Structural setting of Teton Pass with emphasis on fault breccia associated with the Jackson thrust fault, Wyoming
by Ann Marlene Vasko

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

Abstract:
The Jackson thrust fault, exposed on Teton Pass, Wyoming, consists of Cambrian Gallatin Limestone thrust over the Cretaceous Bear River Formation. The Jackson fault is a Late Paleocene, thin-skinned, listric thrust fault that forms the main frontal fault of the foreland fold and thrust belt. The Cache Creek thrust sheet overrode the Jackson thrust sheet from the northeast overturning the Jackson thrust fault to the southwest.

The fault zone of the Jackson thrust fault is defined by a severely deformed cataclastic zone approximately nine meters wide. Thrust- ' related changes in the hanging wall rock (Gallatin Limestone) are: (1) a severely brecciated zone 0-4 m from the fault plane, (2) a relatively less brecciated zone 4-9 m from the fault plane, (3) a decrease in grain size of breccia fragments as the fault plane is approached, (4) an increase in the degree of sorting of breccia fragments nearer the fault plane, and (5) a loss of well defined bedding planes. Movement along the Jackson thrust fault is interpreted to have been aided by (1) loss of cohesion between hanging wall rock and footwall rock units, (2) decrease in normal stress due to pore fluid pressure, and (3) de-' crease in frictional resistance to slip due to the presence of breccia fragments between the hanging wall and footwall blocks.

STRUCTURAL SETTING OF TETON PASS WITH EMPHASIS ON FAULT BRECCIA ASSOCIATED WITH THE JACKSON THRUST FAULT, WYOMING

by

Ann Marlene Vasko

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

December 1982

APPROVAL

of a thesis submitted by

Ann Marlene Vasko

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

12/7/82
Date

Chairperson, Graduate Committee

Approved for the Major Department

12/7/82
Date

Head, Major Department

Approved for the College of Graduate Studies

12-9-82
Date

Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his/her absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Ann Marlene Vasko

Date 12/7/82

ACKNOWLEDGMENTS

Assistance in the field by David Redgrave was greatly appreciated. Financial assistance was received from Montana State University under the school's Research Creativity Program.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF PLATES

ABSTRACT

The Jackson thrust fault, exposed on Teton Pass, Wyoming, consists of Cambrian Gallatin Limestone thrust over the Cretaceous Bear River Formation. The Jackson fault is a Late Paleocene, thin-skinned, listric thrust fault that forms the main frontal fault of the foreland fold and thrust belt. The Cache Creek thrust sheet overrode the Jackson thrust sheet from the northeast overturning the Jackson thrust fault to the southwest.

The fault zone of the Jackson thrust fault is defined by a severely deformed cataclastic zone approximately nine meters wide. Thrust-related changes in the hanging wall rock (Gallatin Limestone) are: (1) a severely brecciated zone 0-4 m from the fault plane, (2) a relatively less brecciated zone 4-9 m from the fault plane, (3) a decrease in grain size of breccia fragments as the fault plane is approached, (4) an increase in the degree of sorting of breccia fragments nearer the fault plane, and (5) a loss of well defined bedding planes. Movement along the Jackson thrust fault is interpreted to have been aided by (1) loss of cohesion between hanging wall rock and footwall rock units, (2) decrease in normal stress due to pore fluid pressure, and (3) decrease in frictional resistance to slip due to the presence of breccia fragments between the hanging wall and footwall blocks.

INTRODUCTION

This thesis addresses the deformational mechanism of fault zone cataclasis associated with the Jackson thrust fault, western Wyoming. The objectives are: (1) to investigate cataclastic deformation along the Jackson thrust fault by documentation of the fabric and texture of the cataclastic zone, and (2) to evaluate cataclastic deformation as it relates to the mechanics of thrust faulting.

