



Sedimentology and paleogeography of the late Triassic Higham Grit, southeastern Idaho and western Wyoming
by David Ralph Hazen

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University
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Abstract:

Stratigraphic and lithofacies analyses of the Late Triassic Higham Grit in the southeastern Idaho and western Wyoming fold and thrust belt show it to be comprised predominantly of coarse to medium-grained pebbly sandstone and pebble conglomerate with lesser amounts of interbedded mudstone. Thickness ranges from 9 to 150 m and increases northwestward. Lithofacies present include massive to crudely horizontally bedded pebbly gravel (Cm), trough crossbedded sand (St), planar tabular crossbedded sand (Sp), horizontally stratified sand (Sh), ripple cross-laminated sand (Sr), and finely laminated sand and mudstone (F1). Deposition occurred in a South Saskatchewan and/or Platte River-type braided stream complex on a broad alluvial plain through the development of longitudinal bars and interbar channel lags (Gm), straight-crested transverse bars (Sp), and sinuous-crested transverse bars and dunes (St). Periodic high-velocity flow resulted in development of upper flow regime plane beds (Sh). Minor episodes of flood plain inundation gave rise to finely laminated sand and mud (F1). These findings differ from previous interpretations of Higham deposition as a coalescing alluvial fan complex.

Pebble size and paleocurrent analysis of medium scale trough and planar-tabular crossbeds denote an overall north to northwest paleoflow direction. Petrographic data indicate erosion of a plutonic/metamorphic source terrain, probably associated with the relict Uncompahgre and/or Front Range components of the Late Paleozoic Ancestral Rocky Mountains uplift. Deposition of Higham detritus thus occurred as a sheet sandstone deposit at a distance (as much as 500 km) from the sediment source which is comparable with the modern South Saskatchewan and Platte Rivers.

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in

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APPROVAL

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ABSTRACT

Stratigraphic and lithofacies analyses of the Late Triassic Higham Grit in the southeastern Idaho and western Wyoming fold and thrust belt show it to be comprised predominantly of coarse to medium-grained pebbly sandstone and pebble conglomerate with lesser amounts of interbedded mudstone. Thickness ranges from 9 to 150 m and increases northwestward. Lithofacies present include massive to crudely horizontally bedded pebbly gravel (Gm), trough crossbedded sand (St), planar tabular crossbedded sand (Sp), horizontally stratified sand (Sh), ripple cross-laminated sand (Sr), and finely laminated sand and mudstone (Fl). Deposition occurred in a South Saskatchewan and/or Platte River-type braided stream complex on a broad alluvial plain through the development of longitudinal bars and interbar channel lags (Gm), straight-crested transverse bars (Sp), and sinuous-crested transverse bars and dunes (St). Periodic high-velocity flow resulted in development of upper flow regime plane beds (Sh). Minor episodes of flood plain inundation gave rise to finely laminated sand and mud (Fl). These findings differ from previous interpretations of Higham deposition as a coalescing alluvial fan complex.

Pebble size and paleocurrent analysis of medium scale trough and planar-tabular crossbeds denote an overall north to northwest paleoflow direction. Petrographic data indicate erosion of a plutonic/metamorphic source terrain, probably associated with the relict Uncompahgre and/or Front Range components of the Late Paleozoic Ancestral Rocky Mountains uplift. Deposition of Higham detritus thus occurred as a sheet sandstone deposit at a distance (as much as 500 km) from the sediment source which is comparable with the modern South Saskatchewan and Platte Rivers.

INTRODUCTION AND PURPOSE OF STUDY

The Late Triassic Higham Grit is a medium to coarse grained gravelly quartz sandstone and gravel conglomerate which crops out in the thrust belt of southeastern Idaho and western Wyoming (Fig. 1). The Higham Grit was deposited as a relatively thin (9-150 m) blanket over a minimum area of 5000 square kilometers in what is now south central Idaho. Mansfield (1916, 1927) and Kummel (1953) give general descriptions and interpretations of the depositional environment of the Higham Grit, but no detailed petrographic or sedimentologic work has been done previous to this study.

Previous investigations of the Higham Grit postulate a source area to the west of the Idaho-Wyoming thrust belt. Westward coarsening and thickening of the Higham Grit has been used to support interpretations of deposition by a series of coalescing alluvial fans originating from an uplift in central Idaho (Mansfield 1927). Oriel (in McKee, 1959) and Rubey (1955) cite lithologic and faunal evidence for a mountain chain separating western Idaho from eastern Idaho during the Late Triassic. Armstrong and Oriel (1965, p. 1853) interpret deposition of the Higham Grit to represent initiation of the breakup of the Cordilleran miogeosyncline. Thus, the Higham Grit could represent detritus shed from incipient uplifts associated with onset of the Sevier orogeny or from some other poorly documented Late Triassic orogenic event. However, Wiltschko

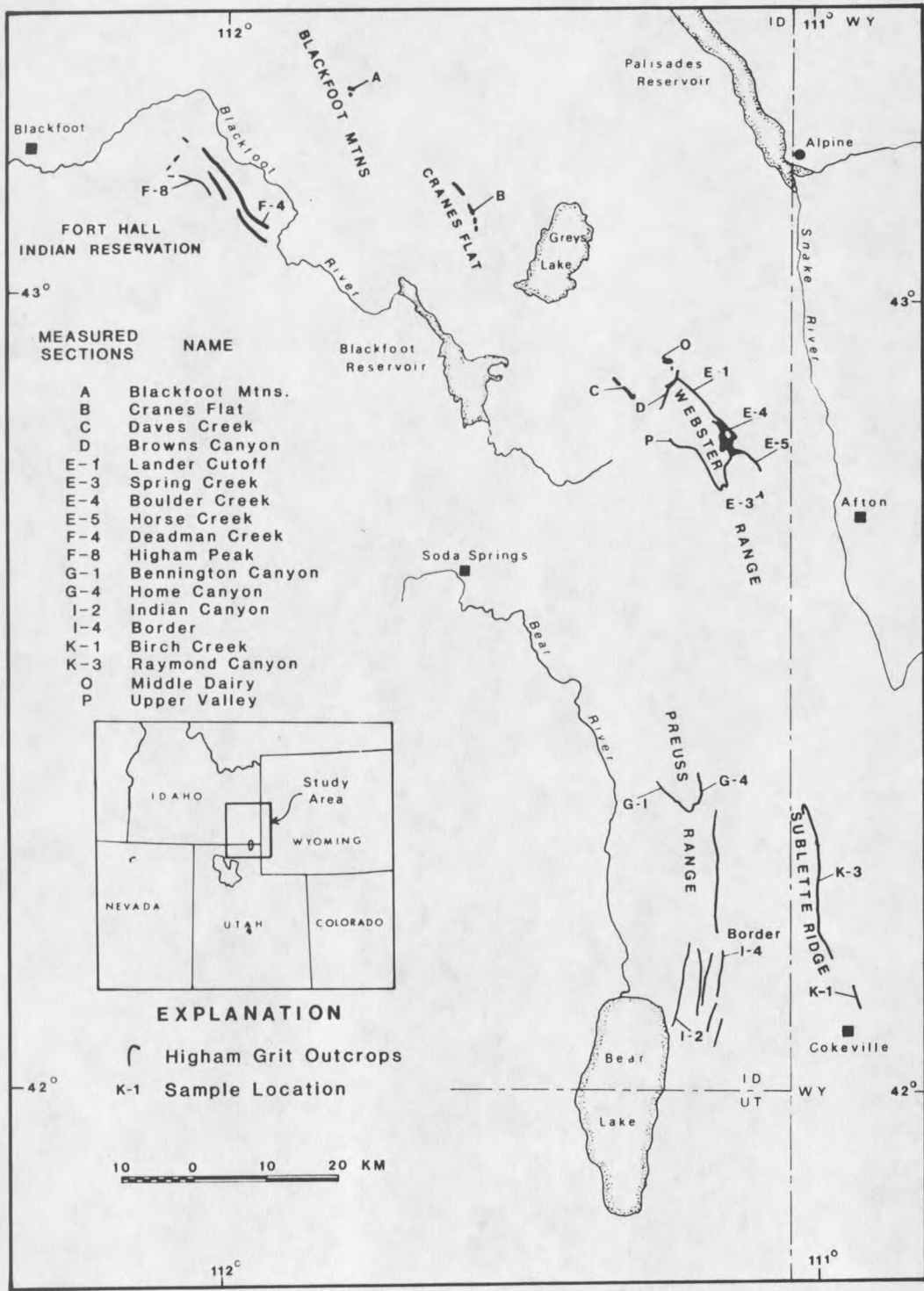


Figure 1. Location of Higham Grit outcrops and measured sections.

and Dorr (1983, p. 1309) note that "neither the specific cause of the uplift nor the exact location of the source area for the Higham Grit is yet well established."

Possible causes of Late Triassic tectonic activity and uplift of the source area for the Higham Grit can be interpreted from recent plate tectonic models of the tectonic evolution of the western Cordillera. Current models postulate the accretion of a microplate (Sonoma) in the early to middle Triassic to the passive western margin of North America (Speed, 1977,1979; Hamilton, 1978; Schweikert and Snyder, 1981). An accretionary wedge of ocean floor strata in front of Sonoma was thrust westward over the continental slope creating the Golconda Allochthon (Speed, 1979). In the latter half of the Triassic, after the Sonoman orogeny, additional packages of rocks containing Mississippian to Upper Triassic chert, argillite, carbonates, greenstone, and Alpine type ultramafic rock were accreted to the western edge on North America (Davis and others, 1978). A volcanic arc then developed on the western edge of North America as a result of eastward subduction of oceanic crust, resulting in Late Triassic arc magmatism extending into the continent (Burchfiel and Davis, 1975; Davis and others, 1978; Hamilton, 1978; Burchfiel, 1981; Dickinson, 1981). It is possible that uplifts associated with the accretion of these terranes is the provenance of the Higham Grit. Figure 2 shows the general regional tectonic setting, sediment transport directions and sediment thickness of the Late Triassic.

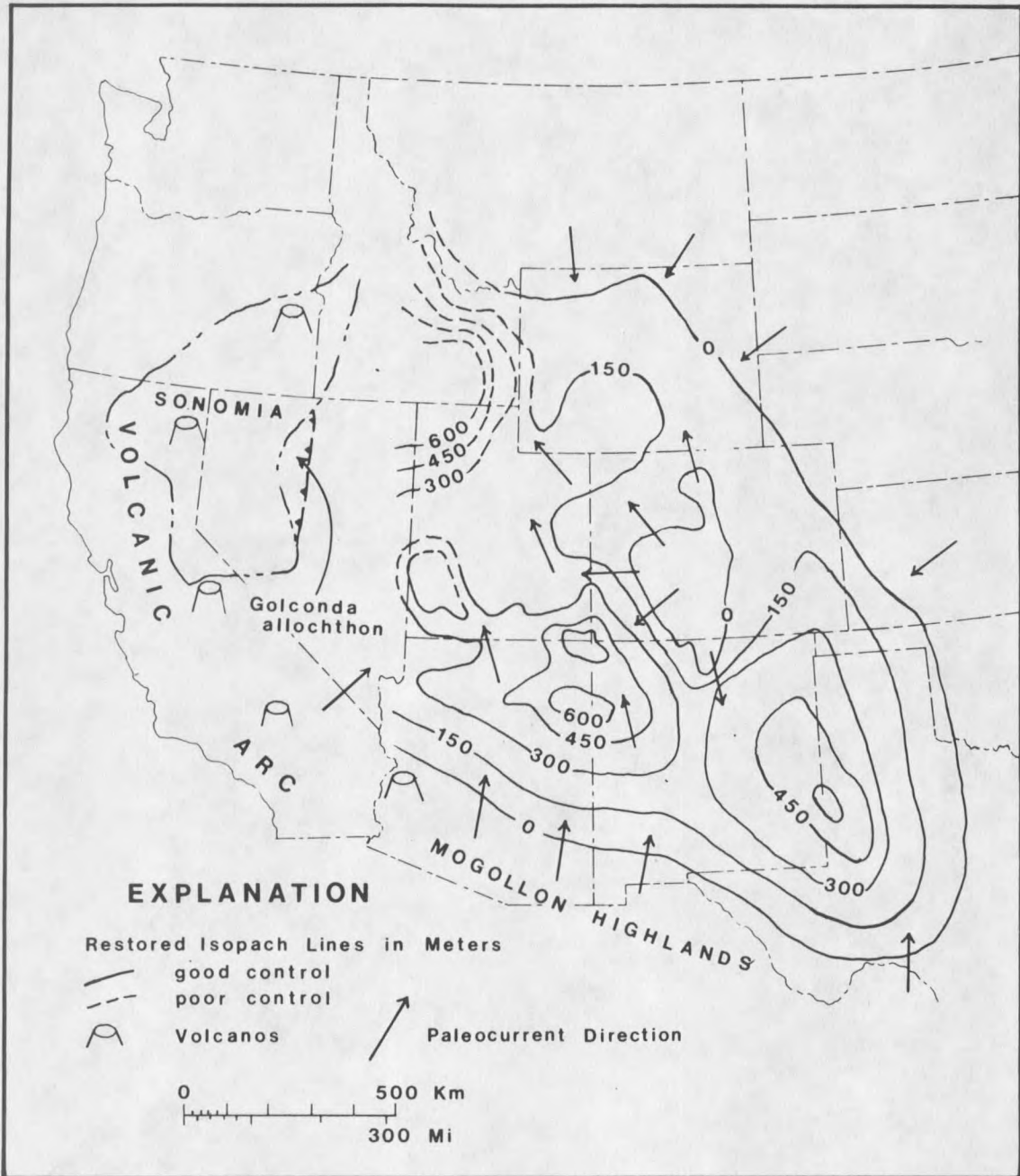


Figure 2. Generalized regional tectonic setting, sediment transport directions, and isopach map of Late Triassic sedimentation, western United States (modified from McKee, 1959; Speed, 1979; and Dickinson, 1981).

The approach taken in this study is to apply modern lithofacies analysis and sedimentary petrographic techniques to the Higham Grit in order to determine its sedimentology and provenance. More specifically, questions to be addressed include: 1) What depositional environments played a roll in Higham accumulation?, 2) What is the composition of Higham detritus?, 3) In which direction(s) was the Higham detritus transported?, and 4) Does the Higham represent an initial synorogenic deposit within the Sevier foreland basin sedimentary sequence, or can it be related to orogenic activity of a different nature elsewhere in the region?

METHODS

FIELD METHODS

Detailed stratigraphic sections within the Higham Grit were measured and described at 18 localities in southeastern Idaho and western Wyoming (Fig. 1). Lithofacies present in each were classified using the terminology of Miall (1977). Approximately 700 crossbed orientations were measured throughout the study area. Both trough and planar crossbeds were utilized. In addition, the size of the largest 20 to 30 gravel-sized clasts was measured at each measured section.

LABORATORY METHODS

Correction for tectonic tilt ranging from 5 to 90 degrees was required for all of the crossbed measurements. Vector orientation and magnitude (consistency factor) were calculated according to Carver (1977) and Curray (1956). When right and left limbs of trough crossbeds were differentiated, plots using the technique described by DeCelles and Langford (1983) were made to determine the average trough axis orientation.

A total of 58 thin sections were prepared from representative lithologic samples for study with the petrographic microscope. All thin sections were stained for potassium feldspar. An average of 320 points were counted per thin section. Modal size (Appendix 1) was visually estimated for most samples from thin section and by examination of the samples with a binocular microscope. Grain size

of six samples was determined by measuring 250 points in thin section. Five samples were disaggregated by hand and sieved. No conversion of the modal size estimated from thin section to sieve modal sizes (as determined by Friedman, 1958) was made because of the relatively small difference this would make in the grain size classification of the samples.

PALINSPASTIC RESTORATIONS

All outcrops of the Higham Grit are located in the fold and thrust belt of Wyoming, Idaho, and northeastern Utah (Fig. 3). The most extensive outcrop trends occur in the Crawford and Meade thrust allochthons. Thrusting has transported these strata many kilometers east of their original site of deposition. Also, the northernmost outcrops of Higham may have been rotated in a counterclockwise direction as a result of thrust belt impingement with the ancestral Teton-Gros Ventre foreland uplift, (Grubbs and Van der Voo, 1976). Accurate paleogeographic placement of Higham outcrops relative to other Late Triassic tectonic features requires palinspastic restoration of the thrust sheets. To accomplish this, seven cross sections from Dixon (1982) were restored utilizing his film overlay method. The restored positions of Higham outcrops given by this method are 100 to 150 km west of their present locations (Fig. 3). Thus thrusting has produced shortening on the order of 40 to 65% in the area.

The accuracy of any such restoration is dependent upon the correctness of the original cross sections. The cross sections of the thrust belt used represent the best available at this time.

