A comprehensive analysis of the variable temporal and spatial responses of tropical-subtropical high-altitude glaciers to climate change is critical for successful model predictions and environmental risk assessment in the Himalayan-Tibetan orogen. High-frequency Holocene glacier chronostatigraphies are therefore reconstructed in 79 glaciated valleys across the orogen using 519 published and 16 new terrestrial cosmogenic $^{10}$Be exposure age dataset. Published $^{10}$Be ages are compiled only for moraine boulders (excluding bedrock ages). These ages are recalculated using the latest ICE-D production rate calibration database and the scaling scheme models. Outliers for the individual moraine are detected using the Chauvenet’s criterion. In addition, past equilibrium-line altitudes (ELAs) are determined using the area-altitude (AA), area accumulation ratio (AAR), and toe-headwall accumulation ratio (THAR) methods for each glacier advance. The modern maximum elevations of lateral moraines (MELM) are also used to estimate...
modern ELAs and as an independent check on mean ELAs derived using the above three methods. These data may serve as an essential archive for future studies focusing on the cryospheric and environmental changes in the Himalayan-Tibetan orogen. A more comprehensive analysis of the published and new $^{10}$Be ages and ELA results and a list of references are presented in Saha et al. (2019, High-frequency Holocene glacier fluctuations in the Himalayan-Tibetan orogen. Quaternary Science Reviews, 220, 372–400).

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## Specifications table

| Subject | Earth and Planetary Sciences |
|---------|-----------------------------|
| Specific subject area | Earth-Surface Processes; Geology. |
| Type of data | Table |
| How data were acquired | Accelerated mass spectrometry (AMS); Google Earth imagery; Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) global digital elevation models (GDems) V2; Landsat Enhanced Thematic Mapper Plus (ETM+). ArcGIS 10.5; Read ArcGrid; MATLAB, R ‘luminescence’ statistical package: https://crep.otelo.univ-lorraine.fr/#; http://hess.ess.washington.edu/; http://cronus.cosmogenicnuclides.rocks/2.0/html/al-be/.
| Data format | Analyzed |
| Parameters for data collection | $^{10}$Be ages from moraine boulders are used after detecting and removing outliers to maintain consistency. No bedrock sample data are used in this study. Limited statistical analyses were performed for moraines that have $<2^{10}$Be ages before/after removing outliers. Former ELAs and change in ELAs ($\Delta$ELAs) are measured only for those glaciated valleys where the modern glacier-ice is present. Seventy-seven of the total 79 glaciated valleys fulfill the criteria. |
| Description of data collection | Approximately 500g of rock to a depth of $\leq 3.5$cm from the top of each moraine boulder was collected using a hammer and chisel for $^{10}$Be dating. Sample preparation was performed at the Quaternary Geochronology Laboratories in the University of Cincinnati. AMS measurements were performed at the Purdue Rare Isotope Measurement Laboratory at Purdue University. Raw data for ELA estimates were extracted using satellite images acquired in 26th February 2016 at https://search.earthdata.nasa.gov/search. Present and past glaciated areas were mapped (as vector layers) using Google Earth, and Landsat ETM + images and the raw elevation data were extracted from the ASTER GDems (as raster layers). |
| Data source location | New $^{10}$Be samples were collected from Sonapani glacier in the Kulti valley (32.44° N, 77.33° E) and the Parkachik valley in Nun Kun massif (34.05° N, 76.00° E). Published $^{10}$Be ages and all ELA dataset covers a vast area including the Himalaya, Tibet, Pamir, and Tian Shan with a latitudinal range of 27.04°–43.12° N and longitudinal range of 71.62°–102.74° E. Note that the sample coordinates are also provided in the tables. |
| Data accessibility | Data is provided in the paper. |
| Related research article | Saha, S., Owen, LA., Orr, E.N., Caffee, M.W. (2019). High-frequency Holocene glacier fluctuations in the Himalayan-Tibetan orogen. Quaternary Science Reviews, 220, 372–400. |

## Value of the data

- These data contain an exhaustive list of $^{10}$Be ages and reconstructed past ELAs and $\Delta$ELAs of moraines across the Himalaya, Tibet, Pamir, and Tian Shan for the past 15,000 years.
- These data offer valuable information to anyone interested in the paleoclimatic changes in the region, especially in the past cryospheric (freshwater resources) responses to climate variability.
- The $^{10}$Be data can be used/reproduced directly to recalculate exposure ages with future modifications in the dating techniques.
- The ELA data are comprehensive and can be directly incorporated into numerical models that use terrestrial glaciers as a proxy for climate change.
- The $^{10}$Be ages and ELAs may have the potentiality to model paleotemperatures in this high-altitude mountainous region.
1. Data

Table S1 contains all the new and published $^{10}\text{Be}$ apparent moraine ages for the past 15 ka in the 79 glaciated regions of the Himalayan-Tibetan orogen (see also Supplementary item 1). We identified 128 outliers (in blue in Supplementary item 1) from a total age population of 535 in this study. Note that the ages are organized from oldest to youngest local glacial stages for each climatic zone. For an extended discussion on climatic zones, the readers are encouraged to see the article “High-frequency Holocene glacier fluctuations in the Himalayan-Tibetan orogen” in the Quaternary Science Reviews [1]. A comprehensive list of references is also provided in the article. Table 1 contains the ELAs and $\Delta$ELAs for the 77 glaciated regions (see also Supplementary item 2).

