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Order of Authors:	Alena Ebinghaus, Ph.D.
	David Jolley, Ph.D.
	Adrian Hartley, Ph.D.
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Extrinsic forcing of plant ecosystems in a LIP: the Columbia River Flood Basalt Province, Washington State, USA

Alena Ebinghaus[1], David W. Jolley[1], and Adrian J. Hartley[1]

[1]*University of Aberdeen, Department of Geology and Petroleum Geology, Aberdeen, AB24 3UE, UK*

ABSTRACT

Volcanism associated with Large Igneous Provinces (LIPs) has been implicated in both global climate and environmental change. To determine the plant ecological impact of LIP volcanism we have examined plant community succession in sedimentary interbeds of the Columbia River Flood Basalt Province (CRBP). Inter-basaltic vegetation is characterised by primary succession communities that inhabit fresh lava surfaces until terminated by the next eruptive event, and it is assumed that longer volcanic hiatuses should lead to more mature plant communities. This expected succession trajectory is contradicted by palynological data which show that seral succession declines during the phase of waning CRPB volcanism and prolonged interbed intervals. Frequent volcanic activity and increased deposition of Snake River Plain hot spot ashes during this phase resulted in ecological disturbance of intra-lava field vegetation. This suggests that the CRBP flora was driven largely by extrinsic forcing, and implies that LIP volcanism of similar scale and magnitude to that of the CRBP had less environmental impact than understood as yet. This study supports the theory that past biotic extinctions were triggered by numerous factors rather than a single geological event.

INTRODUCTION

Large Igneous Province (LIP) volcanic activity is considered to have either directly or indirectly triggered global climate change and mass extinction events (Self et al., 2005; Bond and Wignall, 2014); however, the effect of LIP volcanism on both global and regional plant ecosystems is more poorly constrained. Analysis of the composition and structure of modern plant communities on Krakatau (Whittaker et al., 1989) and ancient plant communities of the Miocene Columbia River Flood Basalt Province (CRBP) and Paleogene North Atlantic Igneous Province (Jolley, 1997; Jolley et al., 2008) indicates a strong relationship between duration of volcanic quiescence and plant seral succession (Jolley, 1997). This suggests that longer hiatuses in eruptive activity will be associated with more mature seral successions proximal to the volcanic centre. Investigation of the drivers of this relationship could provide important constraints on the environmental and climatic effects of LIP volcanism and inter-lava plant ecosystems.

To test the relationship between interflow field quiescence and plant seral succession status required an LIP with a relatively robust chronostratigraphic framework for the eruptive events. The CRBP provides such a framework allied to well developed and mapped sedimentary interbeds with good exposure and ease of accessibility. For this study, interbed sediments were examined in the CRBP in south central Washington State, USA (Fig. 1). The CRBP comprises up to 4500 m of basaltic to andesitic lava flows intercalated with siliciclastic, volcaniclastic, and bioclastic sediments. The intercalated strata were deposited in fluvial and lacustrine environments during phases of volcanic quiescence (Fecht et al., 1987; Ebinghaus et al., 2014). CRBP volcanic evolution is characterised by gradually decreasing eruption periodicity and eruption volumes accompanied by longer periodicities between eruption events. CRBP formation should thus be associated with more mature plant successions during both waning and cessation of volcanic activity.

GEOLOGICAL SETTING

The CRBP is located within the back-arc basin of the High Cascade Range in the northwest USA. Flood basalt volcanism began in the late Early Miocene on the Oregon Plateau and was accompanied by rhyolithic to andesitic volcanism of the Cascade volcanoes and the Snake River Plain (Camp and Ross, 2004). Flood basalt flows of the CRBP and the Oregon Plateau are assigned to the Columbia River Flood Basalt Group (CRBG). Eruption of the CRBG commenced at 16.72 ± 0.21 Ma with emplacement of the Steens Basalt based on ^{40}Ar-^{39}Ar dating (Jarboe et al., 2008). From late Early Miocene to early Late Miocene the locus of volcanic activity migrated along the Chief Joseph Dike Swarm from southeastern Oregon (Steens Basalt) through northeastern Oregon to form the Imnaha and Grande Ronde Basalts and to southeastern Washington State where eruption of the Grande Ronde, Wanapum and Saddle Mountains Basalts occurred (Tolan et al., 1989; Camp, 1995). A second northward migration trend exists along the Monument Dike Swarm, from which the Picture Gorge and Prineville Basalts were erupted (Camp and Ross, 2004).

Eruption of the Steens, Picture Gorge, Prineville, Imnaha and Grande Ronde Basalts marks the main phase of flood basalt volcanism, characterized by high eruption rates and volumes. This initial phase was followed by a progressive decrease in volcanic activity which includes the less voluminous Wanapum and Saddle Mountain Basalts (Reidel et al., 2013) and was accompanied by an increase in interbed duration.

PALYNOFLORA

The palynological record within the interbeds was examined to reconstruct vegetation community dynamics throughout CRBP evolution. A total of 46 samples were taken from interbeds of the Douglas Creek, Vantage, Squaw Creek, Quincy, Selah and Rattlesnake Ridge members (Fig. 2, Supplemental Material A). The palynological data were analyzed by performing Detrended Correspondence Analysis (DCA) which arranges taxa along environmental gradients (Supplemental Material B and C). DCA is an ordination technique to identify groups of taxa and to place them into their ecological context.

Sediments of the Douglas Creek Member were deposited between the R_2 and N_2 magnetostratigraphic unit of the Grande Ronde Basalt (16.25 ± 0.27 to 15.46 ± 0.21 My, (Barry et al., 2013) and consist of fluvial floodplain and sand-dominated channel deposits (Ebinghaus et al., 2014). The comparison of residual major element composition of the interbed with that of the underlying basalt flow indicates an interbed duration of 4 - 8ka (Jolley et al., 2008). Palynological investigations have yielded abundant *Quercoidites microhenrici* (oak), *Cupuliferoipollenites* (chestnut type), and *Intratriporopollenites* (basswood). DCA allied to botanical affinities of these floras indicated a late-successional mixed mesophytic forest. This is interpreted as the dominant vegetation community in the relatively dry, more elevated areas of the Douglas Creek Member paleosurface. During deposition of the Vantage Member interbed (15.97 ± 0.4 My, Barry et al., 2010), this community was replaced by mid-successional true swamp communities dominated by *Caryapollenites*, *Platycaryapollenites platycaryoides*, and *Momipites* (all walnut family). ^{40}Ar-^{39}Ar isotope dating of the Grande Ronde and Frenchman Springs basalts indicates a duration time of < 250,000 years for the Vantage Member (Barry et al., 2010). With ongoing CRBP volcanism mature forest communities changed into mid-successional riparian to transitional swamp and early successional open floodplain communities. This is indicated by abundant *Alnipollenites* (alder), *Salixpollenites* (willow), and *Trivestibulopollenites paleobetuloides* (birch), accompanied by chlorophyceae algae (e.g. *Botryococcus braunii*), and disturbance-tolerant ruderals, such as sphagnaceaen mosses (*Stereisporites* spp.), club mosses, spike mosses, and polypodiacean ferns. Interbed duration times at this stage are estimated to have been < 1000 years during the Squaw Creek Member (Jolley et al., 2008) and > 3My during the Selah Member (Barry et al., 2013).

DISCUSSION

The observed distribution of plant communities through CRBP evolution does not support the proposed simple hypothesis of maturing plant successions in response to longer interbed intervals, and suggests repeated ecological disturbance during prolonged interbed formation. The deposition of thick fluvial sediments during the phase of waning volcanism indicates the formation of extensive drainage systems in the Rattlesnake Ridge Member. Lateral migration of river channels may be capable of cutting off large areas of vegetation, and hence hindering plant seral succession along river banks and floodplains. The fluvial deposits of the interbed site of the Douglas Creek Member suggest a migrating network of multiple small river channels and point bars associated with floodplains similar to those of the later interbeds (Ebinghaus et al. 2014). Palynological analyses record high abundances of *Pinus* and *Picea*, bisaccate pollen which indicates a strong fluvial-derived input (see Supplemental Material D). The fluvial characteristics and the presence of fluvial-derived palynomorphs suggest that there is no pronounced correlation between drainage system dimension and seral plant succession.

