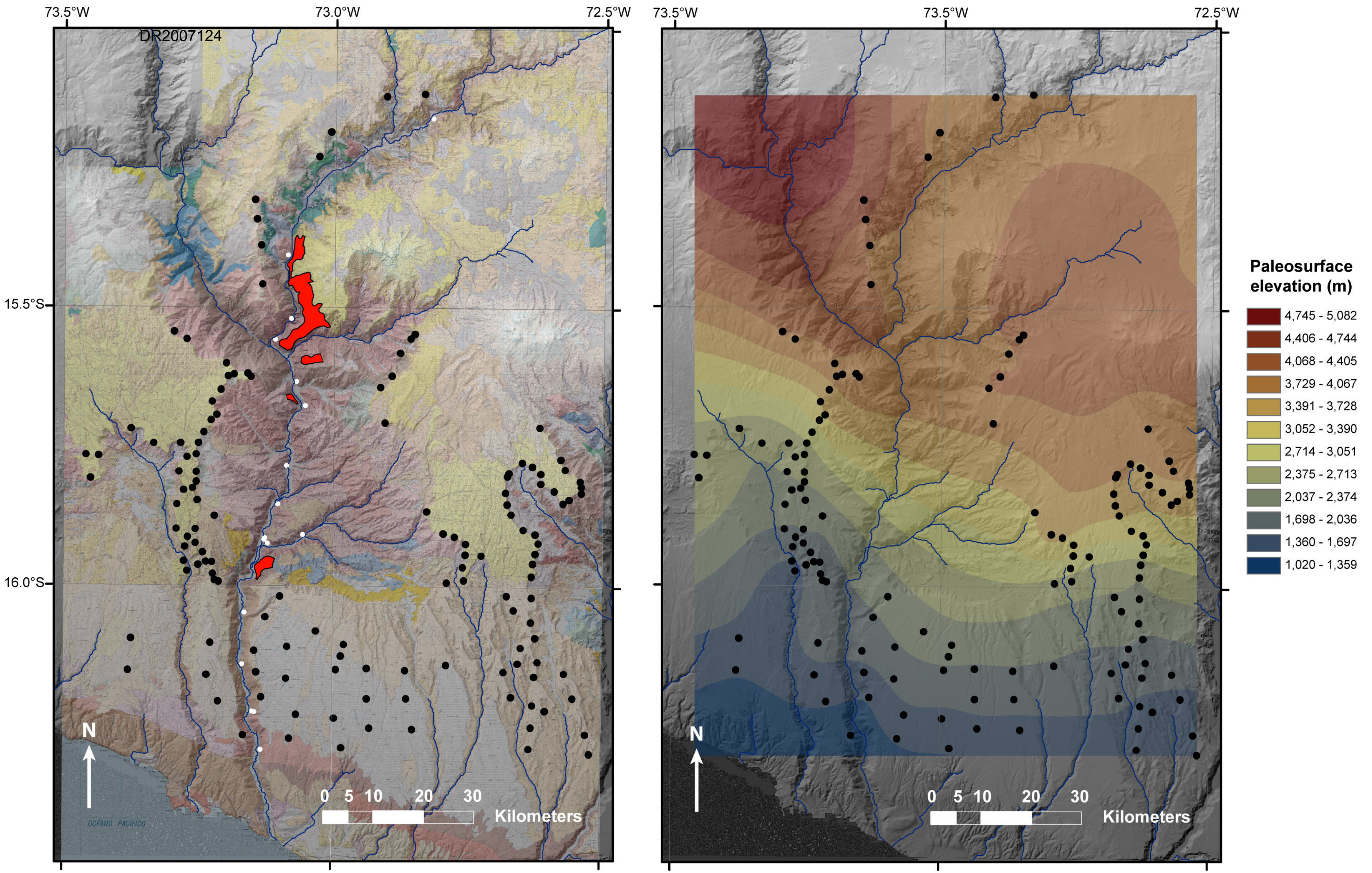

Figure DR1. Creation of paleosurface reference layer. Left panel illustrates how points (black dots) were selected where bedrock outcrops beneath the regionally-blanketing Huaylillas Ignimbrite, Elevations are defined by intersections with topographic contour lines. Right panel shows the surface spline fit to the selected points to create a representation of the (now deformed) paleosurface under the Huaylillas ignimbrite. This paleosurface shows a flat region in the upper catchment which then ramps down toward the coast. Also shown on left panel are valley-filling volcanic flows (bright red) we mapped in the field. Other volcanic units are shown in yellow. Low-temperature themochronology sample locations are shown (white dots) such that a comparison between sample locations and volcanic flows can be made. Young volcanics flows (c. 1.4 to 3.8 Ma, Thouret et al., 2005, and data presented here) dominate the landscape in the uppermost catchment and probably affected (U-Th)/He ages in that region.

TABLE DR1. APATITE (U-Th)/He INDIVIDUAL CRYSTAL DATA

Sample	Mass (µg)	Radius (µm)	U (ppm)	Th (ppm)	Sm (ppm)	4He (nmol/g)	Ft	Corrected age* (Ma)	2 σ[†] (Ma)	Depth[§] (km)	Distance (km)	Elevation (m)
04TS12aA	6.67	63.5	148	106	187	6.28	0.79	8.54	0.31	2.04	56.4	702
04TS12aB	2.63	42.8	180	114	168	7.33	0.70	9.31	0.34	2.04	56.4	702
04TS12aC	1.15	34.3	174	143	152	7.14	0.63	10.1	0.37	2.04	56.4	702
04TS12aD	2.32	44.3	189	115	220	5.81	0.70	7.05	0.26	2.04	56.4	702
04TS12aE	1.11	32.5	197	107	165	6.82	0.62	9.18	0.35	2.04	56.4	702
04TS12aF	1.81	39.8	244	156	225	8.07	0.68	7.85	0.29	2.04	56.4	702
04TS13aA	1.08	32.3	84.8	53.8	179	7.17	0.62	22.1	0.83	1.85	51.7	552
