DR Table 1: U-series disequilibria data for Bluewater Flow

		Th [ug/g]	2σ	U [ug/g]	2σ	(^{238}U/^{232}Th)	2σ	(^{230}Th/^{232}Th)	2σ	(^{230}Th/^{238}U)	2σ	^{226}Ra [fg/g]	2σ	(^{226}Ra/^{230}Th)	2σ
LANL (BW-1)[A]	WR	0.724	0.004	0.261	0.001	1.093	0.005	1.139	0.006	1.041	0.008				
	(0.77gm)														
	Olivine	0.037	0.001	0.014	0.001	1.142	0.006	1.182	0.019	1.035	0.019				
	(1.73gm)														
	Magnetite	1.263	0.006	0.416	0.002	0.998	0.008	1.091	0.012	1.092	0.014				
	(0.55 gm)														
	Pheno Plag	0.173	0.001	0.062	0.001	1.096	0.005	1.166	0.023	1.064	0.024				
	(0.15gm)														
	G-mass Plag	0.208	0.001	0.067	0.001	0.980	0.006	1.089	0.013	1.112	0.014				
	(1.09 gm)														
	Groundmass	0.932	0.005	0.338	0.001	1.100	0.005	1.142	0.006	1.038	0.007				
	(0.97 gm)														
UCLA[B]	WR	1.116	0.006	0.406	0.002	1.104	0.009	1.140	0.010	1.033	0.015				
WHOI[C]	WR	0.762	0.004	0.275	0.002	1.093	0.008	1.141	0.005	1.044	0.009	97.2	1.3	1.004	0.013
WHOI[D]	WR							1.140	0.014						

Notes:

1) ^{238}U and ^{232}Th concentrations were measured by isotope dilution using TIMS at A) LANL using an NBS 1290; B) UCLA using a VG Sector 54 and C) at WHOI using a single collector sector Thermofinnigan Element ICPMS. Uncertainties on Th and U consider both in-run standard-errors and uncertainties in the spike calibrations (~ 0.4% at WHOI; based on calibrations with gravimetric standards of ^{232}Th and ^{238}U).

2) ^{230}Th/^{232}Th measured by: A) high-abundance sensitivity Thermal Ionization Mass Spectrometry (HAS-TIMS) at LANL using an S–configuration, double magnetic-sector NBS 1290 (Goldstein et al., 1989); B) HAS-TIMS at UCLA using a VG Sector 54 with an electrostatic analyzer C) Plasma Ionization Multi-collector Mass Spectrometry (PIMMS) using a Thermofinnigan Neptune at WHOI (Sims and Hart, 2006). D) Secondary Ionization Mass Spectrometry (SIMS) using WHOI's Cameca IMS 1270 (Layne and Sims, 2001 Parenthesis ( ) denotes activity; λ_{230} = 9.195 x 10^{-6} yr^{-1}, λ_{232} = 4.948 x 10^{-11} yr^{-1}. Uncertainties represent in-run standard error and do not include uncertainties in λ_{230} (0.4%) or λ_{232} (0.5%). ^{230}Th/^{232}Th results from these different measurements agree within respective analytical uncertainties.

3) Parenthesis ( ) denotes activity; λ_{238} = 1.551 x 10^{-10} yr^{-1}; errors (2σ) range from 0.4% - 0.5% and do not include uncertainties in λ_{238} (0.07%) or λ_{230}.

4) [^{226}Ra] was measured by isotope dilution using a Thermofinnigan ELEMENT2. ( ) denotes activity; λ_{226} = 4.331 x 10^{-4} yr^{-1}. Uncertainties consider both in-run standard-errors (< 0.2%) and uncertainties in the spike calibrations (1.2%) and do not include uncertainties in λ_{226} (0.4%) or λ_{230}.

5) Weights of mineral separates analyzed are provided.

