig. 4). The Luman Tongue and Wilkins Peak Member of the Green River Formation and the Niland Tongue of the Wasatch Formation do not occur in the study area but are present in other parts of the Washakie basin.

The Tipton Tongue of the Green River Formation in the study area consists of 20–120 ft of mostly tan and brown sandstone and oil shale. The tongue is underlain by more than 2,000 ft of variegated mudstone and sandstone that compose the main body of the Wasatch

Formation. It is overlain by 1,400 ft of similarly variegated rocks that compose the Cathedral Bluffs Tongue of the Wasatch Formation.

The name Lake Gosiute was first used by King (1878) and was later applied by Bradley (1929) to the tongues and members of the Green River Formation in the greater Green River basin. The waters of Lake Gosiute in ascending sequence were alternately fresh during deposition of the Luman and Tipton Tongues, saline during the deposition of the Wilkins Peak Member, and fresh again during the deposition of the Laney Member. More than 3,500 ft of rocks were deposited in the greater Green River basin during the 6-million-year history of the lake.

The Tipton Tongue of the Green River Formation was named by Schultz (1920) for 200–250 ft of lacustrine "fissile shale, conglomerate, oolitic limestone, shale, clay and sandstone" that are exposed near Tipton Station on the Union Pacific Railroad at the northern edge of the Washakie basin 46 mi northwest of the study area. The type Tipton Tongue was redefined by Roehler (1968) to exclude the upper part of the tongue, composed mostly of dolomitic mudstone and sandstone, that was found to be the lithostratigraphic and chronostratigraphic equivalents of the lower part of the Wilkins Peak Member. The redefined Tipton Tongue near Tipton Station can be traced in 2°–5°-basinward-dipping beds around the eastern part of the Washakie basin into the study area.

The Cottonwood Creek delta is composed mostly of sandstone, but thin lenses and beds of siltstone, shale, and oil shale are locally interbedded with the sandstone. The sandstone is composed of 65–85 percent clear to milky quartz grains and 15–35 percent feldspar, variously colored rock fragments, and tan calcareous cement. The sand grains are angular to subangular and are poorly sorted (fig. 5). In general, the longest grain dimensions range from 0.09 mm (very fine) to 0.75 mm (coarse). The fluvial sandstones that were deposited in feeder streams of the delta are usually very coarse grained and commonly contain lenses and isolated pebbles of gray and tan chert and quartzite. Isolated chert and quartzite pebbles are also locally present in finer textured sandstone in more distal (lakeward) parts of the delta as indicated on plate 1. The sandstone is slightly hematitic in places and mollusk shells are sometimes completely replaced by hematite.

Organic mud (oil shale) was deposited in the Tipton Tongue in offshore environments of Lake Gosiute in areas underlying and laterally adjacent the Cottonwood Creek delta. The oil shale occurs mostly as alternating tan and dark-brown laminations or varves. The dark-brown laminations are composed of the organic remains of indigenous phytoplankton and zooplankton and some introduced larger plant and animal debris. The bulk of the organic material was probably derived from seasonal

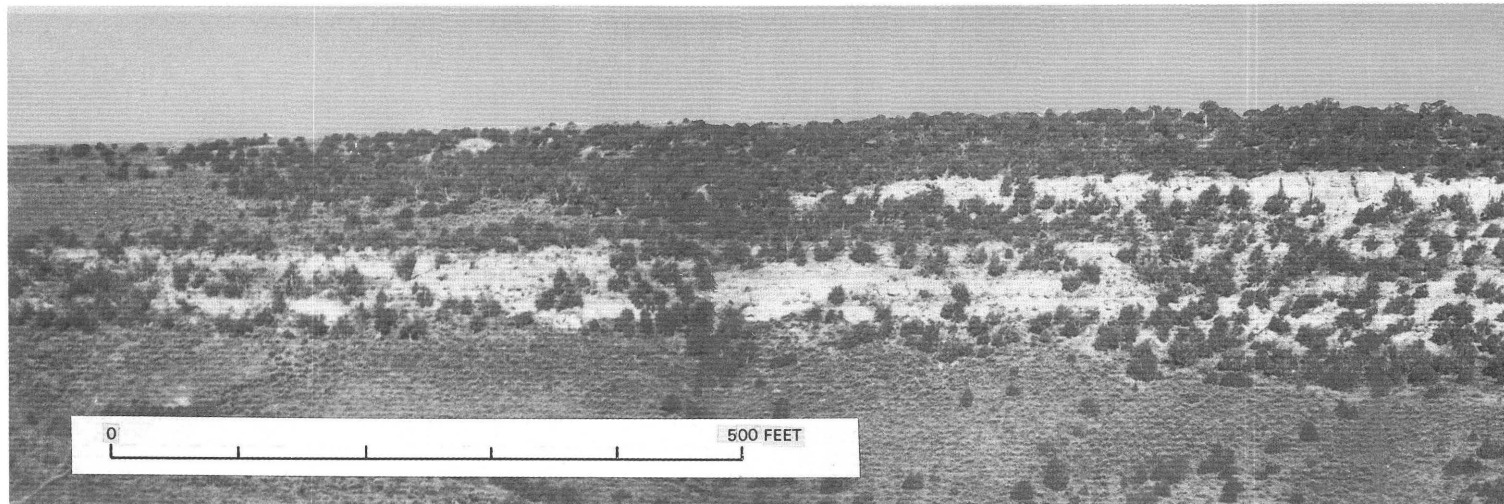


Figure 2. Outcrops of the southern part of the Cottonwood Creek delta in the Tipton Tongue of the Green River Formation

mortalities of planktonic blue-green algae (Bradley, 1929). The algal mortalities occurred during late fall and early winter, when the hours of daylight shortened, causing the lake waters to cool and nutrients to become scarce. The tan laminations represent spring and summer deposition when the lake waters warmed as the days became longer. Nutrient input was high, algal blooms occurred, and carbonates were precipitated from the lake waters. The preservation of the varves and organic material suggest that the organic mud was deposited in stagnant lake waters tens of feet deep, below wave base where circulation was restricted and where most burrowing organisms could not live.

Delta Cross Section from Measured Sections

A stratigraphic cross section of the Cottonwood Creek delta and associated rocks (pl. 1) was constructed from 18 sections measured on outcrops at the locations shown on the geologic map, figure 6. The measured sections show that the lower part of the Tipton Tongue is interbedded with and replaced laterally southward across the study area by the upper part of the main body of the Wasatch Formation. The thinning of the Tipton Tongue reflects a northeast trend for the early Tipton shorelines. Red soils were deposited on flood plains in the southeast part of the study area, while organic mud (oil shale) was contemporaneously deposited in Lake Gosiute in the northwest part of the study area. Later, following the appearance of the Cottonwood Creek delta, the Tipton shoreline shifted to a north-south to slightly northwest orientation.

The stratigraphic cross section (pl. 1) shows that the Cottonwood Creek delta is lenticular, approximately 2 mi long, and has a maximum thickness of about 80 ft.

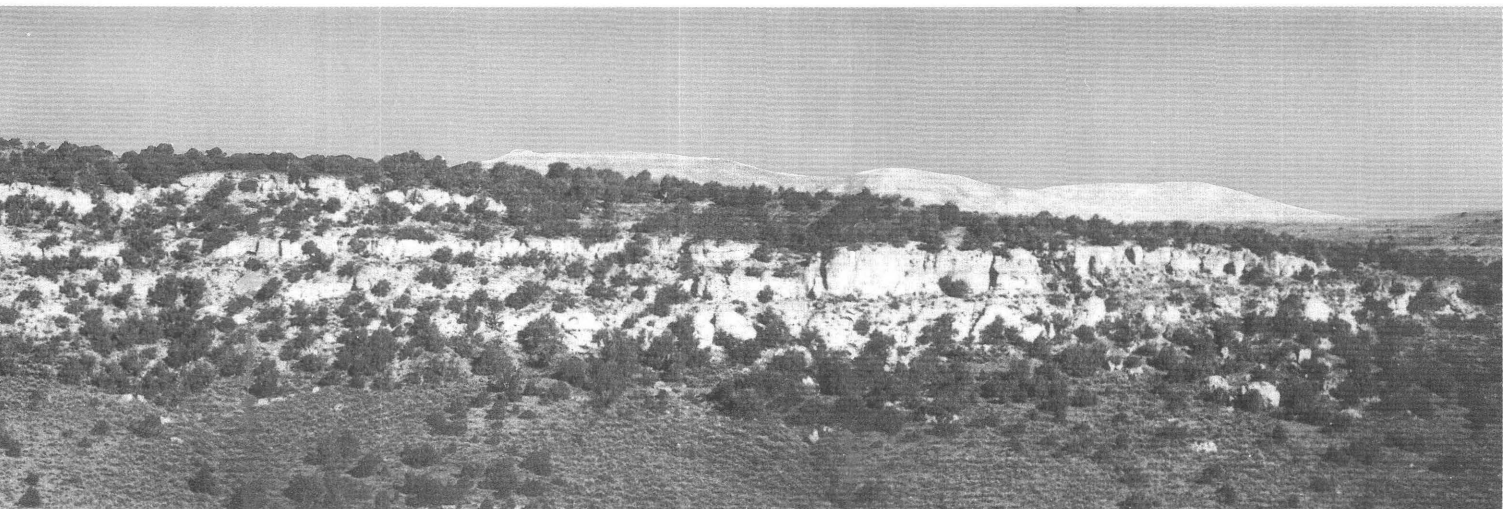
It contains distinctive sandstone lithofacies and scattered concentrations of mollusks, fish, crustacean, and trace fossils.

Primary Sedimentary Structures and Lithofacies

Six types of primary sedimentary structures that characterize high- and low-energy fluvial and lacustrine environments of deposition are present in sandstone outcrops in the study area. The structures define six distinct lithofacies that are illustrated on figure 7.

The largest primary sedimentary structures are present in the lenticular sandstones that comprise the fluvial feeder channels of the delta. The structures consist of superposed large-scale, trough crossbeds up to several feet in height and tens of feet in width that display basal scour and fill (fig. 7A). The streams that occupied the feeder channels appear to have been narrow and deep and had moderate gradients and high discharge. The feeder streams entered the lake from flood plains located to the east, usually as a single artery. After entering the lake they bifurcated by means of distributary channels and constructed fan deltas along the shallow shorelines of the lake. Point bars and other accretionary beds were not recognized within the crossbedded channel sequences studied. This observation suggests that the stream courses were straight where they entered the lake.

An accretionary bar sandstone lithofacies occupied most of the shoreward part of the delta. The accretionary bar sandstone beds are characterized by unidirectional planar crossbeds that are up to 3 ft thick (fig. 7B). These beds formed as megaripples and sand waves that migrated southward from the mouths of feeder streams. A height of nearly 10 ft and a 40°-dip in foreset laminae were observed in an extremely large sand wave located in



in the south-center of sec. 6 and the north-center of sec. 7, T. 13 N., R. 91 W. View is to the west.

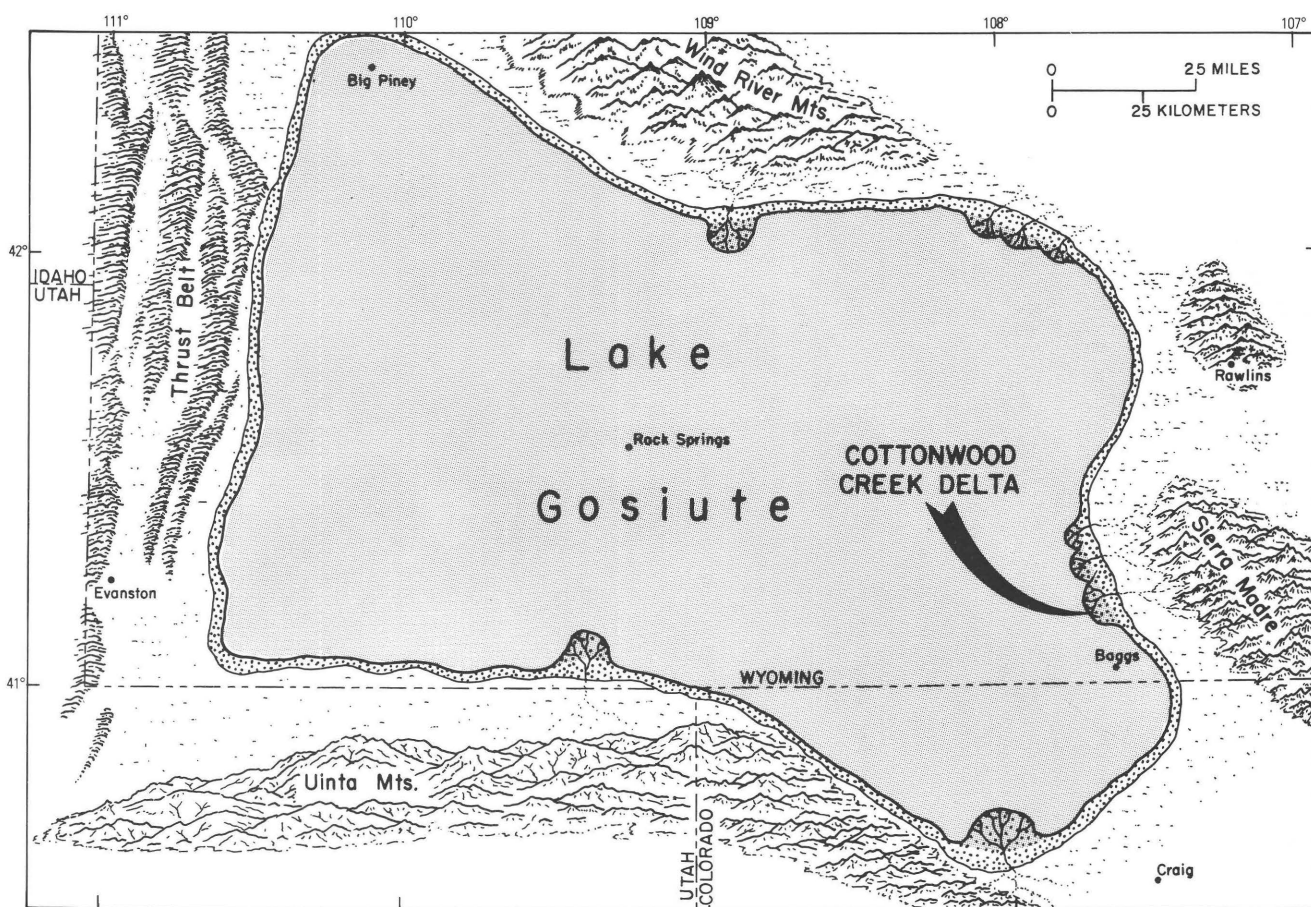


Figure 3. Paleogeographic map of Eocene Lake Gosiute during deposition of the Tipton Tongue of the Green River Formation. The Cottonwood Creek delta was located on the east shores of the lake.

measured section 7982 (figs. 6, 7C). The exceptionally large size of this and associated sand waves suggest, that they had very broad, low-angle, stoss-side slopes and

narrow, high-angle, slipface slopes. The stoss-side slopes probably formed extensive shallow-water areas that were interrupted by sudden deep-water dropoffs formed by the

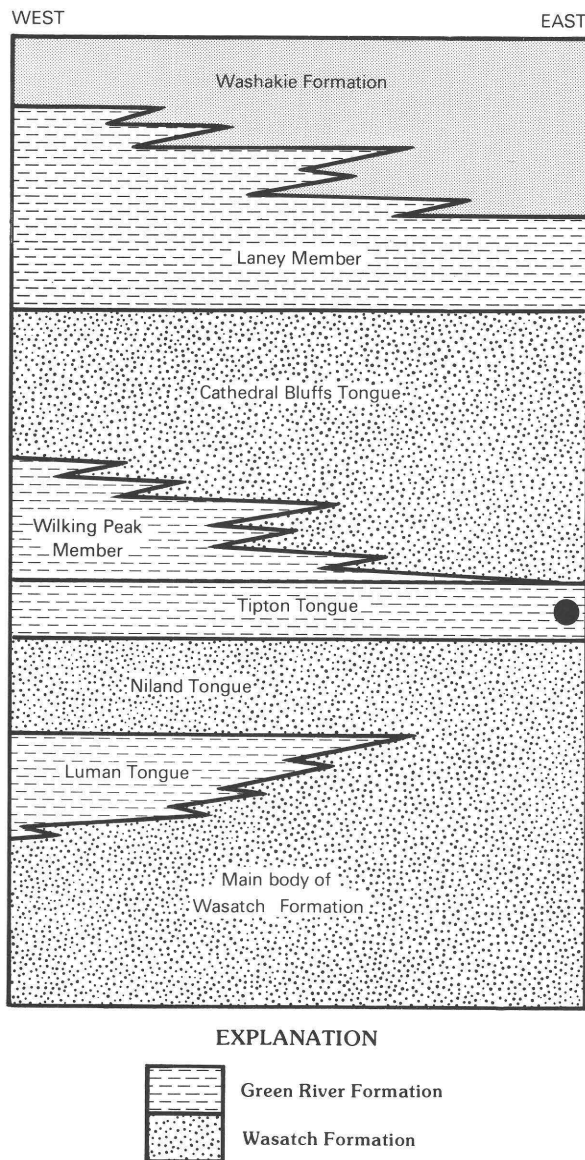


Figure 4. Generalized stratigraphic section of Eocene rocks in the Washakie basin, Wyo. The dot shows the location of the study area.

slipface slopes. The crests of some of the larger sand waves undoubtedly formed arcuate bars that were oriented perpendicular to the shoreline.

The shoreline sandstones of the lake consisted partly of a subaqueous nearshore lithofacies (fig. 7D) and partly of a subaerial beach lithofacies (fig. 7E). Both lithofacies contain lenses of mollusk shells and mollusk shell fragments. The nearshore sandstone lithofacies was deposited as irregularly thick and thin (from 1 to 3 ft thick), subparallel, partly wave-rippled beds, where the bottom sediments were affected by longshore currents but were only slightly reworked by waves. The beach sandstone lithofacies is composed of uniformly thin (from 0.1

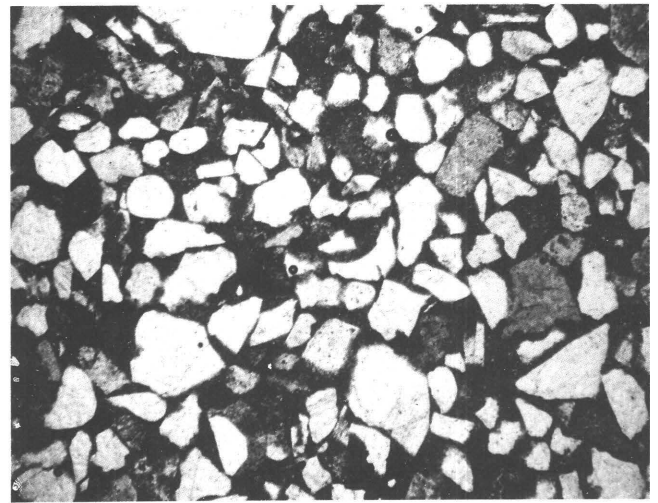


Figure 5. Photomicrograph of sandstone in the Tipton Tongue from the Cottonwood Creek delta. Sample is from outcrops of a channel mouth lithofacies in SE¼SE¼ sec. 6, T. 13 N., R. 91 W. Magnification is X20.

to 1.0 ft thick), parallel-bedded sandstone that dips at low angles westward (lakeward). The beds were deposited by the laminar flow produced by waves as they broke along the shores of the lake and washed upward onto the beach. Sediment infilling of the margins of the lake caused the beaches to prograde. Lithofacies data from sections 8282 and 8482 provide evidence that long, narrow sandbars projected lakeward from the beaches near the mouths of the feeder streams.

The flow velocities and load-carrying capacities of the feeder streams abruptly decreased upon entering the shallow, standing waters of the lake. This loss of energy is reflected by a change in primary sedimentary structures. The large trough crossbeds that characterize the feeder channel lithofacies rapidly change to small-scale festoon crossbeds that characterize the channel mouth lithofacies (fig. 7F). The festoon crossbeds exhibit trough axes and foreset laminae that dip westward (lakeward) near the mouth of the feeder channels. As the lake waters deepened at the outer edge of the delta, the orientation of the trough axes and the direction of dip of the foreset laminae in the festoon crossbeds shifted southward in response to prevailing northerly winds and south-trending longshore currents. These relations suggest that water circulation in Lake Gosiute was clockwise during deposition of the Tipton Tongue. (Circulation is directed to the right and is usually clockwise in the northern hemisphere because of the Coriolis force.) The southward wind-forced transport of sediments at the delta front on the east shores of Lake Gosiute is similar to the sediment movements described by Csanady (1978) for Holocene Lake Ontario.

