Paleogeographic and paleotectonic setting of Laramide sedimentary basins in the central Rocky Mountain region

WILLIAM R. DICKINSON
MARGARET A. KLUTE
MICHAEL J. HAYES*
SUSANNE U. JANECKE*
ERIK R. LUNDIN
MARY A. McKITTRICK
MARK D. OLIVARES*
Laboratory of Geotectonics, Department of Geosciences, University of Arizona, Tucson, Arizona 85721

ABSTRACT

In the Rocky Mountain region between central Montana and central New Mexico, sedimentologically isolated nonmarine basins were produced by basement deformation during the Laramide orogeny within the area formerly occupied by a broad Late Cretaceous foreland basin in which laterally continuous marine facies had accumulated previously. Laramide structures of varying trend and scale reflect heterogeneity of crustal strain caused by shear between the continental lithosphere and an underlying subhorizontal slab of subducted oceanic lithosphere. Laramide basins include perimeter basins along the cratonic periphery of the arcuate Laramide province, axial basins along a north-south intramontane trend, and ponded basins located farther west closer to the overthrust belt.

Twelve specific stratigraphic and sedimentologic criteria for the onset, duration, and termination of Laramide deformation allow the chronology of basin development to be inferred independently for each basin. Maastrichtian initiation of Laramide deformation was approximately synchronous throughout the Laramide province, but termination of Laramide deformation was systematically diachronous from north to south between early and late Eocene time. Widespread Eocene erosion surfaces truncate syntectonic Laramide sequences and are overlain by largely volcanic and volcaniclastic post-Laramide strata of Eocene age in the north and Oligocene age in the south.

Fluvial depositional systems draining toward the Great Plains were dominant in perimeter and axial basins, but ponded basins were occupied at times by large lakes that served as regional sediment traps. Paleocene drainages from ponded basins also led eastward toward the continental interior, but partly interconnected lakes that developed within several ponded basins by mid-Eocene time were either closed hydrologically, or else they drained westward into the "Tyee" paleoriver of the Pacific Northwest.

INTRODUCTION

Latest Cretaceous and early Tertiary Laramide deformation in the Rocky Mountain region produced geometrically complex tectonic elements and equally complex paleogeographic patterns whose geodynamic relations to plate interactions are debated. This paper presents a synthesis of the history of sedimentation within key Laramide basins of the central Rocky Mountain region to help constrain hypotheses about the causes of Laramide deformation. Laramide uplifts and basins formed concurrently, delimited jointly by Laramide folds and faults, and "sediments deposited in the basins are a principal record of Laramide orogeny" (Tweto, 1980). In typical instances, Laramide basin subsidence can be ascribed to the flexural effects of tectonic loads imposed on the lithosphere by thrust masses emplaced along the flanks of adjacent uplifts (Hagen and others, 1985).

LARAMIDE OROGENY

The term "Laramide" has a varied and controversial history of usage (Tweto, 1975), but is traditionally applied to tectonic movements that occurred during latest Cretaceous and early Tertiary time in the western Cordillera (Spieker, 1946; Berg, 1962; Coney, 1972). We confine our analysis here to the central Rocky Mountains and adjoining regions where the classic Laramide structural style of basement-cored uplifts and intervening sediment-filled basins developed over a wide contiguous area (Dickinson and Snyder, 1978). This domain of distinctively Laramide deformation lay east of the Sevier overthrust belt of the intermountain region (Coney, 1976), and thin-skinned Cretaceous thrusting during the Sevier orogeny largely predated the basement-involved deformation of the Laramide orogeny in the latitude of the central Rocky Mountains (Armstrong, 1968).

Thin-skinned Sevier-style deformation along the overthrust belt and basement-involved Laramide deformation farther east, however, partly overlapped in time. In the Idaho-Wyoming segment of the Sevier belt, continued thrusting and backthrusting were coeval with Laramide thrusts that cut basement along the flanks of nearby foreland uplifts (Dorr and others, 1977; Wiltschko and Dorr, 1983). In the complex Laramide foreland of southwest Montana (Tonnsen, 1982; Schmidt and Garihan, 1983; Tysdal, 1986), basement uplifts developed in front of the overthrust belt through much of the period of Cretaceous thrusting (Schwartz, 1982; Perry and others, 1983; Tysdal and others, 1986). Sediment dispersal reflected subtle tectonic partitioning of the nonmarine foreland basin in southwest Montana as early as mid-Cretaceous time (DeCelles, 1986).

Prior to the onset of Laramide deformation, the Rocky Mountain region in front of the active Sevier overthrust belt was occupied earlier in Cretaceous time by a broad foreland basin within which marine facies were continuous laterally for long distances (Weimer, 1960; Kauffman, 1977). Isopach analysis shows that subsidence within this retroarc foreland basin was not uniform (Weimer, 1970; Cross and Pilger, 1978b), and the

---

*Present addresses: (Hayes) Department of Geological Sciences, University of California, Santa Barbara, California 93106; (Janecke) Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah 84112-1183; (Olivares) Geology Department, Stanford University, Stanford, California 94305.

Geological Society of America Bulletin, v. 100, p. 1023–1039, 12 figs., July 1988.

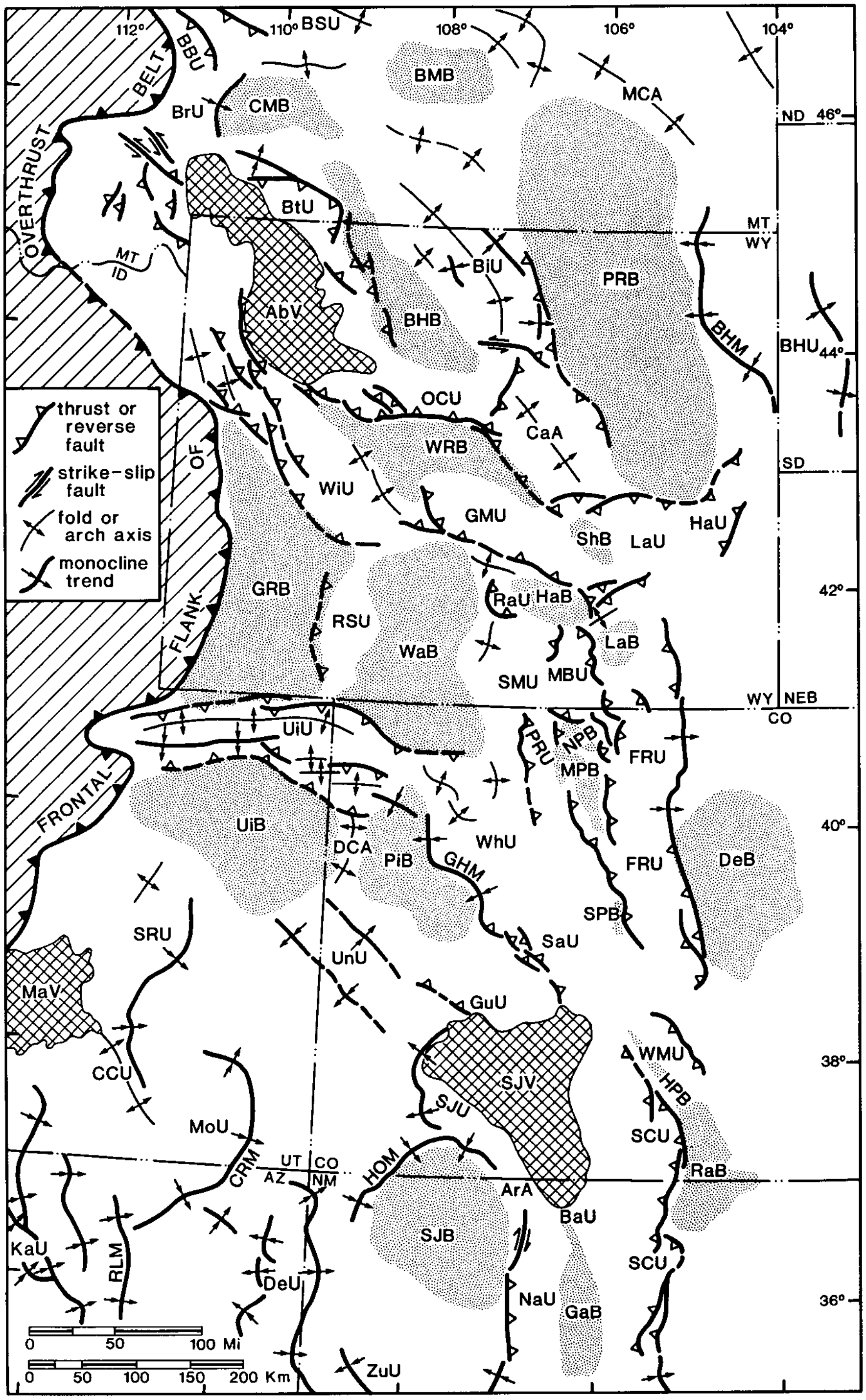


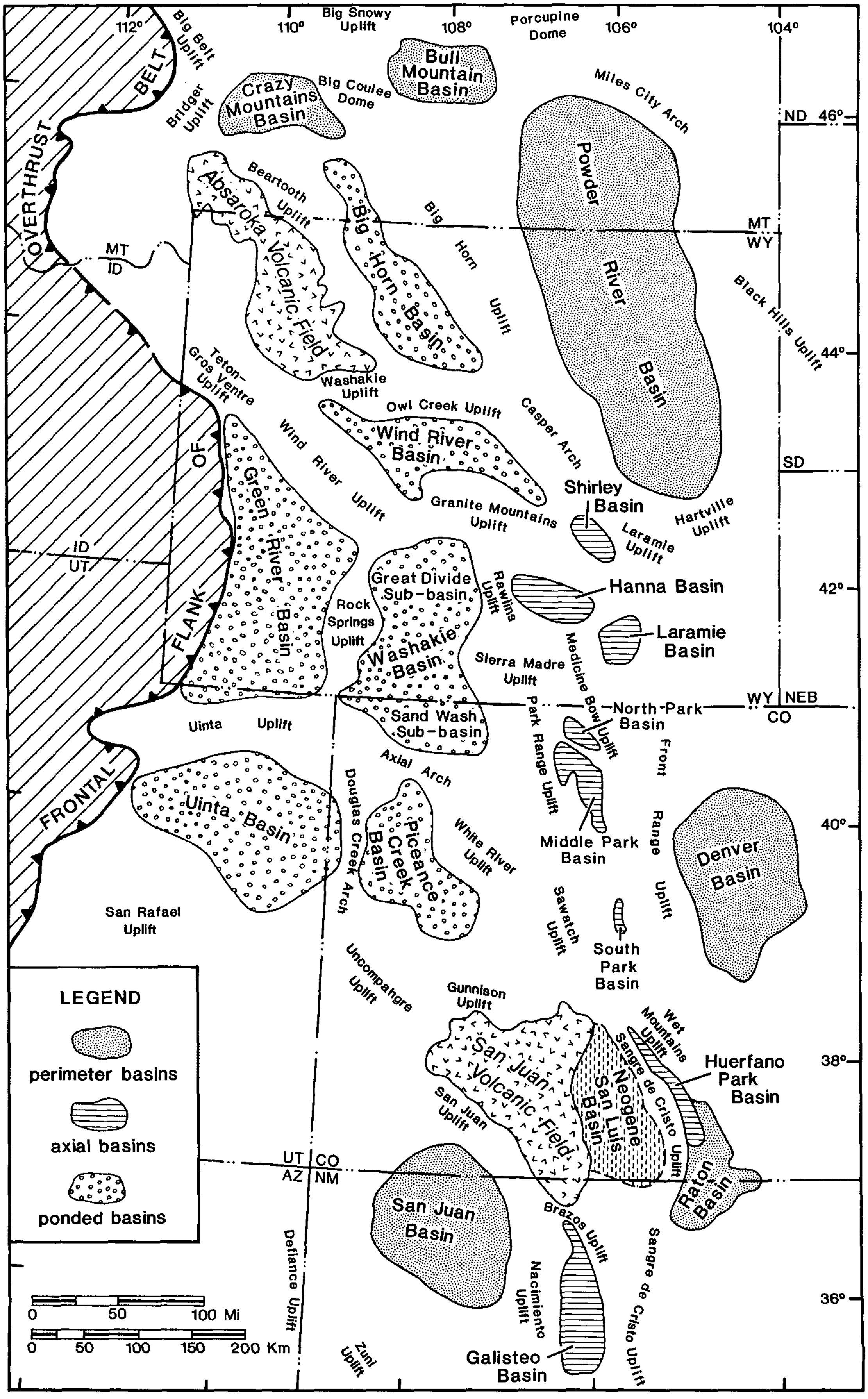
Figure 1. Major Laramide structural features of the central Rocky Mountains compiled from local and regional geologic maps. SEDIMENTARY BASINS (stippled): BHB, Bighorn; BMB, Bull Mountain; CMB, Crazy Mountains; DeB, Denver; GaB, Galisteo; GRB, Green River; HaB, Hanna; HPB, Huerfano Park; LaB, Laramie; MPB, Middle Park; NPB, North Park; PiB, Piceance Creek; PRB, Powder River; RaB, Raton; ShB, Shirley; SJB, San Juan; SPB, South Park; UiB, Uinta; WaB, Washakie; WRB, Wind River. UPLIFTS (U) AND ARCHES (A): ArA, Archuleta; BaU, Brazos; BBU, Big Belt; BHU, Black Hills; BiU, Big Horn; BrU, Bridger; BSU, Big Snowy; BtU, Beartooth; CaA, Casper; CCU, Circle Cliffs; DCA, Douglas Creek; DeU, Defiance; FRU, Front Range; GMU, Granite Mountains; GuU, Gunnison; HaU, Hartville; KaU, Kaibab; LaU, Laramie; MBU, Medicine Bow; MCA, Miles City; MoU, Monument; NaU, Nacimiento; OCU, Owl Creek; PRU, Park Range; RaU, Rawlins; RSU, Rock Springs; SaU, Sawatch; SCU, Sangre de Cristo; SJU, San Juan; SMU, Sierra Madre; SRU, San Rafael; UiU, Uinta; UnU, Uncompahgre; WhU, White River; WiU, Wind River; WMU, Wet Mountains; ZuU, Zuni. MONOCLINES (M): BHM, Black Hills; CRM, Comb Ridge; GHM, Grand Hogback; HoM, Hogback; RLM, Red Lake. VOLCANIC FIELDS (crosshatched where they form semicontinuous cover masking Laramide structures): AbV, Absaroka; MaV, Marysvale; SJV, San Juan.

intermittent rise of broad basement-cored swells produced disconformities of varied extent as early as mid-Cretaceous time (Merewether and Cobban, 1986). Intrabasinal deformation, however, was not severe enough to cause the stripping of Cretaceous cover from older rocks nor to prevent the spread of marine and associated deltaic facies across the whole Rocky Mountain region (McGookey, 1972).

When Laramide deformation began within the central Rocky Mountain region, the entire foreland province was broken up into discrete local basins that were sedimentologically isolated and separated by strongly emergent basement-cored uplifts, which served as local sources of orogenic sediment (Dickinson, 1976). Essentially the whole Laramide province was then occupied by varied nonmarine environments, and local facies tracts were limited in lateral extent to individual basins confined by nearby uplifts. Final regression of the Late Cretaceous seaway from the western interior region was associated with onset of the Laramide orogeny (Tweto, 1980) but may also have been influenced by a eustatic fall in sea level (Williams and Stelck, 1975).