The long-standing paradox of thrust faulting is that the shear stress required to initiate lateral movement far exceeds the laboratory shear strength of the rock. Smoluchowski (1909) calculated the force necessary to push a 200 km long thrust plate along a horizontal surface to be seven times the crushing strength of granite at the ground surface. Breccia, resulting from cataclasis, is a deformational product commonly associated with thrust faulting, and is a friction-dependent mechanism of brittle deformation involving both fracture and rigid-body rotation (Borg and others, 1960) at low pressures and temperatures (Higgins, 1971). By studying cataclastic deformation along thrust faults, the dynamics of thrust faulting may be better understood.

The first half of this thesis is an introduction and brief review of the contemporary views on the structure and tectonic history of the Idaho-Wyoming foreland fold and thrust belt. This portion of the thesis is designed to familiarize the reader with the study area, and serves to set up a few premises that are used in the latter half of the thesis.

Study Area

The phenomenon of cataclasis was studied in the hanging wall block of the Jackson thrust fault in western Wyoming (Fig. 1). This fault extends from the northwestern Idaho-Wyoming boundary, south into west-central Wyoming, where it becomes known as the Prospect thrust, and continues southward into southwest Wyoming as the Darby thrust, terminating at the Uinta Mountains in northeastern Utah (Figs. 1 and 7). The Jackson thrust fault is the easternmost thrust of the Idaho-Wyoming-northern Utah foreland fold and thrust belt. It is a Late Paleocene-Early Eocene, thin-skinned fault with relative transport from southwest to northeast (Dorr and others, 1977). A more detailed discussion of the Jackson fault will be presented in subsequent sections.

Location and Accessibility

The study area is located in western Teton County, Wyoming (Fig. 1), 22-24 kilometers west of Jackson, Wyoming on State Highway 22 in Range 117 west, Township 41 north. This location was chosen because of good cross-sectional exposures of the Jackson thrust fault, its associated cataclastic zone, and easy accessibility from either Driggs, Idaho or Jackson, Wyoming.

The Jackson thrust fault is exposed in a road cut 3.6-3.7 km west of Teton Pass, or 0.6 km southeast of Coal Creek campground. The study area is bounded to the north by the Teton Range which is a north-trending, Late Cenozoic basin and range structure, and to the south by the Snake River Range which is a northwest-trending foreland fold and thrust belt terrain (Blackstone, 1980).

