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Interior ramp-supported uplifts: Implications for sediment provenance in foreland basins

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ABSTRACT

The composition of syntectonic conglomerates in foreland-basin sequences is strongly controlled by the lithology of strata exposed to erosion in uplifted thrust plates. Consideration of the styles and mechanisms of uplift in thrust belts, combined with knowledge of sediment provenance and dispersal in eroding thrusted terranes, leads to the concept of interior ramp-supported uplift as a potential mechanism for generating syntectonic conglomerates in foreland basins. Interior ramp-supported uplift occurs when an older, inactive thrust plate that is part of the upper plate of a younger, active thrust is transported over a ramp in the younger thrust. Uplift and folding of the inactive thrust plate re-establish the older thrusted terrane as a sediment source area.

This mechanism is utilized to account for the deposition of a thick accumulation of quartzite-clast conglomerate (Harebell and Pinyon Formations) in the Sevier foreland basin of northwestern Wyoming. Other hypotheses of uplift-erosion-deposition suggested to explain the origin of these deposits include (1) basement-involved uplift, (2) progressive clast recycling through multiple episodes of fluvial transport during uplift on successive thrust plates, and (3) direct transport from the toe of active thrusts. Although these mechanisms all undoubtedly operate in eroding thrusted terranes, each has limitations to its potential validity as source for quartzite debris in the northwestern Wyoming foreland basin. The concept of interior ramp-supported uplift alleviates many of the inconsistencies of other models and is compatible with observations elsewhere in the Cordilleran thrust belt.

The interior uplift model also implies that uplift of an older, inactive thrusted terrane over ramps of active thrusts may be the primary factor in the development of topographic relief in fold-thrust belts.

INTRODUCTION

In foreland basins which develop adjacent to fold-thrust belts, syntectonic conglomerates are usually interpreted to represent detritus which has been eroded from the uplifted plates of active thrust faults (Royse and others, 1975), transported to the foreland basin and deposited. When datable, and where crosscutting and overlapping relations between syntectonic conglomerates and associated faults can be documented by field mapping or subsurface studies, the conglomerates are assumed to indicate time of motion along particular thrusts. If crosscutting and overlapping relations are unclear or absent, provenance studies utilizing paleocurrent and compositional data have been employed (for example, Dorr and others, 1977; DeCelles, 1986). The basis for use of provenance studies is that the location and structural geometry of a thrust plate must be compatible with paleocurrent and compositional data from any syntectonic conglomerate inferred to have been derived by motion along that thrust. More simply, the structural geometry along an active thrust, combined with the lithologic character of strata in the thrust sheet, controls the ultimate composition of the syntectonic debris (Graham and others, 1986; Lawton, 1986; Steidtmann and Schmitt, 1988).

Uplift in fold-thrust belts is related primarily to the vertical component of thrusting or ramping, where thrust faults cut up-section through competent stratigraphic layers. The effect of ramping of a thrust at depth is to deform the actively moving thrust plate into a structurally and topographically elevated fold (Serra, 1977). The folding and elevation of strata in a thrust plate carried over a thrust ramp leads to development of an uplifted terrane subject to erosion and production of syntectonic debris. Where the hanging walls of active thrust systems are composed of older, inactive thrust plates, these too are uplifted, folded, and exposed to further erosion. This process of uplift of an inactive thrust hanging wall has been termed "passive uplift" (Lawton, 1985; Steidtmann and Schmitt, 1988); however, because this term is an oxymoron created by the paradoxical conjunction of the contradictory terms "passive" and "uplift," we propose the more descriptive term, "interior ramp-supported uplift." From a sedimentological perspective, such interior uplift can elevate a dormant thrust allochthon above base level and subject it to erosion. If the ramp-supported uplift contains unique lithologies, debris containing distinctive clasts may be shed into the foreland basin in front of the active thrust. Repeated interior uplift and erosion of a dormant thrust terrane by sequential development of younger basinward thrust faults may eventually result in breaching of lower stratigraphic levels within the hanging wall.

In this paper, we employ the concept of interior ramp-supported uplift to explain the generation of an anomalously thick succession of Upper Cretaceous through lower Tertiary, quartzite-clast–bearing conglomerate in the Sevier foreland basin of northwestern Wyoming. Several uplift-erosion-deposition hypotheses proposed by other workers are reviewed, and their viability relative to what is known concerning uplift styles and mechanisms in fold-thrust belts and sediment provenance in, and dispersal from, thrusted terranes is evaluated. We have chosen this comparative approach to illustrate the potential utility of the interior-uplift concept for interpretation of synorogenic deposits in foreland-basin sequences.

QUARTZITE-CLAST–BEARING CONGLOMERATES

The Sevier foreland basin in northwestern Wyoming contains thick deposits of Upper Cretaceous to lower Tertiary, quartzite-rich cobble and boulder conglomerate. Specifically, these coarse-grained units include the Upper Cretaceous Harebell Formation, which crops out over an area of 450 km^2 (Fig. 1) and attains a maximum thickness of ~3,300 m; and the Upper Cretaceous to Paleocene Pinyon Con-

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glomerate, which covers 255 km^2 and reaches a maximum thickness of 1,142 m (Love, 1973) (Fig. 2).

Both formations contain quartzite gravel derived from erosion of upper Precambrian, Cambrian, and Ordovician strata of the Cordilleran miogeocline (Lindsey, 1972; Love, 1973; Ryder and Scholten, 1973). Maximum clast size is 2.3 m, although most are less than 46 cm long. The quartzite cobbles are well rounded, polished, and have crescentic percussion marks as well as concentric and radiating fractures related to postdepositional compaction.

