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ABSTRACT

The Pass Peak Formation is a Tertiary basin-flank deposit exposed throughout much of the Hoback Basin; a depression physiographically distinct from, but structurally continuous with, the northern Green River Basin. Two lithofacies of the Pass Peak Formation are identified. A northern quartzite conglomerate-sandstone facies, possibly as thick as 3200 ft, intertongues southward with a sandstone-siltstone facies 1500 ft thick. This in turn extends southward and intertongues with the Wasatch Formation. Arkosic sandstone and conglomerate intertongues with the Pass Peak on the east.

Trends in grain size and sandstone composition, and directional structures indicate that: (1) a sedimentary source to the north supplied quartzite cobbles and associated garnet-bearing sand and (2) an igneous or metamorphic source, or both, to the northeast supplied abundant arkosic debris. Regional geology suggests that the Pinyon Conglomerate to the north was the source for Pass Peak sediments and the Precambrian core of the Wind River Range to the northeast was the source for the arkosic sediments to the east.

Uplift in the Mt. Leidy Highlands, the Gros Ventre Mountains, and the Wind River Range during the early Eocene resulted in the deposition of fanglomerate in the northern part of the basin and coarse arkosic alluvial plain sediments in the eastern part. The finer debris from the north was carried southward onto a floodplain where it mixed with the finer sediments from the east.

INTRODUCTION

Objectives

The sequence of Laramide sedimentational events in central-western Wyoming is complex, and evidence from previous investigations is inconclusive with regard to timing. As a result, reconstructions of the Tertiary geologic history of this area are contradictory. A thorough investigation of the nature and distribution of orogenic sediments and the relations of the various sequences to one another is necessary if the Tertiary history is to be reconstructed.

The early Tertiary Pass Peak Formation is orogenic in origin, having been deposited in response to local or regional uplift, or both. Determination of the source and distribution of the Pass Peak sediments and an understanding of the sedimentary processes involved in their deposition are fundamental to the interpretation of the sequence of early Tertiary events in central-western Wyoming. The investigation of the Pass Peak was undertaken with the following objectives: (1) to describe the formation and to map its distribution; (2) to determine and describe the provenance and dispersal pattern of the sediments; and (3) to determine the environment or environments of deposition.

Previous Investigations

The Pass Peak Formation was named by Eardley *et al.* (1944) from Pass Peak, a high point on the Hoback-Green River divide, where the rocks are exposed in a slide scar 1800 ft high (Fig. 1). The lowest yellow sandstone was defined as the base of the formation and was mapped over much of the southern and eastern part of the Hoback Basin and northward between the Gros Ventre and Hoback Ranges. Dorr (1958, Fig. 1) remapped the Pass Peak using the lowest conglomerate as the base. He placed the sandstones beneath this in the Hoback Formation or in his so-called "transition zone." The distribution of the Pass Peak Formation, therefore, was limited to a

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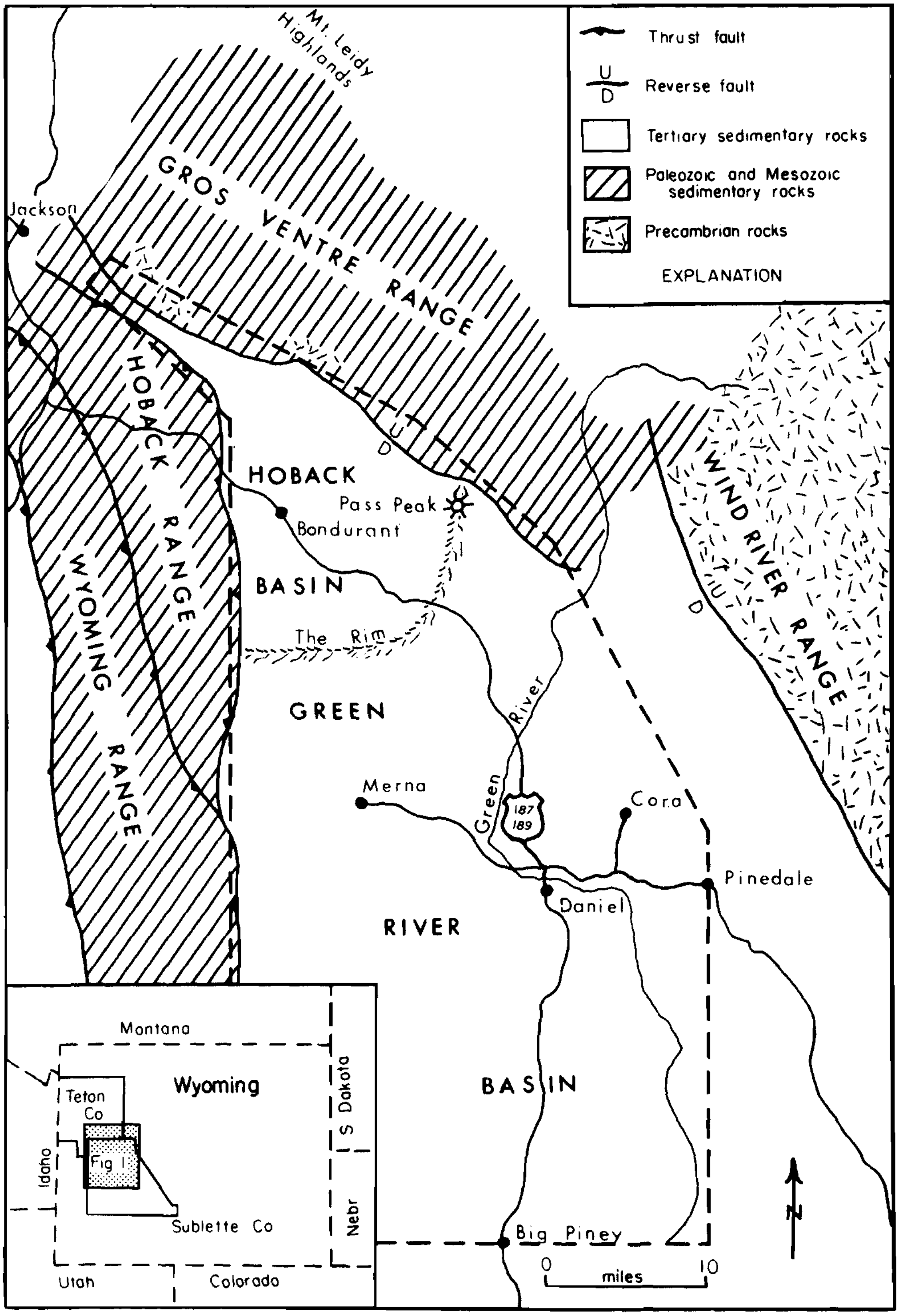

Figure 1. Major physiographic and geologic features of central western Wyoming. Area of investigation enclosed by dashed line. Adapted from Love et al. (1955).

smaller area in the southern and eastern part of the basin.

Keefer (1964) demonstrated that the Pass Peak Formation was involved in the faulting along the southernmost margin of the Gros Ventre Mountains. Antweiler and Love (1967, p. 7) described the occurrence of gold in the Pass Peak Formation. On the basis of vertebrate evidence, Dorr (1969) determined that the age of the Pass Peak ranges from late Graybullian (late early Wasatchian) through Lysitean (middle Wasatchian; that is, middle early Eocene), and possibly into early Lostcabinian (early late Wasatchian, that is, late early Eocene).

Techniques

Mapping, sampling, section measuring, and collection of detailed information concerning sedimentary structures were conducted for a total of seven months. One hundred seventy-one sandstone samples were examined in hand specimens. The heavy minerals from 131 of these samples were studied, and grain counts were made on 142 sandstone thin sections. Both heavy minerals and thin sections were studied in 102 of the samples. Thin sections of other rock types were also examined and described.

