
**SUPPLEMENTAL FILE 1**

### Dose rate information

<table>
<thead>
<tr>
<th>Sample num.</th>
<th>USU num.</th>
<th>Grain size (µm)</th>
<th>H₂O¹ (%)</th>
<th>K (%)²</th>
<th>Rb (ppm)²</th>
<th>Th (ppm)²</th>
<th>U (ppm)²</th>
<th>Cosmic (Gy/ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB-10</td>
<td>USU-582³</td>
<td>90-150</td>
<td>2.8</td>
<td>1.60 ± 0.04</td>
<td>88.2 ± 3.5</td>
<td>12.0 ± 1.1</td>
<td>1.3 ± 0.1</td>
<td>0.05 ± 0.01</td>
</tr>
<tr>
<td>IDP-1</td>
<td>USU-583</td>
<td>90-150</td>
<td>1.9</td>
<td>1.77 ± 0.04</td>
<td>106.0 ± 4.2</td>
<td>12.1 ± 1.1</td>
<td>1.7 ± 0.1</td>
<td>0.02 ± 0.00</td>
</tr>
<tr>
<td>IDP-6.1</td>
<td>USU-818</td>
<td>90-150</td>
<td>1.1</td>
<td>1.47 ± 0.04</td>
<td>109.5 ± 4.4</td>
<td>13.9 ± 1.3</td>
<td>1.7 ± 0.1</td>
<td>0.02 ± 0.00</td>
</tr>
<tr>
<td>IDP-2</td>
<td>USU-586⁴</td>
<td>75-180</td>
<td>1.6</td>
<td>0.90 ± 0.09</td>
<td>52.6 ± 5.3</td>
<td>6.9 ± 0.7</td>
<td>1.5 ± 0.2</td>
<td>0.17 ± 0.02</td>
</tr>
<tr>
<td>IDP-3</td>
<td>USU-584</td>
<td>90-180</td>
<td>1.7</td>
<td>0.90 ± 0.02</td>
<td>52.6 ± 2.1</td>
<td>6.9 ± 0.6</td>
<td>1.5 ± 0.1</td>
<td>0.17 ± 0.02</td>
</tr>
<tr>
<td>IDP-4</td>
<td>USU-1752</td>
<td>150-250</td>
<td>2.8</td>
<td>0.74 ± 0.02</td>
<td>36.9 ± 1.5</td>
<td>4.4 ± 0.4</td>
<td>1.0 ± 0.1</td>
<td>0.16 ± 0.02</td>
</tr>
<tr>
<td>IDP-5</td>
<td>USU-817⁵</td>
<td>150-250</td>
<td>1.9</td>
<td>0.51 ± 0.01</td>
<td>22.0 ± 0.9</td>
<td>2.7 ± 0.2</td>
<td>0.7 ± 0.1</td>
<td>0.15 ± 0.02</td>
</tr>
<tr>
<td>IDP-7</td>
<td>USU-829</td>
<td>75-250</td>
<td>0.2</td>
<td>0.21 ± 0.01</td>
<td>8.5 ± 0.3</td>
<td>0.9 ± 0.2</td>
<td>0.4 ± 0.1</td>
<td>0.10 ± 0.01</td>
</tr>
<tr>
<td>IDP-8</td>
<td>USU-816⁵</td>
<td>90-150</td>
<td>10.8</td>
<td>1.50 ± 0.04</td>
<td>97.6 ± 3.9</td>
<td>11.4 ± 1.0</td>
<td>1.6 ± 0.1</td>
<td>0.02 ± 0.00</td>
</tr>
<tr>
<td>IAC-6.2</td>
<td>USU-825</td>
<td>90-150</td>
<td>0.4</td>
<td>0.67 ± 0.02</td>
<td>42.4 ± 1.7</td>
<td>4.0 ± 0.4</td>
<td>1.0 ± 0.1</td>
<td>0.04 ± 0.00</td>
</tr>
<tr>
<td>ITC-9</td>
<td>USU-826</td>
<td>75-150</td>
<td>0.0</td>
<td>1.19 ± 0.03</td>
<td>52.1 ± 2.1</td>
<td>3.8 ± 0.3</td>
<td>1.2 ± 0.1</td>
<td>0.03 ± 0.00</td>
</tr>
</tbody>
</table>

¹ In-situ gravimetric water content, assumed 3±3% for moisture content to represent burial history for values <3%.
² Radioelemental concentrations determined by ALS Chemex using ICP-MS and ICP-AES techniques, dose rate is derived from concentrations by conversion factors from Guerin et al. 2011.
³ Th:U ratio is >3SD of USU dose rate samples and may have possible dose rate disequilibrium.
⁴ Dose rate derived from chemistry data from USU-584, errors increased to 10% to reflect dose rate derived from different sample.
⁵ Dose rate calculated from an average of two grain sizes.

