Twenty-first Annual Field Conference—1969
Wyoming Geological Association Guidebook

STRATIGRAPHY AND SEDIMENTATION OF THE PALEOCENE - EOCENE HOBACK FORMATION WESTERN WYOMING[1]

by
Darwin R. Spearing[2]
Littleton, Colorado

ABSTRACT

In early Tertiary time, the western Wyoming overthrust region underwent several stages of uplift accompanied by synorogenic deposition of thick sediments into subsiding intermontane basins. The Hoback Formation in the Hoback Basin is an examble of one of these thick, early Tertiary deposits. The Hoback Formation ranges in age from Middle Paleocene (Torrejonian) to early Eocene (Graybullian). In the center of the Hoback Basin, it is about 16,000 feet thick, but thins southward to about 8,000 feet before plunging into the subsurface in the north end of the Green River Basin, where it intertongues with the Chappo Member of the Wasatch Formation. A conformable, intertonguing and gradational contact separates the Hoback from the overlying Pass Peak Formation, except in a local area along the front of the Gros Ventre Mountains, where the Pass Peak unconformably overlies the Hoback.

Six facies within the Hoback Formation suggest three major environments of deposition. A *thick sandstone facies*, characterized by large-scale cross-bedded, tabular, fine-grained sandstones, delineates a flood plain stream belt. A *conglomerate and sandstone facies* and a *pebbly sandstone facies*, distinguished by stratified pebble deposits with upper flow regime bedding and lenticular form, suggest major stream deposition on an alluvial plain. A flood plain is indicated by three facies: *thin sandstone-dark shale*, *thin sandstone-varicolored shale*, and *limestone-dark shale*. In these facies, thick clays accumulated as overbank deposits, enveloping thin, small-scale cross-bedded, lenticular sand deposits of ephemeral stream channels.

Hoback sandstones are composed chiefly of quartz, chert, and limestone fragments with distinctive assemblages of minor constituents including zircon, opaques (chiefly leucoxene), colorless epidote–clinozoisite and collophane. Hoback conglomerates are composed entirely of Paleozoic and Mesozoic sedimentary rocks. The pebbles and light and heavy minerals in lower Hoback strata are mainly Mesozoic derivatives, whereas in upper Hoback strata, Paleozoic derivatives are dominant. This vertical distribution implies progressively deeper erosion of the source area. Cross-stratification measurements indicate predominant west-to-east sediment transport throughout most of Hoback time. The Snake River Range west of the Hoback Basin was a likely source for most of the Hoback sediments for several reasons: (1) The range is located west of the Hoback Basin, (2) It was uplifted in Late Cretaceous time just prior to Hoback deposition, (3) The Mesozoic rocks have been stripped off along the axis of the Snake River Range, exposing Paleozoic rocks.

INTRODUCTION

The Hoback Basin covers 315 square miles in northwestern Wyoming (Fig. 1). It is bounded on the west by the Hoback Range and on the north and east by the Gros Ventre Mountains. Though structurally a part of the northern end of

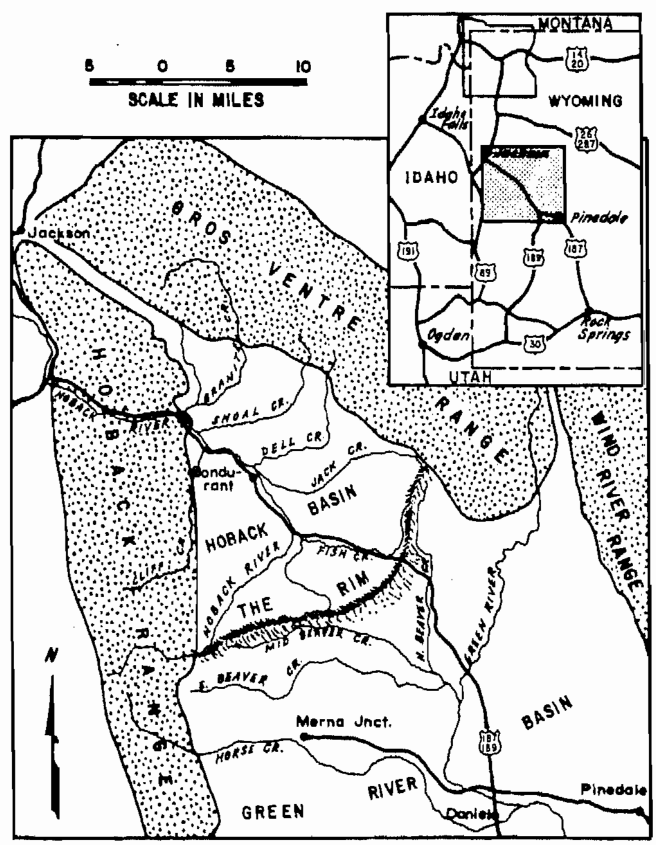


Fig. 1.—Map of western Wyoming showing the location of the Hoback Basin.

[1]This article is a summary of the writer's doctoral thesis, The University of Michigan, 1969, the details of which are being submitted to the Geological Society of America for publication in the *Bulletin*. Louis I. Briggs, John A. Dorr, Jr., and James R. Steidtmann contributed much time, interest and guidance to this project. Financial support was provided by the National Science Foundation (Grant No. GA-456). Steven S. Oriel, John B. Hayes, and John C. Harms offered valuable suggestions and critical manuscript reviews.

[2]Research Geologist, Marathon Oil Company, Denver Research Center, Littleton, Colorado.

the Green River Basin, the Hoback Basin is topographically bounded on the south by a drainage divide called The Rim.

Eardley, Horberg, Nelson and Church (1944) were the first to apply the name "Hoback" to the Lower Tertiary gray and buff sandstone and shale sequences within the Hoback Basin. Dorr (1952) reviewed the literature prior to 1940 which deals with the stratigraphic nomenclature in this area. The structural geology of the borders of the Hoback Basin and surrounding ranges was discussed by Dorr (1952, 1956, 1958b), Eardley (1944, 1960, 1962), Horberg, Nelson and Church (1949), Love, (1956a, 1956b) Keefer (1964), and Berg (1961). Stratigraphic studies of the surrounding ranges and portions of the Hoback Basin may be found in papers by Wanless, Belknap and Foster (1955), Love (1956a), Foster (1943) and Froidevaux (1968). Invertebrate fossils from the Hoback Formation were described by Moore (1955, 1960) and Peck (1956). Vertebrate fossils were discussed by Dorr (1952, 1956, 1958a, 1958b). Plant fossils are generally so poorly preserved that the flora has not been systematically studied, though Peck (1956) briefly discussed fossilized algal öogonia. Stratigraphic investigations of the main body of the Hoback Formation were reported by Dorr (1951, 1956), Eardley *et al.* (1944) and Moore (1960). Oriel (1969) discussed Hoback subsurface stratigraphy and related units in the northern Green River Basin.

Structural deformation is not intense except locally at the basin margins. The Hoback Formation dips generally eastward at 40 degrees over much of the western half of the basin and only 10 degrees over the eastern half (Fig. 2). On the west side of the basin, the Hoback is overriden by the Jackson-Prospect thrust sheet and is folded along the Little Granite-Monument Ridge anticline (Fig. 2). On the east side of the basin, the dips are toward the southwest in a band about one mile wide along the Cache fault. In this area the Pass Peak Formation rests with angular unconformity on the Hoback Formation. Along the rest of their contact, however, the Pass Peak and Hoback are conformable and the contact is gradational and interfingering. The Hoback-Pass Peak contact is selected from petrographic evidence and bed continuity. It is placed at the base of a prominent, laterally continuous sandstone of Pass Peak composition (see Petrography). Below this level, Hoback-type sandstones predominate, and above this level Pass Peak sandstones are dominant. The few Pass Peak-type sandstones below the contact are considered tongues within the Hoback Formation, whereas Hoback-type sandstones above the contact are considered tongues within the Pass Peak Formation.

The regional stratigraphic relations of the Hoback Formation and other early Tertiary units as indicated by investigations to date are shown in Figure 3. In the southwest corner of the Hoback Basin, a thick section of red and gray conglomerates overlies the Jackson-Prospect fault and unconformably overlaps the marginally deformed Hoback Formation. Pending adequate dating and further mapping of this unit, it is considered to be the northern extension of the Conglomerate Member of the Wasatch Formation (Oriel, 1962).

