Journal of Asian Earth Sciences 107 (2015) 232–243

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Earthquake potential of the Sichuan-Yunnan region, western China

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ARTICLE INFO

Article history:
Received 16 October 2014
Received in revised form 10 April 2015
Accepted 21 April 2015
Available online 9 May 2015

Keywords:
Seismic hazard
Sichuan-Yunnan region
Seismic moment accumulation
Strain rate
Earthquake catalog

ABSTRACT

We estimate the seismic hazard potential in the Sichuan-Yunnan region, western China using three different approaches. Our first approach, based on the assumption that the earthquake probability is proportional to the past seismicity rate, uses a regional earthquake catalog to constrain the probability model. A retrospective test shows that the 'forecasts' have some predictive power for strong events occurred on fault segments with shorter earthquake recurrence time, but not for that with longer recurrence time such as the Longmenshan fault. Our second approach, based on the assumption that the earthquake probability is proportional to crustal strain rate, uses secular geodetic strain rate deduced from GPS velocity data to constrain the probability model. A retrospective test of the model with earthquake occurrence of the past 30 years shows that the model 'forecasted' poorly. However, the model seems to 'forecast' spatial intensity of earthquakes for the past 500 years reasonably well, suggesting that the geodetic strain rate obtained at the decadal scale may still be a good indicator of long term earthquake activity in the region, but only at a time scale of hundreds of years. Our third approach uses GPS velocity data to determine the seismic moment accumulation rates on major faults, and a historical earthquake catalog to estimate seismic moments released in the past. Comparison of the two yields estimates of present day seismic moments cumulated on major faults, and a retrospective test shows some predictive power of the method. Our result suggests that numerous faults in the Sichuan-Yunnan region have cumulated seismic moments capable of producing $M > 7.5$ earthquakes, including the Xiaojiang, Jiali, Northern Nujiang, Nandinghe, and Red River–Puer faults, and the junction fault between the Xianshuihe and Ganzi-Yushu faults.

1. Introduction

The Sichuan-Yunnan region (97–108°E, 21–33°N) is located at the southeast margin of the Tibetan plateau (Fig. 1). Being manifested by the NNE indentation of the India plate into Asia and eastward extrusion of the Tibetan plateau, this region is tectonically active, and deforming in the form of faulting between blocks of various sizes and grand clockwise rotation around the eastern Himalaya syntax (Tapponnier and Molnar, 1977). The region is sliced by several groups of faults, among which the most prominent one is the sinistral Xianshuihe–Anninghe–Zemuhe–Xiaojiang fault system, delineating the north and east boundaries of a regional clockwise rotation around the eastern Himalaya syntax. The east–west shortening along the eastern margin of the plateau is partitioned into thrust motion along the Longmenshan fault separating Sichuan basin from the Songpan–Ganzi plateau, and dextral motion along the Longriba fault located ~150 km northwest of the Longmenshan fault (Chen et al., 2000; Shen et al., 2005). The Nanhua–Chuxiong–Jianshui, Red River, Wuliangshan, and Longling-Lancang faults are located at the southern end of the clockwise rotation, striking southeast and slipping right-laterally. Other faults in the region include the sinistral Xiaojinhe, Longling-Ruili, Dayingjiang, and Daluo-Jinghong faults striking northeast.

Accompanied with active tectonic deformation, many strong earthquakes struck the region in the past. According to the Chinese earthquake catalog composed by the Chinese Seismic Network Data Management Center (http://www.csndmc.ac.cn/newweb/index.jsp), more than 110 $M \geqslant 6.0$ events occurred in the region 1970–2013 (Fig. 1), including the 2008 Mw 7.9 Wenchuan earthquake on the Longmen Shan fault. Some of the strong earthquakes resulted in great damages and losses of human

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http://dx.doi.org/10.1016/j.jseaes.2015.04.041
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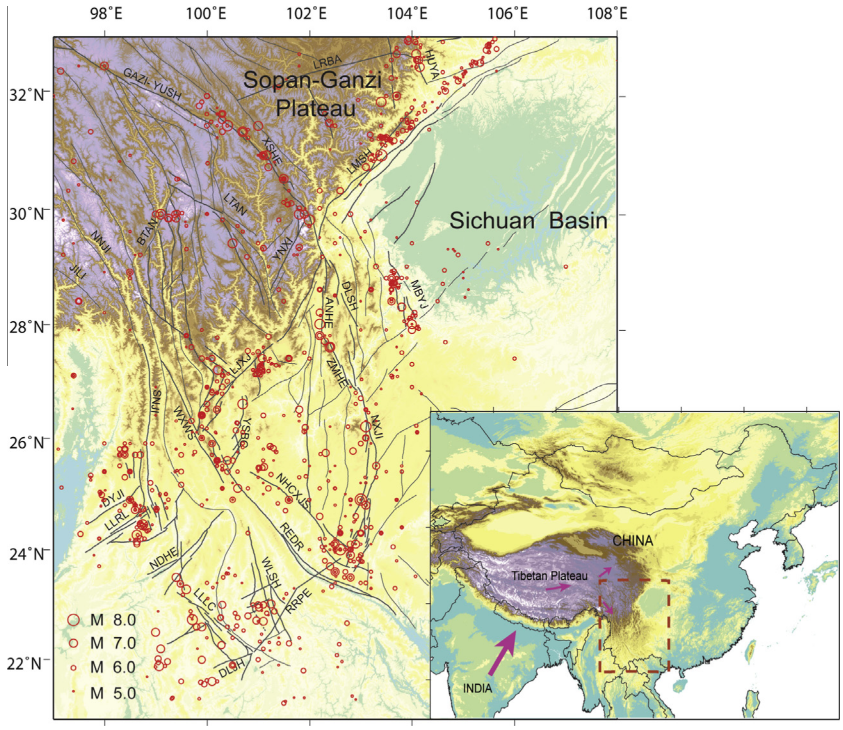