Global climate warming during the Miocene (Mid-Miocene Climate Optimum) may have caused significant stress to plant communities. The Miocene climate change is reflected by a positive trend in marine carbon isotopes ($\delta^{13}C$), a negative trend in marine oxygen isotopes ($\delta^{18}O$) (Zachos et al. 2001) and rise of atmospheric CO_2 (Pagani et al., 1999) correlating with Earth's orbital cycles (Zachos et al. 2001). The climatic optimum was followed by gradual surface cooling associated with growth of the East Antarctic ice sheet and expansion of the West Antarctic ice sheet at c. 10 Ma (Flower and Kennett, 1994). The decrease in temperature would have led to a shift of biomes from mixed mesophytic forests to broad-leaved evergreen forests characterised by higher dominance and less diversity (e.g. Wolfe, 1979). However, this trend cannot be recognised in the palynological record of the CRBP, which suggests a shift in the successional status, without any corresponding change in biome composition.

Severe ecological disturbance could have been caused by deposition of the volcanic ash beds that are exposed in the Rattlesnake Ridge Member (Ebinghaus et al., 2014). Their X-ray fluorescence chemical composition (Supplemental Material E) corresponds with the chemical composition of the Yellowstone hotspot lavas (= Snake River Plain hot spot, data from Sarbas, 2015, georoc database) as indicated by Nb-Zr-Yt, and Zr-SiO_2, and Nb-Zr ratios. Electron microscope analyses of the Snake River Plain hot spot ashes revealed high proportions of coarse glass shards ranging in diameter between 200 and 600 µm. Individual ash beds have a typical thickness of 0.25 to 0.5 m. The ecological effects of ash fall on flora are diverse, but depend mainly on tephra thickness, seasonal timing, chemical composition and physical properties of glass shards. Deposition and wind-blown coarse-grained ash may cause defoliation and branch damage. Photosynthesis, germination and plant growth can be lowered or hindered if soil and small plants are covered by ash. Volcanic ejecta may have toxic effects of both flora and fauna through acid leachates and acid rain. In addition, there may be effects on regional and global climate from the increased albedo of the Earth's surface, and accumulation of carbon and sulphur compounds in the atmosphere. As a consequence, tephra deposition is capable of limiting or hindering plant growth for decades; however plant species show different levels of vulnerability to ash fall depending on site characteristics, ecological requirements, reproduction and growth rate (Thornton, 2000; Jones, 2015).

Nash and Perkins (2012) and Coble and Mahood (2012) record frequent eruptive activity of the Snake River Plain hot spot throughout the Miocene, with increased deposition of ashes within the CRBP during deposition of the Rattlesnake Ridge Member as observed in this study. The timing of the seral successional 'stalling' suggests a direct relationship between the Snake River Plain volcanic activity and enhanced deposition of ash within the CRBP. This correlation together with the potential effects of explosive eruptions suggests that the Snake River Plain volcanism is likely to have had a significant ecological impact on the Miocene CRBP flora by re-setting plant succession after each major eruption event. Snake River Plain volcanism is likely to have caused disturbances to climate and atmospheric patterns (e.g. Jones et al., 2007), which together with global climate cooling following the Mid-Miocene Climate Optimum could have caused additional stress on vegetation.

CRBP volcanic activity is implicated to have contributed to macronutrient availability through thermal fixation during short-term syn-volcanic interbed formation proximal to the volcanic centre. This is inferred from high abundances of the chlorophycean algae *Pediastrum bifidites*, which in modern environments requires high nitrate availability (Jolley et al., 2008). Thermal fixation of macronutrients through CRBP volcanism appears negligable in this study, since 1) *Pediastrum bifidites* is absent at this stage, and 2) the volcanic centres of the lavas under- and overlying the Rattlesnake Ridge Member (Pomona and Elephant Mountain basalts) are estimated to be > 200 - 300 km away from the interbed localities (e.g. Swanson et al. 1979).

The aspects outlined above suggest that CRBP vegetation change at this stage was controlled by extrinsic factors rather than intra-lava field processes. This further indicates that LIPs should not be considered as separate systems, but as inter-active open environments. This study also implies that past global environmental changes and mass extinctions were triggered by multiple factors rather than single events.

CONCLUSIONS

Investigations of plant recovery and ecosystem development in volcanic terrains indicate a strong relationship between duration of volcanic hiatus and maturity of plant communities. Plant succession is expected to succeed or to achieve a climax until it becomes terminated by the resumption of volcanic activity. In this study this hypothesis is tested by examining the palynofloral record of the CRBP from different stages of LIP formation. Statistical analysis of the palynological assemblage records a drastic successional decline during the phase of waning volcanism and longer interbed intervals (e.g. Rattlesnake Ridge Member), which does not support the hypothesis as stated above.

During Rattlesnake Ridge Member time intra-lava field plant ecosystems appear to have been largely forced by contemporary Snake River Plain volcanic activity as indicated by sedimentological and geochemical analyses. Repetitive explosive emissions of volcanic particles and deposition of several decimetres thick ash beds onto the CRBP lava field caused major disturbance of the plant ecosystem and re-setting of seral succession after each major eruption event.

The successional decline throughout CRBP formation implies that LIPs with the scale and volcanic activity comparable to the CRBP are likely to have had less impact on regional and global ecosystems than understood as yet, and that past major global environmental changes were driven by multiple factors rather than a single catastrophic event.

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FIGURE CAPTIONS

Figure 1: Location of the Columbia River Flood Basalt Province (modified after Reidel et al., 2013), and migration of adjacent High Lava Plains and Snake River Plain hot spot track, with ages given in million years (Camp and Ross, 2004, and Reidel et al., 2013).

Figure 2: Correlation of CRBP stratigraphy, eruption volumes (adapted from Barry et al., 2013; Martin et al., 2013; Reidel et al., 2013) and seral plant succession. Detrended correspondence analysis (DCA) records a decline in successional status during the phase of reduced eruption volumes. Contemporary deposition of volcanic ashes derived from the Snake River Plain hot spot track volcanism suggests strong correlations between inter-basaltic seral plant succession and extrinsic volcanic activity. Eruption and depositional record of Snake River Plain hot spot track adapted from Coble and Mahood (2012) and Nash and Perkins (2012).

