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Stratigraphy and Tectonic Setting of the Lower Cretaceous
King Lear Formation, Jackson Mountains, northwest Nevada

by

Aaron James Martin

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE
MASTER OF ARTS

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May, 1999
ABSTRACT

Stratigraphy and Tectonic Setting of the Lower Cretaceous
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The Lower Cretaceous King Lear Formation (KLF) is a gently east-dipping succession of alluvial conglomerates and sandstones that were deposited in a small intra-arc basin. Supracrustal strata of Cretaceous age from within the western U.S. magmatic arc are extremely rare, so the KLF offers an opportunity to obtain palaeoenvironmental information about the Cretaceous arc. A new division of the KLF into three members based on clast provenance provides a framework for understanding deposition in the King Lear Basin and thus is essential for palaeoenvironmental studies on this portion of the arc. New structural observations and a shallow reflection seismic profile suggest that the KLF was deposited in a half-graben and never experienced compressive deformation. This conclusion means that compressive deformation both in the Jackson Mountains and also in the crustal-scale Luning-Fencemaker Fold and Thrust Belt must have been complete prior to the Early Cretaceous.
ACKNOWLEDGMENTS

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I wish to thank Honore Rowe, Diego Sanabria, Dr. John Bradford, Dr. Peeter Akerberg, Christine Reif, and Johanna Rogers for their assistance in the field. The Nufer Family and the Teichert Family of Denio, Nevada made the seismic experiment both possible and more enjoyable. The staff at the BLM office in Winnemucca, Nevada also helped make the 1997 field season possible.

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CHAPTER 1. GENERAL INTRODUCTION

Throughout most of the Mesozoic Period, the evolution of the Cordillera of western North America was controlled by interactions between relatively stable North American continental crust and oceanic crust that existed to the west of the continent (Burchfiel et al., 1992; Engebretson et al., 1985). The products of these interactions include a magmatic arc located near the boundary between the two types of crust and back-arc regions extending toward the craton (Fig. 1.1). Regions of the Cordillera ranging from the fore-arc through the arc and the back-arc region and onto the craton were deformed at different times throughout the Mesozoic as a result of stresses generated by the interaction between continental and oceanic crust (Burchfiel and Davis, 1975; Saleeby and Busby-Spera, 1992; Burchfiel et al., 1992). These Mesozoic paleogeographic elements, and in particular the Early Mesozoic elements, were dismembered by later plate boundary tectonics and distributed along the margin of North America (Oldow et al., 1984; Engebretson et al., 1985; Oldow et al., 1989; Schweickert and Lahren, 1993; Wyld et al., 1996). What remains is a discontinuous belt of early Mesozoic oceanic and arc terranes stretching from Sonora to Alaska (Oldow et al., 1989; Burchfiel et al., 1992; Saleeby and Busby-Spera, 1992).

One of these arc terranes is exposed in the Jackson Mountains in northwest Nevada (Fig. 1.1). The Jackson Mountains are dominated by Triassic and Jurassic volcanic and plutonic rocks formed in a magmatic arc setting (Quinn et al., 1997). Relations in the Jackson Mountains have become very important in regional syntheses (e.g. Saleeby and Busby-Spera, 1992; Burchfiel et al., 1992) because the age of compressive
Figure 1.1: Location of major Early Mesozoic features in the Western U.S. Cordillera, with Jackson Mountains (JM) shown. Frontal thrusts of the Luning-Fencemaker Fold and Thrust Belt are also shown. Modified from Quinn et al. (1997).
deformation in the Jackson Mountains is used to constrain the timing of regional shortening in major deformational belts such as the Luning-Fencemaker Fold and Thrust Belt (Fig. 1.1) (Oldow, 1983; 1984). The age of compressional deformation in the Jackson Mountains remains somewhat controversial, however. One interpretation is that shortening in the Jackson Mountains was complete prior to the Early Cretaceous (Quinn et al., 1997), while another interpretation holds that shortening continued throughout the Early Cretaceous (Willden, 1958; Russell, 1984; Maher, 1989). One of the major goals of this thesis is to resolve this controversy using data that constrains the tectonic setting for the deposition of Lower Cretaceous strata in the Jackson Mountains.

Another major goal of this thesis is to derive a detailed stratigraphy for Lower Cretaceous intra-arc sedimentary rocks that occur along the axis of the central Jackson Mountains (Fig. 1.2) These rocks are named the King Lear Formation. Although the Jackson Mountains have been the subject of numerous studies (Willden, 1958; 1963; 1964, Russell, 1984; Maher, 1989; Quinn et al., 1997), most of these researchers (with the notable exception of Willden) focused on structural relations involving the King Lear Formation rather than on the stratigraphy and sedimentology of the formation. The structural and tectonic relations established as a result of this previous work in the central Jackson Mountains provide a framework for the new interpretation of the sedimentology and stratigraphy of the King Lear Formation. The stratigraphy of the King Lear Formation is important because it is one of the few known exposures of Cretaceous supracrustal rocks within the magmatic arc. Further, this new work in the Jackson Mountains provides the basis for correlation of the King Lear Formation outside the Jackson Mountains and into the back-
Figure 1.2: Simplified geologic map of the central Jackson Mountains showing the position of the King Lear Formation along the central axis of the range. Modified from Quinn et al. (1997).
arc region, as first proposed by Willden (1958). This correlation outside
the arc impacts the timing of shortening deformation in the back-arc
region.

A third goal of this thesis is to tightly constrain the Middle Jurassic-
Early Cretaceous uplift history of the central Jackson Mountains using the
apatite fission track dating method on igneous rocks. Although it is known
that the Jackson Mountains were uplifted sometime between the Middle
Jurassic and Early Cretaceous because clasts from Middle Jurassic plutons
were deposited in the Lower Cretaceous King Lear Formation, it is not
known exactly when this uplift occurred. The apatite fission track method
could constrain the Mesozoic uplift history of the central Jackson
Mountains provided that the fission tracks in the apatite crystals were not
annealed between the middle Mesozoic and the present. The Mesozoic
uplift of the Jackson Mountains is most likely related to Mesozoic
compressive deformation observed in the Jackson Mountains, so dating the
uplift would place an important constraint on compressive deformation as
well. The apatite fission track method was not successful in constraining
the Middle Mesozoic uplift history of the central Jackson Mountains.
Instead, the apatites yielded Tertiary uplift ages, indicating that the fission
tracks were annealed after the Middle Mesozoic, probably during Basin and
Range extension.

The following three chapters describe the results of the work
undertaken to meet the goals described above. Chapter 2 is intended to be
a self contained manuscript capable of standing alone, although further
discussion in the other two chapters does contribute to a better
understanding of the concepts discussed in Chapter 2. Chapters 3 and 4 do
not stand alone; they are dependent upon relations described in Chapter 2.
CHAPTER 2

This chapter is concerned with the sedimentology and stratigraphy of the King Lear Formation. The King Lear Formation is divided into three new members based on the dominant sediment provenance for each stratigraphic interval and the differing sedimentary structures formed in each member as a result of changes in sediment source. The dominant depositional environment for the King Lear Formation is herein interpreted to be braided streams flowing across a proximal alluvial fan, although debris flow and hyperconcentrated flow deposits derived from a nearby volcanic center are also significant. One distinctive member, which is composed of conglomerates and sandstones whose clasts were derived external to the arc, is correlated outside the Jackson Mountains and into the back arc region. This correlation places an important constraint on the timing of shortening deformation in the back-arc region.

This chapter also presents new evidence about structures involving the King Lear Formation that suggest it was deposited in an extensional setting and at no time experienced compressive deformation. One new data set is a high resolution reflection seismic profile that indicates the King Lear Formation was deposited in a half-graben. New field observations also are introduced that suggest that the King Lear Formation never experienced shortening deformation. This new evidence confirms the conclusions of Quinn et al. (1997), who suggest that all compressive deformation in the Jackson Mountains was complete prior to deposition of the King Lear Formation in the Early Cretaceous. The timing of
shortening in the Jackson Mountains is used to constrain the timing of shortening in this portion of the Luning-Fencemaker Fold and Thrust Belt.

CHAPTER 3

This chapter is devoted to the apatite fission track geochronology performed on igneous rocks from the central Jackson Mountains. The goal of this work is to constrain the middle Mesozoic uplift of the Jackson Mountains because such a constraint would impact the timing of shortening in the Jackson Mountains. Attainment of this goal is complicated by the low annealing temperature of fission tracks in apatite. Chapter 3 shows that fission tracks in apatite crystals from igneous rocks located in the central Jackson Mountains were annealed after the uplift of the central Jackson Mountains during the Middle Mesozoic. The apatite fission track geochronology indicates that the Jackson Mountains were last uplifted and cooled during Tertiary Basin and Range extension. Although the apatite fission track method constrains very well the Tertiary uplift of the Jackson Mountains, this was not the goal of the project so not all samples collected from the Jackson Mountains were dated.

CHAPTER 4

This chapter describes small but significant modifications to the map of the northern part of the King Lear Basin that was made by Quinn (1996). These modifications provide explanations for questions that arise upon careful examination of the old map in light of the new stratigraphy for the King Lear Formation described in Chapter 2. Chapter 4 shows that
the Jackson Creek Member is in fact present at the base of the King Lear Formation in the northern part of the basin as it is in the central part of the basin. Chapter 4 also provides a possible structural explanation for the double thickness of the King Lear Formation in the northern part of the basin. These slight modifications to the map of Quinn (1996) are important because they explain features on that map without necessitating the reevaluation of the stratigraphy of the King Lear Formation described in Chapter 2.
CHAPTER 2. STRATIGRAPHY AND STRUCTURAL SETTING OF THE LOWER CRETACEOUS KING LEAR FORMATION, NORTHWEST NEVADA

CHAPTER SUMMARY

The Lower Cretaceous King Lear Formation is a horizontal to gently east-dipping succession of alluvial conglomerates and sandstones that were deposited in a small intra-arc basin located in the Jackson Mountains in northwest Nevada. The Jackson Mountains and the surrounding Black Rock Desert region are a segment of the Cretaceous Cordilleran magmatic arc of western North America. Outside the Jackson Mountains, in the remainder of the magmatic arc, supracrustal strata of Cretaceous age are extremely rare. The King Lear Formation, then, represents rare deposits of Cretaceous intra-arc supracrustal strata and thus could be instrumental in providing information about paleoenvironmental conditions in the Cretaceous arc.