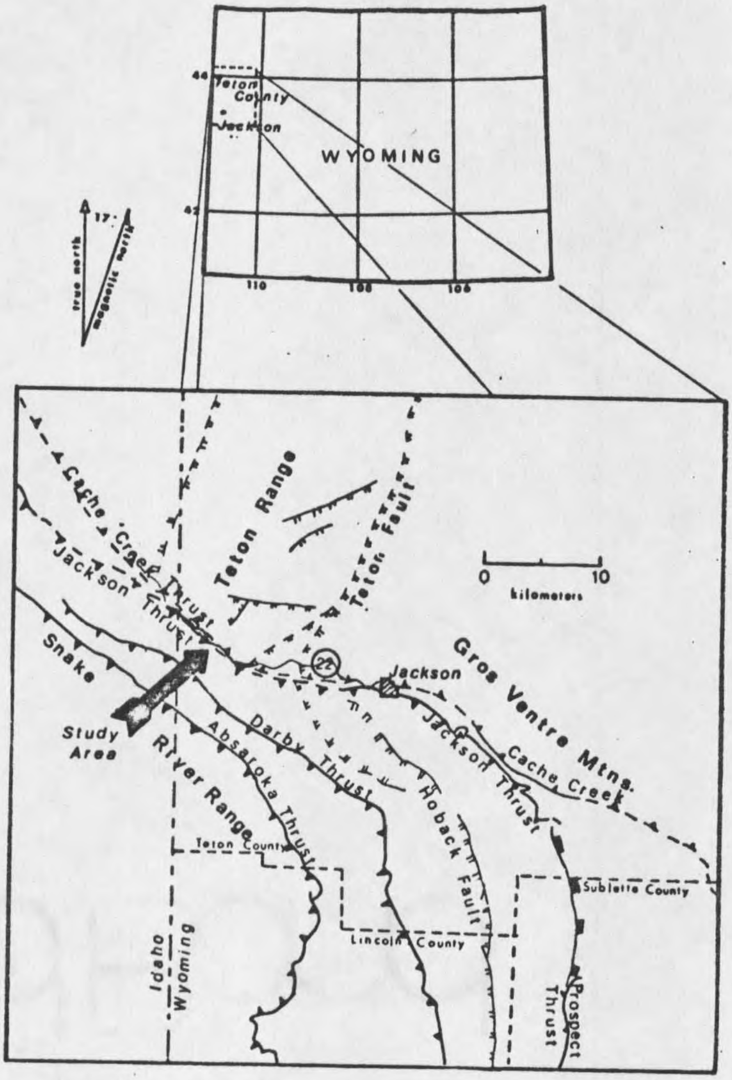


Figure 1. Index map of the study area and major tectonic elements (modified from Ver Ploeg, 1982).

Method of Study

Field study in the Teton Pass area was started in September 1981 and completed in June 1982 with valuable assistance rendered by David Redgrave during this phase of the study. A descriptive approach was used in this study, rather than theoretical modelling. The method of study consisted of: (1) collection and description of fault zone material at measured intervals away from the fault plane at two localities (one 3.6 km and another at 1.5 km west of Teton Pass, Wyoming), (2) detailed mapping of the fault zone with plane table and alidade, and (3) use of thin sections and photographs to examine the mineralogy, grain size, grain characteristics, and overall petrofabric of the cataclastically deformed rocks.

A total of forty-two samples of fault breccia from the hanging wall of the Jackson thrust fault were collected at measured intervals from the fault plane. Thirty-two samples were thin-sectioned and examined to determine mineralogy and textural features. Eight-by-ten black and white photographs of the thirty-two slabbed and polished breccia samples were used to measure and count the size of breccia fragments. A circular template was used to measure fragment diameter, a pin hole through the photograph kept track of the fragments counted, and a record of the number of fragments of each diameter was kept on a tally sheet. Due to the intense weathering of samples at one location (1.5 km west of Teton Pass), only 18 samples (photographs) from one locality (3.6 km from Teton Pass) were used to generate histograms, the cumulative frequency curve, the median grain size versus distance from the fault graph, and the graph of sorting versus distance from fault.

Breccia fragments and cement were differentiated on the photographs. By measuring the area of both the fragments and cement, dilatancy, or an increase in volume, as determined by the relationship:

$$\epsilon_{mean} = 1/2 \ln (A/A_o),$$

where A = area of breccia fragments, and A_o = area of fragments and cement. Dilatancy was determined on 10 samples of fault breccia.

PREVIOUS WORK

Teton Pass Area

Classic papers on the Idaho-Wyoming thrust belt include the regional geology by Rubey and Hubbert (1959) and Armstrong and Oriel (1965), a summary of the orogenic phases in the thrust belt by Eardley (1965), and geologic quadrangle maps by Schroeder (1972, 1973), and Rubey (1973b). The geology of the Jackson Hole area was summarized by Love and others (1973) and mapped by Love and Albee (1972). Geology on Teton Pass was mapped by Zeller (1982). Regional Paleozoic and Mesozoic stratigraphy was described by Wanless and others (1955), and the Late Cretaceous and Tertiary formations were described by Love (1956) and Rubey (1973a).

Cataclastic Deformation

Higgins (1971) classified cataclastic rocks on the basis of cohesion, which is the shear strength of a rock that is not related to interparticle friction. Higgins recognized two types of cataclastic rocks: those with primary cohesion and those without primary cohesion (Table 1).

Primary cohesion refers to the congenital or inherent coherence of a rock, as opposed to that produced by secondary cementation. Cataclastic rocks with primary cohesion are metamorphic rocks and their

Table 1. Cataclastic rock classification (modified from Higgins, 1971).

