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Bridger Formation Sandstones Used as an Indication of Tectonics in the Green River Basin and Western Wyoming

Lisa S. Novins
Oberlin College

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Abstract

Sandstone from the Eocene Bridger Formation of southwestern Wyoming can be used as a tool to constrain the timing and order of controversial tectonic events in the region. The key tectonic element in this region is the Wind River Range. Sandstones in the Bridger were derived from two source areas to the north, one being the basement rocks from the Wind River Range and the other volcanic rocks from the Absaroka Volcanic field (AVF). The abundance of volcanic grains increases upsection in the Bridger indicating that more volcanic material was carried through the Wind River Range. This evidence supports the theory that the southern Wind River Range was initially uplifted during the Laramide Orogeny, eroded throughout the Eocene, and uplifted during a second event in the Oligocene. This theory contrasts the traditionally accepted tectonic history of the Wind River Range which says the last uplift was during the Eocene Laramide Orogeny. The base of the Bridger has been dated at between 51 and 48 Ma (Groll and Steidtmann, 1987; Clyde et al, 1997). The Bridger at Continental Peak in the northeastern Green River basin contains volcanic quartz which is believed to be from the AVF and constrains the timing of Bridger deposition.

Introduction

The Bridger Formation is significant to geologists and paleontologists for a number of reasons. One is that its sedimentology can be used to understand the complicated structural evolution of the southwestern Wyoming region. Bridger sediments are derived from two sources, an Eocene volcanic source in the Absaroka Volcanic field (AVF) and an Archean basement source in the Wind River Range. The proportion of sediment derived from these two groups changed during deposition of the Bridger, and these changes must reflect shifts in tectonics and/or volcanism in the source areas. The most important question it can be used to address is the Eocene rise and fall of the Wind River Range.

Another point of interest is the rich vertebrate fauna the Bridger contains. The Green River Basin and the formations within it, including the Bridger, were deposited in a brief period of time when archaic and modern orders of mammals coexisted (Trapini, 1998). Sequences of evolutionary stages in mammalian faunas defined by index fossils, first and last occurrences of species, characteristic fossils and typical correlative areas (Prothero, 1996) have been used to define North American Land Mammal Ages (NALMA) (Fig. 1). Any improvement in understanding the depositional conditions of the Bridger Formation is helpful in understanding the environment in which these mammals lived. The work presented here is part of a broader investigation aimed at learning more about the depositional environment and physical stratigraphy in the eastern part of the greater Green River basin.

Background

Geographical Extent

The middle Eocene Bridger Formation is found primarily in the greater Green River basin of southwestern Wyoming. The basin is surrounded by modern topographic highs including the Uinta Range to the south and the Wind River Range to the north (Fig. 2 and Fig. 3a). The Wind River Range stretches approximately 100 miles through central western Wyoming. The AVF is north of the Wind River Range in the Yellowstone National Park region of northwestern Wyoming and southwestern Montana. The field ranges approximately 150 miles from north of Yellowstone in MT to the northern Wind River basin (Fig. 2). The southern Absarokas lie about 75 miles from the northeastern Green River Basin which is not significantly different than during the Eocene.

Geologic Setting

The Green River basin is one of many basins formed as a result of Laramide deformation during the late Cretaceous and early Tertiary. The Laramide event probably ranged from 70-45 Ma with the most intense deformation between 65-50 Ma (Dickinson and Snyder, 1978), but there is still considerable debate as to the precise timing, particularly in Wyoming. For example, Lillegraven (1993) shows evidence that the Laramide Orogeny ended by 57 Ma and others believe it may have begun as early as 90+ Ma (Steidtmann and Middleton, 1991). The Wyoming basins formed by the Laramide consist of an extremely rich sedimentary record representing all Tertiary epochs and have one of the best preserved sections of nonmarine Eocene strata in the world.

The Green River basin was formed as a flexural response to uplift of the Wind River block during the Laramide Orogeny (Steidtmann et al, 1989). The basin was an ideal setting for high sedimentation rates because it was a topographical low surrounded by source areas that were rapidly producing sediment during the Eocene. The Green River basin contains the most complete section of Eocene sedimentary rocks in Wyoming (Roehlar, 1992a). The Bridger Formation is one of these units, and it generally lies stratigraphically above the Green River Formation. The contact between the Green River and Bridger Formations is gradational and probably time transgressive, as the two formations interfinger in many places. As a result of this complex interfingering, the base of the Bridger has been defined differently at different sites. Historically, workers have chosen a distinct marker in their field area at or near a change from light gray calcareous shale typical of the Green River Formation to green and brown shales and sandstones typical of the Bridger Formation. In contrast, the top of the Bridger is easy to pinpoint; it is either erosionally truncated by the modern land surface or disconformably overlain by Oligocene sediments of the Bishop Conglomerate.

Most previous studies in the Bridger Formation have focused on paleontology rather than geology (Keonig, 1960; Wood, 1966; Gunnell and Bartels, 1994), so most descriptions of the strata themselves focus on the physical stratigraphy and/or present generalized interpretations of depositional environment. These studies show a high degree of lateral variability in the Bridger (Table 1) because the formation was deposited during a transition from a lacustrine to fluvial environment (Wood, 1966; Groll, 1986). The Bridger is a dominantly clastic unit composed of sand sized volcanic and basement detritus, shale and limestone. Paleocurrent measurements indicate the sediment source lay to the north (Fig. 4) (Wood, 1966; Groll, 1986; Groll and Steidtmann, 1987).

The Wind River Range is the closer of the two potential sediment sources. It is one of several ranges composed of uplifted basement rock in Wyoming. Paleocurrent measurements indicate that sediment came from the north through the Wind River Range, which suggests that the range is the source of Bridger basement derived grains. The Wind River Range is composed of tectonically uplifted Archean granitic basement rocks (Mtira, 1993). Controversy surrounds the timing of uplift of the Wind River Range, there being two main proposals. The traditional view is that the last deformation/uplift episode was the Laramide Orogeny, which had ceased by about 50 Ma and was responsible for modern relief (Yonkee and Mitra, 1993). Recently other workers have argued that there was uplift subsequent to the Laramide. The second interpretation includes two additional events subsequent to the Laramide that the traditional view does not include. One is that the southern toe of the range was rapidly eroded during the Eocene, leaving little or no relief. The other additional event is that the southern part of the range was uplifted during an Oligocene faulting event along reactivated Precambrian shear zones between 30 and 23 Ma (Groll, 1986; Steidtmann et al, 1989; Steidtmann and Middleton, 1991; Cerveny and Steidtmann, 1993).

The only known source for the abundant volcanic detritus in the Bridger is the AVF (Groll, 1986; Steidtmann and Middleton, 1991). In contrast to the Wind River Range, the AVF consists of a suite of undeformed extrusive and intrusive rocks formed during the early Tertiary. The extrusive rocks of the AVF are known as the Absaroka Volcanic Supergroup (AVS) (Smedes and Prostka, 1972). Absaroka volcanism began about 50 Ma (early Eocene) and ended about 38 Ma (late Eocene) (Sundell, 1993) and increased progressively in volume from the middle to late Eocene (Love, 1960).

The AVS consists mainly of andesitic lava flows, although basalts trachyandesites, dacites and rhyolites are locally important (Sundell, 1993; Smedes & Prostka, 1972; Parsons, 1974; Love 1960). They were extruded via a wide variety of extrusion styles and include flow breccias, autobrecciated andesitic flows, Vulcanian breccias, pyroclastic flow breccias, explosion and intrusive breccias and laharic breccias. Petrologic data have been gathered on only a small fraction of the rocks in the range, mainly those that are rich in minerals or have easy access (Sundell, 1993).