04TS13aB	1.34	32.3	81.7	49.2	145	4.90	0.63	15.5	0.60	1.85	51.7	552
04TS17aA	4.42	47.0	9.39	100	309	7.76	0.71	60.0	1.98	1.01	27.7	290
04TS17aB	3.04	41.3	11.2	109	318	8.15	0.68	59.2	1.97	1.01	27.7	290
04TS17aC	2.53	45.3	14.7	98.0	283	10.1	0.69	70.2	2.32	1.01	27.7	290
04TS17aD	2.97	45.8	8.83	94.7	279	6.99	0.70	58.7	2.00	1.01	27.7	290
04TS18aA	2.21	40.3	4.72	31.8	138	1.31	0.67	29.3	1.25	0.89	27.7	415
04TS18aB	1.34	36.3	5.33	78.6	307	5.92	0.62	72.5	2.98	0.89	27.7	415
04TS21aA	1.02	37.3	258	148	221	67.6	0.64	66.7	2.48	1.09	12.4	73
04TS21aB	1.57	36.0	22.5	66.3	92.1	7.46	0.64	56.1	1.95	1.09	12.4	73
05TS02_A	2.40	46.7	64.9	140	309	3.70	0.71	9.86	0.41	2.28	61.1	590
05TS02_B	1.40	35.6	63.9	114	267	2.91	0.64	9.22	0.40	2.28	61.1	590
05TS02_C	1.43	37.1	62.9	113	274	3.09	0.65	9.81	0.42	2.28	61.1	590
05TS02_D	2.24	49.2	31.6	47.8	165	3.18	0.71	19.2	0.82	2.28	61.1	590
05TS09_A	1.86	39.7	111	110	233	2.85	0.68	5.68	0.25	2.99	80.1	816
05TS09_B	2.50	43.4	106	118	255	2.56	0.70	5.05	0.22	2.99	80.1	816
05TS09_C	1.77	41.1	97.8	85.8	217	2.22	0.68	5.11	0.23	2.99	80.1	816
05TS11_A	1.49	37.3	45.1	74.4	189	1.87	0.65	8.45	0.38	2.64	68.7	647
05TS11_B	2.11	45.1	74.4	145	258	4.57	0.70	11.16	0.47	2.64	68.7	647
05TS11_C	1.87	42.5	111	223	310	5.25	0.68	8.68	0.36	2.64	68.7	647
05TS11_D	1.27	38.6	126	239	327	5.25	0.65	8.19	0.34	2.64	68.7	647
05TS39_A	2.28	44.5	51.9	31.9	167	4.54	0.70	20.0	0.92	1.92	52.8	490
05TS39_B	2.47	47.5	90.2	48.3	169	5.21	0.72	13.2	0.59	1.92	52.8	490
05TS39_C	3.84	51.1	52.4	28.0	174	2.09	0.74	8.79	0.33	1.92	52.8	490
05TS39_D	2.48	40.8	84.7	50.9	112	5.44	0.69	15.0	0.55	1.92	52.8	490
05TS39_E	3.37	51.9	54.5	35.8	251	4.55	0.74	18.0	0.66	1.92	52.8	490