Volume % fragments	Rocks without primary cohesion	Rocks with primary cohesion		
		Cataclasis dominant over neomineralization-recrystallization		Neomineralization-recrystallization dominant over cataclasis
		Rocks without fluxion structure	Rocks with fluxion structure	Rocks with fluxion structure
	Fault breccia	Microbreccia	Protomylonite	Mylonite gneiss
			Mylonite	
30%	Fault gouge	Cataclasite		Blastomylonite
			Ultramylonite	

cohesion is the product of neomineralization-recrystallization processes. Mylonites, mylonite-gneisses, and blastomylonites are examples of rocks where neomineralization-recrystallization (constructive processes) are dominant over cataclasis (destructive processes) (Higgins, 1971). Cataclastic rocks with primary cohesion are metamorphic rocks and are not to be discussed in this thesis.

Fault breccia and fault gouge are cataclastic rocks without primary cohesion and are generally associated with near-surface faulting, low confining pressures, and low temperatures (Higgins, 1971). The degree of cataclasis depends on the confining pressure, original character of the rock, amount of movement, and the duration of movement (Higgins, 1971). The following definitions proposed by Higgins will be used in this thesis:

> Fault breccia -- rock composed of angular to rounded fragments, formed by crushing or grinding along a fault. Most fragments are large enough to be visible to the naked eye, and they make up more than 30% of the rock. Coherence, if present, is due to secondary processes.
>
> Fault gouge -- pastelike rock material formed by crushing or grinding along a fault. Most individual fragments are too small to be visible to the naked eye, and fragments larger than the average groundmass grains make up less than 30% of the rock. Coherence, if present, is due to secondary processes.

Experimental research on the mechanical behavior of rocks has resulted in quantitative knowledge which can be applied to practical or field situations. Experimental study of the relationships between brittle rock deformation and mechanics of thrust faulting was addressed in the following papers. Jaeger (1959) and Brace and Byerlee (1966) studied the frictional properties of rocks and the relationship to stick-slip faulting. Borg and others (1960), Engelder (1974), Lajtai and others (1974), and Mandl and others (1977) are among the experimentalists who have attempted to generate fault gouge and breccia. However, experiments have failed to simulate the natural stresses that produced the magnitude of cataclastic rock observed in nature. This discrepancy is due in part to the fact that laboratory tests normally give information about the properties of the material itself, but do not determine the properties of the rock as a whole unit. Paterson (1978) provided a summary of the laboratory apparatus, classical views, and recent developments of experimental brittle rock deformation.

Engelder (1974), in an attempt to characterize the texture and fabric of quartz gouge, collected specimens from (1) the Bonita normal fault in New Mexico with gouge in the Cretaceous Mesa Rica Sandstone, (2) the Muddy Mountain thrust fault in southeast Nevada with gouge in the Jurassic Aztec Sandstone, (3) the Hurricane high-angle fault in Utah with the gouge in the Permian Coconino Sandstone, and (4) a high-angle reverse fault on the north flank of the Uinta Mountains, Utah with gouge in sandstones of the Precambrian Uinta Mountain Group. Engelder concluded that natural gouge develops as a result of cataclasis and increases in volume until it reaches a critical value. He also stated that the development of natural gouge involves a decrease in size and sorting which is an important observation that will be discussed with respect to the Jackson fault. Brock and Engelder (1977) reexamined the Muddy Mountain thrust of Nevada and came to the same conclusion that during cataclastic deformation, grain size and sorting decrease with increasing confining pressure and increasing displacement.

Lageson (1980) investigated cataclastic deformation associated with the Absaroka thrust fault of western Wyoming. His study revealed four levels of deformation: (1) a moderately brecciated footwall, (2) a sharply demarcated fault plane, (3) an interval of intensely brecciated rock overlain by (4) a transitional interval of moderately brecciated rock. Lageson (1980) also found evidence for stable-sliding such as striations and steps along the fault plane. He concluded that two different mechanisms of deformation, one producing the breccia zone and one producing the discrete fault plane, occurred at different times along the same fault. He stated that the two mechanisms were probably stick-slip (brecciation) and stable-sliding (discrete fault plane) motion.

