Landslide mapping, monitoring and early warning based on multi-source data

Case study of the Qingpo landslide (Wenchuan, China)

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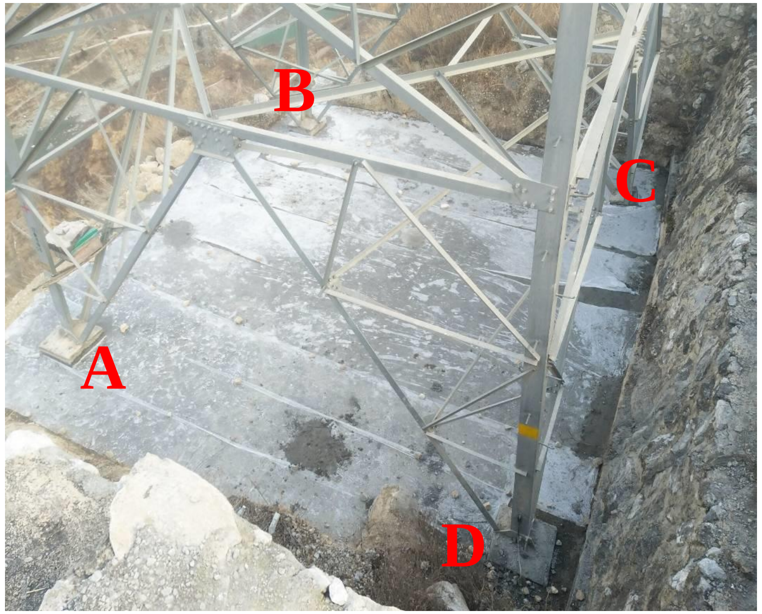
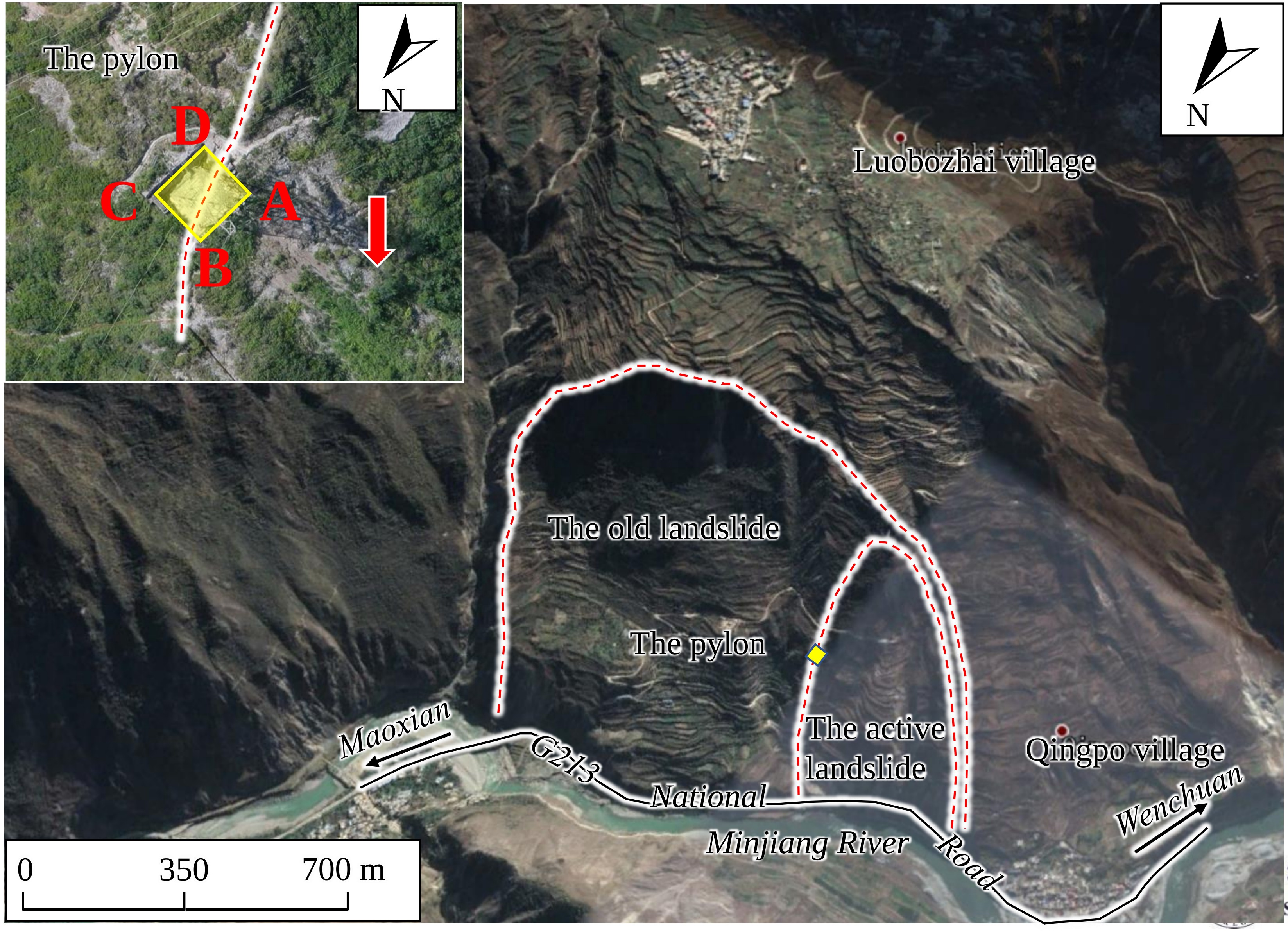
Discovery of the landslide



- On November 28 and December 4, 2018, deformation and tension cracks were discovered in the ground. The settlement of two pylon legs (A and B) was obvious, while the other two appeared stationary.

- Then the company reinforced the surface with concrete.
- After the treatment, the deformation did not stop completely, and the deformation was still developing until July 2019. Concrete and retaining walls also cracked with large cracks.

Discovery of the landslide



In July 2019, after commissioning a field investigation, it was found that:

- the pylon was deformed because it was located at the boundary of an active landslide (two legs inside the landslide and two legs outside).
- The active landslide is located within an old landlside.