In the north end of the Hoback Basin a different red conglomerate of as yet undetermined age overlies Hoback strata. The conglomerate is deformed along the Cache fault as evidenced by crushed and broken cobbles and upturned strata near the fault trace. Because datable fossils have not been

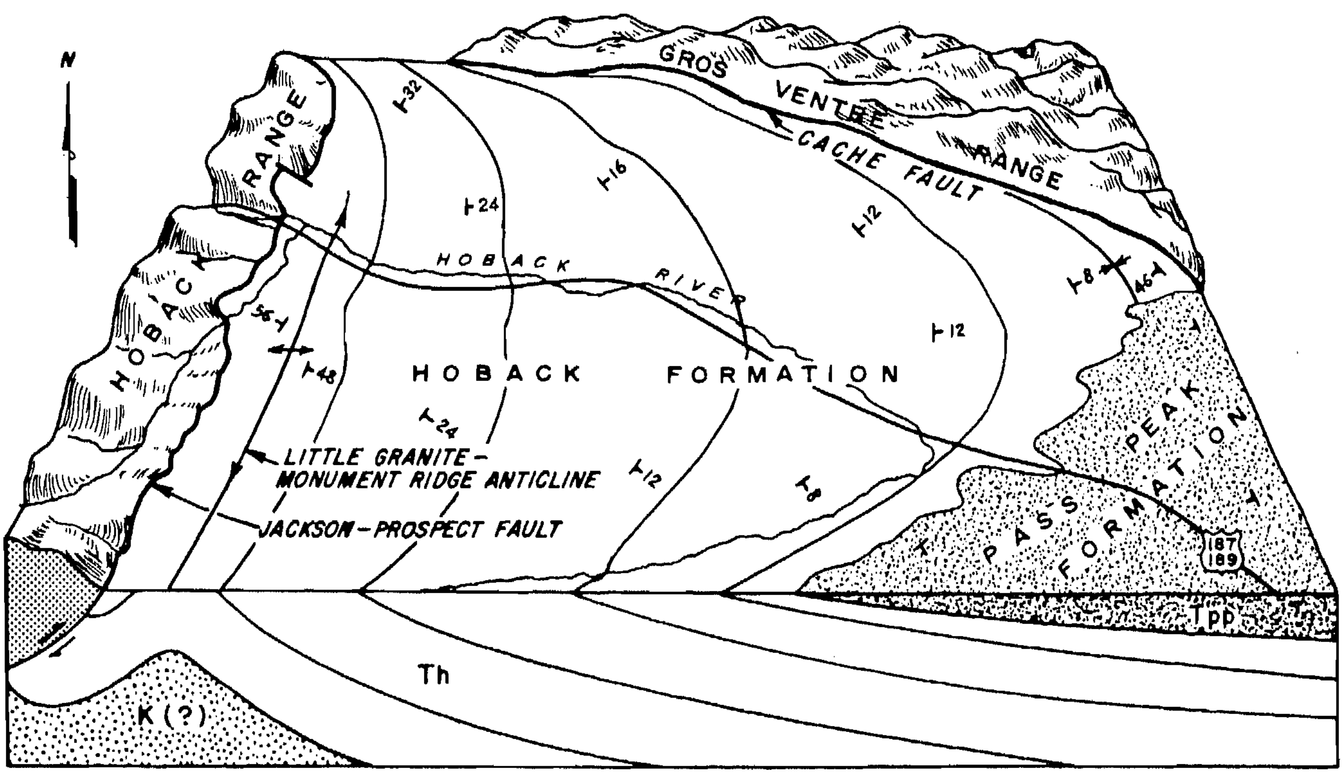


Fig. 2.—Block diagram of part of Hoback Basin.

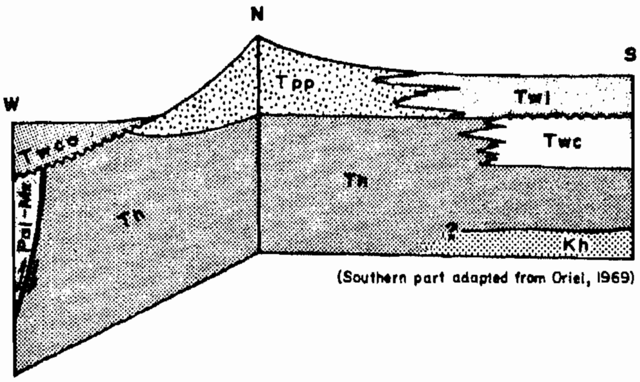


Fig. 3.—Idealized sections in Hoback and northern Green River Basins, showing relations of Hoback Formation to other units. Tpp, Pass Peak Fm.; Th, Hoback Fm.; Tw, Wasatch Fm., with Twco, Conglomerate Mbr.; Twl, LaBarge Mbr.; Twc, Chappo Mbr.; Kh, Hilliard Sh.; Pal-Mz, undifferentiated Paleozoic and Mesozoic rocks.

found in the conglomerate, its stratigraphic position is inconclusive. The unit may be part of the Pliocene Camp Davis Formation, as it has been previously mapped (Dorr, 1958b), or it may constitute an upper marginal facies of the Hoback Formation, or it may be a laterally equivalent unit to the Pass Peak Formation.

STRATIGRAPHY

The total thickness of the Hoback Formation can only be inferred. The top can be located to within several hundred stratigraphic feet in the "transition zone", between the Hoback and Pass Peak Formation. The bottom of the Hoback is nowhere exposed. Measurements of the exposed strata total 16,000 feet in the north center of the basin and about 8,000 feet in the south (Fig. 4). Oriel (1969) measured about 2,500 feet of Hoback Formation in the subsurface at the north end of the Green River Basin. Thus, the Hoback appears to be wedge-shaped, with the main sedimentary axis and site of maximum basin subsidence located in the central to north central part of the present Hoback Basin.

Shales volumetrically are the major sediments of the Hoback Formation. They are poorly exposed except in road cuts and stream banks. The shales are mostly calcareous, poorly-laminated to non-laminated and poorly indurated. In the lower part of the section, somber colors of dark brown, dark gray, gray, and brown predominate. Weathered surfaces are generally light tan and gray. Within the lower shales are coal layers with disseminated pyrite and small gypsum crystals on bedding surfaces. In the upper part of the formation, the shales are varicolored, being tan, red, yellow, buff, pink, brown, and gray. Calcium carbonate nodules are common in the upper shales, but coal is rare.

Hoback sandstones are generally gray or "salt and pepper" colored, well-cemented by calcite and composed of fine-grained, quartzose sand. They are lenticular, discontinuous and cross-bedded. The sandstones fine upward from sharp, erosional bases, through basal gravels or coarse to medium sand, to cross-stratified fine sand, and finally to horizontally bedded, ripple-stratified, very fine sand or silt at the top. The top beds are gradational upward to shale.

Limestones constitute only a small part of the stratigraphic thickness of the Hoback Formation. They are generally less than 5 feet thick, discontinuous, and traceable for only a few hundred yards. They are generally very dense and fine-grained (micritic). Colors include brown, dark gray, black, yellow, and yellow-tan. Broken and unbroken gastropod tests, gyrogonites, ostrocods and vegetative algal debris are common.

Siltstones are probably more common than observed due to the extent of covered intervals developed on slopes underlain by this rock type. Exposed siltstones display colors of tan, buff, brown, dark brown, gray, dark gray, gray-green, and black, generally weathering to lighter shades of gray or tan. They generally form thin "flags" in shaly sections above lenticular sandstones.

FACIES AND ENVIRONMENTS OF DEPOSITION

Hoback sediments can be divided into six lithofacies (Fig. 4), based on lithologic distributions, maximum grain size, and conglomerate and sandstone thickness. Three major environments of deposition are suggested by lithofacies distributions, fossils, sand body shapes and primary sedimentary structures. These environments are: flood plain, alluvial plain, and major flood plain stream belt.