Volcanic quartz crystals are present in the Bridger Formation and quartz phenocrysts have only been reported in two units in the entire AVS. One is the Slough Creek Tuff which is coeval with the Wapiti and a member of the Mount Wallace Formation. This quartz latitic ash flow tuff contains phenocrysts of plagioclase, sanidine, hornblende, biotite, hypersthene, and augite (Hickenlooper and Gutmann, 1982) and is found in the north central part of the AVF. The other unit that may contain quartz phenocrysts is the Sepulcher Formation, which is located in the northwestern part of the AVF. The Sepulcher Formation is a dominantly andesitic unit, which contains some sections of dacitic alluvial facies. While quartz is not explicitly mentioned in reports on the Sepulcher, it is identified as the source of detritally reworked volcanic quartz crystals in the Pitchfork Formation which is coeval with the Wapiti (Hay, 1960; Smedes and Prostka, 1972).

Geologic Age

Radiometric dates and faunal remains indicate deposition of the Green River Formation began roughly 52 Ma and ended around 50 Ma in the northeastern part of the Green River basin (Lillegraven, 1993). Due to the variable nature of the base and top of the Green River Formation deposition may have lasted several million years longer in adjacent basins where it was also deposited (Remy, 1992). Based on magnetostratigraphic work by Clyde et al (1997) from the western Green River basin the dates of deposition of the Green River Formation may be 1.5 Ma younger than previously thought. The source of uncertainty in the dates reflects uncertainty in the correlation with magnetic reversal time scales. Based on the older set of Green River Formation dates, the start of Bridger deposition in the northeastern Green River basin is estimated at 50 Ma with deposition lasting at least 2 Ma (Lillegraven, 1993; Groll and Steidtmann, 1987). Given the variable nature of the contact between the Bridger and Green River Formations, the deposition of the Bridger could have commenced as much as a million years earlier or later in other parts of the Green River basin.

The Bridger Formation at Continental Peak

Our study of the Bridger Formation was conducted in and around Continental Peak in the northeastern greater Green River basin (Fig. 3). Continental Peak is an 8,400 foot mountain located near the southeast flank of the Wind River Range amidst dry, non-vegetated badlands. In this area, the Bridger consists of shale, sandstone, limestone and mudstone. It is well exposed from its disconformable upper contact with the Oligocene Bishop Conglomerate down to an ill-defined lower contact with the Green River Formation, the later being well exposed in the area. For the base of the Bridger, we chose the top of a laterally extensive oolitic limestone containing stromatolites that capped a thick sequence of typical gray Green River shales. Shales above the limestone were brown to gray-green and, unlike those beneath it, contained interbeds of sandstone and limestone.

During the summer of 1998 we measured three sections totaling approximately 520 meters in the Bridger formation on the southeast, north and northwest sides of Continental Peak (Fig. 3b). We informally divided the Bridger into "lower" and "upper" units in our sections but our subdivision does not necessarily correlate to previously described "upper" or "lower" units in the Bridger Formation (e.g. Matthew, 1909). The entire Bridger is exposed at the northwest site, but only the "lower" Bridger is exposed at the other two sites. At the southeast and north sites the "lower" Bridger is about 120 and 110 meters thick, respectively (Fig. 5). At the northwest site the entire Bridger Formation is exposed and is 215 meters thick, 120 meters of which is "lower" Bridger Formation. The "upper" Bridger consists of sandstone except for a total of about 1-2 meters of mudstone. The "lower" Bridger is dominantly brown to gray-green shale with interbedded mudstone, limestone, and sandstone. Shale is distinguished from mudstone by its fissile texture. There are eight sandstone beds at the southeast site ranging from one to five meters thick. The thickness of sandstone beds increases drastically at the top of the "lower" Bridger. The contact between the ""lower" and "upper" Bridger is very abrupt. The sandstone of the "upper" Bridger weathers red in contrast to the tan/brown weathering of the "lower" Bridger sandstones. Bridger siliciclastic sands are well sorted and average medium grain size. Limestones range from micrites to oosparites.

Our sections of Bridger Formation in the Continental Peak area contain the same sorts of sediments that have been described in earlier published works (Table 1), the lack of conglomerates being the main difference. We interpret the shale dominated "lower" Bridger as being deposited in a mixed fluvial lacustrine to fluvio-delatic environment whereas the sandstones of the "upper" Bridger appear to be entirely fluvial in origin. The unit we informally called the "donut" sandstone appears to mark this transition (Fig. 5)

Methods of Study

At the southeast site, only the "lower" Bridger was present and it contained eight discrete beds of sandstone. I collected one or two samples from each of the beds (Fig. 5). If a bed looked homogenous, I only took one sample, but if I noted a vertical change in lithology within an individual bed, I took two samples, one from the bottom and one from the top of the bed. At the northwest site the "lower" Bridger contains 13 beds of sandstone and I collected samples from three of the uppermost four beds (Fig. 5). I also collected four samples from the "upper" Bridger. The "lower" Bridger is also present at the north site but no samples were taken from there. A unique layer we informally called the "donut sandstone" was used to correlate between the southeast and northwest sites.

Thin sections were made from all sandstone samples, except for two samples from the "upper" Bridger which proved two fine grained and too matrix rich. I measured the relative abundance's of different types of sand grains by counting 500 points on each thin section using a scheme with eight categories (Table 2 and Table 3). Volcanic lithics were the most abundant type of grain and I subdivided them into four categories (Table 4) based on the presence of phenocrysts and groundmass textures. Third, I counted volcanic and basement derived quartz and feldspar using several criteria (Table 5) to divide grains into six categories (Table 2 and Table 6). For a grain to be classified as volcanic or basement it had to show at least two of the criteria unless it had two phase fluid inclusions or plaid twinning indicating basement derived or had quenched magmatic inclusions or was a zoned feldspar indicating volcanic origin. I determined the maximum grain size by measuring the maximum axis of the cross sections of the largest grain in each of ten fields of view.

Petrography of Bridger Sandstone

The constituent grains in all of the Bridger sandstones are in the medium sand grade except for one (NW14) which consists of very fine sand (Table 7). The sands are well sorted and consist of angular to subangular lithic fragments, quartz and feldspar. The volcanic lithics are the most abundant grain type and show a variety of textures rich in feldspar throughout the formation. Most commonly, the volcanic lithic grains contain feldspar laths. Some volcanic lithic grains also have euhedral, zoned phenocrysts up to about 0.1 mm long while others contain fragments of even larger feldspar phenocrysts. The feldspar phenocrysts in the volcanic lithic fragments are primarily plagioclase. The basement feldspar grains are primarily microcline. Monocrystalline quartz exhibits a wide range of extinction patterns from straight to undulose and many contain either two phase fluid inclusions or quenched magmatic inclusions. The sandstones contain variable proportions heavy minerals, primarily hornblende, throughout the formation, as well as other miscellaneous clast types but no evidence of any volcanic glass shards.

All of the samples of Bridger sandstones contain calcite cement except for two samples from one bed where the cement is chalcedonic (Fig. 6). Whether calcite or chalcedony, cement is fairly abundant averaging 23% by volume in all the samples counted. Only three samples had less than 20% cement and the maximum abundance observed was 29 percent by volume. There are not signs of any other significant diagenetic alteration in any of the samples. In fact, hornblende and other easily altered grains are extremely fresh and highly unmodified.

Stratigraphic Trends

There is little variation in the relative abundance of quartz, feldspar, and lithic grains as a function of stratigraphic position, although feldspar grains did decrease a few percent upsection (Fig. 7). However, there are significant changes upsection in the kind of quartz, the kind of feldspar (volcanic vs. basement derived), the types of lithics, and the composition of clasts in the miscellaneous category. One of the "upper" Bridger samples had over two to three times as much hornblende as the average of the "lower" Bridger sediments.

The abundance of volcanic lithics increases upsection in the proportion of total lithic grains. This increase is accompanied by a corresponding decrease in the abundance of lithic fragments from the intermediate basement source (Fig. 7c and Fig. 8). There was also an increase upsection in volcanic lithics with quartz phenocrysts (Fig. 9). No systematic variation in the relative abundance of volcanic lithics with laths or volcanic lithics with feldspar phenocrysts (including the zoned and euhedral categories) as a function of statigraphic position was observed. The relative abundance of volcanic detritus also rises upsection relative to basement derived crystals (Fig. 10).

