



Quaternary tectonic activity within the northern arm of the Yellowstone tectonic parabola and associated seismic hazards, southwest Montana
by Chester Allan Ruleman, III

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University
© Copyright by Chester Allan Ruleman, III (2002)

Abstract:

The area of southwest Montana encompassing the Madison, Absaroka-Beartooth, and Bridger Ranges lies within the northern arm of the Yellowstone tectonic parabola (YTP). Detailed mapping along the Madison Range fault (MRF) and morpho-metric analyses were compared to the morphometry of two other faults in southwest Montana (Emmigrant/Deep Creek/Luccock Park fault - EDLF, and Bridger Range fault - BRF) in order to determine long-term tectonic activity rates and their correlation to the YTP. Morpho-metric analyses, including Ms, Vf mountain-front morphology, and the RTAC, quantify long-term tectonic activity rates of > 0.1 mm/yr for all three faults. However, the basal facet reconnaissance technique yields late Pleistocene slip rates for the BRF of 0.01 mm/yr. The basal facet analyses provide a more accurate late Pleistocene slip rate for the BRF. This possibly suggests that the BRF experienced pre-late Pleistocene slip rates an order of magnitude greater (> 0.1 mm/yr) than the late Pleistocene (< 0.01 mm/yr), which is not modeled by the YTP. Mid- to late-Pleistocene tectonic activity between these three faults has been greater southward towards the Yellowstone volcanic field. In addition to late Pleistocene heterogeneous spatial and temporal earthquake activity, pre-existing structural controls on Quaternary normal faulting suggest that a simplistic parabolic deformational model does not adequately explain the neotectonics between the faults under investigation and southwest Montana.

Along with the neotectonic implications, the calibration and application of morpho-metric analyses to the northern Basin and Range province, coupled with surficial geology and contemporary seismicity, derive a seismic hazard assessment for the MRF, EDLF, and BRF. The MRF and EDLF have late-Pleistocene to Holocene slip rates ranging from 0.1-0.5 mm/yr. Based on basal facet analyses, the BRF has late-Pleistocene to Holocene slip rates of 0.01 mm/yr, but morpho-metric analyses (i.e., RTAC) quantify long-term average Quaternary slip rates of > 0.1 mm/yr. All three faults possibly have long-term tectonic activity rates > 0.1 mm/yr, with bifurcations in slip rates over periods > 100 ky. Maximum earthquakes for the three faults range from Mw 6.5-7.2, in accordance with historic seismicity of the Basin and Range province.

QUATERNARY TECTONIC ACTIVITY WITHIN THE NORTHERN ARM
OF THE YELLOWSTONE TECTONIC PARABOLA AND ASSOCIATED
SEISMIC HAZARDS, SOUTHWEST MONTANA

by

Chester Allan Ruleman III

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

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY
Bozeman, MT

April, 2002

© COPYRIGHT

by

Chester Allan Ruleman III

2002

All Rights Reserved

N378
R8612

APPROVAL

of a thesis submitted by

Chester Allan Ruleman III

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.

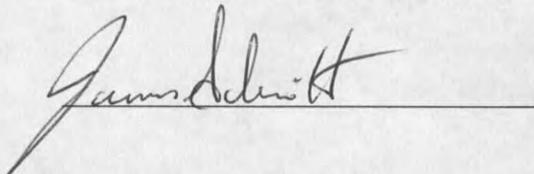
Dr. David R. Lageson



4-15-02
Date

Approved for the Department of Earth Sciences

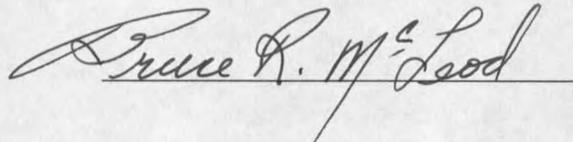
Dr. James G. Schmitt



4-15-02
Date

Approved for the College of Graduate Studies

Dr. Bruce McLeod



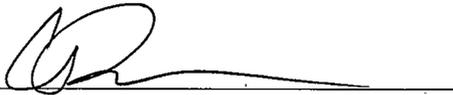
4-16-02
Date

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 the rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature

A handwritten signature in black ink, appearing to be a stylized 'R' or similar character, written over a horizontal line.

