GSA Data Repository 2017357

Davis et al., 2017, Sulfur release from main-phase Columbia River Basalt eruptions: Geology, doi:10.1130/G39371.1.

Data repository item: electron microprobe analysis

Samples were analyzed using the JOEL JXA-8500F field emission electron microprobe (EMPA) at the Washington State University Geoanalytical Lab. The probe operating conditions were set at 30 nA and 15 kV and beam spot size was 3 µm. The standards used were the WSU lab standards for spessartine, VGT-A99 glass, Wilburforce hornblend, K-412, Glass Butte glass, Wilburforce apatite, KCl, and chalcopyrite #5.

Glass analyses were screened for effects of weathering and interference from mineral phases; the latter is especially important for melt inclusions, but microlites may also interfere with host glasses. Analyses showing anomalous excesses of Al, Ca (plagioclase interference) , Fe, Ti (oxide interference) or Mg, Fe, Ca (pyroxene interference) were rejected. Analyses with oxide totals <92 wt. % and with <0.5 wt. % Na_2O were also rejected. The residue of 223 glass analyses, of melt inclusions (n = 65) and host lapilli (n = 158), form the basis for the paper. Glasses have experienced variable post-eruptive preferential loss of Na, apparent when Wapshilla Ridge Member analyses ("Zumwalt glasses", see below) are compared to crystalline whole rocks (glasses, Na_2O = 2.39±0.82, whole rocks = 3.27±0.18; whole rock data from Reidel et al., 1989; Hooper et al., 2000 and Reidel and Tolan, 2013). There is no correlation between S or Cl abundances and Na, or between Na and K, or between S or Cl and the shortfall from 100% of the analytical total; we conclude that, of the elements analyzed here, Na was uniquely mobile during post-eruptive hydration of basaltic glass, and that all components other than Na represent pristine values unaffected by weathering.

