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Characteristics of surface damage in China during the 25 April 2015 Nepal earthquake

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Abstract: The seismic effects in Nyalam, Gyirong, Tingri and Dinggye counties along the southern border of Tibet were investigated during 2-8 May, 2015, a week after the great Nepal earthquake along the Main Himalaya Thrust. The intensity was VIII in the region and reached IX at two towns on the Nepal border; resulting in the destruction of 2,700 buildings, seriously damaging over 40,000 others, while killing 27 people and injuring 856 in this sparsely populated region. The main geologic effects in this steep rugged region are collapses, landslides, rockfalls, and ground fissures; many of which are reactivations of older land slips. These did great damage to the buildings, roads and bridges in the region. Most of the effects are along four incised valleys which are controlled by N-S trending rifts and contain rivers that pass through the Himalaya Mountains and flow into Nepal; at least two of the larger aftershocks occurred along the normal faults. Areas weakened by the earthquake pose post-seismic hazards. Three valleys have the potential for dangerous post-seismic debris flows that could create dangerous dams especially during the monsoon season. Loosened rock and older slides also may fail. In addition, there is an increased seismic hazard along active N-S trending grabens in southern Tibet due to the shift in stress resulting from the thrust movement that caused the Nepal earthquake. NW trending right-lateral strike-slip faults also may be susceptible to movement. The results of the findings are incorporated in some principle recommendations for the repair and reconstruction after the earthquake.

Key Words: Nepal earthquake, Himalaya Mountains, Seismic hazard, Post-seismic hazards, southern Tibet

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1. Introduction

On 25 April 2015 at 14:11:26 MGT+8 (Beijing Time), a Ms 8.1 (Mw 7.8) great earthquake struck Nepal and adjacent regions. The epicenter was near Pokhara 77 km northwest of the capital of Kathmandu and the hypocenter was at a depth of 10-24 km. Many aftershocks occurred of magnitude 4.5 Mw or greater, of which a Ms 7.5 (Mw7.3) aftershock occurred after 17 days, on 12 May 2015 at 15:05: the epicenter was near the Chinese border 77 km east-northeast of Kathmandu and the hypocenter was at a depth of 12-16 km. According to incomplete statistics, this Nepal great earthquake killed more than 8,800 people and injured more than 23,000.

The earthquake occurred on the south slope of the Himalaya Mountains and formed a 120-140 km long, about 80 km wide rupture zone with a dip-slip of 3.5-5.5 m, which shows an expansion from west to east (U.S. Geological Survey National Earthquake Information Center, 2015a, b；IRIS, 2015). The aftershock distribution, the focal mechanism solution and the source rupture inversion suggest that the earthquake was a release of built-up strain along the Main Himalaya Thrust (MHT) fault zone; part of the ongoing process of the Indian Plate underthrusting the Eurasian Plate (Fig. 1). This was a strongest seismic event since the 2005 Pakistan Kashmir Ms 7.8 earthquake, which also occurred along the MHT. This activity may indicate that the seismic activity along the thrust is entering a new active phase.

The earthquake affected northern India, Pakistan, Bhutan, and the southern Tibetan region of China. In China the tremors were felt in Xigazê and Lhasa to the north but were strongest in the China-Nepal border area which is only about 40 km (Fig. 1, 2) from the epicenter. The earthquake disaster caused 27 deaths, 856 injured, and 3 missing, and extensive damage in China (Fig. 3a). The affected people are about 30 thousand and the direct economic loss is more than 33,000 million Yuan (RMB). Fortunately, the border area has a low population density and the earthquake occurred in the afternoon when many were outside, otherwise the casualty and economic loss would be much higher. Due to the rapid response of local government the affected people were soon resettled in southern Tibet (Fig. 3b).

In order to quickly know the effects caused by the earthquake and potential future threats to provide the basis for the post-earthquake reconstruction, an emergency seismic hazard investigation group of 12 people that was organized by the Ministry of Land and Resources did a field survey in the hardest hit four counties of Nyalam, Gyirong, Tingri and Dinggye on 2-8 May, a week after the main shock. The group then presented their findings to the local government. This paper is a brief summary of the investigation.