Date

4/11/02

ACKNOWLEDGEMENTS

This study has been partially funded by the following organizations: American Association of Engineering Geologists, Colorado Scientific Society, Tobacco Root Geological Society, Billings Geophysical Society, Wyoming Geological Association, American Alpine Club, and Geological Society of America. I am gratefully appreciative of Dr. David Lageson and his trust and faith that I could complete this project in a thorough manner, as well as the high expectations set forth in front of me by Dr. Lageson. I also thank Dr. Kenneth Pierce (United States Geological Survey) for the time, patience, and helpful insight that he gave throughout this study. I appreciated the timely mental support given by Dr. Jim Scmitt. Dr. Craig dePolo (Nevada Bureau of Mines and Geology) was very helpful with insight towards the methods used herein and provided wonderful encouragement throughout the last few years. I thank Michael Stickney (Montana Bureau of Mines and Geology) for assistance with the manuscript and insight toward regional neotectonics. Overall, I am very thankful for the opportunity to work with a wide array of professionals offering differing perspectives on neotectonics and broadening my vision for future investigations.

Most importantly, I would like to thank my wife, Amanda, and family for the mental and physical support throughout our lives together. Without my second-half being completely supportive of my work, I would not have made this achievement. I also thank my family (Mom, Dad, and Elise) for listening to my ideas with respect, patience, and interest throughout the last couple of years.

TABLE OF CONTENTS

1. INTRODUCTION.....	1
2. DISCIPLINARY CONTEXT	6
3. PREVIOUS WORK	11
Regional	11
Madison Range Fault.....	13
Emmigrant/Deep Creek/Luccock Park Fault	14
Bridger Range Fault.....	15
Seismicity.....	15
4. REGIONAL TECTONIC ACTIVITY RECONNAISSANCE TECHNIQUE UTILIZING BASAL FACET HEIGHTS AND CALIBRATION TO THE NORTHEASTERN BASIN AND RANGE PROVINCE.....	17
5. TECTONIC ACTIVITY RATES AND SLIP RATES: HOW THEY RELATE.....	25
6. METHODS	29
Slip/Tectonic Activity Rate.....	29
Fault Scarp Analyses	33
Basal Facet Height Reconnaissance Analyses	34
Field Mapping	35
7. MADISON FAULT ZONE	37
Structural Setting	38
Quaternary Deposits and Depositional History.....	54
Morpho-Metric Analyses	57
Fault Scarp Profiles and Offset Deposits	57
Relative Tectonic Activity Class Designation Chart	66
Basal Facet Reconnaissance Technique.....	69
8. EMMIGRANT/DEEP CREEK/LUCCOCK PARK FAULT	72
Structural Setting	73
Quaternary Deposits and Depositional History.....	75
Morpho-Metric Analyses	77
Fault Scarps and Offset Deposits.....	77

TABLE OF CONTENTS - CONTINUED

Relative Tectonic Activity Class Designation Chart	79
Basal Facet Reconnaissance Technique	81
9. BRIDGER RANGE FAULT	82
Structural Setting	82
Quaternary Deposits and Depositional History	86
Morpho-Metric Analyses	88
10. SEISMIC HAZARD ANALYSES	91
Madison Range Fault	92
Seismicity	92
Segmentation and Maximum Earthquakes	94
Slip Rate and Recurrence Intervals	98
Emmigrant/Deep Creek/Luccock Park Fault	100
Seismicity	100
Segmentation and Maximum Earthquakes	102
Tectonic Activity Rates and Inferred Slip Rates	103
Recurrence Intervals	103
Bridger Range Fault	104
Seismicity	104
Segmentation and Maximum Earthquakes	105
Tectonic Activity and Inferred Slip Rates	106
Recurrence Intervals	107
11. DISCUSSION	108
Methodology	108
Regional Neotectonics	110
12. CONCLUSIONS	113
REFERENCES CITED	116
APPENDICES	132
APPENDIX A: MADISON RANGE FAULT SCARP PROFILE DATA	133

