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A huge deep-seated ancient rock landslide: recognition, mechanism and stability

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Abstract

The identification of deep-seated landslides is a difficult problem and its failure mechanism is a research hotspot. This paper mainly discusses a very attractive huge deep-seated ancient landslide, it is a very good case to go further research. About 15 years ago a large-scale abnormal geomorphy and geological phenomenon, containing a discontinuous stratum in output and color, was found in the new city of Fengjie, Three Gorges Project Reservoir, China. Two hypotheses for the interpretation of the abnormal phenomenon are a fault graben or a large-scale landslide. From then on continue collecting and analyzing relevant information, field investigation and test, now the results show that the fault graben, consisting of normal faults, could not have been formed under the north-south compressive structure stress of the local region. Meanwhile, a lot of unique geological features, interesting sliding trails and marks of the ancient landslide are discovered and identified in field and experiments. The deformation process and failure mechanism of the ancient landslide are clearly reappeared by a large centrifuge model experiment. Its failure mechanism can be analyzed as "creep-crack-cut". The experiment strongly confirms that it is a huge deep-seated ancient rock landslide. And the failure precursor and key factors of rock slope are discussed. At last, the stability analysis shows that the landslide as a whole is stable and the secondary landslides at the front are basically stable. The results provide a technical support for decision making of the land use planning and construction of the new city, Fengjie.

1 Introduction

The identification and failure mechanism of deep-seated landslides is a hot spot subject (Crosta et al., 1996, 2000). In this paper discuss a very attractive huge deep-seated ancient landslide. The old city of Fengjie, Chongqing, China, would be inundated when the Three Gorges Project was completed in 2003. The Sanma Mountain, located upriver on the northern bank of the Yangtze River, was recommended as a site for the new city of Fengjie (Fig. 1). However, during the construction process, it was found that there is a large-scale abnormal phenomenon of geomorphy and geological structure. It contains a discontinuous stratum in output and color (Fig. 2). This strata discontinuity has been speculated to be the result of an ancient landslide (Wu, 1998; Nanjiang Geological Team, 1999) (Fig. 3). However, Li et al. (2002) put forward the hypothesis that it was caused by tectonic activity, and the surrounding area and the base of the body are cut by four normal faults (F8, F20, F19, and F26), that is to say it is a local fault graben (Fig. 4), and this idea was supported by Wang et al. (2006). We know that no matter the landslide or the tectonic activity can cause the phenomenon of a discontinuous stratum (Illies, 1981; Chang, 1981; Crosta et al., 1996, 2000; Cruden, 2007; John, 2012). Both above follow own scientific principles, but each other is easy to be misunderstood. Michael et al. (2012) found that the landslide scarp is easy to be misinterpreted as fault. On the other hand the tectonic activity can also play a key role on the development of large rock slope failures (Brideau, 2009). These two different hypotheses for the origin of the abnormal geological phenomenon caused confusion in land use planning and geological hazard prevention in the new city of Fengjie. This abnormal phenomenon of the strata discontinuity was caused by an ancient landslide or the tectonic activity? How to explain scientifically this natural phenomenon, failure mechanism and process? It need a lot of evidence and scientific analysis. In this paper, using field surveys, investigations of existing tunnels, deep drilling hole, research on the local tectonic setting and analysis on centrifuge model tests, a lot of geomorphic, structure evidence and sliding trace is found out, and it is confirmed that the fault graben consisting of normal faults could not have formed under the local region of north-south structure compressive stress. The result that it is a huge deep-seated ancient landslide and its failure mechanism of "creep-crack-cut" as a result of river rapidly incision into a nearly level layered slope with hard rock overlying soft rock.

Methods applied shall be explained in an individual Chapter.

i.e. results (not introduction), mechanisms shall be explained more precisely.

2 Geologic setting

Methods applied shall be explained in an individual Chapter.

We conducted field surveys and reviewed available geological maps, photographs and aerial photographs, papers and previous reports on the area (No. 107 Geological Team of Sichuan Province, 1980; Chen and Zhang, 1998). The regional setting of the area is summarized below.

2.1 Regional geological structure

unclear; please explain.

references (data sources) shall be cited.

Fengjie, in the Three Gorges Reservoir Area, is located at the eastern edge of the secondary terrain of China. It belongs to the Yangtze platform which contains basement rock mainly composed of early Proterozoic metamorphosed volcaniclastic rocks and intrusions of magmatic rocks. The overlying sedimentary rocks, which were deposited during the Triassic Period, were folded during uplift as part of the Yanshan Movement at the end of the Jurassic Period. As a result, secondary tectonic units, including the upper Yangtze platform fold belt, the marginal depression of the Sichuan Basin, and the Dabashan platform fold belt, were formed. These secondary tectonic units converge in Fengjie under compressive north-south stress (Figs. 5–7).

2.2 Strata and rocks

Soils missing, please revise.

The rocks of the Sanma Mountain are sedimentary rocks of Triassic age (Fig. 7). The Jialingjiang Group (T_{1j}), which is of Early Triassic age, was deposited in shallow lagoon facies, and contains sedimentary limestone, dolomitic limestone, and marlite. These rocks occur in the core of the Zhuyi duplex inverted anticline. The Middle Triassic Badong Group (T_{2b}) was formed in inland lake and lagoon facies, with both clastic and carbonate deposition. The rocks making up the group consist of mudstone, silty mudstone, and marlite. The group is divided into units T^1_{2b} to T^5_{2b}. T^1_{2b} to T^4_{2b} occur in the new city of Fengjie.

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3 ~~Fault graben can not form~~

(local) structural setting (of landslide area)

The Zhuyi anticline at Sanma Mountain is a duplex inverted anticline (an ove[…] and closed fold, axial plane slanting, and overturned strata occur) (Figs. 7–9), and there is strong crumpling of strata in the core of the Zhuyi anticline (Figs. 7 (2), (3), (4) and 9). We investigated and measured the Zhuyi anticline tectonic stress field, the conjugate shear joint structural stress (Fig. 10) and the compression structural stress. The regional maximum principal stress direction is 344–352.5° by means of stereographic projection analysis of occurrence of conjugate shear jointing and reversal stratum (Fig. 11). The result is the new city of Fengjie has a N-S compressive stress field as the tectonic background. The crust and mantle stresses and resulting rock deformation have resulted in closed fold and thrust compressional structures. The regional tectonic background is not consistent with formation of a graben structure under tensional stress. Under the control of N-S compressive stress, the geological structure in new city of Fengjie changed from potential strike-slip type in the early stage to potential thrust type during formation of the main structure.

please explain more precisely, incl. explanation of figures.

i.e. paleo-stress reconstruction (…plane analyses), but not measu[…] of recent in-situ stress!

In field we found that the four tension faults, F_8, F_{20}, F_{19}, and F_{26} (Li Huizhong, 2002) (Fig. 4), share some common characteristics. The fault extension length is not long (F_8: 1110 m, F_{19}: 150 m, F_{26}: 100 m), and the fault fracture zone width is not large (F_8: 3.5 m, F_{19}: 0.1–1.1 m, F_{26}: 1–2 m; conversely, fault displacement is very large (F_8: 150–180 m, F_{26}: 25–35 m). Studies have shown that the four normal faults, F_8, F_{20}, F_{19}, and F_{26} (Li et al., 2002), did not form in a compressive stress field, according to geological mechanics (Illies, 1981; Chang et al., 1981). The footwall rock mass of the fault is preserved intact, although the hanging wall has almost entirely disintegrated; this observation is also not consistent with formation of a deep fault under confined conditions. The preserved thickness of T_{2b}^2 is only 200 m (Li Huizhong, 2002); a 300 m thickness of this formation has been lost as a result of faulting, which cannot have happened as part of normal faulting. Faults F_{20} and F_{26} cannot be observed on the ground, and faults F_8 and F_{19} show characteristics of sliding (pressure-shear), rather

Numbering unclear, please ex[…] F26 only inferred (see Fig. 4).

than tension as with a normal fault. Thus, interpretation of the abnormal geological phenomenon at Sanma Mountain as a fault graben is not in agreement with the observed evidence.

Slope model ("abnormal") and discussion of fault pattern ("graben") unclear, shall be explained more precisely.

4 Identification of the Sanmashan landslide

The work that disproved the fault graben hypotheses also provided a lot of evidence for the abnormal geological phenomenon at Sa[...] ancient landslide. Details of the morphology evide[...] and trace in the landslide are given below.

terminology/classification unclear; please explain why not "inactive" or "dormant" (classification shall be provided in accord with international standards, e.g. Cruden & Varnes 1996, WP/WLI 1993)

4.1 Geomorphic evidence and sliding mark or trace

There is a steep cliff over 100 m height in the trailing edge of the landslide, and a gully called Baiyangping at the western lateral edge, and a gully called Sunjia at the eastern lateral edge, and the Yangtze River in front of the landslide. The terrain gradient of the landslide is 15–20°. The length of landslide is over 780 m, the width is about 1020 m, the maximum thickness is 170 m, the average thickness is about 125 m, and the volume is about 100 million m^3. We subdivided the landslide into five domains (I–V) based on differences in morphology, geological structure, and inferred failure mechanics (Figs. 12 and 13).

Crown or head scarp (Fig. 14): there is [...] elevation of 300–410 m. During an foundat[...] Fengjie city, the sliding face and scar in the end of the landslide were exposed (Fig. 15).

unclear (elevation above sea level or height difference ?); in general, please explain all cited data more precisely.

Eastern lateral edge: a deep gully, called Sunjiagou, is present at this edge of the landslide (Fig. 16). A sliding zone and marks are very obvious (Fig. 17), which have been misidentified as fault F_{19} in the past (Li et al., 2002).

Before Chapt. 4, an individual Chapter "Methods" shall be provided, explaining all field surveys, geophysic surveys, drillings (incl. borehole logs, borehole tests, sampling etc.), lab tests etc.

Western lateral edge: there is a shallow groove called Longzibaogou leading into Yangjiaping gully (Fig. 18). Sliding scratches were observed during level drilling (Fig. 19).

The elevation of the slide tongue is about 90 m. The three secon at the foot of Sanmashan landslide are called as Houzishi, Zhiwuyou, landslides.

Before Chapt. 4, an individual Chapter "Metho provided, explaining all field surveys, geophys drillings (incl. borehole logs, borehole tests, sa lab tests etc.