Several hypotheses have been suggested to explain the origin of these thick quartzite-rich conglomeratic deposits. They include (1) derivation from erosion of the Targhee Uplift, a hypothetical basement-cored block uplift (Love, 1973); (2) progressive recycling through time of quartzite debris uplifted on successive thrust sheets (Lindsey, 1972; Ryder and Scholten, 1973); and (3) direct transport from the toe of an active thrust plate (Kraus, 1985). Each of these hypotheses and the evidence which supports them are briefly reviewed below and evaluated with respect to principles of sediment provenance and dispersal in thrusted terranes.

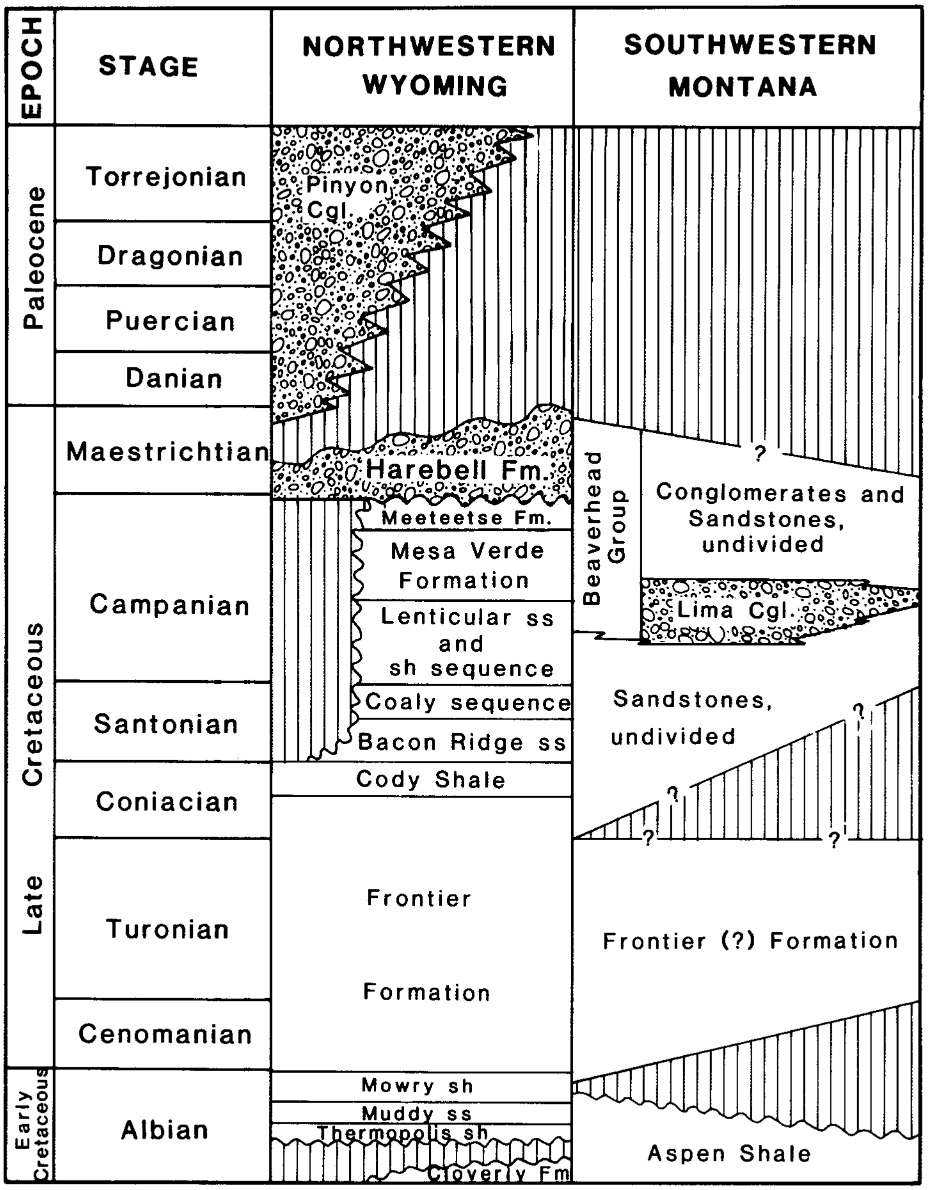

Figure 1. Stratigraphic column of Cretaceous to early Tertiary strata in northwestern Wyoming and southwestern Montana. Gravel pattern indicates that units are composed predominantly of quartzite-cobble and -boulder conglomerate. Age relations are based on information in Love (1973) and Nichols and others (1985).

TARGHEE UPLIFT

A hypothetical now-buried uplift located beneath the Snake River downwarp west and northwest of Jackson Hole was inferred by Love (1956) as the probable source of the large volume of quartzite debris that comprises the Harebell and Pinyon Formations (Fig. 2). It was later named the "Targhee uplift" (Love and Reed, 1971, p. 83). Love (1973, 1982) postulated that the Targhee uplift was subject to erosion from Late Cretaceous through Paleocene and perhaps middle Eocene time. Paleozoic and upper Precambrian quartzites were exposed in, and eroded from, the core of the uplift during this period. High-energy streams carried the quartzite debris from the Targhee uplift to the east and southeast, depositing it as the Harebell and Pinyon quartzite conglomerates in the ancestral Box Creek downwarp north of the Jackson Hole area (Fig. 2). Lesser volumes of quartzite clasts in the Upper Cretaceous (Santonian) Bacon Ridge Sandstone and middle Eocene Hominy Peak Formation of the Jackson Hole area, as well as a thick sequence (1,060 m) in the lower Eocene Pass Peak Formation of the Hoback basin were also attributed by Love (1982) to episodes of uplift of the Targhee uplift. The presence of very similar quartzite debris to the north and northwest in the Divide quartzite conglomerate lithosome of the Beaverhead Group of southwestern Montana was attributed by Love (1973) to erosion of the Targhee uplift by northward-flowing streams. Love (1973) thought that the Targhee uplift subsided in post-Eocene time along normal faults and is presently buried beneath upper Tertiary and Quaternary sediments and basalts of the Snake River Plain.

