



Geomorphic impacts, age and significance of two giant landslide dams in the Nepal Himalayas: Ringmo-Phoksundo (Dolpo District) and Dhampu-Chhoya (Mustang District).

Monique Fort, Regis Braucher, Didier Bourles, Valery Guillou, Lila Nath Rimal, Natasha Gribenski, Etienne Cossart

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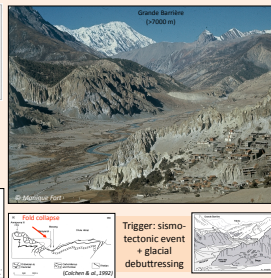
1. INTRODUCTION: MAIN ISSUES

Large catastrophic slope failures have recently retained much attention in the northern dry Himalayas (Hewitt 2009). They play a prominent role in the denudation history of active orogens at a wide range of spatial and time scales (Korup & Clague, 2009), and they impact durably landforms and process evolution in upstream catchments. Their occurrence mostly results from three different potential triggers: earthquakes, post-glacial debudding, and permafrost melting. We focus on two examples of giant rock slope failures that occurred across and north of the Higher Himalaya of Nepal and assess their respective influence on the regional, geomorphic evolution.

From Fract., 2011

[illegible]

8 massive landslides (volume > 1 km³) reported in Nepal (Fort, 2011).



Mechapophara (6993 m) Annapurna IV (7524 m) Annapurna II (7937 m) Lamjung Himal (6883 m)

50 m

New Road

© Monocled Owl

The Pokhara gravels fill (M3): result of a giantic rock avalanche 500-years old. Mechanism? Catastrophic collapse of the Annapurna IV (thrust) front, possibly seismically triggered in 1505 (Fort 1987, 2010)

2. DATING METHODS: COSMIC RAY EXPOSURE DATING

AMS measurements of the ^{36}Cl and ^{10}Be concentrations were performed at the 5 MV national AMS facility ASTER located at CEREGE, Aix en Provence, France. All ^{36}Cl concentrations were normalized to the NIST6010 calibration material $^{36}\text{Cl}/^{35}\text{Cl} = 1.6 \cdot 10^{-12}$ provided by Nishizumi) and all ^{10}Be concentrations were normalized to the SRM 4325 NIST reference material with an assigned $^{10}\text{Be}/^{9}\text{Be}$ value of $(2.79 \pm 0.03) \cdot 10^{-11}$. The ^{36}Cl decay constant of $(2.303 \pm 0.016) \cdot 10^{-4} \text{ a}^{-1}$ corresponds to a half-life ($T_{1/2}$) of $(3.014 \pm 0.021) \cdot 10^5$ years and the ^{10}Be decay constant of $(4.987 \pm 0.036) \cdot 10^{-7} \text{ a}^{-1}$ to a half-life of $(1.39 \pm 0.01) \cdot 10^6$ years. Analytical uncertainties include the counting statistics, machine stability (0.5%) and blank correction, the associated $^{36}\text{Cl}/^{35}\text{Cl}$ blank ratio being $\sim 10^{-14}$ and the $^{10}\text{Be}/^{9}\text{Be}$ blank ratio $\sim 2 \cdot 10^{-15}$. Cosmic ray exposure ages derived from these cosmogenic nuclide concentrations were calculated using production rates corrected for topographic shielding following *Dunne et al. (1999)* and scaled to the sites position (latitude, altitude) using the Stone scheme (*Stone, 2000*) from a sea level and high latitude production rate of 4.5 ± 0.3 atoms of ^{10}Be $\text{g}_{(\text{SiO}_2)}^{-1} \text{yr}^{-1}$ for ^{10}Be and integrating all production pathways (spallation, including a spallation production rate of 42.0 ± 2.0 atoms of ^{36}Cl $\text{g}^{-1} \text{a}^{-1}$ and at sea level and high latitude, thermal neutron, muon captures and radiogenic production) and the rock's chemical composition for ^{36}Cl .