Interpretations and Implications

To verify the assumption that the AVF was the source of volcanic detritus in the Bridger, I obtained 13 thin sections from samples of the Wapiti Formation, one of the thickest, most widespread units in the AVF. The Wapiti is a heterogeneous formation consisting of andesitic lava flows rich in hornblende and biotite, crosscut by numerous dikes and sills (Smedes and Prostka, 1972; Bartels, 1999). Both the groundmass textures and phenocrysts in these thin sections are strikingly similar to those of the volcanic lithics in the Bridger sandstones, only two of the five classifications of volcanic lithic texture fragments were not represented by Wapiti samples. These two categories make up less than 20% of the total lithic fragments in the Bridger. The two groups of lithics not represented by the Wapiti include quartz phenocrysts which probably do not come from andesitic beds but may have come from other sources in the AVF.

As noted above, two possible sources for detrital volcanic quartz have been reported from the AVF, namely the dacitic beds of the Sepulcher Formation and the Slough Creek Tuff. The Slough Creek has been tentatively dated at 48.0±1.3 Ma and is definitely older than a 47.7±1.5 Ma intrusive. The Sepulcher Formation is 49.2±1.5 Ma. Provided the volcanic quartz in the Bridger was derived from these units, the question arises as to why no other detritus from these units, such as glass shards or pumice fragments, has been identified in the Bridger. Davies et al (1978) documented that glass shards may disappear altogether or decrease drastically in abundance downstream in the sand size fraction relative to quartz and feldspar grains in a distance less than or equal to the inferred distance of travel from the AVF to the Green River basin.

Since the Bridger volcanic detritus is extremely fresh and shows little or no sign of weathering, it must have been quickly fragmented and eroded without being significantly altered chemically in a hot and wet climate. Phreatomagmatic eruptions may be an explanation for how this occurred. These explosive eruptions occur when there is an interaction between external water and magma, which causes fragmentation in existing rocks and as well as juvenile fragments. The climate was appropriate for hydrovolcanism, fossil flora and fauna indicate an average of 60 inches of rain per year (Parsons, 1965).

My studies in the Bridger Formation indicate a systematic upsection increase in the proportion of volcanic quartz, feldspar and lithic fragments and an associated decrease in basement derived quartz, feldspar and lithic fragments through 220 meters of stratigraphic section. The consistent grain size through the section shows that this change is not caused by differential changes in environmental energy. All of the samples are well sorted and all but one consists of medium sand. The excellent state of preservation of such easily weathered minerals such as hornblende indicates there has been little post-depositional alteration. This is in keeping with the abundance of cement, which indicates these sands were cemented early in diagenesis, which would help protect them from subsequent alteration. Given the apparent lack of selective dissolution of sand grains during diagenesis and the constant grain size, there must be another explanation for the upsection change in sandstone composition; it must be controlled by provenance.

The first order provenance controls on the composition of nonmarine clastic sands are climate, volcanism and regional tectonics. Although the regional climate became cooler and drier during the Eocene (Roehlar, 1993), this change in climate was probably not responsible for the observed changes in sandstone composition for two reasons. One is the lack of notable changes in weathering upsection; all the sand grains in the Bridger are very fresh and unaltered. The other is that one would expect the relative abundance of basement derived feldspars to increase as easily as the volcanic lithics if the climate became drier since they too, are easily weathered. The opposite is true there are fewer basement derived feldspars upsection in the Bridger. Therefore, I believe the climate change could not have been responsible for the changing composition of Bridger sandstones.

Changes in volcanism are also not responsible for changes in Bridger sandstone composition. The absence of evidence of glass shards in Bridger sandstones shows that the sand was not directly deposited by a pyroclastic eruption. Although volcanism in the AVF increased through the middle to late Eocene (Love, 1960) this increase in not necessarily represented by the Bridger Formation. Moreover, an increase in andesitic volcanism in the source area would not account for the increase in the relative abundance of volcanic quartz.

This leaves shifts in tectonic activity as the best explanation for changes in composition of Bridger sandstones. Bridger sandstones were deposited in a fluvio-deltaic to fluvial environment that originated to the north, through the modern Wind River Range. For a river to carry such a high proportion of volcanic material relative to basement material through the range, the relief must have been low. If relief of the range were decreasing during deposition of the Bridger Formation, this would mean less basement-derived sediment was available for transport into the Green River basin. This would also lead to a progressively greater percentage of volcanic sediment from the AVF to be carried to the greater Green River basin through the Wind River Range.

Conclusions

A detailed study of the composition of sand grains in the sandstones of the Bridger Formation has lead to two conclusions about the history of southwestern Wyoming. One is that lowest sandstone in the Bridger Formation cannot be older than the oldest source of volcanic quartz in the AVF, which may be the Sepulcher Formation. Two is that the southern toe of the Wind River Range must have been uplifted subsequent to the Eocene because it was probably not a major topographical high during deposition of the Eocene Bridger Formation.

For reasons explained above, the most likely source of volcanic quartz in the Bridger Formation is the Slough Creek Tuff or the dacitic beds of the Sepulcher Formation in the Absaroka Volcanic Supergroup. This information offers constraints on the age of the lowest sandstone in the Bridger Formation in the Continental Peak area, it cannot be older than 48.0±1.3 Ma if the quartz is from the Slough Creek Tuff. If the quartz is from the Sepulcher Formation, the Bridger cannot be older than 49.2±1.5 Ma.

The variation of sediments in the Bridger Formation contributes new information to the debate over the tectonic history of the Wind River Range. Although regional scale uplift stopped with the end of the Laramide Orogeny, the Wind River Range must have been uplifted again by local faulting after Eocene erosion. The increase in the proportion of volcanic relative to basement derived sediments shows that the range was eroding and becoming a less dominant source through Bridger time. The abundance of volcanics present in the Bridger Formation shows that the southern Wind River Range was not a dominant topographic high throughout the Eocene; the range was disappearing. The southern flank of the Wind River Range must have been uplifted to its present height after the Eocene, which is consistent with the Steidtmann et al (1989) theory that the Range was rejuvenated during the Oligocene.

Acknowledgements

I would like to thank Bruce Simsonson for all his guidance, criticisms and patience through this entire year. He helped make this project an invaluable learning experience about the methods, processes and philosophy of geological research. I would also like to thank Bill Bartels for his help and talks about the Bridger Formation, without his research this project would have never began. Thanks also to Pete Munk for all his work making thin sections out of my tiny "hand" samples and to Erich Heydweiller for sending me several of those tiny samples.

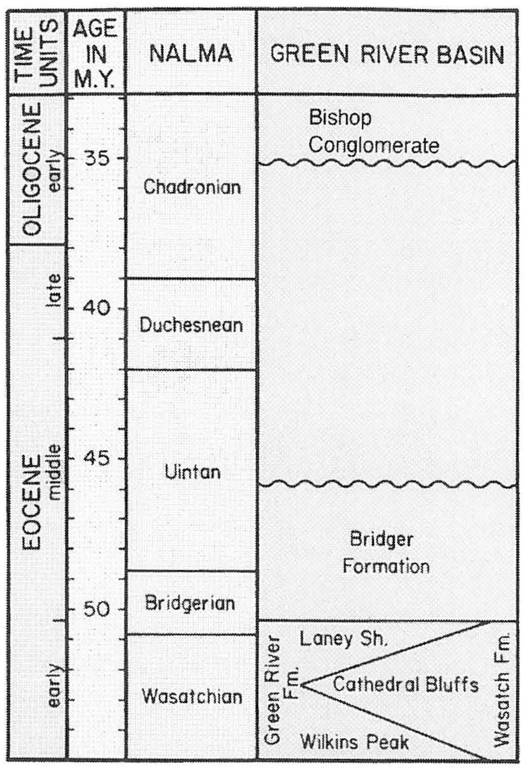

Figure 1: Time scale showing the relationship between NALMAs, radiometric ages and the Geologic time scale. Adapted from Groll and Steidtmann (1987).

