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ABSTRACT

The late Middle Jurassic–early Eocene (∼120 m.y.) sediment-accumulation history of the Cordilleran foreland basin in northern Utah exhibits a sigmoidal pattern on a rate vs. time plot, with moderate rates of accumulation during late Middle Jurassic, very low net rates during Late Jurassic–earliest Cretaceous, increasingly rapid rates during Early-middle Cretaceous, and low rates during Late Cretaceous–early Eocene time. This pattern is consistent with deposition in a prograding foreland-basin system that comprised integrated back-bulge, forebulge, foredeep, and wedge-top depozones. The upper Middle Jurassic represents the back-bulge depozone; the Upper Jurassic was deposited on the eastern flank of a flexural forebulge; the basal Cretaceous unconformity is the result of eastward migration of the forebulge; the thick, Lower-middle Cretaceous succession represents the foredeep depozone; and the Upper Cretaceous–early Eocene embodies the syndepositionally deformed wedge-top depozone. Previous models that explain Middle-Late Jurassic stratigraphic patterns in terms of foredeep subsidence (alone) and a Late Jurassic hiatus in crustal shortening in the Cordilleran orogen are shown to be neither necessary nor supported by evidence from the Cordilleran hinterland.

INTRODUCTION

Cordilleran orogenesis in the western United States spanned at least 120 m.y. from Middle Jurassic to early Eocene time and involved thrust faulting and folding, ductile shortening and dynamothermal metamorphism, and igneous intrusion (Miller et al., 1988; Allmendinger, 1992). The deformation front migrated ∼1000 km eastward from central Nevada to Colorado (Fig. 1). The hinterland in Nevada and western Utah largely consists of Precambrian basement and Precambrian-Paleozoic sedimentary rocks that were deformed at greenschist to amphibolite grade and intruded by widespread plutons during Middle Jurassic to Early Cretaceous time. The Sevier fold-and-thrust belt was active from Early Cretaceous through early Eocene time, involving large Precambrian basement culminations and thrust sheets of Proterozoic-Paleozoic quartzite and carbonate rocks in its rear and unmetamorphosed Paleozoic-Mesozoic cover rocks in its frontal part. The Laramide foreland region was the site of mainly basement-involved shortening from Late Cretaceous through early Eocene time. The total amount of horizontal shortening exceeded 250 km (Allmendinger, 1992; Elison, 1991).

Coeval foreland-basin development in the western interior shows a straightforward association between Early Cretaceous–Eocene synorogenic deposition and kinematic events in the Sevier thrust belt (Jordan, 1981; Wiltschko and Dorr, 1983; DeCelles, 1994). Similarly, Laramide foreland uplifts have been correlated with local intraforeland basins (Cross, 1986; Dickinson et al., 1988). Much less understood are the links between Middle-Late Jurassic deformation in the hinterland and basin development in the western interior. Provenance data from Middle-Late Jurassic sandstone and conglomerate in Utah and Wyoming indicate the likely existence of an orogenic source terrane in Nevada and western Utah (Furer, 1970; Jordan, 1985). Heller et al. (1986) and Heller and Paola (1989), however, suggested that foreland-basin subsidence did not commence until late Early Cretaceous time because the Upper Jurassic Morrison Formation in the foreland region does not exhibit the westward thickening predicted by foreland-basin models. Instead, they proposed that the Morrison accumulated during a period of thermal doming and/or regional, erosion-driven isostatic rebound in the absence of thrusting. Based on flexural modeling, Bjerrum and Dorsey (1995) attributed the Middle Jurassic stratigraphic record of Utah to deposition in a retroarc foredeep. Their model produced reasonable flexural profiles, but the loads employed are located >100 km east of the region of Jurassic crustal shortening (Fig. 1). Lawton (1994) explained Middle and Late Jurassic deposition in terms of regional dynamic subsidence (e.g., Gurnis, 1992) caused by viscous coupling between the mantle wedge and overlying North American plate. This paper presents a new interpretation of the entire Middle Jurassic–lower Eocene stratigraphic succession of the western interior in terms of a general model of foreland-basin systems (DeCelles and Giles, 1996). This interpretation is consistent with known horizontal shortening, metamorphism, and igneous activity in the Cordillera and does not require highly unsteady thrust loading or regional isostatic events.

