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

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.

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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.

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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.

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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_S7.5, and 1983 Borah Peak, ID, M_S7.3). 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

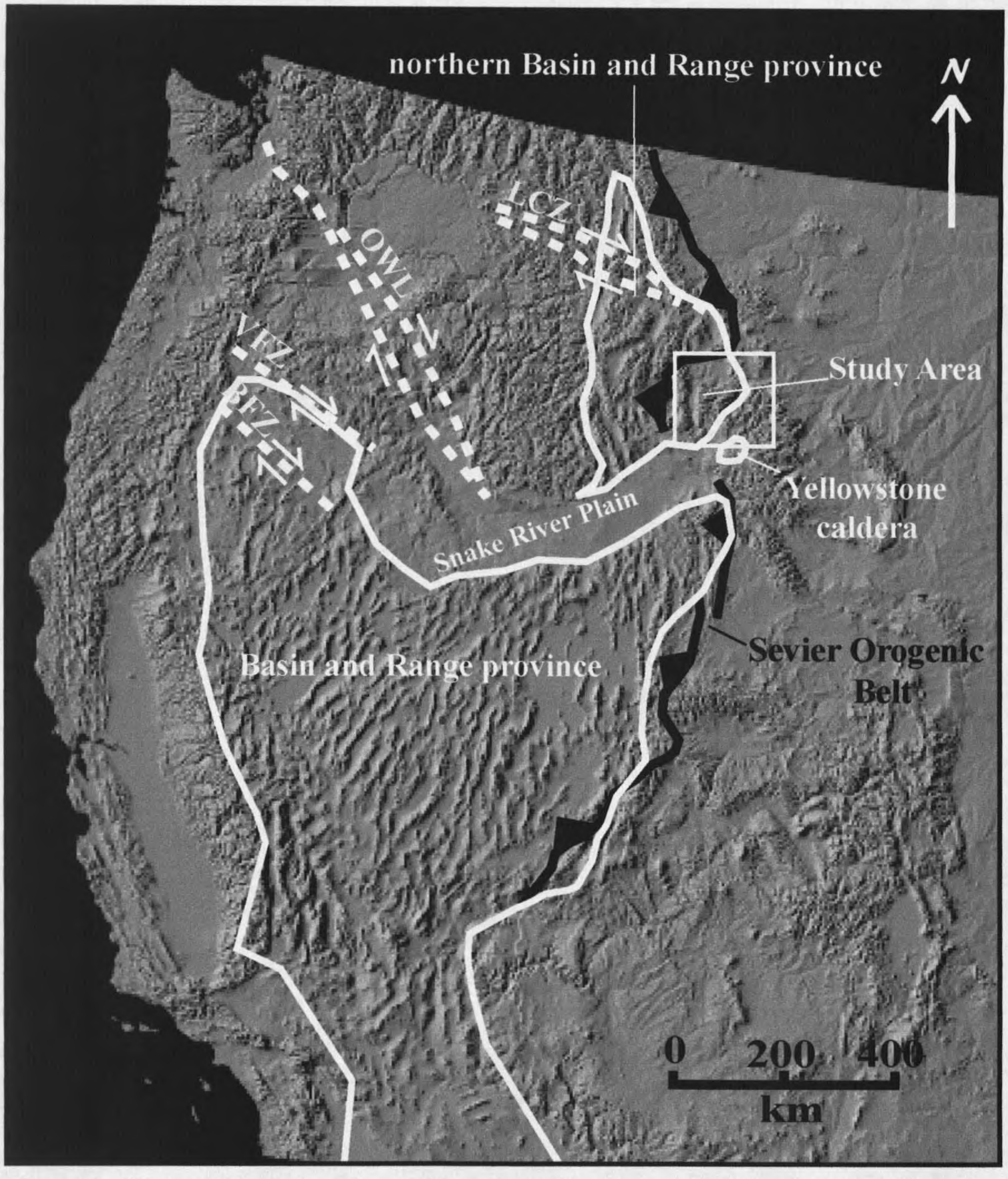

Figure 1. Western North America and location of study area. Regional zones of lateral shear in relation to the Basin and Range province include BFZ - Brothers fault zone, VFZ - Vale fault zone, OWL - Olympic-Wallowa lineament (Mann and Meyer, 1993), LCZ - Lewis and Clark zone (Hamilton and Meyers, 1966).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