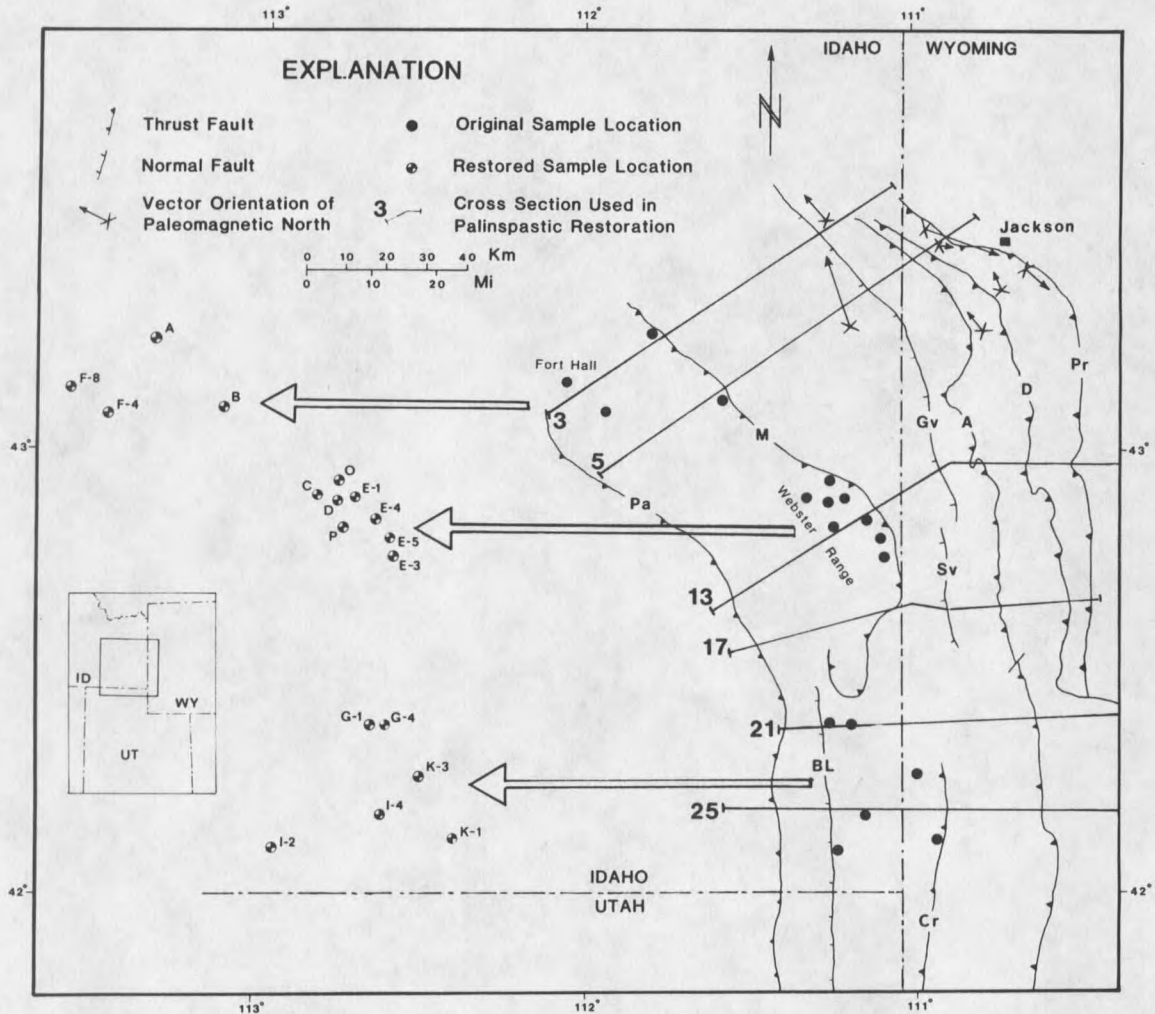


Figure 3. Palinspastic restoration of thrusts in study area. Cross sections used in palinspastic restoration are from Dixon (1982). Vector orientations of paleomagnetic north are from Grubbs and Van Der Voo (1976). Large arrows show general movement of sample locations due to palinspastic restoration. Faults shown are: Pa, Paris thrust; M, Meade thrust; BL, Bear Lake fault; Cr, Crawford thrust; Sv, Star Valley fault; Gv, Grand Valley fault; A, Absaroka thrust; D, Darby thrust; Pr, Prospect thrust;

However, several problems with the palinspastic restoration process require that the restored positions of the outcrops be considered only as approximations. For example, curvature of the northern part of the thrust belt (Fig. 3) causes a basic problem in "pulling" the thrust sheets westward. In order to balance the cross section, it must be drawn perpendicular to the strike of the thrusts. In this case, if the sections in the north end of the thrust belt are restored with their east end fixed, an unrealistic situation results. For example, restored outcrop locations from the Webster Range are superimposed upon restored locations of outcrops in the Fort Hall Indian Reservation. To avoid this superposition of outcrops, it is assumed that the major component of tectonic transport of the thrust sheets was due east. It is also assumed that displacement of rocks in the northern part of the thrust belt was approximately equal to the "east-west" component of the total restoration distance, as determined from the cross-sections. Because these assumptions are only approximations, only an approximate original position of outcrops can be determined. Nonetheless, the restored positions of outcrops are probably much closer to their original position than are their present locations.

Another problem associated with outcrops in the northern part of the area is the possibility that they have been rotated. Paleomagnetic studies by Grubbs and Van der Voo (1976) show that rocks in the hanging wall of the Absaroka, Darby, and Hogsback thrusts were tectonically rotated counterclockwise within a horizontal plane. In these thrust sheets, rotation probably occurred

because of impingement of the thrust sheets upon basement involved foreland uplifts of the Teton-Gros Ventre block. Figure 2 shows the present direction of paleomagnetic north in late Triassic red beds as determined by Grubbs and Van der Voo (1976). They indicate that paleomagnetic north in the rocks has been rotated to a position that is approximately parallel to the trace of thrust faults.

Because no paleomagnetic work has been done on formations in thrust sheets further to the west, there exists the possibility that outcrops in the hanging wall of the Crawford thrust were either: 1) rotated to a position similar to those in the later and more eastern Absaroka, Darby, and Hogsback thrusts, 2) not rotated because the Crawford thrust was not directly impinging upon basement uplifts to the east, or 3) were rotated some intermediate amount. Conceivably, resultant paleocurrent vector azimuths in the northern part of the study area could have been rotated a maximum of 45 degrees in a clockwise direction. Either rotated or non-rotated paleocurrent azimuths in this area are possibilities at the present time. Paleocurrent data gathered in this study are presented herein in their non-rotated positions.

STRATIGRAPHY

HISTORY OF INVESTIGATIONS

The first description of the Higham Grit was published by Mansfield (1916, 1920) after geologic investigations on the Fort Hall Indian Reservation, Idaho. He named the formation for Higham Peak on which the Higham Grit is well exposed as a resistant ridge. Mansfield differentiated the Timothy Sandstone, Higham Grit, Deadman Limestone, Wood Shale, and Nugget Sandstone from rocks previously assigned to the Nugget Formation by Gale and Richards (1910). These formations lie above the lower Triassic Thaynes Limestone and below the Jurassic Twin Creek Limestone (Fig 4). All except the Timothy Sandstone were tentatively placed by Mansfield in the Upper Triassic (Mansfield, 1927). However, no fossils were found to support a Late Triassic age for the units. Additional mapping by Mansfield (1927) delineated further outcrops of the Higham Grit in southeastern Idaho and western Wyoming.

Williams (1945) correlated the Higham Grit from Indian, Home, and Montpelier Canyons in the Preuss Range of southeastern Idaho with a lithologically similar sandstone and conglomerate present in the Ankareh Formation of northeastern Utah. This grit, extending eastward into Colorado, was thought to correlate with the Shinarump Conglomerate of the Colorado Plateau (Williams, 1945). Thomas and Krueger (1946) named this sandstone and

		Southeastern Idaho				Western Wyoming	Southeastern Utah		Central Wyoming			
		Gale and Richards (1910)	Ft. Hall Mansfield (1927)	Grays Range Kummel (1954)	East of Bear Lake Kummel (1954)	Cokeville Kummel (1954)	Central Wasatch Kummel (1954)	Brush Creek Stewart & others (1972)	High and Picard (1969)			
Jurassic	Twin Creek Limestone											
	Hugget Sandstone											
Upper Triassic	Nugget Sandstone	Wood Shale Tongue Ankareh Formation				Ankareh Formation	Ankareh Formation	Stanaker Member	Upper Member	Chugwater Group	Popo Agie Formation	
		Deadman Limestone							Ocher Siltstone Mbr.		Jelm Formation	
		Higham Grit							Gartra Member		Mottled Member	Gartra Member
		Timothy Sandstone Member							Mahogany Member		Moenkopi Formation	
Lower Triassic	Ankareh Sandstone	Portneuf Limestone Member										

Figure 4. Correlation chart of Triassic and lower Jurassic formations, southeastern Idaho, northeastern Utah, and western Wyoming (modified from Kummel, 1954).

conglomerate unit the Gartra Grit member of the Stanaker Formation. Regional stratigraphic work has shown that the Gartra occurs only in the northern and northeastern parts of the Colorado Plateau (Poole and Stewart, 1964; Stewart and others, 1972). Thus, the Gartra Grit is not laterally continuous with the Shinarump Member of the Chinle Formation, which does not extend north of central Utah (Stewart, 1957, Stewart and others, 1972).

Kummel (1954) described the Higham in the Preuss and Webster Ranges and at Sublette Ridge. After regional stratigraphic on the

Triassic in Idaho, he concludes that the Higham Grit is probably equivalent to the Gartra Grit (Kummel 1953, p. 179). Kummel subdivided the Ankareh Formation, previously named by Boutwell (1907), into the Mahogany, Gartra, and Stanaker members. Oriel (in McKee, 1959) thought the Gartra and Higham not related because of the higher percentage of feldspar in the Gartra Grit.

REGIONAL STRATIGRAPHY

Regional stratigraphic relations of the Higham Grit and associated formations are shown in figure 5. Analysis of underlying and overlying formations and their depositional environments allow a generalized interpretation of the regional changes in Late Triassic paleogeography that occurred in the area of Higham Deposition. This information is also helpful in understanding the regional tectonic factors influencing deposition of the Higham Grit.

The Timothy Sandstone underlies the Higham Grit in all of the sections examined except for Sublette Ridge in the southeast part of the study area. Mansfield (1927) measured up to 270 m of fine grained arkosic Timothy Sandstone at the Fort Hall Indian Reservation and interpreted it as a possible beach deposit. The Timothy thins to the east and south and pinches out in western Wyoming (Kummel, 1953). Pinchout of the Timothy Sandstone is evidence of an unconformity at the base of the Higham (Mansfield, 1927; Kummel, 1953). The unconformity at the base of the Higham is one of the most widespread and conspicuous unconformities of Triassic and Jurassic time and was designated the Tr-3 unconformity by Pipringos and O'Sullivan (1978). This unconformity is found

throughout the Colorado Plateau where the hiatus separates the underlying Moenkopi Formation from the Shinarump Member of the Chinle Formation. In northwestern Colorado and northeastern Utah the unconformity underlies the Gartra Grit member of the Ankaresh or Chinle Formation. The Tr-3 unconformity also extends into western Wyoming where it was placed within the Jelm and Crow Mountain Formations by Pipringos and O'Sullivan (1978).

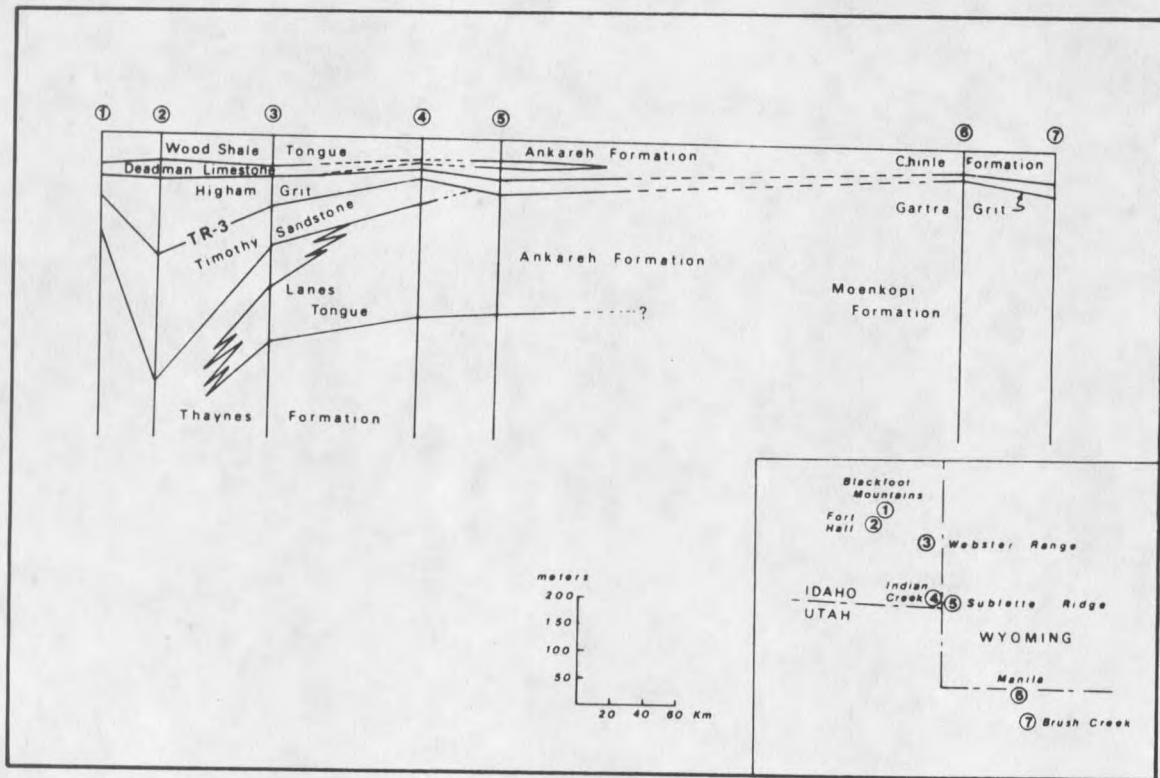


Figure 5. Regional stratigraphy of the Higham Grit and related formations (after Mansfield, 1927, and Kummel, 1953).

By regional extension, the Tr-3 unconformity must be located in the Ankareh Formation of western Wyoming where the Higham and possibly the Gartra Grit thin, become discontinuous, and do not constitute mappable units (W. W. Rubey, 1958; Oriel, 1969). At Sublette Ridge the Higham Grit occurs as a tongue entirely within the Ankareh Formation. The upper contact of the Higham in the Pruess Range and at Indian Creek is gradational with the Ankareh while the underlying Timothy Sandstone is lithologically similar to the Lower Ankareh Formation of northern Utah (Kummel, 1954). The Ankareh Formation is a sandy, calcareous mudstone and sandstone redbed sequence with occasional beds of dense limestone. The Ankareh also contains numerous carbonaceous sandstone beds and abundant mudstone and limestone rip up clast conglomerates and desiccation structures. In southeastern Idaho and western Wyoming the Ankareh represents either lagoonal (Mansfield, 1927, p. 191) or overbank fluvial (High and Picard, 1969) deposits of a basin separated from the open sea. The Ankareh Formation is equivalent to the Jelm and Popo Agie Formations of central Wyoming, which are fluvial and fluvial-lacustrine in origin (High and Picard, 1969). The Mahogany Member of the Ankareh Formation of northcentral Utah (Stewart, 1972) must grade into the red bed sediments of the Lower Ankareh Formation (Mahogany Member of the Ankareh Formation) of southeastern Idaho and western Wyoming.

The Deadman Limestone directly overlies the Higham Grit in the Fort Hall and Webster Range areas. At the Southern Blackfoot Mountains and in the Preuss Range, red mudstones and sandstones, lithologically similar to those of the Ankareh Formation are

located between the Higham and Deadman Formations. The Deadman Limestone is thought to represent a lacustrine limestone (Mansfield, 1927). Rubey (1958, 1973), Oriel (1969), and Rubey and others, (1975, 1980) describe discontinuous limestone beds within the Ankareh Formation in west-central Wyoming thought to be related to the Deadman Limestone. Thin limestone and limestone pebble conglomerate beds are present in the Ankareh Formation in the Gros Ventre Range, Teton Pass area, and Snake River Range (Wanless and others, 1955, p. 46). A limestone pebble conglomerate is also present in the Ankareh in the Salt River Range of western Wyoming (Lageson, 1980). At Manila, Utah, the Gartra Grit contains abundant limestone and mudstone pebble conglomerate. These conglomerate beds appear to be intraformational rip-up clast conglomerates.

INTERPRETATION

Interpretations of the depositional environments of lithofacies associated with the Higham Grit indicate a transition in the Late Triassic from marine dominated sedimentation to continental dominated sedimentation (Kummel, 1953). The Higham Grit has been interpreted to represent the first continental deposit in this transition (Kummel, 1953). A regional isopach map of late Triassic sediment in the western United States (Fig. 2) indicates three depositional basins. The northernmost basin is located in southeast Idaho and northwestern Utah. The thickening of the basinal deposits in a northwestward direction generally corresponds to thickening of the Higham Grit in this direction (Table 1).

Mansfield (1927, p.190) states that the source of the Higham Grit was probably to the west. His reasons for this include thickening of the Higham from 60 m in the Pruess Range to 150 m at Fort Hall to the west. Mansfield also states that the Higham coarsens to the west and that Triassic sediments up to 6000 m in thickness were reported by King (1878) in the western Humboldt Range of Nevada. According to Mansfield, these facts indicate the presence of a Late Triassic mountain range to the west which was the source of the Higham Grit.

SECTION NO.	DESCRIPTION	LOCATION	THICKNESS (m)	PEBBLE SIZE (cm) ^a	TOTAL CROSSBEDDING			TROUGH CROSSBEDDING		
					Azimuth	C. F.	N	Azimuth	C.F.	N
A	Blackfoot Mtns.	SE 12, T2S, R39E, ID	31	2.4	98	.48	4	-	-	-
B	Cranes Flat	NW 35, T3S, R41E, ID	52	3.5	300	.59	37	300	.59	37
C	Daves Creek	NE 19, T3S, R44E, ID	60	3.5	199	.14	74	-	-	-
D	Browns Canyon	SW 14, T6S, R44E, ID	60	3.1	234	.64	31	-	-	-
E-1	Lander Cutoff	SE 19, T6S, R45E, ID	40	4.0	233	.29	153	-	-	-
E-3	Spring Creek	NW 5, T8S, R46E, ID	17	-	270	.63	35	270	.63	35
E-4	Boulder Creek	NW 2, T7S, R45E, ID	60	2.9	301	.40	50	333	.57	35
E-5	Horse Creek	SE 19, T7S, R46E, ID	60	3.6	242	.58	22	-	-	-
F-1	Deadman Creek	SW 12, T4S, R38E, ID	107	2.6	275	.28	73	303	.57	35
F-8	Higham Peak	SE 23, T3S, R37E, ID	120	2.0	283	.16	47	300	.32	12
G-1	Bennington Canyon	NW 21, T12S, R44E, ID	-	-	-	-	-	-	-	-
G-4	Home Canyon	NW 21, T12S, R45E, ID	9	-	218	.20	16	163	.30	11
I-2	Indian Canyon	NW 30, T15S, R45E, ID	18	-	85	.56	15	85	.56	15
I-4	Border	NW 26, T14S, R45E, ID	35	-	-	-	-	-	-	-
K-1	Birch Creek	NW 26, T25N, R119W, WY	32	3.2	29	.17	62	18	.10	47
K-3	Raymond Canyon	NW 32, T27N, R119W, WY	12	3.8	323	.92	29	319	.93	19
O	Middle Dairy	SW 29, T5S, R44E, ID	60	2.8	191	.20	15	-	-	-
P	Upper Valley	NW 12, T7S, R44E, ID	54	2.4	278	.44	31	-	-	-

a - Pebble size is the average of the ten longest axes at each location

Table 1. Location, thickness, pebble size, and paleocurrent data for Higham Grit sample locations and measured sections

LITHOFACIES

Lithofacies, as defined by Miall (1977), present in the Higham Grit include: massive to crudely horizontally bedded pebbly gravel (Gm), crudely to well defined trough crossbedded sand and pebbly sand (St), planar crossbedded sand (Sp), horizontally stratified sand (Sh), ripple crosslaminated sand (Sr), and finely laminated mudstone (Fl). The most common lithofacies present in most sections of Higham Grit is trough crossbedded sand. Planar crossbedded sand, and horizontally stratified sand vary in relative abundance both laterally and vertically in the sandstone deposits. Pebbly gravel, ripple crosslaminated sand and finely laminated mudstone, are present in limited quantities in most of the sections examined.