2. Experimental design, materials, and methods

2.1. New $^{10}\text{Be}$ ages

We sampled multiple (≥2) boulders from each moraine using a chisel and hammer after carefully considering the moraine morphostratigraphy, physical setting, and surficial characteristics of moraine boulders [2]. Moraines were first mapped and grouped from oldest to youngest based on their relative position from each other (i.e., morphostratigraphy). Since Holocene moraines show similar surficial characteristics, relative dating based on the degree of weathering, vegetation cover, and soil development was not possible. We recorded the stability, degradation, and post-depositional hillslope contribution on each moraine in the field before sampling. We only sampled well-inset stable boulders with no evidence of post-depositional surface deflections, detrital cover, surface spallation, fracturing, and/or extensive weathering. Preferences were also given to boulders with well-developed lichen cover with the idea that boulders have not recently been exhumed and/or toppled allowing the steady growth of lichens. The sampled boulders have heights ranging from 0.3 to 1.3 m (Table S1). Approximately 500 g of rock was collected from the top of each boulder to a depth was ≤3.5 cm. Topographic shielding from the boulder surface to the horizon was measured using a compass and an inclinometer at $^{10}$° azimuth interval [2,3]. No correction for snow shielding was performed, assuming a windswept condition throughout the year [3].

Quartz extraction and $^{10}\text{Be}$ sample preparation were executed at the Quaternary Geochronology Laboratories of the University of Cincinnati [4,5]. Our sample preparation includes crushing and sieving the boulder samples to obtain a 250–500 μm particle size fraction. Subsequently, samples were leached for about 10 hours in aqua regia to remove any organics and dried for 24 hours. The dry samples were then etched in 1% HF for approximately 1 h. Since quartz is hydrophilic (sticky) in nature, the froth flotation technique was applied to remove excess muscovite and feldspar (which are hydrophobic) in the sample. Samples were then treated two to three times with 5% and 1% HF/HNO$_3$. Any remaining feldspar, mica, and other heavy minerals were removed by using lithium heteropolytungstate heavy liquid separation (density 2.7 g/cm$^3$) and a Frantz magnetic separator. About 25–15 g of extracted pure quartz was dissolved in 49% concentrated HF acid after adding low background $^9\text{Be}$ carrier (0.495 mg/g for Kulti and 1.0459 mg/g for Parkachik) and fumed with perchloric (HClO$_4$) acid to remove fluorine atoms. In addition, to remove Fe and Ti and separate the $^{10}\text{Be}$ fraction, samples were passed through the anion and cation exchange columns using (6–1 N) HCl acid. Beryllium hydroxide (Be(OH)$_2$) gel was extracted from the $^{10}\text{Be}$ fraction by adding Ammonium hydroxide. The Be(OH)$_2$ was heated at an oven at 900 °C for 30 minutes to form BeO, mixed with acetone, Nb powder, and then loaded into a steel target. A minimum of two blanks were prepared to assess the $^9\text{Be}$ carrier and laboratory background level of $^{10}\text{Be}$ for each set of samples. We measured the ratios of $^{10}\text{Be}/^9\text{Be}$ using the accelerator mass spectrometry (AMS) at the Purdue Rare Isotope Measurement (PRIME) Laboratory at Purdue University. 07KNSTD (standard) is used to normalize our Be isotopic. The $^{10}\text{Be}/^9\text{Be}$ ratios were subsequently converted into $^{10}\text{Be}$ concentrations, i.e., in atoms [2] and exposure ages (Table S1) were estimated using the available online age calculators (https://crep.otelo.univ-lorraine.fr/#; http://hess.ess.washington.edu/; http://cronus.cosmogenicnuclides.rocks/2.0/html/al-be/).
| Glaciated Valley | Glacial Stage | Mean moraine age (ka) | Head (m asl) | Toe (m asl) | MELM (m asl) | Area-Altitude ratio | Area-Accumulation ratio | Toe-Headwall altitude ratio | Mean ELA (m asl) | D ELA (m) |
|-----------------|---------------|----------------------|--------------|-------------|--------------|---------------------|------------------------|------------------------|-------------------|-----------|
| Bordoo Valley, Tian Shan | Present | - | 4467 | 3870 | 4100 | 4188 | 4199 | 4159 | 4109 | 4037 | 4113 | 4190 | 4137±56 |
| BOR 1 | 0.64±0.23 | 4458 | 3745 | - | 4135 | 4159 | 4109 | 4039 | 3974 | 4059 | 4145 | 4089±67 | 54±10 |