Though usually considered part of the general flood plain environment, a distinctive stream belt, as defined by a *thick sandstone facies*, appears to have persisted throughout most of Hoback deposition. North of Highway 187-189 (Fig. 4), the facies continues vertically through about 12,000 feet of section. Sandstones comprise about 30 percent of a 2500 foot section measured in this area. In the Monument Ridge area (Figs. 2 and 4), the facies is about 5000 feet thick and confined to the lower part of the Hoback section.

The association of sedimentary features suggests the sandstones of this facies are mainly fluvial, lateral accretion deposits. The tabular-shaped sand bodies embedded in shales and silty shales are the channel and inter-channel (overbank) deposits, respectively, of the flood plain stream belt. Thick sandstones are common, ranging from 20 to 100 feet thick. Thinner sandstones ranging from 20 feet to 1 foot thick are less abundant. The sandstones are fine-grained, well-sorted and cross-stratified. They fine upward from sharp, erosional bases to tops that commonly grade into siltstones and shales.

Large scale, trough cross-stratification typifies the lower to middle portions of the sand bodies, whereas small-scale, current ripple laminations are dominant in the upper parts. Intraformational clay pebbles are abundant in lower parts of the sand bodies, but basal conglomerates are entirely absent. This lack of channel-lag gravels is indicative of streams flowing over a clay flood plain surface some distance from source (Harms, MacKenzie, and McCubbin, 1963).

A *conglomerate-sandstone facies* and a *pebbly sandstone facies* (Fig. 4) indicate fluvial deposition on an alluvial plain. With the exception of the lower conglomerate unit in the Monument Ridge area (A in Fig. 4), conglomerates are rare in

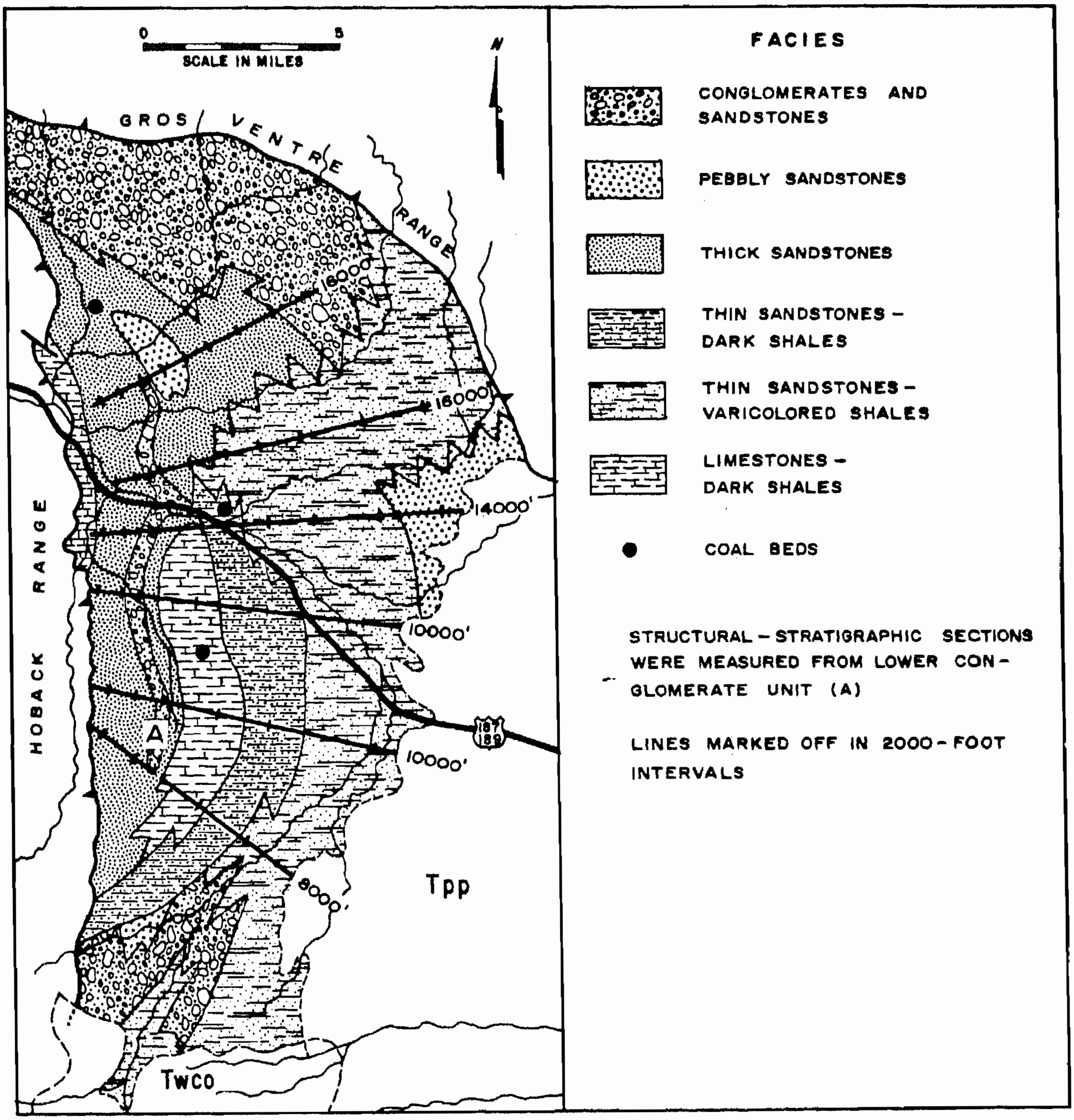


Fig. 4.—Thickness and facies map of the Hoback Formation.

lower Hoback strata, but become increasingly abundant upsection in the northeast part of the basin and in an area in the southwest corner of the basin. The northeastern conglomerate-sandstone facies lies stratigraphically above the thick sandstone facies, and the pebbly sandstone facies lies above the southwestern conglomerate-sandstone facies (Fig. 4). These facies distributions and the cross-stratification current measurements (Figs. 4 and 9) imply that two major stream systems in the north and south ends of the basin transported sediment from the west throughout most of Hoback deposition. In the north end of the basin, the upsection, basinward (eastward) shift from flood plain stream deposits to coarse, alluvial plain stream deposits indicates basinward extension of the alluvial plain out over the flood plain through time. One conglomerate-sandstone body (X in Fig. 9) shows east to west transport, and does not fit the above pattern. It may be part of the shift in sedimentation during late Hoback time which introduced Pass Peak-type sand into the basin, though this conglomerate contains no Pass Peak-type quartzites.

The stratigraphic implications of the occurrence of the lower conglomerate unit in the center of the basin and its north to south transport directions are also somewhat obscure. It most likely represents a southward swing of a major stream resulting from the normal alteration of the surface slope of the alluvial plain by alluviation.

The *conglomerate-sandstone facies* is characterized by lenticular, cross-bedded sandstones with stratified, basal conglomerates. Maximum conglomerate clast size rarely exceeds one foot in diameter. Horizontally-bedded, coarse sandstone lenses interbedded with the basal lag gravels indicate deposition in the upper flow regime (Harms and Fahnstock, 1965). Lower flow regime, trough cross-bedding is abundant in the sandstones overlying the conglomerates. Channel scours and cut-and-fill structures are also common. The sandstones fine upward, and small-scale, ripple cross-stratification is dominant in the upper beds.

The conglomerate-sandstone bodies generally are 20 feet or more thick, but rarely exceed 100 feet in thickness. Thus, Hoback conglomerates are unlike the basin-margin, alluvial-fan conglomerates which attain aggregate thicknesses of 1000 feet or more in the Pass Peak Formation and the Conglomerate Member of the Wasatch Formation.

The *pebbly sandstone facies* (Fig. 4) probably represents distal alluvial plain deposition. The sand bodies range in thickness from a few feet to a few tens of feet, but most are less than 20 feet thick. They are lenticular, and poorly sorted with local lenses of pebbles and coarse sand. Some have basal lag gravels, but the largest clasts are less than three inches in diameter. The bedding consists mainly of trough cross-stratification, though there is some horizontal, upper flow regime stratification.

A *limestone-dark shale facies*, a *thin sandstone-dark shale facies*, and a *thin sandstone-varicolored shale facies* (Fig. 4) indicate deposition in a flood plain environment. Taking these three facies together, flood plain deposits comprise the greatest volume of Hoback sediments. In the central part of the basin, middle and upper Hoback strata are mainly flood plain sediments which were deposited between the north and south stream belts (Fig. 4).