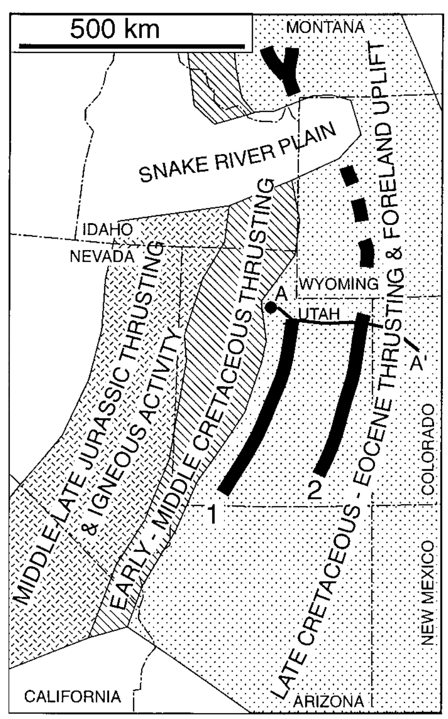

Figure 1. Map showing distribution and timing of Middle Jurassic–early Eocene thrusting, metamorphism, and igneous activity in Cordilleran orogen, western United States (based on Cross, 1986; Allmendinger, 1992; Royse, 1993a). Line 1 is Middle-Late Jurassic forebulge; line 2 is Early Cretaceous forebulge (from Fig. 9 of DeCelles and Giles, 1996). A–A′ shows location of Figure 3. Solid circle in northeast Utah shows location of sediment-accumulation curve in Figure 4.

FORELAND-BASIN SYSTEMS

A foreland-basin system is a regionally elongated zone of potential sediment accommodation that develops on the forelandward side of a contractional orogen in response to flexural processes associated with convergent plate boundaries. It consists of wedge-top, foredeep, forebulge, and back-bulge depozones (Fig. 2). The depozone identity of a sediment particle is based on its location during deposition rather than its ultimate position with respect to the fold-and-thrust belt, which may change drastically as the orogenic wedge advances toward the foreland. The wedge-top depozone consists of sediment that accumulates on top of the frontal part of the orogenic wedge, including "piggyback" basins. It is character-