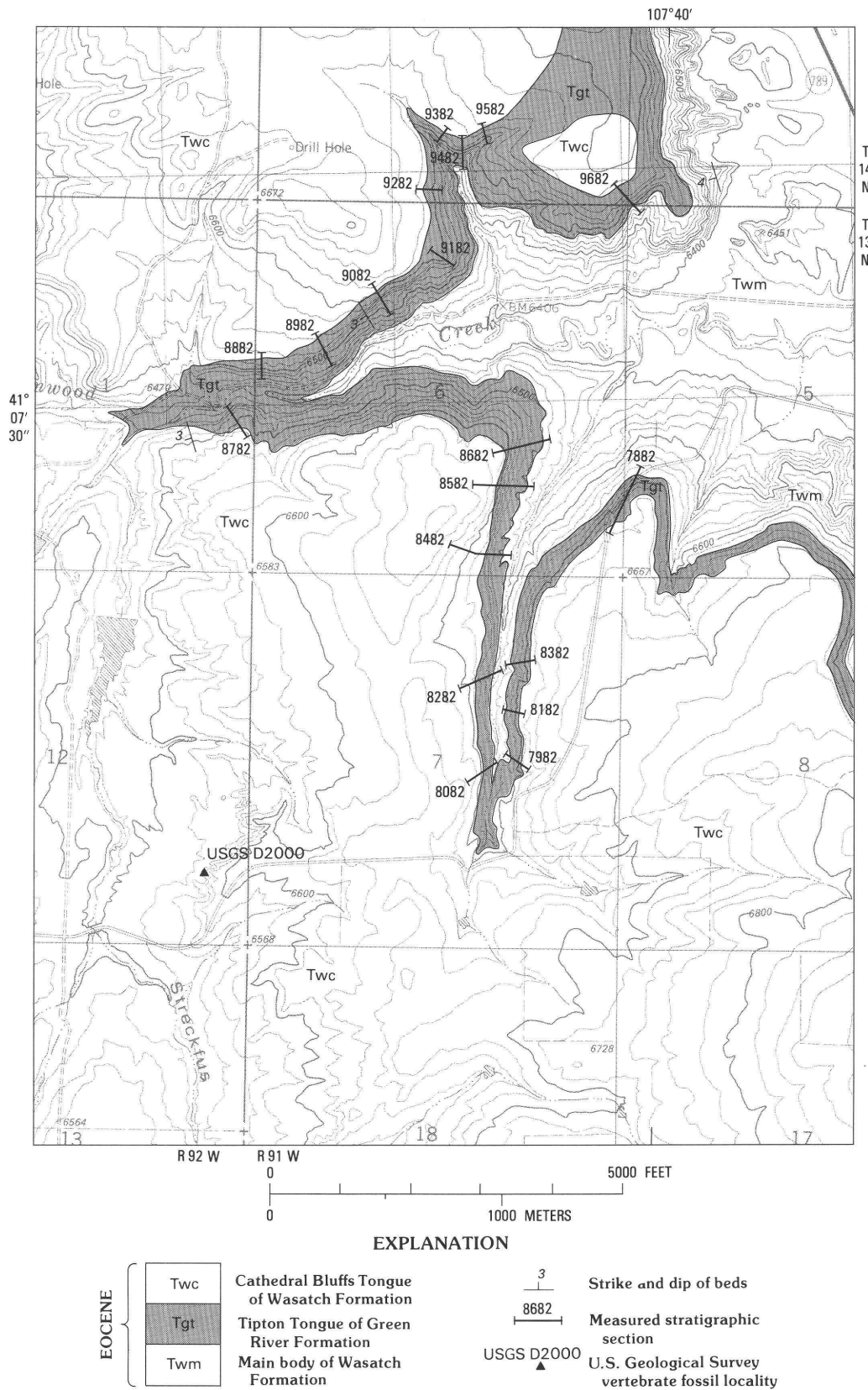


Figure 6. Geologic map of the Cottonwood Creek study area showing the location of measured sections. (Base from USGS Peach Orchard Flat, Wyo. and Baggs, Wyo-Colo. 7.5 min. quadrangles; scale 1:24,000)

Restored Cross Section and Paleogeography

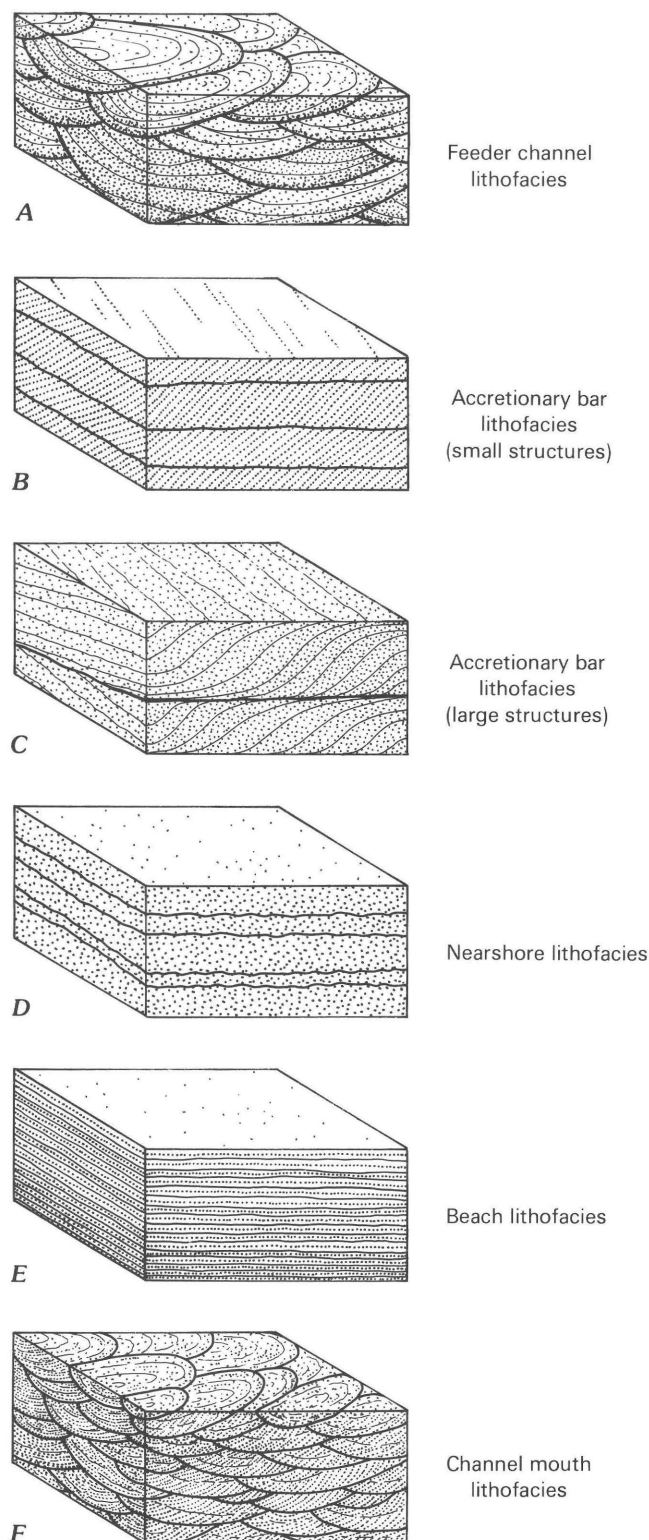


Figure 7. Sketches of primary sedimentary structures that define sandstone lithofacies of the Tipton Tongue in the Cottonwood Creek study area.

Sedimentological data from the measured sections illustrated on plate 1 were used to prepare a restored cross section of the Cottonwood Creek delta, plate 2. Plate 2 illustrates the general size, shape, and stratigraphic positions of the various sandstone lithofacies shown on figure 7. A paleogeographic map for the lower part of the delta, figure 8, was constructed using a hypothetical time line indicated by dots and labeled *T* on plate 2.

Measured section 7882 (fig. 9) contains 28 feet of sandstone deposited in feeder channels near the head of the Cottonwood Creek delta. The section is located several hundred feet east of and offsets the line of outcrops where the remaining sections in the study area were measured (fig. 6). Consequently, measured section 7882 was not included on plates 1 and 2. The data from measured section 7882 also were not used in constructing the paleogeographic map (fig. 8) because sediment-transport directions indicated by the channel bedforms (mostly west) suggest that the channels were situated too far south to be represented by hypothetical time line *T*.

The paleogeographic map (fig. 8) shows that the Cottonwood Creek delta occupied about 2 mi² of the eastern shoreline of Lake Gosiute. Beach and nearshore sandstones bulged lakeward at the delta front in response to the influx of sediments. The recurved shape of the delta is similar to a larger subaqueous delta that is present at the mouth of the Niagara River in Lake Ontario (Sutton and others, 1976, from Sly, 1978). The Niagara delta is affected by west-east longshore sediment transport and is characterized by a frontal offshore bar, shoreward of which is a complex network of ridges and open and closed channels.

The width of nearshore sandstones along the east shores of Lake Gosiute (nearly 1 mi) and the presence of quiet-water oil-shale beds (deposited below wave base at water depths probably between 50 and 100 ft) lakeward of the nearshore sandstones indicate that the paleoslope of the shorelines was between $1/2^\circ$ and 1° . The low angle of paleoslope suggests that the shoreline areas had very low rates of subsidence. Behind the shorelines were forested flood plains that rose topographically eastward across areas of low relief toward the foothills of the Sierra Madre. East of the foothills were mountainous source areas.

The areal distribution of the lithofacies shown on the paleogeographic map of the delta (fig. 8) is supported by sediment transport (paleocurrent) data. Sediment-transport directions were taken on bedforms along outcrops by Brunton compass. From these data, rose diagrams were constructed (fig. 10). Primary azimuth

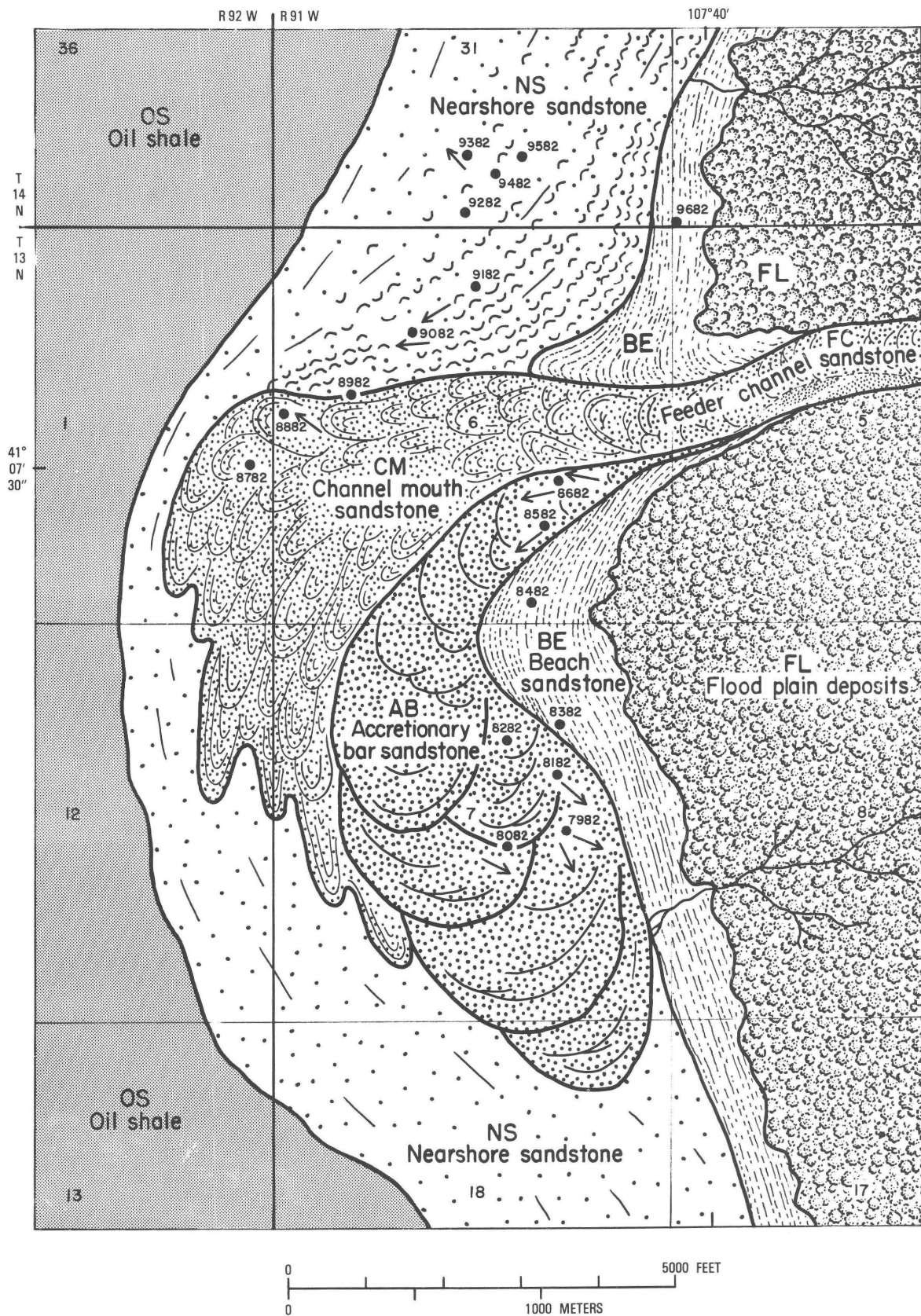


Figure 8. Paleogeographic map of the Cottonwood Creek delta showing the areal distribution of depositional environments and lithofacies during hypothetical time line T (pl. 2). Measured sections are located by numbered dots; paleocurrent directions are indicated by arrows; mollusk concentrations are shown by short curved lines.

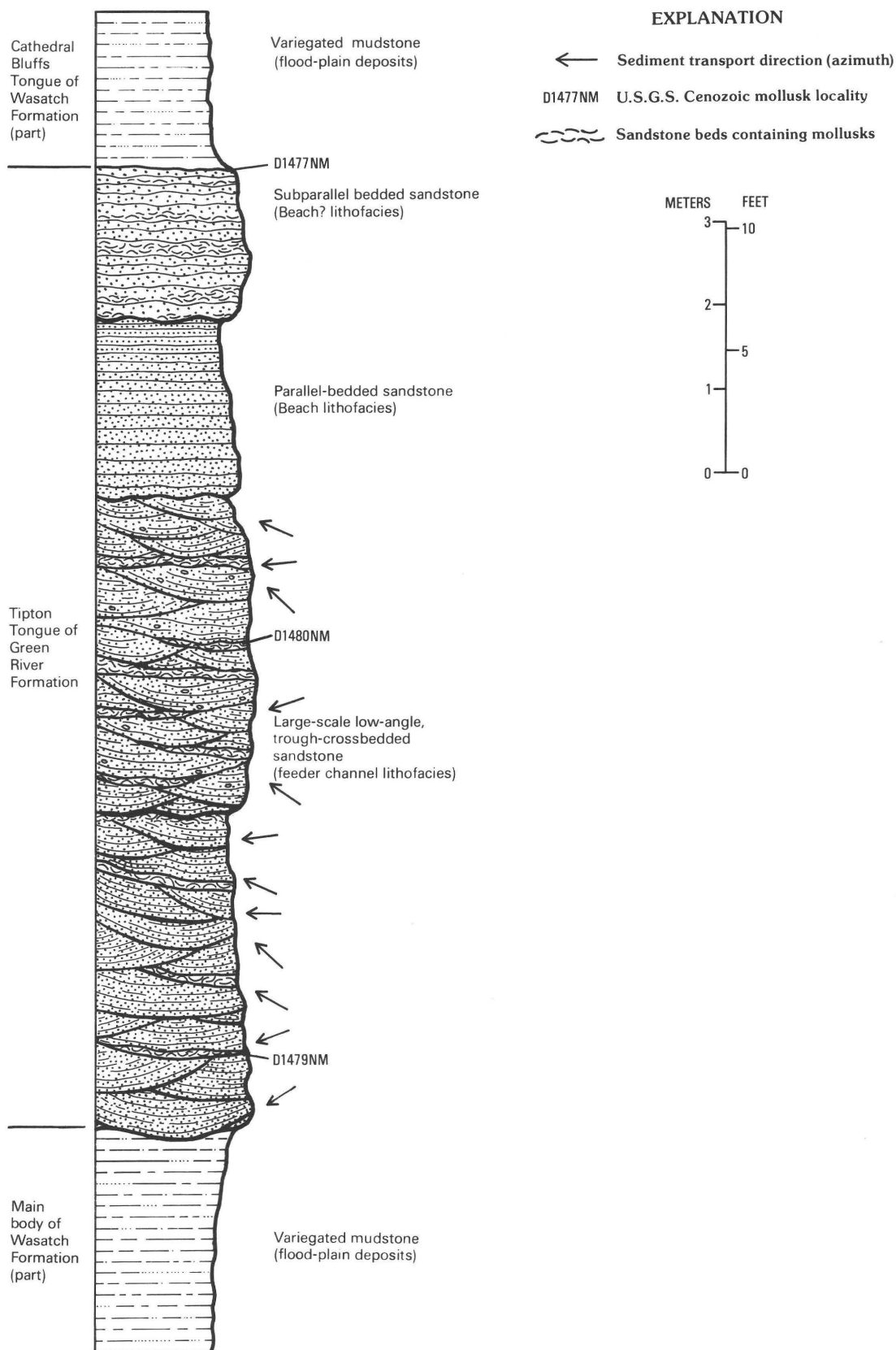


Figure 9. Measured section 7882 (dugway road cut) in SW¼ sec. 5 and SE¼ sec. 6, T. 13 N., R. 91 W., southeast Washakie basin, Wyo.

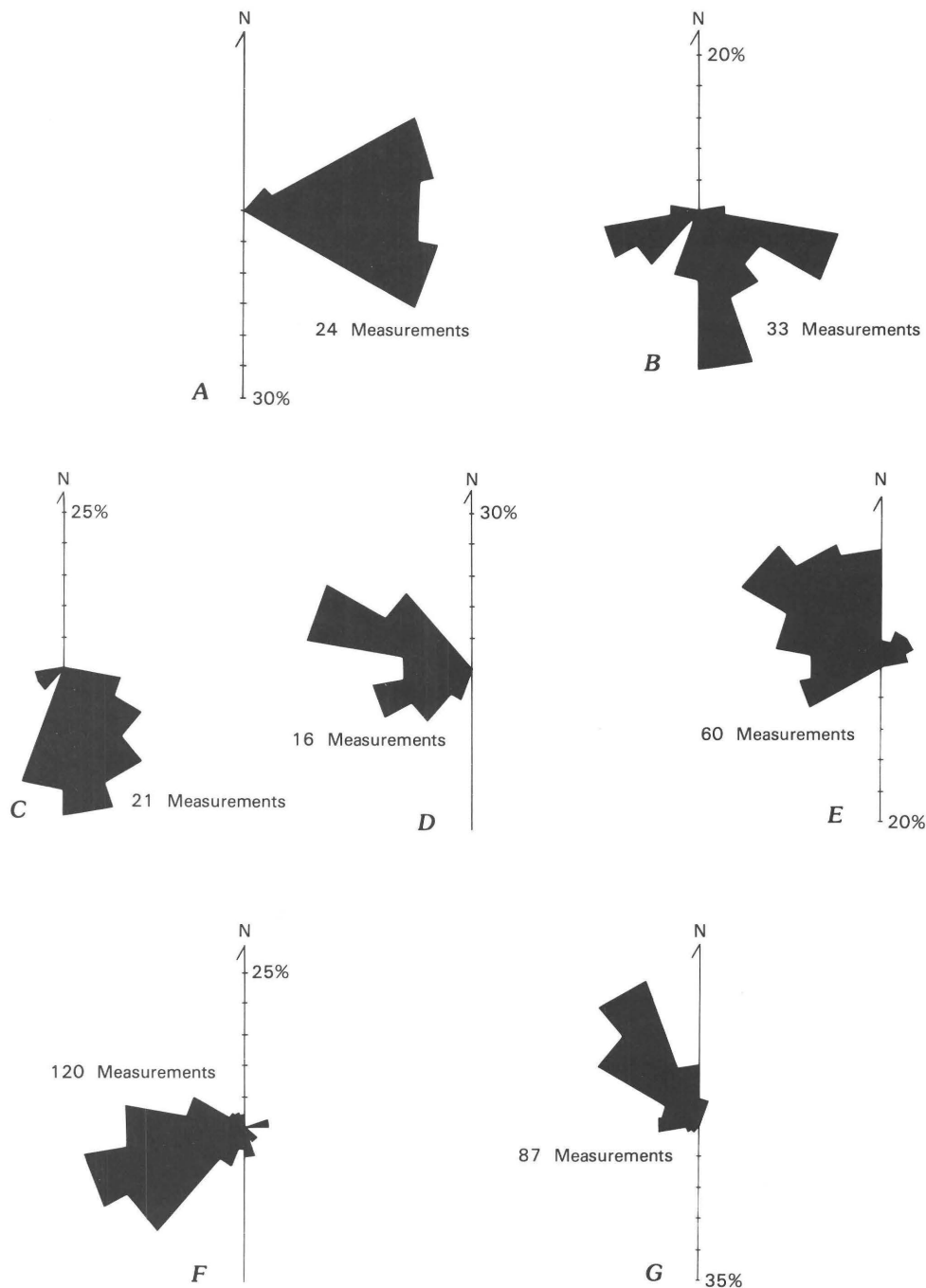


Figure 10. Rose diagrams showing sediment-transport (paleocurrent) directions from the Tipton Tongue in the Cottonwood Creek delta. A, measured section 7982 (middle); B, measured section 7982 (lower); C, measured section 8282 (upper); D, measured section 8682 (lower); E, measured section 8882 (lower); F, measured section 9082 (lower); G, measured section 9382 (lower). The stratigraphic positions of the measured intervals are shown on plate 1.

directions for the sediment transport were plotted on plate 1 and figure 8. The azimuth directions are variable and reveal complex and changing flow patterns across the surface of the delta and along the lake shoreline. For example, during hypothetical time line *T* (fig. 8) some sediments moved westward at measured sections 8582,

8682, and 8882 because of fluvial currents, while other sediments contemporaneously moved southwestward at measured section 9082 and southeastward at measured sections 7982, 8082, and 8182 because of longshore currents. The northwest paleocurrent direction recorded at measured section 9382 is anomalous but may indicate the

downslope movement of nearshore sands into deeper waters off the shoreline of the lake.

PALEONTOLOGY AND AGE

Vertebrates

A small mammalian fauna was collected by J. G. Honey near the base of the Cathedral Bluffs Tongue of the Wasatch Formation in a small area of badlands located on the east slopes of Streckfus Draw in SE $\frac{1}{4}$ /SE $\frac{1}{4}$ sec. 12, T. 13 N., R. 92 W. (fig. 6, USGS loc. D-2000). The fossil collection site is situated stratigraphically about 120 ft above the top of the Cottonwood Creek delta, as shown on plate 2. The fossils are weathering from a white sandstone and red mudstone. They are fragmentary and dispersed, but include the following:

Primates

Microsyops cf. *M. scottianus*

Microsyops sp.

Cantius sp., cf. *C. venticolus*

Cantius sp., cf. *C. frugivorus*

Condylarthra

Hyopsodus sp.

Tillodontia

Esthonyx sp.

Dinocerata

Undetermined uintatheriid

Perissodactyla

Lambdotherium popoagicum

Helalestes sp.

Undetermined *Hyracotherium* sp. or

Orohippus sp.

The Streckfus Draw fauna is late Wastachian (Wood and others, 1941) based on the presence of *Lambdotherium* and *Cantius*. A fauna containing *Lambdotherium* was collected from the upper part of the main body of the Wasatch Formation a few miles north of the study area near Dad, Wyo. (Wood and others, 1941; Gazin, 1962). These localities bracket the Tipton Tongue, which dates the Cottonwood Creek delta late early Eocene. A detailed description and correlation of taxa from USGS Locality D-2000 are presented by J. G. Honey in chapter C of this volume.