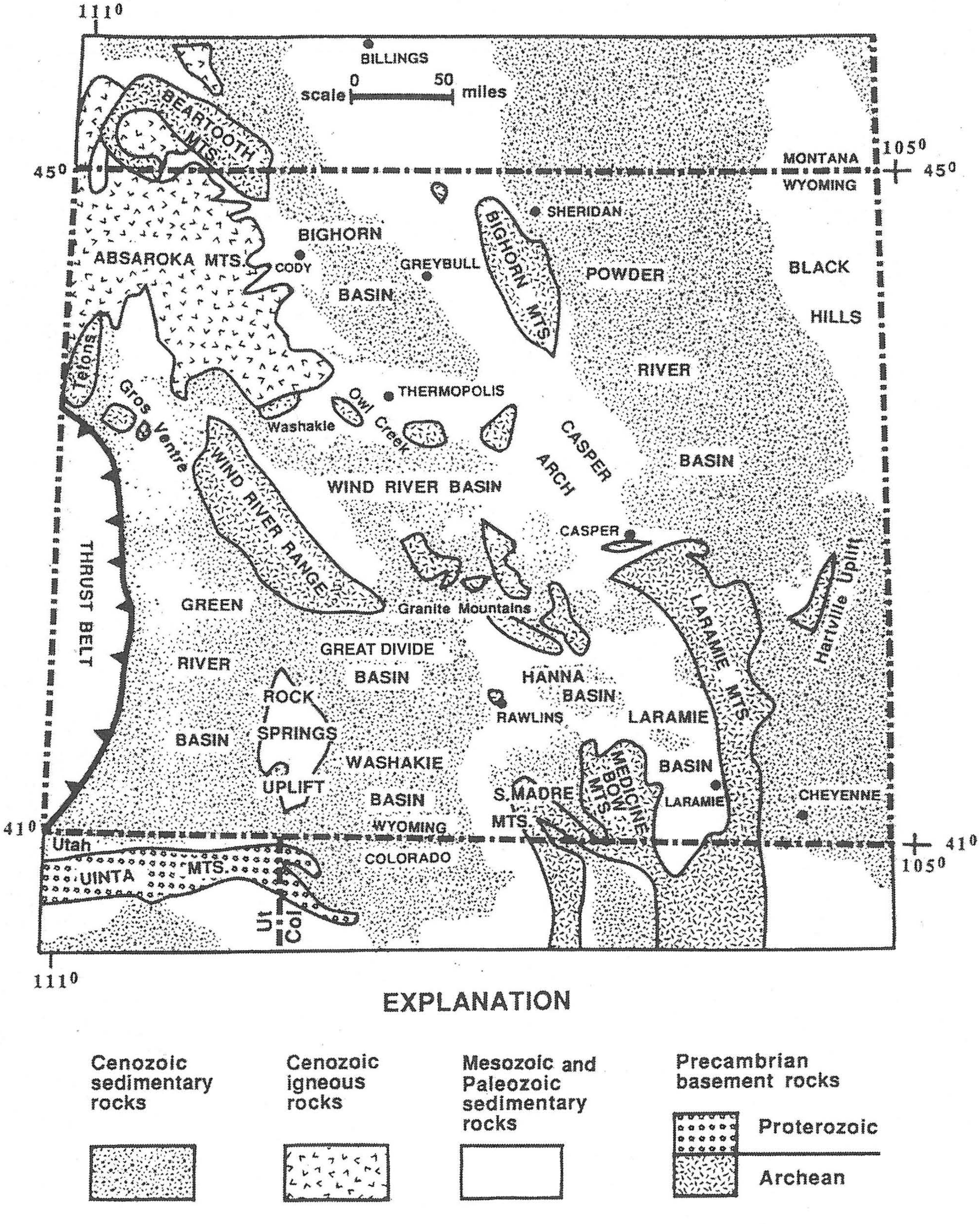

Figure 2: Map of Wyoming highlighting major geological features. Adapted from Brown (1993).

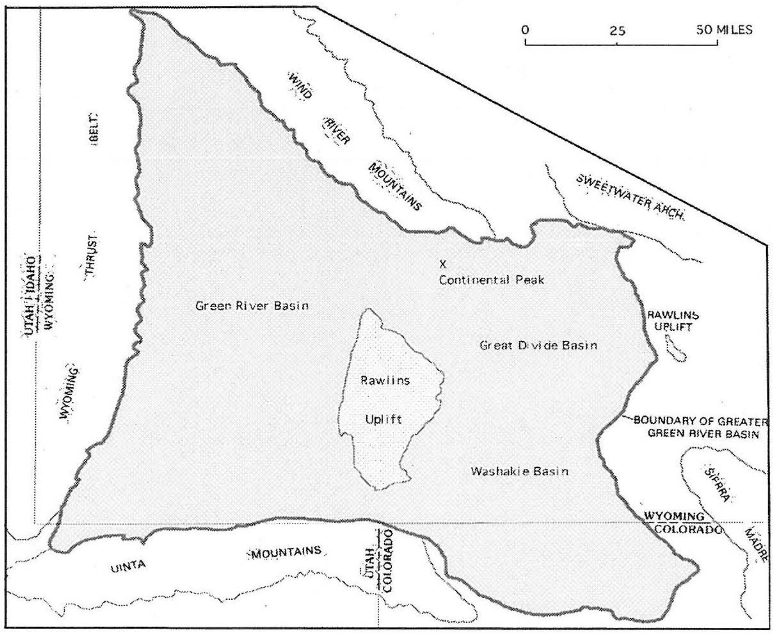

Figure 3a: The Green River basin of southwestern Wyoming. The Continental Peak study area is marked by X. Adapted from Roehlar (1992).

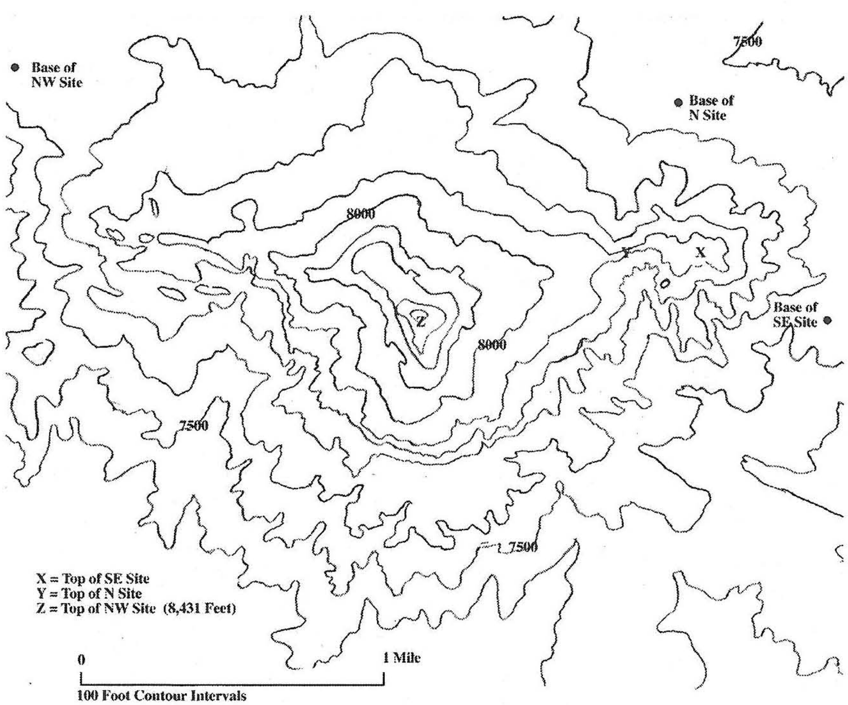

Figure 3b: Topographic map of the Continental Peak field area with the base and tops of each section labeled.

