Influence of inherited taper on structural variability and conglomerate distribution, Cordilleran fold and thrust belt, western United States

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ABSTRACT

North-south changes in thickness of the prethrust stratigraphy of the North American Cordillera within the United States controlled kinematic development of the late Mesozoic (Sevier) fold and thrust belt. Variation in stratigraphic thickness determined the initial slope (β_o) of the basal decollement beneath the thrust wedge. As predicted by critical-wedge theory, segments of the Sevier thrust belt with initially thick Precambrian and Paleozoic stratigraphic sections are structurally simple and are composed of few thrust sheets; segments with thin prethrust stratigraphy and comparably low values of β_o are intensely imbricated. The difference in structural style resulted because wedge segments with higher values of β_o required less internal deformation to build and maintain the critical taper required for thrust-wedge advance. Transverse structural zones, across which kinematic style differed, formed at the terminations of thrust-belt segments and controlled the locations of long-lived antecedent drainage systems that transported gravel to the foreland. Therefore, along-strike changes in prethrust stratigraphic thickness resulted in an observed disjunct distribution of conglomerate in synorogenic deposits of the thrust wedge and foreland basin.

INTRODUCTION

The structural style of the Cordilleran fold and thrust belt in the United States varies along strike (Beutner, 1977) to form alternating segments, some linear to broadly arcuate and imbricated, and some lobate and structurally simpler. We note that structurally simple segments correspond to intervals of the thrust orogen with anomalously thick preexisting stratigraphic sections of either Proterozoic or Paleozoic age and relatively steep dips on underlying basement. Imbricate segments correspond to intervals with thinner stratigraphic sections and lower dip of the basement surface. The critical-wedge model for thrust-belt development (Davis et al., 1983) predicts that the slope of the basement surface should directly affect internal deformation of the sedimentary section during thrusting. Along-strike changes in initial basement slope or decollement angle thus can be expected to produce contrasts in structural styles and kinematic histories of adjacent thrust-belt segments (Boyer, 1991). Adjacent segments are linked by transverse structure-transfer zones that may serve as conduits for long-term gravel transport to the adjacent foreland basin. We postulate that transverse structural zones within the Cordilleran fold and thrust belt resulted from along-strike variation in geometry of the critical wedge; therefore, the critical-wedge model explains the distribution of coarse-grained, proximal conglomerate within the Cordilleran foreland basin.

IMPACT OF INITIAL β ON THRUST-WEDGE KINEMATICS

Variation in structural style along a thrust orogen is in part controlled by the dip angle, β, of the basal decollement (Fig. 1A). Because major thrusts commonly propagate along bedding surfaces or the basement-cover contact, β is inherited from the geometry of the preexisting sedimentary basin or superposed sedimentary basins involved in shortening. In order for a thrust wedge to advance, a topographic slope (α) must be created by internal deformation such that α plus β attains a threshold angle, termed the critical taper (6°–10°; Davis et al., 1983). High initial values of β, termed here β_o, that approach the critical-taper angle favor the development of large dominant sheets (Boyer and Elliott, 1982, p. 1221) because little internal shortening is required to build the necessary topographic slope (Boyer, 1991). Low values of β_o conversely require that the wedge shorten by thrust imbrication to attain sufficient α (Fig. 1A). A given displacement at the back of a thrust orogen causes wedges with high β_o to advance farther toward the foreland because less of the displacement is absorbed by shortening within the wedge. The spacing of thrusts within the wedge is also controlled by the thickness of the sedimentary section (Lui et al., 1992), such that a thicker section results in more widely spaced thrusts. A thicker sedimentary prism and higher β_o therefore combine to create wider thrust belts with fewer thrusts, and fewer, wider piggyback basins (Fig. 1A). Along-strike changes in β_o and sedimentary thickness in turn create along-strike contrasts in contractional styles and histories that must be accommodated by transverse structural zones (Fig. 1, B and C).

