EGU General Assembly 2020 Vienna, Austria

Risk analysis of the 2018 Sedongpu glacial debris flows in the southeastern Tibet

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May. 5, 2020

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- Earthquake and Dammed lakes
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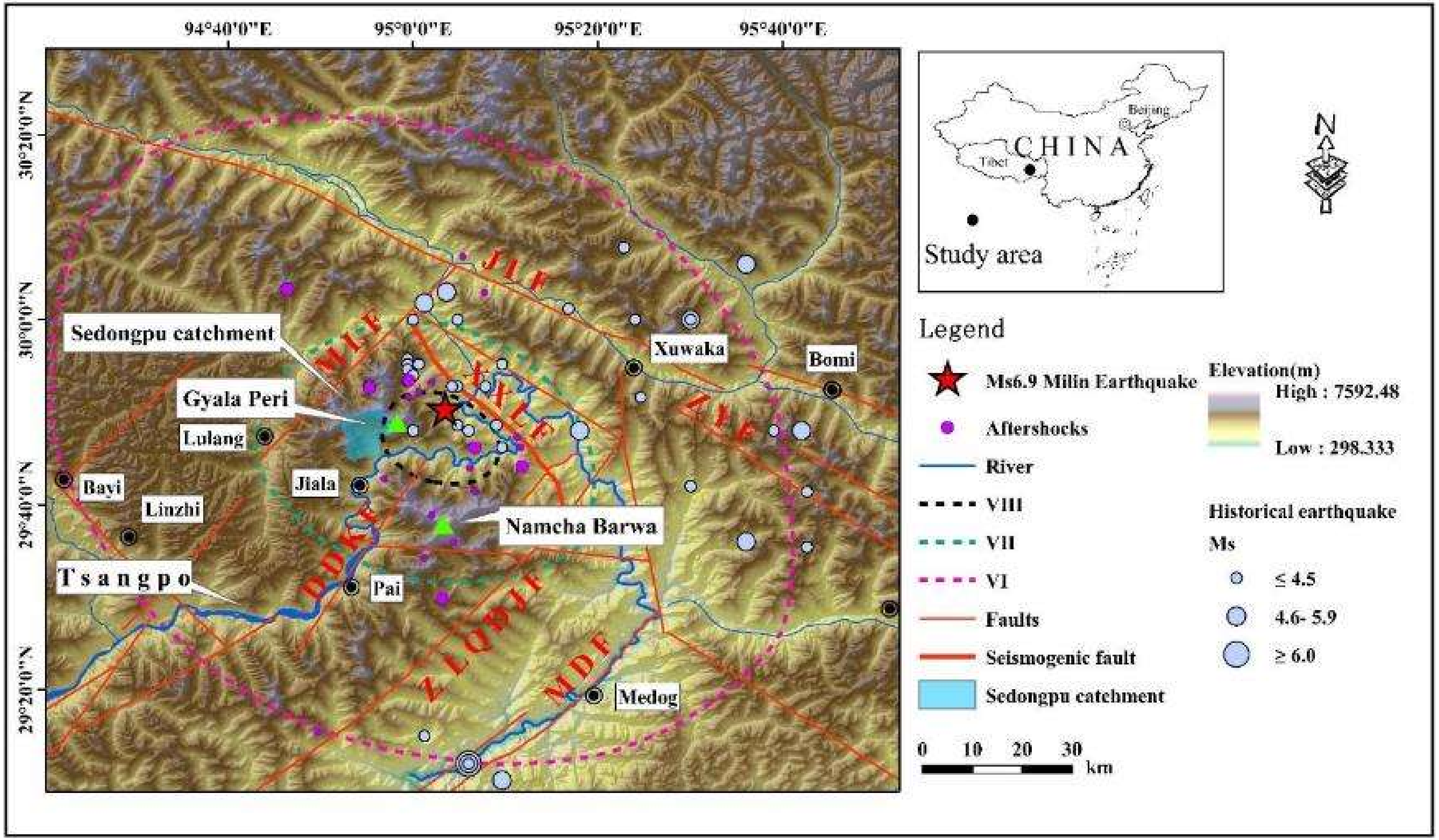
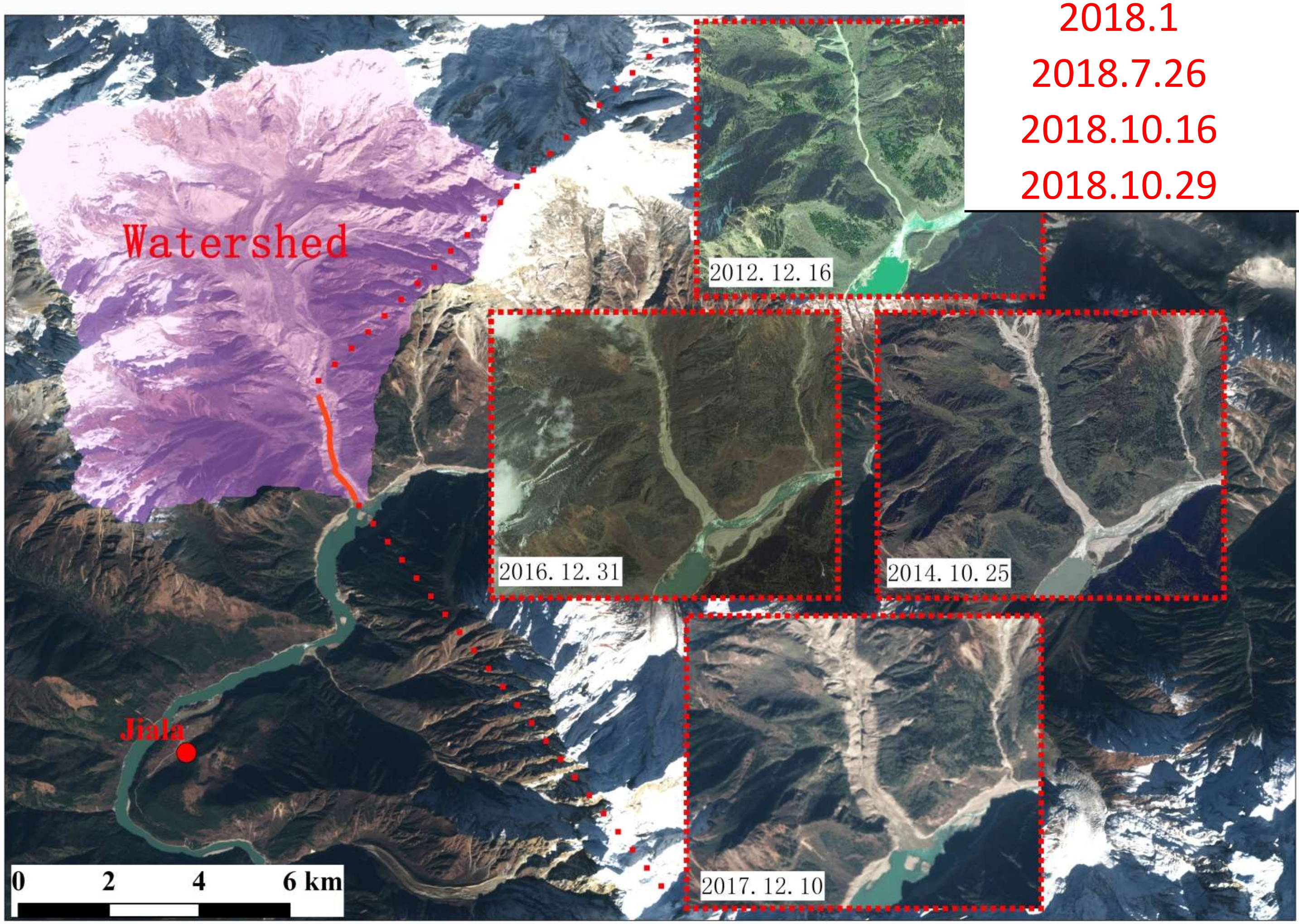
Sedongpu debris flows