2. Seismic-Geological Setting

The Tibetan Plateau is well known for its numerous E-W to NW north-dipping thrust faults that facilitated its rise as the India plate collided and was thrust beneath it. Most of the uplift occurred by the Miocene (Dewey et al, 1988; Wu et al., 2008) and

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most of the thrusting ceased as the movement evolved and concentrated along fewer strike-slip faults, which remain very active and capable of great earthquakes (Fig. 1). However, thrusting remains dominant in the collision zone at the south edge of Tibet south of the Himalaya Mountains with the continued northward movement of India. Here the greatest activity occurs along the very shallow north-dipping Main Himalaya Thrust (MHT), which gave rise to the Nepal earthquake and has a log history of great earthquakes along its length (Fig. 1). Less generally known are a series of nearly N-S-trending normal faults and grabens to the north of the MHT that complement some of the movement across the MHT. These also are capable of producing significant earthquakes although they are much shorter in length (Wu et al, 2011). This array of active faults plus a set of NW right-lateral strike-slip faults that may aid extension constitute the seismic framework of the region.

The China-Nepal border region is located on the south slope of the Himalaya Mountains close to the MHT and contains many active normal faults that control the transverse valleys that lead into Nepal. The high rugged steep landforms and the well-developed incised river valleys in this region further amplify earthquake disasters. Therefore, it is not strange that it was greatly affected by the disastrous Nepal earthquake.

3. Seismic Intensity

Overall 2,699 houses and one temple were destroyed, 39,981 houses and 242 temples seriously damaged, and about 2,600 km of long trunk highway, 263 bridges, and a part of communication, power and water facilities damaged to some degree in the southern Tibetan region affected by the Nepal earthquake. The seismic intensity distribution based on observations of 26 sites of the 10 affected counties (data from China Earthquake Administration), and Combined with our observations of 16 sites to seismic intensity around China-Nepal border is shown in Fig. 2 and listed in Table 1.

In different intensity area, the feeling of people, damage of buildings with different materials and structures and damage surface are obvious differences. Only a handful of people in the room felt the earthquake occurred in Lhasa in where the seismic intensity is only III degrees. But in Xigazê city, most of the people of inside and outside of biuldings are obviously felt the earthquake and show the seismic intensity maybe IV degrees at here. The differences of the damage of building and surface have been simply described in table 1 from IX to VI intensity zone.

Among the four counties we investigated, Nyalam County is located on the south slope of the Himalaya Mountains, while Gyirong County, Tingri County, and Dinggye County are located north of the Himalaya Mountains. For their seismic intensities, see Table 1. The main effects and economic losses are concentrated in Nyalam, Tingri, and Gyirong Counties where about 80% of the houses were completely destroyed or damaged to a large extent. The damage is heaviest in the towns of Zhangmu, Nyalam County; Jilong and Sale in Gyirong County, and Rongxia, Gyirong County. Moreover, the damage to highways and communications to the towns of Zhangmu, Tingri, and Resuo Bridge as well as connections to Zhangmu, Tingri, Chentang and others in

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Nyalam County were broken.

The general seismic intensity in the southern Tibet region was mainly dependent on the magnitude of the Nepal earthquake and the distance from the epicenter, but the damage was mainly related to the material and structure of buildings. The general pattern of the intensity reflects the strength of the ground motion and its decrease away from the epicenter.

There was a variation of earthquake damage and seismic intensity between different sites in the same affected area. The intensity IX appeared at some sites in Zhangmu, Nyalam County and Jilong, Gyirong County equals the seismic intensity of some parts of Kathmandu, while seismic intensity VIII appeared in other sites of the same towns (Fig. 3c~f). This seems to be mainly because of differences in building material and structure: most houses in the former are earlier self-built of blocks of stone masonry or adobe structure without seismic resistance, while most houses in the latter are newly built of cement-bonding stone or brick structure. For example, in Jifu Village about 2.4 km south of Jilong, all houses built of stone block masonry were almost completely destroyed, while most newly built ones of cement-bonded stone or brick are still standing with only minor cracks in the walls (Fig. 3c~d), and the same situation occurred at Sale Town Primary School (Fig. 3e).

The E-W elongation of the intensity pattern as seen between that from IX to VIII (Table 1) shows a greater rate of attenuation between south and north of the Himalaya Mountains than along them. This can be attributed to the shielding or absorption of the seismic energy by the E-W-trending fault structure and lithologic units of the great Himalaya Mountain block.