Fish scales and coprolites were identified from oil-shale beds in the lower part of measured section 9682. The scales are light brown, chitinous, circular, and usually about $\frac{1}{4}$ inch in diameter. They probably belong to fish of the superorder Teleostei. The fish coprolites are tan, clayey, and have rough external surfaces. They are usually about 1 inch long and less than $\frac{1}{4}$ inch wide.

Mollusks

Two assemblages of mollusks representing different

freshwater habitats were identified by the author in the field. The first assemblage is dominated by the large turreted prosobranch gastropod, *Goniobasis* sp., with lesser numbers of the large conical prosobranch gastropod, *Viviparus* sp., and a few Lampsilis-like, large unionid pelecypods. Hanley (1974) believed that *Goniobasis* and *Viviparus* could tolerate wide ranges in temperature, but they had little tolerance for water of high salinity; he reported that many living unionids require fresh, clear, oxygenated, calcium-rich water having a current and at least seasonably warm temperatures. The *Goniobasis*-*Viviparus*-“*Lampsilis*” assemblage in the study area preferred sandy substrates and occupied the feeder streams, shoals, and small distributaries of the Cottonwood Creek delta. It was also present along the shorelines of Lake Gosiute. The assemblage usually forms coquina lenses that may be as much as 20 ft thick and several hundred feet long. The *Goniobasis* shells in these lenses commonly exhibit pronounced current orientations (fig. 11).

A second assemblage of mollusks includes scattered specimens of the small gastropod, *Valvata* sp., and the small pelecypod, *Musculium* sp. (commonly known as a fingernail clam). The presence of *Valvata* and *Musculium* in oil-shale beds in the Tipton Tongue in the study area suggests that they preferred the organic-rich, muddy substrates of quiet, open-water, offshore parts of Lake Gosiute.

The number and type of molluscan assemblages and the paleocological interpretations presented here are expanded in chapter B of this volume, by J. H. Hanley.



Figure 11. Current-oriented *Goniobasis* shells in nearshore sandstone lithofacies in the Tipton Tongue of the Cottonwood Creek delta, north-center of sec. 6, T. 13 N., R. 91 W. Pencil point indicates the direction from which the current is flowing.

Crustaceans

Small valves of unidentified ostracodes are present throughout the oil-shale beds in the study area. The valves are tan, calcified, unornamented, and generally less than 1/16 inch long.

Trace Fossils

Trace fossils are fairly common in the sandstone beds in the study area, but they probably are not good environmental indicators. Smooth-walled, variously oriented burrows about 1/4 inch in diameter are the most abundant. These have been identified by the author as crustacean burrows. Small worm trails and burrows about 1/8 inch in diameter are also abundant locally.

Unidentified tubular impressions are present in the uppermost sandstone bed of the Cottonwood Creek delta in measured section 9382 (fig. 12). These fossils are vertically oriented and lined by calcareous siltstone. They are 1/2 to 1 inch in diameter and as much as 2 ft long. The upper few inches of the sandstone bed in which the tubes are found contain numerous small root casts and molds, a fact that suggests the tubes are possibly tap roots of large plants, perhaps small trees, that were growing along the margins of the lake.

SUMMARY

Geological investigations of a sandstone lens that intertongues with oil-shale beds in the Tipton Tongue of the Green River Formation along Cottonwood Creek indicate that the sandstone lens was deposited as a freshwater fan delta on the eastern shores of Eocene Lake Gosiute. The delta sandstone is quartzose and nearly 2 mi long and about 80 ft thick. The investigations reveal that the delta formed as a result of high sediment influx from major streams that carried coarse clastics from areas of provenance in the Sierra Madre located east of the study area. The elongated shape of the delta, southward and parallel to the lake shoreline, is interpreted as the product of (1) sandstone accretion by a network of distributary channels across low paleoslopes on the shoreline of Lake Gosiute, (2) low rates of shoreline subsidence, and (3) prevailing northerly winds and south-trending longshore currents.

The sandstone in the study area is characterized by six types of primary sedimentary structures that define distinct delta and shoreline lithofacies. These lithofacies include large, lenticular, crossbedded feeder channels; large- and small-scale planar crossbedded accretionary bars; thick and thin parallel-bedded to subparallel-bedded nearshore deposits; thin, parallel-bedded beach deposits;

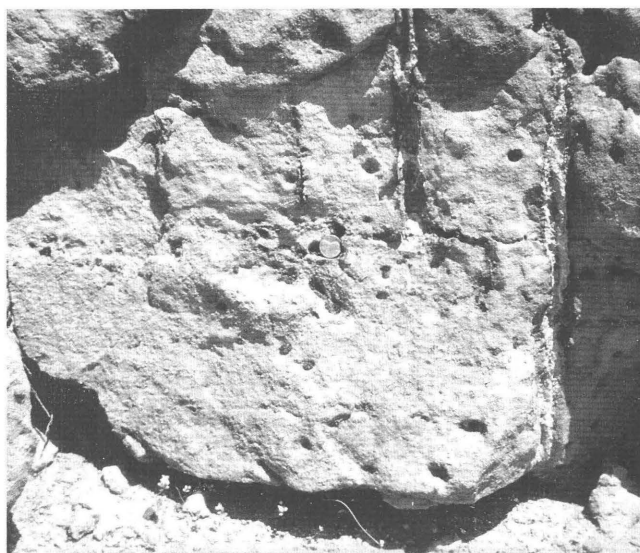


Figure 12. Worm burrows and tree roots(?) in sandstone of the Cottonwood Creek delta in NW¼SW¼SE¼ sec. 31 T. 14 N., R. 91 W. Scale is indicated by a 3/4-inch-diameter coin near the center of the photograph.

and small-scale festoon crossbedded channel-mouth deposits. The shape and areal distribution of these lithofacies have provided data for reconstructing the delta and shoreline paleogeography.

The delta sandstone and associated rocks contain abundant freshwater mollusks that are present in two assemblages that reflect different habitats. A *Goniobasis-Viviparus*-“*Lampsilis*” assemblage preferred the sandy substrates of shallow, moving water parts of streams and shallow nearshore lake waters. A *Valvata-Musculium* assemblage preferred the quiet-water, muddy substrates of deeper parts of the lake. The presence of *Lambdaotherium* and *Cantius* vertebrate among the fossils collected from red floodplain deposits in the Wasatch Formation overlying and underlying the Cottonwood Creek delta indicates the delta is of late early Eocene age.

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Taphonomy and Paleoecology of Nonmarine Mollusca in Fluvial and Lacustrine Environments of the Cottonwood Creek Delta, Tipton Tongue of the Green River Formation (Eocene), Southeast Washakie Basin, Wyoming

By JOHN H. HANLEY

Nonmarine mollusks are used to interpret
paleoenvironments and sedimentation during
deposition of a fan delta in Lake Gosiute

GEOLOGICAL SURVEY BULLETIN 1669

GEOLOGY AND PALEOECOLOGY OF THE COTTONWOOD CREEK DELTA IN THE
EOCENE TIPTON TONGUE OF THE GREEN RIVER FORMATION AND A
MAMMALIAN FAUNA FROM THE EOCENE CATHEDRAL BLUFFS TONGUE OF THE
WASATCH FORMATION, SOUTHEAST WASHAKIE BASIN, WYOMING

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Taphonomy and Paleoecology of Nonmarine Mollusca in Fluvial and Lacustrine Environments of the Cottonwood Creek Delta, Tipton Tongue of the Green River Formation (Eocene), Southeast Washakie Basin, Wyoming

By John H. Hanley

Abstract

Nonmarine mollusks in the Tipton Tongue of the Green River Formation are used to interpret paleoenvironments and patterns of sedimentation of the Cottonwood Creek fan delta, on the east margin of Lake Gosiute in the late early Eocene. Distribution of mollusk assemblages and complex Tipton lithofacies relations reflect the interaction of southeast-trending longshore currents within Lake Gosiute and west-trending fluvial currents that supplied sediments to the fan delta. Most mollusk assemblages have been affected by post-mortem depositional processes such as transport, reworking, and concentration of shells. Depositional processes that produced shell accumulations are reflected by physical characteristics (for example, lithology, stratification sequences, and assemblage biofabric) that are indicative of discrete paleoenvironments. Taphonomy of assemblages and sedimentology of Tipton lithofacies differentiate nearshore and offshore lacustrine, fluvial-channel, and shoreline and channel-mouth fluvio-lacustrine environments.

Goniobasis-dominated assemblages thrived in nearshore lacustrine environments north of sites where delta feeder channels flowed into Lake Gosiute. Reworking of *Goniobasis* by longshore currents produced azimuth orientation of shell apices and inclination of axes of shell coiling. Offshore lacustrine environments were locally inhabited by sphaeriid bivalves and gastropods questionably identified as *Viviparus* and *Valvata*. Floodplain fluvial channels were inhabited by *Goniobasis*, *Viviparus*, and unionid bivalves; assemblages were locally transported and preserved as lag concentrations in channels. *Viviparus* lived abundantly in floodplain fluvial channels near the shoreline of Lake Gosiute, and within the lake in fluvio-lacustrine environments that were affected by the flow of rivers and streams which entered the lake. Characteristics of *Viviparus*-dominated assemblages preserved in fluvio-lacustrine environments reflect partial loss of channelized flow by rivers as they entered Lake Gosiute; shells accumulated under the influence of fluvial currents as lag concentrations that were variably reworked by lacustrine currents.

INTRODUCTION

Aquatic mollusks in the Tipton Tongue of the Green River Formation facilitate paleoenvironmental interpretation of a sandstone fan delta (Cottonwood Creek delta of Roehler, this volume) deposited on the east margin of Lake Gosiute during the late early Eocene (Honey, this volume). The influx of clastic sediments during delta deposition produced complex lithofacies relations. Interpretations of mollusk taphonomy and Tipton sedimentology document mollusk paleoecology, paleoenvironments, and patterns of sedimentation.

Hanley (1974, 1976, 1977) described the composition and paleoecology of mollusk assemblages in the Tipton Tongue, Tipton Shale Member, and coeval Fontenelle Tongue of the Green River Formation. The juxtaposition of fluvial, lacustrine, and fluvio-lacustrine environments during delta sedimentation in the Cottonwood Creek study area permits interpretation of taphonomy and paleoecology in more diverse paleoenvironments than those previously studied. Interpretations of mollusks are based on six sampled (Appendix 1) and numerous other unsampled assemblages studied during field investigations north of Baggs, Wyo., in the southeast part of the Washakie basin (fig. 1). The location, geography, and Eocene paleogeographic setting of the study area are discussed by Roehler (this volume). Assemblages were studied in stratigraphic sections measured by H. W. Roehler (pl. 1 and fig. 2), which permit interpretation of the distribution of assemblages in time and space relative to Tipton lithofacies. Assemblages were studied in the feeder-channel, beach, channel-mouth, and nearshore sandstone lithofacies and the oil shale lithofacies (pl. 2 and fig. 3). Physical and biologic characteristics (for example, lithology, stratification sequences, bed configurations, and mollusk abundances and biofabric) provide

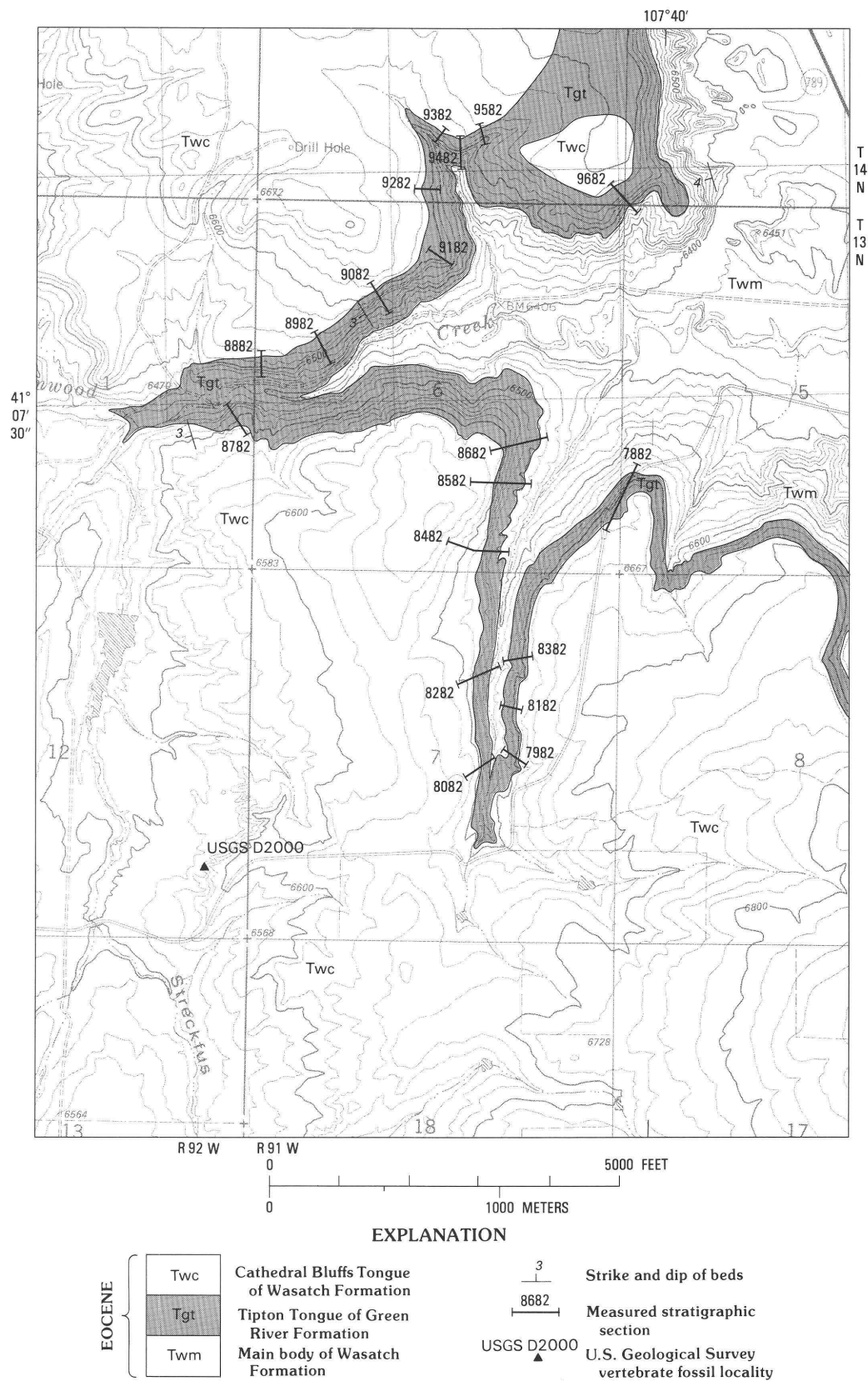


Figure 2. Geologic map of the study area illustrating the outcrop distribution of the Tipton Tongue (shaded) and the location of measured stratigraphic sections. Base from USGS Peach Orchard Flat, Wyo., and Baggs, Wyo.-Colo. quadrangles; scale 1:24,000. (From Roehler, this volume.)

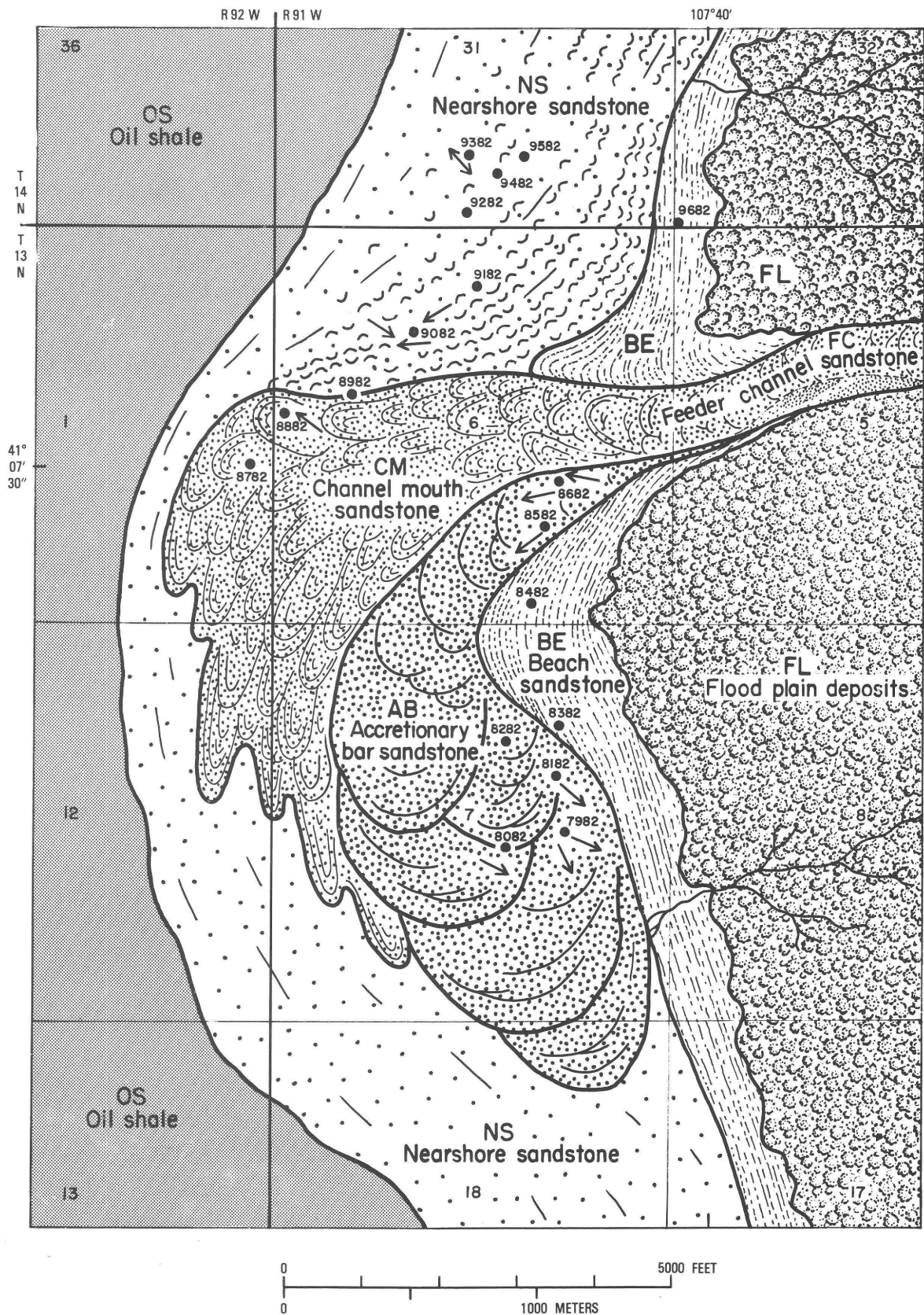


Figure 3 (facing page). Map illustrating the inferred paleogeographic relations of lithofacies and paleoenvironments of the Cottonwood Creek delta during hypothetical time line T' shown in plate 2. Locations of measured stratigraphic sections are shown by the numbered dots; coquinal accumulations of mollusks in the nearshore sandstone lithofacies are shown by short curved lines. Paleocurrent directions are indicated by arrows; directions shown at sections 9382 and 9082 are based on azimuth orientations of *Goniobasis* at localities D1476NM and D1478NM (figures 6A and 6B), respectively. (Modified from Roehler, this volume.)

criteria for differentiation of fluvial channel, nearshore and offshore lacustrine, and shoreline and channel-mouth fluvio-lacustrine environments.

ACKNOWLEDGMENTS

H. W. Roehler and J. G. Honey provided valuable data pertaining to lithostratigraphic relations of the Tipton Tongue of the Green River Formation in the study area. R. O'Donnell and J. G. Honey assisted in the collection of paleontologic samples, and O'Donnell prepared samples for study. H. W. Roehler, J. G. Honey, and M. E. Taylor reviewed the manuscript and offered suggestions for its improvement.

COMPOSITION AND PRESERVATION

Mollusk assemblages in the Tipton Tongue in the study area are typically composed of unionid bivalves and the gastropods *Goniobasis* and *Viviparus*. The effects of diagenesis limit interpretation of taxonomy. With the

exception of mollusks in the oil shale lithofacies, specimens are preserved as internal molds of sandstone or as recrystallized shells. Compaction of mollusks preserved in the oil shale lithofacies also obscures shell form. The majority of gastropods are confidently identified to genus; unionid bivalves are unidentified or, rarely, assigned to four morphotypes (table 1). Bivalve morphotypes and the gastropods *Goniobasis tenera* (Hall) cf. morphotype C of Hanley (1974) and *Viviparus* cf. *V. paludinaeformis* (Hall) are rare in assemblages. The recognition of these mollusks is controlled by quality of preservation; only a few of the best preserved specimens in some assemblages could be assigned to these taxa.

Although generic composition of most assemblages is too similar to provide a basis for differentiation of assemblages, abundances of *Goniobasis* and *Viviparus* vary between assemblages. Coincidence between the variations in abundances of these gastropods and physical characteristics (for example, lithology, stratification sequences, bed configurations, and assemblage biofabric) can be used to interpret paleoenvironments.

Goniobasis tenera and *Viviparus paludinaeformis* have been reported from the Green River and Wasatch Formations of the Green River basin, Wyo. and Colo. (Hanley, 1974 and 1976). *G. tenera* is abundant in nearshore, shallow-water environments of Lake Gosiute, which are preserved in the Green River and Wasatch; the species also rarely occurs in flood-plain lake environments of the Wasatch. A few well-preserved specimens of *Goniobasis* in the study area are tentatively identified as *G. tenera* morphotype C of Hanley (1974). Morphotype C was described from the Fontenelle Tongue of the Green River Formation, which is coeval with the Tipton Tongue.

Table 1. Taxonomic composition of nonmarine mollusk assemblages from the Tipton Tongue of the Green River Formation in the Cottonwood Creek study area. Unionid bivalves and gastropods of the genera *Goniobasis* and *Viviparus* are informally designated as being rare (R), common (C), or abundant (A), to indicate variations in abundances of these taxa within and between assemblages.