After examining sections of the Higham Grit, a braided stream depositional environment is thought probable for a variety of reasons. Facies associated with the Higham Grit and known paleogeography indicate a transition from marine to continental type deposition in the Late Triassic (Kummel, 1953; McKee, 1959). No shell debris, trace fossils, or bioturbation of Higham Grit sediments was found in the studied sections which would indicate a beach, deltaic, or shallow marine environment. Lagoonal, washover fan, or gently dipping parallel laminated facies also associated with beach and offshore bar sandstones also were not found in the Higham sandstones. In addition, facies typical of meandering fluvial systems such as typical point bar sequences (Reading, 1978),

lateral accretion surfaces, clay plugs, and extensive mudstone deposits were not found in the Higham Grit sediments. All of the above evidence indicates that another type of depositional environment was responsible for the Higham deposits. Comparison of lithofacies found in the Higham Grit with those found in modern sand dominated braided stream systems illustrates the striking similarity of the Higham deposits with modern braided stream deposits and allows interpretation of bedform types that existed in the Higham stream system.

PEBBLY GRAVEL (Gm)

Beds of massive to crudely horizontally bedded pebbly gravel (Fig. 6) are found in all sections of the Higham Grit examined except at locations in the Preuss Range, which do not contain gravel sized clasts. Gravel beds range from a single clast in thickness to a maximum of 0.4 m thick. Most thick gravel beds are clast supported with a sand matrix. Gravel clasts are generally composed of rounded to subrounded quartz and range in size from granules to pebbles (4 - 76 mm). The visually estimated average size of gravel in all the gravel beds is between 15 and 25 mm. Gravel beds are generally very planar in nature and, in some locations, a single gravel layer could be traced for over fifty meters parallel to bedding. Gravel beds generally comprise less than 5% of the total volume of Higham sediment.

INTERPRETATION

Gravel beds similar to the ones found in the Higham Grit have been interpreted as channel lag deposits by numerous authors (Reineck and Singh, 1973; Cant and Walker, 1978; Reading, 1978; and Miall, 1978). Smith (1977, p. 2994) interprets gravel beds to represent the initial bedload deposition that typically results in aggradation of longitudinal bars. Some of the thicker gravel lenses may represent longitudinal bar deposits when there was enough gravel size sediment available for development of these bedforms. Deposition by upper flow regime plane bed flow is indicated by the planar nature of the gravel beds.

TROUGH CROSSBEDDED SAND (St)

The trough crossbedded sandstone facies is the most prevalent lithofacies found in the study area. Crude and well defined trough crossbedded sand (Fig. 7) occurs within thin to very thick beds (3.0 cm to 1.5 m). Medium and large scale (0.2 to 0.5 m) crossbed sets are most common. Troughs vary from 0.5 to 2.0 m wide. Cosets of 2-10 trough crossbedded sets are common in most of the Higham outcrops. This facies is composed predominantly of medium to very coarse grained, moderately sorted sand. Isolated, rounded to subrounded gravel sized clasts are commonly found in the sandstone.

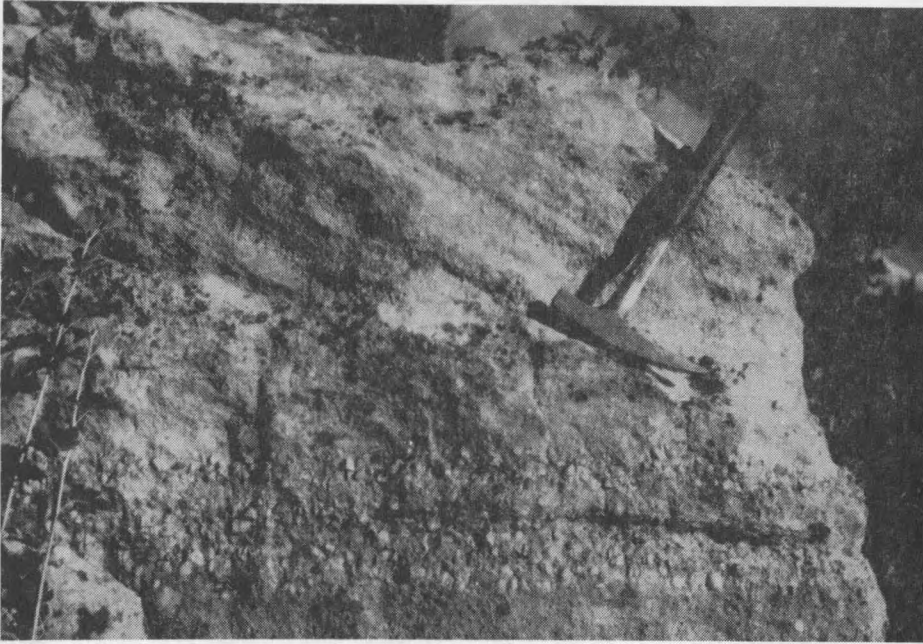


Figure 6. Pebbly gravel bed (Gm) overlain by planar crossbedded sand (Sp) lithofacies. (Horse Creek Section)



Figure 7. Trough crossbedded sand (St) lithofacies, note solitary pebble at left. (Daves Creek Section)

INTERPRETATION

Trough crossbedded sand and gravelly trough crossbedded sand were likely deposited by lower flow regime solitary or coalesced dunes as described by Harms and Fahnestock (1965), Smith (1970), Miall (1977), and Cant and Walker (1978). Dunes of various sizes are commonly found in channels and on transverse and linguoid bars in modern braided rivers (Smith, 1970; Collinson, 1970; Cant and Walker, 1978). Dunes occur under a variety of flow conditions (Cant, 1978) and can range in height from 0.05 m to 10.0 m (Leeder, 1982). The abundance of trough crossbedded sand in the Higham deposits indicate that dunes were a prevalent bedform in the Higham fluvial system. Occasional lag clasts were picked up and deposited on foresets of the migrating dunes resulting in the pebbly sandstone common in this lithofacies.

PLANAR CROSSBEDDED SAND (Sp)

Thin to thick bedded (0.02 - 0.7 m) planar crossbedded sand (Fig. 8) is present at most locations in the study area. Beds average 0.3 m in thickness and occur singly and in cosets of up to six individual planar sets. This facies consists of moderately sorted, medium to very coarse grained sand with occasional pebbles and occurs as planar tabular crossbedded sets with wedge planar sets also present. Alternating coarse and fine layers are present in the foreset beds. The lateral extent of planar crossbedded sets and cosets is variable but some extend a minimum of 50 to 100 m along strike.

INTERPRETATION

The origin of planar crossbedding has been detailed by numerous authors in studies of modern braided rivers (Ore, 1964; Harms and Fahnstock, 1965; Smith, 1972; Collinson, 1970, Cant and Walker, 1978). The primary means of its formation is accretion of foresets along the downstream margins of transverse bars or sinuous crested transverse bars (linguoid bars). Smith (1972) described transverse bars as "large solitary or repetitive tabular forms with wide flat tops and irregular to lobate crestlines". Continuous slipfaces of more than 200 m were observed by Smith (1972) in the Platte River. Collinson (1970) describes linguoid bars in the Tana River which are very similar to the longitudinal bars in the Platte described by Smith (1970). The planar crossbeds of the Higham are interpreted to have been deposited by this type of bedform. Alternating coarse and fine layers in foreset beds result from alternation of coarse and fine grained sediment in dunes avalanching down the face of a transverse or linguoid bar. Smith (1972) describes this process in detail.

HORIZONTALLY STRATIFIED SAND (Sh)

Thinly bedded (1.0 cm - 10 cm) horizontally stratified sand (Fig. 9) is found in most Higham outcrops examined. This facies is composed of fine to very coarse sand with normally graded bedding (Fig. 10) common. Thickness of this lithofacies varies from several centimeters to as much as a meter.

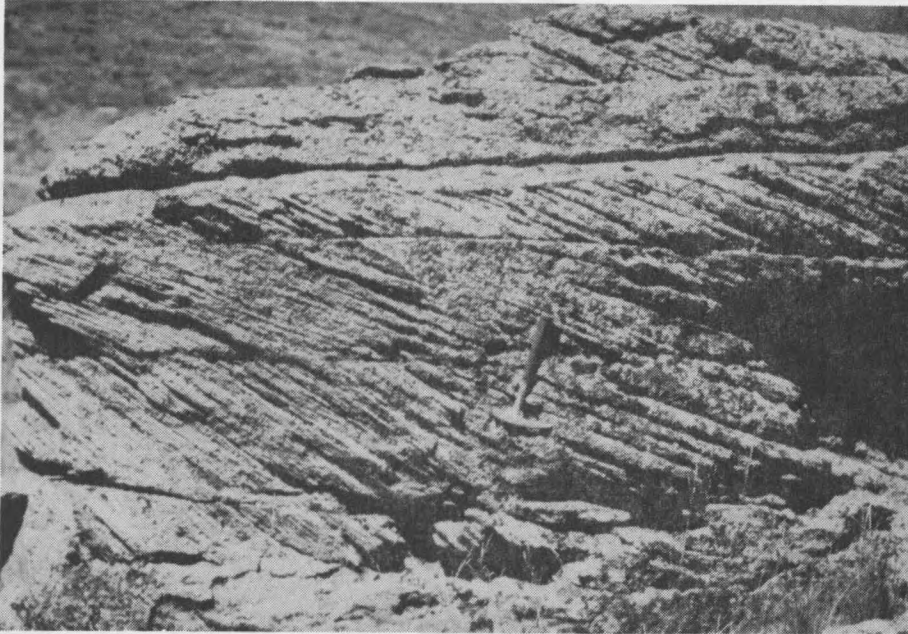


Figure 8. Coset of six planar tabular crossbedded sand (Sp) sets. (Higham Peak Section)

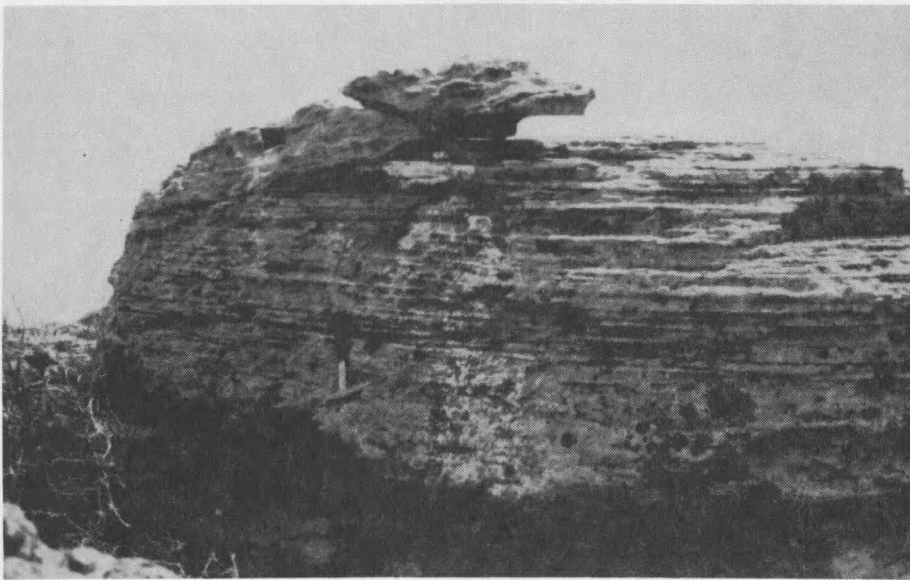


Figure 9. Horizontally stratified sand (Sh) with trough crossbedded sand (St) filling erosional scour. (Higham Peak Section)

INTERPRETATION

Miall (1977) interprets the horizontally laminated sand facies to result from planar flow of either upper or lower flow regime. Harms and others (1982) also describe horizontally laminated beds as originating from either upper or lower flow regime flow. Harms and others (1982, p. 3-26) noted that for sediment coarser than 0.5 mm and a low current velocity, lower flow regime plane beds are the stable bed configuration. Smith (1970) described horizontally bedded sand occurring in longitudinal bars in the South Platte river. The beds of horizontally laminated sand in the Higham could represent deposits from either upper or lower flow regime planebeds.

RIPPLE CROSSLAMINATED SAND (Sr)

Ripple crosslaminated sand (Fig. 11) occurs as thin to very thin (0.5 - 4.0 cm) beds in the Higham. This lithofacies is composed of very-fine to medium grained sand. Mud content varies from almost none to 43% in some samples. Climbing ripple crosslamination is also present. A continuous transition from this lithofacies to finely laminated sand and mud (F1) lithofacies occurs in at least one location. This lithofacies occurs in finer grained and better sorted sand than the trough cross-stratified sand (St) lithofacies.

INTERPRETATION

Ripple crosslaminated sand is deposited by lower flow regime ripples (Harms and Fahnstock, 1965; Mial, 1978). This lithofacies probably represents deposits which accumulated during waning flow in shallow channels or on the tops of transverse bars (Smith, 1970).



Figure 10. Normally graded bedding in horizontally stratified pebbly sand. (Daves Creek Section)

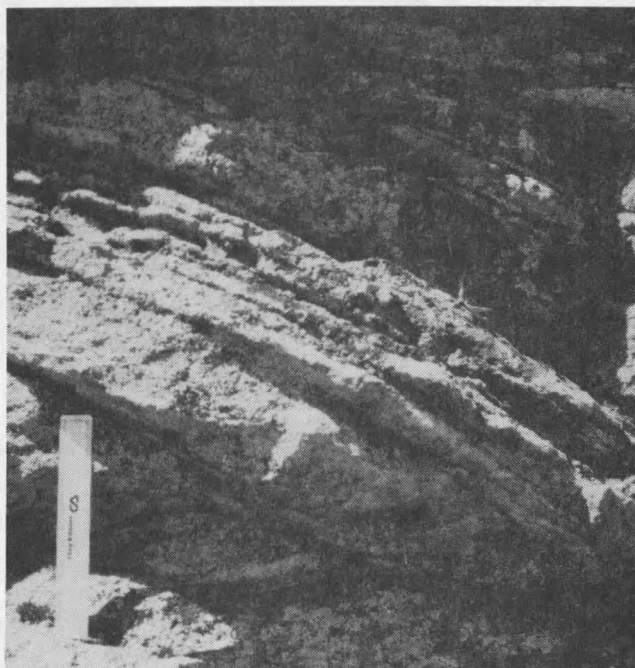


Figure 11. Ripple crosslaminated sand (Sr) located below planar crossbedded sand (Sp). Ruler is 15 cm long. (Higham Peak Section)

FINELY LAMINATED SAND AND MUD (F1)

Finely laminated sand and mud (Fig. 12) is very poorly exposed at most locations. Thickness of this lithofacies varies from 0.5 - 2.0 m. Composition is highly variable from sand to mud. Color varies from red to purple, mottled or varicolored and most occurrences would be classified as a sandy mudstone. This lithofacies is transitional upward from the ripple crosslaminated (Sr) lithofacies.

INTERPRETATION

Finely laminated sand and mud lithofacies probably represent vertical accretion deposits of overbank or waning flood flow conditions (Miall, 1978). This is indicated by the finer grain size and transition upward from ripple crosslaminated sand (Sr) lithofacies. Many modern braided stream floodplains contain abandoned areas which are covered by standing water during highest flood flows. Deposition typically occurs as settling from standing water or by low velocity currents (Miall, 1978).



Figure 12. Thinly interbedded and ripple crosslaminated very fine sand and mud (F1). Long bed is approximately 5 cm thick. (Daves Creek Section)

FACIES MODEL

Lithofacies types, sequences of lithofacies, and the relative abundance of lithofacies in the Higham Grit strongly correlate with the deposits of modern braided streams. Because of this, vertical profiles from the Higham were compared with the vertical profile models of braided stream deposits presented by Miall (1978) in order to select an appropriate depositional model. The South Saskatchewan and Platte River models of Miall (1978) compare most closely with the Higham deposits. Comparison of lithofacies and sequences of lithofacies of the models with those of the Higham Grit will illustrate the similarities and differences of the Higham deposits with the models.

COMPARISON OF LITHOFACIES

Channels in the South Saskatchewan River have abundant sinuous crested dunes, with the larger ones located in the deeper channels (Cant and Walker, 1978). Trenching shows that these dunes are composed of trough cross stratified sand (St). Trough crossbedded sand (St) is the most abundant lithofacies present in the Higham Grit, and likely represents dune deposits.

Large (0.5 - 2.0 m) and small (0.3 - 0.5 m) planar crossbedding occurs in transverse bars in the South Saskatchewan River (Cant and Walker, 1978). Transverse bars in the Platte River (Smith, 1970) are composed of planar crossbedded sand cosets. Cosets of planar crossbedded sand (Sp) in the Higham Grit are very similar to those

described by Cant (1978) for the South Saskatchewan River and Smith (1970) for the Platte River.

Horizontally laminated sand beds (Sh) up to 0.4 m thick characterize flood stage deposits in the South Saskatchewan River (Cant and Walker, 1978), and are also found in the Higham Grit. Small scale trough cross-stratified sand (St), small scale planar tabular cross-stratified sand (Sp), ripple cross laminated sand (Sr), and finely laminated sand and mud (Fl) are also common components of sand flats in the South Saskatchewan River (Cant and Walker, 1978). Similar lithofacies have been described above as occurring in the Higham Grit.

