



Speculations on the Origins of Mid-Cretaceous Clastic Wedges, Central Rocky Mountain Region, United States

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Abstract

Within foreland basin settings, major clastic wedges (at the scale of third-order cycles or sequences of some authors) are most likely the result of (1) eustatic changes in sea level, (2) varying rates of sediment supply from the orogenic belt, or (3) a combination of the two. Accordingly, clastic wedges may be generally characterized as (1) eustatic-type, (2) tectonic-type, or (3) hybrid-type on the basis of their areal distributions, contained rock types, and the nature of associated unconformities.

The Cretaceous basin of the Rocky Mountain region includes examples of all three types of clastic wedges. The late Albian clastic wedge that comprises the Dakota, Bear River and Muddy formations in Wyoming is a eustatic-type wedge. Although spanning only a relatively short period of time, it is widely distributed. It lacks conglomerates in all but its westernmost part and contains several subaerial unconformities. The Cenomanian-Turonian clastic wedge represented by the Chalk Creek-Belle Fourche part of the Frontier Formation in Wyoming is a tectonic-type wedge. It is areally restricted, includes widespread conglomerates, and lacks significant unconformities. The Turonian-Coniacian clastic wedge that comprises the Oyster Ridge and Dry Hollow members of the Frontier in Wyoming and Utah and the Ferron Sandstone Member in Utah is a hybrid-type wedge. It combines the characteristics of the other two types.

Résumé

Les biseaux sédimentaires détritiques importants (à l'échelle des cycles de troisième ordre ou séquences de certains auteurs) des environnements d'avant-pays sont vraisemblablement le résultat: (1) de changements eustatiques, (2) de variations dans l'apport de sédiments de la source orogénique, ou (3) d'une combinaison des facteurs précédents. En conséquence, on peut en général classer ces biseaux sédimentaires détritiques en (1) type eustatique, (2) type tectonique, ou (3) type hybride, selon leur étendue, la nature des roches qu'ils contiennent, et la nature des discordances associées.

Le bassin de Crétacé de la région des Montagnes Rocheuses comprend des exemples de chacun de ces trois types de biseaux détritiques sédimentaires. Le biseau de l'Albien supérieur, qui comprend les Formations de Dakota, de Bear River et de Muddy dans le Wyoming, est du type eustatique. Bien qu'il corresponde à une période relativement courte, il s'étend sur une grande surface. Il est dépourvu de conglomérats syn-orogéniques, sauf à l'extrémité de sa partie ouest, et il comprend plusieurs discordances d'exondation. Le biseau Cénomaniens-Turonien que représente la partie Chalk Creek-Belle Fourche de la

Formation Frontier du Wyoming, est du type tectonique. Il n'est pas très étendu, comprend des conglomérats largement dispersés et ne montre pas d'indices convaincants de discordances. Le biseau Turonien-Coniacien qui comprend les membres de Oyster Ridge et de Dry Hollow de la Formation Frontier dans le Wyoming et l'Utah ainsi que le Membre Ferron Sandstone dans l'Utah, et du type hybride. Il montre des caractéristiques des deux autres types.

INTRODUCTION

Intertonguing of marine and non-marine facies within the sedimentary section that accumulated along the western margin of the Cretaceous North American Interior seaway was first recognized by Hatcher (1904; see account by Waage, 1975). The significance and complexity of the intertonguing, however, was not widely appreciated until the publication of studies by Sears *et al.* (1941), Spieker (1949), Cobban and Reeside (1952), Young (1955) and Fisher *et al.* (1960), among others. These innovative works demonstrated that the Cretaceous stratigraphy is best understood and described in the context of clastic wedges – seaward-thinning packages of predominantly sandy sediment separated by landward-thinning wedges of marine shale. These early works set the stage for many subsequent publications, from which the data have been synthesized to establish the basic stratigraphic (Young, 1970; McGookey *et al.*, 1972; Kauffman, 1977, 1984; Williams and Stelck, 1975) and paleostructural (Armstrong, 1968; Royse *et al.*, 1975; Bond, 1976; Jordan, 1981; Wiltschko and Dorr, 1983; Lawton, 1985) frameworks for the Cretaceous Western Interior Basin.

ORIGIN OF CLASTIC WEDGES

The rate of sediment supply to a basin and fluctuations of relative sea level within it are generally regarded as the principal factors responsible for transgressions and regressions of the sea, and hence of clastic wedges. These are both complicated terms (Fig. 1). Relative sea level is a function of both eustatic sea level and local sea level (Curry, 1964); sediment supply is a function of tectonics and, within a shorter time frame, climatic fluctuations and autocyclic processes. In a foreland basin, thrusting and the resultant crustal loading cause rapid basin subsidence (Bond, 1976; Karner, 1987), *i.e.*, a relative rise in sea level. Thrusting also has a direct effect upon sediment input to a basin. The thrust sheet that causes basin subsidence simultaneously erodes and contributes sediment that fills, partially or entirely, the space created by the subsidence, the sediment contributing to additional subsidence in the process. With respect to an analysis of transgressions and regressions and, more particularly, the balance that regulates them, tectonics in a foreland basin setting works at cross-purposes, tipping the balance toward transgression on the sea-level side of the equation and toward regression on the sediment supply side. For this reason, tectonic controls can be very difficult to decipher in the stratigraphic record.