Measured stratigraphic sections, point counts of sandstones and conglomerates, and correlations of stratigraphic sections permit the division of the King Lear Formation into three members based on clast provenance. The lowermost member, the Jackson Creek Member, was derived entirely from the erosion of older arc igneous rocks in the Jackson Mountains. 80% of the clasts for the middle member, the Krum Hills Member, were derived external to the arc, probably from exposures of the Roberts Mountain Allochthon to the southeast of the Jackson Mountains. The uppermost member, the Clover Creek Member, is dominated by volcaniclastics derived from an active volcanic center located at the
southern end of the King Lear Basin. My new division of the King Lear Formation provides a framework for understanding deposition in the King Lear Basin and thus could be extremely useful for determining paleoenvironmental conditions in this portion of the Cretaceous Cordilleran magmatic arc. Additionally, correlation of the Krum Hills Member outside the Jackson Mountains and into the back-arc region places an important age constraint on compressive deformation in the back-arc region.

Understanding the middle to late Mesozoic tectonic evolution of the western U.S. Cordillera depends in part on constraints on the timing of compressive deformation in the Jackson Mountains. This dependence stems from the realization that compressive deformation in the Jackson Mountains is related to shortening in major crustal-scale compressional belts such as the Luning-Fencemaker Fold and Thrust Belt (Oldow, 1983; 1984). Older interpretations that compressive deformation affected the Lower Cretaceous King Lear Formation led Oldow (1983; 1984) to conclude that the Luning-Fencemaker Fold and Thrust Belt was active during the Cretaceous. This conclusion gained widespread acceptance in regional syntheses, in which the Luning-Fencemaker Fold and Thrust Belt is widely held to be an expression of shortening in the Sevier Hinterland. However, recent work in the Jackson Mountains (Quinn et al., 1997) suggests that the King Lear Formation never experienced compressive deformation, indicating that all compressive deformation in the Jackson Mountains was complete prior to the Early Cretaceous.

I present new structural observations and a shallow seismic reflection profile that provide new insights into the timing of compressive deformation in the Jackson Mountains. These new data suggest that the King Lear Formation never experienced compressive deformation and thus
that all compressive deformation in the Jackson Mountains must have been complete prior to the Early Cretaceous. This conclusion means that deformation in the Luning-Fencemaker Fold and Thrust Belt also must have been complete prior to the Early Cretaceous.

INTRODUCTION

One important paleogeographic feature present along the western margin of North America during the Mesozoic period was a magmatic arc that formed as a result of subduction of oceanic plates beneath continental North America (Burchfiel and Davis, 1975; Engebretson et al., 1985; Burchfiel et al., 1992). This Mesozoic magmatic arc was later dismembered by plate boundary tectonics, distributing pieces of the arc along the continental margin from Sonora to Alaska (Oldow et al., 1984; Engebretson et al., 1985; Oldow et al., 1989; Wyld et al., 1996). An important characteristic of the magmatic arc during the Cretaceous period is that supracrustal strata from within the arc are very rare; most arc rocks of Cretaceous age are plutonic. This dearth of supracrustal arc rocks of Cretaceous age has resulted in a lack of information about Cretaceous paleoenvironments within the arc province of western North America.

One of the now dispersed Mesozoic magmatic arc terranes is present in the Jackson Mountains, located at the eastern edge of the Black Rock Desert in northwest Nevada (Fig. 2.1). The Jackson Mountains portion of the arc is remarkable because it contains very rare exposures of arc derived supracrustal strata of Cretaceous age, the Lower Cretaceous King Lear Formation (Fig. 2.2). The King Lear Formation dominantly consists of arc derived alluvial sandstones and conglomerates that were deposited in
Figure 2.1: Location of major Mesozoic geographic features in the western U.S. Northwest Nevada ranges discussed in text are: JM- Jackson Mountains, KH- Krum Hills, and SR- Sonoma Range.
Figure 2.2: Generalized geologic map of the central Jackson Mountains modified from Quinn (1996).
a small intra-arc basin. The King Lear Formation thus provides an uncommon opportunity to study paleoenvironments within the province of the Cretaceous magmatic arc.

The King Lear Formation has become very important both in structural interpretations of the Jackson Mountains and in regional tectonic syntheses because it is at the center of controversy involving the timing of shortening deformation in the Jackson Mountains and in northwest Nevada. Some previous workers suggest that compressional deformation affected both the Cretaceous King Lear Formation and older arc igneous rocks, resulting in cleavage formation, folding of bedding, and thrusting of the older arc rocks over the younger King Lear Formation (Willden, 1958; 1963; 1964; Russell, 1984; Maher, 1989). Other workers conclude that the Lower Cretaceous King Lear Formation never experienced compressional deformation and that a normal fault separates the King Lear Formation from older arc rocks at one edge of the basin (Quinn et al., 1997). Figure 2.3 highlights the differences between these conflicting interpretations by comparing cross sections from Russell (1981, 1984), Maher (1989), and Quinn et al. (1997). The implications of the later interpretation that the King Lear Formation never experienced compressional deformation are profound: the shortening observed in the older arc rocks must then be older than the age of the King Lear Formation. The age of shortening deformation in the Jackson Mountains is critical because it has been used to constrain the timing of shortening in major deformational belts such as the Luning-Fencemaker Fold and Thrust Belt (Oldow, 1983; 1984). In fact, based on the interpretation of compressional deformation affecting the Cretaceous King Lear Formation, shortening in the Luning-Fencemaker Fold and Thrust Belt is widely believed to be an expression of shortening
**Figure 2.3:** Cross sections along the same line of section (A-A', Fig. 2.2) from three previous studies in the Jackson Mountains, generalized from Quinn (1996). Symbols are identical to those in Figure 2.2.
in the Sevier hinterland, coeval with the Sevier Fold and Thrust Belt (Oldow, 1983; 1984). This interpretation has gained widespread acceptance in regional tectonic syntheses, significantly impacting our understanding of the Sevier orogeny and thus orogenic processes in general (Burchfiel et al., 1992; Saleeby and Busby-Spera, 1992; Cowan and Bruhn, 1992). However, the critical issue of the timing of compressional deformation in the Jackson Mountains remains somewhat controversial.

This chapter presents new evidence that impacts both the issue of paleoenvironment in the Cretaceous magmatic arc of western North America and the issue of the timing of shortening deformation in the Luning-Fencemaker Fold and Thrust Belt. Stratigraphic analysis of the King Lear Formation results in a new division of the King Lear Formation into three members based on sediment provenance. This new division illustrates the changing nature of deposition in the intra-arc King Lear Basin and provides a framework for further investigations into the paleoenvironment of the Cretaceous magmatic arc. New structural observations, including the interpretation of a shallow reflection seismic profile, strongly support the interpretation that the King Lear Formation in the Jackson Mountains was deposited in a half-graben and never experienced compressive deformation. Correlation of the King Lear Formation outside the Jackson Mountains and into the back-arc region (Fig. 2.1) using the stratigraphic framework developed in this chapter places a constraint on the timing of shortening deformation in the back-arc region, since the King Lear Formation is undeformed there as well. Since compressional deformation in both the arc and in the back-arc region was a result of shortening in the Luning-Fencemaker Fold and Thrust Belt (Oldow, 1983; 1984), the conclusion that compressive deformation in both
regions was complete prior to deposition of the Lower Cretaceous King Lear Formation means that shortening in the Luning-Fencemaker Fold and Thrust Belt must now be regarded as older than Early Cretaceous.

**STRATIGRAPHY OF THE KING LEAR FORMATION IN THE JACKSON MOUNTAINS**

Although the Jackson Mountains have been the subject of much research in the past forty years, most workers after Willden focused more on the structural problems in the central part of the range, including the ones discussed above, than on the sedimentology and stratigraphy of the King Lear Formation. However, detailed examination of the King Lear Formation, including measurement and description of stratigraphic sections and point counting of sandstones and conglomerates, reveals several significant features about the King Lear Formation. I found no regional unconformities, soil horizons, or depositional hiatuses within the King Lear Formation. This means that the entire formation probably was deposited very rapidly. This conclusion confirms the work of Russell (1984) and Quinn et al. (1997), who conclude that the entire King Lear Formation was deposited during the Early Cretaceous. Another conclusion is that one member of the King Lear Formation was derived from a source external to the magmatic arc, probably from the Roberts Mountain Allochthon. This conclusion affirms earlier work by Willden (1958, 1963, 1964). Stratigraphic correlation of this externally derived member in the Jackson Mountains with an identical exposure outside the Jackson Mountains that unconformably overlies deformed back-arc sediments allows me to place an upper age constraint on deformation in the back-arc region.
Previous Work and New Division of the King Lear Formation

Willden (1958, 1963, 1964) defines the King Lear Formation as Lower Cretaceous arc derived clastic sediments unconformably deposited on older arc igneous rocks. He also defines the Pansy Lee Conglomerate as conformably overlying the King Lear Formation and dominantly composed of clasts derived external to the arc, but it is unclear whether the Pansy Lee Conglomerate was deposited in the Cretaceous or in the Tertiary. Russell (1984) recognizes that both the King Lear Formation and the Pansy Lee Conglomerate were deposited during the Cretaceous and adds the Pansy Lee Conglomerate into the definition of the King Lear Formation. All later workers accept this addition. However, the important fact that one part of the King Lear Formation has a very different provenance than the rest of the King Lear Formation has been overlooked in the addition of the Pansy Lee Conglomerate and in the focus on the structural geology of the Jackson Mountains.

In order to maintain consistency and reduce confusion, I retain the definition of the King Lear Formation as used by the later workers in the Jackson Mountains, preserving the addition of the Pansy Lee Conglomerate to the definition of the King Lear Formation. Thus the King Lear Formation as defined by Quinn et al. (1997) is exactly the same as the King Lear Formation as I define it. However, I divide the King Lear Formation in the Jackson Mountains into three members based on sediment provenance (Figs. 2.4, 2.5). This division not only illustrates the changing nature of sedimentation in the King Lear Basin but also facilitates the
Figure 2.4: Measured sections B and C in the King Lear Formation, central Jackson Mountains. Location of B and C is given in Figure 2.2. Crossed-out units are mostly covered.
Figure 2.5: Correlation of the King Lear Formation between the Jackson Mountains (Section C) and the Krum Hills.
recognition and correlation of the King Lear Formation outside the Jackson Mountains.

