



Comparative petrology of Tertiary sandstones of southern Piceance Creek Basin, Colorado

Allan M. Ochs and Rex D. Cole

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COMPARATIVE PETROLOGY OF TERTIARY SANDSTONES OF SOUTHERN PICEANCE CREEK BASIN, COLORADO

ALLAN M. OCHS
Southland Royalty, 410 17th Street, Suite 1000
Denver, Colorado 80202

REX D. COLE
2921 F 1/2 Road
Grand Junction, Colorado 81501

INTRODUCTION

Comparative petrographic analyses of channel-form and tabular sandstone bodies in the upper Wasatch Formation (Paleocene-Eocene) and lower Green River Formation (Eocene) in the southern Piceance Creek basin show that compositional and textural variability reflects the environment of deposition.

Sandstones from the sampled intervals are generally similar in texture and composition but have varying concentrations of (1) angular to well-rounded monocrystalline quartz grains, some with abraded overgrowths; (2) fresh and slightly altered potassic and sodic feldspars; and (3) volcanic-lithic fragments, mostly andesite. Wasatch sandstones generally contain slightly more lithic fragments than those of the Green River, which are more quartzose. The difference is attributed to the fluvial mode of deposition recognized in the Wasatch Formation which contrasts with the marginal-lacustrine nature of the sampled portion of the Green River Formation. Lacustrine sandstone also commonly contains accessory analcime and pyrite.

Paleocurrent data suggest a south, southwest, and southeasterly source for the lower Tertiary sediment. Petrographic evidence further suggests that the source terranes were compositionally consistent during the development of the lake and that the sediment was primarily derived from Mesozoic and Paleozoic sedimentary rocks and early Cenozoic silicic volcanics and intrusives.

This paper describes lacustrine and fluvial sandstones of the Wasatch and Green River Formations as they outcrop at several localities along the southern margin of the Piceance Creek basin. The description combined with petrographic analyses of thin-sectioned samples provide a basis for determining the provenance of the sand, as well as a crude comparison of compositional and textural features that resulted from differences in depositional processes.

Sandstones in marginal lacustrine settings in the Wasatch and Green River Formations are proven reservoirs for significant hydrocarbon reserves in the Uinta and Piceance Creek basins. Altamont-Bluebell field in the northern part of the Uinta Basin is a major field discovery with an estimated ultimate recovery of 250 million barrels (40 billion liters) (Lucas and Drexler, 1975). The trapping mechanism is stratigraphic in nature, comprising stacked lacustrine and fluvial sandstone bodies that are sealed by an updrift prograding sequence of alluvial facies composed of red siltstones, shales, and sandstones. Similar traps are found in the Piceance Creek basin, although not as large as Altamont-Bluebell. Although the producing sandstones are fractured, production is greater from lacustrine sandstones than from fluvial sandstones. This suggests that lacustrine and fluvial sandstone porosity and permeability may be related to compositional and textural modifications of the sediment during deposition.

METHODS

Four sections were described and sampled in the southern portion of Piceance Creek basin (fig. 1): 1) Douglas Pass, on the Douglas Creek arch, 2) Red Pinnacle on the southwest edge of the basin, 3) Parachute Creek on the southeast margin of the basin, and 4) Rio Blanco along the eastern edge of the basin. Sampling was commonly restricted to the uppermost 50 m of the Wasatch Formation and from all sandstone-bearing members or facies in the lower part of the Green River Formation.

Outcrop descriptions provided information on sandstone body geometry; type, size and orientation of sedimentary structures; and lithologic sequence. Textural and compositional attributes of the sandstone were determined quantitatively from thin-sectioned samples. Average framework grain size was determined by measuring the apparent long axes of twenty-five grains per thin section. The relative amount of framework grains, matrix (<30 ϕ) minerals, cement, and porosity were assessed with two hundred counts per thin section. Framework grain mineralogy was evaluated by three hundred counts per thin section. Ten thin sections were randomly chosen and recounted confirming the reproducibility of the point count data. Approximately eighty other thin sections from samples taken from carbonate and mudrock portions of the sequence were also described.

Three sedimentary rock classifications are utilized: 1) Dunham's (1962) classification for carbonates, 2) Folk and others (1970) sandstone classification, and 3) Picard's (1971a) classification for fine-grained sedimentary rocks. Sedimentary structures were described in terms of their type, size, and orientation and directional data gathered from these were grouped into primary, secondary, and tertiary intervals using an adaptation of Tanner's (1959) technique developed by High and Picard (1972).

GEOLOGIC FRAMEWORK

The Piceance Creek basin is a structural basin that has been uplifted to a broad plateau (Donnell, 1961a, p. 835). Several structural features surround the basin: the Axial Basin uplift in the north, the White River uplift on the east, the Elk and West Elk mountains on the southeast and south respectively, the Uncompahgre uplift on the southwest, and the Douglas Creek arch on the west. Laramide development of these structures controlled the formation of the basin while post-Laramide, probably Pliocene, movement of the structures has resulted in the basin's present configuration (Murray and Haun, 1974, p. 33). The basin is asymmetrical with gently dipping limbs on the south and west, and steeply dipping limbs on the north and east (Donnell, 1961a). The axis of the basin trends northwest to southeast with a maximum depositional thickness located twelve kilometers northwest of Rio Blanco, Colorado (Smith, 1974). Tertiary rocks in the basin comprise alluvial, deltaic,