ACROSS-STRIKE STRUCTURAL DISCONTINUITIES

The presence of prominent transverse structural zones provides a means for dividing the Cordilleran thrust belt into geographic segments based on the key parameters of thrust number and spacing. We divide the orogen into geographic segments (Fig. 2) consisting of one dominant thrust sheet (Helena salient, Provo salient) and segments composed of three or more master sheets (Wyoming salient, southern Utah imbricate zone). The southwestern Montana segment, where Proterozoic rocks are comparatively thin, forms a transition between the Helena salient, composed of a thick Proterozoic succession to the north, and the Wyoming salient to the south. The

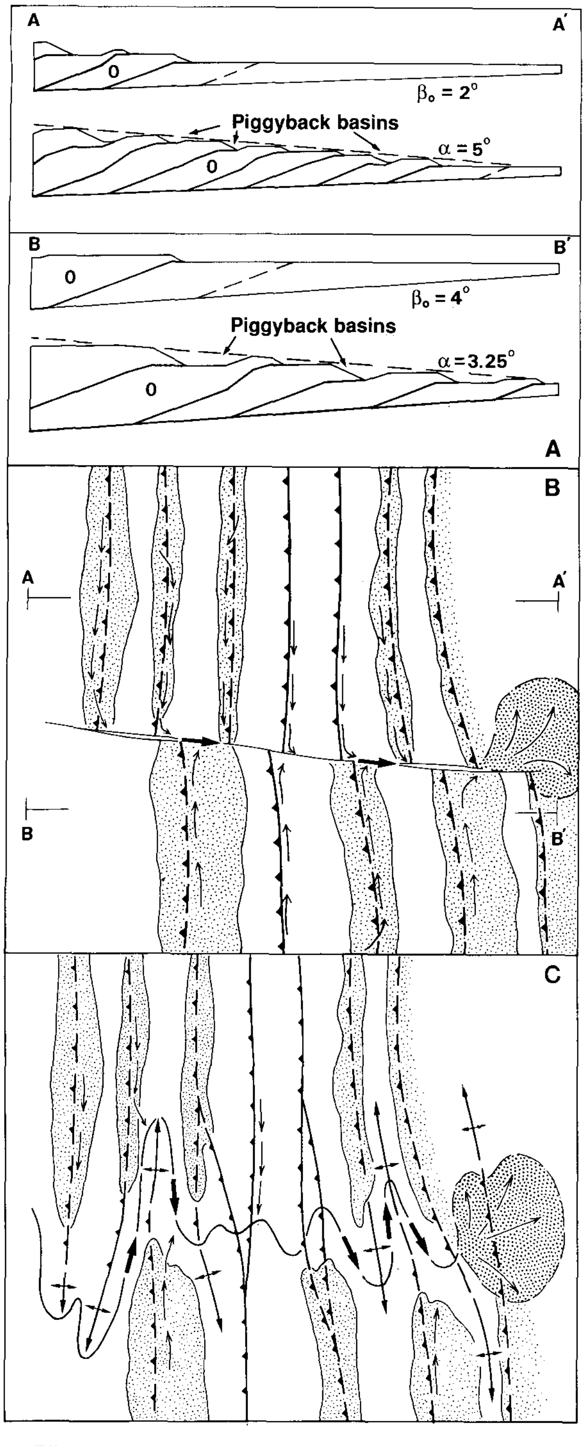

Figure 1. Effect of initial decollement angle (β_o) on development of critical thrust wedge and location of transverse structural zone between thrust-belt segments. A: Sequential cross sections showing influence of variable β_o upon thrust imbrication of two sedimentary prisms for equivalent amount of displacement at back of wedge; α is resultant topographic slope of thrust wedge required for critical taper, which permits wedge to advance toward foreland (Davis et al., 1983; Boyer, 1991); O indicates same thrust sheet, displaced during shortening, in each sequence. Space beneath dashed lines (average topographic slope) may fill with sediment to become piggyback basins. B: Schematic map view corresponding to sections A-A′ and B-B′ in A, illustrating abrupt transverse structural zone, predicted sediment-dispersal routes (thin arrows), and potential depositional sites (light stipple) within thrust wedge. Coarse clastic deposition (heavy stipple) occurs at foreland terminus of transverse structural zone, which controls major cross-wedge dispersal (thick arrows). C: Map view comparable to that in B, but illustrating diffuse transverse structural zone, across which β_o changes gradually from north to south.