| BOR 2 | 13.08±2.13 | 4452 | 3629 | - | 4044 | 4079 | 3979 | 3869 | 3890 | 3987 | 4085 | 3990±86 | 152±46 |
| Kitschi-Kurumdu, Tian Shan | M2 | 15.16±3.03 | 4268 | 3787 | - | 3999 | 3969 | 3930 | 3899 | - | - | - | 3949±44 |
| Ala Archa, Kyrgyz Tian Shan | Present | - | 4299 | 3722 | 3950 | 4004 | 3989 | 3949 | 3889 | 3769 | 3769 | 3720±97 | 244±50 |
| Ala Archa | 0.49±0.25 | 4258 | 3400 | - | 3765 | 3739 | 3659 | 3569 | 3660 | 3769 | 3720±97 | 244±50 |
| Aksai valley, Kyrgyz Tian Shan | Present | - | 4139 | 3843 | 4100 | 4006 | 3989 | 3979 | 3949 | - | - | - | 4005±57 |
| Aksai | 5.70±0.16 | 4072 | 3408 | - | 3700 | 3689 | 3629 | 3549 | 3602 | 3683 | 3765 | 3660±71 | 339±46 |
| Daxi valley, Tian Shan | Present | - | 4400 | 3801 | 4000 | 4075 | 4049 | 4019 | 3969 | 3972 | 4043 | 4115 | 4030±50 |
| LIA | 0.33±0.02 | 4390 | 3684 | - | 4013 | 3999 | 3949 | 3909 | 3909 | 3989 | 4070 | 3977±58 | 58±9 |
| Alay Range (Koksu Valley) | Present | - | 4917 | 3621 | 4059 | 4180 | 4209 | 4159 | 4099 | 4019 | 4149 | 4280 | 4144±84 |
| AV | 14.02±0.16 | 4921 | 3442 | - | 4060 | 4129 | 4029 | 3899 | 3893 | 3981 | 4041 | 4190 | 4034±110 |
| Muztag Ata and Kongur Shan, NW Tibet | Present | - | 6853 | 2773 | 3809 | 3972 | 3829 | 3729 | 3559 | 4003 | 4111 | 4280 | 4017±409 |
| Olimde 7 stage (m3I) | - | 6873 | 2462 | - | 3870 | 3769 | 3619 | 3449 | 3792 | 4233 | 4675 | 3915±413 | 131±51 |
| Muztag Ata and Kongur Shan, NW Tibet | Present | - | 7349 | 4271 | 5609 | 5998 | 6259 | 5979 | 5609 | 5203 | 5511 | 5820 | 5749±332 |
| Olimde 7 stage (m7H) | - | 7349 | 4054 | - | 5772 | 6029 | 5659 | 5229 | 5049 | 5379 | 5710 | 5547±341 | 222±100 |
| Muztag Ata and Kongur Shan, NW Tibet | Present | - | 6847 | 4300 | 5809 | 6030 | 6189 | 5989 | 5809 | 5068 | 5324 | 5580 | 5725±379 |
| Olimde 6 stage (m5H) | - | 6852 | 4003 | - | 5866 | 6099 | 5879 | 5629 | 4864 | 5149 | 5435 | 5560±440 | 153±40 |
| Olimde 6 stage (m6H) | - | 6852 | 3919 | - | 5793 | 6059 | 5829 | 5539 | 4801 | 5095 | 5390 | 5501±442 | 212±53 |
| Olimde 4 stage (m4H) | - | 6839 | 3591 | - | 5437 | 5759 | 5279 | 4529 | 4574 | 4899 | 5225 | 5100±454 | 612±317 |
| Olimde 2 stage (m3H) | - | 6852 | 3515 | - | 5377 | 5679 | 5069 | 4469 | 4521 | 4855 | 5190 | 5023±442 | 690±334 |
| Muztag Ata and Kongur Shan, NW Tibet | Present | - | 6991 | 4348 | 4969 | 5602 | 5459 | 5119 | 4849 | 5144 | 5409 | 5675 | 5278±301 |
| Olimde 8 stage (m6C) | 0.51±0.15 | 7008 | 4273 | - | 5528 | 5389 | 4970 | 4769 | 5101 | 5375 | 5650 | 5255±317 | 68±42 |
| Stage | Site/Location | Age (ka) | Site Coordinates | Notes |
|-------|--------------|----------|------------------|-------|
| Olimde 2 stage | Muztag Ata and Kongur Shan, NW Tibet | 11.71±0.40 | 7008 4209 | Present |
| Olimde 8 stage | Muztag Ata and Kongur Shan, NW Tibet | 0.69±0.27 | 6075 4152 | Present |
| Olimde 7 stage | Muztag Ata and Kongur Shan, NW Tibet | 2.20±0.07 | 6075 4018 | Present |
| Olimde 4 Stage | Muztag Ata and Kongur Shan, NW Tibet | 7.80±0.32 | 6075 3782 | Present |
| Olimde 3 stage | Muztag Ata and Kongur Shan, NW Tibet | 10.25±0.16 | 6682 3582 | Present |
| Olimde 3 stage | Muztag Ata and Kongur Shan, NW Tibet | 9.69±0.34 | 6747 3413 | Present |
| Olimde 5 stage | Muztag Ata and Kongur Shan, NW Tibet | 5.05±0.14 | 6865 4059 | Present |
| Olimde 4 Stage | Muztag Ata and Kongur Shan, NW Tibet | 7.74±0.27 | 6075 3787 | Present |
| Olimde 3 stage | Muztag Ata and Kongur Shan, NW Tibet | 13.18±0.64 | 5324 4599 | Present |
| BO8 stage | Great Bogchigir Valley | 13.18±0.64 | 5326 4425 | Present |
| Batura stage (t6) | Batura - Hunza Valley | 14.30±0.01 | 7606 2502 | Present |
| Batura stage (t6) | Batura - Hunza Valley | 12.49±0.01 | 7112 2542 | Present |
| Askole 2 stage (m2b) | Central Karakoram | 5.98±0.69 | 5173 4290 | Present |
| Mungo 2 stage (m2G) | Central Karakoram | 6.64±0.35 | 5202 2991 | Present |
| Mungo 2 stage (m1G) | Central Karakoram | 13.77±0.53 | 5202 2889 | Present |
| Askole 3 stage (m1H) | Central Karakoram | 1.03±0.28 | 6260 2977 | Present |

**Climatic Zone 1a: Arid and semiarid colder climatic region — Transhimalaya**

| Climate Zone | Site/Location | Age (ka) | Site Coordinates | Notes |
|--------------|--------------|----------|------------------|-------|
| Batura - Hunza Valley | Present | 14.30±0.01 | 7606 2502 | - |
| Batura stage (t6) | 12.49±0.01 | 7112 2542 | - |
| Askole 2 stage (m2b) | 5.98±0.69 | 5173 4290 | - |
| Mungo 2 stage (m2G) | 6.64±0.35 | 5202 2991 | - |
| Mungo 2 stage (m1G) | 13.77±0.53 | 5202 2889 | - |
| Askole 3 stage (m1H) | 1.03±0.28 | 6260 2977 | - |