Structural features that delineated Laramide basins and uplifts record net northeast-southwest shortening of the continental block, but crustal strain was complex in detail (Fig. 1). Marked heterogeneity of deformation

Figure 2. Distribution of key Laramide sedimentary basins and intervening uplifts in the Rocky Mountain region between central Montana and central New Mexico. Eocene Absaroka and Oligocene San Juan volcanic fields mask Laramide relations locally.



is indicated by (a) wide variation in the orientations of major structures that merge along strike to form curvilinear structural trends, (b) lack of evidence for structural truncations that might reflect systematic overprinting of early structures by later structures having different orientations, (c) folds and faults that display varied vergences and offsets throughout the Laramide province, (d) belts of intense deformation separated by less-deformed intervening zones, and (e) geometric implications that transfer zones of crustal torsion or wrench deformation linked partially isolated belts of more intense deformation.

REGIONAL SCOPE

Within the classic Laramide province between central Montana and central New Mexico (Grose, 1972), we here treat sedimentary basins containing Paleogene depocenters in three paleogeographic groups (Fig. 2).

1. Perimeter basins, distributed along the eastern periphery of the Laramide province and drained by fluvial systems leading toward the Great Plains of the mid-continent region.
2. Axial basins, aligned along a north-south intramontane trend now occupied by the younger Rio Grande rift system and small in size relative to basins of the other two groups.
3. Ponded basins, closer to the overthrust belt than those of the other two groups and occupied at times during their histories by lakes that served as regional sediment traps.

Our paleogeographic grouping of the Laramide basins differs from the morphostructural classification of Chapin and Cather (1981, 1983). Although we do not find their scheme helpful for our paleogeographic analysis, we here present our compilation of data in its own context without attempting to redefine their basin types, which may be useful for other purposes.

Coeval Laramide basins not discussed here occur farther south in central and southern New Mexico (Lucas and Ingersoll, 1981; Seager, 1983; Cather and Johnson, 1984, 1986; Seager and Mack, 1986) but appear to be absent east of the overthrust belt north of central Montana (Mudge, 1982).

LARAMIDE BASINS

Laramide basins and associated uplifts of various shapes, sizes, and orientations are irregularly distributed throughout the central Rocky Mountain region (Figs. 1, 2). Structural relief between basin floors and the crests of adjacent uplifts is commonly in the range of 5 to 10 km. All of the basins contain nonmarine successions of dominantly latest Cretaceous to mid-Eocene age, although some lack nonmarine Cretaceous beds and others include upper Eocene strata as well. Post-Laramide strata overlie unconformities that extend across tectonic boundaries between basins and adjacent uplifts.

Local facies relations and the resulting stratigraphic nomenclature for Laramide sequences are complex, and past failure to distinguish clearly between chronostratigraphic and lithostratigraphic units makes many correlations uncertain in detail. We here adopt current usage within each basin, and assign ages according to the present standard scale for Cenozoic geochronology (Berggren and others, 1985). We also follow available interpretations of Laramide depositional systems, but note that many uncertainties still exist, particularly for subsurface assemblages.

Perimeter Basins

Perimeter basins were relatively broad bowls with gentle structural relief along basin flanks that merged with the stable continental craton and received mainly stream deposits with local paludal or lacustrine facies (Fig. 3). By mid-Eocene time, filling of the basins had produced transport surfaces across which sediment was bypassed toward the mid-continent, and no beds younger than mid-Eocene are preserved beneath unconformities that underlie post-Laramide strata. Laramide basin fills are only about 1,000 m thick in the southern perimeter basins but exceed 2,000 m in the Powder River basin farther north. In the Crazy Mountains basin, early phases of synorogenic sedimentation were influenced by waning deformation in the nearby overthrust belt (Schmidt and Garihan, 1983), and the nonmarine sequence locally approaches 5,000 m in thickness. The Livingston Group is composed largely of volcaniclastic detritus derived from partly coeval volcanic fields of dominantly Campanian age within the overthrust belt to the west (Roberts, 1972).

Axial Basins

Axial basins are relatively small in area, but high structural relief marks nearly all basin flanks, and conglomeratic facies are prevalent (Fig. 4). Most axial basins are elongate, are nestled among prominent adjacent uplifts, and are arranged as a group in an en echelon pattern. Configurations of some were controlled by transpressional or transtensional wrench deformation along a belt of torsional strain that followed the same trend as the younger Rio Grande Rift along the eastern side of the Colorado Plateau block (Chapin and Cather, 1981, 1983). Nonmarine Cretaceous strata are rare in the axial basins, and thin where present. Depocenters generally received 1,200–2,000 m of Paleogene stream deposits, but the Hanna basin contains perhaps 5,000 m of nonmarine strata (Dobbin and others, 1929; Glass and Roberts, 1980; Hansen, 1986). Fluvial drainages from axial basins typically led into larger perimeter basins located nearby.

Ponded Basins

In the ponded basins within the core of the Laramide province, Paleogene fluvial drainages were blocked at times to form large fresh-water or saline lakes. Consequently, depocenters contain thick sequences of dark, organic-rich lacustrine shale and associated calcareous strata deposited in perennial lakes, and some ponded basins also contain widespread saline deposits that record ephemeral lacustrine phases. Lacustrine facies accumulated mainly between mid-Paleocene and mid-Eocene time but are diachronous in detail from basin to basin (Fig. 5). Nonmarine basin fills are generally 3,000–5,000 m thick. Locally abrupt structural relief is present along basin flanks adjacent to prominent nearby uplifts that are fault-bounded. Broad arch-like basement highs separating basinal depocenters locally, however, make the distinction between subbasins and separate basins somewhat arbitrary (Fig. 1).

TIMING OF LARAMIDE DEFORMATION

Figure 6 defines twelve criteria we have used to evaluate the time of inception, progress, and termination of Laramide deformation associated with individual sedimentary basins. The criteria were applied uniformly throughout the Laramide province during a systematic review of existing literature for each basin. The symbols adopted for the various criteria are used diagrammatically to annotate Figures 7–9, which are chronostratigraphic charts for ponded, axial, and perimeter basins, respectively. The ages inferred for the different criteria in each case are best estimates for which margins of error are indeterminate. Although each individual criterion is thus interpretive and not reliable without confirmation, conclusions based upon grouped criteria are regarded as valid.

We also plotted geohistory diagrams (Van Hinte, 1978) to test for pulses of basin subsidence that might mark either the onset of Laramide deformation or different phases of the Laramide orogeny. We could detect

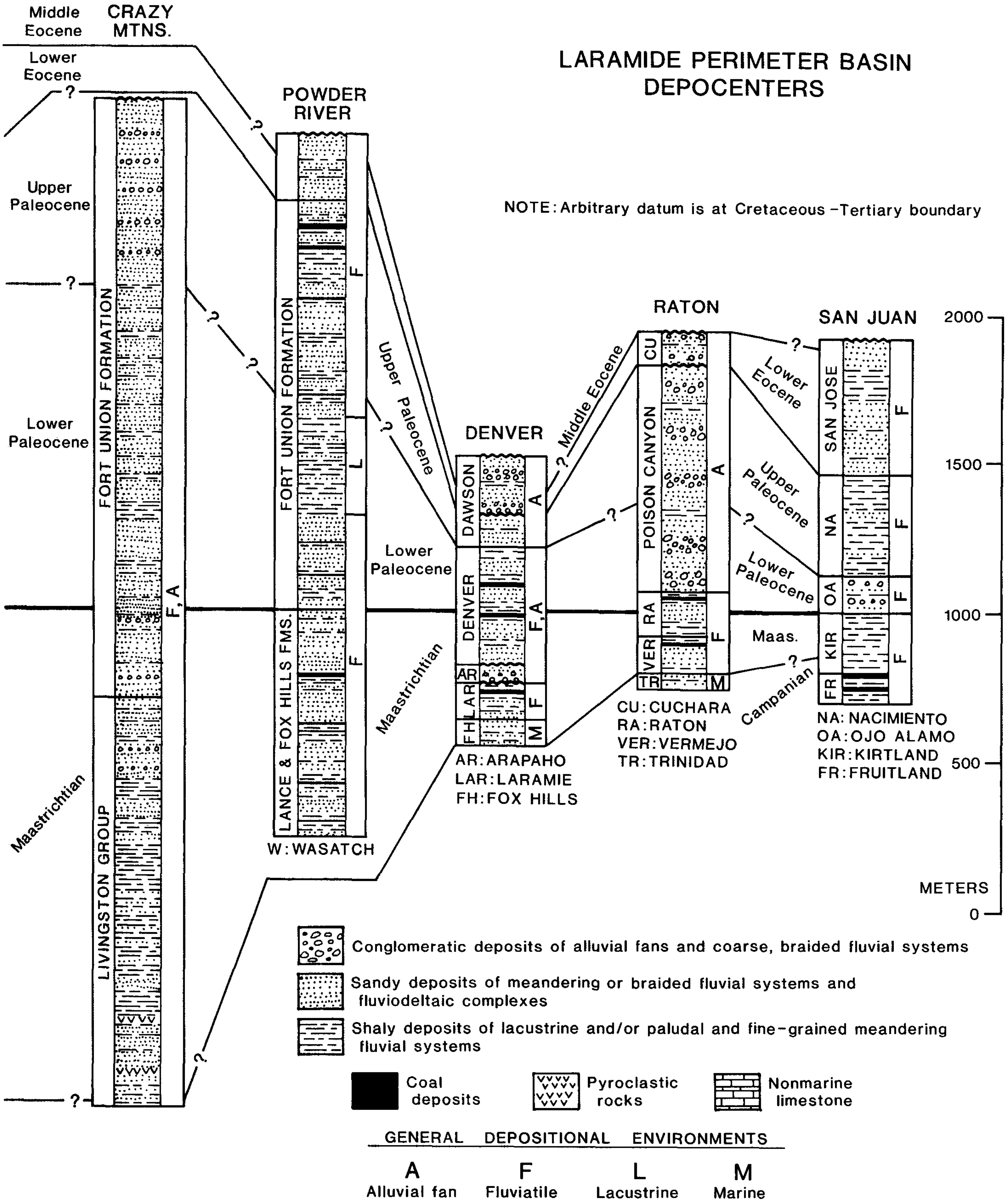


Figure 3. Lithostratigraphic columns of Laramide sedimentary successions in depocenters of selected perimeter basins (Fig. 2). Key basin references: Roberts (1972), Skipp and McGrew (1972), Rice (1976) for Crazy Mountains; Lillegraven (1970), Curry (1971), Ayers and Kaiser (1984) for Powder River; Weimer (1973), Soister (1978), Soister and Tschudy (1978) for Denver; Baltz (1965), Lucas and Ingersoll (1981), Smith and others (1985) for Raton; Baltz (1967), Fassett and Hinds (1971), Fassett (1974), Molenaar (1977), Lucas and Ingersoll (1981), Lucas and others (1981), Smith and others (1985), Klute (1986) for San Juan. The lower Livingston Group also includes ~600 m of Campanian volcaniclastic strata not shown here.

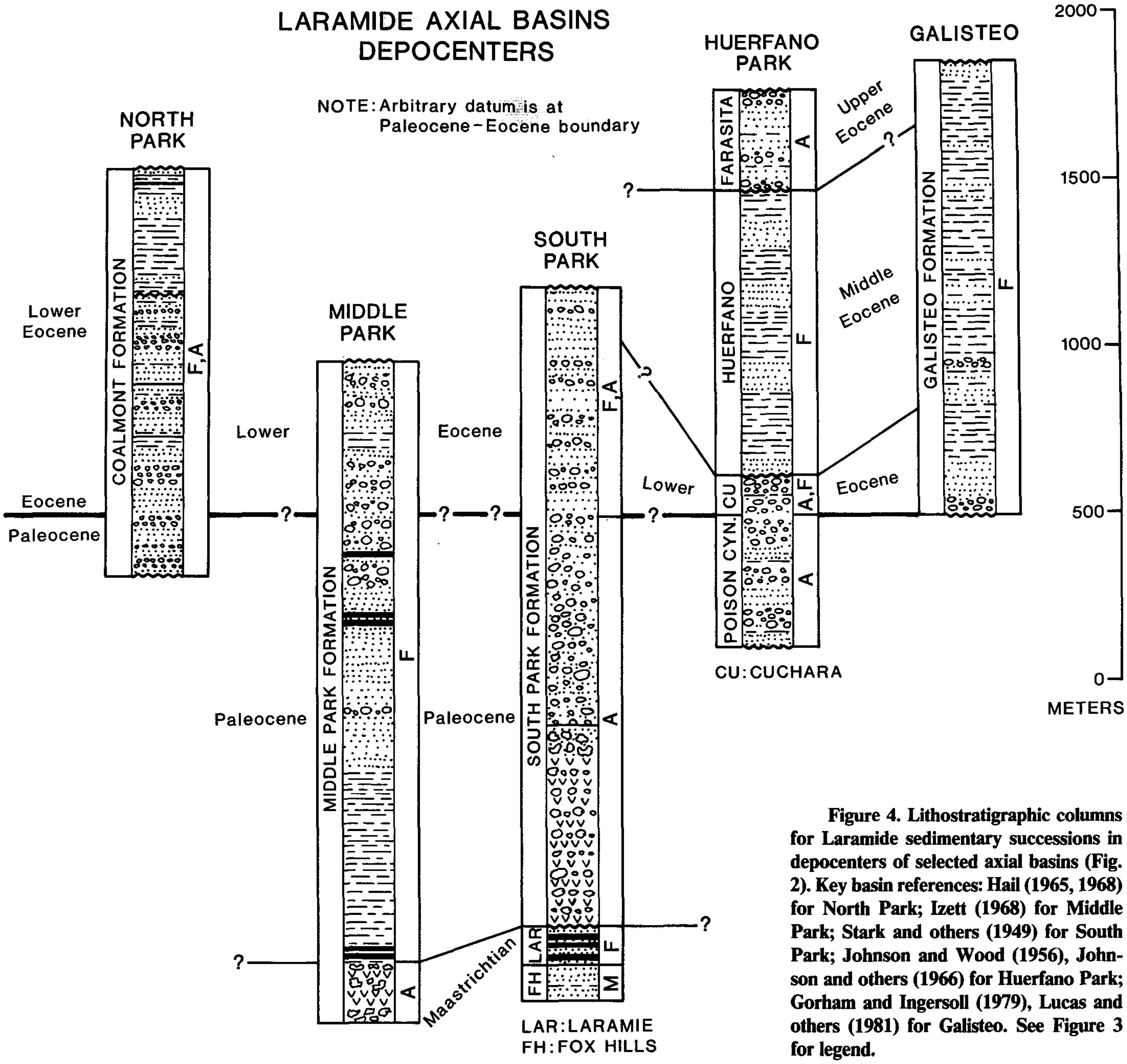


Figure 4. Lithostratigraphic columns for Laramide sedimentary successions in depocenters of selected axial basins (Fig. 2). Key basin references: Hail (1965, 1968) for North Park; Izett (1968) for Middle Park; Stark and others (1949) for South Park; Johnson and Wood (1956), Johnson and others (1966) for Huerfano Park; Gorham and Ingersoll (1979), Lucas and others (1981) for Galisteo. See Figure 3 for legend.

no consistent signals of Laramide events through geohistory analysis for three reasons: (a) within Laramide basins, subsidence related to Laramide breakup of the foreland region immediately followed Late Cretaceous subsidence of the entire foreland region, and the two phases of subsidence cannot be distinguished with confidence on geohistory plots; (b) uncertainties about the absolute elevations of sedimented surfaces during the accumulation of Laramide nonmarine facies make it difficult to establish a reliable topographic datum for plotting Laramide geohistory diagrams; and (c) available subsurface data on thick basinal sequences of nonmarine Laramide strata provide insufficient geochronologic control for accurate geohistory plots.