4.2 Structural evidence

Based on regional geological mapping, drill holes, and a large excavation at the site, six engineering geological units were identified in the landslide. The units are as follows (Figs. 12 and 20):

The bedrock: (1) the third unit of the Middle Triassic Badong Group (T^3_{2b}). This unit contains gray or dark gray limestone and marlite, with a regional thickness of up to 205 m. (2) The second unit of the Badong Group, which consists of kermesinus or dark red-brown mudstone and silty mudstone, with a regional thickness of up to 550 m. (3) The first unit of the Badong Group. This unit consists of earthy yellow or light gray marlite and shale, with a regional thickness of about 70 m.

unclear, please explain.

Artificial soil (Q^{ml}): the artificial soil is loose to dense, consists of clay and sand within crushed stone, and is randomly distributed on the landslide surface. The observed unit thickness is up to 10 m.

Soils (units "Q") are not mentioned in Chapt. 2.2, shall be revised accordingly.

Alluvium (Q^{apl}): the alluvium is loose to less dense, sub-round cobbles, and boulders of mixed limestone and silty mudstone within sand, distributed at the front of landslide. The observed unit thickness is up to 15 m.

Landslide deposits (Q^{del}): including three units followed. (1) The first unit is dense to denser, and contains gray or dark gray crushed stone, within silty clay and sand. The crushed stone is derived from limestone and marlite (T^3_{2b}). A large foundation pit was constructed in the center of the landslide during field surveys (Figs. 21 and 22). The slide zone of the Zhiwuyou secondary landslide is exposed in the eastern wall (Figs. 23 and 24), and the rock masses in the western wall have anomalous attitudes

unclear, please explain.

with respect to each other (Figs. 23 and 25). (2) The second unit is denser, reddish or dark red-brown, and contains crushed stone, within clay and silty clay. The crushed stone is derived from mudstone and silty mudstone (T^2_{2b}). (3) The third unit is denser, earthy yellow or light gray, and contains crushed stone, within sand and silty clay. The crushed stone is derived from limestone and shaly limestone (T^1_{2b}). The thickness of three units is up to 170 m.

5 Failure mechanism of the Sanmashan landslide

unclear why "centrifuge experiment" performed; please explain what / which landslide mechanisms were tested/analysed.

In order to research the deformation process and failure mechanism of the Sanmashan landslide, We carried out a large centrifuge model experiment. The centrifuge technology is widely applied in geotechnical and geological engineering, especially in the simulation of slope deformation and f

unclear why "centrifuge experiment" (remark: for the investigated landslide slope, other lab tests may be even more appropriate, e.g. direct & triax shear tests, ring shear tests, etc.)

5.1 Test device and principle

A centrifuge is a piece of equipment that puts an object in rotation around a fixed axis (spins it in a circle), applying a potentially strong force perpendicular to the axis of spin (outward). Geotechnical centrifuge modeling is used for physical testing of models involving soils and rock. Centrifuge acceleration is applied to scale models to scale the gravitational acceleration and enable prototype scale stresses to be obtained in scale models. Problems such as building and bridge foundations, earth dams, tunnels, and slope stability, including effects such as blast loading and earthquake shaking. Large centrifuges are used to simulate high gravity or acceleration environments. This experimental modeling used a centrifuge at the State Key Laboratory of Geohazard Prevention and Geoenvironment Protection in China (Fig. 26). Its maximum acceleration is 500 gt, and it is the largest geotechnical centrifuge in Asia.

It's mathematical description is similarity theory (Taylor, 1995). So according to the dimension relationship between geological model and experimental model, similarity coefficient is deduced Unclear/not explained; Fig. 28 and related test shall be explained which natural slope (landslide) processes were analysed/simulated.

a test model (Fig. 28). Rock parameters were obtained from physical and mechanical geotechnical engineering tests (Table 2).

5.2 ~~Test result analysis~~

Lab test results unclear, shall be explained which natural slope (landslide) processes were analysed/simulated.

The experiment situations and observed results were as follows. First, there was a quiet period in which the Yangtze River cut into the central part of T_{2b}^3. Tension cracking appeared at the surface of the slope, extending and scaling down (Figs. 27 and 29). Second, an intense period of incision in the bottom par… took place along the bottom weak zone, and there was… crack (Figs. 27 and 30). The third phase was a short an… the bottom part of T_{2b}^2. The crack cut through the botto… swiftly occurred (Figs. 27 and 31).

These are not results obtained from lab tests, but rather reflects a conceptual model incl. some speculative interpretations...(unclear if cross-check with / validated by field/lab tests..)

The deformation and failure mechanism can be summarized as "Creep–Crack–Cut" (Fig. 32). This failure mode generally occur as a result of river incision into a nearly level layered slope with hard rock overlying soft rock. S… Longyangxia in the Yellow River (Fig. 33) and the Yanchihe… China. In order to early recognition and warning of such l… and failure precursors of slope failure are discussed (Table 3).

terminology/classification unclear; shall be provided in accord with international standards, e.g. Cruden & Varnes 1996, WP/WLI 1993, etc.

6 ~~Stability of the Sanmashan landslide~~

Slope stability analyses

On the basis of the research above, we analyzed the seepage and stability of the Sanmashan deep-seated landslide using Geostudio 2007 (Fig. 34). The results of the analysis are discussed below.

Not included in Chapt. "References"

If the reservoir water level increases from 145 to 175 m, using the current rate of reservoir scheduling, landslide stability will increase as a result of a rise in the groundwater level behind the water level of the reservoir. After rising of the water

Chapt. 6 is not sufficient; analyses shall be explained more clearly / documented more properly, incl. assessment of geotechnical input parameter, model geometry etc.

level of the reservoir to 175 m, landslide stability will begin to decrease with further rises in groundwater level. If the reservoir water level is reduced from 175 to 145 m, at the current rate of reservoir scheduling, the resulting decline in the groundwater level behind the water level of the reservoir will cause landslide stability to decrease. After reduction of the water level of the reservoir to 145 m, further decline of the ground[...] level will cause landslide stability to increase gradually. (Fig. 35).

Considering the amount of rainfall (120 mm d^{-1}, 3 days) during the period wh[...] reservoir water level changes from 175 to 145 m, and comparing with the situation with no rain, rainfall has little effect on the stability of the whole landslide, but has a[...] influence on the occurrence of secondary landslides at the front of the main[...] (Fig. 36).

At present, the stability coefficient of the Sanmashan landslide is greater than 1.20, and that of the secondary landslide at the front of the main slide is more than 1.076 before treatment.

Hardly/not comprehensible; parameter, analyses and results shall be explained more detailed.

Based on which source data / references ? Please revise.

unclear; please explain if factor of safety valid for the whole landlside area, and/or for individual sub-slabs (see e.g. Fig. 12 !) ?

unclear, "treatment" (mitigation measures) shall be explained.

7 Discussion

As is known to all, the geological phenomenon of a discontinuous stratum in output and color can be maybe interpreted as a fault graben or a large-scale landslide, but their genetic mechanism is different. In this paper the abnormal geologic body is a good case in the new city of Fengjie, Three Gorges Project Reservoir, Ch[...]

Firstly In order to find out the truth, the scientific method is tha[...] it is contrary to the principle of geological mechanics. By means of survey analysis of geological structure stress and forming condition, we think that the fault graben consisting of four normal faults could not have formed under the local region of north-south compressive structure stress. Fengjie City, which is in the Three Gorges reservoir area, is located on the eastern edge of the secondary terrain of China. The region belongs to the Yangtze paraplatform, in which the basement rock is mainly composed of early Proterozoic metamorphic volcaniclastic rocks and magmatic

unclear, project shall be explained above (e.g. Ch[...] Introduction, not in "Discussion"), espec. concerni[...] fluctuations and related slope stability...

Chapt. 7 shall be revised basically.

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Chapt. 7 shall be revised basically.

intrusions. The overlying sedimentary strata underwent folding during the Jurassic Yanshan Movement. As a result of the Yanshan Movement, secondary tectonic units were formed, including the upper Yangtze platform fold belt, the marginal depression of the Sichuan Basin, and the Dabashan platform fold belt. These secondary tectonic units converge in Fengjie under north-south compressive stress. Thus, the new city of Fengjie is sited at a special tectonic position. Sanma Mountain is located in the northern wing of the Zhuyi double reversal anticline. Under the influence of the N-S compressive stress field, deformation has mainly taken the form of closed-type folds and thrust compression structures, so the regional tectonic conditions are not suitable for formation of a fault graben. In addition, the hypothetical faults F_{20} and F_{26} cannot be observed in the field, while faults F_8 and F_{19} have the characteristics of sliding (pressure-shear) faults rather than those of normal faults. Thus, the interpretation of the geological anomaly as the fault graben is not supported by the available evidence.

Correspondingly, there is plenty of evidence to interpret as a landslide. In this paper the geomorphologic and geological features, subsurface geological units, and many sliding marks or trails of the Sanmasha field. Especially the sliding marks and scrap mechanical property is compressive. This is completely contrary to normal fault of a fault graben, because of their mechanical property is tensi their anomalous attitudes each other in the western wall of t of geologic structure is only generated by landslides. The results of this study have confirmed that the Sanma Mountain in the new city of Fengjie is a large-scale ancient deep-seated landslide. From analysis of the slope deformation process and failure in centrifuge experiment model, it is reasonable to summarize the deformation and failure mechanism of landslide as "creep-crack-cut." This type of failure generally o a nearly level layered slope with overlying hard rock and underlying soft ro rapid incision by a river takes place. Due to the limited level of the author, sor phenomenon is not well presented, but it is a very attractive case to further the huge deep-seated ancient landslide.

unclear; local stress regime depending on the local setting (slope position)...

shall be discussed if/how landslide can be reactivated (e.g. earthquakes, water-level fluctuations, etc.)

depending on soil/rock mass properties, slope characteristics (orientation, inclination, breaklines, etc.), characteristics of discontinuities (joint orientations, lenghts, etc.), thus shall be explained/discussed more extensively.

unclear; why then intend to publish in an internat. scientific journal as NHESS...?

We also discussed landslide stability under increasing and decreasing of the reservoir water level, thinking reservoir scheduling at the current rate. Landslide stability will increase if the reservoir water level rises from 145 to 175 m, but landslide stability will decrease if the water level continues to rise above 175 m. Landslide stability will decrease if the reservoir water level drops from 175 to 145 m. Further water level decreases, to less than 145 m, will cause landslide stability to increase gradually. Rainfall has little impact on the stability of the whole landslide, but does have a great influence on the secondary landslide at the front of the main slide. At present, the landslide is stable as a whole; and the secondary landslide at the front is basically stable. But it needs to further research whether it can maintain long-term stability.