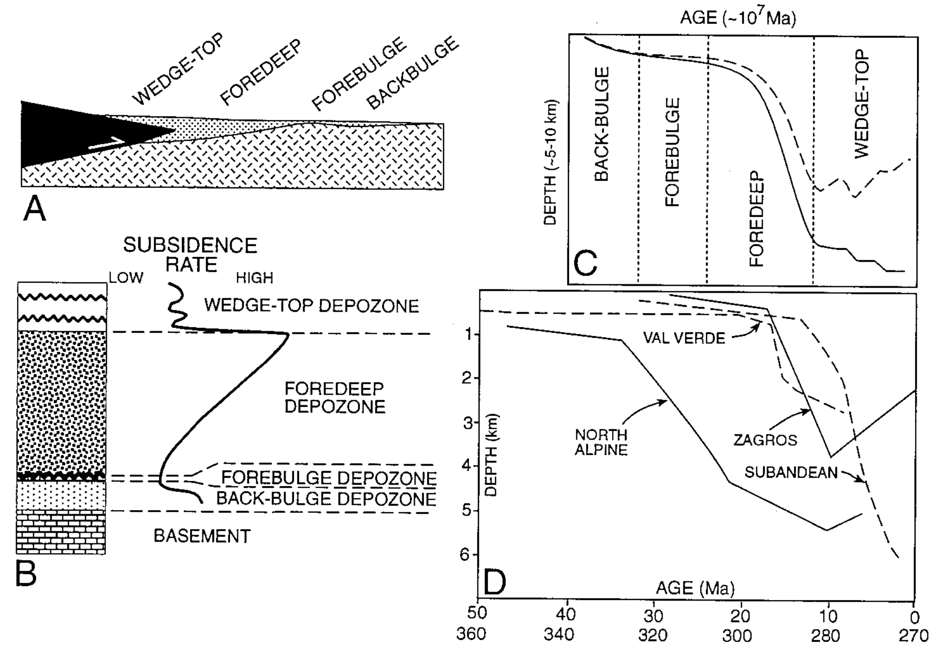

Figure 2. A: Schematic cross section showing an orogenic wedge (black) and adjacent foreland-basin system, after DeCelles and Giles (1996). B: Idealized stratigraphic fill and subsidence-rate curve of a foreland-basin system, produced by progradational stacking of depozones. Wiggly lines represent unconformities. C: Idealized, long-term total subsidence (solid line) and tectonic subsidence (dashed line) curves for a foreland-basin system. D: Examples of long-term total (Subandean) and tectonic (North Alpine, Zagros, and Val Verde) subsidence curves from four well-documented foreland-basin systems. Sources: Homewood et al. (1986), Jordan et al. (1988), Bordenave and Burwood (1990), Dorobek (1995). Lower age scale is for Val Verde; upper is for Zagros, North Alpine, and Subandean.

ized by numerous local and regional tectonic unconformities, coarse-grained sediment, and regional thinning toward the fold-and-thrust belt. The foredeep depozone is the region of thick accumulation between the tip of the orogenic wedge and the proximal side of the forebulge. It decreases in thickness toward the craton. The forebulge depozone is the region of potential accommodation in the vicinity of the forebulge. In some foreland-basin systems the forebulge is a zone of nondeposition or erosion (Crampton and Allen, 1995); in others, sediment derived from the fold-and-thrust belt or produced locally (e.g., carbonate build-ups in submarine systems; Giles and Dickinson, 1995) is deposited on top of the forebulge. These deposits are typically thin and condensed, and nondepositional forebulge regions may be marked by an unconformity (Crampton and Allen, 1995). The back-bulge depozone is the broad region of potential accommodation between the forebulge and the undisturbed craton.

If an orogenic wedge advances a distance comparable to the width of the foreland-basin system, locations originally in the back-bulge depozone will be buried progressively by younger forebulge, foredeep, and wedge-top deposits. The resulting accumulation history as shown on a rate vs. time plot should be crudely sigmoidal; initially there are low to moderate accumulation rates in the back-bulge depozone, followed by very low accumulation rates or erosion in the forebulge depozone, followed by increasingly rapid rates in the foredeep depozone, followed by abruptly decreased rates and local erosional events in the wedge-top depozone (Figs. 2B and 2C). This long-term pattern may be punctuated by short-term changes in accumulation resulting from intraforeland structural complexities, changes in rates of orogenic shortening, and changes in sea level, climate, sediment supply, source-rock types, and depositional systems, among others. Nevertheless, the *first-order* sigmoidal pattern is controlled by cratonward migration of the flexural wave, a process that occurs over tens of millions of years and dominates the accumulation history in most foreland regions (Fig. 2D).

STRATIGRAPHIC HISTORY

Middle Jurassic–lower Eocene rocks in northern Utah and western Colorado constitute three depositional sequences separated by regional unconformities. The first sequence includes the Twin Creek, Preuss, Stump, and Morrison Formations and their correlatives (Middle-Upper Jurassic; Fig. 3). Its basal unconformity (the J2 of Pipiringos and O'Sullivan, 1978) spans an eastward-increasing chronostratigraphic gap caused by eastward onlap of Middle-Upper Jurassic units. In northern Utah, the Middle-Upper Jurassic sequence is up to 1.4 km thick but decreases to ~250 m in northeast Utah (Imlay, 1980).