Deformational Criteria

The significance of each of the deformational criteria (Fig. 6) is interpreted as follows.

1. Continuation of marine sedimentation to produce beds conformable with underlying marine formations of the retroarc foreland basin is inferred to predate Laramide deformation, which disrupted the integrated marine basin to form isolated nonmarine Laramide basins.
2. Even nonmarine strata that were laterally continuous at the time of deposition from the area of one Laramide basin to other adjacent or nearby basins are inferred to predate isolation of the basins by Laramide growth of intervening uplifts.
3. Isopachs that define the initial development of a local Laramide depocenter are direct evidence for the inception of Laramide deformation, but stratigraphic correlations are rarely precise enough to date basin initiation closely.
4. The presence of locally derived clasts within basin fill is definite evidence that Laramide structures were active enough to induce erosion of detritus from adjacent or nearby Laramide uplifts.
5. The presence of lacustrine facies in basin fill indicates times during

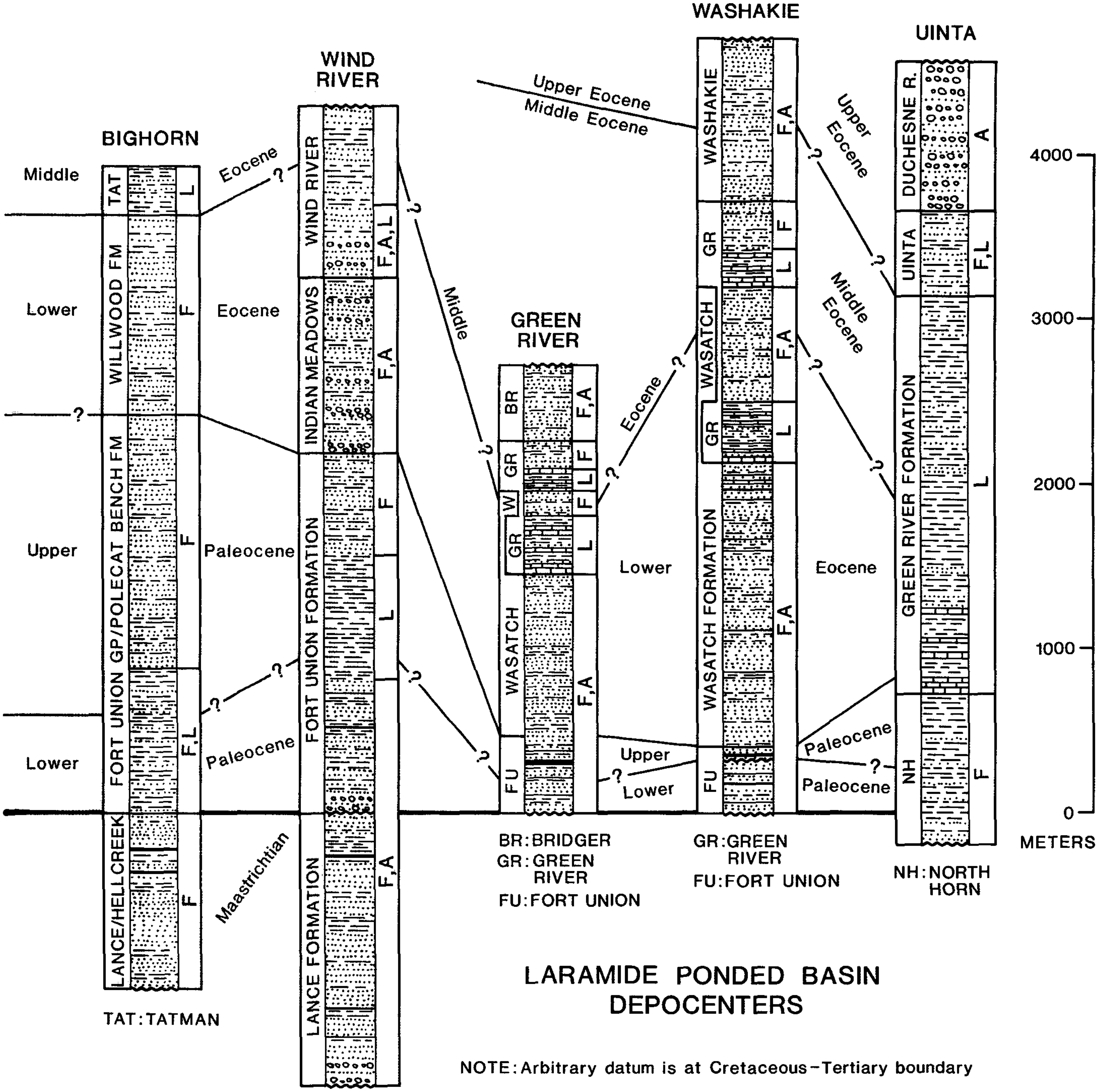


Figure 5. Lithostratigraphic columns of Laramide sedimentary successions in depocenters of selected ponded basins (Fig. 2). Key basin references: Bown (1975), Rea and Barlow (1975), Rose (1981), Gingerich (1983), Kraus (1985) for Bighorn; Keefer (1965a, 1965b), Seeland (1978a), Winterfeld and Conard (1983), Phillips (1983) for Wind River; Curry (1973), Roehler (1979a, 1979b), Surdam and Stanley (1980a), Sullivan (1980), Sklenar and Andersen (1985) for Green River and Washakie; Andersen and Picard (1972), Fouch (1975), Ryder and others (1976), Johnson (1985), Dickinson and others (1986) for Uinta. See Figure 3 for legend.

which structural and topographic relief between a given basin and adjacent Laramide uplifts was sufficient to pond water within the depocenter.

6. Uninterrupted accumulation of fluvial facies within a given Laramide basin reflects its continued existence as a receptacle for sediment but provides no other specific information about its stage of development.

7. Deposition of coarse alluvial fans along basin flanks indicates strong topographic relief between the basin floor and adjacent Laramide uplifts, where positive elevation was maintained by continued Laramide deformation.

8. Local unconformities within Laramide successions or along the structural flanks of Laramide basins reflect orogenic deformation severe enough to disrupt patterns of sedimentation and cause local erosion.

9. The age of the youngest strata preserved beneath the unconformity capping a Laramide succession is a measure of the earliest time that

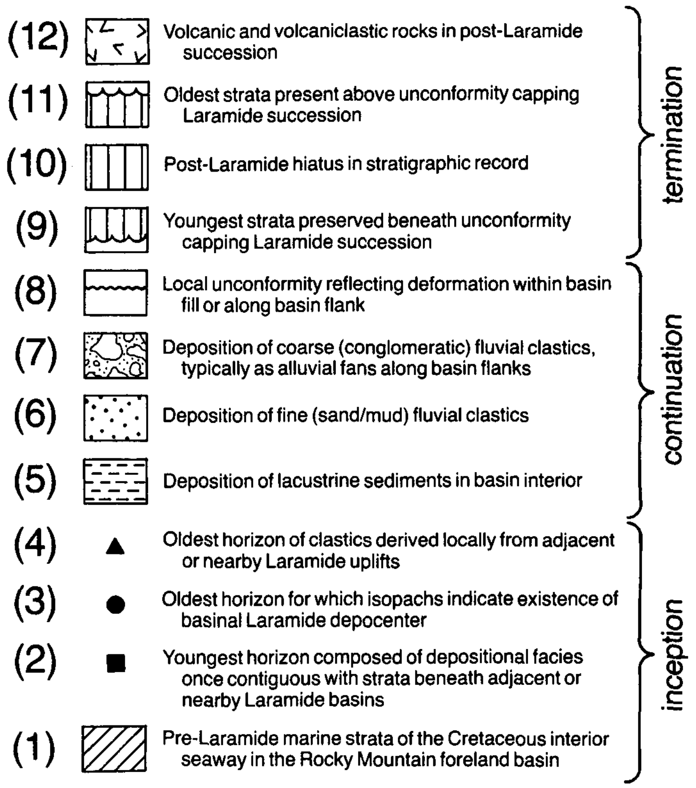


Figure 6. Symbols for deformational criteria plotted on chronostratigraphic charts of Laramide basins (Figs. 7–9).

Laramide sedimentation could have ceased within a particular basin.

10. The hiatus between Laramide and post-Laramide successions spans the time during which the Laramide episode of deformation and sedimentation came to a close in the vicinity of a given basin.

11. The age of the oldest strata present above the unconformity capping a Laramide succession is a measure of the latest time that Laramide sedimentation could have ceased within a particular basin.

12. Volcanic fields that locally overlap Laramide structural features reflect the onset of migratory arc volcanism that diachronously succeeded Laramide tectonism in some parts of the Rocky Mountain region.

Regional Relations

The sedimentary record of Laramide basins indicates that Laramide deformation began during Maastrichtian time (65–75 Ma) throughout the central Rocky Mountain region, and it implies no systematic areal diachroneity for inception of deformation (Fig. 10). A recent parallel analysis of initiation and cessation of movement on individual Laramide structures leads to the same conclusions (Cross, 1986). In the central Rocky Mountain region, deformation began no earlier in the ponded basins on the west than in the perimeter basins on the east, nor any earlier in the north than in the south (compare with Cross, 1986).

Anomalous pre-Maastrichtian deformation and associated volcaniclastic sedimentation in the Crazy Mountains basin (Fig. 9) were related to tectonic and volcanic activity within the adjacent overthrust belt. Early termination of Cretaceous marine sedimentation in the Uinta basin (Fig. 7) reflected progradation of nonmarine facies eastward from the overthrust belt into the integrated foreland basin associated with Sevier deformation (Dickinson and others, 1986). Marine foreland sedimentation persisted

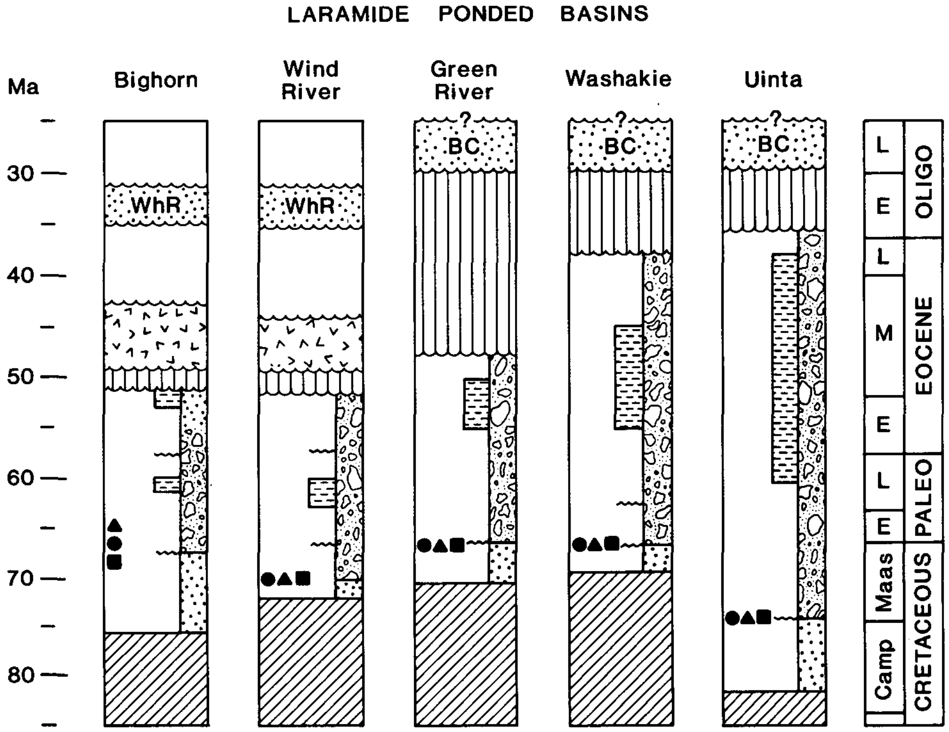
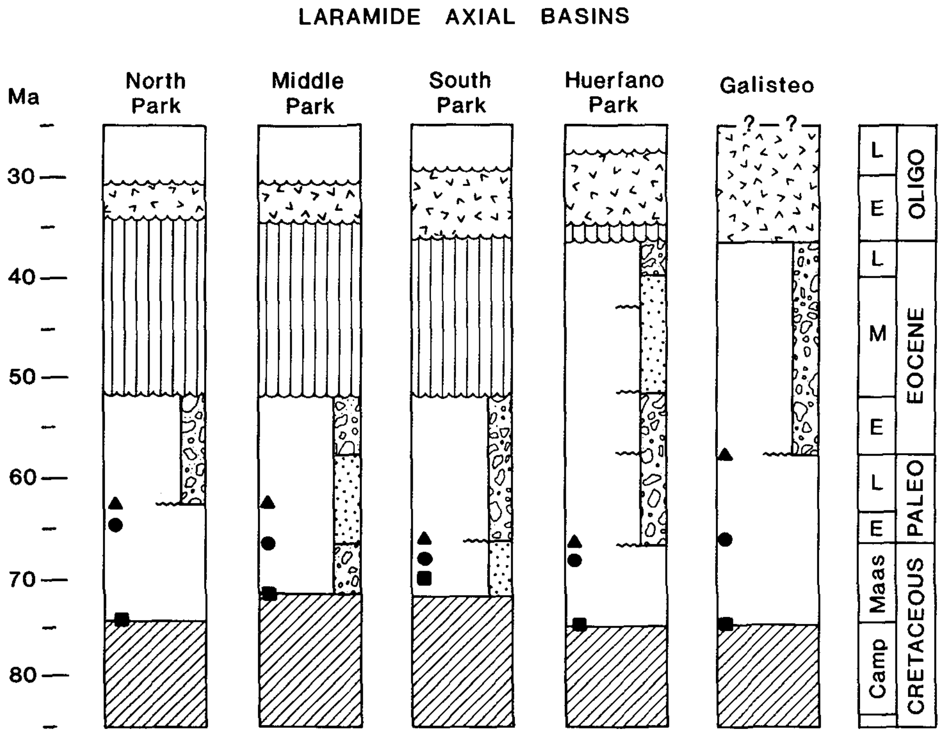


Figure 7. Chronostratigraphic charts for selected ponded basins showing timing of key paleotectonic and paleogeographic events (Fig. 6); WhR is White River Formation, and BC is Bishop Conglomerate. Data from Figure 5, Love (1970, 1971), Bown (1982), and Hansen (1984).