The distribution of sampling over the area was not randomized because of the irregular distribution of exposures. Instead, localities were chosen to cover the geographic and stratigraphic range of the Pass Peak Formation and associated arkosic deposits as completely as time and accessibility would allow. Samples used for comparative purposes were collected from the Pinyon Conglomerate (Paleocene), the Camp Davis Formation (Pliocene), and the LaBarge Member and the New Fork Tongue of the Wasatch Formation (Eocene).

Approximately 950 paleocurrent directions were determined from cross-stratification. Exposure was rarely sufficient to permit determination of the orientation of axes of trough cross-bedding and many directions of maximum dip were measured on trough flanks. Measurable pebble imbrication was observed, and twelve readings were taken at three locations. Large accumulations of plant debris were seen on bedding planes, but no preferred orientation could be determined.

Pebble and cobble-size and composition counts were made in the field. Samples were taken at 6-in. or 1-ft intervals depending on the coarseness of the conglomerate. Each clast was broken, and its lithology determined. Approximately 50 were examined at each location. The "largest size" method, suggested by Pettijohn (1957, p. 249), was used to obtain a clast-size index. The maximum axes of the ten largest clasts found at each outcrop were measured with large calipers. The ten measurements were averaged, and this result was used as the clast-size parameter for that location.

Heavy mineral concentrates were obtained by a centrifugation process described by Steidtmann (1969b). The "line method" described by Ramesam (1966, p. 630) was used for making grain counts. In the present study an average of 200 nonmicaceous grains were counted in each sample. Sandstone, conglomerate matrix, and limestone samples were examined in thin section. Where possible, 200 to 250 counts on light minerals were made on each sandstone and conglomerate matrix thin section. These petrographic data are on file in the Department of Geology, The University of Michigan, Ann Arbor, Michigan.

A maximum grain-size parameter was obtained from 70 of the sandstone samples arbitrarily selected to cover the geographic distribution of the Pass Peak Formation and associated arkose as evenly as sample coverage would allow. The observed maximum diameter of the ten largest grains was measured and averaged. The result was used as an index of maximum grain size for respective samples.

A grid of 1-sq mi units was superposed on the base map showing the locations of current direction data. Thus each paleocurrent direction was located by its coordinates. A computer program, utilizing an automatic plotter, was used to correct data for tectonic tilt where necessary, to calculate statistical parameters, and to plot a map of the smoothed data.

Trends in the area distribution of composition and grain size were determined using computer trend-surface mapping. This technique fits first-, second-, and third-degree surfaces to the data using the least squares method. The surface which best fits the data is indicated by the amount of reduction of the sum of squares. Howarth (1967) described the basis for using the percent sum of squares to test the significance of a trend.

The samples used for both compositional and size trends were selected by superposing a grid of 1-sq mi units on the sample location map and randomly choosing one sample from those available in each unit segment. Stratigraphic separation of samples is small over much of the area studied, particularly that part south and east of The Rim where there is little relief. However, in the Hoback Basin north and west of The Rim, stratigraphic separation of the samples may be as great as 1900 ft. Separate trend maps were computed for the Hoback Basin and for the area south and east of The Rim and made it possible to assess the effect of stratigraphic changes in composition and grain size on the trend surfaces for the entire area.

GEOLOGIC SETTING

Regional Geology

The area of investigation occupies approximately 700 sq mi in Sublette and Teton Counties in central-western Wyoming (Fig. 1). The northern one-fourth of the area is in the Hoback Basin; the remainder extends southward into the Green River Basin. The two basins are separated by a low drainage divide called The Rim, but are structurally continuous. The Hoback Basin is bounded on the west by the Hoback Range and on the north and northeast by the Gros Ventre Range. The Wind River Range lies to the east of the Gros Ventre Range and extends southward forming the eastern boundary of the Green River Basin. The western edge of the basin is bounded by the Wyoming and Hoback Ranges.

Rocks exposed in the bordering ranges represent all periods, from Precambrian through Cretaceous, with the possible exception of the Silurian (Wanless *et al.*, 1955, p. 1). Thick Late Cretaceous and Tertiary deposits are exposed in the Hoback and Green River Basins and in the Mt. Leidy Highlands north of the Gros Ventre Range.

Precambrian igneous and, to a lesser extent, metasedimentary rocks are exposed along the southwest front of the Gros Ventre Range and throughout the entire core of the Wind River Range. These exposures are the result of uplift along reverse faults in the relatively thin sediments of the foreland. Paleozoic and Mesozoic sediments of the foreland are exposed along both north and south flanks of the Gros Ventre Range and east flanks of the Wind River Range. Miogeosynclinal sediments attain an aggregate thickness of 18,000 ft (Wanless *et al.*, 1955, p. 1) in the Hoback and Wyoming Ranges where they are cut by a complex series of eastwardly directed thrust faults. Paleocene and Eocene rocks are exposed in the Hoback Basin, where they are approximately 17,000 ft thick, along the northern flank of the Gros Ventre Range and in the northern Green River Basin. Conglomerates and sandstones of Pliocene age crop out north of the Hoback Basin between the Hoback and Gros Ventre Ranges.

Stratigraphy and Structure

The distribution of the Pass Peak Formation, its constituent lithofacies and their relation to the arkose are shown in Figure 2. In the north, where the exposed thickness of the Pass Peak Formation may be as great as 3200 ft, it dips 35° SW. along a fault contact with the deformed Paleozoic and Mesozoic sedimentary rocks on the flank of the Gros Ventre Range. In the same area, folded Paleocene Hoback sandstone is overlain unconformably by Pass Peak conglomerate and sandstone. This angular unconformity disappears to the southwest, toward the center of the Hoback Basin, where the contact is gradational through an intercalated sequence. Here, the exposed thickness is approximately 1500 ft and the dip is 4° to 6° E. Sandstones of the Pass Peak Formation extend southward to Daniel, Wyoming, where they

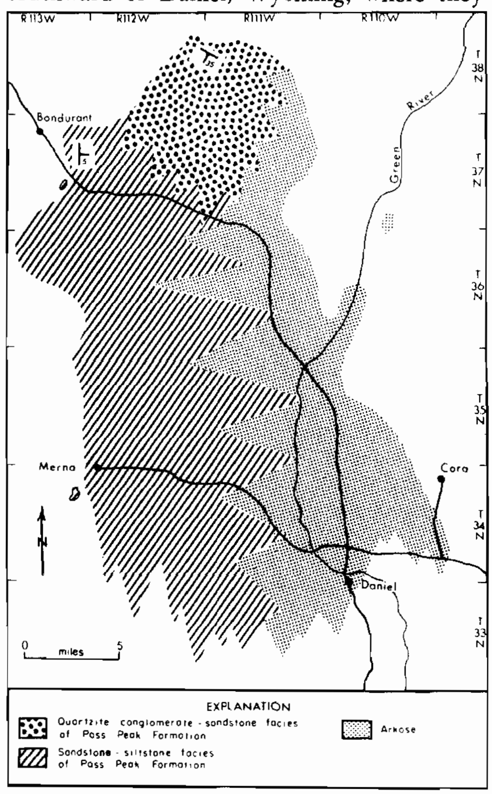

Figure 2. Distribution of the Pass Peak Formation, its constituent lithofacies, and associated early Eocene arkose.

intertongue with red and light-gray variegated mudstones of the Wasatch Formation.

The quartzite conglomerate-sandstone facies is composed almost entirely of conglomerate in the northern part of the area. Toward the south and southwest, sandstone units interbedded with the conglomerate become increasingly abundant, thicker, and more widespread, and only channel conglomerates persist. The major sandstone units of the quartzite conglomerate-sandstone facies continue to the south where they become interbedded with thick siltstone, silty shale, and thin limestone lenses. This sequence constitutes the sandstone-siltstone facies which extends to the southern limit of the formation. Arkosic sandstone and conglomerate intertongue with the eastern part of the Pass Peak Formation. Massive beds of arkosic sandstone and conglomerate are exposed along the Green River just east of Highway 187–189. These beds thin rapidly westward, but persist as thin lenses of arkosic lag sediment at the base of small scours in the sandstone-siltstone facies.