TABLE OF CONTENTS - CONTINUED

APPENDIX B: VF RATIO DATA 142

APPENDIX C: BASAL FACET HEIGHTS 146

APPENDIX D: STAR VALLEY, WY DATA..... 149

APPENDIX E: MADISON RANGE MAP UNIT DESCRIPTIONS..... 152

LIST OF TABLES

Table	page
1. Relative Tectonic Activity Class Designation Chart	8
2. Comparison of slip rates determined through several analyses for the Star and Swan Valley faults, southeast Idaho and western Wyoming	24
3. Madison Range (MF) moment magnitude (M_w) parameters and maximum earthquake.....	97
4. Emmigrant/Deep Creek/Luccock Park fault (EDL) moment magnitude (M_w) parameters and maximum earthquake.....	103
5. Bridger Range fault (BRF) moment Magnitude (M_w) parameters and maximum earthquake.....	105

}

LIST OF FIGURES

Figure	page
1. Western North America and location of study area.....	2
2. Physiography of the Yellowstone tectonic parabola (YTP).....	3
3. Precipitation versus mean annual sediment yield.....	21
4. Maximum basal facet for the Star Valley segment of the Grand-Swan-Star Valley fault system, southeast Idaho and western Wyoming.....	23
5. Valley-Floor Width to Valley Height Ratio (Vf) measurements and calculations.....	30
6. Mountain-Front Sinuosity (Smf) measurements and calculations.....	32
7. Relationships between tectonic activity and alluvial fan deposition.....	33
8. Madison Range structural setting.....	39
9. Madison Range fault (MRF) physiography.....	42
10. Simplified cross section line A-A', southern Madison Range fault.....	44
11. Simplified cross section B-B', Taylor-Hilgard section of the Madison Range fault.....	45
12. Seismicity of the Hebgen Lake/southern Madison Range region, 1982-2000.....	47
13. Simplified cross section C-C', Indian Creek segment of the Madison Range fault.....	48
14. Structural relationships between the Hilgard thrust system and the Madison Range fault.....	49
15. Thrusts and overturned syncline with normal faults at Shell Creek.....	51
16. Madison Range cross section line D-D'.....	52
17. Scarp height vs maximum slope angle plot for fault scarp profiles along the Madison Range fault.....	58
18. Taylor-Hilgard and Madison Canyon/Missouri Flats sections fault scarps.....	60

LIST OF FIGURES - CONTINUED

19. Cameron and Taylor-Hilgard section fault scarps	62
20. Fault scarps along the northern MRF.....	64
21. V_f values for the Madison Range fault.....	67
22. Basal facet heights for the Madison Range fault (MRF)	70
23. Paradise Valley structural framework.....	74
24. V_f values for the Emmigrant/Deep Creek/Luccock Park fault.....	79
25. Basal facet heights for the Emmigrant/Deep Creek/Luccock Park fault (EDLF)	81
26. Bridger Range/Gallatin Valley structural framework.....	83
27. Cross section of the southern Bridger Range showing relationships between Laramide compressional structures and Neogene normal faults	85
28. V_f ratio values for the Bridger Range fault.....	88
29. Madison Range fault late Pleistocene to mid Holocene (< 130 ka) surface ruptures and sections.....	95

PLATES

Plate

1. Geology of the Taylor-Hilgard and Madison Canyon/Missouri Flats segments of the Madison Range fault.
2. Geology of the Indian Creek and southern Cameron segments of the Madison Range fault.
3. Geology of the northern Cameron and Spanish Peaks segments of the Madison Range fault.

