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SEDIMENTOLOGY AND STRATIGRAPHY OF TRIASSIC
CLASTIC AND CARBONATE UNITS OF THE CHULITNA
TERRANE, ALASKA RANGE, SOUTH-CENTRAL ALASKA

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Major Professor's Signature

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SEDIMENTOLOGY AND STRATIGRAPHY OF UPPER TRIASSIC CARBONATE AND CLASTIC STRATA OF THE CHULITNA TERRANE, ALASKA RANGE, SOUTH-CENTRAL ALASKA

By

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ABSTRACT

SEDIMENTOLOGY AND STRATIGRAPHY OF UPPER TRIASSIC CARBONATE AND CLASTIC STRATA OF THE CHULITNA TERRANE, ALASKA RANGE, SOUTH-CENTRAL ALASKA

By

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The Chulitna terrane of the southern Alaska Range is one of the more enigmatic tectonic terranes in the North American Cordillera and is defined in part by the occurrence of Upper Triassic red bed and carbonate units that occur in association with basalt and serpentinite in the Alaska Range suture zone. New geologic mapping and measured stratigraphic sections of Upper Triassic strata from the Chulitna terrane reveal a continuous record of siliciclastic, volcaniclastic, and carbonate sedimentation. Red bed units consist largely of interbedded successions of poorly-sorted and matrix-supported sandstone, siltstone, and conglomerate. Individual beds are typically 0.25–2 m thick and exhibit tabular geometries. Upper Triassic units in the Chulitna terrane were originally thought to represent three distinct successions that were stratigraphically unrelated. However, measured sections revel that carbonate and red bed units are interbedded throughout the Chulitna terrane. Clastic and carbonate strata are interpreted to represent deposition in a marginal marine fan-delta complex characterized largely by debris flow processes, fluvial-deltaic and beach-barrier island sedimentation, as well as lagoon and carbonate reef/bank sedimentation. Upper Triassic carbonate and clastic strata of the Chulitna terrane are interpreted to represent sedimentation associated with an isolated period of exhumation and clastic sedimentation, bimodal volcanism, and carbonate precipitation during at the end of the Triassic.

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*****Images in this thesis are presented in color***

CHAPTER I: INTRODUCTION

THE ALASKA RANGE

The northernmost extent of the North American Cordillera in southern Alaska is defined by the Talkeetna Mountains, Wrangell-St Elias Mountains, and the Alaska Range (Figure 1.1). The Alaska Range extends >600 km throughout south-central Alaska and parts of the Yukon Territory and contains some of the highest topography in North America (Mount McKinley at an elevation of 20,135 ft.). The northern part of the Alaska Range is dissected by the presently-active Denali fault and Hines Creek fault. The Denali fault is a continent-scale, strike-slip fault that extends >1000 km as an arced lineament though southern Alaska (Csejtey et al., 1982). Right-lateral offset of up to Up to 400 km of dextral displacement has been proposed for the Denali fault since Late Cretaceous time based on geologic studies (Eisbacher, 1976; Nokleberg et al., 1985). The Denali fault can be observed as a discreet north-south trending structure in parts of southeastern Alaska but appears to splay into a more complex series of east-west trending structures in south-central and southwestern Alaska (Figure 1.1). This region of south-central and southwestern Alaska is referred to as the Alaska Range suture zone and contains some of the more complicated and least studied parts of the North American Cordillera.

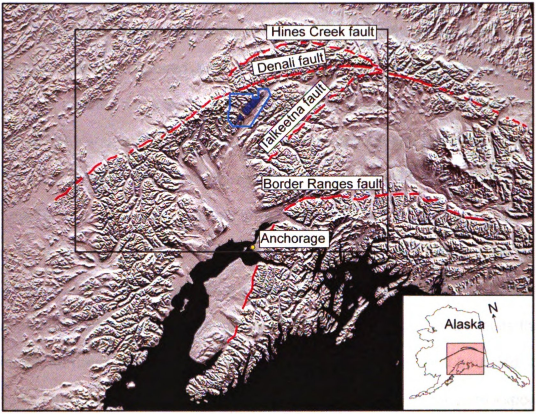


Figure 1.1.

Digital elevation model (DEM) of south-central Alaska and location reference map. The Alaska Range is one of the topographically highest orogenic belts in North America and is bisected by the Denali fault, black line in the bottom right-hand corner reference map, in southern Alaska. The major faults in south-central Alaska are noted by dashed red lines. Note that the Denali fault splays into the at the Hines Creek fault which is one of the faults that has been proposed to represent the suture between the Mesozoic continental margin of North America and the accreted terranes. To the south of the Denali fault system the general location of the Chulitna terrane (purple) is marked by a blue polygon to identify the location of Figure 1.3. (Geologic map of the Chulitna terrane). The Chulitna terrane is shown on this DEM in the context of major faults that dissect the Alaska Range and Talkeetna Mountains. The location of Figure 1.2. (Alaska Range suture zone) is indicated by the black square.

THE ALASKA RANGE SUTURE ZONE

The Alaska Range suture zone (Figure 1.2.) in south-central Alaska consists primarily of exposed Jurassic–Cretaceous sedimentary strata with numerous, isolated occurrence of highly-deformed Triassic and older tectonic terranes. The suture zone is bound and dissected by several large strike-slip faults, each of which has been proposed to represent the suture between the Yukon-Tanana terrane (pericratonic terrane) to the north and the Wrangellia composite terrane (island arc) to the south. The Alaska range suture zone is informally defined to occur across a wide zone (>100 km) between the Talkeetna fault that defined the southern boundary and Hines Creek and Denali faults that mark the northern boundaries. Numerous Triassic and older, fault-bounded tectonic terranes (e.g. Dillinger, Chulitna, McKinley-Windy terranes) are exposed throughout the Alaska Range suture zone (Figure 1.2). Each of these terranes has been studied within the general context of regional mapping projects and, although there are some stratigraphic similarities shared between terranes, there is little consensus on the pre-Jurassic tectonic history of the North American Cordillera in the context of Triassic and older terranes along the inboard margin of the Wrangellia composite terrane in southern Alaska.

Figure 1.2.

Generalized Geology of the Alaska Range Suture Zone. The Alaska Range suture zone is informally defined to occur between the Talkeetna fault (to the south) and Hines Creek and Denali faults (to the north). Note the occurrence of the Chulitna terrane, marked by a C, in the central part of the Alaska Range suture zone. The major faults within the Alaska Range suture zone are indicated by dashed red lines. Note that the Kahiltna assemblage (submarine deposits), shown in black, is thought to represent synorogenic sedimentation associated with the accretion of the Wrangellia composite terrane to the North American Cordillera during Jurassic – Cretaceous time. The focus of this study is on Upper Triassic siliciclastic and carbonate strata of the Chulitna terrane that were deposited prior to accretion of the Wrangellia composite terrane. The blue polygon represents the mapped area of the Chulitna terrane by Clautice et al (2001). Note that the Chulitna terrane is one of several Paleozoic – Mesozoic terranes that occur in the Alaska Range suture zone. Map has been modified from Wilson et al (1998).

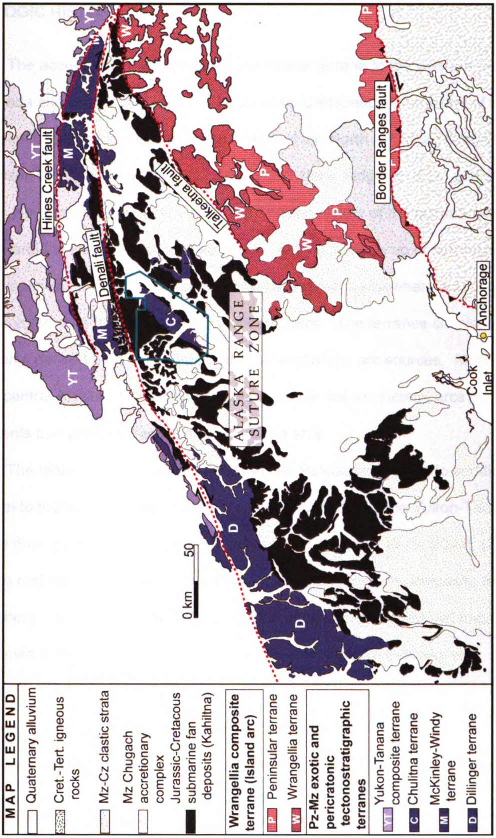

MAP LEGEND
Quaternary alluvium
Cret.-Tert. igneous rocks
Mz-Cz clastic strata
Mz Chugach accretionary complex
Jurassic-Cretacous submarine fan deposits (Kahiltna)
Wrangellia composite terrane (Island arc)
Peninsular terrane
Wrangellia terrane
Pz-Mz exotic and pericratonic tectonostratigraphic terranes
Yukon-Tanana composite terrane
Chulitna terrane
McKinley-Windy terrane
Dillinger terrane
Hines Creek fault
Denali fault
Talkeetna fault
Border Ranges fault
ALASKA RANGE SUTURE ZONE
Anchorage
Cook Inlet
0 km 50

Figure 1.2.

GEOLOGIC HISTORY

The accretion of the Wrangellia Composite terrane to the western margin of Canada and southern Alaska during Jurassic-Cretaceous time is one of the more significant tectonic events in the history of the North American Cordillera (Dickinson W.R., 2004; Plafker, G., Berg, H.C., 1994; Ridgway, K.D., and others, 2002). However, little is known about the Triassic history of the continental margin and the island arc prior to accretion. Alaska is made up of numerous geologic terranes. All of south-central Alaska originated elsewhere and over time was accreted onto the proto North American craton. The terranes consist of fragments derived from continental, oceanic, and island arc sources. Most of south-central Alaska's terranes originated as either volcanic island arcs or sediments that were eroded off of these island arcs.

The major tectonic events, since the late Paleozoic, leading to addition of material to the North American Plate include; (1) addition of the Yukon-Tanana terrane during the Late Paleozoic-Early Triassic (Dickinson, W.R., 2004); (2) Early to mid-Cretaceous accretion of the Wrangellia island arc composite terrane (Nokleberg and others, 2000); (3) Late Cretaceous to present tectonic migration of terranes along the Denali fault to there present locations in Alaska and continued addition of material to southern Alaska (Nokleberg and others, 2000). The tectonic events leading to various terranes discussed previously, other than the Yukon-Tanana and Wrangellia composite terrane, are not well constrained by current models. Generally, in south-central Alaska, the oldest terranes are found inland of the North American craton, and tend to decrease in age toward the plate margin. The youngest terranes are still in the process of accreting onto Alaska. The edges, sutures, of these terranes are typically major strike slip faults such as the Denali Fault and the Border Ranges Fault.

Precambrian–Paleozoic

The Yukon-Tanana composite and Dillinger terranes have been near the northwest part of the North American craton since the Precambrian. In the late Precambrian, the Wrangellia composite terrane began forming through volcanic activity far to the south in the proto-Pacific ocean. By the end of the Paleozoic the Wrangellia composite terrane was composed of two separate island arcs.

Mesozoic

By the end of the Triassic Period the Wrangellia composite terrane was composed of three separate arcs that had joined on the Farallon Plate. The Farallon Plate was moving towards the Mesozoic North America margin. During this time Mesozoic North America was within an equatorial region. In the Late Triassic, on the west side of the Wrangellia composite terrane, a subduction zone formed and is recorded in trench sediments that were compressed onto Wrangellia forming an accretionary prism. The subduction zone is recorded in the Border Ranges fault. Large amounts of sediment were being eroded from the landward side of the Wrangellia composite terrane. These sediments along with sediments from the continental margin of Mesozoic North America filled the basin(s) that formed between the two. Turbidities record deposition before North

America and Wrangellia collided. The basins were faulted and folded towards the end of the Jurassic, when the Wrangellia composite terrane eventually collided with the Yukon-Tanana composite terrane (Nokleberg and others, 2000).

By the Early Cretaceous the Wrangellia composite terrane had come into contact with North America, near eastern Oregon and northeast California. By the mid-Cretaceous, the Kula Plate had rifted apart from the Farallon Plate and began to move the Wrangellia composite terrane northward. The northward movement of the Wrangellia composite terrane is recorded in portions that were scrapped off along the margin of the North American Plate (Nokleberg and others, 2000).

By the Late Cretaceous, the Wrangellia composite terrane was sutured onto North America. Subduction and collision resulted in active volcanism and metamorphism along the plate boundary between the Yukon composite terrane and the Wrangellia composite terrane. The Denali fault marks this collision zone (Nokleberg and others, 2000).

Cenozoic

Collision between the Wrangellia composite terrane and North America resulted in thickening and heating of the crust. Evidence for these events is recorded in the numerous Cenozoic granitic plutons that dot the south-central Alaska. By the Eocene most of the terranes of south-central Alaska were at their present latitude. Approximately 43 million years ago the modern subduction zone, the Aleutian trench was well developed. The formation of this subduction zone coincided with a change in the direction, from the north to the northwest, of the Kula-Pacific plate relative motions. The terranes of south-central Alaska continue to be accreted, resulting in a region that is characterized by mountain ranges, volcanoes, and frequent earthquakes (Nokleberg and others, 2000).

Previous studies have identified nine terranes (Jones and others, 1982) in the Alaska Range of south-central Alaska. Jones and others (1982) identified nine major terranes, in the Alaska Range of south-central Alaska. These nine terranes line from north to south, within the Alaska Range suture zone, as follows; Yukon-Tanana, Pingston, McKinley, Dillinger, Windy, Mystic, Chulitna, Westfork, and the Broad Pass. The Mystic, Chulitna, and Westfork appear to be structurally emplaced within Jurassic-Cenozoic sedimentary basins (Jones and others, 1982).

The Yukon-Tanana terrane is characterized by regionally metamorphosed sedimentary, plutonic, and volcanic rocks (Jones and others, 1982). The majority of units that compose this terrane are Paleozoic in age but Precambrian-Mesozoic strata also exists (Jones and others, 1982). The dominant lithologies of the Yukon-Tanana include quartzite, schist, amphibolite, and granitic rocks (Jones and others, 1982).

The Pingston terrane and McKinley terranes occur as disconnected slivers along the southern side of the Hines Creek fault (Jones and others, 1982). The Pingston terrane is composed of tan weathered phyllite, minor radiolarian chert, limestone, and intrusive masses of gabbro and diorite (Jones and others, 1982).

Pingston terrane units range in age from Pennsylvanian-Triassic (Jones and others, 1982). Strata of the McKinley terrane ranges in age from Mississippian-Cretaceous (Jones and others, 1982). Large blocks (up to 1m) of Devonian limestone occur in the Triassic part of the McKinley terrane stratigraphy (Jones and others, 1982). McKinley terrane strata is characterized by gabbro, basalt, submarine fan deposits with chert and fossil detritus, conglomerate, and Devonian and older rocks (Jones and others, 1982).

Dillinger terrane clastic turbidities and carbonate basin fill occurs on both sides of the Denali fault as folded and faulted thick assemblages (Jones and others, 1982). Dillinger turbidities, shale, and limestone are lower Paleozoic strata that are overlain by Jurassic sandstone and Triassic volcanic strata. Mystic strata structurally overlie Dillinger rocks south of the Denali fault. Mystic strata are dominantly Paleozoic sedimentary rocks with minor amounts of Permian turbidities containing Devonian radiolarian chert (Jones and others, 1982).

The Windy terrane occurs along the Denali faults and Baines Creek fault and is composed of rocks found nowhere else in Alaska (Jones and others, 1982). Windy strata are unique because large blocks of Devonian limestone float in sandstone, conglomerate, and argillite (Jones and others, 1982). The Windy terrane units range in age from Silurian to Cretaceous (Jones and others, 1982).

Chulitna terrane rocks were considered an ophiollite or red beds (Jones and others, 1982). The southwest trending Paleozoic-Mesozoic internally folded and faulted strata is sub-parallel to the Denali fault. The Chulitnia terrane is stratigraphically distinct from turbidities that surround it based on upper Devonian ophiolite, upper Paleozoic chert, volcanic, carbonate, and siliciclastic units are in contact with Upper Triassic siliciclastic, carbonate, and volcanic strata (Jones and others, 1982).

More recent work by Nockelberg and others (2007) divide the south-central Alaska terranes based on tectonic environments and overlap assemblages. The recent stratigraphic summary of Nokleberg and others (2007) provides a basis to compare the Triassic stratigraphy of the Chulitna terrane with that of the Wrangellia island arc, the Yukon-Tanana terrane, and surrounding terranes in the Alaska Range. Refer to Figure 1.2 for location of terranes in the Alaska Range Suture Zone. Yukon-Tanana composite terrane strata is composed of part of an continental margin arc consisting of ancient island arc assemblage with Mississippian to Upper Triassic structural mélange of pillow basalt, basalt, mafic tuff, chert, argillite, and limestone with minor gabbro and diabase (Nokleberg and others, 2007). The Wrangellia composite terrane is composed of arc related rocks and the Upper Triassic to Lower Jurassic part of the stratigraphy consists of metabasalt, argillite, and limestone (Nokleberg and others, 2007). McKinley terrane submarine fan deposits, chert, and pillow basalts are associated with an Upper Triassic seamount (Nokleberg and others, 2007). Windy terrane marine sedimentary and volcanic rocks are associated with oceanic fragments offset by the Denali fault (Nokleberg and others, 2007). The Dillinger terrane and Mystic terrane are connected with the Paleozoic to lower Mesozoic continental margin of

Table 1.1.

Triassic stratigraphy found within the Alaska Range suture zone as summarized by Nokleberg and Richter (2008). These stratigraphic descriptions serve as a basis to evaluate the stratigraphy measured in the Chulitna terrane in comparison with Wrangellia island arc, North American basin fill and exotic terranes. The locations of these terranes are referenced in Figure 2 of this paper with the exception of the Nixon Fork, Pingston, Seventymile, and the Stinkina. The Pingston, Nixon Fork, and Seventymile have been grouped into the Yukon-Tanana composite terrane for simplicity and the Stikinia terrane is approximately 150 miles northeast of the point where the Denali fault splays into the Hines Creek fault.

Epoch	Dates (m.y.)	Chulitna terrane	Windy terrane	McKinley terrane	Dillinger and Mystic terrane	Yukon Tanana Composite terrane	Wrangellia Composite terrane
Late Jurassic	150.8-145.5					Sedimentary rocks include conglomerate, sandstone, and coal. Rhyolite to basalt tuff and flows. Isolated terranes of Early Triassic to Early Jurassic pillow basalt, basalt, mafic tuff, chert, argillite, limestone, gabbro, and diabase and Late Paleozoic to Late Triassic clastic sedimentary rocks	
	155.7-150.8						
	161.2-155.7						
Middle Jurassic	164.7-161.2						
	167.7-164.7						
	171.6-167.7						
	175.6-171.6						
Early Jurassic	183.0-175.6						
	189.6-183.0						metabasalt, argillite, and limestone
	196.5-189.6						
	199.6-196.5	Volcaniclastics, siliciclastics, carbonates, and interbedded carbonates and basalts					
FLate Triassic	203.6-199.6		Limestone	submarine fan deposits, chert and pillow basalt			
	216.5-203.6						
	228.0-216.5						
Middle Triassic	237.0-228.0						
	245.0-237.0						
Early Triassic	249.7-245.0						
	251.0-249.7						
Loping-ian	253.8-251.0				Clastic and carbonate turbidities and basin fill		
	260.4-253.8						
Guadalupian	265.8-260.4						

Table 1.1.

the North American craton (Nokleberg and others, 2007). Table 1.1 summarizes the Triassic stratigraphy from terranes of the Alaska Range suture zone.

THE CHULITNA TERRANE

The Chulitna terrane is located in the central part of the Alaska Range suture zone directly south of the Denali fault. The terrane is bounded by younger Upper Jurassic–Cretaceous siliciclastic strata of the Kahiltna assemblage and is located between the Wrangellia composite terrane to the south and Paleozoic continental margin to the north. Recent potential gravity and magnetotelluric data collected across the Chulitna terrane indicates that the contacts on both sides with Jurassic-Cretaceous strata are defined by faults (Glen and others, 2007). The Chulitna terrane apparently rests on top of these Jurassic-Cretaceous strata.

The Chulitna terrane is defined as a ~50-km-long and ~15-km-wide, southwest-northeast trending belt of structurally imbricated Devonian (?)–Early Jurassic sedimentary and volcanic strata (Figure 1.3.). All units older than Upper Jurassic, within this assemblage, have been subjected to low-grade regional metamorphism (Clautice and others, 2001). Only Triassic and older units have experienced greenschist-facies metamorphism (Clautice and others, 2001). The Devonian strata include banded cherts, siliceous mudstone and sandstones. Shallow marine to marginal marine strata include Permian limestone and Upper Triassic volcaniclastic, sandstone, conglomerate, mudstone, and siltstone units referred to as red beds as well as Upper Triassic limestone and sandy limestone. There is also interbedded Upper Triassic basalt and limestone as well as Jurassic

Figure 1.3.

Geologic map of Devonian (?)–Jurassic units of the Chulitna terrane. Modified from Clautice and others (2001). The focus of this study is on the sedimentology and stratigraphy of the Upper Triassic volcaniclastic, siliciclastic, and carbonate strata of the Chulitna terrane. Normal faults trend northeast across the Chulitna terrane and are shown in red. The outlined region in the Little Shotgun creek region represents the location where a majority of the sedimentologic and stratigraphic data was collected for this study.

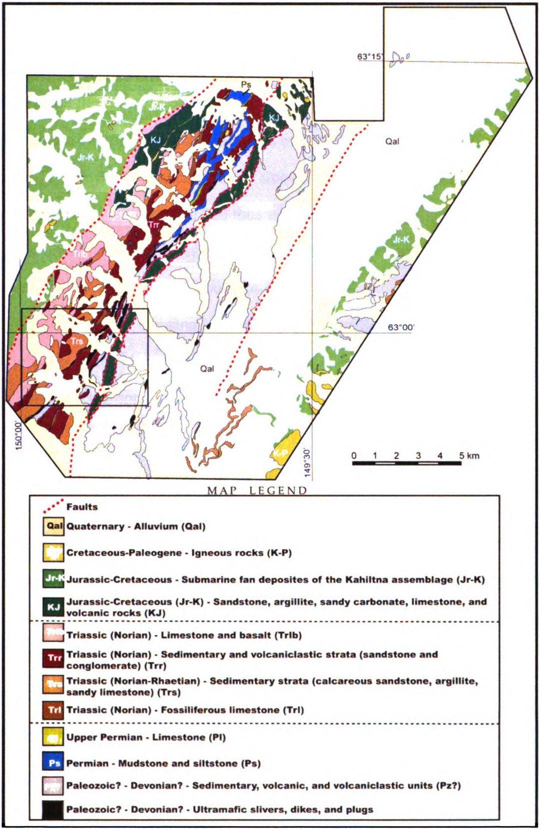

63°15'
Ps
Jr-K
KJ
KJ
Qal
Jr-K
Trr
Trlb
Jr-K
63°00'
Trs
Qal
150°00'
K-P
149°30'
0 1 2 3 4 5 km
MAP LEGEND
Faults
Qal Quaternary - Alluvium (Qal)
Cretaceous-Paleogene - Igneous rocks (K-P)
Jr-K Jurassic-Cretaceous - Submarine fan deposites of the Kahiltna assemblage (Jr-K)
KJ Jurassic-Cretaceous (Jr-K) - Sandstone, argillite, sandy carbonate, limestone, and volcanic rocks (KJ)
Triassic (Norian) - Limestone and basalt (Trlb)
Trr Triassic (Norian) - Sedimentary and volcaniclastic strata (sandstone and conglomerate) (Trr)
Triassic (Norian-Rhaetian) - Sedimentary strata (calcareous sandstone, argillite, sandy limestone) (Trs)
Trl Triassic (Norian) - Fossiliferous limestone (Trl)
Upper Permian - Limestone (Pl)
Ps Permian - Mudstone and siltstone (Ps)
Paleozoic? - Devonian? - Sedimentary, volcanic, and volcaniclastic units (Pz?)
Paleozoic? - Devonian? - Ultramafic slivers, dikes, and plugs

Figure 1.3.

turbidities. The Upper Triassic strata of the Chulitna terrane are widely considered to be one of the more enigmatic stratigraphic successions in southern Alaska given the occurrence of laterally continuous siliciclastic and volcaniclastic units that are interbedded with basalt and limestone in the Triassic part of the section. This is the only occurrence of Upper Triassic siliciclastic red bed units in the Alaska Range suture zone and thus provides an excellent opportunity to begin to understand the Triassic tectonic history of the continental margin as preserved in Triassic strata in southern Alaska.

Age control for Chulitna terrane stratigraphy has been obscured and reset due to the complex Mesozoic –Cenozoic plutonic emplacement in the region combined with the complex history of folding, faulting, and metamorphism.