Location: 29° 47′ 7″, 94° 55′ 24″ Area: 66.7km^2 Elevation: 2750~7294 m

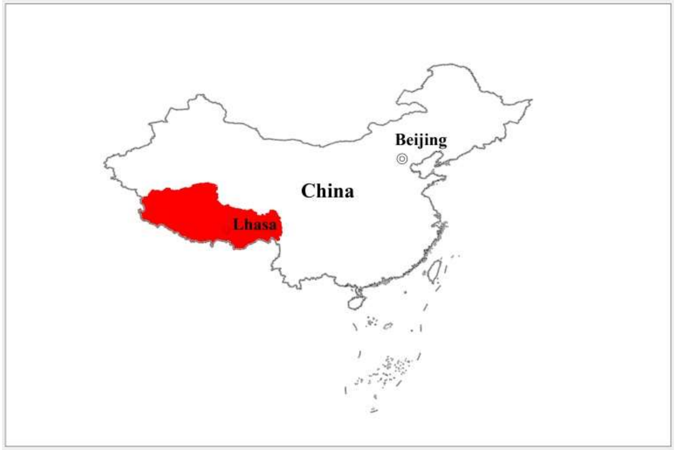
◆Historical interpretation of debris flows

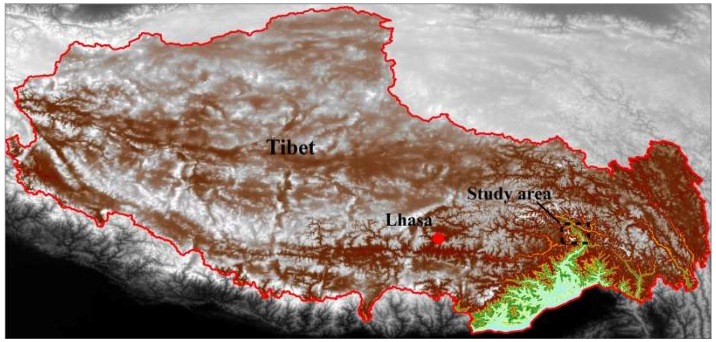
Date	Blockage of the river
2014	Partial
2017.10.22	Complete
2017.11.3	No
2017.12.21	Complete
2018.1	Complete
2018.7.26	No
2018.10.16	Complete
2018.10.29	Complete