COMPARISON OF SEQUENCES OF LITHOFACIES

Miall (1978) describes vertical lithofacies sequences that characterize South Saskatchewan and Platte River (Fig. 13) type deposits. Cant (1978) details three types of vertical lithofacies sequences that are typical of deposits in the South Saskatchewan River. These are the channel, mixed influence, and compound bar or sand flat sequences. The South Saskatchewan facies sequences generally consist of fining upward beds of trough crossbedded dominated lithofacies (channel sequence), planar crossbedded (Sp) and horizontally stratified sand (Sh) dominated lithofacies (sand flat sequence), and mixed trough, planar, and horizontal stratified lithofacies (mixed influence sequence). In most cases the sequences begin with an erosional scour surface, possible channel lag deposits (Gm), and poorly defined large trough crossbedded sand (St). Platte

MODELS OF BRAIDED RIVER DEPOSITS

S. SASKATCHEWAN RIVER MODEL

PLATTE RIVER MODEL

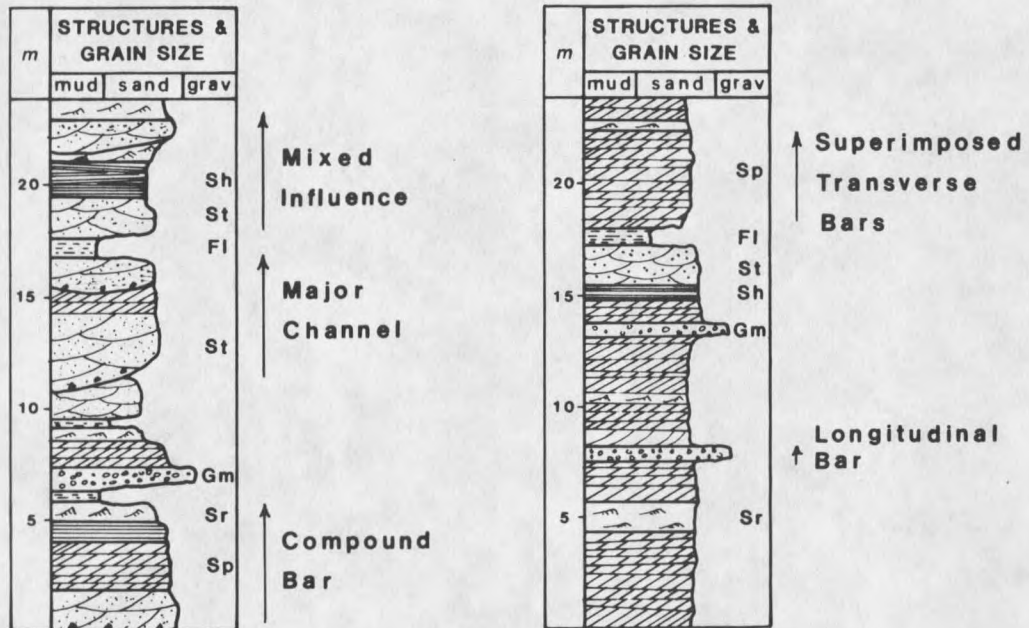


Figure 13. Vertical sequences of lithofacies and their interpretation, South Saskatchewan and Platte type models of braided river deposits (modified from Miall, 1978; and Cant, 1978). Explanation is in figure 14.

River type deposits generally consist of longitudinal bar deposits dominated by pebbly gravel (Gm) and superimposed transverse (linguoid) bar deposits characterized by planar crossbedded sand (Sp). Occasional beds of trough crossbedded sand (St), horizontally laminated sand (Sh), ripple crosslaminated sand (Sr), and fine grained mudstone (Fl) are also present.

Generalized stratigraphic sections from several locations of the Higham Grit are shown in Figure 14. Sequences of lithofacies in the Higham are similar to sequences in both the South Saskatchewan and Platte River models. Sequences within the Higham corresponding to the channel and mixed influence facies sequences of the South Saskatchewan model can be found in all of the Higham sections. Compound bar and longitudinal bar sequences are also present. Superimposed transverse bar sequences of planar tabular crossbedding are common only at the Fort Hall Indian Reservation. Lateral variability of lithofacies type is evident in the Higham outcrops and is also predicted by the models.

Despite the similarity between the Higham Grit and the South Saskatchewan and Platte models, several differences are present. Channel lag deposits composed of mudstone are present in the South Saskatchewan River but were not found in the Higham. Pebbly gravel lag deposits in the Higham Grit consist of quartz pebbles almost entirely. Also, the general decrease in size upward of trough crossbedded sets characteristic of the South Saskatchewan model was not observed in the Higham Grit. The similarity in lithofacies types and sequences of the Higham Grit with models leads to the conclusion that the Higham Grit was deposited in a similar type of stream system.

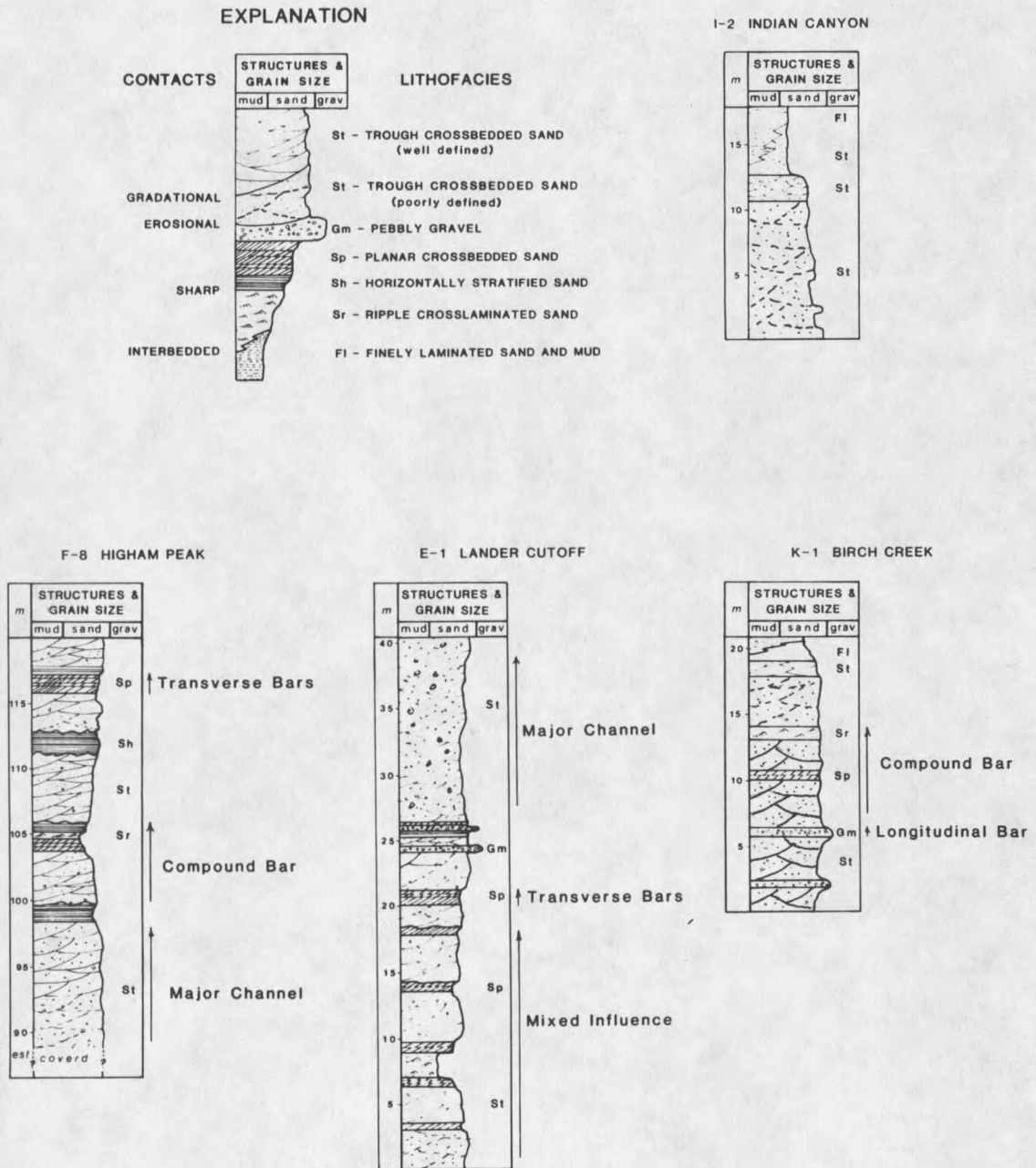


Figure 14. Generalized stratigraphic sections of the Higham Grit.

THICKNESS AND SANDSTONE BODY GEOMETRY

Thickness and sandstone body geometry of the Higham Grit is variable in the study area. Thickness ranges from 9 m to possibly as much as 150 m. Sandstone body geometry varies from broad multistory sheets to multistory ribbons (Blakey and Gubitosa, 1984). Figure 15 illustrates the terminology used to describe the geometry of the sandstone bodies.

SAND BODY TYPES

RIBBONS



SHEETS

Narrow: W/H 15-100

Broad: W/H 100

simple



multistory



Figure 15. Types of sand bodies (from Blakey and Gubitosa, 1984).

DESCRIPTION

Sections of Higham Grit at the Fort Hall Indian Reservation and in the Webster Range contain broad multistory sandstone sheets. Thickness of the sandstone sheets varies from 10 - 30 m with 1 - 2 m thick beds of fine-grained sandstone and mudstone between them. The lower contact of the Higham in these two areas was generally covered, and any local relief that may exist on this unconformity was not discernable. To the south, outcrops of Higham are generally thinner, discontinuous, and more variable in overall geometry. A single sandstone body at Birch Creek varies from 22 m in thickness to 0 m in 100 m along strike. At Raymond Canyon, the Higham Grit is a single 10 - 15 m thick sandstone lens. Sections of Higham at Birch Creek and Raymond Canyon are located within mudrocks of the Ankareh Formation. Deposits at Birch Creek and Raymond Canyon are classified as multistory ribbons and narrow multistory sheets (Fig. 15).

Rubey (1958, 1973), Oriel (1969) and Rubey and others, (1975, 1980) describe a grit in westcentral Wyoming thought to be equivalent to the Higham Grit as discontinuous lenses of quartz sandstone within within the Ankareh Formation. These descriptions of the Higham sediments indicate a ribbon or narrow sheet geometry for the sandstone bodies in this area. Sections at Home, Indian, and Bennington Canyons, and Border are also located within the Ankareh Formation and sandstone body thickness varies from 10 - 18 m. These sections are notable in that they do not contain any gravel size clasts. The sandstone bodies at these locations are tentatively classified as narrow or broad sheets. In the Blackfoot Mountains the

Higham Grit is composed of three layers of coarse to medium grained gravelly sandstone, 1.5 - 8 m in thickness, within a 30 m thick section of red mudstone. These mudstones are similar in nature to the sections of Ankareh examined to the west and south. Higham sandstones at this location are tentatively classified as narrow or broad sheets.

FACTORS CONTROLLING SANDSTONE BODY GEOMETRY - FLUVIAL DEPOSITS

Numerous factors probably controlled the depositional geometry of the Higham Grit. Computer modeling by Bridge and Leeder (1979) found that interconnected sheet sandstone bodies would be expected in stream systems with low flood plain width / channel width ratios, high rates of avulsion, and a slow rate of aggradation (Fig. 16). Friend and others (1979) determined factors that appear to be the most important in controlling lateral migration rates. More rapid lateral migration would produce more interconnected sandstone bodies. A sheet sandstone body would be expected in rivers with: 1) intermediate flow strength and a moderate degree of sinuosity, 2) low bank strength, 3) low flood periodicity and relatively steady stream migration, and 4) no vertical movement of the channel area. Blakey and Gubitosa (1984) relate these studies and propose that the frequency of avulsion/rate of subsidence ratio can be interpreted from the sandstone body geometry. A high ratio will yield broad sheet sandstone deposits and a low ratio will yield ribbon sandstone bodies.

Factors Controlling Depositional
Geometry of Sandstone Bodies

	Sheet Sandstone Bodies	Ribbon Sandston Bodies
<u>Bridge and Leeder, (1979)</u>		
Flood Plain Width/Channel Width	Low	High
Rate of Avulsion	High	Low
Rate of Aggradation	Slow	Fast
<u>Friend and others, (1979)</u>		
Flow Strength	Intermediate	(?)
Sinuosity	Moderate	Low
Bank Strength	Low	High
Flood Periodicity	Low	High
Stream migration	Steady	Irregular
Vertical Movement	None	Uplift
<u>Blakey and Gubitosa, (1984)</u>		
<u>Frequency of Avulsion</u> <u>Rate of Subsidence</u>	High	Low

Figure 16. Factors controlling depositional geometry of sandstone bodies.

FACTORS CONTROLLING SANDSTONE BODY GEOMETRY OF THE HIGHAM GRIT

Sections of Higham Grit in the Webster Range and at Higham Peak indicate that the Higham was deposited with a broad, multistory sheet sandstone body geometry in these areas. This likely resulted from the Higham stream system flowing across a broad alluvial plain with a high frequency of avulsion / rate of subsidence ratio. Numerous reworkings of the detrital sand and gravel winnowed most of

the fines from the sandstone deposits. However, some areas of the alluvial plain were not reworked by channel processes as aggradation progressed. In these areas, waning flood deposits of ripple crosslaminated sandstone (Sr) and finely laminated sandstone and mudstone (F1) were preserved.

The multistory ribbon and narrow, multistory sheet sandstone body geometry of the Higham Grit at Birch Creek and Raymond Canyon indicate a low to intermediate frequency of avulsion / rate of subsidence ratio at these locations. Broad channels carried Higham sediment northward and extensive interchannel and floodplain areas existed where sandstones and mudstones of the Ankareh Formation were deposited.

Deposits of Higham sandstone in the Blackfoot Mountains are interbedded with mudstones and sandstones which appear similar to mudstones and sandstones elsewhere in the Ankareh Formation. This area may represent interfingering of the Higham stream system with other stream systems originating from the craton to the north and east. This area possibly had an intermediate to high frequency of avulsion / rate of subsidence ratio. Narrow to broad sheet sandstone body geometry of the Higham Grit at Home, Indian, and Bennington Canyons and at Border indicate a low to intermediate frequency of avulsion/ rate of subsidence ratio. These areas are anomalous in that they lack any gravel deposits either as channel lags or in the sand facies. Medium to very fine grained trough crossbedded sand predominates and minor horizontally stratified sand is present. The finer grained texture of the Higham deposits in these areas may

indicate deposition by minor channels of the Higham stream system, or possibly influx of detritus from a separate fluvial system with a different (western?) provenance.

Broad and narrow sheet sandstone body geometry characterizes much of the Higham Grit. This indicates a relatively high rate of avulsion / rate of subsidence ratio for most of the Higham stream system. It is difficult to ascertain whether a high rate of avulsion or a low rate of subsidence was the most important factor controlling Higham sand body geometry.

THICKNESS

The Higham Grit generally thickens to the north and west. At Sublette Ridge and in the Pruess Range the Higham is 40 - 60 m thick. At the Webster Range locations in the central part of the study area, the Higham increases in thickness to an average of 60 meters. At the Fort Hall Indian Reservation the Higham is estimated to average 60 to 120 m thick and may reach a maximum of 150 m (Mansfield, 1927). Table 1 contains thickness data for the sections examined.

Thickening of the Higham Grit in a westerly direction has been used in the past as evidence for a western source for the Higham sediment (Mansfield, 1927; McKee and others, 1959; Armstrong and Oriel, 1965). The interpretation of a western source is based on the inference that the Higham Grit accumulated as a medial or distal alluvial fan deposit, which thins away from the source area. Because of new data from this study and refined sedimentologic models of the braided stream depositional environment (Bridge and

Leeder, 1979; Friend and others, 1979), a new interpretation of the factors controlling the geometry and thickness of the Higham sandstone bodies is here proposed.

Thickening of the Higham Grit to the west was probably caused by gradual differential subsidence of different areas within the Higham depositional basin or alluvial plain. Overall, an extremely high frequency of avulsion/rate of subsidence ratio prevailed. The broad sheet geometry of the sandstone body in the Ft. Hall and Webster Range areas suggests a relatively slow rate of aggradation. Thickest accumulation of sediment probably occurred in the Fort Hall area because of only a slightly higher rate of subsidence in this area. Evidence of a higher rate of subsidence of this area is documented by the fact that the thickest deposits of Early Triassic sediments are also in this area (Fig. 5) and the general area remained a clastic and carbonate depositional basin into the Jurassic (Dickinson, 1976).

Deposition of the Higham Grit as an alluvial fan deposit does not appear likely for a variety of reasons. Alluvial fan deposits are typically characterized by abundant massive or crudely bedded gravel (Gm) lithofacies and/or abundant massive, matrix supported gravel (Gms) indicative of debris flow deposits. The Scott and Trollheim models respectively of Miall (1978) represent depositional systems dominated by these type of deposits. Neither of these models can be applied to the lithofacies and sequences of lithofacies found in the Higham Grit.

The aerial extent and thickness of the Higham Grit also argues against an alluvial fan origin. Modern alluvial fans are variable in size and are commonly 1 to 2000 square kilometers in aerial extent. In contrast the Higham alluvial plain covered over 5000 square kilometers. The modern Kosi alluvial fan/plain covers approximately 7000 square kilometers and is a possible analogous river system, but the predominant sediment of the Kosi system is silt and not sand. Modern alluvial fan deposits and ancient deposits attributed to alluvial fan deposition are commonly several kilometers thick and range up to 25 km thick (Reading, 1978). This is much thicker than the 60m average thickness of the Higham Grit.

PETROLOGYTEXTURE

Grain size of the Higham Grit sand and gravel varies from very fine sand to pebble. The majority of the sediment, however, is medium to very coarse grained sand. Sorting (Inclusive Graphic Standard Deviation) of the five samples disaggregated by hand and sieved is moderate to poor (.82 - 1.23 phi). Both positive and negative skewness is represented in these five samples.

Sand grains are predominately subangular to subrounded. Granules and pebbles are generally subrounded to rounded. Most of the grains are equant to subequant and a preferred orientation of grains is not obvious. A preferred orientation of detrital muscovite parallel to bedding was observed in several fine grained samples. Grain to grain relations are primarily tangential to long contacts, with concavo-convex contacts more common in the samples with a higher incidence of quartz overgrowths. Textural maturity varies from immature to submature. In some samples feldspar alteration has introduced authigenic clay and it is sometimes difficult to differentiate this source of clay from detrital clay if partially altered feldspar grains are absent.

The primary textural variations in the Higham Grit are due to grain size variation, the degree to which quartz overgrowths have developed, and the percentage of matrix and/or sedimentary and volcanic rock fragments present. The fabric is generally typical of

quartz arenite with most of the rock supported structurally by the framework grains. A majority of the sedimentary and volcanic rock fragments are squashed into "clay matrix" between the competent framework grains. A few fine and very fine grained samples contain as much as 22 to 65 percent matrix and were matrix supported.

Cementation is primarily by quartz overgrowth but a considerable amount of clay matrix and authigenic clay, iron oxide, and calcite is present in some samples. Quartz overgrowth development varies from very minor amounts to up to 44% of the rock and results in almost total elimination of porosity. Where considerable clay matrix exists in the rock, or compaction of sedimentary or volcanic rock fragments has occurred, quartz overgrowth development is generally not as common. Calcite is present as a cement and replacing feldspar in very minor amounts in several samples.