(continued on next page)
| Glaciated Valley | Glacial Stage | Mean moraine age (ka) | Head (m asl) | Toe (m asl) | MELM (m asl) | Area-Altitude (m asl) | Area-Accumulation ratio | Toe-Headwall altitude ratio | Mean ELA (m asl) | ΔELA (m) |
|-----------------|--------------|-----------------------|-------------|-------------|-------------|----------------------|------------------------|-------------------------|-----------------|--------|
| Mungo 2 stage (m3I) | 13.06±0.40 6262 2977 - | 4744 4939 4820 4669 | 4295 4625 4954 | 4721±226 30±13 |
| Mungo 2 stage (m2I) | 14.08±0.23 6262 2977 - | 4730 4939 4819 4649 | 4295 4625 4954 | 4716±226 35±21 |
| Mungo 2 stage (m1I) | 14.98±0.29 6262 2977 - | 4710 4929 4809 4619 | 4295 4625 4954 | 4706±225 45±32 |
| Central Karakoram Present | - 5840 4224 4939 | 5101 5159 5099 5039 | 4877 5040 5202 | 5057±108 - |
| Central Karakoram Mungo 2 stage (m1E) | 13.44±0.19 5718 4019 4689 | 4916 4979 4929 4839 | 4703 4875 5046 | 4872±125 - |
| Central Karakoram Mungo 2 stage (m1F) | 14.62±0.32 5724 2408 - | 4338 4659 4429 4199 | 4611 4795 4978 | 4807±186 - |
| Ladakh cirque, Ladakh range Present | - 5776 5407 5529 | 5596 5609 5570 5539 | - - 4590 | 4846±271 413±186 |
| Ladakh cirque, Ladakh range Ladakh Chang La Present | 2.29±0.28 5776 5376 - | 5553 5549 5519 5480 | - - 4590 | 5525±34 53±8 |
| Ladakh cirque, Ladakh range Pangong high cirque Present | 0.54±0.11 5984 5386 5679 | 5673 5690 5659 5629 | 5629 5690 5750 | 5675±39 - |
| Stok Kangri, Zanskar Present | - 5721 5288 5459 | 5507 5519 5499 5459 | - - - 5489±28 - |
| Stok valley, Zanskar mS1 | 1.42±0.48 5748 5234 - | 5456 5449 5419 5399 | - - - 5431±27 65±13 |
| Amda Kangri, Lato mg1 | - 5649 5258 5479 | 5510 5539 5509 5479 | - - - 5503±25 - |
| Amda Kangri, Lato mg1 | 1.33±0.12 5649 5149 - | 5455 5499 5459 5430 | - - - 5461±29 49±6 |
| Puga Valley, Zanskar Present | - 6099 5686 5839 | 5893 5909 5870 5839 | - - - 5870±32 - |
| PM-3 stage | 0.28±0.05 6101 5199 - | 5647 5659 5609 5559 | 5563 5655 5746 | 5634±64 259±15 |
| PM-2 stage | 3.50±0.87 6101 4797 - | 5480 5569 5489 5369 | 5323 5455 5556 | 5467±96 401±55 |
| Mentok Kangri, Karzok Present | - 6003 5482 5659 | 5740 5759 5729 5709 | - - - 5719±38 - |
| Mentok Kangri, Karzok mM1 | 0.64±0.09 6003 5447 - | 5714 5739 5710 5679 | - - - 5711±25 24±5 |
| Mentok Kangri, Karzok mM2 | 1.00±0.08 6003 5378 - | 5685 5689 5669 5639 | 5631 5695 5758 | 5681±42 64±8 |
| Gomuche Kangri, Karzok Present | - 6084 5381 5649 | 5873 5939 5909 5869 | 5669 5740 5810 | 5807±110 - |
| Gomuche Kangri, Karzok mg1 | 2.25±0.42 6084 5332 - | 5805 5909 5859 5739 | 5639 5715 5790 | 5779±91 50±39 |
### Climatic Zone 1b: Arid and semi-arid colder climatic region—southern and northeastern Tibet

| Location                          | MELM  | AA  | AAR (0.60) | AAR (0.70) | AAR (0.80) | THAR (0.30) | THAR (0.40) | THAR (0.50) |
|-----------------------------------|-------|-----|------------|------------|------------|-------------|-------------|-------------|
| Dalijia Shan, NE Tibet           | Group D moraines | 13.45±0.25 | 4460 | 3725 | 4029 | 4079 | 4029 | 3949 | 3879 | 3951 | 4025 | 4100 | 4005±74 |
| Xiying He valley, Qilian Shan, NE Tibet | Present | - | 4729 | 4152 | 4379 | 4471 | 4439 | 4399 | 4349 | - | - | - | 4407±48 |
| NW Menyuan, Qilian Shan, NE Tibet | N/A | 13.16±1.05 | 4729 | 3397 | - | 3836 | 3689 | 3629 | 3579 | 3801 | 3935 | 4070 | 3791±174 | 731±65 |
| Anyemaqen Mountains              | Gangshiga glacier (Present) | 10.08±0.53 | 4832 | 4320 | - | 4506 | 4459 | 4409 | 4379 | - | - | - | 4438±56 | 136±15 |
| Anyemaqen Mountains              | Halong glacial I (Present) | 9.48±1.70 | 6183 | 4443 | 4939 | 5140 | 5339 | 4959 | 4729 | 4971 | 5145 | 5320 | 5068±207 | |
| Anyemaqen Mountains              | Halong glacial II (Present) | 13.89±1.26 | 6006 | 4549 | 4884 | 5347 | 5069 | 4989 | 4879 | 4987 | 5133 | 5280 | 5071±173 | |
| Kunlun Shan (northern slopes)    | Halong glacial stage (Present) | 13.39±1.61 | 5935 | 4593 | 5119 | 5861 | 5329 | 5239 | 5119 | 5001 | 5135 | 5270 | 5259±664 | |
| Karola Pass, Mt. Kaluxung, SN Tibet | M2 moraines | 8.04±0.74 | 5960 | 4405 | - | 5268 | 4419 | 4309 | 4199 | 4564 | 4772 | 4980 | 4644±384 | 453±229 |
| Yunam valley, Zanskar            | Present | - | 6604 | 4860 | 5549 | 5861 | 5909 | 5789 | 5385 | 5385 | 5670 | 5735 | 5678±177 | |
|              | Youngest | 3.28±0.74 | - | 5754 | 5809 | 5629 | 5469 | 5369 | 5549 | 5730 | 5313 | 5310 | 5493±255 | 143±167 |
|              | Oldest   | 11.47±0.70 | 6623 | 4806 | - | 5200 | 5749 | 5529 | 5389 | 5355 | 5372 | 5570 | 5497±198 | 200±229 |

