

## **JQS 2665. Supporting information**

### **Appendix S1. Paleopedology methods**

Paleosols are described according to the standard methods and terminology of the Canadian System of Soil Classification (Soil Classification Working Group, 1998), and the Expert Committee on Soil Survey (1983), using Munsell soil colour notation. Our classification is also given based on the U.S. Soil Taxonomy (Soil Survey Staff, 1999) and the World Reference Base (IUSS Working Group WRB, 2006) to facilitate comparisons. Bulk samples of each soil horizon were collected for physical and chemical characterization, along with undisturbed samples for thin section preparation.

Standard characterization analyses of the < 2 mm fractions are reported on an oven-dry basis. Particle size analysis was performed by the pipette method (Gee and Bauder, 1986) after removal of organic matter and secondary carbonates as needed. The particle size class boundaries are those conventionally used in soil science: 0.05 mm for sand-silt, and 2 µm for silt-clay. Soil chemical analyses included total carbon (C) and nitrogen (LECO CHN-600 Elemental Analyzer), and pH, using a Fisher Accumet pH Meter (model 915) and a soil: 0.01 M CaCl<sub>2</sub> ratio of 1:2. Organic C was measured by determination of C concentration (elemental analyzer) after destruction of carbonates with 1 M HCl. Inorganic C is calculated as the difference between total and organic C. Extractable iron (Fe), aluminum (Al), and silicon (Si) were determined by the sodium pyrophosphate, acid ammonium oxalate, and citrate-bicarbonate-dithionite methods (Carter, 1993). Thin sections (30 µm thick) were prepared from intact samples after impregnation with Spurr resin (System Three Resin, Auburn, WA) and described using terminology after Stoops (2003).

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### **Appendix S2. Tephrochronology methods**

The bulk samples were treated with HCl acid to remove carbonates and then sieved to concentrate the size fraction that contained the glass shards. All of the prepared tephra samples were analyzed by microprobing glass shards in order to identify their chemical signature (Larsen, 1981). The composition of the glass in the tephra was determined using the Cameca Camebax electron microprobe in the Geo-Analytical Laboratory located in the Department of Geology at Washington State University. The analytical conditions were: 15 kV acceleration voltage, 8  $\mu\text{m}$  beam diameter, 12 nA beam current, and peak/background counting times (seconds) of 10/5 for Si, Na, Mg and Al, 30/5 for K and Cl, 22/7 for Ca and Ti, and 52/20 for Fe. The concentrations of the nine elements were determined using the following calibration standards (and K-series emission lines): obsidian glass CCNM 211 (Na, K, Al, Si), NBS glass K-412 (Mg and Ca), basaltic glass VG-A99 (Fe), titanite (Ti), and KCl (Cl). No attempt was made to treat variations in the degree of Na mobilization in the glasses. The compositions of the glasses (Table 1) were compared with the standard glasses in the GeoAnalytical Laboratory's database of Pacific Northwest tephtras using the similarity coefficient (SC) of Borchardt *et al.* (1972) as a discriminator. The similarity coefficient is the average of eight oxide concentration ratios between the glasses in the tephra sample and tephra standard. It was calculated using a weighting of 1.0 for the Si, Al, Ca, Fe, Na, and K oxide concentration ratios and 0.25 for the Mg and Ti oxide concentration ratios. Mg and Ti were given lower weighting because of their low concentrations and, consequently, their high relative error of measurement.

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### **Appendix S3. Optical dating methodology**

For each sample, 180–250  $\mu\text{m}$  diameter (fine sand) quartz grains and 4–11  $\mu\text{m}$  diameter (fine silt) polymineral grains (from which the luminescence from potassium feldspar was to be measured) were separated from the bulk material using standard methods (e.g., see Wintle, 1997, pp. 170-171). Prepared grains were mounted on aluminum discs using silicon oil (quartz sand grains) or deposited onto aluminum discs from an acetone suspension (polymineral silt grains). Each polymineral disc (aliquot) contained many thousands of grains, whereas the quartz aliquots contained 200–300 grains. Smaller quartz aliquots could not be used due to the relatively low luminescence intensity of the quartz found at this locality; it is likely that 10-20 quartz grains in an aliquot contributed to the measured luminescence signal (cf. Duller *et al.*, 2000).