4. Geologic Effects

The geologic effects caused by the Nepal earthquake were studied at 33 sites in four towns in Nyalam, Gyirong, Tingri and Dinggye Counties. These are mainly collapse, landslide, rockfall, and ground fissure (Fig. 4). They have the following characteristics:

(1) They occur most densely along four incised river valleys which are controlled by N-S-trending rifts that pass through the Himalaya Mountains, and enter into Nepal (Fig. 2). The four incise river valleys, from west to east, are successively the Gyirong Zangbo valley which follows the Gyirong Graben and extends southwards (Fig. 4b), the Boqu River valley which follows the Nyalam Graben and passes through Zhangmu and connects to the Sunkoxi River valley in Nepal (Fig. 4a); the Rongxiaqu valley which follows the southwest side of the Kong Co-Gangga Graben passes through Rongxia Town, and descends to the Sunkoxi River in Nepal (Fig. 4c), and the Pengqu River valley, which is controlled by the Paiku Co Rift, crosses the Kung Co-Gangga Graben and the Pengqu Graben southwards and passes through Chentang to connect to the Arun River in Nepal (Fig. 4d). The topographic relief in these valley areas is generally about 2,000-3,000 m, which is obviously favorable for landslips during seismic events. Furthermore, there is an overall tendency for the number and size of

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collapse, landslide, and rockfall to increase towards Nepal along these valleys (Fig. 5a). Remotely-sense images issued by Google Earth after the great earthquake show that the Gyirong Zangbo valley and the Buqu River valley contain the maximum density and scale of collapses and landslides. Moreover, some dammed lakes due to the collapse rock and soil can be seen in these two valleys of Nepal. For example, in the Gyirong Zangbo valley, a 0.07 km^2 dammed lake and a 0.04 km^2 dammed lake occur about 2.5 km north of and about 7.3 km southwest of Dhunche Village, respectively, whereas in the Boqu River valley, a 0.24 km^2 dammed lake occurs on the north side of Dabi Village.

(2) Geologic slips occur often in weak, soft or unstable geologic or geomorphic positions: joint or fault-developed, high and steep bedrock cliffs and slopes (Fig. 5b, e); high and steep slopes of Quaternary loose sediment forming river terraces, proluvial fans, and kames (Fig. 5d, f); and unstable slope and highways roadcuts (Fig. 5g, h).

(3) The collapses and landslides commonly result from reactivation of older ones by the earthquake. Such collapses and landslides especially are present on both banks of the Boqu River near Zhangmu (Fig. 6a, b). It is interesting that a seismic effect of a historic earthquake reoccurs near the same position as in this earthquake. At Disigang Village of Zhangmu, for example, a house built on the side of an large rock brought down previously was destroyed by a new large rockfall (Fig. 5C). This is a warning that reconstruction after the earthquake, not only should avoid as far as possible potential new hazards, but at the same time also needs to identify the old collapses, landslides and rockfalls, and make a comprehensive assessment of their stability.

(4) Most of large seismic ground fissures are associated with collapses and landslides. They either occur on collapse and landslide masses or around their edges. Only a few such fissures occur on surface of loose sediments.

These rock and soil slips caused the most serious casualties and damage. The worst collapse found occurred in Disigang Village about 0.8 km southwest of Zhangmu where a slide of about 0.016 km^3 volume destroyed 4 or 5 buildings and killed 7 people (Figs. 3a and 5b). The largest landslide in scale found occurred about 1.3 km southwest of Chongse Village of Jilong Town where about 2,700,000 m^3 of debris blocked the main highway from Jilong to Gyirong Port (Fig. 5e). In addition, 27 small landslides and collapses occurred along the 14km long highway from this landslide to Gyirong Port.

5. Postseismic Increased Potential Geologic Hazards

The investigation found that the Nepal earthquake has left many potential dangers in its wake in this region and nearby seismically active areas in southern Tibet. The principal dangers found to date are: reactivation of the landslide group at Zhangmu, further collapse of the back edge of the Sale Village landslide in Sale, fall of the dangerous rock mass in the Rongxia Primary School, and instability of the old Natang Village landslide and its back edge at Chentang.

The whole of Zhangmu is located on an old landslide group (Figs. 4a and 8a). Discontinuous tension fissures, which are tens to hundreds of meters long, about 10 cm wide and 2-4 m deep, were found to occur at its back edge and on its sides after the earthquake. These fissures indicate a possibility of the reviving the movement of this landslide group.

The Sale Village landslide induced by this earthquake occurred along the highway slope from Sale Village to Seqiong Village. It is nearly 600,000 m^3 in volume and had blocked the road (Fig. 5b). Large tension fissures at its back edge indicate a danger of further collapses (Fig. 7c).

The dangerous rock mass at the Rongxia Village Primary School occupies a convex portion of the cliff behind the school and appears unstable (Figs. 7d and 5c). A rockfall occurred here during the earthquake. The fall appears to have been incomplete and left a cliff that lacks stability and susceptible to further rockfall.