8 Conclusions

Chapts. 7 & 8 somehow mixed up;
in general, results, discussions and conclusions shall be structured more properly.

Using field surveys, investigation of existing tunnels, research into the tectonic setting, borehole drilling, and centrifuge model experiment, the result shows that the fault graben consisting of normal faults could not have been formed under the north-south compressive structure stress of the local region.

Meanwhile a lot of unique geological features and interesting sliding trails or marks of the ancient landslide are discovered or identified in field and experiment. it is proved that the abnormal geological phenomenon in the new city of Fengjie, Three Gorges Project Reservoir, China, is a large-scale ancient deep-seated landslide. The length of landslide is over 780 m, the width is about 1020 m, the maximum thickness is 170 m, the average thickness is about 125 m, and the volume is about 100 million m^3. Three secondary landslides are present at the foot of the Sanmashan landslide: the Houzishi, Zhiwuyou, and Laofangzi landslides. It is summarized the deformation and failure mechanism of landslide as “creep-crack-cut.” And discuss the failure precursors and key factors, including the geological structure, boundary conditions, deformation and failure precursors, that can be refer to early recognition and warning of landslides.

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A huge deep-seated ancient rock landslide

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At last, the stability analysis show that the landslide as a whole is stable and the secondary landslide at the front is basically stable. The results provide a technical support for decision making for the land use planning and construction of the new city of Fengjie. But there is a risk of local deformation and landslides because of the intensive construction and centrated population, So it is very necessary to draw up a strict land use plan.

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Style shall be revised according to NHESS specifications (see www.natural-hazards-and-earth-system-sciences.net/for_authors/manuscript_preparation.html)

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=> therein at least sections of this NHESS article (Text, Figures) were already published but not cited herein...

- references on international landslide classification/terminology,
  e.g. Cruden & Varnes 1996 (Landslide Types and Processes),
  WPI/WLI 1993 (UNESCO Working Party on World Landslide Inventory),
  Australian Geomechanic Society 20007, 2015 (Landslide Risk Management, Landslide Hazards)

- references related to landslides at reservoirs,
  e.g. Zangerl et al. 2010 (Engineering Geology 112),
  Barla et al. 2012 (Engineering Geology 116),
  several recent papers on the Vajont distaster etc.

parameter/model unclear, please explain.

Table 1. Key similarity coefficient in experimental model.

Physical quantity/Symbol	Unit	Similarity coefficient
Acceleration/a	g	$N_a = 30$
Dimension/L	m	$N_L = 1/3000$
Density/ρ	$g\,cm^{-3}$	$N_\rho = 1$
Modulus/E	Pa	$N_E = N_\rho N_a N_L = 1/100$
Internal friction angle/φ	°	$N_\varphi = 1$
Cohesion/c	Pa	$N_c = N_\rho N_a N_L = 1/100$
Poisson's ratio/ν	–	$N_\nu = 1$

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already published in Trang et al (2015), shall be cited...

Modulus unclear (UCS, E, ...?), please specify.

Table 2. Rock parameters in experimental model.

Rock	Modulus (MPa)	Poisson's ratio	Density ($g\,cm^{-3}$)	Cohesion (KPa)	Internal friction angle (°)
limestone T_{2b}^{3}	40–50	0.25 ~ 0.30	2.3–2.5	1.2	30–35
mudstone T_{2b}^{2}	8–10	0.35 ~ 0.40	2.1–2.3	5.0	20–25
marlite T_{2b}^{1}	20–30	0.30 ~ 0.35	2.2 ~ 2.4	3.0	28–35

How were parameter assessed ? Please specify (? estimated values, and/or based on lab analyses etc.) and cite data sources.

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Table shall be explained in text more comprehensibly... (Table 3 then to be deleted?)

Table 3. Key factors and precursors for reference to early recognition of slope failure.

Type of slope	Failure mechanism and type	Key factors			Failure precursor
		Geological structure	Boundary conditions	Deformation	
layered slope	creep–crack–cut; deep seated rotational landslide	weak foundation or weak interlayer, common overlying limestone, dolomite, sandstone, slate and other hard rock; underlying mudstone, shale, coal and other soft rock; the dip angle is $8 \sim 20^{\circ}$ and incline to internal; $-\phi_r < \alpha < -\phi_p$	angle of the free surface slope $> 35^{\circ}$; the nose ridge, or both sides are gully or cracks and joints	depth of crack is 1/3 slope height, width of crack is up to 2 m	crack depth is up to 1/2 slope height, crack tend to be closed; the underlying soft rock cut out; the rock rupture infrasound constantly; spring at the foot of the slope; displacement rate $> 50\,\mathrm{cm\,d^{-1}}$, deformation curve tangent angle is 85–90°, and the direction of displacement vector is uniform.

α is the weak plane angle, ϕ_r is the residual friction angle, ϕ_p is the basic friction angle.

unclear, please specify.

Location of investigated landslide missing, shall be depicted.

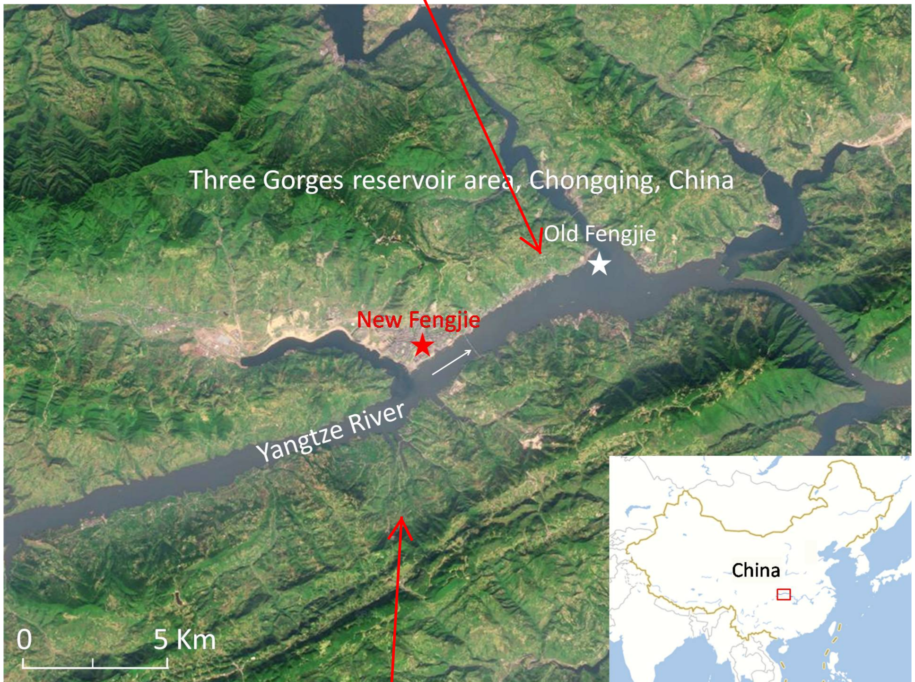

Figure 1. Location of the new city of Fengjie in the Three Gorges reservoir area, China.

Image source and date (year) missing, shall be provided.

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Location unclear; reference to Figs. 1, 3, 4, etc. shall be given.

Landslides (scarps, landslide deposits) and fault systems missing, shall be depicted according to Figs. 3, 4, etc.

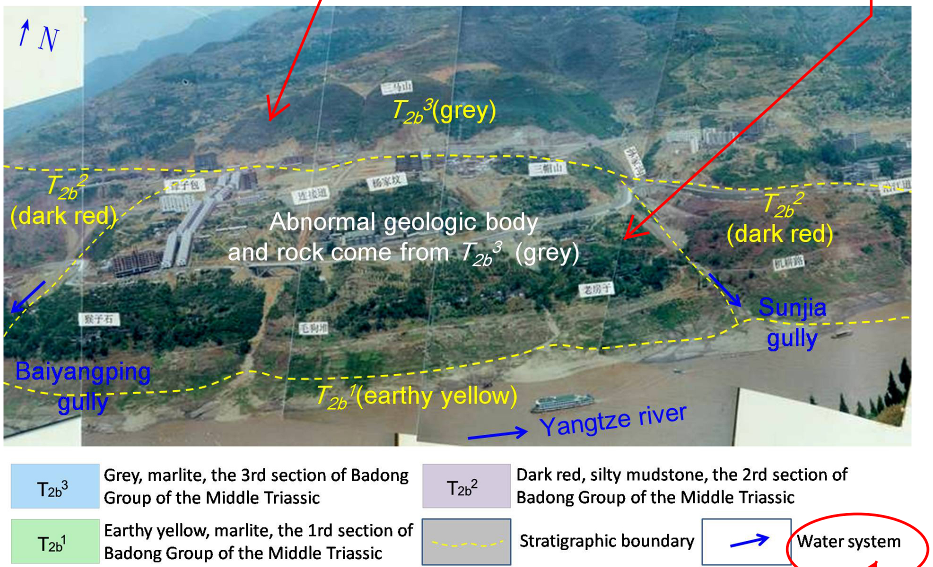
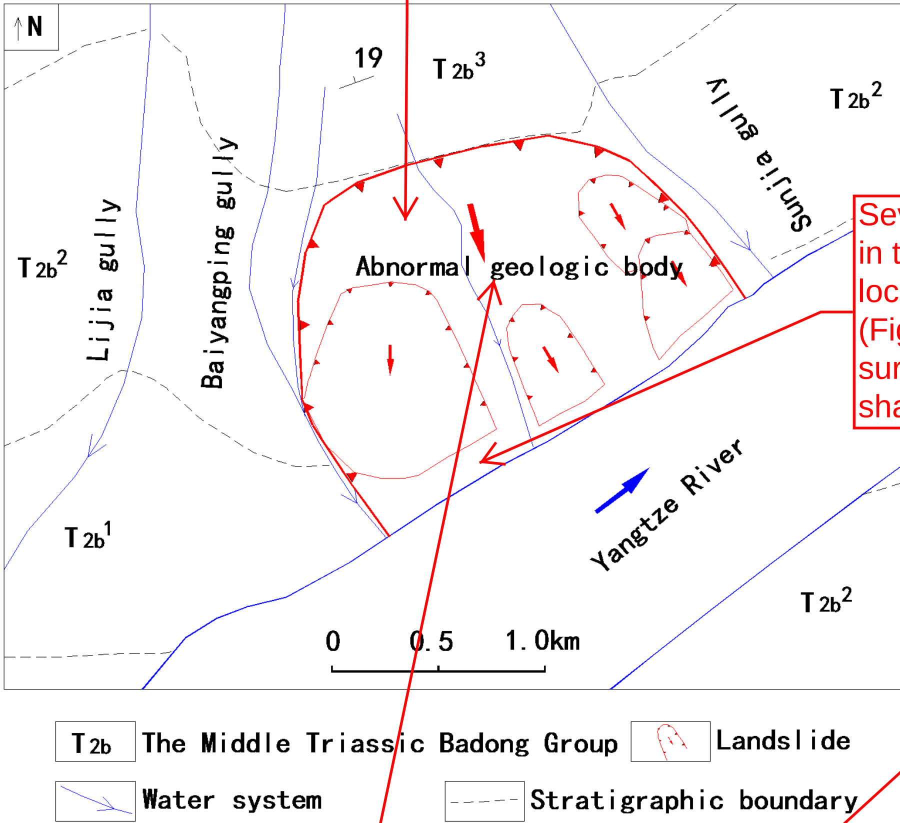


Figure 2. The abnormal geomorphologic and geological phenomenon at Sanma Mountain in the new city of Fengjie (photograph taken in 1998).