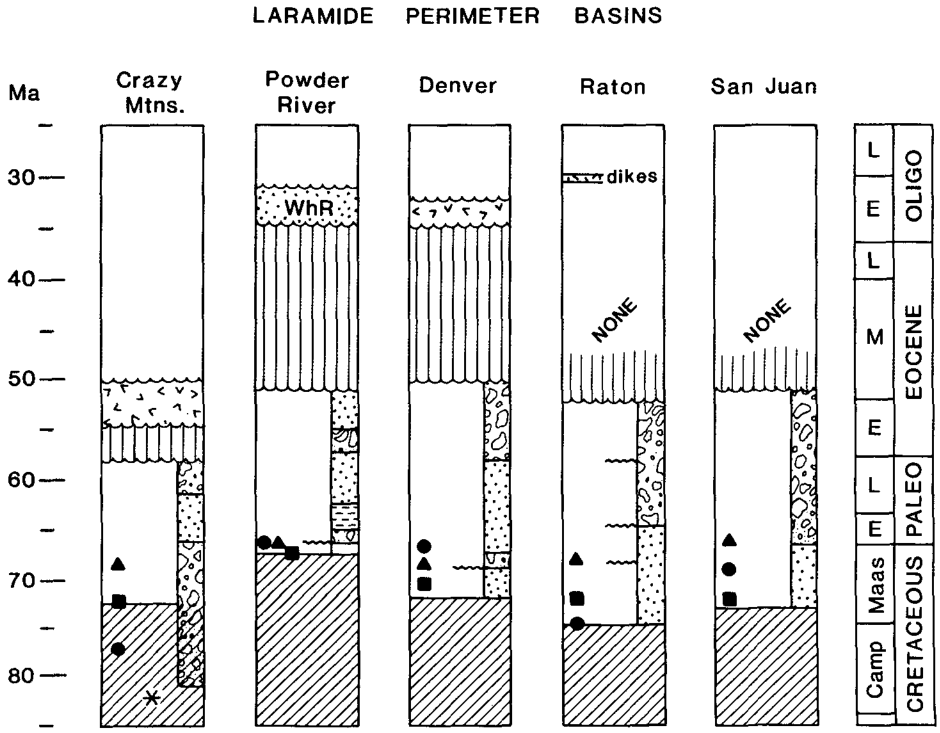
Figure 8. Chronostratigraphic charts for selected axial basins showing timing of key paleotectonic and paleogeographic events (Fig. 6). Data from Figure 4, Scott and Taylor (1975), and Smith and others (1985).



longest in the Powder River basin (Fig. 9), where the Cannonball Sea extended into the fringe of the Laramide province.

Deposition of coarse nonmarine clastic strata was generally most common in Laramide basins from mid-Maastrichtian to mid-Eocene time (50–70 Ma), but it persisted locally until near the end of Eocene time (35–40 Ma). Development of topographic relief strong enough to create silled lacustrine basins was most common in late early to early middle Eocene time (50–55 Ma) but occurred locally from mid-Paleocene through middle Eocene time (40–65 Ma). Tuff beds intercalated with fine-grained lacustrine strata of several ponded basins have been dated isotopically as middle Eocene (40–50 Ma) in age (Mauger, 1977).

Figure 9. Chronostratigraphic charts for selected perimeter basins showing timing of key paleotectonic and paleogeographic events (Fig. 6); asterisk denotes onset of coarse volcaniclastic sedimentation within foreland basin (see text) and WhR is White River Formation. Data from Figure 3, Tweto (1980), Fritz and Harrison (1985), and Morse (1985).



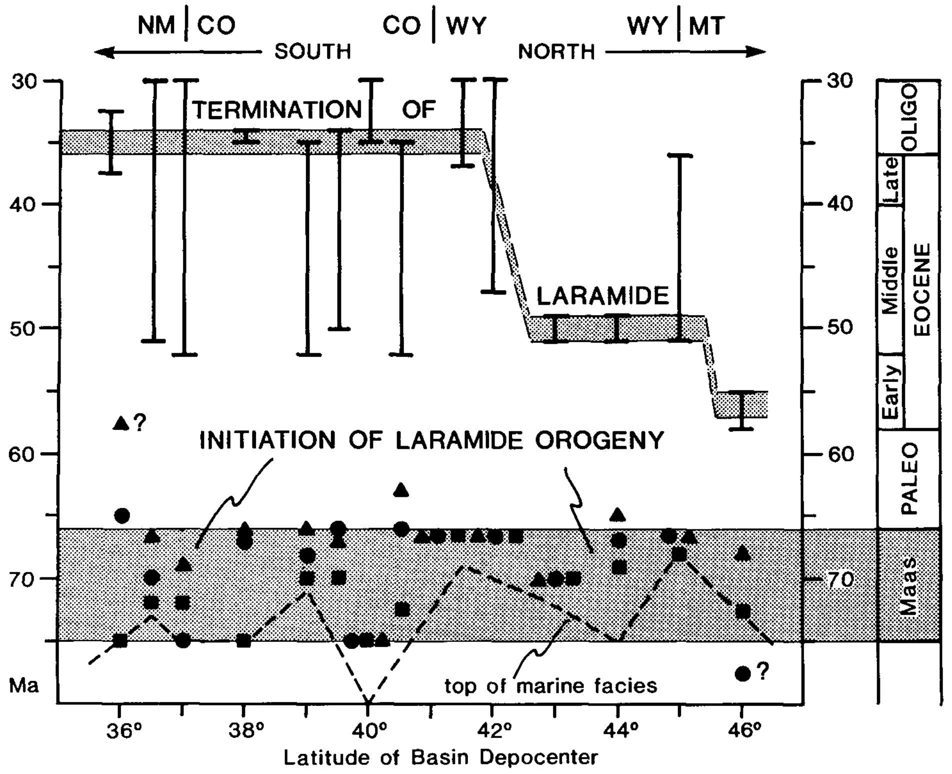


Figure 10. Diagram showing synchronous initiation of Laramide Orogeny during Maastrichtian (MAAS) time, denoted by lower shaded band, and diachronous (from north to south) termination of Laramide Orogeny during Eocene time, as indicated by step-like upper shaded band. Solid symbols (triangles, circles, squares) denote criteria (Fig. 6) for onset of Laramide deformation (Figs. 7–9), and brackets denote local time spans of post-Laramide stratigraphic hiatus (Figs. 6–9).

Laramide deformation ended earlier in the north than in the south. Where the hiatus between Laramide successions and post-Laramide strata represents a short interval of time, the tectonic transition is dated near the boundary between early and middle Eocene time (50–55 Ma) in the north and near the end of Eocene time (35–40 Ma) in the south (Fig. 10). Volcanic and volcaniclastic units are the most characteristic post-Laramide strata in many areas. Evidence for early termination of Laramide deformation in the northwestern part of the Laramide province is provided by the capping volcanic cover of the Absaroka Volcanic Supergroup of middle Eocene age (mainly 46–49 Ma but 43–52 Ma overall) in northwest Wyoming (Smedes and Prostka, 1972; Bown, 1982; Fritz and Harrison, 1985). Absaroka beds were only moderately deformed by waning phases of the Laramide episode (Sundell, 1983, 1986). By contrast, the oldest undeformed strata capping folded and faulted Laramide successions to the southeast in Colorado are Oligocene volcanics, and Laramide sedimentary successions in New Mexico locally pass gradationally upward into Oligocene volcaniclastic strata (Fig. 8).

Igneous Activity

Prior to the Laramide orogeny, the principal axis of arc magmatism followed the trend of major Cretaceous batholiths lying west of the overthrust belt, but marked eastward migration of subduction-related magmatism accompanied the onset of Laramide deformation (Coney and Reynolds, 1977; Cross and Pilger, 1978a; Dickinson and Snyder, 1978). The principal loci of synorogenic Laramide magmatism lay in southwest Montana and central Colorado. In Montana, intense plutonism and associated volcanism are best documented for the cogenetic Campanian to Maastrichtian (68–78 Ma) Boulder batholith and Elkhorn Mountains Volcanics, but slightly older and younger intrusives and eruptives were also widespread in surrounding areas from mid-Campanian (82 Ma) to mid-Paleocene (62 Ma) time (Chadwick, 1981). Coeval Laramide igneous activity in Colorado was most significant along the Colorado Mineral Belt, whose relation to Laramide or other crustal structures remains uncertain (Tweto, 1980).

Paleocene and older magmatism everywhere predated or accompanied Laramide deformation, but the ages of the oldest volcanics that postdate Laramide structures are different in northern and southern parts of the Laramide province. Whereas all Eocene and younger igneous rocks are post-Laramide north of Colorado, only Oligocene and younger igneous rocks south of Wyoming are post-Laramide. The paucity of Tertiary igneous rocks in much of Wyoming makes it unclear whether the regional change in the structural relations of Laramide igneous rocks reflects (1) a sharp contrast in tectonomagmatic timing between Wyoming and Colorado or (2) a gradual shift in the behavior of Laramide tectonism and magmatism from north to south. The overall regional continuity of Laramide structural trends (Fig. 1) makes the latter interpretation more attractive, but the abrupt change in the apparent timing of basin development at the latitude of southern Wyoming (Fig. 10) seemingly favors the former.

LARAMIDE PALEODRAINAGE

The syntectonic Laramide landscape that existed during Paleogene time cannot be reconstructed in detail, but overall patterns of paleodrainage can be inferred from the sedimentary record of the Laramide basins (Fig. 11). Retreat of the Cretaceous sea at first left a landscape of low relief drained by meandering streams that traversed swampy lowlands (Blackstone, 1975). As Laramide deformation intensified, this initial terrestrial surface was segmented into discrete basinal depocenters separated by eroding highlands (McGrew, 1971). The fluvial and lacustrine facies preserved within Laramide basins indicate that the whole Laramide province probably stood above sea level throughout the Laramide orogeny, but the possibility that the floors of some lake basins reached below sea level cannot be

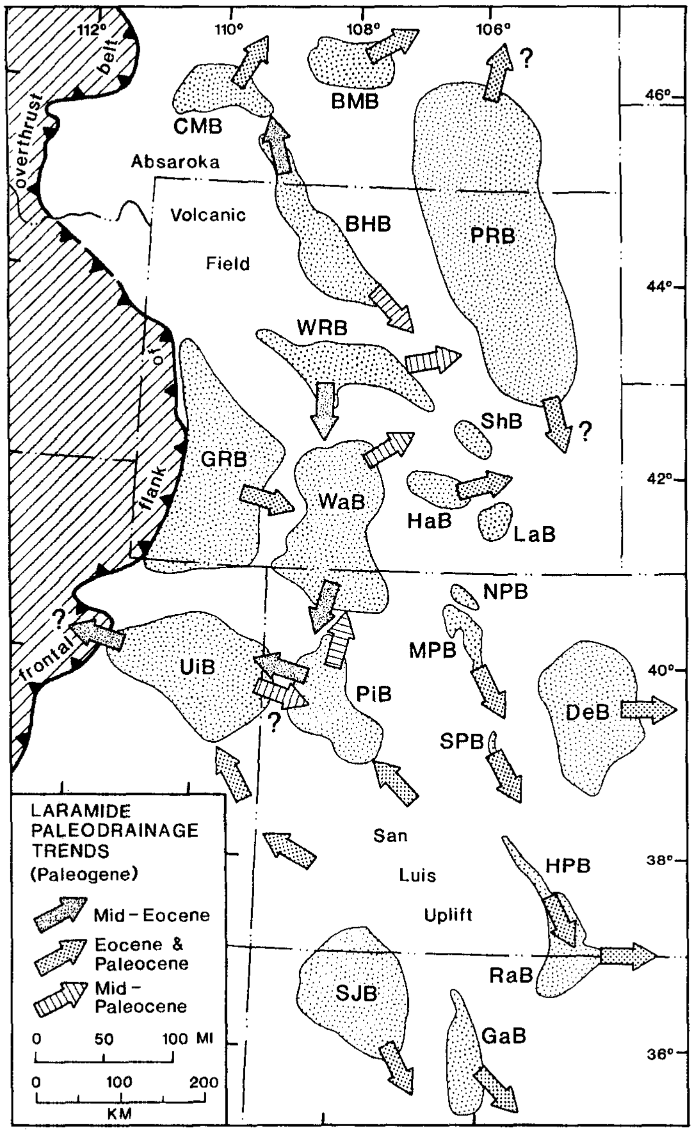


Figure 11. Inferred Laramide paleodrainage trends showing paleoflow directions of major fluvial systems at exit from, and entry into, Laramide sedimentary basins; short dispersal paths from nearby uplifts surrounding basins are omitted. Data from Ayers (1986), Bown (1980), Chapin and Cather (1981, 1983), Childers (1970), Dickinson and others (1986), Flores (1983), Flores and Ethridge (1985), Gorham and Ingersoll (1979), Hansen (1985), Keefer (1965a), Klute (1986), Kraus (1980), Love (1971), Love and others (1963), Neasham and Vondra (1972), Roberts (1972), Ryan (1977), Seeland (1978b), Sklenar and Andersen (1985), Surdam and Stanley (1980b), and Tweto (1980). Laramide basins: BHB, Bighorn; BMB, Bull Mountain; CMB, Crazy Mountains; DeB, Denver; GaB, Galisteo; GRB, Green River; HaB, Hanna; HPB, Huerfano Park; LaB, Laramie; MPB, Middle Park; NPB, North Park; PiB, Piceance Creek; PRB, Powder River; RaB, Raton; ShB, Shirley; SJB, San Juan; SPB, South Park; UiB, Uinta; WaB, Washakie; WRB, Wind River.

ruled out with present data. The areally restricted axial basins formed local sediment traps along the upstream reaches of Laramide paleodrainage networks that led into nearby perimeter or ponded basins of larger size.

Perimeter Basins

Perimeter basins lying along the continental fringe of the Laramide province were drained by fluvial systems flowing eastward toward remnants of the Cretaceous interior seaway (Roberts, 1972; Tweto, 1980), which withdrew gradually into the ancestral Arctic Ocean and Gulf of Mexico. Southeasterly paleodrainage from Laramide basins in New Mexico (Gorham and Ingersoll, 1979; Smith and others, 1985; Klute,1986) may have led directly to the Gulf Coast. The Cannonball Sea, whose shoreline lay just northeast of the Powder River basin during Paleocene time (Cherven and Jacob, 1985), was evidently connected with the Gulf of Mexico through marine waters that flooded the Mississippi embayment (Williams and Stelck, 1975). The Gulf connection is reflected also by the presence of voluminous clastic sediment in subsurface formations of the Texas coastal plain (Winker, 1982).

Laramide depositional systems in the perimeter basins were almost exclusively fluvial, except in the Powder River basin, where lacustrine facies are also present (Fig. 3). In the past, the lacustrine paleoenvironments have been viewed as flood-basin lakes and flood-plain backswamps of a longitudinal stream network flowing northward within the Powder River basin (Seeland, 1976; Flores, 1981; Ethridge and others, 1981; Flores and Hanley, 1984; Flores and Ethridge, 1985). In this view, the lacustrine deposits are interpreted as discontinuous lenses encased within more widespread fluvial strata of compound flood plains traversed by meandering but anastomosed rivers (Flores, 1986). Recent work suggests, however, that ponding of water was more widespread than previously inferred and that it created a broad lake which drained out the southern end of the Powder River basin (Ayers, 1986). The abundance of fluviodeltaic systems leading into the Williston basin (Fig. 12) from the west and southwest is more compatible with the traditional interpretation, but both paleodrainage alternatives for the Powder River basin are indicated by queried arrows on Figure 11.