ABSTRACT

The area of southwest Montana encompassing the Madison, Absaroka-Beartooth, and Bridger Ranges lies within the northern arm of the Yellowstone tectonic parabola (YTP). Detailed mapping along the Madison Range fault (MRF) and morpho-metric analyses were compared to the morphometry of two other faults in southwest Montana (Emmigrant/Deep Creek/Luccock Park fault - EDLF, and Bridger Range fault - BRF) in order to determine long-term tectonic activity rates and their correlation to the YTP. Morpho-metric analyses, including M_s , V_f , mountain-front morphology, and the RTAC, quantify long-term tectonic activity rates of > 0.1 mm/yr for all three faults. However, the basal facet reconnaissance technique yields late Pleistocene slip rates for the BRF of 0.01 mm/yr. The basal facet analyses provide a more accurate late Pleistocene slip rate for the BRF. This possibly suggests that the BRF experienced pre-late Pleistocene slip rates an order of magnitude greater (> 0.1 mm/yr) than the late Pleistocene (< 0.01 mm/yr), which is not modeled by the YTP. Mid- to late-Pleistocene tectonic activity between these three faults has been greater southward towards the Yellowstone volcanic field. In addition to late Pleistocene heterogeneous spatial and temporal earthquake activity, pre-existing structural controls on Quaternary normal faulting suggest that a simplistic parabolic deformational model does not adequately explain the neotectonics between the faults under investigation and southwest Montana.

Along with the neotectonic implications, the calibration and application of morpho-metric analyses to the northern Basin and Range province, coupled with surficial geology and contemporary seismicity, derive a seismic hazard assessment for the MRF, EDLF, and BRF. The MRF and EDLF have late-Pleistocene to Holocene slip rates ranging from 0.1-0.5 mm/yr. Based on basal facet analyses, the BRF has late-Pleistocene to Holocene slip rates of 0.01 mm/yr, but morpho-metric analyses (i.e., RTAC) quantify long-term average Quaternary slip rates of > 0.1 mm/yr. All three faults possibly have long-term tectonic activity rates > 0.1 mm/yr, with bifurcations in slip rates over periods > 100 ky. Maximum earthquakes for the three faults range from M_w 6.5-7.2, in accordance with historic seismicity of the Basin and Range province.

CHAPTER 1

INTRODUCTION

The study of neotectonics and paleoseismology in the northern Basin and Range province (Figure 1) has attracted the attention of researchers in the past due to the large-magnitude seismic history of the region (e.g., 1959 Hebgen Lake, MT, $M_s 7.5$, and 1983 Borah Peak, ID, $M_s 7.3$). Several models have been developed to explain deformational patterns and causative stress fields associated with the interaction of Basin and Range extension and the Yellowstone volcanic field (e.g., Anders et al., 1989; Pierce and Morgan, 1992; Smith and Braile, 1993). Fairly extensive paleoseismologic studies have determined slip rates along multiple faults proximal to the southern boundary of the Snake River Plain (SRP) (Piety et al., 1986; McCalpin, 1993; McCalpin and Warren, 1993), all of which show that westward from the Yellowstone volcanic field, greatest tectonic activity is located increasingly farther southward from the Snake River Plain (SRP). This southward displacement of tectonic activity is modeled to be reflected as a mirror image across the SRP to form the north arm of the Yellowstone tectonic parabola (YTP) (Figure 2) (Anders et al., 1989; Pierce and Morgan, 1992).

Extensive paleoseismologic studies in southwest Montana have involved the Hebgen fault system (Haller et al., 2000; Pierce et al., 2000; Schwartz et al., 2000; Van der Woerd et al., 2000) and the Red Rock and Blacktail faults (Stickney et al., 1987); however, other neotectonic studies have predominantly involved the mapping of fault