The regional stratigraphic relations of the Pass Peak Formation have been discussed by Steidtmann (1969a) and Dorr (1969).

Meaning of the Name "Pass Peak" Formation

Criteria for the recognition of the Pass Peak Formation were discussed by Steidtmann (1969a). At that time, the arkose to the east was considered a facies of the Pass Peak Formation. Recent information, however, has pointed out that this arkose is part of a belt of arkosic sediment which parallels the Wind River Range for almost its entire length (Oriel, 1970, oral commun.) and which may be as thick as 8000 ft (Shaughnessy, 1970, oral commun.). In light of this information and because of the distinctive lithology, the inclusion of only the northern part of the arkose in the Pass Peak Formation no longer seems justified.

The age of the Pass Peak Formation ranges from late Graybullian through Lysitean and possibly into early Lostcabinian (Dorr, 1969). Sandstones of the Pass Peak Formation extend southward to Daniel, Wyoming, where they intertongue with red and gray variegated mudstones of the LaBarge Member of the Wasatch Formation as identified by Oriel (1967, oral commun.). However, the age of the LaBarge Member, determined from fossils collected between 12 and 40 mi south of Daniel, is considered to be Lysitean(?) and Lostcabinian (Oriel, 1962, p. 2170). Additional complications arise from the fact that the LaBarge Member grades westward from these fossil sites into coarse conglomerate which can be traced northward where it has yielded early or middle Graybullian fossil mammals along the westernmost part of The Rim (Dorr and Steidtmann, in press). More faunal evidence is needed to establish age relations consistent with the physical relations.

This conglomerate, exposed on the west end of The Rim, has been mapped as Pass Peak by Foster (1943), Eardley *et al.*, (1944) and Froidevaux (1968). However, it has neither the gross lithologic character nor the heavy mineral composition of the Pass Peak Formation and nowhere can it be seen to grade into the Pass Peak. These facts, in addition to the Graybullian age suggest that this conglomerate should not be considered Pass Peak Formation.

It is proposed that the name Pass Peak be restricted to those rocks included in the quartzite conglomerate-sandstone and sandstone-siltstone facies of the Pass Peak Formation as described in this report. The eastern boundary of the Pass Peak Formation is defined by the appearance of distinct lenses or beds of arkose. Beds of Pass Peak sandstone extend as far south as Daniel, Wyoming, and tongues of the same sandstone may extend much farther. For mapping purposes, however, the southern limit should be drawn where the gray siltstones of the Pass Peak Formation give way to the red and gray variegated siltstones of the LaBarge Member of the Wasatch Formation. On the west, the yellow sandstone of the Pass Peak Formation can be distinguished from the gray, "salt and pepper" sandstone of the underlying Hoback Formation and on the north, Pass Peak conglomerate and sandstone can easily be differentiated from the older rocks in the Gros Ventre Range.

PETROGRAPHY

Quartzite Pebble Conglomerate

The Pass Peak conglomerate consists of extremely well-rounded pebbles, cobbles, and boulders in a sandstone matrix (Fig. 3A). Almost all of the clasts are pressure marked at each contact point. Around each mark there is a rim of calcite-cemented sandstone. Fractures commonly radiate from each mark so that even apparently uncrushed fragments are easily broken. Many clasts are highly polished (Dorr, 1966). Counts indicate that 90 to 100 percent

Figure 3A. Pass Peak conglomerate consisting of well-rounded pressure marked quartzite cobbles and boulders.

of the clasts are composed of quartzite, which is fine to medium grained, and red, tan, gray, green, black, or white. The remainder of the clasts are granite, granite gneiss, red and black volcanic porphyry; and rarely sandstone, limestone, and chert. There are large, angular blocks of pressure—marked Triassic sandstone in the conglomerate just north of Pass Peak (Fig. 3B).

The average maximum diameter of clasts measured at 16 localities is 21 cm. The maximum size examined was 40 cm. The size measurements do not include the large blocks of sandstone. All the quartzite clasts are extremely well-rounded, and many are highly spherical. The conglomerate matrix is similar in composition to the sandstone. It is, however, coarser grained and well cemented with calcite.

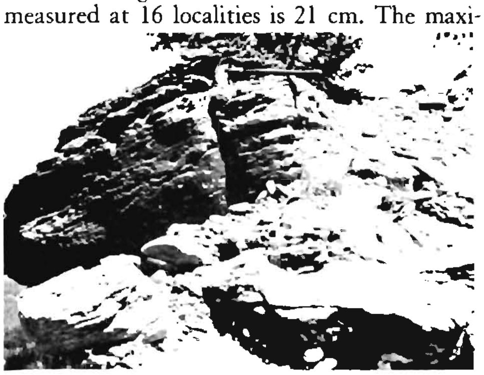

Figure 3B. Angular, pressure marked block of Triassic sandstone in Pass Peak conglomerate, 0.25 mi north of Pass Peak.

Sandstone

Three types of sandstone were recognized. The most common is tan to yellow, friable, micaceous sandstone containing plant fragments, round clay blebs, and pyrite-limonite nodules. The grain size ranges from fine to coarse. Most grains are angular. The matrix is composed of clay, sericite, and very fine quartz and probably acts as cement to some extent. Limonite cement is most common, but calcite is also present in amounts that appear to be directly related to the abundance of fragmental carbonate grains. In outcrop, this sandstone includes zones of crumbled calcite cemented sandstone with septarian nodules, numerous plant fragments with associated heavy limonite stain and limey siltstone nodules containing well-preserved fossil leaves.

Gray, calcite-cemented sandstone occurs as individual beds and as irregular patches and elongate zones within the yellow sandstone, causing irregular weathered surfaces. In hand specimens it appears to be similar to the yellow sandstone, except for the cementation and lack of clay blebs, pyrite nodules, and clay matrix.

Massive yellow and gray arkosic conglomerate and pebbly, feldspathic sandstone occur in outcrops to the east of Highway 187–189 and in lenticular zones at the base of the yellow and gray sandstone units of the sandstone siltstone facies of the Pass Peak. The average grain size is approximately 4 mm, but some grains are as large as 2 cm. The larger grains are composed of feldspar, quartz, quartzite, igneous rock fragments, and limestone fragments, and are surrounded by fine sandstone matrix. Limonite or calcite cement, or both, is present in small amounts.

Lenses of limey clay-pebble conglomerate are present in each of the three types of sandstone. The average grain size is approximately 2 cm, but some grains are as large as 5 cm. The pebbles are subround and consist of light-gray limey silt and clay. The matrix is dark red-brown silty sand, well cemented with calcite.

The grain types counted in sandstone thin sections include carbonate fragments, quartz, chert, quartzite and polycrystalline quartz,

Table 1. SUMMARY OF SANDSTONE LIGHT MINERAL COMPOSITION

Grain Composition	Pass Peak Formation (96 samples) Mean	percent Max.	Min.	Arkose (17 samples) Mean	percent Max.	Min.
Quartz	58.4	79.4	39.1	46.7	67.5	3.7
Carbonate fragments	1.9	7.6	0.0	0.8	2.4	0.0
Chert	3.7	11.6	0.4	3.0	8.4	0.0
Quartzite	3.0	10.0	0.4	2.5	13.0	0.0
Rock fragments	13.2	25.5	1.4	11.4	18.0	5.6
Feldspar	17.1	44.4	6.8	33.2	72.2	11.0
Mica	2.9	8.2	0.0	2.1	7.0	0.0

noncarbonate rock fragments, feldspar, and mica. Carbonate fragments are composed of partially to completely recrystallized micrite and commonly contain unidentifiable shell fragments and oölites. Quartz is the most abundant grain constituent in almost all of the samples. Most grains are angular, but very round grains with overgrowths and broken overgrowths are not uncommon. Much of the quartz is strained. Both chert and quartzite grains are present in almost all the samples, but in relatively small amounts. Noncarbonate rock fragments are common in most of the samples. The most abundant types are sandstone, siliceous carbonate, phosphorite, quartz-mica schist, and igneous rock. Large, angular feldspar grains, including microcline, orthoclase, and some plagioclase are abundant. Biotite composed a small percentage of the grains in most samples and some well-rounded grains of glauconite were observed. Table 1 summarizes the light mineral composition of 113 sandstone samples. All but a few of the sandstone samples are feldspathic arenite, arkosic arenite, or lithic arenite (Gilbert, 1958, p. 293).