Sandstones with structures similar to those described in the major stream belt environment occur throughout the flood plain sequences. The flood plain sandstones are, however, fewer in number, generally thinner and separated by thicker shale intervals. Sandstones comprise about 15% of the stratigraphic section in the thin sandstone-dark shale facies and about 6% in the limestone-dark shale facies. Some thin sandstones, commonly one to ten feet thick, are predominantly composed of small scale, asymmetrical, ripple cross-stratification. These are most likely the deposits of slow ephemeral streams of shallow depth that coursed over the low, flat surface of the flood plain. The thick shale sections enveloping the sandstones are typically structureless, and are the overbank deposits of fine suspended sediments from flood waters. Thin siltstone lenses within the shales are probably the near-stream deposits of the overbank floods.

The *limestone-dark shale facies* comprises one to two thousand feet of lower Hoback strata in two areas in the west-center of the basin (Fig. 4). The facies is characterized by thin, generally less than five feet thick, dark gray to blue-gray, tan, brown and yellow, very dense limestones. They contain gyrogonites, pelecypods, gastropods, ostracods, and vegetative algal debris. The limestones are interbedded with dark gray, buff, tan and brown shales. Most sandstones in this facies are also less than five feet thick, sparsely distributed and only extend laterally a few tens of feet. Coal lenses associated with dark gray and black shales are fairly common.

The coals and limestones were probably deposited in standing water of cut-off channels, shallow lakes and ponds. Calcareous algae apparently thrived in these shallow stagnant waters and contributed significantly to limestone deposition.

The *thin sandstone-dark shale facies* is one to two thousand feet thick and lies stratigraphically above the limestone-dark shale facies (Fig. 4). The sediments of both facies are quite similar, except that coals and limestones are rare in the thin-sandstone-dark shale facies, though sandstones are somewhat more abundant.

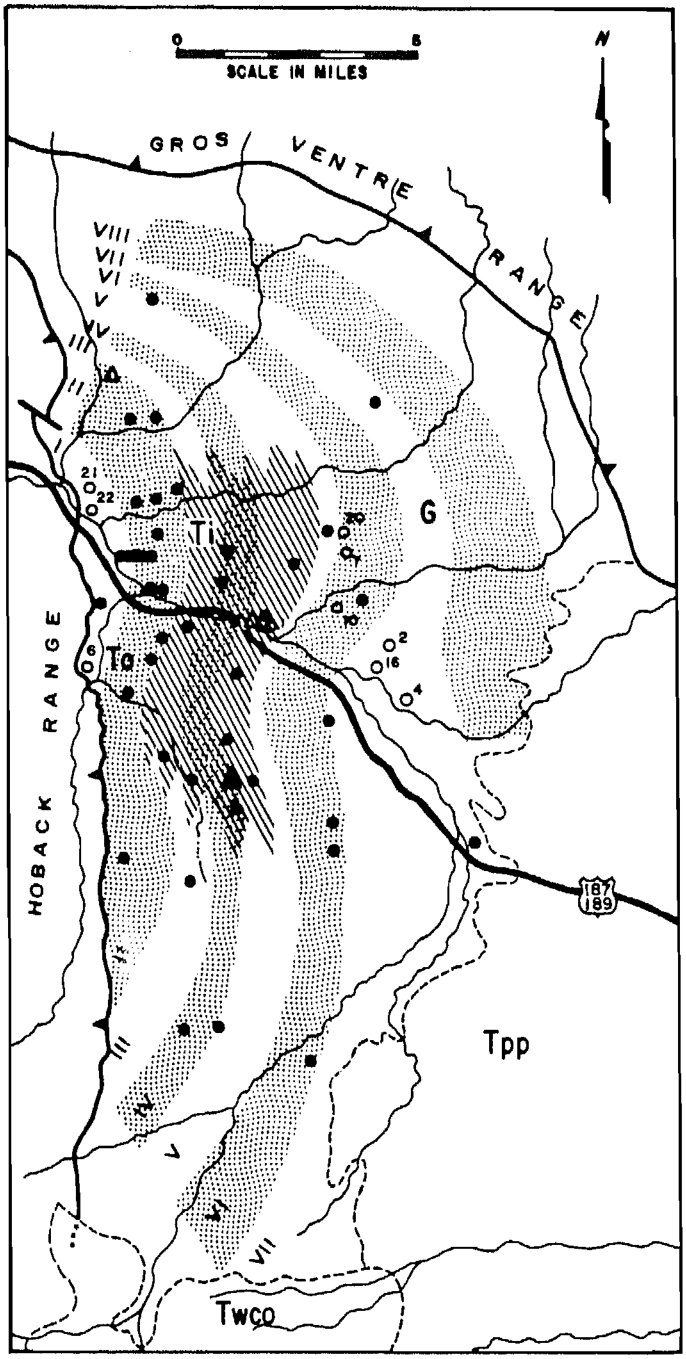
The central part of the upper Hoback strata consists of eight to ten thousand feet of a *thin sandstone-varicolored shale facies.* Sandstones in this facies are also similar in size, shape, and distribution to those in the other two flood plain facies. There are a few red and white sandstones, however, in contrast with the normally gray Hoback sandstone. Intervening shales differ distinctly in color, being red, yellow, tan, brown, buff, pink, and gray. Coal layers, limestone, and plant fragments are rare or absent.

PALEONTOLOGY AND CHRONOLOGY

Fossil algal oögonia, called gyrogonites, are common in Hoback limestones. Peck (1956) reported that recent species of *Chara* grow in freshwater to brackish streams and lakes in water 25 feet deep or less. Many species of *Chara* become encrusted with lime and the continued presence of algae from year to year may result in the deposition of considerable marl in a pond or lake. Thus, the Charophyte algae were probably important contributors to the formation of the fine-grained, fresh-water Hoback limestones.

Carbonaceous leaf, stem and twig fragments, and leaf impressions of deciduous plants and ferns are preserved in the finer-grained sandstones. These fragmentary, poorly preserved plant remains rarely display sufficient taxonomic characteristics for identification to even the family level. There are vertical root zones in silty mudstones and coaly shales below sandstone units and limonitized logs are preserved in some of the sandstones. Three coal and coaly shale zones (Fig. 5) contain dicotyledonous plant fragments, root casts and carbonaceous material.

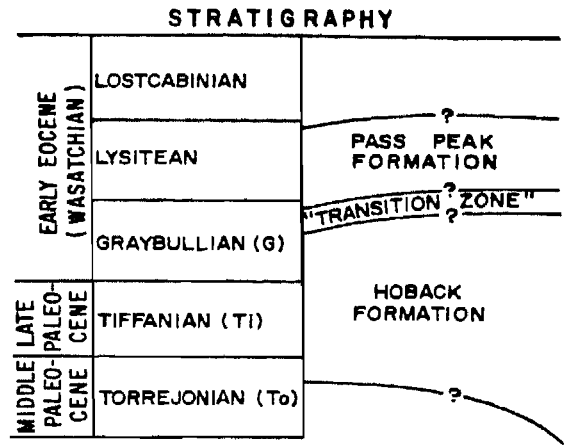
Some of the mollusks preserved in the Hoback Formation lived in fresh-water, fluviatile environments. Others are land snails whose Recent counterparts are commonly associated with deciduous forests of temperate climates (Moore, 1955). Two gastropod genera, according to Moore, are hypsometric indicators. Recent species of *Campeloma* are found consistently below 1300 feet elevation in temperate latitudes and Recent species of *Viviparus* range up to only 1150 feet in



● PLANT FOSSIL SITES

O[10] VERTEBRATE FOSSIL SITES

Δ COAL BEDS



VERTEBRATE FAUNULES AS SHOWN ON MAP (Adapted from Dorr, 1958b)