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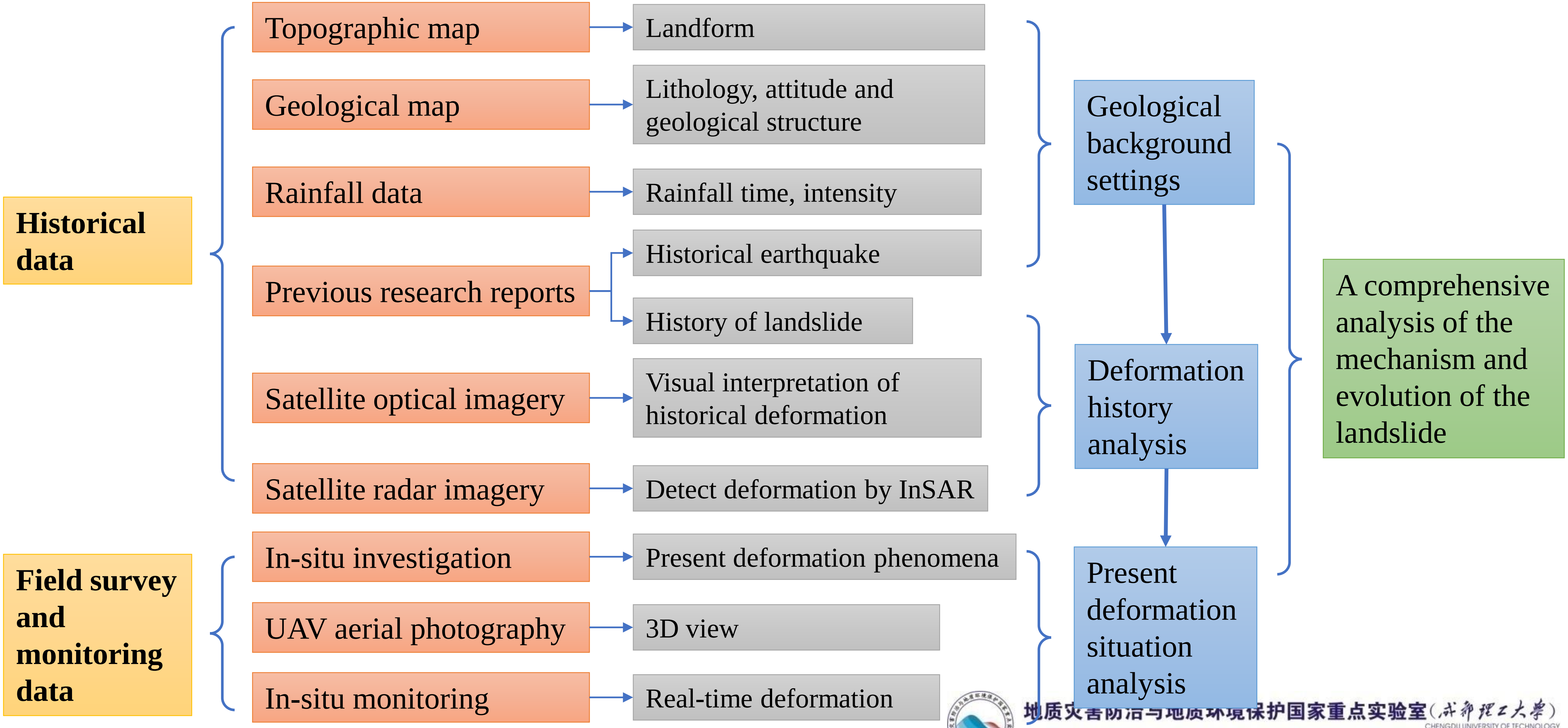
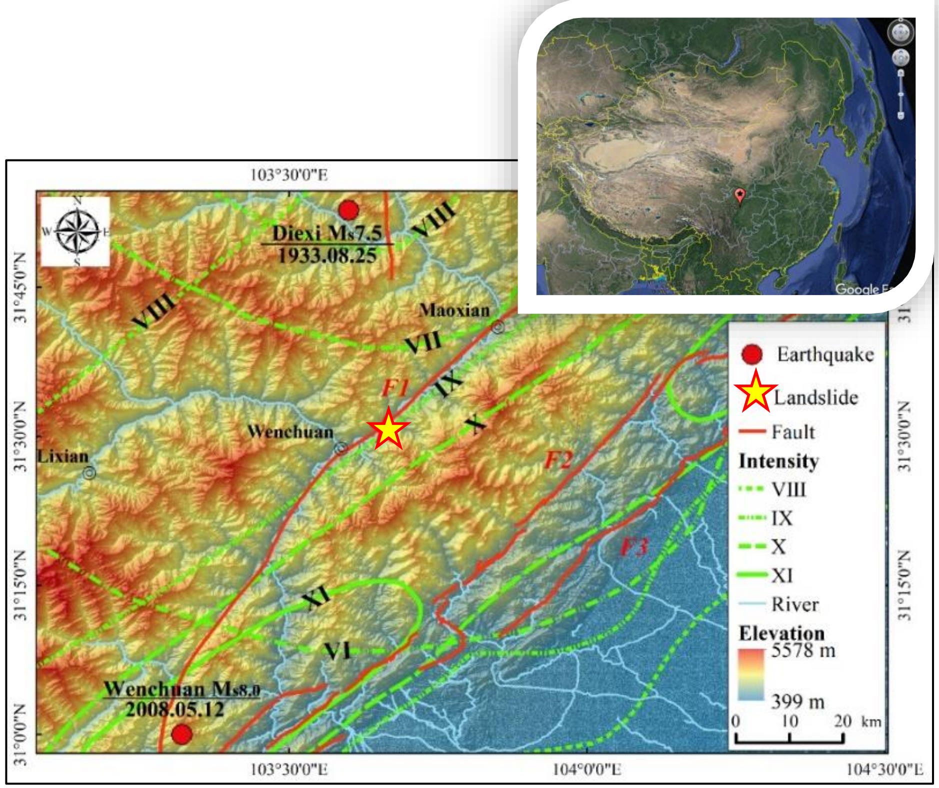
1.2 Problems need to be answered

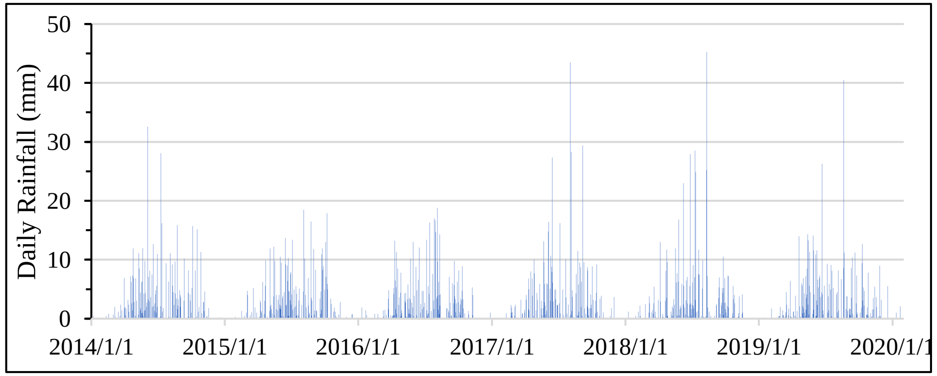
- ◆What were the development characteristics and formation mechanism of the landslide, and what deformation stage was it in?
- ◆During the rainy season (also the construction period of the new pylon), would the landslide experience large deformation or even failure?