The base of the overlying Neocomian-Coniacian depositional sequence is an unconformity of ~20 m.y. duration that bevels the Upper Jurassic Morrison and Stump Formations between the Uinta and Wasatch Mountains. The unconformity consists of an ~10-m-thick zone of intense weathering and

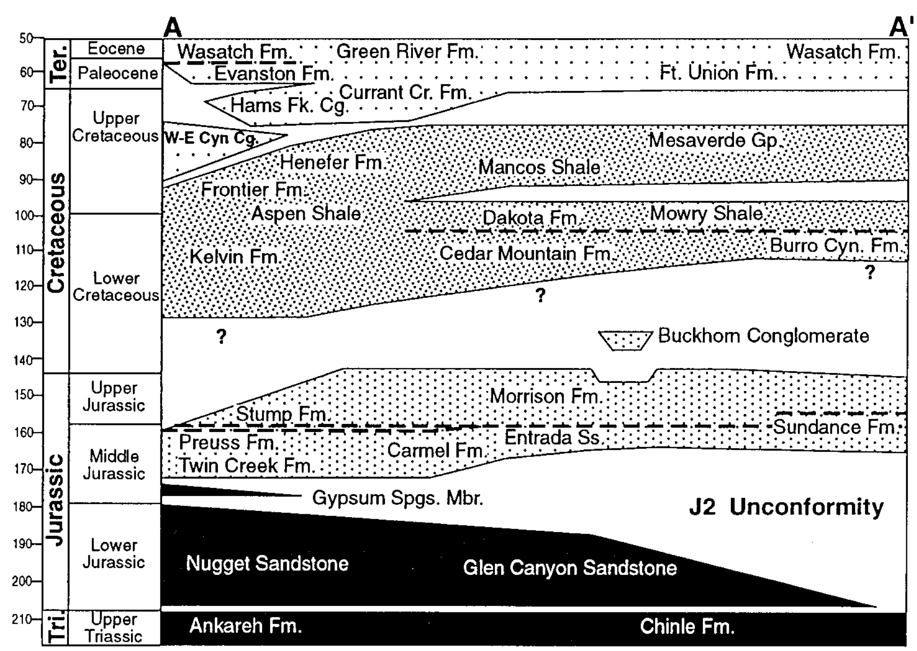

Figure 3. Chronostratigraphic diagram (see Fig. 1 for location) of Middle Jurassic–lower Eocene rocks of Utah and adjacent areas in Wyoming and Colorado. After Imlay (1980), Hintze (1988), and Dyman et al. (1994). White areas represent major unconformities; dashed lines are minor unconformities.

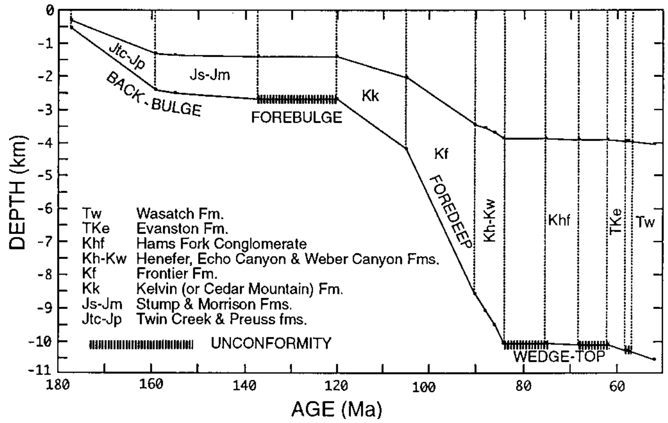

Figure 4. Total subsidence curve for Middle Jurassic–lower Eocene strata in Coalville, Utah, area, decompacted according to method of Sclater and Christie (1980).

early diagenetic alteration of the upper Morrison in northeast Utah and northwest Colorado (Currie, 1996). This sequence consists of the Lower Cretaceous Kelvin Formation and Upper Cretaceous Aspen, Frontier, and Henefer Formation. These rocks correlate with the Cedar Mountain, Dakota, Mowry, and Mancos Formations and part of the Mesaverde Group in northeast Utah and northwest Colorado. The Neocomian-Coniacian sequence decreases in thickness from ~7 km in northern Utah to ~2.5 km in northeast Utah (Royse, 1993a).

