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Seismicity and earthquake hazard analysis of the Teton–Yellowstone region, Wyoming

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ABSTRACT

Earthquakes of the Teton–Yellowstone region represent a high level of seismicity in the Intermountain west (U.S.A.) that is associated with intraplate extension associated with the Yellowstone hotspot including the nearby Teton and Hebgen Lake faults. The seismicity and the occurrence of high slip-rate late Quaternary faults in this region leads to a high level of seismic hazard that was evaluated using new earthquake catalogues determined from three-dimensional (3-D) seismic velocity models, followed by the estimation of the probabilistic seismic hazard incorporating fault slip and background earthquake occurrence rates. The 3-D *P*-wave velocity structure of the Teton region was determined using local earthquake data from the Jackson Lake seismic network that operated from 1986–2002. An earthquake catalog was then developed for 1986–2002 for the Teton region using relocated hypocenters. The resulting data revealed a seismically quiescent Teton fault, at M_L, local magnitude > 3, with diffuse seismicity in the southern Jackson Hole Valley area but notable seismicity eastward into the Gros Ventre Range. Relocated Yellowstone earthquakes determined by the same methods highlight a dominant E–W zone of seismicity that extends from the aftershock area of the 1959 (M_S surface wave magnitude) 7.5 Hebgen Lake, Montana, earthquake along the north side of the 0.64 Ma Yellowstone caldera. Earthquakes are less frequent and shallow beneath the Yellowstone caldera and notably occur along northward trending zones of activity sub-parallel to the post-caldera volcanic vents. Stress-field orientations derived from inversion of focal mechanism data reveal dominant E–W extension across the Teton fault with a NE–SW extension along the northern Teton fault area and southern Yellowstone. The minimum stress axes directions then rotate to E–W extension across the Yellowstone caldera to N–S extension northwest of the caldera and along the Hebgen Lake fault zone. The combination of accurate hypocenters, unified magnitudes, and seismotectonic analysis helped refine the characterization of the background seismicity that was used as input into a probabilistic seismic hazards analysis. Our results reveals the highest seismic hazard is associated with the Teton fault because of its high slip-rate of approximately 1.3 mm/yr compared to the highest rate of 1.4 mm/yr in southern Yellowstone on the Mt. Sheridan fault. This study demonstrates that the Teton–Yellowstone area is among the regions highest seismic hazard in the western U.S.

1. Introduction

The earthquake hazard in the Teton–Yellowstone region is the highest in the U.S. Intermountain region (Petersen et al., 2008). It is not only influenced by lithospheric extension associated with Basin-Range tectonism that extends 700 km west to the Sierra Nevada Mountains, California, but it has the superposition of the effects of Yellowstone volcanic sources that can perturb stresses up to 50 km from the Yellowstone hotspot track, i.e., the effects of the Yellowstone hotspot has a profound effect on seismicity not only on Yellowstone but on the surrounding fault zones of the Intermountain region. These combined fault zones are part of the parabolic-shaped zone of pronounced earthquake activity surrounding the Yellowstone–Snake River Plain volcanic field, encompassing the Teton Range and converges at the Yellowstone Plateau (Smith et al., 1985; Anders and Sleep, 1985; also see the companion paper by Smith et al., 2009-this volume).

To evaluate the earthquake potential and seismic hazard of the Teton–Yellowstone region U.S. (Fig. 1), high-precision earthquake data are needed to understand the seismicity patterns in the area. For the Yellowstone National Park area this type of high-quality data were developed by Husen and Smith (2004) from the Yellowstone seismic network. However similar data have not been available for the Teton area.

In this paper we use earthquake data from the U.S. Bureau of Reclamation's (USBR) Jackson Lake Seismic Network (JLSN) to establish