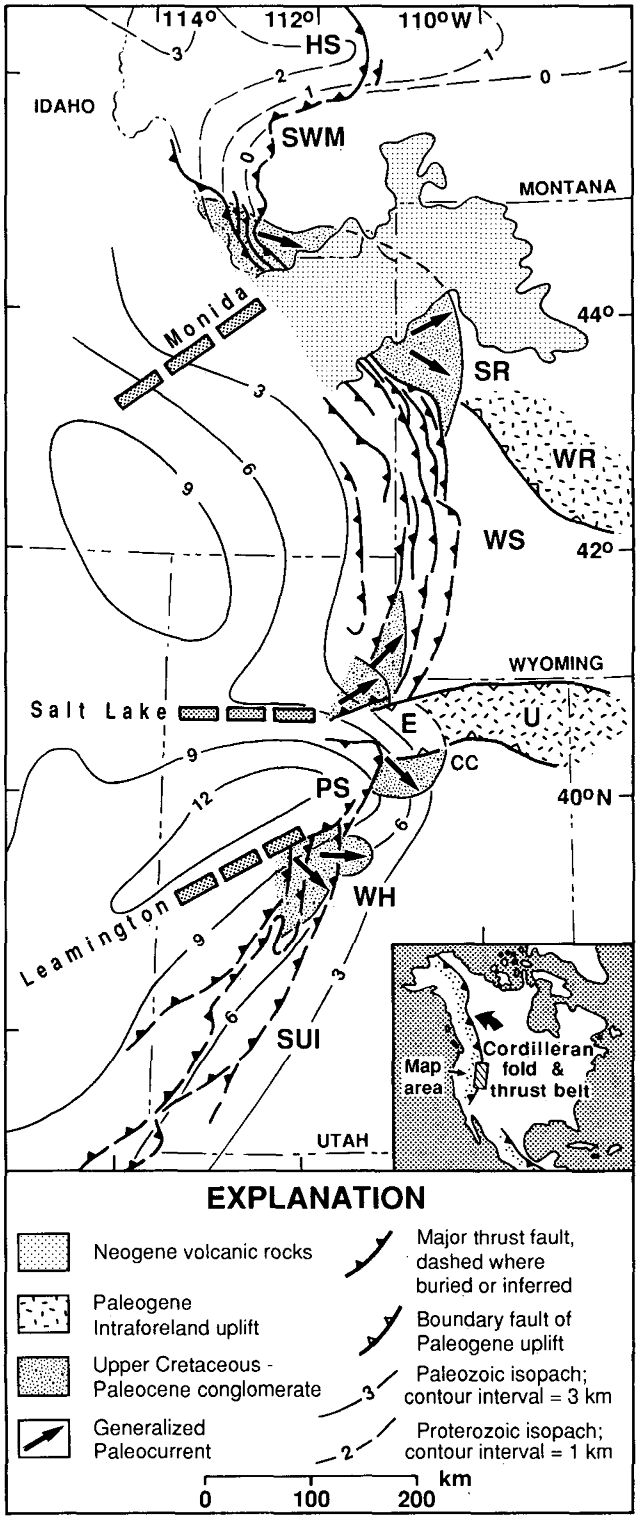

Figure 2. Map of part of late Mesozoic–early Cenozoic Cordilleran fold and thrust belt in western United States, showing segments of thrust belt defined herein, and transverse structural zones (Leamington, Monida, Salt Lake). Palinspastic isopachs of Proterozoic (isopach interval 1000 m) and Paleozoic (isopach interval 3000 m) strata from Peterson and Smith (1986) and Peterson (1977). Segments of thrust belt: HS—Helena salient; PS—Provo salient; SUI—southern Utah imbricate zone; SWM—southwestern Montana segment; WS—Wyoming salient. Conglomerate complexes: E—Emigrant; SR—Snake River; WH—Wild Horse. Paleogene foreland uplifts postdating most gravel deposition: WR—Wind River; U—Uinta. CC: Currant Creek Formation. Western boundary of Utah is displaced ~40 km eastward of current position at long 114°W to restore Neogene extension of thrust belt and isopachs (Allmendinger et al., 1983).