Ponded Basins

Paleodrainage patterns for the ponded basins were more complicated than for the other two basin types, both in space and in time. Most notably, various Paleogene stream captures in central Wyoming strongly influenced the overall geometry of regional paleodrainage networks (Seeland, 1985). Moreover, the drainage history of the ponded basins raises unresolved questions of regional paleogeomorphology. Basic relations were as follows.

1. From the Bighorn basin in north-central Wyoming, Paleocene drainage was dominantly toward the southeast into the Powder River basin, but Eocene drainage was largely toward the northwest (Neasham and Vondra, 1972; Bown, 1980; Kraus, 1980), presumably into the Crazy Mountains basin. Both paleoflow patterns connected the Bighorn basin to paleodrainage networks leading into the continental interior throughout its depositional history.

2. From the Wind River basin in central Wyoming, Paleocene and early Eocene drainage was largely toward the east into the Powder River basin, but later drainage during middle (and late?) Eocene time was southward into Lake Gosiute, which occupied large parts of the Green River and Washakie basins (Keefer, 1965a; Childers, 1970; Love, 1971; Seeland, 1978b). The growth of Laramide uplifts thus shifted a key drainage divide during the depositional history of the Wind River basin.

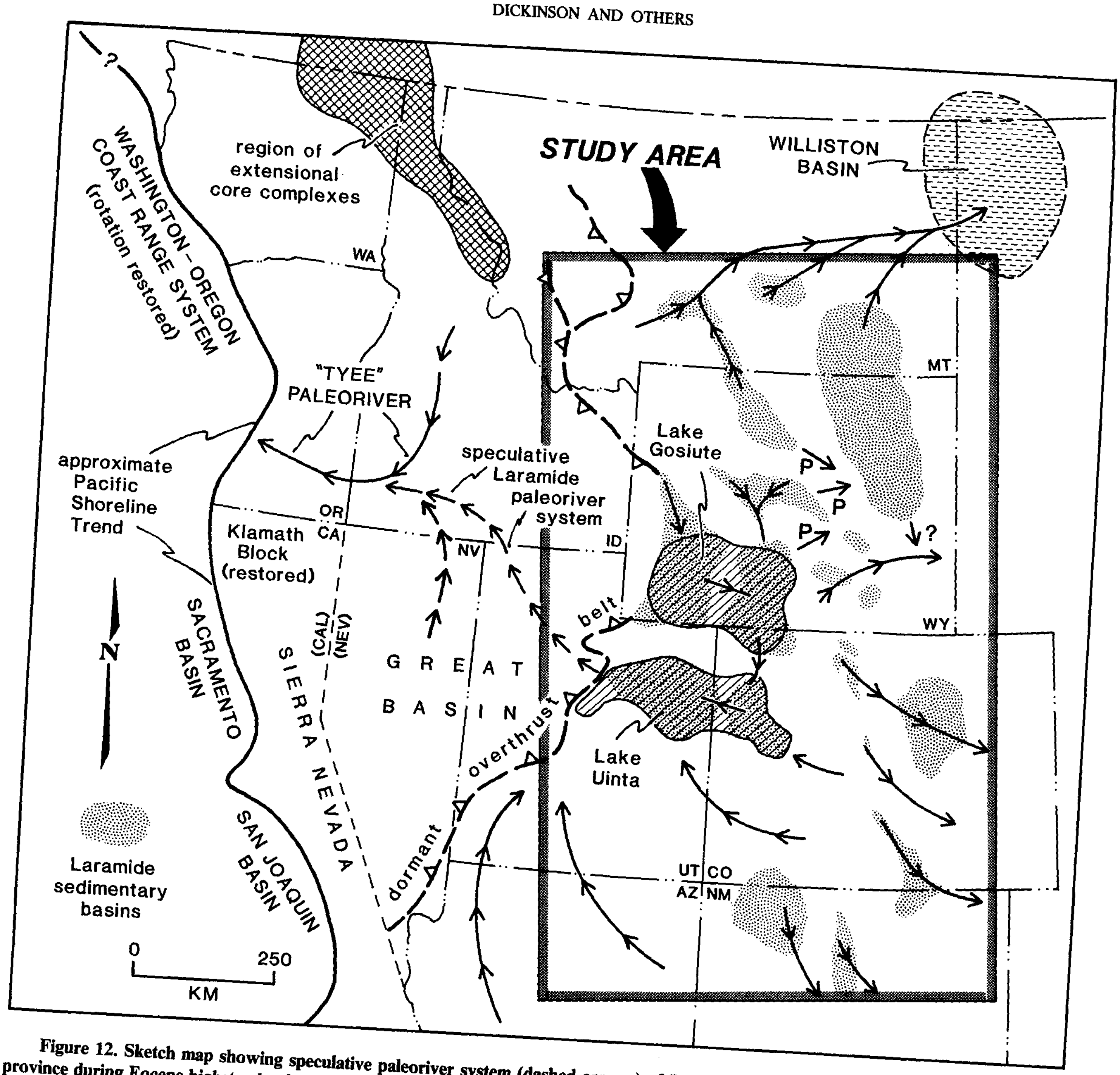


Figure 12. Sketch map showing speculative paleoriver system (dashed arrows) of Pacific watershed draining core region of Laramide province during Eocene highstands of Lakes Uinta and Gosiute; width of Nevada reduced by half to simulate restoration of Neogene crustal extension across Great Basin. Barbed lines indicate schematic paths of other key Eocene paleorivers (short P arrows denote earlier Paleocene dispersal routes in central Wyoming). Maximum extents of Lakes Gosiute and Uinta approximated from Sullivan (1980) and Johnson (1985). Pacific shoreline trend from Dickinson and others (1979) and Heller and others (1987). Montana and Arizona paleodrainage patterns after Cherven and Jacob (1985) and Nations and others (1985). See Figure 11 for details of paleodrainage pattern within Laramide province and identity of Laramide basins shown. Tectonic denudation of Cordilleran metamorphic core complexes lying farther south than shown did not occur until Oligocene-Miocene time (Wust, 1986).

3. From the Green River and Washakie basins, separated only by the subdued Rock Springs uplift in southwest Wyoming, Paleocene and early Eocene drainage was mainly eastward toward the continental interior through irregular paleotopography in southeast Wyoming (Ryan, 1977; Sklenar and Andersen, 1985). By middle Eocene time, however, paleodrainage was mainly southward around the eastern end of the Uinta uplift into Lake Uinta, which occupied large parts of the Uinta and Piceance Creek basins (Surdam and Stanley, 1979, 1980b).

4. From the Piceance Creek basin of northwest Colorado, Paleocene drainage probably led northward to connect with fluvial networks crossing Wyoming (Johnson, 1985), but Eocene drainage later led westward into the Uinta basin of northeast Utah (Bruhn and others, 1986; Dickinson and

others, 1986). The closely associated Piceance Creek and Uinta basins were separated only by the subdued Douglas Creek arch.

5. The depocenter of the Uinta basin was occupied by lacustrine environments of varying extent throughout much of its depositional history from late Paleocene to late Eocene time. During later phases of the Laramide orogeny, if not earlier as well, the Uinta basin thus acted as a lacustrine sump for paleodrainages tapping much or all of the internal part of the Laramide province.

Lacustrine Facies

The nature of the depositional environments in which the lacustrine facies of Lakes Gosiute and Uinta (Fig. 12) were deposited is controversial. Picard (1985) reviewed the two alternate hypotheses that have been advanced for the paleoenvironments in which widespread oil shales accumulated: (a) deep stratified lakes in which anaerobic bottom conditions led to preservation of organic-rich laminae and (b) shallow playa lakes with organic production concentrated on fringing algal mudflats. The latter model implies internal drainage enclosed by hydrologic barriers, whereas the former model allows either internal drainage or external drainage by streams spilling over bounding sills. The best compromise interpretation of the lacustrine conditions appears to be the concept of organic accumulation on the floors of broad perennial lakes surrounded by marginal lacustrine shoals and mudflats (Ryder and others, 1976). Wide fluctuations in lake level allowed the volume of lacustrine waters to oscillate between the end members of deep standing lake and playa salt pan (Surdam and Stanley, 1979; Smoot, 1983; Sullivan, 1985).

Lakes Gosiute and Uinta may have occupied hydrologically closed basins of a wholly interior drainage network during much of their history (Johnson, 1985). The aggregate volume of evaporite deposits that are present in lacustrine facies of the ponded basins, however, may be insufficient to account for all of the residual salts delivered to the lakes over millions of years by streams and springs. Temporary desiccation at intervals is clearly indicated, but systematic evaporation or infiltration of all of the waters that entered the lake basins seems difficult to postulate. We infer that waters may have flowed out of Lake Uinta during high stands in lake level.

Lacustrine Outlet

During Paleocene time, lake waters from the Uinta basin may have flowed eastward into the Piceance Creek basin and thence northward into Wyoming. By mid-Eocene time, however, Lake Uinta occupied both adjacent basins (Johnson, 1985) and evidently received the overflow from Lake Gosiute in Wyoming as well (Surdam and Stanley, 1980b). The route by which the waters of Eocene Lake Uinta might have spilled toward the sea is essentially unknown.

Flow northward was blocked by the Uinta uplift, which was a proximal source of coarse detritus throughout Paleogene time (Sweeney and others, 1987). Flow eastward toward the continental interior seems precluded by the topographic barriers of multiple Laramide uplifts (Fig. 2). The influx of voluminous clastic sediment into the Uinta basin from the southeast blocked any exit in that direction (Dickinson and others, 1986). Flow southward through central Utah also seems impossible, because Laramide drainages from central Arizona led northward into Utah (Nations and others, 1985). To the southwest, lacustrine facies are also replaced by clastic strata derived from the south (Stanley and Collinson, 1979).

A river leading westward through the extinct overthrust belt thus appears to be the only feasible way in which the Uinta basin could have been drained during middle and late Eocene time. Eastward dispersal of coarse detritus from the thrust sheets was important into Paleocene time but was much reduced by Eocene time (Dickinson and others, 1986).

The full course of such a river is entirely conjectural (Fig. 12). The Paleogene sedimentary record of the Sacramento and San Joaquin basins in California, however, affords no evidence for a river system originating east of the Sierra Nevada batholith (Dickinson and others, 1979). On the other hand, reconstruction of Paleogene paleogeography for the Pacific Northwest indicates that a major paleoriver built a deltaic complex along what is now coastal Oregon (Heller and others, 1987). Sedimentological evidence for the existence of such a paleoriver is strongest for middle Eocene time, when Lake Uinta reached its maximum extent, in the form of widespread deltaic sediments in the Tyee Formation (Heller and Ryberg, 1983). Restoration of tectonic rotations detected by paleomagnetic studies suggest that the mouth of this "Tyee" paleoriver lay in south-central Oregon (Heller, 1983; Gromme and others, 1986), with respect to a fixed Uinta basin in Utah. Isotopic provenance studies imply that headwater tributaries of the "Tyee" paleoriver tapped sediment sources as far east as the Idaho batholith (Heller and others, 1985). In our view, other tributaries may well have served as the fluvial outlets for lacustrine environments in the Uinta basin and smaller lacustrine basins in northeast Nevada (Fouch and others, 1979; Solomon and others, 1979a, 1979b). Trapping of detrital sediment within the lacustrine basins would have largely erased the record of upstream Laramide provenance from detritus carried by the "Tyee" paleoriver (Potter, 1978).

The commonality of fish and molluscan faunas from Lakes Gosiute and Uinta (Hansen, 1985) clearly confirms interconnections between the two lacustrine systems, but neither strongly supports nor conclusively denies the hypothesis that Lake Uinta drained into the "Tyee" paleoriver. The fish faunas have affinities mainly with the Mississippi River drainage, but some characteristic fish genera also occur in Paleogene lacustrine deposits of the Pacific Northwest. Paleodrainage leading eastward across Wyoming from the ponded basins toward the Great Plains during some extended interval of time, including the Paleocene (Fig. 11), seems certain; we conclude that paleodrainage westward by mid-Eocene time is also allowed by the available data.

POST-LARAMIDE LANDSCAPE

A distinctive erosion surface of low relief was cut across Laramide structural features over a large region in Colorado during latest Eocene time (Epis and Chapin, 1975). The morphology of the surface is best preserved where it was buried beneath a widespread ignimbrite of earliest Oligocene age (36–37 Ma), but local preservation is common throughout central Colorado beneath an extensive Oligocene volcanic field composed of eroded andesitic stratocones surrounded by aprons of volcaniclastic sediment (Steven, 1975). Analogous erosion surfaces of similar age have been reported from various localities elsewhere within the western Cordillera (Gresens, 1981). Paleotopography was varied, however, and relief in excess of 1,000 m is inferred locally for slopes cut across the eroded flanks of residual Laramide uplifts and leading into adjacent Laramide basins that remained topographic depressions (Hansen, 1984). In New Mexico, Eocene clastic sequences deposited in residual Laramide basins commonly grade upward into post-Laramide volcaniclastic strata whose deposition began near the Eocene-Oligocene time boundary (Smith and others, 1985; Cather, 1986).

Oligocene streams flowed generally eastward from the Laramide province to form an aggrading fluvial plain that extended from Canada southward at least as far as Colorado (Clark, 1975). Within the ancestral Great Plains, a continental divide between watersheds draining northward toward the Arctic Ocean and southward into the Gulf of Mexico lay near the latitude of the Black Hills (Seeland, 1985). Arkosic to subarkosic sands in Oligocene sequences of the Great Plains reflect detrital contributions from Laramide basement uplifts (Singler and Picard, 1979), but floral evidence suggests that their headwaters within the eroded Laramide province stood at elevations generally less than about 1,000 m (Epis and Chapin, 1975). Much lower Paleogene elevations than present ones are also indicated for the Laramide province by warm temperate to subtropical mammalian faunas, suggesting elevations less than about 300 m for the Eocene lakes that occupied large parts of the ponded basins (Hansen, 1985).

Miocene dispersal systems continued to transport sediment eastward into the Great Plains (Scott, 1975). Sandstones of similar petrofacies derived from various sources within the Laramide province recur at stratigraphic horizons ranging in age from Oligocene to Pliocene within the High Plains sequence (Stanley, 1976). Miocene and younger uplift of as much as 3,000 m in central Colorado, however, was accompanied by block faulting that both disrupted and incised local drainages (Epis and others, 1980). Neogene deformation produced structural relief of as much as 10–12 km along the trend of the Rio Grande rift in southern Colorado (Taylor, 1975), and abundant mammalian faunas collected farther south in New Mexico indicate that intrarift sedimentation was Miocene and younger (Tedford, 1981). Sedimentological studies suggest that pronounced Neogene uplift within the Laramide province did not begin until late Miocene or early Pliocene time (Sato and Denson, 1967).

GEODYNAMIC IMPLICATIONS

There is widespread agreement that the formation of Laramide uplifts and basins involved severe contraction of the continental crust (Berg, 1981; Blackstone, 1983; Gries, 1983a; Hamilton, 1988). Seismic reflection profiles across typical Laramide uplifts indicate that thrusts along their flanks penetrate deep into continental basement (Berg, 1963; Smithson and others, 1979; Brewer and others, 1980; Lynn and others, 1983; Erslev, 1986); other Laramide uplifts may be broad, arch-like folds (Bird, 1984).