MINERALOGY

The Higham Grit is primarily a quartzarenite and sub-arkose. Samples from the Pruess Range are arkoses and sub-arkoses. Minerals found in the thin sections include quartz, chert, orthoclase, microcline, perthite, sericite, plagioclase, muscovite and a suite of heavy minerals including zircon, apatite, biotite, hornblende, epidote(?), and tourmaline. Also present are silty argillaceous sedimentary rock fragments, volcanic rock fragments, and a small percentage of what may be quartz sandstone lithic fragments. Appendix 1 contains a summary of the mineralogical data obtained from the point counts.

QUARTZ

Quartz is the dominant mineral constituent of the samples examined, making up an average of 94 percent of the detrital grains. Several types of quartz are present including common, vein, polycrystalline, and volcanic (Folk, 1974). Common and vein quartz were not identified separately and are grouped in Appendix 1.

Common and vein quartz are characterized by a wide variety of deformation features, including deformation lamellae, polygonized grains, (Fig. 17) and deformation bands (Fig. 18) as defined by Young (1976). Some of this low grade strain development may be due to stress during thrusting or folding. This is suggested by the ubiquitous occurrence of strain lamellae in the quartz grains in some of the thin sections. Several samples also contain shear zones along which the quartz was generally fractured and broken into silt sized particles. A small amount of clear quartz possessing straight extinction, sometimes with embayments (Fig. 19), is found in minor amounts in some samples. Quartz with these properties is probably volcanic in origin, according to Folk (1980).

Several types of polycrystalline quartz are present including polyhedral (Fig. 20), stretched metamorphic (Fig. 21), and primary recrystallized. Seven percent of the quartz is polycrystalline quartz. The majority of the polycrystalline quartz grains found in the sections contained more than three crystals. The presence of a high percentage of polycrystalline grains with more than three crystals indicates a primary source of quartz from a plutonic or

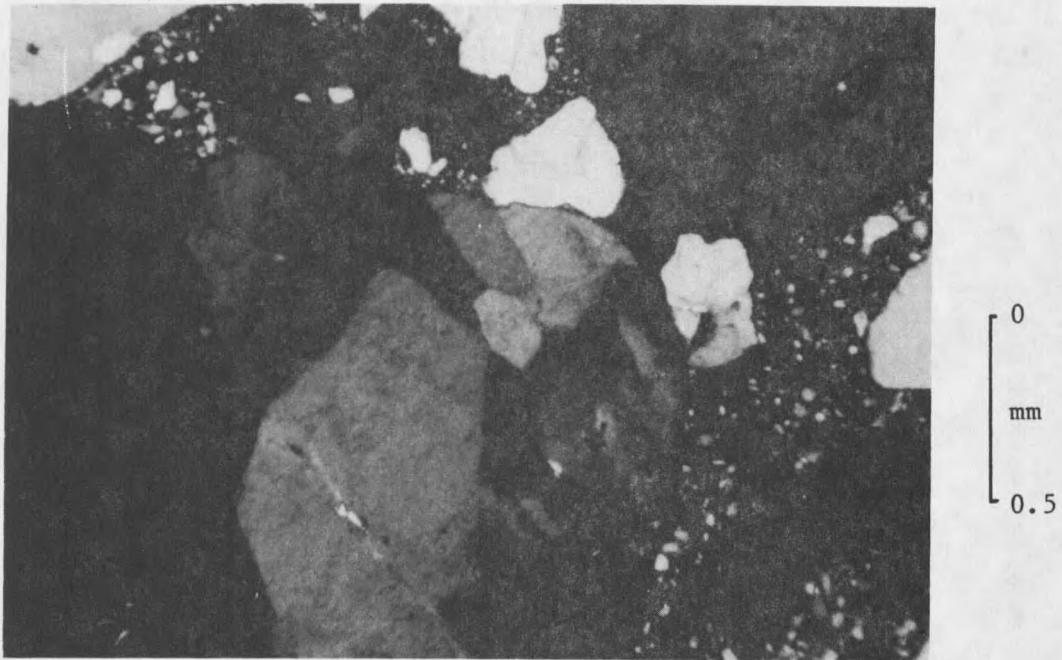


Figure 17. Polygonized upper right hand corner of a large, (2mm) unstrained pebble, possibly due to tectonic stress after deposition. Sample is from Lander Cutoff Section.

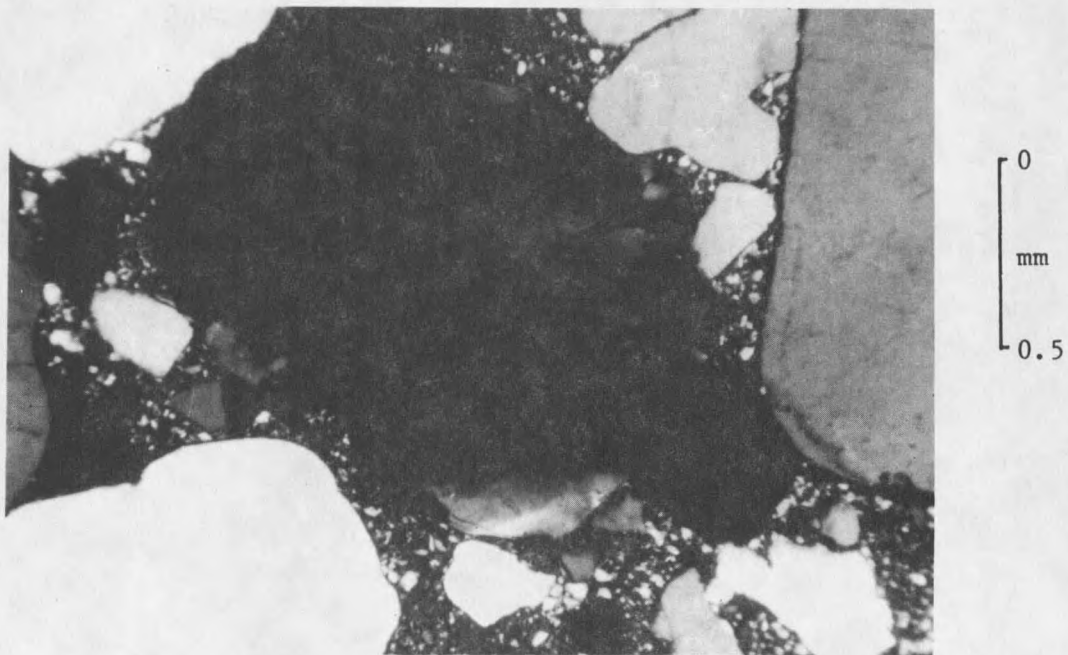
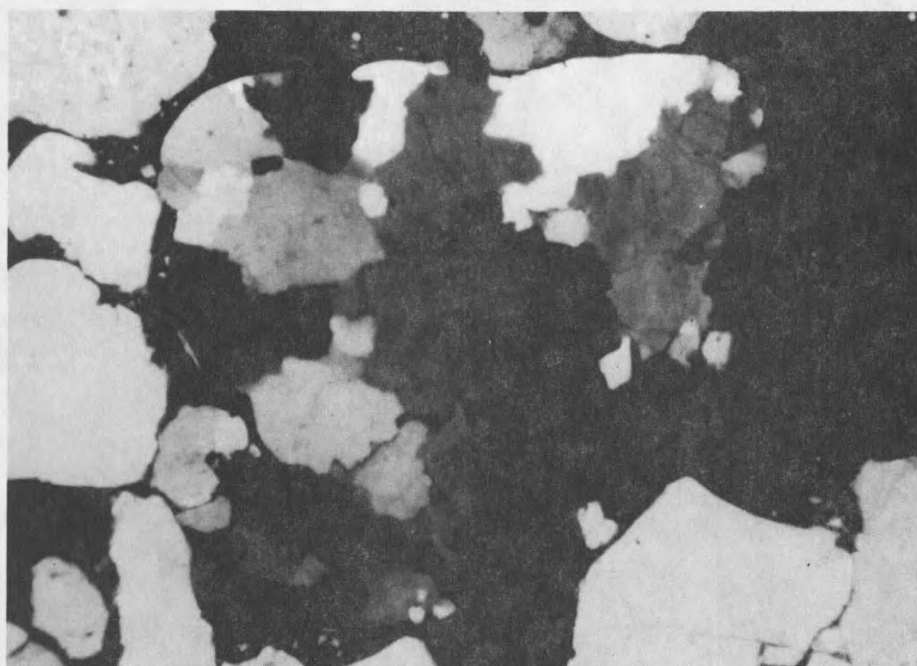


Figure 18. Undulose extinction/deformation bands in quartz grain containing abundant muscovite microliths. Sample is from Lander Cutoff Section.



0
mm
0.5

Figure 19. Clear, embayed quartz, possibly volcanic (Folk, 1974). Sample is from Lander Cutoff Section.



0
mm
0.5

Figure 20. Polycrystalline quartz grain with recrystallized metamorphic (Folk, 1974), or polyhedral (Young, 1976) grains. Sample is from location Lander Cutoff Section.

metamorphic terrane (Blatt and Christie, 1963; Blatt, 1967; Young, 1976). The presence of stretched metamorphic quartz (Blatt, 1967) along with an estimated low percentage of unstable polycrystalline quartz grains (as defined by Young, 1976), would indicate a low to high grade metamorphic provenance (Young, 1976) for the polycrystalline quartz. Coarser grained sandstones of the Higham Grit contain a higher percentage of polycrystalline quartz and in general larger grains were more likely to be polycrystalline. Conolly (1965), in a study of Upper Devonian, Permian, and Triassic sediments in New South Wales, also found that larger quartz grains were more likely to be polycrystalline. Microliths of zircon, muscovite, apatite and other unidentifiable minerals were found in approximately 5% of all the quartz grains.

CHERT

Chert, found in sparse amounts in a few samples, generally constitutes less than 1% of the sand grains. In places it appears to be molded around other quartz grains, indicating that it may have formed authigenically, perhaps by devitrification of volcanic glass fragments.

ORTHOCLASE

Potassium feldspar (Fig. 22) is present in some of the samples and abundant in a few, comprising up to 13 percent of the grains. In most cases it is altered to clay and less commonly calcite. Grain size varies from fine to very-coarse sand. In general, a larger percentage of orthoclase was found in rocks with a finer modal grain size. Perthite is found in minor amounts in some samples.

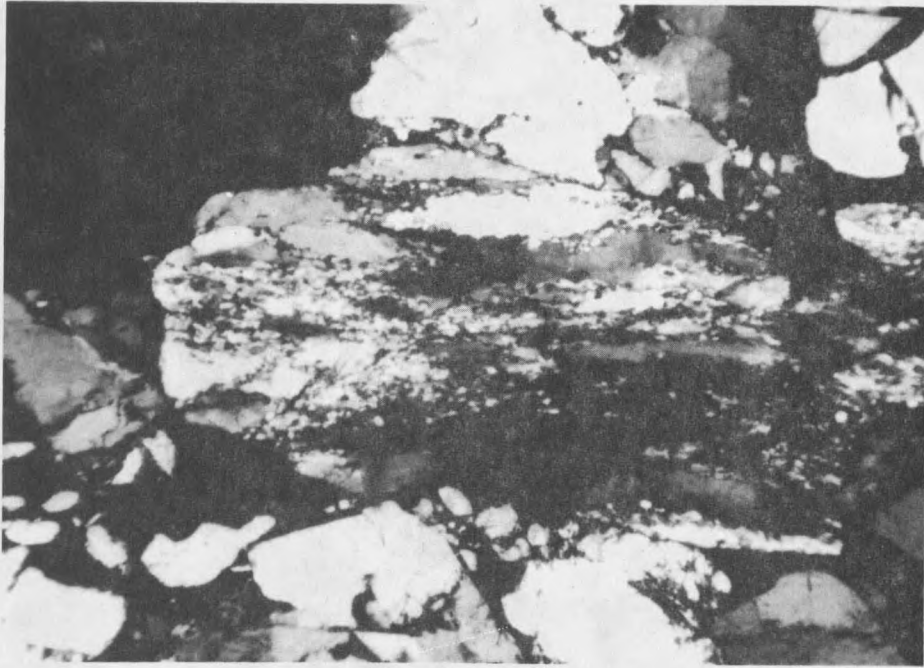


Figure 21. Stretched metamorphic (Folk, 1974) quartz grain. Sample is from location Daves Creek Section.



Figure 22. Large potassium feldspar grain altering to clay. Long muscovite grain (at right) has been deformed by quartz grains. Sample shows almost complete development of quartz overgrowths. Sample is from Birch Creek Section.

Sericitized feldspar is also common in most samples that contain orthoclase.

MICROCLINE

Microcline (Fig. 23) is present in most of the samples that contain orthoclase, but in lesser quantities. Microcline comprises up to four percent of the sand in one sample. Sandstones of smaller grain size usually contain a higher percentage of microcline.

PLAGIOCLASE

Plagioclase (Fig. 24) is found in trace amounts in samples from all locations except those from the Pruess Range where it is common. Plagioclase comprises up to 29 percent of one sample at Indian Canyon. Most of the plagioclase observed is partially altered to clay and has a composition of An 0-20 as determined by the A-normal optic method. Some of the plagioclase is altered to sericite.

MUSCOVITE

Trace amounts of muscovite are present in almost all of the samples. It occurs as detrital grains and also attached to (Figure 22) or embayed in quartz. In a very fine grained sample from Dave's Creek (sample C-5) muscovite comprises almost 4 percent of the rock. In general it comprises less than 1 percent of the sandstone.

HEAVY MINERALS

A variety of heavy minerals were found in minor amounts throughout the samples examined. Listed in order of their approximate abundance they are zircon, magnetite, tourmaline, biotite, and apatite.

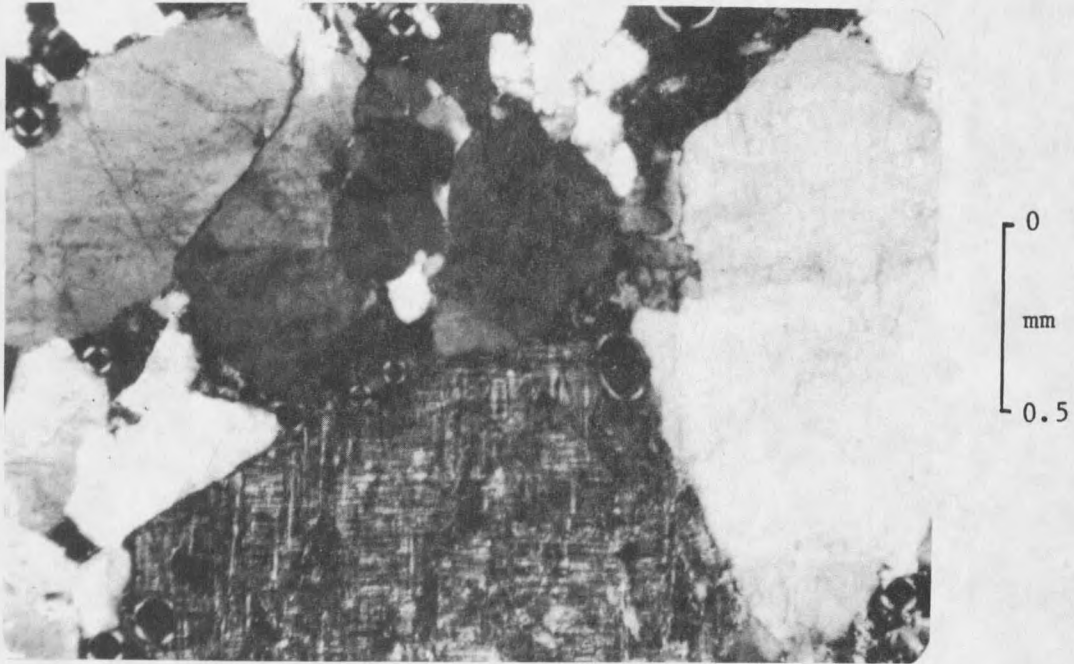


Figure 23. Large microcline grain (3.0 mm). Sample is from Deadman Creek Section

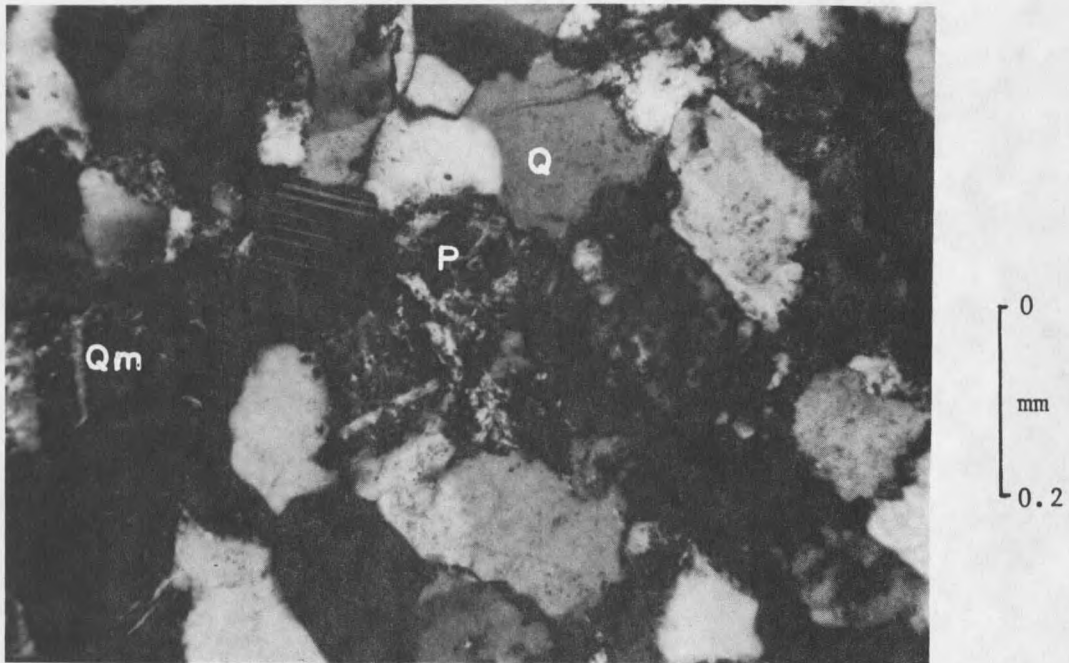


Figure 24. Twinned plagioclase grain with potassium feldspar (P), quartz (Q), and quartz with muscovite inclusions (Qm). Sample is from Home Canyon Section.