MOLLUSK TAXA	U.S. GEOLOGICAL SURVEY CENOZOIC LOCALITY					
	D1476NM	D1477NM	D1478NM	D1479NM	D1480NM	D1481NM
Bivalves —						
Unionidae:						
Morphotype A	—	—	R	—	—	R
Morphotype B	—	—	R	—	—	—
Morphotype C	—	—	—	R	R	—
Morphotype D	—	—	—	—	R	—
Unionidae: Genus and sp. indet.	R	R	R	R	C	R
Gastropods —						
<i>Goniobasis tenera</i> (Hall) cf.						
morphotype C of Hanley (1974)	—	R	R	—	—	—
<i>Goniobasis</i> cf. <i>G. tenera</i> (Hall)	A	C ¹	A	A	A	—
<i>Goniobasis</i> sp. indet.	—	—	—	—	—	R
<i>Viviparus</i> cf. <i>V. paludinaeformis</i> (Hall)	—	R	—	—	—	R
<i>Viviparus</i> sp. indet.	R	A	R	A	C	A

¹*Goniobasis* cf. *G. tenera* (Hall) is locally common in assemblage D1477NM.

V. paludinaeformis is questionably reported from the Luman Tongue of the Green River Formation and the Niland Tongue of the Wasatch Formation; the species is locally common in the Fontenelle Tongue of the Green River.

Poor preservation of unionid bivalves precludes identification to genus. The preservation of bivalves as internal molds in medium-grained sandstone has destroyed umbonal shell morphology, and obscured external shell form and internal morphology (for example, hinge dentition and muscle scars). The preservation of a few specimens is of sufficient quality to interpret shell form and hinge dentition. On the basis of these few specimens, however, it is impossible to assess morphologic variation or to reliably define differences between taxa on the basis of multiple morphologic characteristics. Because living unionid bivalves can exhibit considerable intraspecific morphologic variation (Hanley, 1974, p. 100–105), the bivalves in the study area are informally assigned to four morphotypes, which may represent discrete species. Criteria for differentiating morphotypes include inferred external shell shape, relative proportion of shell height to length, prominence and position of shell beak, and hinge dentition. Hinge dentition of the left and right valves of all morphotypes is incompletely known. Because taxonomy of unionid bivalves is not a basis for paleoenvironmental interpretation of the Tipton Tongue, detailed morphologic description of morphotypes is not provided in this report.

Dissolution of mollusk shells may have provided calcium carbonate that locally served as cement for sand that encloses mollusk assemblages. At locality D1481NM, the sandstone within, above, and below lenses of shells is better indurated than is interbedded unfossiliferous sandstone. Preservation of mollusks at D1481NM as internal molds in resistant lenses, which are somewhat greater in thickness and extent than are the lenses of shells which they enclose, may reflect selective sand cementation by calcium carbonate derived from dissolution of shells.

TAPHONOMY AND PALEOECOLOGY

Methods of Interpretation

Paleoecologic interpretation of mollusks in the Tipton Tongue relies upon deciphering depositional processes responsible for accumulation of shell assemblages. Interpretation of the history of shells from the time of the animal's death to the time of final burial (biostratinomy) and the postburial history (diagenesis) are critical precursors to paleoecologic study. Biostratinomy and diagenesis comprise the study of taphonomy of mollusk assemblages.

Biostratinomy of mollusk assemblages in the Tipton Tongue reflects depositional processes and environments. The composition, species abundances, and spatial and temporal distributions of assemblages were controlled not only by the environments in which the mollusks lived, but also by the depositional processes that affected the mollusks after death and before final burial (for example, transport, reworking, and concentration of shells and mixing of faunal elements from discrete habitats). These processes produced an "overprint" on assemblage characteristics that is a direct reflection of fluvial and lacustrine sedimentation. Johnson (1960), Fagerstrom (1964), and Seilacher (1973) discussed numerous criteria for interpretation of the biostratinomic history of a fossil assemblage. In the Tipton Tongue, postmortem depositional processes that affected mollusk assemblages are reflected by lithology, stratification sequences, and bed configurations, and biofabric of assemblages (the orientation, fragmentation, size sorting, abrasion, density, and dispersion of shells; the nature and extent of shell filling; and the ratio of articulated to disarticulated bivalves). These physical characteristics and variations in abundances of mollusks between assemblages provide criteria for interpretation of mollusk paleoecology and paleoenvironments of the Tipton Tongue during deposition of the Cottonwood Creek delta.

Assemblages of Lacustrine Environments

Nearshore Sandstone Lithofacies

Composition and biostratinomy of gastropods preserved at localities D1476NM and D1478NM, in the nearshore sandstone lithofacies (pl. 2 and fig. 3), indicate that the mollusks inhabited a littoral lacustrine environment and that assemblages were reworked by southeast-trending longshore currents that obliquely intersected the south-trending shoreline of Lake Gosiute.

The faunal composition of assemblages at localities D1476NM and D1478NM is similar to that of the *Goniobasis* marker, which marks the base of the Tipton Shale Member, Tipton Tongue, and the Fontenelle Tongue of the Green River Formation in the greater Green River basin of southwestern Wyoming (Hanley, 1977). The *Goniobasis* marker is characterized by the *Goniobasis-Viviparus* association of Hanley (1976), which was adapted to the shallow freshwater lacustrine habitats within wave base near the shorelines of Lake Gosiute. The distribution of this diachronous marker reflects shoreline transgressions of the lake. In some occurrences of the marker, *Viviparus* is more abundant than in nearshore lacustrine habitats in the study area. At other localities in the Green River basin, mollusks of the marker

are dominated by *Goniobasis* that may exhibit azimuth orientations of shell apices, as was noted in assemblages at D1476NM and D1478NM. Although unionid bivalves are often a constituent of the *Goniobasis-Viviparus* association, they are rare at D1476NM and D1478NM. The inferred reworking of sand substrate indicated by the azimuth orientations, inclination, and physical abrasion of *Goniobasis* at these localities may have limited habitation of the environment by unionid bivalves, and (or) the bivalves may have been selectively removed by current action.

Goniobasis cf. *G. tenera* dominates assemblages in the nearshore sandstone lithofacies at localities D1476NM and D1478NM. Shells are interpreted to have been preferentially concentrated by nearshore currents. The gastropods occur in the following three types of shell accumulations that are parts of a single fossiliferous lens, which persists in north-trending outcrops for 2.7 km:

1. Coquinoid beds that vary between 6 mm and 20 cm in thickness and which exhibit undulatory bases (maximum variation of 6 cm) and relatively planar upper surfaces (fig. 4).

The coquinal accumulations are typically preserved in medium-grained quartz sandstone that lacks sedimentary structures.

2. Disseminated *Goniobasis* in beds of fine-grained quartz sandstone that are typically less than 15 cm thick and which locally exhibit planar stratification.
3. Coquinoid intervals up to 90 cm thick that are composed of upper fine-grained to lower medium-grained quartz sandstone with disseminated grains of coarse sand and rounded quartzite pebbles up to 1.75 cm in diameter. The coquinoid intervals contain laterally discontinuous lenses of upper fine-grained sandstone that include disseminated grains of medium sand and disseminated *Goniobasis*.

In contrast to sandstone with disseminated *Goniobasis*, the coquinoid beds and intervals are coarser grained, are more poorly sorted, and exhibit current-oriented *Goniobasis*. Coquinoid accumulations of *Goniobasis* may reflect either a preference of the genus for coarser substrates and higher energy levels or the preferential



Figure 4. Vertical cross section of two coquinoid beds with abundant *Goniobasis* cf. *G. tenera* in the nearshore sandstone lithofacies of the Tipton Tongue at locality D1476NM. Lines trace undulatory (erosional) basal contacts of coquinal beds. Arrow points to scale, which is 4.5 cm long.

concentration of shells by nearshore currents. The locally erosional bases of coquinoid layers, extensive physical abrasion of shells, and the incomplete filling of shells with sand support the latter interpretation.

Orientations of *Goniobasis* at locality D1476NM are interpreted to be the product of reworking of shells in the nearshore lacustrine environment by southeast-trending longshore currents that obliquely intersected the south-trending shoreline of Lake Gosiute (fig. 3). Coquinoid accumulations of *Goniobasis* typically exhibit parallel alignment of shell axes of coiling and preferential azimuth orientation of shell apices to the northwest (figs. 5 and 6A). In the presence of a unidirectional current, high-spined gastropods such as *Goniobasis* typically assume a current-stable orientation in which the axis of shell coiling approximately parallels current direction and the shell apex points into the current (Seilacher, 1973; Zeigler, 1983, p. 41–43).

Preferential west-northwest orientations of apices of *Goniobasis* at locality D1478NM (fig. 6B) may reflect the interaction of southeast-trending longshore lacustrine

currents with west-trending fluvial currents that supplied sediment to the Cottonwood Creek delta (fig. 3). The nearshore sandstone lithofacies that encloses assemblages at D1476NM and D1478NM intertongues with channel-mouth and accretionary-bar lithofacies of the Cottonwood Creek delta south of the latter locality (pl. 2). At D1478NM, the azimuth orientations of *Goniobasis* indicate that the dominant current directions were from the west-northwest, which reflects somewhat more eastward-trending lacustrine currents than those which affected assemblages at D1476NM.

At localities D1476NM and D1478NM, apices of *Goniobasis* not only exhibit preferential azimuth orientation to the northwest and west-northwest, respectively, but also exhibit preferential oblique inclination of axes of coiling (fig. 7). At these localities, approximately 80 percent of *Goniobasis* exhibit inclination of axes of coiling up to 45° relative to bedding. The vast majority of these specimens are oriented with the shell apices inclined obliquely downward and pointed into the inferred current direction. Inclination of axes of coiling into the



Figure 5. Plan view of *Goniobasis* cf. *G. tenera* in the nearshore sandstone lithofacies of the Tipton Tongue at locality D1476NM. Gastropods exhibit parallel alignment of shell axes of coiling and preferential azimuth orientation of shell apices to the northwest (arrow points to north), which is interpreted to be the product of reworking of shells by southeast-trending longshore currents that obliquely intersected the south-trending shoreline of Lake Gosiute. Scale is divided into centimeter increments.

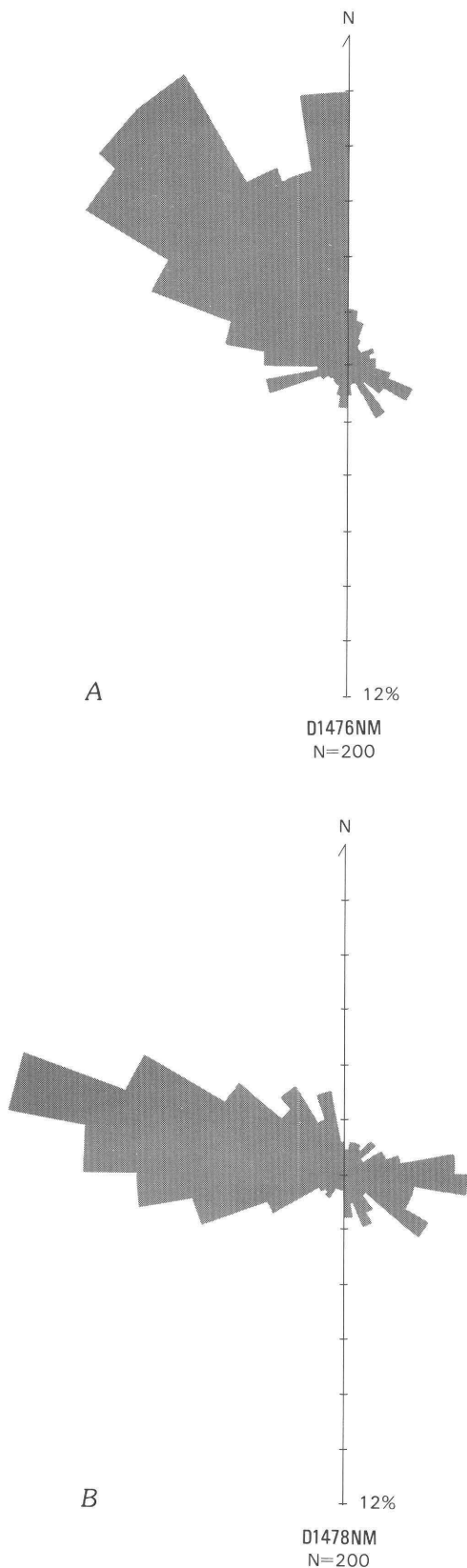


Figure 6. Circular histograms that illustrate unimodal azimuth orientations of apices of *Goniobasis* cf. *G. tenera* in the nearshore

inferred current direction is analogous to the preferential inclination assumed by discoidal pebbles in unidirectional flow (Compton, 1962, fig. 12–10). Axial inclination of *Goniobasis* is inferred to have occurred after shells assumed a current-stable position in the presence of longshore currents.

At localities D1476NM and D1478NM, the presence of multiple coquinoid beds and intervals of *Goniobasis* within the 3.2-m-thick nearshore sandstone lithofacies reflect repetitive deposition of medium-grained sand and contemporaneous reworking and current orientation of *Goniobasis*. The recurring depositional events may reflect successive episodes of clastic influx into Lake Gosiute from a site of deltaic deposition north of the study area. Additional deltaic accumulations north of the study area have been inferred from regional lithostratigraphic relations of the Tipton Tongue (Roehler, this volume, fig. 3). Southward transport of sediments and the azimuth orientation and axial inclination of *Goniobasis* are complementary products of southeast-trending longshore currents. The interpreted paleogeographic distribution of channel-mouth and accretionary-bar lithofacies (fig. 3) also reflect southward redistribution of fluvial sediments along the lake margin by longshore currents.

The sediments that preserve the coquinoid accumulations of *Goniobasis* could also have been derived from the east as part of the Cottonwood Creek deltaic accumulation. However, the azimuth orientations and inclinations of *Goniobasis* at D1476NM and D1478NM reflect current directions from the northwest and west-northwest, respectively. This alternate scenario would have required repeated reorientation of *Goniobasis* by longshore currents following episodes of clastic influx from the east and probably would have produced more bipolar azimuth orientations of shell apices than those observed at D1476NM and D1478NM (fig. 6A and 6B). Roehler interprets paleocurrents at these localities to have been from the southeast and northeast, respectively (sections 9382 and 9082, fig. 3). He bases his interpretations of paleocurrent directions (Roehler, this volume, fig. 10F and 10G) on the azimuth orientations of *Goniobasis* preserved at these localities. The southeast-directed longshore currents indicated by my interpretation of azimuth orientations of *Goniobasis* at sections 9382 and 9082 (fig. 3) are the same longshore currents invoked by him to account for southeastward transport of sand in the accretionary-bar sandstone lithofacies. The sediments that preserve the coquinoid accumulations of *Goniobasis* could also have been derived from the east as part of the Cottonwood Creek deltaic accumulation. However, the

sandstone lithofacies of the Tipton Tongue at localities D1476NM (A) and D1478NM (B). Observations were made on one bedding plane at each locality. *N* = total number of observations.



Figure 7. Vertical cross section of a coquinoid interval with abundant *Goniobasis* cf. *G. tenera* in the nearshore sandstone lithofacies of the Tipton Tongue at locality D1478NM. The gastropods exhibit preferential oblique inclinations of the axes of coiling; shell apices point into the inferred current direction. Inclination of the shell axes is interpreted to have occurred after the shells assumed current-stable orientations in the presence of longshore currents. Scale is divided into centimeter increments.

azimuth orientations and inclinations of *Goniobasis* at D1476NM and D1478NM reflect current directions from the northwest and west-northwest, respectively. This alternate scenario would have required repeated reorientation of *Goniobasis* by longshore currents following episodes of clastic influx from the east and probably would have produced more bipolar azimuth orientations of shell apices than those observed at D1476NM and D1478NM (fig. 6A and 6B). Roehler (this volume) interprets paleocurrents at these localities to have been from the southeast and northeast, respectively (sections 9382 and 9082, fig. 3). He bases his interpretations of paleocurrent directions (Roehler, this volume, fig. 10F and 10G), on the azimuth orientations of *Goniobasis* preserved at these localities. In my opinion, the southeast-directed longshore currents indicated by my interpretation of azimuth orientations of *Goniobasis* at sections 9382 and 9082 (fig. 3) are the same longshore currents invoked by him to account for southeastward transport of sand in the accretionary-bar sandstone lithofacies.

Oil Shale Lithofacies

The oil shale lithofacies (pl. 2 and fig. 3) locally preserves nonmarine mollusks, ostracodes, fish scales, and fish vertebrae. Mollusks rarely occur within this lithofacies, and preservation of shells is poor owing to compaction of the shale. Mollusks observed (unsampled) in oil shale in the basal part of stratigraphic section 9682 (pl. 1) include bivalves of the Family Sphaeriidae ("fingernail clams") and the gastropods cf. *Viviparus* sp. indeterminate and cf. *Valvata* sp. indeterminate.

Limited observations of mollusks preclude interpretation of the biostratinomy of assemblages. Mollusks may have lived in an offshore lacustrine environment or they may have been transported into that habitat from shallower lacustrine environments. The somewhat gritty character of the enclosing oil shale at sites where mollusks occur is interpreted to reflect an admixture of silt and mud that could be the product of local sediment transport.

The author (Hanley, 1976) described mollusks of

the Pisidiidae-*Goniobasis-Valvata* association that occur in low-grade oil shale. These mollusks are interpreted to have inhabited a sublittoral lacustrine environment during deposition of the Luman Tongue of the Green River Formation. This association is composed in part of bivalves of the Pisidiidae (synonymous with Sphaeriidae) and the gastropods *Valvata* and *Viviparus*, all of which were noted to occur in the oil-shale lithofacies of the Cottonwood Creek study area. The similarity in faunal composition between mollusks preserved in the oil-shale lithofacies and those of the Pisidiidae-*Goniobasis-Valvata* association suggests that the assemblages in the oil shale inhabited the offshore environment in Lake Gosiute.

Assemblages of Fluvial and Fluvio-Lacustrine Environments

Aquatic mollusks were locally preserved in fluvial channels on the floodplain adjacent to Lake Gosiute (feeder channel sandstone lithofacies), and on the shoreline of and within Lake Gosiute (beach and channel-mouth sandstone lithofacies) in fluvio-lacustrine environments that were affected by the flow of feeder streams that entered the lake and by lacustrine currents. These assemblages are interpreted to have accumulated under flowing water conditions; fluvio-lacustrine assemblages were contemporaneously reworked by near-shore lacustrine currents.

Feeder-Channel Sandstone Lithofacies

Gastropods and bivalves preserved in assemblages D1479NM and D1480NM (fig. 8) are interpreted to have been transported and concentrated as lag accumulations in the rivers that supplied sediments to the Cottonwood Creek delta (fig. 3). These assemblages are preserved in lenses of fine-grained sandstone that locally contain disseminated grains of medium sand and rounded pebbles as large as 2.5 cm in diameter. Fossiliferous lenses are as much as 30 cm thick and exhibit planar upper contacts and undulatory basal contacts that may include lenses of unfossiliferous sandstone (fig. 9). In outcrop, assemblages at D1479NM and D1480NM are laterally persistent for 8 m and for more than 15 m, respectively. These assemblages occur in an interval of trough cross-stratified sandstone that includes other unsampled, very thin, laterally discontinuous lenses of mollusks that occur parallel to trough cross-strata (fig. 8). The sandstone interval also includes a distinct reactivation surface that underlies a lens of gastropods and bivalves. The lens is as much as 25 cm thick; it persists in outcrop for more than 16 m and exhibits an undulatory basal contact. The lens is composed of fine-grained sandstone that includes disseminated pebbles as large as 2 cm in diameter.

Lithology, stratification sequences, and bed configurations of fossiliferous sandstones indicate that assemblages at D1479NM, D1480NM, and associated lenses of mollusks accumulated as lag concentrations in fluvial channels.

The biofabric of assemblages at localities D1479NM and D1480NM indicates that mollusks were locally transported prior to burial. The majority of specimens of *Goniobasis* and *Viviparus* are oriented with axes of shell coiling subparallel to or at low angles to stratification. Sparry calcite in the apical whorls of the gastropods indicates that the shells were incompletely filled with sand. Virtually all of the bivalves are preserved with the valves articulated and closed; interiors of the majority of these specimens are completely filled with sandstone. Some bivalves exhibit geopetal fabric that reflects incomplete filling of sand within articulated shells. The majority of bivalves are oriented with the planes of commissure parallel to bedding. The current-stable orientations, and incomplete filling of gastropod shells and the articulation, current-stable orientations, and complete filling of the majority of bivalves collectively reflect local transport of shells after death. The absence of mollusks in current-unstable orientations indicates that transport and burial of the assemblages was not catastrophic (for example, transport and very rapid burial of a living assemblage). Similarly, the dominance of articulated bivalves suggests that transport of shells was of short duration or by low current velocities. Biofabric observations indicate that the shells experienced limited transport followed by final burial rather than repetitive episodes of exhumation and transport. Physical characteristics and the inferred biostratigraphy of assemblages at D1479NM and D1480NM indicate that mollusks inhabited a fluvial environment and were preserved as lag accumulations in fluvial channels.

Beach Sandstone Lithofacies

Mollusks at locality D1477NM (fig. 8) are interpreted to have accumulated on the shoreline of Lake Gosiute under the influence of currents from streams that flowed into the lake and to have been contemporaneously reworked by shoreline lacustrine currents. This interpretation is based upon examination of the vertical sequence of lithologies, stratification sequences, and bed configurations of fossiliferous sandstones in stratigraphic section 7882 and by the inferred biostratigraphy of assemblages at D1477NM.