Subducted Slab

The advent of plate tectonics led to inferences that Laramide compressive stresses were transmitted tangentially through continental basement rocks from the active plate boundary along the continental margin to the west (Sales, 1968). Most recent analyses have concluded instead that the compressive stresses arose from shear between the continental lithosphere and an underlying subhorizontal slab of oceanic lithosphere subducted beneath the Laramide province (Dickinson and Snyder, 1978). This model is supported by analogous relations in the modern Andean orogen (Jordan and others, 1983). By inference, magma generation beneath the Laramide province was controlled by the subterranean position of a slab hingeline, where the nearly flat part of the subducted slab curled over to descend into the asthenosphere (Bird, 1984).

Shallow slab subduction during the Laramide episode has been attributed to several possible causes, acting alone or in combination (Coney, 1978; Cross and Pilger, 1978a, 1982; Molnar and Atwater, 1978; Livaccari and others, 1981; Engebretson and others, 1984; Jurdy, 1984): (a) increased net velocity of relative plate convergence at the trench along the continental margin, (b) increased trenchward motion of the overriding plate in an absolute reference frame, (c) decreasing age and consequent increasing buoyancy of the oceanic lithosphere being subducted, and (d) the presence of a buoyant oceanic plateau or aseismic ridge on the plate being subducted.

Diachronous termination of Laramide deformation from north to south (Fig. 10) supports the geometric argument that subduction of a linear aseismic ridge controlled Laramide events (Henderson and others, 1984). A modern analogue of the Laramide province in the Sierras Pampeanas of northwest Argentina may also be related to subduction of an aseismic ridge (Jordan and Allmendinger, 1986), as first suggested by Pilger (1981, 1984). In the Andean case, known variations in plate convergence rate, absolute plate motion, and age of subducted oceanic lithosphere appear insufficient to explain observed variations in slab dip.

Plateau Rotation

Hamilton (1981) suggested that internal deformation within the Laramide province involved a few degrees of clockwise rotation of the Colorado Plateau with respect to the interior of the continent. This effect could have been achieved by partial coupling of the Colorado Plateau block to the underlying subducted plate whose drag beneath the continental lithosphere caused Laramide deformation (Cross, 1986; Hamilton, 1988). Relative clockwise rotation of the Colorado Plateau about a Euler pole located east of the Laramide province requires northward translation of the Colorado Plateau block with respect to the Rocky Mountain region. This implied motion is compatible with suggested wrench tectonism along the trend of the axial basins (Chapin and Cather, 1981, 1983; Gries, 1983b).

Chapin and Cather (1981, 1983) and Gries (1983b) have also suggested that structures related directly to plateau rotation formed at a different time than did other Laramide structures. North-south structures related to east-west crustal contraction are inferred by them to date from latest Cretaceous and Paleocene time, whereas the wrench-related structures around the axial basins, and east-west structures related to north-south crustal contraction, are inferred by them to be Eocene features. Our analysis of the sedimentary evolution of Laramide basins and a parallel analysis of their bounding structures (Cross, 1986) imply instead that the intricate geometry of Laramide uplifts and basins with diverse structural trends probably developed jointly within a complex but generally synchronous strain field imposed across a region of varied crustal architecture.

Crust-Mantle Relations

Bird (1984) has argued that flowage of lower crust being dragged from west to east by the shear traction of the underlying subhorizontal slab of subducted oceanic lithosphere caused crustal thickening and uplift within the Laramide province. A preceding episode of Campanian subsidence throughout the Laramide province records the displacement of underlying asthenosphere by denser lithosphere during initial shallowing of slab dip prior to the Maastrichtian onset of Laramide deformation (Cross and Pilger, 1978b). The present high elevation of the Colorado Plateau, Rocky Mountains, and Great Plains can be attributed in part to the presence of thick crust inherited from Laramide deformation. The nature of the post-Laramide landscape, however, indicates that the region probably did not stand as high during the Oligocene as it does today. Trimble (1980) argued that the present elevation of the Great Plains was attained by regional uplift that began at about the end of Miocene time.

We conclude that a significant proportion of the present elevation of the Laramide province and adjoining regions was produced by Neogene geodynamic processes operating within the mantle. Broad uplift of the region as a whole may reflect the isostatic effect of anomalously warm mantle emplaced by delamination of subcrustal continental lithosphere (Bird, 1979), subduction of an oceanic spreading center (Damon, 1979), or creation of a slab window (Dickinson and Snyder, 1979).

PRINCIPAL CONCLUSIONS

1. Paleogeographic subdivision of Laramide basins into perimeter, axial, and ponded groups differs from previous morphostructural classifications.
2. The onset of Laramide deformation was approximately synchronous throughout the main Laramide province during Maastrichtian time.
3. The termination of Laramide deformation was systematically diachronous from north to south from early to late Eocene time.
4. In parts of Eocene time, large lake basins that occupied much of the Laramide province may have drained to the sea through the Pacific Northwest.
5. Laramide basin chronology supports the concept that subduction of a linear aseismic ridge beneath the continental margin influenced Laramide deformation.

ACKNOWLEDGMENTS

We thank T. J. Brown, R. A. Leveque, S. R. May, K. H. Meldahl, D. R. Richards, C. H. Smith, D. A. Stoneman, L. T. Sumpter, T. C. Sutter, L. K. Vedder, E. E. Wohl, and A. E. Yiannakakis for help in data compilation. Discussions with D. W. Andersen, Peter Bird, Andrew Cohen, C. G. Chase, P. J. Coney, K. P. Furlong, Warren Hamilton, P. L. Heller, T. E. Jordan, T. F. Lawton, J. A. Lillegraven, R. C. Surdam, G. W. Viele, and C. D. Winker also aided our thinking. Our work was supported by the Laboratory of Geotectonics in the Department of Geosciences at the University of Arizona. Reviews by T. A. Cross, W. J. Perry, and J. R. Steidtmann improved the text.

REFERENCES CITED

Andersen, D. W., and Picard, M. D., 1972, Stratigraphy of the Duchesne River Formation, northern Uinta basin, northeastern Utah: Utah Geological and Mineralogical Survey Bulletin 97, 23 p.

Armstrong, R. L., 1968, Sevier orogenic belt in Nevada and Utah: Geological Society of America Bulletin, v. 79, p. 429–458.

Ayers, W. B., Jr., 1986, Lacustrine and fluvial-deltaic depositional systems, Fort Union Formation (Paleocene), Powder River basin, Wyoming and Montana: American Association of Petroleum Geologists Bulletin, v. 70, p. 1651–1673.

Ayers, W. B., Jr., and Kaiser, W. R., 1984, Lacustrine-interdeltaic coal in the Fort Union Formation (Palaeocene), Powder River basin, Wyoming and Montana, *in* Rahmani, R. A., and Flores, R. M., eds., Sedimentology of coal and coal-bearing sequences: International Association of Sedimentologists Special Publication No. 7, p. 61–84.

Baltz, E. H., 1965, Stratigraphy and history of Raton basin and notes on San Luis basin, Colorado–New Mexico: American Association of Petroleum Geologists Bulletin, v. 49, p. 2041–2075.

——— 1967, Stratigraphy and regional tectonic implications of part of Upper Cretaceous and Tertiary rocks, east-central San Juan basin, New Mexico: U.S. Geological Survey Professional Paper 552, 101 p.

Berg, R. R., 1962, Mountain flank thrusting in Rocky Mountain foreland, Wyoming and Colorado: American Association of Petroleum Geologists Bulletin, v. 46, p. 2019–2032.

——— 1963, Laramide sediments along Wind River thrust, Wyoming, *in* Childs, O. E., and Beebe, B. W., eds., Backbone of the Americas: American Association of Petroleum Geologists Memoir 2, p. 220–230.

——— 1981, Review of thrusting in the Wyoming foreland: University of Wyoming Contributions to Geology, v. 19, p. 93–104.

Berggren, W. A., Kent, D. V., Flynn, J. J., and Van Couvering, J. A., 1985, Cenozoic geochronology: Geological Society of America Bulletin, v. 96, p. 1407–1418.

Bird, P., 1979, Continental delamination and the Colorado Plateau: Journal of Geophysical Research, v. 84, p. 7561–7571.

——— 1984, Laramide crustal thickening event in the Rocky Mountain foreland and Great Plains: Tectonics, v. 3, p. 741–758.

Blackstone, D. L., Jr., 1975, Late Cretaceous and Cenozoic history of Laramie basin region, southeast Wyoming, *in* Curtis, B. F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 249–279.

——— 1983, Laramide compressional tectonics, southeastern Wyoming: University of Wyoming Contributions to Geology, v. 22, p. 1–38.

Bown, T. M., 1975, Paleocene and lower Eocene rocks in the Sand Creek–No Water Creek area, Washakie County, Wyoming, *in* Exum, F. A., and George, G. R., eds., Geology and mineral resources of the Bighorn basin: Wyoming Geological Association, 27th Annual Field Conference Guidebook, p. 55–61.

——— 1980, Summary of latest Cretaceous and Cenozoic sedimentary, tectonic, and erosional events, Bighorn basin, Wyoming, *in* Gingerich, P. D., ed., Early Cenozoic paleontology and stratigraphy of the Bighorn basin, Wyoming: University of Michigan Papers on Paleontology No. 24, p. 25–32.

——— 1982, Geology, paleontology, and correlation of Eocene volcaniclastic rocks, southeast Absaroka Range, Hot Springs County, Wyoming: U.S. Geological Survey Professional Paper 1201-A, p. A1–A75.

Brewer, J. A., Smithson, S. B., Oliver, J. E., Kaufman, S., and Brown, L. D., 1980, The Laramide orogeny: Evidence from COCORP deep crustal seismic profiles in the Wind River Mountains, Wyoming: Tectonophysics, v. 62, p. 165–189.

Briggs, L. I., and Goddard, E. N., 1956, Geology of Huerfano Park, Colorado, *in* McGinnis, C. J., ed., Guidebook to the geology of the Raton basin, Colorado: Denver, Colorado, Rocky Mountain Association of Geologists, p. 40–45.

Bruhn, R. L., Picard, M. D., and Isby, J. S., 1986, Tectonics and sedimentology of Uinta arch, western Uinta Mountains, and Uinta basin, *in* Peterson, J. A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 333–352.

Cather, S. M., 1986, Tectonic and petrogenetic implications of the Datil Group (latest Eocene–early Oligocene), west-central New Mexico: Geological Society of America Abstracts with Programs, v. 18, p. 560.

Cather, S. M., and Johnson, B. D., 1984, Eocene tectonics and depositional setting of west-central New Mexico and eastern Arizona: New Mexico Bureau of Mines and Mineral Resources Circular 192, 33 p.

——— 1986, Eocene depositional systems and tectonic framework of west-central New Mexico and eastern Arizona, *in* Peterson, J. A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 623–652.

Chadwick, R. A., 1981, Chronology and structural setting of volcanism in southwestern and central Montana, *in* Tucker, E. E., ed., Southwest Montana: Billings, Montana Geological Society, p. 301–310.

Chapin, C. E., and Cather, S. M., 1981, Eocene tectonics and sedimentation in the Colorado Plateau–Rocky Mountain area, *in* Dickinson, W. R., and Payne, W. D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 173–198.

——— 1983, Eocene tectonics and sedimentation in the Colorado Plateau–Rocky Mountain area, *in* Lowell, J. D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colorado, Rocky Mountain Association of Geologists, p. 33–56.

Cherven, V. B., and Jacob, A. F., 1985, Evolution of Paleogene depositional systems, Williston basin, in response to global sea-level changes, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 3, p. 127–170.

Childers, M. O., 1970, Uranium geology of the Kaycee area, Johnson County, Wyoming, *in* Enyert, R. L., ed., Symposium on Wyoming sandstones: Wyoming Geological Society, 22nd Annual Field Conference Guidebook, p. 13–20.

Clark, J., 1975, Controls of sedimentation and provenance of sediments in the Oligocene of the central Rocky Mountains, *in* Curtis, B. F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 95–117.

Coney, P. J., 1972, Cordilleran tectonics and North American plate motion: American Journal of Science, v. 272, p. 603–628.

——— 1973, Non-collision tectogenesis in western North America, *in* Tarling, D. H., and Runcorn, S. H., eds., Implications of continental drift to the earth sciences: New York, Academic Press, p. 713–727.

——— 1976, Plate tectonics and the Laramide orogeny, *in* Woodward, L. A., and Northrop, S. A., Tectonics and mineral deposits of southwestern North America: New Mexico Geological Society Special Publication No. 6, p. 5–10.

——— 1978, Mesozoic-Cenozoic Cordilleran plate tectonics, *in* Smith, R. B., and Eaton, G. P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 33–50.

Coney, P. J., and Reynolds, S. J., 1977, Cordilleran Benioff zones: Nature, v. 270, p. 403–406.

Cross, T. A., 1986, Tectonic controls of foreland basin subsidence and Laramide style deformation, western United States, *in* Allen, P. A., and Homewood, P., eds., Foreland basins: International Association of Sedimentologists Special Publication No. 8, p. 15–39.

Cross, T. A., and Pilger, R. H., Jr., 1978a, Constraints on absolute motion and plate interaction inferred from Cenozoic igneous activity in the western United States: American Journal of Science, v. 278, p. 865–902.

——— 1978b, Tectonic controls of Late Cretaceous sedimentation, western interior, USA: Nature, v. 274, p. 653–657.

——— 1982, Controls of subduction geometry, location of magmatic arcs, and tectonics of arc and back-arc regions: Geological Society of America Bulletin, v. 93, p. 545–562.

Curry, W. H., III, 1971, Laramide structural history of the Powder River basin, Wyoming, *in* Renfro, A. R., ed., Symposium on Wyoming tectonics and their economic significance: Wyoming Geological Association, 23rd Annual Field Conference Guidebook, p. 49–60.

——— 1973, Late Cretaceous and early Tertiary rocks of southwestern Wyoming, *in* Schell, E. M., ed., The geology and mineral resources of the greater Green River basin: Wyoming Geological Association, 25th Annual Field Conference Guidebook, p. 79–86.

Damon, P. E., 1979, Continental uplift at convergent boundaries: Tectonophysics, v. 61, p. 307–319.

DeCelles, P. G., 1986, Sedimentation in a tectonically partitioned, nonmarine foreland basin: The Lower Cretaceous Kootenai Formation, southwestern Montana: Geological Society of America Bulletin, v. 97, p. 911–931.

Dickinson, W. R., 1976, Sedimentary basins developed during evolution of Mesozoic-Cenozoic arc-trench system in western North America: Canadian Journal of Earth Sciences, v. 13, p. 1268–1287.

Dickinson, W. R., and Snyder, W. S., 1978, Plate tectonics of the Laramide orogeny, *in* Matthews, V., III, ed., Laramide folding associated with basement block faulting in the western United States: Geological Society of America Memoir 151, p. 355–366.

——— 1979, Geometry of subducted slabs related to San Andreas transform: Journal of Geology, v. 87, p. 609–627.

Dickinson, W. R., Ingersoll, R. V., and Graham, S. A., 1979, Paleogene sediment dispersal and paleotectonics in northern California: Geological Society of America Bulletin, Part II, v. 90, p. 1458–1528.

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

Dobbin, C. E., Bowen, C. F., and Hoots, H. W., 1929, Geology and coal and oil resources of the Hanna and Carbon basins, Carbon County, Wyoming: U.S. Geological Survey Bulletin 804, 88 p.

Dorr, J. A., Jr., Spearing, D. R., and Steidtmann, J. R., 1977, Deformation and deposition between a foreland uplift and an impinging thrust belt: Hoback basin, Wyoming: Geological Society of America Special Paper 177, 82 p.