Table DR1

Sample	**Flow Unit**	**S**	**Solubility**	Sample	**Flow Unit**	**S**	**Solubility**
		wt%	wt%				
Host Glass							
L114	Wapshilla Ridge	0.039	0.056	69-13	Meyer Ridge	0.054	0.048
L77	Wapshilla Ridge	0.043	0.054	69-14	Meyer Ridge	0.040	0.049
LP18	Wapshilla Ridge	0.032	0.054	69-15	Meyer Ridge	0.047	0.047
L91	Wapshilla Ridge	0.052	0.054	69-16	Meyer Ridge	0.051	0.048
L23	Wapshilla Ridge	0.082	0.054	69-17	Meyer Ridge	0.054	0.047
L24	Wapshilla Ridge	0.038	0.058	69-18	Meyer Ridge	0.051	0.047
L85	Wapshilla Ridge	0.061	0.053	69-19	Meyer Ridge	0.044	0.045
L25	Wapshilla Ridge	0.108	0.056	69-20	Meyer Ridge	0.056	0.048
L74	Wapshilla Ridge	0.033	0.054	69-21	Meyer Ridge	0.048	0.048
LP6	Wapshilla Ridge	0.046	0.053	69-22	Meyer Ridge	0.053	0.048
LP1	Wapshilla Ridge	0.033	0.052	69-23	Meyer Ridge	0.051	0.047
LP19	Wapshilla Ridge	0.038	0.053	BOW11	Meyer Ridge	0.044	0.043
L32	Wapshilla Ridge	0.036	0.054	BOW12	Meyer Ridge	0.010	0.041
LP17	Wapshilla Ridge	0.032	0.054	BOW13	Meyer Ridge	0.114	0.044
LP2	Wapshilla Ridge	0.050	0.054	BOW14	Meyer Ridge	0.109	0.044
L75	Wapshilla Ridge	0.030	0.054	BOW15	Meyer Ridge	0.112	0.043
L73	Wapshilla Ridge	0.032	0.053	BOW16	Meyer Ridge	0.038	0.041
L28	Wapshilla Ridge	0.029	0.053	BOW17	Meyer Ridge	0.114	0.043
L26	Wapshilla Ridge	0.031	0.053	BOW18	Meyer Ridge	0.103	0.043
L27	Wapshilla Ridge	0.032	0.052	BOW19	Meyer Ridge	0.071	0.043
L33	Wapshilla Ridge	0.032	0.053	BOW110	Meyer Ridge	0.052	0.045
L29	Wapshilla Ridge	0.033	0.051	BOW21	Meyer Ridge	0.059	0.045
L99	Wapshilla Ridge	0.031	0.052	BOW22	Meyer Ridge	0.086	0.044
L41	Wapshilla Ridge	0.037	0.052	BOW23	Meyer Ridge	0.047	0.040
L49	Wapshilla Ridge	0.036	0.052	BOW311	Meyer Ridge	0.082	0.043
L101	Wapshilla Ridge	0.032	0.052	BOW312	Meyer Ridge	0.095	0.040
L40	Wapshilla Ridge	0.035	0.050	BOW313	Meyer Ridge	0.038	0.041
LP4	Wapshilla Ridge	0.022	0.051	BOW321	Meyer Ridge	0.111	0.043
L87	Wapshilla Ridge	0.027	0.051	BOW322	Meyer Ridge	0.106	0.044