05TS39_F	2.31	48.6	56.7	26.6	124	2.90	0.72	11.9	0.56	1.92	52.8	490
05TS40_A	1.03	34.9	108	97.2	161	9.42	0.63	21.2	0.79	1.92	52.1	480
05TS40_B	1.40	39.2	119	98.2	139	6.82	0.66	13.4	0.49	1.92	52.1	480
05TS40_C	0.87	32.1	143	85.5	107	10.1	0.61	18.8	0.71	1.92	52.1	480
05TS40_D	1.12	32.6	141	49.6	112	5.24	0.62	10.2	0.40	1.92	52.1	480
05TS12_A	1.54	36.9	1.86	23.2	473	0.70	0.63	26.1	1.54	1.62	40.0	360
05TS12_B	1.41	40.7	2.79	22.5	356	0.36	0.65	12.1	0.70	1.62	40.0	360
05TS12_C	1.85	38.9	2.24	15.4	337	0.18	0.65	7.95	0.62	1.62	40.0	360
05TS12_D	1.80	46.3	2.43	8.24	330	0.38	0.69	21.5	1.64	1.62	40.0	360
05TS12_E	2.83	47.9	1.37	13.9	380	0.15	0.70	7.70	0.77	1.62	40.0	360
05TS12_F	3.12	49.9	3.22	16.9	434	0.88	0.72	29.2	1.68	1.62	40.0	360
05TS12_G	2.10	40.7	1.33	6.67	377	0.27	0.67	22.0	3.73	1.62	40.0	360
05TS12_H	3.03	50.4	3.37	24.7	369	0.91	0.72	24.4	1.23	1.62	40.0	360
05TS37_A	3.57	48.6	10.9	23.3	151	0.60	0.73	9.15	0.39	3.08	84.5	852
05TS37_B	3.26	42.4	12.6	32.2	186	0.48	0.70	6.26	0.24	3.08	84.5	852
05TS37_C	2.81	43.7	13.7	37.2	189	0.48	0.70	5.60	0.23	3.08	84.5	852
05TS37_D	1.88	40.8	8.01	15.9	134	0.28	0.68	6.42	0.52	3.08	84.5	852
05TS07_A	3.69	44.1	13.8	19.3	144	0.27	0.71	3.79	1.43	3.13	90.2	940
05TS07_B	2.93	42.3	14.9	16.4	85	0.26	0.70	3.66	1.40	3.13	90.2	940
05TS07_C	2.98	48.9	17.1	20.9	149	0.34	0.73	3.87	1.45	3.13	90.2	940
05TS07_D	5.62	51.4	8.33	10.7	104	0.18	0.75	4.10	1.50	3.13	90.2	940
05TS35_A	3.28	45.7	70.1	134	169	0.78	0.72	1.97	0.07	3.00	96.9	1028
05TS35_B	2.76	47.5	86.5	167	177	0.90	0.72	1.84	0.06	3.00	96.9	1028
05TS35_C	3.41	46.4	68.5	136	141	0.84	0.72	2.16	0.07	3.00	96.9	1028
05TS35_D	4.17	53.5	68.5	108	136	0.71	0.75	1.86	0.06	3.00	96.9	1028
05TS30_A	1.30	36.9	62.2	318	149	0.78	0.63	1.66	0.08	2.60	108.6	1355
05TS30_B	1.43	37.8	48.2	212	132	0.30	0.64	0.88	0.05	2.60	108.6	1355
05TS30_C	1.01	35.7	60.8	274	138	0.42	0.61	1.01	0.07	2.60	108.6	1355
05TS23_A	1.48	40.8	10.5	37.3	184	0.04	0.66	0.53	0.18	1.41	139.8	2580
05TS23_B	1.31	36.6	12.1	44.3	228	0.07	0.64	0.86	0.17	1.41	139.8	2580