Evidence for the existence of the Targhee uplift is inferred solely from sedimentologic considerations. Paleocurrent indicators for the Harebell and Pinyon Formations indicate eastward transport from the area of the proposed Targhee uplift. The very coarse nature of these conglomerates suggested to Love (1973) local derivation, precluding long-distance transport. In addition, because the preserved abundance of quartzite gravel in the Jackson Hole area alone is greater than 325 km^3 and is estimated to have previously been as large as 2,500 km^3, Love (1973, 1982) inferred that thin-skinned thrust sheets in the adjacent Idaho-Wyoming thrust belt could not have provided such a large volume of quartzite debris. Rather, a predominantly verti-

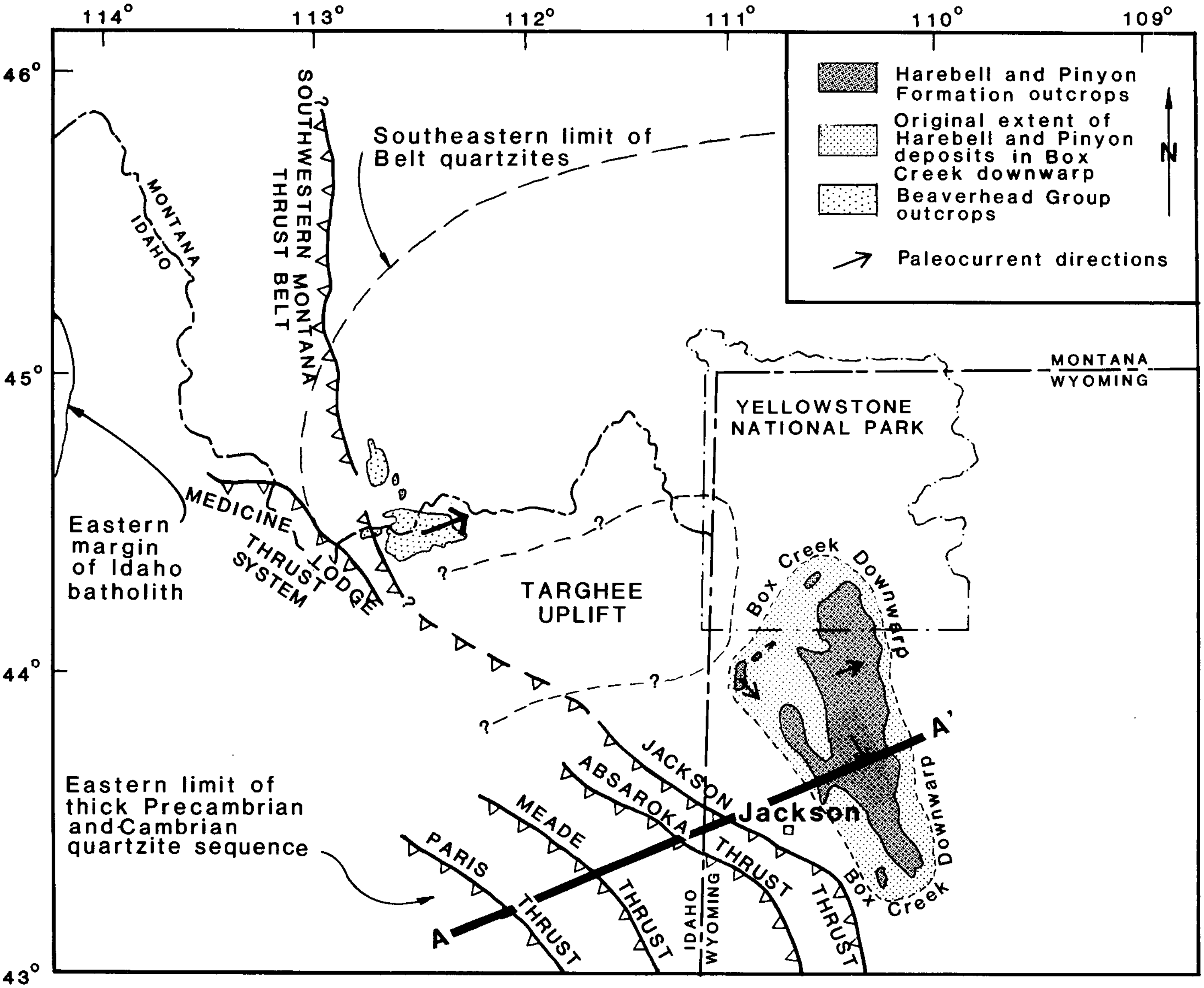

Figure 2. Map of Idaho-Montana and adjacent southwestern Montana thrust belts showing distribution of thick successions of Upper Cretaceous to Paleocene quartzite conglomerates. Modified from Lindsey (1973) and Ruppel and Lopez (1984). Arrows indicate generalized paleocurrent directions as reported by Lindsey (1972).

cal, basement-cored uplift containing thick quartzite sequences was viewed as the only viable source for quartzite detritus to be delivered to the foreland basin from Late Cretaceous through middle Eocene time. Subsequently, the Targhee uplift has been interpreted to be the northwestern extension of the ancestral Teton–Gros Ventre uplift (Love and others, 1978).