L69	Wapshilla Ridge	0.030	0.050	BOW323	Meyer Ridge	0.057	0.044
LP9	Wapshilla Ridge	0.040	0.050	BOW341	Meyer Ridge	0.080	0.044
L70	Wapshilla Ridge	0.042	0.051	BOW342	Meyer Ridge	0.032	0.044
L63	Wapshilla Ridge	0.069	0.052	BOW351	Meyer Ridge	0.024	0.043
LP11	Wapshilla Ridge	0.036	0.050	BOW352	Meyer Ridge	0.053	0.045
L71	Wapshilla Ridge	0.037	0.050	BOW353	Meyer Ridge	0.029	0.042
LP16	Wapshilla Ridge	0.039	0.050	BOW361	Meyer Ridge	0.067	0.043
L62	Wapshilla Ridge	0.075	0.051	BOW362	Meyer Ridge	0.081	0.042
L46	Wapshilla Ridge	0.027	0.050	BOW363	Meyer Ridge	0.064	0.039
LP15	Wapshilla Ridge	0.031	0.050	BOW364	Meyer Ridge	0.077	0.043
LP14	Wapshilla Ridge	0.074	0.050	BOW365	Meyer Ridge	0.045	0.042
L106	Wapshilla Ridge	0.036	0.049	BOW366	Meyer Ridge	0.041	0.043
L107	Wapshilla Ridge	0.038	0.051	BOW367	Meyer Ridge	0.030	0.041
L65	Wapshilla Ridge	0.085	0.048	BOW368	Meyer Ridge	0.079	0.043
L68	Wapshilla Ridge	0.030	0.050				
L50	Wapshilla Ridge	0.034	0.052	**Melt Inclusions**			
L66	Wapshilla Ridge	0.036	0.051	Plagioclase hosted			
L64	Wapshilla Ridge	0.067	0.050	PH182	Wapshilla Rid	0.123	0.043
L67	Wapshilla Ridge	0.028	0.050	PH181	Wapshilla Rid	0.169	0.047
L72	Wapshilla Ridge	0.039	0.050	PH183	Wapshilla Rid	0.131	0.041
L42	Wapshilla Ridge	0.039	0.051	PH184	Wapshilla Rid	0.140	0.048
L48	Wapshilla Ridge	0.039	0.051	PH153	Wapshilla Rid	0.127	0.046
LP10	Wapshilla Ridge	0.037	0.050	PH154	Wapshilla Rid	0.130	0.048
L31	Wapshilla Ridge	0.020	0.051	PH155	Wapshilla Rid	0.158	0.047
L44	Wapshilla Ridge	0.055	0.050	PH156	Wapshilla Rid	0.144	0.054
L45	Wapshilla Ridge	0.035	0.051	PH157	Wapshilla Rid	0.149	0.045
LP20	Wapshilla Ridge	0.044	0.050	PH160	Wapshilla Rid	0.159	0.045
L43	Wapshilla Ridge	0.030	0.050	PH161	Wapshilla Rid	0.158	0.050
L53	Wapshilla Ridge	0.044	0.050	PH201	Wapshilla Rid	0.183	0.045
L39	Wapshilla Ridge	0.048	0.048	PH164	Wapshilla Rid	0.132	0.043
LP5	Wapshilla Ridge	0.056	0.048	PH165	Wapshilla Rid	0.128	0.045