Terminology shall be revised ("abnormal" phenomenon)

Not mentioned/explained in text, shall be revised.

Location unclear; reference to Figs. 1, 3, 4, etc. shall be given.



Several information mentioned in the article is missing, e.g. location of cross-sections (Figs. 6, 8, etc.), boreholes, survey points/lines etc., => shall be revised.

why "speculated" ??
if only speculative, the article shall be revised substantially!

Figure 3. The abnormal geological phenomenon at Sanma Mountain speculated as a landslide.

Terminology shall be revised ("abnormal" phenomenon)

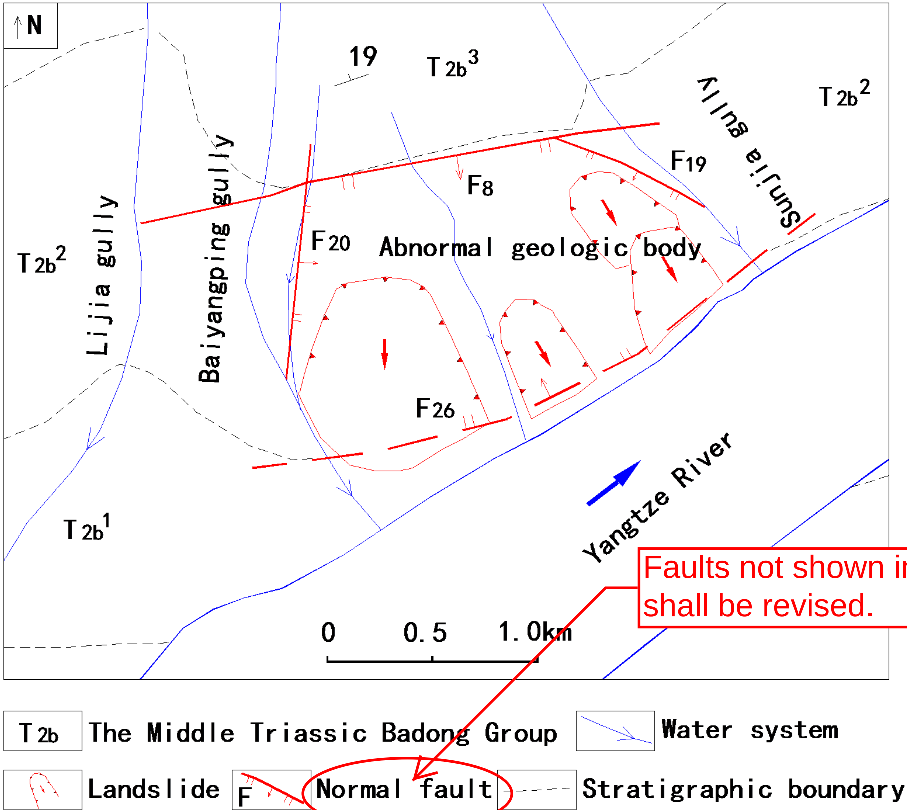


Figure 4. The abnormal geological phenomenon at Sanma Mountain explained as a fault graben (Li et al., 2002).

Faults not shown in Figs. 3, 6, 7, etc., shall be revised.

Figs. 3, 4 and 7 shall be merged and depicted as one comprehensive figure.

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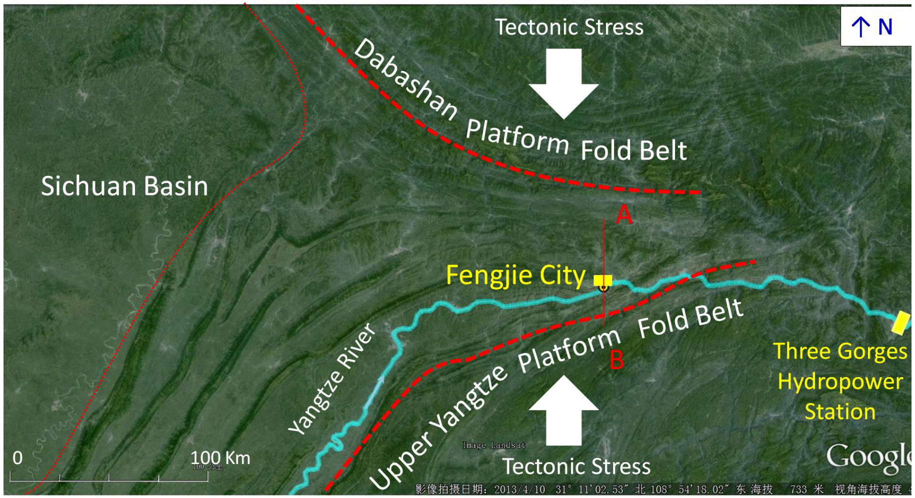

Figure 5. Outline of regional tectonics and stress.

Stress orientation shall be specified more clearly - based on paleo-stress analyses (see comments to Chapt. 3) ? In-situ stress measurements shall be cited, e.g. data from World Stress Map!

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

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Orientation unclear, cardinal points shall be given

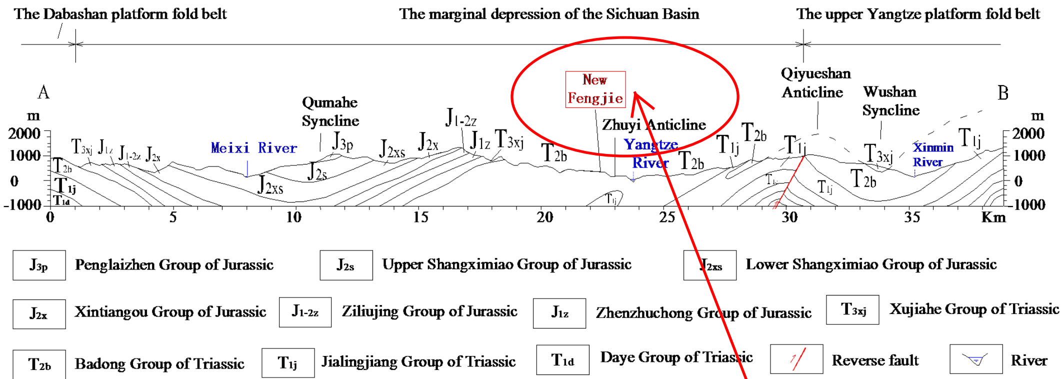

Figure 6. Cross section outline of regional tectonics ~~and stress.~~

Location of landslide unclear; position and spatial extent of landslide shall be depicted.

Location unclear; reference to Figs. 5, 7, 12, etc. shall be given

Stress not shown herein, shall be revised.

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Unclear; structures shall be explained in arcticle text.

Location unclear; reference to Figs. 5, 7, 12, etc. shall be given

Terminology shall be revised ("abnormal body")

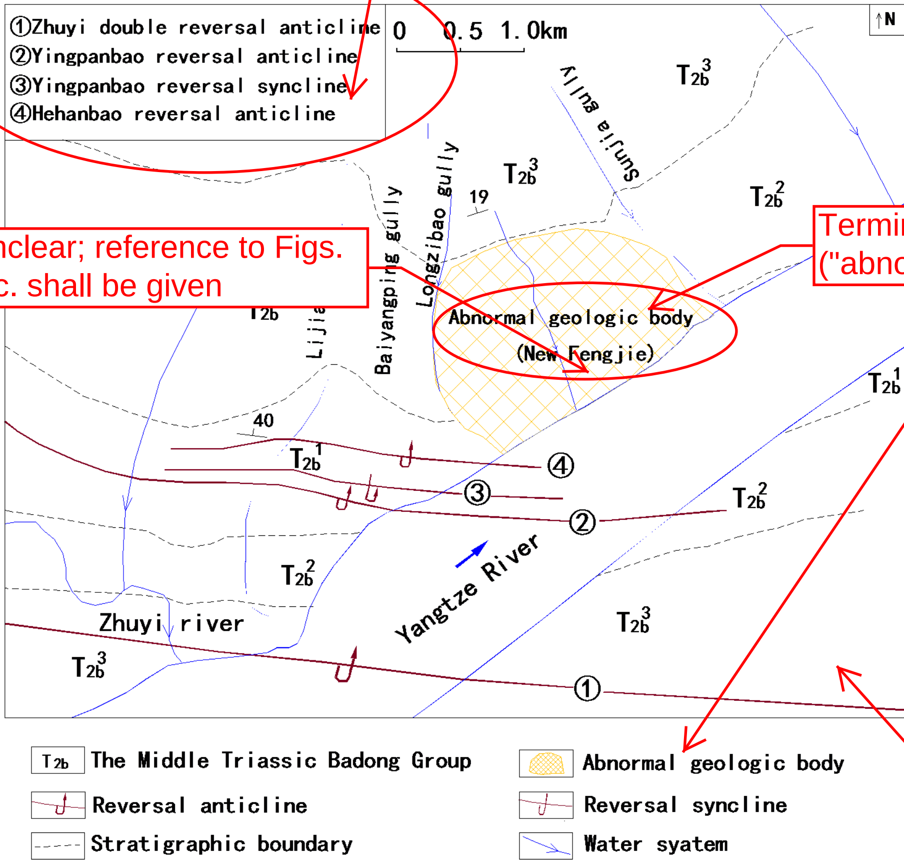

Figure 7. Outline geological map of the new city of Fengjie.