DR Table 2: Helium isotopic data and exposure ages from the Bluewater Flow

Sample	Elevation	Latitude	Longitude	^{3}He/^{4}He$_{Crush}$	±	1 σ	^{4}He$_{Melt}$	±	1 σ	^{3}He/^{4}He$_{Melt}$	±	1 σ	^{3}He$_{cosmo}$	±	1 σ	Age	±	1 σ
	m	N	W	R/Ra			atoms/g x 10^9			R/Ra			atoms/g x 10^6			ka		
BW1/1 *	2012	35° 15.80'	107° 58.23'	6.94	±	0.29	263	±	26.5	84.8	±	9.64	28.4	±	1.6	54.8	±	4.2
BW1/2 *	2012	35° 15.80'	107° 58.23'	7.01	±	0.29	970	±	96.4	28.5	±	3.08	28.8	±	1.9	55.6	±	4.6
BW2/1 *	2012	35° 15.80'	107° 58.23'	6.36	±	0.58	75.3	±	10.8	271	±	41.97	27.5	±	1.6	53.2	±	4.1
BW2/ol *	2012	35° 15.80'	107° 58.23'	7.59	±	0.36	75.3	±	7.8	261	±	31.28	26.4	±	1.6	51.0	±	4.1
BW2/cpx *	2012	35° 15.80'	107° 58.23'	5.56	±	5.49	9.6	±	9.6	2037	±	1,531	27.1	±	1.3	52.4	±	3.7
ZB-93-1	2009	35° 15.97'	107° 58.15'	6.97	±	0.07	715	±	3	31.2	±	0.23	24.5	±	0.3	47.5	±	2.5

Notes:

1) * Data from Laughlin et al., 1994; # Ages calculated with no erosion; R/Ra is the atmospheric ^{3}He /^{4}He = 1.384 x 10^{-6}; ol=olivine, cpx=clinopyroxene. Note the exposure ages for the Laughlin et al. (1994) data have been recalculated using the presently accepted production rates and scaling.

2) Helium isotopes were measured in olivine separates hand picked from a 0.4 to 0.5 mm fraction of ground sample and measured on the Helium Isotope mass spectrometer (MS2) at WHOI. The olivine was crushed to extract the inherited component from fluid and melt inclusions and then the resultant powder melted to release the remaining helium. The cosmogenic ^{3}He was determined by subtracting the crush ^{3}He /^{4}He from the ^{3}He /^{4}He of the melted powder , and multiplying by the ^{4}He concentration of the powder.   This well-established procedure relies on the assumption that the helium is a two-component mixture of cosmogenic and magmatic helium (Kurz, 1986). In-growth of radiogenic ^{4}He from U and Th decay is negligible on these time scales.

3) Age uncertainties include propagated analytical, production rate, and scaling uncertainties. ^{3}He concentrations are scaled to surface.

4) Scaling uncertainties are assumed to be < 2% due to the similar latitude and elevation of the calibration sites to the Bluewater Flow.

5) A sea level production rate of 119 ± 6 ^{3}He atoms/g/yr (olivine) obtained from the Tabernacle Hill and Bonneville Flood calibrations sites (Cerling and Craig, 1994) is scaled for elevation using the formulation of Stone (2000).

DR Table 3: Cl concentration and isotopic data and ^{36}Cl exposure ages of Bluewater Flow.

Sample	Depth (cm)	[Ca] (%)	[K] (%)	Σ^1 (cm^2/g)	±	1σ	[Cl] (ppm)	[^{36}Cl]	± (x10^5 atom/g)	1σ [2]	Age[3]	±	1σ (ka)	Age[4]	±	1σ (ka)
ZB-93-1 *	4	6.88	0.71	0.00647	±	0.00006	54	10.64	±	0.983	44.3	±	4.5	44.5	±	4.6
ZB-93-1 #	2.5	6.29	0.58	0.00735	±	0.00028	38	8.652	±	0.425	38.1	±	2.3	39.3	±	2.4

Notes:
* Data from Dunbar and Phillips (2004), [Cl] by ion specific electrode; # Data from this study, [Cl] by isotope dilution. (note the exposure ages reported in Dunbar and Phillips data are recalculated using the correct elevation which is a slightly different elevation than originally reported)
1) Neutron absorption cross-section of the whole rock; major and trace element concentrations appear in supplement.
2) AMS measurements were made at PRIME lab; concentration corrected for (<.03%) radiogenic ^{36}Cl.
3) Exposure age calculated assuming erosion = 0.
4) Exposure age calculated assuming erosion = 5mm/kyr.PK spallation= 161 ± 9 atoms/gK/yr ;PK muon capture= 10.2 ± 1.3 atoms/gCa/yr; PCa spallation= 48.8 ± 1.7 atoms/gCa/yr; PCa muon capture= 4.8 ± 1.2 atoms/gCa/yr; PFe spallation =1.9 ± 0.2; PTi = 6± 3 ((Stone et al., 1996a, 1996b; 1998; Stone, 2000; Stone, pers comm). Neutron capture including thinkness correction treated according to the method of Phillips et al. (2001). Altitude scaling for spallation and muon reactions after Stone (2000). ^{36}Cl decay constant 2.303 x 10^{-6} /yr.