Sample ID	Sample weight dissolved [g]	% CaO	$^{41}\text{Cl}/^{35}\text{Cl}$ (10^{-14})	$^{37}\text{Cl}/^{35}\text{Cl}$	Cl [ppm]	^{36}Cl [10^{-6} g/g]	Exposure Age of surface (unroded surface)	Uncertainty
PHOK COS 1	67.29	55.18%	133.8	35.64	2.79	6.8	6987	566
PHOK COS 2	69.08	54.70%	382.0	24.08	4.58	19.8	20882	1687
PHOK COS 3	72.015	54.59%	314.8	10.42	13.82	19.5	20888	1661

Two consistent ^{36}Cl ages of $20,885 \pm 1675$ argue for a single, massive event of paraglacial origin

Field assumptions are confirmed by cosmic ray exposure dating: the landslide dam was formed in response to the collapse of the limestone cliff in one single, massive event. The ^{36}Cl dates confirm the paraglacial/post-glacial origin of the failure, an event that fits well with the last chronologies available on the Last Glacial Maximum in the Nepal Himalaya (Owen & Dortch 2014). IRSL dating of silts suggests a progressive trend to dryness of these Northern Himalayan regions from Late Pleistocene to Holocene.

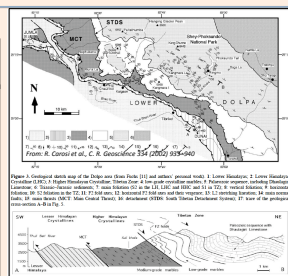
Note on Infrared Stimulated Luminescence (IRSL) dating

The IRSL samples, PHOK 2 and PHOK 1, were collected respectively at the top and the bottom of the silty deposit, below the surface soil. IRSL measurements were performed at Montreal laboratory by S. Balescu, S. Huot and M. Lamothe. The corrected IRSL ages of PHOK 2 and PHOK 1, respectively 4.7 ± 0.3 ka and 12.6 ± 0.7 ka, are stratigraphically consistent (Fort *et al.*, 2013).

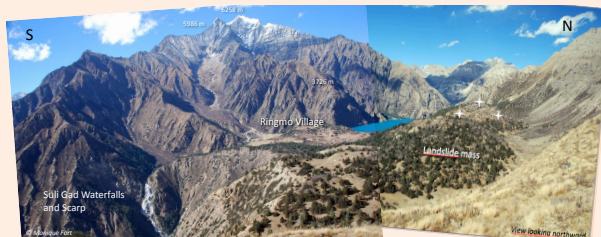
3. RINGMO-PHOKSUNDO SITE



The damming of the lake was caused by rockslide bodies derived from different parts of the rocky face bounding the lake in its SE part.



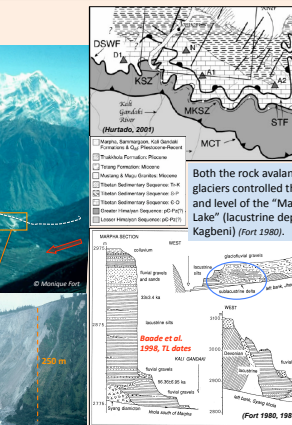
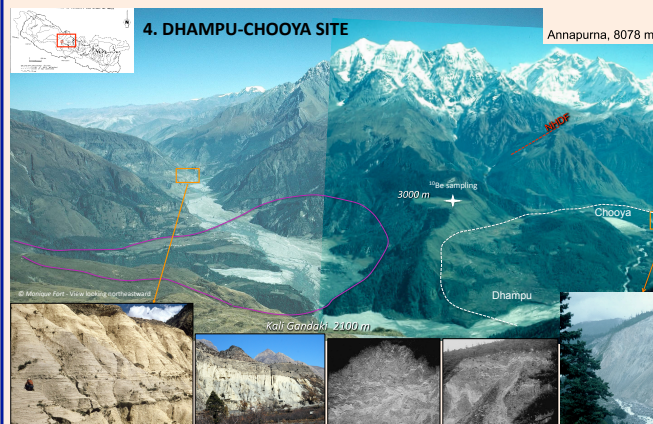
The Phoksumdo lake (3600 m asl.; area of 4.5-to-5 km²) is the second largest lake of Nepal; it owes its origin to the damming of the Suli Gad River by the large (4.5 km³) collapse of a mountain wall (Dhaulagiri limestones) culminating at 5148 m, SE of the lake (Fort & Rimal 2010). According to Yagi (1997), the collapse may have occurred 30 to 40 ka, an interpretation revised by this study.