Pittman (1981) studied quartz gouge in the Simpson Group of Oklahoma and its effect on permeability and porosity. He concluded that both permeability and porosity decrease in the cataclastically deformed fault zones.

GENERAL GEOLOGY OF TETON PASS

The two major thrust faults in the study area are the Jackson and the Cache Creek. They represent two distinct styles of deformation. The Jackson thrust is a product of foreland fold and thrust deformation during the Latest Paleocene-Early Eocene in which only the Phanerozoic sedimentary veneer was involved in faulting (thin-skinned). In contrast, the Cache Creek is a basement-involved (thick-skinned) foreland fault, which overrode the Jackson thrust from the northeast in Early Eocene time.

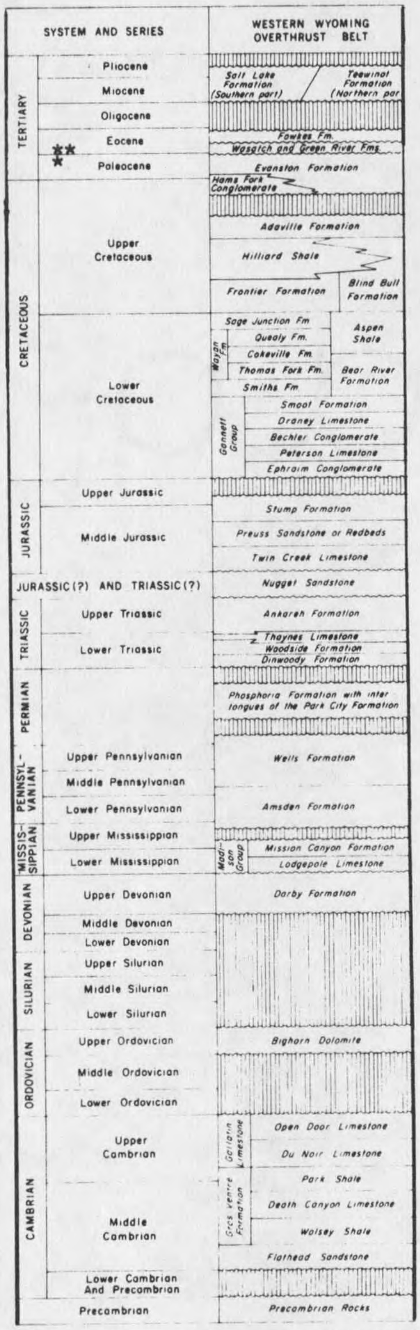
Stratigraphy

Cambrian through middle Upper Cretaceous rocks and extensive Quaternary alluvial and colluvial deposits are present in the Teton Pass area. Figure 2 is the standard stratigraphic section for the Wyoming foreland fold and thrust belt. For a complete stratigraphic description see Wanless and others (1955). Olson (1977) summarized the Triassic through Cambrian. The Mississippian was described by Sando (1977), and the Cenozoic by Warner (1977).

The two major thrust faults in the study area, the Jackson and the Cache Creek, share a common footwall of upper Lower Cretaceous rocks (Fig. 3) (Zeller, 1982). Tectonic transport on the Late Paleocene Jackson fault was from the southwest, whereas transport was from the northeast on the Early Eocene Cache Creek fault (Dorr and others, 1977). Opposing tectonic transport resulted in facies juxtaposition and rapid thickness changes in the present hanging wall sections of the two thrust faults. This will be further discussed in a subsequent section.

Depositional Setting

The study area occupied a transitional position between the Paleozoic and Early Mesozoic miogeocline to the west and the Wyoming shelf to the east (Fig. 4) which influenced placement of the later Sevier and Laramide structures. East of the Wasatch Range and west of the Prospect fault, the crystalline basement passively slopes 2° - 5° west and was not involved in Sevier-style deformation (foreland fold and thrust). East of the Prospect fault the basement rock was involved in Laramide style deformation (foreland) due to the eastward thinning of the



*Skyline Trail Conglomerate, member of the Hoback Formation, which is restricted to the Hoback-northern Green River Basin is time-equivalent to the Upper Evanston Formation (Dorr and others, 1977).