PREVIOUS WORK

Over the past 30 years, a range of geologic and geophysical data has been collected and used to designate terranes in south-central Alaska (Hillhouse and Gromme, 1980; Stone and others, 2001; Csejtey and others, 1976; Jones, and others, 1972, 1980, 1982; Nokelberg and others, 2007; Clautice and others, 1999, 2001; Blodgett and others, 2000; Glen and others, 2007; Ridgway and others, 2002). No distinguishable paleo-latitude for the Chulitna terrane has been determined (Hillhouse and Gromme, 1980; Stone and others, 2001). Instead the Chulitna terrane was distinguished based on the regional extent of a Mesozoic stratigraphic sequence that is markedly different from adjacent stratigraphy (Hawley and Clark, 1968; Jones and others, 1972, Jones and others, 1980; Jones and others, 1982; Clautice and others, 2001).

Some of the first geologic studies of the Chulitna terrane began in the early part of the twentieth century and were focused primarily on documenting the economic potential for the region (Thrumond, 1918; Townsend, 1925; Clautice and others, 2001). These studies consisted of small-scale mapping of fault-controlled mineralization, general identification of sedimentary and volcanic rocks and coal deposits, and engineering geology projects that were associated with the construction of the Alaska railroad (Thrumond, 1918; Townsend, 1925; Leigler, 1940; Moxam and others, 1951). In the early 1900's Chulitna's first mining claims received considerable attention based on the potential for ore production (Thrumond, 1918; Townsend, 1925). Metal was economically important between 1941 and 1942, when the Golden Zone Mine produced Au, Ag, Cu, and Pb (Leigler, 1940; Moxam and others, 1951).

More recent work in this area has consisted of large-scale, regional mapping projects and geochemical studies that have identified the general stratigraphic assemblages and the occurrence of large-scale faults, both of which have resulted in the classification of the Chulitna region as a fault-bounded tectonic terrane (Jones and others, 1980; Jones and others, 1982; Clautice and others, 2001). The Chulitna terrane consists of stratigraphically imbricated Mesozoic and Paleozoic strata (Jones and others, 1972, 1980, 1982; Wilson and others, 1998; Clautice and others, 2001). Clautice and others (2001) traced the dominate faults in the area on the ground and on aeromagnetic maps, which show that these faults are liner zones of high conductivity. This evidence suggests that these faults are high angle faults (Clautice and others, 2001). High-angle faults trend mainly northeast, northwest, and north-northeast in the Chulitna terrane. Northeast trending are the most continuous and define the Broad Pass graben and mark the northwestern margin of the Chulitna terrane (Clautice and others, 2001).

The next set of faults that appear to have a significant effect on offset in the Chulitna terrane trend northwest and are approximately 20 to 30 km apart (Clautice and others, 2001). These two sets of faults are up to 70 My based on cross cutting relationships (Clautice and others, 2001). The most commonly occurring faults in the Chulitna terrane are the north-northeast-trending set of strike slip faults. However, these faults are thought to have minor movements (Clautice and others, 2001). A young age is indicated by cross cutting relationships with veins, skarns, and mineralized Late Cretaceous plutons. Although several sets of structures may pre-date the previously discussed sets of faults these older structure have yet to be defined or traced. Table 1.2. summarizes age constraints for the Chulitna terrane stratigraphy provided by previous workers and outlined in the following discussion.

Devonian Stratigraphy

A narrow, strong magnetic signature trending northeast across the Chulitna terrane produces an aeromagnetic high which has been correlated to ultramafic strata in outcrop (Clautice and others, 2001), see Figure 1.3. Hawley and Clark (1968) documented the occurrence of a massive chromite body within scattered blocks of gabbro, basalt, diabase, and abundant red radiolarian chert. Most serpentinite is clinochrysotile and lizardite indicating a lack of high-temperature metamorphism (Jones and others, 1982). Lenticular and podiform blocks of sheared serpentinite are intercalated with the chert and pillow basalt (Wilson and others, 1998). The serpentinite has a variable composition ranging from serpentinized, chromite bearing dunite to gabbro and transitions to silica-carbonate rocks (Clautice and others, 2001). Major and trace element similarities relate the gabbro to basalt clasts of the Devonian volcaniclastic unit (Clautice and others, 2001). Trace element analysis reveals the serpentinite is similar to andesitic tuff and flows (Clautice and others, 2001). A Devonian age is suggested based on spatial relationship to Devonian chert unit, but age is not well constrained (Clautice and others, 2001). Chert lenses occur within pillow basalt and as isolated blocks within serpentinite. Pillow basalt contains red chert that is thought to contain Devonian age radiolarian, classified as *Entactinospaera* (Jones and others, 1982).

Clautice and others (2001) mapped bedded, Early (?) to Middle Devonian limestone. Rugose and tabulate corals, and brachiopods indicate a Middle Devonian while conodonts indicate Late Silurian to Early Devonian age (Clautice and others, 2001). Jones and others (1982) report *Polygnathus* a conodont of Late Devonian (Famennian age from nine localities, in the northwest, and on Long Creek.

Massive to bedded radiolarian chert can be red, brown, green or black and is up to 0.5 percent MnO (Clautice and others, 2001). Chert is also found as large lenses and blocks in fault zones and as clasts in Middle to Lower Triassic conglomerate and is interlayer at the lower contact (Clautice and others, 2001). Analyses of immobile element compositions, including Ti-Zr-Y, indicate an intro-oceanic island arc (Clautice and others, 2001).

Upper Devonian pyroxene, andesite tuff and flows with compositions ranging from island-arc tholeiitic basalt to dacitic tuff were mapped by Clautice and others (2001). Detritus derived from this sequence is found in the Upper Triassic strata (Jones and others, 1982). The ultramafic, radiolarian chert, pillow basalt, and argillite stratigraphic sequence is interpreted as an ophiolite by Jones and others (1982). They presumed an arc became the dominate source after this time based on the introduction of coarse conglomerate, tuff, andesite, and chert (Jones and others, 1980). Clautice and others (2001) noted that previously mapped Devonian volcanic rocks and tuffs were correlated to units in Broad Pass just south of the Chulitna terrane, see Figure 1.1. Geochemical data from these volcanic rocks indicate an arc-related igneous origin which Clautice and others (2001) interpreted as a link to the Wrangellia Island Arc.

Mississippian–Permian Stratigraphy

Upper Paleozoic(?) argillite and tuff is interbedded with siltstone and chert. Radiolarians in the chert indicate a Mississippian to Permian age (Jones and others, 1982). Sedimentary rocks dominate this sequence, which may correlate to Upper Paleozoic tuff found in the West Fork terrane and the chert and argillite of the Broad Pass terrane (Clautice and others, 2001) see Figure 1.2. The chert and argillite are overlain by massive conglomerate containing cobble to boulder size chert (Jones and others, 1982). Conodonts from the chert clasts include *Polygnathus cf. P. glaber, P. aff. P. webbi* which indicate a Famennian age (Jones and others, 1982). The volcanic conglomerate grades into sandstone, siltstone, and chert (Jones and others, 1982). Chondrites and Scalarituba, brachiopods, bivalves, and bryozoans near the top of sequence were interpreted to indicate a Permian age (Blodgett and Clautice, 2000). Abundant helminthoid feeding tracks overlie the chert but contain no datable fossils according to Jones and other (1982). This Permian unit conformable and gradationally underlies Permian limestone.

Massive crinoidal bryozoan limestone is intercalated with red or brown fossiliferous argillite (Jones and others, 1982). Brachiopods, bryozoans, and rare corals of Permian age are found in massive limestone (Jones and others, 1982). Brachiopods were identified as Fimbrinia sp., which indicates an Early Permian age (Jones and others, 1982). Limestone blocks yield *Neogondolella polygnathiform*is conodonts of Karnian age (Jones and others, 1982). Fragments of brachiopods and bivalves from limestone blocks suggest a Late Triassic age (Jones and others, 1982). Horridonid brachiopods are common in Upper Permian limestone, which contains abundant megafauna typical of the Arctic during the Permian, including brachiopods, bryozoans, pelmatozoan debris, solitary rugose corals, ostracods, and trilobites (Clautice and others, 2001).

More recent petrographic studies of this limestone document hetrotrophic bryozoans and echinoderms as the dominate assemblage while phototropic biota contribute minor amounts (Montayne and others, 2003). The lack of nonskeletal grains, carbonate mud, and presence of mechanical compaction features combined with dominate heterotrophic biota was cited as evidence of cool-water deposition during the Permian (Montayne and others, 2003).

Triassic–Jurassic Stratigraphy

According to previous workers sandstone mudstone and limestone are uncomfortably overlain by volcaniclastic redbeds (Clautice and others, 2001; Wilson and others, 1998). Early Jurassic and Late Triassic red and brown sedimentary rocks including sandstone, siltstone, argillite, and conglomerate grade into fossiliferous brown sandstone and brownish-gray siltstone and basalt (Clautice and others, 2001). Middle(?) to Lower(?) Triassic tuff, andesite, basalt, greywacke, and conglomerate characterized by a predominantly volcanic and volcaniclastic composition was mapped by other field workers as part of the hemaitic sandstone, siltstone, and argillite (Jones and others, 1982). Early Jurassic and Late Triassic strata are more than 2,000 m thick (Wilson and others, 1998).

The red sandstone sequence mapped by Jones and others (1982) contained thin interbeds of brown fossiliferous sandstone, limestone, and intercalated basalt flows. Clasts documented were dominantly basalt cobbles and pebbles derived from underlying basalt and flows within this sequence. In lesser amounts quartzite pebbles, leuco-mica and red radiolarian chert clasts are present. However, there are thick lenses of up to 10 m or more of quartz pebble conglomerate. Jones and others (1982) cited this clast composition as evidence of nonmarine deposition in the Triassic when red beds appear. According to Jones (1982) this unit marks the destruction of a basin based on their interpretation of an ophiolite and the unconformity observed at the base of the red beds, cross-cutting units they had interpreted as older (Jones and others, 1982). Late Triassic units, of the Chulitna, show a southeast to northwest trend interpreted to represent a northeast trending paleo-shoreline (Jones and others, 1982). Jones and other (1982) described two coeval depositional settings; 1.)in the northwest: basalt, minor silicic volcaniclastics, and limestone and 2.) southeastern: nonmarine redbeds, minor basalt, and abundant silicic volcaniclastics.

Clautice and others (2001) interpreted their compositional studies of the red beds as evidence that the "redbeds" of the Chulitna terrane are actually two distinct units. Clautice and others (2001) interpreted aeromagnetic data collected for the red beds as an indication that the diagenetic oxidation of primary Fe-Ti oxides resulted in a generally non-magnetic signature and red color (Clautice and others, 2001). When Clautice and others (2001) compared Ca/Al/Si standards for sandstones, limestones, shales, and mafic to intermediate igneous rocks the major element compositions of red clastic rocks of the Chulitna terrane they found that the red clastic rocks compositionally resemble mafic to intermediate igneous rocks and shales more so than sandstones.

Petrographic analysis of the framework grains shows that they are predominantly mafic volcanics, but also include quartz, felsic volcanics, plutonic and metamorphic rocks (Clautice and others, 2001). The conglomerate contains clasts of chert that contain upper Devonian radiolarian (Clautice and others, 2001). Point counts of these rocks yield values that range from high volcanic content and low in quartz to higher percentages of quartz and lower in volcanic content (Clautice and others, 2001). Clautice and others divided the red beds into Coarser volcaniclastic members that are often calcareous, with a predominantly medium to very coarse grained, poorly sorted matrix containing occasional feldspar, clinopyroxene, and hornblende crystals. Lithic clasts are subangular and consist of predominantly mafic volcanics frequently altered to chlorite, hematite, and calcite. Other lithic fragments include quartz, polycrystalline quartz, felsic volcanics, plutonic, and metamorphic rock. The compositions and lithologies of the lower portion indicate a volcanic arc affinity. The common red color of this unit is due to its andesitic-basaltic bulk composition and to syngenetic or diagenetic oxidation. According to Clautice and others (2001) they did not find evidence that this unit is hematitic sandstone or a "redbed" in the commonly accepted use of the term.

The other unit was described by Clautice and others (2001) as red bed sandstone and conglomerate. Upper Triassic red bed sandstone and conglomerate described by Clautice and others (2001) includes siliciclastic rocks that are red-maroon, coarse-grained with local calcareous cement, and are matrix supported. Clast compositions recorded range from varying amounts of quartz, basalt, and volcaniclastics. This was not placed within a stratigraphic context because no fossils were found and the contact with Upper Triassic limestone and basalt was uncertain (Clautice and others, 2001; Jones and others, 1982). A Late Triassic age was assigned to these rocks based on the lithologic similarity to Upper Triassic redbeds found in the central portion of the Chulitna (Jones and others, 1982). Along Long Creek the redbeds are overlain by thick silicic tuffs and breccias (Jones and others, 1982). Christy Creek samples contain juvavitid of latest Karnian to middle Norian age which were interpreted by Jones and others (1982) to represent contemporaneous deposition of these redbeds and the limestone and pillow basalt sequence.

Red beds grade into brown fossiliferous sandstone and siltstone which contains marine mollusks and Heterastridium (Jones and others, 1982). Ammonites from fossiliferous locations, within this unit, indicate a Sinemurian and Early Jurassic age (Blodgett and Clautice, 2000). Colonial corals, snails, bivalves and Heterastridium in the lower part of the section indicate a Late Norian age (Jones and others, 1982, Blodgett and Clautice, 2000). Fossil evidence in the argillite includes limestone lenses containing ammonites and bivalves: *Paracaloceras rursicostatum, Badouxia canadense, Weyla sp., Lima sp.,* and *Eopecten sp.* which suggest and early Sinemurian age (Blodgett and others, 2000). Lower Triassic limestone of Chulitna contains abundant megafossils (Nichols and Silberling, 1979). The most abundant of the 13 species found representing 13 genera include *Meekoceras, Dieneroceras, Arctoceras, and Paranannites* (Nichols and Silberling, 1979). All species found are indicative of

Early Smithian rocks associated with deposition along the North American craton at paleo-latitudes approximately 10° N (Nichols and Silberling, 1979). Petrographic analysis of intergranular acicular carbonate cement was also interpreted to indicate cementation during warm water, low latitude conditions (Nichols and Silberling, 1979). These ammonites were originally documented by Hawley and Clark (1968) as *Euflemingites romunderi* or *Meekoceras gracilitatis* which they interpreted to indicate deposition at northern and southern paleo-latitudes respectively.

Geochemical analysis of Upper Triassic basalt indicates it is sub alkaline and tholeiitic by trace-element abundances typical of within plate settings (Clautice and others, 2001). Wilson and others (1998) assert that the chemistry of basalt is compositionally analogues with an ocean island shield volcano. Basaltic dikes and sills are indistinguishable compositionally from basalt flows of the same age (Wilson and others, 1998). However, the dikes and sills are at least 179 Ma based on Argon dating (Clautice and others, 2001). Limestone interbedded with the basalt is characterized by colonial scleractinian corals, megalodontid bivalves, and *Spondylospira lewesensi* brachiopods, indicating Norian deposition. Upper Triassic limestone documented in the Long Creek area contains colonial scleractinian thicket reefs with well-preserved Norian age fauna including brachiopods, corals, bivalves, and gastropods (Blodgett and Clautice, 2000). Late Norian Monotis (Pacimonotis) subcircularis found at one location in the southwestern edge of the terrane (Siberling and others, 1997). This Triassic bivalve Monotis is the largest, most widespread Monotis in North America

TRIASSIC AGE CONSTRAINTS FOR THE CHULITNA TERRANE STRATA PROVIDED BY PREVIOUS WORKERS	
Sub-unit (according to Clautice and others, 2001)	Age control
Trr Red bed sandstone and conglomerate	Upper contact with TRlb observed by this team Lower contact with TRlb observed by Clautice(2001) Lower gradational contact with unit TRs
TRs Brown sandstone and argillite	**Norian to Rhaetian** faunal assemblages Heterastridum, snails, and bivalves
TRlb Basalt, Basaltic tuff, and limestone	Limestones composed of colonial scleractinian corals, megalodontid bivalves, and Spondylospira lewesensis brachiopod all indicate that the age is **Norian**
Basaltic Dikes and sills	40Ar/39Ar on dikes and sills indicates a minimum age of **179 Ma** - Compositionally similar to TRlb basalt
Trl Limestone	Bindstone composed of colonial scleracinian thicket reefs as well as **Norian** age brachiopods, scleracinian corals, bivalves(Monotis subcircularis), and gastropods
Trr Red-colored tuff, andesite, basalt, mudstone, and conglomerate	Locally cut by TRb=younger than 179 Ma Overlies limestone with fossils in the Penn-Permian range Basal contact is with conglomerate containing Devonian age radiolarian chert
Trl	13 ammonite fossils of Olemekiam age

Table 1.2.

Summary of the age constraints on the Triassic stratigraphy of the Chulitna terrane provided by Blodgett and Clautice, (2000).

(Siberling and others, 1997). It is found adjacent to the Chulitna terrane in the Susitna, Nenena, and Wrangellia terranes (Siberling and others, 1997) see Figure 1.2.

PURPOSE OF STUDY

There are numerous occurrences of Triassic strata throughout the Alaska Range Suture Zone. Previous studies have focused on the accretionary history of the continental margin since Jurassic time, however, very little is known about the Triassic history of the continental margin and island arc prior to accretion. Numerous Triassic and older, fault-bounded terranes occur north of the Wrangellia composite terrane and south of the Mesozoic continental margin. Each of these terranes has been studied within the general context of regional mapping projects and, although there are some stratigraphic similarities shared between terranes, there is little consensus on the tectonic history of the North American Cordillera, as preserved in Triassic stratigraphy, due primarily to a lack of detailed study.

A second factor that has limited our understanding of the Triassic tectonic evolution of the North American Cordillera is the lack of exposed Triassic age siliciclastic strata in southern Alaska. Siliciclastic strata preserved in mountain belts are often the only remaining record of exhumation associated with tectonic activity along active margins. Many of the terranes in this region share a common stratigraphic link that includes interbedded basalt and limestone units, however, the occurrence of Triassic siliciclastic strata is rare if not absent. One exception is the Chulitna terrane in south-central Alaska. Based on findings from previous studies, three hypotheses have been proposed to explain the stratigraphic history, tectonic evolution, and present day occurrence of the Chulitna terrane in the Alaska Range suture zone. The hypotheses include:

1.) The Chulitna terrane represents an "exotic" tectonic terrane that has no prior association or affiliation with the North American margin or the Wrangellia Composite Terrane. In this model, the Chulitna terrane is considered truly "exotic" or "suspect" within the context of the Alaska Range suture zone and the North American Cordillera. Jones et al. (1982) have proposed that much of the older parts of the Chulitna terrane may represent part of an ophiolite sliver that was obducted to the margin during accretion of the terrane. The enigmatic occurrence of red bed units together with isolated biostratigraphic data have been used as the main evidence for an exotic origin for the Chulitna terrane.

2.) The Chulitna terrane represents a sliver of stratigraphy that was inboard of the Wrangellia composite terrane and possibly accreted to the island arc prior to its eventual accretion to the North American margin (Csejtey and others, 1992). In this model, the Chulitna stratigraphy was thrust northward to its present position and represents a faulted-bounded klippe within the Alaska Range suture zone. Clautice et al. (2001) present a similar model by which the Chulitna stratigraphy correlates with strata of the Wrangellia composite terrane and represents a fault-bounded portion of Wrangellia that has undergone northward structural emplacement. Geochemical studies of parts of the Chulitna stratigraphy indicate a large volcanic component which resembles calc-alkaline arc rocks associated with Wrangellia (Clautice and others, 2001). Geochemical data combined with biostratigraphic similarities between the Chulitna terrane and Wrangellia are cited as evidence that links the two terranes.

3.) The Chulitna terrane may represent a displaced sliver of continental crust associated with the western margin of North America. This model implies that the Chulitna stratigraphy may share some affinity with the North American margin. It is important to note that this is an emerging model based on preliminary U-Pb detrital zircon data from the Chulitna terrane that potentially suggests a stratigraphic link to the North American Cordillera by the end of the Triassic (Hampton and others, 2007).

LITTLE SHOTGUN CREEK STUDY AREA

The Chulitna terrane is oblique to the Denali fault, running NE to SW. At the southwestern corner of the terrane there are several ridges and valleys that provide excellent exposures of the Chulitna terrane stratigraphy. Little Shotgun creek (Figure 1.4.) is the ideal study location to address the hypotheses of this project due to the excellent exposure of Triassic stratigraphy that is part of the Chulitna terrane. Figure 1.4 shows the Paleozoic-Mesozoic stratigraphy that is present along the ridges of the Little Shotgun Creek catchment. It is important to note that within the 10 km^2 study area, located in the western region of the Chulitna terrane, red beds and metavolcaniclastic units described by previous workers are exposed. Siliciclastic and carbonate units make up the bulk of the Little Shotgun creek measured sections shown in the Little Shotgun sections. Figure 1.4 shows the location of measured sections for this study and the general geology of the Little Shotgun creek study area. Jurassic, Permian, and Devonian strata are exposed at the bottom of section LS-062907 for 132.5 meters. The basal Triassic is a conglomerate with Devonian boulders of chert. Serpentinite is highly weathered in this rubble-crop exposure and it appears to be gradational with the Triassic conglomerate. The contacts between Triassic units also appeared gradational in many places. Few erosional contacts were noted, although they could not be traced due to rubble-crop exposure. Overall measured sections show 650 meters of coarsening upward sequences. 550 meters of the total has been connected with the Triassic units. Triassic basalt and tuff units measured approximately 25 meters total in the area. Little Shotgun creek Triassic stratigraphy can be divided into three major units: siliciclastics, carbonates, and interbedded basalt and limestone. These units have been further subdivided by previous workers based on varying interpretations (Jones and others, 1982; Clautice and others, 2001; Blodgett and Clautice, 2000).

METHODS AND APPROACH

In order to determine the significance of the Chulitna terrane in terms of its relationship to Wrangellia, North America, or other terranes within the suture zone a detailed study of the Triassic stratigraphy of the Chulitna terrane was the primary goal of this study. The purpose of this project is to conduct a geologic field and laboratory study to document the sedimentologic and stratigraphic history and determine the general provenance of Triassic strata from the Chulitna terrane in the Alaska Range suture zone. Measured stratigraphic sections provide the data

Figure 1.4.

Geologic map of Devonian (?) – Jurassic units in the Little Shotgun creek study area in the Chulitna terrane. Modified from Clautice and others (2001). Note the location of three measured sections in the Little Shogun creek study area.

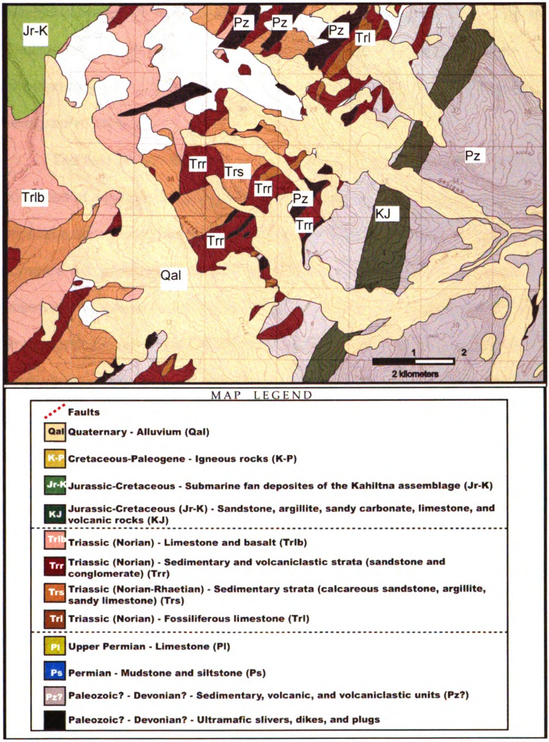

Jr-K
Pz
Pz
Pz
Trl
Trr
Trs
Trr
Pz
Trlb
KJ
Trr
Trr
Pz
Qal
1
2
2 kilometers
MAP LEGEND
Faults
Qal Quaternary - Alluvium (Qal)
K-P Cretaceous-Paleogene - Igneous rocks (K-P)
Jr-K Jurassic-Cretaceous - Submarine fan deposites of the Kahiltna assemblage (Jr-K)
KJ Jurassic-Cretaceous (Jr-K) - Sandstone, argillite, sandy carbonate, limestone, and volcanic rocks (KJ)
Trlb Triassic (Norian) - Limestone and basalt (Trlb)
Trr Triassic (Norian) - Sedimentary and volcaniclastic strata (sandstone and conglomerate) (Trr)
Trs Triassic (Norian-Rhaetian) - Sedimentary strata (calcareous sandstone, argillite, sandy limestone) (Trs)
Trl Triassic (Norian) - Fossiliferous limestone (Trl)
Pl Upper Permian - Limestone (Pl)
Ps Permian - Mudstone and siltstone (Ps)
Pz? Paleozoic? - Devonian? - Sedimentary, volcanic, and volcaniclastic units (Pz?)
Paleozoic? - Devonian? - Ultramafic slivers, dikes, and plugs

Figure 1.4.

needed to determine facies associations and develop a depositional model for the Chulitna terrane. Descriptive petrography along with geochemical studies provided by previous workers will be utilized to suggest provenance within a stratigraphic context.