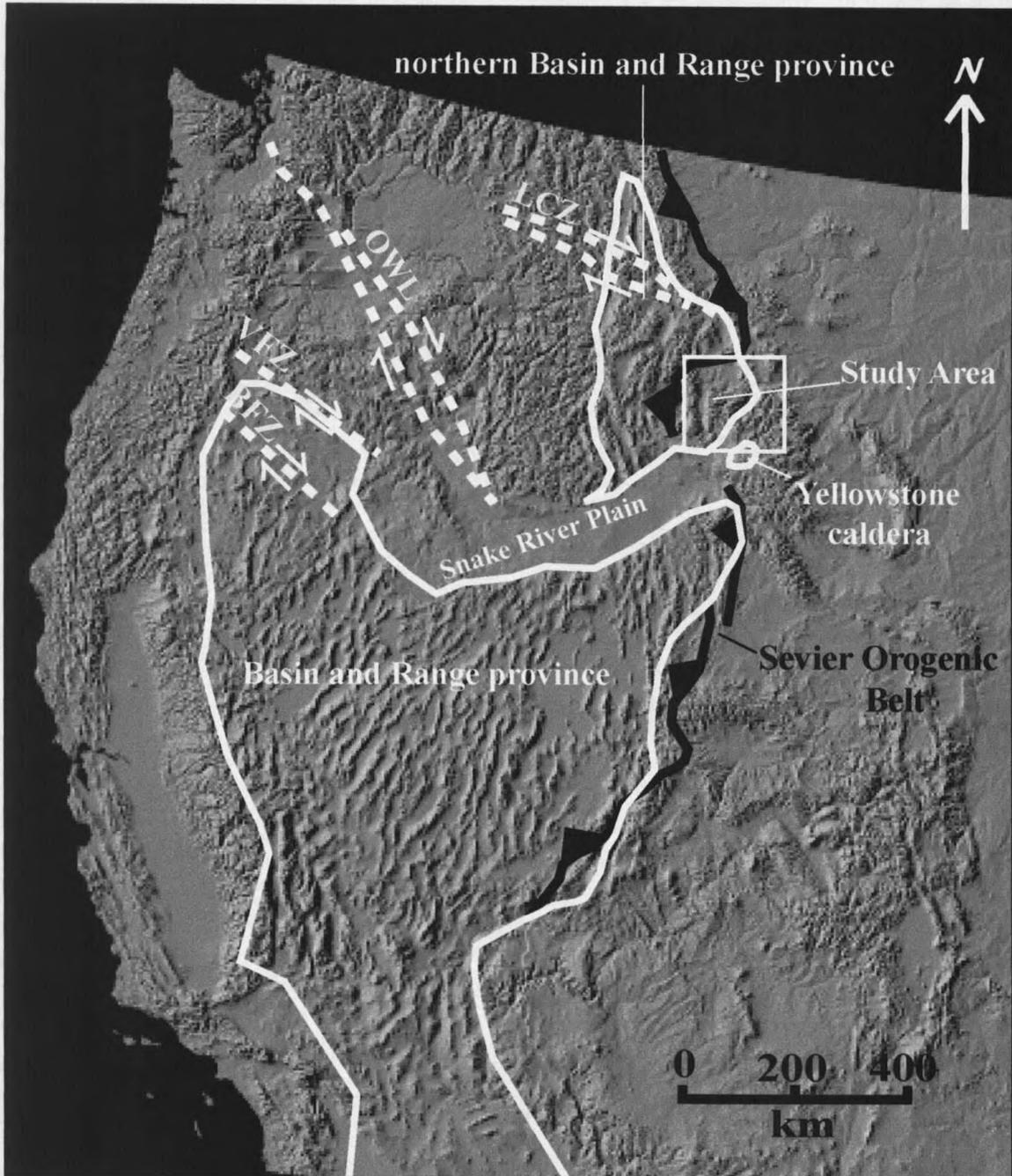


Figure 1. Western North America and location of study area. Regional zones of lateral shear in relation to the Basin and Range province include BFZ - Brothers fault zone, VFZ - Vale fault zone, OWL - Olympic-Wallowa lineament (Mann and Meyer, 1993), LCZ - Lewis and Clark zone (Hamilton and Meyers, 1966). Basin and Range province boundaries modified from dePolo (1994) and Lageson and Stickney (2001). Sevier Orogenic Belt boundary from Snoke (1993).