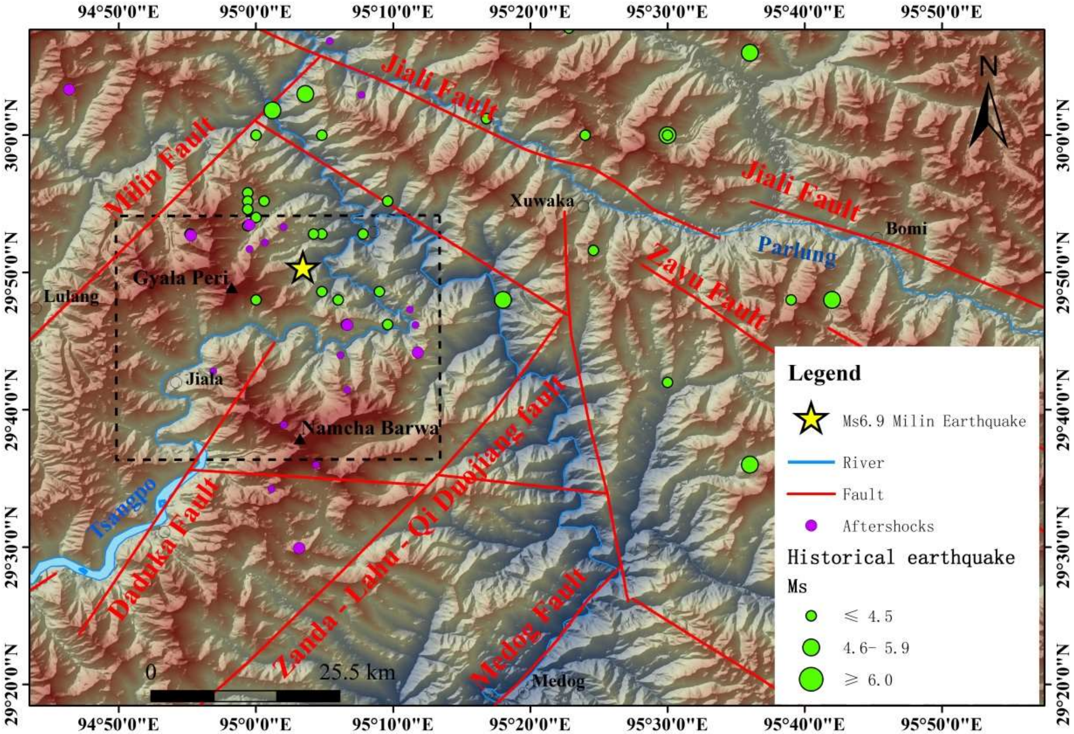


2017 Ms 6.9 Milin earthquake

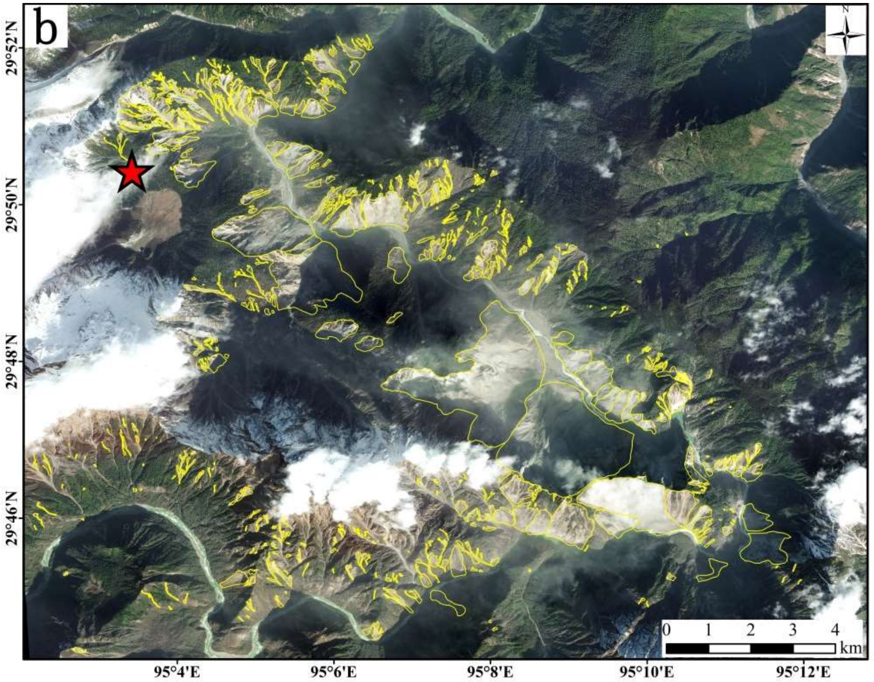
- **Time**: Nov. 18, 2017 (Beijing time 6:34)
- **Magnitude**: Ms 6.9
- **Epicenter location**: 29.75N, 95.02E
- **Focal depth**: 10 km