**Pass Peak Formation which is restricted to the Hoback-northern Green River Basin is time-equivalent to the Middle Wasatch Formation (Dorr and others, 1977).

Figure 2. Standard stratigraphic section of the western Wyoming thrust belt (From Ver Ploeg, 1982).

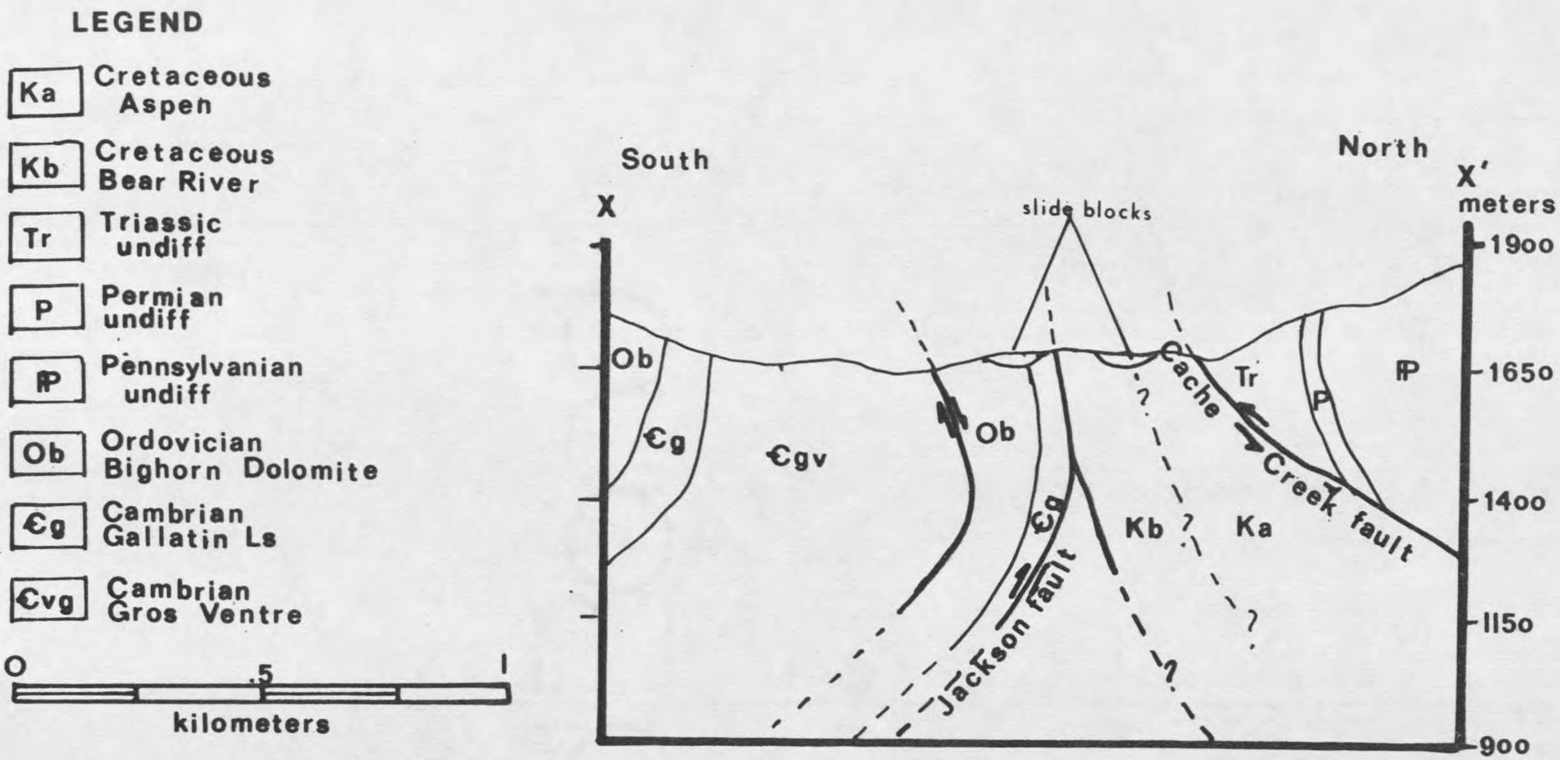


Figure 3. Simplified and reduced cross-section through study area approximately 3.6 km west of Teton Pass, Wyoming. See map in pocket for the location of X-X'. Note that the Jackson fault and Cache Creek fault share a common footwall (modified from Zeller, 1982).

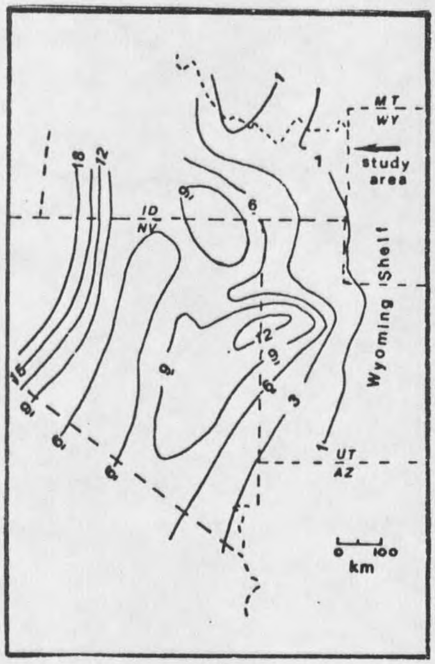


Figure 4. Composite total Paleozoic palinspastic isopach map. Thicknesses in thousands of meters (Modified from Peterson, 1977).

sedimentary veneer and increasing crustal thickness. The present-day foreland fold and thrust belt is roughly coincident with the eastern hinge line of the Paleozoic and Early Mesozoic miogeocline, the depocenter of which was in south-central and southeastern Idaho (Monley, 1971). The total thickness of rocks deposited in the miogeocline has been estimated to be between 15,000 - 30,000 m (Armstrong and Oriel, 1965), whereas time-equivalent shelf rocks deposited to the east in Wyoming are estimated to be 4,800 m thick.

Tectonic Juxtaposition

Monley (1971) illustrated the change from a thick Paleozoic and Mesozoic sedimentary section in the miogeocline to a relatively thin sedimentary section on the western Wyoming shelf by: (1) construction of pre-thrusting isopach maps for the Cambrian through Upper