Engebretson, D. C., Cox, A., and Thompson, G. A., 1984, Correlation of plate motions with continental tectonics: Laramide to Basin-Range: Tectonics, v. 3, p. 115–119.

Epis, R. C., and Chapin, C. E., 1975, Geomorphic and tectonic implications of the post-Laramide, late Eocene erosion surface in the southern Rocky Mountains, *in* Curtis, B. F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 45–74.

Epis, R. C., Scott, G. R., Taylor, R. B., and Chapin, C. E., 1980, Summary of Cenozoic geomorphic, volcanic, and tectonic features of central Colorado and adjoining areas, *in* Kent, H. C., and Porter, K. W., Colorado geology: Denver, Colorado, Rocky Mountain Association of Geologists, p. 135–156.

Erslev, E. A., 1986, Basement balancing of Rocky Mountain foreland uplifts: Geology, v. 14, p. 259–262.

Ethridge, F. G., Jackson, T. J., and Youngberg, A. D., 1981, Floodbasin sequence of a fine-grained meander belt subsystem: The coal-bearing lower Wasatch and upper Fort Union Formations, southern Powder River basin, Wyoming, *in* Ethridge, F. G., and Flores, R. M., eds., Recent and ancient nonmarine depositional environments: Models for exploration: Society of Economic Paleontologists and Mineralogists Special Publication No. 31, p. 191–209.

Fassett, J. E., 1974, Cretaceous and Tertiary rocks of the eastern San Juan basin, New Mexico and Colorado, *in* Siemers, C. T., ed., Central-northern New Mexico: New Mexico Geological Society, 25th Annual Field Conference Guidebook, p. 225–230.

Fassett, J. E., and Hinds, J. S., 1971, Geology and fuel resources of the Fruitland Formation and Kirtland Shale of the San Juan basin, New Mexico and Colorado: U.S. Geological Survey Professional Paper 676, 76 p.

Flores, R. M., 1981, Coal deposition in fluvial paleoenvironments of the Paleocene Tongue River Member of the Fort Union Formation, Powder River area, Powder River basin, Wyoming and Montana, *in* Ethridge, F. G., and Flores, R. M., eds., Recent and ancient nonmarine depositional environments: Models for exploration: Society of Economic Paleontologists and Mineralogists Special Publication No. 31, p. 169–190.

——— 1983, Basin facies analysis of coal-rich Tertiary fluvial deposits, northern Powder River basin, Montana and Wyoming, *in* Collinson, J. D., and Lewin, J., eds., Modern and ancient fluvial systems: International Association of Sedimentologists Special Publication No. 6, p. 501–515.

——— 1986, Styles of coal deposition in Tertiary alluvial deposits, Powder River basin, Montana and Wyoming, *in* Lyons, P. C., and Rice, C. L., eds., Paleoenvironmental and tectonic controls in coal-forming basins of the United States: Geological Society of America Special Paper 210, p. 79–104.

Flores, R. M., and Ethridge, F. G., 1985, Evolution of intermontane fluvial systems of Tertiary Powder River basin, Montana and Wyoming, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 3, p. 107–126.

Flores, R. M., and Hanley, J. H., 1984, Anastomosed and associated coal-bearing fluvial deposits: Upper Tongue River Member, Palaeocene Fort Union Formation, northern Powder River basin, Wyoming, U.S.A., *in* Rahmani, R. A., and Flores, R. M., eds., Sedimentology of coal and coal-bearing sequences: International Association of Sedimentologists Special Publication No. 7, p. 85–103.

Fouch, T. D., 1975, Lithofacies and related hydrocarbon accumulations in Tertiary strata of the western and central Uinta basin, Utah, *in* Bolyard, D. W., ed., Deep drilling frontiers of the central Rocky Mountains: Denver, Colorado, Rocky Mountain Association of Geologists, p. 163–173.

Fouch, T. D., Hanley, J. H., and Forester, R. M., 1979, Preliminary correlation of Cretaceous and Paleogene lacustrine and related nonmarine sedimentary and volcanic rocks in parts of the eastern Great Basin of Nevada and Utah, *in* Newman, G. W., and Goode, H. D., Basin and Range symposium: Denver, Colorado, Rocky Mountain Association of Geologists, p. 305–312.

Fritz, W. J., and Harrison, S., 1985, Early Tertiary volcaniclastic deposits of the northern Rocky Mountains, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 3, p. 383–402.

Gingerich, P. D., 1983, Paleocene-Eocene faunal zones and a preliminary analysis of Laramide structural deformation in the Clark's Fork basin, Wyoming, *in* Boberg, W. W., ed., Geology of the Bighorn basin: Wyoming Geological Association, 34th Annual Field Conference Guidebook, p. 185–195.

Glass, G. B., and Roberts, J. T., 1980, Update on the Hanna coal field, Wyoming, *in* Hollis, S., ed., Stratigraphy of Wyoming: Wyoming Geological Association, 31st Annual Field Conference Guidebook, p. 239–262.

Gorham, T. W., and Ingersoll, R. V., 1979, Evolution of the Eocene Galisteo basin, north-central New Mexico, *in* Ingersoll, R. V., ed., Guidebook of Santa Fe country: New Mexico Geological Society, 30th Annual Field Conference Guidebook, p. 219–224.

Gresens, R. L., 1981, Extension of the Telluride erosion surface to Washington state, and its regional and tectonic significance: Tectonophysics, v. 79, p. 145–164.

Gries, R., 1983a, Oil and gas prospecting beneath Precambrian of foreland thrust plates in Rocky Mountains: American Association of Petroleum Geologists Bulletin, v. 67, p. 1–28.

——— 1983b, North-south compression of Rocky Mountain foreland structures, *in* Lowell, J. D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colorado, Rocky Mountain Association of Geologists, p. 9–32.

Gromme, C. S., Beck, M. E., Jr., Wells, R. E., and Engebretson, D. C., 1986, Paleomagnetism of the Tertiary Clarno Formation of central Oregon and its significance for the tectonic history of the Pacific Northwest: Journal of Geophysical Research, v. 91, p. 14089–14103.

Grose, L. T., 1972, Tectonics of the Rocky Mountain region, *in* Mallory, W. W., ed., Geologic atlas of the Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists, p. 35–44.

Hagen, E. S., Schuster, M. W., and Furlong, K. P., 1985, Tectonic loading and subsidence of intermontane basins, Wyoming foreland province: Geology, v. 13, p. 529–532.

Hail, W. J., Jr., 1965, Geology of northwestern North Park, Colorado: U.S. Geological Survey Bulletin 1188, 133 p.

——— 1968, Geology of southwestern North Park and vicinity, Colorado: U.S. Geological Survey Bulletin 1257, 119 p.

Hamilton, W., 1981, Plate-tectonic mechanism of Laramide deformation: University of Wyoming Contributions to Geology, v. 19, p. 87–92.

——— 1988, Laramide crustal shortening, *in* Schmidt, C. J., and Perry, W. J., Jr., eds., Interaction of the Rocky Mountain foreland and the Cordilleran thrust belt: Geological Society of America Memoir 171 (in press).

Hansen, D. E., 1986, Laramide tectonics and deposition of the Ferris and Hanna Formations, south-central Wyoming, *in* Peterson, J. A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 481–495.

Hansen, W. R., 1984, Post-Laramide tectonic history of the eastern Uinta Mountains, Utah, Colorado, and Wyoming: Mountain Geologist, v. 21, p. 5–29.

——— 1985, Drainage development of the Green River basin in southwestern Wyoming and its bearing on fish biogeography, neotectonics, and paleoclimates: Mountain Geologist, v. 22, p. 192–204.

——— 1986, Neogene tectonics and geomorphology of the eastern Uinta Mountains in Utah, Colorado, and Wyoming: U.S. Geological Survey Professional Paper 1356, 78 p.

Heller, P. L., 1983, Sedimentary response to Eocene tectonic rotation in western Oregon [Ph.D. dissert.]: Tucson, Arizona, University of Arizona, 321 p.

Heller, P. L., and Ryberg, P. T., 1983, Sedimentary record of subduction to forearc transition in the rotated Eocene basin of western Oregon: Geology, v. 11, p. 380–383.

Heller, P. L., Peterman, Z. E., O'Neill, J. R., and Shafiqullah, M., 1985, Isotopic provenance of sandstones from the Eocene Tyee Formation, Oregon Coast Range: Geological Society of America Bulletin, v. 96, p. 770–780.

Heller, P. L., Tabor, R. W., and Suczek, C. A., 1987, Paleogeographic evolution of the U.S. Pacific Northwest: Canadian Journal of Earth Sciences, v. 24, p. 1652–1667.

Henderson, L. J., Gordon, R. G., and Engebretson, D. C., 1984, Mesozoic aseismic ridges on the Farallon plate and southward migration of shallow subduction during the Laramide orogeny: Tectonics, v. 3, p. 121–132.

Izett, G. A., 1968, Geology of the Hot Sulphur Springs quadrangle, Grand County, Colorado: U.S. Geological Survey Professional Paper 586, 79 p.

Johnson, R. B., and Wood, G. H., Jr., 1956, Stratigraphy of Upper Cretaceous and Tertiary rocks of Raton basin, Colorado and New Mexico: American Association of Petroleum Geologists Bulletin, v. 40, p. 707–721.

Johnson, R. B., Dixon, G. H., and Wanek, A. A., 1966, Late Cretaceous and Tertiary stratigraphy of the Raton basin of New Mexico and Colorado, *in* Northrop, S. A., and Read, C. B., eds., Taos-Raton–Spanish Peaks country, New Mexico and Colorado: New Mexico Geological Society, 17th Annual Field Conference Guidebook, p. 88–98.

Johnson, R. C., 1985, Early Cenozoic history of the Uinta and Piceance Creek basins, Utah and Colorado, with special reference to the development of Eocene Lake Uinta, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 3, p. 247–276.

Jordan, T. E., and Allmendinger, R. W., 1986, The Sierras Pampeanas of Argentina: A modern analogue of Rocky Mountain foreland deformation: American Journal of Science, v. 286, p. 737–764.

Jordan, T. E., Isacks, B. L., Allmendinger, R. W., Brewer, J. A., Ramos, V. A., and Ando, C. J., 1983, Andean tectonics related to geometry of subducted Nazca plate: Geological Society of America Bulletin, v. 94, p. 341–361.

Jurdy, D. M., 1984, The subduction of the Farallon plate beneath North America as derived from relative plate motions: Tectonics, v. 3, p. 107–113.

Kauffman, E. G., 1977, Geological and biological overview, western interior Cretaceous basin: Mountain Geologist, v. 14, p. 75–99.

Keefer, W. R., 1965a, Geologic history of Wind River basin, central Wyoming: American Association of Petroleum Geologists Bulletin, v. 49, p. 1878–1892.

——— 1965b, Stratigraphy and geologic history of the uppermost Cretaceous, Paleocene, and lower Eocene rocks in the Wind River basin, Wyoming: U.S. Geological Survey Professional Paper 495-A, p. A1–A77.

Klute, M. A., 1986, Sedimentology and sandstone petrography of the upper Kirtland Shale and Ojo Alamo Sandstone, Cretaceous-Tertiary boundary, western and southern San Juan basin, New Mexico: American Journal of Science, v. 286, p. 463–488.

Kraus, M. J., 1980, Genesis of a fluvial sheet sandstone, Willwood Formation, northwest Wyoming, *in* Gingerich, P. D., ed., Early Cenozoic paleontology and stratigraphy of the Bighorn basin, Wyoming: University of Michigan Papers on Paleontology No. 24, p. 94–101.

——— 1985, Early Tertiary quartzite conglomerates of the Bighorn basin and their significance for paleogeographic reconstruction of northwest Wyoming, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 3, p. 71–91.

Lillegraven, J. A., 1970, Stratigraphy, structure, and vertebrate fossils of the Oligocene Brule Formation, Slim Buttes, northwestern South Dakota: Geological Society of America Bulletin, v. 81, p. 831–850.

Livaccari, R. F., Burke, K., and Sengor, A.M.C., 1981, Was the Laramide orogeny related to subduction of an oceanic plateau?: Nature, v. 289, p. 276–278.

Love, J. D., 1970, Cenozoic geology of the Granite Mountains area, central Wyoming: U.S. Geological Survey Professional Paper 495-C, p. C1–C154.

——— 1971, Relation of Cenozoic geologic events in the Granite Mountains area, central Wyoming, to economic deposits, *in* Renfro, A. R., ed., Symposium on Wyoming tectonics and their economic significance: Wyoming Geological Association, 23rd Annual Field Conference Guidebook, p. 71–80.

Love, J. D., McGrew, P. O., and Thomas, H. D., 1963, Relationship of latest Cretaceous and Tertiary deposition and deformation to oil and gas in Wyoming, *in* Childs, O. E., and Beebe, B. W., eds., Backbone of the Americas: American Association of Petroleum Geologists Memoir 2, p. 196–208.

Lucas, S. G., and Ingersoll, R. V., 1981, Cenozoic continental deposits of New Mexico: An overview: Geological Society of America Bulletin, v. 92, p. 917–932.

Lucas, S. G., Schoch, R. M., Manning, E., and Tsentas, C., 1981, The Eocene biostratigraphy of New Mexico: Geological Society of America Bulletin, v. 92, p. 2268–2307.

Lynn, H. B., Quam, S., and Thompson, G. A., 1983, Depth migration and interpretation of the COCORP Wind River, Wyoming, seismic reflection data: Geology, v. 11, p. 462–469.

Mauger, R. L., 1977, K-Ar ages of biotites from tuffs in Eocene rocks of the Green River, Washakie, and Uinta basins, Utah, Wyoming, and Colorado: University of Wyoming Contributions to Geology, v. 15, p. 17–42.

McGookey, D. P., 1972, Cretaceous System, *in* Mallory, W. W., ed., Geologic atlas of the Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists, p. 190–228.

McGrew, P. O., 1971, The Tertiary history of Wyoming, *in* Renfro, A. R., ed., Symposium on Wyoming tectonics and their economic significance: Wyoming Geological Association, 23rd Annual Field Conference Guidebook, p. 29–33.

McMannis, W. J., 1965, Résumé of depositional and structural history of western Montana: American Association of Petroleum Geologists Bulletin, v. 49, p. 1801–1823.

Merewether, E. A., and Cobban, W. A., 1986, Biostratigraphic units and tectonism in the mid-Cretaceous foreland of Wyoming, Colorado, and adjoining areas, *in* Peterson, J. A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 443–468.

Molenaar, C. M., 1977, Stratigraphy and depositional history of Upper Cretaceous rocks of the San Juan basin area, New Mexico and Colorado, *in* Fassett, J. E., ed., Guidebook of San Juan basin III, northwestern New Mexico: New Mexico Geological Society, 28th Annual Field Conference Guidebook, p. 159–166.

Molnar, P., and Atwater, T., 1978, Interarc spreading and Cordilleran tectonics as alternates related to the age of subducted oceanic lithosphere: Earth and Planetary Science Letters, v. 41, p. 330–340.

Morse, D. G., 1985, Oligocene paleogeography in the southern Denver basin, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountains Paleogeography Symposium 3, p. 277–292.

Mudge, M. R., 1982, A résumé of the structural geology of the northern disturbed belt, northwestern Montana, *in* Powers, R. B., ed., Geologic studies of the Cordilleran thrust belt: Denver, Colorado, Rocky Mountain Association of Geologists, p. 91–122.