Natang Village of Chentang is located at the front edge of an old landslide, which is about 420 m long and 230 m wide, and consists of about 1,200,000 m^3 (Fig. 4d, Fig. 7e). The steep wall of its back edge appears as two large dangerous rock blocks which are about 60,000 m^3 in volume. A 1.7 m wide preexisted crack occurs between the unstable rock blocks and the bedrock (Fig. 7f). The earthquake did not cause a general collapse but did create a partial rockfall and demonstrates a dangerous instability of the mass that might come down easily.

In addition, the danger of postseismic debris flows must be stressed, although these were rare for this earthquake in the southern Tibetan region. There is, however, a lot of loose debris accumulated in mountain valleys and gullies that could provide material for further debris flows, especially on the south slope of the Himalaya Mountains

Rainfall, which provides excessive water to lubricate land slips and adds weight to a lose mass, is a key factor in inducing postseismic debris flows as well as triggering landslides and rockfalls. There is a large difference in rainfall between the south and north slopes of the Himalaya Mountains. The annual average rainfall at Zhangmu on the south slope is up to 2,556.4 mm/a, whereas the annual average rainfall in Jilong and the seat of Nyalam County on the north slope is only 880.3 mm/a and 654.0 mm/a, respectively. The rainfall on the south slope is concentrated in the Indian Ocean summer monsoon season and induced debris flows were already being reported in Nepal at the beginning of June. The several incised valleys in the south mentioned above are sites of potentially dangerous postseismic debris flows in Nepal. Especially in the three deep-incised valleys leading toward Nepal where there is a high potential for flows that may dam the rivers to forms lakes. These are, from west to east, the Gyirong Zangbo river in the upper basin of the Trisuli river, the Boqu river and the Rongxiaqu river in the upper basin of the Sunkoxi river (Fig. 2). Another danger spot is in the Dianchang gulley on the south side of Zhangmu in southern Tibet (Figs. 4a and 7a) where a lot of loose debris is in a very unstable state.

6. Postseismic Increased Potential Seismic Hazard

The release of energy in a great earthquake such as the Nepal earthquake shifts the strain in the adjacent region where other earthquakes may then occur, just like a few strong earthquakes occurred in Tibet after the Ms8.0 Wenchuan earthquake (Wu et al, 2011). The seismic history of southern Tibet appears to bear this out as large earthquakes along the south margin on the Main Frontal Thrust of the Main Himalayan Thrusts are followed by ones along the N-S normal faults in the region to the north (Fig. 1). Based on this past history there now is an increased concern that a significant earthquake may occur along the normal faults in the region.

Southern Tibet itself is an earthquake-prone region with many nearly N-S-striking active normal faults and grabens in addition to the long E-W active thrust faults such as caused the Nepal Earthquake (Fig. 1). These normal faults form at least eight nearly N-S-trending rifts across southern Tibet. Geological estimates and GPS data show that the E-W extension rates cross the rifts were10-13 mm during the Quaternary and Holocene (Armijo et al., 1988; Chen et al., 2004). Such rates are close to the Holocene slip rate of 21±1.5 mm/a along the Main Frontal Thrust (MFT) of the Main Himalaya Thrust (MHT) (Lavé et al, 2000) and to the recent GPS-based shortening rate of 10-19 mm/a across the Himalaya orogenic belt (Larson et al., 1999; Jouanne, et al., 1999; Bettinelli et al., 2006). There appears to be a close kinematic connection between the nearly N-S normal faulting in the southern Tibet region and the thrusting on the MHT (Armijo et al, 1988; Molnar et al, 1989). The historical seismicity also proves the existence of such a connection. Often within a short time interval (one to ~10 years) after great earthquakes on the MHT, strong earthquakes occur on the N-S normal faults in the southern Tibet area (Fig. 1). For example, the Kashmir great earthquake of 1400 was followed by a M 8.0 earthquake in the Damxung-Yangbajain sector of the northern Yadong-Gulu Rift occurred in 1411; a great earthquake in the west part of Nepal in 1803 was followed by a M 7.5 earthquake in the south sector of the Cona- Oiga Rift in1806, and a Kashmir great earthquake in 1905 was followed by a M 7.5 earthquake at Sangri in the northern sector of the Cona- Oiga Rift in 1915. Similarly, after the 1934 Nepal great earthquake, a M 7.0 earthquake in the same year occurred in the N-S Gomang Co graben in northeastern Xainza County and after the 1950 China-Indian border M 8.6 earthquake, a M 7.5 earthquake occurred in 1952 in the northern sector of the Yadong-Gulu Rift in Nagqu County.