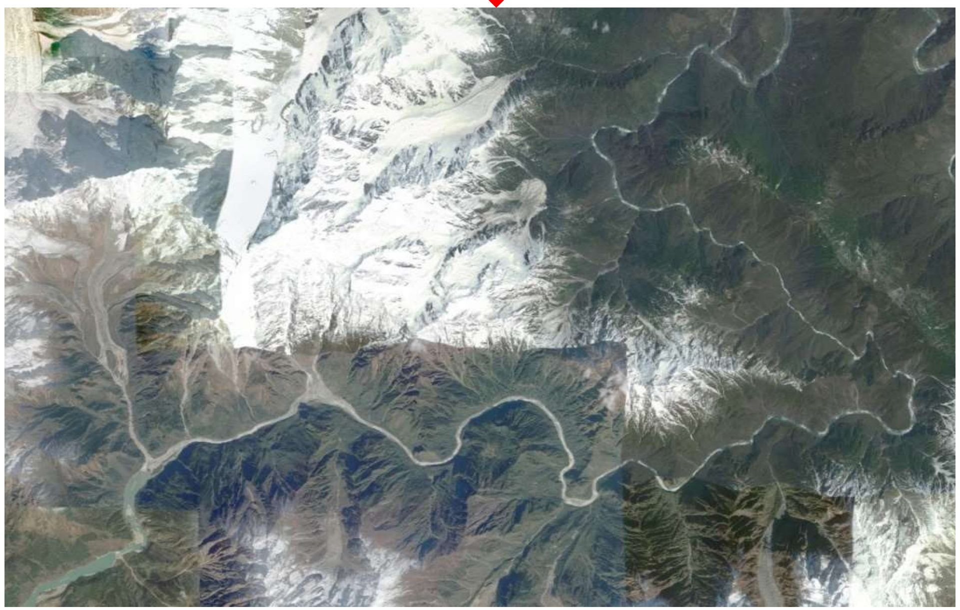


Induced geo-hazards



Post-earthquake satellite image from Sentinel on Dec. 10, 2017

Pre-earthquake satellite image from Google Earth on Mar. 31, 2012



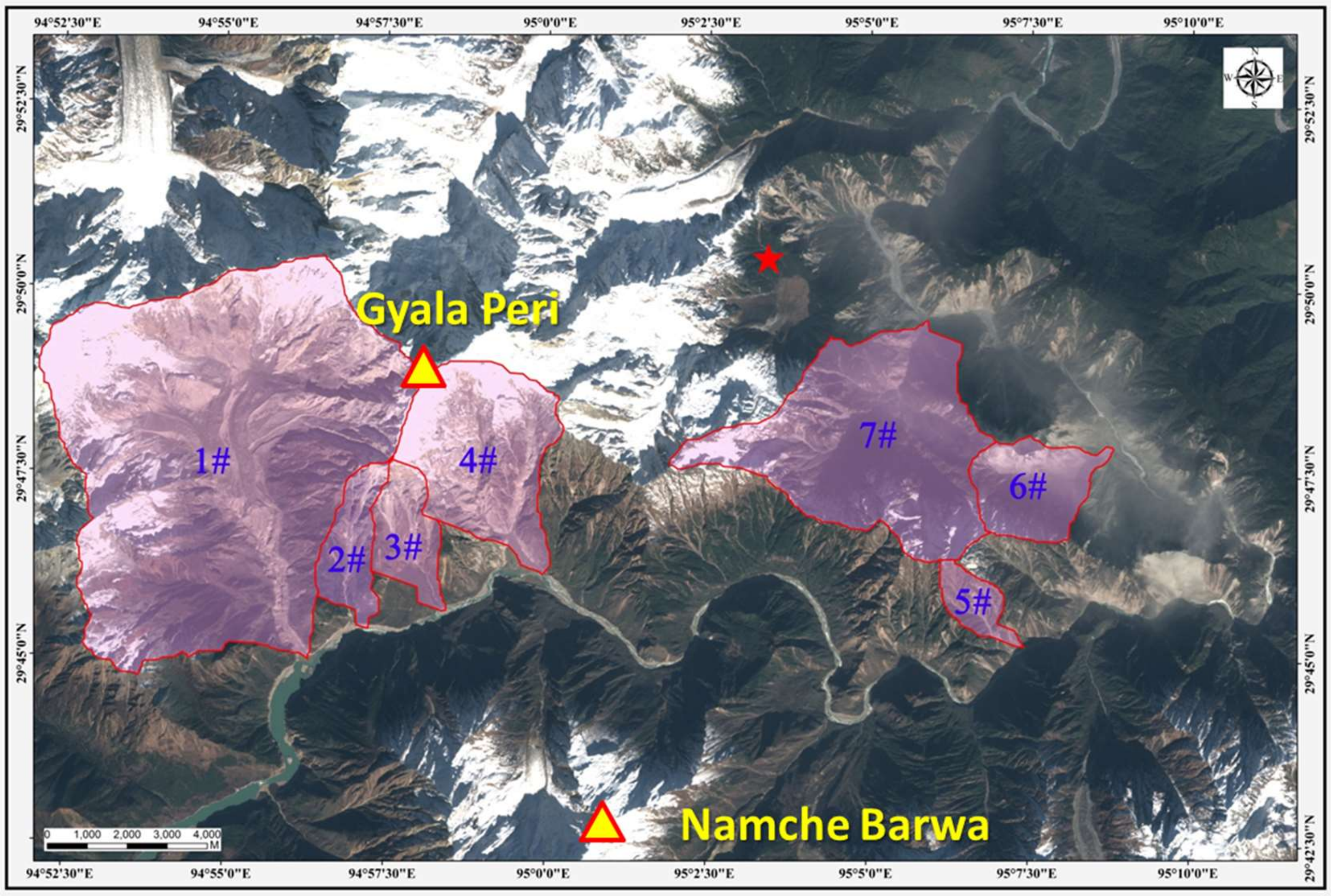
- **The earthquake yields massive loose materials in seven catchments in the area and then augument the magnitude of sequent glacial debris flows in Sedongpu.**

Dammed lakes

- The largest event happened at 22:00 on Oct. 16, 2018. The debris-flow dam was 77 m high. The glacial dammed lake with an impounded water of 0.6 billion m^3 broke out and caused an outburst flood of peak discharge ~ 30,000 m^3/s on October 19.

Risk analysis before the outburst in Oct.