Cretaceous rocks, and (2) comparison of the sedimentary thicknesses of correlative units from west-to-east across the hingeline. Monley's technique of comparing rock thicknesses across the hingeline was used on a smaller scale in this study to compare rock units in the Jackson and Cache Creek thrust sheets.

Comparison of corresponding stratigraphic units in both thrust sheets revealed that similar units are thicker on the Jackson sheet than on the Cache Creek sheet (Fig. 5). For example, the Triassic Woodside Formation is 233 m thick in the hanging wall of the Jackson compared to 116 m in the hanging wall of the Cache Creek. The Pennsylvania Wells Formation, which is 284 m thick in the Jackson hanging wall, is a fine-grained sandstone with intercalated oolitic limestone with chert nodules and stringers (Pattison, 1977). The Wells Formation is structurally juxtaposed against the more clastic and thinner Tensleep Sandstone and Amsden Formation in the Cache Creek hanging wall block. Therefore, rapid thickness changes and sedimentary facies changes over this short distance are a consequence of tectonic juxtaposition by the Jackson and Cache Creek thrust faults.

Regional Tectonic Setting

The Idaho-Wyoming foreland fold and thrust belt is part of a much larger tectonic province, the Cordilleran foreland fold and thrust belt which extends from northern Alaska to southern Mexico (King, 1969), and is divided into nine segments or "salients" (Fig. 6). The study area is located in the Idaho-Wyoming-northern Utah salient which is a 333 km