Fig. 1. Tectonic map of Sichuan-Yunnan region and $M \geqslant 5.0$ earthquakes of 1500–2013. Inset map shows geographic location of the studied region, and the arrows point to block motion directions relative to stable Eurasia plate. Earthquake data (red circles) are provided by Jie Liu of Chinese Earthquake Network Center. Abbreviations of the fault names: ANHE, Anninghe fault; BTAN, Batang fault; CLMS, Central segment of Longmenshan fault; DLJH, Daluo-Jinghong fault; DLSH, Daliangshan fault; DQZD, Deqin–Zhongdian fault; DYJI, Dayingjiang fault; ELMS, Eastern segment of Longmenshan fault; GAZI, Ganzi fault; YUSH, Yushu fault; REDR, Red River fault; HUYA, Huya fault; JILI, Jiali fault; LJXJ, Lijiang–Xiaojinhe fault; LLLC, Longling–Lancang fault; LLRL, Longling–Ruili fault; LRBA, Longriba fault; LTAN, Litang fault; MBYJ, Mabian–Yanjin fault; NHCXJS, Nanhua–Chuxiong–Jianshui fault; NNJI, Northern segment of Nujiang fault; NDHE Nandinghe fault; SNJI, Southern segment of Nujiang fault; WLSH, Wuliangshan fault; WXWS, Weixi–Weishan fault; NXJI, Northern segment of Xiaojiang fault; RRPE, Red River–Puer fault; XSHE, Xianshuihe fault; YNXI, Yunongxi fault; YSBC, Yongsheng–Binchuan fault; ZMHE, Zemuhe fault.

lives, e.g. the 1970 Mw 7.7 Tonghai earthquake caused 15621 fatalities (Han et al., 1996) and the 2008 Mw 7.9 Wenchuan earthquake resulted in more than 80,000 fatalities (http://www.gov.cn/xxgk/pub/govpublic/mrlm/200805/t20080530_32846.html), respectively. Assessment of seismic hazard potential in the region, therefore, is vitally important.

Several previous studies attempted estimation of intermediate to long term seismic potentials in the Sichuan-Yunnan region (Wen, 2001; Yi et al., 2002, 2004, 2006, 2008; Jiang and Wu, 2008; Jiang and Zhang, 2010). Using a simple point process statistics to characterize earthquake recurrence behavior, Yi et al. (2002) and Xu et al. (2005) showed that strong earthquakes in the region were clustered in time, and their recurrence times displayed no obvious periodicity. These strong events also demonstrated no characteristics of "magnitude predictable" or "time predictable" on fault segments in the region. It is, therefore, difficult to assess intermediate and long term seismic potentials based merely on observed time intervals or magnitudes of strong earthquakes on faults.

Since early 1990s, numerous statistical theorems and methods have been used for earthquake forecast and testing, and earthquake statistics has become a dynamic inter-disciplinary field for earthquake research. Kagan and Jackson (1994) first proposed an long-term earthquake forecast method based on earthquake catalog data modeling, and applied the method to seismicities in Japan (Jackson and Kagan, 1999; Kagan and Jackson, 2000), China (Rong and Jackson, 2002), and the world (Kagan and Jackson, 2011). Statistical significance of the method has been verified in these studies. Rundle et al. (2000), on the other hand, using earthquake catalog data as model constraints, developed a pattern recognition algorithm to forecast earthquakes, and applied the algorithm in California earthquake forecast. Jiang and Wu (2008) applied Rundle et al.'s (2000) method to the Sichuan-Yunnan region, and found in a retrospective test that the method had certain predictive power for mid to long term earthquake behavior in the region. Shen et al. (2007) developed a model for intermediate to long term earthquake forecast using geodetically derived strain rates map, and confirmed in a retrospective test that spatial distribution of strong earthquakes in southern California 1950–2000 correlated highly with spatial strain rate concentration. Other earthquake forecast methods, based on certain mechanical assumptions, have also been developed, for example, Keilis-Borok and Rotwain (1990) developed the TIPS (Time of Increased Probability) algorithm for mid-term large earthquake forecast, Bowman et al. (1998) proposed a method for intermediate term earthquake forecast based on regional seismicity acceleration, and Toda et al. (1998) estimated intermediate earthquake potential change after large events through calculation of Coulomb stress change and background seismicity rate. Some of these methods (e.g. Rundle et al. (2000), Keilis-Borok and Rotwain (1990), Bowman et al. (1998), and Toda et al. (1998)) are based on quite different philosophic and mechanism considerations, use fundamentally different methodologies from ours, and work on regions not covering the Sichuan-Yunnan region; we shall not discuss them further in this study.

Seismic activity is a process of energy accumulation and release, and assessment of balance between interseismic moment accumulation and coseismic moment release can be used to estimate the potential of large earthquakes (e.g. Working Group on California Earthquake Probabilities, 1995; Stein and Hanks, 1998; Ward, 1998; Meade and Hager, 2005; Wang et al., 2010; Wang et al.,