### Climatic Zone 2a: Transitional climatic region—western Himalaya

| Location                          | MELM  | AA  | AAR (0.45) | AAR (0.55) | AAR (0.65) | THAR (0.40) | THAR (0.50) | THAR (0.60) |
|-----------------------------------|-------|-----|------------|------------|------------|-------------|-------------|-------------|
| Nun-Kun massif                    | Anantick stage (ST-3) | 13.55±0.88 | - | 3685 | 3699 | 3639 | 3569 | 3705 | 3795 | 3884 | 3711±102 | |
| Nun-Kun massif                    | Present | - | 5571 | 4238 | 4629 | 4905 | 5000 | 4830 | 4629 | 4775 | 4910 | 5044 | 4840±156 | 370±133 |
| Yunam valley, Zanskar            | Present | - | 5601 | 5179 | 5369 | 5409 | 5410 | 5389 | 5369 | - | - | - | 5389±20 | |
| Youngest                          | 0.62±0.15 | 5640 | 4698 | - | 5231 | 5329 | 5269 | 5119 | 5079 | 5175 | 5270 | 5216±84 | 147±58 |
| Lahul Himalaya, Nn India         | Kulti glacial stage | 11.76±0.59 | 5378 | 2756 | - | 3854 | 3869 | 3689 | 3559 | 3811 | 4075 | 4338 | 3885±256 | 525±104 |
| Lahul Himalaya, Nn India         | Present | - | 5746 | 3972 | 4639 | 4960 | 5049 | 4999 | 4939 | 4691 | 4870 | 5048 | 4899±157 | |
| Lahul Himalaya, Nn India         | Kulti glacial stage | 14.03±0.16 | 5746 | 2933 | - | 4530 | 4994 | 4659 | 4499 | 4067 | 4350 | 4632 | 4527±274 | 410±163 |
| Lahul Himalaya, Nn India         | Present | - | 6002 | 4187 | 4909 | 5170 | 5269 | 5169 | 5060 | 4917 | 5100 | 5103 | 5109±124 | |
| Lahul Himalaya, Nn India         | Kulti glacial stage | 14.45±0.70 | 6002 | 3971 | - | 4822 | 4929 | 4650 | 4439 | 4791 | 4995 | 5198 | 4832±245 | 306±212 |
| Lahul Himalaya, Nn India         | Present | - | 4225 | 3470 | 3749 | 3776 | 3739 | 3720 | 3709 | 3774 | 3850 | 3926 | 3780±73 | |
| Lahul Himalaya, Nn India         | Kulti glacial stage | 13.95±0.88 | 4782 | 2411 | - | 3404 | 3639 | 3419 | 3099 | 3367 | 3605 | 3842 | 3482±238 | 303±184 |
| Hamtah Valley, Lahul             | Present | - | 5011 | 4056 | 4569 | 4459 | 4509 | 4449 | 4399 | 4443 | 4540 | 4636 | 4500±78 | |
| mH1a                             | 0.26±0.13 | 5063 | 3941 | - | 4407 | 4559 | 4409 | 4319 | 4397 | 4510 | 4622 | 4460±106 | 30±41 |
| Glaciated Valley                      | Glacial Stage | Mean moraine age (ka) | Head (m asl) | Toe (m asl) | MELM (m asl) | Area-Altitude ratio | Area-Accumulation ratio | Toe-Headwall altitude ratio | Mean ELA (m) | ΔELA (m) |
|--------------------------------------|---------------|-----------------------|--------------|-------------|--------------|---------------------|--------------------------|----------------------------|---------------|----------|
| Sonapani glacier, Kulti Valley, Lahul Himalaya | Present       | -                     | 5063         | 3688        | -            | 4332               | 4149                     | 4319                       | 4810          | 4518     |
| mH3                                  | 10.48±0.48    | 5465                  | 3901         | 4640        | 4815         | 4929               | 4819                     | 4719                       | 4533          | 4846     |
| mK1                                  | 51.01±0.16    | 5478                  | 3662         | -           | 4727         | 4879               | 4759                     | 4590                       | 4403          | 4158     |
| mK2                                  | 0.51±0.16     | 5498                  | 3631         | -           | 4662         | 4839               | 4709                     | 4529                       | 4397          | 4762     |
| mK3                                  | 12.18±0.99    | 5474                  | 3432         | -           | 4641         | 4829               | 4699                     | 4500                       | 4255          | 4664     |
| mK4                                  | 15.30±0.60    | 5498                  | 3151         | -           | 4598         | 4809               | 4659                     | 4469                       | 4099          | 4570     |
| mK5                                  |                  | Location G            | 5883         | 3848        | 4679         | 4570               | 4449                     | 4320                       | 4259          | 4611     |
|                                        |                | Present               | -            | 5063        | 3688         | -                  | 4332                     | 4149                       | 4319          | 4810     |
|                                        |                | Location G            | 0.66±0.34    | 5883        | 3519         | -                  | 4433                     | 4319                       | 4249          | 4467     |
|                                        |                | Location F            | 6.09±0.54    | 5883        | 3277         | -                  | 4329                     | 4269                       | 4140          | 4323     |
|                                        |                | Location F            | 10.26±0.35   | 5883        | 3211         | -                  | 4286                     | 4250                       | 4109          | 4287     |
| Tons Valley, Garhwal Himalaya, Nn. India | Present       | -                     | 5924         | 4014        | 4680         | 5078               | 5199                     | 5109                       | 4989          | 4783     |