Evidence against existence of the hypothetical Targhee uplift is based primarily upon stratigraphic, structural, and geophysical considerations. All workers who have studied the quartzite clasts in detail agree that the major sources were Precambrian miogeoclinal units such as the Swauger Quartzite and Lemhi Group, and the Ordovician Kinnikinic Quartzite (Lindsey, 1972; Love, 1973; Ryder and Scholten, 1973; Perry and Sando, 1983; Perry and others, 1988). The restricted distribution of these quartzite units, however, suggests that the location of the proposed Targhee uplift was an area of limited quartzite occurrence. According to Ruppel (1975), the Precambrian quartzites in Idaho and Montana are not present east of the Medicine Lodge thrust system (as modified by Skipp, 1988) (Fig. 2). To the south in the Idaho-Wyoming thrust belt, upper Precambrian miogeoclinal quartzites are restricted to the Paris-Willard thrust plate (Oriel and Platt, 1980). Thus, the Targhee uplift, as envisioned by Love (1973, 1982), could not have easily provided a large volume of quartzite debris to the adjacent subsiding foreland basin.

Structural studies of both the Idaho-Montana thrust belt to the north and Idaho-Wyoming thrust belt to the south of the Snake River Plain fail to provide evidence of any deflection of thrust plates by the proposed Targhee uplift. If the Targhee uplift actively supplied quartzite detritus as early as Santonian time during Bacon Ridge Sandstone deposition and continuously through at least Paleocene time, then it almost

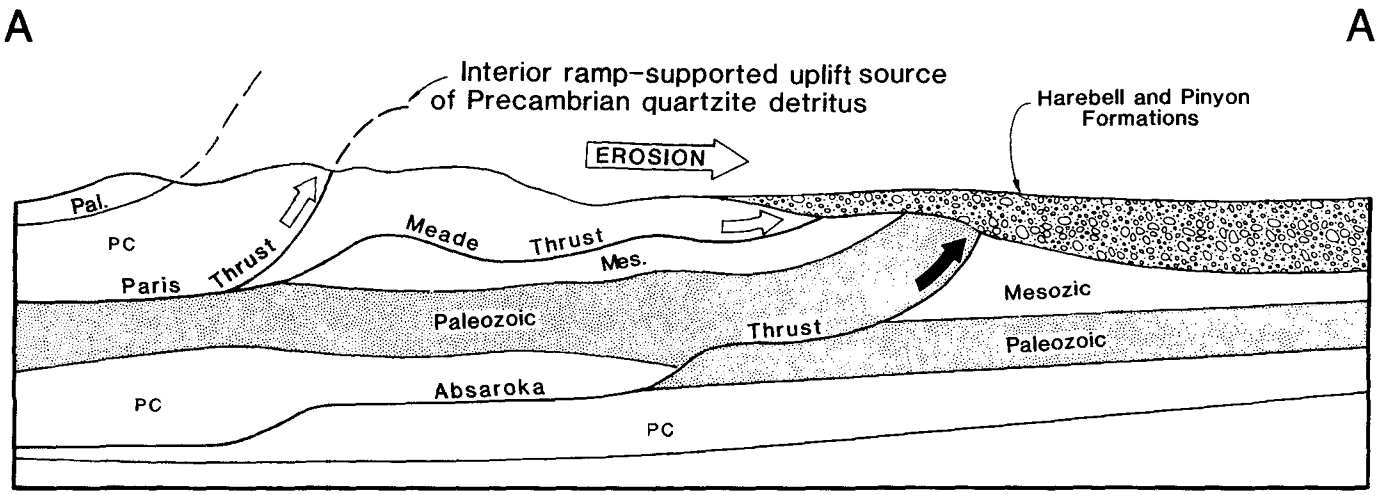

Figure 3. Schematic cross section drawn for earliest Tertiary time, illustrating the concept of interior ramp-supported uplift of the Paris (-Willard) thrust allochthon as a source for the Upper Cretaceous through Paleocene quartzite conglomerates in northwestern Wyoming. Solid black arrow represents active thrust motion. Open arrows indicate older, inactive thrusts. Location of cross section is shown in Figure 2. Modified from Steidtmann and Schmitt (1988).

certainly would have acted as a buttress to Late Cretaceous–early Tertiary thrust faults. Ruppel and Lopez (1984) extend the leading edge of the Montana thrust belt into the Centennial Mountains of southwestern Montana near the proposed north margin of the Targhee uplift with no structural evidence of thrust deflection. Mapping by Woodward (1986) ~20 km south of the Snake River Plain in the Snake River Range provides no indication that the proposed Targhee uplift acted, as suggested by Love (1983), as a buttress during emplacement of the Late Cretaceous Absaroka thrust system.

Paleomagnetic studies of Upper Triassic strata in thrust plates of the northwestern portion of the Idaho-Wyoming thrust belt by Grubbs and Van der Voo (1976) show that these thrusts were rotated counterclockwise by their impingement during emplacement upon the basement-involved ancestral Teton–Gros Ventre foreland uplift. Nonetheless, structural analysis of the Gros Ventre Range by Lageson (1987) revealed that the Cache fault, the major Laramide range-bounding fault, trends north-northwestward in the subsurface through Teton Basin, Idaho, limiting the present westernmost margin of the ancestral Gros Ventre Range to the area immediately west of the present-day Teton Range. This interpretation suggests that the area of the proposed Targhee uplift was not the western end of the ancestral Teton–Gros Ventre uplift of Love (1973). That inference is supported by the absence of any Precambrian quartzites within the upper plate of the Cache fault (Dorr and others, 1977).

Geophysical investigations of the Snake River Plain region have also failed to reveal any evidence for a buried uplift (Pakiser and Baldwin, 1961; LaFehr and Pakiser, 1962; Mabey, 1966). As Love (1973) has pointed out, however, these studies do not unequivocally rule out the presence of a buried uplift.