*Alpha-ejection corrected age; values shaded gray are outliers not plotted in results. "Outliers" were defined based on microscopic inclusions or cracks that were suspected could affect the age; others did not have visible flaws but had ages that were far from the rest of the population of grains analyzed. This can come about for a number of different reasons, such as strong zoning in U and Th, errors in the alpha-ejection correction, radiation damage affecting diffusion characteristics of the grain, He-implantations from adjacent crystal phases in the host rock, etc.

†Error includes analytical precision only; in reality errors noted previously are likely to contribute to uncertainty.

§Depth below paleosurface. Error on this values is estimated to be +/- 100 m.

TABLE DR2. ZIRCON (U-Th)/He INDIVIDUAL CRYSTAL DATA

Sample	Th/U	Mass (μg)	Radius (μm)	U (ppm)	Th (ppm)	^{4}He (nmol/g)	Ft	Corrected age* (Ma)	2 σ† (Ma)	Distance (km)	Depth§ (km)	Elevation (m)
04TS13z_B	0.47	2.92	38.3	233	106	90.9	0.73	88.9	4.50	51.7	0.19	552
04TS13z_A	0.63	3.31	37.5	277	169	125	0.73	99.0	4.95	51.7	0.19	552
04TS16z_A	2.79	14.7	59.8	94.5	257	110	0.82	158	7.28	27.7	0.14	225
04TS16z_B	0.55	14.7	65.3	170	91.4	134	0.84	153	7.67	27.7	0.14	225
04TS18z_A	2.78	7.80	56.8	56.5	153	74.3	0.81	182	8.34	27.7	0.89	415
04TS18z_B	1.31	6.82	57.3	122	156	121	0.81	173	8.23	27.7	0.89	415
04TS20z_A	1.16	2.22	37.5	200	227	210	0.72	210	9.86	20.0	0.66	650
04TS20z_B	1.46	4.14	51.5	123	174	123	0.78	177	8.13	20.0	0.66	650
05TS02z_A	0.83	14.5	54.7	206	166	87.3	0.82	79.9	3.78	61.1	2.28	590
05TS02z_B	0.48	8.21	50.4	340	160	143	0.80	87.5	4.29	61.1	2.28	590
05TS07z_A	0.52	13.3	55.3	228	115	53.0	0.82	46.7	2.25	90.2	3.13	939
05TS07z_B	0.43	12.5	54.3	195	80.8	40.7	0.82	43.1	2.13	90.2	3.13	939
05TS09z_A	0.63	12.4	63.9	365	223	116	0.83	61.7	2.99	80.1	2.99	816
05TS09z_B	1.41	10.3	56.2	600	823	319	0.81	91.2	4.17	80.1	2.99	816
05TS11z_A	0.46	43.8	80.4	294	132	110	0.88	71.2	3.49	68.7	2.64	647
05TS11z_B	0.58	52.8	93.0	202	114	80.2	0.89	72.8	3.51	68.7	2.64	647
05TS12z_A	1.14	20.8	67.0	57.7	64.3	36.7	0.85	110	4.76	40.0	1.62	360
05TS12z_B	0.66	17.7	59.7	111	71.3	71.3	0.84	123	5.63	40.0	1.62	360
04TS12zA	0.72	5.25	43.5	269	188	101	0.77	77.4	2.83	56.4	2.04	702
04TS12zB	0.89	6.78	42.5	194	168	81.5	0.77	83.4	2.94	56.4	2.04	720
04TS15zA	0.27	2.65	40.8	408	108	201	0.75	115	4.44	36.7	1.62	322
04TS15zB	0.32	1.98	40.5	361	111	151	0.73	98.4	3.83	36.7	1.62	322
04TS21zA	0.82	14.6	52.5	78.8	62.7	57.3	0.82	138	4.90	12.4	1.09	73
04TS21zB	1.26	6.96	48.3	61.7	75.6	52.3	0.78	155	5.34	12.4	1.09	73

* Alpha-ejection corrected ages.