Figure 1 Click here to download Figure Geology_Figure 1_small.jpg

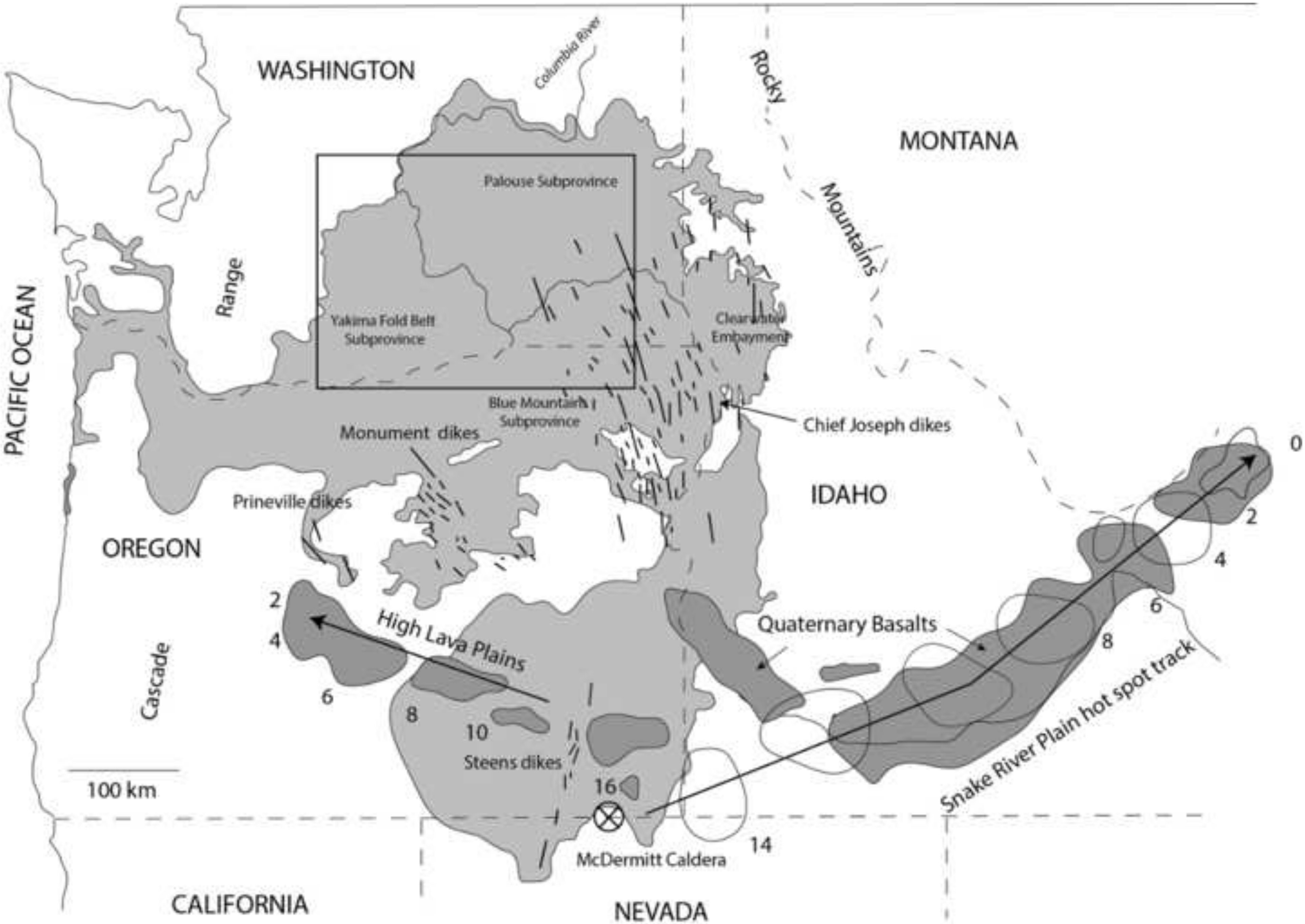
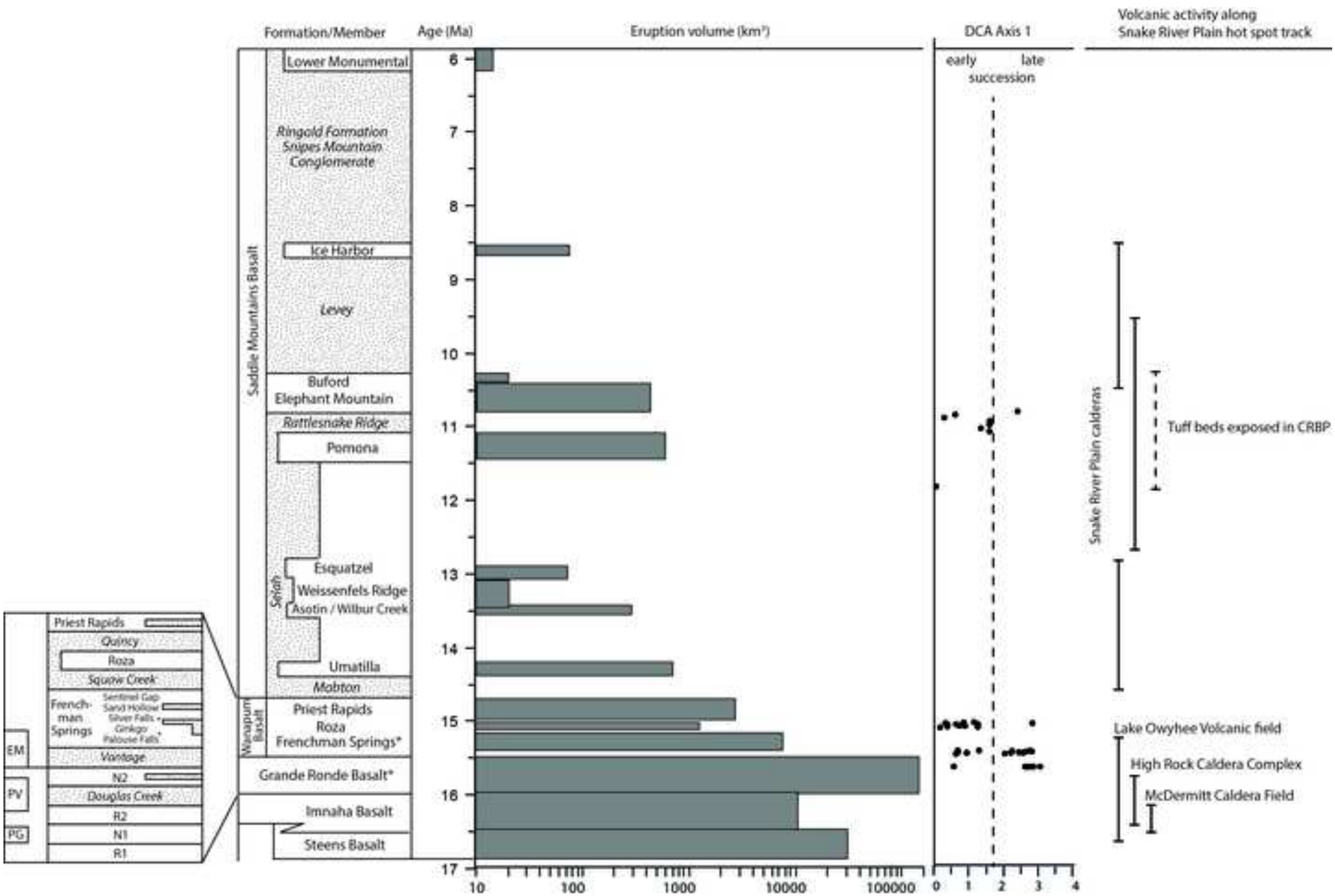


Figure 2 Click here to download Figure Geology_Figure 2_BW.jpg



Interbed locations

Member	Location	Abbr.	Latitude	Longitude
Douglas Creek	Wagon Road	WR	47.464500	-119.873483
Vantage	Edgemont 3	ED3	46.882183	-120.424383
	Umtanum 1	U1	46.912700	-120.505967
	Vantage	V	46.951433	-119.992000
Squaw Creek and Quincy	Hoctor Road	HR	45.779883	-120.502367
	Old Vantage Highway	OVH	47.029483	-119.963683
	Scan Coffine Lake	SCL	47.144767	-119.924817
	Trinidad	T	47.240128	-119.986671
Selah	Ayers Road	AR	46.064583	-118.956550
	Jericho	J	46.822800	-119.818183
	Mattawa (lower part)	MA	46.777583	-119.913317
	Plymouth Road	PRD 1	45.998400	-119.350467
Rattlesnake Ridge	Bert James Road	BJ	46.199933	-119.713433
	Mabton	M	46.141133	-120.025567
	Mabton-Bickleton Road	MB	46.112853	-120.054531
	Mattawa (upper part)	MA	46.777583	-119.913317
	Old Inland Empire	OIE	46.274217	-119.577117
	Plymouth Road	PRD 2	45.998400	-119.350467
	Prosser	P	46.221867	-119.691783
	Sellars Road	SRD	46.127350	-119.845400
	Toppenish Ridge	TR	46.282000	-120.501467
	Wallula Junction	WJ	46.058100	-118.919933
Other interbeds	Palouse Falls	PF	46.665983	-118.224233