The field portion of this study included 30 days in the Chulitna terrane and consisted of geologic mapping, measuring stratigraphic sections, and sample collection from Triassic stratigraphy. Geologic mapping is done in the field area to compare with previous geologic maps and make corrections based on field observations. Measured stratigraphic sections aided in providing the first detailed stratigraphic picture of the Chulitna terrane. In general, working knowledge of stratigraphy allows for upsection (temporal) and along-strike (spatial) comparison of sedimentary depositional environments. As a whole, mapping and measured sections provide the basis for comparing the Chulitna stratigraphy with the Triassic units of the Wrangellia composite terrane, North American continental margin, and other tectonic terranes in the Alaska Range suture zone.

A total of 74 sandstone and limestone samples were collected within the context of measured sections. These samples were prepared for thin sections and descriptive petrography data was collected. Outcrop, hand sample, and petrographic descriptions provide the basis to classify facies. Describing facies within a stratigraphic context results in facies associations. A depositional model for the facies encountered within the measured sections of Little shotgun creek will be developed. Once a depositional model for the Chulitna terrane has been established the environment implicated can be compared with the existing tectonic models. The results of this study will provide a stratigraphic context to compare and contrast the western region of the Chulitna terrane with future stratigraphic measurements of the central and eastern portion of the Chulitna terrane. These results can also be applied to existing geochemical and paleontological studies to add a stratigraphic constraint. Measured Chulitna terrane stratigraphy can be compared and contrasted with the Triassic strata of other terranes within the Alaska Range suture zone measured by previous workers.

CHAPTER II: SEDIMENTOLOGY, STRATIGRAPHY, AND DEPOSITIONAL SYSTEMS

INTRODUCTION

Chulitna terrane stratigraphy is characterized and defined primarily by Paleozoic to Mesozoic volcanic rocks and carbonate and siliciclastic sedimentary strata. Paleozoic units include bedded chert, siliceous mudstone, fine-grained sandstone, limestone, and basalt. Mesozoic (Upper Triassic) units make up some of the more enigmatic strata in the Chulitna terrane and are reported to consist of continental red beds and volcaniclastic strata (Clautice and others, 2001; Jones and others, 1982). Triassic strata of the Chulitna terrane also include interbedded limestone, basalt, and tuff. Although previous workers have provided general descriptions of Upper Triassic strata exposed throughout the Chulitna terrane these units have never been measured or described within a sedimentologic and stratigraphic context. Moreover, the nature of the contacts between these units as well as a general depositional environment has not been constrained for these strata.

The purpose of this study is to measure, document, and classify the Upper Triassic siliciclastic and carbonate sedimentary strata encountered in the Little Shotgun Creek study area and Chulitna terrane for the purpose of better understanding the stratigraphic and tectonic implications of these strata in the context of the Alaska Range suture zone. Consensus regarding a depositional model for these units has eluded previous workers but for the first time this study anchors the depositional model on measured stratigraphy. Any tectonic implications suggested by the resultant depositional model can be reviewed to determine general relationships of the new data to test existing tectonic models for the Chulitna terrane.

GENERAL FACIES METHODOLOGY

The feedback between sedimentary environments and sedimentary facies relies on physical properties. Physical properties as outlined in this study include documentation of sedimentary structures and textures, geometry, thickness, and stratigraphic and structural relationships between individual units. Measurement and description of these properties have be used in this study to constrain facies associations and ultimately to determined depositional environments that were active during deposition of Upper Triassic strata of the Chulitna terrane. Sedimentary facies are classified based on geometry of the deposit, primary sediment properties, and derived sediment properties. In order to work backward from observed facies to specific processes it is necessary to group facies according to environmental or genetic similarities into facies associations.

In order to determine the depositional environment for facies encountered in the Chulitna terrane this study focuses on grain size, sorting, shape, the presence of matrix, general grain composition, fossil content, thickness and lateral extent, geometry of the beds, and sedimentary structures. Documentation of each of these characteristics in the context of measured stratigraphic sections can be used to infer a temporal change in depositional environment for each Upper Triassic siliciclastic unit from the Chulitna terrane.

STRATIGRAPHIC OVERVIEW

Sedimentologic and stratigraphic data were collected from three measured stratigraphic sections in Upper Triassic stratigraphy from the Little Shotgun Creek study area of the Chulitna terrane (Figure 2.1). The Little Shotgun Creek study area is located in the southwestern extent of the Chulitna terrane (Healy A-6 1:36,360 quadrangle) and represent some of the best exposed Upper Triassic strata in the Alaska Range (Figure 2.3, 2.4, 2.5). Figure 2.2 represents a summary of three new measured stratigraphic sections from Upper Triassic strata of the Chulitna terrane. Refer to Appendix A of this document for a detailed, meter-by-meter summary of sedimentologic and stratigraphic data from measured sections.

Overall, Upper Triassic strata measured from the field area consist primarily of two distinct successions (Figure 2.3, 2.4, 2.5). The lowermost succession is characterized by interbedded conglomerate, sandstone, siltstone, and fossiliferous and sandy limestone (Figure 2.4). The upper succession consists primarily of interbedded basalt and limestone (Figure 2.3, 2.5). Previous studies have identified the general lithology of each of these successions; however, this is the first study to present Upper Triassic strata in the context of an upper and lower succession. This study is focused largely on documenting the sedimentologic and stratigraphic trends of interbedded siliciclastic and

Figure 2.1.

Generalized geologic map of the Little Shotgun Creek study area in the southwest part of the Chulitna terrane. The focus of this study is on Upper Triassic (Norian–Rhaetian) siliciclastic and carbonate strata (red and orange map units, respectively). The location of stratigraphic sections measured as a part of this study is denoted by numbered circles. Geologic map is modified from Clautice et al., 2001.

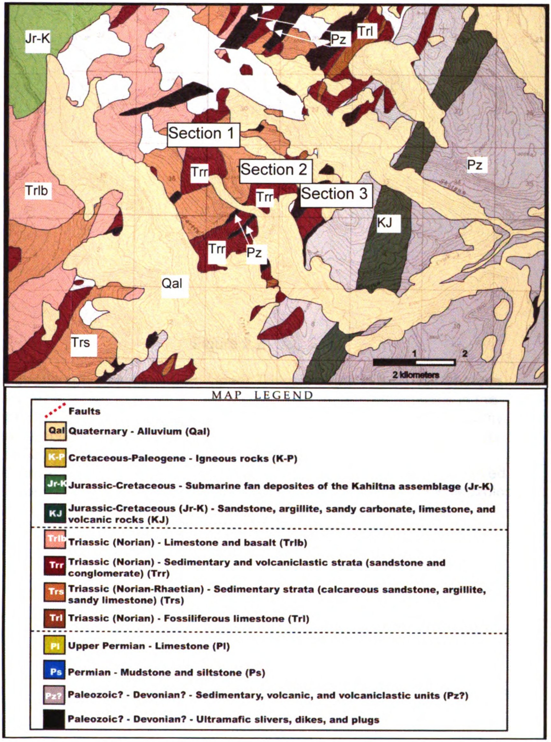

Jr-K
Pz
Trl
Section 1
Trr
Section 2
Trr
Section 3
Pz
Trlb
KJ
Trr
Pz
Qal
Trs
1
2
2 kilometers
MAP LEGEND
Faults
Qal Quaternary - Alluvium (Qal)
K-P Cretaceous-Paleogene - Igneous rocks (K-P)
Jr-K Jurassic-Cretaceous - Submarine fan deposites of the Kahiltna assemblage (Jr-K)
KJ Jurassic-Cretaceous (Jr-K) - Sandstone, argillite, sandy carbonate, limestone, and volcanic rocks (KJ)
Trlb Triassic (Norian) - Limestone and basalt (Trlb)
Trr Triassic (Norian) - Sedimentary and volcaniclastic strata (sandstone and conglomerate) (Trr)
Trs Triassic (Norian-Rhaetian) - Sedimentary strata (calcareous sandstone, argillite, sandy limestone) (Trs)
Trl Triassic (Norian) - Fossiliferous limestone (Trl)
Pl Upper Permian - Limestone (Pl)
Ps Permian - Mudstone and siltstone (Ps)
Pz? Paleozoic? - Devonian? - Sedimentary, volcanic, and volcaniclastic units (Pz?)
Paleozoic? - Devonian? - Ultramafic slivers, dikes, and plugs

Figure 2.1

Figure 2.2

Measured stratigraphic sections from Upper Triassic strata in the Little Shotgun Creek study area, Refer to figure 2.1 for a location of measured sections in the Little Shotgun Creek study area and the Chulitna terrane. Note that the majority of measured sections document Upper Triassic siliciclastic and carbonate units, however stratigraphic relationships have been documented with overlying, younger basal and limestone units. A structural relationship has been observed between Upper Triassic siliciclastic and carbonate units and adjacent Paleozoic (?)–Jurassic (?) siliceous mudstone, pillow basalt, and serpentinite units.

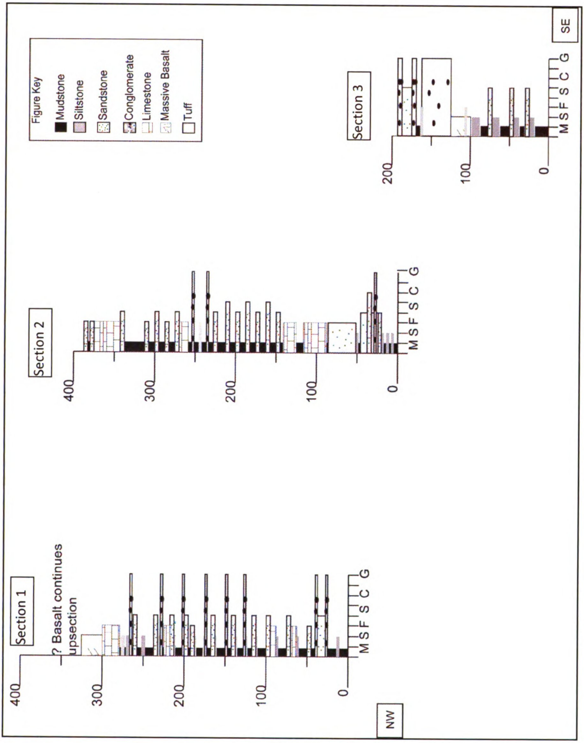


Figure Key
Mudstone
Siltstone
Sandstone
Conglomerate
Limestone
Massive Basalt
Tuff
Section 1
? Basalt continues upsection
Section 2
Section 3
NW
SE
400
300
200
100
0
M S F S C G

Figure 2.2.

Figure 2.3.

Exposure of upper and lower successions of Upper Triassic stratigraphy in the Little Shotgun Creek study area and surrounding regions. (A) View to the north of interbedded siliciclastic and carbonate strata with Devonian (??) basalt and serpentinite (SP/BS) (view to the north). Red arrows denote location of Upper Triassic strata in photo B. (B) View to the east of upright, dipping beds off siliciclastic (Trr) and carbonate strata (Trs) and overlying basalt and limestone (Trlb)). Thick red arrow denotes a thrust fault in the Trr and Trs units.

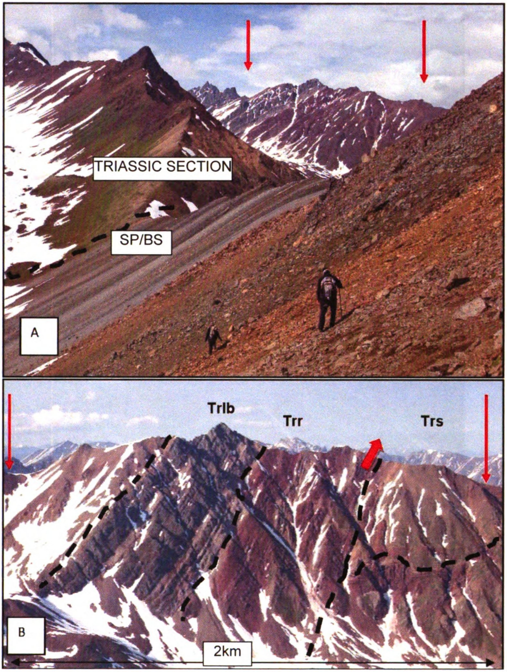


Figure 2.3

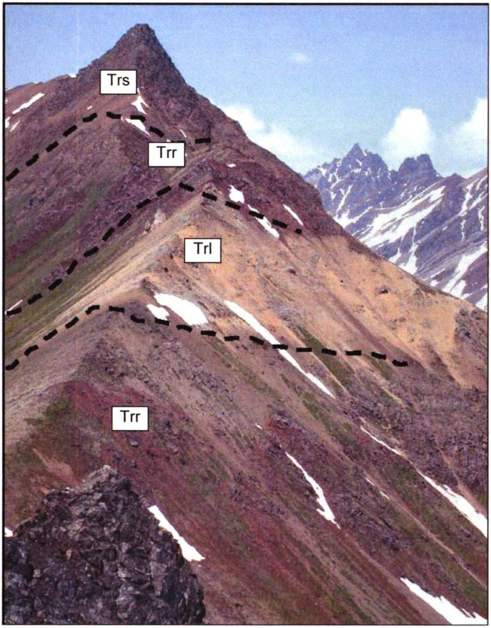


Figure 2.4

Upright, dipping strata comprised of interbedded siliciclastic redbed units (Trr) and limestone (Trl) that make up measured section 2 (refer to figure 2.2. for location of measured section). Measured stratigraphic sections reveal the occurrences of stratigraphic contacts between siliciclastic and carbonate strata and are reported here to represent a continuous stratigraphic succession. View to the north and strata are dipping into the photo. The Trl unit in this figure is ~60 mm thick for scale. Refer to measured section 2 and Appendix for detailed sedimentologic and stratigraphic descriptions from these strata.

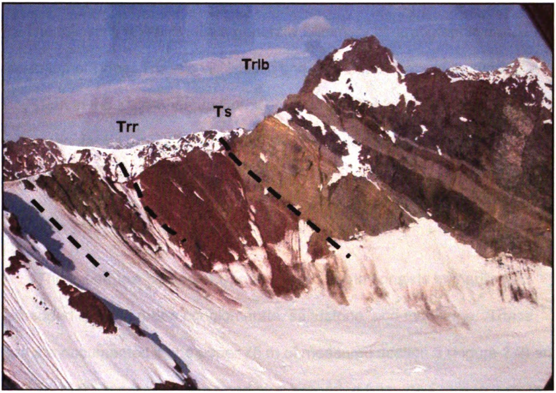


Figure 2.5.

Upright, dipping beds of Upper Triassic strata consisting of a lower succession of interbedded redbed (Trr) and limestone (Ts) units and overlying succession of interbedded basalt and limestone (Trlb). This photo was taken in the central to northeastern parts of the Chulitna terrane. Note the similarity in stratigraphic relationships between Upper Triassic strata in this location as compared with documented measured strata from the Little Shotgun Creek field area of this study.

carbonate strata that are preserved in the lowermost succession of the Upper Triassic strata of the Chulitna terrane. While the study summarizes trends from the southwestern area of the Chulitna terrane, similar stratigraphic relationships have been observed in the northeastern region of the Chulitna terrane (Figure 2.5). The following text provides a generally summary of stratigraphic trends from base-to-top of Upper Triassic siliciclastic and carbonate strata of the upper succession in the Little Shotgun Creek study area. Table 6 is a summary of sedimentary facies classifications that have been documented from the Chulitna terrane in this study.

Upsection Stratigraphic Trends

The lowermost portion of Upper Triassic strata consists primarily of interbedded red and green conglomerate, sandstone, and mudstone. These strata are documented in the upper 75 m of measured section 3 (Figure 2.2) and are some of the most coarse-grained strata reported from the Chulitna terrane consisting primarily of interbedded conglomerate and coarse-grained sandstone. Overall, conglomeratic units have tabular geometries and are characterized largely by matrix- and clast-supported gravel deposits that contain outsized clasts of red chert. Outsized chert boulders when measured along their long axis, range in size from 0.15–1.0 m in length and are on average ~0.25 m long. The occurrence of matrix- and clast-supported conglomerate is common throughout the lower succession of Upper Triassic strata in the study area. However, this is the only location in measured stratigraphic sections where outsized chert clasts have been observed and documented in this study.

The majority of measured sections from the Little Shotgun Creek study area reveal stratigraphic relationships between interbedded Upper Triassic siliciclastic conglomerate and sandstone units and carbonate strata. Siliciclastic units range in thickness between 1-3 m thick while carbonate strata is typically <1 m thick. These strata have been documented in measured section 1 and 2 (refer to Figure 2.1. and 2.2. for location and general upsection trends of measured sections). Section 3 documents a stratigraphic relationship between older Upper Triassic siliciclastic and carbonate strata and younger uppermost Triassic basalt and limestone (Figure 2.2.).

Prior to this study, much of these siliciclastic and carbonate strata where divided into 3-4 separate units that were thought to represent several very different depositional environments (Clautice et al, 2001). In addition, given that much of the stratigraphy of the Chulitna terrane has been structurally deformed, many of the contacts between Upper Triassic siliciclastic and carbonate strata were thought to possibly represent structural contacts rather than stratigraphic contacts. Previous studies have also suggested that Upper Triassic strata from the Little Shotgun Creek region are overturned with the oldest beds being interbedded basalt and limestone and younger units being siliciclastic redbed units and carbonate strata. Measured sections and stratigraphic relationships documented hear reveal that (1) Upper Triassic redbed and carbonate strata are interbedded and potentially reflect a depositional system that includes a strong siliciclastic and carbonate component and (2) that interbedded basalt and carbonate strata that were originally proposed to be older than redbed and carbonate units are actually younger and stratigraphically overlie older siliciclastic and carbonate strata.

SEDIMENTARY FACIES

Sedimentologic and stratigraphic descriptions from measured sections reveal a total of 21 individual lithofacies with 14 representing siliciclastic transport and deposition and 7 representing some combination of carbonate transport, deposition, and in situ precipitation. Table 2.1 and 2.2 present a summary of each facies documented from Upper Triassic siliciclastic strata and carbonate units from the Little Shotgun Creek study area and the corresponding facies codes for each lithofacies. Siliciclastic facies are made up primarily of gravel, sand, silt, and mud facies. Carbonate lithofacies consist largely of muddy limestone, sandy limestone, and fossiliferous limestone. Both siliciclastic and carbonate, Upper Triassic, facies can be found interbedded from base-to-top in the study area.

The coarsest-grained siliciclastic lithofacies consist of massive, matrix-supported pebble and cobble conglomerate (Gmm), matrix-supported conglomerate with crude normal grading (Gmg), and massive, clast-supported conglomerate (Gcm) (Figure 2.6 A, B, C, D). Clast-supported, bedded gravel (Gh), as well as planar (Gp) and trough (Gt) cross-stratified gravel (Figure 2.6. C,

SILICICLASTIC LITHOFACIES

Facies codes	*Sedimentary structures and facies*	*Interpretation*
Gmm	***Massive-structurless; matrix-supported***. Pebble and cobble conglomerate	Sediment gravity flow (plastic); high strength, viscous
Gmg	***Matrix-supported***. Pebble and cobble conglomerate; crude normal grading	Sediment gravity flow (pseudoplatic); low strength, viscous
Gcm	***Massive-structureless; clast-supported***. Pebble and cobble conglomerate	Sediment gravity flow (pseudoplastic); inertial bedload, turbulent flow)
Gh	***Clast-supported, bedded gravel***. Pebble and cobble conglomerate; horizontal bedding; imbrication	Longitudinal bedform migration; lag deposits; bedload, turbulet flow
Gp	***Planar cross-stratification***. Pebble and cobble conglomerate	Longitudinal to transverse bedform migration
Gt	***Trough cross-stratification***. Pebble and cobble conglomerate; no grading; individual beds are typically <0.5 m thick	Deposition of gravel under upper flow regime condistion in scours and small channels
Sm	***Massive-structurless***. Fine- to medium-grained sandstone; no grading or stratification	Sediment gravity flow; near-surface turbidity currents in fluid flow
Sh	***Horizontal stratification***. Fine- to medium-grained sandstone; no grading; flat parallel lamination	Deposition under upper and/or lower plane-bed conditions (critical to sub-critical flow)
Sr	***Ripple cross-stratification***. Fine- to medium-grained sandstone; no grading; asymmetric geometry	Deposition during migration of current (asymmetric) ripples; lower flow regime conditions
Sl	***Low-angle cross-stratification***. Fine- to medium-grained sandstone; no grading; cross-stratification dips <10° with respect to bedding	Migration of small-scale 2D dunes and/or plane-bed macroforms in shallow watter; deposition on a sloped surface
Sp	***planar cross-stratification***. Fine- to medium-grained sandstone; no grading; occur in beds that are typically <0.25 m thick	Migration of small-scale 2D dunes in shallow water; transverse and linguoid bedforms
St	***Trough cross-stratification***. Fine- to medium-grained sandstone; no grading; beds contain trough sets that are <0.5 m thick	Migration of 3D dunes in shallow water; traction processes during lower to upper flow regmine conditions; linguoid bedforms
P	***Pedogenic carbonate***. Mudstone and claystone; massive aggregated texture; sphereoidal (5-7 cm dia.) and elongate (10-25 cm long) calcareous nodules	Soil development of mud deposits resulting from infiltration, leaching, and carbonate precipitation during subaerial exposure
Fsm	***Massive-structureless***. Siltstone and mudstone; no grading or stratification	Suspension fallout; deposition during lower flow regime conditions; waning flow and fallout in standing water

Table 2.1

Summary of siliciclastic sedimentary facies classifications and interpretations from Upper Triassic strata of the Chulitna terrane, utilizing and adapting facies codes from Miall (1977).

CARBONATE LITHOFACIES

Facies codes	*Sedimentary structures and facies*	*Interpretation*
MS	**Mudstone (massive)**. Muddy limestone; isolated fine-grained (<0.03 mm) biogenic and clastic components	Suspension fallout or possible sediment gravity flow (plastic); components not organically bound during deposition
WS	**Wackestone (massive to laminated)**. Matrix-supported muddy limestone with fine-grained (<0.03 mm) biogenic and clastic components	Sediment gravity flow (plastic) or deposition by suspension fallout; components not organically bound during deposition
PS	**Packstone (massive)**. Grain-supported limestone; lime mud matrix with fine- to course-grained (0.03 - 2 mm) clastic and biogenic components	Sediment gravity flow (psudeoplastic) or minor sediment reworking/winnowing; components not organically bound during deposition
Sls	**Sandy limestone (massive to stratified)**. Grain-supported limestone; fine- to course-grained (0.03-2 mm) clastic and biogenic components	Sediment reworking/winnowing or sediment gravity flow (pseudoplastic); components not organically bound during deposition
FS	**Floatstone (massive)**. Matrix supported muddy limestone with coarse-grained (>2 mm) biogenic components	Sediment gravity flow (plastic); components were not bound organically during deposition
RS	**Rudstone (massive)**. Grain-supported limestone; coarse-grained (>2 mm) biogenic components	Sediment gravity flow (pseudoplastic); components were not bound organically during deposition
BS	**Boundstone (bindstone)**. biogenic component bound and encrusted togther by lime mud	Deposition by binding and encrusting of biogenic organism; components were bound organically during deposition

Table 2.2

Summary of carbonate sedimentary facies classifications and interpretations from Upper Triassic strata of the Chulitna terrane, utilizing and adapting carbonate classification from Dunham (1962).

Figure 2.6.

Summary of all gravel facies documented from Upper Triassic siliciclastic strata of the Chulitna terrane. Conglomerate and sandstone units are interbedded throughout measured sections and nearly all siliciclastic and carbonate facies have been documented from base-to-top of measured sections. (A) Massive, matrix-supported pebble conglomerate (Gmm) overlying a massive sandstone bed (hand lens for scale). (B) Interbedded matrix-supported conglomerate (Gmg), and massive (Sm) and horizontally stratified (Sh) medium-grained sandstone (coin for scale). (C) Interbedded massive, clast-supported pebble to cobble conglomerate (Gcm) and bedded pebble conglomerate (Gh) (rock hammer for scale). (D) Lenticular bed of matrix-supported pebble conglomerate (Gmg) and horizontally-stratified (Sh) coarse-grained sandstone bound by massive, clast-supported pebble conglomerate (Gcm) (rock hammer for scale). (E) Trough cross-stratified pebble conglomerate (Gt) bound by massive (Sm) and horizontally-stratified (Sh) medium-grained sandstone (rock hammer for scale). (F) Interbedded planar cross-stratified pebble and cobble conglomerate (Gp) and horizontally-stratified (Sh) medium-grained sandstone (coin near center of photo for scale).

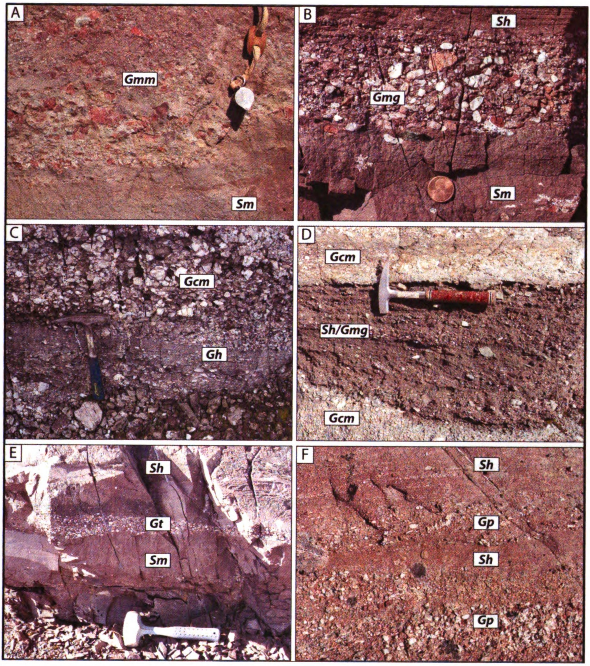


Figure 2.6.