**Jackson Creek Member**

The Jackson Creek Member represents the earliest sedimentation in the King Lear Basin after initiation of extension and subsidence. The defining characteristic of the Jackson Creek Member is that its clasts were derived entirely from local, older arc sources. It is named for spectacular outcrops above the south fork of Jackson Creek. The Jackson Creek Member is distinctively red colored because of its ubiquitous hematite cement. The basal contact is erosive; it is the angular unconformity between older arc igneous rocks and the King Lear Formation (Fig. 2.6). The upper contact is the base of the Krum Hills Member, defined as the first occurrence of clasts derived from sources external to the arc.

**Description** The Jackson Creek Member consists of boulder conglomerates to fine sandstones, with rare interbedded limestones. The conglomerates are dominantly clast supported, poorly sorted, and angular to well-rounded. Trough-shaped channel structures are common. These channels typically are filled by fining upward sequences, sometimes from boulders through medium sands. The channels frequently stack vertically and pinch out laterally over one another. Individual channel thickness averages approximately 1/2 meter. Paleocurrent indicators are not common in these beds. Where observed within a single outcrop, paleocurrent direction of different channels often varies widely.

The sandstones of the Jackson Creek Member are also poorly sorted and angular to subrounded. Channels are less common in the sands than in
Figure 2.6: The King Lear unconformity south of Parrot Peak. Undeformed conglomerates of the King Lear Formation unconformably overlie the Happy Creek Complex, which exhibits a prominent cleavage. Card is 8.5 cm long.
the conglomerates, and individual channels are slightly smaller in the sandstones. Like the conglomerates, the sandstones are dominantly composed of stacked channels. In places, channels filled with cobble to pebble size clasts are stacked between channels filled with coarse to medium sand.

Contained within the boulder conglomerates are rare debris flows. These flows have a muddy matrix, are matrix supported, and contain clasts ranging up to boulder size. The clasts within the debris flows invariably are identical to the clasts within the surrounding clast supported conglomerates. The thickness of the debris flows averages approximately one meter.

The Jackson Creek Member also contains very rare limestones interbedded with the conglomerates. These limestones yield Lower Cretaceous freshwater gastropods (Willden 1958, 1963, 1964). The limestones are very rare and very poorly exposed. They are not observed at all in the outcrops above the south fork of Jackson Creek, and where present, they usually are represented as float. At the one good outcrop I observed, located in the northern part of the King Lear Basin, the limestone was about 10 meters thick. It was composed dominantly of lime mud, with few fossils evident. Near the base, several pebble to cobble size clasts of plutonic origin were contained within the limestone.

**Depositional Environment** From the preceding data I conclude that the depositional environment for the Jackson Creek Member was a proximal alluvial fan sourced entirely from surrounding older arc rocks in the Jackson Mountains. The clast supported conglomerates and sandstones represent stacked braided stream channels. The variation in clast size filling the braid channels is most likely a result of changing rainfall
patterns in the King Lear drainage basin. The debris flows, composed of exactly the same clasts as the braided channels, also are likely the result of changing amounts of rainfall in the basin. The limestones represent intermittent freshwater lakes that filled the King Lear Basin for short periods, either as a result of climate change or of damming of the streams within the basin.

Krum Hills Member in the Jackson Mountains

The Krum Hills Member represents a profound change in clast provenance as compared to the two other members of the King Lear Formation. Whereas the other members are composed entirely of local, arc derived clasts, 80% of the clasts in the Krum Hills Member were derived from sources external to the arc. Clast size variations, clast lithology correlations, and paleocurrent data reveal that the source for these exotic clasts lay to the southeast of the Jackson Mountains. The most likely provenance is the Roberts Mountain Allochthon, the closest exposure of which presently is located 80 km southeast of the Jackson Mountains in the Sonoma Range (Fig. 2.1).

The Krum Hills Member is named for exposures in the Krum Hills, presently located 60 km southeast of the Jackson Mountains in the back-arc region (Fig. 2.1). It is roughly equivalent to the basal parts of the old Pansy Lee Conglomerate in Willden's nomenclature (1958, 1963, 1964). The base of the Krum Hills Member is defined as the first occurrence of external to the arc clasts. In the Krum Hills and in the southern part of the King Lear Basin, the basal contact is erosive, but in the northern part of the basin it is conformable with the Jackson Creek Member. In the Jackson
Mountains, the top contact is with the Clover Creek Member, defined as the first occurrence of clasts derived from the Clover Creek volcanic center.

**Description** The Krum Hills member is composed of boulder conglomerates, sandstones, and siltstones. The conglomerates and sandstones are clast supported, poorly sorted stacked channel fills. Individual channels commonly are filled by crude fining upward sequences (Fig. 2.7a). Clasts derived from within the arc are angular to subrounded while clasts derived external to the arc are well rounded. Foreset beds and clast imbrication are common. The average paleocurrent direction is to the northwest, although individual paleocurrent directions within a single outcrop vary widely, up to 40°.

In the southern to central King Lear Basin, the basal contact of the Krum Hills Member is erosive into the Jackson Creek Member. In the central to northern King Lear Basin, however, the basal contact is conformable. Here, several channels filled with externally derived clasts stack together to form lenses 2-3 meters thick. These lenses interfinger with lenses composed of stacked channels filled entirely with local, arc derived conglomerates. These locally derived lenses are indistinguishable from the Jackson Creek Member. Thus on a 2-3 meter scale, the base of the Krum Hills Member interfingers with and is conformable with the top of the Jackson Creek Member.

Within the conglomerates, there is a decrease in clast size from south to north within the King Lear Basin. In the southern part of the basin, average clast size is cobble, and the largest clasts reach 30 cm. In the northern part of the basin, average clast size is small pebble, and maximum clast size is only 10 cm. This northward decrease in clast size suggests that the sediment source was from the south.
Figure 2.7a: Fining upward channel fill from the Krum Hills Member in the Jackson Mountains. 80% of the clasts were derived external to the arc. Hammer is 35 cm long.
Figure 2.7b: Photomicrograph of a thin section from a quartzite boulder taken from the Krum Hills Member exposed in the Jackson Mountains. Note that quartz makes up approximately 90% of the grains. Crossed polars. A quartz plate has been inserted to enhance interference colors. 31.25X.
The siltstones in the Krum Hills Member are brown to black and devoid of fossils. They contain scattered sand size quartz grains. The siltstones usually are eroded by channel cuts filled with externally derived conglomerate or sand.

**Provenance**  Clasts within the Krum Hills Member are very distinctive. The clasts that I conclude were derived external to the arc are completely unlike any rocks exposed in the Jackson Mountains. There are three exotic clast types: orthoquartzite, chert, and milky quartz. Clast lithology is very easy to recognize in the conglomerates. The same clasts make up the sandstones, but thin sections are required to determine clast lithology.

One common clast type in the Krum Hills Member is orthoquartzite. These quartzites are medium grained and consist of about 90% quartz (Fig. 2.7b). On many boulders and cobbles, relict bedding, approximately 1 cm thick, still can be observed. Another common clast type is chert. This chert is usually gray or black, although rarely it is red or green. A clast type that is less common is opaque white, or milky, quartz. Boulders of milky quartz are not observed; the maximum clast size for the milky quartz is small cobble. In thin section, the milky quartz resembles vein quartz. Together, these three clast types make up 80% of the Krum Hills Member. The other 20% is local, older arc derived clasts.

The most likely source for the orthoquartzite clasts in the Krum Hills Member is the Ordovician Valmy Formation in the Roberts Mountain Allochthon. Willden (1958, 1963, 1964) first suggested the Valmy Formation as a likely source for the exotic clasts. The Roberts Mountain Allochthon is the closest sediment source that possibly could have supplied extremely large orthoquartzite boulders to the Krum Hills and Jackson...
Mountains. One argument in support of the Roberts Mountain Allochthon as provenance is that sedimentologic evidence in the Krum Hills Member indicates that the source for the exotic clasts was to the southeast of the Jackson Mountains, in the direction of the Roberts Mountain Allochthon. The first piece of sedimentologic evidence is that the Krum Hills Member is present in the Krum Hills, far to the southeast of the arc, where 1/2 meter boulders are common (see following section on the Krum Hills). Second, paleocurrent directions in the Krum Hills Member indicate a source to the southeast. Third, clast size also increases to the southeast. The closest exposure of the Roberts Mountain Allochthon currently lies 80 km southeast of the Jackson Mountains in the Sonoma Range south of Winnemucca (Fig. 2.1). Removing Tertiary Basin and Range extension of 100% east-west (Wernicke, 1992), this part of the Roberts Mountain Allochthon was located approximately 60 km southeast of the Jackson Mountains during the Cretaceous.

The lithology of the Valmy Formation matches well the lithology of the orthoquartzite clasts in the Krum Hills Member. The Valmy Formation consists of chert-argillite sequences and interbedded orthoquartzite, greenstone, and limestone turbidite rocks (Roberts, 1964; Ketner, 1966; Madrid, 1987). The thickness of individual quartzite beds ranges from a fraction of an inch to 50 feet and the aggregate thickness of quartzite beds in the Valmy Formation is thousands of feet (Roberts, 1964; Ketner, 1966). Thus there are abundant orthoquartzite beds in the Valmy Formation from which large boulders could be derived. The orthoquartzite clasts in the Krum Hills Member are indistinguishable from the interbedded orthoquartzites in the Valmy Formation (cf. Fig. 2.7b from this study with Fig. 5 from Ketner, 1966). Orthoquartzite boulders from the Ordovician
Valmy Formation commonly are found in younger strata throughout Nevada, such as the latest Devonian to Permian Havallah sequence and equivalents in the Golconda Allochthon (Fagan, 1962; Miller et al., 1984).

Most of the chert clasts in the Krum Hills Member also likely were derived from the Roberts Mountain Allochthon. The Valmy Formation is the closest stratum that contains abundant chert (Roberts, 1964; Ketner, 1966; Madrid, 1987). Another possibility is that some of the chert came from the Golconda Allochthon, which is also present in the Sonoma Range. The Havallah Sequence in the Golconda Allochthon contains abundant chert (Brueckner and Snyder, 1985), but it is currently exposed farther south in the Sonoma Range, farther away from the Krum Hills and the Jackson Mountains.