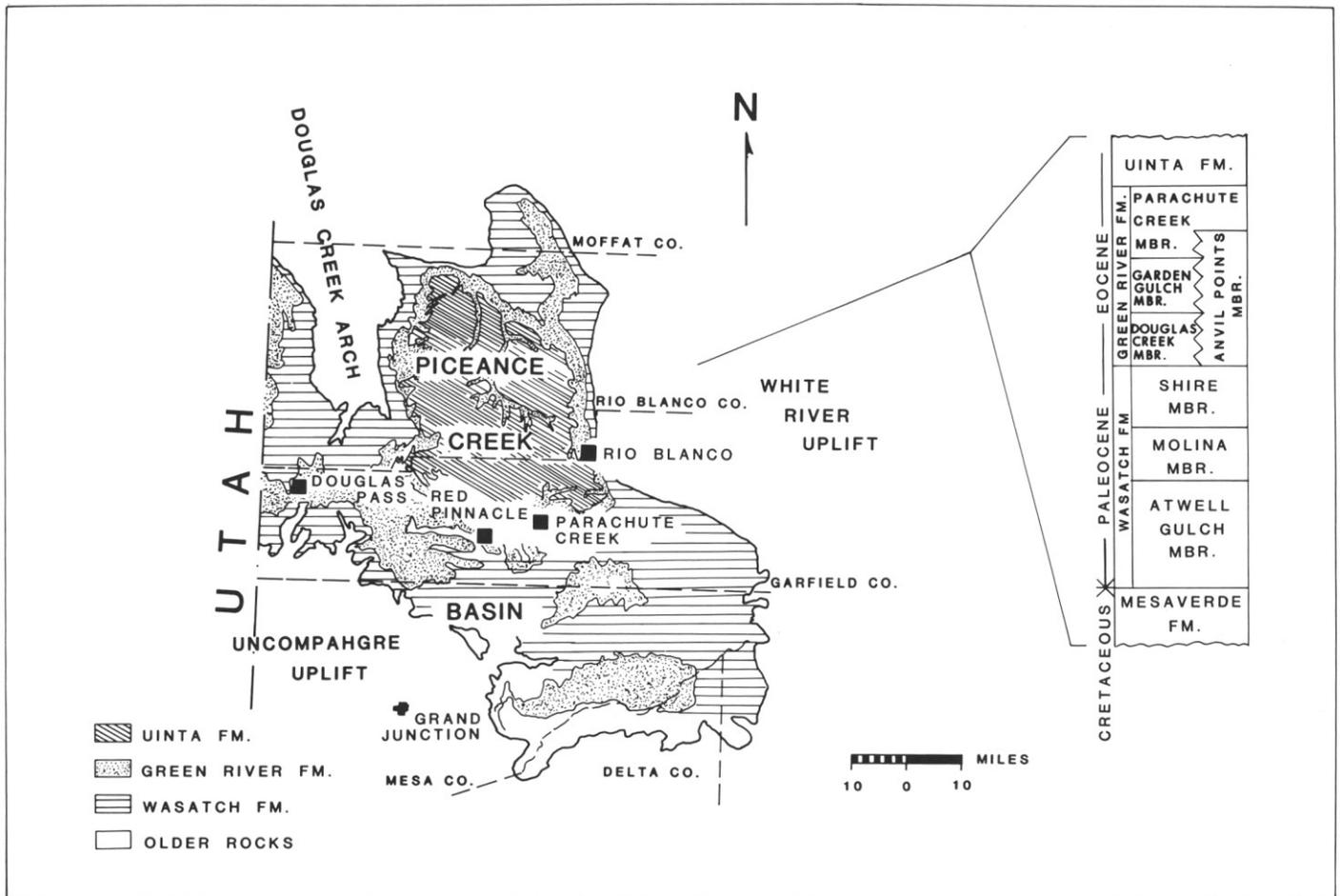


Figure 1. Geologic and location map of the Piceance Creek basin.

and lacustrine deposits of the Wasatch, Green River, and Uinta formations. The Tertiary rocks overlie thick Cretaceous sandstones and shales of the Mesaverde Group.

The Laramide Orogeny (Late Cretaceous-Eocene) in the southern Rocky Mountains was characterized by uplift of previously uplifted and eroded Paleozoic highlands and volcanic and igneous intrusive activity. From Late Cretaceous through Eocene, the Piceance Creek basin served as a catchment basin for both the eroded detritus of previously deposited sedimentary rocks and sediment derived from the volcanics, intrusives, and airfall pyroclastics. Initial sedimentary deposits were largely alluvial in nature, as illustrated by the Wasatch Formation. Extensive floodplains with northwestward flowing drainages were developed in contrast to the previous eastward flowing drainages of the underlying Mesaverde Group (McDonald, 1972, p. 254). Subsidence during the Eocene and formation of the Axial Basin anticline to the north restricted drainages which resulted in ponding and deposition of the lacustrine-dominated Green River Formation. Expansion of Lake Uinta during a supposed humid period of the Eocene merged the lakes of the Uinta and Piceance Creek basins across the Douglas Creek arch (Bradley, 1931; Cashion, 1967; Donnell, 1961a; Roehler, 1974). The lake was ultimately infilled, as recorded in the rocks of the Uinta Formation. Infilling and desiccation may have been initiated by the cutoff of inflowing drainages or a shift to a more arid climatic regime.

STRATIGRAPHY

The Wasatch Formation is the thickest Tertiary unit in the basin, thickening from approximately 120 m at Douglas Pass to more than 1700 m in the basin interior (Donnell, 1961a, p. 846). In the southern portion of the basin, Donnell (1961b, 1969) divided the formation into three members: (1) the Atwell Gulch Member at the base, (2) the Molina Member, and (3) the Shire Member at the top. However, farther basinward, these divisions become less distinct. Location of the Paleocene-Eocene contact within the Wasatch Formation is uncertain. Paleocene leaves and vertebrates have been found in the basal portion of the Atwell Gulch Member while Eocene mammal remains have been found in the Shire Member (Donnell, 1969, p. 13). The intervening Molina Member has not yielded fossil evidence to suggest an age. The Atwell Gulch Member varies from 200 m to 600 m in thickness and is composed of gray lenticular sandstone and siltstone, carbonaceous shale and thin lignite beds. The upper portion of the member consists of lenticular brown sandstone, variegated gray and red claystone, rare thin nonmarine limestone beds, and carbonaceous shale and lignite (Donnell, 1969). The Molina Member is a wedge of brown, thickly bedded, fine- to coarse-grained sandstones with some red and gray variegated claystone partings attaining a thickness of nearly 150 m (Donnell, 1969, p. 11). Basinward the member grades into siltstone and red and gray variegated claystone. The Shire Member is the uppermost and thickest member of the Wasatch

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Formation. The member comprises purple and red claystones and some brown lenticular sandstones that intertongue with and are partial chronologic equivalents to the Douglas Creek Member of the Green River Formation (Donnell, 1969, p. 12). Thicknesses in excess of 1200 m are reported along the western margin of the White River uplift.