The nonmagnetic, nonmicaceous heavy mineral fractions from sandstones are characterized by a relatively large amount of garnet and opaque minerals. Other minerals are commonly present in minor amounts. Table 2 summarizes the heavy mineral composition of 99 sandstone samples.

Shale and Siltstone

Dark-gray to black shale, gray-green shale, and gray and red siltstone are present in the Pass Peak Formation. Pure clay shale is relatively rare, although Love (1969, oral commun.) observed a large exposure of "puffy," red, purple, and gray claystone to the southeast of Pass Peak in the quartzite conglomerate-sandstone facies. Clayey siltstone or silty shale is the most abundant fine clastic, commonly gray, gray-green, and rarely red. Bedding is

Table 2. SUMMARY OF SANDSTONE HEAVY MINERAL COMPOSITION

	Pass Peak Formation (81 samples) Mean	percent Max.	Min.	Arkose (18 samples) Mean	percent Max.	Min.
Heavy mineral weight percent of sample	1.4	7.6	0.1	1.6	4.2	0.1
Magnetite weight percent of heavy minerals	6.2	36.9	0.0	10.0	50.0	0.0
Number percent of heavy minerals counted:						
Garnet	55.5	89.2	27.7	42.5	63.8	0.5
Opaque	23.1	36.5	4.8	19.8	64.7	8.8
Epidote	7.1	19.4	0.6	12.9	52.5	2.0
Zircon	2.6	10.5	0.0	2.6	12.2	0.0
Tourmaline	1.1	4.0	0.0	0.6	1.6	0.0
Sphene	1.3	5.8	0.0	1.0	3.2	0.0
Apatite	1.2	5.9	0.0	0.9	2.9	0.0
Hornblende	5.6	7.0	0.0	8.6	26.5	0.0
Rutile	0.4	1.9	0.0	0.6	1.4	0.0
Collophane	0.0	1.1	0.0	0.0	0.0	0.0
Alterite	5.6	25.8	0.0	9.1	14.0	4.0
Other	1.2	7.7	0.0	1.2	5.4	0.0

well developed in most exposures. Gastropods are abundant at some places in the gray, clayey siltstone, and some vertebrate remains have been found. Shale and siltstone samples were not examined in thin section.

Limestone

Three types of limestone were recognized. The most common is brown, thin bedded to massive, dense, and very brittle. Whole and fragmental gastropods are abundant locally together with ostracod and gastropod fragments and possibly some oögonia. Gray and red-brown mottled limestone is also abundant. It is very thin bedded and contains algal structures which cause well-developed parting. Black, massive, very dense limestone containing recrystallized fossil fragments is present at a few locations.

SEDIMENTARY STRUCTURES

Geometry of Lithosomes

The geometry of the lithosomes is imperfectly known because of poor exposure over much of the area. The shapes and sizes of these bodies can only be estimated by interpolation between outcrops. In the north, the conglomerate body is a prism (Krynine, 1948, Fig. 9) consisting of individual lenticular sheets. It appears to thin to the south and west, at first becoming more tabular and finally separating into shoestring-like bodies only a few feet thick and up to 10 ft wide.

The major sandstone bodies exposed in the Hoback Basin are tabular. The largest of these are approximately 80 ft thick, but 40 to 60 ft is most common. Some are only 10 to 20 ft thick. The lateral extent of these bodies is directly proportional to their thickness; the maximum thickness is 2 to 3 mi for the thickest units and as little as 200 ft for the thinnest unit. Whether the true maximum lateral extent was observed is not known. The thickness of any of these units is essentially constant, except where they thin and pinch out very rapidly. Sandstone units in the southern part of the area appear to be thinner and of greater lateral extent than those in the Hoback Basin.

The siltstone and shale body is an envelope enclosing the sandstone units. Individual beds, separated by sandstone units, are from a few feet to 80 ft thick and can be traced laterally for at least 3 mi. Whereas the sandstone bodies are laterally discontinuous, the siltstone and shale beds are interconnected to form a three-dimensional network which surrounds the sandstone units, except where truncated by channeling.

Limestone bodies occur just above major sandstone units and are interbedded with gray siltstone and shale. Where they overlie sandstone units, they appear to have approximately the same shape in plan view. They are, however, much thinner; the maximum thickness observed is 10 ft.

Channeling

Large conglomerate-filled channels in sandstone are well exposed along Highway 187–189 near The Rim (Fig. 4A). Both the upper and lower contacts of almost all of these channel conglomerates are sharp and well defined with the lower contact somewhat more irregular than the upper. The only exception is where longitudinal sections show cross-bedding in the conglomerate which grades and interfingers downward into coarse sandstone. Channel conglomerates vary in thickness from a few feet to 20 ft. In cross section most display a pronounced lenticular shape and in some cases thin to only a few inches at the edges. The lower contacts are concave upward. The upper contacts are convex upward, probably as a result of differential compaction. Conglomerate-filled channels were not observed in siltstone or shale.

A well-defined gradation of pebble and cobble size is not evident within the conglomerate channels. Rather, the conglomerate unit is composed of small pods or lenses containing pebbles of similar size, irregularly interbedded with lenses containing pebbles of a different size. Locally, the internal structure of the

Figure 4A. Cross-bedded conglomerate exposed in longitudinal section of a channel at top of road cut. Lower conglomerate shows the lenticular shape of a filled channel and indistinct cross-bedding brought out by irregular cementation parallel to cross-strata.

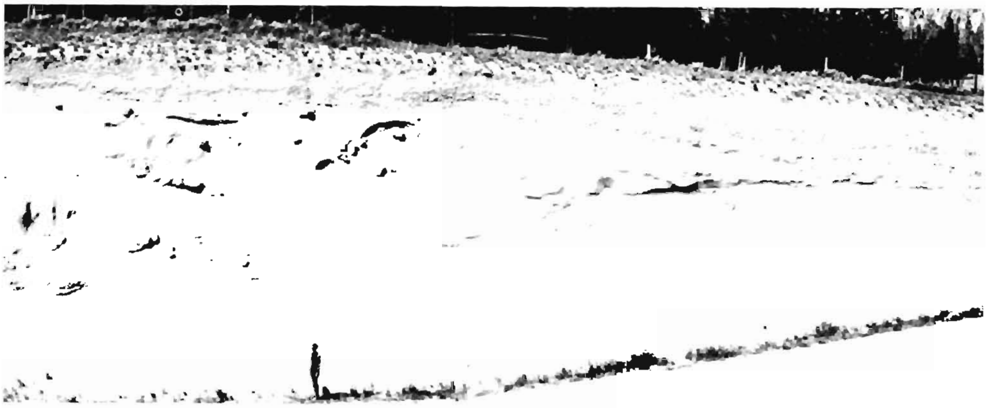

Figure 4B. Sandstone-filled channel in siltstone showing lenticular shape and steplike scours at base.

channel conglomerates consists of large-scale, but indistinct, cross-bedding.