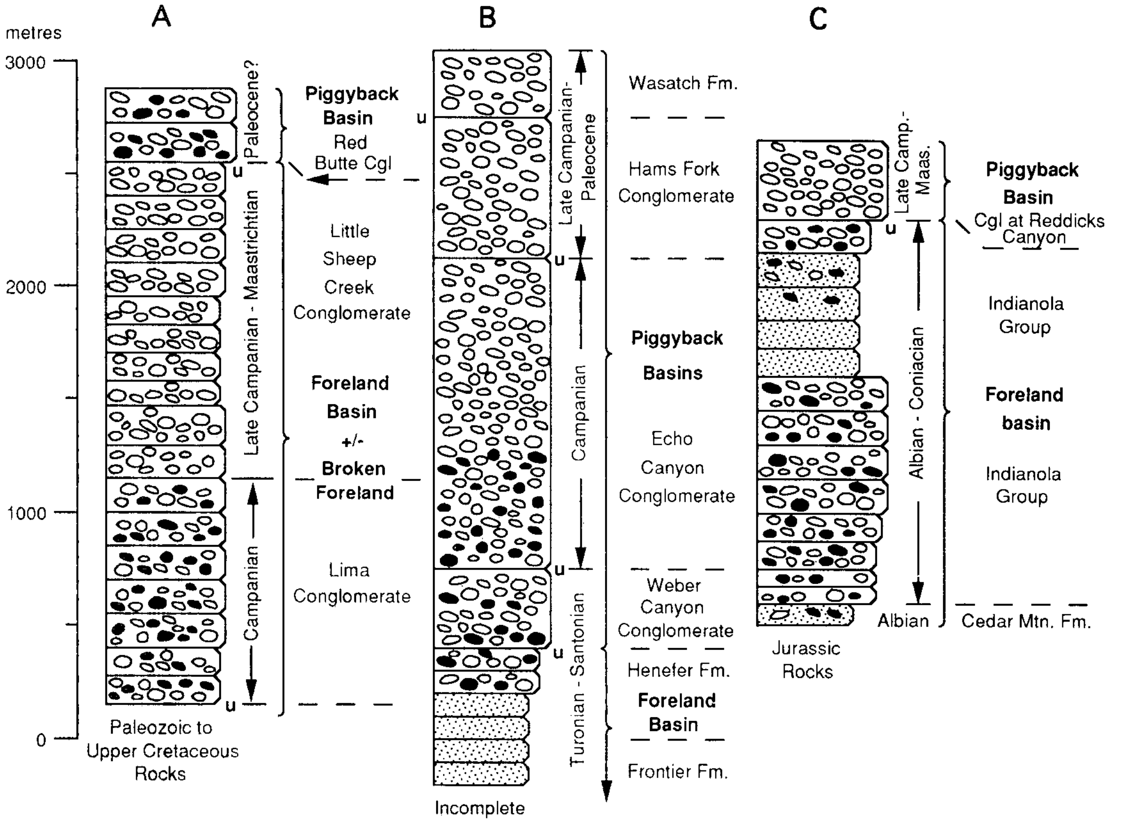

Figure 3. Representative sections of conglomerate complexes in Sevier belt. Structural settings of deposition are in boldface type; local unit names are not. Solid and open clasts indicate conglomerate with significant carbonate-clast population; open clasts only indicate quartzite-clast conglomerate; stippled intervals are dominantly sandstone and siltstone; u is angular unconformity. A: Snake River complex. Composite section of Beaverhead Group in vicinity of Dell, Montana, after Ryder and Scholten (1973) and Perry et al. (1988). Thicknesses are approximate. B: Emigrant complex. Composite section in Weber Canyon, Utah, after DeCelles (1994). C: Wild Horse complex. Stratigraphic section, west side of San Pitch Mountains, Utah, after Lawton (1982) and Schwans (1988).

segment is increasingly imbricated southwestward from the Helena salient; thrust trends were at least in part controlled by a foreland uplift that acted as a buttress (Beutner, 1977; Perry et al., 1988). Four thrust sheets compose the southern part of the Wyoming salient (Royse et al., 1975; DeCelles, 1994), but the belt is more imbricated and folded northward. Directly south of the Wyoming salient, the Provo salient contains more than 9 km of Paleozoic strata (Peterson, 1977). Although the salient is imbricated in its western part, it is formed mostly by a single thrust sheet having minor faulting and internal folding. To the south, the southern Utah imbricate zone contains four major thrust sheets (Royse, 1993).