The Green River Formation conformably overlies and intertongues with the Wasatch Formation. The formation consists of fluvial-deltaic and lacustrine rocks thickening eastward from 300 m at Douglas Pass to more than 900 m in the center of the basin. Four members are recognized in the Green River Formation in this basin: (1) the basal Douglas Creek Member, (2) the Garden Gulch Member, (3) the Parachute Creek Member, and (4) the Anvil Points Member. Bradley (1931) initially described the first three members and Donnell (1953) later described the Anvil Points Member along the eastern margin of the basin. The Anvil Points Member is supposedly stratigraphically equivalent to the Douglas Creek and Garden Gulch Members and the lower portion of the Parachute Creek Member.

Roehler (1974) found the type sections of the Douglas Creek and Garden Gulch members described by Bradley (1931) to be largely temporal equivalents. The type Garden Gulch Member is now incorporated into the redefined Parachute Creek Member which includes all rocks between the black, flaky oil shale of the new Garden Gulch Member and the overlying Uinta Formation (Roehler, 1974). The Parachute Creek Member consists of fluvial-deltaic and lacustrine rocks including the rich oil shale and evaporite deposits of the basin interior.

The Uinta Formation occurs as an erosional remnant over most

of the Piceance Creek Basin, attaining a maximum thickness of 450 m. The formation consists of marlstone, oil-shale, medium- to coarse-grained sandstone with some marlstone, and siltstone partings (Juhan, 1965; Cashion and Donnell, 1974; Ochs, 1978). The rocks in this unit represent the contraction and ultimate infilling of Lake Uinta. The abundant reworked pyroclastics in the rocks were derived from a north-northeasterly source (Cashion and Donnell, 1974, p. 7).

SEDIMENTOLOGY

Rock sequences in both the Wasatch and Green River formations represent fluvial and lacustrine depositional processes. This was recognized by the earliest of workers in the region, W. H. Bradley (1931). However, not until recently have lithofacies been identified and assigned to specific depositional settings. In the Uinta basin, Ryder and others (1976) recognized three major lithofacies: 1) open lacustrine, 2) marginal lacustrine, and 3) alluvial. Each of the lithofacies is made of localized depositional settings in which a characteristic rock type dominates the rock sequence. In this order the major lithofacies form a progression from a core of open lacustrine oil shale and carbonate surrounded by marginal lacustrine sandstone, shale, and marlstone which in turn is haloed by sandstones, siltstones, shales and conglomerates of the outermost alluvial facies. The successive facies halos are characterized by increased abundance of clastic sediments, less carbonate, and a chemical change from reducing to oxidizing conditions toward the basin margin. In the adjoining Piceance Creek basin Roehler (1974) (fig. 2) identified ten depositional settings: 1) mountain front or pediment, 2) red-bed fluvial, 3) non-red-bed fluvial, 4) fresh-

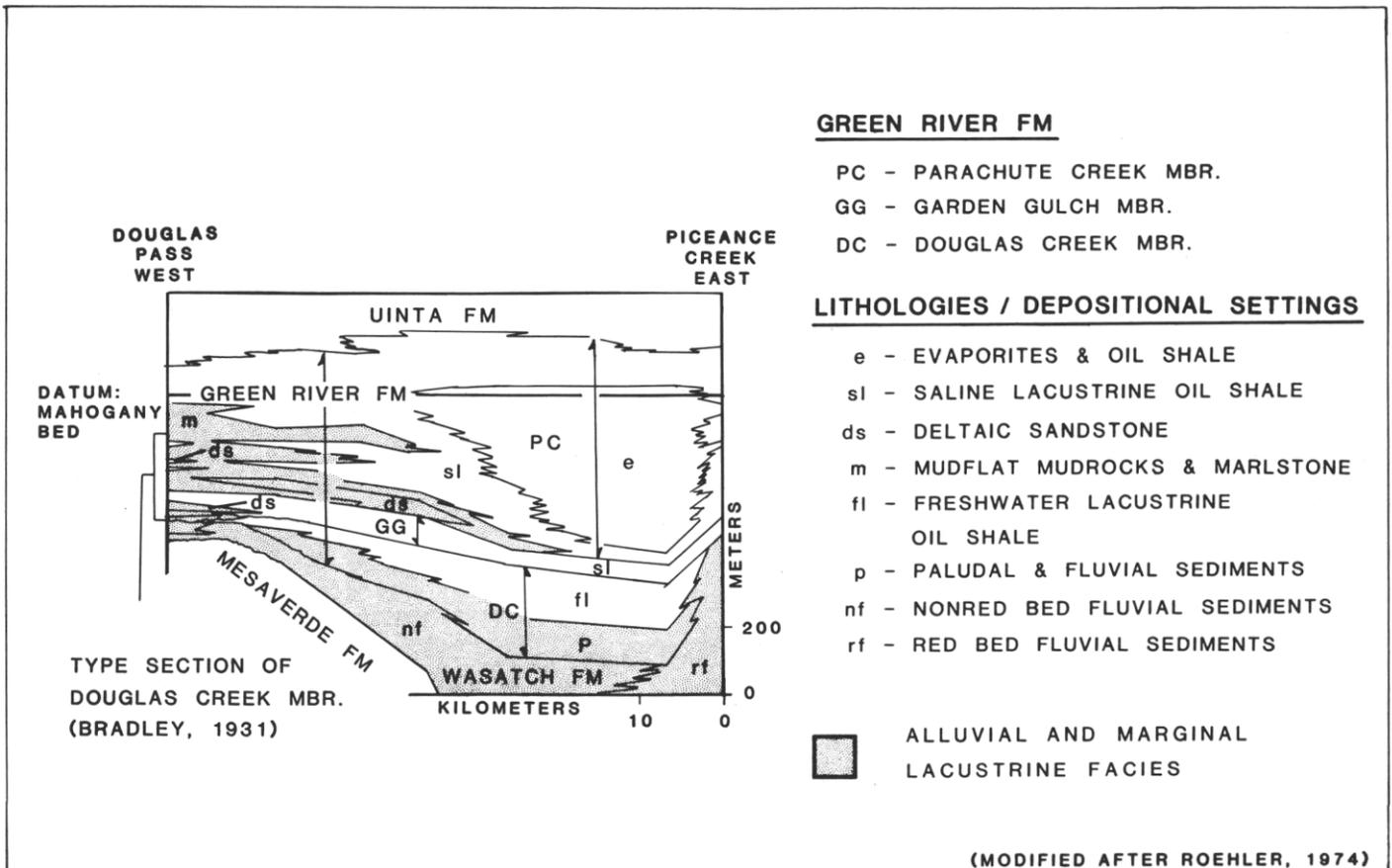


Figure 2. Lithologies and depositional settings associated with the Wasatch and Green River formations (Roehler, 1974).

water pond, 5) swamp or paludal, 6) shoreline or littoral, 7) freshwater lacustrine, 8) saline lacustrine, 9) mudflat, and 10) evaporite. Although differently named, this sequence of facies is similar to those described by Ryder and others (1976) and characterizes similar changes in depositional processes.

