

# The paraglacial, giant landslide dam of Phoksumdo Lake (Dolpo District, Western Nepal Himalaya).

Monique Fort<sup>1</sup>, Lila Nath Rimal<sup>2</sup>, Didier Bourles<sup>3</sup>, Valéry Guillou<sup>3</sup>, Sanda Balescu<sup>4</sup>, Sébastien Huot<sup>5</sup> and Michel Lamothe<sup>5</sup>

<sup>1</sup> Université Paris Diderot (GHSS), S-P-C, CNRS-UMR 8586 PRODIG, 5 rue Thomas Mann 75205 Paris Cedex 13, France

<sup>2</sup> Department of Mines and Geology, Lainchaur, Kathmandu, Nepal

<sup>3</sup> Aix-Marseille Université, CEREGE CNRS UMR 6635, 13545 Aix en Provence, France

<sup>4</sup> Laboratoire Halma Ipel, UMR 8164 (CNRS), Université de Lille 1, 59655 Villeneuve d'Ascq Cedex, France

<sup>5</sup> Laboratoire de Luminescence LUX de Montréal, Département des Sciences de la Terre et de l'Atmosphère, Université du Québec à Montréal, CP 8888 Succ Centre ville, Montréal, QC H3C3P8, Canada  
fort@univ-paris-diderot.fr

Large catastrophic slope failures have recently retained much attention in the northern dry Himalayas and Central Asia [1]. Their occurrence is generally interpreted as resulting from three main potential triggers: earthquakes, post-glacial debuttressing, permafrost melting. The Phoksumdo lake (3600 m asl) is the second largest lake in Nepal (area of 4.5-to-5 km<sup>2</sup>). It owes its origin to the damming of the Suli Gad River by a giant (4.5 km<sup>3</sup>) collapse of a mountain wall culminating at 5148 m asl, SE of the lake [2]. The landslide morphology presents a series of mounds and depressions of varying size (a few-to-ten metres high or deep). The landslide mass is composed of large blocks of massive, palaeozoic dolomites found as far as west of Ringmo Village and down to the southern rim of the landslide dam [3] [Fig. 1]. The coarse debris is widely mantled by a thick (up to 10 m) cover of silts, well prominent downstream above the Suli Gad gorges. Downstream, most of the Suli scarp is upheld by limestone's outcrops, but along the central part, where the former Phoksumdo gorge is filled in by dark grey, fine sediments (till material) [2,3], and overlain by orange conglomerates (including dolomites boulders), then by yellowish, unsorted conglomeratic material composed of blocks and calcareous silty matrix [3]. This indicates 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. On the basis of reddish buried soils in silts, Yagi [2] considered rockslide occurrence at  $\approx$  30-40 ka following glacial retreat.



Figure 1. Left: The giant collapse (4.5 km<sup>3</sup>) of the mountain wall (5148 m asl) made of Dhaulagiri limestones is at the origin of the Phoksumdo lake. Right: View of the rockslide mass and location of dating samples.

In order to test this assumption, we carried out AMS measurements of the <sup>36</sup>Cl concentration of the samples from the main scarp [Fig. 1]. Measurements were performed at the 5 MV national AMS facility ASTER located at CEREGE, Aix en Provence, France. All <sup>36</sup>Cl concentrations were normalized to the KNSTD1600 calibration material (<sup>36</sup>Cl/<sup>35</sup>Cl = 1.6\*10<sup>-12</sup> provided by K. Nishiizumi). The used decay constant of 2.303 ± 0.016 \*10<sup>-6</sup> a<sup>-1</sup> corresponds to a <sup>36</sup>Cl half-life (T<sub>1/2</sub>) of 3.014\*10<sup>5</sup> years. Analytical uncertainties include the counting statistics, machine stability (~0.5%) and blank correction (<sup>36</sup>Cl/<sup>35</sup>Cl blank ratio was on the order of ~10<sup>-14</sup>). Cosmic ray exposure ages derived from these <sup>36</sup>Cl concentrations were calculated using production rates corrected for topographic shielding following [4] and scaled to the sites position (latitude, altitude) using the Stone scheme [5] from sea

level and high latitude production rates integrating all production pathways (spallation - including a spallation production rate of  $42.0 \pm 2.0$  atoms of  $^{36}\text{Cl}$   $\text{g}^{-1}\text{Ca}$   $\text{a}^{-1}$  at sea level and high latitude, thermal neutron and muon captures, radiogenic production) and the rock's chemical composition.

| Sample ID  | Sample weight | % CaO  | $^{36}\text{Cl}/^{39}\text{Cl}$ | $^{35}\text{Cl}/^{37}\text{Cl}$ | Cl    | $^{36}\text{Cl}$ | Exposure Age of surface<br>(uneroded surface) | Uncertainties |
|------------|---------------|--------|---------------------------------|---------------------------------|-------|------------------|---|---------------|
|            | dissolved [g] |        | ( $10^{-11}$ )                  | [ppm]                           |       |                  |   |               |
| 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          |

Table 1: AMS measurements of the  $^{36}\text{Cl}$  concentration of the samples from the main scarp.