The vertical sequence of lithologies and stratification sequences of the Tipton Tongue preserved in stratigraphic section 7882 (fig. 8) is interpreted to reflect a transition from sedimentation in fluvial channels to beach sedimentation. Sandstone intervals that include assemblages at D1477NM and at D1479NM and

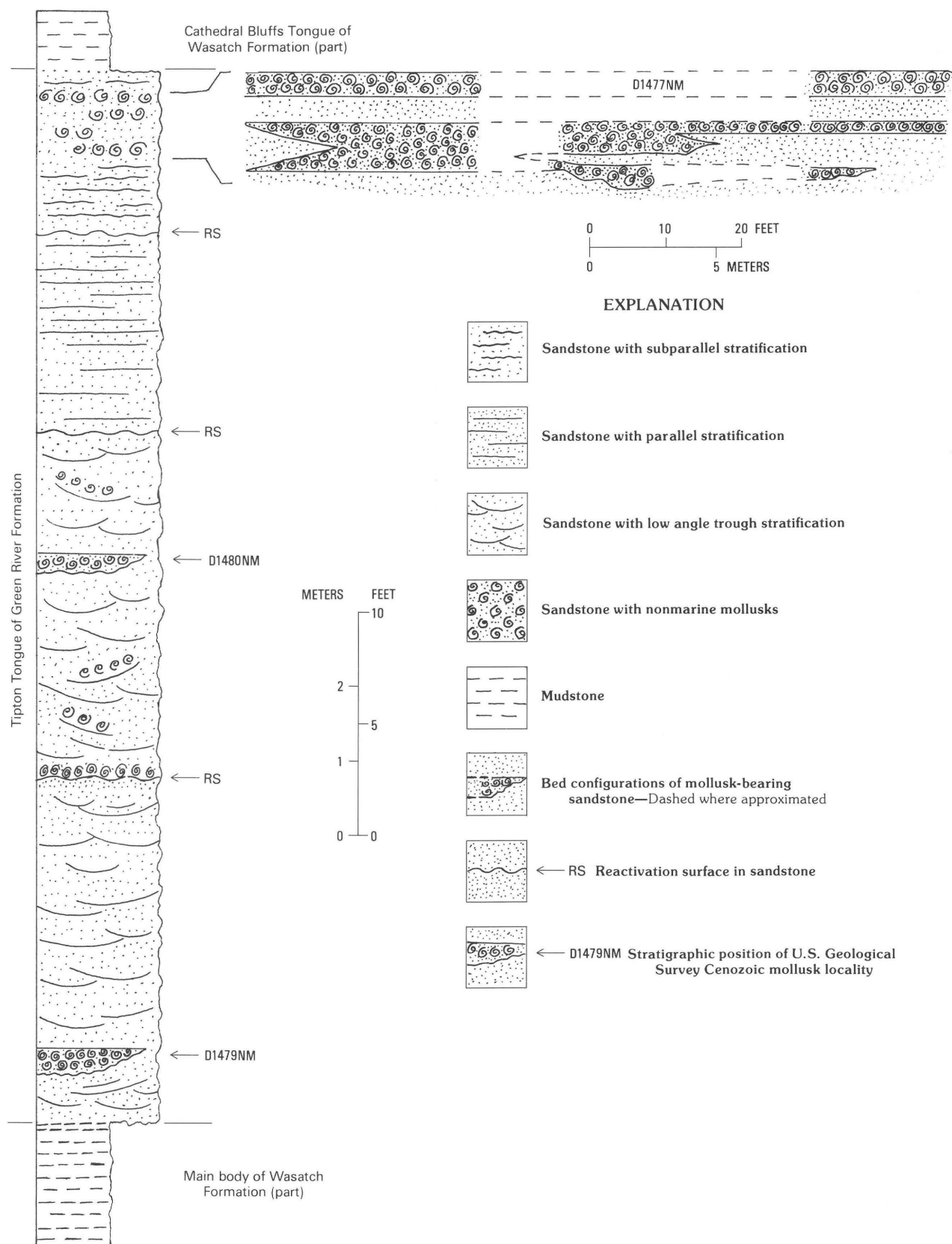


Figure 8. Lithologies, stratification sequences, bed configurations of fossiliferous sandstones, and distribution of mollusk assemblages, in stratigraphic section 7882. Section was measured by H. W. Roehler in dugway roadcut outcrops in E $\frac{1}{2}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 6, T. 13 N., R. 91 W., Carbon County, Wyo.; Baggs 7.5-minute quadrangle.



Figure 9. Vertical cross section of a lens with mollusks (locality D1480NM), which occurs in a sequence of trough cross-stratified sandstone in the feeder channel sandstone lithofacies of the Tipton Tongue. The head of the hammer (28 cm long at arrow) rests on top of the lens, which pinches out immediately to the left of the hammer. Lines trace undulatory (erosional) basal and planar upper contact of lens. The lens of shells is interpreted to have accumulated as a lag concentration in a fluvial channel.

D1480NM are separated by an interval of well-sorted, unfossiliferous fine-grained sandstone that is bounded at the base and top by reactivation surfaces (fig. 8). The unfossiliferous sandstone interval is characterized by parallel beds 5 mm to 15 mm thick, which thin upward. These characteristics suggest that the interval of parallel-bedded sandstone is a beach deposit (Roehler, this volume, fig. 7). The sandstone interval that overlies the inferred beach sandstone, and which includes the assemblage at D1477NM, is interpreted to have been deposited on the shore of Lake Gosiute. The vertical succession of sedimentary environments is also a reflection of lateral proximity of beach and floodplain fluvial channel environments at the margin of Lake Gosiute.

The physical characteristics of fossiliferous sandstones at D1477NM suggest that the shells accumulated on the shore of Lake Gosiute under the influence of fluvial currents and that the mollusks were contemporaneously reworked by shoreline lacustrine currents. Deposition of shells in such a fluvio-lacustrine environment produced tabular beds of variable lateral persistence

with only locally erosional basal contacts, and complexly intertonguing lateral relations with unfossiliferous sandstone (fig. 8). The assemblage at locality D1477NM is preserved in an interval of well-sorted, fine- to medium-grained sandstone characterized by subparallel pinching and swelling beds 10 cm to 20 cm thick and by variably persistent tabular beds of mollusks (fig. 8). The sandstone beds that contain mollusks are as much as 60 cm thick and typically exhibit planar basal contacts. Some beds persist laterally in outcrops for more than 30 m. The bed configurations of the sandstones that enclose mollusks at D1477NM differ from those of sandstones at D1479NM and D1480NM. The sandstones at D1477NM typically exhibit planar rather than undulatory basal contacts and greater lateral persistence as tabular beds.

The biofabric of assemblages at D1477NM suggests that the mollusks were transported and reworked to form an accumulation of high shell density. The fauna at D1477NM is dominated by *Viviparus* that occur in approximately equal proportions in which the axes of shell coiling are inclined at low (0–30°), moderate (31–45°),

and high (greater than 45°) angles relative to planar bed contacts. The axes of coiling and the apices of *Viviparus* exhibit random azimuth orientations. *Viviparus* is preserved almost exclusively as complete internal molds of sandstone that reflect complete filling of original shells with sand. Unionid bivalves are very locally common in assemblages at D1477NM. The majority of bivalves are articulated, and the gaping shells are completely filled with sandstone and internal molds of *Viviparus*. The bivalve shells locally exhibit imbrication of disarticulated shells and questionable nesting of articulated shells within other articulated shells (fig. 10). The majority of bivalves are oriented with planes of commissure at low angles relative to planar bed contacts, but shells exhibit notably greater diversity of orientations than those noted in the feeder channel sandstone lithofacies (D1479NM and D1480NM). The fossiliferous intervals are matrix supported, but internal molds occur in high density and are typically separated by thin veneers of sandstone. These observations indicate that the shells were subjected to protracted and (or) recurring episodes of transport as well

as to reworking and concentration. Diverse orientations of the axes of coiling and the high density of *Viviparus*, as well as local nesting and imbrication of bivalve shells, are interpreted to be the product of concentration of shells through reworking by lacustrine currents. Under such conditions, orientations of the *Viviparus* and the bivalves were affected by proximity to other shells at the time of final burial. Reworking and concentration of the mollusks in tabular beds are interpreted to have occurred on the lake shore. The *Viviparus*-dominated assemblages at locality D1477NM may have lived in a floodplain fluvial channel proximal to the shoreline of Lake Gosiute and (or) in a shallow-water fluvio-lacustrine setting within the lake.

Viviparus-dominated assemblages (not sampled) were also noted to overlie shoreline sandstones at the top of the Tipton Tongue in stratigraphic section 9682 (pls. 1 and 2). These *Viviparus*-dominated assemblages are interpreted to have accumulated on the shoreline of Lake Gosiute, possibly under the influence of fluvial currents, and to have been reworked and concentrated by nearshore

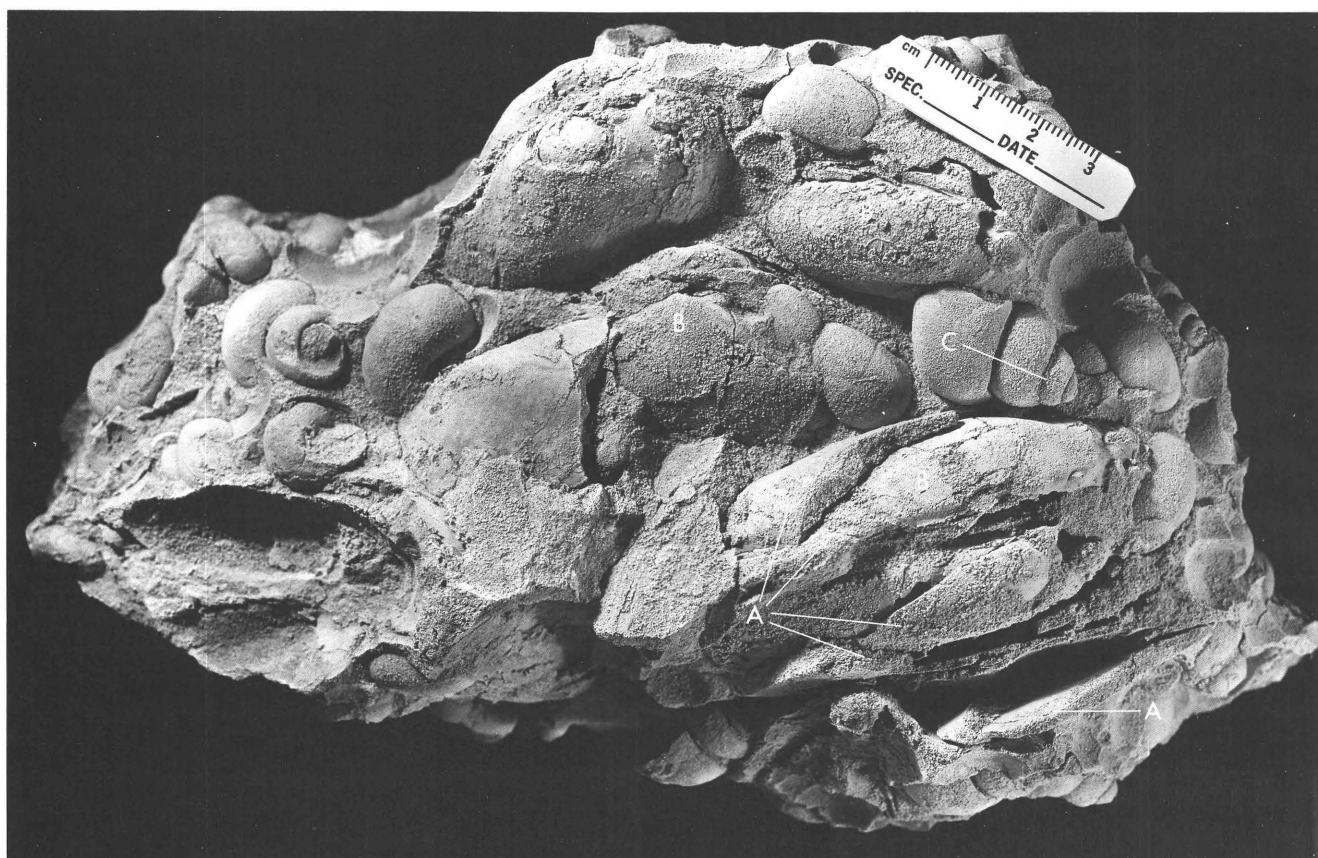


Figure 10. Cross section of the biofabric of *Viviparus* and locally common unionid bivalves from the Tipton Tongue at locality D1477NM. Arrows (A) indicate a local accumulation of imbricated bivalve shells. The majority of unionid bivalves (preserved as internal molds: specimens (B) are articulated and were completely infilled with sand. The *Viviparus* occur in high density, exhibit random orientations of axes of coiling, and random azimuth orientations of shell apices (arrow is parallel to axis of coiling and points toward the shell apex on specimen C). The scale is divided into centimeter increments.

lacustrine currents as was inferred for the assemblage at D1477NM. The beach units, which include interbedded nearshore sandstones with coquinoïd beds dominated by *Goniobasis*, are interpreted to have accumulated during subsidence of the shoreline of Lake Gosiute. *Viviparus*-dominated assemblages occur in tabular beds that overlie the shoreline sandstones. The biofabric of the assemblages is similar to that of the assemblages at D1477NM; randomly oriented *Viviparus* occur in high density and are separated by thin veneers of sandstone. The preservation of *Viviparus* as nearly complete internal molds of sandstone reflects extensive filling of shells with sand.

A third *Viviparus*-dominated assemblage (not sampled) that occurs within a channel-form sandstone (fig. 11) supports the inference that *Viviparus* lived in abundance in floodplain fluvial channels proximal to the shoreline of Lake Gosiute. The basal part of the Tipton Tongue near the base of stratigraphic section 8282 (pls. 1 and 2) is composed of an interval of beach sandstone lithofacies with lenses and beds of mollusks. The inferred lateral persistence of this shoreline sandstone reflects partial coincidence in the orientation of the restored cross section with the south-trending shoreline of Lake Gosiute. The beach sandstone lithofacies is interpreted to laterally intertongue with the oil shale lithofacies. In section 8282, an interval of complexly intertonguing lenses and beds of fossiliferous and unfossiliferous sandstone is erosionally superimposed on an interval of parallel stratified, unfossiliferous beach sandstone (fig. 11). These intervals are separated by an undulatory contact that reflects incision of a fluvial channel in the beach sand. The fluvial lens includes very abundant, complete molds of *Viviparus* preserved in fine- to medium-grained, poorly sorted sandstone that includes disseminated grains of coarse sand and subrounded pebbles as large as 2.5 cm in diameter. Axes of coiling of the majority of *Viviparus* are inclined at very low angles (0–15° degrees) relative to horizontal. Lithologies, stratification sequences, bed configurations, and biostratigraphy of the *Viviparus*-dominated assemblage indicate that shells were transported and concentrated as a lag accumulation in a fluvial channel incised in beach sand on the shore of Lake Gosiute. The presence of the *Viviparus*-dominated assemblage in a lens with a distinct erosional base indicates that, in contrast to the assemblage at D1477NM, shells were not reworked by nearshore lacustrine currents. These observations and interpretations indicate that *Viviparus* lived in abundance in some fluvial channels proximal to the shoreline of Lake Gosiute in the study area. The fluvial lens with abundant *Viviparus* is overlain by a tabular bed of sandstone that is identical in texture to the underlying fluvial sandstone. The tabular bed is dominated by *Goniobasis* with associated *Viviparus* and unionid bivalves (fig. 11). The gastropods are completely filled with sandstone, and inclination of axes of coiling is the same as that noted in

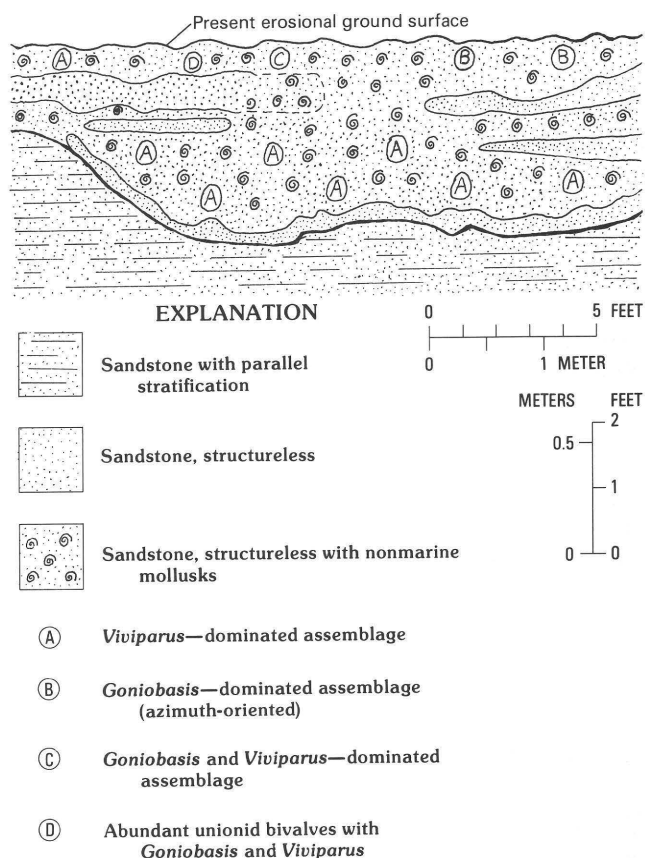


Figure 11. Diagrammatic cross section of lithologic relations, stratification sequences, bed configurations, and distribution of mollusk assemblages in basal part of the Tipton Tongue near the base of stratigraphic section 8282. The undulatory contact between structureless sandstone that preserves a *Viviparus*-dominated assemblage (A) and parallel-stratified sandstone reflects the incision of a fluvial channel in beach sand. The overlying azimuth-oriented *Goniobasis*-dominated assemblage (B) is interpreted to have accumulated in a shallow-water lacustrine environment near the shoreline of Lake Gosiute.

the underlying fluvial sandstone. The *Goniobasis* exhibit azimuth orientations of shell apices approximately 25–35° west of north. Ninety percent of the unionid bivalves are disarticulated and are oriented concave down with the planes of commissure at very low angles relative to horizontal. The *Goniobasis*-dominated assemblage is interpreted to have accumulated in a shallow-water lacustrine environment near the shore of Lake Gosiute. The azimuth orientations of the *Goniobasis* indicate that the assemblage was affected by longshore currents as was noted in the assemblages at localities D1476NM and D1478NM in the nearshore sandstone lithofacies.

Channel-Mouth Sandstone Lithofacies

Gastropods and bivalves in the assemblage at locality D1481NM are interpreted to have accumulated in a

shallow fluvio-lacustrine environment of the Cottonwood Creek delta that was affected by currents from rivers entering Lake Gosiute (channel-mouth sandstone lithofacies; pl. 2 and fig. 3). The stratification sequences in the unfossiliferous sandstones and the configurations of coquinal lenses suggest that assemblages accumulated under the influence of fluvial currents as lag concentrations. Mollusks at D1481NM are preserved in coquinal lenses of structureless very fine to fine-grained sandstone (fig. 12). Fossiliferous lenses are as much as 26 cm thick and are laterally persistent as tabular beds for 7 m to 14 m. Some of the lenses are discontinuous and persist for as little as 60 cm. The lenses locally exhibit undulatory basal contacts, but basal and top contacts are typically planar. Unfossiliferous fine- to medium-grained sandstone is interbedded with fossiliferous lenses and exhibits subparallel stratification and small-scale, low-angle planar and trough cross stratification. The base of one fossiliferous lens coincides with a low-angle planar or tangential reactivation surface (fig. 12).

The inferred biostratinomy of the assemblages at locality D1481NM indicates that the mollusks were subjected to protracted and (or) recurring episodes of transport and that they were concentrated by contemporaneous reworking. The assemblages are dominated by *Viviparus* that exhibits random orientations of axes of coiling in relation to planar bed contacts and relative to azimuth direction. Virtually all of the *Viviparus* are preserved as internal molds of sandstone, many of which are complete. The internal molds reflect both complete and incomplete filling of the original shells by sand. The incomplete filling is reflected by sparry calcite preserved in the apical whorls of some specimens. Similar variation of shell filling was noted in *Goniobasis* which occurs locally in the fossiliferous lenses. Bivalves are rare in the assemblage, and articulated specimens are completely filled with sandstone. The shells in the coquinal lenses are matrix supported, but the internal molds are typically separated by thin veneers of sandstone. Diverse orientations of *Viviparus* are interpreted to be the



Figure 12. Vertical cross section of two coquinal lenses (A and B) with abundant *Viviparus* in the channel mouth sandstone lithofacies of the Tipton Tongue at locality D1481NM. Preferential cementation of sandstone above and below the fossiliferous lenses obscures top and bottom contacts; this cementation produced sandstone lenses (dark bands A and B in which coquinal lenses occur), which are of greater resistance to weathering than is the interbedded unfossiliferous sandstone. The discordance between the lenses is caused by the occurrence of lens A on a low-angle planar or tangential reactivation surface. Lens A pinches out immediately left of the hammer, which is 28 cm long.

product of reworking and concentration of shells during which orientations of *Viviparus* were affected by proximity of other shells at the time of final burial.

The lithologies and stratification sequences of unfossiliferous sandstones, and the bed configurations and biostratinomy of the interbedded coquinoid lenses indicate that the assemblages at locality D1481NM accumulated in a fluvio-lacustrine environment in the channel-mouth sandstone lithofacies. Roehler (this volume) states that this lithofacies was deposited where the flow of feeder streams abruptly diminished upon entering shallow standing lake waters (fig. 3). Fossiliferous lenses may have been deposited during pulses of sediment influx into Lake Gosiute that were followed by reworking and concentration of shells by lacustrine currents. The occurrence of the assemblages at D1481NM in the channel-mouth lithofacies suggests that shells accumulated in a fluvio-lacustrine setting more distal to the shoreline of Lake Gosiute than that inferred for the assemblages at D1477NM. Faunal composition of assemblages is similar; both are dominated by *Viviparus*. The dominance of *Viviparus* in fluvio-lacustrine settings in Lake Gosiute that are inferred to be proximal (D1477NM) and distal (D1481NM) to the shoreline of the lake supports the interpretation that *Viviparus* lived in abundance in shallow-water fluvio-lacustrine settings in the lake as well as in some floodplain fluvial channels near the lake shore.

Accretionary-Bar Sandstone Lithofacies

Mollusks do not occur in the accretionary-bar (delta) lithofacies (pl. 2 and fig. 3). This lithofacies is characterized by unidirectional planar cross beds that are as much as 3 m thick, reflecting southward transport of sand from the mouths of feeder channels by longshore currents (Roehler, this volume). Southward migration of megaripples and sand waves on the shoreward part of the Cottonwood Creek delta (fig. 3) may have produced shifting, unstable substrate that was unsuitable for habitation by mollusks. The absence of mollusks may also indicate that longshore currents did not redistribute either the assemblages that were transported into the lake or the assemblages that lived in fluvio-lacustrine environments along the shoreline.

SUMMARY OF MOLLUSK TAPHONOMY AND PALEOECOLOGY

Taphonomy of aquatic mollusks preserved in the Tipton Tongue of the Green River Formation documents paleoenvironments and patterns of sedimentation during deposition of the Cottonwood Creek fan delta on the eastern margin of Lake Gosiute during the late early

Eocene. The distribution of mollusk assemblages and the complex Tipton lithofacies relations reflect the dynamic interaction between the original habitat preferences of the mollusks, the southeast-trending longshore lacustrine currents, and the west-trending fluvial currents that supplied sediments to the delta. The taphonomy of mollusk assemblages, variations in abundances of gastropods, and sedimentology of Tipton lithofacies provide criteria for recognition of nearshore and offshore lacustrine, fluvial-channel, and shoreline and channel-mouth fluvio-lacustrine environments.