Although most authors recognize the duality of sea-level and sediment supply control of transgression and regression (*e.g.*, Kauffman, 1984), most discussions of the subject tend to focus primarily upon one or the other to explain the origin of clastic wedges. For instance, papers by Kauffman (1977), Hancock and Kauffman (1979) and Weimer (1984) emphasize the role of sea-level fluctuations; those by Young (1955), Jeletzky (1978) and Fouch *et al.* (1983) stress the importance of tectonic controls on subsidence and sediment input.

The sea-level school of thought has gained many new adherents in recent years with the publication of various generations of Exxon's global sea-level curves (Vail *et al.*, 1977; Haq *et al.*, 1987) and their attendant depositional models. Beautiful in their simplicity and valuable because of their predictive power, the Vail models have led many geologists to focus almost entirely on eustatic sea-level and variations in the rate of sea-level change as the controlling mechanisms. Doing so may pose no particular problems in interpreting passive-margin settings, for which the models were primarily designed, but can lead to serious misinterpretations in foreland basins, like that which existed along the western margin of the Cretaceous Western Interior Basin.

It is the premise of this paper that tectonic and eustatic mechanisms are of approximately equal importance in producing the Cretaceous clastic wedges of the Western Interior. Some wedges appear to be primarily the result of one or the other mechanism; some reflect the influences of both. Examples can be found in Albian through Coniacian strata in Wyoming, Utah and Colorado.

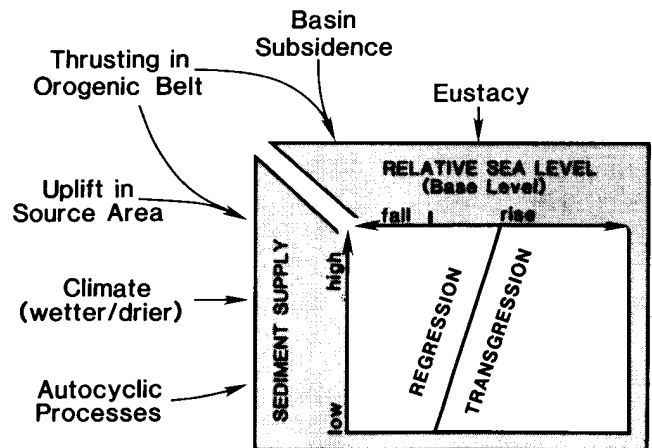


Figure 1. Diagram relating transgression and regression to changes in relative sea level and sediment supply. The mechanisms that affect these variables are listed above and to the left. (Modified from Curry, 1964).

MID-CRETACEOUS CLASTIC WEDGES OF THE CENTRAL ROCKY MOUNTAIN REGION

Three clastic wedges are identified in the mid-Cretaceous section in the central Rocky Mountain portion of the Western Interior Basin. Describing them involves use of a large number of formation and member names (Fig. 2). One or more key references are provided for each of the stratigraphic units cited, but no attempt is made here to describe stratigraphic relationships in detail.

The landward limits of clastic wedges are mapped on the basis of the landward-thinning marine shale units that bound them. Where a marine shale unit tongues out, over- and underlying clastic wedges merge. Landward from this position, the boundary between clastic wedges can be readily defined only so long as shallow-marine or brackish-water facies equivalent to the shale tongues persist, *i.e.*, generally no more than about 16 km (10 miles). This poses problems in areas where the feather-edges of succes-

sive shale units are situated far apart: large volumes of sediment remain unassigned to one or another of the recognized clastic wedges.

The seaward limits of clastic wedges can be defined either on the basis of (1) the position of the shoreline at the regressive maximum of the wedge, as recognized on the basis of rooted horizons, coaly beds, or other non-marine facies, or (2) the basinward limit of sandy sediment. Sandy strata may extend far beyond the shoreline in instances where the wedge grades seaward into sandy deposits of a broad, shallow shelf. This is particularly true for the youngest of the clastic wedges described here, but less so for the older ones. Arguments can be made favouring either method of defining clastic wedges. The former method, utilizing approximate shoreline position, is easier in many respects and is used here.