Marginal lacustrine facies represent an interface between fluvial and lacustrine processes which is manifested in the texture and corn position of the sandstones. Differentiating lacustrine from fluvial sandstone can be accomplished on the basis of the sandstone body geometry, sedimentary structures, and associated lithologies. Criteria for recognition of these sandstone types were developed largely by Picard and High (1970, 1972, 1972a) in portions of the Uinta basin. Although the criteria specifically referred to the P. R. Springs area of the southern Uinta basin, some features can be extrapolated to the rocks examined and discussed herein. Picard and High (1970) found that fluvial sandstone of the Wasatch Formation and the Douglas Creek Member of the Green River Formation to be lenticular and channel-form with erosional bases. The channel-fill deposits are made up of a fining-upward sequence commonly with a basal channel lag. Common sedimentary structures include abundant trough cross-stratification, parting lineations, and horizontal stratification. Lacustrine sandstones from the Douglas Creek Member are tabular, more laterally persistent (several kilometers) with flat or slightly undulatory bases (Picard and High, 1970, p. 16). Associated sedimentary structures include horizontal stratification, asymmetric ripple bedding, low-angle

trough cross stratification (thinner than those measured in the fluvial sandstones), and some disturbed bedding (Picard and High, 1970, p. 16). Another attribute of lacustrine sandstone bodies, is the associated algal, oolite, and ostracode-bearing beds. Similar characteristics were also observed in the lacustrine sandstones of the Parachute Creek Member at Raven Ridge in the northeastern Uinta basin (Picard and High, 1972a).

LOCAL SECTIONS

At the four measured and sampled sections, the Wasatch Formation consists of gray and red variegated shale and siltstone and gray to white channel-form and lenticular sandstone. The sandstones were deposited as channel-fill, point bar, and overbank deposits. The presence of red shales suggests that the depositional setting was well drained leading to oxidation of the iron-bearing minerals. Common sedimentary structures found within the sandstone bodies include horizontal bedding, trough cross-stratification, asymmetric ripple marks, and climbing ripples. Channel-fill deposits commonly contain lag deposits at the base grading to trough cross-stratification and ultimately to ripple and horizontal bedding. This upward sequence of structure was accompanied by a general decrease in grain size. Lenticular sand bodies were usually horizontally stratified with occasional ripple marks. The section of Wasatch Formation described at Parachute Creek is a point bar deposit that infilled a meandering channel (fig. 3).

Conformably overlying the floodplain sequences of the Wasatch

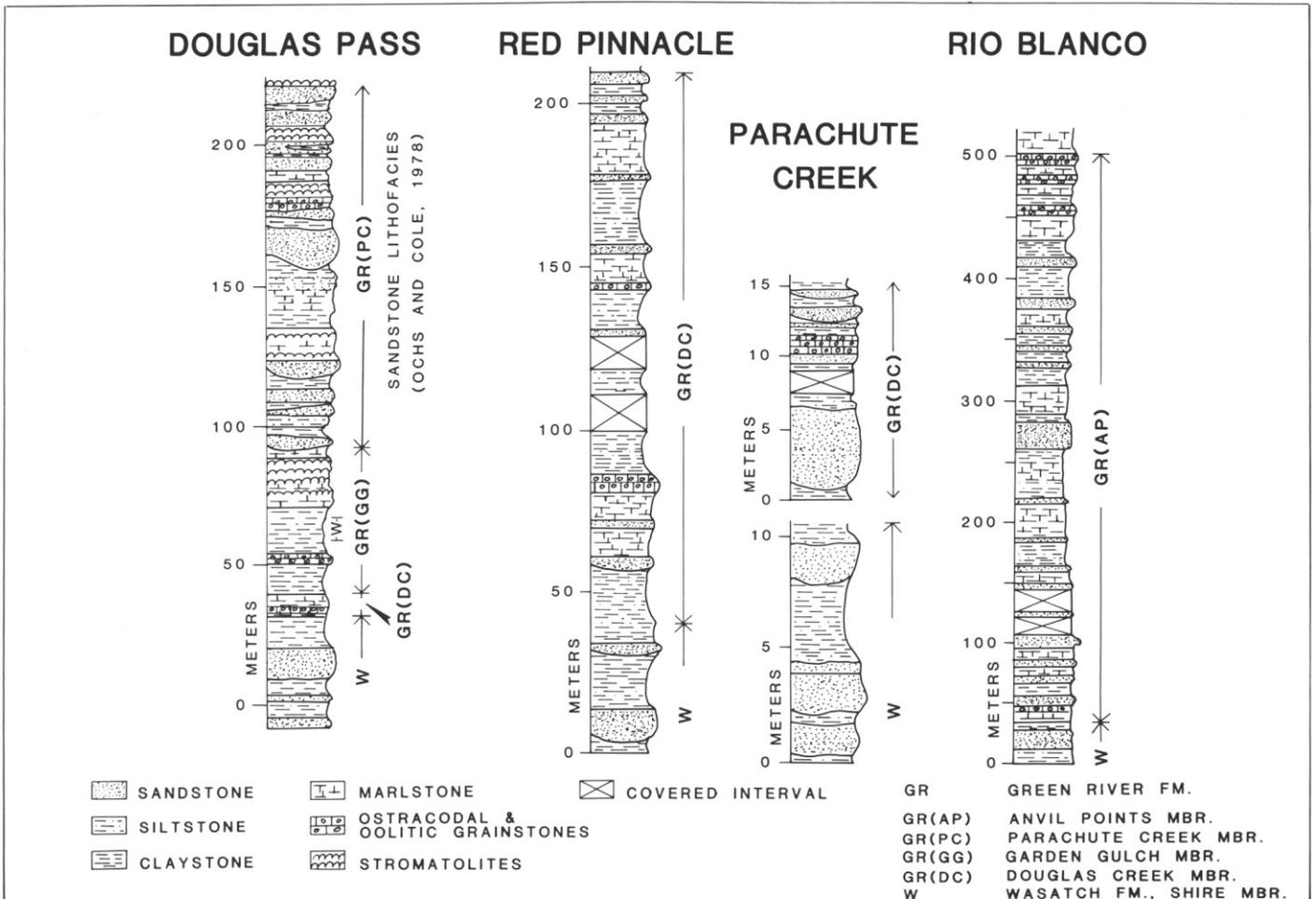


Figure 3. Measured sections from four principal localities along the southern margin of the Piceance Creek basin.