Faults not shown (see Fig. 4), shall be revised

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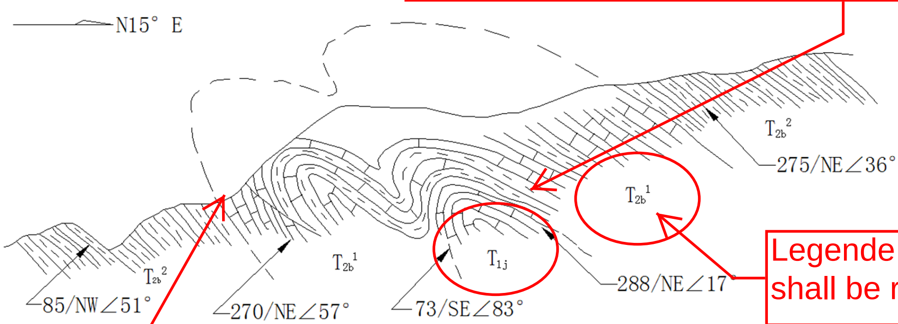
Orientation unclear, cardinal points and reference to Figs. 6, 12, etc. shall be given

Main rock types shall be given as text (e.g. marls, limestones, etc.), not as symbols/numbers of unknown data source/reference.



Legende missing (rock units), shall be revised.

Figure 8. The geological profile of a duplex inverted anticline in the core of the Zhuyi anticline.

Location of landslide and Fengjie city not depictedd, thus relevance of Fig, 8 unclear, shall be revised.

Duplex unclear since no faults shown, shall be revised.

Figure 9. Ripples displaying reversal rock.

unclear, please explain relevance for the slope model / landslide.

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Figure 10. Conjugate shear jointing.

unclear, please explain relevance for the slope model / landslide.

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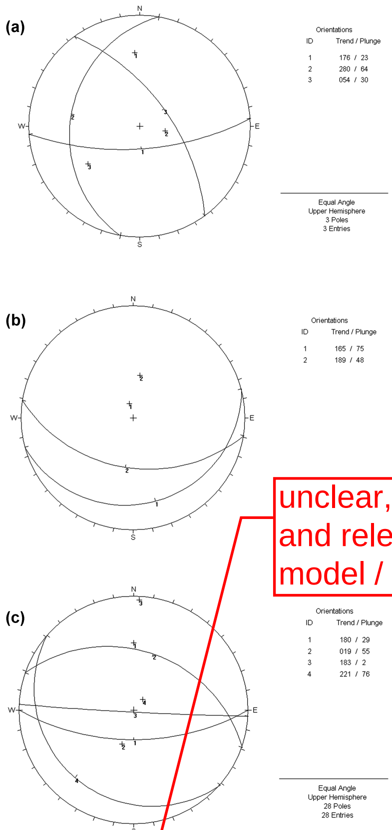

unclear, please explain analyses and relevance for the slope model / landslide.

Figure 11. Stereographic projection analysis. **(a)** Occurrence of conjugate shear jointing. **(b)** Occurrence of stratum in the north wing. **(c)** Occurrence of stratum in the south wing.

Location unclear; coordinates (Lat/Long) and reference to Figs. 1, 3, 4, etc. shall be given.

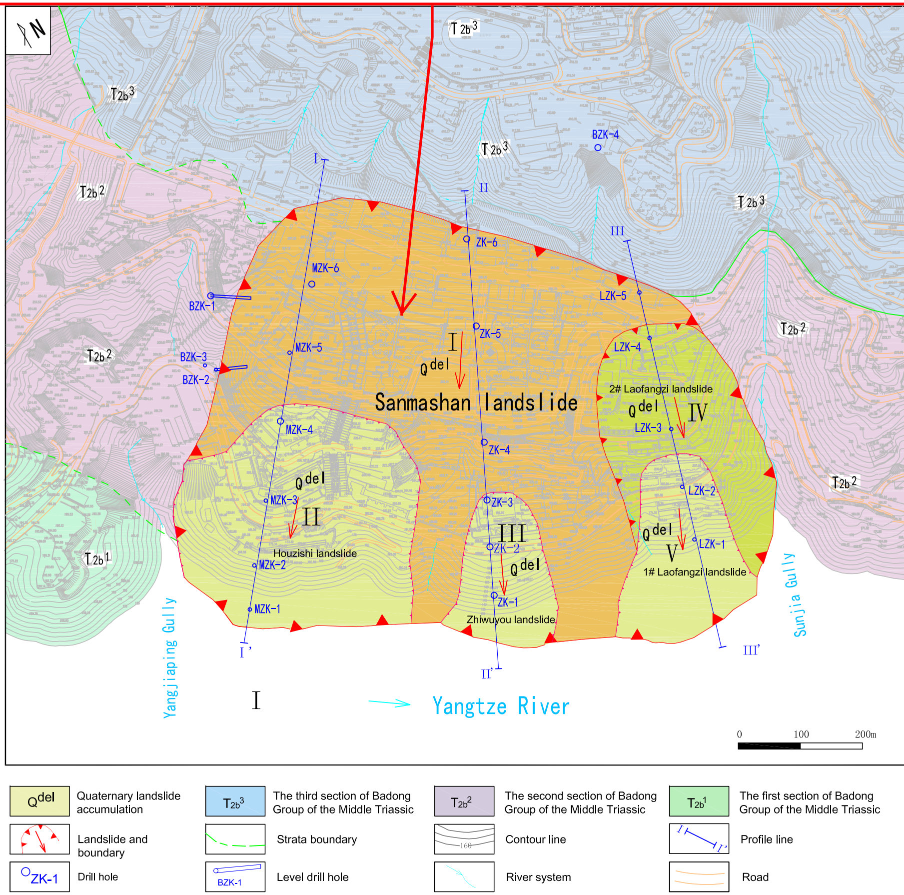

Figure 12. The geological map of the Sanmashan landslide (topographic map in October 2002).

Crucial figure, thus shall be placed above (e.g. as Fig. 2).

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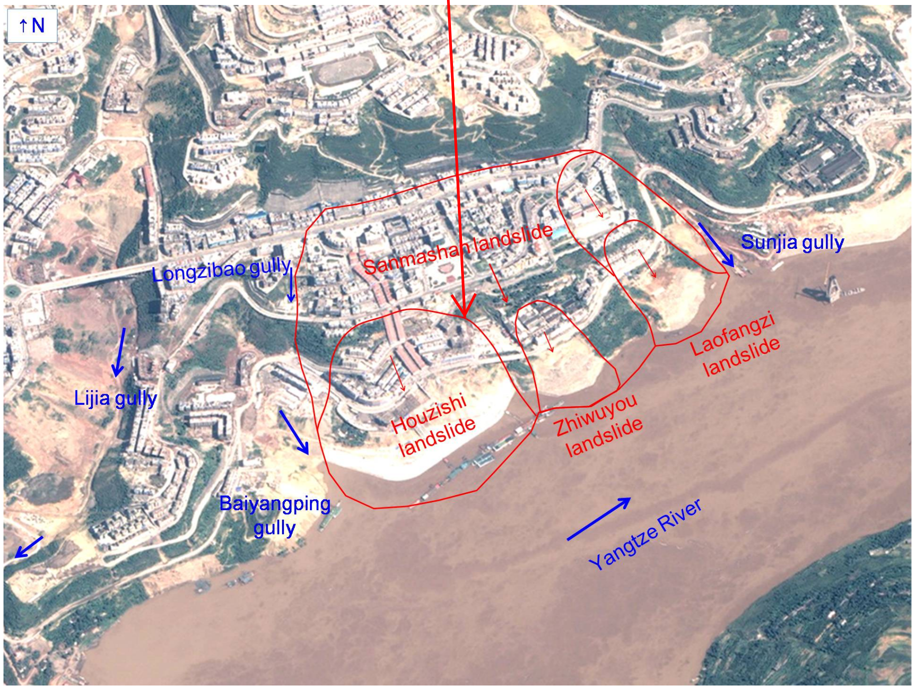

Figure 13. The remote image of the Sanmashan landslide (Satellite image in September 2004).

Reference of data source (satellite) shall be given.

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Location unclear; coordinates (Lat/Long) and reference to Figs. 12, 13, etc. shall be given.

Figure 14. The scarp of the Sanmashan landslide (March 2006).

Fig. 14 shall be explained in the arcticle text, including the obvious slope stabilisation measures.

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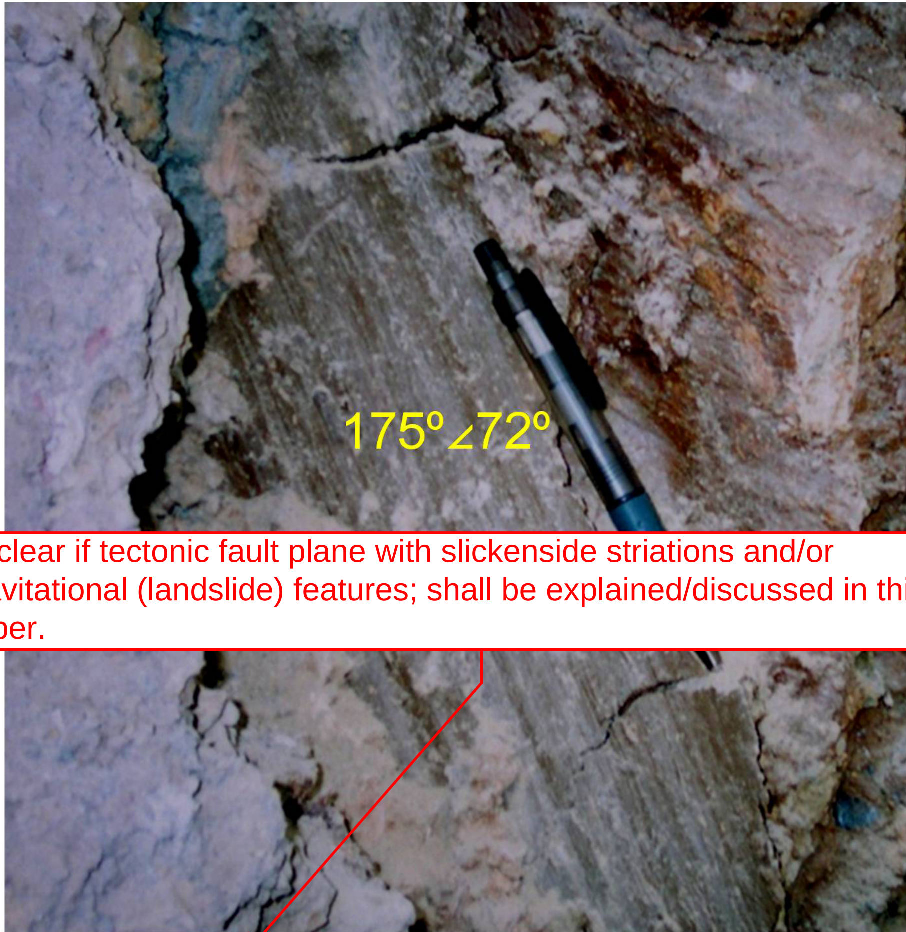

Figure 15. The sliding scrape of the scarp be revealed by foundation excavation.