The first and oldest of the clastic wedges considered here (Fig. 3) is represented by the Muddy Sandstone of Wyoming (Paull, 1962; Stone, 1972; Dresser, 1974). It also includes the upper part of the Bear River Formation of western Wyoming (Royse *et al.*,

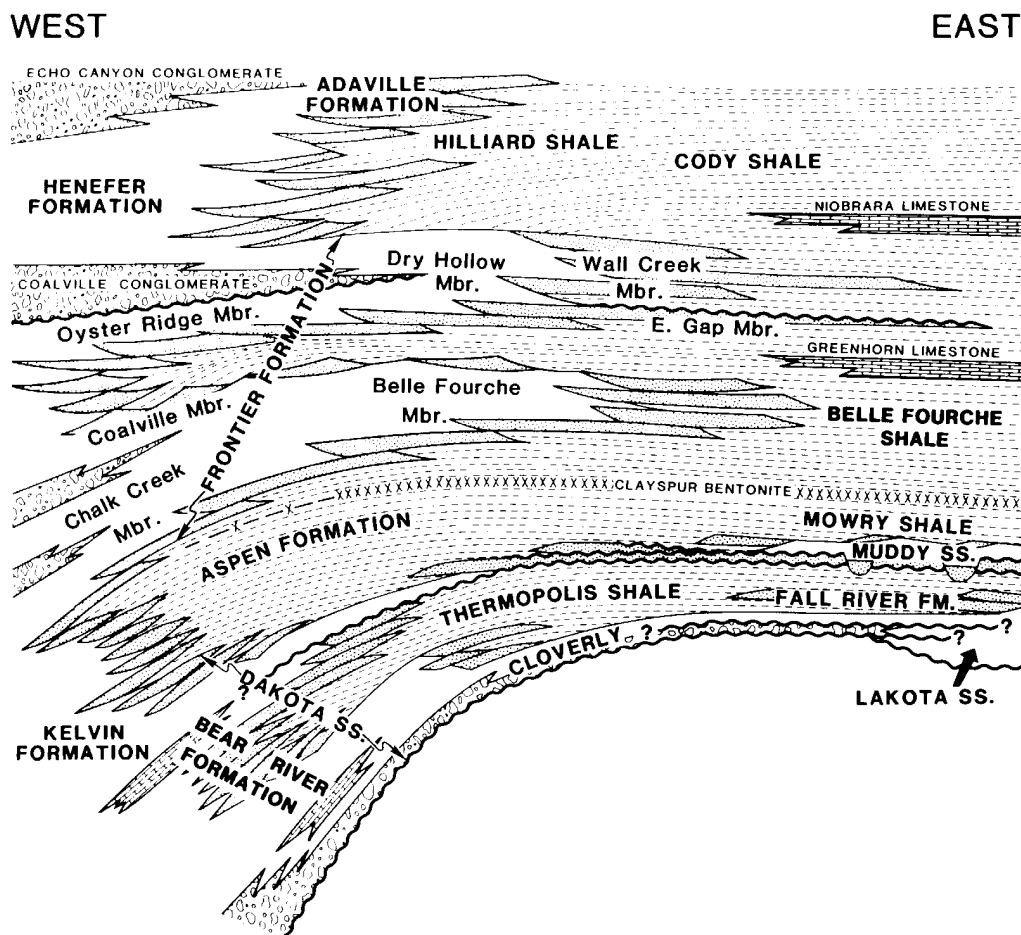


Figure 2. Diagrammatic cross-section extending from north-central Utah and western Wyoming to eastern Wyoming. The three clastic wedges discussed are typified by the Muddy Sandstone, the Chalk Creek Member of the Frontier Formation, and the Wall Creek Member of the Frontier Formation. Many of the stratigraphic names cited in the text, particularly those from central and southern Utah, do not appear in this cross-section. Diagram is not to scale; differential subsidence in the westernmost part of the basin was actually much greater than indicated.

1975; Wallem *et al.*, 1981), the upper part of the Dakota Sandstone in southwestern Wyoming (Ryer *et al.*, 1987), and the J Sandstone of the Denver Basin (MacKenzie, 1965). The landward limit of the wedge is defined by the underlying Skull Creek and Thermopolis shales and the overlying Aspen and Mowry shales. This wedge was deposited in late Albian time.

The second wedge, comprising the Longwall Sandstone, Chalk Creek and Coalville members of the Frontier Formation in north-central Utah (Hale, 1960; Ryer, 1976) and western Wyoming (Love, 1956; Myers, 1977) and the Belle Fourche Member of the Frontier Formation in eastern Wyoming (Merewether *et al.*, 1979), accumulated in early Cenomanian (and possibly latest Albian; Ryer, 1977) through early middle Turonian time. It is underlain by the late Albian Aspen and Mowry Shales. In eastern Wyoming, it interfingers extensively with, and tongues out into, the Cenomanian Belle Fourche Shale; it is overlain by a tongue of marine shale and, locally, calcareous shale that is, in part, equivalent to the Greenhorn Limestone of the central part of the Western Interior Basin. Identified as the Greenhorn Formation in eastern Wyoming and Colorado, this shale interval is known as the Allen Hollow Shale Member of the Frontier, Tununk Shale Member of the Mancos Shale, Allen Valley Shale and Tropic Shale in areas to the west.