Palynological data set						
Number	3.00	6.00	7.00	8.00	12.00	13.00
Depth	33.44	54.01	57.23	62.52	78.57	79.37
Sample Code	BJ-1-14	M-1-5	M-1-3m	MB-1-10m	OIE-1-6	OIE-1-4
Angiosperms						
Alnipollenites verus	3.00	0.00	0.00	1.00	4.00	1.00
Carpinus -type	0.00	0.00	0.00	0.00	0.00	0.00
Caryapollenites simplex	1.00	0.00	0.00	5.00	0.00	0.00
Chenopodium -type	0.00	0.00	0.00	0.00	2.00	1.00
Corsinipollenites oculusnoctis	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoidaepollenites liblarensis	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoidaepollenites sp.	0.00	0.00	0.00	0.00	1.00	1.00
Cupuliferoipollenites cingulum	0.00	0.00	0.00	0.00	2.00	2.00
Cupuliferoipollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00
Ilexpollenites iliacus	1.00	0.00	0.00	0.00	0.00	0.00
Intratriporopollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00
Juglanspollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00
Liquidambarpollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00
Momipites spp.	0.00	0.00	0.00	0.00	0.00	0.00
Nyssapollenites satzveyensis	0.00	0.00	0.00	0.00	0.00	0.00
Nyssapollenites spp.	16.00	0.00	0.00	2.00	16.00	0.00
Platycaryapollenites platycaryoides	0.00	0.00	0.00	0.00	0.00	0.00
Poaceae -type	0.00	0.00	0.00	0.00	0.00	0.00
Pterocaryapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00
Quercoidites microhenrici	0.00	0.00	0.00	0.00	0.00	0.00
Rhoipites viburnoides	0.00	0.00	0.00	0.00	3.00	0.00
Salixpollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00
Salixpollenites discolorpites	0.00	0.00	0.00	0.00	0.00	0.00
Scabratricolpites spp.	0.00	0.00	0.00	0.00	0.00	0.00
Triporopollenites coryloides	0.00	0.00	0.00	0.00	0.00	0.00
Trivestibulopollenites paleobetuloides	4.00	0.00	0.00	0.00	0.00	0.00
Ulmipollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00
Gymnosperms						
Cycadopites spp.	0.00	0.00	0.00	0.00	3.00	0.00
Cupressicates sp.	1.00	0.00	0.00	0.00	0.00	0.00
Polypodiopsida **(ferns)**						
Baculatisporites primarius	0.00	0.00	0.00	0.00	0.00	41.00
Deltoidospora spp.	0.00	0.00	0.00	0.00	0.00	3.00
Laevigatosporites haardtii	1.00	0.00	0.00	7.00	0.00	0.00
Laevigatosporites sp.	0.00	0.00	0.00	0.00	0.00	0.00
Microfoveolatosporites spp.	0.00	0.00	0.00	0.00	0.00	0.00
Verucatosporites favus	0.00	0.00	0.00	0.00	1.00	0.00
Lycopodiophyta **(fern allies)**						
Echinosporis spp.	0.00	0.00	0.00	0.00	0.00	0.00
Lycopodiumsporites spp.	0.00	0.00	0.00	0.00	2.00	0.00
Bryophyta **(mosses)**						
Stereisporites spp.	0.00	0.00	0.00	4.00	1.00	1.00
Trilete type 1	0.00	1.00	0.00	0.00	0.00	0.00
Chlorophyceae **(green algae)**						
Botryococcus braunii	2.00	10.00	48.00	0.00	1.00	11.00
Schizosporis parvus	0.00	0.00	0.00	0.00	1.00	6.00
Pediastrum bifidites	0.00	0.00	0.00	0.00	0.00	0.00
Chlorophyceae undiff.	0.00	0.00	0.00	0.00	0.00	30.00
Fungi						
Fungal fruiting body	0.00	0.00	2.00	0.00	2.00	2.00
Fungal hyphea	0.00	2.00	9.00	20.00	0.00	2.00
Fungal spore	0.00	14.00	0.00	1.00	96.00	59.00
Sum	**29.00**	**27.00**	**59.00**	**40.00**	**135.00**	**160.00**

Number	14.00	19.00	23.00	32.00	33.00	34.00	35.00
Depth	103.07	171.72	199.29	284.42	287.31	289.88	293.15
Sample Code	P-1-4	TR-3-2	AR-1-4b	HR-1-3	OVH-1-5	OVH-2-5	OVH-3-1
Angiosperms							
Alnipollenites verus	1.00	0.00	4.00	2.00	1.00	0.00	0.00
Carpinus -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caryapollenites simplex	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Chenopodium -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corsinipollenites oculusnoctis	0.00	0.00	0.00	0.00	3.00	0.00	0.00
Cupuliferoidaepollenites liblarensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoidaepollenites sp.	0.00	0.00	0.00	0.00	12.00	0.00	0.00
Cupuliferoipollenites cingulum	0.00	0.00	0.00	0.00	11.00	0.00	0.00
Cupuliferoipollenites spp.	1.00	0.00	1.00	0.00	30.00	0.00	0.00
Ilexpollenites iliacus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Intratriporopollenites spp.	0.00	0.00	0.00	0.00	13.00	0.00	0.00
Juglanspollenites spp.	0.00	0.00	0.00	1.00	5.00	0.00	0.00
Liquidambarpollenites spp.	3.00	0.00	11.00	0.00	0.00	0.00	0.00
Momipites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nyssapollenites satzveyensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nyssapollenites spp.	2.00	0.00	5.00	0.00	26.00	2.00	0.00
Platycaryapollenites platycaryoides	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poaceae -type	0.00	0.00	0.00	0.00	3.00	0.00	0.00
Pterocaryapollenites spp.	0.00	0.00	0.00	0.00	3.00	0.00	0.00
Quercoidites microhenrici	0.00	0.00	0.00	1.00	3.00	0.00	0.00
Rhoipites viburnoides	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salixpollenites sp.	6.00	0.00	0.00	0.00	0.00	0.00	0.00
Salixpollenites discolorpites	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scabratricolpites spp.	0.00	0.00	0.00	0.00	22.00	0.00	0.00
Triporopollenites coryloides	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trivestibulopollenites paleobetuloides	1.00	0.00	0.00	0.00	1.00	0.00	0.00
Ulmipollenites spp.	0.00	0.00	0.00	0.00	21.00	0.00	0.00
Gymnosperms							
Cycadopites spp.	0.00	0.00	0.00	2.00	0.00	0.00	0.00
Cupressicates sp.	0.00	0.00	0.00	0.00	38.00	0.00	0.00
***Polypodiopsida* (ferns)**							
Baculatisporites primarius	0.00	1.00	0.00	0.00	0.00	8.00	0.00
Deltoidospora spp.	0.00	0.00	3.00	0.00	5.00	1.00	0.00
Laevigatosporites haardtii	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laevigatosporites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Microfoveolatosporites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Verucatosporites favus	0.00	0.00	1.00	0.00	2.00	1.00	0.00
***Lycopodiophyta* (fern allies)**							
Echinosporis spp.	0.00	0.00	14.00	1.00	1.00	1.00	0.00
Lycopodiumsporites spp.	0.00	0.00	49.00	1.00	5.00	3.00	0.00
***Bryophyta* (mosses)**							
Stereisporites spp.	0.00	0.00	17.00	0.00	16.00	0.00	0.00
Trilete type 1	0.00	0.00	4.00	0.00	0.00	2.00	0.00
***Chlorophyceae* (green algae)**							
Botryococcus braunii	6.00	9.00	17.00	7.00	0.00	17.00	5.00
Schizosporis parvus	0.00	0.00	1.00	0.00	0.00	0.00	13.00
Pediastrum bifidites	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chlorophyceae undiff.	0.00	0.00	0.00	3.00	7.00	0.00	0.00
Fungi							
Fungal fruiting body	0.00	42.00	45.00	26.00	0.00	0.00	37.00
Fungal hyphea	0.00	76.00	65.00	70.00	0.00	80.00	70.00
Fungal spore	1.00	1.00	30.00	8.00	0.00	8.00	0.00
Sum	**21.00**	**129.00**	**267.00**	**122.00**	**229.00**	**123.00**	**125.00**