FAUNA	FAUNAL LOCALITIES (SHOWING NUMBER OF SPECIES) SITES ARRANGED LEFT TO RIGHT FROM LOWEST (OLDEST) TO HIGHEST (YOUNGEST)								
	6	21,22	1	10	20	7	16	2	4
BONY FISH	1	1		1		1			1
TURTLES		1		1		1	1		
CROCODILIANS			1						
LIZARDS			2						
MAMMALS									
MULTITUBERCULATES		1	2			1			
INSECTIVORES		1	5						
PRIMATES		2	4					1	
CARNIVORES		1	3						
CONDYLARTHS		5	1	1	1	2		1	
TILLODONTS								1	1
PANTODONTS						1	1		
UINTATHERES						1			
EQUIDS								1	
ASSOCIATED INVERTEBRATES AND/OR PLANTS RELATIVELY COMMON	•		•	•				•	•
GEOLOGIC TIME CHART — EPOCH / PROVINCIAL AGE	TORREJONIAN (MIDDLE-PALEOCENE)		TIFFINIAN (LATE PALEOCENE)	WASATCHIAN (EARLY EOCENE) (GRAYBULL SUBAGE = EARLY WASATCH)					

Fig. 5.—Vertebrate faunas, fossil sites and stratigraphic age levels within the Hoback Formation (adapted from Dorr, 1958b).

elevation. To Moore, the Hoback mollusks suggest the following:

1. A temperate climate.
2. A deciduous forest (at least locally), is implied by the gastropod *Discus*, the present species of which are most abundant in deciduous forests in temperate regions,
3. The basin was fairly low-lying, probably below 1300 feet in elevation during Hoback deposition,
4. The early Tertiary rivers probably drained to the Gulf of Mexico, because the *Unionidae* are similar to the fauna now inhabiting the Mississippi River drainage, but are unlike those of the Pacific Coast drainages.

Vertebrate faunas from several localities have been extensively studied by Dorr (1952, 1956, 1958a, 1958b) and serve as the chief basis for age determinations within the Hoback Formation. Faunal lists and localities are summarized in Fig. 5, adapted from Dorr (1958b). In the lower two-thirds, the

Paleocene part of the Hoback Formation, the predominant arboreal elements such as insectivores and primates indicate a forest fauna. In the upper, largely Eocene, part of the Formation, large mammals such as *Coryphodon* and *uintatheres* suggest a savanna-like environment with glades, plains and forested stream courses.

The beginning of Hoback deposition can only be inferred, because the base is covered, and a datable vertebrate fauna is not found in even the lowest exposed units. The fauna at sites 6, 21, and 22 (Fig. 5) indicate the lower quarter of the exposed portion of the Hoback Formation is of Middle Paleocene (Torrejonian) age. At approximately the mid-point of the exposed Hoback strata, the fauna at site 1 is of Late Paleocene (Tiffanian) age. All vertebrate sites above this level are of early Early Eocene (Graybullian) age. Sedimentation in the Hoback Basin continued uninterrupted into the Eocene with the deposition of the Pass Peak Formation. Mammalian fossils indicate the Pass Peak is of Early Eocene age (Fig. 5), ranging from late Graybullian to Lysitean? or early Lostcabinian (Dorr, 1969).

The association of dark shales, limestones with fresh water invertebrates and algae, fluvial sandstones, abundant plant material, and forest dwelling vertebrates in the lower part of the Hoback Formation indicates that during Middle to Late Paleocene time a fairly humid-temperate to possibly warm climate prevailed in the Hoback Basin. Forested river lowlands and back swamps were probably common. Invertebrate fossils indicate the area stood much lower than present, probably less than 1300 feet above sea level. Later during Early Eocene time, a somewhat drier climate with open savannas and fewer trees is indicated by grazing vertebrates, varicolored shales, and the general lack of limestones, dark shales and preserved plant material in the upper part of the Hoback Formation.

PETROGRAPHY AND PROVENANCE

Sandstone Composition

Hoback sandstones are generally gray to "salt and pepper" color, composed of well-rounded, well-sorted particles and strongly cemented by calcite. Quartz, chert and carbonate fragments are the dominant light minerals (Table I). Of the heavy minerals observed, callophane, colorless epidote-clinozoisite, zircon and non-magnetic opaques (chiefly leucoxene) are most common. Abundances vary and any of these minerals can dominate the heavy mineral suite of a given Hoback sandstone sample.

The mineral assemblages (Table I) indicate that sedimentary source rocks in surrounding ranges supplied the sediment to the Hoback Basin during Middle Paleocene to Early Eocene time. Moreover, mineral assemblages and their occurrence in the stratigraphic column indicate that several distinct types of sedimentary source rocks supplied detritus to the basin at different times.

Quartz, the most common constituent, displays secondary overgrowths on many well-rounded grains, and because the overgrowths themselves are commonly rounded off, the grains must be at least second-cycle derivatives. Marginal corrosion of quartz by calcite replacement is a common feature. Black chert grains occur frequently and abundantly throughout the Hoback Formation, comprising nearly 40 percent of the grain counts in some sandstones (Table I). It is these black chert fragments scattered among the white quartz grains which give the Hoback sandstones their gray to "salt and pepper" color in fresh specimens. Chert may be the product of two general sources:

1. Recycling from older (Mesozoic) sandstones,
2. Erosion from chert-bearing carbonate rocks of the Paleozoic Big Horn, Darby, Madison, Amsden, Tensleep, and Phosphoria formations (Wanless *et al.* 1955).

Most of the so-called "quartzite fragments" (Table I) are well-cemented, polygranular sand grains composed of very fine-grained quartz and some chert. Quartzitic sandstones such as the Jurassic Nugget and Pennsylvanian Tensleep were likely sources.

Rock fragments include brown shales with organic fragments and silt-sized quartz particles, and bright red to red-brown shales. The red rock fragments are abundant enough in some Hoback sandstones to impart a red color. These grains probably came from the abundant red and brown shales and siltstones of the Triassic Dinwoody and Woodside formations.

Biotite, muscovite and chlorite occur in small amounts,

SUMMARY OF MINERAL COMPOSITION OF HOBACK SANDSTONES

LIGHT MINERALS (BASED ON 109 THIN SECTION POINT COUNTS)	AVERAGE PERCENT	RANGE MAX.	RANGE MIN.
QUARTZ	57.2	78.1	27.4
CHERT	18.0	37.6	4.4
CARBONATE FRAGMENTS	10.4	37.6	0.0
"QUARTZITE" FRAGMENTS	1.9	9.1	0.0
SEDIMENTARY ROCK FRAGMENTS	2.1	8.0	0.0
MICAS	1.2	9.1	0.0
FELDSPARS	1.9	9.7	0.0
OTHERS (Includes all accessory minerals)	6.8	21.9	0.6
HEAVY MINERALS (BASED ON 125 MIN. MOUNT POINT COUNTS)			
APATITE	5.9	37.5	0.0
BIOTITE	0.4	4.7	0.0
COLLOPHANE	26.5	76.8	0.0
COLORLESS EPIDOTE-CLINOZOISITE	11.2	77.9	0.0
GREEN EPIDOTE-CLINOZOISITE	0.5	3.2	0.0
GARNET	0.9	9.9	0.0
RUTILE	1.8	8.5	0.0
BROWN TOURMALINE	2.6	9.5	0.0
GREEN TOURMALINE	1.2	5.1	0.0
BLUE TOURMALINE	0.1	2.7	0.0
TOTAL TOURMALINE	3.9	12.0	0.0
ZIRCON	23.6	64.5	3.0
NON-MAGNETIC OPAQUES †	20.8	71.7	4.4
OTHERS ††	4.2	28.2	0.0