On the first and second day of the 2015 Nepal earthquake a Mw 5.4 earthquake occurred in Nyalam County and a Ms 5.9 earthquake in Tingri County, respectively. Both are nearly N-S normal faulting-type earthquakes: the former occurred in the Nyalam-Coqên Rift and the latter in the southern end of the Xainza-Dinggye Rift. However, this has unlikely released all the extensional forces. Recently, Elliott et al. (2010) found from the InSAR and body wave seismological images of normal faulting earthquakes that the nearly N-S extension rate due to the contribution of the seismic energy released through normal faulting for the past 43 years in the southern Tibet region is 3-4 mm/a, which is only equivalent to 15-20% of the extension rate obtained by GPS measurements. This means that there still is about 80% of the energy due to extension to be released, possibly in coming seismic activity.

Extension may also affect a set of NW right-lateral strike-slip fault zones with significant activity in the southern Tibet region. These are: the Karakorum fault zone, the Gyaring Co fault zone, and the Bengcuo fault zone from west to east (Fig. 1). Their Quaternary strike-slip rate may reach to 10-20 mm/a (Armijo et al., 1989; Chevalier et al., 2005). Such faults with high strike-slip rates also can play an important role in adjusting of the nearly E-W extension deformation in the area. For example, a M 8.0 earthquake in southwestern Nagqu in 1951, which occurred along the NW trending Bengco fault zone, followed the 1950 M 8.6 Zayü earthquake of eastern Tibet that is known as Assam earthquake in India.

7. Recommendations

Our investigation is still preliminary and very generalized and our recommendations are still tentative.

First, southern Tibet is a region with remarkable historical seismicity where earthquakes and the seismic effects cannot effectively be forecasted, but an earthquake early warning system should be established as soon as possible to indicate the potential danger spots.

Second, in considering moving and reconstruction of some residential areas the potential dangers of postseismic hazards and stability of old seismically induced geologic effects needs be taken into account. The southern Tibet region is vast inconsideration of its very low population density, to provide a wide selection for new safer sites.

Third, in the repair and reconstruction of buildings, new anti-seismic construction codes must be adopted.

Forth, in the next several years there should be heightened awareness and preparations for a possible earthquake in one of the grabens of southern Tibet.

Finally, although more detailed seismic-geological study is, of course, necessary, the greater urgency should be directed at the construction of high anti-seismic buildings and facilities in areas that avoid potential geological hazards that may be triggered by earthquakes.

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Table 1 Distribution of seismic intensity of the Nepal earthquake in the southern Tibet region

Intensity	Area (km^2)	city, county and town covered by seismic intensity	damage of building and surface
IX	105	The Zhangmu Town of Nyalam County, Jilong Town of Gyirong County.	Most of the mud-brick and stone piled up building were collapsed and severely damaged and some brick houses also have obvious damage and partial collapse. Collapse and landslide is widespread, and the existence of large landslides.
VIII	1,945	The Zhangmu Town and Nyalam Town of Nyalam County, Jilong Town and Sale Town of Gyirong County, Rongxia Town of Tingri County.	Some of the mud-brick and stone piled up buildings were collapsed or severely damaged, but the buildings of brick structure are mainly moderate to slightly damaged and are more of the wall cracks. Medium and small collapses and landslides are common but are rarely large landslide.
VII	9,590	Gyirong County, Nyalam County, Tingri County and Dinggye County.	A few of the mud-brick and stone piled up buildings were severely damaged, but most buildings are slightly damaged only. There are some small collapses, landslides and rockfalls along slope of valley and highway roadcuts.
VI	35,460	Zhongba County, Saga County, Gyirong County, Nyalam County, Tingri County and Dinggye County, Gamba County, Sàgya County, Ngamring County and Lhazê.	Only a few the mud-brick and stone piled up buildings were slightly damaged, and collapses and landslides are rare. A small amount of rockfall may appear near the highways roadcuts.
Felt area	300,000	Lhasa, Xigazê, Burang, Gar and Nêdong etc.	