Number	36.00	37.00	38.00	39.00	40.00	41.00	43.00
Depth	296.21	295.89	298.86	299.06	299.10	299.14	301.62
Sample Code	SCL-1-4b	SCL-1-2t	T-1-5	T-1-4	T-1-3	T-1-2	T-2-4
Angiosperms							
Alnipollenites verus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carpinus -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caryapollenites simplex	0.00	0.00	2.00	0.00	0.00	0.00	0.00
Chenopodium -type	0.00	0.00	4.00	0.00	0.00	0.00	0.00
Corsinipollenites oculusnoctis	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoidaepollenites liblarensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoidaepollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoipollenites cingulum	0.00	0.00	3.00	0.00	0.00	0.00	0.00
Cupuliferoipollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilexpollenites iliacus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Intratriporopollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Juglanspollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Liquidambarpollenites spp.	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Momipites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nyssapollenites satzveyensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nyssapollenites spp.	0.00	0.00	59.00	6.00	0.00	0.00	1.00
Platycaryapollenites platycaryoides	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poaceae -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pterocaryapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quercoidites microhenrici	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhoipites viburnoides	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salixpollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salixpollenites discolorpites	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scabratricolpites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triporopollenites coryloides	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trivestibulopollenites paleobetuloides	0.00	1.00	2.00	0.00	0.00	0.00	0.00
Ulmipollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gymnosperms							
Cycadopites spp.	0.00	0.00	3.00	0.00	0.00	0.00	0.00
Cupressicates sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
***Polypodiopsida* (ferns)**							
Baculatisporites primarius	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deltoidospora spp.	0.00	0.00	51.00	0.00	3.00	0.00	2.00
Laevigatosporites haardtii	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laevigatosporites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Microfoveolatosporites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Verucatosporites favus	0.00	0.00	0.00	1.00	1.00	0.00	0.00
***Lycopodiophyta* (fern allies)**							
Echinosporis spp.	0.00	1.00	72.00	0.00	10.00	0.00	0.00
Lycopodiumsporites spp.	4.00	0.00	84.00	0.00	0.00	0.00	9.00
***Bryophyta* (mosses)**							
Stereisporites spp.	0.00	0.00	38.00	0.00	13.00	0.00	0.00
Trilete type 1	0.00	0.00	0.00	1.00	0.00	0.00	0.00
***Chlorophyceae* (green algae)**							
Botryococcus braunii	2.00	1.00	26.00	0.00	12.00	1.00	19.00
Schizosporis parvus	2.00	16.00	0.00	0.00	4.00	0.00	0.00
Pediastrum bifidites	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chlorophyceae undiff.	0.00	1.00	22.00	0.00	39.00	0.00	1.00
Fungi							
Fungal fruiting body	70.00	71.00	436.00	11.00	179.00	7.00	5.00
Fungal hyphea	26.00	119.00	26.00	45.00	58.00	18.00	18.00
Fungal spore	59.00	0.00	96.00	0.00	100.00	0.00	3.00
Sum	**163.00**	**211.00**	**924.00**	**64.00**	**419.00**	**26.00**	**58.00**

Number	47.00	48.00	49.00	50.00	51.00	58.00	59.00	60.00
Depth	304.35	304.45	304.62	304.67	306.79	334.31	350.57	350.72
Sample Code	T-3-4	T-3-3	T-3-2	T-3-1	T-4-7	ED3-1-8	PF-1-3	PF-1-2
Angiosperms								
Alnipollenites verus	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00
Carpinus -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caryapollenites simplex	0.00	0.00	0.00	0.00	0.00	0.00	3.00	52.00
Chenopodium -type	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corsinipollenites oculusnoctis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoidaepollenites liblarensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoidaepollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoipollenites cingulum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoipollenites spp.	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00
Ilexpollenites iliacus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Intratriporopollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00
Juglanspollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Liquidambarpollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Momipites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nyssapollenites satzveyensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nyssapollenites spp.	10.00	0.00	3.00	0.00	3.00	0.00	5.00	0.00
Platycaryapollenites platycaryoides	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.00
Poaceae -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pterocaryapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Quercoidites microhenrici	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhoipites viburnoides	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salixpollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salixpollenites discolorpites	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scabratricolpites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triporopollenites coryloides	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trivestibulopollenites paleobetuloides	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ulmipollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gymnosperms								
Cycadopites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupressicates sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00
***Polypodiopsida* (ferns)**								
Baculatisporites primarius	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deltoidospora spp.	2.00	0.00	5.00	0.00	0.00	0.00	1.00	26.00
Laevigatosporites haardtii	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laevigatosporites sp.	0.00	0.00	7.00	0.00	0.00	0.00	0.00	0.00
Microfoveolatosporites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Verucatosporites favus	0.00	0.00	2.00	0.00	0.00	0.00	0.00	6.00
***Lycopodiophyta* (fern allies)**								
Echinosporis spp.	0.00	0.00	16.00	0.00	0.00	0.00	0.00	2.00
Lycopodiumsporites spp.	0.00	3.00	0.00	0.00	0.00	1.00	0.00	31.00
***Bryophyta* (mosses)**								
Stereisporites spp.	0.00	0.00	6.00	0.00	0.00	0.00	0.00	32.00
Trilete type 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
***Chlorophyceae* (green algae)**								
Botryococcus braunii	9.00	9.00	5.00	4.00	1.00	1.00	0.00	0.00
Schizosporis parvus	0.00	0.00	0.00	0.00	0.00	15.00	0.00	72.00
Pediastrum bifidites	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chlorophyceae undiff.	1.00	0.00	24.00	0.00	0.00	0.00	1.00	29.00
Fungi								
Fungal fruiting body	15.00	1.00	0.00	4.00	4.00	37.00	0.00	0.00
Fungal hyphea	14.00	19.00	17.00	26.00	50.00	56.00	15.00	0.00
Fungal spore	0.00	0.00	319.00	7.00	0.00	0.00	0.00	0.00
Sum	**52.00**	**32.00**	**404.00**	**41.00**	**58.00**	**116.00**	**26.00**	**272.00**

Number	61.00	62.00	63.00	64.00	65.00	67.00	68.00	71.00
Depth	352.95	253.10	353.17	353.19	353.35	355.63	355.73	369.25
Sample Code	PF-2-5t	PF-2-4b	PF-2-3	PF-2-2	PF-2-1	PF-3-2b	PF-3-1	V-1-2t
Angiosperms								
Alnipollenites verus	0.00	32.00	43.00	6.00	0.00	1.00	0.00	0.00
Carpinus -type	0.00	0.00	43.00	0.00	0.00	0.00	0.00	0.00
Caryapollenites simplex	23.00	22.00	133.00	28.00	95.00	33.00	32.00	0.00
Chenopodium -type	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corsinipollenites oculusnoctis	1.00	0.00	6.00	0.00	2.00	1.00	0.00	0.00
Cupuliferoidaepollenites liblarensis	0.00	0.00	0.00	0.00	13.00	0.00	0.00	0.00
Cupuliferoidaepollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoipollenites cingulum	0.00	5.00	4.00	0.00	0.00	0.00	0.00	0.00
Cupuliferoipollenites spp.	0.00	0.00	0.00	9.00	0.00	0.00	0.00	0.00
Ilexpollenites iliacus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Intratriporopollenites spp.	1.00	1.00	3.00	2.00	3.00	10.00	0.00	0.00
Juglanspollenites spp.	1.00	12.00	20.00	8.00	1.00	1.00	0.00	0.00
Liquidambarpollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Momipites spp.	0.00	0.00	2.00	0.00	0.00	14.00	9.00	0.00
Nyssapollenites satzveyensis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nyssapollenites spp.	0.00	0.00	18.00	0.00	1.00	0.00	0.00	0.00
Platycaryapollenites platycaryoides	4.00	2.00	48.00	20.00	2.00	6.00	8.00	0.00
Poaceae -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pterocaryapollenites spp.	0.00	10.00	30.00	0.00	0.00	0.00	0.00	0.00
Quercoidites microhenrici	0.00	0.00	9.00	0.00	0.00	0.00	0.00	0.00
Rhoipites viburnoides	0.00	0.00	20.00	7.00	21.00	15.00	0.00	0.00
Salixpollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salixpollenites discolorpites	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scabratricolpites spp.	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00
Triporopollenites coryloides	24.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00
Trivestibulopollenites paleobetuloides	0.00	4.00	5.00	0.00	0.00	0.00	0.00	0.00
Ulmipollenites spp.	0.00	13.00	0.00	3.00	0.00	0.00	0.00	0.00
Gymnosperms								
Cycadopites spp.	9.00	3.00	7.00	5.00	0.00	0.00	0.00	0.00
Cupressicates sp.	3.00	0.00	1.00	0.00	11.00	4.00	1.00	0.00
***Polypodiopsida* (ferns)**								
Baculatisporites primarius	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deltoidospora spp.	29.00	3.00	23.00	11.00	48.00	2.00	10.00	0.00
Laevigatosporites haardtii	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00
Laevigatosporites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Microfoveolatosporites spp.	0.00	13.00	6.00	0.00	0.00	0.00	0.00	0.00
Verucatosporites favus	0.00	15.00	6.00	0.00	4.00	0.00	0.00	6.00
***Lycopodiophyta* (fern allies)**								
Echinosporis spp.	0.00	1.00	26.00	0.00	6.00	0.00	8.00	0.00
Lycopodiumsporites spp.	1.00	0.00	3.00	19.00	3.00	5.00	1.00	21.00
***Bryophyta* (mosses)**								
Stereisporites spp.	0.00	1.00	56.00	18.00	26.00	32.00	29.00	0.00
Trilete type 1	3.00	0.00	1.00	0.00	7.00	0.00	0.00	0.00
***Chlorophyceae* (green algae)**								
Botryococcus braunii	2.00	0.00	7.00	0.00	5.00	0.00	1.00	14.00
Schizosporis parvus	64.00	2.00	58.00	0.00	109.00	7.00	12.00	8.00
Pediastrum bifidites	0.00	0.00	11.00	0.00	0.00	0.00	0.00	0.00
Chlorophyceae undiff.	47.00	7.00	0.00	14.00	106.00	0.00	0.00	0.00
Fungi								
Fungal fruiting body	0.00	0.00	0.00	0.00	8.00	0.00	0.00	0.00
Fungal hyphea	0.00	0.00	0.00	0.00	13.00	0.00	0.00	13.00
Fungal spore	0.00	0.00	0.00	0.00	1.00	0.00	0.00	30.00
Sum	**213.00**	**150.00**	**593.00**	**150.00**	**485.00**	**131.00**	**111.00**	**92.00**