- **Strong activity of induced geo-hazards will last at least 5 years.**
- **The most dangerous hazards are debris flows.**



◆The area-volume empirical formula proposed by Larsen et al.(2010)

$V = \sum$

Will the risk of the dammed lakes increase greatly if large-scale debris flows happen in near future?

The volume of the loo... aterials inc... ses about **0.1 km^3** after ...e earthquake.

➢Flow chart of risk analysis

RS
- Magnitude-frequency analysis

CFD
- Numerical simulation

GIS
- Prediction of the dammed lakes

Hydro
- Peak discharge of outburst floods

➢Magnitude-frequency

- **The empirical formula to estimate the overall volume proposed by Zhou et al. (1991)**

$$V_c = 19\,T_s\,Q_c/72$$

$$\boldsymbol{Q_c = \{[0.526(\gamma_s - 1)/(\gamma_s - \gamma_c)](0.58P - 14) + 0.5\}F}$$

⇩

The event in a certain period during **2013** and **2014**, the overall debris flow volume was approximately **4.5 million** cubic meter
The event in **2017**, the overall debris flow volume was approximately **13 million** cubic meter

➢Numerical Simulation of debris flows

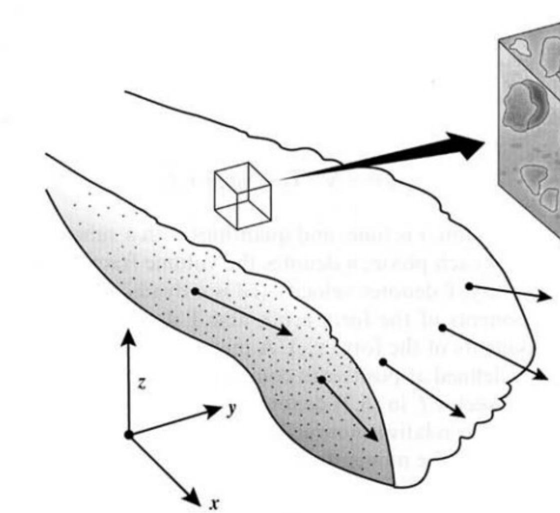
◆Resistance Calculation Model

Mass conversation equation： $\frac{\partial h}{\partial t}+\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial y}=0$

Momentum equation：

$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left(\frac{P^2}{H}\right)+\frac{\partial}{\partial y}\left(\frac{PQ}{H}\right)=-gH\frac{\partial \eta}{\partial x}-S_{fx}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{PQ}{H}\right)+\frac{\partial}{\partial y}\left(\frac{Q^2}{H}\right)=-gH\frac{\partial \eta}{\partial y}-S_{fy}$$



Resistance Model

$$S_{fx}=(1-C_s)\left(\frac{P}{\sqrt{P^2+Q^2}}\frac{\tau_B}{\rho}+2\mu\frac{P}{\rho H^2}\right)+\frac{P}{\sqrt{P^2+Q^2}}\frac{C_s gH\left(\rho_s-\rho_f\right)\tan(\psi)}{\rho}$$

Liquid resistance（Binghamm Model） **Solid resistance (Particle Friction Model)**

$$S_{fy}=(1-C_s)\left(\frac{Q}{\sqrt{P^2+Q^2}}\frac{\tau_B}{\rho}+2\mu\frac{Q}{\rho H^2}\right)+\frac{Q}{\sqrt{P^2+Q^2}}\frac{C_s gH\left(\rho_s-\rho_f\right)\tan(\psi)}{\rho}$$

➢ Sedongpu case

Take some debris flow gullies in the study area as examples, and make a numerical simulation on different scales.

（1） Calculation of density of debris flow：

$$\gamma_D = P_{05}^{0.35} P_2 \gamma_v + \gamma_0$$

（2） Calculation of Yield Stress and Viscosity Coefficient of debris flow:

Yield Stress： $$\tau_B = 0.098 \exp(8.45 \frac{C_f - C_{f0}}{C_{fm}} + 1.5)$$

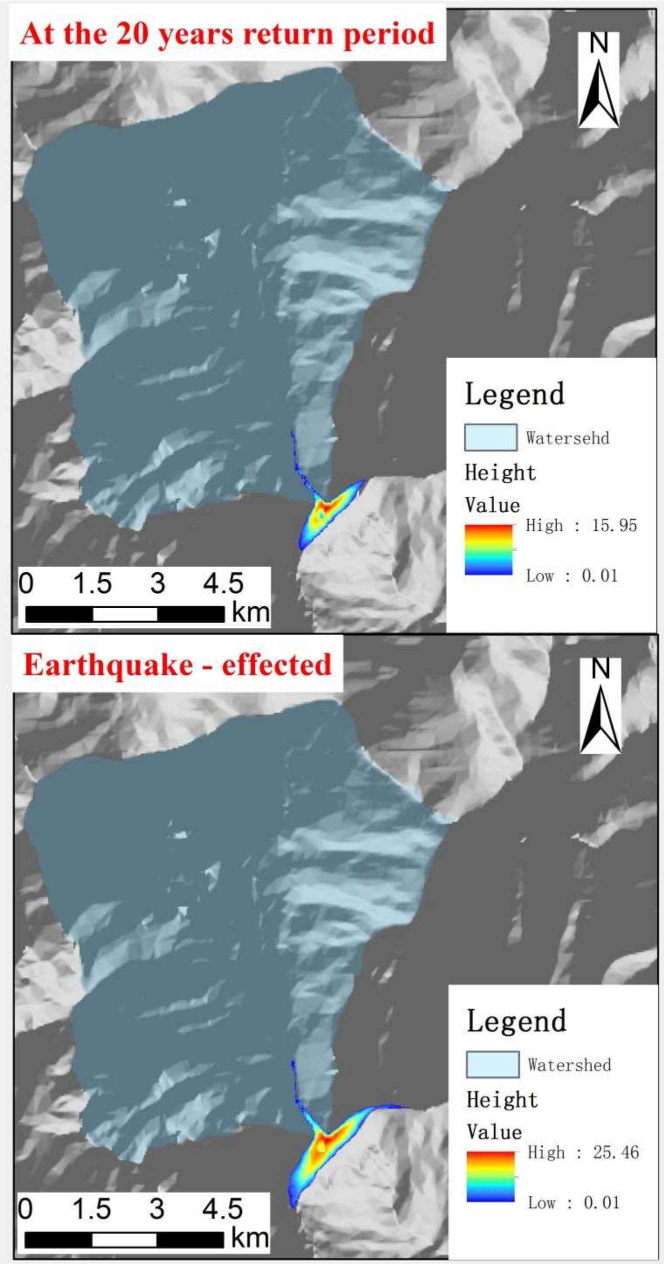
Viscosity Coefficient： $$\eta = \eta_0 (1 - k \frac{C_f}{C_{fm}})^{-2.5}$$