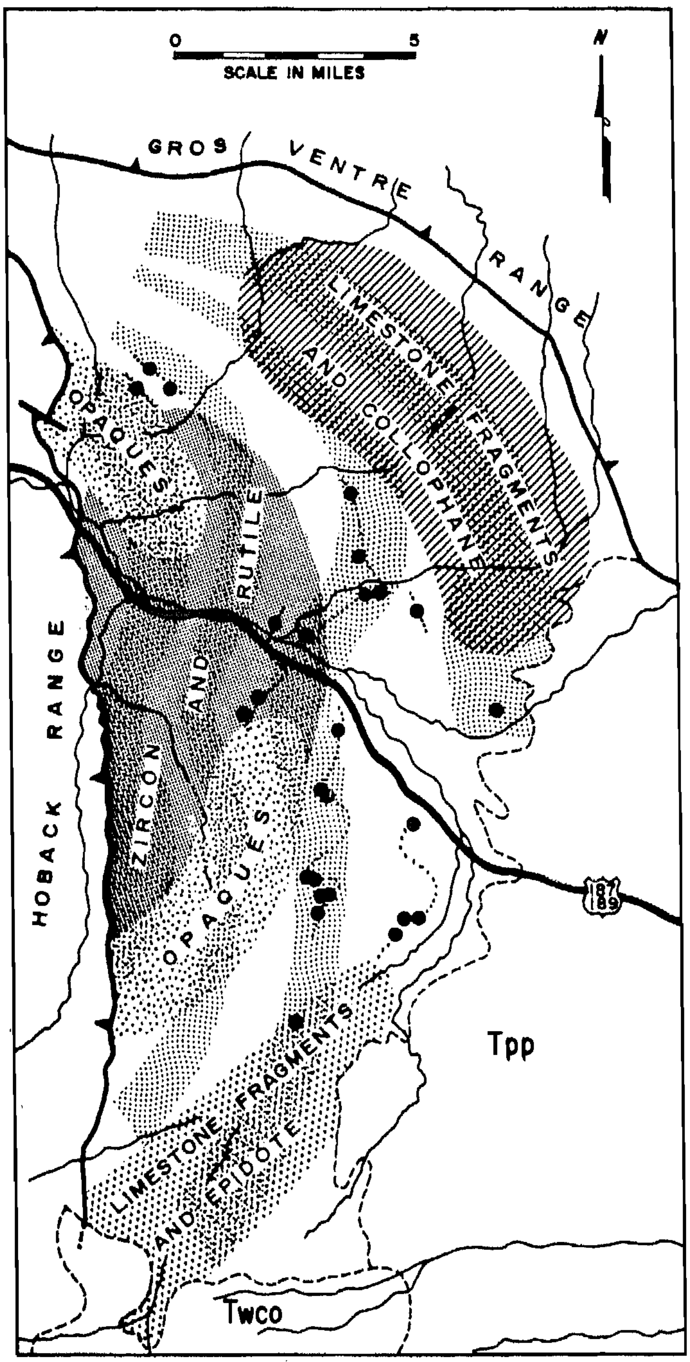
† Includes leucoxene, hematite, limonite, ilmenite, magnetite (those not removed by magnetic separation)

†† Includes cassiterite, sphene, xenotime, zoisite, hornblende, glauconite, muscovite, chlorite, alterites and unknowns.

Table 1.

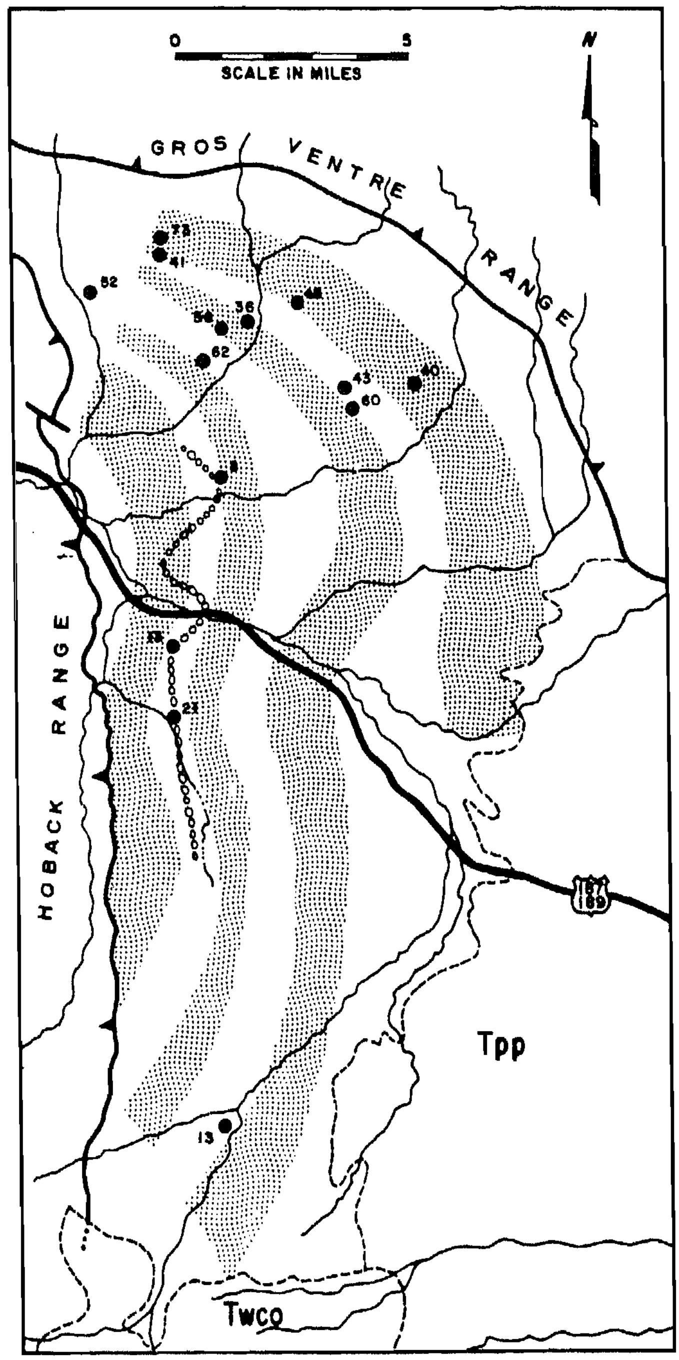
but rounded, brown and red biotite flakes are by far the most abundant. Feldspars are rare. Some grains, probably plagioclase, are sericitized, whereas perthitic grains, probably microcline, appear unaltered. Though indicative of ultimate igneous sources, the rarity and altered and rounded nature of both the feldspars and micas suggests Mesozoic sandstones as the immediate source.

A dominant zircon and rutile assemblage (Fig. 6) in many sandstones of the lower part of the Formation is a mature, ultra-stable assemblage, probably a second-cycle derivative from older sandstones (Hubert, 1962). Likely source rocks are the Mesozoic sandstones of several formations. Houston and Love (1956) and Houston and Murphy (1962, 1965) report high concentrations of zircons and rutile from Upper Creta-



● LOCATIONS OF SANDSTONES WITH HIGH PERCENTS OF GARNETS, FELDSPAR, GREEN EPIDOTE; e.g. PASS PEAK-TYPE COMPOSITION.

Fig. 6.—Summary of compositional trends in Hoback sandstones.



LOWER CONGLOMERATE HORIZON, HOBACK FORMATION.

●[15] % TOTAL PALEOZOIC CLASTS

Fig. 7.—Distribution of percent paleozoic clasts in Hoback conglomerates.

ceous and Upper Jurassic sandstones of western Wyoming.

High concentrations of non-magnetic opaques also occur in sandstones of the lower part of the formation. These opaques consist mostly of white, rounded grains of leucoxene which are probably second-cycle products of ilmenite-bearing sandstones. Mesozoic sandstones are again the most probable source; high concentrations of ilmenite occur in Upper Cretaceous and Upper Jurassic sandstones (Houston, *et al.* 1956, 1962, 1965).

Colorless epidote-clinozoisite dominates in some sandstones at the extreme southern end of the basin. The altered state of these grains suggests second-cycle erosion from Mesozoic sandstones in which epidote-clinozoisite is common (Houston, *et al.*, 1956, 1962).

Carbonate fragments are mostly made up of micritic calcite and contain oöliths and small fossil fragments. The dissolution, redeposition and recrystallation of these grains probably account in large part for the predominant calcite cement of the Hoback sandstones. Collophane and detrital limestone fragments predominate in many sandstones of the upper part of the Hoback Formation (Fig. 6). Paleozoic source rocks are implied by this assemblage, with collophane most likely being derived from the Permian Phosphoria Formation (Wanless, 1955), whereas thick Paleozoic limestones and dolomites, including the Boysen, Big Horn, Leigh, Darby and Madison formations, are likely sources of the carbonate grains.

Several sandstones in the upper part of the Hoback Formation have a distinctive composition which is unlike other Hoback sandstones. These have comparatively high concentrations of garnets, green epidote-clinozosite, micas, and feldspars. Rarely are they cemented with calcite. In addition, they have low concentrations of collophane, colorless epidote, zircon, opaques (leucoxene) chert and carbonate fragments, which further distinguish them from the typical Hoback sandstone. These sandstones have a composition like that of the Pass Peak Formation (see Steidtmann, this guidebook) and are regarded as Pass Peak-type compositional tongues within the main body of the Hoback Formation (Fig. 6).