Equivalent Dose ($D_E$) Radial Plots

- **USU-582, IDP-10**: CAM $D_E = 264.2 \pm 28.27$ Gy
- **USU-583, IDP-1**: CAM $D_E = 200.0 \pm 33.08$ Gy
- **USU-818, IDP-6.1**: CAM $D_E = 115.6 \pm 13.59$ Gy
- **USU-829, IDP-7**: MAM $D_E = 24.02 \pm 3.67$ Gy
- **USU-816, IDP-8**: CAM $D_E = 115.6 \pm 13.59$ Gy
- **USU-825, IAC-6.2**: CAM $D_E = 94.42 \pm 9.93$ Gy
- **USU-826, ITC-9**: CAM $D_E = 148.2 \pm 12.40$ Gy
- **USU-586, IDP-2**: MAM $D_E = 12.59 \pm 1.64$ Gy
- **USU-584, IDP-3**: MAM $D_E = 14.22 \pm 1.40$ Gy
- **USU-817, IDP-5**: MAM $D_E = 13.98 \pm 1.71$ Gy
- **USU-825, IAC-6.2**: CAM $D_E = 94.42 \pm 9.93$ Gy
### SUPPLEMENTAL FILE 2
Sample data information and AMS analytical results of terrestrial cosmogenic nuclide (TCN) $^{10}$Be geochronology*

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location (Lat/Long)</th>
<th>Elevation (m above sea level)</th>
<th>Depth (cm)</th>
<th>Production Rate (atoms g$^{-1}$ yr$^{-1}$)</th>
<th>Shielding Factor</th>
<th>Quartz (g)</th>
<th>Be Carrier (mg)</th>
<th>$^{10}$Be/$^{9}$Be[f,g] (10$^{-13}$)</th>
<th>Error $^{10}$Be/$^{9}$Be[f,g] (10$^{-15}$)</th>
<th>$^{10}$Be Concentration (10$^4$ atoms/g quartz)[h,i]</th>
<th>Error $^{10}$Be Concentration (10$^4$ atoms/g quartz)[h,i]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB-QTC-Surf</td>
<td>33.1205N, 74.8201E</td>
<td>750</td>
<td>0</td>
<td>6.245</td>
<td>0.233</td>
<td>0.998</td>
<td>24.857</td>
<td>0.2545</td>
<td>1.246</td>
<td>5.7</td>
<td>8.52</td>
</tr>
<tr>
<td>IB-QTC-0.5 m</td>
<td>33.1205N, 74.8201E</td>
<td>750</td>
<td>50</td>
<td>6.245</td>
<td>0.233</td>
<td>0.998</td>
<td>27.457</td>
<td>0.2545</td>
<td>1.590</td>
<td>7.0</td>
<td>9.85</td>
</tr>
<tr>
<td>IB-QTC-1.0 m</td>
<td>33.1205N, 74.8201E</td>
<td>750</td>
<td>100</td>
<td>6.245</td>
<td>0.233</td>
<td>0.998</td>
<td>32.476</td>
<td>0.2552</td>
<td>1.050</td>
<td>2.4</td>
<td>5.51</td>
</tr>
<tr>
<td>IB-QTC-1.5 m</td>
<td>33.1205N, 74.8201E</td>
<td>750</td>
<td>150</td>
<td>6.245</td>
<td>0.233</td>
<td>0.998</td>
<td>26.734</td>
<td>0.2530</td>
<td>6.750</td>
<td>3.3</td>
<td>4.27</td>
</tr>
<tr>
<td>IB-QTC-2.0 m</td>
<td>33.1205N, 74.8201E</td>
<td>750</td>
<td>200</td>
<td>6.245</td>
<td>0.233</td>
<td>0.998</td>
<td>39.780</td>
<td>0.2523</td>
<td>3.880</td>
<td>4.7</td>
<td>1.64</td>
</tr>
</tbody>
</table>

*Samples were collected in a depth profile at intervals of 50 cm from the surface to the bottom of the soil pit.

$^{a}$A sea level, high latitude production rate value for spallation of 3.99 ± 0.22 atoms/g ($^{10}$Be) was used (Heyman, 2014). Scaling based on constant (time invariant) local production rate based from Lal [1991], Stone [2000], and Heyman [2014].

$^{b}$Constant (time invariant) local production rate based on Heisinger et al. [2002a, 2002b].

$^{c}$Geometric shielding correction using CRONUS online calculator.

$^{d}$A density of 2.5 g/cm$^3$ was used on the granitic composition of the surface samples.

$^{e}$Isotopes ratios were normalized to $^{10}$Be standards prepared by Nishiizumi et al., [2007] with a value of 2.85 X 10$^{12}$ and using a $^{10}$Be half-life of 10$^6$ years.