The third wedge includes the late middle to early late Turonian Oyster Ridge Member and the Coniacian Dry Hollow Member of the Frontier Formation in north-central Utah (Hale, 1960; Ryer, 1976) and western Wyoming (Love, 1956; Myers, 1977), the Emigrant Gap Member¹ (the "unnamed member" of Merewether, 1980) and the Wall Creek Member of the Frontier in eastern Wyoming (Merewether, 1983), the entirety of the Frontier Formation in western Colorado and parts of southern Wyoming (Hansen, 1965; Maione, 1971), and the Ferron Sandstone Member of the Mancos Shale (Hale, 1972; Cotter, 1975; Ryer and McPhillips, 1983), Funk Valley Formation (Lawton, 1982), and all but the youngest part of the Straight Cliffs Formation of Utah (Peterson, 1969; Johnson and Vaninetti, 1982). Underlain by the Greenhorn-equivalent shale tongue, it is overlain by a shale tongue that is equivalent to the Sage Breaks Member of the Carlile Shale and the Niobrara Limestone of northeastern Wyoming. This shale inter-

¹ The Emigrant Gap Member is a new stratigraphic name. I object to the increasingly formalized use of the name "unnamed member" in the literature for what is a well-defined, mappable and genetically very important stratigraphic unit. Merewether's decision not to formally name the unit reflects a certain amount of initial uncertainty about the significance of the member compounded by difficulties involved in gaining acceptance of a new member name within the United States Geological Survey. Merewether (pers. comm.) regards the section at Emigrant Gap, near Casper, Wyoming, as a suitable type section for the member. I take the liberty of naming the member here. E.A. Merewether should be considered its author.

val, too, is known by a variety of locally applied names: Cody Shale, Baxter Shale, Hilliard Shale, Judd Shale Member of the Frontier, and Blue Gate Shale Member of the Mancos Shale.

The three mid-Cretaceous clastic wedges, although sharing many characteristics, display some important differences in their areal distributions, thicknesses, lithologies and presence or absence of subaerial unconformities. Analysis of these characteristics provides evidence that the wedges had different origins.

Muddy Clastic Wedge

The oldest of the clastic wedges considered here is, in some respects, the most complicated. Compared to the wedges that followed, it is extremely thin; it attains thicknesses exceeding 76 m (250 ft) in the Bear River Formation of western Wyoming, but only locally exceeds 30 m (100 ft) throughout the rest of Wyoming and in Colorado (Dolson *et al.*, 1991). Despite its thinness, the wedge is remarkably widespread. The regression that led to its deposition is recognized throughout the central and northern Rocky Mountain regions of the U.S. and northward into Canada, where the Viking Formation is its equivalent (Evans, 1970; Beaumont, 1984).

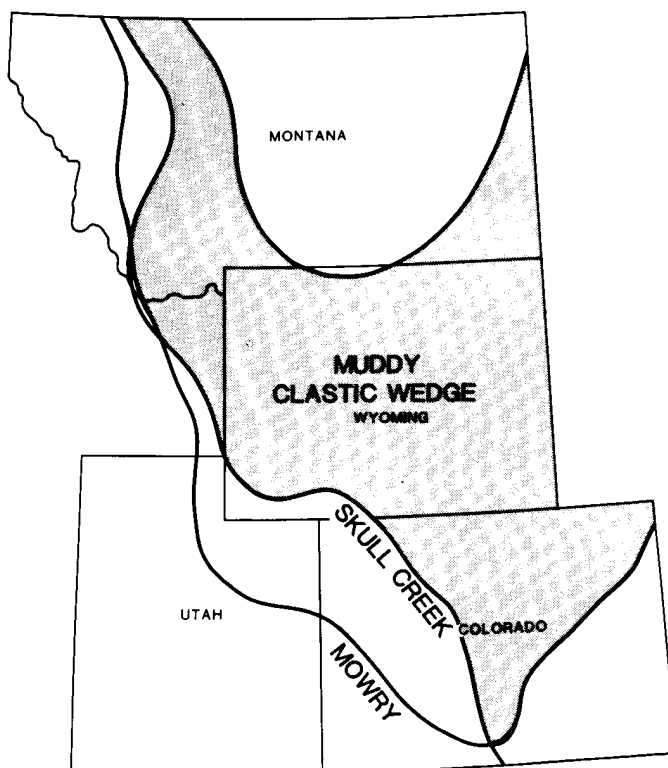


Figure 3. The late Albian Muddy clastic wedge is areally widespread. The landward limit of the wedge is defined by the feather-edges of the underlying Skull Creek and overlying Mowry Shale; its seaward limit is defined by the approximate shoreline position at peak regression.