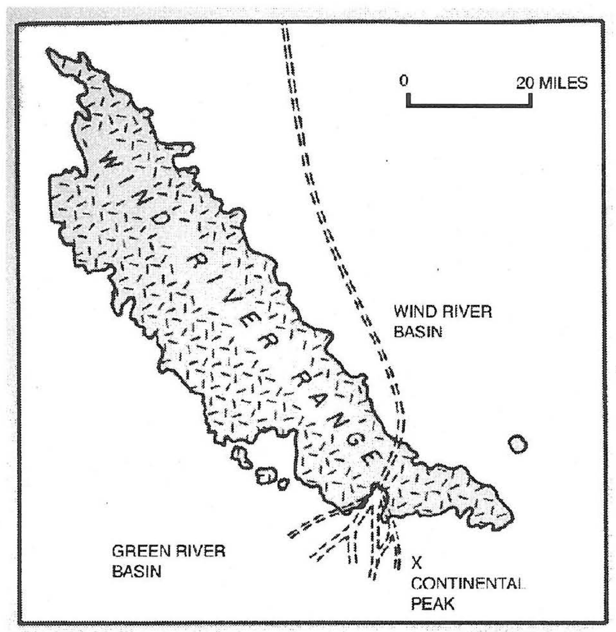

Figure 4: Simplified model of Eocene paleodrainage system from the north through the Wind River Range. Modified from Groll and Steidtmann, (1987).

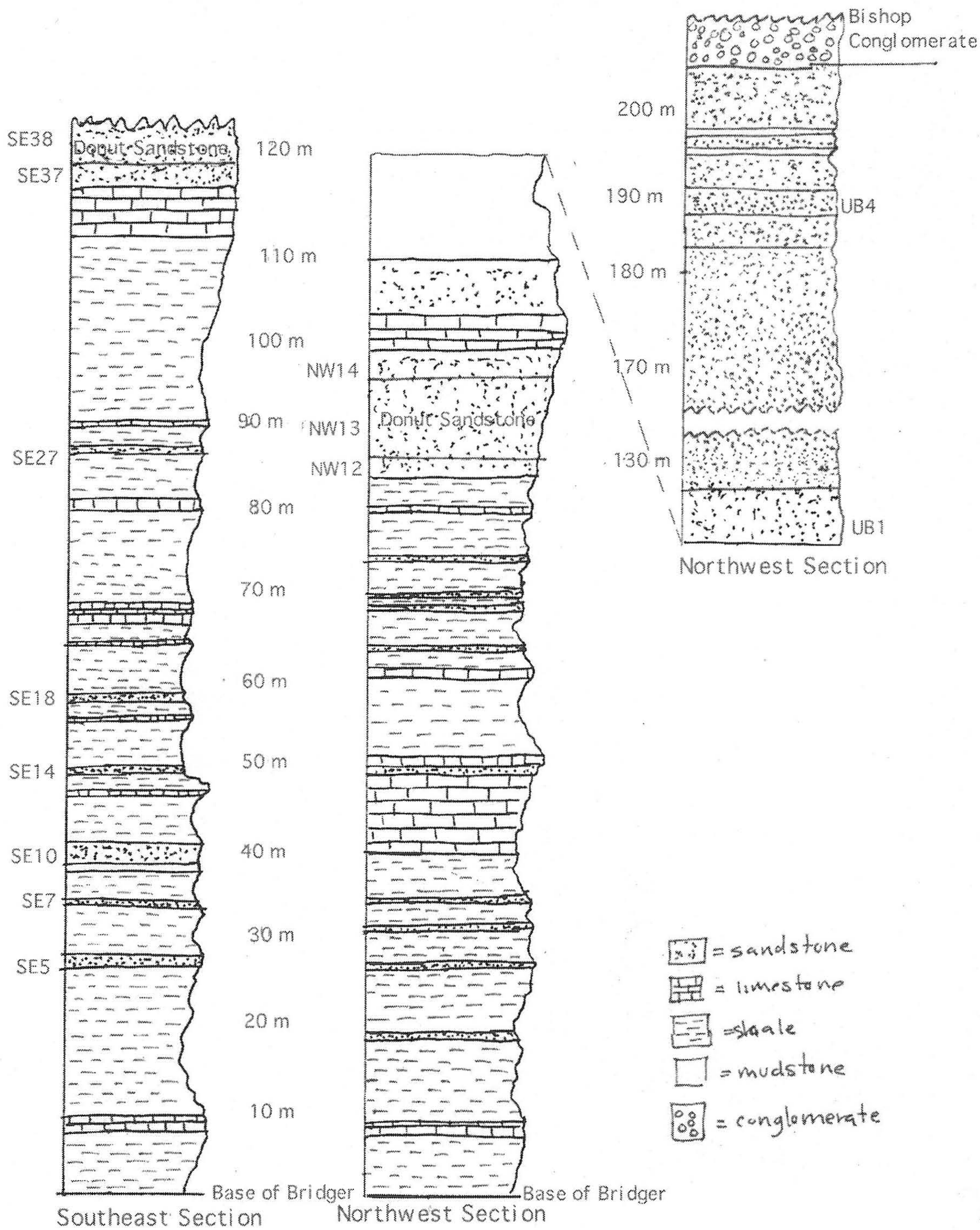

Figure 5: Stratigraphic columns of the Bridger Formation from the northwest (right) and southeast (left) sides of Continental Peak.

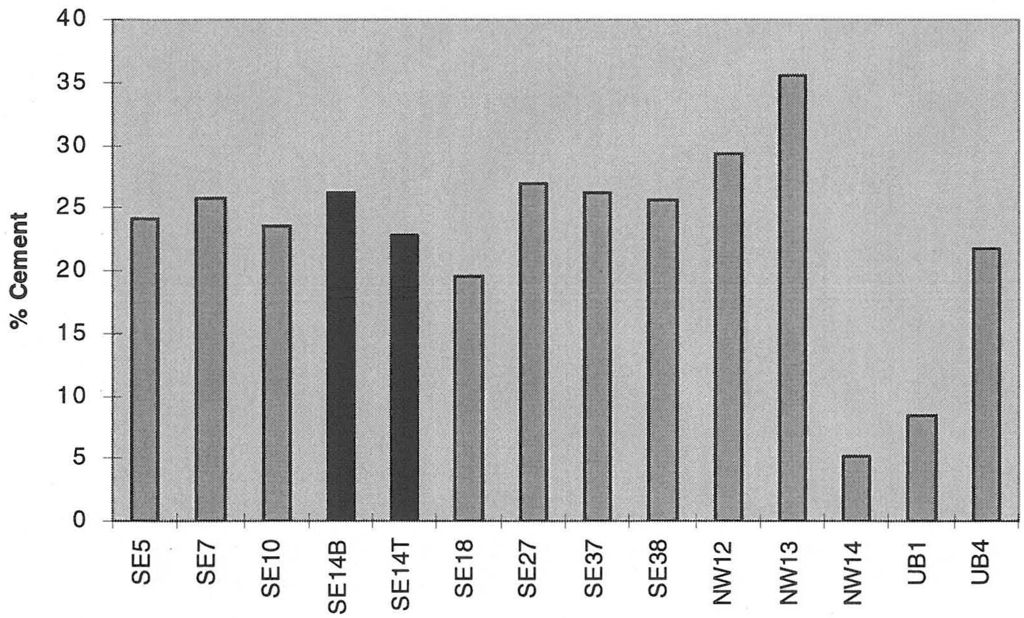

Figure 6: Bar chart of percent cement in each sample. The dark bars are samples with chalcedonic cement.