Number	72.00	73.00	79.00	80.00	81.00	82.00	83.00
Depth	369.55	371.98	393.39	394.29	396.99	397.59	403.31
Sample Code	V-1-1b	V-2-7t	WR-1-11b	WR-1-9	WR-1-4	WR-1-3	WR-2-6t
Angiosperms							
Alnipollenites verus	0.00	0.00	14.00	9.00	1.00	22.00	17.00
Carpinus -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caryapollenites simplex	0.00	0.00	0.00	14.00	0.00	0.00	3.00
Chenopodium -type	0.00	0.00	0.00	0.00	7.00	0.00	0.00
Corsinipollenites oculusnoctis	0.00	0.00	8.00	0.00	0.00	0.00	0.00
Cupuliferoidaepollenites liblarensis	0.00	0.00	0.00	5.00	0.00	1.00	0.00
Cupuliferoidaepollenites sp.	0.00	4.00	29.00	1.00	0.00	12.00	0.00
Cupuliferoipollenites cingulum	0.00	0.00	14.00	1.00	0.00	14.00	24.00
Cupuliferoipollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilexpollenites iliacus	0.00	0.00	1.00	0.00	0.00	1.00	2.00
Intratriporopollenites spp.	0.00	0.00	51.00	5.00	0.00	5.00	15.00
Juglanspollenites spp.	0.00	0.00	0.00	10.00	0.00	1.00	2.00
Liquidambarpollenites spp.	0.00	0.00	1.00	3.00	0.00	0.00	0.00
Momipites spp.	0.00	0.00	13.00	0.00	0.00	0.00	0.00
Nyssapollenites satzveyensis	0.00	0.00	0.00	0.00	0.00	22.00	0.00
Nyssapollenites spp.	0.00	0.00	2.00	30.00	0.00	7.00	12.00
Platycaryapollenites platycaryoides	0.00	0.00	0.00	14.00	0.00	2.00	6.00
Poaceae -type	0.00	0.00	0.00	7.00	0.00	1.00	0.00
Pterocaryapollenites spp.	0.00	0.00	1.00	2.00	0.00	2.00	0.00
Quercoidites microhenrici	0.00	0.00	68.00	26.00	0.00	0.00	21.00
Rhoipites viburnoides	0.00	0.00	0.00	0.00	0.00	1.00	6.00
Salixpollenites sp.	0.00	0.00	0.00	17.00	0.00	1.00	0.00
Salixpollenites discolorpites	0.00	0.00	0.00	0.00	0.00	26.00	0.00
Scabratricolpites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Triporopollenites coryloides	0.00	0.00	0.00	8.00	0.00	12.00	0.00
Trivestibulopollenites paleobetuloides	0.00	0.00	4.00	1.00	0.00	3.00	9.00
Ulmipollenites spp.	0.00	0.00	1.00	27.00	0.00	2.00	11.00
Gymnosperms							
Cycadopites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cupressicates sp.	0.00	0.00	0.00	0.00	0.00	0.00	17.00
***Polypodiopsida* (ferns)**							
Baculatisporites primarius	0.00	0.00	0.00	4.00	0.00	0.00	3.00
Deltoidospora spp.	6.00	0.00	4.00	2.00	0.00	5.00	9.00
Laevigatosporites haardtii	0.00	0.00	30.00	23.00	0.00	5.00	0.00
Laevigatosporites sp.	0.00	0.00	2.00	8.00	0.00	13.00	0.00
Microfoveolatosporites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Verucatosporites favus	0.00	0.00	0.00	0.00	0.00	1.00	0.00
***Lycopodiophyta* (fern allies)**							
Echinosporis spp.	0.00	0.00	1.00	2.00	0.00	1.00	3.00
Lycopodiumsporites spp.	0.00	0.00	6.00	0.00	2.00	2.00	1.00
***Bryophyta* (mosses)**							
Stereisporites spp.	0.00	47.00	0.00	6.00	0.00	11.00	2.00
Trilete type 1	0.00	0.00	3.00	0.00	0.00	0.00	0.00
***Chlorophyceae* (green algae)**							
Botryococcus braunii	0.00	0.00	4.00	0.00	0.00	0.00	1.00
Schizosporis parvus	0.00	0.00	5.00	1.00	0.00	8.00	3.00
Pediastrum bifidites	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chlorophyceae undiff.	0.00	0.00	0.00	0.00	0.00	2.00	0.00
Fungi							
Fungal fruiting body	0.00	0.00	9.00	0.00	0.00	1.00	8.00
Fungal hyphea	18.00	0.00	0.00	0.00	28.00	0.00	0.00
Fungal spore	49.00	0.00	5.00	0.00	0.00	0.00	7.00
Sum	**73.00**	**51.00**	**276.00**	**226.00**	**38.00**	**184.00**	**182.00**

Number	84.00	85.00	86.00
Depth	404.41	408.84	411.44
Sample Code	WR-2-3t	WR-3-11t	WR-3-3t
Angiosperms			
Alnipollenites verus	9.00	9.00	12.00
Carpinus -type	0.00	0.00	0.00
Caryapollenites simplex	9.00	7.00	16.00
Chenopodium -type	7.00	0.00	0.00
Corsinipollenites oculusnoctis	0.00	0.00	0.00
Cupuliferoidaepollenites liblarensis	0.00	0.00	0.00
Cupuliferoidaepollenites sp.	13.00	38.00	26.00
Cupuliferoipollenites cingulum	23.00	2.00	9.00
Cupuliferoipollenites spp.	0.00	0.00	0.00
Ilexpollenites iliacus	0.00	4.00	1.00
Intratriporopollenites spp.	25.00	0.00	9.00
Juglanspollenites spp.	6.00	8.00	1.00
Liquidambarpollenites spp.	0.00	0.00	0.00
Momipites spp.	0.00	0.00	0.00
Nyssapollenites satzveyensis	0.00	0.00	0.00
Nyssapollenites spp.	1.00	2.00	0.00
Platycaryapollenites platycaryoides	0.00	0.00	7.00
Poaceae -type	0.00	0.00	0.00
Pterocaryapollenites spp.	11.00	0.00	0.00
Quercoidites microhenrici	18.00	62.00	39.00
Rhoipites viburnoides	0.00	0.00	0.00
Salixpollenites sp.	0.00	0.00	0.00
Salixpollenites discolorpites	0.00	0.00	0.00
Scabratricolpites spp.	0.00	16.00	1.00
Triporopollenites coryloides	0.00	0.00	0.00
Trivestibulopollenites paleobetuloides	13.00	6.00	0.00
Ulmipollenites spp.	6.00	11.00	11.00
Gymnosperms			
Cycadopites spp.	0.00	0.00	0.00
Cupressicates sp.	19.00	25.00	8.00
***Polypodiopsida* (ferns)**			
Baculatisporites primarius	1.00	0.00	1.00
Deltoidospora spp.	4.00	6.00	27.00
Laevigatosporites haardtii	0.00	10.00	0.00
Laevigatosporites sp.	26.00	4.00	9.00
Microfoveolatosporites spp.	0.00	0.00	0.00
Verucatosporites favus	2.00	0.00	1.00
***Lycopodiophyta* (fern allies)**			
Echinosporis spp.	2.00	2.00	2.00
Lycopodiumsporites spp.	2.00	1.00	4.00
***Bryophyta* (mosses)**			
Stereisporites spp.	11.00	1.00	1.00
Trilete type 1	3.00	0.00	1.00
***Chlorophyceae* (green algae)**			
Botryococcus braunii	2.00	0.00	0.00
Schizosporis parvus	0.00	6.00	0.00
Pediastrum bifidites	0.00	0.00	0.00
Chlorophyceae undiff.	0.00	0.00	2.00
Fungi			
Fungal fruiting body	21.00	0.00	0.00
Fungal hyphea	0.00	0.00	0.00
Fungal spore	0.00	9.00	0.00
Sum	**234.00**	**229.00**	**188.00**