$^{f}$Uncertainties are reported at the 1σ confidence interval.

$^{g}$A mean blank value of 53,540 ± 10,845 $^{10}$Be atoms (10Be/9Be = 2.994 x 10$^{-15}$ ± 6.03 x 10$^{-16}$) was used to correct for background.

$^{h}$Propagated uncertainties include error in the blank, carrier mass (1%), and counting statistics.

*Data reporting format following Frankel [2010].
Model parameters of Monte Carlo simulator for modeling Be10 depth profiles from Hidy et al. [2010]
Supplemental File 3.
Explanations for cross section interpretation in Figure 13.

1. The ~2.5° N regional dip of the basement-cover interface south of the Main Boundary thrust (MBT) for the Kashmir Himalayas is taken as analogous to nearby region of Kangra reentrant or central Salt Range and Potwar Plateau, constrained by well data and reflection profiles (Burbank et al., 1986; Baker, 1987; Leathers, 1987; Baker, 1987; Pennock et al., 1989; Powers et al., 1998).

2. Regional dips of depositional wedges for the Siwalik and Murree strata based from analogous reflection profiles and well data in Kangra reentrant (Powers et al., 1998).

3. Suruin-Mastgarh anticline constrained by dip data and a published seismic signature of the anticline core from nearby area across the Jammu Foothills (Raiverman et al., 1983), northeast of the city of Jammu (Fig. 2).

4. Horse of Lower Murree strata required to fill space beneath structures, as no Salt Range Formation or equivalent ductile strata at the basement-cover interface (e.g. Pennock et al., 1989), is known to be present beneath the Jammu Foothills area.

5. Main Riasi thrust (MRT) and Frontal Riasi thrust (FRT) interpreted as fault splays, which join at depth into Riasi fault system (RF), constrained by field dip data and map pattern in Riasi study area (Figs. 4 and 5).

6. Step in décollement of the Main Himalayan thrust (MHT) inferred from indications of basement high in subsurface, focused seismicity and map pattern of Sirban Formation at the Chenab reentrant (Karunakaran and Ranga Rao, 1976; Raiverman, 1983).

7. Inferred thrust at depth to explain anticline structure in the Sirban Formation in the map pattern (Fig. 2).

8. Inferred unnamed thrusts to explain truncated Subathu Formation, overthickened and steeply folded Murree formations in a structural higher décollement level to the MHT. Evidence of numerous thrusts within the Murree formations exists along-strike seen on the map pattern (Fig. 3.2).

9. Minimum required depth to restore the top and bottom of the Sirban Formation (4 km thick) prior to RF movement and exhumation of overlying Siwalik and Murree formations.

10. Inferred stratigraphic relationship of Lesser Himalayan strata Ramban Formation (Late Proterozoic = 1.4-1.1 Gya), based on published studies (Wadia, 1937; Bhatia and Bhatia, 1973; Thakur and Rawat, 1992). Ramban Formation could also be attributed as lower Lesser Himalayan strata, which has been dated in Nepal, Proterozoic = 1.4-1.1 Gy), based on published studies (Wadia, 1937; Bhatia and Bhatia, 1973; Thakur and Rawat, 1992). Ramban Formation could also be attributed as lower Lesser Himalayan strata, which has been dated in Nepal.

11. Inferred basement step at this location to coincide with major MHT ramp, that explains relief in the Pir Panjal, apparent northeast tilts of Quaternary sediments at the southern boundary of the Kashmir basin, and in order to project appropriate regional basement depth (2.5-3 km) beneath Indian-Gangetic foreland, analogous to nearby region of Kangra reentrant and central Salt Range and Potwar Plateau, constrained by reflection profiles and well data from Powers et al., [1998].

12. Large ramp at depth on MHT determined from dip data of Kashmir Tethys thrust sheet and its consistent northward tilting across Pir Panjal, ending with synformal structure of the Kashmir basin; iii) stratigraphic truncation of Sirban Limestone; and iii) maintaining stratigraphic thickness of thrust sheets.

13. Predicted steepening regional dip of décollement (~4.5° N) beneath Kashmir basin and more hinterland areas of High Himalayas, as similarly observed in more hinterland areas of Pakistan and Nepal Himalayas (e.g. Pennock et al., 1989; Powers et al., 1998; HeCelles et al., 2001).

14. SW tilting of thrust sheet above the Main Central thrust (MCT) to explain synform structure of Kashmir basin, crustal thickening and duplex structures further NE along the MHT.

15. Dip data of MBT based on dips of major foliations within and below MBT thrust sheet.

16. Nappe zone consisting of metasediments Salkhala Fm (Precambrian) and deformed crystalline bodies (Cambrian). Internal structure is poorly constrained, but MCT dip data is based from major foliation in underlying MBT thrust sheet and overlying Kashmir Tethys strata.
REFERENCES CITED