◆ **At the 20 years return period:**

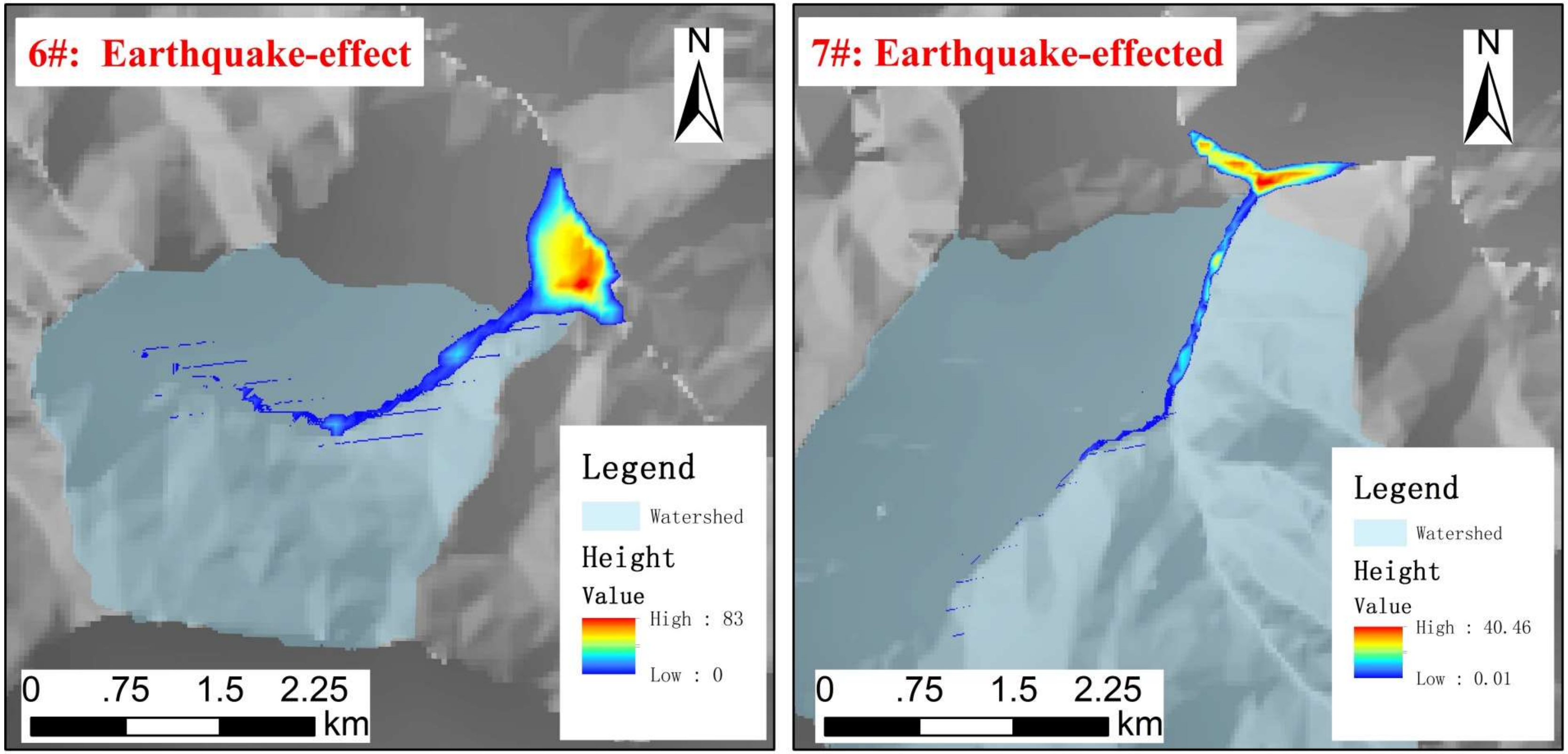
total volume up to 4.5 Mm^3

◆ **Earthquake-effected:**

total volume up to 13 Mm^3



➢ 6# and 7# debris flow gullies



◆ **Earthquake-effected:**

6#:total volume up to 13.64 Mm^3 **7#:total volume up to 4.62 Mm^3**

Large slope due to strong changes in local topography, these two case can't form large dammed lakes.