Large sandstone-filled channels in siltstone and shale are present throughout the area. An outstanding example, similar to those seen elsewhere is exposed in the roadcut along Highway 187–189 at The Rim (Fig. 4B). Most channel sandstones display upper and lower bounding surfaces which are sharp and well defined. The lower contacts are concave upward and somewhat irregular because of steplike scours. The upper surfaces are generally very smooth and convex upward as the result of differential compaction. Channel-fill thickness ranges from a few feet to 25 ft. Even the largest of these thins to a feather edge.

Very coarse pebbly sand occupies the lower part of most of the channels. This grades upward and outward into medium and, in some places, fine sand. The bedding at the base conforms to the shape of the channel, but within a few feet of the bottom it becomes irregularly cross-laminated because of local scour and fill. Some of these scour and fill structures within the sandstone are of such magnitude that they may be considered filled channels within the sandstone. As in the major channels, the bedding at the base of these large scours conforms to the base of the scour and grades upward into irregular cross-bedding.

Many small channels within the sandstone are filled with limey, clay-pebble conglomerate. In general these are not more than 4 ft thick and 20 ft in lateral extent. Most are much smaller and probably represent only very local scour and fill.

Cross-Stratification

Large-scale cross-stratification in conglomerate-filled channels is present along Highway 187–189 just west of The Rim (Fig. 4A). It was not observed in the massive conglomerates in the northern part of the area. The cross-stratification is generally quite indistinct because the high sphericity of the clasts precludes preferred orientation on bedding surfaces. As a result, the conglomerate appears to be massive, except where interfingering sandstone or irregular cementation parallel to the bedding emphasizes the internal structure.

One cross-bed set occupies an entire channel so that the lower and upper bounding surfaces of the set are the bottom and top of the channel. The sets are up to 20 ft thick. The infilling cross-beds are straight near the top and curved near the bottom, becoming almost tangential with the lower bounding surface. The average dip of these cross-beds is 14°. The exact geometry of this cross-bedding is not known because it was observed only in longitudinal and oblique sections.

Five types of cross-stratification were observed in sandstone. Large-scale trough cross-stratification is present in sets from 1 to 3 ft thick. The lower boundary is erosional, concave upward, and plunges in one direction. The infilling laminae are most commonly discordant with the lower bounding surface. They are straight near the top and curved near the bottom, becoming almost tangential. Each set is truncated by the set above. This structure is found throughout the entire area. In the quartzite conglomerate-sandstone facies of the Pass Peak and the arkosic sediments to the east, it is characterized by extreme inference between the sets and a high degree of discordance between the infilling laminae and the lower bounding surfaces. In the sandstone units of the sand-

Figure 5A. Planar and slightly curved cross-stratification overlying large scale, very low-dipping, planar cross-stratification in Pass Peak sandstone.

Figure 5B. Solitary set of large scale planar cross-stratification in Pass Peak sandstone.

stone-siltstone facies of the Pass Peak this cross-stratification is much less abundant, and there is less interference between the sets.

Planar and slightly curved cross-stratification (Fig. 5A) is present in sets from 0.5 to 1.5 ft thick. The lower surface of each set truncates the bedding below. Individual laminae are tangential with this surface, very slightly to extremely concave upward, and truncated by the next higher set. Sets in which the infilling laminae are concave upward are also commonly slightly trough-shaped. These structures are found throughout the sandstone-siltstone facies, but were not observed in either the quartzite conglomerate-sandstone facies or the arkose.

Large-scale, very low-dipping, planar to slightly curved cross-stratification occurs as channel-fill bedding in the northern part of the sandstone-siltstone facies. Farther south in this facies, it underlies planar and slightly curved cross-stratification (Fig. 5A), and is separated from it by a smooth erosional upper bounding surface. The lower bounding surface of a set is erosional and slightly concave upward. Sets are up to 5 ft thick where overlain by planar and slightly curved cross-stratification and up to 12 ft thick further north where the latter are not present. The infilling laminae are slightly curved and dip from 5° to 10°.

Large-scale planar cross-stratification occurs in solitary sets from 1 to 3 ft thick throughout the sandstone-siltstone facies (Fig. 5B). Each set is bounded underneath by an irregular erosional surface and truncated by massive sandstone beds at the top. The infilling laminae are discordant with the lower bounding surface and straight or slightly curved in plan view.

Small-scale trough cross-stratification is present at only a few locations. Individual troughs are approximately 1 in. deep, 2 in. wide, and 2 to 4 in. long. Each set has an erosional lower surface that is scoop-shaped, plunging in one direction, and filled with discordant laminae. The average dip is 15°. Pettijohn and Potter (1964, Pl. 39) refer to this structure as ripple cross-lamination.

Other Structures

Contorted lamination (Friend, 1965, p. 51) is abundant in sandstones of both the quartzite conglomerate-sandstone and sandstone-siltstone facies. The contortions range in scale from irregular bedding surfaces with only a few inches of relief to fanlike folds 4 ft high.

Clay blebs and balls are abundant in the sandstone of the sandstone-siltstone facies. They range in size from less than an inch to about 2 ft in maximum diameter and are composed of almost pure dark-gray to black clay. They show no fissility or other internal structure. The surface in contact with the enclosing sandstones is smooth. The largest of these structures are generally found "wedged" between sets of cross-beds along scoured surfaces. Laminations in the enclosing sandstones are continuous around the ball. The very small blebs occur along laminations within the larger sets of cross-beds.

Some pebble and cobble imbrication is present in the massive conglomerate exposed in the northern part of the area. It is generally poorly developed because of the high sphericity of almost all of the clasts. Even clasts which are relatively flat rarely show preferred orientation. Imbrication is confined to only a few of the lenticular conglomerate sheets where the flat pebbles dip in a more-or-less constant direction at an angle between 15° and 45°.

RESULTS OF DATA ANALYSIS

Pebble and Cobble Size

The average maximum diameter of the largest pebbles or cobbles at 16 locations is shown in Figure 6. The data are unevenly distributed, but generally cover the area over which the conglomerate is exposed. A decrease in pebble and cobble size to the south is apparent, but the few data and their variability preclude meaningful contouring or trend-surface mapping.

Grain Size

The average size (in phi units) of the 10 largest quartz grains measured in thin section from each of 70 samples distributed over the entire area is expressed by the second-degree trend surface in Figure 6. The percent reduction in the sum of squares for this surface is 16.6. The critical value for a second-degree surface is 12.0 at the 0.05 level of significance (Howarth, 1967, p. 624).

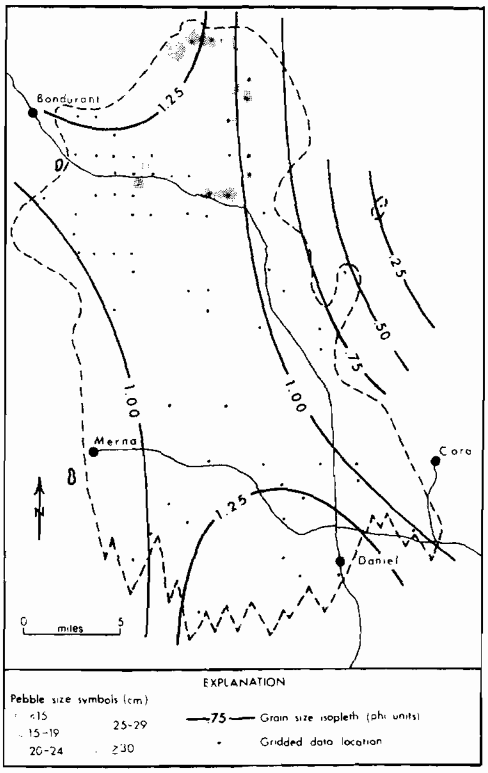

Figure 6. Distribution of average of ten largest clasts in quartzite conglomerate and second-degree trend surface on average of ten largest quartz grains in sandstone.