Detrended Correspondence Analysis: Methods
Detrended correspondence analysis (DCA) was performed with a tolerance of the eigenanalysis set at 1 x 10-7. Rare species were downweighted by using the Hill logarithm and data were square root transformed. DCA produced a scatter plot that shows the spatial distribution of the palynological taxa along two axes (environmental gradients). The scatter plot produced here includes 47 variables (= taxa) and 46 cases (= samples), with axis 1 having an eigenvalue of 0.54, a percentage of 23.919 and a cumulative percentage of 23.919, and with axis 2 having an eigenvalue of 0.15, a percentage of 6.644 and a cumulative percentage of 30.563.

DCA axes

Sample ID	Axis 1	Axis 2
BJ-1-14	2.474	0
M-1-5	0.68	0.732
M-1-3m	0.346	0.796
MB-1-10m	1.673	1.293
OIE-1-6	1.635	1.012
OIE-1-4	1.415	0.93
P-1-4	1.678	0.465
TR-3-2	0.177	1.126
AR-1-4b	1.121	1.429
HR-1-3	0.833	1.255
OVH-1-5	2.824	1.04
OVH-2-5	0.677	0.992
OVH-3-1	0.335	1.439
SCL-1-4b	0.575	1.291
SCL-1-2t	0.509	1.388
T-1-5	1.262	1.412
T-1-4	0.407	1.029
T-1-3	0.888	1.445
T-1-2	0	1.243
T-2-4	0.741	1.26
T-3-4	0.761	0.887
T-3-3	0.301	1.288
T-3-2	1.224	1.118
T-3-1	0.188	1.081
T-4-7	0.093	1.052
ED3-1-8	0.712	1.545
PF-1-3	1.319	1.281
PF-1-2	2.267	2.273
PF-2-5t	2.232	1.749
PF-2-4b	2.767	1.235
PF-2-3	2.581	1.701
PF-2-2	2.612	2.256
PF-2-1	2.048	1.949
PF-3-2b	2.84	2.5
PF-3-1	2.441	2.566
V-1-2t	0.951	1.437
V-1-1b	0.644	1.192
V-2-7t	2.673	2.587
WR-1-11b	2.861	0.672
WR-1-9	2.881	0.753
WR-1-4	0.575	1.05
WR-1-3	2.612	0.836
WR-2-6t	2.705	0.848
WR-2-3t	2.786	0.676
WR-3-11t	3.087	0.581
WR-3-3t	3.083	0.932

Bisaccate data set

Number	3.00	6.00	7.00	8.00	12.00	13.00	14.00
Depth	33.44	54.01	57.23	62.52	78.57	79.37	103.07
Sample Code	BJ-1-14	M-1-5	M-1-3m	MB-1-10m	OIE-1-6	OIE-1-4	P-1-4
Abiespollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cathaya -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cedripites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cycadopites spp.	0.00	0.00	0.00	0.00	3.00	0.00	0.00
Monocolpopollenites tranquilus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piceapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus diplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus haplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinuspollenites spp.	2.00	0.00	0.00	3.00	21.00	0.00	1.00
Podocarpidites spp.	0.00	0.00	0.00	0.00	2.00	0.00	0.00
Pseudotsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sciadopityspollenites serratus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sequoiapollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Number	19.00	23.00	32.00	33.00	34.00	35.00	36.00
Depth	171.72	199.29	284.42	287.31	289.88	293.15	296.21
Sample Code	TR-3-2	AR-1-4b	HR-1-3	OVH-1-5	OVH-2-5	OVH-3-1	SCL-1-4b
Abiespollenites spp.	0.00	0.00	0.00	3.00	0.00	0.00	0.00
Cathaya -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cedripites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cycadopites spp.	0.00	0.00	2.00	0.00	0.00	0.00	0.00
Monocolpopollenites tranquilus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piceapollenites spp.	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Pinus diplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus haplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinuspollenites spp.	0.00	5.00	0.00	5.00	0.00	0.00	0.00
Podocarpidites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pseudotsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sciadopityspollenites serratus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sequoiapollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Number	37.00	38.00	39.00	40.00	41.00	43.00	47.00
Depth	295.89	298.86	299.06	299.10	299.14	301.62	304.35
Sample Code	SCL-1-2t	T-1-5	T-1-4	T-1-3	T-1-2	T-2-4	T-3-4
Abiespollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cathaya -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cedripites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cycadopites spp.	0.00	3.00	0.00	0.00	0.00	0.00	0.00
Monocolpopollenites tranquilus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piceapollenites spp.	0.00	7.00	0.00	0.00	0.00	0.00	0.00
Pinus diplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus haplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinuspollenites spp.	0.00	13.00	1.00	1.00	0.00	5.00	3.00
Podocarpidites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pseudotsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sciadopityspollenites serratus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sequoiapollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Number	48.00	49.00	50.00	51.00	58.00	59.00	60.00
Depth	304.45	304.62	304.67	306.79	334.31	350.57	350.72
Sample Code	T-3-3	T-3-2	T-3-1	T-4-7	ED3-1-8	PF-1-3	PF-1-2
Abiespollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cathaya -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cedripites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cycadopites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monocolpopollenites tranquilus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piceapollenites spp.	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Pinus diplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus haplox	0.00	0.00	0.00	0.00	0.00	0.00	2.00
Pinuspollenites spp.	0.00	3.00	0.00	0.00	0.00	0.00	3.00
Podocarpidites spp.	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Pseudotsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sciadopityspollenites serratus	0.00	0.00	0.00	0.00	0.00	0.00	9.00
Sequoiapollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Number	61.00	62.00	63.00	64.00	65.00	67.00	68.00
Depth	352.95	253.10	353.17	353.19	353.35	355.63	355.73
Sample Code	PF-2-5t	PF-2-4b	PF-2-3	PF-2-2	PF-2-1	PF-3-2b	PF-3-1
Abiespollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cathaya -type	0.00	0.00	2.00	0.00	0.00	0.00	0.00
Cedripites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cycadopites spp.	9.00	3.00	7.00	5.00	0.00	0.00	0.00
Monocolpopollenites tranquilus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piceapollenites spp.	0.00	0.00	2.00	17.00	1.00	0.00	0.00
Pinus diplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus haplox	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinuspollenites spp.	2.00	6.00	25.00	0.00	0.00	0.00	0.00
Podocarpidites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pseudotsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sciadopityspollenites serratus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sequoiapollenites sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	2.00	0.00