➢ Prediction of the dam height

Based on the calculation results, dams scale were estimated under the conditions of the 20 years return period and earthquake-effected of debris flow.

Number	Scale	Dam height increase(m)	Backwater area(km^2)	Original capacity(m^3)	Increase capacity(m^3)	Total capacity(m^3)
Sedongpu	a 20-year	15	2.4	0.77×10^7	2.13×10^7	2.9×10^7
	earthquake-effected	25	4.41	0.77×10^7	5.58×10^7	6.35×10^7

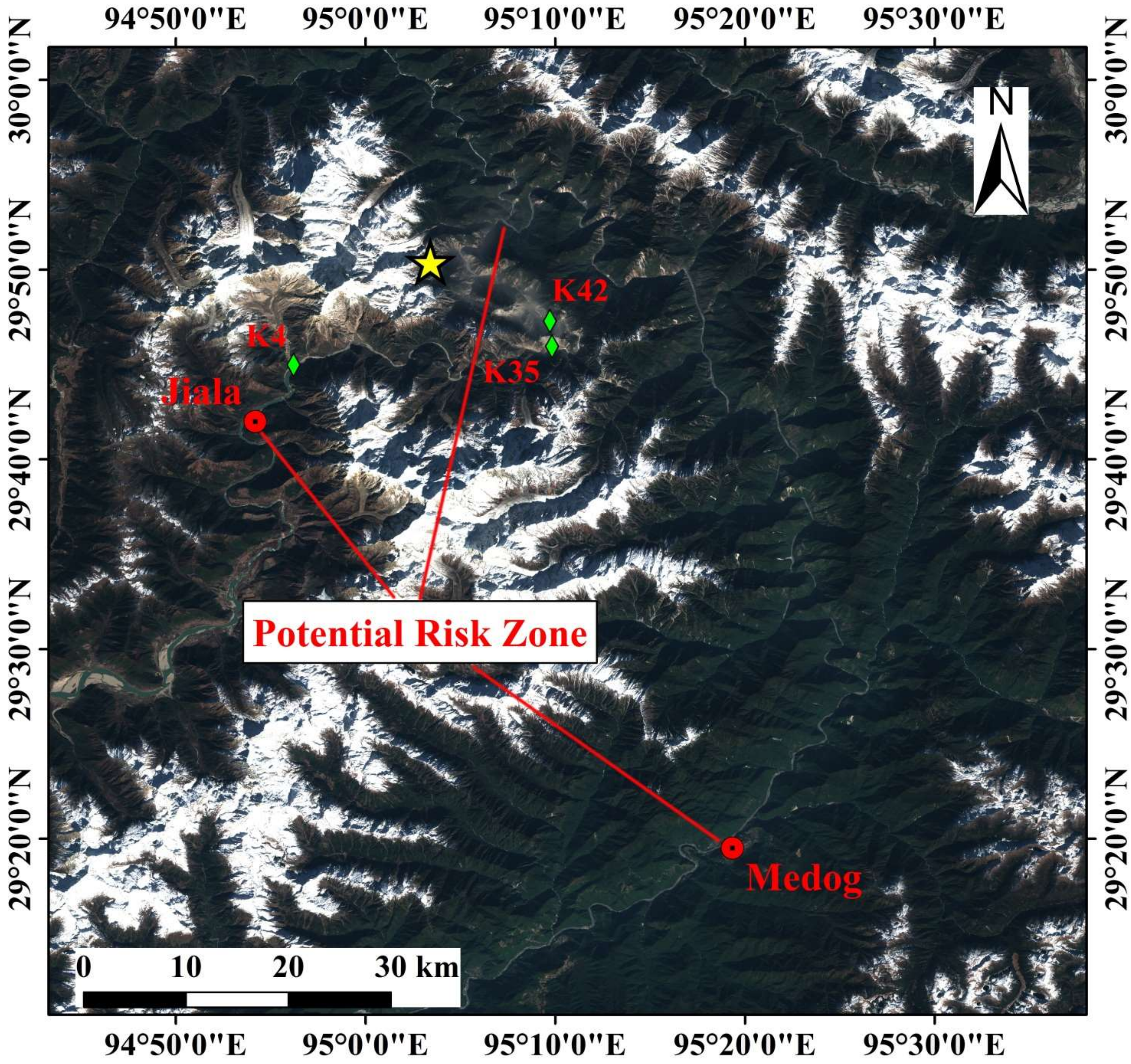
Considering the debris flow events under the influence of the earthquake, the backwater of the lake will affect the rope bridge crossing the river and some roads in the upstream, Jiala village.