Formation at all sample localities are the various members of the lacustrine dominated Green River Formation. Sandstone-bearing marginal lacustrine facies occur in all members of the Green River Formation. At Douglas Pass the Wasatch Formation is overlain and intertongued with mudstones (dominately gray clayey siltstone and green claystone) of the Douglas Creek Member. These rocks grade upward into the more open lacustrine papy oil shale, ostracode-bearing shale, marlstone, and stromatolitic limestone, of the Garden Gulch Member (fig. 3). The Parachute Creek Member is in gradational contact with the underlying Garden Gulch Member and consists of gray sandstone (channel-form and tabular), gray to green claystone and mudstone, stromatolitic limestone, and lean oil shale. In this order, the sequence records expansion of the lake across the Douglas Creek Arch effectively merging the Uinta and Piceance Creek basins. The basal 130 m of this member comprises channel-form and tabular deltaic sandstone representing distributary channels and offshore bars respectively, of a lacustrine delta complex. Distributary channels are 1 to 2 m thick and 20 to 30 m wide (fig. 4) suggesting a low depositional gradient. Distributary channels clearly cross-cut and inter-tongue with underlying marlstone and claystone. The upper 50 m of this basal sandstone lithofacies (Ochs and Cole, 1978) is increasingly dominated by tabular sandstones and algal boundstones (fig. 5) indicating the influence of more open lacustrine processes. The Douglas Creek Member of the Green River Formation at Red Pinnacle was the only sandstone-bearing member. In contrast to the proximal deltaic sandstone of the Parachute Creek Member at Douglas Pass the sandstones at Red Pinnacle suggest a more basinal position relative to distributary portions of a delta. Laterally persistent tabular sandstone and lenticular sandstone are intercalated with marlstone, ostracodal and oolitic grainstones, as well as green claystones and clayey siltstones. Sandstone bodies in the 130 m sequence seldom exceed 0.5 m thickness and are commonly ripple-bedded with nearly symmetric ripple marks. Horizontal stratification is common and occasional trough cross-stratification is encountered.

The small sampled section of the Douglas Creek Member at Parachute Creek (fig. 3) consists of channel-form and lenticular sandstone interbedded with green siltstone and claystone. The base of the channel contains rip-up clasts from the underlying gray-green shale. The stacked channel sequence is interpreted as distributary channels very proximal to the central portion of the delta lobe.

The Anvil Points Member is supposedly equivalent to most of the section described at the previous localities. At Rio Blanco (fig. 3) the member is composed of lenticular and tabular sandstone interstratified with green claystone, ostracodal and oolitic grainstones (fig. 6) and marlstone. These lithologies grade upward into saline lacustrine oil shale. The thin tabular and lenticular sandstones (< 1 m thickness) belong in the distal portion of a delta where the sand is exposed to reworking by open lacustrine circulation. One small section (<30 m thickness) contains channel-form sandstone suggesting sporadic progradation of a delta.

PETROGRAPHY

Distinguishing lacustrine from fluvial sandstone on the basis of compositional and textural attributes is not a novel idea. Petrographic criteria were also developed by Picard (1976) in the P. R. Spring area of eastern Utah. In general, fluvial sandstone contains a few percent more terrigenous matrix, coarse mica, plagioclase, potassic feldspar and rock fragments than lacustrine sandstone. In contrast the lacustrine sandstones are texturally and mineralogically more mature, containing more authigenic carbonate grains,



Figure 4. Distributary channel, one of many, characterizing the "sandstone lithofacies" of the Parachute Creek Member at Douglas Pass (channel thickness approximately 1.2 m).



Figure 5. Laterally-linked hemispheroid stromatolites common in the "stromatolite lithofacies" and in the upper portion of the "sandstone lithofacies" of the Parachute Creek Member at Douglas Pass (keys for scale).

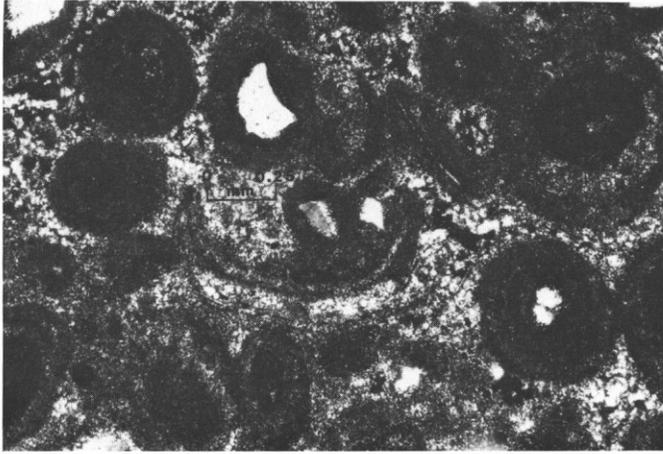


Figure 6. Photomicrograph of oolitic and ostracodal grainstone in the Anvil Points Member at Rio Blanco; also typical of other measured members of the Green River Formation.

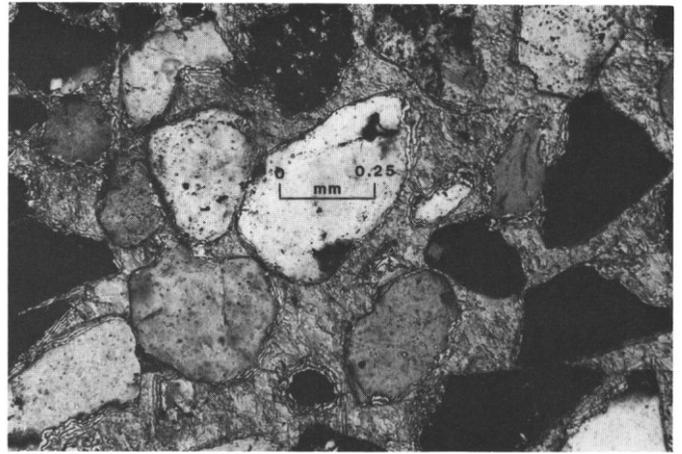


Figure 7. Photomicrograph of Douglas Creek Member sandstone from Red Pinnacle.

quartz, and accessory analcime. The common association of allochemical constituents, such as oolites, and shell fragments also characterize lacustrine sandstones.