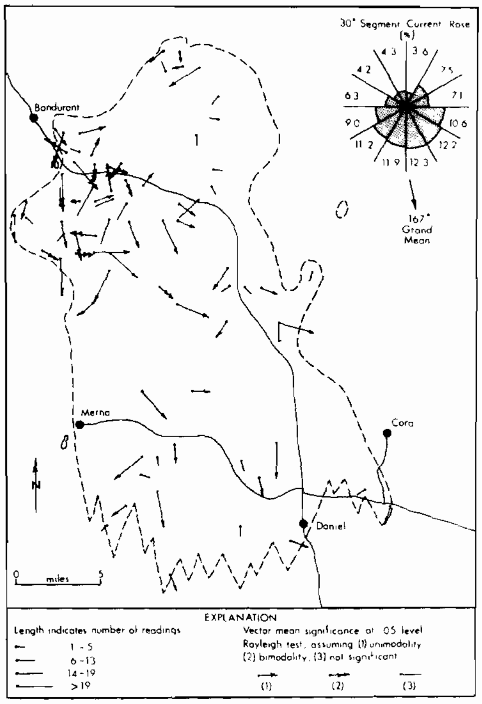

Figure 7. Orientation of vector means of current direction data from the Pass Peak Formation and equivalent arkose. Averaged in 1-mi grid segments.

The surface in Figure 6 shows a rapid decrease in grain size from the northeast to the center of the area of outcrop of the Pass Peak Formation and a further slight decrease to the northwest and southeast. The similarity of this surface to that computed on data exclusive of that from the Hoback Basin indicates that the trends in grain size over the entire area are not significantly affected by stratigraphic variation in the data representing the large stratigraphic interval exposed in the Hoback Basin.

Current Direction

Vector means from 955 rotated cross-bedding readings, analyzed in grid segments 1 mi on a side are shown in Figure 7. Each mean was tested for significance at the 0.05 level assuming both unimodal and bimodal (at 180°) distributions. The Rayleigh test for uniformity of two-dimensional orientation data modified for small sample size (Durand and Greenwood, 1958, p. 234) was used. Figure 8 shows the results of smoothing the vector means in 1-mi grid segments. The current rose and grand mean in each of these figures is a summary of all data. The vector means in Figure 7 show a general

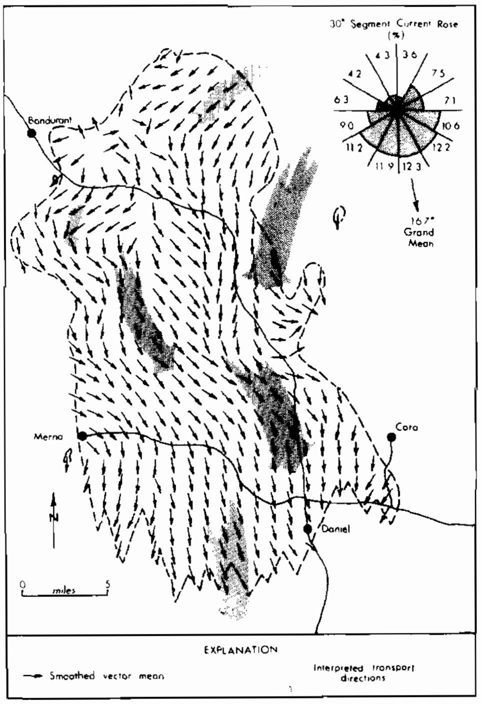

Figure 8. Orientation of vector means in 1-mi grid segments (that is, data *in* Fig. 7) smoothed over the entire area.

transport direction from north to south as do the current rose and grand mean. Current lineation and pebble imbrication generally conform to the adjacent cross-bedding dip directions.

A high degree of variability is evident, particularly in the northwest. Six of the vector means are not significant at the 0.05 level when both unimodal and bimodal distribution are tested and 16 means are significant only when a bimodal distribution is assumed. Figure 8 shows the vector means in unit grid segments (that is, the data in Fig. 7) smoothed over the entire area. Variability in the northwest is still apparent, and the general current direction to the south is emphasized by the conforming nature of the smoothed vectors.

Light and Heavy Mineral Composition

Trends in the areal distribution of garnet, rock fragments, and feldspar percent frequencies were determined using trend-surface mapping. These particular minerals were selected from the observed grain categories for the following reasons: (1) cursory examination of the data suggested that garnet and feldspar are inversely related in the samples analyzed and that, therefore, they may reflect separate dispersal systems; (2) all three constituents are present in the samples analyzed and in relatively large amounts in most; and (3) they may be diagnostic in terms of source-rock composition. Although other grain types may be diagnostic in terms of composition, most are not present in all of the samples, and their frequencies are generally low.

The percent frequency of garnet in the heavy mineral fractions of 67 samples distributed over the entire area is expressed by the cubic trend surface in Figure 9. The percent reduction in the sum of squares for this surface is 54.5. The critical value for a cubic surface is 16.2 at the 0.05 level of significance (Howarth, 1967, p. 624). Over most of the area, the garnet frequency is between 40 and 60 percent with a slight tendency toward a decrease from northwest to southeast indicated by the shape of the 50-percent isopleth. A rapid decrease in garnet frequency from west to east is shown by isopleths in both the eastern and western portions of the area. This surface is similar to that computed on data exclusive of the Hoback Basin.

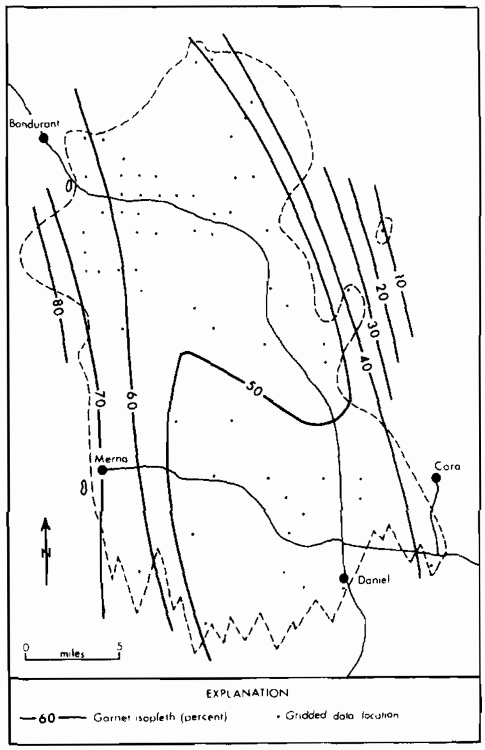

Figure 9. Third-degree trend surface of the percent garnet in the heavy minerals from Pass Peak sandstone and equivalent arkose.

This similarity suggests that the trends in garnet frequency over the entire area are not significantly affected by stratigraphic variation in the data representing the large stratigraphic interval exposed in the Hoback Basin.

The percent frequency of feldspar in the light minerals from 67 samples distributed over the entire area is expressed by the cubic trend surface in Figure 10. The percent reduction in the sum of squares is 35.2 and is significant at the 0.05 level. The trend shown by this surface indicates a decrease in feldspar frequency from the northeast to the south-central portion of the area and a further decrease to the northwest and southeast. As before, the similarity of this surface to that computed on data exclusive of the Hoback Basin indicates that the trend in feldspar frequency over the entire area is not significantly affected by stratigraphic variation in the data from the Hoback Basin.

No significant trends in the frequency of rock fragments were observed.