†Error includes analytical precision only; in reality, zoning in U and Th and crystal measurement error also likely contribute to uncertainty.

§Depth below paleosurface. Error on this measurement is estimated to be +/- 100 m.

TABLE DR3. $^{40}Ar/^{39}Ar$ DATA FOR VALLEY-FILLING VOLCANIC FLOWS AND HUAYLILLAS IGNIMBRITE

Information on Analysis	Weighted Average Analysis							Inverse Isochron Analysis					
Laser-Fusion	40(r)/39(k)	± 2σ	Age (Ma)	± 2σ	MSWD	39Ar(k) (%,n)	K/Ca	40(a)/36(a)	± 2σ	40(r)/39(k)	± 2σ	Age (Ma)	± 2σ
Sample 05TS03 Material Feldspar	1.360	± 0.036 ± 2.64%	**1.865**	**± 0.050 ± 2.65%**	1.12	84.0 11 of 13	0.746	295.3	± 16.8 ± 5.69%	1.361	± 0.081 ± 5.93%	1.867	± 0.111 ± 5.94%
Sample 05TS04 Material Feldspar	1.413	± 0.015 ± 1.03%	1.937	± 0.021 ± 1.07%	1.13	84.4 20 of 23	0.872	327.8	± 27.6 ± 8.41%	1.387	± 0.027 ± 1.91%	1.901	± 0.037 ± 1.94%
Sample 05TS04 Material Feldspar	1.385	± 0.015 ± 1.06%	1.930	± 0.021 ± 1.08%	1.04	100.0 16 of 16	1.137	290.7	± 12.56 ± 4.32%	1.390	± 0.019 ± 1.40%	1.937	± 0.027 ± 1.41%
	Wtd. Mean Age:		**1.934**	**± 0.015 ± 0.78%**	0.05								
Sample 05TS25 Material Sanidine	2.802	± 0.008 ± 0.30%	**3.825**	**± 0.016 ± 0.42%**	1.49	100.0 18 of 18	14.49	285.7	± 10.1 ± 3.55%	2.809	± 0.011 ± 0.37%	3.834	± 0.018 ± 0.48%
Sample 04TS10 Material Sanidine	4.334	± 0.008 ± 0.18%	**14.20**	**± 0.04 ± 0.27%**	1.29	100.0 12 of 12	70.8	291.1	± 8.5 ± 2.91%	4.336	± 0.009 ± 0.21%	14.21	± 0.04 ± 0.29%
Sample 04TS22 Material Sanidine	4.373	± 0.010 ± 0.23%	**14.29**	**± 0.04 ± 0.30%**	2.00	100.0 11 of 11	50.2	294.3	± 47.0 ± 16.0%	4.374	± 0.014 ± 0.31%	14.30	± 0.05 ± 0.37%
Sample 05TS43 Material Sanidine	11.57	± 0.013 ± 11.0%	**16.12**	**± 0.04 ± 0.23%**	0.82	100.0 20 of 20	59.3	272.1	± 68.2 ± 25.1%	11.576	± 0.027 ± 0.23%	16.13	± 0.05 ± 0.30%
Furnace Step-Heating	40(r)/39(k)	± 2σ	Age (Ma)	± 2σ	MSWD	39Ar(k) (%,n)	K/Ca	40(a)/36(a)	± 2σ	40(r)/39(k)	± 2σ	Age (Ma)	± 2σ
Sample 05TS08 Material Gndmass	1.597	± 0.007 ± 0.44%	**2.196**	**± 0.012 ± 0.53%**	0.96	93.7 13 of 17	0.651	295.2	± 2.5 ± 0.85%	1.598	± 0.010 ± 0.63%	2.197	± 0.015 ± 0.69%
Sample 05TS38 Material Gndmass	1.663	± 0.057 ± 3.42%	2.284	± 0.079 ± 3.44%	0.78	80.4 12 of 16	0.826	293.7	± 3.6 ± 1.21%	1.727	± 0.140 ± 8.13%	2.373	± 0.193 ± 8.13%
Sample 05TS38 Material Gndmass	1.669	± 0.041 ± 2.45%	2.249	± 0.056 ± 2.47%	0.64	84.7 21 of 27	0.799	293.1	± 2.8 ± 0.97%	1.754	± 0.106 ± 6.03%	2.363	± 0.143 ± 6.04%
	Wtd. Mean Age:		**2.261**	**± 0.046 ± 2.03%**	0.13								