PROGRESSIVE RECYCLING

The hypothesis of progressive recycling of quartzite debris is interpreted to involve repeated episodes of successive thrust-generated uplift, erosion, and deposition. Initial erosion of upper Precambrian through Ordovician quartzites from thrust sheets near the Idaho batholith in east-central Idaho is thought to have been followed by subsequent periods of progressive eastward-thrust plate motion which is inferred to have caused recycling of previously deposited quartzite gravels (Lindsey, 1972; Ryder and Scholten, 1973). Continued recycling of quartzite-bearing synorogenic units thus led to mechanical destruction of most of the unstable clasts during episodes of fluvial transport, ensuring the dominance of quartzite-clast lithologies upon deposition of the Harebell and Pinyon Formations in the Jackson Hole area.

Progressive recycling as a mechanism for delivery of quartzite debris to northwestern Wyoming was suggested to account for two limiting factors. First, Lindsey (1972) interpreted the Harebell and Pinyon Formations to have been deposited as alluvial-fan complexes. This interpretation requires the presence of a local uplift, interpreted by Lindsey (1972) to be related to nearby thrusting, from which the Harebell and Pinyon alluvial fans could prograde into the adjacent foreland basin. Previously deposited quartzite-bearing synorogenic gravels derived from the west during an earlier period of thrusting must have been contained in the locally uplifted thrust plate. Reconnaissance investigation of the sedimentology of the Harebell and Pinyon Formations suggests, however, that deposition occurred not on alluvial fans, but in a high-energy gravelly braided fluvial system which occupied a rapidly subsiding foreland basin (Kraus, 1985). Thus, the conglomerates may have been deposited at a greater distance from the active uplift than envisioned by Lindsey (1972).

Second, successive thrusting and sediment recycling was required by the interpretation that fluvial systems were not capable of transporting cobble- and boulder-sized debris during a single cycle of transport from quartzite-bearing thrust sheets in eastern Idaho, a distance of more than 160 km from the Jackson Hole area (Love, 1973; Ryder and Scholten, 1973). Thus, a more local thrust uplift which exposed slightly older quartzite-bearing gravels seemed more plausible. As the calculations of Lindsey (1972) himself show, however, long-distance (160-km) transport of cobbles and boulders in a high-energy fluvial system is hydraulically possible. Furthermore, Paola (1988) showed that downstream decrease in gravel size is not only a function of stream power but is also governed by clast durability and rate of subsidence of basins near their source area. Hence, in a slowly subsiding basin, coarse gravel, especially when composed of resistant quartzite, can be transported within fluvial systems far into the basin.

ACTIVE THRUST FRONT UPLIFT

Direct derivation from the front of quartzite-bearing thrust plates undergoing progressive eastward thrusting was suggested by Kraus (1985) as a plausible mechanism for deposition of the Harebell and Pinyon Formations. In this interpretation, Late Cretaceous through Paleocene thrust faulting in the western portion of the Idaho-Montana (Medicine Lodge thrust system), and Idaho-Wyoming (Paris-Willard thrust) thrust belts transported and uplifted quartzite-bearing upper Precambrian through Ordovician strata. Continued eastward thrusting would have renewed paleoslopes, permitting transport over a long interval of time and carrying the quartzite source rocks closer to the basin of deposition. Thus, long-distance fluvial transport is envisioned as the process by which quartzite detritus was delivered to the Jackson Hole area.

This interpretation requires that either or both of the quartzite-bearing thrust sheets in the Idaho-Montana and Idaho-Wyoming thrust belts were active from Late Cretaceous through Paleocene time. Although the timing of displacement along the Medicine Lodge thrust system in Idaho and Montana is not well constrained, combined stratigraphic and radiometric evidence suggests that motion was complete by Late Cretaceous time (70–75 Ma) (Ruppel and Lopez, 1984). Final thrust development along the front of the Montana thrust belt in the Helena salient, however, is known to be of Paleocene age (58 Ma) (Harlan and others, 1988). Although thrusting continued well into Tertiary time in Montana, displacement along the more western, quartzite-bearing Medicine Lodge thrust system seems to have ceased before the end of the Cretaceous.

The timing of thrusting in the Idaho-Wyoming thrust belt salient is similar to that in Montana. Major motion along the quartzite-bearing Paris-Willard thrust is interpreted to have occurred during Early Cretaceous time (119–97.5 Ma) (Royse and others, 1975; Heller and others, 1986), whereas thrusting on more eastern plates continued well into the Eocene (Dorr and others, 1977; Wiltschko and Dorr, 1983). As in Montana, major displacement along the appropriate quartzite-bearing thrust came to a close prior to the end of the Cretaceous and well before major deposition of quartzite conglomerates in the foreland basin.

INTERIOR RAMP-SUPPORTED UPLIFT

As previously discussed, uplift in fold-thrust orogens commonly occurs where older, inactive thrust plates are transported over footwall ramps of active thrusts as components of the younger thrust allochthon. We envision that such a mechanism explains the presence of upper Precambrian quartzite clasts in the Upper Cretaceous (Maastrichtian) Hams Fork Conglomerate Member of the Upper Cretaceous–Paleocene Evanston Formation in the northeastern Utah and southwestern Wyoming Sevier foreland basin (Schmitt, 1985; Steidtmann and Schmitt, 1988). There, Oriel and Tracey (1970) and Crawford (1979) recognized that the distinctive upper Precambrian quartzite clasts in the Hams Fork Conglomerate must have been derived from quartzite source rocks to the west carried only in the hanging wall of the Paris-Willard thrust (Oriel and Platt, 1980; Royse and others, 1975). Overlapping stratigraphic and structural relations described in detail by Oriel and Tracey (1970) show that Late Cretaceous motion along the Absaroka thrust shed the Hams Fork Conglomerate and its characteristic quartzite clasts. The Absaroka thrust plate, however, contains upper Precambrian strata only in the Paris-Willard plate located well within the interior of the fold-thrust belt more than 50 km west of the Absaroka thrust front.