| Location E                           | 0.26±0.08     | 5955                  | 3884         | -           | 4997         | 5170               | 5039                     | 4889                       | 4717          | 4925     |
| Location D                           | 11.09±0.50    | 5955                  | 3527         | -           | 4879         | 5109               | 4969                     | 4719                       | 4501          | 4745     |
| Location C                           | 14.06±0.10    | 5955                  | 3352         | -           | 4166         | 4189               | 4059                     | 3939                       | 4065          | 4370     |
| Tons Valley, Garhwal Himalaya, Nn. India | Present       | -                     | 6429         | 4581        | 4900         | 5084               | 5059                     | 4969                       | 4899          | 5093     |
| Gangotri, Garhwal Himalaya, Nn India  | Present       | Kedar glacial stage   | 8.28±0.45    | 6429        | 4218         | -                  | 5053                     | 5030                       | 4949          | 5003     |
| Gangotri, Garhwal Himalaya, Nn India  |                | Present               | -            | 7003        | 4017         | 4900               | 5151                     | 5149                       | 5000          | 5215     |
| Bhullanganga and Dudhanga valleys, Sn. Garhwal Himalaya | mbd4         | 0.13±0.11             | 6068         | 3806        | 4710         | 4956               | 5069                     | 4919                       | 4710          | 4717     |
| Bhullanganga and Dudhanga valleys, Sn. Garhwal Himalaya | mbd3         | 0.15±0.10             | 6082         | 3526        | -            | 4871               | 5019                     | 4849                       | 4609          | 4534     |
| Bhullanganga and Dudhanga valleys, Sn. Garhwal Himalaya | mbd2         | 0.16±0.15             | 6082         | 3459        | -            | 4840               | 4999                     | 4819                       | 4569          | 4511     |
| Bhullanganga and Dudhanga valleys, Sn. Garhwal Himalaya | Present      | -                     | 5616         | 4523        | 5019         | 5092               | 5079                     | 5049                       | 4969          | 5092     |
| Bhullanganga and Dudhanga valleys, Sn. Garhwal Himalaya | mbd1         | 0.21±0.02             | 5616         | 3776        | -            | 5005               | 5060                     | 5029                       | 4999          | 4519     |
| Location                        | Present | MELM | AA | AAR (0.50) | AAR (0.60) | AAR (0.70) | THAR (0.30) | THAR (0.40) | THAR (0.50) |
|---------------------------------|---------|------|----|------------|------------|------------|-------------|-------------|-------------|
| Kedarnath, Sn. Garhwal Himalaya |         | 6136 | 3805 | 4730 | 4985 | 5189 | 4959 | 4730 | 4745 | 4980 | 5214 | 4941±195 |
| present                        |         |      |     |     |     |     |     |     |     |     |     |         |
| mk2                            | 0.31±0.17 | 6136 | 3597 | -   | 4897 | 5089 | 4830 | 4619 | 4619 | 4875 | 5130 | 4866±201 | 106±17 |
| mk1                            | 10.25±0.83 | 6136 | 3180 | -   | 4466 | 4519 | 4179 | 4039 | 4368 | 4665 | 4962 | 4457±306 | 515±206 |
| Mayalil, Sn. Garhwal Himalaya   |         | 5121 | 4620 | 4839 | 4893 | 4919 | 4869 | 4839 | -   | -   | -   | 4872±35  |         |
| Present                        |         |      |     |     |     |     |     |     |     |     |     |         |
| mm1                            | 13.62±0.66 | 5121 | 4327 | -   | 4758 | 4809 | 4759 | 4699 | 4649 | 4730 | 4810 | 4745±58  | 124±16 |
| Nanda Devi, Garhwa, Nn Indial   |         | 6862 | 3560 | 4466 | 4519 | 4179 | 4039 | 4368 | 4665 | 4962 | 5546 | 5056±285 |         |
| Present                        |         |      |     |     |     |     |     |     |     |     |     |         |
| Moraine m4                    | 0.60±0.28 | 6875 | 3478 | -   | 4894 | 5169 | 4729 | 4549 | 4839 | 5180 | 5520 | 4996±325 | 86±60  |
| Moraine m2                    | 13.71±0.69 | 6870 | 3432 | -   | 4954 | 5119 | 4699 | 4529 | 4815 | 5160 | 5504 | 4971±356 | 113±66  |
| Muguru valley, Gurla Mandhata   |         | 6739 | 5621 | 5969 | 6190 | 6249 | 6159 | 5989 | 5959 | -   | -   | 5693±78  | 295±61  |
| Present                        |         |      |     |     |     |     |     |     |     |     |     |         |
| M10                            | 0.24±0.15 | 6739 | 5489 | -   | 6115 | 6189 | 6089 | 5989 | 6089 | 6111 | 6238 | 5609±119 | 79±18  |
| M9                             | 0.46±0.10 | 6753 | 5430 | -   | 6062 | 6119 | 5999 | 5869 | 5962 | 6095 | 6228 | 5604±117 | 130±45  |
| M8                             | 5.01±0.88 | 6760 | 5262 | -   | 5935 | 5949 | 5829 | 5739 | 5869 | 6020 | 6170 | 5930±139 | 248±81  |
| M7                             | 8.75±0.55 | 6760 | 5207 | -   | 5904 | 5920 | 5800 | 5767 | 5935 | 6102 | 6102 | 5875±133 | 303±62  |
| Muguru valley, Gurla Mandhata   |         | 6108 | 5728 | 5969 | 5985 | 6019 | 5989 | 5959 | -   | -   | -   | 5982±25  |         |
| Present                        |         |      |     |     |     |     |     |     |     |     |     |         |
| M5                             | 15.30±0.60 | 6108 | 5474 | -   | 5756 | 5759 | 5659 | 5599 | -   | -   | -   | 5693±78  | 295±61  |