The milky quartz cobbles resemble vein quartz that is very common in the back-arc region. Of course, most areas in northwest Nevada contain some amount of quartz veins, but the back-arc region contains abundant quartz veins which are also very large, up to dike size. The milky quartz clasts in the Krum Hills Member contain reddish brown inclusions that are indistinguishable from inclusions usually found in the back-arc quartz veins. Additionally, milky quartz clasts are more abundant in the Krum Hills outcrops, where they are unconformably deposited on back-arc rocks, than in the Jackson Mountains (see following section on the Krum Hills). Thus the most likely source for the milky quartz clasts is vein quartz derived from the back-arc region.

**Depositional Environment** The depositional environment for the Krum Hills Member was a distal alluvial fan derived from a source external to the arc. The clast supported conglomerates and sandstones represent stacked braided stream channels that transported exotic clasts into
the King Lear Basin. Variability in grain size filling the braid channels is most likely the result of changing rainfall patterns in the basin. The presence of local, arc-derived clasts indicates that the older arc rocks in the Jackson Mountains continued to provide small amounts of sediment during deposition of the Krum Hills Member. The interbedded siltstones are inter-channel deposits on the distal alluvial fan.

**Clover Creek Member**

The Clover Creek Member represents the final filling of the King Lear Basin after cessation of faulting. The Clover Creek Member is dominantly composed of clasts derived from the Clover Creek volcanic center, located in the southern end of the King Lear Basin (Fig. 2.2). The Clover Creek volcanic center was active at about 125 Ma (Quinn et al., 1997), and it is from the Clover Creek Member that an age for the King Lear Formation is derived. The base of the Clover Creek Member is defined as the first occurrence of clasts derived from the Clover Creek volcanic center. The top of the Clover Creek Member is not observed because it is faulted away by the King Lear Fault, the master normal fault for the King Lear Basin.

**Description** The Clover Creek Member is dominantly composed of interbedded matrix-rich sandstones and breccias, matrix-poor sandstones, and siltstones. Because the source volcanics contain abundant large plagioclase feldspar phenocrysts, the Clover Creek Member is dominated by plagioclase clasts. Plagioclase content increases steadily upsection, reaching 70% near the top of the Clover Creek Member (Fig.
2.5). No clasts derived external to the arc are found in the Clover Creek Member.

The matrix-rich sandstones and breccias in the Clover Creek Member only are present in the southern part of the King Lear Basin near the Clover Creek volcanic center (Fig. 2.4). These sandstones and breccias make up slightly less than half the total thickness of the Clover Creek Member here. These sandstones and breccias have a muddy matrix, are matrix supported, and contain clasts up to cobble size. The clasts are mostly of Clover Creek affinity, but older arc igneous clasts are not uncommon. Clasts are angular to subangular. I conclude that these sandstones and breccias are debris flow deposits dominantly derived from the Clover Creek volcanic center.

Matrix-poor sandstones are common in the Clover Creek Member near the Clover Creek volcanic center and dominate away from the volcanic center (Fig. 2.4). The matrix-poor sandstones can be divided into two types: sandstones without sedimentary structures, which are common, and sandstones with sedimentary structures, which are rare.

Most of the matrix-poor sandstones are bedded on a 1-2 meter scale but otherwise are completely devoid of sedimentary structures. These sandstones exhibit no bedding at a scale finer than 1-2 meters, no cross bedding, and no graded bedding. They are poorly sorted and angular to subangular (Fig. 2.8). Clast lithology is dominated by plagioclase feldspar. I conclude that these sandstones are hyperconcentrated flow deposits that froze in place, resulting in no development of sedimentary structures other than bedding at a large scale (cf. Smith and Lowe, 1991).

Rare matrix-poor sandstones in the Clover Creek Member exhibit sedimentary structures. These sandstones are bedded on a 1-2 meter scale,
Figure 2.8: Photomicrograph of a thin section from the Clover Creek Member. All white colored grains are plagioclase feldspar. Note the angularity of clasts. Plane light. 31.25X.
but they also contain planar bedding at a finer scale, cross bedding, and channel features. These sandstones are poorly sorted and subrounded to rounded. Most of these sandstones are extremely rich in plagioclase and were derived from the Clover Creek volcanic center, but a few are composed entirely of grains derived from the older arc igneous rocks. I conclude that these sandstones are braided stream deposits, formed under dilute streamflow conditions.

Siltstones within the Clover Creek Member are interbedded with sandstones and debris flows. The siltstones are a monotonous gray to black and are devoid of fossils. The siltstones commonly are eroded into by the sandstones and debris flows.

The Clover Creek Member contains an ash flow tuff, located in the central part of the basin (Section C). This tuff is up to 15 meters thick and contains abundant charred wood fragments. The tuff yielded a U/Pb zircon age of 125±1 Ma (Quinn et al., 1997). The age of the tuff agrees within analytical error with an age obtained for intrusions of the Clover Creek Igneous Complex (see below) confirming the interpretation that the Clover Creek volcanic center was the eruptive source for the ash flow tuff.

Channelized conglomerates composed entirely of older arc igneous clasts occur throughout the Clover Creek Member. These conglomerates are much more abundant away from the Clover Creek volcanic center. The conglomerates are often distinctively red colored due to hematite cement. They are clast supported, poorly sorted, well rounded, and often contain fining upward sequences. The channels sometimes stack to form lenses and beds that range from 1-10 meters thick.

The Clover Creek Member also contains extremely rare limestones interbedded with the sandstones. These limestones are very rare and very
poorly exposed. They are composed mostly of lime mud and contain no obvious fossils. However, the limestones are so badly weathered that fossils could exist within them that are impossible to see in the scant outcrop. The thickness of the one limestone bed that I observed is approximately 5 meters. Since similar rare limestones in the Jackson Creek Member were deposited in a fresh water lake, it is likely that the limestones in the Clover Creek Member also were deposited in a fresh water lake.

The Clover Creek Member is intruded by hyabbyssal andesites and dacites that compose the Clover Creek Igneous Complex (Fig. 2.4). The Clover Creek Igneous Complex is interpreted to be the remains of the sub-volcanic feeder system for the Clover Creek volcanic center (Quinn et al., 1997). It is dominantly composed of dacite that contains abundant large plagioclase feldspar phenocrysts. The intrusions yielded a U/Pb zircon age of 123±1 Ma, which agrees within error with the ash flow tuff bed within the Clover Creek Member (Quinn et al., 1997). I conclude that activity in the Clover Creek volcanic center, including intrusion of the hyabbyssal andesite and dacite, was coeval with deposition of the Clover Creek Member because the ash flow tuff and the intrusions are the same age and because the Clover Creek Member deposits are compositionally and spatially related to the Clover Creek volcanic center.

**Depositional Environment** The depositional environment for the Clover Creek Member was a proximal alluvial fan located on the flanks of an active volcanic center. This volcanic center experienced numerous eruptions, triggering debris flows and hyperconcentrated flows that moved across the alluvial fan. In many cases, debris flows near the volcanic center (Section B) were transformed into hyperconcentrated flows away
from the volcanic center (Section C) by dilution of the flow, probably with water. During non-eruptive periods, Clover Creek volcanics were eroded into braided streams, resulting in the deposition of conglomerates and sandstones within channels and interbedded siltstones outside channels on the proximal alluvial fan. Erosion of older arc igneous rocks continued, resulting in a few braided stream conglomerates and sandstones dominated by older igneous clasts. The fan was occasionally covered by an intermittent freshwater lake, resulting in the deposition of very rare limestones.

Deposition Rates and Implications

The only radiometric age constraints on the King Lear Formation come from near the top of the formation, in the Clover Creek Member (Fig. 2.4). However, sedimentologic evidence demonstrates that the entire King Lear Formation was deposited very rapidly. Thus I agree with Russell (1984) and Quinn et al. (1997), who argue that the entire King Lear Formation is Early Cretaceous in age. In fact, the entire 350-1000 meters of sediment likely was deposited in less than the 1 million year uncertainty on the U/Pb dates that constrain the age of the King Lear Formation.

In addition to the 125±1 Ma age constraint on the timing of deposition of the King Lear Formation obtained near the top of the section (Quinn et al., 1997), there is a biostratigraphic constraint on the timing of deposition from near the bottom of the section. Rare limestones interbedded with the conglomerates and sandstones of the Jackson Creek Member yielded Lower Cretaceous freshwater gastropods, suggesting a
Lower Cretaceous age for the Jackson Creek Member (Willden, 1958). Thus biostratigraphic and radiometric age constraints bracket the section and indicate that the entire King Lear Formation was deposited during the Early Cretaceous.

The King Lear Formation contains no large, regional unconformities or depositional hiatuses within its strata. There must have been some modification to the King Lear Basin prior to the deposition of the Krum Hills Member in order to allow exotic clasts to enter the basin. However, this modification to the basin did not result in a regional unconformity at the base of the Krum Hills Member, since the contact with the underlying Jackson Creek Member is conformable in the central to northern part of the basin. In fact, the Jackson Creek Member exhibits remarkably consistent thickness across the central to northern part of the basin: in the central part of the basin it is 58 meters thick and in the northern part of the basin it is 57 meters thick. Additionally, no soil horizons were observed within the King Lear Formation, despite the alluvial setting for the deposition of the formation. Taken together, these observations suggest that no major unconformities exist within the strata of the King Lear Formation and thus that the entire 350-1000 meters of sediment was deposited rapidly.

The rapid deposition of the King Lear Formation during the Early Cretaceous is significant because in a later section I constrain the timing of deformation in the back-arc region by correlating the Krum Hills Member outside the Jackson Mountains into the Krum Hills. My conclusion in that section, that compressional deformation in the back-arc region was over by 125 Ma, is dependent on the age of the Krum Hills Member as determined in the Jackson Mountains.
TIMING AND NATURE OF DEFORMATION IN THE
JACKSON MOUNTAINS

Controversy surrounding the important question of whether the Lower Cretaceous King Lear Formation ever experienced compressional deformation turns on two aspects of the King Lear Formation: 1) observable structures deforming the strata of the King Lear Formation, and 2) the sense of motion on the controlling fault at the eastern edge of the basin (Fig. 2.3). Those who argue in favor of compression infer cleavage formation and folding of bedding both in the King Lear Formation and in older arc igneous rocks and make the basin bounding fault a thrust fault (Willden, 1958; 1963; 1964; Russell, 1984; Maher, 1989). Those who argue in favor of an extensional setting and no compression describe an undeformed King Lear Formation, with no cleavage formation or folding of bedding, and make the King Lear Fault a normal fault (Quinn et al., 1997). The validity of these two contrasting interpretations can be evaluated by determining the sense of motion on the King Lear Fault, i.e. whether the fault dips below the basin or away from it (Fig. 2.3).