L86	Wapshilla Ridge	0.046	0.054	PH166	Wapshilla Rid	0.125	0.045
L109	Wapshilla Ridge	0.050	0.049	PH196	Wapshilla Rid	0.176	0.048
L56	Wapshilla Ridge	0.044	0.050	PH194	Wapshilla Rid	0.159	0.045
L51	Wapshilla Ridge	0.034	0.051	PH192	Wapshilla Rid	0.180	0.049
LP12	Wapshilla Ridge	0.042	0.050	PH188	Wapshilla Rid	0.169	0.046
LP7	Wapshilla Ridge	0.026	0.049	PH172	Wapshilla Rid	0.188	0.049
LP13	Wapshilla Ridge	0.040	0.048	PH175	Wapshilla Rid	0.176	0.046
L54	Wapshilla Ridge	0.048	0.050	PH176	Wapshilla Rid	0.125	0.043
L60	Wapshilla Ridge	0.038	0.050	PH185	Wapshilla Rid	0.131	0.043
L57	Wapshilla Ridge	0.041	0.050	BWAL1PH1	Wapshilla Rid	0.035	0.056
L55	Wapshilla Ridge	0.042	0.050	BWAL1PH2	Wapshilla Rid	0.032	0.055
L52	Wapshilla Ridge	0.041	0.049	BWAL1PH3	Wapshilla Rid	0.187	0.058
L36	Wapshilla Ridge	0.020	0.048	BWAL1PH4	Wapshilla Rid	0.166	0.058
L104	Wapshilla Ridge	0.044	0.047	BWAL1PH5	Wapshilla Rid	0.027	0.046
L88	Wapshilla Ridge	0.025	0.047	BWAL2PH1	Wapshilla Rid	0.033	0.052
L82	Wapshilla Ridge	0.042	0.047	BWAL3PH1	Wapshilla Rid	0.035	0.054
L80	Wapshilla Ridge	0.129	0.044	BWAL3PH2	Wapshilla Rid	0.139	0.052
L79	Wapshilla Ridge	0.033	0.041	TWAL2PH1	Wapshilla Rid	0.174	0.052
BWAL11	Wapshilla Ridge	0.032	0.051	TWAL6PH1	Wapshilla Rid	0.170	0.045
BWAL12	Wapshilla Ridge	0.029	0.052	BOW1PH1	Meyer Ridge	0.087	0.044
BWAL13	Wapshilla Ridge	0.033	0.052	BOW1PH2	Meyer Ridge	0.110	0.045
BWAL21	Wapshilla Ridge	0.033	0.053	BOW1PH3	Meyer Ridge	0.125	0.044
BWAL31	Wapshilla Ridge	0.034	0.053	BOW1PH4	Meyer Ridge	0.126	0.043
BWAL32	Wapshilla Ridge	0.033	0.051	BOW1PH5	Meyer Ridge	0.117	0.045
TWAL21	Wapshilla Ridge	0.046	0.052	BOW1PH6	Meyer Ridge	0.106	0.041
TWAL22	Wapshilla Ridge	0.068	0.053	BOW1PH7	Meyer Ridge	0.111	0.041
TWAL31	Wapshilla Ridge	0.051	0.052	BOW1PH8	Meyer Ridge	0.119	0.043
TWAL32	Wapshilla Ridge	0.043	0.050	BOW32PH1	Meyer Ridge	0.118	0.042
TWAL41	Wapshilla Ridge	0.037	0.052	BOW32PH2	Meyer Ridge	0.109	0.044
TWAL42	Wapshilla Ridge	0.126	0.051	BOW32PH3	Meyer Ridge	0.117	0.043
TWAL61	Wapshilla Ridge	0.088	0.049	BOW32PH4	Meyer Ridge	0.118	0.043
TWAL62	Wapshilla Ridge	0.041	0.048	BOW32PH5	Meyer Ridge	0.118	0.039
53-1	Meyer Ridge	0.029	0.050	53PH1	Meyer Ridge	0.156	0.056
53-2	Meyer Ridge	0.031	0.056	53PH2	Meyer Ridge	0.174	0.052
53-3	Meyer Ridge	0.031	0.056	53PH3	Meyer Ridge	0.171	0.054
53-4	Meyer Ridge	0.029	0.055	53PH4	Meyer Ridge	0.167	0.045
53-5	Meyer Ridge	0.023	0.053	67PH1	Meyer Ridge	0.176	0.050
53-6	Meyer Ridge	0.062	0.054	67PH2	Meyer Ridge	0.160	0.045
53-7	Meyer Ridge	0.026	0.053	67PH3	Meyer Ridge	0.159	0.045
67-1	Meyer Ridge	0.090	0.055	67PH4	Meyer Ridge	0.190	0.049
67-2	Meyer Ridge	0.023	0.049	67PH5	Meyer Ridge	0.164	0.047
67-3	Meyer Ridge	0.037	0.051				
67-4	Meyer Ridge	0.069	0.050	Fe-Ti Oxide hosted			
67-5	Meyer Ridge	0.030	0.049	TH197	Wapshilla Rid	0.133	0.048
69-1	Meyer Ridge	0.057	0.049	TH200	Wapshilla Rid	0.166	0.047
69-3	Meyer Ridge	0.039	0.047	TH162	Wapshilla Rid	0.143	0.052
69-4	Meyer Ridge	0.036	0.046	TH167	Wapshilla Rid	0.130	0.053
69-5	Meyer Ridge	0.051	0.047	TH168	Wapshilla Rid	0.129	0.054
69-6	Meyer Ridge	0.047	0.047	TWAL1TH1	Wapshilla Rid	0.151	0.048
69-7	Meyer Ridge	0.052	0.047	53TH1	Meyer Ridge	0.184	0.051
69-8	Meyer Ridge	0.053	0.048				
69-9	Meyer Ridge	0.031	0.047	Pyroxene hosted			
69-10	Meyer Ridge	0.042	0.047	BWAL2AH1	Wapshilla Rid	0.028	0.057
69-11	Meyer Ridge	0.055	0.047	BWAL2AH2	Wapshilla Rid	0.058	0.055
69-12	Meyer Ridge	0.050	0.047	BWAL1AH3	Wapshilla Rid	0.033	0.056