Unconformably overlying the Neocomian-Coniacian sequence is the Santonian–lower Eocene depositional sequence, which includes the Echo Canyon, Weber Canyon, and Hams Fork Conglomerates; the Evanston and Wasatch Formations (in northern Utah); and the Currant Creek, Fort Union, Green River, and Wasatch Formations (in eastern Utah; Fig. 3; Hintze, 1988). The thickness of the Santonian–lower Eocene sequence across the region is variable owing to syndepositional uplift in the frontal Sevier thrust belt and Uinta Mountains.

LONG-TERM SEDIMENT ACCUMULATION

A decompacted sediment-accumulation curve for Middle Jurassic–lower Eocene strata of northern Utah (Fig. 4) is similar to curves from central Utah and southeast Idaho (Heller et al., 1986; Cross, 1986). The curve exhibits several short-term (~10 m.y.) changes in accumulation rate, but overall is clearly sigmoidal as would be expected from progressive stacking of foreland-basin depozones (Fig. 2). The period 177–160 Ma brackets deposition in the back-bulge depozone; 160–120 Ma represents deposition and erosion in proximity to the forebulge; 120–86 Ma brackets the foredeep depozone; and 86–55 Ma, the wedge-top depozone.

Lithofacies, unconformities, regional onlap patterns, and internal syndepositional structure of the entire succession provide further support for this interpretation. Coarse-grained, proximal alluvial-fan deposits, progressive and interformational angular unconformities, and growth fault–propagation folds typify the Santonian–lower Eocene wedge-top part of the succession (DeCelles, 1994). Provenance data indicate sources in the hinterland and along antiformal ridges that grew above frontal thrust ramps. The low net rate of accumulation reflects competing effects of local uplift and erosion in the orogenic wedge, regional flexural subsidence, and local accumulation behind structural dams produced by thrust-tip anticlines.

The Neocomian-Coniacian interval (120–86 Ma) consists of thick, marginal-marine, fluvial, and fan-delta deposits and lacks *syndepositional* thrust-related deformation. Provenance data indicate sources in the Willard-Paris-Meade-Laketown thrust system, the westernmost and structurally highest of the major thrusts in this part of the Sevier belt (Royse, 1993a). These rocks represent the rapidly subsiding foredeep depozone (Jordan, 1981). Regional isopach patterns in the Neocomian(?)-Albian Cedar Mountain Formation indicate a northeast-trending zone of thinning in eastern Utah (Fig. 1), which Currie (1995) interpreted as a manifestation of the Early Cretaceous forebulge.

The Late Jurassic–earliest Cretaceous (160–120 Ma) part of the curve exhibits extremely low rates of net accumulation during and after deposition of the Stump and Morrison Formations (Fig. 4), which consist of west-southwesterly derived marginal-marine, nonmarine, and volcanogenic deposits (Currie, 1996). We interpret the top Morrison unconformity as a result of forebulge uplift just east of the Wasatch Mountains (Fig. 1). Westward beveling of Morrison stratigraphic members to an erosional zero-edge in northeast Utah matches the pattern expected from deposition and subsequent erosion on the cratonward side of a forebulge. The overlying Kelvin (or Cedar Mountain) Formation represents distal foredeep deposits that prograded across the forebulge unconformity.

The Middle Jurassic (177–160 Ma) segment of the accumulation curve is represented by ~1.8 km of shallow- to marginal-marine and nonmarine carbonate, siliciclastic, and evaporitic rocks in the Twin Creek and Preuss Formations (Fig. 3). The top of the Middle Jurassic is beveled downsection to the west by the same unconformity that bevels the Morrison Formation; ~300 m of section has been cut out. The underlying J2 unconformity and the eastward onlap pattern in the Middle Jurassic rocks are results of erosion and subsequent onlap of distal back-bulge sediments onto the cratonic margin of the western interior. The Middle-Upper Jurassic back-bulge deposits were subsequently uplifted and partly eroded on the eastern flank and crest of the Late Jurassic–Early Cretaceous forebulge.