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Figures

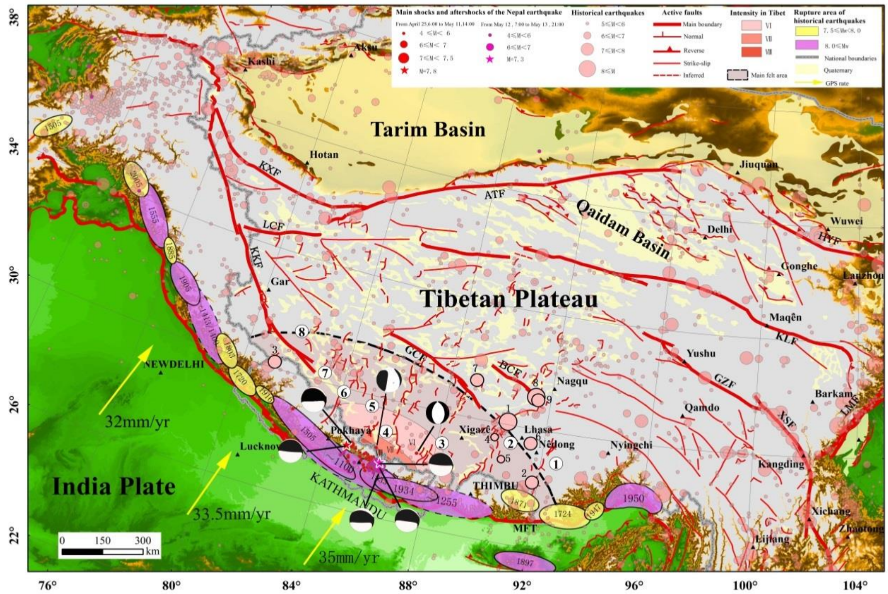

Fig.1 Principal active faults and historic earthquakes in the Himalaya mountains, Tibetan Plateau and neighboring areas. The great earthquake data after The Science and Technology Committee and the archives in Xizang Autonomous Region, 1982; Bilham, 2004; Avouac, 2007; GPS data from Bettinelli et al, 2006; The focal mechanism solution data from USGS, Institute of Geophics; and China Earthquake Administration.

Explanation: Rifts in southern Tibet, ①, Cona-Oiga rift; ②, Yadong-Gulu rift; ③, Dinggye-Xainza rift; ④, Gangga-Tangra Yumco rift; ⑤, Nyalam-Coqên rift; ⑥, Zhongba-Gêrzê rift; ⑦, Kunggyu Co- Yagra rift; ⑧, Burang-Gêgyai rift.

Thrust and strike-slip faults; MFT, Main Frontal Thrust fault zone of Himalaya; KKF, Karakorum fault zone; GCF, Gyaring Co fault; BCF, Beng Co fault; GZF, Ganzi fault zone; XSF, Xianshuihe fault zone; KLF, Kunlunshan fault zone; LMF, Longmenshan fault zone; LCF, Longmu Co Fault; KXF, Kangxiwa fault zone; AFT, Altyn Tagh fault zone; HYF, Haiyuan fault zone. Numbers 1-9 of M≥6.8 earthquakes in southern Tibet triggered by the Himalayan historical great earthquakes: 1, 1411 M 8.0 Damxung-Yangbajain; 2, 1806 M 7.5 Cona; 3, 1883 M 7.0 Burang; 4, 1901 M 6.8 Nyêmo; 5, 1909 M 6.8 Nagarzê; 6, 1915 M 7.0 Sangri; 7, 1934 M 7.0 Gomang Co of Xainza; 8, 1951 M 8.0 Beng Co of Nagqu; 9, 1952 M 7.5 Gulu of Nagqu.

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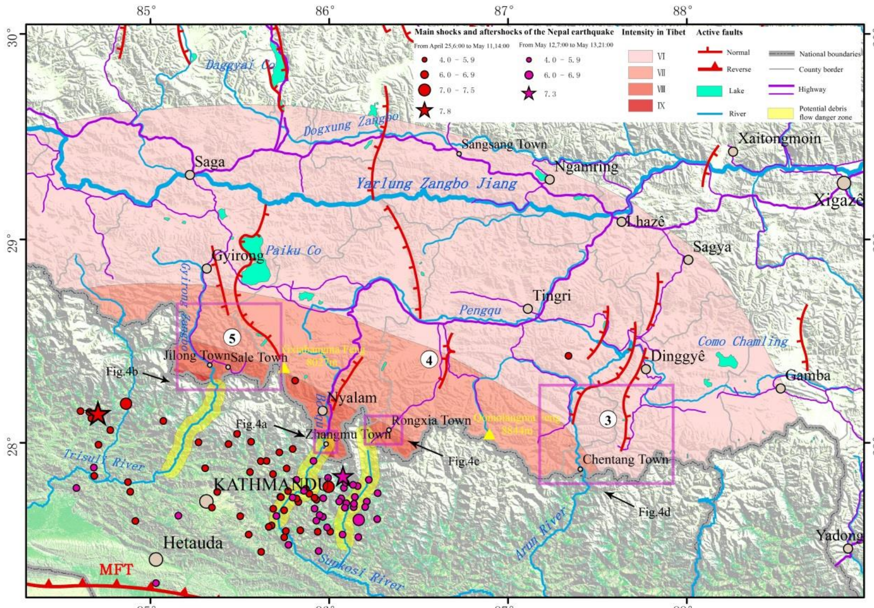