E, F). Bedded gravel is characterized by horizontal bedding and isolated occurrences of crude pebble imbrication. Sandstone facies that occur in Upper Triassic strata consist primarily of trough cross-stratification (St), horizontal stratification (Sh), planar cross-stratification (Sp), as well as low-angle cross-stratification (Sl) (Figure 2.7. A, B, C, F). The most commonly occurring facies is massive, fine- to medium-grained sandstone (Sm) (Figure 2.7. B, F), Ripple cross-stratification (Sr) is rare and occurs sporadically throughout these strata (Figure 2.7 F). The majority of conglomerate and sandstone deposits are deep red in color; however there are repeated occurrences of green to gray conglomerate deposits throughout Upper Triassic stratigraphy.

Fine-grained siltstone and mudstone occurs throughout measured sections and is most commonly massive to slightly laminated (Fsm) and often exhibits an aggregated texture (P) (Figure 2.8. A, B, C, D). Spheroidal (3-8 cm dia.) to elongate (6-20 cm long) carbonate nodules are common in aggregated mudstone deposits (Figure 2.8. E, F). Siltstone and mudstone beds are typically <3 m thick, however deposits can be up to 15 m thick. Fine-grained strata throughout the Upper Triassic succession of redbeds is characterized by dark red colors as well as isolated occurrences of light green aggregated deposits with carbonate nodules (Figure 2.8. C, D, E, F). Siltstone and mudstone are interbedded with conglomerate and sandstone facies from base to top of measured sections in both siliciclastic and carbonate strata.

Carbonate lithofacies observed from Upper Triassic strata in the study area consist largely of muddy limestone (MS), sandy limestone (Sls), massive to

Figure 2.7.

Summary of all sandstone facies documented from Upper Triassic siliciclastic strata of the Chulitna terrane. Sandstone and conglomerate units are interbedded throughout measured sections and nearly all sandstone facies have been documented from base-to-¬top of measured sections. (A) Trough cross-stratified, medium- to coarse-grained sandstone (coin for scale). (B) Interbedded horizontally-stratified (Sh) and planar cross-stratified (Sp) fine-grained sandstone (hammer for scale). (C) Interbedded low-angle, cross-stratification (Sl) and horizontal stratification (Sh) (coin for scale). (D) Interbedded horizontal stratification (Sh), matrix-supported pebble conglomerate (Gmg), and massive sandstone (Sm) (rock hammer for scale). (E) Massive sandstone (Sm) beds ranging from 0.25-1 m thick (rock hammer for scale). (F) Individual beds of horizontally-stratified (Sh), ripple cross-stratified (Sr), and planar cross-stratified, medium- to coarse-grained sandstone interbedded with planar cross-stratified conglomerate (Gp), and massive, matrix-supported conglomerate (Gmm) (rock hammer for scale).

SANDSTONE FACIES

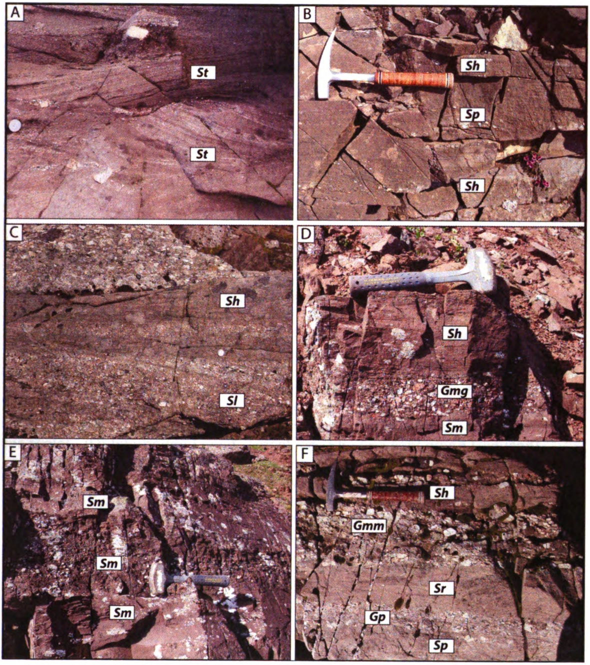


Figure 2.7.

Figure 2.8.

Summary of all mudstone and siltstone facies documented from Upper Triassic siliciclastic strata of the Chulitna terrane. Mudstone and siltstone is interbedded with sandstone and conglomerate units throughout measured sections. (A) Interbedded massive sandstone (Sm) and massive mudstone (Fsm); individual bed is~0.75 m thick (hammer for scale). (B) A thick (~15 m) succession of red to yellow aggregated mudstone (P) with carbonate nodules (red and yellow oxidized region represents ~15 m of aggregated mudstone for scale). (C) Interbedded red (oxidized) and light green (slightly reduced) aggregated mudstone (P) (hammer for scale). (D) Interbedded sandy limestone (Sls) and light green (reduced) aggregated mudstone with gravel stringers (rock hammer for scale). (E) Massive mudstone and siltstone (Fsm) overlain by aggregated mudstone with yellow spheroidal (3-8 cm dia.) carbonate nodules (P) (rock hammer for scale). (F) Dark red (oxidized) aggregated mudstone with yellow elongate (6-15 cm long) carbonate nodules (hammer for scale).

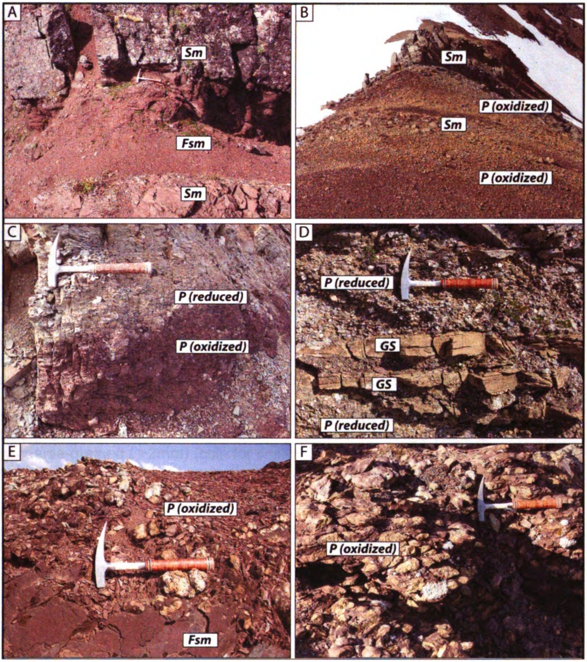

A
Sm
Fsm
Sm
B
Sm
P (oxidized)
Sm
P (oxidized)
C
P (reduced)
P (oxidized)
D
P (reduced)
GS
GS
P (reduced)
E
P (oxidized)
Fsm
F
P (oxidized)

Figure 2.8.

Figure 2.9.

Summary of all carbonate facies documented from Upper Triassic siliciclastic strata of the Chulitna terrane. Carbonate strata are sporadically interbedded with siliciclastic redbeds units from the middle to upper parts of measured sections. Carbonate facies are primarily indicative of sedimentation by transport of eroded carbonate material. There are repeated occurrences of in situ carbonate precipitation as well. (A) Tabular beds of muddy limestone (MS); beds range are on average ~0.10-0.25 m thick (hammer for scale). (B) Tilted interbedded succession of muddy limestone (MS) and massive wackestone (WS) (hammer for scale). (C) Interbedded sandy limestone (Sls), packstone (PS), and fossiliferous floatstone (FS) (hammer for scale). (D) Thin (0.10-0.25 m), tabular beds of sandy limestone (Sls) (rock hammer for scale). (E) Interbedded packstone (PS) and fossiliferous floatstone (FS); fossil hash in floatstone is typically coarse-grained (>2mm) (coin for scale). (F) Rudstone (RS) consisting largely of fossil hash with lesser amounts of lime mud matrix (coin for scale). (G) Interbedded, tabular beds of sandy limestone (Sls) and floatstone (FS); beds are typically <0.25 m thick (rock hammer for scale). (H) Tabular to irregular beds of Boundstone (bindstone) (BS); primary fossil occurrences include hydrozoan Heterastridium (round gray limey nodules in bed just above rock hammer).

CARBONATE FACIES

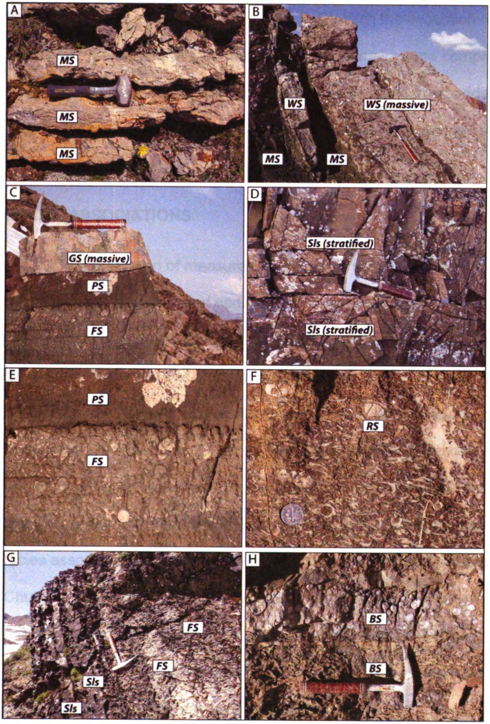


Figure 2.9.

laminated, matrix-supported wackestone (WS), and matrix-supported, massive floatstone (FS), as well as massive, grain-supported packstone (PS) and rudstone (RS) (Figure 2.9. A, B, C, D, E, F, G). With the exception of muddy limestone, the majority of carbonate lithofacies contain some component of fossil hash. Fossiliferous boundstone (BS) is commonly found interbedded with the carbonate facies listed above and contains abundant occurrences of the hydrozoan Heterastridium (Figure 2.9 H)

FACIES ASSOCIATIONS

Documentation of measured stratigraphic sections, including bed thickness and geometry, and sedimentary facies identification have resulted in classification and interpretation of six distinct facies associations that occur throughout Upper Triassic strata in the Little Shotgun Creek study area and the greater Chulitna terrane. Facies associations were determined by grouping sedimentary facies (Table 2.1. and 2.2.) that reflect similar depositional patterns and environments. It is important to note that any one individual facies may occur in more than one facies association. Table 2.3. provides a summary of facies associations identified from siliciclastic and carbonate strata of the Chulitna terrane and includes descriptions on bed thickness, lateral extent, geometry (tabular vs. lenticular), and facies distribution as well as general descriptions on lithology and color. The following text accompanies Table 2.3. and provides a summary for each facies association.

Facies Association 1 (FA 1)

Description. Individual beds in Facies Association 1 (FA 1) are tabular and lenticular and consist largely of interbedded fine- to coarse-grained sandstone and conglomerate bodies. Beds are laterally extensive for 75-150 m and are typically 2-3 m thick. Lenticular beds exhibit with-to-thickness ratios of >25:1. Overall, sandstone and conglomerate deposits of FA 1 range from light to dark red to green in color. Conglomerate units consist primarily of pebble and cobble conglomerate bodies that are made up primarily of matrix-supported, massive gravel deposits (Gmm) and massive gravel with isolated yet regular occurrences of crude normal grading (Gmg). Clast-supported massive gravel deposits (Gcm) occur sporadically throughout these deposits and are interbedded with massive gravel deposits and sandstone. Sandstone bodies consist primarily of fine- to medium-grained massive sandstone (Sm) and are interbedded with conglomerate throughout measured sections. Thin deposits (<1 m thick) of massive and structureless mudstone (Fsm) are sporadically interbedded with sandstone and conglomerate units from base to top of measured sections.

Interpretation – Debris flow (clastic). Facies Association 1 is interpreted here to represented deposition by punctuated sediment gravity flows characterized by plastic/pseudoplastic deposition. Conglomerate, sandstone, and mudstone facies distribution is likely due to (1) initial high-energy debris flow events followed by (2) subsequent waning flow and nondeposition (Collinson, 1996). The red color of the majority of these strata are interpreted to reflect oxidation in a nonmarine setting. The green color of strata are thought to reflect sedimentation in slightly-reduced shallow marginal marine conditions (Collinson, 1996; Bridge and Demicco, 2008). Overall sediment gravity flows are interpreted to have occurred under plastic to pseudoplastic conditions based on the distribution of facies reflecting massive to crudely graded bedding. Individual events likely varied from low to high strength debris flow events. Individual flow events were commonly viscous with isolated occurrences of near-surface turbidity as evidence by isolated occurrence of clast

supported conglomerate. Debris flow events were characterized by gravel, sand, silt, and mud size fraction. Deposition of mudstone likely occurred during the waning flow stages of sediment gravity flows during low flow regime conditions and/or suspension fallout (Collinson, 1996; Boggs, 2001) .

Facies Association 2 (FA 2)

Description. Facies Association 2 (FA 2) consist entirely of sandstone and conglomerate bodies that exhibit lenticular geometries. Individual units are laterally extensive for 50-75 m and beds are typically 1-3 m thick exhibiting with-to-thickness ratios of >15:1. Deposits range from dark red to light green in color. The coarsest grained lithology in FA 2 includes pebble and cobble conglomerate bodies that consist of clast-supported, bedded gravel (Gh) and planar cross-stratified (Gp), and trough-cross stratified (St) gravel. Gravel stringers are common and crude pebble imbrication can be observed in isolated instances.

Sandstone units of FA 2 are made-up of fine- to coarse-grained sandstone characterized by horizontal (Sh), ripple (Sr), low-angle (sl), planar (Sp), and trough (St) cross-stratification. Thin deposits (<0.10 m) of massive and structureless mudstone (Fsm) are sporadically interbedded with sandstone and conglomerate throughout measured sections

Interpretation – Channels and bars (fluvial/deltaic/tidal). Facies Association 2 (FA 2) is interpreted to represent deposition by (1) ephemeral flow and bar migration in poorly-confined, fluvial channels (nonmarine), (2) small-scale delta mouth bar migration (marginal marine) of lateral and transverse bars, and/or (3) lateral and transverse bar migration in tidal channels (marginal marine) (Collinson, 1996; Reading and Collinson, 1996). Nonmarine fluvial deposits likely owe their red color to oxidization while deltaic and tidal deposits are typically green in color, which is attributed to sedimentation in a slightly less-oxidizing shallow, marginal-marine environment. Stratified conglomerate and sandstone is interpreted to reflect migration in channels of gravel and sand bars (Reading and Collinson, 1996; Boggs, 2001) . Bar migration reflects downstream and lateral migration of longitudinal to transverse bars during upper flow regime conditions. Mudstone deposits are observed in fluvial channels and likely represent sedimentation during waning channel flow and/or suspension fallout in standing water that remains in ephemeral channels after flow events. Much of the stratified sandstone and conglomerate deposits may be the result of fluvial reworking of the top of debris flow deposits (FA 1).

Facies Association 3 (FA 3)

Description. Deposits of Facies Association 3 (FA 3) consist entirely of massive- to slightly laminated mudstone (Fsm) and massive, aggregated mudstone that occurs in conjunction with extensive carbonate nodule horizons (P). Overall these deposits are tabular and individual units are laterally extensive for >150 m. Beds are typically 2-3 m thick, however, interbedded fine-grained deposits can range in thickness from 5-15 m. All mudstone units have nonerosive contacts at base of beds and deposits are dominantly dark red with isolated occurrences of light green aggregated mudstone. Carbonate nodules are pervasive throughout aggregated fine-grained deposits and are typically yellow in color with individual nodules are spheroidal (3-8 cm dia.) to elongate (6-20 cm long).

Interpretation – Floodplain/tidal flat. Facies Association 3 (FA 3) is interpreted to represent deposition of silt and mud during extensive, unconfined sheet flooding in nonmarine floodplain (red) and marginal-marine tidal flat (red to green) regions. Red coloration is attributed to extended periods of nondeposition, subaerial exposure, oxidation, and pedogenic soil formation (Collinson, 1996; Reading and Collinson, 1996) . Light green aggregated mudstone deposits are interpreted to reflect soil development in tidal regions where deposits are initially subaerialy exposed during low tide condition and subsequently submerged during high tide and storm surge conditions. Overall deposits of FA 3 are interpreted to reflect sedimentation in overbank floodplain and tidal flat regions that are adjacent to fluvial or tidal channel and/or distal, waning debris flow (Collinson, 1996; Reading and Collinson, 1996; Johnson and Baldwin, 1996) . In either case prolonged subaerial exposure and soil formation occurred after deposition.

Facies Association 4 (FA 4)

Description. Facies Association 4 (FA 4) consist largely of tabular, very well-sorted bodies of fine-grained sandy limestone (Sls). Individual units are laterally extensive for 75-150 m and consist largely of low-angle cross-stratification. Beds are 1-3 m thick and composed entirely of fine- to medium-grained sandy limestone (Sls) that is bound by calcite cement. Individual units are stratified and very well sorted and sand grains are rounded to subrounded. These strata are typically gray to yellow in color and occur sporadically in conjunction with other carbonate facies throughout measured sections.

Interpretation – Beach/barrier island. Facies Association 4 (FA 4) is interpreted to represent deposition in the presence of high- to medium energy wave action along a beach/barrier island setting. Facies distribution reflects a beach front environment where sedimentation and reworking of sand occurred during high-energy wave action in foreshore beach and upper shoreface environments (Reading and Collinson, 1996; Johnson and Baldwin, 1996; Pettijohn et al., 1987). Facies are consistent with wave action above mean fairweather wave base. Stratified beach deposits may represent reworked debris flow deposits and/or reworked fluvial, deltaic, and tidal deposits of FA 1 and FA 2, respectively (Reading and Collinson, 1996; Johnson and Baldwin, 1996) .

Facies Association 5 (FA 5)

Description. Facies Association 5 (FA 5) is characterized by tabular beds of interbedded fossiliferous boundstone (BS) and muddy limestone (MS). Individual units are laterally extensive for >150 m and beds are typically 0.25-1 m thick. Deposits are gray to yellow in color. Boundstone (bindstone) units are bound and encrusted by lime mud and contain fossiliferous horizons that consist primarily of the hydrozoan Heterastridium. Muddy limestone deposits are typically <1 m thick and have very rare occurrence of primary fossils or fossil hash.

Interpretation – Carbonate reef/bank – Lagoon. Facies Association 5 (FA 5) is interpreted to reflect in situ precipitation and deposition by binding and encrusting of biogenic organisms in a low energy, shallow marine carbonate reef/bank to lagoonal environment. All biogenic components were originally bound during deposition and are interpreted to reflect development of isolated, small-scale, reefs and banks (Wright and Burchette, 1996; Boggs, S., 2001). Reef/bank development was likely characterized by in situ precipitation and deposition in low energy shelf-edge reef and/or lagoonal carbonate bank environment that may be part of a rimmed carbonate platform to ramp depositional system (Wright and Burchette, 1996). Muddy limestone was likely deposited during suspension settling and or the waning stages of submarine sediment gravity flow (Reading and Collinson, 1996; Wright and Burchette, 1996). Very little to no siliciclastic strata is found interbedded with FA 5.

Facies Association 6 (FA 6)

Description. Facies Association 6 (FA 6) consists primarily of tabular units of interbedded muddy limestone (MS) and massive to laminated wackestone (WS) as well as massive floatstone (FS), and rudstone (RS). Individual beds are laterally extensive >75 m and are typically 0.1-0.5 m thick; gray to green-yellow in color. Fossil hash is common throughout these deposits and consist primarily of diarticulated bivalve shells. Fine-grained units of FA 6 consist of massive- to laminated, matrix-supported, muddy limestone with fine-grained (0.03-2 mm) to coarse-grained (>2 mm) fossil hash. Packstone, and rudstone units consist of massive, grain-supported limestone with fine-grained (0.03-2 mm) to coarse-grained (>2 mm) fossil hash. Muddy matrix is present in packstone deposits. Floatstone units are massive, matrix-supported with >2mm components. Deposits of lime mud (MS and WS) also occur throughout this facies association and are typically <1 m thick. Primary fossils and fossil hash is rare in muddy limestone deposits.

Interpretation – Debris flow (carbonate). Facies Association 6 (FA 6) is interpreted to represent, punctuated submarine sediment gravity flows in a mid to outer ramp region of a rimmed carbonate platform/ramp shallow marine environment. Fossil debris (hash) is likely derived from mid- to inner ramp reefs/banks that have been eroded by wave energy. Debris flows originated on unstable slopes in mid-ramp regions and may have undergone further gravity flow to deeper outer ramp regions (Wright and Burchette, 1996; Boggs, S., 2001) . Due to the amount of mud preserved in these deposits, debris flows likely deposited sediment below storm wave base and have not been reworked by wave action. Wackestone and floatstone are interpreted to reflect sediment gravity flow under plastic to pseudoplastic conditions. Flows were likely high strength and viscous due to high amount of mud throughout these deposits. Packstone and rudstone are interpreted to represent pseudoplastic, turbulent sediment gravity flows; dominated by coarse-grained fossil hash and lesser amounts of mudstone. In this case turbulence during transport would winnow mud resulting in preservation of primary fossil hash. Muddy limestone units are interpreted to be the result of suspension settling after debris flows or the waning stages of sediment gravity flow. Overall these deposits are interpreted to have accumulated below storm wave base (Wright and Burchette, 1996).

DEPOSITIONAL SYSTEM

Upper Triassic strata from the Little Shotgun Creek study area and greater Chulitna terrane clearly reflect a depositional system that is dominated by mixed siliciclastic and carbonate environments. Energy during deposition ranged from very high in the case of sediment gravity flows and channels to very low in the case of carbonate bank and reef environments. Previous studies have provided

Table 2.3

Summary of descriptions and interpretations of siliciclastic and carbonate sedimentary facies and facies associations for Upper Triassic strata of the Chulitna terrane.

TABLE 2.3.