Quartz and the single-aliquot regenerative-dose (SAR) technique (as described in Fig. 9) were chosen because (i) the luminescence “clock” resets more rapidly for quartz than for feldspar, which minimizes the chance of measuring an inherent signal; (ii) the SAR technique is, in practice, relatively simple, and it has been shown to be successful in many studies around the world; (iii) ages are calculated from single aliquots, thus allowing for the possibility of detecting aliquots consisting of grains with different age populations; and (iv) quartz does not suffer from anomalous fading which results in an underestimation of the calculated age unless a correction for it can be made (see Huntley and Lamothe, 2001). Fine-silt potassium feldspar and the multiple-aliquot Australian slide method (Prescott *et al.*, 1993, and as described in *Appendix S5* for Figure 10) were chosen because (i) for a given dose of radiation, feldspar emits much more luminescence than does quartz, and this can lead to better precision, especially at localities, such as Okanagan Centre, where the luminescence emitted from quartz is very dim; (ii) the luminescence signal measured from feldspars saturates at higher radiation doses compared to that from quartz, which allows older samples to be dated; and (iii) because of the success of fine-grained potassium feldspar and the Australian slide method with similar sediments of known age collected from sites in the Fraser River valley, to the northwest of Okanagan Centre (Lian and Huntley 1999).

All the experiments were performed using a Risø TL/OSL-DA-20 Minisys reader fitted with a  $^{90}\text{Sr}/^{90}\text{Y}$  source that delivered beta particles to the aliquot at  $6.24 \pm 0.12$  Gy/min (180-250  $\mu\text{m}$  fine sand) or  $5.49 \pm 0.11$  Gy/min (4-11  $\mu\text{m}$  fine silt).

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### **Appendix S4. References used in the supporting information files.**

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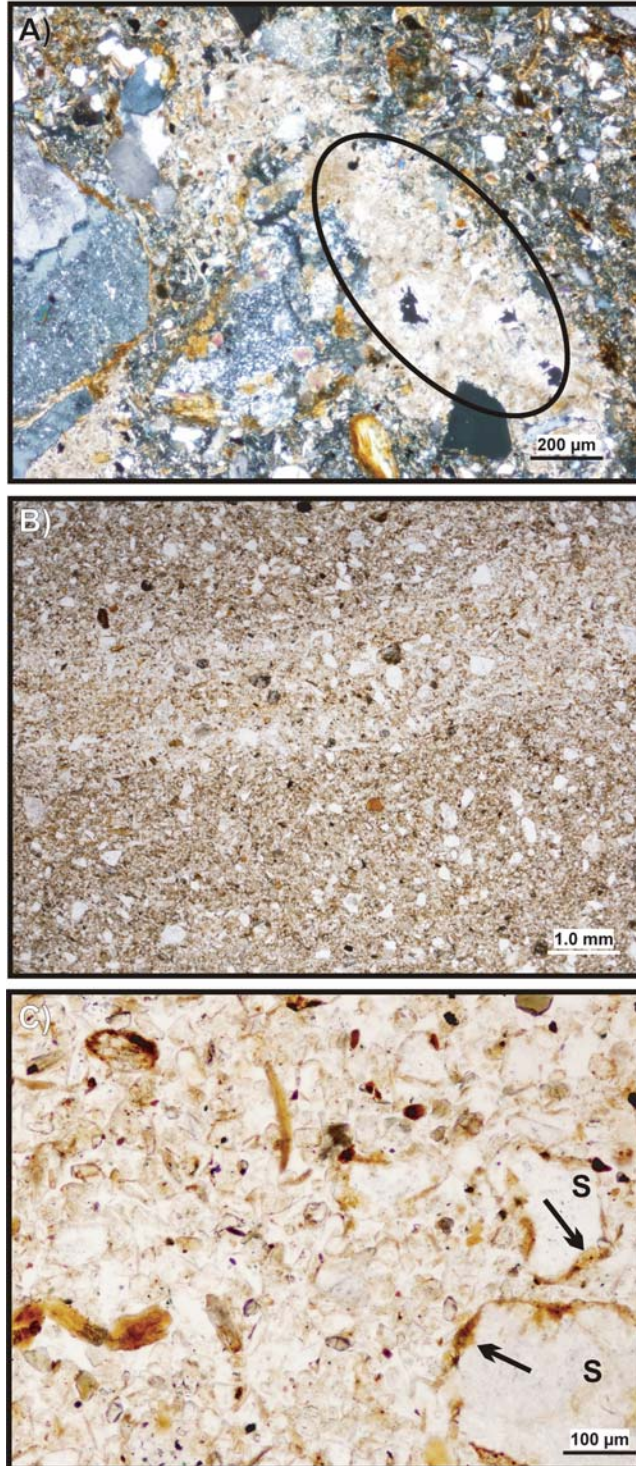
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**Figure S1 legend.** Paleosol micromorphology. A) Secondary carbonate infilling (approximately outlined by ellipse) near upper boundary of IVBmkb horizon, Paleosol 1 (thin section BC09-18-A) (XPL). B) Massive microstructure in Paleosol 2, IIBmb1 horizon (thin section BC09-18-B) (PPL). C) Reddish brown coatings (arrowed) on sand grains (s) in IIBmb2 horizon of Paleosol 2 (thin section BC09-18-C) (PPL).