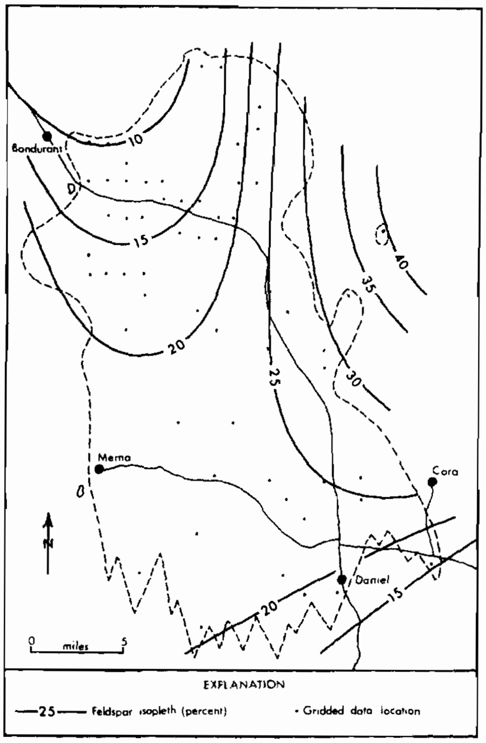

Figure 10. Third-degree trend surface of the percent feldspar in Pass Peak sandstone and equivalent arkose.

INTERPRETATIONS

Sediment Dispersal and Paleocurrent System

The general decrease in pebble and cobble size toward the south (Fig. 6) indicates that coarse detritus was deposited by a current system from the north. The decrease in sand size from the northeast to the center of the area and then southward (Fig. 6) indicates a separate current system which flowed into the basin from the northeast and continued southward. The decrease in grain size to the northwest is not consistent with the trend indicated by the pebble-size data. One or both of the following situations may have been responsible for this apparent inconsistency: (1) sand associated with the pebbles and cobbles is generally finer than that in other parts of the area. Since the grain size data represent maximum size, a trend in this finer sand would be masked by the major trend over the area. (2) Size trends in sediments from the northeast would dominate the general trend if these sediments constituted the greatest proportion of the total sediment brought into the basin and if there was sufficient sediment mixing.

The quartzite conglomerate-sandstone facies of the Pass Peak Formation and arkose to the east apparently represent basin margin deposition. The thinning and pinching out of the conglomerate to the south and southwest indicates a transport direction to the south across the northern part of the area. This transport direction also is suggested by the large blocks of Triassic sandstone in the conglomerate just north of Pass Peak. These could not have traveled far without rounding and fracturing and must have come from the uplifted sedimentary rocks now exposed immediately to the north on the flank of the Gros Ventre Range. Observations on the distribution of the arkose are less definitive in terms of sediment dispersal because of poor exposure. However, beds of arkosic sandstone thin westward and intertongue with feldspathic and lithic sandstone suggesting that the arkosic sediments were brought into the basin by a current system from the east.

Trends in the percent frequency of garnet and feldspar (Figs. 9 and 10) also indicate that two separate current systems brought sediment into the basin. The general decrease in garnet frequency from west to east and the slight decrease from northwest to southeast indicates an easterly or southeasterly transport direction for the garnet-bearing sediment. The decrease in feldspar frequency from the northeast to the south-central portion of the area and a further decrease to the southeast and northwest suggests a current system which flowed from the northeast into the central portion of the basin and continued to the south. The further decrease in feldspar to the northwest may be the result of dilution of the sediment from the east by that brought from the north.

The current system from the west, indicated by the trend in garnet frequency, is not consistent with the other dispersal patterns postulated. This and the fact that this writer knows of no western source for a great amount of garnet (source areas to be discussed more fully under Provenance) suggest that this trend does not reflect the true dispersal pattern of sediments characterized by high garnet frequency. Instead, this trend may reflect the dilution of garnet-bearing sands from the north by a greater quantity of arkosic sand from the east, a situation similar to that postulated to explain the absence of an increase in sand size to the north.

The results of the analysis of directional sedimentary structures indicate a general current flow from north to south. This is consistent with the general pattern of transport indicated by the other evidence previously cited, except that separate current systems from the north and northeast are not delineated. The failure of the directional data to be more definitive probably stems from one or more of the following: (1) the irregular distribution of the data; (2) the variability inherent in the formation of directional structures; and (3) operator error.

Interpretations of the transport directions during the time of deposition of the Pass Peak and equivalent beds are summarized by the large shaded arrows in Figure 8.

Provenance

Certain grain types observed in thin sections of Pass Peak and equivalent sandstones are particularly diagnostic of provenance. Strained quartz, quartzite, quartz mica schist, igneous rock, and unweathered feldspar fragments suggest an igneous or metamorphic source, or both. Rounded quartz with broken overgrowths, chert, sandstone, collophane, and round glauconite indicate a sedimentary source. In addition, the well-rounded quartzite clasts in the conglomerate indicate either a distant metamorphic source or a conglomerate source at an unspecified distance. The blocks of Triassic sandstone indicate an adjacent sedimentary source.

Sediment dispersal patterns and the above petrographic characteristics indicate the following: (1) a source to the northeast with high relief in primarily igneous or metamorphic terrane, or both, capable of supplying a great amount of arkosic sediment; and (2) a source to the north in terrane capable of supplying large blocks of Triassic sandstone, well-rounded quartzite pebbles and cobbles, and garnet-bearing sand.

Sedimentary rocks of Paleozoic and Mesozoic age now exposed in the Gros Ventre Range were a northern source for some detritus including large blocks of Triassic sandstone, chert, collophane, glauconite, and quartz grains with overgrowths. The Paleocene Pinyon Conglomerate, now exposed to the north of the Gros Ventre Range in the Mt. Leidy Highlands, probably supplied the rounded quartzite clasts and associated sand to the quartzite conglomeratic-sandstone facies of the Pass Peak. Heavy mineral analyses of Pinyon Conglomerate matrix (Lindsey, 1969, written commun.) indicate that it has a garnet content similar to that of the Pass Peak Formation. It is, therefore, likely that the Pinyon Conglomerate was the source of the garnet as well as the quartzite cobbles in the Pass Peak, and the decrease in garnet frequency from west to east (Fig. 9) is the result of sediment mixing and dilution as previously postulated.

The core of the northern Wind River Range satisfies all the requirements for a northeast sediment source. Its present characteristics indicate that it was of sufficient size, composition, and relief to supply a great quantity of unweathered arkosic sediment with associated minerals of igneous or metamorphic origin, or both.

Depositional Environments

Alluvial Fan. The semicircular shape, location against the Gros Ventre front, and coarseness of the detritus of the quartzite conglomerate-sandstone facies strongly suggest deposition in an alluvial fan environment (Eckis, 1928; Beaty, 1963; Bull, 1963; Denny, 1965). The large angular blocks of sandstone in the extreme northerly exposures of this facies probably represent talus deposits and indicate proximity to source.

The decrease in pebble and cobble size and the increase in the number and thickness of sandstone units interbedded with the fanglomerate indicate a decrease in stream competence down the depositional slope, as described by Lustig (1963). The cross-bedded fanglomerate channel fill in the southern part of the fan (Fig. 4A) indicates that stream flow rather than mudflow or sheetflow was the mode of transport (Blissenbach, 1954, p. 186; Bluck, 1965, p. 232). Mudflow transport was probably prohibited by the incoherent nature of the debris due to the lack of clay associated with the coarse material. Pebble imbrication in the north indicates that there was some stream flow transport near the apex of the fan (Bluck, 1965, p. 233), but the lense-shaped units suggest that sheet-flow transport was dominant. The individual pods and lenses composing the fanglomerate units indicate that flow was intermittent, a characteristic of alluvial fan deposition and a response to periods of high rainfall in the source area.

Large-scale trough cross-bedding in the sandstone units interbedded with fanglomerate is similar to that reported in alluvial fan deposits by Blissenbach (1954, p. 186), Howard (1966, p. 148), and Nilsen (1968). Allen (1963, p. 110) attributed this structure to the filling of spoon-shaped scours or to the migration of large-scale lunate dunes over the bottom. Filling of scours is the most likely origin for these deposits as indicated by the extreme interference between adjacent sets and their association with scours and channels. Large-scale, very low-dipping planar to slightly curved cross-stratification in the sandstone units of the alluvial fan deposits is probably the result of the filling of channels. Allen (1963, p. 104) reported that cross-bedding of this type forms by accretion on the gentle channelward slope of the point bars, but it is doubtful that point bars would form in the flow conditions found on alluvial fans.