**Climatic Zone 2b: Transitional climatic region—central and eastern Himalaya**
### Table 1 (continued)

| Glaciated Valley               | Glacial Stage     | Mean moraine age (ka) | Head (m asl) | Toe (m asl) | MELM (m asl) | Area-Altitude ratio | Area-Accumulation ratio | Toe-Headwall altitude ratio | Mean ELA (m) | ΔELA (m) |
|--------------------------------|-------------------|-----------------------|--------------|------------|--------------|--------------------|--------------------------|---------------------------|--------------|----------|
| Recessional moraine            |                   | 6.03±1.97             | 7354         | 2482       | -            | 4750               | 5099 4969 4149           | 3950 4437 4925          | 4611±440    | 348±262  |
| Local LGM moraines             |                   | 10.10±0.73            | 7354         | 1697       | -            | 4071               | 3769 3309 2969           | 3397 3963 4530          | 3715±529    | 1244±550 |
| **Climatic Zone 3: Wet-temperate climatic region — central and eastern Himalaya** |                   |                       |              |             |              |                    |                          |                           |              |          |
| Lete valley, Annapurna, Nepal  |                   | Present               | 6.36±1.21    |             | -            | -                  | -                        | -                          | -             |          |
| Ganhaizi and Ganheba, southeastern Tibet |                   | Present               | 12.97±1.41   | 5108       | 4502         | 4670               | 4841 4839 4819 4779      | 4667 4743 4820          | 4772±72     |          |
| Annapurna Range, Nepal         |                   | Syakta glacier stage  | 9.48±0.91    | 5311       | 4987         | 5099               | 5144 5139 5109 5079      | -                          | -             |          |
| Annapurna Range, Nepal         |                   | Lyapche glacier stage | 11.54±0.80   | 6641       | 3549         | -                  | 5380 5559 5439 5269      | 4479 4789 5100          | 5145±387    | 443±265  |
| Annapurna Range, Nepal         |                   | Yak glacier stage     | 8.72±0.40    | 5144       | 4870         | 4979               | 5012 5099 4989 4969      | -                          | -             | 4992±19    |          |
| Annapurna Range, Nepal         |                   | Danfe Glacier stage   | 8.87±0.36    | 5420       | 4621         | 5029               | 5000 4899 4849 4809      | 4869 4949 5030          | 4929±85     |          |
| Milarepa's Glacier, Annapurna Range, Nepal |               | Present               | 0.55±0.16    | 5504       | 3513         | -                  | 4469 4379 4329 4329      | 4116 4315 4515          | 4337±135    | 104±73   |
| Dudh Khola Valley, Annapurna, Nepal |               | Present               | -            | 6673       | 3552         | 4529               | 5295 5679 4929 4529      | 4495 4807 5120          | 4923±423    |          |
| Neoglacial                     |                   | Present               | 1.70±0.50    | 6673       | 3084         | -                  | 5196 5559 4689 4449      | 4166 4525 4885          | 4781±474    | 198±98   |
| Macha Khola Valley, Gorkha Himal, Nepal |       | Present               | 4.99±0.92    | 5304       | 3735         | -                  | 4523 4659 4379 4079      | 4210 4367 4525          | 4392±199    | 654±230  |
| Mailun Khola, Ganesh Himal, Nepal |       | Present               | 7.04±0.64    | 5562       | 4257         | -                  | 5024 5090 5019 4939      | 4652 4783 4915          | 4917±153    | 192±119  |

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| Location                                    | Period          | Elevation                      |
|--------------------------------------------|-----------------|--------------------------------|
| Langtang Valley, Langtang Himal, Nepal     | Present         | 6319, 3983, 4909, 4861, 4769, 4629, 4439, 4691, 4925, 5160, 4798 ± 218 |
|                                            | Yala I          | 0.76 ± 0.20, 6328, 3774, 4648, 4509, 4339, 4229, 4547, 4803, 5060, 4591 ± 280 |
|                                            | LT6             | 4.42 ± 0.15, 6328, 3506, 4491, 4329, 4189, 4049, 4358, 4641, 4925, 4426 ± 292 |
|                                            | Langtang Stage  | 10.90 ± 0.43, 6525, 3915, 5169, 5259, 5069, 4869, 4702, 4963, 5225, 5037 ± 204 |
|                                            | LT3             | 4.42 ± 0.15, 6525, 3915, 5169, 5259, 5069, 4869, 4702, 4963, 5225, 5037 ± 204 |
|                                            | Langtang glacial stage II | 4.60 ± 0.33, 6563, 3344, 4747, 4869, 4619, 4449, 4315, 4637, 4960, 4657 ± 226 |
|                                            | Langtang glacial stage I | 5.47 ± 0.40, 6563, 3079, 4374, 4499, 4049, 3419, 4126, 4475, 4825, 4252 ± 448 |
| Nyalam County, Sn Xixabangma, Sn Tibet     | Fu Qu glacier   | - 5566, 4446, 4929, 4845, 4709, 4620, 4579, 4788, 4901, 5015, 4798 ± 153 |
|                                            | Puluo 1 moraine | - 5552, 4013, 4509, 4439, 4379, 4329, 4481, 4635, 4790, 4509 ± 158 |

- No data.

m asl Meter above sea level.