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Location unclear; coordinates (Lat/Long) and reference to Figs. 12, 13, etc. shall be given.

Figure 16. The eastern lateral edge of the Sanmashan landslide.

Basal shear zone (sliding plane) cutting trough houses, roads, etc., but infrastructure damages not(?) encountered ?
Tunnel here situated beneath/outside of landslide (compare to Fig. 17)?
Situation shall be explained in this paper.

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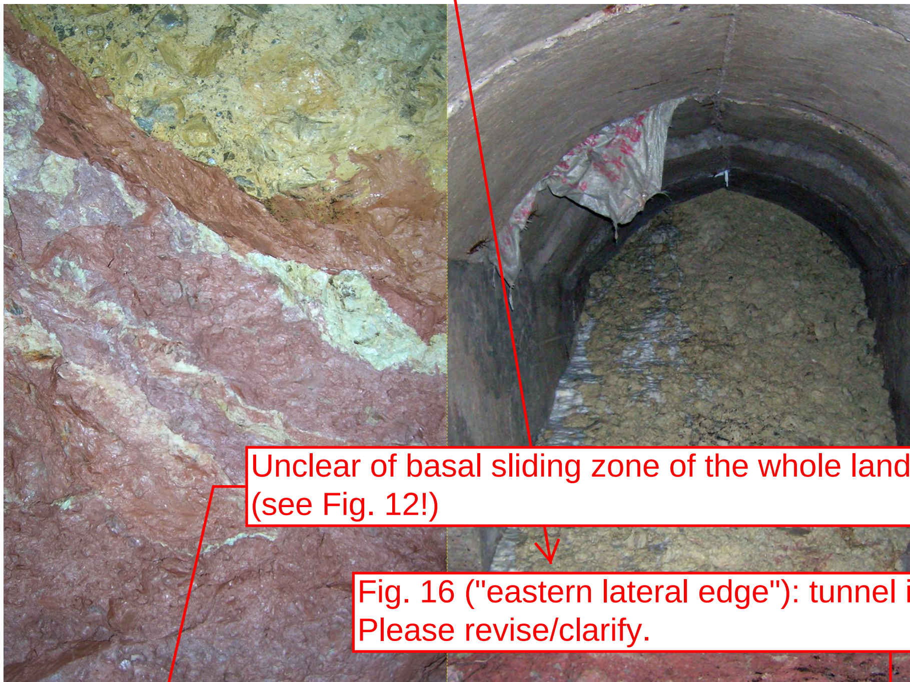
Location unclear; coordinates (Lat/Long) and reference to Figs. 12, 13, 16, etc. shall be given.



Unclear of basal sliding zone of the whole landslide system or of a sub-slab (see Fig. 12!)

Fig. 16 ("eastern lateral edge"): tunnel is beneath/outside the landslide. Please revise/clarify.

Figure 17. The sliding zone and slip mass in tunnel near by the eastern lateral edge.

Exceptional situation that sliding zone is penetrated by a tunnel, thus situation and findings shall be explained in this paper more extensively.

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It seems that (sub-)horizontally stratified rock units are encountered; if so, please explain situation (with reference to cross-section Fig. 8) and why these stratified units encountered at the toe of the landslide.

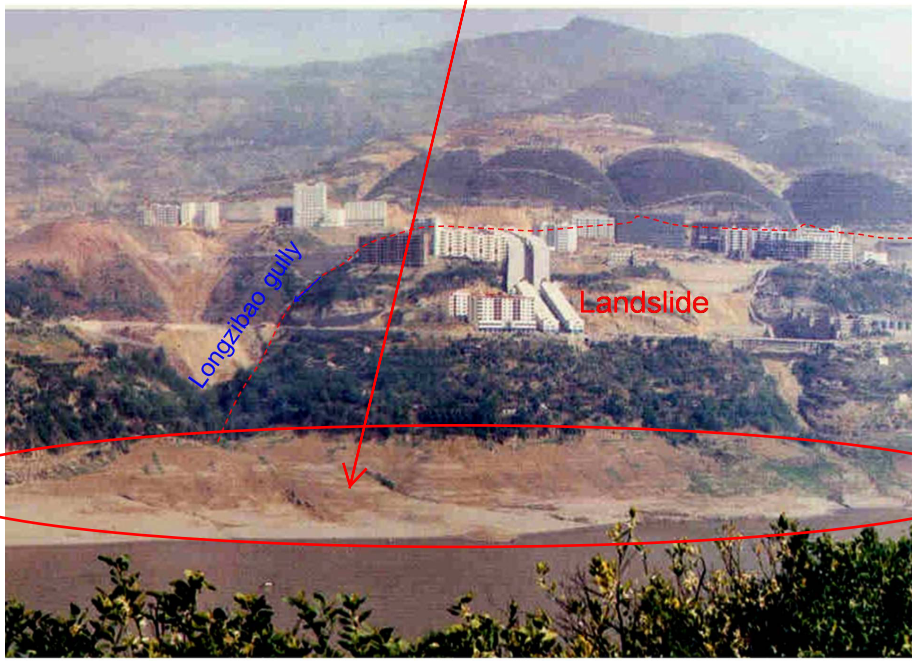

Figure 18. The western lateral edge of the Sanmashan landslide.

Location unclear; coordinates (Lat/Long) and reference to Figs. 12, 13, 16, etc. shall be given.

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Location unclear; coordinates (Lat/Long) and reference to Figs. 12, 13, etc. shall be given.

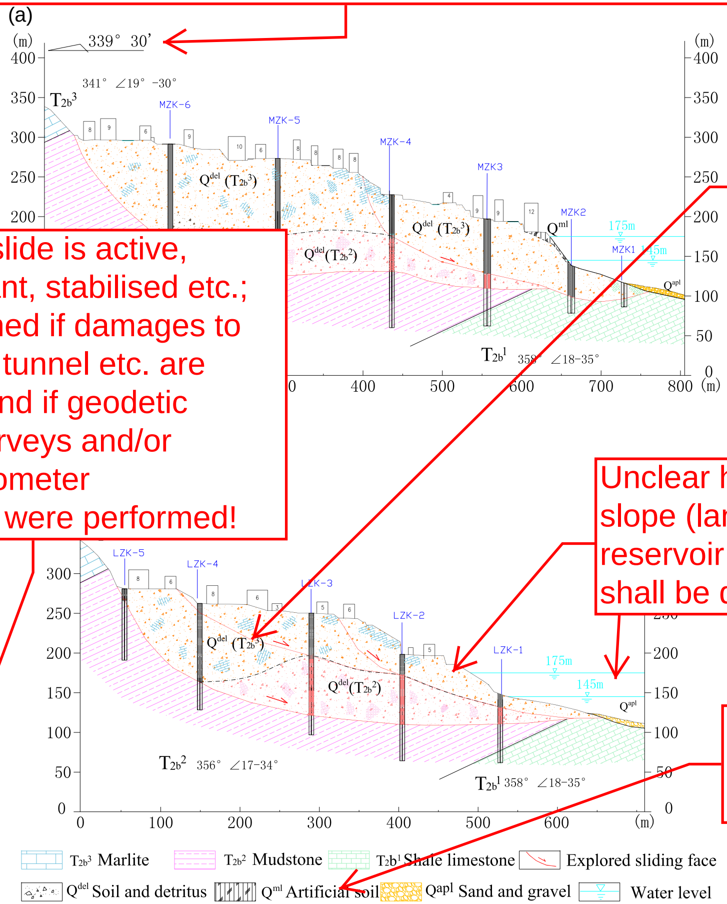
Boreholes ("level drill hole") not mentioned/explained in the text, shall be revised.

Figure 19. The sliding scrape in level drill hole near by the western lateral edge.

Basal shear zone (sliding plane) cutting trough houses, roads, etc., but infrastructure damages not(?) encountered ? Please explain/discuss.

Please provide arguments why landslide-related "sliding scrape" and not fault-related slickenside striations of tectonic origin (see comments to Fig. 15).

Location unclear; cardinal points and reference to Fig. 12 (?) etc. shall be given.



Based on this profiles, the landslide may be classified as a "rotational debris slide" (acc. to Cruden & Varnes 1996), shall be explained/discusses in the text.

Unclear if landslide is active, inactive, dormant, stabilised etc.; shall be explained if damages to houses, roads, tunnel etc. are encountered, and if geodetic deformation surveys and/or borehole inclinometer measurements were performed!

Unclear how groundwater-situation in the slope (landslide) correponds to the river/ reservoir level; groundwater in boreholes shall be depicted and explained in the text.

Rock/soil units in profile & borelogs not recognisable. Legend shall be revised and depicted more clearly.

Figure 20. The geological profile of the Sanmashan landslide. **(a)** Section of I–I′. **(b)** Section of III–III′.

as shown in Fig. 12?

Location and relevance unclear;
=> Fig. 21 shall be deleted / information merged with other figures (depicting foundation pit)

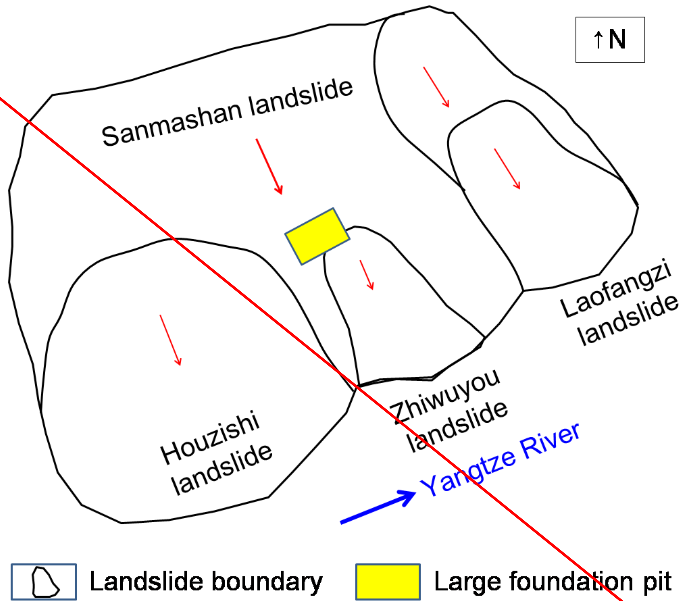


Figure 21. Location of the large foundation pit in the center of the landslide.