Alluvial Plain. The arkose which intertongues with the Pass Peak Formation on the east probably represents deposition on an alluvial plain. Although the meager exposure of this facies does not permit a conclusive interpretation, the location and inferred distribution of this facies with respect to its source in the Wind River Range, suggests a broad apron of sediment which paralleled the trend of the range. Its present distance from the mountain front and the absence of deep channeling and very coarse detritus indicate deposition somewhat farther from the source than an alluvial fan.

The transport and deposition of sediments on the alluvial plain was accomplished by braided streams as indicated by the absence of fine clastic deposits of overbank origin. Braided stream deposits are dominated by channel sediments and overbank deposition is reduced to a minimum (Moody-Stuart, 1966, p. 1104) due to the ease with which the streams can comb across the floodplain (Allen, 1965, p. 163). After the stream has aggraded for some time, its bed is raised above the floodplain, and it changes its course suddenly by avulsion.

Trough cross-stratification and discontinuous horizontal bedding in the arkose is similar to the sedimentary structures described from Holocene deposits of braided streams by Doeglas (1962, p. 171) and Ore (1964, p. 10). Interference between sets of trough cross-stratification indicate that they formed by the filling of spoon-shaped scours rather than from the migration of lunate dunes (Ore, 1964, p. 11). Discontinuous horizontal bedding is formed by the superposition and interference of channel-bottom deposits.

Floodplain. Sediments of the sandstone-siltstone facies of the Pass Peak represent a typical floodplain sequence. The tabular sandstone bodies encompassed by a shale-siltstone envelope, the cross-bedded, scoured, and channeled nature of the sandstone, and the presence of both terrestrial and aquatic fossils are indicative of floodplain deposition (Allen, 1965). Channel, overbank, and transitional deposits (Allen, 1965, p. 127) are present. The channel deposits are represented by channel-lag gravel and bar sandstone, the overbank deposits by natural levees and floodplain siltstone, and the transitional deposits by limestone.

The lenticular beds of arkosic gravel within sandstone units are lag deposits which accumulate as residual material during the normal process of stream action and are concentrated in the deepest part of channels and scours.

The major sandstone units consist almost entirely of bar deposits. Evidence as to whether these are point bar sands, as in a meandering stream, or channel bar sands, as in a low sinuosity or braided stream, is inconclusive. Both types of deposition may be represented. Features of the sandstone units which have been recognized in "modern" point bar deposits include accumulations of plant debris (Frazier and Osanik 1961, p. 135; Harms *et al.*, 1963, p. 570), trough cross-stratification (Frazier and Osanik, 1961, p. 124; Bernard and Major, 1963; Harms *et al.*, 1963, p. 570), and planar cross-stratification (Harms *et al.*, 1963, p. 576; Potter and Pettijohn, 1963, Pl. 8B). Steplike scours (Fig. 4B), caused by lateral cutting of the stream, and large-scale, very low-dipping planar cross-stratification (Fig. 5A) are thought to be diagnostic of meandering streams (Moody-Stuart, 1966, p. 1105), and, therefore, the sandstones containing such an association represent point bar deposition. Following the lines of reasoning of Moody-Stuart (1966, p. 1106) the association of cross-stratification shown in Figure 5A is interpreted as originating in a meandering stream between 50 and 70 ft wide and having a depth of from 5 to 7 ft. A detailed discussion of this interpretation is presented by Steidtmann (1970). Trough and planar cross-stratification, however, are not limited to meandering streams (Doeglas, 1962, p. 171; Ore, 1964, p. 11), and periodic braided conditions are not precluded.

The shale and siltstones of the sandstone-siltstone facies are overbank deposits and represent the settling of suspended sediment from standing water which remained after the streams flooded their banks. Sandstone channels in the siltstone formed either when meandering streams migrated across the floodplain or when braided streams filled their channels and rapidly changed course. Channeling of the overbank deposits resulted in the reworking of clayey sediments, the subsequent deposition of clay blebs and balls, and the formation of lenses of limey clay-pebble conglomerate in the bar deposits.

The zones of crumbled, calcite-cemented sandstone with associated septarian nodules, plant fragments, and heavy iron stain are similar to the deposits interpreted as natural levees by Moody-Stuart (1966, p. 1108). The lenticular shape of these zones suggest braided stream deposition. A thin sheet of levee sediments overlying point bar deposits would be expected in deposits of a meandering stream while only poorly preserved lenticular levee deposits, as observed in this study, would be expected in a braided stream sequence. The limestone of the sandstone-siltstone facies may represent transitional deposition. These deposits must have originated by biochemical precipitation from the standing water in small lakes which occupied cut-off channels no longer receiving clastic debris.

CONCLUSIONS

Arkosic detritus and sediments of the early Eocene Pass Peak Formation were deposited in the rapidly sinking northern edge of an intermontane basin flanked on the north and east by the rising Gros Ventre and Wind River Ranges, and on the west by the Hoback and Wyoming Ranges. The basin was filled from the north by quartzite boulders and sand derived from the Pinyon Conglomerate. The coarsest debris was deposited on an alluvial fan along the northern edge of the basin and the sand was carried southward onto a floodplain. Arkosic sediments, derived from the exposed Precambrian core of

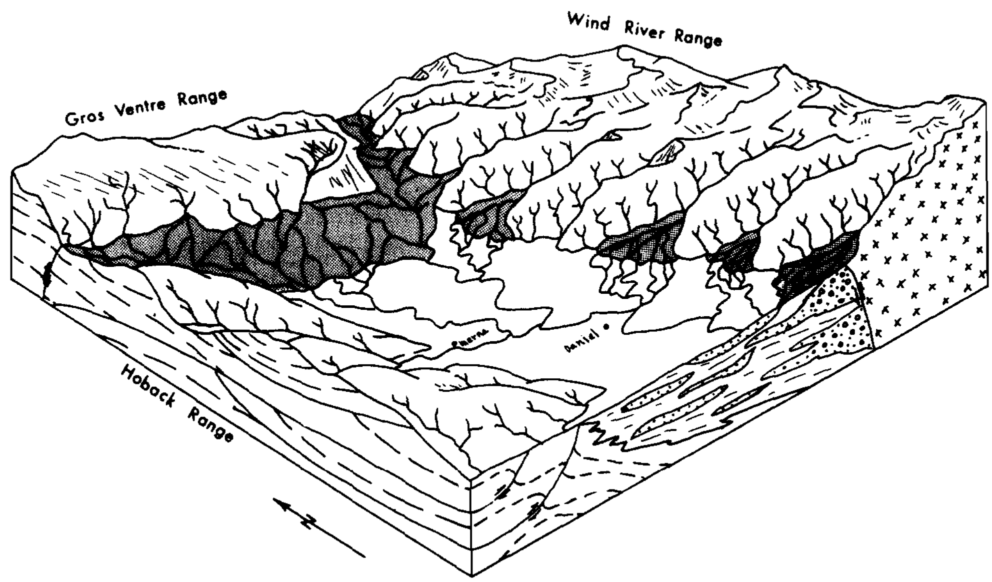

Figure 11. Model of early Eocene depositional environments and a paleogeographic reconstruction of the Hoback and northern Green River basins. Older Tertiary basin deposits not represented. Shaded area represents coarse alluvial fan deposits. Not drawn to scale.

the rising Wind River Range, were deposited along the eastern edge of the basin by streams which combed across an alluvial plain in front of fans now covered by younger deposits. These two current systems coalesced in the central portion of the basin and continued southward. As a result, a floodplain sequence consisting of tabular bar deposits channeled into fine-grained overbank sediments was deposited. Little, if any, debris was shed by the ranges to the west. The major elements of the model of early Eocene deposition and a paleogeographic reconstruction of the Hoback and northern Green River basins is shown in Figure 11.

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