The Muddy clastic wedge is relatively fine grained. Its shale content generally increases westward in the vicinity of the Sevier Orogenic Belt, reflecting higher rates of subsidence and hence greater preservation of fine-grained, fluvial overbank deposits and lacustrine muds. Except for conglomerates deposited on alluvial fans immediately east of the orogenic belt, the only conglomerates known from the wedge are pebbly lags in the lower parts of Muddy fluvial valley systems. But these are rare and occur far to the east of the source area; they are probably attributable to local reworking of coarse-grained deposits of the older, Aptian-Albian Lakota, Cloverly and Cedar Mountain formations.

Perhaps the most distinctive characteristic of the Muddy clastic wedge is that it contains at least two widespread unconformities (Gustason *et al.*, 1988). These are the products of subaerial erosion brought about by lowering of relative sea level and withdrawal of the sea. In areas where rates of subsidence were low during Muddy time, such as the Powder, Wind River and Big Horn basins, Muddy regressive shoreline sands were commonly stripped away, leading to deposition of Muddy valley-fill deposits directly upon the Thermopolis Shale. Where regres-

sive sands remain, they commonly contain large amounts of kaolinite clay within the interstitial spaces and coarse-sand-sized siderite concretions directly beneath the unconformable surfaces.

There is no evidence for any dramatic increase in the amount of sediment supplied to the Cretaceous Interior Basin from the Sevier Orogenic Belt during deposition of the Muddy clastic wedge. Any coarse clastics supplied to the western edge of the foreland basin was effectively trapped there.

The characteristics of the Muddy clastic wedge — widespread distribution despite its thinness, sparseness of coarse clastics, and presence of widespread subaerial unconformities — point to a eustatic drop of sea level during a period of relative tectonic quiescence. If this is so, the Muddy wedge represents an end member, a eustatic-type clastic wedge.

Chalk Creek Clastic Wedge

The second mid-Cretaceous wedge was deposited during early Cenomanian through early middle Turonian time. It is localized in Wyoming (Fig. 4), where it extends about 320 km (200 miles) into the basin. Although the wedge is represented by the Belle Fourche Member of the Frontier Formation over much of Wyoming, the name Chalk Creek was chosen to represent it since the name Belle Fourche also applies to a thick formation of marine shale in eastern Wyoming and the Dakotas. In southwestern Wyoming and north-central Utah, the Chalk Creek Member of the Frontier Formation is truncated toward the southeast and east by an unconformity that probably resulted from early uplift along the axis of what is now the Uinta Mountains (Weimer, 1962; Ryer and Lovekin, 1986). Elsewhere in Wyoming, the wedge thins and disappears basinward as a result of interfingering with marine shales of the underlying and laterally equivalent Belle Fourche Shale and to a lesser degree with overlying calcareous marine shales of the Greenhorn Formation.

To the north, in Montana, Cenomanian through early Turonian deposits do not record a major regression. To the south, throughout the remainder of Utah, this time span was characterized by transgression of the Tununk-Tropic sea. Unlike the Muddy clastic wedge that preceded it, the Chalk Creek wedge contains a substantial amount of coarse-grained material. Rivers transported pebbles all the way to the distal edge of the wedge in what is now the western part of the Powder River Basin in northeastern Wyoming. There, conglomeratic lags cap thick, progradational shoreline sequences in the Belle Fourche Member of the Frontier Formation. Most of this coarse material appears to have been delivered by fluvial systems that flowed across the foreland basin in northern Wyoming, that is, within the northern portion of the clastic wedge.

The Chalk Creek clastic wedge is relatively thick. It attains thicknesses of 1220 (4000), 335 (1100) and 150 (500) m (ft), respectively, in north-central Utah,