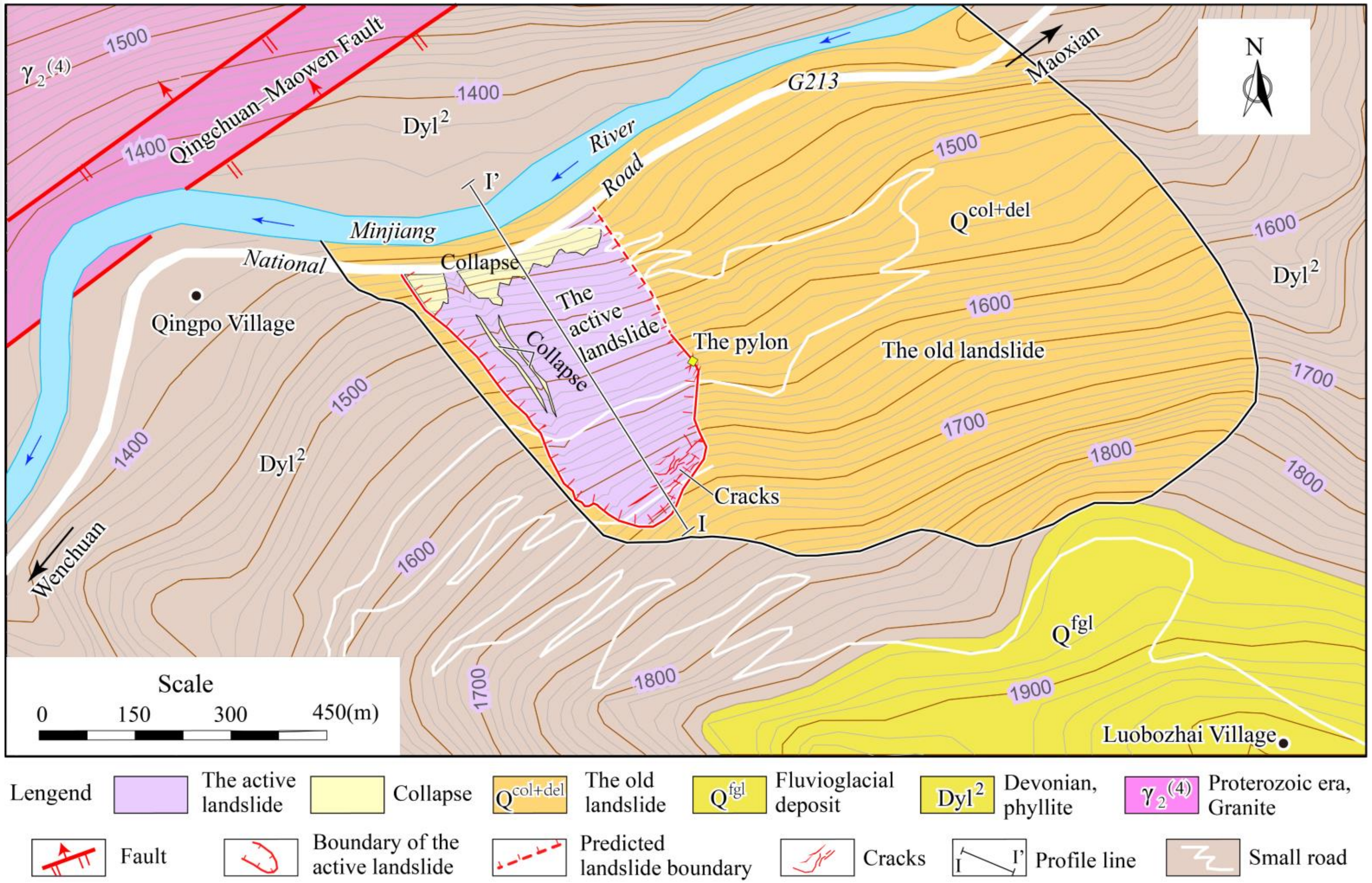
1.3 Data and technical methods



2 Geological background setting of the landslide

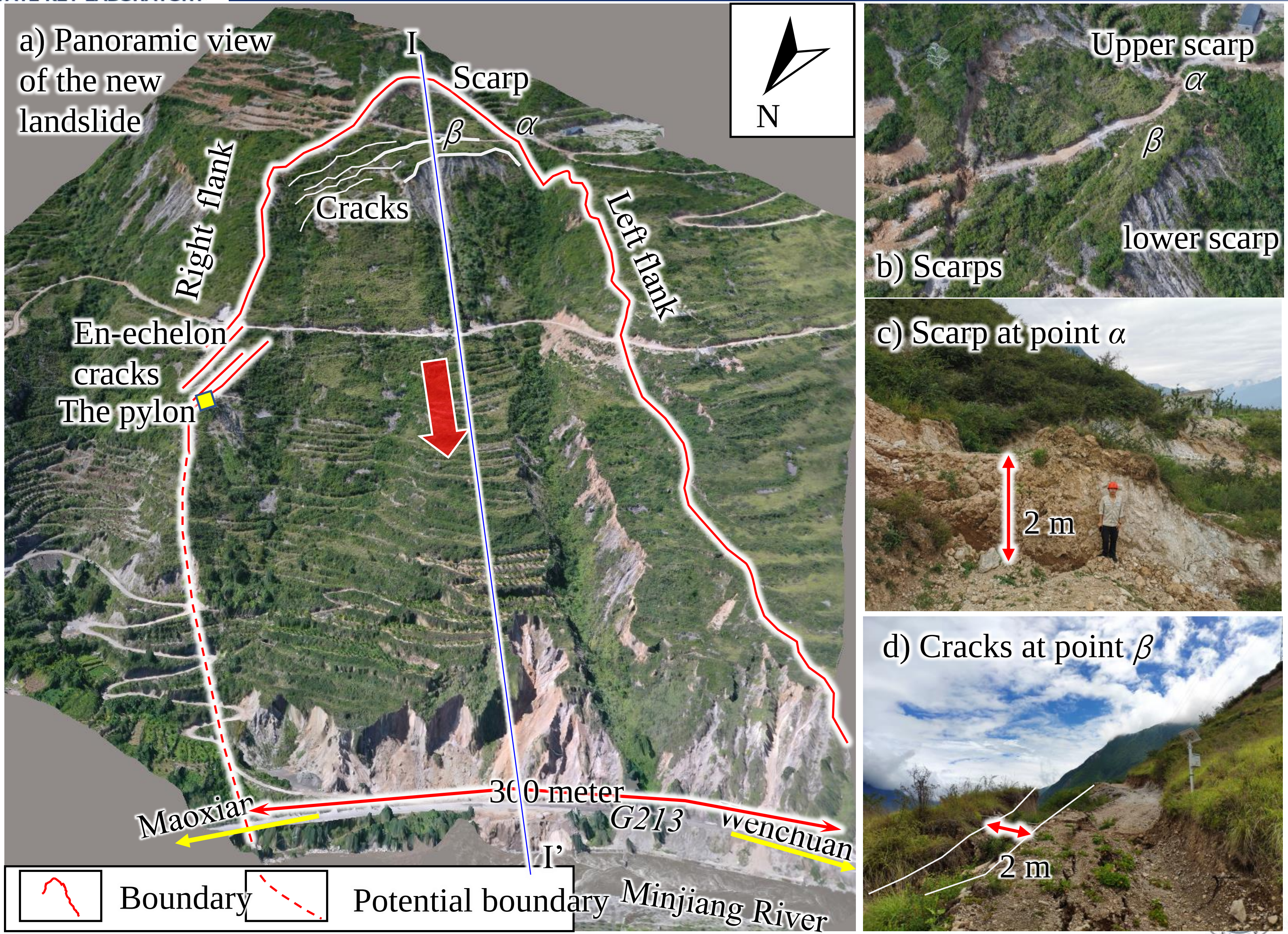






F1: Qingchuan–Wenmao Fault

2.2 In-situ and UAV investigation



A panoramic view of the landslide taken by UAV on July 20, 2019.

The main scarp and the left flank (facing the sliding direction) cracks have formed.

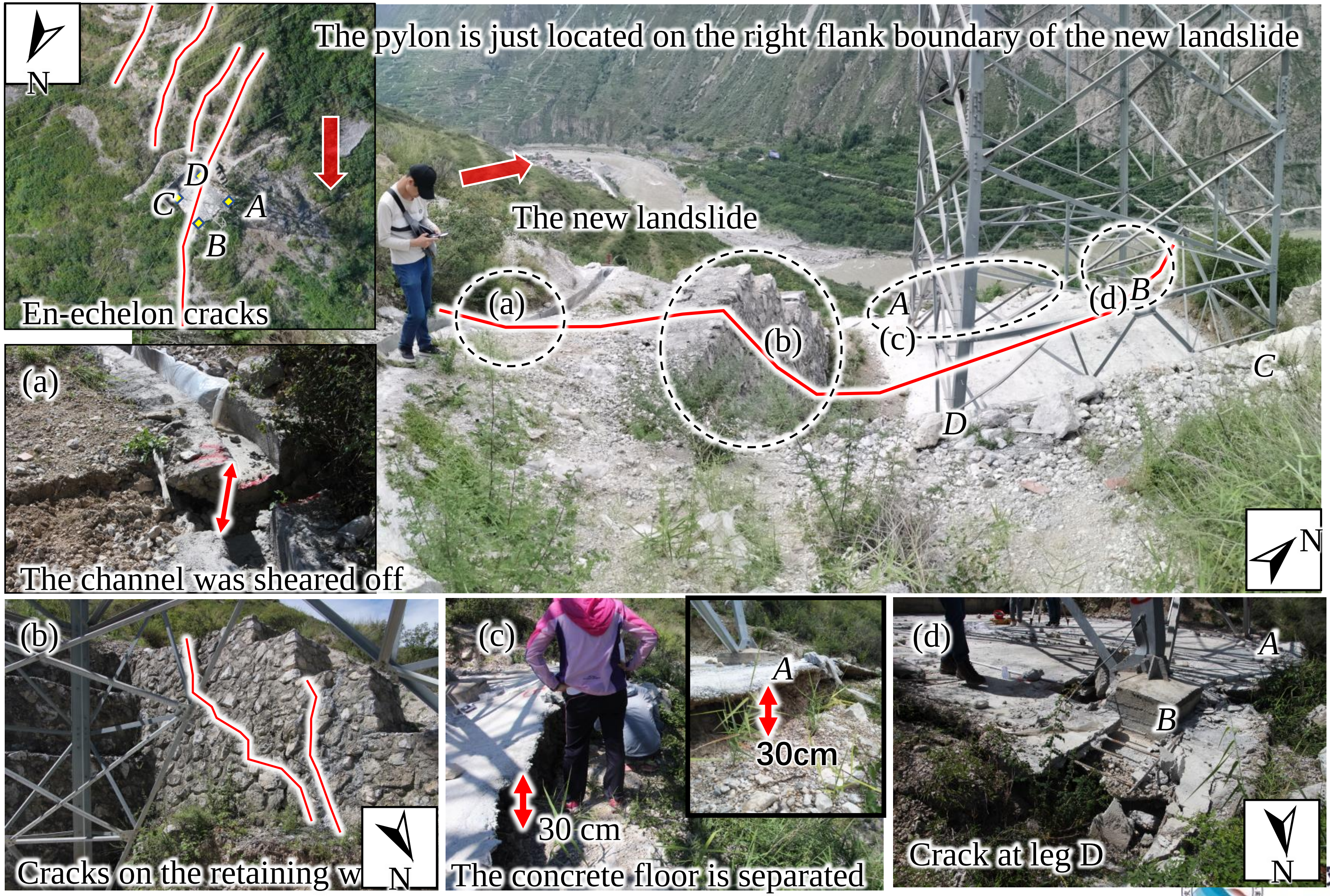
a) Cracks in the main scarp and left frank have formed but are not fully formed at the right flank boundary.