Nations, D., Wilt, J. C., and Hevly, R. H., 1985, Cenozoic paleogeography of Arizona, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 3, p. 335–355.

Neasham, J. W., and Vondra, C. F., 1972, Stratigraphy and petrology of the lower Eocene Willwood Formation, Bighorn basin, Wyoming: Geological Society of America Bulletin, v. 83, p. 2167–2180.

Perry, W. J., Jr., Wardlaw, B. R., Bostick, N. H., and Maughan, E. K., 1983, Structure, burial history, and petroleum potential of frontal thrust belt and adjacent foreland, southwest Montana: American Association of Petroleum Geologists Bulletin, v. 67, p. 725–743.

Phillips, S. T., 1983, Tectonic influence on sedimentation, Waltman Member, Fort Union Formation, Wind River Basin, Wyoming, *in* Lowell, J. D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colorado, Rocky Mountain Association of Geologists, p. 149–160.

Picard, M. D., 1985, Hypotheses of oil-shale genesis, Green River Formation, northeast Utah, northwest Colorado, and southwest Wyoming, *in* Picard, M. D., ed., Geology and energy resources, Uinta basin of Utah: Salt Lake City, Utah Geological Association, p. 193–210.

Pilger, R. H., Jr., 1981, Plate reconstructions, aseismic ridges and low-angle subduction beneath the Andes: Geological Society of America Bulletin, Part I, v. 92, p. 448–456.

——— 1984, Cenozoic plate kinematics, subduction and magmatism: South American Andes: Geological Society of London Journal, v. 141, p. 793–802.

Potter, P. E., 1978, Petrology and chemistry of modern big river sands: Journal of Geology, v. 86, p. 423–449.

Rea, B. D., and Barlow, J. A., Jr., 1975, Upper Cretaceous and Tertiary rocks, northern part of Bighorn basin, Wyoming and Montana, *in* Exum, F. A., and George, G. R., eds., Geology and mineral resources of the Bighorn basin: Wyoming Geological Association, 27th Annual Field Conference Guidebook, p. 63–71.

Rice, D. D., 1976, Stratigraphic sections from well logs and outcrops of Cretaceous and Paleocene rocks, northern Great Plains, Montana: U.S. Geological Survey Oil and Gas Investigations Chart OC-71, 3 sheets.

Roberts, A. E., 1972, Cretaceous and early Tertiary depositional and tectonic history of the Livingston area, southwestern Montana: U.S. Geological Survey Professional Paper 526-C, p. C1–C120.

Roehler, H. W., 1973, Stratigraphy of the Washakie Formation in the Washakie basin, Wyoming: U.S. Geological Survey Bulletin 1369, 40 p.

——— 1974, Depositional environments of rocks in the Piceance Creek basin, Colorado, *in* Murray, D. K., ed., Energy resources of the Piceance Creek basin, Colorado: Rocky Mountain Association of Geologists, 25th Field Conference Guidebook, p. 57–64.

——— 1979a, Geology and energy resources of the Sand Butte Rim NW quadrangle, Sweetwater County, Wyoming: U.S. Geological Survey Professional Paper 1055-A, p. A1–A54.

——— 1979b, Geology and energy resources of the Cooper Ridge NE quadrangle, Sweetwater County, Wyoming: U.S. Geological Survey Professional Paper 1065-B, p. B1–B45.

Rose, K. D., 1981, The Clarkforkian land-mammal age and mammalian faunal composition across the Paleocene-Eocene boundary: University of Michigan Papers on Paleontology No. 26, 196 p.

Ryan, J. D., 1977, Late Cretaceous and early Tertiary provenance and sediment dispersal, Hanna and Carbon basins, Carbon County, Wyoming: Wyoming Geological Survey Preliminary Report No. 16, 17 p.

Ryder, R. T., Fouch, T. D., and Elison, J. H., 1976, Early Tertiary sedimentation in the western Uinta basin: Geological Society of America Bulletin, v. 87, p. 496–512.

Sales, J. K., 1968, Crustal mechanics of Cordilleran foreland deformation: A regional and scale-model approach: American Association of Petroleum Geologists Bulletin, v. 52, p. 2016–2044.

Sato, Y., and Denson, N. M., 1967, Volcanism and tectonism as reflected by the distribution of nonopaque heavy minerals in some Tertiary rocks of Wyoming and adjacent states: U.S. Geological Survey Professional Paper 575-C, p. C42–C54.

Schmidt, C. J., and Garihan, J. M., 1983, Laramide tectonic development of the Rocky Mountain foreland of southwestern Montana, *in* Lowell, J. D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colorado, Rocky Mountain Association of Geologists, p. 271–294.

Schwartz, R. K., 1982, Broken Early Cretaceous foreland basin in southwestern Montana: Sedimentation related to tectonism, *in* Powers, R. B., ed., Geologic studies of the Cordilleran thrust belt: Denver, Colorado, Rocky Mountain Association of Geologists, p. 159–183.

Scott, G. R., 1975, Cenozoic surfaces and deposits in the southern Rocky Mountains, *in* Curtis, B. F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 227–248.

Scott, G. R., and Taylor, R. B., 1975, Post-Paleocene Tertiary rocks and Quaternary volcanic ash of the Wet Mountain Valley, Colorado: U.S. Geological Survey Professional Paper 868, 15 p.

Seager, W. R., 1983, Laramide wrench faults, basement-cored uplifts, and complementary basins in southern New Mexico: New Mexico Geology, v. 5, p. 69–76.

Seager, W. R., and Mack, G. H., 1986, Laramide paleotectonics of southern New Mexico, *in* Peterson, J. A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 669–685.

Seeland, D. A., 1976, Relationships between early Tertiary sedimentation patterns and uranium mineralization in the Powder River basin, Wyoming, *in* Laudon, R. B., ed., Geology and energy resources of the Powder River basin: Wyoming Geological Association, 28th Annual Field Conference Guidebook, p. 53–64.

——— 1978a, Sedimentology and stratigraphy of the lower Eocene Wind River Formation, central Wyoming, *in* Boyd, R. G., ed., Resources of the Wind River basin: Wyoming Geological Association, 30th Annual Field Conference Guidebook, p. 181–198.

——— 1978b, Eocene fluvial drainage patterns and their implications for uranium and hydrocarbon exploration in the Wind River basin, Wyoming: U.S. Geological Survey Bulletin 1446, 21 p.

——— 1985, Oligocene paleogeography of the northern Great Plains and adjacent mountains, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 3, p. 187–205.

Singler, C. R., and Picard, M. D., 1979, Petrography of White River Group (Oligocene) in northeast Nebraska and adjacent Wyoming: University of Wyoming Contributions to Geology, v. 18, p. 51–67.

Skipp, B., and McGrew, L. W., 1972, The Upper Cretaceous Livingston Group of the western Crazy Mountains basin, Montana, *in* Lynn, J., Balster, C., and Warne, J., eds., Crazy Mountains basin: Montana Geological Society, 21st Annual Field Conference Guidebook, p. 99–106.

Sklenar, S. E., and Andersen, D. W., 1985, Origin and evolution of an Eocene lake system within the Washakie basin of southwestern Wyoming, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 3, p. 231–245.

Smedes, H. W., and Prostka, H. J., 1972, Stratigraphic framework of the Absaroka Volcanic Supergroup in the Yellowstone National Park region: U.S. Geological Survey Professional Paper 729-C, p. C1–C33.

Smith, L. N., Lucas, S. G., and Elston, W. E., 1985, Paleogene stratigraphy, sedimentation, and volcanism of New Mexico, *in* Flores, R. M., and Kaplan, S. S., eds., Cenozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain Paleogeography Symposium 3, p. 293–315.

Smithson, S. B., Brewer, J. A., Kaufman, S., Oliver, J. A., and Hurich, C. A., 1979, Structure of the Laramide Wind River uplift, Wyoming, from COCORP deep reflection data and from gravity data: Journal of Geophysical Research, v. 84, p. 5955–5972.

Smoot, J. P., 1983, Depositional subenvironments in an arid closed basin; the Wilkins Peak Member of the Green River Formation (Eocene), Wyoming, U.S.A.: Sedimentology, v. 30, p. 801–827.

Soister, P. E., 1978, Stratigraphy of uppermost Cretaceous and lower Tertiary rocks of the Denver basin, *in* Pruitt, J. D., and Coffin, P. E., eds., Energy resources of the Denver basin: Denver, Rocky Mountain Association of Geologists, p. 223–230.

Soister, P. E., and Tschudy, R. H., 1978, Eocene rocks in the Denver basin, *in* Pruitt, J. D., and Coffin, P. E., eds., Energy resources of the Denver basin: Denver, Colorado, Rocky Mountain Association of Geologists, p. 231–235.

Solomon, B. J., McKee, E. H., and Andersen, D. W., 1979a, Stratigraphy and depositional environments of Paleogene rocks near Elko, Nevada, *in* Armentrout, J. M., Cole, M. R., and TerBest, H., Jr., eds., Cenozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 3, p. 75–88.

——— 1979b, Eocene and Oligocene lacustrine and volcanic rocks near Elko, Nevada, *in* Newman, G. W., and Goode, H. D., eds., Basin and Range symposium: Denver, Colorado, Rocky Mountain Association of Geologists, p. 325–337.

Spieker, E. M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geological Survey Professional Paper 205-D, p. 117–161.

Stanley, K. O., 1976, Sandstone petrofacies in the Cenozoic High Plains sequence, eastern Wyoming and Nebraska: Geological Society of America Bulletin, v. 87, p. 297–309.

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

Stark, J. T., Johnson, J. H., Behre, C. H., Jr., Powers, W. E., Howland, A. L., and Gould, D. B., 1949, Geology and origin of South Park, Colorado: Geological Society of America Memoir 33, 188 p.

Steven, T. A., 1975, Middle Tertiary volcanic field in the southern Rocky Mountains, *in* Curtis, B. F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 75–94.

Sullivan, R., 1980, A stratigraphic evaluation of the Eocene rocks of southwestern Wyoming: Wyoming Geological Survey Report of Investigations No. 20, 50 p.

——— 1985, Origin of lacustrine rocks of Wilkins Peak Member, Wyoming: American Association of Petroleum Geologists Bulletin, v. 69, p. 913–922.

Sundell, K. A., 1983, Volcanic stratigraphy, timing, and petroleum exploration in southeastern Absaroka Range, Big Horn basin, Wyoming [abs.]: American Association of Petroleum Geologists Bulletin, v. 67, p. 1357–1358.

——— 1986, Petroleum exploration in Absaroka basin of northwestern Wyoming [abs.]: American Association of Petroleum Geologists Bulletin, v. 70, p. 1058.

Surdam, R. C., and Stanley, K. O., 1979, Lacustrine sedimentation during the culminating phase of Eocene Lake Gosiute, Wyoming (Green River Formation): Geological Society of America Bulletin, Part I, v. 90, p. 93–110.

——— 1980a, The stratigraphic and sedimentologic framework of the Green River Formation, Wyoming, *in* Hollis, S., ed., Stratigraphy of Wyoming: Wyoming Geological Association, 31st Annual Field Conference Guidebook, p. 205–221.

——— 1980b, Effects of changes in drainage-basin boundaries on sedimentation in Eocene Lakes Gosiute and Uinta of Wyoming, Utah, and Colorado: Geology, v. 8, p. 135–139.

Sweeney, J. J., Burnham, A. K., and Braun, R. L., 1987, A model of hydrocarbon generation from Type 1 kerogen: Application to Uinta basin, Utah: American Association of Petroleum Geologists Bulletin, v. 71, p. 967–985.

Taylor, R. B., 1975, Neogene tectonism in south-central Colorado, *in* Curtis, B. F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 211–226.

Tedford, R. H., 1981, Mammalian biochronology of the late Cenozoic basins of New Mexico: Geological Society of America Bulletin, v. 92, p. 1008–1022.

Tonnsen, J. J., 1982, Zone of impingement between the western thrust belt and the foreland province in the Madison and Gallatin Ranges, southwestern Montana, *in* Powers, R. B., ed., Geologic studies of the Cordilleran thrust belt: Denver, Colorado, Rocky Mountain Association of Geologists, p. 185–192.

Trimble, D. E., 1980, Cenozoic tectonic history of the Great Plains contrasted with that of the southern Rocky Mountains: A synthesis: Mountain Geologist, v. 17, p. 59–69.

Tweto, O., 1975, Laramide (Late Cretaceous–early Tertiary) orogeny in the southern Rocky Mountains, *in* Curtis, B. F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 1–44.

——— 1980, Summary of Laramide orogeny in Colorado, *in* Kent, H. C., and Porter, K. W., eds., Colorado geology: Denver, Colorado, Rocky Mountain Association of Geologists, p. 129–134.

Tysdal, R. G., 1986, Thrust faults and back thrusts in Madison Range of southwestern Montana foreland: American Association of Petroleum Geologists Bulletin, v. 70, p. 360–376.

Tysdal, R. G., Marvin, R. F., and DeWitt, E., 1986, Late Cretaceous stratigraphy, deformation, and intrusion in the Madison Range of southwestern Montana: Geological Society of America Bulletin, v. 97, p. 859–868.

Van Hinte, J. E., 1978, Geohistory analysis—Application of micropaleontology in exploration geology: American Association of Petroleum Geologists Bulletin, v. 62, p. 201–222.

Weimer, R. J., 1960, Upper Cretaceous stratigraphy, Rocky Mountain area: American Association of Petroleum Geologists Bulletin, v. 444, p. 1–20.

——— 1970, Rates of deltaic sedimentation and intrabasin deformation, Upper Cretaceous of Rocky Mountain region, *in* Morgan, J. P., ed., Deltaic sedimentation, modern and ancient: Society of Economic Paleontologists and Mineralogists Special Publication Number 15, p. 270–292.

——— 1973, A guide to uppermost Cretaceous stratigraphy, central Front Range, Colorado: Deltaic sedimentation, growth faulting, and early Laramide crustal movement: Mountain Geologist, v. 10, p. 53–97.

Williams, G. D., and Stelck, C. R., 1975, Speculations on the Cretaceous paleogeography of North America, *in* Caldwell, W.G.E., ed., The Cretaceous system in the western interior of North America: Geological Association of Canada Special Paper No. 13, p. 1–20.

Wiltschko, D. V., and Dorr, J. A., Jr., 1983, Timing of deformation in overthrust belt and foreland of Idaho, Wyoming, and Utah: American Association of Petroleum Geologists Bulletin, v. 67, p. 1304–1322.

Winker, C. D., 1982, Cenozoic shelf margins, northwestern Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 32, p. 427–448.

Winterfeld, G. F., and Conard, J. B., 1983, Laramide tectonics and deposition, Washakie Range and northwestern Wind River basin, Wyoming, *in* Lowell, J. D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colorado, Rocky Mountain Association of Geologists, p. 137–148.

Wust, S. L., 1986, Regional correlation of extension directions in Cordilleran metamorphic core complexes: Geology, v. 14, p. 828–830.

MANUSCRIPT RECEIVED BY THE SOCIETY MAY 28, 1987
REVISED MANUSCRIPT RECEIVED FEBRUARY 8, 1988
MANUSCRIPT ACCEPTED FEBRUARY 8, 1988

Printed in U.S.A.