DESCRIPTION	***INTERPRETATION***
FACIES ASSOCIATION 1 (FA 1) Tabular and lenticular sandstone and conglomerate bodies; individual units are laterally extensive for 75-150 m and beds are typically 2-3 m thick and exhibit with-to-thickness ratios of >25:1; overall, deposits range from light to dark red to green in color ***(A) Conglomerate***. Pebble and cobble conglomerate bodies are made up of primarily of matrix-supported, massive gravel deposits (Gmm); crude, normal grading (Gmg) is common; clast-supported massive gravel deposits (Gcm) occur sporadically throughout these deposits ***(B) Sandstone.*** Fine- to medium-grained sandstone bodies are interbedded with conglomerate and primarily massive and structureless (Sm) ***(C) Mudstone.*** Thin deposits (<1 m thick) of massive and structurelss (Fsm) mudstone are sporadically interbedded with sandstone and conglomerate	***DEBRIS FLOW (SUBAERIAL/SUBAQUEOUS)*** Punctuated sediment gravity flows characterized by plastic/pseudoplastic deposition; facies distribution is likely due to (1) initial high-energy debris flow events event and (2) subsequent waning flow and nondeposition; red deposits were oxidized (nonmarine); green strata were slightly reduced (marine) ***(A) Sediment gravity flow.*** Low to high strength debris flow events (plastic to pseudoplastic); individual flow events were commonly viscous with isolated occurrences of near-surface turbidity currents; gravel-size fraction ***(B) Sediment gravity flow***. Debris flow events characterized by near surface turbidity currents in fluid flow; sand-size fraction ***(C) Sediment gravity flow (waning stages).*** Deposition during the waning flow stages of sediment gravity flows during low flow regime conditions and/or suspension fallout
FACIES ASSOCIATION 2 (FA 2) Lenticular sandstone and conglomerate bodies; individual units are laterally extensive for 50-75 m and beds are typically 1-3 m thick and exhibit with-to-thickness ratios of >15:1; overall, deposits range from dark red to light green in color ***(A) Conglomerate***. Pebble and cobble conglomerate bodies are made up clast-supported, bedded gravel (Gh) and planar cross-stratified (Gp), and trough-cross stratified (St) gravel ***(B) Sandstone.*** Fine- to medium-grained sandstone bodies consist largely of horizontal (Sh), ripple (Sr), low-angle (sl), planar (Sp), and trough (St) cross-stratification ***(C) Mudstone.*** Thin deposits (<0.10 m) of massive and structurelss mudstone (Fsm) are sporadically interbedded with sandstone and conglomerate	***CHANNELS AND BARS*** Deposition by (1) Ephemeral flow and bar migration in poorly-confined fluvial channels, (2) small-scale delta mouth bar migration, and/or (3) bar migration in tidal channels; fluvial strata (red) was likely oxidized while deltaic and tidal deposits (green) were deposited in a less-oxidizing environment ***(A) Gravel bars - channel fill.*** Longitudinal to transverse bar migration in upper flow regime conditions; possible reworking of the top of debris flow deposits; gravel-size fraction (with sand) ***(B) Sand bars - channel fill.*** Longitudinal to transverse bar migration in upper to lower flow regime conditions; possible debris flow reworking; sand-size fraction (with gravel stringers) ***(C) Suspension settling (fluvial channels).*** Deposition during the waning flow of ephemeral in fluvial channels

TABLE 2.3. continued

DESCRIPTION	INTERPRETATION
FACIES ASSOCIATION 3 (FA 3) Tabular mudstone and siltstone beds; individual units are laterally extensive for >150 m and beds are typically 2-3 m thick; fine-grained deposits are 5-15 m thick; nonerosive contacts at base of beds deposits range from dark red to light green in color ***(A) Mudstone.*** Fine-grained deposits (1-3 m thick) of massive and structurelss mudstone (Fsm) ***(B) Aggregated mudrock.*** Extensive fine-grained deposits consisting of massive mudstone and spheroidal (3-8 cm dia.) to elongate (6-20 cm long) yellow nodules	***FLOODPLAIN - TIDAL FLAT*** Deposition of silt and mud during extensive, unconfined sheet flooding in nonmarine floodplain (red) and marginal-marine tidal flat (red to green) regions; overbank channel and/or distal, waning debris flow; prolonged subaerial exposure and soil formation after deposition ***(A) Suspension fallout (floodplain).*** Unconfined flow and suspension settling ***(B) Pedogenic alteration.*** Soil formation in floodplain and tidal flat regions resulting from subaerial exposure possibly during arid conditions (carbonate nodules)
FACIES ASSOCIATION 4 (FA 4) Tabular, very well-sorted bodies of fine-grained sandy limestone; individual units are laterally extensive for 75-150 m and consist largely of low-angle cross-stratification; beds are 1-3 m thick ***(A) Sandstone.*** Fine-grained sandy limestone (Sls) with calcite cement; individual units are stratified and very well sorted; sand grains are rounded to subrounded; gray to yellow in color	***BEACH - BARRIER ISLAND*** High- to medium energy wave action along a beach/barrier island; Beach strata may represent reworked debris flow deposits and/or reworked fluvial, deltaic, and tidal deposits ***(A) Beach front.*** Deposition and reworking during high-energy wave action foreshore beach and upper shoreface regions; wave action above mean fairweather wave base
FACIES ASSOCIATION 5 (FA 5) Tabular beds of interbedded fossiliferous boundstone (BS) and muddy limestone (MS); individual units are laterally extensive for >150 m and beds are typically 0.25-1 m thick; gray to yellow in color ***(A) Boundstone (bindstone).*** Biogenic components are bound and encrusted by lime mud; fossiliferous horizons consist primarily of the hydrozoan *Heterastridium* ***(B) Muddy limestone.*** Deposits of lime mud that are typically <1 m thick; fossils occurrence is rare	***CARBONATE REEF - BANK - LAGOON*** In situ deposition by binding and encrusting of biogenic organims in a low energy, shallow marine carbonate reef/bank to lagoonal environment; all components were originally bound during deposition ***(A) Reef/bank framework.*** In situ precipitation and deposition in low energy shelf-edge reef and/or lagoonal carbonate bank environment; rimmed carbonate platform to ramp environment ***(B) Suspension settling/sed. gravity flow.*** Deposition of lime mud in reef/bank/lagoon setting

TABLE 2.3. continued

DESCRIPTION	INTERPRETATION
FACIES ASSOCIATION 6 (FA 6) Dominantly tabular units of interbedded muddy limestone (MS) and massive to laminated wackestone (WS) as well as massive floatstone (FS), and rudstone (RS); individual beds are laterally extensive >75 m and typically 0.1-0.5 m thick; gray to green-yellow in color; fossil has is common	***DEBRIS FLOW (SUBAQUEOUS)*** Punctuated submarine sediment gravity flows in a mid to outer ramp region of a rimmed carbonate platform/ramp environment; fossil debris is likely derived from mid- to inner ramp reefs/banks; the majority of debris flow deposits accumulated below storm wave base and have not been reworked
(A) Wackestone and floatstone. Massive to laminated, matrix-supported, muddy limestone with fine-grained (0.03-2 mm) to coarse-grained (>2 mm) fossil hash	***(A) Wackestone and floatstone***. Plastic/Pseudoplastic sediment gravity flows; high strength; viscous
(B) Packstone and Rudstone. Massive, grain-supported limestone with fine-grained (0.03-2 mm) to coarse-grained (>2 mm) fossil hash; muddy matrix is common in packstone deposits	***(B) Packstone and Rudstone***. Pseudoplastic, turbulent sediment gravity flows; dominated by coarse-grained fossil hash
(C) Muddy limestone. Deposits of lime mud that are typically <1 m thick; fossils occurrence is rare	***(C) Suspension settling/sediment gravity flow***. Deposition below storm wave base (no reworking)

Table 2.3.

general stratigraphic descriptions for redbed and carbonate units, however the relationship and interplay between siliciclastic and carbonate strata has gone undocumented until this study. Based on the 21 total sedimentary facies, bedding thickness, geometry, and lateral extent, as well as the 6 facies association identified here, Upper Triassic redbed and carbonate units of the Chulitna terrane are interpreted to reflect (1) nonmarine siliciclastic sedimentation as a result of subaerial debris flows, fluvial channels, and overbank floodplain regions, (2) marginal marine sedimentation in tidal channels, deltaic front bar migration, tidal flat, and beach/barrier island regions, and (3) marine sedimentation by carbonate reef and bank development and submarine slumps and debris flows of fossil hash and fine-grained muddy limestone. Figure 2.10. provides a conceptual diagram and summary on how all six facies associations are related and interact in a mixed siliciclastic-carbonate fan-delta depositional system.

PROVENANCE OVERVIEW

In addition to sedimentary facies provenance trends were documented from conglomerate and sandstone units from base to top of measured sections. The summary presented here represents a preliminary overview of mineralogy observed from the base to top of each measured section. This report is not intended to be a comprehensive petrographic and provenance analysis for Upper Triassic strata, but rather a general description and documentation of compositional trends from these strata. Table 2.4., 2.5., and 2.6. present an

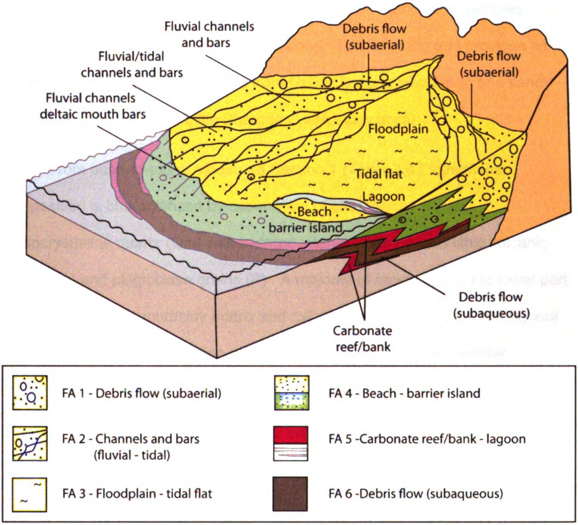


Figure 2.10.

Conceptual model for a mixed siliciclastic-carbonate fan-delta depositional system that includes sedimentation in the following environments: (1) subaerial debris flows (FA 1), (2) fluvial/deltaic/tidal channels (FA 2), (3) overbank floodplain and tidal flat (FA 3), (4) beach/barrier island. (5) carbonate reef/bank – lagoon (FA 5), and (6) submarine debris flows (FA 6). Modified from Nemec and Steel (1988).

overview of sandstone composition as observed from sandstone samples collected from throughout measured sections. The following text provides an upsection summary of composition from Upper Triassic siliciclastic and sandy carbonate strata from the Little Shotgun Creek study area.

From base-to-top of measured Section 1 (Table 2.4.) sandstone composition is characterized by occurrence of chert grains (C) and monocrystalline quartz (Qm) with isolated intervals that contain lithic volcanic grains (Lv) and plagioclase grains (P). A majority of sandstone in the lower part of Section 1 have a mud/clay matrix and calcite cement is common throughout these strata. The upper portion of measured Section 1 contains similar occurrence of chert (C), monocrystalline quartz (Qm), lithic volcanic grains (Lv) and also exhibits isolated occurrence of polycrystalline quartz (Qp) and rare, isolated lithic metamorphic grains (Lm). Grains of serpentinite (S) also occur sporadically throughout measured Section 1.

Measured Section 2 represents the thickest documented stratigraphic interval from This study and contains occurrences of monocrystalline (Qm) and polycrystalline (Qp) quartz, red and green chert (C), lithic volcanic (Lv) and lithic metamorphic (Lm) grains, as well as isolated chlorite grains (Table 2.5). Serpentinite occurs sporadically but throughout measured Section 2. A majority of these samples are characterized by calcite cement. Isolated occurrences of silica cement do occur sporadically in several samples where calcite cement is not observed. The middle portion of measured Section 2 contains primarily chert

Table 2.4.

Description of samples from Section 3. Appendix A shows the exact location where each sample was collected.

Little Shotgun Creek, Healy A-6, south-central Alaska Collected by Jennifer DeLoge, Brian Hampton Collected June 2007		Section 3 LS-062907
Sample ID	Hand sample description	Petrographic description
LS-062907-01	Greenish gray matrix with vf-c clasts of black and green chert and quartz. Slight reaction with HCL.	Plagioclase and Lv are dominate with minor amount of Qm, Qp, and chert. 100% calcite cement and 75% calcite grain coating.
LS-062907-02	Greenish gray matrix with vf-c clasts of black and green chert and quartz. No reaction with HCL.	Chert and Qp dominate with lesser amounts of serpentinite and Lv. 100% calcite cement.
LS-062907-04	Greenish gray matrix with vf-g clasts of quartz and plagioclase laths. No reaction with HCL.	Volcaniclastic
LS-062907-06	Greenish gray matrix with vf-c clasts of black and glassy red chert. Pyrite flakes in matrix. No reaction with HCL.	Volcaniclastic
LS-062907-07	Greenish gray matrix with vf-vc clasts of black, brown, and red chert. Highly reactive with HCL.	Serpentinite dominate with plagioclase, Qm, and chert.
LS-062907-09	Red matrix with vf-g size clasts of quartz, black and red chert, and plagioclase.	Cherts dominate with plagioclase and Qm. Clay matrix.
LS-062907-11	Black and tan banded chert. Tan is chert and black is siliceous mud.	Banded chert
LS-062907-10	Red matrix with vf-g size clasts of quartz, black and red chert, and plagioclase. HCL reacts with grain edges only.	Cherts dominate with minor amount of Qm. Clay matrix.

Table 2.4.

Table 2.5.

Description of samples from Section 2. Appendix A shows the exact location where each sample was collected.

Little Shotgun Creek, Healy A-6, south-central Alaska Collected by: Jennifer DeLoge, Brian Hampton Collected: June 2007		Section 2 LS-063007 LS-062607 LS-061907
LS-061907-03	Gray, sandy matrix with f-c size clasts of green and red chert	Cherts dominate with Lv and plagioclase laths. 95% calcite cement.
LS-061907-04	Gray, sandy matrix with f-c size clasts of green and black chert. Red chert only makes up 1%.	Cherts dominate with Qp, Qm, Lm, and serpentinite. 75% calcite cement.
LS-061907-05	Dark gray matrix with vf black chert. Highly reactive with HCL. Possible trace fossils.	Chert framework grains with 95% calcite cement
LS-061907-06	Dark gray mudstone. Highly reactive with HCL.	Individual grains to small to see.
LS-061907-07	Red matrix with f-g size clasts of sub angular red and green chert. Moderate reaction with HCL.	Cherts dominate with Lm and Qp. 85% calcite cement.
LS-061907-08	Red matrix with vf-vc size clasts of sub-angular red and green chert. Slight reaction with HCL.	Cherts dominate with Qp. 75% calcite cement.
LS-062607-01	Red matrix with f-vc size clasts of sub-rounded red and green chert. Slight reaction with HCL.	Cherts dominate with Qm. 50/50 calcite and clay cement.
LS-062607-02	Red matrix with vf-c size clasts of sub-angular-sub-rounded red and green chert. Slight reaction with HCL.	Chert, Lv, and plagioclase dominate with minor amounts of Qp and Qm. 5% calcite cement.
LS-062607-03	Red matrix with vf-f size clasts of green chert. Slight reaction with HCL.	Cherts dominate with Qp, Qm, and Lv. No calcite cement.
LS-062607-04	Green matrix with cs-g size clasts of angular-sub-rounded quartz and red, brown, and green chert	Cs- G size Chert, Qp, and Qm. No calcite cement.

Table 2.5. continued

LS-062607-05D	Green - gray matrix with vf black chert clasts and f-m red chert and m-vc quartz. Slight reaction with HCL.	Tuff
LS-062607-06	Red matrix with vf-m sized quartz and red and green chert clasts. Slight reaction with HCL	Cherts dominate with Qp, Qm, and plagioclase. No calcite cement.
LS-062607-07	Dark gray matrix with vf clasts of black and gray chert and quartz. Microfolds in secondary calcite fracture fill. Highly reactive with HCL.	Cherts dominate with Qm. 75% calcite cement.
LS-062607-09	Dark gray matrix with vf clasts of black and gray chert and quartz. Highly reactive with HCL.	Chert and Qm dominate with minor amount of Qp. 75% calcite cement.
LS-063007-01	Dark gray matrix with vf clasts of black and gray chert and quartz. Highly reactive with HCL.	Cherts dominate with Qm. 75% calcite cement.
LS-063007-02	Dark gray matrix with vf clasts of black and gray chert and quartz. No reaction with HCL.	Cherts dominate with Qm with minor amount of chlorite. No calcite cement.
LS-063007-03	Dark gray matrix with vf clasts of black and gray chert and quartz. Slight reaction with HCL.	Chert and Qm dominate with minor amounts of Qp and plagioclase. 50% calcite cement.
LS-063007-04	Dark gray matrix with vf clasts of black and gray chert and quartz. Slight reaction with HCL.	Chert and Qm dominate with minor amounts of Qp and plagioclase. 50% calcite cement.
LS-063007-05	Dark gray matrix with vf clasts of black, green, and brown chert and quartz. No reaction with HCL.	Cherts dominate with Qm with minor amount of chlorite. No calcite cement.
LS-063007-06	Dark gray matrix with vf clasts of black and green chert and quartz. Slight reaction with HCL.	Cherts dominate with Qm with minor amount of chlorite. Minor calcite cement.

Table 2.5. continued

LS-063007-07	Dark gray matrix with vf clasts of black and green chert and quartz. Slight reaction with HCL.	Cherts dominate with Qm with minor amount of chlorite, Qp and plagioclase. Minor calcite cement.
LS-063007-08	Dark gray matrix with vf clasts of black and green chert and quartz. Slight reaction with HCL.	Cherts dominate with Qm with minor amount of chlorite. Minor calcite cement.
LS-063007-09	Dark gray matrix with vf clasts of black and green chert and quartz. Slight reaction with HCL.	Cherts dominate with Qm with minor amount of plagioclase, Qp, Lm, and Lv. Minor calcite cement.
LS-063007-10	Dark gray matrix with vf clasts of black and green chert and quartz. Slight reaction with HCL.	Cherts dominate with Qm with minor amount of plagioclase, Qp, Lm, and Lv. Minor calcite cement.

Table 2.5.

Table 2.6.

Description of samples from Section 1. Appendix A shows the exact location where each sample was collected.

Little Shotgun Creek, Healy A-6, south-central Alaska Collected by: Jennifer DeLoge, Brian Hampton Michigan State University Collected: June 2007		Section 1 LS-062707
LS-062707-04	Dark greenish gray matrix with vf-m size quartz. Plagioclase laths. Slight reaction with HCL.	Qp and Qm dominate with minor amount of chert. 50/50 clay and calcite cement
LS-062707-05	Dark greenish gray matrix with f green chert, quartz, and feldspar. No reaction with HCL.	Qm and chert dominate with minor amount Qp. 50/50 clay and calcite cement
LS-062707-06	Dark greenish gray matrix with vf-f tan and black chert and quartz. Pyrite flakes present in matrix. No reaction with HCL.	Plagioclase, Qm, Lv, and chert in approximately equal amounts. Clay matrix and grain coating.
LS-062707-07	Dark greenish gray matrix with vf-vc chert, feldspar, and quartz. No reaction with HCL.	Cherts dominate with minor amount of Qm and Qp. 80/20 clay/calcite cement.
LS-062707-08	Red matrix with vf chert, quartz and feldspar. Only fractures react with HCL.	Cherts dominate with minor amount of Qp, Qm, and plagioclase. Clay matrix.
LS-062707-09	Green matrix supported conglomerate. Clasts of quartz and unidentified black laths. Some grains react slightly with HCL.	Cherts dominate with minor amount of Qp and Lv. Clay matrix with (40%) calcite replacement.
LS-062707-10	Gray matrix with vf-f aqua green, black, and red chert. Pyrite flakes present in matrix. No reaction with HCL.	Cherts dominate with Qm, Qp, Plagioclase, and Lm. 50% calcite cement.
LS-062707-11	Dark gray matrix with vf clasts of red, green, and black chert. No reaction with HCL.	Chert dominate with minor amount of Qm and Qp. 50% calcite cement.
LS-062707-12	Red matrix with vf-f clasts of green and red chert. Pyrite flakes in matrix.	Cherts dominate with Qm and plagioclase. 50/50 calcite and clay matrix.

Table 2.6. continued

LS-062707-13A	Red matrix with vf-f clasts of green, black, and red chert. Pyrite flakes in matrix. No reaction with HCL.	Cherts dominate with Qm, Qp, and plagioclase. Clay matrix.
LS-062707-13B	Red matrix with vf-f clasts of green, black, and red chert. Pyrite flakes in matrix. No reaction with HCL.	Cherts dominate with Qm, Qp, and plagioclase. Clay matrix.
LS-062707-14	Light greenish gray matrix with vf-g size clasts of green, red, and tan chert. No reaction with HCL	Chert and Qm dominate with minor amounts of plagioclase and Qp. Clay matrix.
LS-062707-15	Greenish gray matrix with vf-vc size clasts of chert and quartz.	Cherts dominate with Qm, Qp, Lm, and oversized serpentinite. 50/50 calcite and clay matrix.

Table 2.6.

(C) with minor components of monocrystalline quartz (Qm), and lithic volcanic grains (Lv). Polycrystalline quartz (Qp) and lithic metamorphic grains (Lm) are observed near the top of Section 2.

From base-to-top of measured Section 3, grains consist primarily of monocrystalline (Qm) and polycrystalline quartz (Qp), chert (C), plagioclase (P), and lithic metamorphic (Lm) and lithic volcanic (Lv) components (Table 2.6). Chert and plagioclase are most common throughout the middle and upper portions of measured Section 3. Overall sandstone are characterized by mud/clay matrix with calcite being the dominant cement. Isolated occurrence so sandstone with silica cement do occur throughout measured Section 3 but are isolated.

Preliminary provenance summary

Upper Triassic siliciclastic strata from the Little Shotgun Creek study area potentially reveal a mixed provenance history that include derivation of volcanic detritus from a possible arc source area and metamorphic detritus that may have been derived from recycled orogen-continental block regions. Further study will be needed to to provide a robust provenance analysis of Upper Triassic strata in the Chulitna region. However, preliminary results presented here are the first approach at documenting upsection trends in the modal composition of siliciclastic strata from this region of the Alaska Range suture zone. While descriptions presented here are only a first-order look at compositional trends, it is clear that these strata contain detritus that was derived from both magmatic source regions, as evidenced by lithic volcanic and plagioclase grains, as well as metamorphic source areas, evidenced by lithic metamorphic and polycrystalline quartz grains. Based on this preliminary study, at least two source areas may have contributed material during Upper Triassic time which could likely have been magmatic arc regions and metamorphosed continental margin-recycled orogen regions.

DISCUSSION

Upper Triassic siliciclastic and carbonate strata in the Chulitna terrane are interpreted here to represent nonmarine, marginal marine and marine sedimentation in a fan-delta style depositional system (Figure 2.10.). Deposition of siliciclastic and carbonate material appears to have been coeval and linked in a mixed system characterized by high energy erosive subaerial debris flow events and fluvial/deltaic/tidal transport and adjacent low-energy floodplain and tidal flat sedimentation. At the same time this depositional system allowed for isolated carbonate reef and bank development, likely in distal low-energy environments. The occurrence of all six facies associations throughout the Little Shotgun Creek measured sections suggest that high and low energy conditions persisted throughout deposition of these strata. This may be a reflection of continually changing locus of nonmarine sedimentation and may also reflect periods of rising or falling sea level. Another likely scenario for the ubiquitous distribution of these facies throughout measured sections is tidal influenced in marginal marine settings that would drive regular temporary changes in sea level along the margin of nonmarine and marginal marine components of this depositional system.

Preliminary provenance analysis potentially reveals possible magmatic and metamorphic source areas for Upper Triassic siliciclastic strata in the Chulitna terrane. These strata have been described by previous workers to consist of dominantly volcaniclastic deposits that were derived from magmatic sources (Clautice, et al., 2001). Isolated siliciclastic strata have been reported from this region but are not considered to be a major component to this stratigraphy. Preliminary findings from this study support a largely volcaniclastic stratigraphic framework, however the repeated occurrence of metamorphic grains and polycrystalline quartz throughout measured sections suggest that a second metamorphic source area was likely contributing detritus to this region during Late Triassic time. While past studies have provided general descriptions for volcaniclastic and siliciclastic units, these have previously been mapped separate from each other and independent from Upper Triassic carbonate strata. Based on finding from this study, it is proposed that Upper Triassic siliciclastic and carbonate strata of the Chulitna terrane consists of interbedded volcaniclastic, siliciclastic, and carbonate units and should be treated as one depositional unit that makes up a mixed fan-delta depositional system.

Preliminary basin model and tectonic framework

Clearly much more work is needed in the Chulitna terrane to determine a robust basin model for Upper Triassic strata exposed in the Alaska Range suture zone. Based on the data presented here, one possible model is proposed to account for the sedimentology and stratigraphy documented herein, and regional geology and stratigraphy that is exposed above and below the stratigraphy of interest in this project. Figure 2.11. outlines a backarc tectonic setting that respects the finding from this study as well as the regional Paleozoic–Jurassic stratigraphy of the Chulitna terrane. As a review, the Chulitna terrane is considered one of the more enigmatic terranes in the North American Cordillera due largely to the unique occurrence of Upper Triassic siliciclastic, volcaniclastic, and carbonate stratigraphy. Directly above the stratigraphy of interest of this project lies uppermost Triassic basalt and limestone (Figure 2.1.). Stratigraphically older stratigraphic units in the Chulitna terrane consist of sheared serpentinite and pillow basalt (Figure 2.1.). Isolated occurrences of andesite have also been reported from Chulitna terrane.

In order to account for bimodal volcanism as well as pillow basalt and serpentinite occurrences in the Chulitna terrane, a backarc basin model is proposed hear as one possible explanation to account for the diverse lithologies observed from the Chulitna terrane. It is important to note that while much of the Late Paleozoic and Mid Mesozoic tectonic history of the North American Cordillera is widely thought to be characterized by compressional tectonics, Late Triassic (Norian) basalt has been reported from many terranes in the Alaska Range suture zone throughout southern Alaska as well as locations further south in Yukon, and western British Columbia. Back arc basins are typically dominated

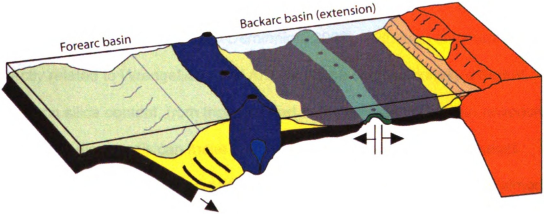


Figure 2.11.

Conceptual model for basin development during the Triassic development of the Chulitna terrane. In this scenario, mixed nonmarine, marginal marine, marine fan delta development would take place along the margin of a continental block. This model, while non-unique, accounts for the depositional facies observed in Upper Triassic stratigraphy from the Chulitna terrane and allows for magmatic source areas (blue and green) as well as metamorphosed continental source areas (orange). Yellow deposits depict expected depocenters in this tectonic configuration. Backarck extension allows for the occurrence of bimodal volcanism (basalt and andesite) observed in the Chulitna terrane. This tectonic setting also allows for a mechanism (rifting) to explain older occurrences of serpentinite and pillow basalt that are reported form the Chulitna terrane. Backarc extension allows for one possible explanation for the pervasive occurrence of Paleozoic and Triassic basalt that is observed throughout the Chulitna terrane and nearly all other terranes in the Alaska Range suture zone.

by sediments derived from the arc and the deposits are commonly associated with immature clastic deposits in ocean-continent settings (Allen, Allen, 2005). As arcs converge on continental margins the following may occur; 1. volcanism generally becomes enriched in silica, 2. volcaniclastic sandstones, ash falls and flows, and reworked volcaniclastic sediments are deposited (Pettijohn, et al., 1987; Einsele, 2000; Bridge and Deminnico, 2008). Although sedimentary rocks directly related to Wrangellia Island Arc should be compositionally different, based on silica content, from those related to the continental margin reworking, mixing and diagenesis can make it difficult to distingue in ancient deposits (Pettijohn et al., 1987; Fisher, 1994). Future studies should clearly be aimed at determining the continental block source along the inboard margin of this system as well as the arc source along the outboard margin of the basin.