DISCUSSION

This interpretation solves several problems in Middle-Late Jurassic stratigraphy in the western interior. Some authors (Heller and Paola, 1989; Bjerrum and Dorsey, 1995) have proposed that westward thinning of the Morrison Formation resulted from a regional erosional event coupled with isostatic uplift or thermal doming in the Cordilleran hinterland. Westward beveling of the top of the Morrison indicates that erosion occurred *after*, not during, Morrison deposition. The youngest dates from the upper part of the Morrison are 144 Ma ($^{40}Ar/^{39}Ar$; Peterson, 1994) or 137 Ma (U-Pb; G. E. Gehrels, 1995, personal commun.), which means that the proposed isostatic uplift or thermal doming event must have occurred during earliest Cretaceous time. This was a period of regional crustal shortening in the Cordillera, which included emplacement of the Manning Canyon thrust sheet in northwest Utah (Allmendinger and Jordan, 1984) and the Willard (Yonkee, 1992) and Canyon Range (Royse, 1993a; DeCelles et al., 1995) thrust sheets in northern and central Utah. The widespread Late Jurassic plutons in Nevada and western Utah that are supposed to have been associated with thermal doming were synkinematic with regional shortening (Miller et al., 1988; Allmendinger, 1992). Our interpretation explains the "anomalous" Morrison isopach pattern and the overlying unconformity as results of forebulge migration into the back-bulge depozone of the foreland-basin system.

Also resolved by our interpretation is the issue of forebulge location. Bjerrum and Dorsey (1995) suggested that the minor unconformities (reported by Pipiringos and O'Sullivan, 1978) between individual Middle Jurassic stratigraphic units were produced by forebulge migration. These unconformities lack evidence for major erosion, do not exhibit the typical cratonward-increasing stratigraphic gap, and would imply that the forebulge migrated rapidly east and west several times during the Middle Jurassic. In turn, this interpretation would require a highly unsteady thrust-belt load, whereas evidence from most young mountain belts indicates that orogenic wedges migrate cratonward in a relatively steady fashion (e.g., Covey, 1986), with most of the loading concentrated above crustal ramps in the hinterland. Episodic frontal thrusting, therefore, is not a realistic explanation for unsteady forebulge behavior. The interpretation presented above has the forebulge migrate eastward from central Utah (Middle-Late Jurassic) to eastern Utah (Early Cretaceous) at a reasonable rate of ~0.5 cm/yr, consistent with known rates of thrusting in the Sevier belt (Jordan, 1981; DeCelles, 1994) and flexural modeling results (Currie, 1995).

A potential problem with our interpretation is the thick Middle Jurassic back-bulge deposits, which accumulated in a region where flexural subsidence due to topographic loads could have produced only a few tens of metres of accommodation. Isostatic compensation of the back-bulge sediment load and aggradation up to a stratigraphic base level tangent to, or higher than, the crest of the forebulge may have permitted another few hundred metres of accumulation. Moreover, in general, dynamic subsidence may exceed 1 km in back-bulge regions hundreds of kilometres inboard of the trench (Gurnis, 1992; Holt and Stern, 1994). The abundance of shallow-marine carbonate in the proposed back-bulge depozone (Twin Creek Formation) supports the interpretation of a submarine back-bulge. A second question raised by our interpretation is the whereabouts of the Middle-Late Jurassic foredeep depozone. We concur with Royse (1993b) that restored regional cross sections provide space for several kilometres of Middle-Late Jurassic foredeep deposits that subsequently were eroded as the orogenic wedge propagated into central Utah.

CONCLUSIONS

Middle Jurassic through lower Eocene sedimentary rocks in the western interior United States accumulated in an eastward-migrating foreland basin system that progressively stacked the deposits of back-bulge, forebulge, foredeep, and wedge-top depozones on top of each other, producing a long-term, sigmoidal sediment-accumulation pattern. Foreland-basin systems in general exhibit sigmoidal patterns of long-term sediment accumulation in response to migration of depozones and associated forebulge unconformities. Failure to recognize back-bulge and forebulge depozones can lead to erroneous stratigraphic interpretations of orogenic load distributions and the onset of synorogenic subsidence in foreland-basin systems.