Mollusk assemblages are typically composed of unionid bivalves and the gastropods *Goniobasis* and *Viviparus*, all of which are preserved as internal molds or as recrystallized shells. Assemblages have been transported or reworked by fluvial and lacustrine processes, with the exception of those that inhabited the offshore lacustrine environment. In spite of diagenetic processes that adversely affected shell preservation, similarity in faunal composition between assemblages, and potential alteration of original faunal characteristics by postmortem depositional processes, discrete paleoenvironments can be defined on the basis of sedimentological characteristics. These characteristics include lithology, stratification sequences, bed configurations, and assemblage biofabric, which collectively reflect depositional processes that produced shell accumulations. Variation in these sedimentological characteristics and in ecological differences in abundances of *Goniobasis* and *Viviparus* between assemblages are criteria for recognition of paleoenvironments.

Goniobasis lived abundantly in nearshore lacustrine environments north of the Cottonwood Creek delta; shells are preserved in coquinoid intervals and beds of greater lateral persistence than those of fluvial and fluvio-lacustrine environments. The reworking of *Goniobasis* by southeast-trending longshore currents produced physical abrasion of shells, azimuth orientation of shell apices, and inclination of axes of shell coiling. Unionid bivalves and *Viviparus* rarely lived in nearshore lacustrine habitats affected by longshore currents. The inferred continuous reworking of sand substrate indicated by the orientation, inclination, and abrasion of *Goniobasis* may have limited habitation of the environment by unionid bivalves and *Viviparus*. Current-oriented *Goniobasis* in coarse-grained and poorly sorted sandstone is interpreted to be the product of repetitive episodes of clastic influx from a site of deltaic deposition north of the study area. The transport of sediments from the north and the azimuth orientation and axial inclination of *Goniobasis* are complementary products of longshore currents. Sediments of the channel-mouth and accretionary-bar lithofacies also exhibit southward redistribution by longshore currents.

The offshore environment of Lake Gosiute was

inhabited by sphaeriid bivalves and gastropods questionably identified as *Viviparus* and *Valvata*. The discontinuous distribution of mollusks in the offshore oil shale probably reflects the original patchy distribution of mollusks in the environment.

Floodplain fluvial channels were inhabited by abundant *Goniobasis*, common to abundant *Viviparus*, and rare to common unionid bivalves. Shells were locally transported in channels and accumulated in lenses of limited lateral persistence as lag concentrations on reactivation surfaces and at the base of bedforms.

Viviparus is interpreted to have lived abundantly in floodplain fluvial channels near the lake shore and in shoreline and channel-mouth fluvio-lacustrine environments of Lake Gosiute that were proximal and distal, respectively, to sites where rivers flowed into the lake. Although *Viviparus*-dominated assemblages preserved in shoreline and channel-mouth environments were transported and (or) reworked, repetitive occurrences of such assemblages indicate that the abundance of *Viviparus* is a product of habitat preference and paleoenvironment rather than an artifact of postmortem depositional processes.

Sandstone that encloses fluvio-lacustrine assemblages is better sorted than that of nearshore lacustrine and floodplain fluvial assemblages. Fluvio-lacustrine assemblages also exhibit the greatest density of shells, most complete infilling of shells with sand, greatest variation in shell orientations, and greatest abundance of *Viviparus* relative to assemblages from nearshore lacustrine and floodplain fluvial environments.

Viviparus-dominated assemblages that were preserved on the shoreline of Lake Gosiute typically occur in tabular beds, most commonly with planar basal contacts; shells are randomly oriented, completely infilled, and occur in high density. These characteristics reflect partial loss of channelized flow after rivers entered the lake, as well as reworking and concentration of gastropods by lacustrine currents.

Viviparus-dominated assemblages preserved distal to the lake shore in the channel-mouth environment occur in lenses characterized by a high density of randomly oriented shells. Relative to assemblages deposited proximal to the shoreline of Lake Gosiute, the channel-mouth assemblages exhibit less complex intertonguing relations

with interbedded unfossiliferous sandstone and somewhat less complete filling of shells with sand. These characteristics may reflect less reworking of gastropods by lacustrine currents following lag concentration of shells.

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APPENDIX: FOSSIL LOCALITIES

Following is a summary of locality and stratigraphic data for paleontologic samples from the Tipton Tongue of the Green River Formation in the study area. Samples were collected from stratigraphic sections measured by H. W. Roehler (pl. 1 and fig. 2). The stratigraphic distribution of localities is shown in figure 8 and plate 2.

USGS Cenozoic Mollusk Locality D1476NM:

240 m SL 835 m EL Sec. 31, T. 14 N., R. 93 W., Carbon County, Wyo.; Peach Orchard Flat 7.5-minute quadrangle. Collected from one of numerous fossiliferous beds within a 3.2 m-thick coquinal interval, the base of which is 0.9 m above the base of the exposed section of the Tipton Tongue in stratigraphic section 9382. The exposed base of the fossiliferous interval is approximately 21.25 m above the base of the Tipton Tongue.

USGS Cenozoic Mollusk Locality D1477NM:

15 m EL 295 m SL Sec. 6, T. 13 N., R. 91 W., Carbon County, Wyo.; Baggs 7.5-minute quadrangle. Collected from one of several coquinal beds in the upper 2 m of the Tipton Tongue, in stratigraphic section 7882.

USGS Cenozoic Mollusk Locality D1478NM:

380 m NL 635 m WL Sec. 6, T. 13 N., R. 91 W., Carbon County, Wyo.; Peach Orchard Flat 7.5-minute quadrangle.

Collected from the lower part of a 5.5 m-thick coquinal interval that composes the basal Tipton Tongue as exposed in stratigraphic section 9082. The exposed base of fossiliferous interval is approximately 11.25 m above the base of the Tipton Tongue.

USGS Cenozoic Mollusk Locality D1479NM:

20 m WL 395 m SL Sec. 5, T. 13 N., R. 91 W., Carbon County, Wyo.; Baggs 7.5-minute quadrangle. Collected in a dugway roadcut from a coquinal lens in the lower part of a sandstone comprising the basal 4.27 m of Tipton Tongue, in stratigraphic section 7882.

USGS Cenozoic Mollusk Locality D1480NM:

5 m EL 345 m SL Sec. 6, T. 13 N., R. 91 W., Carbon County, Wyo.; Baggs 7.5-minute quadrangle. Collected in dugway roadcut from a coquinal lens that occurs approximately 6.1 m above the stratigraphic level of sample D1479NM, and 7 m above the base of the Tipton Tongue in stratigraphic section 7882.

USGS Cenozoic Mollusk Locality D1481NM:

430 m SL 490 m EL Sec. 6, T. 13 N., R. 91 W., Carbon County, Wyo.; Baggs 7.5-minute quadrangle. Collected from one of several coquinal beds and lenses that occur in a 4.6-m-thick sandstone interval, the base of which is approximately 11.7 m above the base of the Tipton Tongue in stratigraphic section 8582.

Chapter C

A Mammalian Fauna from the Base of the Eocene Cathedral Bluffs Tongue of the Wasatch Formation, Cottonwood Creek Area, Southeast Washakie Basin, Wyoming

By JAMES G. HONEY

Description and correlation of a
late Wasatchian (early Eocene) fauna

GEOLOGICAL SURVEY BULLETIN 1669

GEOLOGY AND PALEOECOLOGY OF THE COTTONWOOD CREEK DELTA IN THE
EOCENE TIPTON TONGUE OF THE GREEN RIVER FORMATION AND A
MAMMALIAN FAUNA FROM THE EOCENE CATHEDRAL BLUFFS TONGUE OF THE
WASATCH FORMATION, SOUTHEAST WASHAKIE BASIN, WYOMING

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A Mammalian Fauna from the Base of the Eocene Cathedral Bluffs Tongue of the Wasatch Formation, Cottonwood Creek Area, Southeast Washakie Basin, Wyoming

By James G. Honey

Abstract

A fossil mammal locality (USGS D-2000) occurs near the base of the Cathedral Bluffs Tongue of the Wasatch Formation, about 5 mi (8 km) northwest of Baggs, Wyo. The fossils are fragmentary and occur in a sequence of gray sandstone and red mudstone about 125 ft (38 m) above the base of the Cathedral Bluffs. The following mammalian orders are present: Primates, Condylarthra, Tillodontia, Dinocerata, and Perissodactyla. The presence of *Lambdaotherium* and *Cantius* indicates a late Wasatchian (Lostcabinian) age for the fauna and a late early Eocene age for the lower part of the Cathedral Bluffs Tongue of the Wasatch Formation and the underlying Tipton Tongue of the Green River Formation. This fauna, and a higher undescribed fauna from near the top of the Cathedral Bluffs, demonstrates that in the eastern Washakie basin the Cathedral Bluffs Tongue contains faunas of both Wasatchian and earliest Bridgerian age.

INTRODUCTION AND LOCATION

This report describes a small mammalian fauna collected from near the base of the Cathedral Bluffs Tongue of the Wasatch Formation. The locality (USGS fossil vertebrate locality D-2000) was discovered in July 1982, during stratigraphic and mapping studies of the Green River and Wasatch Formations. The fauna is important in that it faunally dates as late Wasatchian (Lostcabinian) the lower part of the Cathedral Bluffs Tongue of the Wasatch Formation and the underlying Tipton Tongue of the Green River Formation on the eastern margin of the Washakie basin. The fossil site is located about 5 mi (8 km) northwest of Baggs, Wyo., and is reached by an improved dirt road that joins Wyoming Highway 789 (Roehler, this volume, fig. 1). The site is located in a small area of badlands at the base of a line of bluffs on the east slopes of Streckfus Draw, a north-flowing tributary of Cottonwood Creek (fig. 1).

ACKNOWLEDGMENTS

I thank R. Hettinger and J. Delzer for assistance in the field in collecting fossils and matrix. P. Robinson, T. Bown, H. Roehler, and J. Hanley read the manuscript, and their criticisms are appreciated.

GEOLOGIC AND STRATIGRAPHIC OVERVIEW

The Streckfus Draw fossil site (USGS D-2000) is located in the southeast part of the Washakie basin. The site is situated north of the Cherokee ridge, a faulted fold belt that separates the Washakie basin in Wyoming from the Sand Wash basin in Colorado. Figure 2 is a geologic map showing the formations exposed in the eastern part of the Washakie basin and the approximate locations of fossil localities mentioned in the text (Quaternary alluvial deposits are not shown). In the northern and eastern parts of the map, Eocene rocks dip at less than 5° south and west into the Washakie basin (Bradley, 1945). In the vicinity of Cottonwood Creek (locality 3 in fig. 2), the Tipton Tongue of the Green River Formation and the Cathedral Bluffs Tongue of the Wasatch Formation dip 2–3° west toward the basin center. Northwest of Baggs the Tipton and Cathedral Bluffs Tongues dip 4–13° north from the Cherokee ridge into the Washakie basin (Cronoble, 1969).

Figure 3 is a generalized columnar section that shows the nomenclature and thicknesses of some of the formations in the vicinity of the Streckfus Draw locality and the approximate stratigraphic positions of other fossil vertebrate localities. The Fort Union Formation is the lowest stratigraphic unit shown and is about 985 ft (300 m) thick at the outcrop; the columnar section shows only a partial thickness for this unit. The Fort Union is coal bearing and consists of interbedded sandstone, siltstone, mudstone, and coal. The upper part of this unit

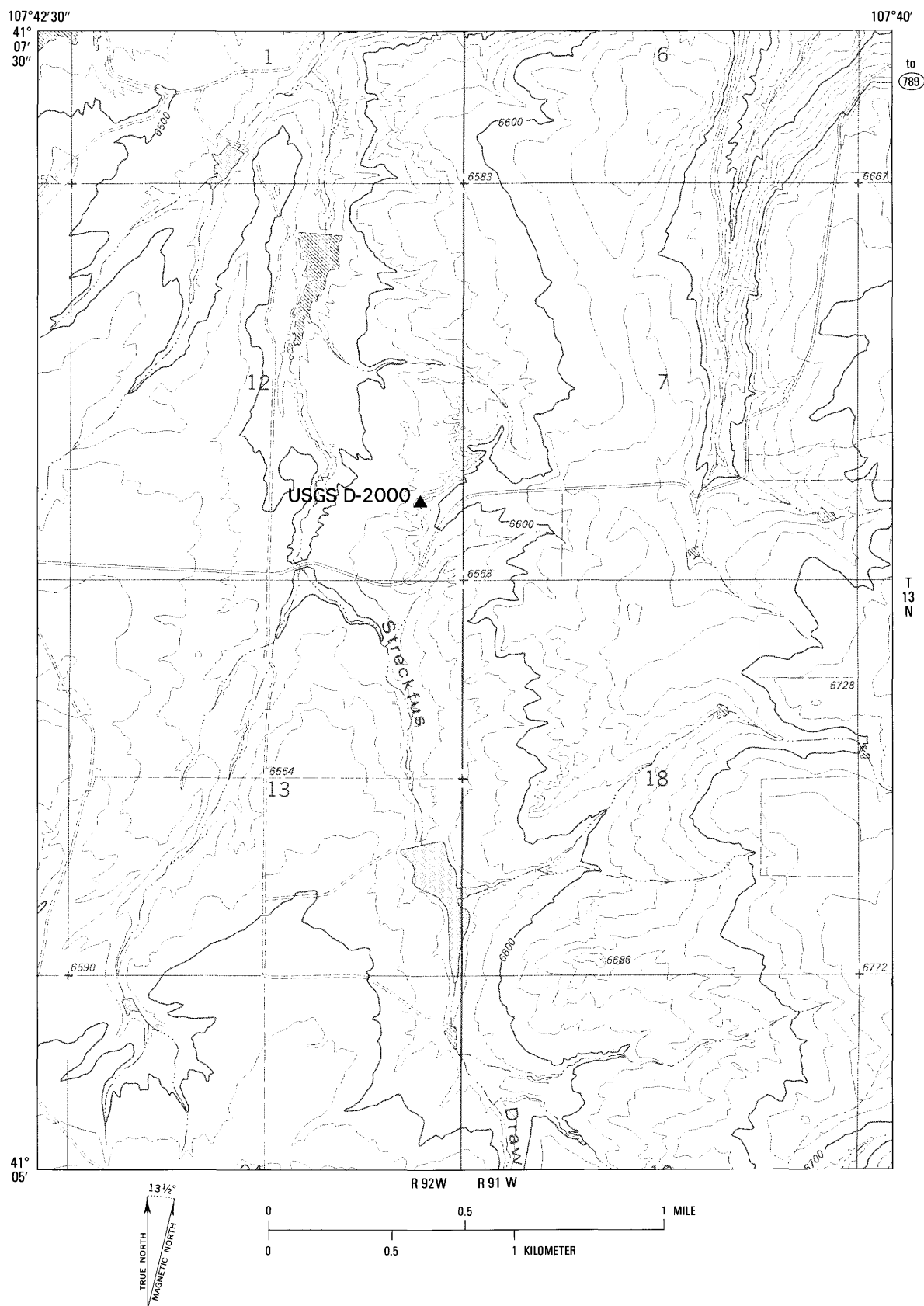


Figure 1. Topographic map showing the location of USGS fossil vertebrate locality D-2000, at Streckfus Draw, Carbon County, Wyo. Base from Baggs 7½ minute quadrangle, Wyoming-Colorado.

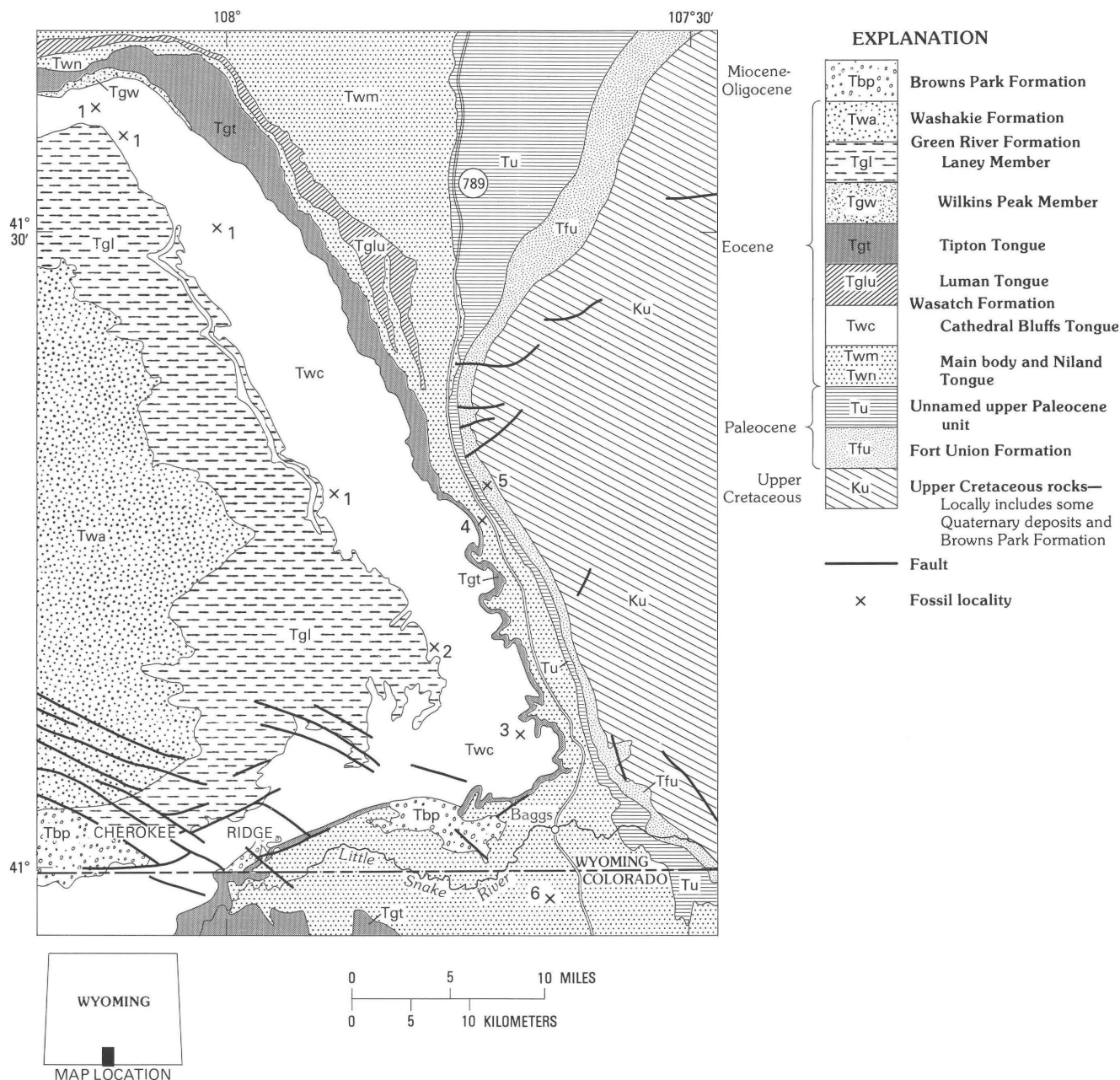


Figure 2. Geologic map showing the distribution of Upper Cretaceous and Tertiary rocks, and the approximate locations of Tertiary fossil mammal localities, in the eastern Washakie and northeast Sand Wash basins, Carbon County, Wyo., and Moffat County, Colo. Numbered stars designate fossil localities: 1, Morris' (1954) Cathedral Bluffs localities; 2, UCM 83120; 3, Streckfus Draw locality (USGS D-2000); 4, Dad local fauna; 5, Swain Quarry; 6, Alheit Pocket of the Four Mile fauna. Geology modified from Love and Christiansen (1985) and Tweto (1979).

is of middle Paleocene (Torrejonian) age, based on the fossil mammal fauna from Swain Quarry, about 12.5 mi (20 km) north of Cottonwood Creek (Rigby, Jr., 1980).

Overlying the Fort Union Formation is a rock unit informally referred to as the unnamed upper Paleocene unit. This unnamed unit consists of light-gray sandstone, siltstone, and mudstone and is about 550 ft (168 m) thick at Streckfus Draw. Based on palynomorph, molluscan,

and reptilian fossils, this unit is of late Paleocene age (Sanders, 1974; Edson, 1979; Honey and Hettinger, unpub. data). The unnamed unit roughly corresponds to Swain's (1957a and b) upper unit of the Fort Union Formation and is included within the Fort Union on previous large-scale, surface geologic maps in Wyoming (Edson, 1979; Sanders, 1974). However, subsurface correlation studies (Colson, 1969; Cronoble, 1969; Beaumont, 1979;

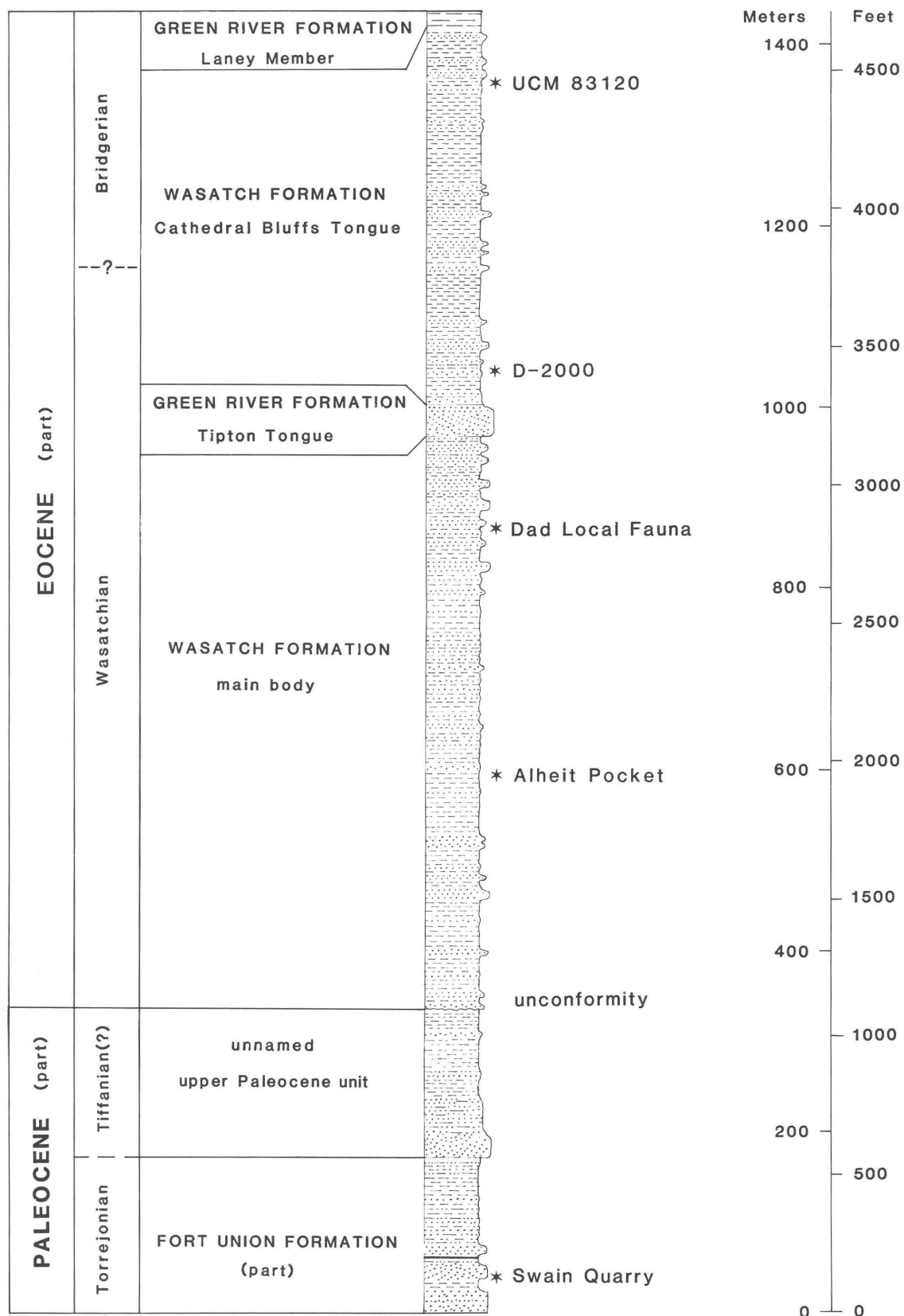


Figure 3. Generalized columnar section showing formations and thicknesses in the Streckfus Draw area, Carbon County, Wyo. Stars denote the stratigraphic positions of fossil mammal localities. Laney Member of the Green River Formation is exposed west of the study area.