In this section I first summarize structural data from previous studies in the Jackson Mountains and present new structural data that suggest that the King Lear Formation was deposited in an extensional setting and that it never experienced compressional deformation. I then present new evidence in the form of a shallow reflection seismic profile that further suggests the King Lear Formation was deposited in a half-graben controlled by a normal fault that dips west beneath the basin. Considered together, the old and new evidence presented in this section strongly
Figure 2.9a: Exposures of the King Lear Formation west of Delong Peak. Note the horizontality of beds and the complete lack of folding or disruption of bedding.
Figure 2.9b: Exposures of the King Lear Formation south of Parrot Peak. Note the continuity of bedding and the complete lack of folding or disruption of bedding.
suggests that the King Lear Formation was deposited in an extensional setting and that it never experienced compressional deformation. These relations are important because inferred shortening in the King Lear Formation has been related to major crustal shortening in contractional belts such as the Luning-Fencemaker Fold and Thrust Belt (Fig. 2.1) (Oldow, 1983, 1984).

**Structural Observations**

The King Lear Formation is a horizontal to gently dipping succession of arc derived clastics and externally derived siliciclastics. Where tilted, it uniformly dips on a gentle homocline to the east, into the basin bounding fault. The King Lear Formation sits with angular unconformity on older deformed arc igneous rocks.

The King Lear Formation does not exhibit shortening deformation at any scale. Figure 2.9 shows two photographs of horizontal to gently dipping King Lear Formation strata. Note the utter lack of any disruption or deformation of bedding. Figure 2.10 presents an equal area stereonet plot of poles to bedding from the entire King Lear Formation (from Quinn et al., 1997). Again note the horizontal to gently east dipping nature of the beds and the utter lack of development of any fold axis within the King Lear Formation.

Figure 2.11 shows a photograph of syn-depositional normal faults in the King Lear Formation. These faults dip toward the west and thus would be synthetic with the basin master fault if it is a normal fault (Fig. 2.3). The faults in Figure 2.11 clearly offset the sandstone beds in the center of the photograph with a normal sense of motion but do not affect the
Figure 2.10: Equal area stereonet (lower hemisphere) with contoured bedding pole data from the King Lear Formation, overlain by the bedding data itself. From Quinn et al. (1997).
Figure 2.11: Syn-depositional normal faults in the King Lear Formation. View is to the north, so faults dip to the west. Hammer is 35 cm long.
overlying conglomerate. Additionally, growth strata are present within the sandstone beds: in the footwall of each fault, the topmost sandstone beds become thicker toward the fault. Thus I conclude that these are syn-depositional normal faults. These observations suggest that the King Lear Formation was deposited in an extensional environment and never experienced compressional deformation.

**Reflection Seismic Data**

The controversy surrounding the presence or absence of shortening deformation in the King Lear Formation turns on the question of whether the basin bounding fault is a thrust fault or a normal fault. Since the field relations described in the previous section merely suggest that the King Lear Fault is a normal fault, an entirely different type of data was obtained in order to help constrain the sense of motion on the fault. These new data are presented in Figure 2.12, which shows a stacked reflection seismic profile from the King Lear Basin. The following paragraphs describe the acquisition and processing of the seismic data. I then detail evidence that suggests the profile images the King Lear Fault as it dips beneath the basin.

Several factors make seismic imaging of the King Lear Fault difficult. One difficulty stems from the low signal to noise ratio expected from a land based shallow seismic survey. Another disadvantage to the survey is that the target of the survey, the King Lear Fault, should dip very steeply, especially near the surface. Steeply dipping features are often difficult to image seismically. Further difficulty in imaging the fault is expected because strata are present only on one side of the fault (Fig. 2.3). An advantage to the survey is that a high acoustic impedance contrast is
Figure 2.12: Stacked seismic reflection profile. Location shown in Figure 2.2. TWTT- Two Way Travel Time.
expected at the interface between the sedimentary rocks of the King Lear Formation and the crystalline rocks surrounding the King Lear Formation (see Fig. 2.3). Another advantage to the survey is that the location of the surface expression of the fault is known from geologic mapping in the Jackson Mountains.

The seismic data were collected over one week during the summer of 1997. The line was oriented perpendicular to the surface expression of the fault to maximize the likelihood of imaging it. The location of the line is shown in Figure 2.2. The source was a Betsey Firing Rod with 8-gauge, 500 grain black powder blanks. Both shots and receivers were spaced at 5 meter intervals. Selected shot and receiver locations were accurately located using a GPS receiver in order to improve geometry and statics calculations during processing. The seismograph recorded 60 channels at a 1 ms sampling rate. Two receiver spreads were used yielding a maximum offset of 600 meters.

Common processing techniques for shallow seismic data were employed (e.g. Steeples and Miller, 1998). A first break static was necessary to account for undesirable effects from both near surface heterogeneity and from a crooked line. An F-K filter was applied to attenuate coherent noise. The velocity field was chosen using NMO velocity analysis. Due to the presence of near-offset coherent noise, only far-offset data were stacked to produce the section shown in Figure 2.12. Note that this section is displayed in two way travel time and has not been converted to depth.

The surface expression of the fault is located at the right edge of the seismic profile (Fig. 2.12). There are several lines of evidence to suggest the reflection seismic profile successfully images the King Lear Fault as it
dips beneath the basin. One observation is that reflections in the King Lear Formation terminate against the fault. The shallowest reflector imaged in the King Lear Formation is labeled on Figure 2.12; all energy above this reflector is noise. In addition to the termination of reflectors, three important features that distinguish energy reflected from the fault from a processing artifact are: (1) The reflector becomes less steep with depth, as would be expected for a fault but not for some artifact of processing; (2) The reflector has a different slope than obvious coherent noise within the section; and (3) The reflector has a different frequency content than coherent noise within the section. Because shallow land based seismic is extremely noisy, only hints of reflection hyperbolae from the fault are observed in shot gathers.

Comparison of Figure 2.12 with Figure 2.3 reveals that the fault orientation imaged in the seismic section is identical to the fault orientation in the cross section of Quinn et al. (1997); that is, the fault is a normal fault. My interpretation of the seismic data is not definitive: other interpretations of the data are possible using the seismic data alone. However, the interpretation presented in Figure 2.12 is preferred because it is consistent with geologic observations presented in the previous section that indicate that the King Lear Fault is a normal fault.

**Relationship to features outside the Jackson Mountains**

The structural and geophysical evidence described in the preceding paragraphs strongly suggests that the King Lear Formation was deposited in an extensional setting and never experienced compressional deformation. This conclusion significantly impacts our understanding of the Mesozoic
tectonic evolution of the Jackson Mountains as well as this portion of the western U.S. Cordillera. Specifically, I show that shortening deformation in the Jackson Mountains must have been complete prior to the Early Cretaceous. I agree with Quinn et al. (1997), who suggest that shortening in the Jackson Mountains probably is entirely Jurassic in age. The timing of shortening deformation in the Jackson Mountains is important because it is used to constrain the age of major contractional belts such as the Luning-Fencemaker Fold and Thrust Belt (Fig. 2.1), which previously had been accepted as a Cretaceous feature (Oldow, 1983, 1984). In the following section I delineate another constraint on the age of the Luning-Fencemaker Fold and Thrust Belt. This constraint stems from the correlation of the Lower Cretaceous King Lear Formation into the Krum Hills in the back-arc region (Fig. 2.1), where the undeformed King Lear Formation sits with angular unconformity upon deformed Triassic phyllites.

TIMING OF COMPRESSIONAL DEFORMATION IN THE BACK-ARC REGION

The King Lear Formation is not restricted to the Jackson Mountains; it is also present in the Krum Hills, presently located 60 km southeast of the Jackson Mountains in the back-arc region (Fig. 2.1). A geologic map of the Krum Hills region is presented in Plate 1. Key aspects of the King Lear Formation in the Krum Hills are identical to aspects in the Jackson Mountains. In both localities, the King Lear Formation is essentially horizontal, it has never experienced compressive deformation, and it sits with obvious angular unconformity on older deformed rocks, in the case of the Krum Hills on Triassic back-arc phyllites. Correlation of the King
Lear Formation between the Jackson Mountains and the Krum Hills is based on the distinctive clast lithology of the Krum Hills Member. Compressive deformation of the back-arc phyllites is constrained by this correlation to be older than 125 Ma. This conclusion refutes the widely held belief that deformation of the back-arc in the Luning-Fencemaker Fold and Thrust Belt occurred during the late Cretaceous (e.g. Oldow, 1983; 1984; Burchfiel et al., 1992). Instead, deformation in the Luning-Fencemaker Fold and Thrust Belt must be older than 125 Ma.

**Previous Work**

Willden (1958) was the first to correlate sedimentary rocks in the Krum Hills with sedimentary rocks in the Jackson Mountains. He describes these rocks as conglomerates dominantly composed of exotic to the arc clasts, specifically quartzite and chert, and names these exposures the Pansy Lee Conglomerate. Willden (1958) is able to place a lower age limit on the Pansy Lee Conglomerate because it overlies the Lower Cretaceous King Lear Formation in the Jackson Mountains, but it is unclear whether the Pansy Lee Conglomerate was deposited in the Cretaceous or in the Tertiary. Russell (1984) recognizes that the Pansy Lee Conglomerate and the King Lear Formation both were deposited in the Cretaceous, so he adds the Pansy Lee Conglomerate to the definition of the King Lear Formation, and all later workers in the Jackson Mountains accept this addition. Lost in this addition, however, is the fact that the Pansy Lee Conglomerate also exists outside the Jackson Mountains, in the Krum Hills. As discussed in a previous section, I retain the addition of the Pansy Lee Conglomerate to the King Lear Formation in order to maintain consistency and reduce
confusion. Thus the Pansy Lee Conglomerate nomenclature has been abandoned completely by all later workers, and the old Pansy Lee Conglomerate is now considered a part of the King Lear Formation, both in the Jackson Mountains and in the Krum Hills.