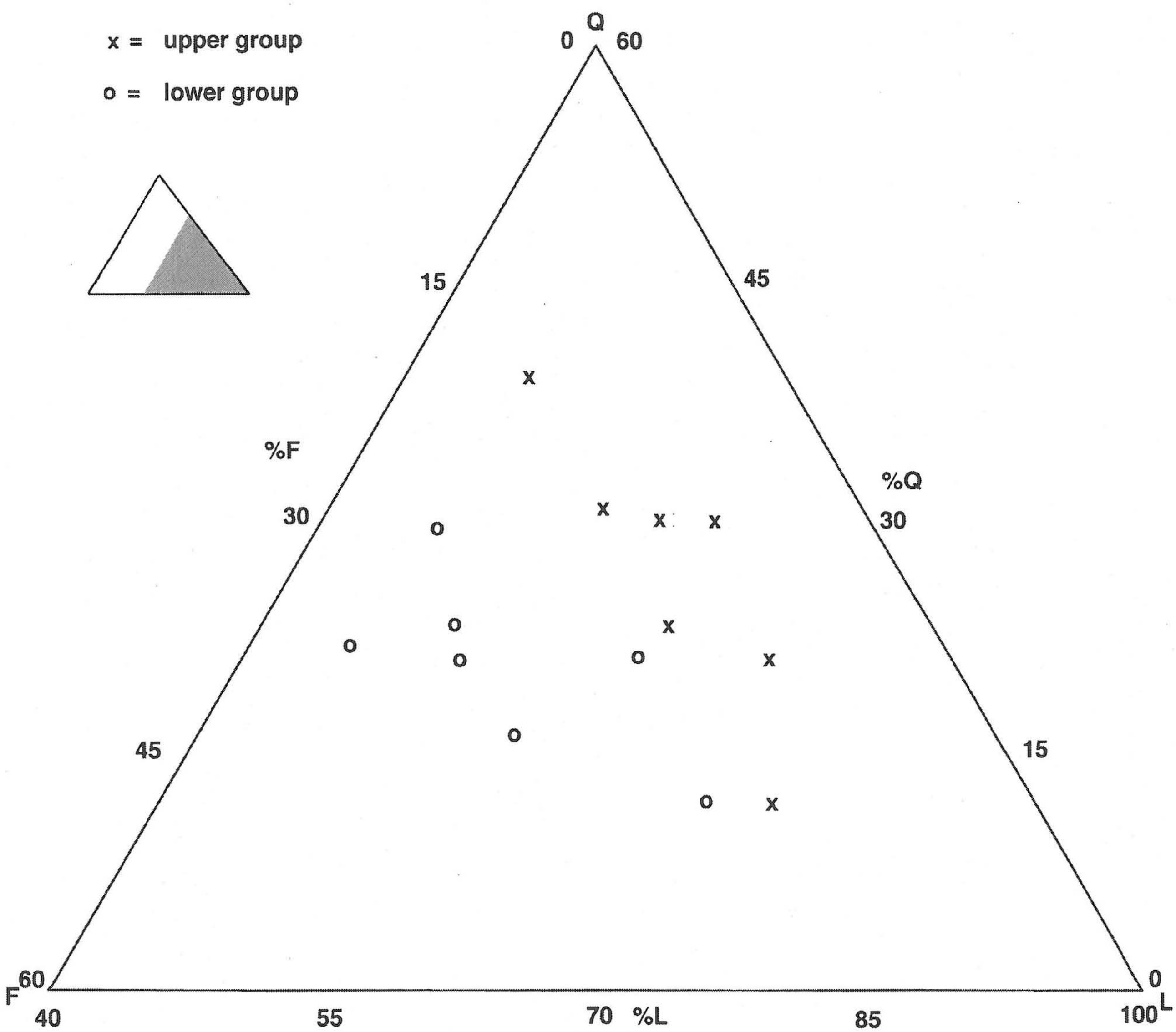

Figure 7a: QFL diagram of the Bridger sandstones. The samples are divided into two groups based on stratigraphic level. Group 1 corresponds to the lower part of the Bridger and Group 2 corresponds to the upper part of the Bridger. These categories are not the same as the "upper" and "lower" field divisions. The groups are divided by occurrence of shale, shale is common in the "lower" group but absent in the "upper" group.

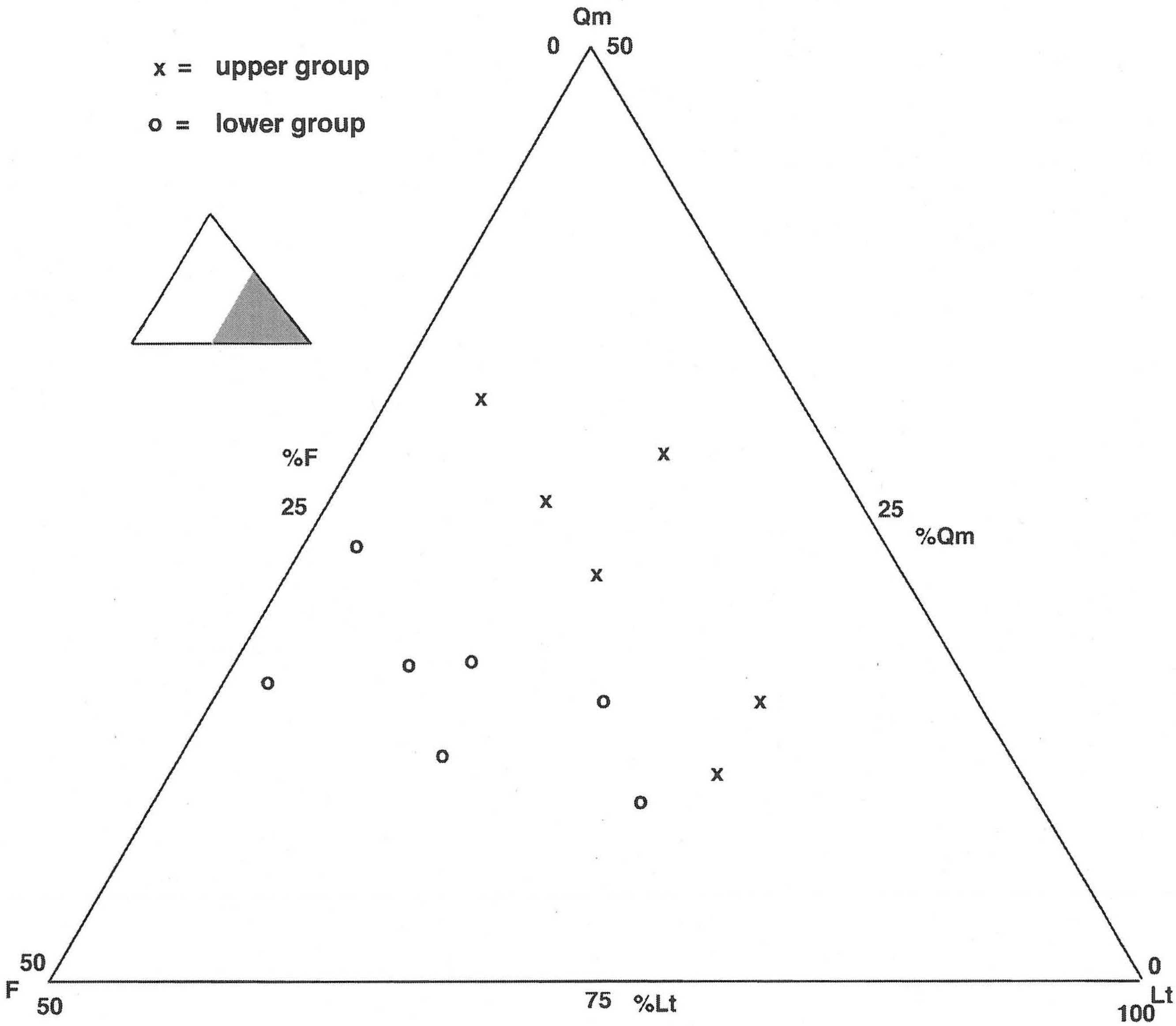

Figure 7b: QmFLt diagram of Bridger sandstones.