In summary, the distribution pattern of light and heavy minerals in Hoback sandstones indicates progressive erosion in the highland source area. Minerals such as rutile, zircon and opaques were derived from Mesozoic sources. They dominate the mineral assemblages of lower Hoback sandstones. Minerals from Paleozoic sources, such as collophane and limestone fragments, are dominant in upper Hoback sandstones. Epidote-clinozoisite, derived from Mesozoic sandstones, dominates the mineral assemblages of some upper Hoback sandstones at the south end of the basin. This distribution does not apparently fit with the progressive-erosion pattern suggested above. However, as will be discussed later, the anomalous epidote-clinozoisite distribution may be the result of a southward facies change.

Conglomerate Composition

Hoback conglomerates are composed entirely of Mesozoic and Paleozoic sedimentary rock fragments. Predominant lithologies include light-colored, quartzitic sandstones, several types of limestones, siltstones, chert clasts and friable quartzose sandstones. Only some of the clasts can be recognized with fair confidence as derivatives from certain formations. Most limestones are probably fragments of lower Paleozoic units such as the Madison, Darby, Leigh and Big Horn formations. White-gray, quartzitic sandstones are from the upper Paleozoic Tensleep Formation, and tan-pink quartzitic sandstones are from the Jurassic Nugget Formation. More friable quartzose sandstones and siltstones can generally be ascribed to Mesozoic sources.

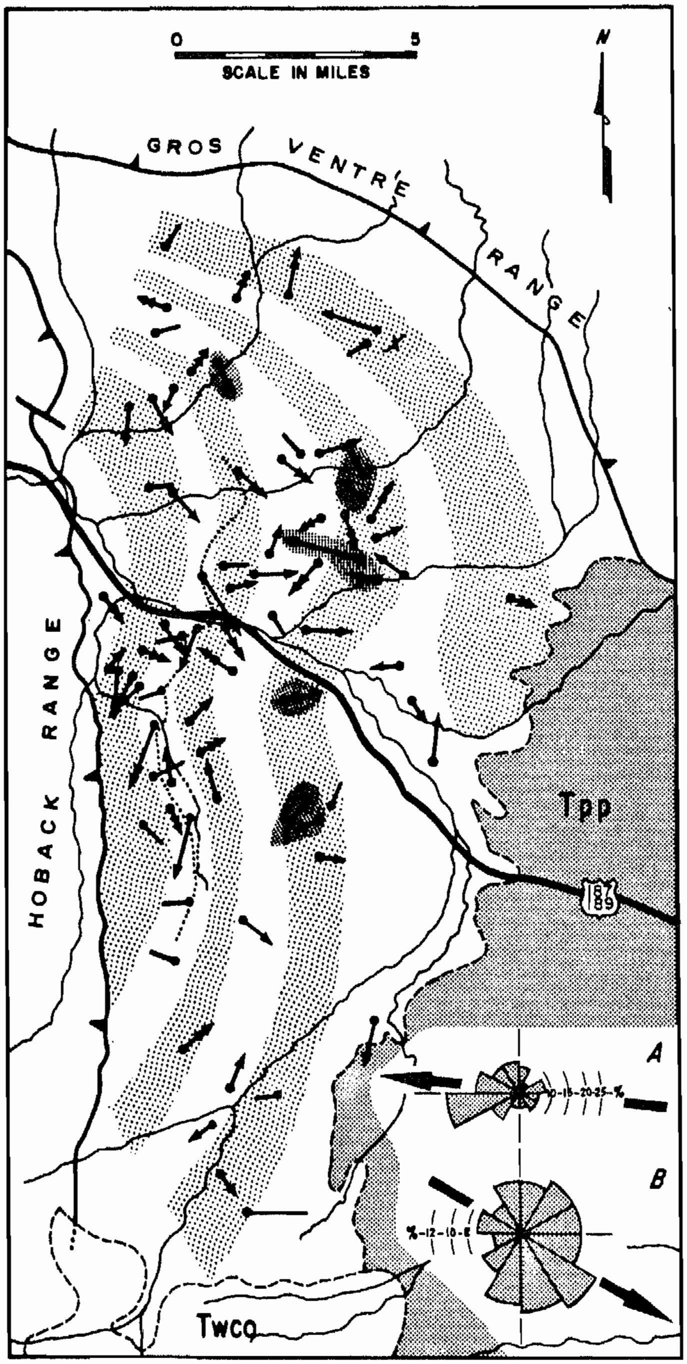
The distribution map (Fig. 7) indicates that clasts attributable to Paleozoic sources predominate in upper Hoback conglomerates, whereas cobbles from Mesozoic sources are dominant in lower Hoback conglomerates. However, few of the clasts are indicative of transport direction, because all the surrounding ranges contain similar Mesozoic and Paleozoic sections.

Hoback conglomerates can be distinguished from the distinctive Pass Peak conglomerates composed almost entirely of rounded, pressured-marked, Precambrian quartzites. The red conglomerates at the north end of the Hoback Basin contain extremely large boulders up to eight feet in diameter, an abundance of red siltstones, and abundant clay and silt in the matrix. By contrast, Hoback conglomerates have much smaller clasts ranging up to only 14 inches maximum diameter, a tan to gray color, and have little clay or silt in the matrix. In The Rim area, the Conglomerate Member of the Wasatch Formation contains distinctive clasts derived from the Brigham Quartzite. The conglomerates are generally a bright red color though gray units are also present. Clasts several feet in diameter and abundant silt and clay in the matrix further distinguish these conglomerates from those of the Hoback Formation.

CURRENT DIRECTIONS INDICATED BY CROSS-STRATIFICATION DIP MEASUREMENTS

Current directions within eight stratigraphic levels within the Hoback Formation are shown in Figures 8 and 9. Because, with one exception, marker beds are generally absent, these levels are to be considered approximations of vertical sequence. One conglomerate horizon (Fig. 8) is traceable for several miles and was used as the base for stratigraphic measurement. The relative positions of the eight levels are based on the combined evidence of faunal levels, stratigraphic measurements and air photo mapping. Zone I is the oldest (lowest) stratigraphic level, and Zone VIII is the youngest (highest) level.

The current directions related to these stratigraphic levels (Fig. 9) show that during Middle Paleocene time, represented by Zones I and II, the prevailing transport direction was from northwest to southeast. Zones III, IV, and V represent approximately Late Paleocene time. Zone III (the lower conglomerate unit) displays a strong north to south current direction. Zones IV and V suggest a "fanning" arrangement of sediment transport in the northern part of the basin, generally