SEDIMENTARY ROCK FRAGMENTS (SRF)

Detrital silty argillaceous sedimentary rock fragments (Fig. 25), comprising up to 3 percent of one sandstone, are found in some of the samples. These clasts are commonly deformed by the more competent framework grains and molded around them and into the pore space. This indicates that they were soft and not likely to survive large distances of transport. Most SRF's are likely intraformational in origin. The original grain size of many of these fragments is difficult to estimate but appears to be slightly larger than the grain size of the detrital quartz. Many of the SRF's are altered to chert in varying proportions.

VOLCANIC ROCK FRAGMENTS (VRF)

Volcanic rock fragments and possible volcanic rock fragments are found in several locations (Figure 26). Euhedral plagioclase crystals and deformed bubble wall glass shards are found in the VRF's. Positive identification was possible for only a few of these clasts in several samples, but a much larger percentage of volcanic detritus is possible because of the abundance of clay and the general texture of some samples. Many VRF's are altered to chert. The total abundance of volcanic material in the rocks is very difficult to estimate. A large percentage of the sedimentary rock fragments may have had a volcanic origin but it is not possible to differentiate the exact nature of most of the lithic fragments.

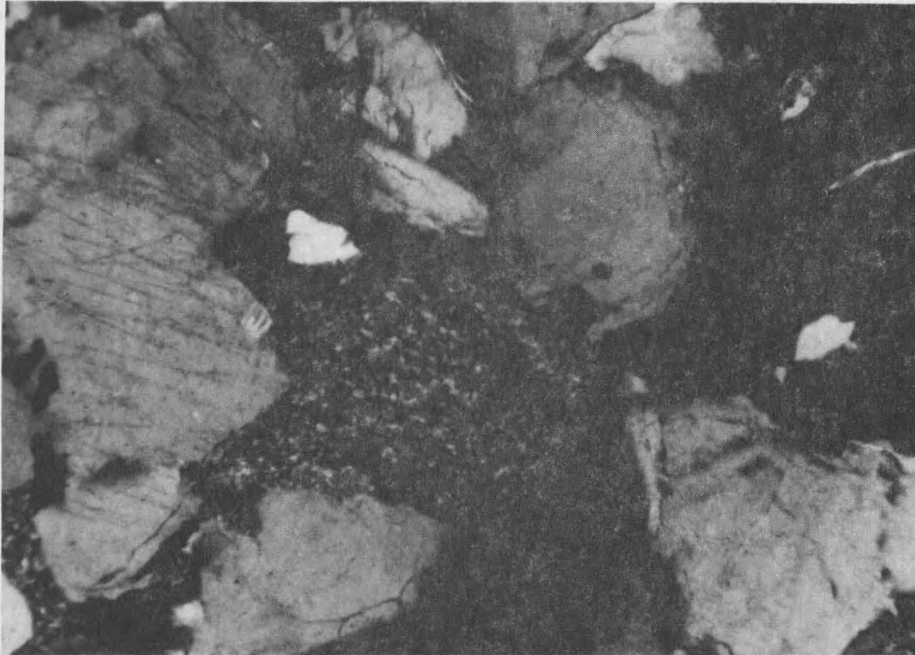


Figure 25. Sedimentary rock fragment with sharply defined edges. Sample is from location C.

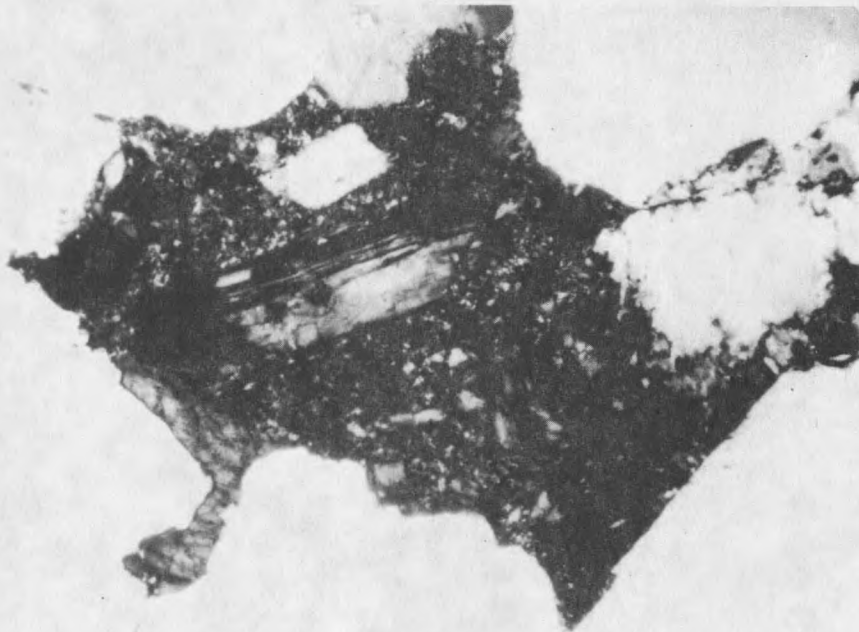


Figure 26. Volcanic rock fragment with euhedral plagioclase crystal. VRF has been moulded into pore space between framework grains of quartz. Sample is from Indian Canyon Section.

MATRIX

Chert and/or clay matrix is present in approximately half of the thin sections examined. Generally less than five percent of the rock is composed of matrix, but up to 42 % is present in some very fine grained samples. Several samples were comprised of sand grains floating in a matrix of silty clay (Figure 27), with or without iron oxide present. The matrix material may be either sedimentary or volcanic in origin. Differentiation of these two origins is not possible due to diagenesis of the samples.

DISCUSSION

Higham sandstones are broken down into three grain size categories and plotted on a QFL ternary plot (Fig. 28). Classification of the sandstones using Folk's (1974) classification show that most of the thin sections examined are quartzarenite and subarkosic in composition. Exceptions to this are fine and medium sand samples from the Preuss Range, which are arkosic in composition. Samples from Indian Canyon show a definite increase in feldspar content with decrease in grain size. Similar relations are noted by Odom and others (1976) in Cambrian and Ordovician sandstones from the upper Missouri Valley and the Permian-Pennsylvanian Webber Sandstone of Utah.

Plotting of sandstone provenance fields (Dickinson and Suczek, 1979) on the QFL diagram (Fig. 28) indicate a continental block provenance as a likely source terrane for the Higham detritus. A QmFLt plot (Fig. 29) with typical provenance fields (Dickinson and Suczek, 1979) indicates a mixed continental block/recycled orogen

provenance for the sediment. This agrees with the igneous/metamorphic provenance indicated by abundant high grade polycrystalline quartz grains possessing more than three crystals.

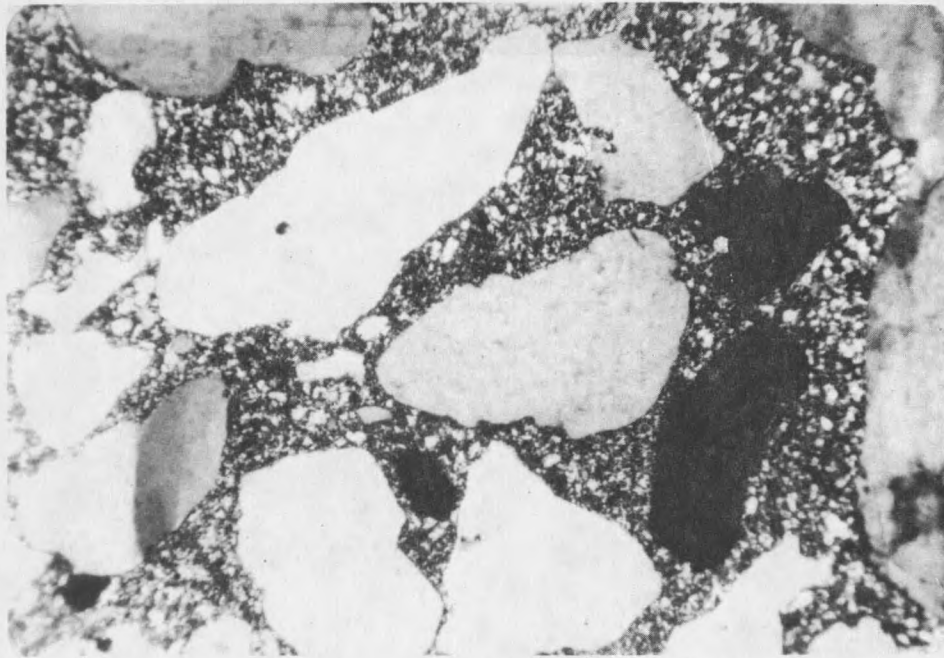


Figure 27. Quartz grains embedded in silty-clay matrix. Sample is from Cranes Flat Section.

QFL Diagram

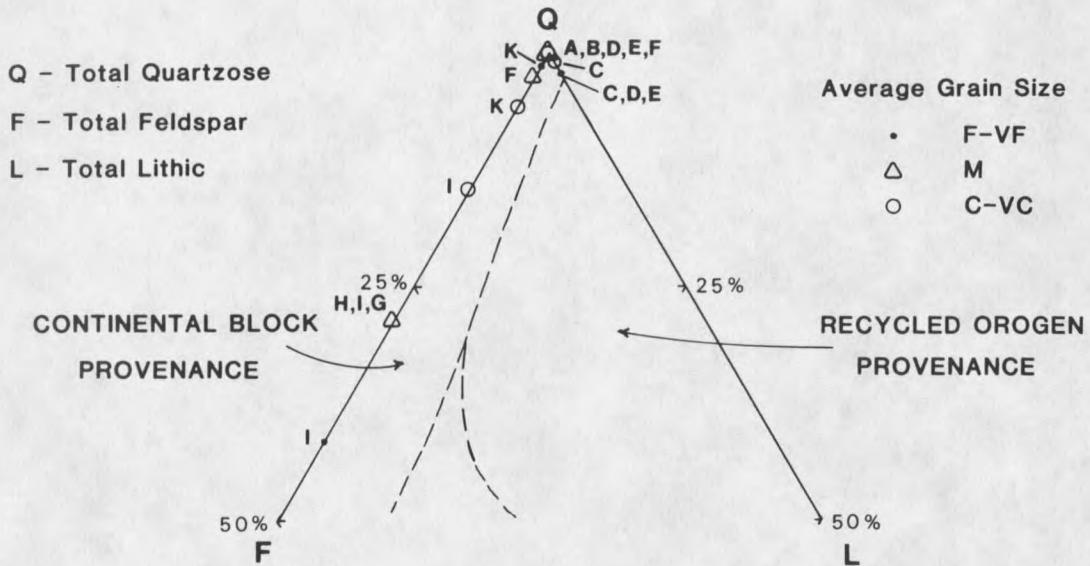


Figure 28. QFL plot of Higham Grit samples. Provenance fields are from Dickinson and Suczek (1979).

QmFLt Diagram

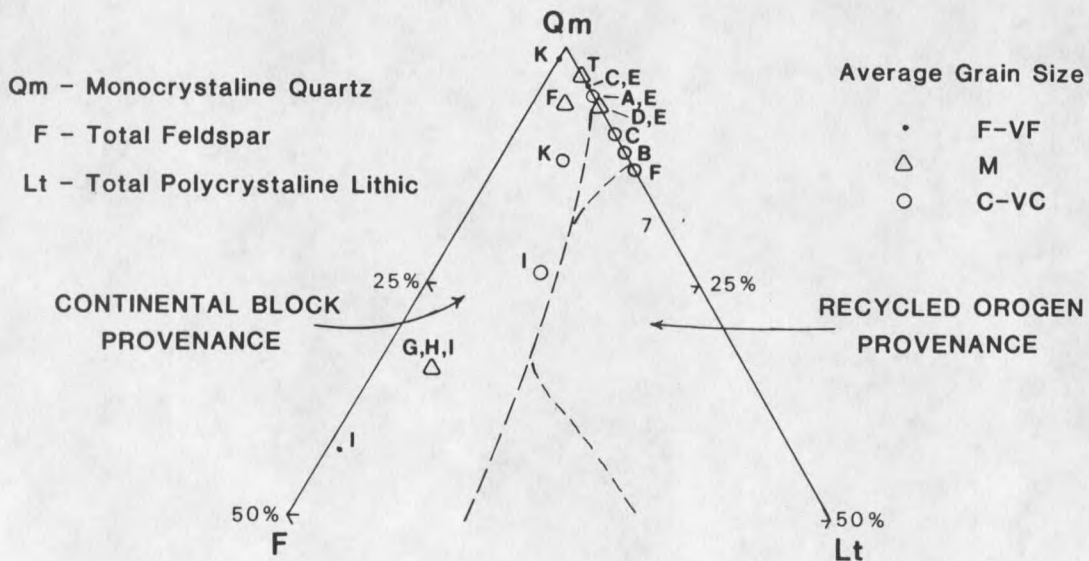


Figure 29. QmFLt plot of Higham Grit samples. Provenance fields are from Dickinson and Suczek (1979).

PALEOCURRENTS

CROSSBEDDING

Paleocurrent analysis of crossbedding was undertaken to help determine depositional patterns and source area location. Approximately 700 readings were taken of trough and planar crossbeds in the study area. Determination of resultant vector orientation and magnitude or consistency factor was made for trough and combined trough and planar readings (Table 1). Consistency factors (Table 1) vary from very low (.16) to very high (.93), and are consistently between .3 and .5. The consistency factors are within the range found by Smith (1972) for bar foreset azimuths for the South Platte River. Resultant crossbedding azimuths of the combined trough and planar foresets are plotted in Figure 30. The vector resultant of the trough crossbedding where present is also plotted on Figure 30. The length of the arrows are proportional to the consistency factor at each location. Sample locations on this map are palinspastically restored.

Combined trough and planar crossbedding data from each location generally contain a significant amount of scatter to either side of the calculated vector resultant (see rose diagrams, Fig. 30). Calculation of the trough axis orientation using the average location of the left and right limbs according to DeCelles and Langford (1983), generally results in a trough axis orientation within 30 degrees of the vector resultant determined for the cross-

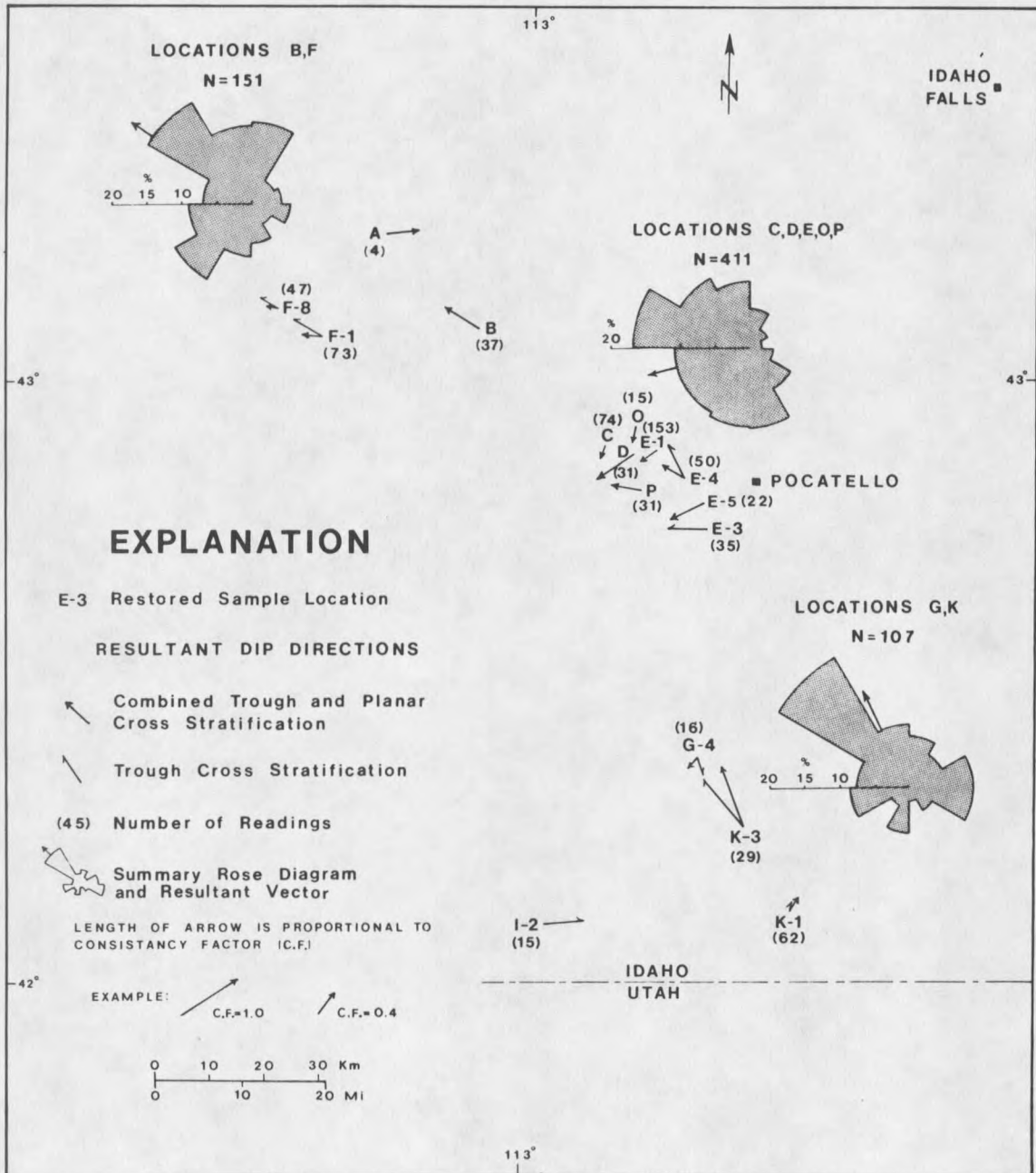


Figure 30. Paleocurrent direction map of the Higham Grit. Paleocurrent locations are palinspastically restored.

strata. Vector resultant azimuths for the trough and planar cross strata were generally within 47 degrees of each other.

As discussed previously, eastward translation of the Higham Grit may have also rotated the rocks in a counterclockwise direction. If paleocurrent trends in the northern part of the study area are rotated clockwise the maximum amount of rotation probable (45 degrees), a north to northwest trend would still exist for most of the data points. Possible error in the amount of eastward thrusting would move the locations of the paleocurrent vectors, but would not significantly alter regional interpretations of the paleogeography.

PEBBLE SIZE DATA

Long axis lengths of the ten largest gravel clasts at each location were measured and averaged to obtain the data plotted on Figure 31. The sample locations on this map are palinspastically restored. The data show a rough overall decrease in clast size to the northwest, but considerable scatter exists in the data.

A semi-log plot of the data was made to determine if the clast size trend follows Sternbergs Law (cited in Barell, 1925) as numerous other studies of conglomeratic deposits have indicated (Potter, 1955; Schlee, 1957; Pelletier, 1958; Smith, 1974). The scatter in the data available is so great that correlation of meaningful size reduction with distance of transport was not possible. This result may be caused by variations in the: 1) size range of gravel available for transport through time or 2) competence of the stream(s) remaining the same over large distances.