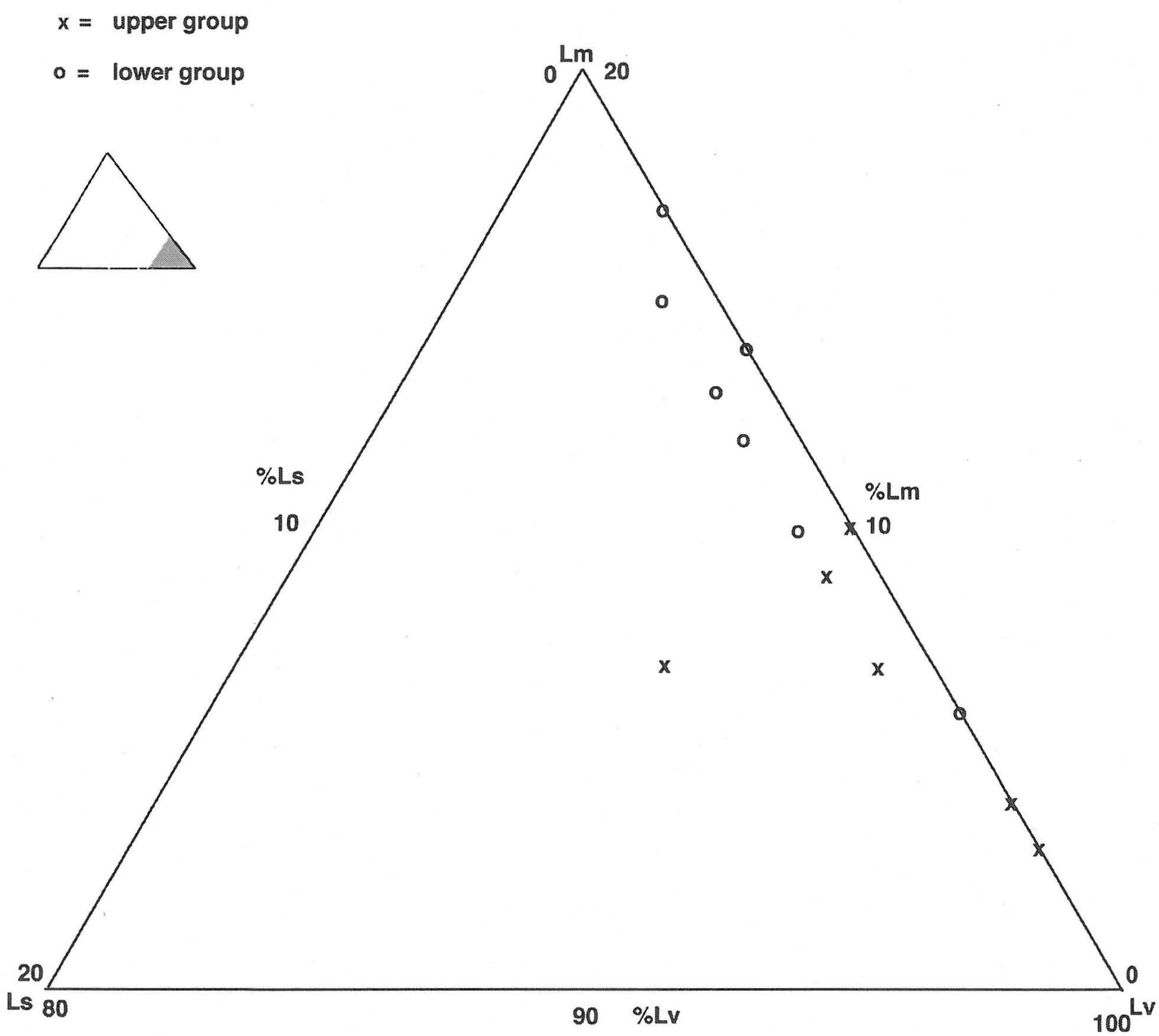

Figure 7c: LmLsLv diagram of Bridger sandstones.

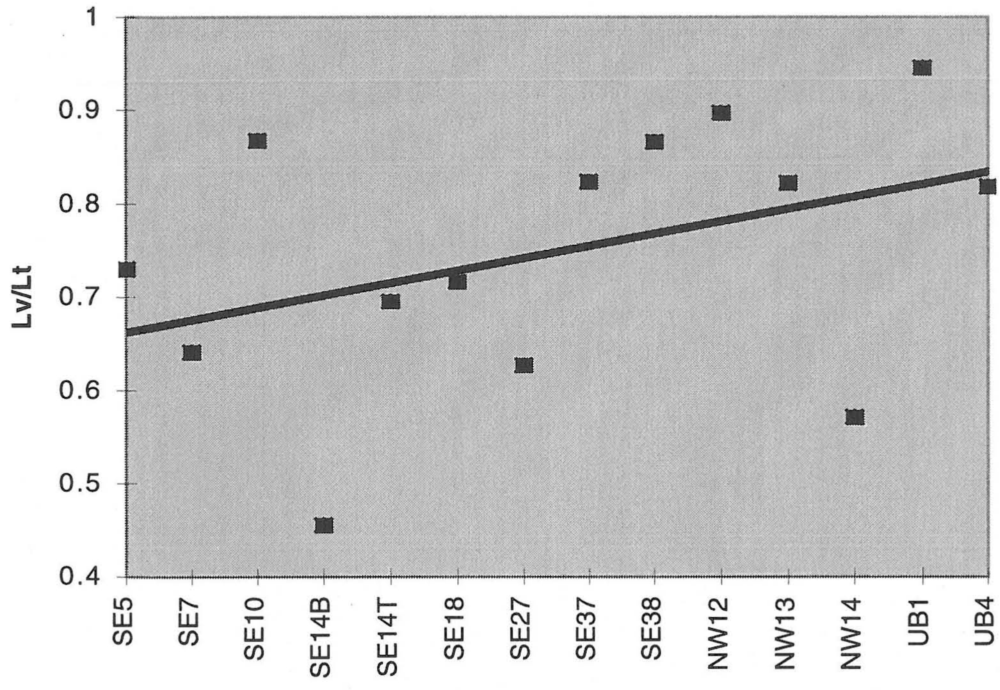

Figure 8: Graph showing increase in relative abundance of volcanic lithic fragments upsection in the Bridger.

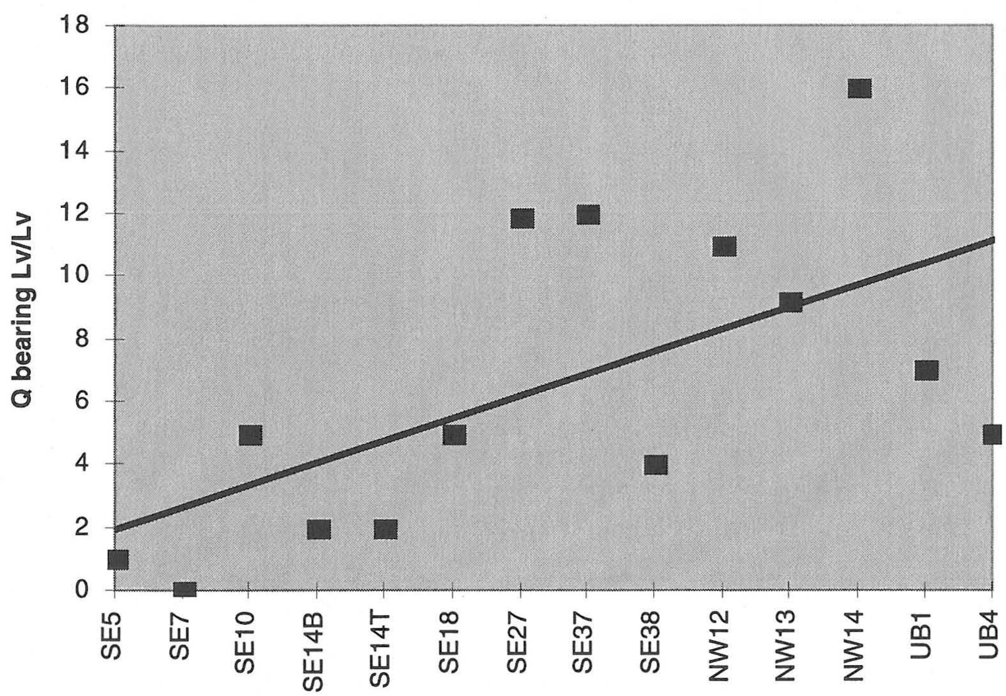

Figure 9: Graph showing the increase in relative abundance of quartz phenocryst bearing volcanic lithic fragments upsection.