CHAPTER III: CONCLUSIONS

SUMMARY OF STUDY

The unique occurrence of Upper Triassic siliciclastic, volcaniclastic, and carbonate stratigraphy, of the Chulitna terrane, distinguishes this terrane within the collage of terranes that compose the North American Cordillera. Stratigraphically older stratigraphic units in the Chulitna terrane consist of serpentinite, volcanics, sedimentary, and carbonate strata. New geologic mapping and measured stratigraphic sections of enigmatic Upper Triassic strata from the Chulitna terrane reveal a continuous record of competing volcaniclastic, siliciclastic, and carbonate sedimentation. Sedimentation is interpreted to represent a combination of nonmarine siliciclastic sedimentation, marginal marine siliciclastic-carbonate sedimentation, and marine carbonate sedimentation.

The purpose of this study is to measure, document, and classify the Upper Triassic siliciclastic and carbonate strata encountered in the Little Shotgun Creek study area and Chulitna terrane for the purpose of better understanding the stratigraphic and tectonic implications of these strata in the context of the Alaska Range suture zone. Consensus regarding a depositional model for these units has eluded previous workers but for the first time this study anchors the depositional model on measured stratigraphy.

Prior to this study, much of these siliciclastic and carbonate strata where divided into 3-4 separate units that were thought to represent several very different depositional environments (Clautice et al, 2001). However, measured sections reveal that carbonate and siliciclastic successions are interbedded throughout. In addition, given that much of the stratigraphy of the Chulitna terrane has been structurally deformed, many of the contacts between Upper Triassic siliciclastic and carbonate strata were thought to possibly represent structural contacts rather than stratigraphic contacts. Previous studies have also suggested that Upper Triassic strata from the Little Shotgun Creek region are overturned with the oldest beds being interbedded basalt and limestone and younger units being siliciclastic redbed units and carbonate strata. Measured sections and stratigraphic relationships documented hear reveal that (1) Upper Triassic redbed and carbonate strata are interbedded and potentially reflect a depositional system that includes a strong siliciclastic and carbonate component and (2) that interbedded basalt and carbonate strata that were originally proposed to be older than redbed and carbonate units are actually younger and stratigraphically overlie older siliciclastic and carbonate strata.

Sedimentologic and stratigraphic descriptions from measured sections reveal a total of 21 individual lithofacies with 14 representing siliciclastic transport and deposition and 7 representing some combination of carbonate transport, deposition, and in situ precipitation. Based on the 21 total sedimentary facies, bedding thickness, geometry, and lateral extent, as well as the 6 facies association are identified and interpreted. Upper Triassic redbed and carbonate units of the Chulitna terrane are interpreted to reflect (1) nonmarine siliciclastic sedimentation as a result of subaerial debris flows, fluvial channels, and overbank floodplain regions, (2) marginal marine sedimentation in tidal channels, deltaic front bar migration, tidal flat, and beach/barrier island regions, and (3) marine sedimentation by carbonate reef and bank development and submarine slumps and debris flows of fossil hash and fine-grained muddy limestone.

Upper Triassic siliciclastic strata from the Little Shotgun Creek study area potentially reveal a mixed provenance history that include derivation of volcanic detritus from a possible arc source area and metamorphic detritus that may have been derived from recycled orogen-continental block regions. While descriptions presented here are only a first-order look at compositional trends, it is clear that these strata contain detritus that was derived from both magmatic source regions, as evidenced by lithic volcanic and plagioclase grains, as well as metamorphic source areas, evidenced by lithic metamorphic and polycrystalline quartz grains.

While past studies have provided general descriptions for volcaniclastic and siliciclastic units, these have previously been mapped separate from each other and independent from Upper Triassic carbonate strata. Based on finding from this study, it is proposed that Upper Triassic siliciclastic and carbonate strata of the Chulitna terrane consists of interbedded volcaniclastic, siliciclastic, and carbonate units and should be treated as one depositional unit that makes up a mixed fan-delta depositional system. Based on the data presented here, one possible model is proposed to account for the sedimentology and stratigraphy documented herein, and regional geology and stratigraphy that is exposed above and below the stratigraphy of interest in this project. A back arc tectonic setting respects the findings from this study as well as the regional Paleozoic–Jurassic stratigraphy of the Chulitna terrane. The general back arc basin model would account for the diverse lithologies observed from the Chulitna terrane. Much of the Late Paleozoic and Mid Mesozoic tectonic history of the North American Cordillera is widely thought to be characterized by compressional tectonics, however Late Triassic (Norian) basalt has been reported from many terranes in the Alaska Range suture zone throughout southern Alaska as well as locations further south in Yukon, and western British Columbia.

CONCLUSIONS

The Chulitna terrane of the southern Alaska Range is defined in part by the occurrence of Upper Triassic red bed and carbonate units that occur in the Alaska Range suture zone. Measured sections and stratigraphic relationships documented in this study reveal that (1) Upper Triassic redbed and carbonate strata are interbedded and potentially reflect a depositional system that includes a strong siliciclastic and carbonate component and (2) that interbedded basalt and carbonate strata that were originally proposed to be older than redbed and carbonate units are actually younger and stratigraphically overlie older siliciclastic and carbonate strata.

21 facies identified in the Little Shotgun Creek study area are grouped into 6 facies associations. Facies association one includes subareial to subaqueous debris flows that are interpreted to represent a delta-fan system. Mudstones,

sandstones, and matrix supported, poorly sorted conglomerates are typical of facies association one strata. Facies association 2 includes mudstones, sandstones and conglomerates that are interpreted as fluvial and tidal channels and bars. Facies association 3 includes mudstones, siltstones, and paleosols which are interpreted to represent overbank deposition and subareial exposure on a floodplain and tidal flat. Facies association 4 includes fine grained, well sorted sandy limestones interpreted to represent deposition within a beach and barrier Island. Facies association 5 includes bindstones and limey mudstones which are interpreted to represent deposition on a carbonate reef/bank and within a lagoon. Facies association 6 includes rudstones, floatstones, wackestones, and mudstones which are interpreted to represent debris flows at the back reef and fore reef.

Based on this preliminary study of provenance, at least two source areas that may have contributed material during Upper Triassic time could likely have been magmatic arc regions and metamorphosed continental margin-recycled orogen regions. Future study is needed in order to constrain the source of these sediments. Quantitative data is needed in order to compare with findings from similar studies of terranes within the Alaska Range suture zone in order to compare results.

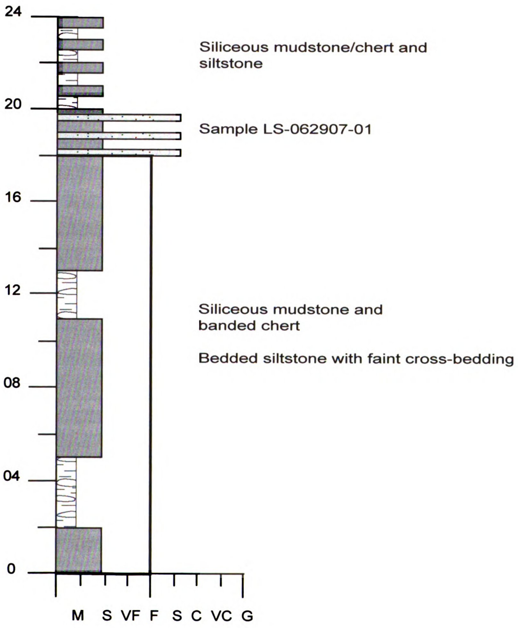
Based on finding from this study, it is proposed that Upper Triassic siliciclastic and carbonate strata of the Chulitna terrane is one interbedded unit that makes up a mixed fan-delta depositional system. Previous tectonic models for the Chulitna terrane were tested minding the constraints provided by this study and the known plate configurations during the collision of the Wrangellia Composite terrane and the Yukon-Tanana Composite terrane. Although a back arc basin fits the tectonic and stratigraphic constraints it is only one possible explanation and requires further investigation.

APPENDIX A

LITTLE SHOTGUN CREEK DETAILED MEASURED SECTIONS

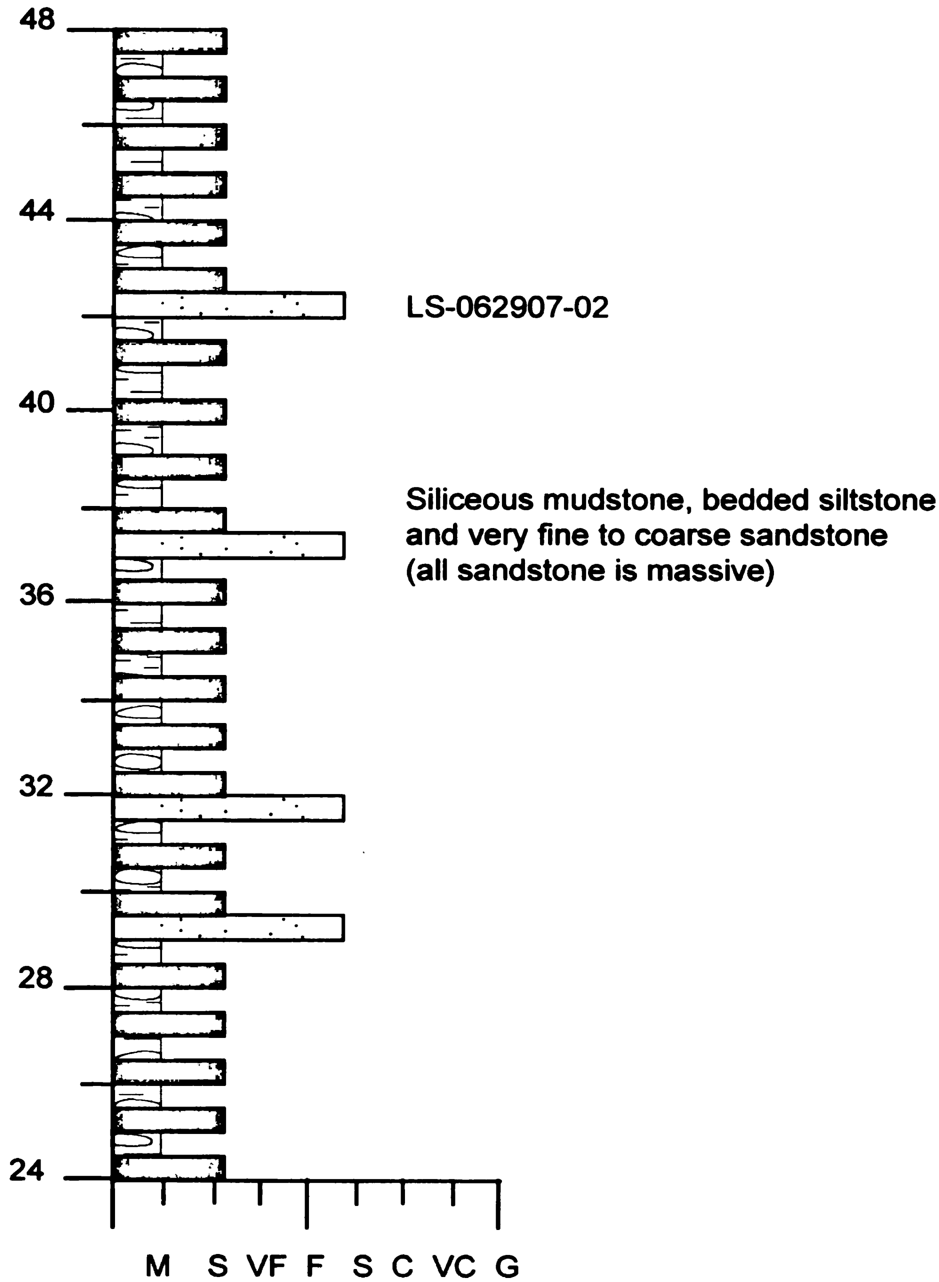
Little Shotgun Creek
Chulitna terrane
measured section #062907
page 1/9

0-24/195 meters



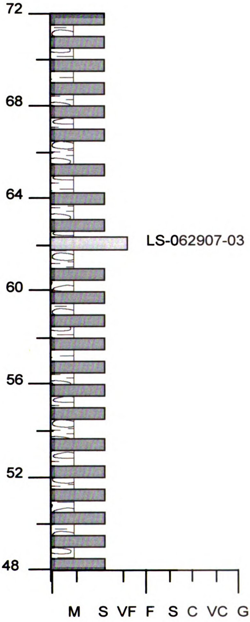
Little Shotgun Creek
Chulitna terrane
measured section #062907
page 2/9

24-48/195 meters



Little Shotgun Creek
Chulitna terrane
measured section #062907
page 3/9

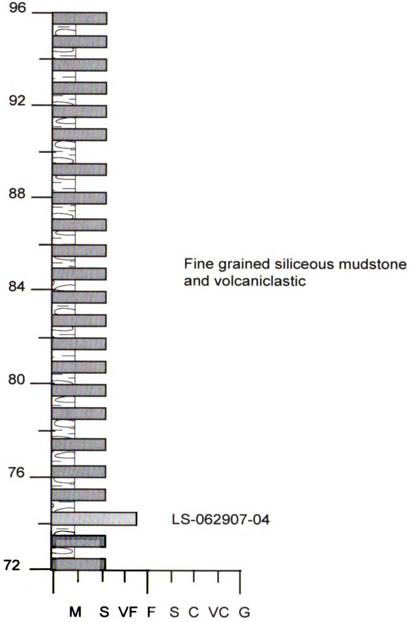
48-72/195 meters



Siliceous mudstone, bedded siltstone and minor volcaniclastic unit

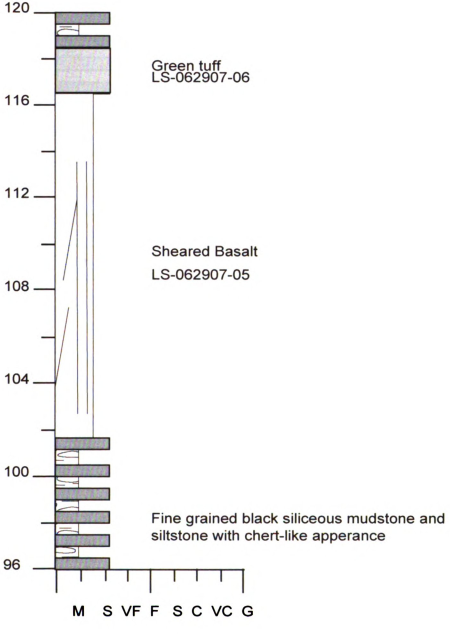
Little Shotgun Creek
Chulitna terrane
measured section #062907
page 4/9

72-96/195 meters



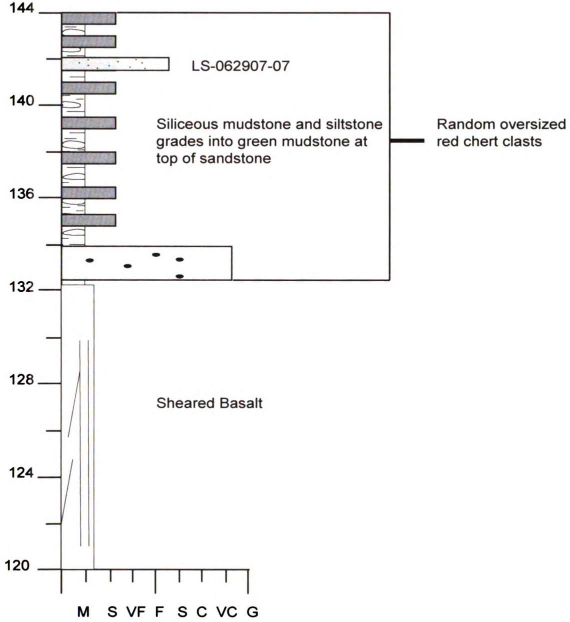
Little Shotgun Creek
Chulitna terrane
measured section #062907
page 5/9

96-120/195 meters



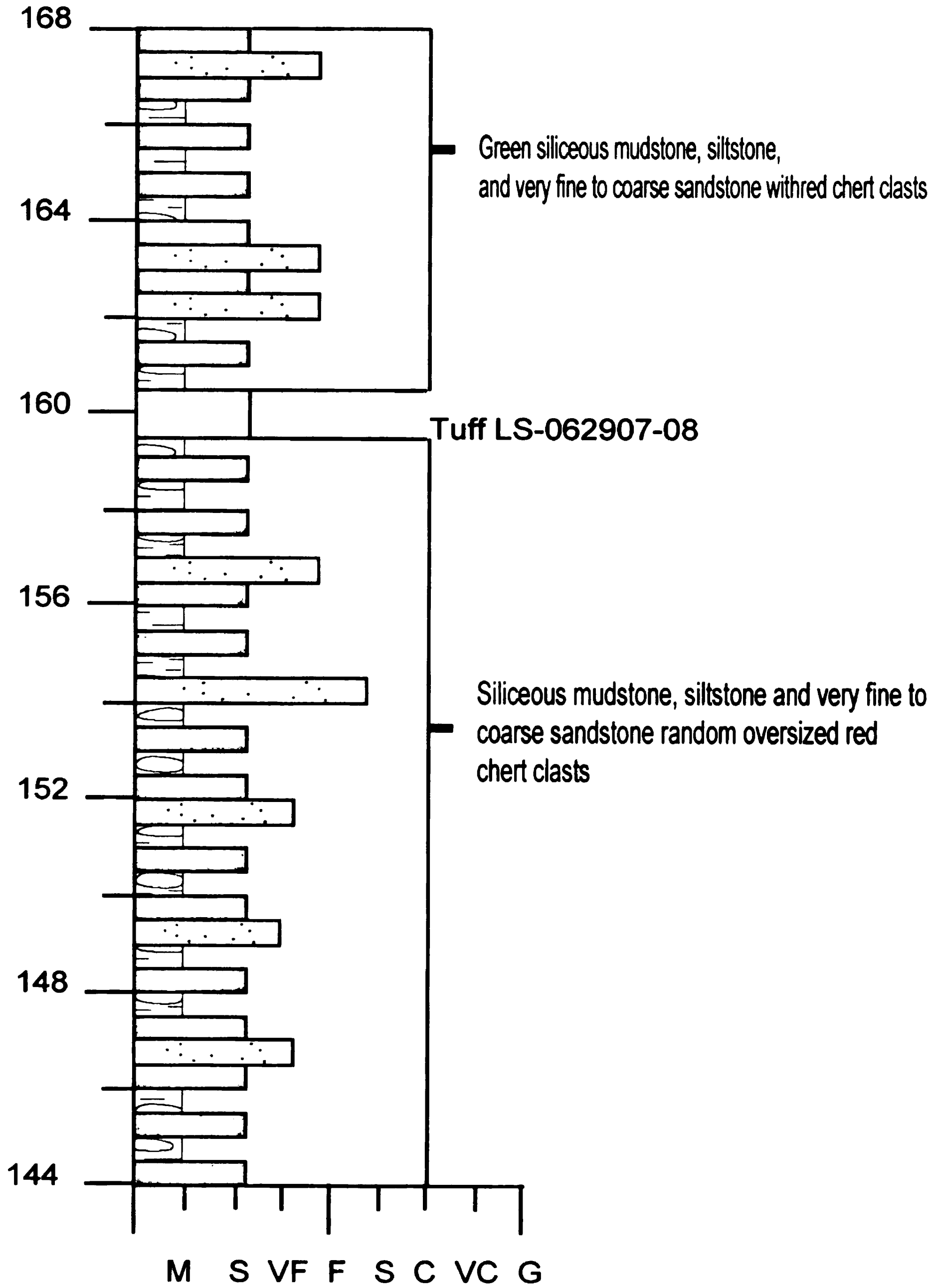
Little Shotgun Creek
Chulitna terrane
measured section #062907
page 6/9

120-144/195 meters



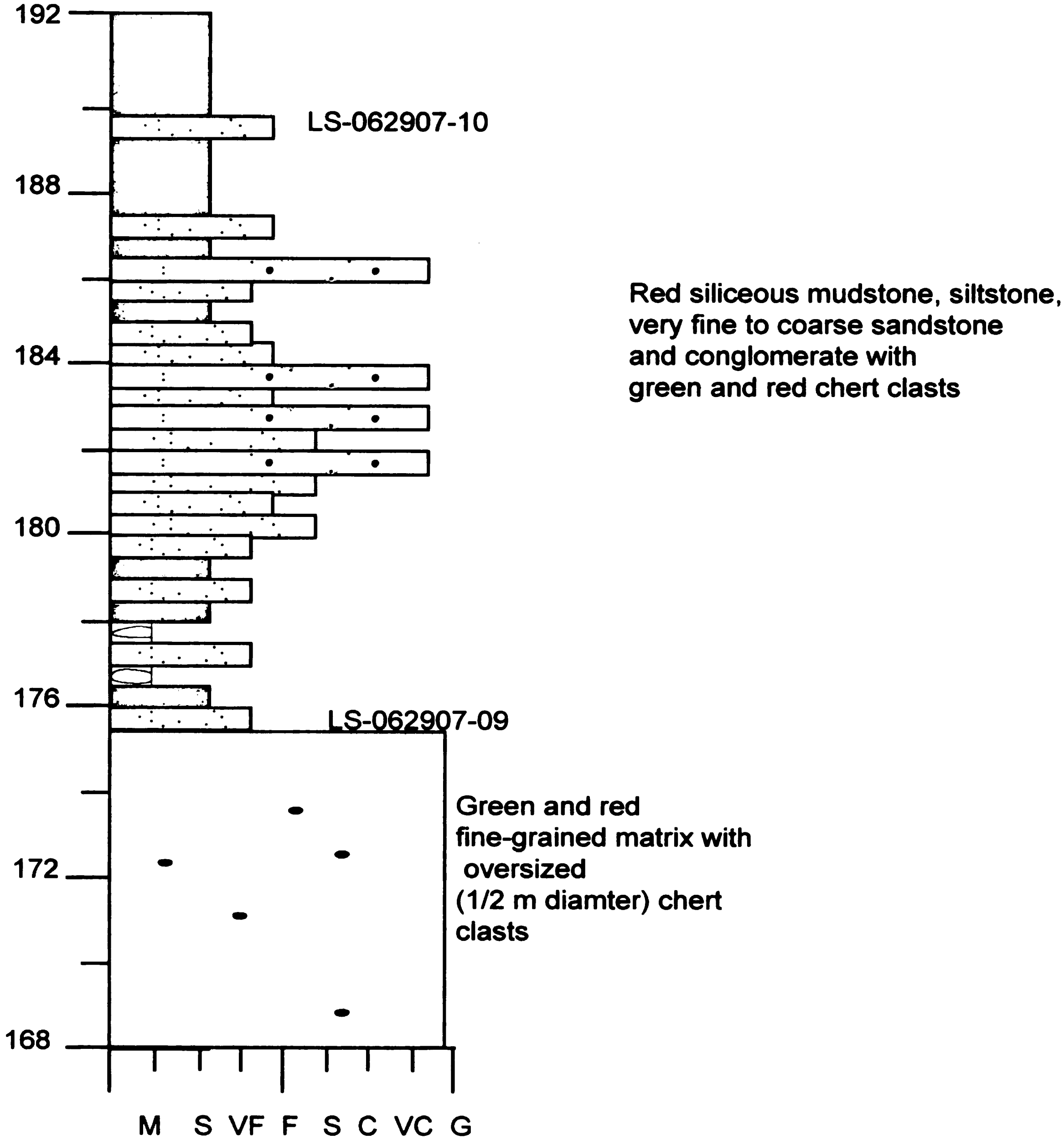
Little Shotgun Creek
Chulitna terrane
measured section #062907
page 7/9

144-168/195 meters



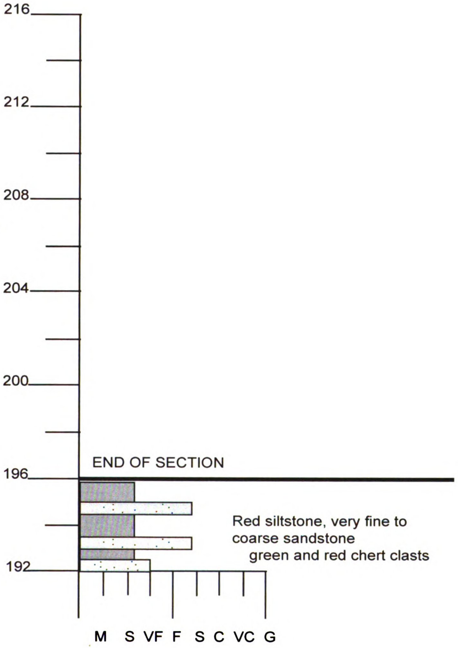
Little Shotgun Creek
Chulitna terrane
measured section #062907
page 8/9