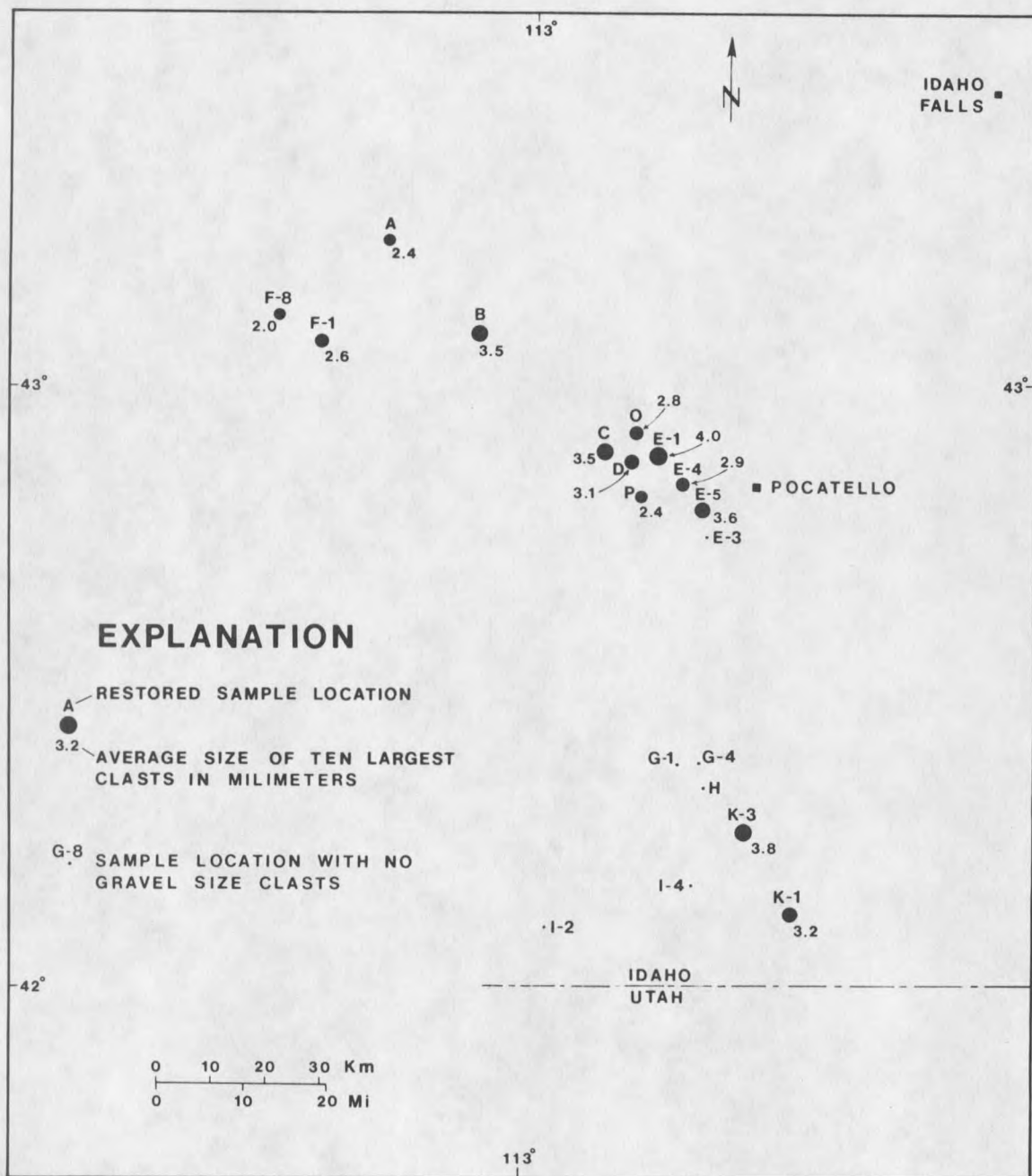


Figure 31. Clast size trends in the Higham Grit. Sample locations are palinspastically restored.

The sections in the Pruess Range are anomalous in several aspects. First of all they are finer in average grain size than the majority of the Higham detritus and do not contain gravel sized clasts. Secondly, they contain a relatively large percentage of plagioclase. The finer grain size of the sediments in these areas can be interpreted to represent deposits of less competent stream flow associated with minor channels of the Higham stream system. Finer grained deposits with the same provenance as the Higham Grit, (Odom and others, 1976) would be expected to contain a higher percentage of total feldspar.

Another possible interpretation is that the deposits represent influx of clastic material from a western source area. There is ample evidence of highlands existing to the west at this time and acting as a barrier to the Pacific Ocean (Dickinson, 1981 ; Burchfiel and Davis, 1975; Hamilton, 1978). Fluvial systems draining this area may have been the source for some or all of the sediment the Pruess Range. Paleocurrent data from Indian Canyon and Currie, Nevada tend to support the western source hypothesis. However, the Higham at Currie, Nevada does not contain any plagioclase as would be expected if these sediments had a western source.

REGIONAL PALEOCURRENTS AND PEBBLE SIZE DATA

A regional compilation of crossbedding derived paleocurrent directions and pebble size data from the Gartra Grit and Higham Grit was made to determine what, if any, relationship exists between the two units. Data from Stewart et. al. (1972); Saltier, (1966);

McCormick and Picard (1969) and this study is combined in figures 32 and 33. One sample location from this study is just north of Currie, Nevada. A section of Upper Triassic Chinle Strata with coarse sand and conglomerate beds is exposed at this location. A 1 m thick basal gravel layer at this location contains large chert, quartz, and quartzite pebbles and grades quickly upward into trough crossbedded quartz sandstone similar to the Higham and Gartra Grits. The vector resultant at this location comes from 26 trough and planar crossbeds.

Regional paleocurrent trends shown on Fig. (32) are generally to the northwest. A rough decrease in pebble size (Fig 33) also occurs to the northwest although there are large gaps in the data. This overall regional slope indicated by the data is compatible with the regional pattern of basins and uplifts in Late Triassic time (Fig. 5). The current directions at Currie, Nevada and at Indian Canyon indicate that east to northeast flowing streams were also present in the western portion of the region. They may have originated from a volcanic arc and an adjacent highlands associated with accretion of Paleozoic and Mesozoic marine sedimentary and volcanic terranes to western North America (Hamilton, 1978; Burchfiel and Davis, 1975; Dickinson, 1981; Davis and others, 1981).

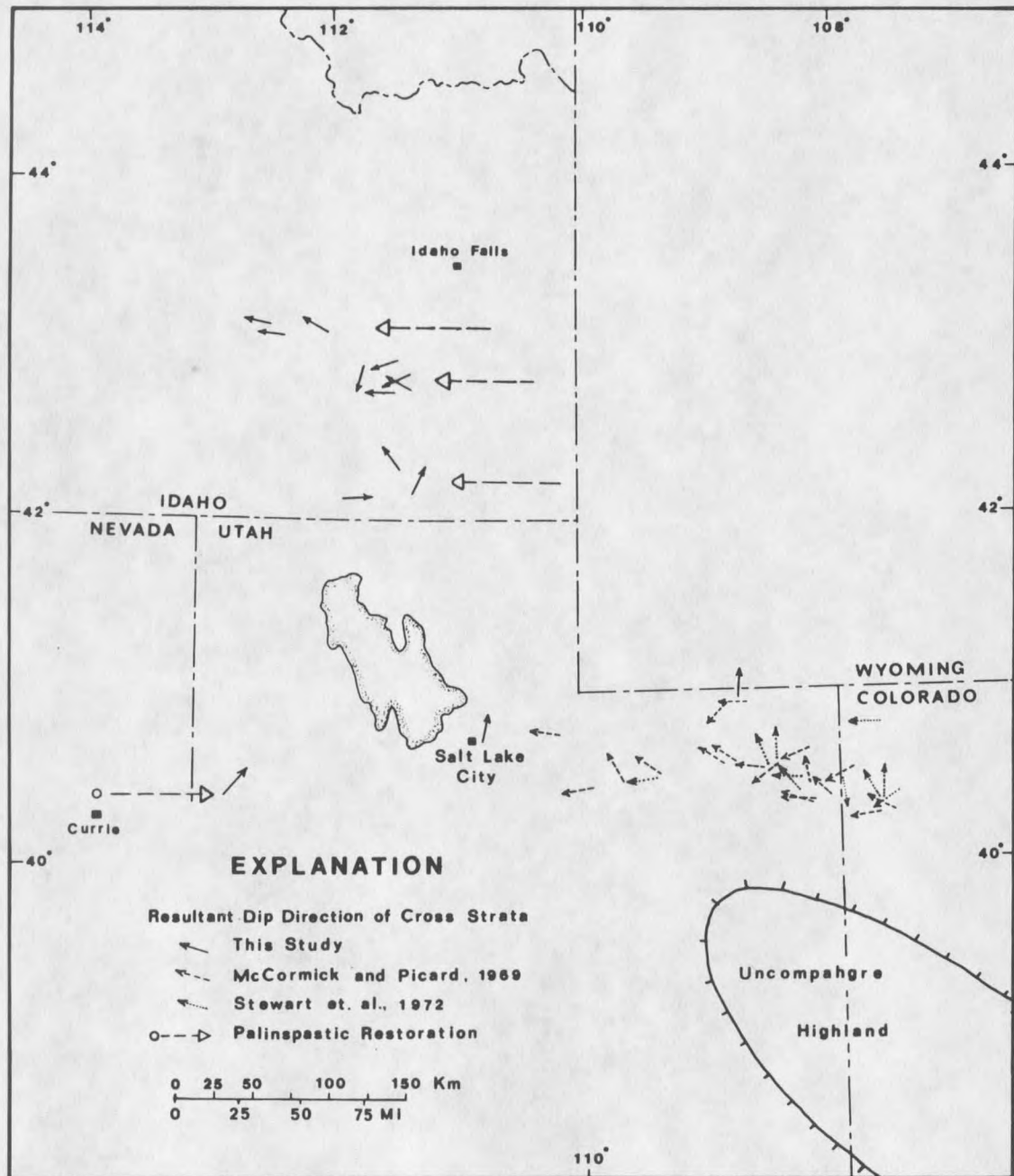


Figure 32. Regional paleocurrent directions of the Higham Grit and Gartra Grit. Higham Grit sample sites are palinspastically restored. Outcrop at Currie, Nevada was restored using an estimated 50 percent crustal extension west of Salt Lake City.

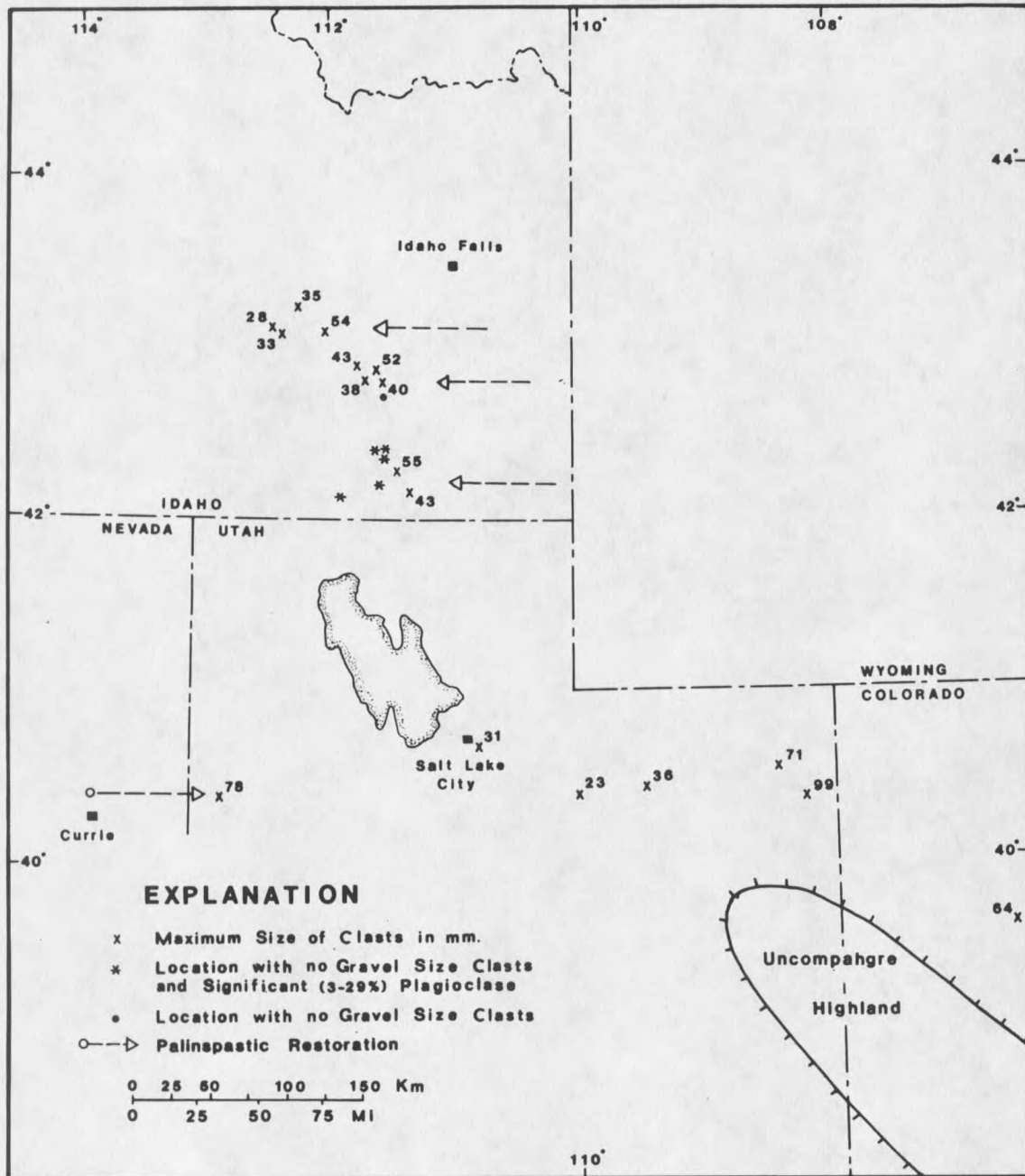


Figure 33. Regional clast size trends of the Higham Grit and Gartra Grit. Higham Grit sample sites are palinspastically restored. Clast sizes of Gartra Grit are in Utah and Colorado and are from Stewart and others, (1972), except sample location at Salt Lake City which was measured as a part of this study. Sample location at Currie, Nevada is restored using an estimated 50 percent crustal extension west of Salt Lake City.

PROVENANCE AND PALEOGEOGRAPHY

Sedimentologic and petrographic data from the Higham Grit allows refined interpretations of the late Triassic paleogeography of southeast Idaho and adjacent areas (Fig. 34). The Higham was deposited in a braided fluvial system with the source area located to the south and east. In the Fort Hall area and Preuss Range areas the fluvial system was developed into a alluvial braid plain with streams flowing in a generally northwest direction depositing a broad sheet sandstone. To the south in western Wyoming, a more northerly flowing Higham stream system deposited thinner and more discontinuous sheet and ribbon sand bodies along with mudstones of the Ankareh Formation.

The environment of deposition is similar to that proposed for the Shinarump and Moss Back members of the Late Triassic Chinle Formation of the Colorado Plateau by Blakey and Guibitosa (1983). The Mossback Member of the Chinle Formation is comprised of locally conglomeratic fine to coarse grained quartz sandstone with trough and planar tabular cross-stratification and planar bedding being the most abundant sedimentary structures (Blakey and Guibitosa, 1983). The Gartra Grit is also characterized by abundant trough and planar cross-stratification and horizontal bedding in medium and coarse grained quartz sandstone (Salter, 1966; McCormick and Picard, 1969). These formations were deposited at about the same time as the Higham Grit and likely under similar depositional and tectonic settings.

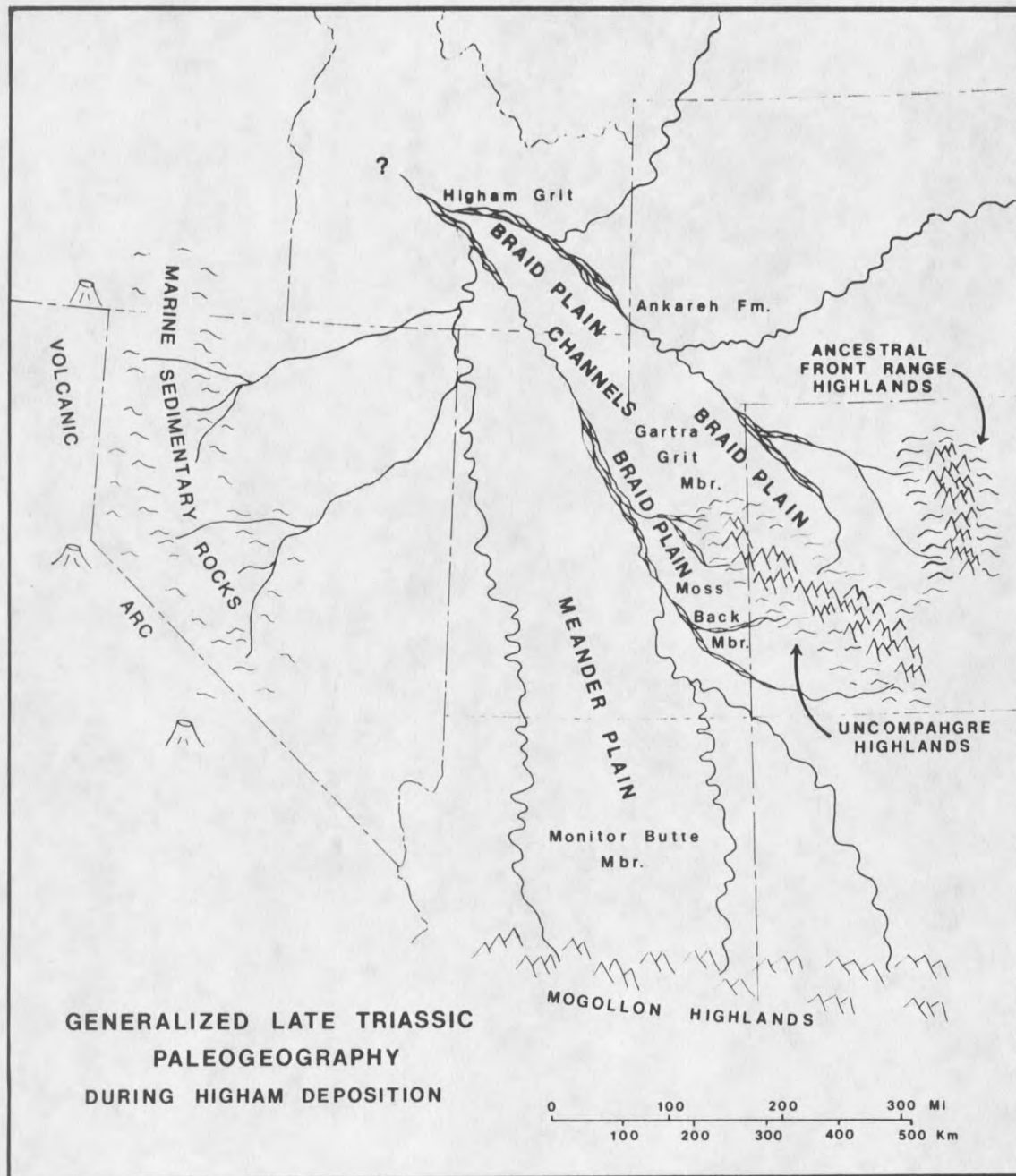


Figure 34. Generalized paleogeography during Higham Grit deposition. (modified from McKee, 1959; and Blakey and Gubitosa, 1983)

Petrographic analysis of the Higham indicates a plutonic or metamorphic provenance for the majority of the Higham detritus. The overall mineralogy of the Gartra (Salter, 1966; McCormick and Picard, 1969; and Stewart and others, 1972) is very similar to the Higham, with a large percentage of quartz and accessory minerals typical of a plutonic or metamorphic source. The two formations are located in stratigraphically similar positions and have been inferred to be probable lateral equivalents (Williams, 1945; Kummel, 1954).