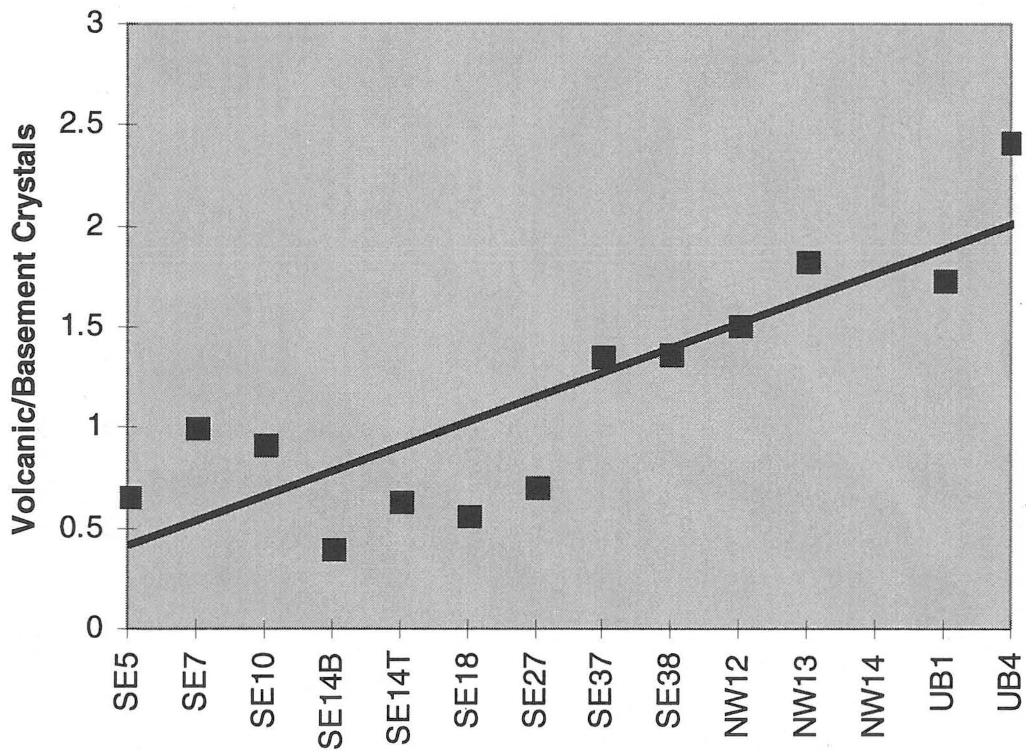

Figure 10: Graph showing the increase in abundance of volcanic quartz and feldspar crystals relative to basement derived crystals.

Author	Steidtmann & Middleton, 1991	Groll & Steidtmann, 1987	Steidtmann & Middleton, 1991	Wood, 1966	Koenig, 1960	Nace, 1939
OBSERVATIONS	• conglomerate deposits with volcanic and plutonic clasts • more tuffaceous up section. • lenses of pebbly sandstone and conglomerate with volcanic and plutonic clasts	• siltstone, sandstone, marlstone, limestone, claystone. • higher proportion of volcanogenic material in the upper Bridger • lenses of pebbly sandstone and gravel with volcanic and plutonic clasts.	• conglomerate deposits with volcanic and plutonic clasts • more tuffaceous up section. • lenses of pebbly sandstone and conglomerate with volcanic and plutonic clasts	• claystone, siltstone, marlstone, and limestone. • not abundant shale • channel sandstones near the middle • fine grained lacustrine sediments near the bottom & top	• freshwater limestone, marl, mudstone, and lacustrine shale and sandstone • channel sandstone • volcanic material	• sandstones, siltstones, clays, mudstones, shales and limestones. • poorly sorted not highly lithified clastic deposits • cross bedded sandstones • algal beds and petrified wood
INTERPRETATIONS		• initially fluvio-deltaic environment with increasing fluvial influence. • entirely fluvial upper Bridger		• fluctuations in lake level must have produced limestone marker beds containing ostracods and algal structures.	• sediments range from lacustrine to fluvial with some lacustrine to fluvial up section	

Table 1: Summary of sediment observation in the Bridger from various studies.

Main Categories	Volcanic Lithic Subdivisions	Monocrystalline Q and Feldspar Subdivisions
1) Monocrystalline Quartz (Qm)	1) Lv with F laths	1) Volcanic Qm
2) Polycrystalline Quartz (Qp)	2) F phenocrysts	2) Basement Qm
3) Feldspar (F)	3) Q phenocrysts	3) Ambiguous Qm
4) Volcanic Lithic (Lv)	4) Q and F phenocrysts	4) Volcanic F
5) Metamorphic Lithic (Lm)	5) Lv with phenocrysts & lathes	5) Basement F
6) Sedimentary Lithic (Ls)	6) Miscellaneous	6) Ambiguous F
7) Miscellaneous (M)		
8) Cement		

Table 2: Point count categories for Bridger sandstone grains.

Main Categories	SE5	SE7	SE10	SE14B	SE14T	SE18	SE27	SE37	SE38	NW12	NW13	NW14	UB1
Monocrystalline Quartz (Q)	43	59	54	32	47	85	52	51	90	86	33	128	89
Polycrystalline Quartz (Qp)	14	20	12	9	19	19	22	21	16	10	4	6	5
Feldspar (F)	90	86	84	61	54	86	105	36	50	53	42	38	59
Lv	183	147	156	211	169	143	129	212	177	167	217	183	249
Metamorphic Lithic (Lm)	20	24	10	35	23	30	23	22	15	18	8	5	9
Sedimentary Lithic (Ls)	1	2	0	0	2	0	1	4	3	0	0	99	0
Miscellaneous (M)	28	33	66	21	72	39	33	23	21	19	18	15	47
Cement (C)	121	129	118	131	114	98	135	131	128	147	178	26	42

Table 3: Main categories count data.

Volcanic Lithics	SE5	SE7	SE10	SE14B	SE14T	SE18	SE27	SE37	SE38	NW12	NW13	NW14	UB1	UB4
Lv with laths	58	52	65	56	55	64	68	34	62	64	46	59	60	40
F phenocrysts	12	14	5	8	8	6	10	7	17	8	22	1	16	7
Q	1	0	5	0	0	3	9	6	1	11	6	16	7	5
Q & F	0	0	0	2	2	2	3	0	3	0	3	0	0	0
Miscellaneous	1	5	7	9	10	6	1	0	6	8	13	2	8	41

Table 4: Volcanic lithic count categroies and data.

Volcanic Quartz Criteria:	Volcanic Feldspar Criteria:
Quenched magmatic inclusions Euhedral shapes Straight/ Parallel extinction Bubble wall texture	Quenched magmatic inclusions Oscillatory or growth zoning Euhedral Shapes Irregular, blocky twinning
Basement Quartz Criteria:	**Basement Feldspar Criteria**
Bubble tracks and trails Fluid inclusions Bent lattice, sweeping extinction Rounded outlines Polycrystalline	Thin, parallel, bent twins No zoning Grid twinning

Table 5: Criteria for basement versus volcanic derived grains.

Q & F	SE5	SE7	SE10	SE14B	SE14T	SE18	SE27	SE37	SE38	NW12	NW13	UB1	UB4
Volcanic Quartz	15	14	16	6	14	12	14	22	22	22	27	26	31
Metamorphic Quartz	31	29	34	47	42	38	36	27	27	27	23	21	16
Ambiguous Quartz	3	8	17	8	7	14	10	12	11	10	9	10	11
Volcanic Feldspar	21	25	19	17	20	17	21	27	26	28	26	26	27
Metamorphic Feldspar	23	10	4	11	11	13	13	9	8	6	6	9	8
Ambiguous Feldspar	7	14	10	11	6	6	6	1	6	7	9	8	7

Table 6: Basement vs. volcanic derived monocrystalline quartz and feldspar grain categories and counts data.

Sample	Grain Size
SE5	Lower coarse sand
SE7	Medium upper sand
SE10	Fine upper sand
SE14B	Course lower sand
SE14T	Course lower sand
SE18	Medium lower sand
SE27	Medium upper sand
SE37	Medium lower sand
SE 38	Medium upper sand
NW12	Medium lower sand
NW13	Medium upper sand
NW14	Fine lower sand
UB1	Medium upper sand
UB4	Medium upper sand

Table 7: Grain size of samples in ½ Wentworth grades.

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