b) The landslide is characterized by two scarps, the upper scarp and the lower scarp.

c) The main scarp is approximately 2 m high at the small road (point α).

d) Tensile cracks at point β. I–I' is the location of profile.

2.2 In-situ and UAV investigation



from debris

Deformation near the pylon: the pylon (with four legs A, B, C, and D) is located at the right flank boundary of the new landslide. The crack passes through the drainage channel (a), retaining wall, (b) and concrete floor. There is obvious deformation at the leading edge of the concrete (c and d).

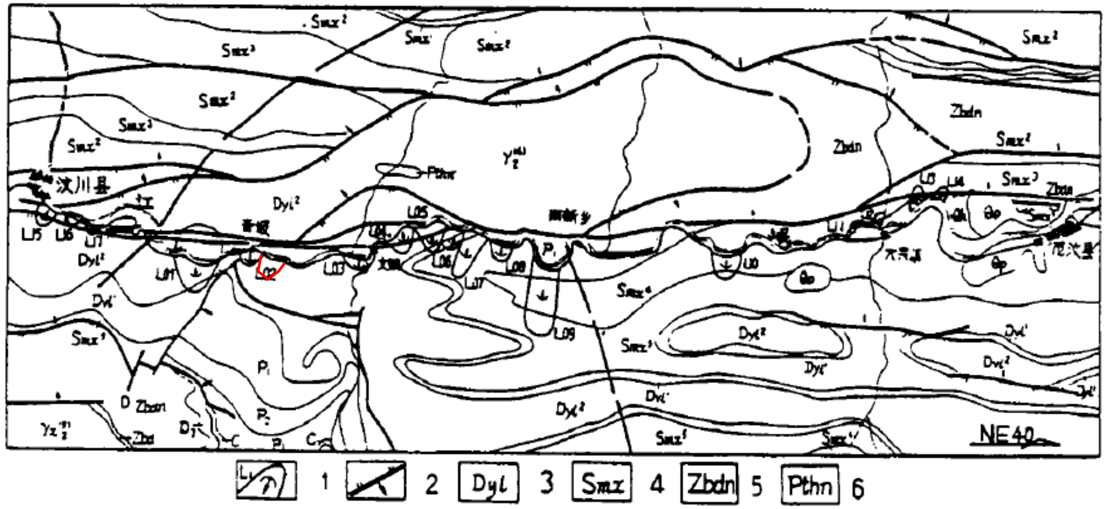
2.2 In-situ and UAV investigation

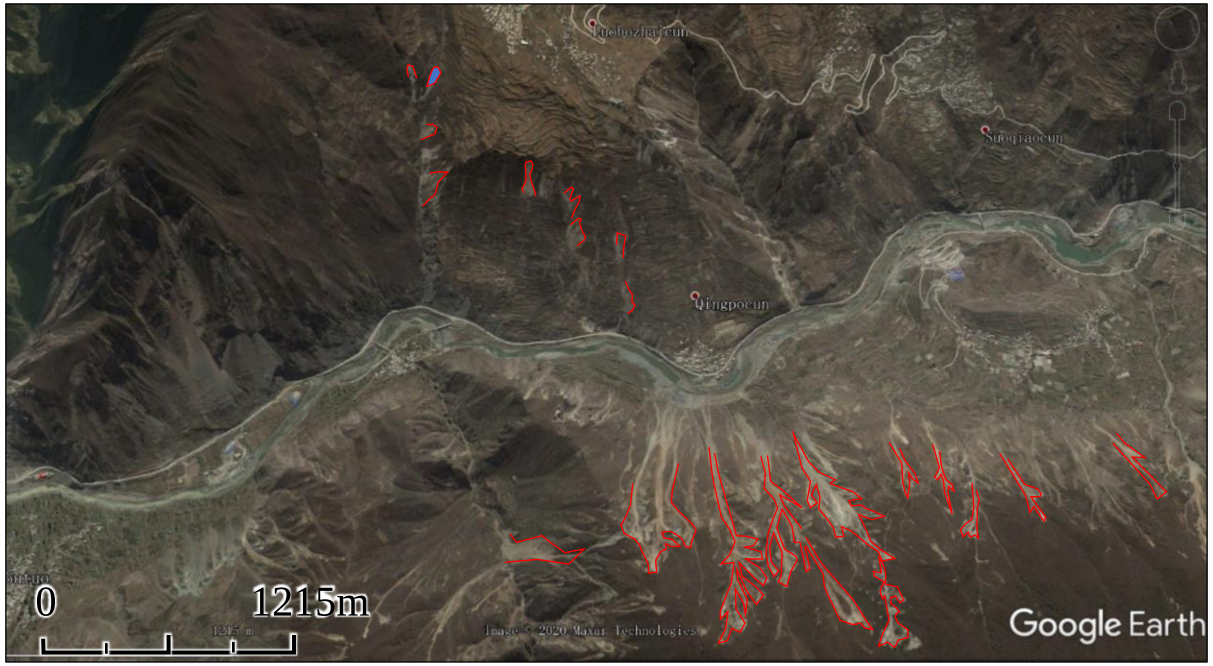
The national road *G213* is located on the leading edge of the landslide, and is the only fast passage from Wenchuan to Maoxian.

- The landslide material is mainly silty soil containing crushed, among which the crushed stone is mainly composed of crushed
- The slope often collapses, and the retaining wall is also destroyed.
- Frequent collapses often blocks traffic, threatening traffic and lives.

3 Deformation history and rea-time monitoring

The sketch map of landslide distribution along Minjiang river between Maowen and Wenchuan (Yan et al. 1998)





The remote sensing image of the study area on April 4, 2010 (two years after the Wenchuan earthquake, , no clear remote sensing image was found in 2008-2009)

- There were 17 landslides along the Minjiang river. However, the site of the landslide is not mentioned in this paper, which means the landslide shows no obvious signs of deformation.