JQS 2665. Figure S1



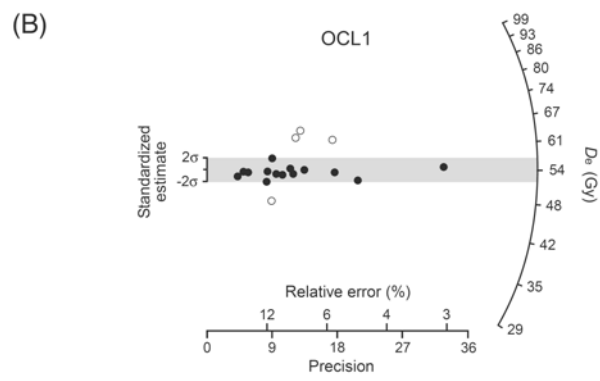
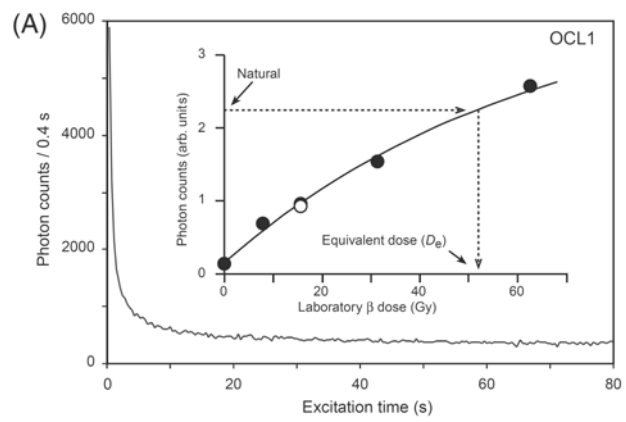


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**Figure S2 legend.** Main graph: luminescence vs. excitation time (shine-down) curve of a natural fine-grained potassium feldspar aliquot of sample OCS2. Inset graph: illustration of the multiple-aliquot Australian slide method used to find the equivalent dose ( $D_e$ ) of OSC2, and those of the other potassium feldspar samples.

[Several aliquots of 4-11  $\mu\text{m}$  (fine silt) polymineral sediments were prepared as described in Lian and Huntley (1999); all were normalized using a short infrared (IR) shine (30  $\text{mW}/\text{cm}^2$  of 880 nm/1.4 eV light for 0.5 s) and roughly half of them were given various laboratory doses (N+  $\beta$  set; open points) to construct the sample's dose-response, while the others were given an extended exposure to light to empty all of the light-sensitive traps, followed by various regenerative doses (N + bleach +  $\beta$  set; solid points). Both sets of aliquots were then preheated together (160° C for 4 hours) and, after a delay of two weeks, were measured with IR light. The resulting luminescence (400 nm, 3.1 eV) was measured with an Electron Tubes 9235QB photomultiplier tube mounted behind Schott BG-39 and Kopp 7-59 optical filters. The luminescence recorded (over the first 5 s) from the N +  $\beta$  set is then shifted along the dose axis to where it coincides with that measured from the N + bleach +  $\beta$  set, the magnitude of the shift being equal to the  $D_e$  after a correction for incomplete laboratory bleaching. Refer to Lian and Roberts (2006) for a more thorough discussion of the method.]