168-192/195 meters



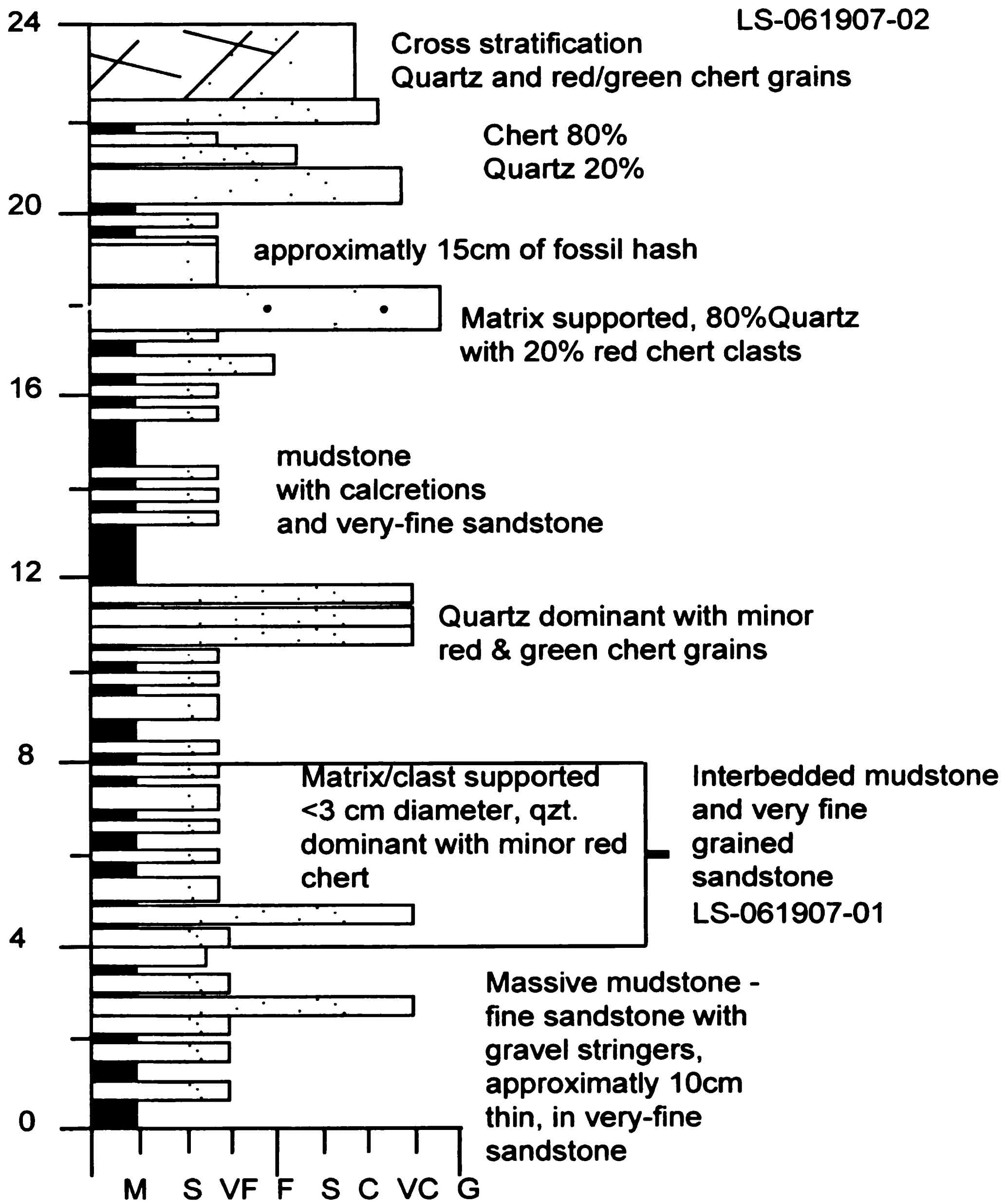
Little Shotgun Creek
Chulitna terrane
measured section #062907
page 9/9

192-195/195 meters



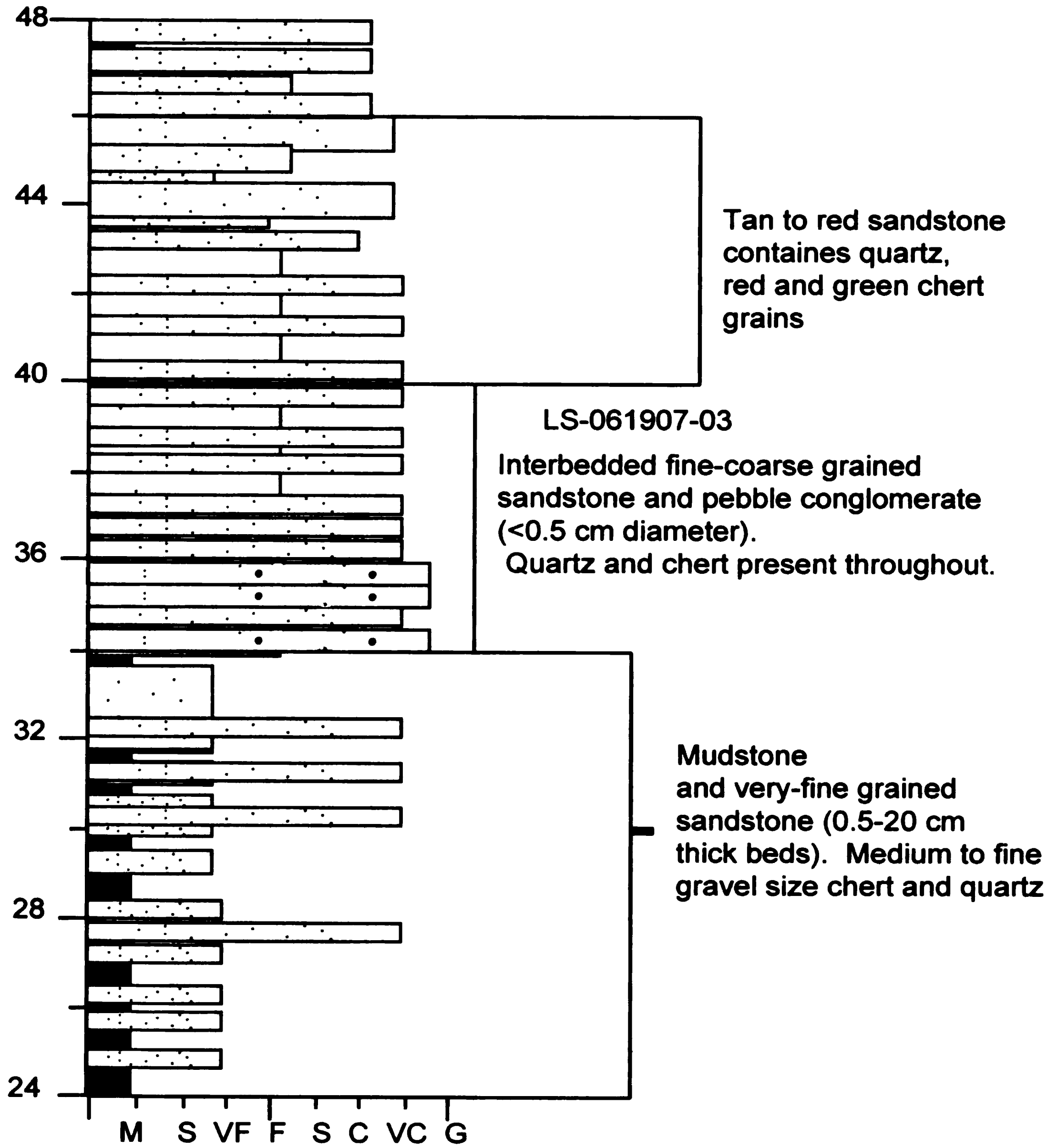
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 1/17

0-24/394 meters



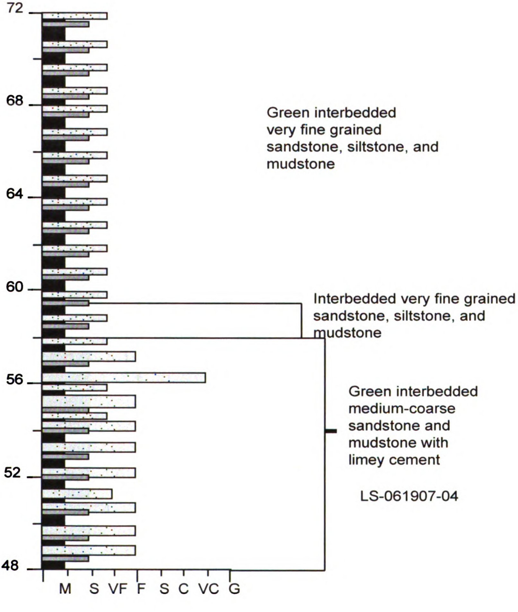
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 2/17

24-48/394 meters



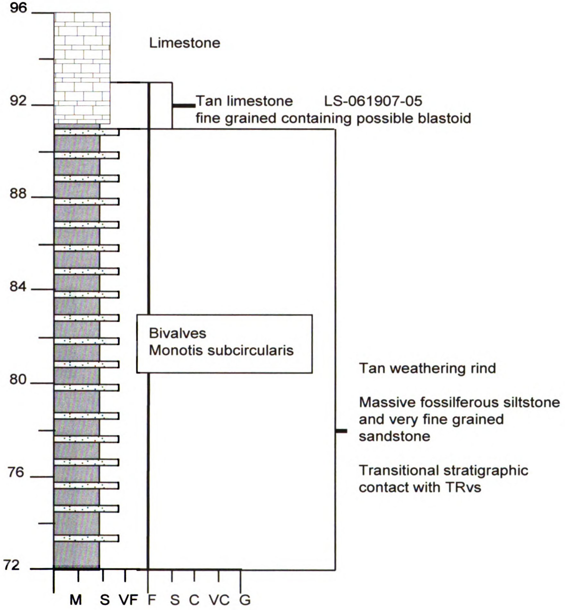
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 3/17

48-72/394 meters



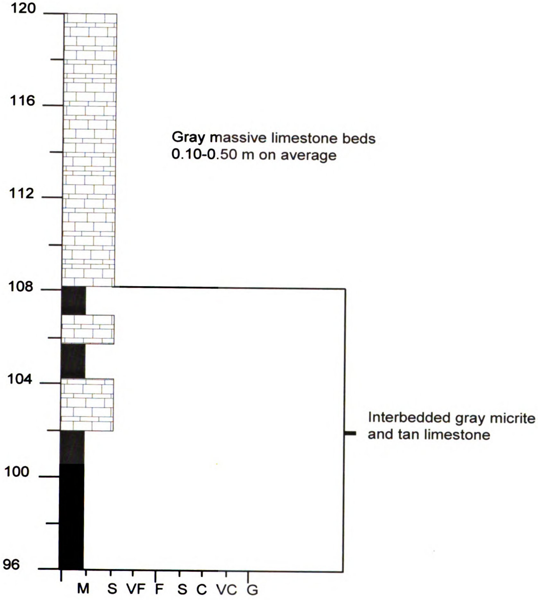
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 4/17

72-96/394 meters



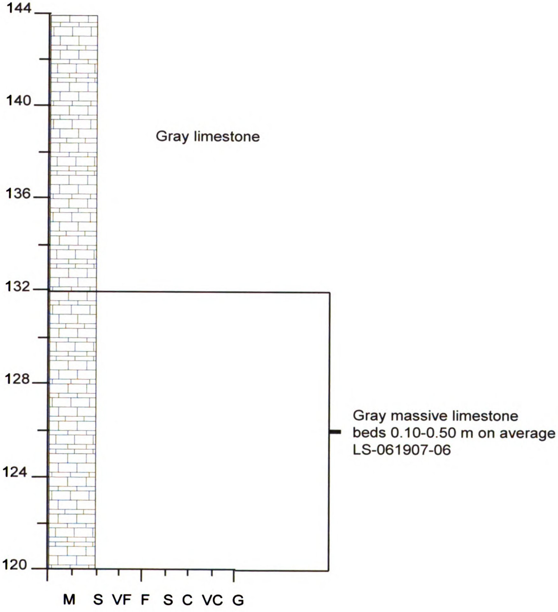
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 5/17

96-120/394 meters



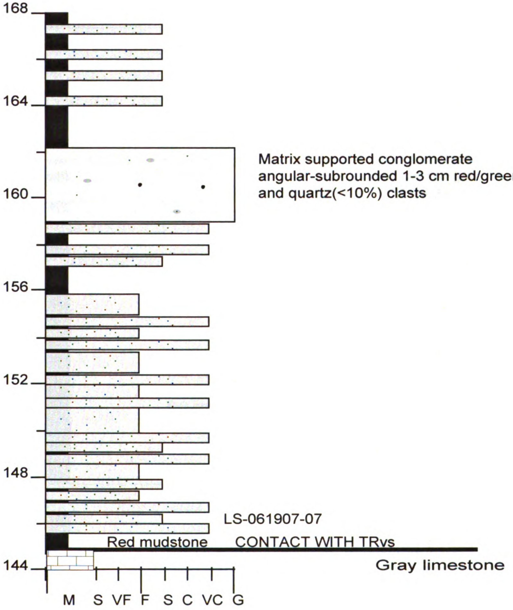
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 6/17

120-144/394 meters



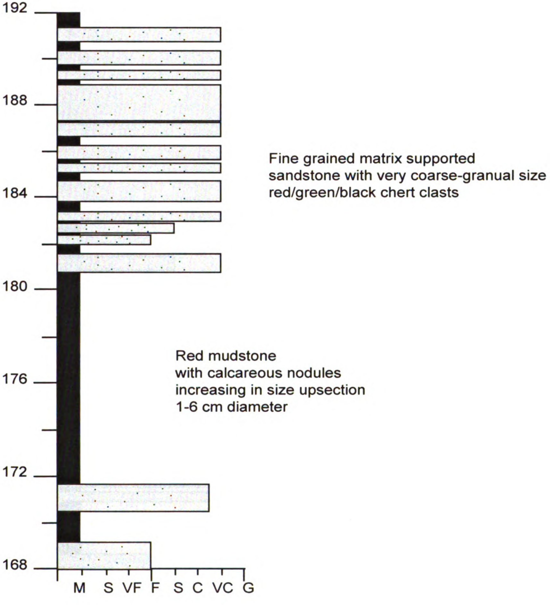
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 7/17

144-168/394 meters



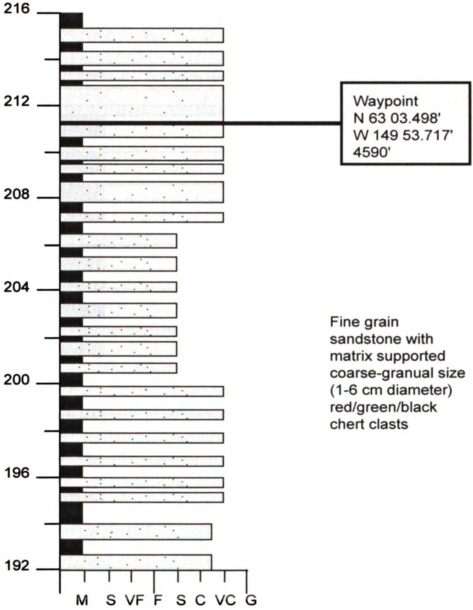
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 8/17

168-192/394 meters



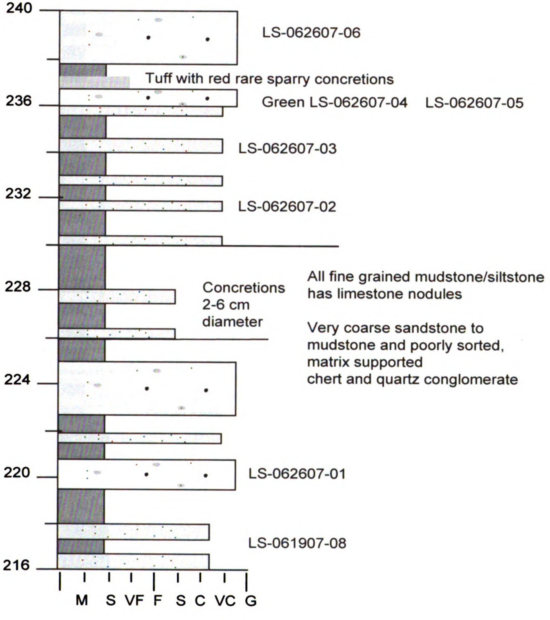
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 9/17

192-216/394 meters



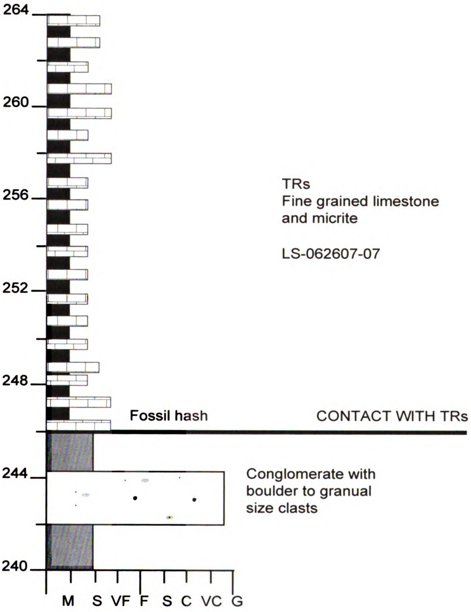
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 10/17

216-240/394 meters



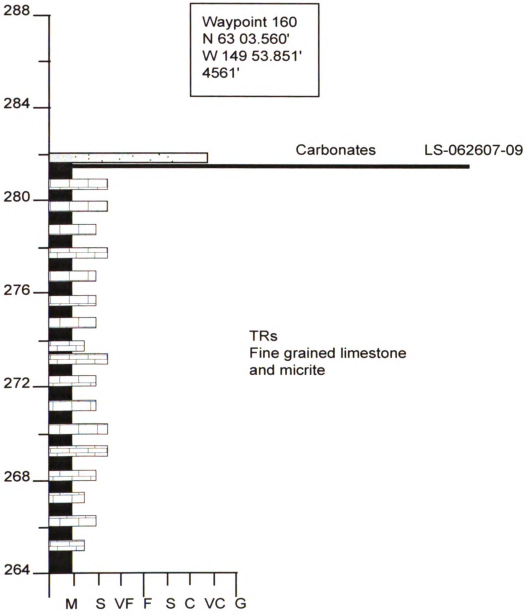
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 11/17

240-264/394 meters



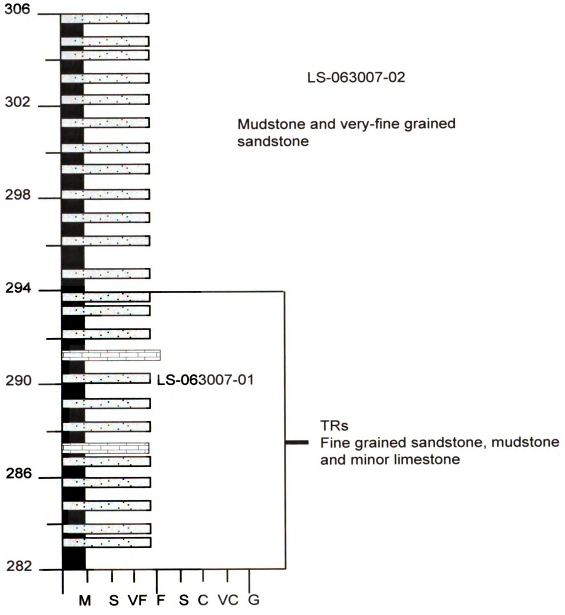
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 12/17

264-288/394 meters



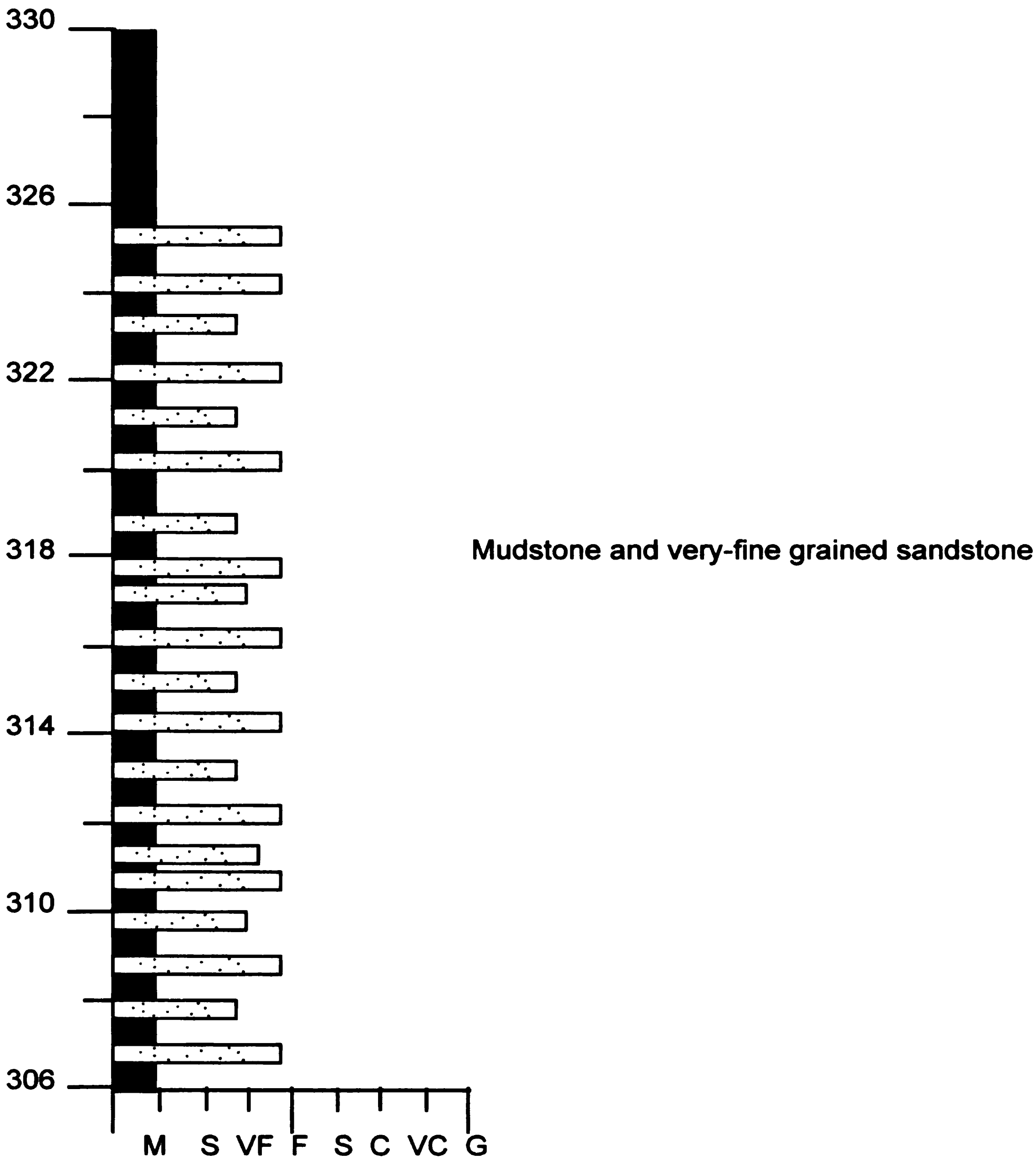
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 13/17