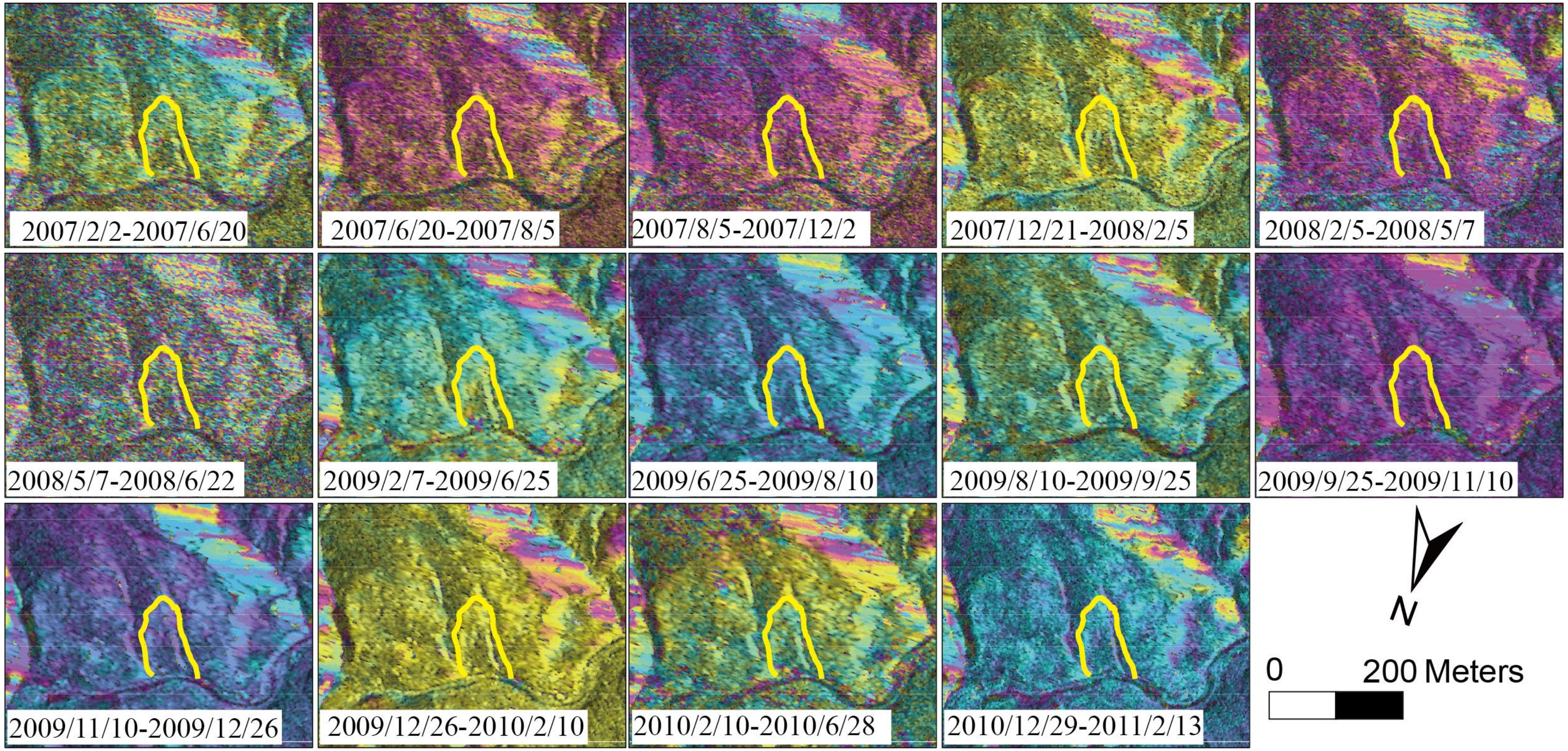
- A large number of small-scale collapses occurred in the vicinity of the study area, and only small collapses occurred in the landslide area studied, but the study slope still did not deform as a whole.

3.2 InSAR long-term deformation history

(1) InSAR result based on ALOS PALSAR data (2007-2011)

There's no obvious change of interference fringe, that is, no obvious deformation in the landslide area from 2007 to 2011.

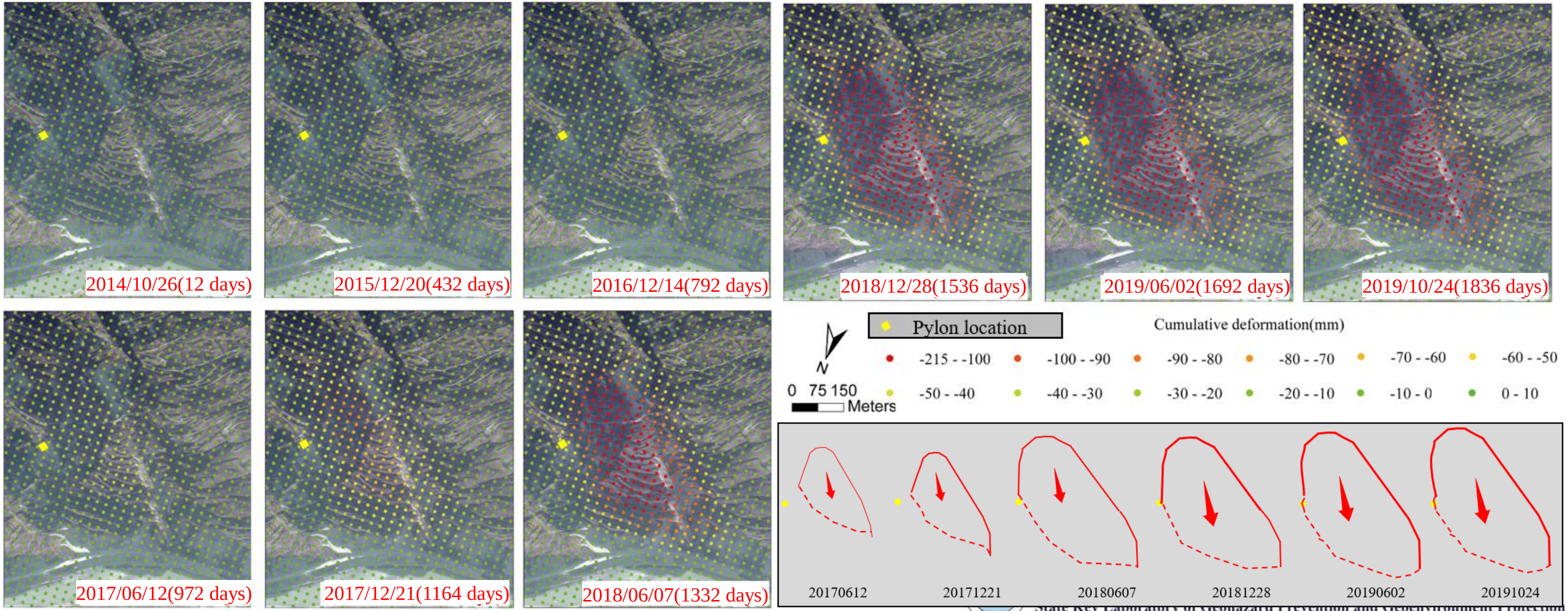
The Wenchuan earthquake did not cause significant deformation of the slope.