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REFERENCES CITED

Allmendinger, R. W., 1992, Fold and thrust tectonics of the western United States exclusive of the accreted terranes, *in* Burchfiel, B. C., et al., eds., The Cordilleran orogen: Conterminous U.S.: Boulder, Colorado, Geological Society of America, Geology of North America, v. G-3, p. 583–607.

Allmendinger, R. W., and Jordan, T. E., 1984, Mesozoic evolution, hinterland of the Sevier orogenic belt: Geology, v. 9, p. 308–313.

Bjerrum, C. J., and Dorsey, R. J., 1995, Tectonic controls on deposition of Middle Jurassic strata in a retroarc foreland basin, Utah-Idaho trough, western interior, United States: Tectonics, v. 14, p. 962–978.

Bordenave, M. L., and Burwood, R., 1990, Source rock distribution and maturation in the Zagros orogenic belt: Provenance of the Asmari and Bangestan reservoir oil accumulations: Organic Geochemistry, v. 16, p. 369–387.

Covey, M., 1986, The evolution of foreland basins to steady state: Evidence from the western Taiwan foreland basin, *in* Allen, P. A., and Homewood, P., eds., Foreland basins: International Association of Sedimentologists Special Publication 8, p. 77–90.

Crampton, S. L., and Allen, P. A., 1995, Recognition of forebulge unconformities associated with early stage foreland basin development: Example from the North Alpine foreland basin: American Association of Petroleum Geologists Bulletin, v. 79, p. 1495–1514.

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 8, p. 15–40.

Currie, B. S., 1995, Configuration of the Early Cretaceous Cordilleran foreland basin system, Utah and Colorado: Geological Society of America Abstracts with Programs, v. 27, p. 7.

Currie, B. S., 1996, Upper Jurassic–Lower Cretaceous Morrison and Cedar Mountain Formations, NE Utah–NW Colorado: Relationships between nonmarine deposition and early Cordilleran foreland basin development, *in* Carpenter, K., et al., eds., The Upper Jurassic Morrison Formation: An interdisciplinary study: Geological Society of America Special Paper (in press).

DeCelles, P. G., 1994, Late Cretaceous–Paleocene synorogenic sedimentation and kinematic history of the Sevier thrust belt, northeast Utah and southwest Wyoming: Geological Society of America Bulletin, v. 106, p. 32–56.

DeCelles, P. G., and Giles, K. A., 1996, Foreland basin systems: Basin Research, v. 8, no. 2, p. 105–123.

DeCelles, P. G., Lawton, T. F., and Mitra, G., 1995, Thrust timing, growth of structural culminations, and synorogenic sedimentation in the type area of the Sevier orogenic belt, western United States: Geology, v. 23, p. 699–702.

Dickinson, W. R., Klute, M. A., Hayes, M. J., Janecke, S. U., Lundin, E. R., McKittrick, M. A., and Olivares, M. D., 1988, Paleogeographic and paleotectonic setting of Laramide sedimentary basins in the central Rocky Mountain region: Geological Society of America Bulletin, v. 100, p. 1023–1039.

Dorobek, S. L., 1995, Synorogenic carbonate platforms and reefs in foreland basins: Controls on stratigraphic evolution and platform/reef morphology, *in* Dorobek, S. L., and Ross, G. M., eds., Stratigraphic evolution of foreland basins: Society of Economic Paleontologists and Mineralogists Special Publication 52, p. 127–147.

Dyman, T. S., and six others, 1994, Stratigraphic transects for Cretaceous rocks, Rocky Mountains and Great Plains regions, *in* Caputo, M. V., et al., eds., Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 365–391.

Elison, M. W., 1991, Intracontinental contraction in western North America: Continuity and episodicity: Geological Society of America Bulletin, v. 103, p. 1226–1238.

Furer, L. C., 1970, Nonmarine upper Jurassic and lower Cretaceous rocks of western Wyoming and southeastern Idaho, American Association of Petroleum Geologists Bulletin, v. 54, p. 2282–2304.