This observation has been interpreted by Bruhn and others (1983) and Schmitt (1985) to be the result of uplift and folding of the inactive, upper Precambrian, quartzite-bearing Paris-Willard thrust plate, as it was transported over a footwall ramp in the more easterly active Absaroka thrust during Late Cretaceous time. Structural and seismic studies reveal that in northeastern Utah the Paris-Willard thrust has indeed been folded by transport over an Absaroka thrust ramp (Royse and others, 1975; Bruhn and others, 1983). Thus, the quartzite-bearing terrane of the Paris-Willard thrust plate was once again uplifted in Late Cretaceous (Maastrichtian) time as a component of the Absaroka thrust plate, long after its period of development during Early Cretaceous (Aptian) time, and it served as the source for quartzite clasts in the Hams Fork. DeCelles (1988) documented the presence of upper Precambrian quartzite-clast lithologies in the underlying Upper Cretaceous (Coniacian-Santonian) Echo Canyon Conglomerate and interpreted their origin from uplift and erosion of the Paris-Willard thrust sheet during displacement along the younger Crawford thrust. The observation that the Echo Canyon and Hams Fork conglomerates are the oldest syntectonic units containing upper Precambrian quartzite clasts in the southwestern Wyoming foreland basin suggests that erosion to deep stratigraphic levels of the Paris-Willard thrust plate was attained only after it had been uplifted during tectonic transport in the hanging wall of the Crawford and Absaroka thrust sheets.

Another example of interior uplift in the Sevier thrust belt is contained in the coarse clastic deposits of the Lower to Upper Cretaceous Indianola Group of central Utah (Lawton, 1985). Conglomerates in the lower half of the Indianola section are composed of clasts eroded from middle to upper Paleozoic carbonates on the hanging wall of the Canyon Range thrust during Early to Late Cretaceous time. In contrast, the upper half of the Indianola contains abundant quartzite clasts derived from erosion of upper Precambrian and Cambrian strata of the same thrust plate. Lawton (1985, 1986) attributed the influx of quartzite debris to motion on the younger, more easterly Nebo-Pavant thrust, which uplifted and folded the overlying, inactive Canyon Range thrust plate over a footwall ramp, promoting erosion to deep stratigraphic levels where Precambrian source rocks were breached.

The mechanism of interior ramp-supported uplift is also a viable explanation for the generation of quartzite conglomerates in the northwestern Wyoming foreland basin. The ultimate source of the upper Precambrian, Cambrian, and Ordovician miogeoclinal quartzite clasts must have been in the westernmost thrust plates of the Idaho-Wyoming and Montana thrust belts. Uplift of these allochthonous plates, the Medicine Lodge, and (or) Paris-Willard thrust systems, however, could have subjected them to erosion long after their initial development. In fact, as stated above, major displacement along both of these faults is thought to have predated deposition of most quartzite gravel in northwestern Wyoming. Thus, if either or both the Medicine Lodge and Paris-Willard thrust plates were subject to Late Cretaceous to Paleocene erosion, it must have resulted from uplift long after their original development.

The production of quartzite debris of the Harebell and Pinyon conglomerates is depicted in Figure 3 and involves initial Late Cretaceous uplift of the older, inactive Paris-Willard and (or) Medicine Lodge thrusted terranes over a footwall ramp in a younger, active fault interpreted to be the Absaroka and (or) an imbricate of the Medicine Lodge thrust system. Uplift of the quartzite-bearing strata of these older thrusted terranes provided the source for eroded quartzite gravel which was transported eastward by fluvial systems into the adjacent subsiding foreland basin. As already mentioned, the Paris-Willard thrust has indeed been folded in northeastern Utah (Bruhn and others, 1983). Although tentatively interpreted as a result of Tertiary block faulting by Ruppel (1982), the folded nature of imbricate thrusts of the Medicine Lodge thrust system (as modified by Skipp, 1988) in the Lemhi Range of eastern Idaho is also well documented.

Although the detailed structural relations in the western part of the Idaho–northwestern Wyoming thrust belt are less well known than those to the south, biostratigraphic and structural data concerning the timing of thrust deformation in southwestern Wyoming are compatible with an interior ramp-supported uplift hypothesis for northwestern Wyoming. Initial displacement along the Absaroka thrust in southwestern Wyoming shed the Santonian conglomerate on Little Muddy Creek (Royse and others, 1975) and is correlative with initial appearance of quartzite debris in the Santonian Bacon Ridge Sandstone of the Jackson Hole area (Love, 1982). As mentioned above, the first appearance of quartzite debris in southwestern Wyoming–northeastern Utah is in the Coniacian-Santonian Echo Canyon Conglomerate (Jacobson and Nichols, 1982; DeCelles, 1988). Additionally, both the major influx of upper Precambrian quartzite debris of the Hams Fork Conglomerate in the southwestern Wyoming foreland basin segment, generated by displacement along the Absaroka thrust, and the first accumulation of thick quartzite gravel in the Harebell Formation of the northwestern Wyoming foreland basin occurred during Maastrichtian time. Deposition of quartzite debris in northwestern Wyoming spanned a greater period, extending well into Paleocene time as the Pinyon Conglomerate was deposited. Younger quartzite conglomerates in the region such as those of the Eocene Pass Peak Formation in the Hoback basin, Willwood Formation in the Bighorn basin, and Wind River Formation in the Wind River basin have been interpreted as reworked Harebell and Pinyon conglomerates derived during Eocene uplift of the Jackson Hole region (Steidtmann, 1971; Seeland, 1978; Kraus, 1985). Conversely, in southwestern Wyoming, accumulation of quartzite detritus ended in early Paleocene time, and the volume of debris deposited was much smaller.