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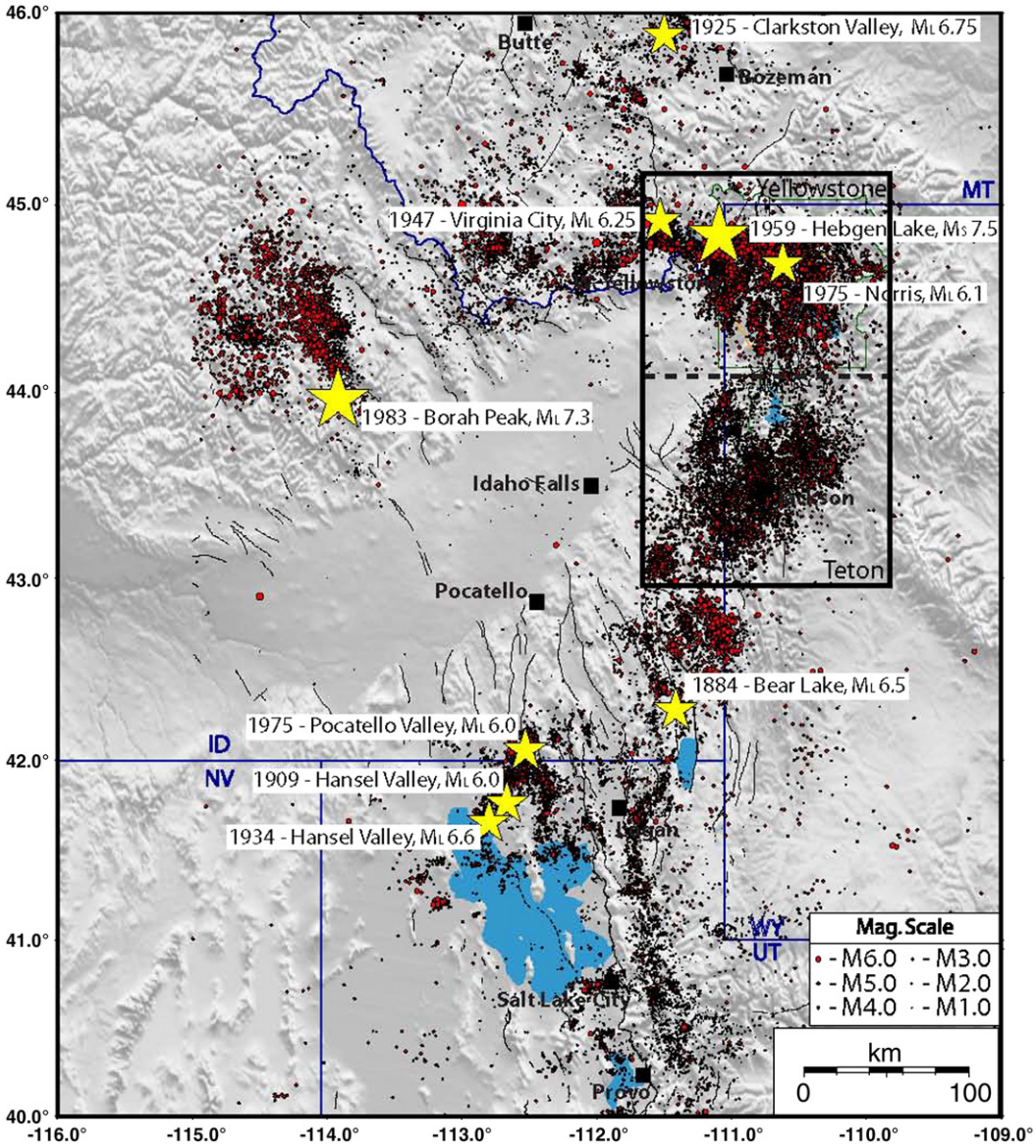

Fig. 1. Epicenter map of the central Intermountain region, Wyoming, Idaho, Montana and Utah showing the Teton and Yellowstone regions are marked by the black box. Earthquake epicenters from ~1850–2005 are shown as red dots and state boundaries are shown by blue lines. Large historic earthquakes and magnitudes are labeled. The earthquake data are from the compilation of historic seismicity of the central Intermountain west by Wong et al. (2000) and updated for earthquake catalog data of the Montana Bureau of Mines and Geology, the Yellowstone seismic network (University of Utah Seismograph Stations, UUSS), the Idaho National Laboratory, the Jackson Lake seismic network, U.S. National Seismic Network and the Utah seismic network (UUSS).

a high-quality earthquake data set for the Teton region, including high-precision hypocenter locations and focal mechanisms. In a second step, this data set was merged with earthquake data of similar quality of the Yellowstone region. The combined data set was then used to derive a preliminary probabilistic seismic hazard assessment for the Teton–Yellowstone region. Our approach includes the relocation of the earthquakes of the Teton region using a probabilistic nonlinear relocation method by incorporating a tomographically determined 3-D *P*-wave velocity (V_P) model that has been derived as part of this study and the computation of focal mechanisms and the stress field for the Teton region. The combination of the earthquake data for the Teton and Yellowstone regions aids in an improved understanding of the seismotectonics of the region, volcanic seismicity and provides a basis for a more accurate seismic hazard evaluation of the region. Our study thus builds upon a preliminary earthquake hazard assessment of the Jackson Lake, Wyoming, dam site by Gilbert et al. (1983) and volcano hazard analysis of Yellowstone (Christiansen et al., 2007).

2. Tectonic setting of the Teton–Yellowstone region

Earthquakes of the Teton–Yellowstone region represent a high level of seismicity of the Intermountain West that is associated with intraplate extension of the Yellowstone hotspot and the surrounding region including the Teton and Hebgen Lake faults. The greater study region is comprised of the Teton Mountain Range, the valley of Jackson Hole, and southern Yellowstone (Fig. 1). This region forms an important part of the Intermountain Seismic Belt (ISB), extending southward 130 km from the Yellowstone volcanic system to the northern Star Valley area of Wyoming and Idaho. For a review on the tectonic–volcanic setting of the Yellowstone region, see the companion paper of Smith et al. (2009) in this issue.

The Teton fault is a youthful normal-fault that bounds the Teton Range in northwestern Wyoming, south of the Yellowstone Plateau volcanic field, and is probably the dominant source of large earthquakes in the Teton area. It is a key feature of the central part of the ISB