Tyler, 1980) place this unit in the Wasatch Formation. Laterally equivalent rocks to the south in the Craig, Colo., area have been mapped as part of the Wasatch Formation.

Except for the lower and upper parts, the main body of the Wasatch Formation is covered largely by alluvium and terrace deposits along Muddy Creek. The thickness and much of the lithology were interpreted from the electric logs of the True Oil Company, Robber's Gulch No. 1 well, in the SW¼SW¼, sec. 31, T. 14 N., R. 91 W. The exposed parts of the main body consist of variegated gray, brown, maroon, and red mudstone, with interbedded fine- to coarse-grained, locally conglomeratic sandstone. The early Wasatchian (Graybullian) Four Mile fauna (McKenna, 1960) is present in the lower part of the main body of the Wasatch Formation about 10 mi (16 km) south of the Streckfus Draw area in northern Colorado. Based on comparisons with the inferred contact between the main body of the Wasatch Formation and the unnamed upper Paleocene unit in the Development Services Corporation, Pole Gulch No. 7 Unit well, in sec. 22, T. 12 N., R. 92 W., the Alheit Pocket localities of the Four Mile fauna are estimated to be between 800 and 900 ft (244–274 m) above the base of the main body. The uppermost part of the main body is of late Wasatchian (Lostcabinian) age, based on fossils from the Dad local fauna collected mainly from exposures about 10 mi (16 km) north of Cottonwood Creek, near Dad, Wyo. (Gazin, 1962). McKenna (1955) indicated that the Dad local fauna comes from approximately the top hundred feet of the main body; however, I have also collected fossils including fragmentary teeth of *Lambdaotherium* nearly 325 ft (99 m) below the Tipton in sec. 15, T. 15 N., R. 92 W.

The Tipton Tongue of the Green River Formation is well exposed along Cottonwood Creek and its tributaries east and northeast of the Streckfus Draw locality. The Tipton is predominantly oil shale but includes a lenticular sandstone body about 2 mi (3.2 km) wide and 80 ft (24 m) thick. The sandstone represents a fan delta that prograded into Lake Gosiute from the east (Roehler, this volume). The thickness of the Tipton Tongue along Cottonwood Creek ranges from 30 to 117 ft (9 to 35.7 m). Mollusks and ostracods are locally abundant. The lithofacies and environments of deposition of the Tipton Tongue are described by Roehler in chapter A of this volume, and the taphonomy and paleoecology of the mollusks are described by Hanley in chapter B.

The lower part of the Cathedral Bluffs Tongue of the Wasatch was examined in detail at the Streckfus Draw locality. It consists mainly of interbedded red- and purple-gray mudstones and sandstones, which were deposited in a floodplain environment. Red badlands and cliffs are also developed near the top of the tongue at the base of

Flat Top Mountain a few miles west of the study area. The thickness and generalized lithology of the Cathedral Bluffs (fig. 3) were interpreted from electric logs of the True Oil Company, Mattie No. 1 well, in sec. 14, T. 14 N., R. 93 W. The lower part of the Cathedral Bluffs Tongue is of late Wasatchian (Lostcabinian) age (this report), and the upper part of the Cathedral Bluffs Tongue is of early Bridgerian age (Gardnerbuttean of Robinson, 1966) (Robinson, oral commun., 1982; Stucky 1984a).

VERTEBRATE PALEONTOLOGY

Streckfus Draw Locality (USGS D-2000)

The thickness of the stratigraphic interval between the top of the Tipton Tongue and the Streckfus Draw fossil locality (USGS D-2000) was measured in sec. 7, T. 13 N., R. 91 W. The locality is about 125 ft (38 m) above the top of the Tipton Tongue. The entire thickness of the Cathedral Bluffs Tongue is not preserved at the Streckfus Draw locality, but in the vicinity of Flat Top Mountain, about 5 mi (8 km) west of the Streckfus Draw locality, the tongue is about 1350 ft (411 m) thick (fig. 3). A short stratigraphic section of the Cathedral Bluffs Tongue was measured at the fossil locality and has the following lithologies:

Measured section of part of the Cathedral Bluffs Tongue of the Wasatch Formation at the Streckfus Draw fossil locality (USGS D-2000) in the NW¼SE¼SE¼ and NE¼SE¼SE¼, sec. 12, T. 13 N., R. 92 W.

	Thickness (equivalents)	
	Meters	Feet
11. Alluvium at the top of bluffs	3.1	10.0
Wasatch Formation		
Cathedral Bluffs Tongue (in part):		
10. Mudstone, reddish-brown, with some lavender layers; forms red band at top of section	1.5	5.0
9. Mudstone, lavender	1.3	4.25
8. Mudstone, reddish-brown, sandy, in- terbedded with lavender to greenish-gray, fine-grained sandstone; forms reddish- brown slopes	4.9	16.0
7. Sandstone, light greenish-gray, fine-grained, silty	1.5	5.0
6. Sandstone, light-gray, very fine grained, silty, calcareous; forms resistant ledge	1.1	3.5
5. Sandstone, light-gray, very fine grained, silty, with some interbeds of siltstone. Units 5 through 7 contain sparse bone fragments	0.4	1.25
4. Mudstone, reddish-brown with purple mot- tling, slightly sandy; forms prominent red band; grades into overlying sandstone	1.5	5.0

	Thickness (equivalents) Meters Feet	
Wasatch Formation—Continued		
3. Mudstone, purplish-gray, with some yellow mottling; upper 6 ft (1.8 m) has interbedded mottled reddish- and purplish-gray mudstone and light greenish-gray, very fine grained sandstone, which forms lenticular bands up to 6 in. (15.2 cm) thick	4.3	14.0
2. Mudstone, mottled reddish- and purplish-gray, sandy; weathers orangish-red. <i>Helaletes</i> sp. was found in lower part of unit	2.1	7.0
1. Sandstone, light greenish-gray, fine-grained, silty; weathers white. This unit is exposed at the base of the badlands and is of unknown thickness; in places it appears to be at least 1 ft (0.3 m) thick. This is the main zone of fossil accumulation. Base of exposures		
Total measured section	21.6	71.0

The fossils at the Streckfus Draw locality are fragmentary and are dispersed over the surface of a white-weathered, fine-grained, silty sandstone (Bed No. 1), which forms the floor of the badland area. The fossils are weathering from this sandstone and from the lower part of the overlying red mudstone (Bed No. 2). Most of the fossils were collected by surface prospecting in about three man-days. The fossils are not concentrated; four burlap bags of matrix from the white sandstone and one bag of matrix from the overlying red mudstone were washed and yielded about one tooth per bag.

The following mammalian fossils have been identified from the Streckfus Draw locality (USGS D-2000):

Order Primates

Microsyops sp., cf. *M. scottianus*

Microsyops sp.

Cantius sp., cf. *C. venticolus*

Cantius sp., cf. *C. frugivorus*

Order Condylarthra

Hyopsodus sp.

Order Tillodontia

Esthonyx sp.

Order Dinocerata

Bathyopsinae

Order Perissodactyla

Lambdotherium popoagicum

Equidae, gen. et sp. indeterminate

Helaletes sp.

Abbreviations

The following abbreviations are used in this report: AMNH, American Museum of Natural History; UCM,

University of Colorado Museum; USGS-D, U.S. Geological Survey (Denver); UW, The Geological Museum, The University of Wyoming; AP, anteroposterior measurement; AW, anterior width; BL, buccal length; L, left (when placed before a tooth, as in LM₁) or length (when placed after a tooth, as in RM²L); LL, lingual length; M, molar; P, premolar; PW, posterior width; R, right; TR, transverse measurement; W, width. Parentheses around a measurement, such as AP=(12.1), indicate that the measurement is approximate.

Systematic Paleontology

The small fauna from the Streckfus Draw locality is indicative of a late Wasatchian (Lostcabinian) age. The fossils consist mainly of isolated teeth, whole and fragmentary, and broken postcrania. However, a three-toothed maxillary of *Hyopsodus* was recovered, as was an associated upper and lower dentition of *Helaletes*. Unfortunately, the *Helaletes* material was shattered and dispersed after years of weathering in a mudstone matrix, and only fragments were recovered. The dental materials are described and identified in the following section. This collection is housed at the U.S. Geological Survey in Denver, Colo.

Order PRIMATES

Suborder PLESIADAPIFORMES

Family MICROSYOPIDAE

Subfamily MICROSYOPINAE

Microsyops sp., cf. *M. scottianus* Cope, 1881

Plate 1A, B

Referred specimens.—USGS 10000, RP₄; USGS 10001, RM²?

Discussion.—The Cathedral Bluffs P₄ is slightly longer than, but otherwise compares well with, measurements given for *M. scottianus* and *M. elegans* by Szalay (1969, tables 14 and 16), and for *Microsyops* sp., cf. *M. scottianus* from the *Lambdotherium* zone of the Eocene Wind River Formation (Stucky, 1982). USGS 10000 is larger than the P₄ of *M. latidens* and smaller than those of *M. lundelusi* and *M. annectens*. Morphologically, USGS 10000 is identical to the P₄ on some *M. scottianus* from the Lost Cabin Member of the Wind River Formation; the Cathedral Bluffs and Lost Cabin specimens are similar in the width of the talonid, in the distinctness of the talonid cusps, and in the presence of a large, cuspsate metaconid that is smaller than the protoconid. The P₄ of *M. elegans* is slightly more molariform than that of *M. scottianus*, with the protoconid and metaconid equal in height on *M. elegans* (Matthew, 1915; West, 1973). Compared to *Microsyops* sp., cf. *M. elegans* from the middle Eocene Aycross Formation of the Thorofare

Creek Group (Bown, 1982), the Cathedral Bluffs P₄ has a slightly less robust metaconid and a slightly narrower talonid.

The Cathedral Bluffs M²? has a distinct mesostyle. USGS 10001 is larger than the M² of *M. latidens* and smaller than that of *M. annectens*, falling in the ranges reported for *M. scottianus* from the Lost Cabin Member (Guthrie, 1971) and for *M. elegans* from the Bridger A and B of Matthew (1909)¹ (Szalay, 1969). This tooth is assumed to belong to the same species as the P₄.

Measurements.—(mm): RM²?L=4.30, AW=5.15, PW=4.60; RP₄L=4.35, AW=2.75, PW=2.80.

***Microsyops* sp.**

Referred specimen.—USGS 10002, LM₁.

Discussion.—A possible second, smaller species is represented by a single tooth. The relatively large paraconid indicates that this is an M₁ rather than an M₂. USGS 10002 compares well with measurements given by Guthrie (1967, table 11) for *M. latidens* from the Lysite Member of the Wind River Formation, and with measurements for some specimens referred to *Cynodontomys knightensis* (= *Microsyops latidens* according to Szalay, 1969) from localities VI and VIII in the lower faunal level of the Eocene Huerfano Formation (Robinson, 1966). USGS 10002 falls at the large extreme of the measurements given by Szalay (1969, tables 12 and 13) for *M. latidens* from the Lysite Member and from the La Barge fauna of the Wasatch Formation. USGS 10002, however, is also very near the mean given by Szalay (1969, table 16) for *M. elegans* from the Bridger A and B. The Cathedral Bluffs specimen is slightly smaller than specimens of *M. scottianus* and *M. annectens* reported in Szalay (1969, tables 14 and 17), but is slightly longer and the same width as specimens of *Microsyops* sp., cf. *M. scottianus* reported by Stucky (1982) from the *Lambdotherium* zone of the Wind River Formation. Morphologically, USGS 10002 is virtually identical to some specimens of *M. latidens* from the lower Eocene Willwood Formation and the Lysite Member.

Measurements.—M₁L=3.73, AW=2.45, PW=2.75.

¹Matthew (1909) subdivided the Bridger Formation into five superposed levels, A (lowest) through E (highest), for the purpose of accurately recording the stratigraphic position of fossil mammal collections. Laterally extensive, calcareous white layers were used to separate Bridger B, C, and D from each other. McGrew and Sullivan (1970) separated Bridger A from B at a limestone marker bed, and West and Hutchison (1981) suggested lithologic criteria for recognizing Bridger E as a member of the Bridger Formation, the Cedar Mountain Member. The faunas of the combined Bridger A and B and the combined Bridger C and D are recognizably distinct (Gazin, 1976), which fact prompted Wood (1934) to designate the Bridger A and B as the Black's Fork Member and the Bridger C and D as the Twin Buttes Member of the Bridger Formation. Bradley (1964) noted that Wood's members are not distinguishable lithologic units, although they are mappable by means of the Sage Creek white layer separating them.

Suborder STREPSIRHINI
Infraorder LEMURIFORMES
Family ADAPIDAE
Subfamily NOTHARCTINAE
***Cantius* sp., cf. *C. venticolus* (Osborn, 1902)**
Plate 1C

Referred specimen.—USGS 10018, RM².

Discussion.—The taxonomy employed herein follows that of the most recent revisions of the Notharctinae (Gingerich and Simons, 1977; Gingerich and Haskin, 1981). An isolated upper molar compares well with the M² of advanced *Cantius*. A small, cusped mesostyle is present and connected by a short ridge to the centrocrista. The postparacrista and premetacrista are only slightly deflected buccally toward the mesostyle. The parastyle is prominent and more strongly developed than the metastyle. The hypocone is distinct, and small para- and metaconules are present. Basal cingula are well developed and, except at the mesostyle and metastyle, completely encircle the tooth.

The Cathedral Bluffs specimen compares well with *Cantius venticolus*, which differs from other species of *Cantius* in having a well-developed mesostyle and hypocone (Gingerich and Simons, 1977). USGS 10018 differs from the M² of *C. ralstoni*, *C. mckennai*, and *C. trigonodus* in having a larger size, and a stronger hypocone and mesostyle, and from *C. abditus* in having a stronger mesostyle and hypocone. Compared to specimens of *C. frugivorus* examined by me, USGS 10018 is larger, with a slightly more cusped mesostyle; the hypocone is comparable in development to that of *C. frugivorus*.

Compared to *Notharctus robinsoni* and *N. tenebrosus*, USGS 10018 has a smaller mesostyle and a less V-shaped centrocrista. *N. robinsoni* is also larger and has a longer lingual margin because of a larger hypocone. USGS 10018 is distinctly smaller than *N. robustior* and *N. pugnax*, and is more comparable in size to *N. tenebrosus*.

Compared to *Smilodectes* molars, USGS 10018 has a weaker mesostyle, a less V-shaped centrocrista, and is more transverse. USGS 10018 differs from known species of *Copelemur* in having a stronger mesostyle.

Measurements.—(mm): M²L=5.00, M²W=7.50.

***Cantius* sp., cf. *C. frugivorus* (Cope, 1875)**
Plate 1D

Referred specimen.—USGS 10019, RM₃.

Discussion.—A second, smaller species of *Cantius* appears to be present at USGS D-2000. The trigonid of USGS 10019 is worn, with indications of a reduced paraconid nearly confluent with the metaconid. The hypoconulid is twinned, and on the lingual side of the tooth are two worn cusps between the hypoconulid and

the talonid notch. In size and morphology, USGS 10019 is very similar to specimens of *C. frugivorus* and is smaller than *C. venticolus*. USGS 10019 differs from the M_3 of *Copelemur* in having a wider, more complex heel and in lacking an entoconid notch. In contrast to *Smilodectes*, the crista obliqua on USGS 10019 exhibits a flexure directed toward the protoconid. On USGS 10019, the paraconid is more closely appressed to the metaconid and is relatively higher than on specimens of *Notharctus* (*N. tenebrosus*, *N. robinsoni*, and *N. robustior*) examined by me.

Measurements.—(mm): $M_3L=6.15$, $AW=3.60$, $PW=3.50$.

Order CONDYLARTHRA
Family HYOPSODONTIDAE
Hyopsodus sp.
Plate 1E, F, G, H

Referred specimens.—USGS 10006, RM^{1-3} ; USGS 10008, RP^3 ; USGS 10010, $LM^1?$; USGS 10010, $LM^2?$; USGS 10009, LP_4 ; USGS 10007, $LM_1?$.

Discussion.—Because of high intrapopulation morphological variation, separation of contemporaneous species of *Hyopsodus* has generally been based on metrical rather than morphological grounds (Robinson, 1966; Gazin, 1968; West, 1979). Although morphological distinction of *Hyopsodus* species separated by relatively long time periods (for example, early Wasatchian and Bridgerian species) is not difficult, distinction of temporally closer species (late Wasatchian and Bridgerian) is difficult (West, 1979). Gazin (1968) and West (1979) have listed criteria useful in distinguishing Wasatchian from Bridgerian species, but these criteria are less useful in separating late Wasatchian and Bridgerian specimens. The small sample from the Cathedral Bluffs exhibits a mosaic of Wasatchian and Bridgerian features, and consequently the confident assignment of these specimens to one or another species is impossible. The disparate elements possibly represent more than one species, but this cannot be proved on the basis of this small sample.

The Cathedral Bluffs P^3 is less triangular, with a larger internal cusp, than in early Wasatchian *H. loomisi*. The parastyle is prominent, which is a feature considered by Gazin (1968) to be generally better developed in

Wasatchian than in Bridgerian species. Although there is overlap, the parastyle of USGS 10008 tends to be better developed than on most *H. paulus* specimens seen by me. The upper molars exhibit well-developed hypocones on the M^{1-3} , though smaller on the M^3 , and the M^2 is as much enlarged relative to the M^1 as in *H. paulus*. In contrast to some Bridgerian specimens, the crest between the protocone and hypocone of the Cathedral Bluffs specimens is only weakly developed on M^1 and is absent on M^2 . The Cathedral Bluffs P_4 has an enlarged metaconid and a basined talonid with a distinct posteroexternal cusp and a smaller posterointernal cusp. The elongate, cuspidate P_4 talonid contrasts with the more shortened P_4 talonid type commonly found in the Bridgerian (Gazin, 1968). However, the single lower molar from the Cathedral Bluffs resembles molars of Bridgerian species in (1) lacking a paraconid, (2) having the talonid basin broadly open lingually, as in *H. paulus*, (3) having a distinct metastylid (also reported on some *H. miticulus* [West, 1973]), and (4) lacking an entostylid.

The Cathedral Bluffs specimens are larger than *H. wortmani* and smaller than *H. powellianus* and *H. walcottianus*. The M_1 length falls within the ranges of *H. miticulus* and *H. paulus*, and is greater than in *H. minusculus* (Gazin, 1968; Guthrie, 1971; West, 1973, 1979). In addition, USGS 10007 lacks the entostylid reported on some *H. minusculus* (West, 1973). The upper molars fall into the small end of the range for *H. miticulus* reported by Guthrie (1971), and they are slightly smaller than those of *H. miticulus* from the Eocene New Fork Tongue of the Wasatch Formation (West, 1973). The upper molars (except M^1) are slightly larger than the molars of *H. minusculus* from the lower Bridger B and from the Powder Wash locality, Utah, and are at the upper end of the range for *H. minusculus* from the Bridger Formation and from the Cathedral Bluffs Tongue of the Wasatch Formation in the New Fork-Big Sandy area (West, 1973, 1979). They tend to be narrower than the molars of *H. paulus* from the Bridger B and are smaller than stratigraphically higher Bridger specimens (West, 1979). They are very similar in size and morphology to *Hyopsodus* sp., cf. *H. paulus* from the Aycross Formation (Bown, 1982).

Measurements.—See table 1.

Table 1. Measurements of teeth of *Hyopsodus* sp. from USGS locality D-2000 [in millimeters]

USGS No.	P^3L	P^3W	M^1L	M^1AW	M^1PW	M^2L	M^2AW	M^2PW	M^3L	M^3AW	P_4L	P_4W	M_1L	M_1AW	M_1PW
10008	2.80	3.30													
10006			3.45	4.25	4.05	3.70	5.05	4.60	3.35	4.60					
10010 ¹			3.20	4.25	4.15										
10010 ¹						3.80	4.90	4.75							
10009											3.55	2.35			
10007 ¹													4.15	2.87	2.97

¹Identification as a specific molar not certain.

Order TILLODONTIA
Family ESTHONYCHIDAE
Subfamily ESTHONYCHINAE
Esthonyx sp.

Referred specimen.—USGS 10004, RM_x.

Discussion.—A worn, fragmentary talonid of a small tillodont is referred to *Esthonyx*. Although the trigonid and metastylid are not preserved, the relatively wide and somewhat elongate talonid with bulbous hypoconid indicates that this tooth is an M₁ or M₂ rather than a P₄. This specimen is too fragmentary for confident specific allocation, but significantly the width of the talonid fits easily within the ranges given for *Esthonyx acutidens* by Gingerich and Gunnell (1979) and Stucky and Krishtalka (1983) and is wider than in most *E. bisulcatus*. The teeth of *Megalesthonyx*, *Trogosus*, and *Tillodon* are much larger.