282-306/394 meters



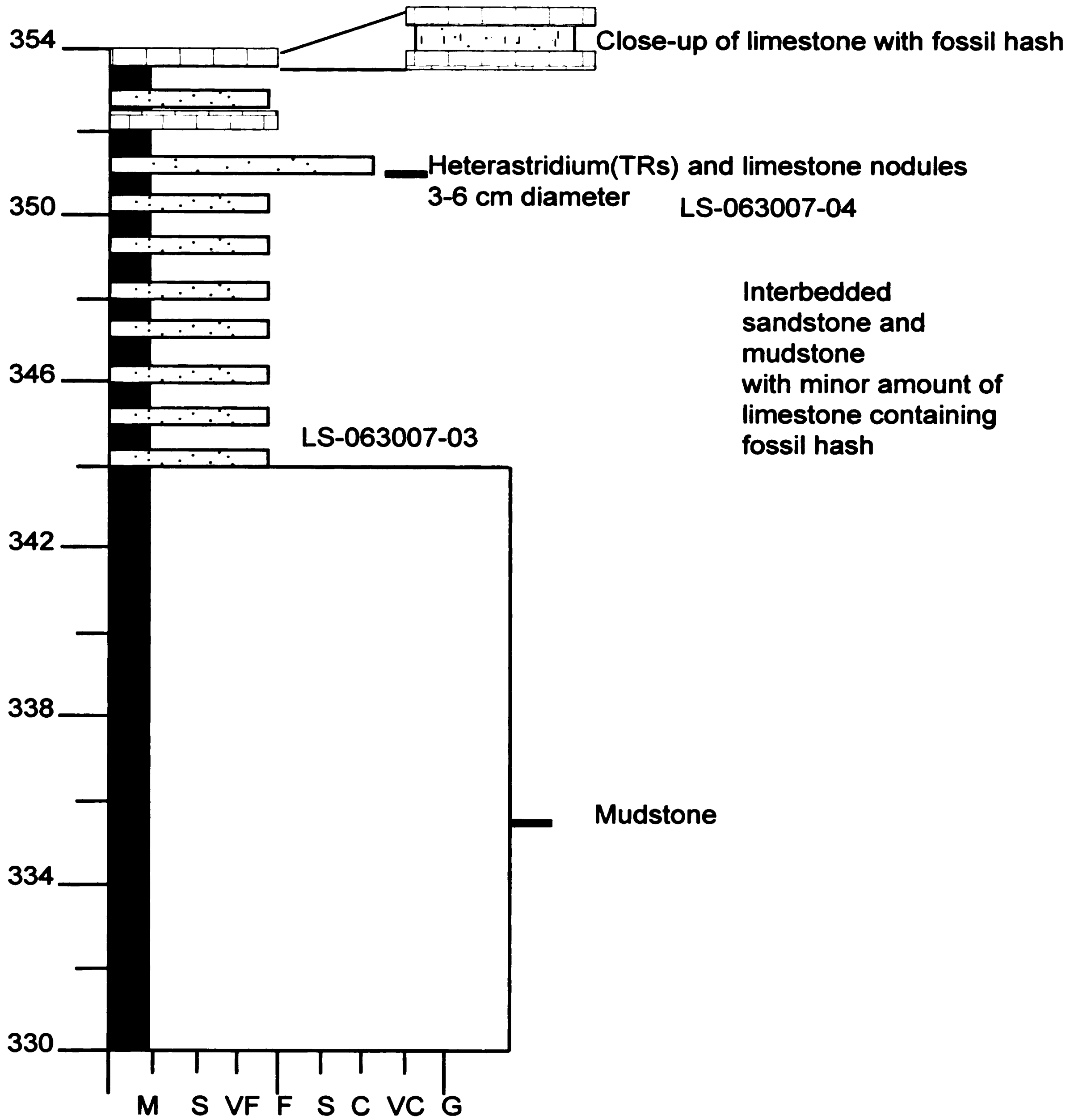
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 14/17

306-330/394 meters



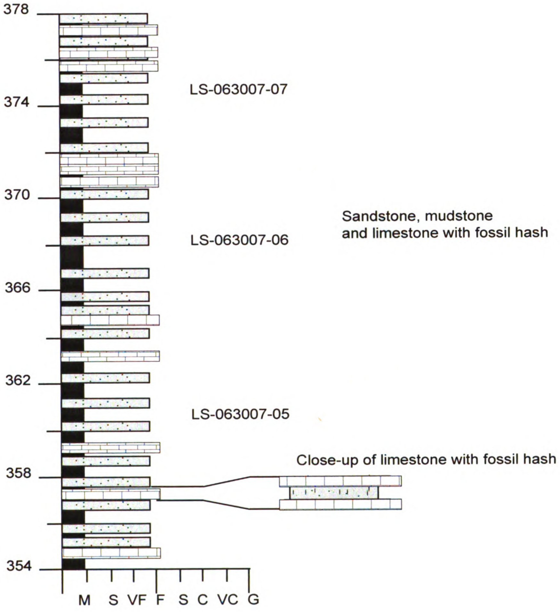
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 15/17

330-354/394 meters



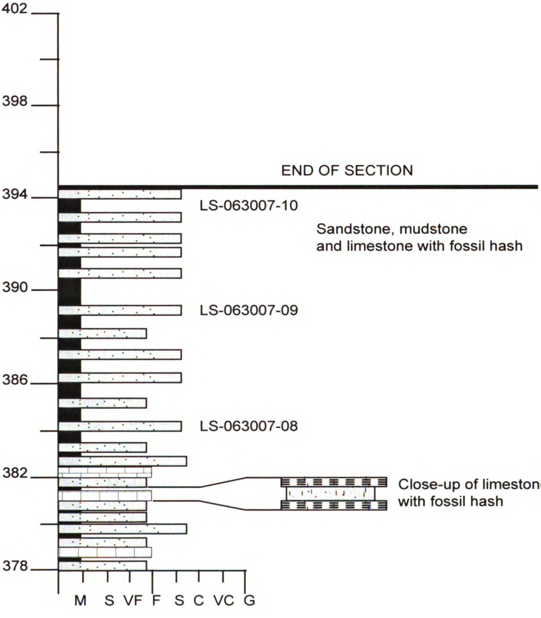
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 16/17

354-378/394 meters



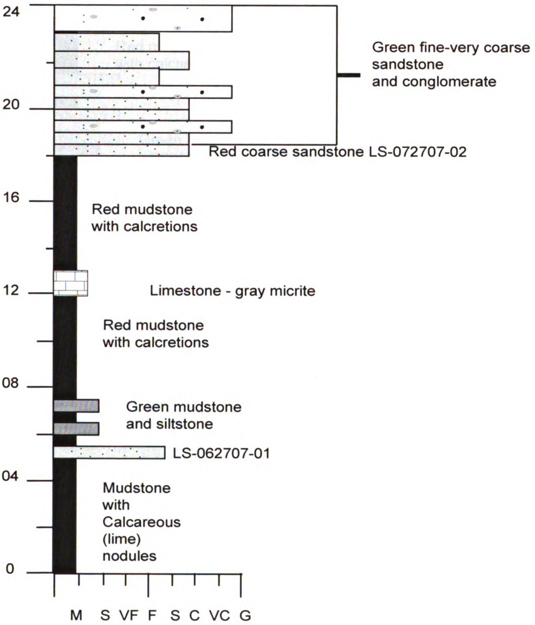
Little Shotgun Creek
Chulitna terrane
measured section #061907, 062607, 063007
page 17/17

378-394/394 meters



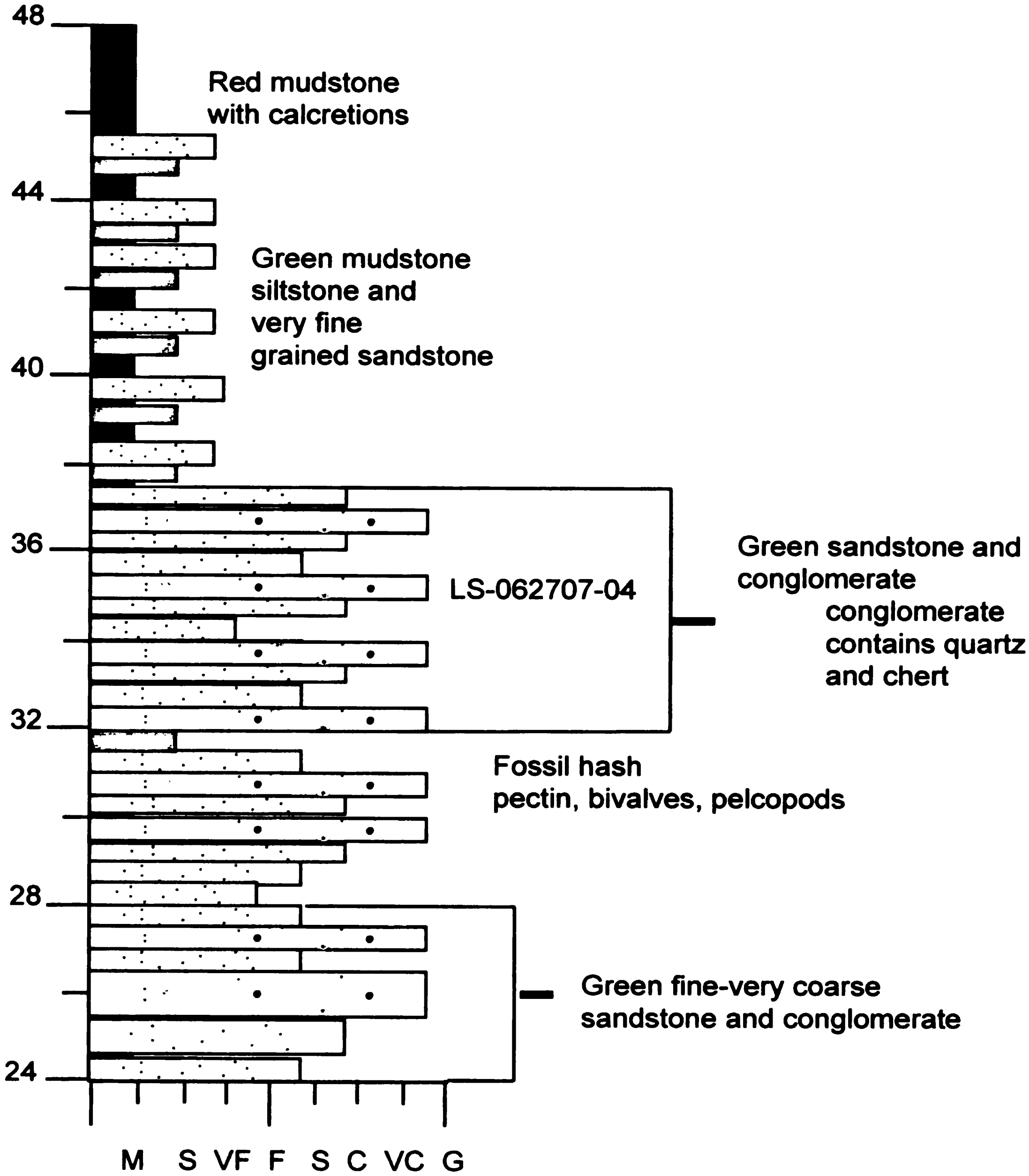
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 1/14

0-24/325 meters



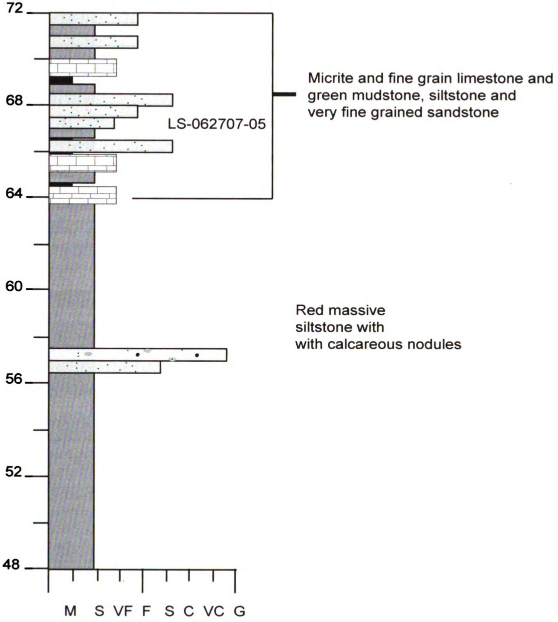
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 2/14

24-48/325 meters



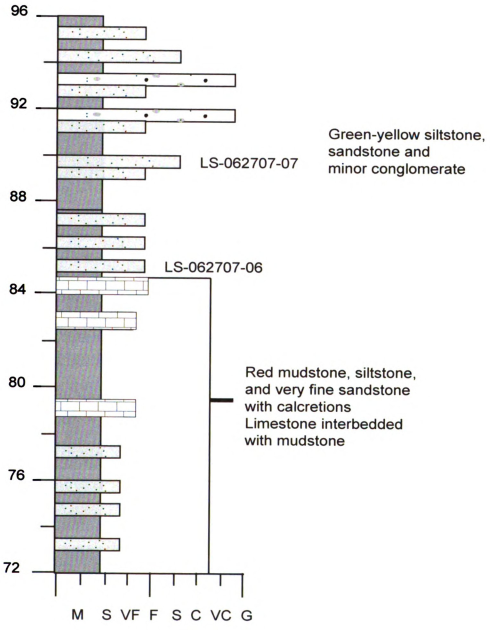
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 3/14

48-72/325 meters



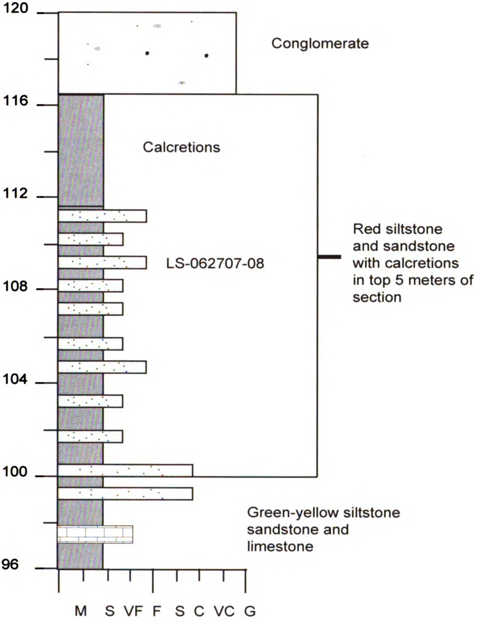
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 4/14

72-96/325 meters



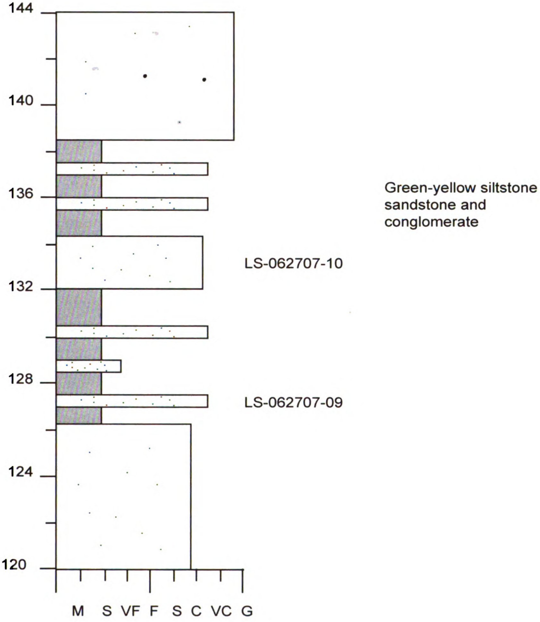
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 5/14

96-120/325 meters



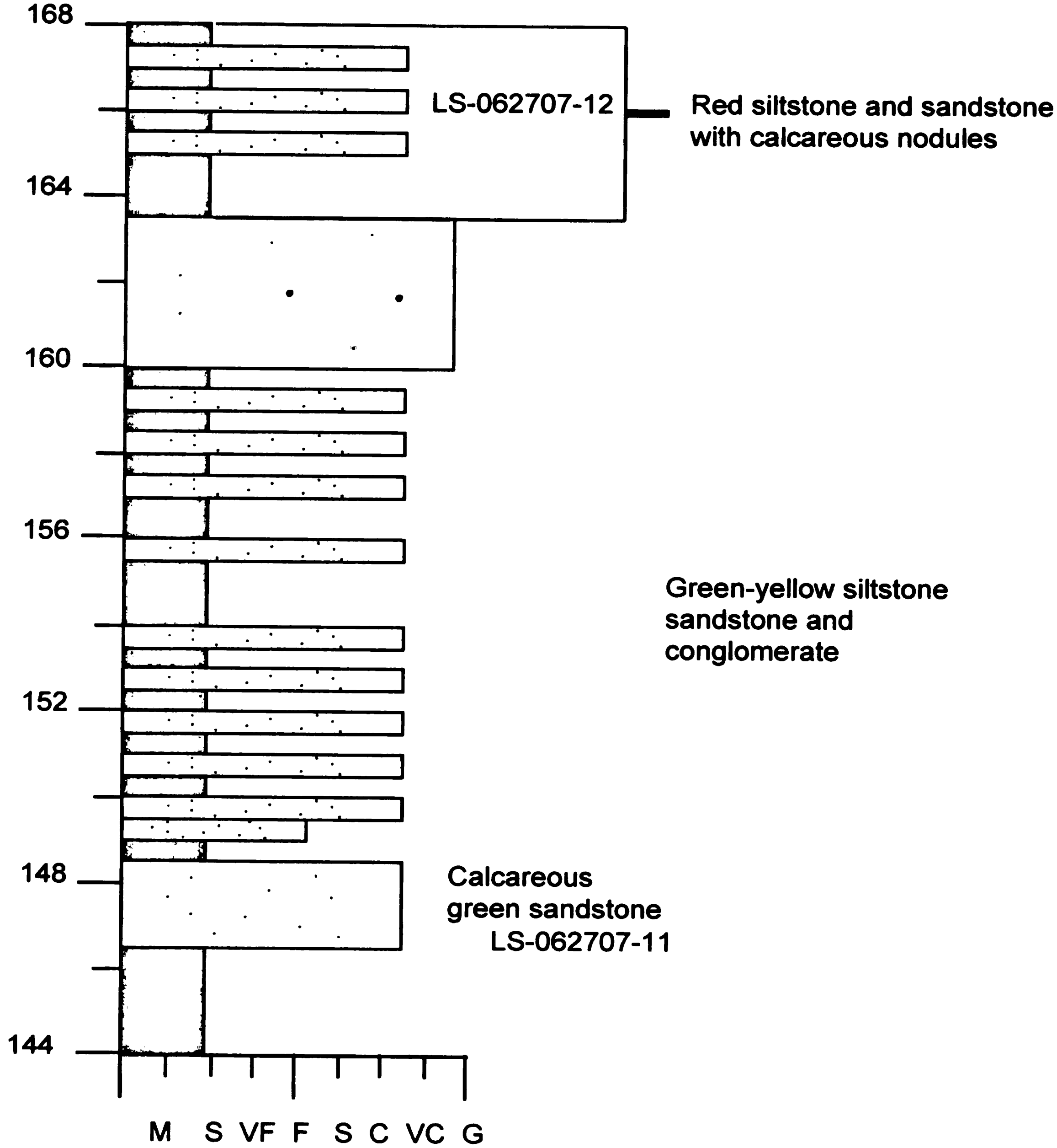
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 6/14

120-144/325 meters



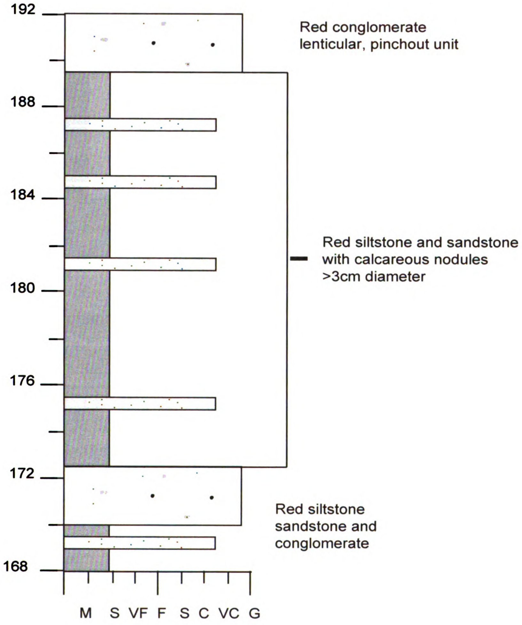
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 7/14

144-168/325 meters



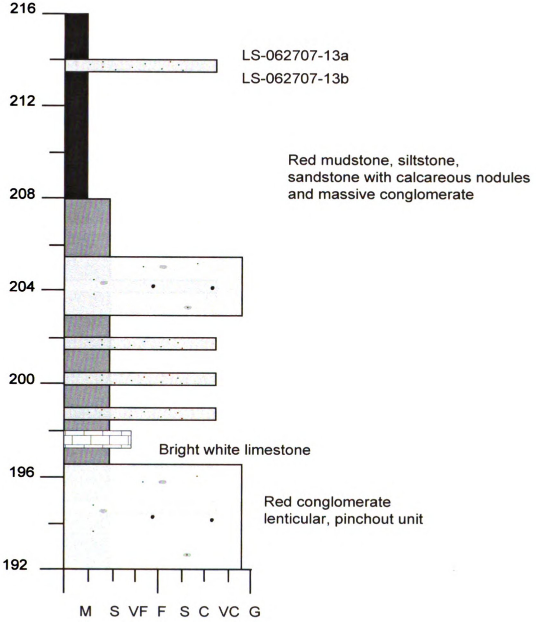
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 8/14

168-192/325 meters



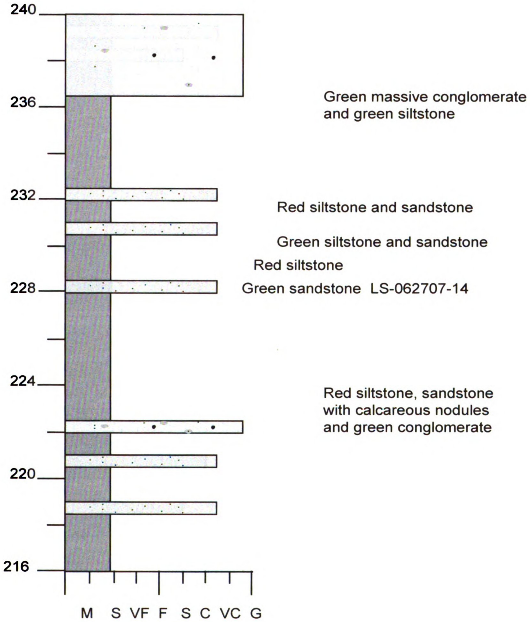
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 9/14

192-216/325 meters



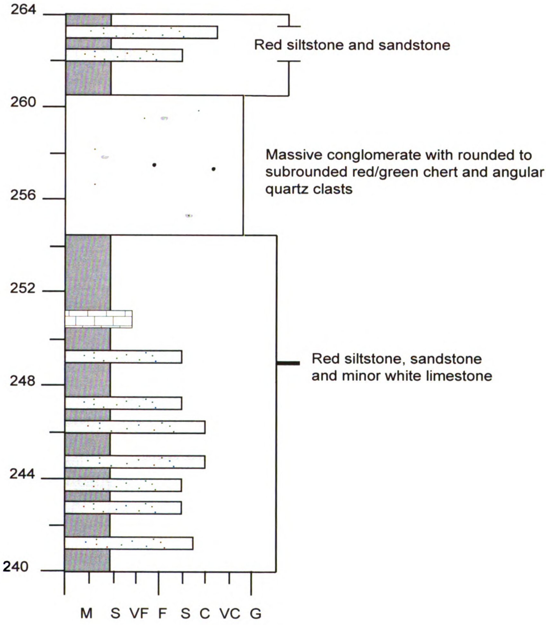
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 10/14

216-240/325 meters



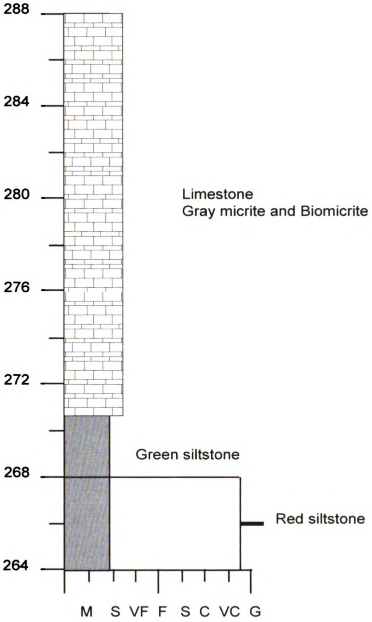
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 11/14

240-264/325 meters



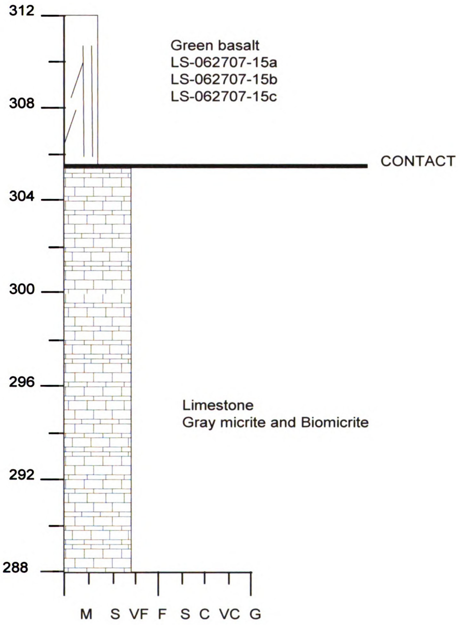
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 12/14

264-288/325 meters



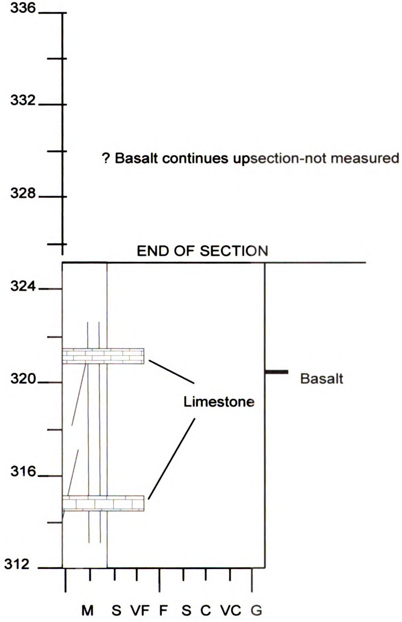
Little Shotgun Creek
Chulitna terrane
measured section #062707
page 13/14

288-312/325 meters



Little Shotgun Creek
Chulitna terrane
measured section #062707
page 14/14

312-325/325 meters



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