JQS 2665. Figure S2



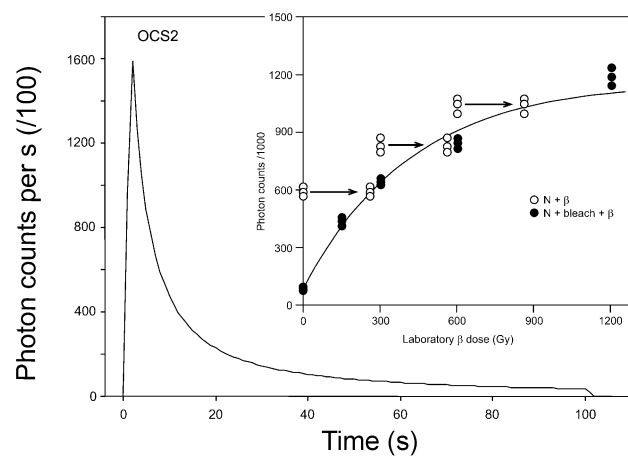
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### **Figure S3 legend.**

Main graph: luminescence vs. excitation time (shine-down) curve of a natural fine-grained potassium feldspar aliquot of sample OCS2. Inset graph: illustration of the multiple-aliquot Australian slide method used to find the equivalent dose ( $D_e$ ) of OSC2, and those of the other potassium feldspar samples.

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**Table S1. Description of paleosols at Okanagan Centre section.**

Horizon (sample #)	Depth (cm) <sup>a</sup>	Description
C (BC09-18-01)	+40 - 0	Yellowish brown (10YR 5/4 m) sand; single grain; very friable; few, medium and coarse roots; abrupt, wavy boundary.
<b><i>Paleosol 2</i></b>		
IIBmb1 (BC09-18-02)	0-20	Dark yellowish brown (10YR 4/6 m) silt loam; massive; firm; very few, medium and coarse roots; gradual, wavy boundary; 20-25 cm thick.
IIBmb2 (BC09-18-03)	20-65	Yellowish brown (10YR 5/4 m) silt loam; massive, friable; clear, wavy boundary; 40-50 cm thick.
IICcab (BC09-18-04)	65-105	Very pale yellow (10YR 7/3 d) silt; massive; hard; spotted, common, fine, irregular, very pale brown (10YR 8/2 d) secondary carbonates; strongly effervescent; gradual, smooth boundary; 40-50 cm thick.
IICk (BC09-18-05)	105-175	Light gray (10YR 7/2 m) silt; massive; firm; few, fine and medium roots; few, irregular secondary carbonate concretions up to 5 cm long, 2 cm diameter; moderately effervescent; abrupt, wavy boundary; 60-75 cm thick.
IIIC (BC09-18-06) OKC-Teph2	175-180	White (10YR 8/1 d); abrupt, smooth boundary; 3-6 cm thick.
<b><i>Paleosol 1</i></b>		
IVBmb (BC09-18-07)	180-205	Yellowish brown (10YR 5/4 m) loam; massive; hard; weakly effervescent; 10% gravel; clear, smooth boundary; 20-35 cm thick.
VCcab1 (BC09-18-08)	205-240	Pale brown (10YR 6/3 m) sandy clay loam; massive; hard; discontinuous induration with secondary carbonates, clasts have 1-2 mm thick carbonate pendants; strongly effervescent; 60-70% gravel (some lithologies strongly disintegrated); gradual, wavy boundary; 25-40 cm thick.
VCcab2 (BC09-18-09)	240-300+	Light yellowish brown (10YR 6/4 m) and grayish brown (2.5 Y 5/2 m) sandy loam; single grain; loose; few, fine roots; clasts have ~ 1 mm thick carbonate pendants; strongly effervescent; 80% gravel (some lithologies strongly disintegrated); [includes discontinuous pockets with siltier matrix].