These discrepancies in quantity and duration of quartzite deposition may be related to differential amounts and durations of motion along the trace of the Absaroka thrust, which apparently produced greater uplift and erosion in northwestern Wyoming. Conversely, the magnitude of thrust motion and concomitant supply of quartzite debris may have been similar throughout the thrust belt, but regional variation in rates of foreland-basin subsidence may have led to thicker accumulations of syntectonic debris in northwestern Wyoming and sediment bypassing in southwestern Wyoming.

The interior ramp-supported uplift hypothesis is actually a modification of the active thrust uplift interpretation of Kraus (1985). Its advantage is that generation of quartzite debris may take place long after activity along the far-distant, quartzite-bearing thrust plates ceased. Additionally, a great volume of quartzite debris could be generated by erosion as the inactive thrust plate was continuously transported eastward over the thrust ramp in the younger underlying plate. Upper Precambrian through Ordovician quartzite-bearing strata could have been continuously fed into the uplifted source area, rising through and above base-level in a conveyor-belt–like fashion.

Ramp-supported uplift of older, thrusted terranes in thrust belts is a documented mechanism which produces a large component of vertical motion combined with lateral displacement of strata (Hurst and Steidtmann, 1986; Lawton, 1986; Steidtmann and Schmitt, 1988) and can unquestionably influence the composition and dispersal of syntectonic sediment. On the other hand, the Targhee uplift hypothesis requires development of a major, long-lived basement-involved (Laramide-style?) uplift directly within the trend of the Sevier thrust belt. Although Sevier thrust-belt interaction with coeval evolving Laramide-style uplifts is well documented along the zone of impingement between the two structural provinces (Dorr and others, 1977), the presence of a major basement-cored uplift in the trend of the Cordilleran fold-thrust belt is highly anomalous and requires a profound discontinuity in regional tectonic fabric.

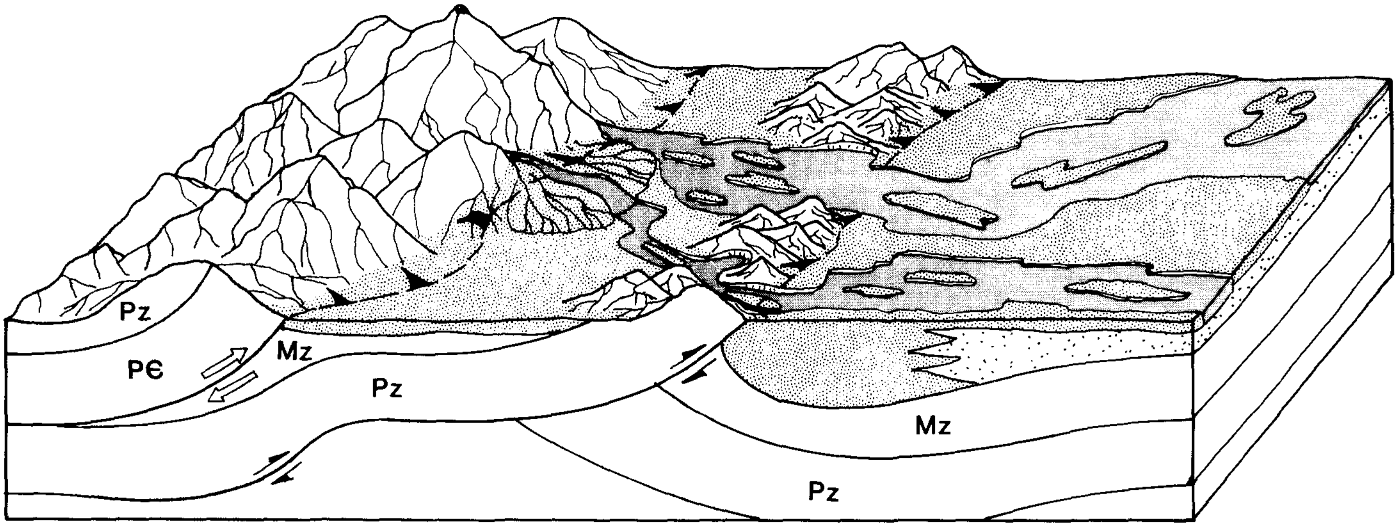

Figure 4. Generalized block diagram showing differential relief generated by interior ramp-supported uplift of an inactive thrust plate over footwall ramp in active frontal thrust. Stippled pattern represents alluvial plain characterized by high-energy fluvial systems transporting coarse-grained debris basinward from passively uplifted highlands and across a frontal region of relatively lower relief. Much of the syntectonic detritus is preserved in the subsiding foreland basin adjacent to the front of the fold-thrust belt.