Note: All ages reported relative to TCR-2a Sanidine @ 28.34 Ma

TABLE DR4. LOCATION AND CONTEXT FOR SAMPLES DATED WITH $^{40}Ar/^{39}Ar$

Sample	Description	Age ± 2 σ (Ma)	Ht. above river (m)	Latitude (°S)	Longitude (°W)
05TS03	Feldspar from basal vitrophyre ash; Cotahuasi valley fill	1.865 ± 0.050	400	15°33'48.91"	73°06'16.22"
05TS04	Feldspar from basal vitrophyre obsidian; Cotahuasi valley fill	1.934 ± 0.015	400	15°33'48.91"	73°06'16.22"
05TS25	Sanidine from base of welded tuff in-filling upper Cotahuasi valley	3.825 ± 0.016	450	15°12'41.86"	72°52'49.87"
04TS10	Sanidine from Huaylillas Fm., near town of Aplao	14.20 ± 0.04	n/a	16°14'45.83"	72°30'06.56"
04TS22	Sanidine from Huaylillas Fm., north of Aplao	14.29 ± 0.04	n/a	15°57'20.85"	72°34'59.70"
05TS08	Andesite groundmass, from andesite valley fill near Chaucalla	2.196 ± 0.012	450	15°35'31.51"	73°04'05.70"
05TS43	Sanidine from undeformed ignimbrite crossing range front fault zone 100 km SE of Cotahuasi range front	16.12 ± 0.04	n/a	16°11'16.08"	72°01'36.33"
05TS38	Basaltic andesite groundmass from valley fill near Llauce	2.261 ± 0.056	125	15°39'28.30"	73°04'35.36"

TABLE DR5. PARAMETERS USED IN THERMAL MODEL CALCULATIONS AND RESULTS

Parameter used in model	20°C/km run	30°C/km run
Diffusion radius (micrometers)*:	60	60
Activation energy for closure temperature (kJ/mol)*:	138	138
Normalized frequency factor, $\Omega(s^{-1})$*:	7.64E+07	7.64E+07
<u>Thermal parameters:</u>		
Layer depth to constant temperature (km)†:	60	60
Thermal diffusivity (km^2/my)§:	30	30
Internal heat production (°C/my)§:	8	8
Surface temperature (°C):	10	10
Predicted temperature at base of layer (°C)#:	730	1330
<u>Estimates assuming steady-state heat flux and no erosion:</u>§		
Surface thermal gradient (°C/km):	20	30
Estimate for volumetric heat production (mW/m^3):	0.583	0.583
Estimate for thermal conductivity (W/(m*Kelvin)):	2.186	2.186
Predicted surface heat flux (mW/m^2)#:	43.73	65.59
Crustal avg. product of thermal conductivity and density (kJ/ (Kelvin*m^3))	2300	2300
<u>AGE2EDOT results:</u>		
Erosion rate (km/myr):	0.7	0.5
Depth to closure temperature (km):	2.0	1.4
Closure temperature (°C):	72	72

*Farley, K.A., 2000, Helium diffusion from apatite: General behavior as illustrated by Durango fluorapatite: Journal of Geophysical Research, v. 105, no. B2, p. 2903–2914, doi: 10.1029/1999JB900348.

†Beck, S.L., Zandt, G., Myers, S.C., Wallace, T.C., Silver, P.G., and Drake, L., 1996, Crustal-thickness variations in the central Andes: Geology, v. 24, no. 5, p. 407-410.

§Details in Brandon, M.T., Roden-Tice, M.K., Garver, J.I., 1998, Late Cenozoic exhumation of the Cascadia accretionary wedge in the Olympic Mountains, northwest Washington State: GSA Bulletin, v. 110, p. 985-1009.

#Values predicted based on input parameters.