Fig. 2 Principal active faults and the distribution of seismic intensity of the 2015 Nepal earthquake in the southern Tibet region. Epicentral data from the USGS and seismic intensity from the China Earthquake Administration. The numbers and names of the principal S-N trending rifts in southern Tibet are same as on Fig. 1.

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Fig. 3 Typical earthquake damage in southern Tibet and comparison of houses of different construction (locations in Fig. 4). A, Huge rockfall smashed the resident committee office building at Disigang Village about 0.7 km south of Zhangmu, where seven persons were killed (site 1, Fig. 4a); b, A makeshift settlement of quake survivors at Jilong; c, Destroyed houses of stone block masonry or adobe construction in Jifu Village southwest of Jilong (site 8, Fig. 4b); d, Houses with cement-bonded stone or brick construction in Jifu Village; e, Destroyed old houses and standing new buildings at Sale Town Primary School (site 7, Fig. 4b); f, Zhangmu after the earthquake with few collapsed houses due to the brick structure or reinforced concrete construction.

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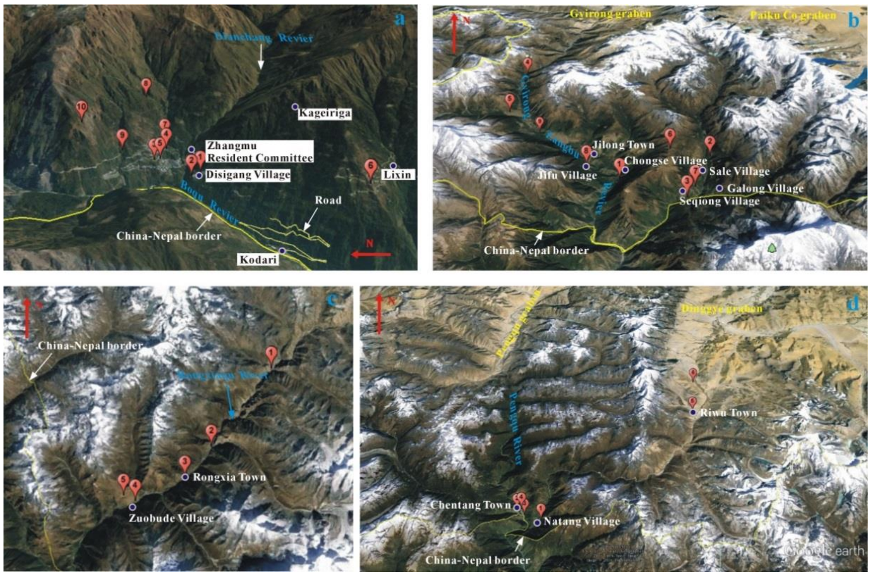

Fig. 4 Main field surveying sites of seismic geohazards after the Nepal earthquake, see Fig. 2 for the location. (Images source: Google Earth). a. Zhangmu Town. b. Jilong Town and around it. c. Rongxia Town and around it. d. from Riwu Town to Chentang Town.

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Fig. 5 Geologic effects caused during the Nepal earthquake: a, collapses in the Boqu valley; b, collapse at Disigang Village (Site1, Fig. 4a); c. new and old rockfalls at Disigang Village (Site1, Fig. 4a); d, destroyed buildings in Kodari, Nepal (Site in Fig. 4a); e, large landslide in Chongse Village (Site1, Fig. 4b); f, collapses in Galong Village(Site 7, Fig. 4b); g, collapses along highway from Gyirong County to Jilong Town (Site 4, Fig. 4b); h, collapses and fissures along the highway from Jilong to ChongseVillage (Site1, Fig. 4b).