Data repository item: identification of glasses with Grande Ronde R2 units

The area of Zumwalt Prairie appears on the geologic map of Walker (1979), in which the rocks are mapped as corresponding to the lower Yakima basalt of Wright et al. (1973). The lower Yakima basalt is equivalent to the Grande Ronde Basalt. Considerable progess, summarized by Reidel et al. (1989) and Reidel and Tolan (2013) has been made in understanding the stratigraphy of the Grande Ronde Basalt since 1979. The Wapshilla Ridge Member is present at the top of Reidel's (1983) Buckhorn Springs section, located at the NE corner of the Zumwalt Prairie plateau (units L1 and N of Reidel, 1983, identical with Wapshilla Ridge Member, Reidel et al., 1989), and is present over most of the Zumwalt Prairie surface.

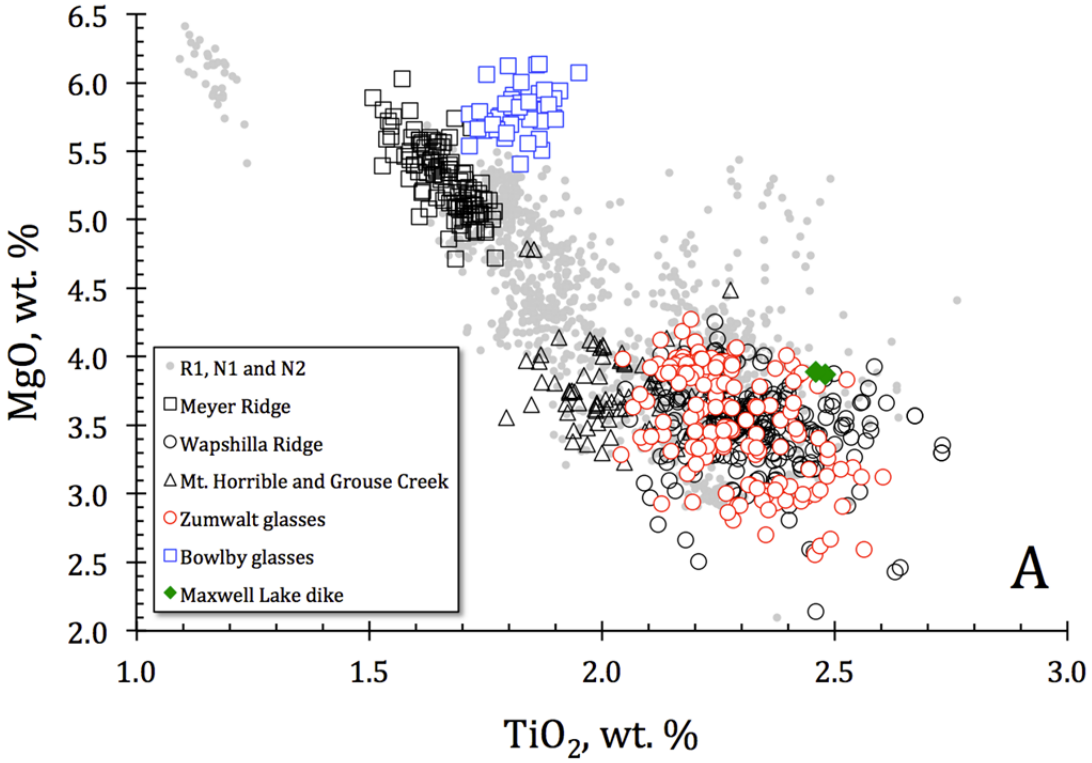
Individual Columbia River Basalt Group lavas tend towards chemical homogeneity, and hence chemical fingerprinting provides the most useful and widely employed means of distinguishing between its members (Wright et al., 1973; Hooper, 2000). No flow is perfectly homogeneous, but the great majority vary within narrow and well-characterized limits (see Hooper, 2000, and Reidel and Tolan, 2013, for numerous examples). Chemical fingerprinting is especially useful in distinguishing between members of the Grande Ronde Basalt, which exhibit less flow-to-flow textural and lithologic variation than those of other formations within the Group. The major and minor elements most useful in distinguishing between Grande Ronde units are Ti, Mg and P. The Wapshilla Ridge Member is distinct from other R2 units, and from most other Grande Ronde Basalt units, in having high TiO_2 (Fig. DR1). In addition, the Wapshilla Ridge Member is petrographically distinguished from other units in close stratigraphic proximity by having abundant plagioclase microphenocrysts, typically <1 mm in length.

Glassy lapilli recovered from phreatomagmatic tuffs on and at the margins of Zumwalt Prairie (Zumwalt glasses in Fig. DR1) have a range in TiO_2 contents, extending to >2.4%, which is unique to Wapshilla Ridge compositions (Fig. DR1). Most of the exposures are very limited in extent; the single exception we have found is at the rim of Little Sheep Creek canyon (Fig. DR2, [45°20'09.0"N 117°04'48.1"W]), where tuff containing glassy lapilli of Wapshilla Ridge composition with plagioclase microphenocrysts is underlain and overlain by lavas having the composition of Grouse Creek and Mt. Horrible members. The latter two lavas are near-identical in compostion, despite being separated by the voluminous Wapshilla Ridge Member, and lack plagioclase microphenocrysts; thus this section (Fig. DR2) corresponds exactly to the established stratigraphy of magnetostratigraphic unit R2 (Reidel et al., 1989; Reidel and Tolan, 2013). The Zumwalt glasses also overlap with Grouse Creek – Mt. Horrible lava compositions. Given the field evidence for simultaneous eruption of the Mt. Horrible lava and Wapshilla Ridge tuff (Fig. DR2; see also Brown et al., 2015), a fraction of the Zumwalt glasses may also be representative of Mt. Horrible magma. However, there is considerable overlap between Wapshilla Ridge and Mt. Horrible - Grouse Creek lava compositions (Reidel and Tolan, 2013, and Fig. DR1); the TiO_2-poor Zumwalt glasses could simply be a slightly variant Wapshilla composition.