The landslide morphology presents a series of mounds (metres to tens of metres high) and depressions of varying size. Its mass is composed of large blocks of massive dolomites found as far as west of Ringmo Village and down to the southern rim of the landslide dam.

Most of the Suli scarp is upheld by limestones outcrops, but along the central part, the former Phoksumdo gorge is filled in by dark grey, fine sediments (till material) and overlain by orange conglomerates (including dolomites boulders), then by yellowish, unsorted conglomeratic material blocks and calcareous silt matrix). **The presence of glacial till at the very base of the sequence suggests the rockslide event is post-glacial.**

4. DHAMPU-CHOOYA SITE



The Dhampur-Chhoya rock avalanche (10^9 m³, area extent 10 km²) was derived from the northward failure of the Kaiku ridge, upfold by north-dipping, upper crystallines of the Higher Himalaya (Fort 1974; 2000). It dammed the Kali Gandaki River, with complex interactions with the Late Pleistocene ice tongues derived from the Dhaulagiri (8167 m) and Nilgiris (7061 m) peaks.

Be-10 cosmic ray exposure ages (CEREGE, Gribenski 2010)

Ti09-01 :	29 674 ± 1 022 ka
Ti09-02 :	24 844 ± 628 ka
Ti09-03 :	29 694 ± 1 011 ka

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 TI09-01 : 29 674 ± 1 022 ka
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 TI09-03 : 29 694 ± 1 011 ka

The discrepancy in the dating of both lacustrine and failure events raise the issue of the nature of the lacustrine dam: (i) rock-avalanche as initially thought (Fort 1974; 1980; Boode 2000) or (ii) possibly a glacial tongue controlling the lake level (Fort and Cossart 2013); (iii) repeated failures cannot be ruled out (Zech et al. 2010).



The fact that both Zech *et al.* (2009) and our team (Fort *et al.*, *in prep.*) have obtained consistent exposure duration to cosmic ray, from different samples and different laboratories, provides very good evidence of a chronologically, well constrained Dhumpu-Chhoya rock-avalanche event, i.e. about 30,000 years ago. Conversely, dating of lacustrine sediments has not been cross-checked to date, and some uncertainty cannot entirely be ruled out.

5. COMPARISONS and CONCLUDING REMARKS

Phoksundo-Ringmo

- Efficient drainage blockage, but no backwash sedimentation (predominant carbonates + low discharge)
- Prominent knick point: karst + boulder pavement reducing incision => prominent hanging valley
- Triggering factor: glacial retreat («paraglacial collapse»), cf. ³⁶Cl dates

Dhampu-Chooya

- Efficient drainage blockage, and extensive lacustrine sedimentation (glacial sediment reworking + Spiti shales + glacial- and snow-melt discharges)
- Knick points and associated epigenetic gorges + braided Kali Gandaki valley: delayed incision => relatively hanging valley
- No climate forcing, cf. ^{10}Be dates => Triggering factor related to the North Himalayan Detachment Fault + foliation dip of Upper Himalayan Gneisses
- Complex interplay between glaciers and mountain wall collapses (For 2000)

Both examples confirm that giant landslides play a significant role in the:

- Destruction of Himalayan topography (Fort 1988),
- Bedrock protection from river incision (Korup et al. 2010),
- Delay of sediment transport outward from the mountain zone (cf. sediment storages & budgets; Fort & Cossart 2013; Blüthner J. & Korup O., 2013)
- Local controls exerted by topography and climate (e.g. magnitude of glaciation & snow $\leftrightarrow$ discharge) + lithology (e.g. sediment supply $\leftrightarrow$ storage)

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