The transverse zones between thrust-belt segments form both abrupt discontinuities (Fig. 1B) and diffuse structural transitions (Fig. 1C). Abrupt transverse zones reflect rapid lateral changes in thickness of the sedimentary section and, therefore, β_0; diffuse transverse zones are inferred to result from gradual changes in lateral thickness. The Leamington transverse zone, at the southern edge of the Provo salient, exemplifies the abrupt across-strike discontinuity. It parallels Paleozoic isopach trends and has been interpreted as a high-angle fault system (Morris, 1983), a reverse fault (Higgins, 1982), and a lateral ramp (P. G. DeCelles, 1993, written commun.). The Oquirrh basin, which has a thick upper Paleozoic section, lies to the north of the Leamington zone. To the south, the Oquirrh section is absent and corresponds instead to a Mississippian-Permian unconformity (Hintze, 1988). The Monida transverse zone is an example of a diffuse transition zone, in which displacement of the Helena salient is transferred to the south along the southwestern Montana segment of the orogen. This transverse zone is a complex of foreland-bounding faults, the locations of which were controlled by Proterozoic structures (O'Neill et al., 1990). At the southwest end of this complex, the trend of the exposed Snowcrest-Greenhorn thrust system projects southwestward beneath the Snake River volcanic field along a structural discontinuity formed by a series of lateral ramps in the thrust belt (Perry et al., 1988); we have placed the Monida transverse zone along the projection of this discontinuity. The Salt Lake transverse zone is an abrupt boundary between imbricated Archean crystalline rocks and Paleozoic through Mesozoic strata on the north and folded, very thick Proterozoic and Paleozoic strata on the south (Bryant and Nichols, 1988; Yonkee, 1992). This dramatic stratigraphic boundary was a locus of lateral ramps in Cretaceous thrust sheets and subsequently accommodated an east-trending lateral ramp that formed the Paleocene Uinta uplift (Bruhn et al., 1986; Bryant and Nichols, 1988).

CONGLOMERATE DISTRIBUTION IN FORELAND

The disjunct distribution of thick, coarse-grained conglomerate bodies in the Cordilleran foreland basin (Beutner, 1977) is a direct consequence of along-strike variation in critical-wedge geometry. Three major conglomerate complexes are present along the thrust front. Each comprises a thick (2–4 km) succession of conglomerate that accumulated over a time interval roughly equivalent to the deformation history of the thrust belt (Ryder and Scholten, 1973; Lawton, 1982; Perry et al., 1988; DeCelles, 1994). These conglomerate complexes were deposited in the foreland basin and in piggyback basins on the distal part of the thrust wedge. Quartzite clasts common in all complexes, and particularly abundant in Upper Cretaceous (Campanian-Maastrichtian) levels, were derived from the interior of the thrust orogen (Schmitt and Steidtmann, 1990; DeCelles et al., 1993). The names of the complexes, Snake River, Emigrant, and Wild Horse (Fig. 3), emphasize their separate geographic and structural affinities. The Snake River complex, inferred to be physically connected beneath the Snake River volcanic field (Ryder and Scholten, 1973), includes the Beaverhead Group in southwestern Montana and the Pinyon and Harebell Formations in northwestern

Wyoming. The Emigrant complex includes the Henefer, Weber Canyon, Echo Canyon, Hams Fork, and Wasatch Formations in northern Utah and southwestern Wyoming. These units were derived from thrust sheets in the Wyoming salient (Royse et al., 1975; DeCelles, 1994). The lower part of the Campanian-Maastrichtian Currant Creek Formation (Fig. 2) south of the Uinta uplift contains Proterozoic clasts (Bruhn et al., 1986) and evidence of southeast paleocurrents (Beutner, 1977), indicating a probable source in Proterozoic rocks of the Willard allochthon north of the Uinta uplift (Bruhn et al., 1986). The Currant Creek is thus an extension of the Emigrant complex and was separated from it by Cenozoic uplift of the Uinta block. The Wild Horse complex, named for Wild Horse Peak in the Canyon Range of central Utah, includes the Cedar Mountain Formation, Indianola Group, and overlying boulder conglomerate in the western San Pitch Mountains (Fig. 3). The Canyon Range Conglomerate of Christiansen (1952) is probably equivalent to the Upper Cretaceous part of the section in the San Pitch Mountains (DeCelles et al., 1993).

DISCUSSION AND IMPLICATIONS

We postulate that positions of transverse structural zones determined the locations of adjacent conglomerate complexes in the Cordilleran foreland (Figs. 1, B and C; Fig. 2). Transfer zones provided fixed, easily eroded avenues through the orogen that focused antecedent drainages (Fig. 1C). Moreover, trunk rivers flowing in the transfer zones inherited large, integrated drainage basins as the thrust front evolved. The hypothesis presented herein is readily testable with integrated field study of the structural development and provenance of the Sevier belt.

The longevity of the transverse structures described here appears to have exceeded the life of the contractional orogen. Negative structural inversion of the Sevier orogenic belt by Cenozoic Basin and Range extension reversed some of the major late Mesozoic drainages. The Sevier River, which flows northward along structural strike for 225 km from the top of the Pink Cliffs near the Arizona-Utah border, enters the Great Basin westward along the Leamington fault zone. Likewise, the Snake River enters the Snake River Plain at the latitude of our postulated Monida transverse structural zone. The geomorphic influence of these stratigraphically controlled structural features thus may have persisted through several major tectonic events.

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