In addition, we have analyzed glassy lapilli and melt inclusions from a block of phreatomagmatic basaltic tuff of a type locally known as "Bowlby Stone", historically used as a building material in Enterprise, OR. The block was kindly donated to us by Mr. and Mrs. Wieck and was taken from a quarry located at 45°27'23.6"N 117°11'39.9"W (Fig. 1), on a slight rise within the south-central part of the Zumwalt Prairie (at the time of our investigations, 2013 – 2015, the Bowlby quarry itself was inaccessible for legal reasons). The lapilli and melt inclusion glasses are of a composition unique in the Grande Ronde (Bowlby glasses in Fig. DR1), with MgO contents only matched by the Meyer Ridge Member in R2 and the Fields Spring Member in N2. The latter, however, is very distinct with the lowest TiO_2 contents of any Grande Ronde unit (Fig. DR1). The Bowlby glasses are most similar to the Meyer Ridge Member, albeit with only slight overlap in MgO – TiO_2 space (Fig. DR1A). Over most of their extent, Meyer Ridge Member lavas overlie other R2 units but are intercalated within the Grouse Creek member to the northwest (Hagstrum et al., 2010; Reidel et al., 2013). Given the location of the quarry in an area of near-horizontal strata and no faulting, surrounded by occurrences of Wapshilla Ridge tuff and Grouse Creek lava (Figs. 1, DR2), we conclude that the Bowlby Stone glasses represent a compositional variant of the Meyer Ridge Member, with slightly higher TiO_2 than the known Meyer Ridge lavas.

In summary, Zumwalt glasses represent the Wapshilla Ridge Member, and are so named in the main text of the paper. The Zumwalt glasses may also represent the Mt. Horrible and/or Grouse Creek members. Bowlby glasses are taken to represent the Meyer Ridge Member, and are so named in the main text of the paper.

Figure DR1 (next page): A. MgO vs. TiO_2 and **B.** P_2O_5 vs. TiO_2 for glasses described in this study, plus compositions of whole rock samples of Meyer Ridge, Wapshilla Ridge, Grouse Creek and Mt. Horrible members of the R2 magnetostratigraphic unit of the Grande Ronde Basalt and N1, R1 and N2 magnetostratigraphic units. The isolated group of points at ~1.1% TiO_2 are all of Fields Spring Member lava in N2. Whole rock samples are from Reidel et al. (1989), Hooper et al. (2000) and Reidel and Tolan, 2013. Two samples of the Maxwell Lake dike reported by Petcovic and Dufek (2005) are also shown. Thermal modeling of the Maxwell Lake dike provides the minimum estimate for the duration of the Wapshilla Ridge eruption(s) discussed in the main paper.


MgO, wt. %
TiO2, wt. %
R1, N1 and N2
Meyer Ridge
Wapshilla Ridge
Mt. Horrible and Grouse Creek
Zumwalt glasses
Bowlby glasses
Maxwell Lake dike
A