LOWER CONGLOMERATE UNIT

SANDSTONES WITH PASS PEAK-TYPE COMPOSITION

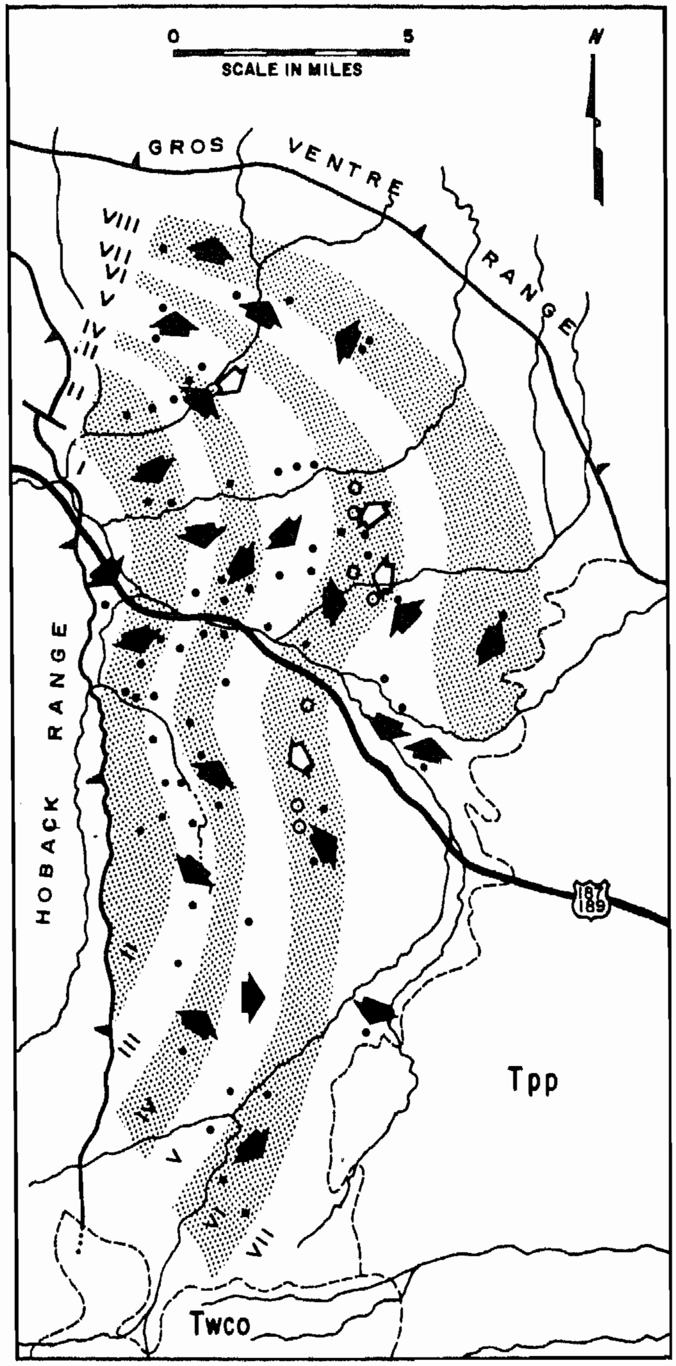
4 to 7
8 to 12
13 to 17
18 to 22
LENGTH OF ARROW INDICATES NUMBER OF READINGS/OUTCROPS

(1) UNIMODALITY
(2) BIMODALITY
(3) NOT SIGNIF.
VECTOR MEAN SIGNIFICANCE AT .05 LEVEL, RAYLEIGH TEST, ASSUMING (1), (2) & (3)

A CURRENT ROSE FOR SANDSTONES WITH PASS PEAK-TYPE COMPOSITION

B CURRENT ROSE FOR "PURE" HOBACK SANDSTONES

Fig. 8.—Vector means of cross-stratification dip measurements.



SUMMATION OF CURRENT DIRECTIONS WITHIN PASS PEAK-TYPE COMPOSITIONAL SANDSTONE TONGUES WITHIN HOBACK FORMATION

o SAMPLE LOCATIONS

SUMMATION OF CURRENT DIRECTIONS WITHIN "PURE" HOBACK SANDSTONES

• SAMPLE LOCATIONS

BANDS DENOTE STRATIGRAPHIC LEVELS, I IS LOWEST (OLDEST), VIII IS HIGHEST (YOUNGEST)

Fig. 9.—Sums of vector means from contiguous outcrops within similar stratigraphic levels.

directly toward the east but with northeast and southeast components. The average currents in the southern parts of Zone IV and V display a northeastward trend, toward the center of the basin. The predominantly west-to-east and northwest-to-southeast current directions, which prevailed during most of the Middle and Late Paleocene phases of Hoback deposition, indicate a relatively constant, though probably continually downwarping, eastward-dipping paleoslope.

A reversal in paleoslope during Early Eocene (Graybull) time, at least in the eastern part of the basin, is implied by the reversal in cross-bedding direction in some sandstones in Zone VI. This level marks the first introduction of the Pass Peak-type sandstones into the Hoback sedimentary sequence. These tongues show a consistent east to west transport direction, which differs from the current directions of nearby Hoback-type sandstones within the same stratigraphic level. However, transport of sediments from the west continued after the beginning of Pass Peak deposition from the east. The sediments of the two opposing alluvial plains intermingled at their margins, as indicated by the interfingering, gradational nature of the Hoback-Pass Peak contact.

The vector means of cross-stratification measurements within Hoback sandstones are shown in Figure 8. The dip and dip direction of the bedding surfaces within large scale cross-strata were measured at more localities than shown in Figure 8. Only those localities are mapped which have four or more dip direction readings, because the significance of less than four readings per outcrop is difficult to evaluate. All measurements were corrected for tectonic tilt. Because angle of repose in water-laid sediments rarely exceeds 30 degrees, all measurements with inclinations greater than 30 degrees were eliminated before the vector means were calculated. For outcrops with four to six readings, only those are mapped whose vector means are significant at the 0.05 level of confidence. Confidence level was established by the Rayleigh test for uniformity of two-dimensional orientation data modified for small sample size (Durand and Greenwood, 1958). It tests significance for both unimodal and bimodal data. All outcrops with more than six readings are plotted in Figure 9. The Rayleigh test was also applied to these localities and the results are indicated on the map. Localities in sandstones with a Pass Peak composition were treated separately and are also indicated in Figure 8.

The grand vector mean for all "pure" Hoback sandstones, as indicated by the current rose and grand mean, shows a general northwest to southeast transport direction. The vector means, current rose and grand mean for the Pass Peak tongues show a significantly different and opposite east to west transport direction. In Figure 9, each large current arrow represents the average direction of a small group of closely spaced outcrops within the same stratigraphic level. Estimates of current directions within Pass Peak compositional sandstone tongues are indicated in Figure 9 by the white arrows.

SOME UNSOLVED PROBLEMS

Current drilling in the northwest corner of the Green River Basin, aimed at testing the recoverability of gas by nuclear fractionation in probably Cretaceous sands, will be penetrating the Hoback Formation. Surface information on the Hoback resulting from this study and subsurface data of Oriel (1969) suggest that both problems and possible stratigraphic solutions may be fostered by the drill. Identification of parts of the Hoback Formation may be difficult. There is a probable facies change in The Rim area, where the Hoback Formation becomes more varicolored and "Wasatch-like" as it begins to intertongue with the Chappo Member of the Wasatch Formation. Hoback sediments exposed at the south end of the Hoback Basin (Figs. 4, 6, 7, 8) consist of varicolored shales, conglomerates, and sandstones, with an epidote-carbonate association. Conglomerates and current directions show that a major west-to-east stream system operated in that area, but the sandstone composition indicates a different source supplied sediment to that area in contrast to other parts of the Hoback Formation. A second important problem that may be solved in the subsurface is the nature of the southward thinning of the Hoback Formation from 16,000 feet to approximately 2,000 feet within only a few miles (Oriel, personal communication). In the Fort Hill Quadrangle, along the northwest Green River Basin edge, Oriel (1969) maps Cretaceous Hilliard shale and thin slices of questionable Adaville Formation beneath the Hoback Formation. Drill penetration should reveal the nature of the base of the Hoback contact and whether those Cretaceous units underlie the Hoback in a more northerly and basinward direction.

CONCLUSIONS

A predominant west-to-east transport direction throughout most of Hoback deposition points to highland sources somewhere in the Overthrust Belt. The Snake River Range was the likely source. It was uplifted in latest Cretaceous time (Oriel and Armstrong, 1966), just prior to Hoback deposition. Most of the Mesozoic rocks have been eroded away and mainly Paleozoic rocks are now exposed in the Snake River Range. This progressive erosion pattern fits the compositional trends in Hoback conglomerates and sandstones: Mesozoic clasts dominate lower Hoback strata, and Paleozoic clasts are most common in upper Hoback sediments. Predominantly Mesozoic rocks are exposed in the Overthrust ranges east of the Snake River Range. Thus, if these ranges were significant contributors to Hoback sediments, mainly Mesozoic clasts should persist throughout the formation.

The 16,000 feet of alluvial plain and flood plain sediments comprising the Hoback Formation indicate continuous basin subsidence, approximately balanced by equally continuous sedimentation from Middle Paleocene to Early Eocene time.

Uplifts in the Gros Ventre and Wind River mountains to the east did not begin to shed sediments into the Hoback Basin until earliest Eocene (Graybull) time. Cross-stratification in a few sandstones in upper Hoback strata shows east-to-west transport. These sandstones have a Pass Peak-type composition, and mark the beginning of the shift in Hoback Basin sedimentation from mainly western to predominantly eastern sources. The shift culminated in the deposition of the coarse, quartzite conglomerates of the Pass Peak Formation.

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