DR Table 4: Major and trace elements abundances and Nd, Sr and Pb isotopic compositions.

		ZB-93-1
	UCLA[1]	**WHOI**[2]
SiO2	52.12	54.43
TiO2	1.34	1.32
Al2O3	15	14.72
Fe2O3 (tot)	11.27	10.83
MnO	0.16	0.15
MgO	7.81	6.73
CaO	9.39	8.8
Na2O	2.67	2.37
K2O	0.46	0.7
P2O5	0.16	0.19
Total	100.38	100.24
Ba	120	
Rb	8	
Sr	227	
V	160	
Cr	220	
Ni	174	
Zn	100	
Y	18	
Zr	88	
Nb	8	
Nd	11.1	
Ce	25	
Sm	3.05	3.2
Sc	26	

Co	85	
Ga	17	
Gd		3.72
B		31
Pb	1.9	
La	12	

$^{87}\text{Sr}/^{86}\text{Sr}$	0.70485±0.00001
$^{143}\text{Nd}/^{144}\text{Nd}$	0.51274±0.00001
$\mathbf{\varepsilon_{Nd}}$	2.0
$^{208}\text{Pb}/^{204}\text{Pb}$	38.422±0.002
$^{207}\text{Pb}/^{204}\text{Pb}$	15.568±0.002
$^{206}\text{Pb}/^{204}\text{Pb}$	18.374±0.002

Notes:

1) Major- and trace-elements measured by XRF at WSU except for Nd, Sm, and Pb which were measured by ID-TIMS at UCLA. Estimated relative errors on major elements < 5%. Estimated relative errors for trace elements are 5–15%. Sr isotopes were measured at UCLA by TIMS using a VG Sector 54 with $^{87}\text{Sr}/^{86}\text{Sr}$ normalized to $^{86}\text{Sr}/^{88}\text{Sr}=0.1194$ in dynamic mode. Uncertainties in measured Sr isotope ratios represent analytical errors ($2\sigma/\sqrt{n}$, where n is the number of measured ratios) reported in the last decimal place. NBS987=0.710248±0.000012 during the analytical period and analytical reproducibility is estimated to be ≤0.000025 based on replicate runs of NBS987. Nd isotopes measured at UCLA by TIMS using a VG Sector 54 equipped with an electrostatic analyzer. La Jolla=0.512859±0.000010 during the analysis period, $^{143}\text{Nd}/^{144}\text{Nd}$ was normalized to $^{146}\text{Nd}/^{144}\text{Nd}=0.7219$ and ratios were measured dynamically. Uncertainties in measured Nd isotope ratios are analytical errors ($2\sigma/\sqrt{n}$, where n is the number of measured ratios) reported in the last decimal place and analytical reproducibility is estimated to be ≤0.000015. ε_{Nd} values calculated using $(^{143}\text{Nd}/^{144}\text{Nd})_{Chur(0)} = 0.512638$. Pb isotopes were measured at UCLA by TIMS using a VG Sector 54 in static mode. NBS981 $^{208}\text{Pb}/^{206}\text{Pb}=36.504$, $^{207}\text{Pb}/^{204}\text{Pb}=15.472$, and $^{206}\text{Pb}/^{204}\text{Pb}=16.889$, and ratios presented have not been normalized.

2) Major elements measured by XRF; trace elements by ICP-MS, at SGS Mineral Services (formally XRAL Laboratories), 1885 Leslie St., Toronto, Ontario, M3B 2M3. Major elements given in weight percent; detection limit was .01%. Relative error estimated from replicates is < .5%. Trace elements given in ppm. Detection limit (ppm) for trace elements are Gd (.05), Sm (.01) and B (10); relative errors estimated from replicates are Gd (5%), Sm (6%) and B (41%).

DR Appendix 1: Preparation of mineral separates.:
The Bluewater flow is a silica-saturated, tholeiitic basalt with a holocrystalline texture. Its modal mineralogy consists of olivine and plagioclase phenocrysts, with a groundmass dominated by plagioclase and clinopyroxene microphenocrysts and subordinate opaque oxides and olivine. The following details the methodology used to obtain mineral separates for the study.