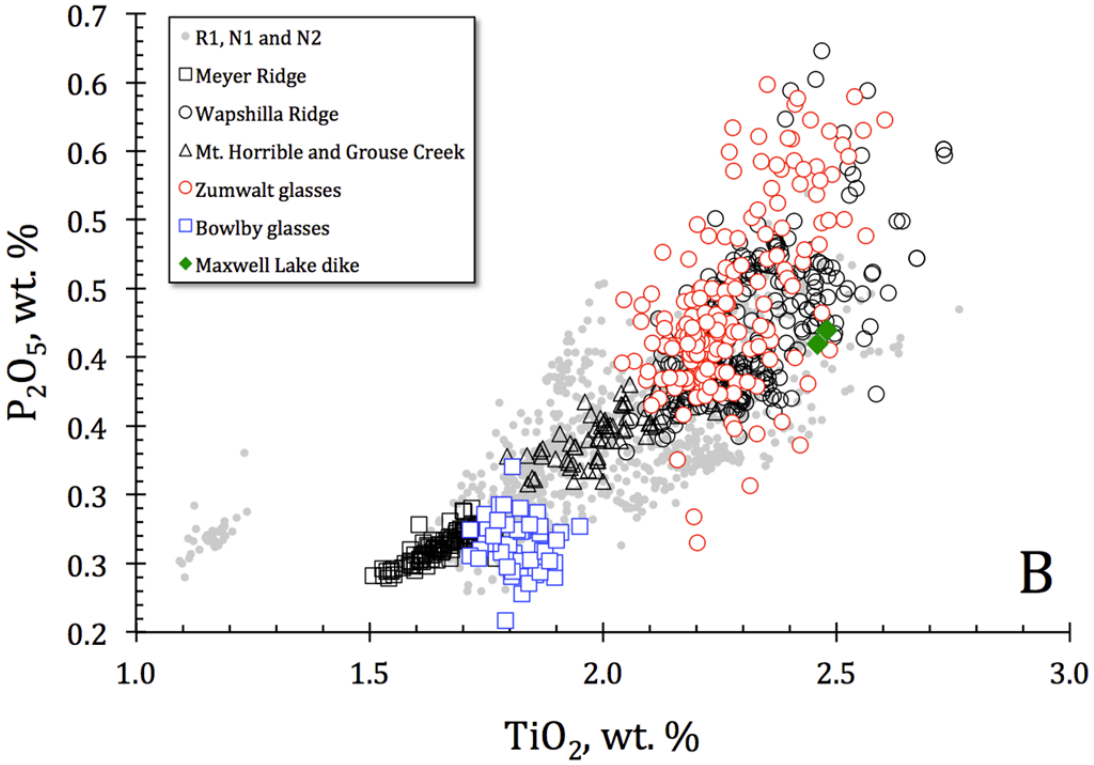

P2O5, wt. %
TiO2, wt. %
R1, N1 and N2
Meyer Ridge
Wapshilla Ridge
Mt. Horrible and Grouse Creek
Zumwalt glasses
Bowlby glasses
Maxwell Lake dike
B

Figure DR1

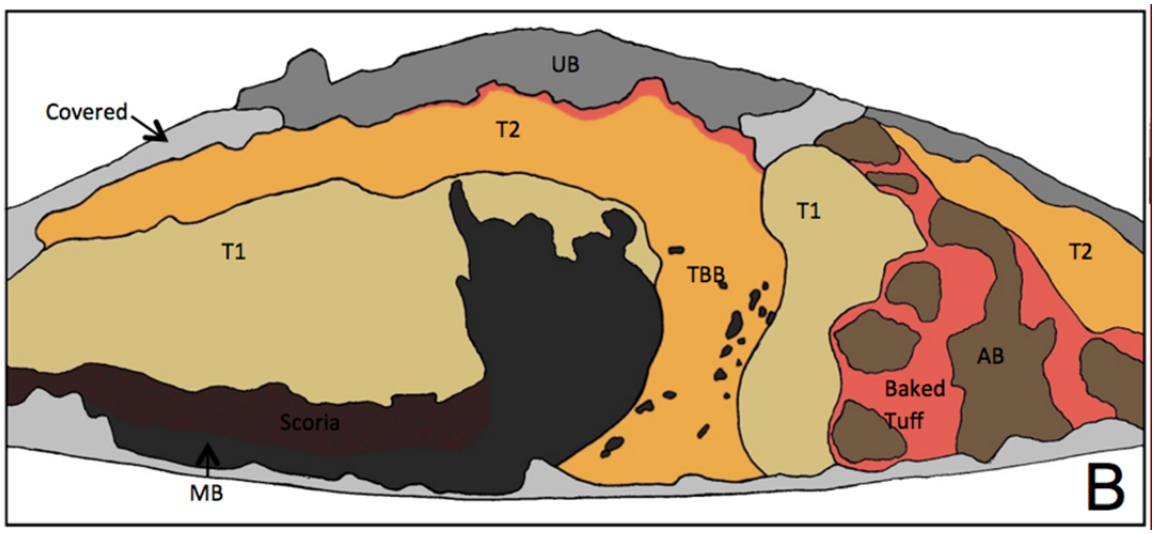


Figure DR2. A. Photograph and **B.** Sketch of photograph through Wapshilla Ridge phreatomagmatic tuff, which is underlain and intruded by Mt. Horrible lava and overlain by Grouse Creek lava. UB: Upper basalt (Grouse Creek member); MB: massive basalt (Mt. Horrible member); AB: a'a basalt (Wapshilla Ridge Member); T1: lower tuff, (Wapshilla Ridge Member); T2: upper tuff (Wapshilla Ridge Member); TBB: block-bearing tuff (Wapshilla Ridge Member). Note that Wapshilla Ridge tuff overlies Mt. Horrible lava to the left, but is also intruded by it (center) and by Wapshilla Ridge lava (right). These relationships demonstrate simultaneous eruption of Mt. Horrible and Wapshilla Ridge units (see also Brown et al., 2015). The whole sequence is capped by Grouse Creek lava overlying baked Wapshilla Ridge tuff. Despite the complex relationships, the whole sequence conforms to the formal Grande Ronde R2 stratigraphy of Reidel and Tolan (2013).

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