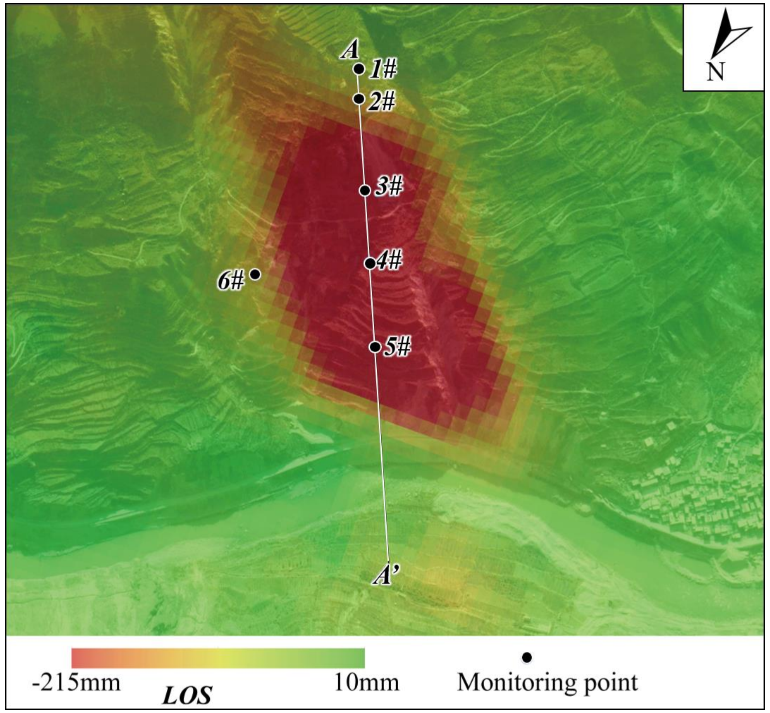
3.2 InSAR long-term deformation history

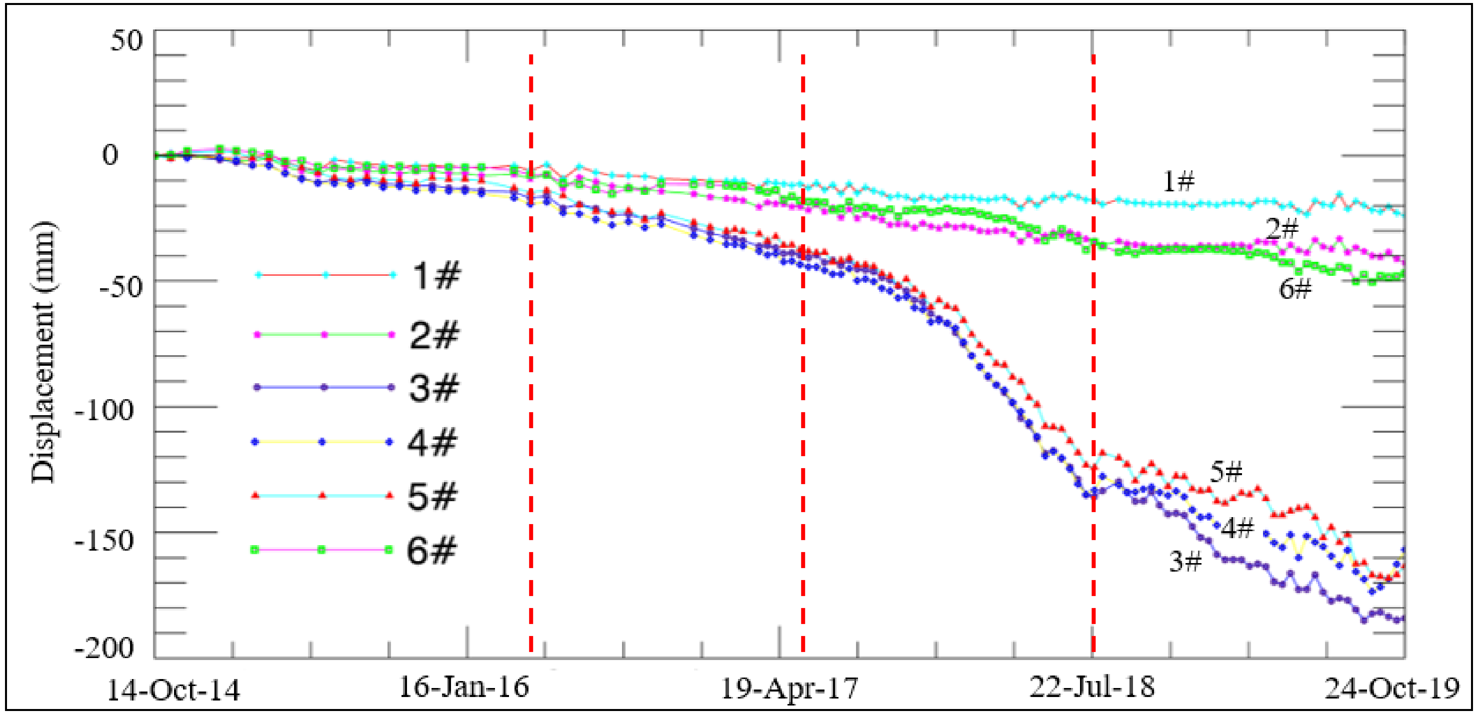
(2) InSAR result based on Sentinel-1A data (2014-2019)

The spatial deformation evolution law of the landslide shows that it gradually develops forward from the rear, and the deformation of the left side (facing the river) is greater than that of the right side.



3.2 InSAR long-term deformation history





The **temporal deformation** of the landslide can be divided into four sections.

1) From October 2014 to May 2016, the landslide began to deform, and the deformation value was small.
2) From May 2016 to around July 2017, the deformation rate of the landslide began to accelerate, but the deformation value and acceleration were still relatively small.
3) From July 2017 to July 2018, the landslide deformed rapidly. During this period, displacement increased at a relatively fast rate.
4) From July 2018 to October 2019, the deformation value was still increasing, but the rate of increase slowed.

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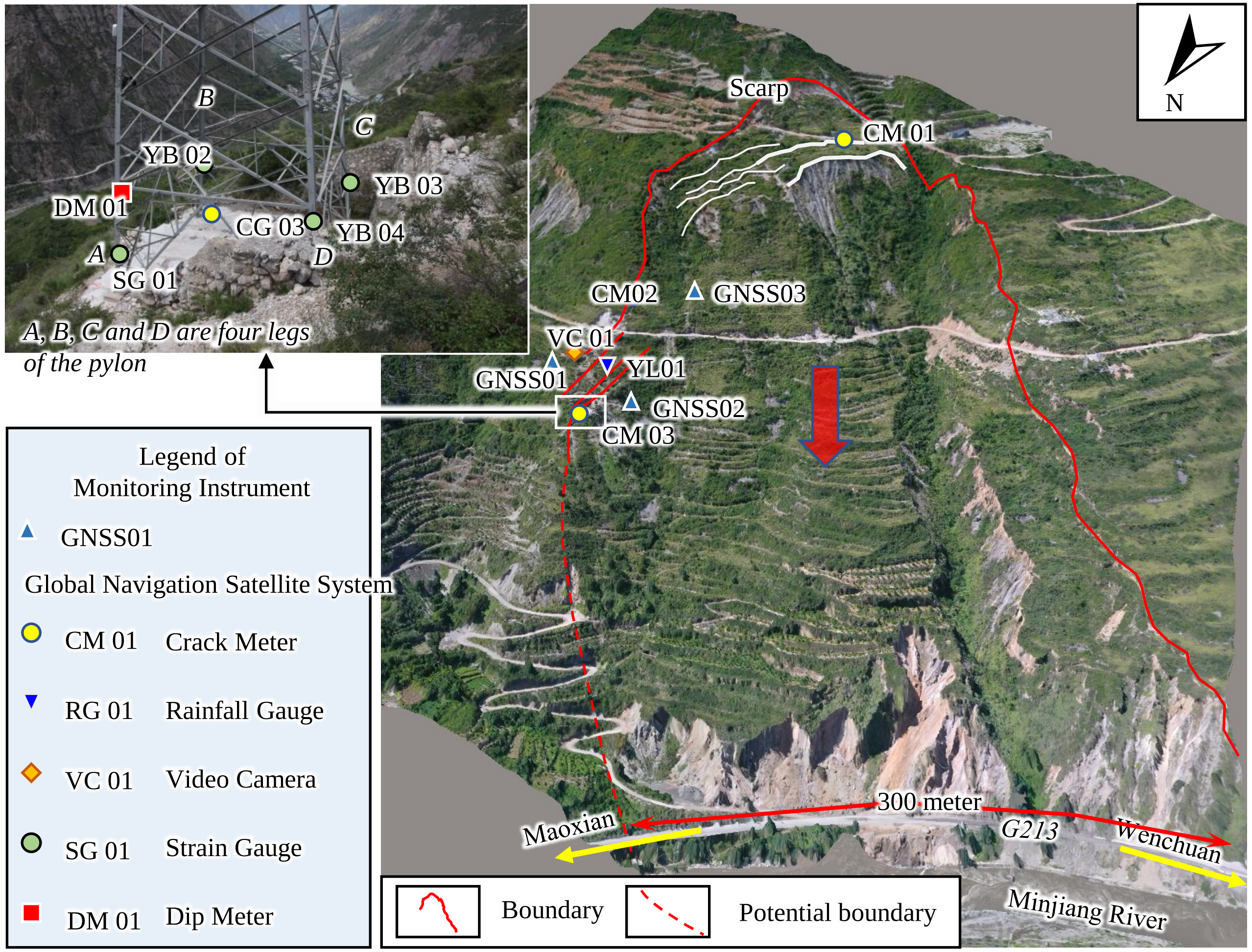
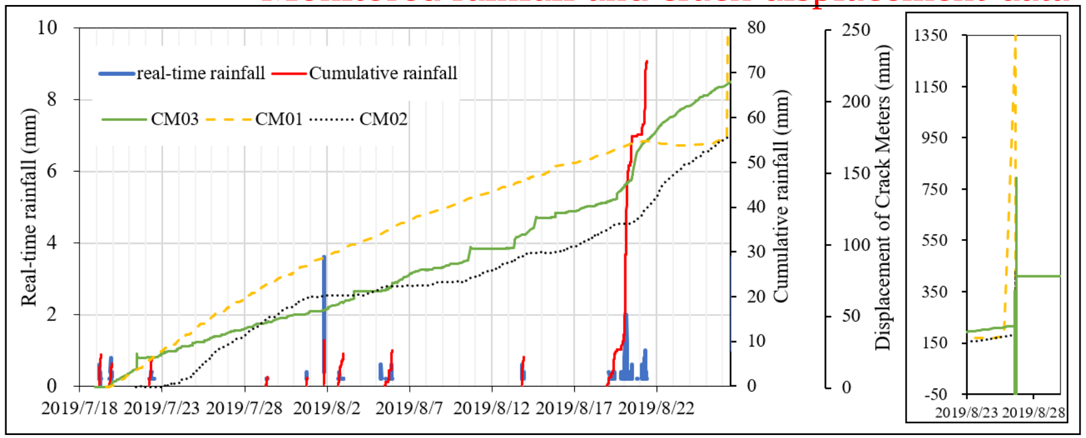
3.3 In-situ real-time monitoring