Giles, K. A., and Dickinson, W. R., 1995, The interplay of eustasy and lithospheric flexure in forming stratigraphic sequences in foreland settings: An example from the Antler foreland, Nevada and Utah, *in* Dorobek, S. L., and Ross, G. M., eds., Stratigraphic evolution of foreland basins: Society of Economic Paleontologists and Mineralogists Special Publication 52, p. 187–211.

Gurnis, M., 1992, Rapid continental subsidence following the initiation and evolution of subduction: Science, v. 255, p. 1556–1558.

Heller, P. L., and Paola, C., 1989, The paradox of Lower Cretaceous gravels and the initiation of thrusting in the Sevier orogenic belt, United States western interior: Geological Society of America Bulletin, v. 101, p. 864–875.

Heller, P. L., Bowler, S. S., Chambers, H. P., Coogan, J. C., Hagen, E. S., Shuster, M. W., Winslow, N. S., and Lawton, T. F., 1986, Time of initial thrusting in the Sevier orogenic belt, Idaho, Wyoming and Utah: Geology, v. 14, p. 388–391.

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

Holt, W. E., and Stern, T. A., 1994, Subduction, platform subsidence, and foreland thrust loading: The late Tertiary development of Taranaki basin, New Zealand: Tectonics, v. 13, p. 1068–1092.

Homewood, P., Allen, P. A., and Williams, G. D., 1986, Foreland basins: An introduction, *in* Allen, P. A., and Homewood, P., eds., Foreland basins: International Association of Sedimentologists Special Publication 8, p. 3–12.

Imlay, R. W., 1980, Jurssic paleobiogeography of the conterminous United States in its continental setting: U.S. Geological Survey Professional Paper 1062, 134 p.

Jordan, T. E., 1981, Thrust loads and foreland basin evolution, Cretaceous, western United States: American Association of Petroleum Geologists Bulletin, v. 65, p. 2506–2520.

Jordan, T. E., 1985, Tectonic setting and petrography of Jurassic foreland basin sandstones, Idaho-Wyoming-Utah: Utah Geological Association Publication 14, p. 201–213.

Jordan, T. E., Flemings, P. B., and Beer, J. A., 1988, Dating thrust-fault activity by use of foreland-basin strata, *in* Kleinspehn, K. L., and Paola, C., eds., New perspectives in basin analysis: New York, Springer-Verlag, p. 307–330.

Lawton, T. F., 1994, Tectonic setting of Mesozoic sedimentary basins, Rocky Mountain region, United States, *in* Caputo, M. V., et al., eds., Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 1–25.

Miller, E. L., Gans, P. B., Wright, J. E., and Sutter, J. F., 1988, Metamorphic history of the east-central Basin and Range province: Tectonic setting and relationship to magmatism, *in* Ernst, W. G., ed., Metamorphism and crustal evolution of the western United States: Englewood Cliffs, New Jersey, Prentice-Hall, p. 649–682.

Peterson, F., 1994, Sand dunes, sabkhas, streams, and shallow seas: Jurassic paleogeography in the southern part of the western interior basin, *in* Caputo, M. V., et al., eds., Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 233–272.

Pipiringos, G. N., and O'Sullivan, R. B., 1978, Principal unconformities in Triassic and Jurassic rocks, western interior United States—A preliminary survey: U.S. Geological Survey Professional Paper 1035-A, p. 1–29.

Royse, F., Jr., 1993a, An overview of the geologic structure of the thrust belt in Wyoming, northern Utah, and eastern Idaho, *in* Snoke, A. W., et al., eds., Geology of Wyoming: Geological Survey of Wyoming Memoir 5, p. 272–311.

Royse, F., Jr., 1993b, Case of the phantom foredeep: Early Cretaceous in west-central Utah: Geology, v. 21, p. 133–136.

Sclater, J. G., and Christie, P. A. F., 1980, Continental stretcting: An explanation of the post Mid-Cretaceous subsidence of the central North Sea basin: Journal of Geophysical Research, v. 85, p. 3711–3739.

Wiltschko, D. V., and Dorr, J. A., 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.

Yonkee, W. A., 1992, Basement-cover relations, Sevier orogenic belt, northern Utah: Geological Society of America Bulletin, v. 104, p. 280–302.

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