Measurement.—(mm): RM_xPW=6.65.

Order DINOCERATA
Family UINTATHERIIDAE
Subfamily BATHYOPSINAE
Plate 11

Referred specimen.—USGS 10005.

Discussion.—A small bathyopsine uintatheriid is represented by a posterior lower premolar or anterior molar. The tooth is long, narrow, and heavily worn, and the posterior talonid crest is broken. The paraconid crest ends lingually in a slight swelling. At this stage of wear the hypoconid is strongly united to the posterior talonid crest. Because of breakage, the strength of the entoconid is not determinable. Anterior and posterior cingula are present, and a weak external swelling is present across the protoconid and hypoconid. The enamel is relatively thin, and possibly this is a deciduous premolar.

Similarities to *Proathyopsis* include the relatively strong paraconid crest, the union of the hypoconid and posterior talonid crest, and the small size. Although *Proathyopsis* is distinguished from *Bathyopsis* by the presence of a hypoconulid crest (Wheeler, 1961), a referred molar of *Bathyopsis* sp. from the Aycross Formation (Bown, 1982, specimen USGS 1989) shows that in extreme wear the hypoconid will unite with the posterior talonid crest. The Cathedral Bluffs specimen is smaller than the premolars or molars of *Bathyopsis fissidens* and approaches more closely the dimensions of the posterior premolars and anterior molars of *Proathyopsis* species (Kelley and Wood, 1954; Dorr, 1958; Guthrie, 1967; Rose, 1981). Guthrie (1971), however, indicated that highly worn teeth of *B. fissidens* are identical in size to those of *Proathyopsis lysitensis*.

Measurements.—(mm): AP=(12.1), TR=8.1.

Order PERISSODACTYLA
Suborder HIPPOMORPHA
Superfamily EQUOIDEA
Family PALAEOTHERIIDAE
Lambdotherium popoagicum Cope 1880
Plate 2A, B, C

Referred specimens.—USGS 10011, RM³; USGS 10012, RM_x; USGS 10013, RM₃; USGS 10014, RM₃; USGS 10015, LM₃; USGS 10016, RM₃; USGS 10017, unassociated, broken teeth.

Discussion.—*Lambdotherium* has recently been studied by Wallace (1980) who, in agreement with Bonillas (1936), concluded that the genus is represented by only one valid species, *L. popoagicum*. Wallace also provisionally reassigned *Lambdotherium* to the family Palaeotheriidae. *Lambdotherium* is a common element of this fauna, represented by isolated teeth. The M³ has a large parastyle, smaller mesostyle, and weak metastyle. The protoconule is large and close to the base of the paracone. The metaloph is strong and without evidence of a metaconule. The hypocone is large and the lingual cingulum is absent. An unworn right lower molar (USGS 10012) has crenulated enamel on the basins and ridges. The metastylid is almost as large as the metaconid, but with wear the metastylid disappears. The hypoconulids on the M₃s are large with well-developed basins that are completely enclosed lingually. The buccal wall of the hypoconulid joins the hypolophid buccal to the entoconid. A large, flat, wear facet is present on the posterior margin of the hypoconulid of USGS 10015.

The size of the Cathedral Bluffs M³ falls within the range reported for *Lambdotherium* from the New Fork Tongue of the Wasatch Formation (West, 1973, table 55). The values for lengths and widths of the lower molars tend to lie on the small ends of the ranges or to be smaller than the values reported by West (1973), Robinson (1966, table 29), and Guthrie (1971, table 34) for *Lambdotherium popoagicum*.

Measurements.—(mm): USGS 10011, RM³BL=10.45, LL=9.75, AW=14.65, PW=11.1; USGS 10012, RM_xL=9.95, AW=6.85; USGS 10013, RM₃L=(14.3); USGS 10014, RM₃PW=6.9; USGS 10015, LM₃PW=7.3; USGS 10016, RM₃AW=7.0.

Family EQUIDAE
gen. et sp. indeterminate
Plate 2F

Referred specimen.—USGS 10513, LM^x.

Discussion.—A moderately worn equid upper molar is broken transversely across the protoloph. The paraconule and metaconule are large and cusped. The ectoloph is slightly deflected buccally between the paracone and metacone. A low vertical ridge, which could be considered an incipient mesostyle, is present on the

buccal wall of the ectoloph, running between the ectocingulum and the lowest point of the ectoloph between the paracone and metacone. The ectocingulum is prominently developed between the parastyle and the posterobuccal corner of the metacone but is not elevated to form a cuspule.

No equid premolars were found at USGS locality D-2000, so comparisons of USGS 10513 with *Hyracotherium* and *Orohippus* rest solely on the fragmentary molar. The tooth closely resembles that of *Hyracotherium*, based on the weak mesostyle and the ectoloph not being markedly V-shaped between the paracone and metacone. Kitts (1956, 1957), who last reviewed *Orohippus* and American species of *Hyracotherium*, distinguished these genera by, among other features, the presence of a mesostyle on the upper molars of *Orohippus* and its absence in *Hyracotherium*, and the ectoloph being V-shaped between the paracone and metacone in *Orohippus*. Hooker (1980), however, noted that in the English species *Hyracotherium leporinum*, the type species of *Hyracotherium*, the upper molars exhibit a strongly buccally flexed centrocrista and a weak mesostyle. The tooth from the Cathedral Bluffs compares well with some specimens of *Hyracotherium* in the USGS collections (locality D-1452, Willwood Formation). These Willwood specimens, which are referable to *Hyracotherium* on the basis of P³⁻⁴ having only three major cusps, also possess incipient mesostyles between the paracones and metacones, and have slightly V-shaped ectolophs. A similar morphology is occasionally present on *Hyracotherium vasaccense*, as shown by AMNH 4839 and AMNH 4832 (the latter being the type of *Hyracotherium venticolus*, illustrated in Wortman, 1896, fig. 14). Specimens of *Orohippus* from Carter Mountain and from the Aycross Formation examined by me exhibited stronger ridges on the ectoloph or had the ectocingulum distinctly elevated between the paracone and metacone, sometimes forming a distinct cuspule. West (1973), however, noted that on some *Orohippus* sp., cf. *O. pumilus* from the Bridger Formation, the mesostyle is commonly poorly developed and sometimes only barely visible, as his illustration (pl. XIV) seems to confirm. Because of the variability in mesostyle strength in advanced *Hyracotherium* and primitive *Orohippus*, the specimen from the Cathedral Bluffs cannot be allocated to either genus.

Measurement.—(mm): M×W = 10.95.

Suborder CERATOMORPHA
Superfamily TAPIROIDEA
Family HELALETIDAE
Helaletes sp.
Plate 2D, E

Referred specimens.—USGS 10514

Discussion.—Several associated partial teeth of a

single helaletid tapiroid individual were recovered. A fragmentary LP^x is broken from the metacone to the protocone. The metacone is well separated from, and apparently nearly as large as, the paracone. A prominent parastyle and anterior cingulum are present. The protocone is broken posteriorly, so the presence or absence of the hypocone cannot be determined.

A broken LM¹ possesses a prominent parastyle, a high conical paracone, and a metacone slightly convex labially and strongly shifted lingually. A short, narrow cingulum is present on the buccal margin of the parastyle, and a more prominent cingular shelf is present on the buccal margin of the metacone. A cingulum is present posteriorly. The M² is represented by fragmentary right and left teeth. The parastyle is prominent, and the metacone is slightly convex and shifted lingually, with a pronounced posterobuccal cingulum. Anterior and posterior cingula are present. A fragmentary M³ is nearly unworn and shows a metacone less lingually shifted than on the M². Consequently, the M³ metaloph is slightly larger than the M² metaloph. A prominent cingulum is present on the labial margin of the metacone.

The P₃ is elongate and narrows anteriorly. The protoconid is the largest cusp. The metaconid is slightly lower than the protoconid, and is well separated from and only slightly posterior to it. The paralophid descends anteriorly from the protoconid and turns sharply lingually, giving the front margin of the tooth a squared appearance. The talonid basin is broad and shallow. A metalophid extends from the hypoconid to the posterior wall of the protoconid. A cuspsate entoconid is separated from the posterolingual margin of the posterior cingulum by a narrow notch. The posterior cingulum is continuous with the hypoconid.

The P₄ is broken across the protoconid. The metaconid is relatively larger than on the P₃ and is connected to the protoconid by a protolophid. The anterior termination of the protolophid is prominent, but is slightly weaker than on the P₃. The talonid is broad but is relatively shorter than on the P₃ and has a more pronounced entoconid, which is connected to the hypoconid by a low hypolophid. A posterior cingulum descends lingually from the hypoconid, terminating low on the posterior slope of the entoconid.

The M₁ shows a prominent protolophid and hypolophid, and a reduced paralophid. The metalophid is highly worn and is weakly connected to the base of the protoconid. A low posterior cingulum exhibits a small central hypoconulid.

Two nearly unworn M₃'s display prominent proto- and metalophids. The paralophid forms a strong anterior shelf. The metalophid extends about halfway from the hypoconid to the protoconid before dying out, and a ridge extends anteriorly from the entoconid about halfway to the metaconid. A narrow anterior cingulum is present.

The hypoconulid is prominent, but narrow and unbasined. A short, narrow cingulum is present buccally between the hypoconid and hypoconulid, and a tiny cusplule is present lingually in the notch between the hypoconulid and entoconid.

The tapiroid from the Cathedral Bluffs has a combination of features found in both *Heptodon* and *Helaletes* but is assigned to *Helaletes* on the basis of the presence of a distinct cusplate entoconid on both P_3 and P_4 . According to Radinsky (1963), *Helaletes* has entoconids on the P_{3-4} , whereas *Heptodon* has the entoconid only variably present on the P_4 . The P_3 entoconid on USGS 10514 is as well developed as the entoconid on *Helaletes nanus* AMNH 13124 from the Bridger B. Also indicative of affinities to *Helaletes* is the advanced structure of the P_3 trigonid, in which the protoconid and metaconid are well separated, and the hypolophid is almost transversely aligned.

The upper premolars are advanced in showing the M^{1-2} metacone strongly lingually shifted and only slightly convex. According to Radinsky (1963), the M^{1-3} metacones of *Helaletes* are slightly shorter, flatter, and more lingually depressed than those of *Heptodon*; the metacones on the Cathedral Bluffs teeth are as flat labially and as depressed lingually as in specimens of *Helaletes nanus* (UW 3189, AMNH 11647) examined by me. On the other hand, the M^3 (USGS 10514) has the metacone less lingually shifted, and the metaloph longer, than in the same specimens of *Helaletes*; in this respect, the tooth is more similar to the condition in *Heptodon*.

The M_1 from the Cathedral Bluffs is indistinguishable from that of *Helaletes* or *Heptodon*. However, the M_3 is virtually identical to those of some specimens of *Heptodon*, and differs from the M_3 of *Helaletes* that I have seen in having a larger, more elongate hypoconulid. Both Radinsky (1963) and Bown (1982) noted that the M_3 hypoconulid of *Heptodon* averages larger than in *Helaletes*. Except for the length of the M_3 , the teeth of the Cathedral Bluffs tapiroid fall within the range given by Radinsky (1963) for *Helaletes nanus*; the Cathedral Bluffs M_3 is longer because of the presence of the elongate hypoconulid.

On the Cathedral Bluffs tapiroid, the similarities to *Heptodon* are considered primitive retentions. The more advanced features, particularly on the lower premolars, are used to allocate the specimen to *Helaletes*. This specimen cannot be allocated with certainty to any particular species of *Helaletes*.

Measurements.—(mm): $RP_3L=7.0$, $W=4.8$; $RP_4L=7.6$, $W=5.3$; $LM_1W=6.0$; $RM_3L=15.5$; $LM_3W=8.0$.

AGE OF THE CATHEDRAL BLUFFS FAUNA

The Streckfus Draw fauna is of late Wasatchian (Lostcabinian) age, based primarily on the presence of

Lambdotherium. *Lambdotherium* has long been considered characteristic of Lostcabinian faunas, and recent studies by Stucky (1984a and b) have emphasized its absence in post-Lostcabinian faunas. *Cantius venticolus* is considered late Wasatchian in age (Gingerich and Simons, 1977; Gingerich and Haskin, 1981), and in the Wind River Basin, where the type was found, specimens of *Cantius* sp. cf. *C. venticolus* (*Notharctus* of Stucky, 1984a) are found only in the *Lambdotherium* range zone (Stucky, 1984a). *Cantius frugivorus* (including *Notharctus nunienus*) is found in late Wasatchian faunas in southwest Wyoming and in the Huerfano Basin, in the *Lambdotherium* range zone in the Wind River Basin, and in middle Wasatchian rocks in the San Juan and Bighorn Basins (Gazin, 1962; West, 1973; Gingerich and Simons, 1977; Schankler, 1980; Lucas and others, 1981; Stucky, 1984a). *Cantius frugivorus* has not been reported from the Bridgerian.

Other taxa from the Streckfus Draw locality fauna are not specifically diagnostic as to age. In the Wind River Basin, *Microsyops* sp. cf. *M. scottianus* is common both in the *Lambdotherium* range zone of the late Wasatchian (Lostcabinian) and in the *Paleosyops borealis* assemblage zone of the earliest Bridgerian (Gardnerbuttean) (Stucky, 1984a and b). Although *Esthonyx* is a common Wasatchian fossil, it also occurs in the early Bridgerian *Paleosyops borealis* zone in the Wind River Basin and in the Gardner Butte local fauna in the Huerfano Basin (Stucky, 1984a; McKenna, 1976). *Helaletes* is usually considered a diagnostic Bridgerian taxon (Wood and others, 1941; Radinsky, 1963); it occurs in faunas from early (Gardnerbuttean) to late (Bridger C and D) Bridgerian age. Although Stucky (1984b) suggested that the first appearance of *Helaletes* (in conjunction with the first appearance of other taxa) can be used to mark the beginning of the Bridgerian, Stucky (1984a and b) reported its somewhat questionable occurrence in the *Lambdotherium* zone of the Wind River Formation. The occurrence of the morphologically primitive *Helaletes* in the Streckfus Draw fauna can be viewed as compatible with a late Wasatchian age.

The Streckfus Draw fauna dates the basal part of the Cathedral Bluffs and the Tipton Tongue as of late Wasatchian age on the eastern margin of the Washakie Basin. The main body of the Wasatch underlying the Tipton Tongue has yielded a late Wasatchian mammalian fauna a few miles north of the study area near Dad, Wyo. (Wood and others, 1941; Gazin, 1962, 1965). *Lambdotherium popoagicum* was identified at this locality. Gazin (1962) reported the occurrence of a questionable *Cantius frugivorus* (called *Notharctus limosus* by Gazin) and a small *Esthonyx* from the Dad fauna, although for both finds the precise stratigraphic horizon in the main body of the Wasatch was not known. An illustrated *Heptodon ventorum* from the Dad fauna (Gazin, 1962,

pl. 13) shows no evidence of the P₃ entoconid that is present on the USGS tapiroid. On the basis of the presence of *Lambdaotherium*, the Tipton Tongue has been dated as late Wasatchian on the northwest side of the Great Divide Basin and at Table Rock on the northwest side of the Washakie Basin (McGrew and Roehler, 1960; Gazin, 1965).

Morris (1954) reported on a small fauna collected from several sites within the Cathedral Bluffs in the northeast part of the Washakie Basin. He considered the age of the fauna to be intermediate between late Wasatchian (Lostcabinian) and early Bridgerian (Bridger B) and suggested a possible time correlation with the Bridger A. West (1969, 1973) reexamined Morris' collection and suggested that it was probably of early Bridgerian age, in agreement with Morris. This conclusion was based in part on the absence in Morris' collection of common late Wasatchian fossils, including *Lambdaotherium* and *Esthonyx*. Gazin (1959, 1962, 1965) had previously studied Morris' collection and concluded that it was of late Wasatchian age, although it contained a few forms typical of the Bridgerian (for example, *Trogosus*? cf. *T. latidens* and a brontotheriid, near *Palaeosyops fontinalis*). He noted that the two forms typical of the Bridgerian were from higher in the Cathedral Bluffs and implied that all of the fossils may not have been contemporaneous. McGrew and Roehler (1960) reported a tooth of a probable Bridgerian rodent, *Sciuravus nitidus*, from the upper part of the Cathedral Bluffs west of Dad.

Recently, a fauna (UCM locality 83120; see fig. 4) of earliest Bridgerian (Gardnerbuttean) age has been recovered about 200 ft (61 m) below the top of the Cathedral Bluffs Tongue in the eastern Washakie Basin (Robinson, oral commun., 1982; Stucky, 1984a). The USGS and UCM localities demonstrate that the Cathedral Bluffs Tongue in the eastern Washakie Basin contains faunas of latest Wasatchian and earliest Bridgerian age. These faunas are separated by about 1000 ft (305 m) of mostly poorly exposed rocks. Intervening faunas with stratigraphic data have not been reported. Additional biostratigraphic work is needed to locate the precise Wasatchian-Bridgerian boundary.

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PLATES 1 AND 2

Contact photographs of the plates in this report are available, at cost, from the
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PLATE 1

[All figures are stereophotographs; scale in mm]

FIGURES *A, B. Microsyops* sp., cf. *M. scottianus*.

A. Occlusal view of USGS 10000, RP₄.

B. Occlusal view of USGS 10001, RM²?

C. Cantius sp., cf. *C. venticolus*.

Occlusal view of USGS 10018, RM².

D. Cantius sp., cf. *C. frugivorus*.

Occlusal view of USGS 10019, RM₃.

E-H. Hyopsodus sp.

E. Occlusal view of USGS 10006, RM¹⁻³.

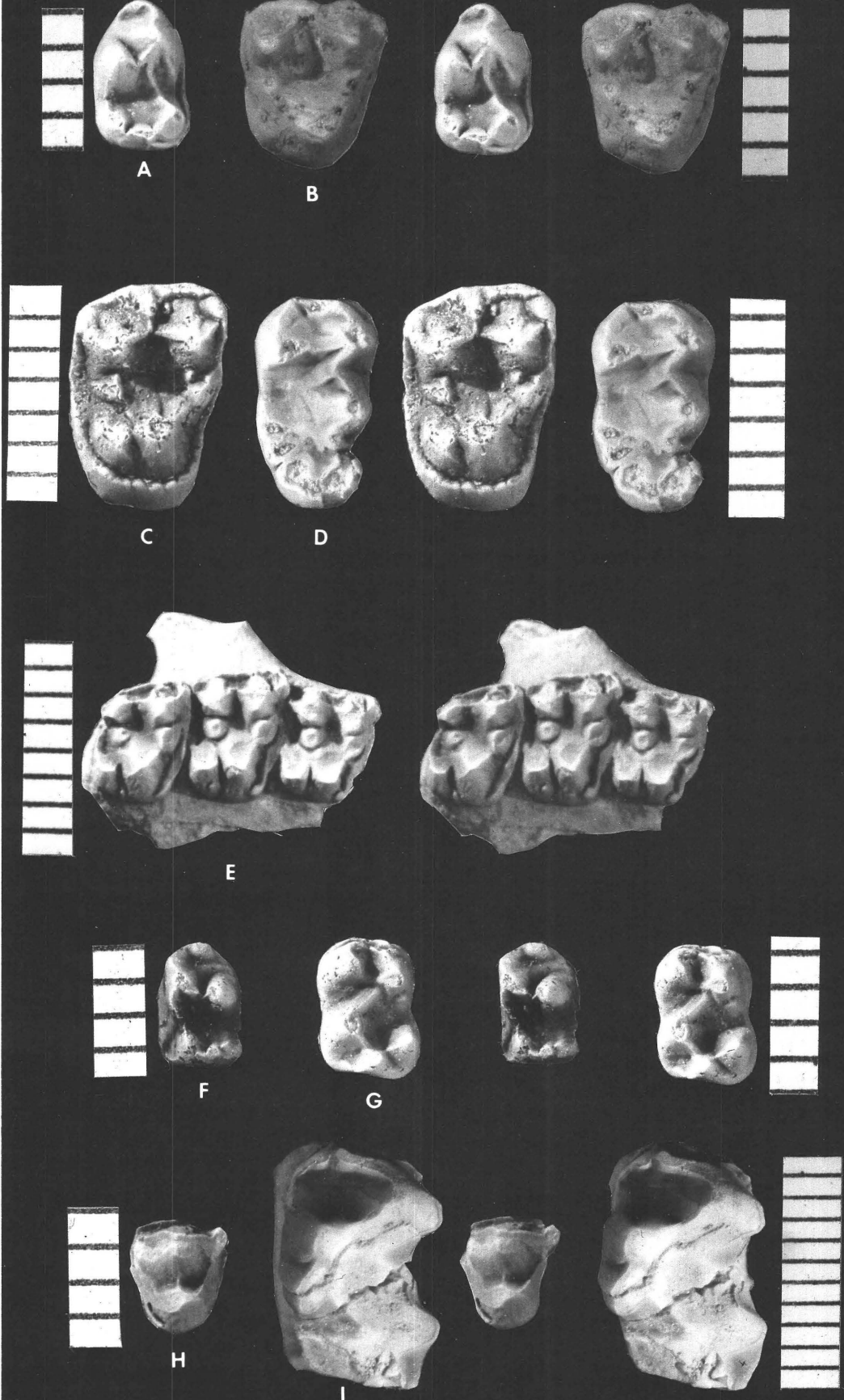
F. Occlusal view of USGS 10009, LP₄.

G. Occlusal view of USGS 10007, LM₁?

H. Occlusal view of USGS 10008, RP³.

I. Bathyopsinae.

Occlusal view of USGS 10005, lower premolar or molar.



MICROSYOPS, CANTIUS, HYOPSODUS, AND BATHYOPSINAE

PLATE 2

[All figures are stereophotographs; scale in mm]

FIGURES A-C. *Lambdaotherium popoagicum*.

A. Occlusal view of USGS 10011, RM³.

B. Occlusal view of USGS 10012, RM_x[?].

C. Occlusal view of USGS 10015, LM₃.

D, E. *Helaletes* sp.

D. Occlusal view of USGS 10514, RP₃₋₄.

E. Occlusal view of USGS 10514, LM₃.

F. Equidae.

Occlusal view of USGS 10513, LM^x.



A



B



C



D



E



F