Note: The present here refers to the year 2016 AD.
No corrections for residual boron, radioactive decay, and muongenic production [6] were made; they are negligible for the timescale of this study. Native $^9$Be in nearby (uniform) lithology is also insignificant ($-0.0190 \pm 0.0160$ to $0.0015 \pm 0.0001$ ppm in Ref. [1]) to account for any adjustments in our calculated exposure ages.

2.2. Published $^{10}$Be ages

For consistency, we followed a strict procedure while compiling the published $^{10}$Be ages. This includes only using moraine boulder ages, excluding any bedrock ages from the analysis (Table S1; Supplementary item 1). $^{10}$Be ages that do not follow the moraine morphostratigraphic order as outlined in the original literature were excluded. Slip rate studies on moraines that only dated pebbles/cobbles were also not used in this compilation. Only studies that used the standard [4,5] $^{10}$Be extraction procedure are targeted. Since published studies used different standards (e.g., LLNL3000, SS55, NIST_Certified, NIST_27900, KNSTD, 07KNSTD) to normalize their Be isotopic measurements (Table S1), a correction factor is used whenever required while recalculating the ages [7]. We used 5 cm as the maximum depth of sample collection and zero erosion rates for studies that did not report any such information. Using the raw data provided in the original literature, we therefore recalculated all the published $^{10}$Be ages following the same parameters (Table S1; Supplementary item 1).

2.3. Exposure age calculation

We calculated/recalculated $^{10}$Be ages using the community standard Cosmic Ray Exposure program (CREp of [12]), CRONUS-Earth V3 [3], and CRONUScale program [9] (Table S1). Apparent exposure ages are calculated using the scaling schemes of Lifton-Sato-Dunai (LSD; [8]), time-dependent Lal and Stone (Lm; [3]), and time-independent Lal and Stone (St; [10,11]) (Table S1). The global sea-level high-latitude (SLHL) spallogenic $^{10}$Be production rate of $4.08 \pm 0.23$ atoms/g/a was used for the LSD scaling scheme along with the ERA40 atmospheric model and VDM2016 geomagnetic database [12,13] (http://calibration.ice-d.org/). We assumed zero-erosion rates and reported all the ages in thousands of years (ka) before 2016 CE.

We performed several statistical treatments if $>2$ concordant boulder ages are available for a moraine. We applied reduced chi-squared ($\chi^2$) statistics to assess the distribution of ages. Any age population with $\chi^2 > 1$ likely had outliers, and further statistical treatment was performed. Chauvenet’s criterion [14] was used to detect outliers and highlighted in blue in Table S1. Outliers for new $^{10}$Be ages were only removed if convincing field evidence supported our statistical results (e.g., possible recent hillslope deposits, shallow burial, and/or toppling). For published studies, we relied on statistical treatment and the recommendations in the original studies to detect and remove outliers. Mean moraine ages (local glacial stages) are reported using arithmetic means $\pm 1\sigma$, weighted mean $\pm 1\sigma$, and peaks in the probability distribution (Table S1).

2.4. Equilibrium-line altitudes (ELAs)

Present and past ELAs were determined using area-altitude (AA), area accumulation ratio (AAR), and toe-headwall accumulation ratio (THAR) methods for each glacier advance in 77 glaciated valleys (Table 1; Supplementary item 2) [15]. Additionally, the modern maximum elevations of lateral moraines (MELM) were used to evaluate the modern estimated ELAs derived using the above three methods (Table 1). ELAs and $\Delta$ELAs are only measured for those glaciated valleys where the modern glacier-ice is present.

Raw data for ELA estimates were extracted using satellite images acquired in 26th February 2016 at https://search.earthdata.nasa.gov/search. Present and past glaciated areas were mapped as vector layers using Google Earth and Landsat ETM+ images in ArcGIS 10.5 (Supplementary item 2). In addition, we used ASTER GDEMs to prepare Hillshade and Slope maps (Spatial Analyst Tools in ArcGIS) to further aid in outlining modern glaciated areas and paleo-ice extents. Paleo-ice extents were defined on the satellite images using moraine positions in the individual valley (Supplementary item 2). The vector layers/maps of the modern and the past glacier extents are then used to extract the DEM values.
and converted into ASCII files. The ASCII files were inserted into the Read ArcGrid program developed by Professor David Nash of the University of Cincinnati to generate the glacier’s hypsometry. The Read ArcGrid program calculates basic statistics, including Elevation Relief Ratio (hypsometric integral), for a matrix of elevations. Using the steps outlined in Ref. [15] and a combination of AA, AAR, and THAR ratios, we finally measured the ELAs. Different combinations of AARs (e.g., ranging from 0.45 to 0.80) and THARs (e.g., varies from 0.3 to 0.6) were used depending on the glacier setting, physical characteristics, and climate (Table 1). We obtained these ratios from the published literature for each distinct climatic zone (see Ref. [1] for details on climatic zones and references therein). In Table 1, we report the (arithmetic) mean ELA and $\Delta$ELA with $\pm 1\sigma$ uncertainty.

**Acknowledgments**

The current project was funded by the SEED grant of PRIME laboratory, Purdue University to AMS measure $^{10}$Be samples. SS, LAO and ENO thank the Department of Geology at the University of Cincinnati for fieldwork support. SS acknowledges support from the Geological Society of America for Graduate Student Research Grant and the Graduate Student Governance Association of the University of Cincinnati for Research Fellowship to conduct fieldwork.

**Conflict of interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Appendix A. Supplementary data**

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.dib.2019.104412.

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