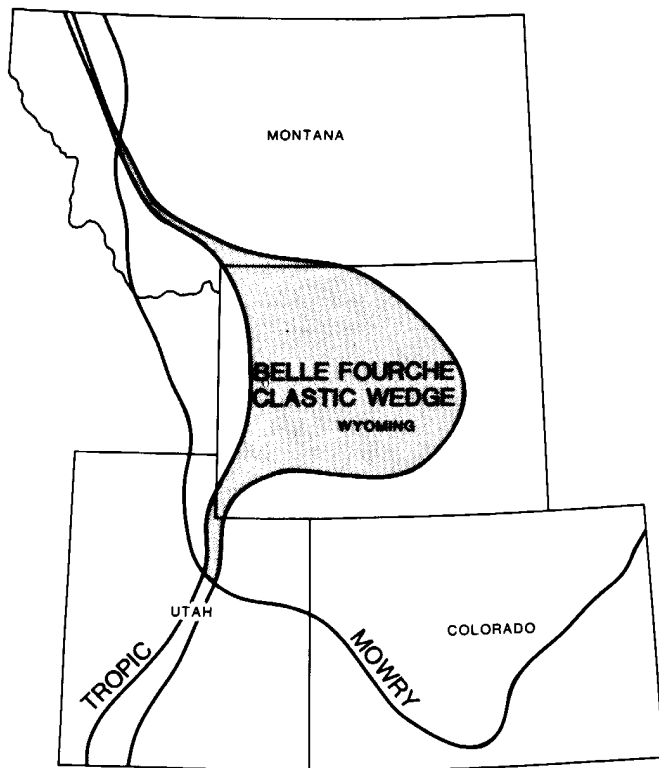


Figure 4. The Cenomanian-Turonian Chalk Creek clastic wedge is localized in Wyoming, where the shoreline, at peak regression, reached the western part of the Powder River Basin. The landward limit of the wedge is defined by the underlying Mowry Shale and overlying Tropic-equivalent shales.

southwestern Wyoming, and west-central Wyoming. It maintains a thickness in the 120-275 m (400-900 ft) range across central Wyoming to its depositional limit in the western Powder River Basin, where it interfingers with and disappears eastward into the Belle Fourche Shale.

The Chalk Creek clastic wedge differs markedly from the Muddy wedge in one other important respect: it includes no widespread subaerial unconformities. The only unconformity known to be associated with the Chalk Creek wedge — the one that removed it in the vicinity of the Uinta Mountains — is areally restricted and is clearly the result of localized tectonics.

The Chalk Creek wedge appears to be a product of tectonics. Thrusting within the Wyoming portion of the orogenic belt led to rapid crustal loading and subsidence of the foreland basin in western Wyoming and north-central Utah. Erosion of material from the uplifted thrust sheet provided more than enough sediment to fill the space created by subsidence. Some of the excess sediment, including coarse debris, was carried eastward across northwestern Wyoming to accumulate on the prograding shoreline, which advanced basinward to form the prominent bulge in the shoreline. The bypassing of coarse debris across the foreland basin was probably greatest during the later phases of the tectonic pulse, during which time the rate of erosion of the thrust sheets in the orogenic belt exceeded the amount of uplift and the westernmost part of the foreland isostatically adjusted upward as the load was reduced.

There is no evidence of a lowering of sea level in the Western Interior Basin during the deposition of the Chalk Creek clastic wedge, this having been a time of rising relative sea level and transgression elsewhere in the Rocky Mountain region. The Chalk Creek wedge, then, can be characterized as a tectonic-type clastic wedge.

Ferron-Wall Creek Clastic Wedge

Deposition of a third clastic wedge spanned mid-Turonian through Coniacian time. This wedge displays many of the distinguishing characteristics of the previous two and, thus, appears to be a hybrid. It is represented by the Ferron Sandstone Member of the Mancos Shale in Utah and the Wall Creek Member of the Frontier Formation in Wyoming.

The regression that marked the progradation of the Ferron-Wall Creek wedge is recognized through the Western Interior of the United States; it is also recognized in Canada, where it is represented by the Cardium Formation (Walker, 1983) and its equivalents. Although the regression was widespread, regression was particularly pronounced in Wyoming (Fig. 5), where a conspicuous lobe of sandy sediment essentially overlies the older lobe of the Chalk Creek clastic wedge.

The thickness of the Ferron-Wall Creek clastic wedge is intermediate between the thicknesses of the Muddy and Chalk Creek wedges. It attains a

maximum thickness of about 730 m (2400 ft) in north-central Utah. Locally, as in north-central Wyoming, it thins to zero owing to erosion on contemporaneous upwarps. Near the depositional limit of the wedge in the western Powder River Basin, the Wall Creek Sandstone Member of the Frontier Formation generally ranges in thickness between 30 and 90 m (100 and 300 ft). The middle Turonian Codell Sandstone in central and northern Colorado (Krutak, 1970) and the late Turonian Turner Sandy Member of the Carlile Shale in northeastern Wyoming (Weimer and Flexer, 1985) and western South Dakota represent shelf accumulations deposited off the distal end of the clastic wedge.