The Uncompahgre and Front Range elements of the Ancestral Rocky Mountains uplifts in Colorado and Utah are known to have still existed as highlands during Late Triassic time (Stewart and others, 1972). These relict uplifts are interpreted as source areas for the Moss Back Member of the Chinle Formation (Stewart and others, 1972; Blakey and Gubitosa, 1983) and the Gartra Member of the Ankareh Formation (McCormick and Picard, 1969).

Paleocurrent, pebble size, and petrographic data indicate that the Ancestral Rocky Mountains uplifts in Colorado and Utah were also the source for the majority of the Higham detritus. Sand comprising the Higham Grit was thus transported a distance of 500 - 700 km from the sediment source. This is comparable to sand transport distances in the South Saskatchewan (Cant and Walker, 1976) and Platte River (Smith, 1970) river systems. Uplift of Paleozoic rocks and sediments associated with the Sonoman Orogeny, volcanic arc activity, and accretion of the arc and/or microplates during the Late Triassic (Davis and others, 1981; Dickinson, 1981) may also have been a

source for some of the Higham detritus. Eastward paleoflow indicators at Currie, Nevada and at Indian Canyon, Idaho indicate that highlands existed to the west. The presence of a coarse chert pebble conglomerate at the base of the Currie section is evidence for a provenance containing eugeosynclinal sedimentary rock assemblages such as those associated with Sonomia (Speed, 1979; Davis and others, 1981).

Collision of incoming terranes from the west with the western margin of North America may be responsible for re-activation of the Ancestral Rocky Mountain Highlands during the Late Triassic. Late Triassic rift basins in Texas (Dickinson, 1981) suggest that rifting was in progress to the south and thus an unlikely cause of "foreland" style basement uplifts 1000 km inboard on the craton. The addition of the Sonoma microplate in the Early to Middle Triassic (Speed, 1979) and other rock assemblages (Davis and others, 1981) to the western edge of North America may have resulted in crustal shortening and "foreland" style uplifts of the Ancestral Rockies.

CONCLUSIONS

Composition of sediment and lithofacies present in the Higham Grit are similar to those found in the modern South Saskatchewan and Platte braided river systems. The Higham Grit is comprised predominately of coarse to medium-grained pebbly quartz sandstone with lesser amounts of mudstone. Lithofacies present include massive to crudely horizontally bedded pebbly gravel (Gm), trough crossbedded sand (St), planar tabular crossbedded sand (Sp), horizontally bedded sand (Sh), ripple laminated sand (Sr), and mudstone (F1). Bedforms existing in the Higham stream system which deposited these lithofacies include sinuous-crested transverse bars and dunes (St), straight - crested transverse bars (Sp) longitudinal bars (Gm) and interbar channel lags (Gm). Periodic high velocity flow (Sh) and overbank deposition (F1) is also indicated by lithofacies present in the Higham.

The Higham Grit was deposited as a relatively thin (9 - 150 m) thick blanket over a large (~ 5000 square kilometer) area of the Cordillerian Miogeocline. It is classified as having a broad, multistory sheet depositional geometry over most of its depositional area. This depositional geometry indicates that deposition occurred on a broad, stable, alluvial plain by a stream system with a high rate of avulsion / rate of subsidence ratio.

The source of the Higham Grit is postulated to have been the Front Range and Uncompahgre elements of the Ancestral Rockies. This

source of detritus is supported by compositional and paleocurrent data from the Higham Grit. The composition of the Higham Grit detritus indicates a plutonic / metamorphic source for most of the Higham sediment. North and northwest paleoflow indicators from the Higham Grit also support an Ancestral Rockies source. Regional stratigraphic studies indicate that the Moss Back Member of the Chinle Formation in southeastern Utah and the Gartra Grit Member of the Ankareh Formation in northeastern Utah are possible temporal equivalents of the Higham Grit. It is possible that the Higham fluvial system was a distal northwesterly extension of the Moss Back and Gartra Grit fluvial systems. Studies of these formations indicate that they were deposited by renewed uplift of the Ancestral Rockies in the Late Triassic. The cause of Late Triassic rejuvenation of the Ancestral Rockies is not known but may have been related to collisions of continental and volcanic rock packages to the western margin of the North American plate.

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APPENDICES

APPENDIX A

PETROGRAPHIC DATA

Table 2 - Petrographic data

LOCATION	Framework Constituents in Percent											Cement and Matrix Constituents in Percent						
	Qtz. Mono	Qtz. Poly	Qtz. Met	Orth	Micr	Plag	Ser	Musc	Chert	SRF	VRF	Qtz. O. G.	Clay	Hem/Lim	Chert	Carb	Matrix	Other
Coarse Sandstone																		
A	59	4	-	-	-	-	-	-	-	-	-	26	7	-	-	-	4	-
A	65	2	T	-	-	-	-	-	-	-	-	7	25	-	-	-	-	-
B	56	5	1	-	-	-	-	-	-	-	-	8	3	T	T	-	28	-
B	68	5	-	-	-	-	-	-	-	-	-	14	13	-	-	-	-	-
C	81	5	1	-	-	-	-	-	-	-	-	9	4	-	-	-	-	-
D	64	4	1	-	-	-	-	-	-	-	-	21	7	3	-	-	-	-
E-1	72	6	-	-	-	-	-	-	-	-	-	15	5	-	T	T	2	-
E-1	64	3	T	-	-	-	-	-	-	-	-	2	-	14	-	-	17	-
E-1	69	6	-	-	-	-	-	-	-	3	-	11	11	-	-	-	-	-
E-3	47	5	T	10	4	T	-	-	T	1	-	9	2	-	-	20	1	-
F-1	62	3	-	-	-	-	-	-	-	-	-	22	14	-	-	-	-	-
F-1	67	7	1	-	-	-	-	-	T	-	-	18	5	-	2	-	-	-
F-1	60	23	T	-	-	-	-	-	-	-	-	5	12	-	-	-	-	-
F-8	64	2	-	5	1	-	-	-	T	-	-	14	12	1	-	-	-	-
F-8	61	9	1	T	T	-	-	-	T	-	-	17	10	1	-	-	-	-
F-8	71	4	1	2	-	-	-	-	-	-	-	16	7	-	-	-	-	-
F-8	67	6	T	-	-	-	-	-	-	-	-	16	5	6	-	-	1	-
I-2	50	4	T	-	T	5	1	-	-	-	-	23	10	4	1	-	1	-
I-2	50	7	1	-	-	6	6	-	-	-	2	10	8	-	-	-	3	-
O	67	3	-	-	-	-	-	1	-	-	-	21	9	-	-	-	-	-
P	68	4	-	-	-	-	-	-	-	-	-	22	4	-	1	-	2	-
K-3	65	2	-	2	-	-	-	-	-	-	-	29	5	-	-	-	-	-
K-1	49	4	1	-	-	-	-	-	-	-	-	44	3	-	-	-	-	-
K-1	60	14	-	4	T	T	-	T	-	-	-	12	9	-	-	-	-	-
Very coarse Sandstone																		
B	56	12	1	-	-	T	-	-	-	-	-	30	10	T	-	-	-	-
C	62	6	1	-	-	-	-	-	-	2	-	20	2	7	-	-	-	-
E	59	3	-	-	-	-	-	-	-	-	-	14	4	1	-	-	19	-
E-5	59	11	1	-	-	-	-	-	-	-	-	18	7	-	-	-	4	-
F-1	66	11	-	1	1	-	-	-	T	-	-	10	6	-	-	-	6	-
F-1	66	13	-	-	-	-	-	-	T	-	-	5	6	-	-	-	10	-

T = Trace

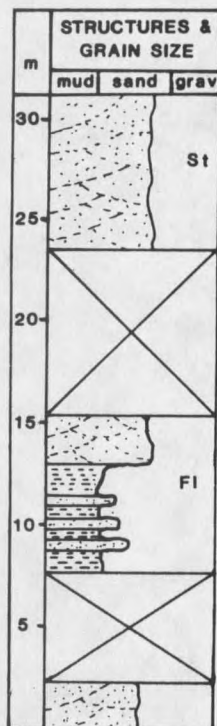
Table 2 (continued)

LOCATION	Framework Constituents in Percent											Cement and Matrix Constituents in Percent								
	Qtz. Mono	Qtz. Poly	Qtz. Met	Orth	Micr	Plag	Ser	Musc	Chert	SRF	VRF	Qtz. O. G.	Clay	Hem/Lim	Chert	Carb	Matrix	Other		
	Fine and Very fine Sandstone																			
C	49	2	-	-	-	-	-	4	-	-	-	2	1	T	6	-	35	1		
D	34	-	-	-	-	-	-	2	1	-	-	11	1	T	8	-	43	-		
E-5	28	1	-	T	-	-	-	1	-	1	-	1	1	1	-	-	65	-		
G-4	54	2	-	12	2	6	T	1	-	-	-	20	4	1	2	-	-	-		
I-2	17	1	-	-	2	29	-	1	-	-	1	8	15	-	5	-	22	-		
I-4	42	1	-	-	-	12	7	1	-	-	-	23	3	1	4	6	-	-		
K-1	41	-	-	T	-	-	-	2	-	-	-	44	3	-	-	-	-	-		
	Medium Sandstone																			
D	71	4	-	-	-	-	-	-	-	-	-	14	7	-	1	-	2	-		
E-1	68	2	-	-	-	-	-	2	-	-	-	20	3	-	2	-	4	-		
E-1	66	5	1	-	-	-	-	T	-	-	-	17	6	3	1	-	t	-		
F-1	56	3	T	-	-	-	-	T	-	-	-	26	7	-	7	-	-	-		
F-1	52	1	T	-	-	-	-	-	-	-	-	22	3	3	11	-	6	-		
F-8	71	2	-	-	-	-	-	-	-	-	-	23	3	-	2	-	-	-		
F-8	57	2	T	1	-	T	-	-	-	-	-	29	2	1	-	-	-	-		
F-8	59	1	-	4	-	-	-	-	-	-	-	29	5	1	1	-	-	-		
F-8	65	4	-	1	-	-	-	-	-	-	-	18	12	-	T	-	-	-		
G-1	44	3	T	9	3	8	-	1	-	-	-	19	9	2	1	-	-	-		
G-4	48	2	T	9	3	10	-	T	T	-	-	19	2	1	1	4	-	-		
I-2	54	3	-	-	-	10	-	-	1	-	-	22	1	1	8	-	-	-		
I-4	42	4	-	13	3	3	3	-	T	-	-	9	2	1	T	20	T	-		
O	69	3	T	-	-	-	-	T	-	-	-	15	3	9	1	-	-	-		
K-3	56	2	-	10	T	T	-	-	-	-	-	30	5	-	-	-	-	-		
K-1	62	1	-	7	-	-	-	-	-	-	-	26	3	-	1	-	-	-		

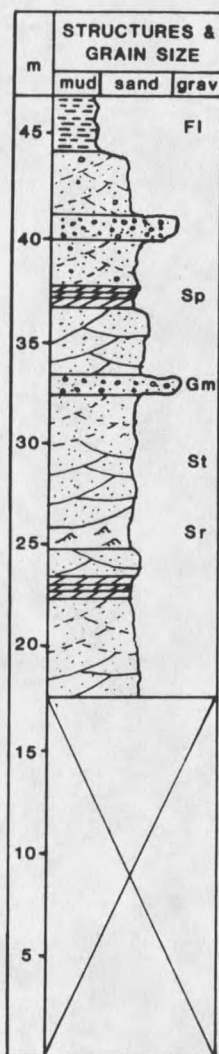
APPENDIX B

STRATIGRAPHIC SECTIONS

A BLACKFOOT MTNS.



B CRANES FLAT



P UPPER VALLEY

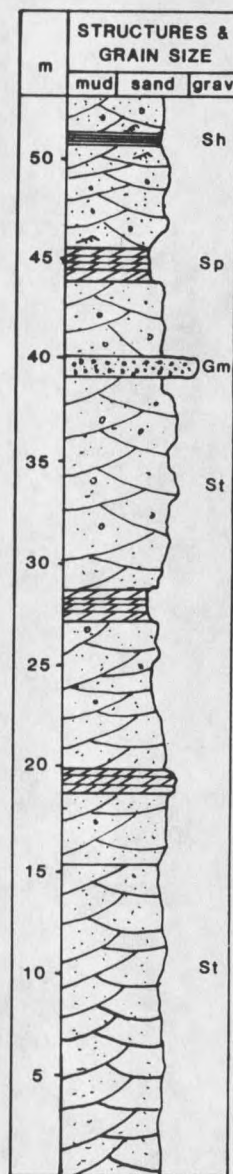
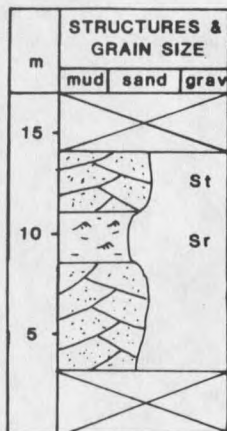
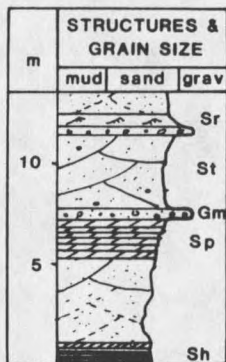


Figure 35. Stratigraphic Sections A, B, and P. Key to stratigraphic sections is in figure 14 in text.

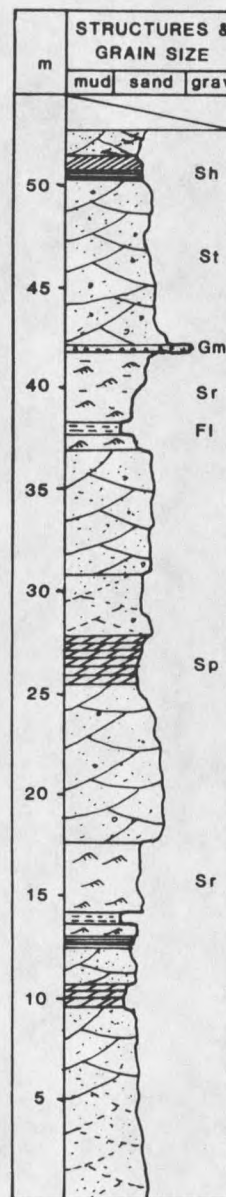
E-3 SPRING CREEK



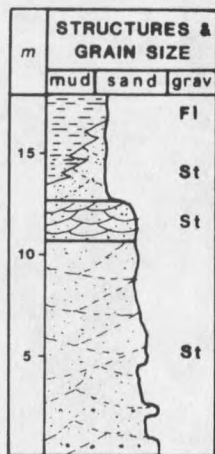
K-3 RAYMOND CANYON



C DAVES CREEK



I-2 INDIAN CANYON



G-4 HOME CANYON

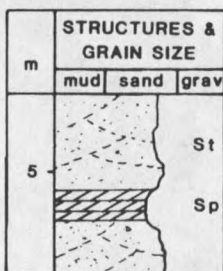
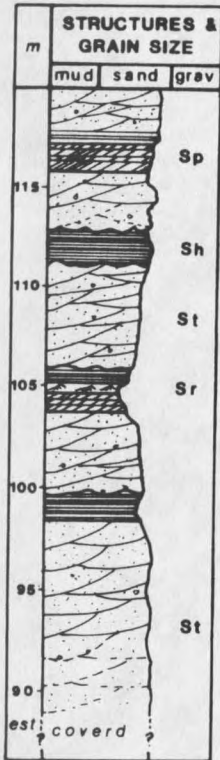
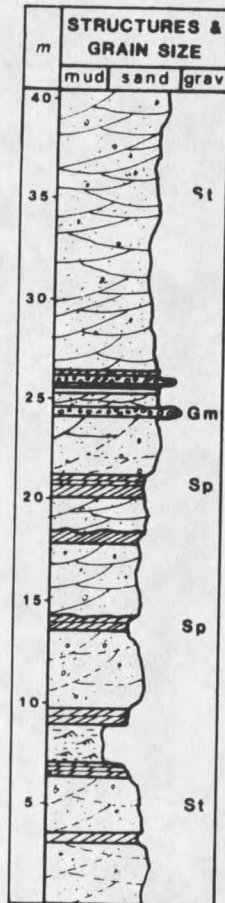


Figure 36. Stratigraphic Sections E-3, K-3, C, I-2, and G-4.

F-8 HIGHAM PEAK



E-1 LANDER CUTOFF



K-1 BIRCH CREEK

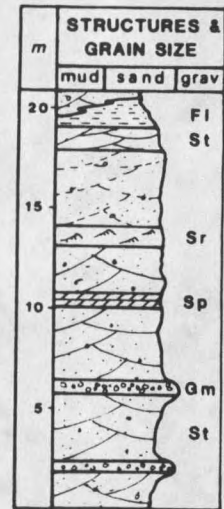


Figure 37. Stratigraphic Sections F-8, E-1, and K-1.



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