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Rock and soil types encountered shall be explained

Figure 22. Overview of the foundation pit (photograph taken in 2013).

Location see Fig. 12 (?)

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Figure 23. The geologic structure of four walls in the foundation pit.

Unclear; rock / soil types and structures shall be explained

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Unclear; rock / soil types and structures shall be explained

Figure 24. Close-up view of the slide zone of the Zhiwuyou secondary landslide.

Location unclear; coordinates /Lat./Long) and reference to overview map (Fig. 12?) shall be given.

Unclear; rock / soil types and structures shall be explained

Unclear; rocks feat. varying orientations of discontinuities (bedding planes) may also be generated by tectonic folding and/or faulting.... please explain why structures are attributed to a landslide.

Figure 25. Rockmass showing their anomalous attitudes each other in the western wall of the foundation pit, and this kind of geologic structure is only generated by landslides.

Unclear; figure (test device) and its relevance for the investigated Fengjie landslide shall be explained more comprehensible

Figure 26. The geotechnical centrifuge used in experimental modeling.

geomechanic lab test

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Unclear if/how geological slope model is in accord with other Figs (e.g. Fig. 8, Fig. 20, etc.); please revise/explain.

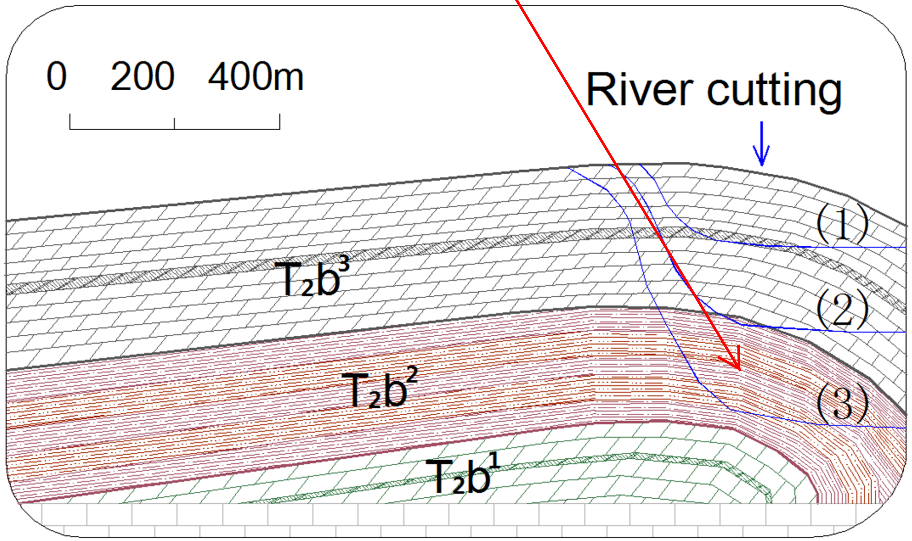

Figure 27. The geological model of slope.

Unclear; figure (slope model) and its relevance for the investigated Fengjie landslide shall be explained more comprehensible

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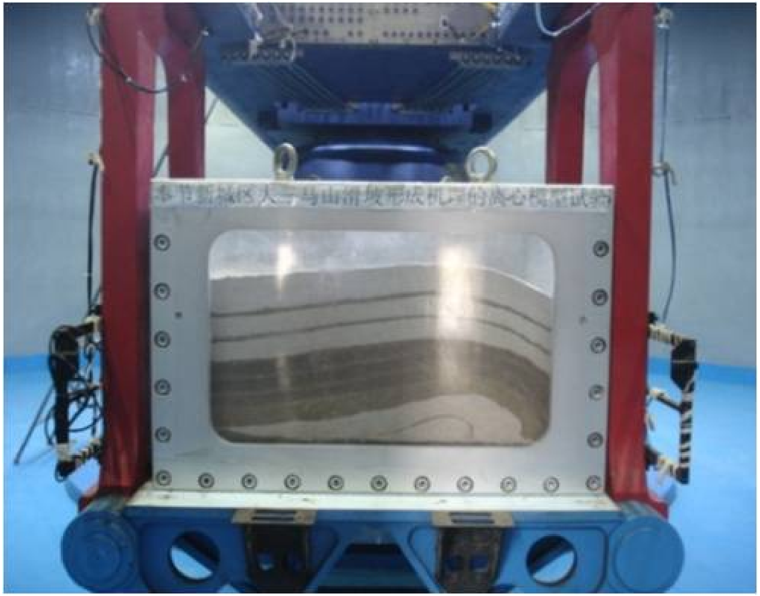

Figure 28. The experimental model.

Unclear; figure (model) and its relevance for the investigated Fengjie landslide shall be explained in the text.

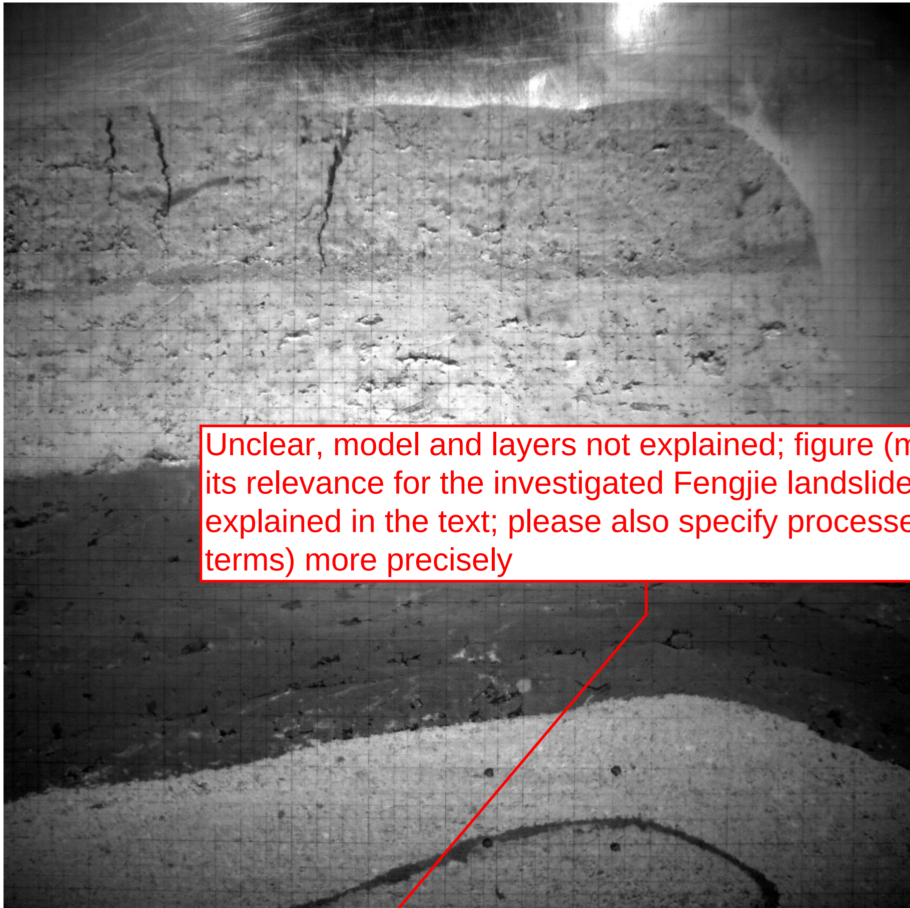

Figure 29. Tension cracking in trailing edge and top.

Unclear, model and layers not explained; figure (model) and its relevance for the investigated Fengjie landslide shall be explained in the text; please also specify processes (english terms) more precisely