The post glacial origin is now confirmed by cosmogenic dating: two consistent  $^{36}\text{Cl}$  ages of  $20,885 \pm 1675$  [Tabl.1] argue for a single, massive event of paraglacial origin, that fit well with the last chronologies available on the Last Glacial Maximum in the Nepal Himalaya [6].

The IRSL samples (PHOK 2 and PHOK 1) were collected respectively at the top and the bottom of the silty deposit, with the reddish soil between. IRSL measurements were performed on alkali feldspar grains (60-80 mm). These were extracted by dry sieving, then treated with HCl and  $\text{H}_2\text{O}_2$  to remove calcium carbonate and organic matter. The heavy liquid isolation of alkali feldspars (density  $< 2.58$  s.g.) was achieved by using sodium polytungstate. Palaeodose (De) determinations on alkali feldspars were done using the single-aliquot regenerative-b dose (SAR) method, following the Montreal laboratory protocol on very small aliquots (about 50 grains per aliquot). This protocol [7] has been applied to correct for the observed fading. The corrected IRSL ages of the samples, respectively  $4.7 \pm 0.3$  ka and  $12.6 \pm 0.7$  ka, are stratigraphically consistent. They suggest a progressive trend to dryness of these Northern Himalayan regions. The high lime content of the landslide components explains the dam stability and the persistence of the sacred lake of Phoksumdo.

As many other examples this mega-collapse confirms the fact that giant landslides play a significant role in both the destruction of Himalayan topography and in bedrock protection from river incision, hence delaying sediment transport outward from the mountain zone [1, 8, 9, 10].

- [1] Hewitt K. Catastrophic rock slope failures and late Quaternary developments in the Nanga Parbat-Haramosh Massif, Upper Indus basin, northern Pakistan. *Quaternary Science Reviews*, 28, 1055-1069 (2009).
- [2] Yagi, H. Origin of the Phoksundo Tal (Lake), Dolpa district, western Nepal. *Jour. Nepal Geol.Soc.*, 15, 1-7 (1977).
- [3] Fort M. and Rimal L.N. Preliminary report on a field visit to Phoksundo lake, Dolpa district. Report to the Department of Mines and Geology, Lainchaur, Kathmandu, Nepal. 7 pages (2010).
- [4] Dunne, J., Elmore, D., Muzikar, P. Scaling factors for the rates of production of cosmogenic nuclides for geometric shielding and attenuation at depth on sloped surfaces. *Geomorphology* 27, 3-11 (1999).
- [5] Stone, J.O. Air pressure and cosmogenic isotope production. *J. Geophys. Res.* 105, 23753-23759 (2000).
- [6] Owen L.A. Latest Pleistocene and Holocene glacier fluctuations in the Himalaya and Tibet. *Quaternary Sciences Review* 28, 2150-2164 (2009).
- [7] Huntley D.J., Lamothe M. Ubiquity of anomalous fading in K-feldspars and the measurement and correction for it in optical dating. *Canadian Journal of Earth Sciences* 38, 1093-1106 (2001).
- [8] Fort M. Sporadic morphogenesis in a continental subduction setting: an example from the Annapurna Range, Nepal Himalaya. *Zeitschrift für Geomorphologie, Supplement-Band NF*, 63, 9-36 (1987).
- [9] Korup O., Montgomery D.R., Hewitt K. Glacier and landslide feedbacks to topographic relief in the Himalayan syntaxes. *PNAS*, 107: 12, 5317-5322 (2010)
- [10] Fort M., Rimal L.N., Bourles D., Guillou V. (in prep.). Large Landslides in the Nepal Himalayas and their geomorphic significance: examples from Phoksundo (Dolpo District) and Dhumpu (Mustang District) Nepal Himalayas.

-----  
 Key words (for online publication): Catastrophic rock failure, Landslide dam, Paraglacial,  $^{36}\text{Cl}$  Cosmogenic dating, IRSL dating, Phoksumdo Lake, Dolpo District, Nepal Himalaya