**Correlation to Jackson Mountains Stratigraphy**

The base of the King Lear Formation in the Krum Hills is an angular unconformity, just as it is in the Jackson Mountains (cf. Figs. 2.6 and 2.13). In the Krum Hills, the King Lear Formation sits with obvious angular unconformity on Triassic back-arc phyllites which were deformed in the Luning-Fencemaker Fold and Thrust Belt (Oldow, 1983; 1984). No matter where exposed, the King Lear Formation exhibits no compressive deformation at any scale. In the Krum Hills, bedding is approximately horizontal, and folding is never observed. The extensional parting fabric that is sparsely developed in the King Lear Formation in the Jackson Mountains is not present at all in the Krum Hills.

The basal member of the King Lear Formation in the Krum Hills is an unnamed breccia composed entirely of angular phyllite clasts and milky quartz clasts. Phyllite is a more common clast type than milky quartz. The breccia ranges in thickness from 0-5 meters. In many localities the breccia is not present; there, the Krum Hills Member sits directly on the Triassic phyllites. The phyllite breccia in the Krum Hills is analogous to the Jackson Creek Member in the Jackson Mountains in that both were derived entirely from erosion of local rocks (Fig. 2.5).

The thickest part of the King Lear Formation in the Krum Hills is the Krum Hills Member. Exposures of the Krum Hills Member in the
Figure 2.13: The King Lear unconformity in the Krum Hills. The undeformed King Lear Formation (above card) unconformably overlies the Triassic Raspberry Formation, which displays a cleavage, dipping steeply. Card is 8.5 cm long.
Krum Hills are identical to exposures in the Jackson Mountains (cf. Figs. 2.7 and 2.14) except that clast size is much larger in the Krum Hills. The Krum Hills Member is composed of stacked braided stream channels. Individual channels are approximately 50 cm thick and commonly are filled with boulder to pebble fining upward sequences. Clasts are very well rounded. Clast size is significantly larger in the Krum Hills than in the Jackson Mountains. Average clast size in the Krum Hills is boulder, and maximum size for orthoquartzite and chert clasts is 75 cm. In the Jackson Mountains, average clast size is cobble and maximum clast size is 30 cm. Outcrop is poor in the Krum Hills, but the few indicators observed yield a paleoflow direction to the northwest, toward the Jackson Mountains.

Clast composition of the Krum Hills Member is identical in the Jackson Mountains and in the Krum Hills. In both locales, exotic clasts account for 80% of the total clast population. The other 20% of the clasts were derived from local sources. In the Krum Hills, there are two types of exotic clasts, orthoquartzite and chert. The orthoquartzite is medium grained and is composed of approximately 90% quartz. On some boulders, relict bedding, approximately 1 cm thick, still can be observed. The orthoquartzite clasts in the Krum Hills are identical to those in the Jackson Mountains (cf. Figs. 2.7b and 2.14b). Chert clasts in the Krum Hills also are identical to those in the Jackson Mountains. Chert clasts are commonly gray or black; occasionally they are red or green. As discussed in a previous section, the orthoquartzite and chert clasts in both the Krum Hills and the Jackson Mountains were most likely derived from the Ordovician Valmy Formation in the Roberts Mountains Allochthon, presently located only 20 km from the Krum Hills in the Sonoma Range (Fig. 2.1).
Figure 2.14a: Channel fill conglomerates in the Krum Hills Member exposed in the Krum Hills. Note the increased size of clasts as compared to Figure 2.7a. Hammer is 40 cm long.
Figure 2.15b: Photomicrograph of a thin section from a quartzite boulder taken from the Krum Hills Member exposed in the Krum Hills. Note that 90% of the grains are quartz. Crossed polars. 31.25X.
Constraints On Deformation In The Back-Arc Region

Triassic and Lower Jurassic back-arc basinal strata were compressively deformed in the Luning-Fencemaker Fold and Thrust Belt, resulting in metamorphism, cleavage development, and folding of bedding (Speed, 1978; Oldow, 1983; 1984). Deformation in this major contractional belt is widely believed to be Cretaceous in age. However, the angular unconformity that separates the deformed Triassic phyllites from the undeformed King Lear Formation in the Krum Hills is a significant surface that must have developed prior to deposition of the King Lear Formation. Correlation of the King Lear Formation into the Krum Hills from the Jackson Mountains allows me to date its deposition at ~125 Ma, thus constraining deformation in this part of the back-arc region to be older than 125 Ma. This age constraint on the Luning-Fencemaker Fold and Thrust Belt necessitates a significant change to accepted thought on this contractional belt, since it is widely believed to be a Cretaceous feature, and thus an expression of shortening in the Sevier Hinterland. Instead, my data demonstrate that deformation in this portion of the Luning-Fencemaker Fold and Thrust Belt must be older than Early Cretaceous and therefore must be unrelated to the Sevier Belt both spatially and temporally.

DISCUSSION AND IMPLICATIONS

Geologic thought about the tectonic evolution of northwest Nevada has been dominated by interpretations of shortening deformation affecting the Lower Cretaceous King Lear Formation in the Jackson Mountains.
This inferred Cretaceous shortening in the Jackson Mountains became extremely important in regional syntheses because it was used to date the Luning-Fencemaker Fold and Thrust Belt (Oldow, 1983; 1984). In fact, the Luning-Fencemaker Fold and Thrust Belt is widely interpreted to be an expression of shortening in the Sevier hinterland, coeval with the Cretaceous Sevier Fold and Thrust Belt (Oldow, 1983; 1984; Burchfiel et al., 1992; Saleeby and Busby-Spera, 1992; Cowan and Bruhn, 1992). My conclusions represent a major departure from this school of thought. My work demonstrates that the 125 Ma King Lear Formation was never involved in any shortening deformation, and thus I conclude that shortening in northwest Nevada, both in the arc and in the back-arc region, was complete prior to 125 Ma. This means that shortening in the Luning-Fencemkaer Fold and Thrust Belt was complete before the onset of deformation in the Sevier Belt during the late Early Cretaceous (Lawton, 1985, Heller et al., 1986). This conclusion suggests the need to reevaluate our understanding of the Mesozoic tectonic evolution of this portion of the western U.S. Cordillera, since the Luning-Fencemaker Fold and Thrust Belt must now be regarded as unrelated to the Sevier Fold and Thrust Belt both temporally and spatially.

**Relation of Jackson Mountains Extension to Cretaceous Crustal Boundaries**

In this chapter I demonstrate the existence of extension in the Jackson Mountains during the Early Cretaceous. A question remains, however: What was the cause of extension in the Jackson Mountains at this time? A possible answer to this question comes from the Mojave-Snow Lake Fault,
a major dextral strike-slip fault that is inferred to lie in the Black Rock Desert just west of the Jackson Mountains (Wyld et al., 1996).

The Mojave-Snow Lake Fault was first recognized based on evidence from the eastern Sierra Nevada. Offset relations of the Independence Dike Swarm and other rocks suggest the fault accommodated up to 450 km of dextral strike-slip motion (Schweickert and Lahren, 1990; 1993). Importantly, these relations in the Sierra Nevada restrict motion along this major crustal boundary to the Early Cretaceous. Schweickert and Lahren infer that the Mojave-Snow Lake Fault extends north of the Sierra Nevada into northwest Nevada, and suggest several possible locations for the extended trace of the fault. Based on contrasts in style and timing of deformation between the Black Rock Desert and other arc terranes, Wyld et al. (1996) also infer that a major Late Jurassic to Early Cretaceous crustal boundary exists in northwest Nevada. Wyld et al. place this boundary in the Black Rock Desert, adjacent to the Jackson Mountains, and suggest that it is related to the Mojave-Snow Lake Fault. If these workers suggestions are confirmed, that is, if the Mojave-Snow Lake fault is proven to exist in the Black Rock Desert and if motion along it is proven to have occurred during the Early Cretaceous, then the existence of the King Lear Fault is probably related to motion along the Mojave-Snow Lake Fault. In this case, the King Lear Basin was a trans-tensional basin associated with a major strike-slip crustal boundary located just to the west. This explanation differs significantly from previous explanations for the existence of the King Lear Basin.
CHAPTER 3. UPLIFT HISTORY OF THE CENTRAL JACKSON MOUNTAINS USING THE APATITE FISSION TRACK METHOD ON IGNEOUS ROCKS

CHAPTER SUMMARY

Two episodes of Mesozoic compressive deformation are expressed in the central Jackson Mountains, D1 and D2 (Quinn, 1996). D1 deformation is well constrained to have occurred during the Early Jurassic. D2 deformation, however, is only poorly constrained to the interval Lower Jurassic to Early Cretaceous. Uplift of the central Jackson Mountains also occurred during the Lower Jurassic to Early Cretaceous, which suggests that compressive deformation and uplift of the central Jackson Mountains were related. If the uplift and deformation were related, then dating the middle Mesozoic uplift of the Jackson Mountains would place an important constraint on the timing of D2 deformation. I used the apatite fission track method on igneous rocks to attempt to constrain the Middle Mesozoic uplift history of the central Jackson Mountains. However, later tectonic events reheated the rocks of the central Jackson Mountains, completely annealing the apatite fission tracks that formed during the earlier middle Mesozoic exhumation. The apatite fission track dating constrained only the latest uplift of the Jackson Mountains, the exhumation that occurred during Tertiary Basin and Range extension. The data indicate that the last uplift of the Jackson Mountains occurred at approximately 16 Ma. This age is consistent with published exhumation ages across the Basin and Range province.
INTRODUCTION

The Jackson Mountains experienced two episodes of shortening deformation during the middle Mesozoic, D1 and D2 (Quinn, 1996). Field relations and an $^{40}\text{Ar}/^{39}\text{Ar}$ syn-deformational hornblende date constrain the age of D1 to the Early Jurassic, about 201 Ma (Quinn, 1996). However, the age of D2 structures is poorly constrained. D2 deformation is present in Lower Jurassic plutons, but is not observed in the Lower Cretaceous King Lear Formation. Thus D2 occurred sometime between the Early Jurassic and the Early Cretaceous. Uplift of the central Jackson Mountains also occurred sometime between the Middle Jurassic and the Early Cretaceous, since clasts of Middle Jurassic plutons were deposited in the King Lear Basin at about 125 Ma (Quinn, 1996). Given the spatial and temporal overlap between D2 deformation and uplift of the Jackson Mountains, it is likely that both the deformation and the uplift of the central Jackson Mountains were a result of the same shortening event. Thus if the time of uplift can be determined, a constraint can be placed on the age of shortening and D2 deformation.