The problem of whether or not to include shelf sands in clastic wedges aside, defining the shape of the Ferron-Wall Creek clastic wedge is complicated by the fact that, upon closer examination, it appears to include two distinct parts. The lower part consists of middle Turonian regressive sequences of the Oyster Ridge Sandstone Member of the Frontier Formation in north-central Utah and southwestern Wyoming, the Tibbet Canyon Member of the Straight Cliffs Formation in southwestern Utah, the lower part of the Ferron Sandstone Member of the Mancos Shale in central and east-central Utah,

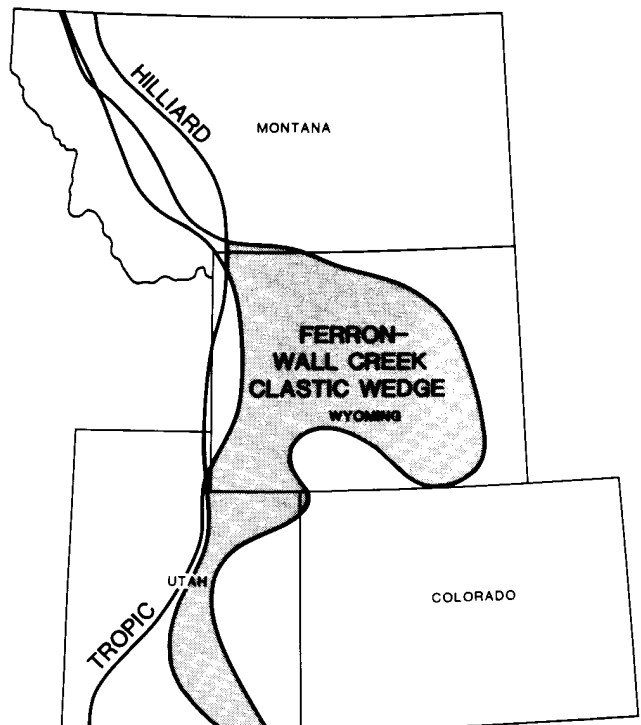


Figure 5. The Turonian-Coniacian Ferron-Wall Creek clastic wedge is recognized throughout Wyoming and Utah. The regression was most pronounced in Wyoming, where the shoreline prograded eastward across most of the width of the state. The landward limit of the wedge is defined by the underlying Tropic Shale and equivalents and by the overlying Hilliard Shale and equivalents.

and the Frontier Formation in south-central Wyoming, in the adjacent, eastern part of Utah, and in northwestern Colorado.

The regression that led to deposition of the lower part of the Ferron-Wall Creek wedge appears to have occurred in response to a lowering of sea level throughout the Cretaceous Western Interior Basin. Large areas of the sea floor in the eastern part of the basin, far from the direct tectonic influence of the orogenic belt, shoaled to depths where waves could rework the bottom. Some areas may have become emergent.

A widespread unconformity, possibly of subaerial origin, truncates the Emigrant Gap Member of the Frontier Formation over much of central and eastern Wyoming (Merewether and Cobban, 1972). Another unconformity, one that is certainly of subaerial origin, marks the top of the Ferron Sandstone Member in the Henry Mountains Basin of central Utah (Peterson and Ryder, 1975). Whether this unconformity developed at the close of deposition of the lower part of the Ferron-Wall Creek wedge or concurrently with deposition of its upper part is unclear. Another widespread erosional surface is present beneath or within the lower part of the Turner Sandy Member in northeastern Wyoming. This surface, which probably formed while the Codell Sandstone was being deposited to the south, may, at least in part, have been formed subaerially (Weimer and Flexer, 1985).

Although strata of the lower part of the wedge contain conglomerates, these are, for the most part, confined to areas immediately adjacent to the Sevier Orogenic Belt. Examples are the Indianola braided-stream conglomerates of central Utah (Lawton, 1982) and conglomeratic lenses in the wave-dominated shoreline sequences of the Oyster Ridge Sandstone Member in north-central Utah (Ryer, 1976). Some coarse material, however, did find its way to the western part of the Powder River Basin, where it is concentrated locally as a lag on the top of the Emigrant Gap Member. Although the evidence can be interpreted in various ways, it appears likely that there was no major tectonic event in the thrust belt during deposition of the lower part of the Ferron-Wall Creek wedge.

Accumulation of the lower part of the Ferron-Wall Creek clastic wedge was terminated in earliest late Turonian time by a transgression of the sea across the regressive deposits. The transgression was short-lived; it was closely followed by another regressive shift of the shoreline. In central Utah, river-dominated deltaic deposits of the upper Ferron prograded well beyond the basinward limits of the lower Ferron shoreline. Similarly, in Wyoming, the sandy Wall Creek Member of the Frontier extends farther eastward than did the older Emigrant Gap sandstones, grading eastward into sandy, distal shelf deposits of the Turner Sandy Member, which extends into South Dakota.

Although the upper part of the Ferron-Wall Creek

clastic wedge records a regression, there is no evidence to indicate that sea level lowered regionally at this time. The wedge can be explained by a tectonically induced increase in sediment supply from the Sevier Orogenic Belt superimposed upon a continually rising sea level.

Tectonic control upon deposition of the upper part of the Ferron-Wall Creek wedge is suggested by the fact that the wedge contains widespread units of conglomerate and pebbly sandstone. The Calico bed of the Straight Cliffs Formation in southwestern Utah and the Coalville conglomerate of north-central Utah both appear to belong in this interval. Pebbly fluvial sandstones also occur in an equivalent stratigraphic position in southwestern Wyoming.