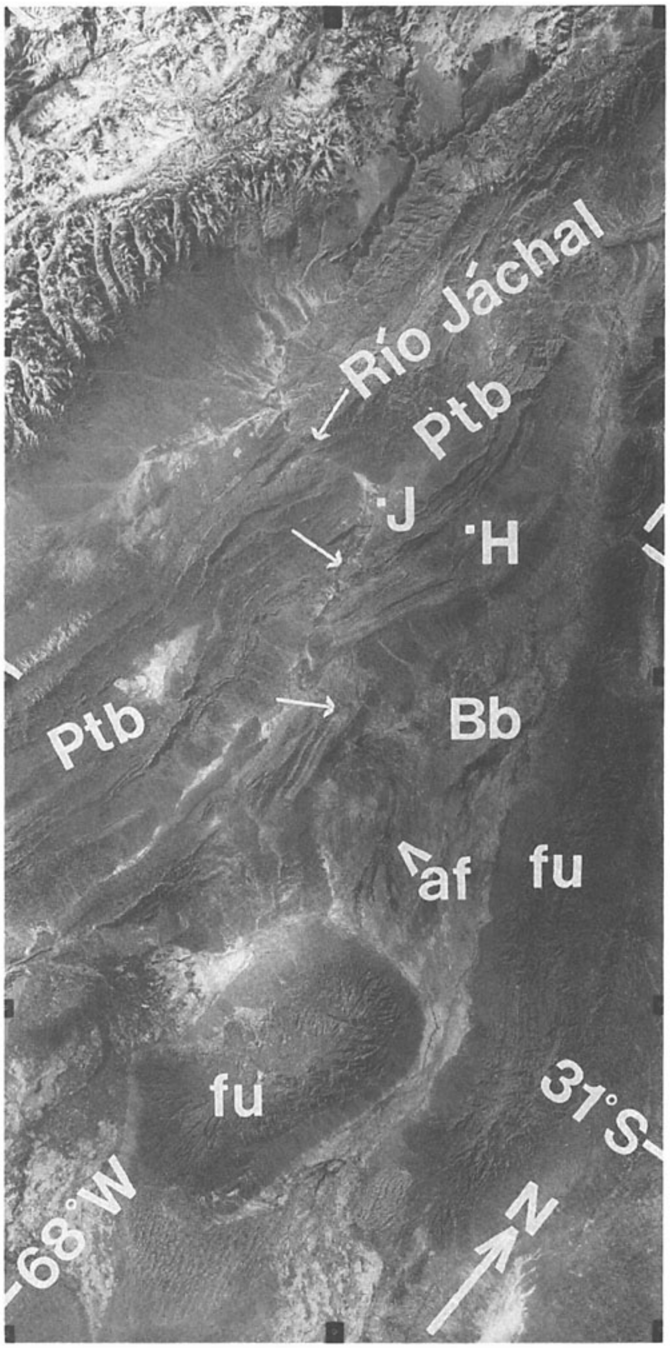

Figure 5. Challenger Space Shuttle photograph of the pre-Cordillera-foreland boundary in Argentina. The antecedent Rio Jachal (small arrows), whose headwaters are to the west in the Cordillera (snow-capped area in upper left) and older pre-Cordilleran thrust belt (Ptb), has maintained its course by incising its channel at about the same rate as successively younger thrusts have been uplifted. It is now building an alluvial fan (af) into the foreland basin (Bb, Bermejo basin) with sediment derived from the Cordillera and interior of the pre-Cordillera thrust belt. fu, basement-cored foreland uplifts; J, town of Jachal; H, town of Huerco. Photograph courtesy of T. Jordan.

IMPLICATIONS

The concept of interior ramp-supported uplift has significant implications for the development of topographic relief in fold-thrust belts. Most important is the observation that during thrusting, ramp-supported uplift of inactive thrust plates located well within the core of the fold-thrust orogen served as important sources of clastic debris delivered to the foreland basin. In the case of the Harebell and Pinyon quartzite conglomerates, upper Precambrian and lower Paleozoic quartzites, exposed only in the upper plate of the Paris-Willard thrust, provided erosional debris to the foreland basin while there was displacement along the frontal Absaroka thrust (Fig. 4). Furthermore, this source–depositional setting relationship indicates that displacement of the Absaroka thrust sheet did not block eastward drainage into the foreland basin and that an antecedent river system was able to continue downcutting through successively younger thrust sheets as they rose in its path. An almost exact modern analogy to this situation is described by Damanti and others (1988) for the modern Argentine Precordillera and is shown in Figure 5. It is likely, however, that in the case of Harebell-Pinyon deposition, the combination of a wet, temperate to tropical climate and initial abundance of nonresistant sedimentary source rocks would have resulted in even less relief than in the Argentine example. Transport of detritus across low-relief thrusted terrane would also result in deposition of conglomerate within the frontal portion of fold-thrust belts. Frequently, these conglomerates are eroded by subsequent uplift in the thrusted terranes (Perry and Sando, 1983). They may, however, occasionally be preserved as "high-level" deposits, such as the conglomerate on Sublette Ridge in southwestern Wyoming noted by Oriel and Platt (1980), which escaped erosion during subsequent uplift within the fold-thrust belt, or in piggyback basins such as the Fossil basin of southwestern Wyoming (Hurst and Steidtmann, 1986). In contrast to the frontal terrain, significant relief on interior ramp-supported uplift was favored by a repeated and thickened stratigraphic section and resistant source lithologies.

Evidence for at least minor relief along frontal thrusts, however, is provided by the Upper Cretaceous synorogenic conglomerate on Little Muddy Creek in southwestern Wyoming, deposited in response to an early phase of thrusting along the Absaroka thrust (Royse and others, 1975). Sedimentologic analysis shows that this unit represents the deposits of an alluvial fan-delta which prograded directly into the Cretaceous seaway; proximal debris-flow facies interfinger with marine-shoreline sandstone, suggesting that the fan surface, and hence the adjacent uplifted terrane, was at or near sea level during its entire history (Schmitt and others, 1986; Pivnik, 1988). Similar facies relations characterize the lower Eocene Lookout Mountain Conglomerate Member of the Wasatch Formation in the Hoback Range of northwestern Wyoming. Coarse-grained alluvial-fan facies grade abruptly eastward into finer-grained fluvial flood-plain deposits of the Wasatch Formation. Dorr and others (1977) suggested that minor relief existed along the front of the thrust belt during Lookout Mountain Conglomerate deposition.

CONCLUSIONS

The complex uplift histories and styles characteristic of fold-thrust belts result in equally complex provenance relations and dispersal patterns for related tectogenic deposits (Jordan and others, 1988; Steidtmann and Schmitt, 1988). This paper provides an example of the potential importance of interior ramp-supported uplift to accumulation of coarse, synorogenic strata in foreland basins. It is a model which may be applied to interpretation of fold-thrust orogen/foreland basin couplets elsewhere and should stimulate further investigation of relations between tectonism and sedimentation in these settings.

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