<sup>a</sup> Horizon depths measured from arbitrary datum set at upper boundary of Paleosol 2

**Table S2. Selected analytical data for paleosols and associated horizons at Okanagan Centre section.**

	Horizon	Depth (cm)	Sand	Silt (%)	Clay	pH (CaCl <sub>2</sub> )	C <sub>org</sub>	C <sub>inorg</sub>	Total N	Fe <sub>p</sub>	Fe <sub>o</sub>	Fe <sub>d</sub>	Al <sub>p</sub>	Al <sub>o</sub>	Si <sub>o</sub>
												(%)			
	C	40	88.5	9.6	1.9	7.2	0.19	< 0.001	0.01	0.01	0.06	0.22	0.01	0.03	0.03
Paleosol 2	IIBmb1	0-20	35.2	57.3	7.6	7.2	0.2	< 0.001	0.013	0.03	0.28	0.74	0.02	0.13	0.13
	IIBmb2	20-65	32.6	62.6	4.9	7.39	0.23	0.01	0.014	0.03	0.21	0.67	0.02	0.09	0.09
	IICca	65-105	8.9	88.1	3	7.54	0.42	0.62	0.01	0.02	0.17	0.54	0.01	0.06	0.07
	IICk	105-175	11	86.7	2.3	7.58	0.35	0.23	0.01	0.04	0.24	0.58	0.02	0.12	0.15
Paleosol 1	IVBmkb	180-205	46.9	43.4	9.7	7.48	0.24	0.03	0.015	0.02	0.17	0.7	0.01	0.1	0.1
	VCca	205-240	51.1	26.1	22.9	7.61	0.39	0.6	0.014	0.02	0.14	0.53	0.01	0.1	0.09
	VCK	240-300+	62.8	20.3	16.9	7.57	0.29	0.19	0.011	0.02	0.16	0.53	0.01	0.08	0.08

C<sub>org</sub>=organic carbon, C<sub>inorg</sub>=inorganic carbon. Subscripts for iron (Fe), aluminum (Al), and Si (silicon) extractions: p=pyrophosphate, o = oxalate, d = dithionite.

**Table S3. K, U, and Th concentrations determined from in situ  $\gamma$ -ray spectroscopy.**

Sample	K (%)	Th <sup>a</sup> ( $\mu\text{g}\cdot\text{g}^{-1}$ )	U <sup>a</sup> ( $\mu\text{g}\cdot\text{g}^{-1}$ )	Apparent $\gamma$ dose rate <sup>b</sup> ( $\text{Gy}\cdot\text{ka}^{-1}$ )
OCL4	1.96 $\pm$ 0.05	6.30 $\pm$ 0.35	2.86 $\pm$ 0.23	1.10 $\pm$ 0.03
OCL3	2.02 $\pm$ 0.05	6.92 $\pm$ 0.36	2.66 $\pm$ 0.23	1.12 $\pm$ 0.03
OKPS3	1.91 $\pm$ 0.05	13.4 $\pm$ 0.5	4.00 $\pm$ 0.32	1.55 $\pm$ 0.04
OCL1	1.77 $\pm$ 0.05	12.6 $\pm$ 0.4	3.92 $\pm$ 0.31	1.47 $\pm$ 0.04
OCS2	1.75 $\pm$ 0.05	9.07 $\pm$ 0.38	3.30 $\pm$ 0.26	1.23 $\pm$ 0.03

<sup>a</sup> Equivalent concentrations calculated from the activities of <sup>214</sup>Bi for U and <sup>208</sup>Tl for Th, assuming secular equilibrium. *Note: values shown have not been corrected for the presence of water, and are thus smaller than those that would have been calculated if sediments were dry.* <sup>b</sup> from counts in the 0.8–2.6 MeV energy range, corrected for relative proportions of K, Th, and U.

<sup>b</sup> From counts in the energy range 0.8-2.6 MeV, corrected for relative proportions of K, U, and Th.