Apatite fission track geochronology is a well known method for dating the uplift of rocks (Ravenhurst and Donelick, 1992). Apatite is a common accessory mineral in intermediate to felsic igneous rocks and also is commonly found as a detrital mineral in sedimentary rocks. Fission tracks are created when atoms of uranium-238, which is contained within apatite, undergo spontaneous fission. Once created, fission track damage is easy to destroy, or anneal. At temperatures above $\sim 160 \, ^\circ\text{C}$, fission tracks completely anneal and the apatite crystal returns to its original state. Thus each apatite crystal records its own thermal history: when a crystal cools
below \(\sim 160 ^\circ C\), fission tracks begin to accumulate at a known rate. The number of tracks present at any given time is directly proportional to the length of time the apatite crystal has been at temperatures cooler than \(\sim 160 ^\circ C\), thus counting the number of tracks present today permits the calculation of the time when the apatite crystal was uplifted and cooled through \(\sim 160 ^\circ C\).

The goal of this study is to date the Mesozoic uplift of the central Jackson Mountains using the apatite fission track method. Realization of this goal would place an important age constraint on D2 deformation in the Jackson Mountains. Attainment of this goal is complicated by the low annealing temperature of fission tracks in apatite. If any elevated heat flows existed in the Jackson Mountains between the Middle Jurassic and the present, annealing of apatite fission tracks is likely. Since the Jackson Mountains have been located near an active plate boundary throughout this time interval, and since numerous deformational events have affected the western U.S. during this time, it is highly probable that elevated heat flows existed and that apatite fission tracks were annealed at least once between the Middle Jurassic and the present. In fact, that is the observed result. The apatite fission track ages obtained from the Jackson Mountains reveal that the rocks last cooled through \(\sim 160 ^\circ C\) at approximately 16 Ma, probably as a result of uplift related to Basin and Range extension.

**THEORY**

Because nuclear fission and fission tracks in apatite crystals are not common topics of discussion or research in geology and geophysics, in this section I provide a brief background on both the fission process and the
relation of apatite chemistry to fission products. This discussion is intended only as a primer to these topics. It should not be viewed as a thorough discussion of either fission or apatite fission tracks. For a thorough discussion on fission, see Bohr and Wheeler (1939). For a thorough discussion on fission tracks, see Dartyge et al. (1981) and Paul and Fitzgerald (1992). For a thorough discussion on annealing of fission tracks in apatite, see Donelick (1991).

**Fission and Uranium**

Fission of an atomic nucleus can occur in any element. Fission is essentially the division of the nucleus into smaller particles. These particles are both sub-atomic particles, such as neutrons, and nuclear fragments, which are smaller nuclei containing both protons and neutrons. In the first moments after fission, the positively charged neutron fragments are very close together. These positively charged fragments repel each other very strongly, so that they move away from each other at very high velocities. If the original nucleus is contained within a mineral with a crystal structure, the trajectories of the high-energy fragments cause linear damage to the crystal lattice. This damage is called a fission track.

There are two naturally occurring isotopes of uranium, $^{238}U$ and $^{235}U$. $^{238}U$ is the heaviest isotope found in nature. Its nucleus contains so many protons that the opposing forces from the closely packed positive charges make it quasi-stable; the addition of one more proton or neutron makes the nucleus unstable (Bohr and Wheeler, 1939). $^{238}U$ undergoes spontaneous fission at a constant, measurable rate. Fission in $^{238}U$ cannot be induced by bombardment by thermal neutrons. Unlike $^{238}U$, $^{235}U$
does not undergo spontaneous fission. However, fission in $^{235}\text{U}$ can be induced by bombardment by thermal neutrons. If the neutron flux into a sample containing $^{235}\text{U}$ is known, then the rate at which fission occurs can be calculated. In summary, $^{238}\text{U}$ undergoes spontaneous fission but not induced fission, whereas $^{235}\text{U}$ undergoes induced fission but not spontaneous fission. The fission track dating method makes use of this relationship to determine the uranium concentration in each crystal. This determination is important because fission track density in a crystal is directly proportional to the uranium concentration in that crystal.

**Apatite**

Apatite is a calcium phosphate, $\text{Ca}_5(\text{PO}_4)_3(\text{F, Cl, OH})$. Many different elements may substitute into this idealized formula. Substitution of different elements into the lattice sites drastically alters the annealing behavior of apatites. The temperature at which complete annealing takes place (the closure temperature) varies greatly depending on the exact composition of the apatite in question. Thus there is no one closure temperature to fission tracks for all apatite crystals: the exact closure temperature depends on the exact composition of the apatite crystal. An empirical relationship between fluorine or chlorine content and annealing behavior has been found. Apatites that contain abundant chlorine are found to anneal much slower and at much higher temperatures than apatites that are rich in fluorine (Carlson et al., in press).

One important element that substitutes into apatite is uranium. Uranium, a cation, substitutes into the cation lattice site in apatite, which is usually occupied by calcium. When uranium substitutes for calcium, there
is no fractionation of the isotopes of uranium. This means that $^{238}$U and $^{235}$U enter the lattice of apatite during crystallization in exactly the same ratio as exists in the melt from which the apatite is crystallizing (R. Donelick, personal commun., 1998). $^{238}$U then continues to undergo spontaneous fission, producing fission tracks in the surrounding apatite.

METHODS

Sample Collection

Samples of the six plutons mapped by Quinn (1996) were collected for this study. These plutons are: Deer Creek Pluton, Parrot Peak Pluton (diorite), Harrison Grove Pluton, Delong Peak Pluton, Trout Creek Stock, and Willow Creek Pluton. Two whole granite boulders, approximately 25 cm in diameter, were collected from the King Lear Formation. A sample of the ash-flow tuff from the Clover Creek Member of the King Lear Formation was also collected. Additionally, a sample from the granitic dikes that are associated with the Parrot Peak Pluton was collected (Quinn, 1996). Only four of these samples were apatite fission track dated because results from the first four samples did not warrant further work on the other six samples (Table 3.1).

Sample Preparation and Analysis

All mineral separations were performed at the laboratory of Donelick Analytical, Inc. in Katy, Texas. Grain mounting, polishing, and etching were also performed at the Donelick Analytical laboratory. The
samples were irradiated by thermal neutrons to induce fission in uranium-235 at the research fission reactor at Texas A&M University in College Station, Texas. These induced fission tracks were recorded in muscovite. The samples for measuring track length were irradiated by californium-252 to allow the nitric acid etchant to reach more confined tracks. Irradiation by californium-252 was conducted at the irradiation laboratory of Donelick Analytical. Determination of track density and measurement of track length were performed using the microscope and digitizing pad at Donelick Analytical. All counting and measuring of tracks was performed at a magnification of 1250X. Calibration of counting and measuring techniques was accomplished using Durango fluorapatite, a standard calibration apatite whose fission track age and length distribution are well known.

RESULTS

The results of the four apatite fission track analyses are summarized in Table 3.1. Although the rocks from the central Jackson Mountains must have been uplifted during the Middle Jurassic to Early Cretaceous, the apatite fission tracks recorded during this uplift have been completely annealed. Only the last uplift and cooling event is preserved in the apatite fission track record: the uplift associated with Basin and Range extension during the Tertiary. There is remarkable agreement between three of the apatite fission track ages, therefore the average of these ages is taken as the uplift age for the central Jackson Mountains.

The ages presented in Table 3.1 are apatite fission track pooled ages. Pooling of ages is a means of averaging fission track ages from different
<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>AFT POOLED AGE</th>
<th>U/Pb ZIRCON AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash-Flow Tuff in King Lear Formation</td>
<td>15.7±2.5 Ma</td>
<td>125±1 Ma</td>
</tr>
<tr>
<td>Willow Creek Pluton</td>
<td>16.7±5.6 Ma</td>
<td>163±1 Ma</td>
</tr>
<tr>
<td>Granite Boulder in King Lear Formation</td>
<td>16.7±4.4 Ma</td>
<td>168±2 Ma</td>
</tr>
<tr>
<td>Deer Creek Pluton</td>
<td>51.5±7.7 Ma</td>
<td>196±2 Ma</td>
</tr>
</tbody>
</table>

**Table 3.1:** Pooled apatite fission track (AFT) ages for four samples analyzed with U/Pb ages included. U/Pb data and pluton names from Quinn, 1996.
crystals from the same rock. The process of pooling ages essentially treats all fission track counts from numerous individual crystals as though they were counted in a single crystal. This method of averaging produces the most meaningful age for a rock in which tracks in numerous individual crystals were counted (R. Donelick, personal commun., 1998).

The central Jackson Mountains were uplifted and cooled at approximately 16 Ma. This age is very consistent with published exhumation ages across the Basin and Range (e.g. Duebendorfer and Sharp, 1998), so uplift of the Jackson Mountains at 16 Ma is also most likely related to Basin and Range extension. Although the data presented here are valid apatite fission track ages, they do not contribute to achieving the goal of constraining the Middle Jurassic to Early Cretaceous uplift history of the central Jackson Mountains. Only four samples were analyzed because the likelihood that any of the other samples would yield a Mesozoic uplift history was deemed extremely small.

One of the plutons, Deer Creek Pluton, yielded an apatite fission track age of 52 Ma, which is extremely different from the apatite fission track ages of the other samples. There is no geological evidence to suggest that the Deer Creek Pluton was uplifted 35 million years before the rest of the Jackson Mountains or that it experienced a lower heat flow during Basin and Range extension, so I conclude that the 52 Ma age is not the result of an earlier uplift of this pluton. Instead, the most likely explanation for the older fission track age lies in the apatite chemistry. If the Deer Creek Pluton contains apatites that have a very different chemistry than the other igneous rocks, then the annealing behavior of fission tracks in the Deer Creek Pluton apatites should be very different from the annealing behavior in apatites from the other igneous rocks. The
differing apatite chemistry interpretation is preferred because it explains the older apatite fission track age for the Deer Creek Pluton without requiring an earlier uplift of a single pluton. This interpretation could be tested by determining the exact composition of the Deer Creek Pluton apatites using an electron microprobe.
CHAPTER 4. REMAPPING AND NEW OBSERVATIONS IN THE NORTHERN KING LEAR BASIN, JACKSON MOUNTAINS

CHAPTER SUMMARY

Conclusions drawn from the detailed examination of geologic maps made by Quinn (1996) for the northern part of the King Lear Basin are incongruous with the new stratigraphy developed for the King Lear Formation in chapter 2 of this thesis. In chapter 4, I show that the Jackson Creek Member is present at the base of the King Lear Formation in the northern part of the basin, just as it is in the central part of the basin. Additionally, I present minor structural modifications to Quinn's (1996) map that suggest that the double thickness of the King Lear Formation in the northern part of the basin is a result of structural doubling of the formation along a small normal fault and not to stratigraphic thickness variations. These minor changes to Quinn's (1996) map explain the outcrop pattern of the King Lear Formation in the northern part of the basin without necessitating a modification or reevaluation of the new stratigraphy for the King Lear Formation developed in chapter 2.