Number	71.00	72.00	73.00	79.00	80.00	81.00	82.00
Depth	369.25	369.55	371.98	393.39	394.29	396.99	397.59
Sample Code	V-1-2t	V-1-1b	V-2-7t	WR-1-11b	WR-1-9	WR-1-4	WR-1-3
Abiespollenites spp.	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Cathaya -type	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cedripites spp.	0.00	0.00	0.00	0.00	0.00	0.00	4.00
Cycadopites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monocolpopollenites tranquilus	0.00	0.00	0.00	0.00	0.00	0.00	6.00
Piceapollenites spp.	0.00	0.00	0.00	0.00	20.00	0.00	6.00
Pinus diplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinus haplox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinuspollenites spp.	0.00	0.00	0.00	3.00	9.00	0.00	27.00
Podocarpidites spp.	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Pseudotsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sciadopityspollenites serratus	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Sequoiapollenites sp.	0.00	0.00	0.00	5.00	0.00	0.00	0.00
Tsugapollenites spp.	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Number	83.00	84.00	85.00	86.00
Depth	403.31	404.41	408.84	411.44
Sample Code	WR-2-6t	WR-2-3t	WR-3-11t	WR-3-3t
Abiespollenites spp.	0.00	0.00	1.00	1.00
Cathaya -type	0.00	0.00	0.00	0.00
Cedripites spp.	0.00	0.00	0.00	0.00
Cycadopites spp.	0.00	0.00	0.00	0.00
Monocolpopollenites tranquilus	0.00	0.00	0.00	0.00
Piceapollenites spp.	0.00	0.00	10.00	9.00
Pinus diplox	0.00	0.00	0.00	1.00
Pinus haplox	4.00	2.00	0.00	0.00
Pinuspollenites spp.	20.00	0.00	9.00	20.00
Podocarpidites spp.	0.00	0.00	0.00	1.00
Pseudotsugapollenites spp.	0.00	0.00	0.00	3.00
Sciadopityspollenites serratus	0.00	0.00	0.00	0.00
Sequoiapollenites sp.	0.00	0.00	0.00	1.00
Tsugapollenites spp.	0.00	0.00	0.00	0.00

XRF geochemical composition of volcanic ashes

%	AR-1-4b	AR-1-6	AR-1-6a	BJ-1-10	MA-1-6t	PRD-1-3	WJ-1-1	SRD-1-2
P2O5	0.04	0.05	0.04	0.02	0.05	0.04	0.01	0.02
MnO	0.05	0.03	0.04	0.04	0.06	0.03	0.01	0.09
TiO2	0.42	0.36	0.39	0.23	0.57	0.34	0.15	0.25
MgO	0.95	0.14	1.33	0.16	2.17	0.15	0.63	0.55
CaO	1.12	0.84	0.91	0.74	1.92	0.85	0.37	0.93
Na2O	1.57	2.39	1.66	2.16	1.22	2.59	0.14	1.67
FeO*	3.48	2.16	2.87	2.10	3.49	2.06	1.37	2.28
K2O	5.41	6.38	5.84	6.04	3.05	5.99	0.36	5.73
Al2O3	12.52	12.08	12.90	12.10	17.35	12.05	3.03	12.77
SiO2	74.44	75.57	74.01	76.42	70.12	75.88	93.93	75.71
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
ppm								
NiO	1.53	2.04	10.94	2.16	12.47	3.69	2.67	9.16
Cr2O3	2.48	5.70	8.04	5.41	12.72	5.70	13.15	1.32
Sc2O3	8.59	8.59	7.98	4.45	11.35	7.06	5.52	5.68
V2O3	79.15	12.95	76.94	9.42	83.27	10.00	53.25	22.95
BaO	956.95	1036.45	817.95	646.34	743.48	972.47	296.88	693.79
Rb2O	187.44	225.39	186.68	223.75	120.08	230.09	24.06	208.44
SrO	63.98	59.01	57.36	32.64	143.10	57.71	28.86	41.86
ZrO2	597.05	578.82	595.16	502.09	753.21	560.58	40.39	524.92
Y2O3	56.26	69.47	64.51	97.28	71.37	72.51	7.62	93.98
Nb2O5	50.36	58.08	58.08	60.37	67.09	60.23	5.58	60.51
Ga2O3	21.91	22.99	24.87	28.09	28.36	23.79	6.59	27.42
CuO	9.64	4.26	8.39	6.26	13.77	5.01	5.01	9.64
ZnO	63.25	58.99	63.25	98.19	77.03	57.99	18.54	96.32
PbO	27.36	32.53	30.27	34.04	42.01	32.75	4.09	34.58
La2O3	76.11	87.61	91.48	108.83	92.06	89.83	9.38	106.61
CeO2	160.42	180.95	187.09	227.66	235.89	183.40	10.33	232.21
ThO2	32.77	36.08	36.19	39.94	42.70	37.63	1.66	40.61
Nd2O3	55.40	63.92	65.43	83.28	66.95	68.70	7.81	78.50
U2O3	7.16	9.69	6.83	11.12	4.40	9.80	0.44	8.48
Cs2O	2.12	5.41	2.65	1.80	7.42	7.85	0.00	1.27
As2O5	5.06	5.98	20.25	0.00	0.00	0.00	0.00	0.00
W2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum tr.	2464.99	2564.88	2420.33	2223.13	2628.73	2496.79	541.83	2298.23
in %	0.25	0.26	0.24	0.22	0.26	0.25	0.05	0.23

%	U-1-2	J-1-4	J-1-5b	MA-1-4b	MA-1-5m	PRD-1-4	MB-1-13	SRD-1-1t
P2O5	0.08	0.05	0.06	0.04	0.04	0.05	0.02	0.03
MnO	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.03
TiO2	0.75	0.51	0.47	0.40	0.40	0.37	0.83	0.99
MgO	1.31	0.98	1.41	1.31	0.37	0.17	1.32	1.88
CaO	1.03	1.12	1.09	1.49	1.21	0.90	1.55	1.75
Na2O	1.70	1.37	1.35	1.33	1.40	2.70	1.59	0.70
FeO*	3.31	2.97	2.63	2.29	2.23	2.22	3.42	7.52
K2O	2.80	4.51	4.49	5.32	5.94	5.86	1.66	1.16
Al2O3	14.67	14.06	13.52	12.86	12.56	12.15	9.96	16.84
SiO2	74.33	74.39	74.93	74.92	75.82	75.55	79.61	69.10
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
ppm								
NiO	25.96	4.96	4.45	2.42	3.44	2.67	7.76	23.54
Cr2O3	71.91	13.45	13.15	4.53	7.02	5.12	27.92	77.17
Sc2O3	15.03	10.12	9.66	7.52	7.98	6.29	7.98	22.85
V2O3	107.69	43.99	48.99	28.25	20.60	10.15	79.00	249.80
BaO	822.19	938.75	986.65	855.80	1048.17	1046.83	630.26	337.41
Rb2O	131.12	205.16	204.50	203.96	237.42	225.06	42.76	52.27
SrO	271.64	119.68	121.93	79.94	70.72	61.50	224.22	136.24
ZrO2	486.56	524.11	510.20	591.11	576.25	597.46	362.82	262.46
Y2O3	35.69	67.56	74.80	67.82	69.21	71.24	20.07	25.91
Nb2O5	29.47	53.93	50.36	58.94	55.51	58.37	29.90	21.17
Ga2O3	24.87	25.94	24.73	23.39	25.54	23.12	14.65	25.27
CuO	22.53	13.02	11.64	4.38	5.88	3.25	29.04	35.05
ZnO	119.36	75.52	74.65	60.12	60.87	60.62	23.30	99.82
PbO	17.56	28.76	29.84	32.21	31.13	32.10	18.64	16.48
La2O3	50.43	84.32	88.19	86.67	89.83	89.48	30.14	30.73
CeO2	91.58	173.82	184.51	183.90	183.28	179.10	55.69	59.25
ThO2	13.35	32.11	32.22	36.96	35.20	36.30	8.72	9.93
Nd2O3	38.61	63.80	69.87	63.68	66.60	64.38	18.66	25.89
U2O3	3.96	7.16	7.93	7.60	9.36	8.70	0.99	1.98
Cs2O	3.82	8.06	5.51	3.92	3.39	2.33	1.59	5.73
As2O5	0.00	0.00	0.00	0.00	3.22	3.07	3.37	0.00
W2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum tr.	2383.33	2494.23	2553.78	2403.10	2610.62	2587.15	1637.47	1518.95
in %	0.24	0.25	0.26	0.24	0.26	0.26	0.16	0.15