All of the sandstone sampled in the Wasatch and Green River formations is moderately to well sorted and very fine- to medium-grained. Lacustrine sandstone in the Green River Formation tends to be fine- to very fine-grained. Comparison of the relative abundances of framework, matrix, cement, and porosity does not clearly distinguish lacustrine from fluvial sandstone. However, there is a tendency for lacustrine sandstone framework grains to be cement supported. Framework grains make up 54 to 90 percent of the sandstone.

Detrital matrix material is relatively scarce, constituting from only 1.0 to 10.0 percent of the sandstone. Three samples out of the entire sample population contained more than 15 percent matrix. Higher matrix values are usually found in the Wasatch Formation, especially at Douglas Pass where the average matrix content is 11.9 percent. Most Green River sandstone has less than 10 percent matrix, some of which is authigenic and is composed of reworked volcanic ash. At Parachute Creek there is more quartzose silt-sized material in the matrix of the Wasatch samples. In those samples of the Wasatch Formation where volcanoclastic grains make up a substantial portion of the framework mineralogy, volcanic lithic fragments are badly deformed and highly altered. This impairs the accurate discrimination of pseudomatrix from cementing agents. Devitrification of volcanic glass and the alteration of the andesite lithic fragments to analcime creates matrix material that fills in what may have been primary porosity. Surdam and Boles (1979) made similar observations in volcanic sandstones in New Zealand. The type of cement, not the abundance, was found to be useful in distinguishing lacustrine from fluvial sandstone. Cement types and the time of cementation are critical factors in determining the resulting texture of the sandstone. There is strong correlation between lacustrine depositional settings and the occurrence of calcite as the principal cementing agent. When calcite occurs as the dominant cementing agent, the framework grains are commonly suspended in the calcite (fig. 7) suggesting early cementation or original deposition of micrite and subsequent recrystallization to spar. Silica cement is the second most abundant cement type associated with fluvial sandstone bodies. This is especially apparent in the Parachute Creek Member at Douglas Pass where calcite occurs only in tabular sandstones interstratified with oolite and ostracode

grainstone beds. In contrast to the dominance of point-edge framework grain contacts of calcite-cemented sandstones, most fluvial sandstone is characterized by edge-edge contacts resulting in grain suturing as a product of pressure solution.

Quartz is the most abundant component of sandstone from the Wasatch and Green River formations averaging 56.0 and 62.0 percent, respectively. More than 95 percent of the quartz is monocrystalline "common" quartz. Most grains are angular with the remainder being rounded to subrounded. Quartz grains with quartz overgrowths are abraded (fig. 8). Polycrystalline quartz is present, in about one-third of the samples, in amounts less than 4.0 percent. The least abundant quartz variety is volcanic quartz, and it is found in amounts less than 2.0 percent.

The total feldspar content ranges from 6.3 to 45.0 percent with respective averages of 18.4 and 22.4 percent for Wasatch and Green River samples respectively. Orthoclase dominates in both formations. Plagioclase is the next most abundant feldspar variety which is followed by microcline. Orthoclase content commonly varies from 2.3 to 24.7 percent with Wasatch and Green River sandstone averaging 10.5 to 10.8 percent. Plagioclase concentrations range from 2.0 to 18.0 percent with respective averages of 5.5 and 7.8 percent for Wasatch and Green River sandstone. Anor-

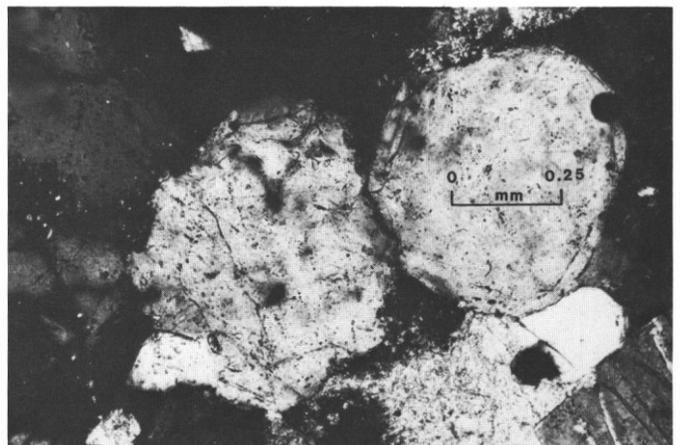


Figure 8. Photomicrograph of Wasatch Formation sandstone at Red Pinnacle but representative of many Wasatch sandstones.

thite contents of properly oriented plagioclase grains were determined using the Michel-Levy method as prescribed by Heinrich (1965). Anorthite values of plagioclase vary from AN₁ to AN₁₀, (albite to andesine). Trace amounts (<1.0 percent) of sanidine are found in a few samples from both formations. Microcline content varies from 0.1 to 5.4 percent with Wasatch and Green River sandstone averaging 2.1 and 3.7 percent respectively. Feldspar grains are generally angular, however, a few grains are subangular to rounded (fig. 9).

More than 95 percent of the lithic fragments are of volcanic origin. The volcanic lithic fragments are composed of volcanic glass, andesite, and rhyolite. The remainder of the lithics are composed of claystone (possibly phyllite) fragments. Volcanic glass is the most abundant constituent of the volcanic fraction in both formations. Rhyolite and andesite grains have been distorted through compaction and subsequent alteration (fig. 9). Alteration is especially apparent in non-calcite cemented sandstones. Volcanic glass content varies from 3.3 to 37.3 percent with respective Wasatch and Green River sandstone averaging 19.1 and 10.0 percent. Andesite fragments are found in samples at all localities. Andesite concentrations range from 2.0 to 10.5 percent in Wasatch sandstone and 1.0 to 3.5 percent in Green River sandstone. Rhyolite fragments are found only in the sandstone at Parachute Creek where values vary from 0.3 to 2.7 percent with respective Wasatch and Green River sandstone averaging 0.7 to 0.3 percent.