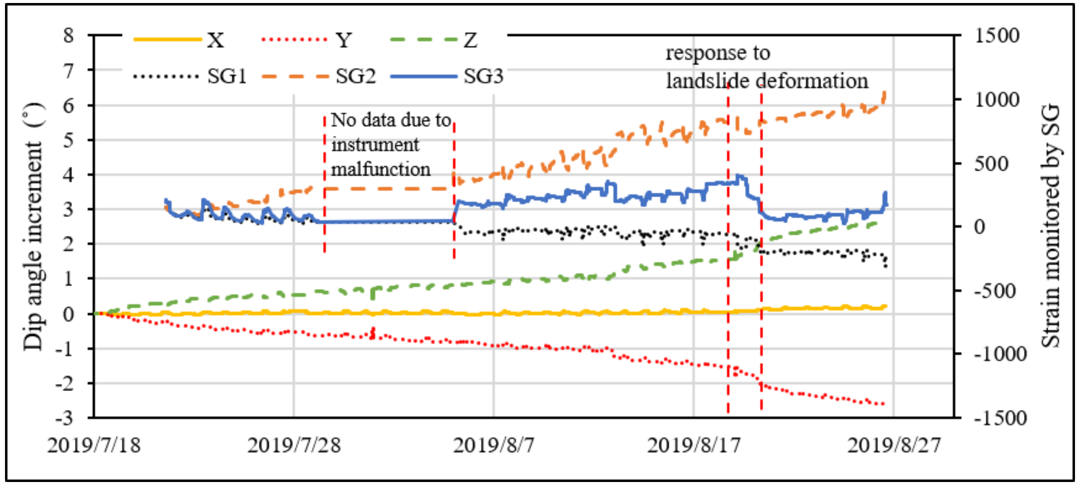
Monitoring began on July 22, 2019 and lasted until August 26, 2019, when the pylon was relocated.



Monitored rainfall and crack displacement data



Dip angle and strain data of the pylon



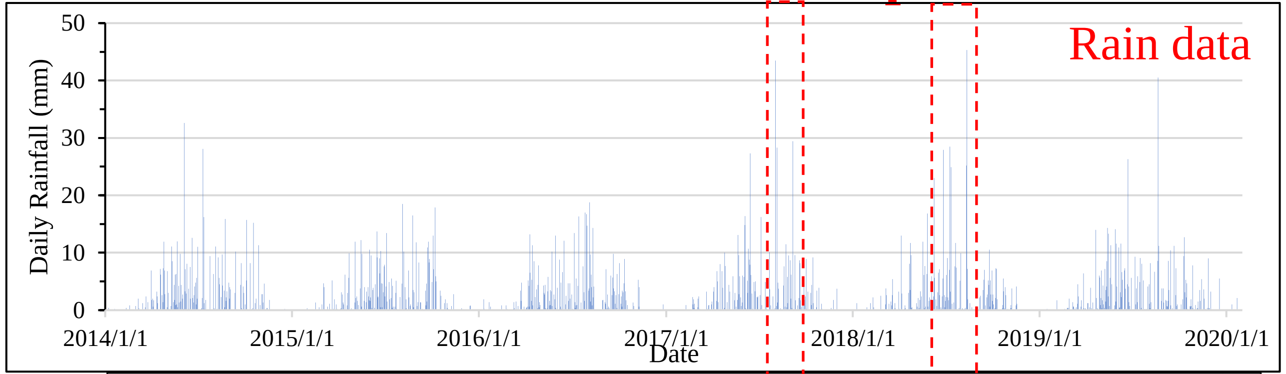
- During the monitoring period, the landslide continued deforming, but the deformation rate was not high (the monitoring curves increased slowly).
- The deformation and dip change of the four legs are small, but are affected by the landslide deformation during August 19 and 20.

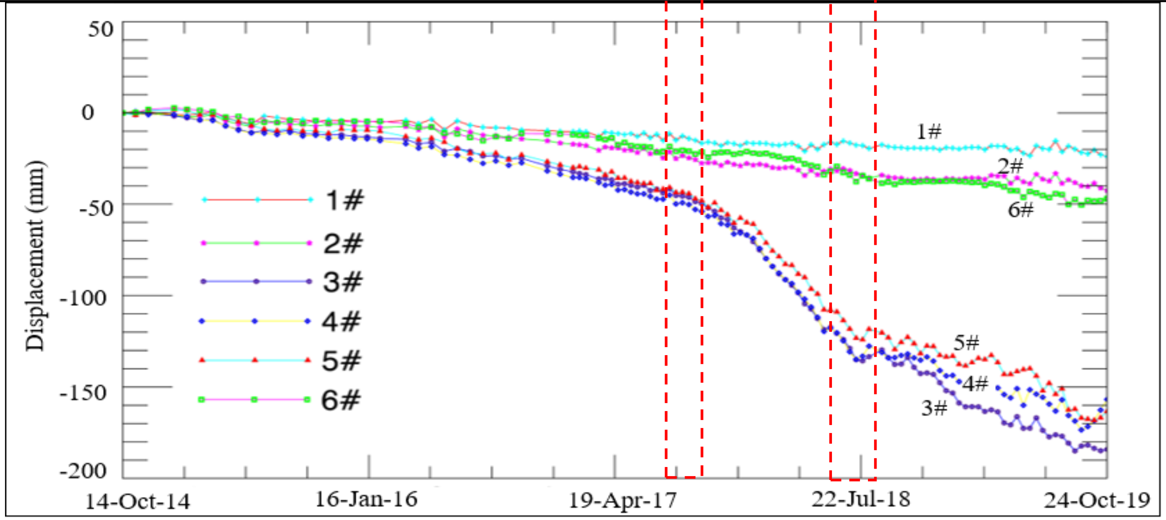
4 Discussion on landslide evolution and multi-source data

4.1 Comprehensive analysis of landslide deformation mechanism and evolution process

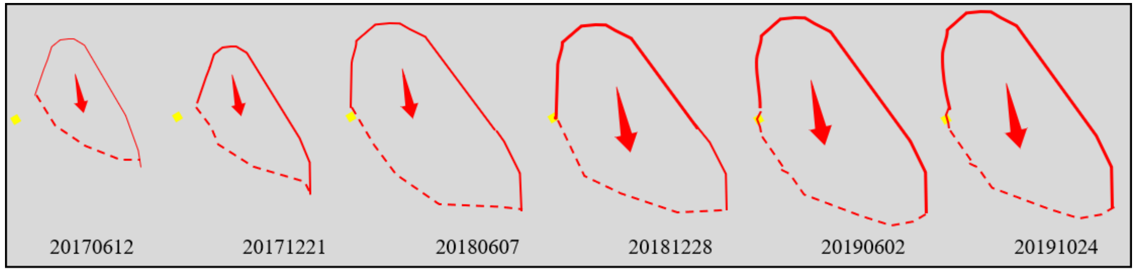
(1) Deformation mode of the active landslide

- According to the long-term InSAR deformation analysis, from October 2014 to October 2019 the landslide continued to creep over a period of 5 years.
- The landslide also gradually expanded from the rear edge to the front edge.
- Combining deformation evolution history with historical rainfall data, the landslide deformation is considered sensitive to rainfall.