➢ Outburst flood

◆ **The empirical formula for the peak discharge forecast for dam breach proposed by Froechlich (1995)**

$$Q_{max} = 0.607 H_w^{1.24} V_w^{0.295}$$
$$\bar{b} = 0.1803 K_o V_w^{0.32} H_W^{0.19}$$

	Destruction level	Total volume (V_w : m^3)	Outburst volume (V_w : m^3)	Depth of water level (H_w: m)	average width of the breach (b: m)	Peak discharge (Q_{max}: m^3/s)
K4	50%	2.9×10^7	2.4×10^7	18	100.53	3287.68
	100%	2.9×10^7	2.9×10^7	36	183.40	8211.29
	50%	6.35×10^7	5.58×10^7	23	137.97	5714.63
	100%	6.35×10^7	6.35×10^7	46	164.03	14022.54
K35	50%	2.7×10^7	1.65×10^7	27	96.31	4866.73
	100%	2.7×10^7	2.7×10^7	58	130.38	14524.18
K42	50%	3.1×10^7	1.93×10^7	49.5	113.63	10807.83
	100%	3.1×10^7	3.1×10^7	89	174.40	29968.00

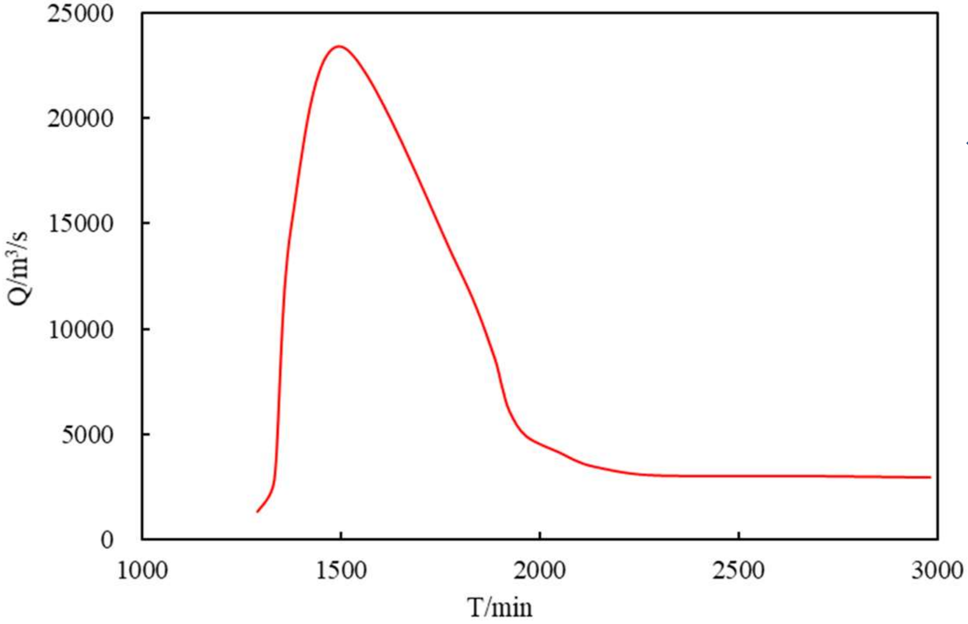


94°50'0"E
95°0'0"E
95°10'0"E
95°20'0"E
95°30'0"E
30°0'0"N
29°50'0"N
29°40'0"N
29°30'0"N
29°20'0"N
N
K42
K4
K35
Jiala
Potential Risk Zone
Medog
0
10
20
30 km

Outburst flood discharge estimation

➢ **There are many empirical models for predicting landslide dam outburst flood discharge**

Source	Forumla	Year	Sample number
Kirkpatrick	$Q_{max} = 1.268(H_w + 0.3)^{2.5}$	1977	34
SCS	$Q_{max} = 16.6{H_w}^{1.85}$	1981	32
U.S. Bureau of Reclamation	$Q_{max} = 19.1{H_w}^{1.85}$	1988	13
	$Q_{max} = 48{H_w}^{1.63}$	1988	13
Hagen	$Q_{max} = 0.54(S - H_d)^{0.5}$	1982	7
Singh and Snorrason1	$Q_{max} = 13.4{H_d}^{1.89}$	1984	28
Singh and Snorrason2	$Q_{max} = 1.776S^{0.47}$	1984	34
MacDonald and Langridge-Monopolis	$Q_{max} = 3.85(H_w V_w)^{0.41}$	1984	36
Costa1	$Q_{max} = 1.122S^{0.57}$	1985	
Costa2	$Q_{max} = 0.981(SH_d)^{0.42}$	1985	30
Costa3	$Q_{max} = 2.634\ (SH_d)^{0.44}$	1988	30
Evens	$Q_{max} = 0.72{V_w}^{0.53}$	1986	39
Froechlich	$Q_{max} = 0.607{H_w}^{1.24}{V_w}^{0.295}$	1995	31
Webby	$Q_{max} = 0.0443g^{0.5}{V_w}^{0.365}{H_d}^{1.4}$	1996	



Outburst flood hydrograph measured by a hydrologic station 168 km downstream of the Sedongpu dam

Formula	Kirkpatrick	SCS	U.S. Bureau of Reclamation		Hagen	Singn & Snorrason1	Singn & Snorrason2
Q_{max} (m^3/s)	66614	51300	59026	57045	13500	49269	24183
误差	+35162	+19847	+27573	+25593	-17953	+17816	-7270
模型	MacDonald and Langridge	Costa1	Costa2	Evens	Froechlich	Webby	
Q_{max} (m^3/s)	92307	115783	30079	33048	52146	98537	
误差	+60854	+84330	-1373	+1596	+20694	+67085	

the 1985 Costa's model shows best agreement with the measured data.

Conclusions

- Following the 2017 quake, several high-magnitude glacial debris flows happened at Sedongpu in 2018.
- A comprehensive methodology is developed to assess the potential hazard of the glacial-debris-dammed lake before the outburst.
- Although the prior risk analysis underestimated the debris flow volume and outburst flood peak discharge, the method shows a good application.
- With regard to the Sedongpu event, the 1985 Costa's model shows best agreement with the measured data.

Thank you for your attention!

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