The characteristics of the Ferron-Wall Creek clastic wedge appear to be best explained in terms of both sea level and tectonics, although these acted out of phase: lowering of sea level during middle Turonian time brought about the initial regression, resulting in deposition of the lower part of the wedge; rising of sea level during late Turonian time brought on the short-lived transgression whose marine shale deposits separate the lower and upper parts of the wedge; and a tectonically caused increase in the rate of sediment input to the basin during late Turonian time overwhelmed the effect of rising sea level, leading to a second regression represented by the upper part of the wedge. The supply of sediment probably waned during latest Turonian time. This permitted rising sea level to once again predominate, and the shoreline transgressed. The Niobrara sea attained its maximum areal extent in the Rocky Mountain region during Coniacian and earliest Santonian time.

The Ferron-Wall Creek clastic wedge appears to be a hybrid-type wedge: its lower part formed primarily in response to changes in sea level; its upper part reflects a tectonically produced increase in sediment input during a period of overall rising sea level.

DISCUSSION

The Cretaceous rocks of the Western Interior of North America are among the most intensively studied and best understood in the world. These rocks display intricate interfingering of facies, which occurs at a variety of scales and which was brought about by a variety of causes. Deciphering these causes and defining the criteria by which they can be distinguished in the stratigraphic record will be the basis for a new round of studies whose results will be valuable in developing predictive models that can be applied in less well-known areas.

The depositional histories of the three mid-Cretaceous clastic wedges described here must be regarded as speculative; the working out of the details remains to be accomplished. What is known about the wedges so far, however, suggests that their causative mechanisms can be distinguished on the basis of their areal distributions, their thicknesses, and whether or not they contain widespread beds of

conglomerate and subaerial unconformities. The assumptions upon which the conclusions of this paper are based are:

1. Widespread areal distribution of a clastic wedge suggests that the wedge is the result of a sea-level lowering. A more localized distribution suggests a tectonic origin, the wedge being situated basinward of the portion of the thrust belt that was active and that supplied the sediment to it. However, if many segments of the thrust belt are active concurrently, a widespread, tectonic wedge can be formed.

2. Tectonically produced wedges are relatively thick, particularly so within the foreland basin, near the thrust load. Wedges produced by lowering of sea level are relatively thin, although they, too, thicken markedly into the foreland basin.

3. Widespread subaerial unconformities are produced in less rapidly subsiding portions of the basin during periods of lowered sea level. They may disappear in the foreland basin, where lowering of sea level is counterbalanced by more rapid basinal subsidence (Fig. 1). Rapid loading of sediment into the basin from an active portion of the thrust belt, on the other hand, leads to continuous subsidence and an absence of unconformities. An exception may be the late stage of formation of a tectonic clastic wedge, during which erosion of the thrust sheet might lead to some rebounding and subsequent reworking of the sedimentary section within the foreland basin. (The unconformity beneath the Coalville conglomerate might be of this kind.)

4. Conglomerates are shed from the orogenic belt in greatest abundance during periods of tectonic activity. Ideally, clastic wedges produced by tectonism include more conglomerate than wedges produced by lowering of sea level. Most, or even all, of the conglomerate, however, may be deposited within the foreland basin, only finer-grained material reaching the more distal parts of the wedge. The presence or absence of conglomerates, therefore, is probably the weakest criteria for purposes of determining the origins of clastic wedges.

Analysis of the three mid-Cretaceous clastic wedges of the Rocky Mountain region, with respect to these criteria, indicates that they formed in substantially different ways.

The Muddy clastic wedge is areally widespread, is thin, is generally fine grained, and includes several widespread subaerial unconformities. Erosion during formation of these unconformities led to complete removal of regressive shoreline deposits over large areas. The Muddy clastic wedge appears to have been deposited primarily in response to a lowering of sea level throughout the Western Interior. This is inferred to be a eustatic lowering of sea level. The Muddy wedge can be described as a eustatic-type clastic wedge.

The Chalk Creek clastic wedge constitutes a localized lobe of sediment. It is thick. It contains beds of conglomerate, some of which occur near its seaward limit. Widespread subaerial unconformities

have not been recognized within it. The wedge formed eastward of a portion of the Sevier Orogenic Belt that contributed a large volume of sediment during Cenomanian and Turonian time. Inasmuch as tectonics appears to have exerted the dominant influence on this wedge, it is termed a tectonic-type clastic wedge.

The Ferron-Wall Creek wedge displays the characteristics of both eustatic- and tectonic-type wedges and so is believed to be a hybrid-type clastic wedge. Its lower and upper parts reflect overriding control of sea level and tectonics, respectively.

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