Accessory minerals such as biotite, muscovite, analcime, and pyrite make up 0.3 to 14.0 percent of the framework grains. Mica (biotite and muscovite) content ranges from 0.3 to 8.0 percent of the framework grains with Wasatch and Green River sandstone averaging 1.3 and 1.7 percent respectively. Analcime is considered a framework mineral although it probably formed authigenically. Analcime concentrations range from 0.3 to 13.3 percent making up an average of 0.8 percent of the Wasatch framework grains and 1.6 percent of the Green River framework grains.

Allochemical constituents, such as shell fragments, oolites, and micrite chips, make up less than 5.0 percent of the framework grains and are restricted to lacustrine sandstone bodies. Oolites are concentric and commonly contain single quartz grains in their cores. Ostracode debris makes up most of the shell fragments (fig. 6). Abraded edges on some ostracode shells suggest transportation or agitation prior to deposition.

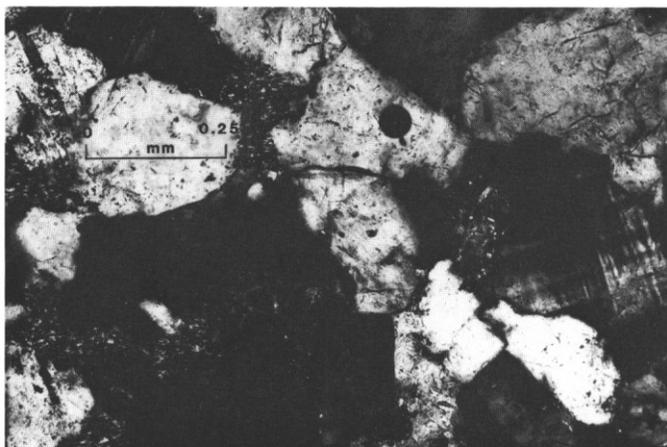


Figure 9. Photomicrograph of Douglas Creek Member sandstone from Parachute Creek.

PROVENANCE

The mineralogy of framework grains in the Wasatch and Green River Formations reflect source terranes composed of (1) fine- to medium-grained clastics, (2) acid igneous intrusives, and (3) intermediate volcanics, probably andesites and rhyolites. Sub-angular to rounded monocrystalline quartz grains, some with abraded quartz overgrowths, indicate recycling of pre-existing sedimentary rocks, probably fine- to medium-grained sandstones. Transparent, angular, monocrystalline quartz may suggest a sedimentary origin, but this may infer an acid igneous source terrane as well. A plutonic source may also be implied from the relatively large size and freshness of the potassic and plagioclase feldspar grains. However, a feldspathic sandstone proximal to the site of deposition may have also contributed the feldspars. Volcanic lithic fragments are common constituents of the framework grain mineralogy. Although dominated by the abundance of volcanic glass, lithic fragment contents commonly contain andesite fragments. The source terrane for the volcanic material is likely andesitic in nature. The volcanic material was probably supplied to the basin directly as airfall pyroclastics.

Paleocurrent data (fig. 10) from the sample localities suggest sediment input from source areas to the southwest, south and east. A thick sequence of Mesozoic and Paleozoic clastic sedimentary rocks covered most of the area south and east of the Piceance Creek basin prior to and during the Larimide Orogeny. The clastic sediments were originally deposited in the Colorado Trough which received sediment shed from the strongly positive Uncompahgre and Front Range uplifts. King (1977) estimated Permian and Pennsylvanian thicknesses in the trough in excess of 3000 m. Erosion of the structures and exposure of the Precambrian core in the uplifts through the Permian was followed by deposition of fine-grained clastics during the Triassic, Jurassic and Lower Cretaceous. Rejuvenation of the structures along pre-existing Precambrian shear zones (Tweto, 1975) stripped much of the rock from the structures depositing the detritus in the intermontane basins. The White River uplift is an extension of the larger Sawatch

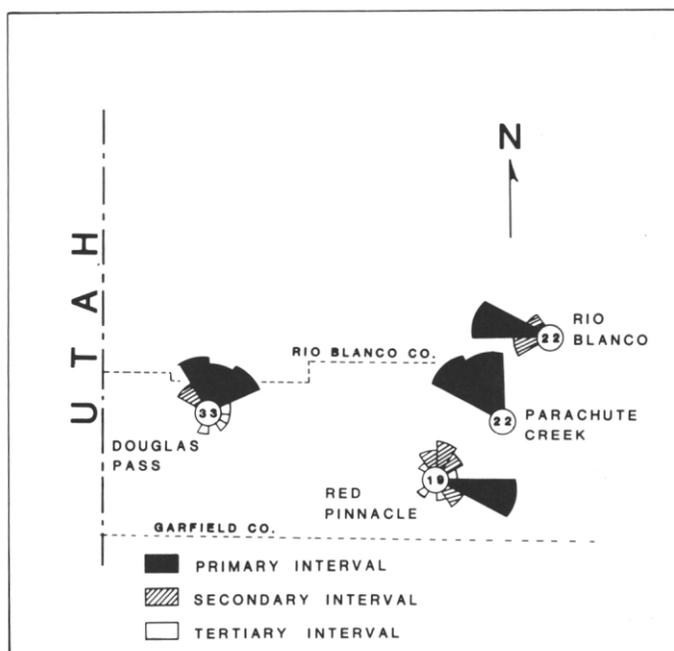


Figure 10. Paleocurrent data collected at sample localities.

uplift (McDonald, 1972; King, 1977) and was initially positive during the Paleocene. To the west, the Douglas Creek arch, an extension of the Uinta uplift (McDonald, 1972), was active prior to the Late Cretaceous which is recorded by the thinning of the Mesa-verde Formation over the arch. This provided effective closure of the basin until the transgression of Lake Uinta over the arch during the Eocene.

Intrusion and volcanic activity occurred concurrently with the uplift of the surrounding areas. The presence of volcanic glass and andesitic volcanolithics in the sandstone within the basin suggest a large areal extent of this source terrane. Cenozoic volcanism and intrusive activity were generally restricted to the northeast trending Colorado Mineral Belt along the southern and eastern margin of the basin (Stevens and others, 1972). The strongest period of volcanism occurred during the Miocene (Stevens and others, 1967) in the San Juan Mountains of southern Colorado. Volcanic activity in this area during the late Cretaceous and Paleocene may also have occurred (Larsen and Cross, 1956). In the Elk and West Elk mountains intrusion was preceded by andesitic volcanism during the Paleocene (Stevens and others, 1972). Potassium-argon dating and cross-cutting internal relations of the dikes indicate emplacement at 65 to 72 million years ago (Obradovich and others, 1969). The volcanics and intrusives of the Elk and West Elk mountains probably supplied much of the lithic fragments in the sandstone units in the southern Piceance Creek basin. Although the activity may have ceased during the Paleocene, erosion of the source terrane throughout the Eocene continued to influence the composition of the sandstones. A source for the abundant volcanic ash are airfall pyroclastics which may have had their source farther north in the central Rocky Mountains. This is especially appealing when attempting to explain the source for the volcanic material in the Uinta Formation. The volcanic activity which occurred in the central Rocky Mountains; specifically the Absaroka Mountains, began in the Late Eocene (King, 1977). These centers of activity may have supplied airfall material to a rather large surrounding area.