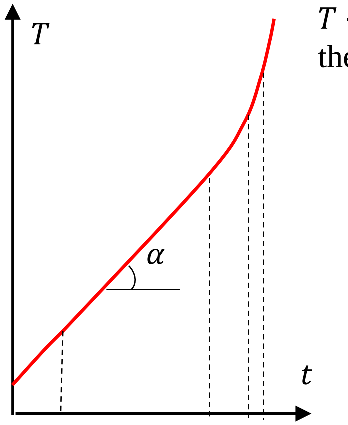
Displacement monitored by InSAR



4 Discussion on landslide evolution and multi-source data

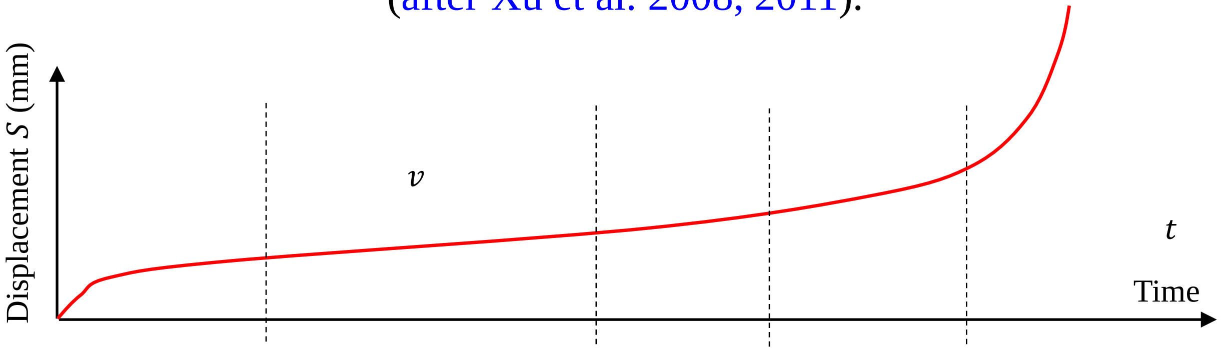
(2) Temporal deformation evolution

- The long-term monitoring curve revealed that the landslide began to deform in 2014, however, the rate decreased after July 18 and remained relatively constant.
- The real-time monitoring curves from July 2019 to August 2019 also showed that the deformation at the cracks were at a constant rate.



$T-t$ curve converted from the $S-t$ curve.

The evolution stages and early warning model of creep landslide. Slope deformation experiences three temporal stages: the initial, constant, and accelerative deformation stages. (after Xu et al. 2008, 2011).

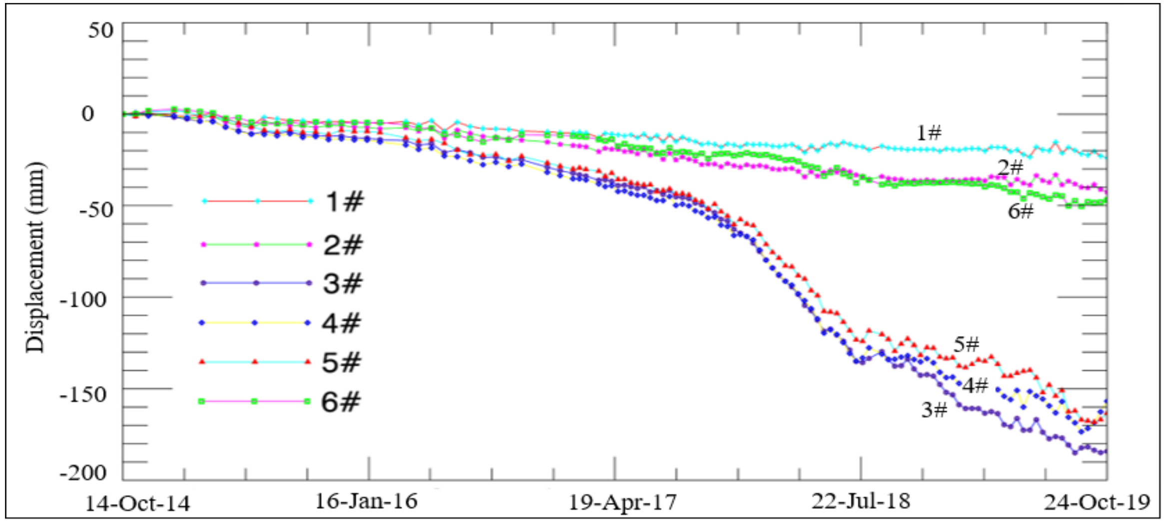


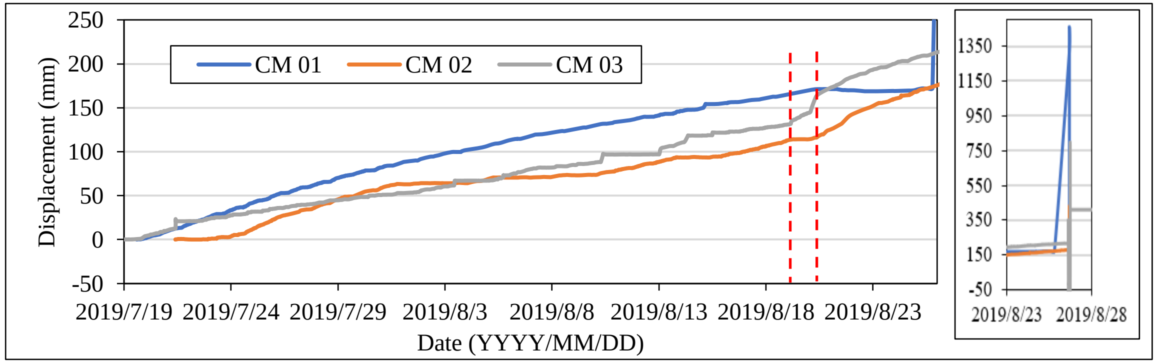
Warning parameters	Rate Increment (Δv)	--	$\Delta v \approx 0$	$\Delta v > 0$		
	Tangential angle α (°)	--	$\alpha = 45$	$\alpha > 45$	$\alpha \geq 80$	$\alpha \geq 85$
Deformation stage		Initial deformation	Constant deformation	Accelerative deformation		
Warning level		Secure	Attention	Caution	Vigilance	Alarm

Although the landslide has undergone a deformation history of up to five years, the boundary crack system of the landslide has not yet been fully formed and is still in the stage of constant deformation.

4 Discussion on landslide evolution and multi-source data

4.2 Comparison of InSAR and Real-time monitoring





- It is noted that the total deformation value of the InSAR monitoring curve is less than 200 mm from 2014 to 2019, while the real-time monitoring of the crack meters exceeded 150 mm in a month.

- One of the limitations of InSAR is that it is only capable of measuring a 3D projection of a real deformation vectors on the radar LOS; therefore, it is not possible to retrieve the full displacement vector. InSAR data are more applicable to judge the evolution trend rather than the accurate displacement of landslides.

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Conclusion

The temporal and spatial evolution characteristics of the landslide were comprehensively analyzed through on-site deformation investigation, long-term deformation monitoring by InSAR, and ground-based real-time monitoring.

- The deformation and failure mode of the landslide is that of a creep landslide. Although the landslide has undergone a five-year deformation history, it is still in the stage of constant deformation.
- To realize real-time and effective early warning, ground-based real-time monitoring methods are more applicable and accurate on the premise of understanding the evolution mechanism of landslide and spatial distribution of cracks.
- Furthermore, it should be noted that the landslide is sensitive to rainfall. Therefore, as the landslide is still deforming it remains a great threat to the national road at its leading edge.

Continuous monitoring based on multi-source remote sensing is still under way.