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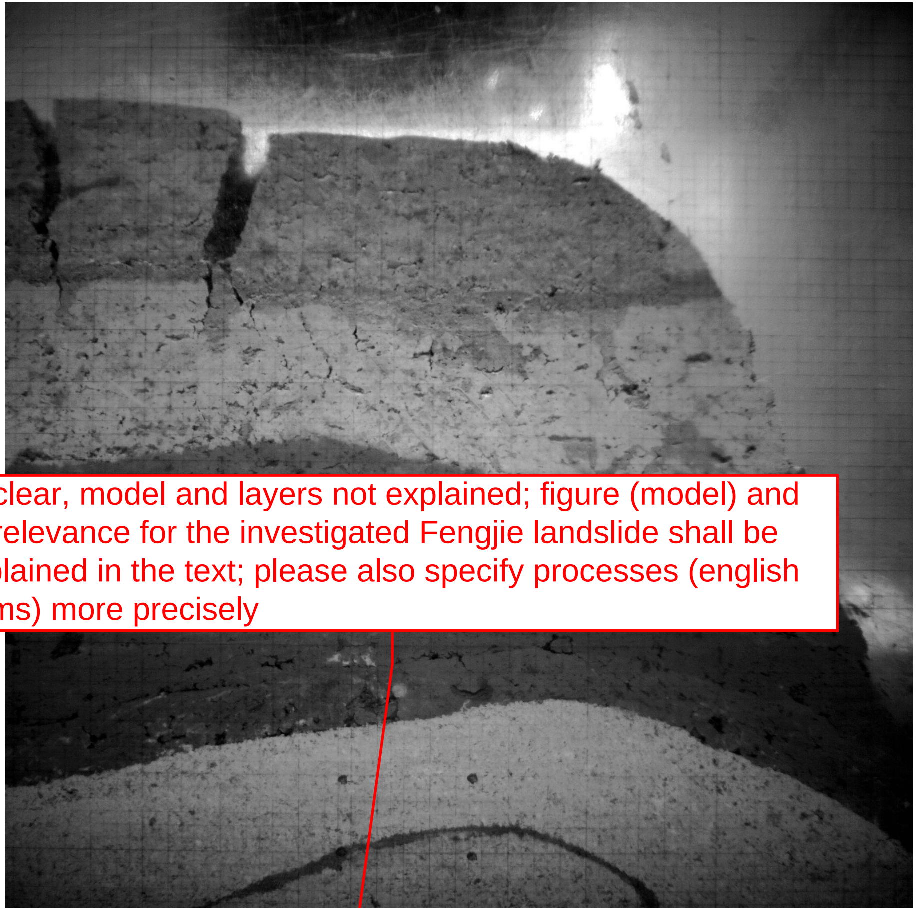
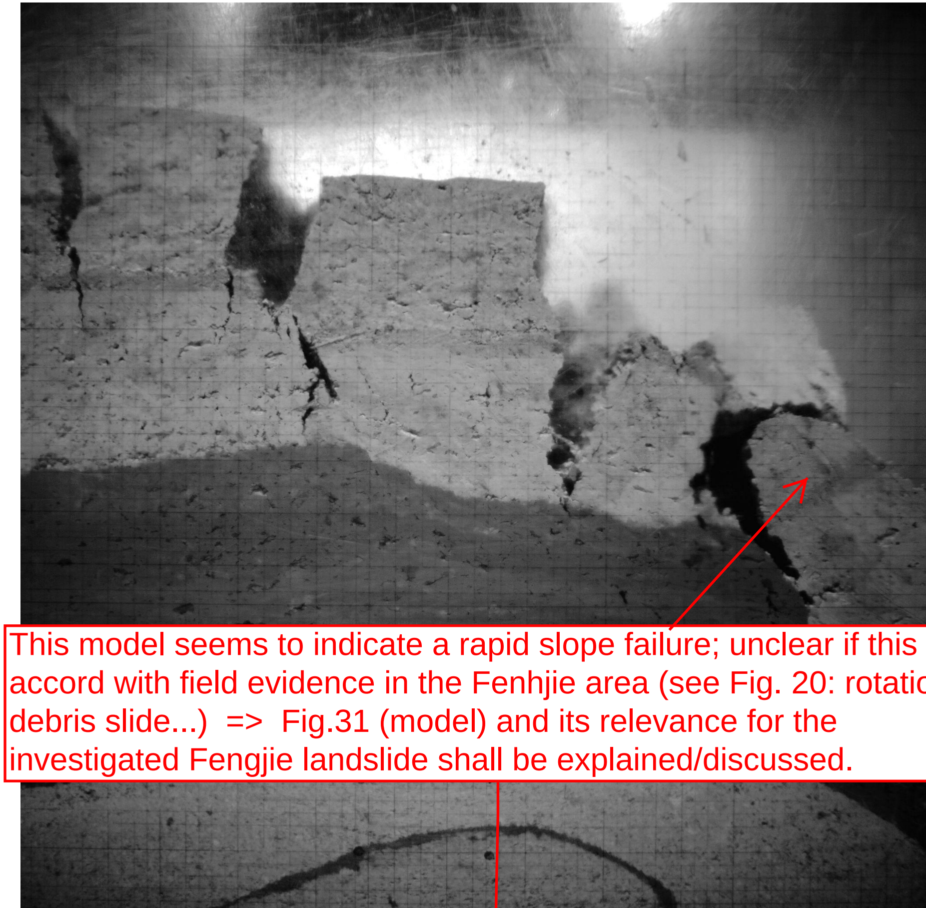


Unclear, model and layers not explained; figure (model) and its relevance for the investigated Fengjie landslide shall be explained in the text; please also specify processes (english terms) more precisely

Figure 30. Going cracking and shear creeping at the bottom.



This model seems to indicate a rapid slope failure; unclear if this is in accord with field evidence in the Fenhjie area (see Fig. 20: rotational debris slide...) => Fig.31 (model) and its relevance for the investigated Fengjie landslide shall be explained/discussed.

Figure 31. Whole sliding, breaking up and collapsing.

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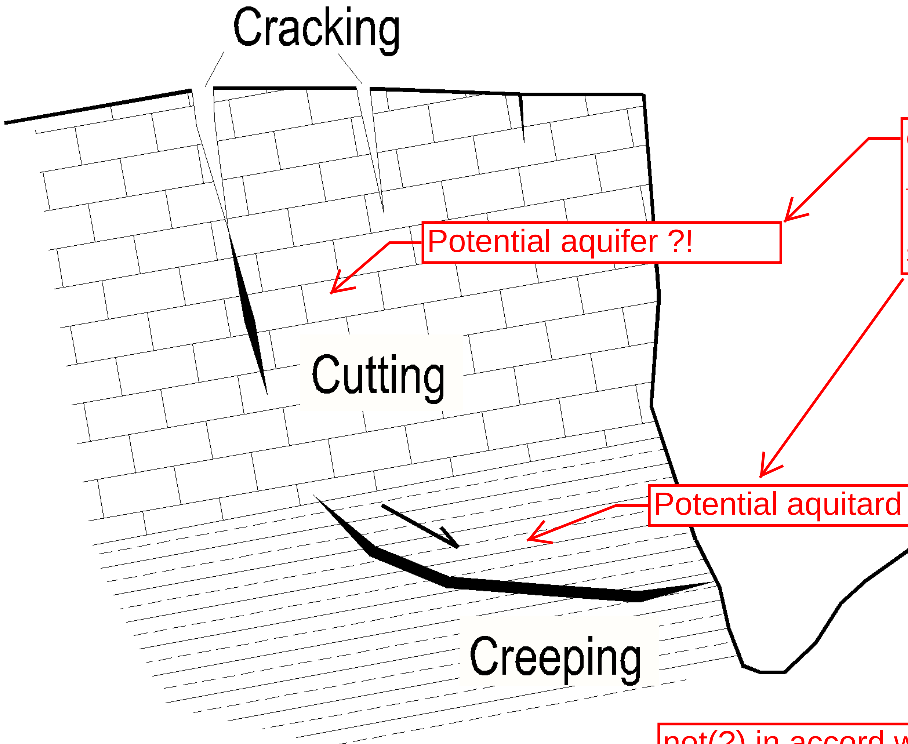
Legende missing, symbols of rock units shall be given/explained.



geomechanical and hydrogeological rock mass characteristics shall be explained

Figure 32. Sketch of failure type of the landslide.

not(?) in accord with Fig.20
=> rotational debris slide

according to this model:
rotational rock slide

Relevance of centrifuge tests (Fig. 26) for this failure type unclear; shall be explained.

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Location unclear; coordinates (Lat/Long) and reference to overview maps (e.g. Fig. 1) shall be given.

Figure 33. The Chana landslide, Longyangxia, China.

Unclear if/how this geological setting and failure processes are relevant for the Fengjie landslide; please explain.

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Location unclear; cardinal points and references to overview maps (e.g. Fig. 12) and geol. cross-sections (e.g. 20) shall be given.

Unclear, please explain

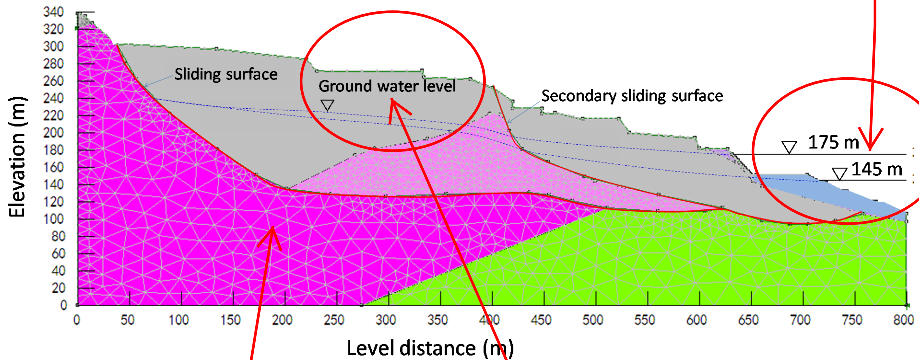

Figure 34. Stability analysis model of the Sanmashan landslide.

Legende of geotechnical model units missing, shall be provided.

Groundwater not depicted in Fig. 20, and not explained in the text (borehole water levels, springs etc.), shall be revised.

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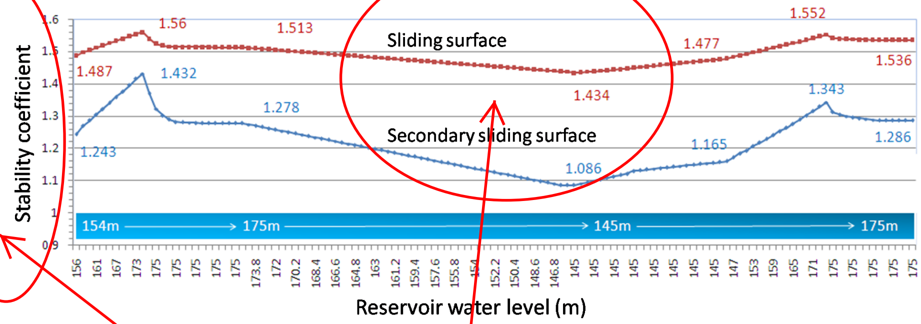

Figure 35. Stability changes with water level of the Three Gorges reservoir.

Unclear; shall be explained/discussed in the text more comprehensible.

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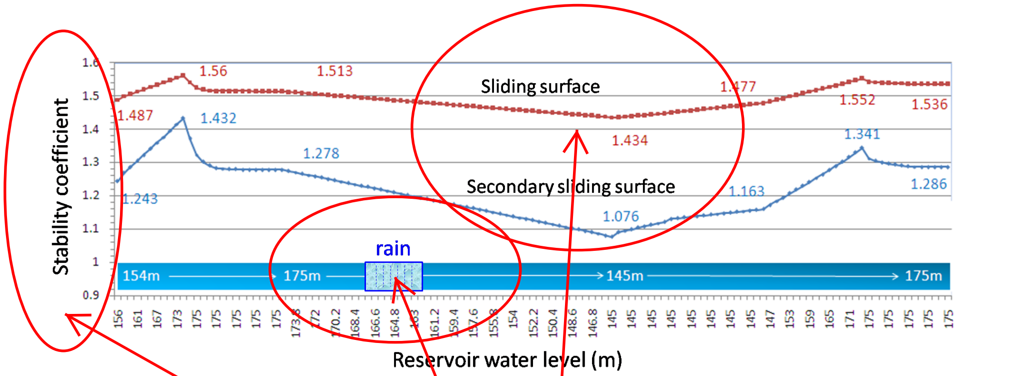

Figure 36. Stability changes with water level of the Three Gorges reservoir and rainfall.

Unclear; shall be explained/discussed in the text more comprehensible.

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