SUMMARY

A comparison of averages of textural and compositional components of Wasatch and Green River sandstones reveals interesting though subtle differences (fig. 11) that are more than likely related to different environments of deposition. Almost all of the samples were fine- to very fine-grained, and therefore the textural and compositional attributes are not likely to be artifacts of different grain sizes.

As a group, the deltaic sandstones of the Green River Formation are texturally more mature than Wasatch sandstones. Matrix content is higher (usually 2.0 to 5.0 percent) in the floodplain-deposited Wasatch sandstones. This reflects the amount of energy applied to the sediment and the number of times the sediment has been exposed to reworking. The abundance of cement in the Green River sandstones is another criteria that distinguishes marginal-lacustrine from fluvial sandstones. Early cementation by carbonate cements in some sandstones resulted in the appearance of framework grains floating in the cement (fig. 7).

Compositional elements also reflect the relative difference in the amount of energy applied to the sediment. This is most apparent in the feldspar, lithic fragment, and quartz contents. Generally, Green River sandstone is more quartzose and feldspathic. The increased feldspar content may be an artifact of mechanical breakdown of larger feldspar grains along cleavage planes. Marginal lacustrine sandstones also contain less lithic fragments. Volcanic lithic fragments are almost the sole component of the total lithic fragment content, therefore, they are very sensitive to mechanical

and chemical degradation. Quartz, being the most common framework constituent, is noticeably more abundant in marginal lacustrine sandstones, especially in those sandstone bodies further away from the active distributary portions of the delta. Fluvial sandstone quartz content is usually lower than in marginal lacustrine sandstones. Quartz overgrowths are also more common in fluvial sandstones, again reflecting the lesser total amount of energy applied to the sediment.

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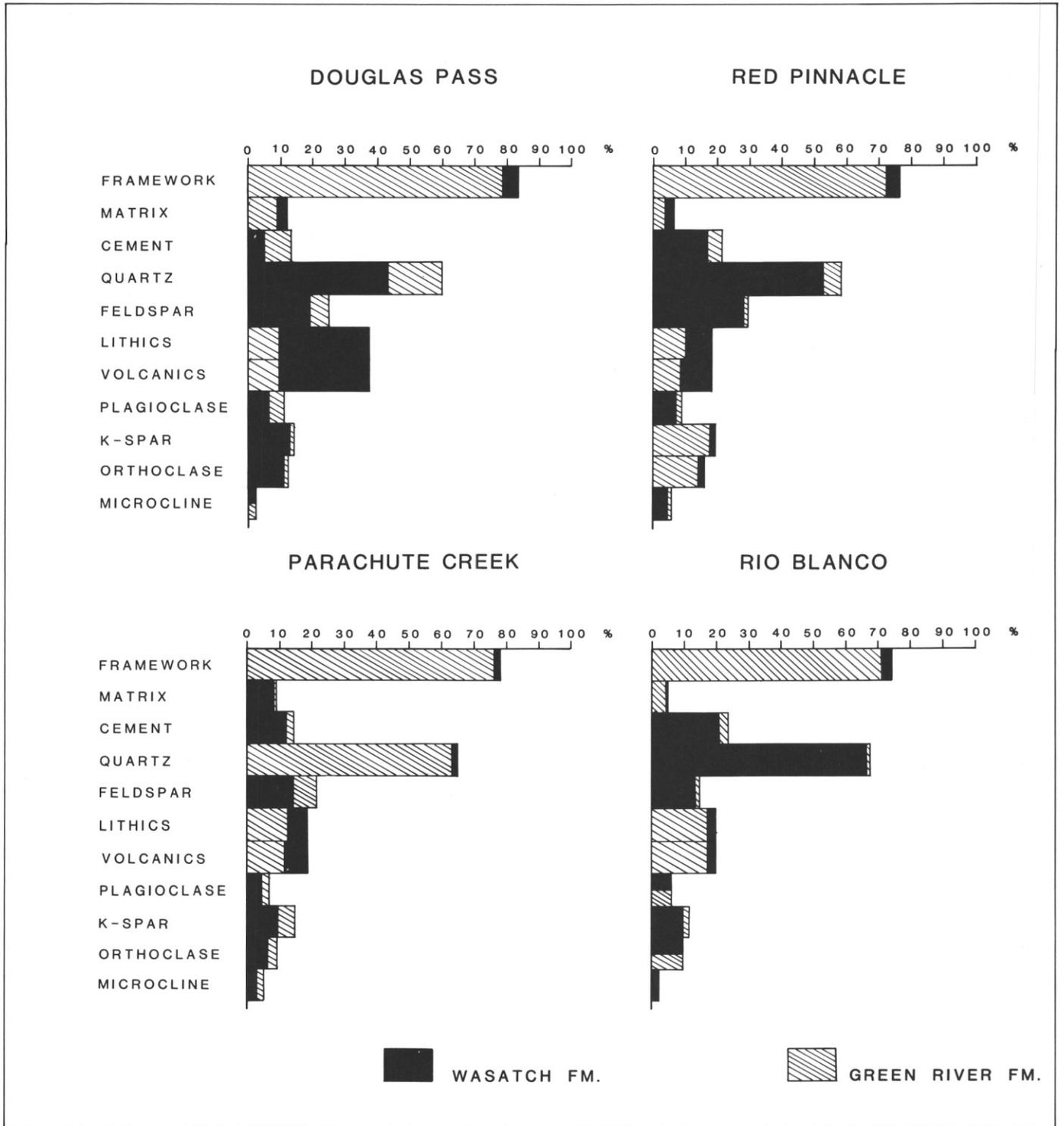


Figure 11. Comparison of averages of Wasatch and Green River sandstone textural and compositional features.

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