1) An approximately 15 pound sample from the flows interior was wrapped in several layers of thick polyethylene plastic and broken up with a hammer into ~2–4 cm pieces. The plastic was replaced several times to avoid direct contact of the sample with the hammer.

2) These 2–4 cm pieces were washed with de-ionized water and examined for hammer marks. Visible hammer marks were either scrubbed off with a Teflon scratch pads or if necessary discarded. Any samples with apparent alteration of vesicles was also discarded.

3) The clean 2-4 cm pieces were then ground in agate mortar and pestle into <5 mm 'pea-size' pieces.

4) The entire sample was then sieved into four fractions: >1 mm; 0.5–1mm; 0.1– 0.5 mm and < 0.1 mm. Plagioclase and olivine phenocrysts (>40 um) were hand picked from the fractions under a binocular microscope. The fines, < 0.1 mm, from this grinding and sieving were then discarded.

 5) The three larger fractions were then reground in an hand agate mortar and pestle and again sieved into four fractions: >1 mm; 0.5– 1mm; 0.1– 0.5 mm and < 0.1 mm and the phenocrystic olivine and plagioclase were again hand picked under a binocular microscope from the smaller fractions.

6) The above process was repeated until enough plagioclase and olivine phenocrysts were obtained for U-Th disequilibria analysis (> 1 gm).

7) The 0.5–1mm; 0.1– 0.5 mm and < 0.1 mm fractions were then hand-picked under a binocular microscope with the explicit goal of obtaining pieces visibly devoid of phenocrysts to minimize mixing of the plagioclase and olivine phenocrysts with the groundmass phases.

8) These fractions, reduced of visible phenocrysts, were ground again and sieved into three fractions: >0.1mm; 0.0.04– 0.1 mm and < 0.04 mm and again hand-picked under a binocular microscope to separate rock pieces visibly devoid of phenocrysts from plagiocalse and olivine phenocrysts.

9) The fractions reduced of visible phenocrysts were then combined, ground again and sieved into two fractions: < 0.04 mm and > 0.04 mm. The fraction < 0.04 mm was discarded. The fraction > 0.04 mm was again hand picked to remove any visible olivine and plagioclase phenocrysts. The plagioclase and olivine phenocrysts were added then to the olivine and plagioclase phenocryst separates obtained in steps 4–6.

10) The remaining material > 0.04 mm was ground again so that the entire sample was < 0.04 mm. This was then put through a Frantz magnetic separator to separate the plagioclase groundmass fraction from the more magnetic fraction. This step was repeated until a large groundmass plagioclase fraction was obtained.

11) The remaining more magnetic ground mass fraction was put into a large Petri dish and covered with acetone. A hand magnet was then wrapped in weighing paper and stirred amongst the immersed sample to remove the groundmass magnetite. This fraction was then released (by separating the magnet from the weighing paper from the magnet) into another Petri dish containing acetone. This process was repeated with several iterations to obtain a clean magnetite fraction. The remaining fraction, which is dominated by glass and pyroxene and olivine microphenocrysts, was then set aside as the groundmass fraction shown in figure 2.

12) The separated mineral fractions– plagioclase phenocrysts; olivine phenocrysts phenocryts (> 30 ums); ground mass plagioclase; and magnetite– were then crushed in a small agate hand mortar and pestle. Tfter grinding these fractions were then placed in a density adjusted solution of Sodium Metatungstate to separate the olivine and plagioclase phenocrysts and plagioclase and magnetite groundmass in order to remove glass adhering to the mineral surfaces and melt inclusions.

13) The final mineral separates and residual groundmass were then cleaned using several iterations of de-ionized water and thoroughly dried prior to analysis.

DR Appendix 2: Photo of Bluewater Flow Sampling Site for Cosmogenic Nuclides. Photo of Bluewater flow sampling site for [36]Cl and [3]He analyses collected during 1993 El Malpais Geochronology Sampling Field Trip organized by W Laughlin. The extensive erosion and lack of original surface features such as glassy rinds and ropy pahoehoe led Dunbar and Phillips (2004) to suggest that at least 10 cms of erosion have occurred on this flows surface. Photo by Nelia Dunbar.

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