INTRODUCTION

The northern part of the King Lear Basin (Fig. 4.1) was mapped by Quinn (1996), as presented in his Plate 1B. A reproduction of this map is shown in Figure 4.2a. Examination of this map in detail raises several questions given the new stratigraphic interpretation of the King Lear
Figure 4.1: Geologic map of the central Jackson Mountains with area of Figures 4.2a and 4.2b shown. Modified from Quinn (1996).
Formation presented in Chapter 2 of this work. For example, why are there no deposits of the Jackson Creek Member (approximately equivalent to Kkl1 on Quinn's (1996) map) present just above the basal angular unconformity at the western edge of the basin? Since the basal contact of the Krum Hills Member (approximately equivalent to Kkl2 on Quinn's (1996) map) is not erosive in the central to northern part of the King Lear Basin, there is no reason that the Jackson Creek Member should be missing from its position as the basal member of the King Lear Formation, as shown on the map of Quinn (1996).

Another question that arises from the map of Quinn (1996) involves the thickness of the King Lear Formation in the northern part of the basin. Why is the thickness of the King Lear Formation there approximately twice that in the central part of the basin? There is no sedimentologic or stratigraphic basis for a thicker King Lear Formation in the northern part of the basin as there is in the southern part. The southern part of the basin was located not only closer to the source of external clast input for the Krum Hills Member but also adjacent to an active volcanic center during deposition of the Clover Creek Member (Chapter 2). Neither of these ratiocinations are applicable to the northern part of the King Lear Basin. Thus another explanation must be proposed for the double thickness of the King Lear Formation in the northern part of the basin.

This chapter presents answers to these questions based on slight but significant modifications to the map of Quinn (1996). These modifications are presented in Figure 4.2b. Specifically, this chapter shows that the Jackson Creek Member is present at the base of the King Lear Formation just above the angular unconformity at the western edge of the basin. Additionally, this chapter details a possible structural solution to the
problem of the double thickness of the King Lear Formation in the
northern part of the basin. This structural explanation is that the King
Lear Formation was doubled as a result of a normal fault that runs through
the center of the northern King Lear Basin.

MODIFICATIONS TO EXISTING MAPS

Presence of basal Jackson Creek Member

As outlined above, there is no reason that the Jackson Creek Member
should be missing from its position at the base of the King Lear Formation
as shown on the map of Quinn (1996). The absence of the Jackson Creek
Member just above the angular unconformity at the western edge of the
basin would require either an unusual rationalization or a reevaluation of
the sedimentology and stratigraphy of the King Lear Formation as detailed
in Chapter 2. Recognition of the Jackson Creek Member just above the
basal angular unconformity removes the need for such rationalizations or
reevaluations. The Jackson Creek Member is shown as map symbol Kk11
on Figure 4.2b in order to maintain consistency between Figures 4.2a and
4.2b. The relation between the new division of the King Lear Formation
into members (Chapter 2) and Quinn's (1996) division into lithofacies is
discussed below.

Deposits of the Jackson Creek Member in the northern part of the
King Lear Basin are identical to deposits in the central part of the basin. In
the northern part of the basin, the Jackson Creek Member is 57 meters
thick, compared to 58 meters in the central part of the basin. In both
localities, the Jackson Creek Member consists of conglomerates and
Figure 4.2a: Map of northern King Lear Basin, copied directly from Quinn (1996). See Figure 4.2c for explanation of map symbols.
Figure 4.2b: Map of northern King Lear Basin, with slight modifications made in this study. See text for details and significance of changes.
EXPLANATION OF MAP SYMBOLS

Figure 4.2c: Explanation of map symbols used in Figures 4.2a and 4.2b, following Plate 3, Quinn (1996). Note that unit patterns are different than those used in Figure 4.1.
sandstones whose clasts were derived entirely from older, local arc igneous rocks. The depositional environment for both localities was a braided stream flowing over a proximal alluvial fan.

Quinn (1996) divided the King Lear Formation into lithofacies, labeled Kkl1, Kkl2, and Kkl3. Kkl1 is a lithofacies defined as dominantly composed of clasts derived from older arc igneous rocks (Quinn, 1996, Plate 3). Kkl2 is a lithofacies defined as dominantly composed of clasts derived from sedimentary sources. Kkl3 is a lithofacies defined as dominantly composed of volcanoclastic derived from the Clover Creek volcanic center (see Chapter 2 for location). One important aspect of this division into lithofacies is that each lithofacies is not tied to a specific stratigraphic level. Thus any channel filled with clasts derived from local arc igneous rocks, for example, is a part of lithofacies Kkl1, no matter where in the stratigraphic succession the channel is found. Chapter 2 of this work details the division of the King Lear Formation into members which conformably stack atop one another, regardless of which lithofacies is contained within each member. Thus the lithofacies of Quinn (1996) do not match exactly the members in this study. However, because the Jackson Creek Member is composed entirely of clasts derived from older arc igneous rocks, it is approximately equivalent to the lower portions of Kkl1 shown in Figure 4.2b. Likewise, because the Krum Hills Member is dominantly composed of clasts derived external to the arc, it is approximately equivalent to the lower portions of Kkl2 shown in Figure 4.2b. The addition of deposits of map unit Kkl1 to Figure 4.2b is equivalent to the addition of Jackson Creek Member deposits to the map. The symbol Kkl1 is used to maintain consistency between Figures 4.2a and 4.2b.
Strike-slip faults and more extensive landslide deposits

According to the map of Quinn (1996), the King Lear Formation is approximately twice as thick in the northern part of the basin as it is in the central part (Fig. 4.1, 4.2a). However, based on the stratigraphic and sedimentologic relations described in Chapter 2, there is no stratigraphic reason for the double thickness of the King Lear Formation in the northern part of the basin. Thus a slight modification to the structural interpretation of the northern King Lear Basin is necessary to explain the apparent anomalous thickness of the King Lear Formation there.

The first relations that bear on the problem of the double thickness of the King Lear Formation are the newly recognized strike-slip faults in the northern part of the basin, labeled Y and Z on Figure 4.2b. These strike-slip faults are placed where strata of the Lower Cretaceous King Lear Formation strike into outcrops of the Upper Triassic-Lower Jurassic Happy Creek Igneous Complex. The contact relation between these two units is not the angular unconformity found at the base of the King Lear Formation. Instead, the contact is a strike-slip fault. The significance of these newly recognized strike slip faults will be discussed after other new observations are presented.

Another modification to the map of Quinn (1996) shown on Figure 4.2b is the increased extent of the Quaternary landslide deposits (map unit Q1s) near fault Z. In fact, much of the low relief area just north of the landslide which is occupied by springs is probably best mapped as Quaternary cover, either landslide deposits or alluvium. Although this is a minor change to the map, it is significant because there is a small normal
fault whose trace strikes directly into this covered area (Fig. 4.2b). This normal fault is shown on the map of Quinn (1996) as dying out into this area (Fig. 4.2a). What is not clear from the map of Quinn (1996) is that the area where the fault dies out on the map is actually covered by Quaternary deposits, not outcrops of the Cretaceous King Lear Formation, so structures older than Quaternary would be covered as well as the King Lear Formation.

This work suggests that the normal fault shown in Figure 4.2a actually continues beneath the Quaternary deposits shown in Figure 4.2b. If this is the case, then the strike-slip faults described in the preceding paragraph are best interpreted as accommodation structures between the main normal fault at the eastern edge of the basin and the small normal fault in the center of the basin. One result of this interpretation is that the apparent double thickness of the King Lear Formation in the northern part of the basin is a result of repetition of the stratigraphic section caused by motion along the normal fault in the center of the basin.

IMPLICATIONS

The modifications made to the map of Quinn (1996) that are described above and presented in Figure 4.2b are minor, but significant. These modifications mean that apparent anomalous stratigraphic relations in the King Lear Formation found on the map of Quinn (1996) can be explained without revising the stratigraphy of the King Lear Formation as described in Chapter 2. Specifically, these modifications show that the Jackson Creek Member is present at the base of the King Lear Formation both in the northern and central parts of the basin. Additionally, these
modifications suggest that the King Lear Formation is twice as thick in the northern part of the basin as compared to the central part because of a small normal fault running through the middle of the basin and not because of true depositional thickness variations.
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Geologic map of the Barrett Springs region, Knum Hills, northwest Nevada

by Aaron James Martin (1999)
BARRETT SPRINGS, NEVADA

PROVISIONAL EDITION 1981

SCALE 1:24,000

CONTOUR INTERVAL 10 METERS
SUPPLEMENTARY CONTOUR INTERVAL 5 METERS
ELEVATIONS SHOWN TO THE NEAREST 0.1 METER

contact: solid where accurate, dashed where approximate
strike and dip of cleavage

STRATA

Qq
undivided, mainly alluvium

Tb
basalt

Kk1
King Lear Formation
~125 Ma

QUADREANGLE LOCATION

NEVADA

KILOMETERS

METERS

MILES

FEET

1
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000

0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000

0
"
BARRETT SPRINGS, NEVADA

PROVISIONAL EDITION 1981

SCALE 1:24 000

KILOMETERS
1 0 5
METERS
0 1000 2000
METERS
0 1000 2000
FEET
1 0 5

QUADRANGLE LOCATION

CONTOUR INTERVAL 10 METERS
SUPPLEMENTARY CONTOUR INTERVAL 5 METERS
ELEVATIONS SHOWN TO THE NEAREST 0.1 METER

contact: solid where accurate,
dashed where approximate

strike and dip of cleavage

CENOZOIC

TERTIARY, QUATERNARY

Q4u
undivided,
mainly alluvium

Tb
basalt

MESOZOIC

CRETACEOUS

Upper Triassic

Kk1
King Lear Formation
~125Ma

Triassic

Raspberry Formation
(phyllite)
IMAGE EVALUATION
TEST TARGET (QA-3)

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