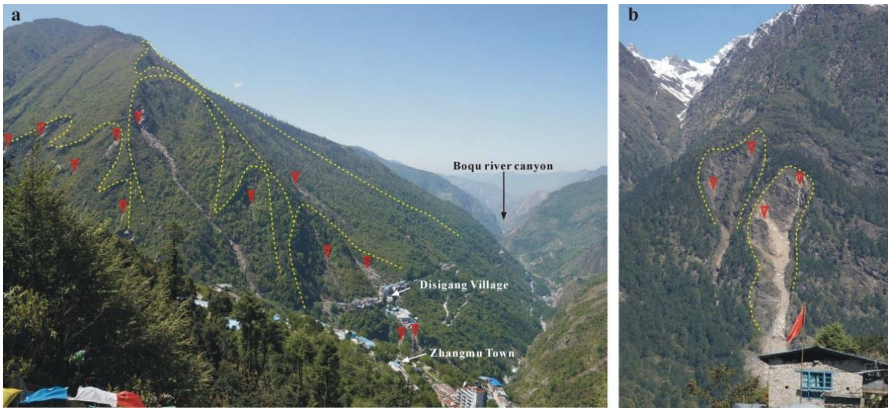

Fig. 6 New and old collapses and landslides on both banks of the Boqu River in Zhangmu Town. a. the east bank, b. the west bank. Explanation: yellow dotted line, boundary of old collapses and landslides; red triangle, new collapses during the Nepal earthquake.

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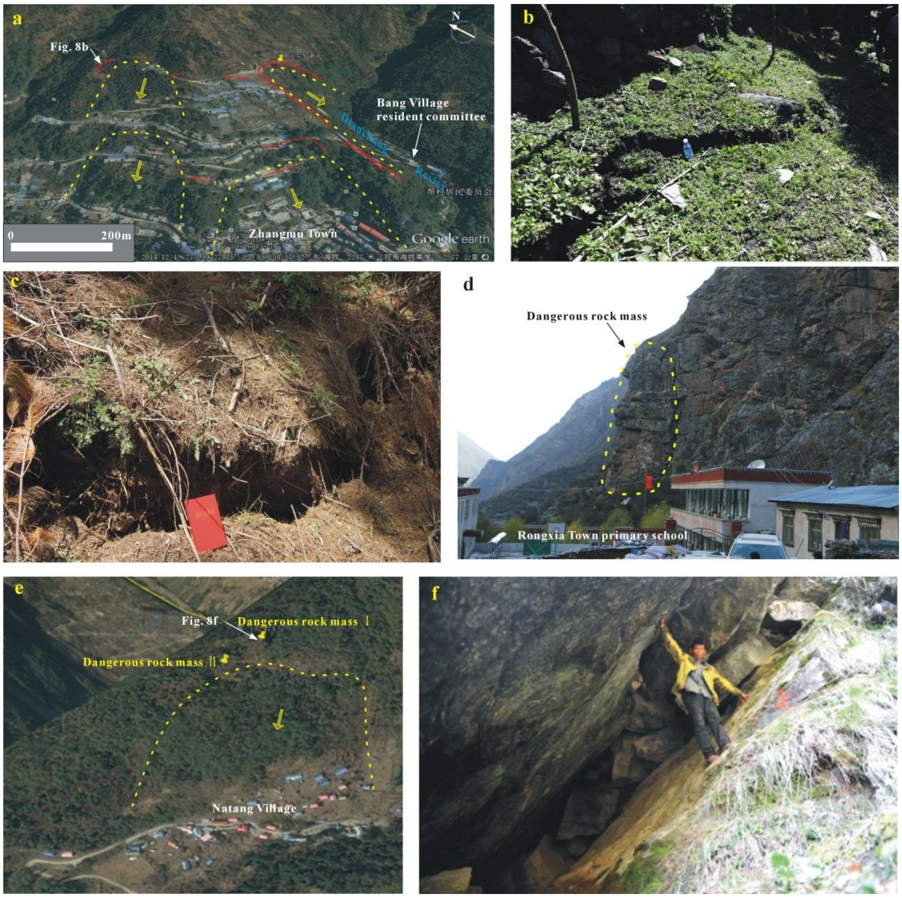

Fig. 7 Potential landslides and rockfall. Explanation: yellow dotted line, landslide group; arrow, slip direction; red line, new fissures formed during the Nepal earthquake; a, old landslide group at Zhangmu. b. new fissure in the old landslide group at Zhangmu (site in Fig. 7a); c, Tension fissures at the back edge of Sale Village landslide (site7 in Fig. 4b); d, dangerous rock mass at Rongxia Primary School (site 3 in Fig. 4c); e, Old landslide with unstable rock at Chentang Village (site 1 in Fig. 4d) and; f, Fissure between unstable rock and bedrock at Chentang (site in Fig. 7e).