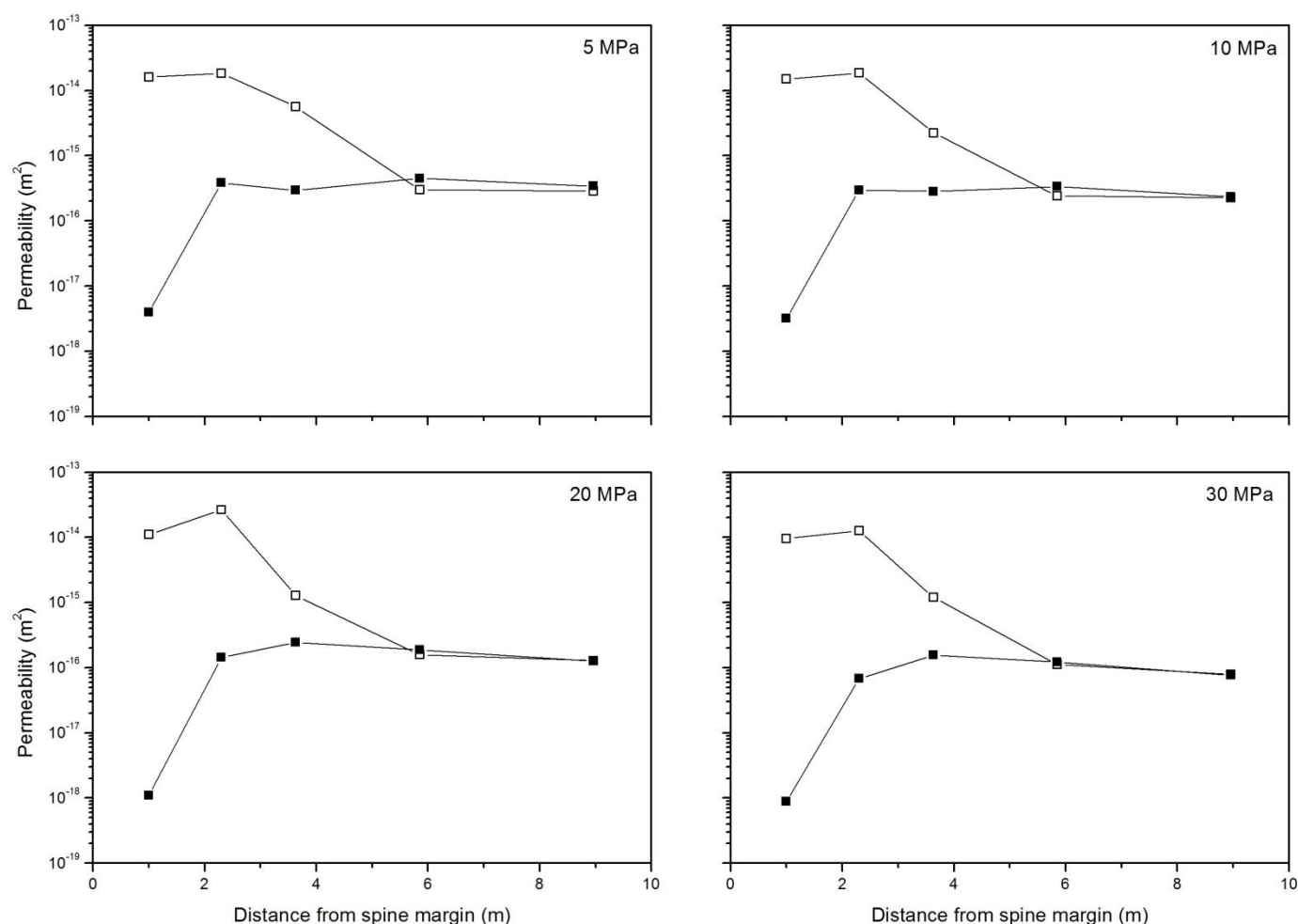


## Supplementary Information 1



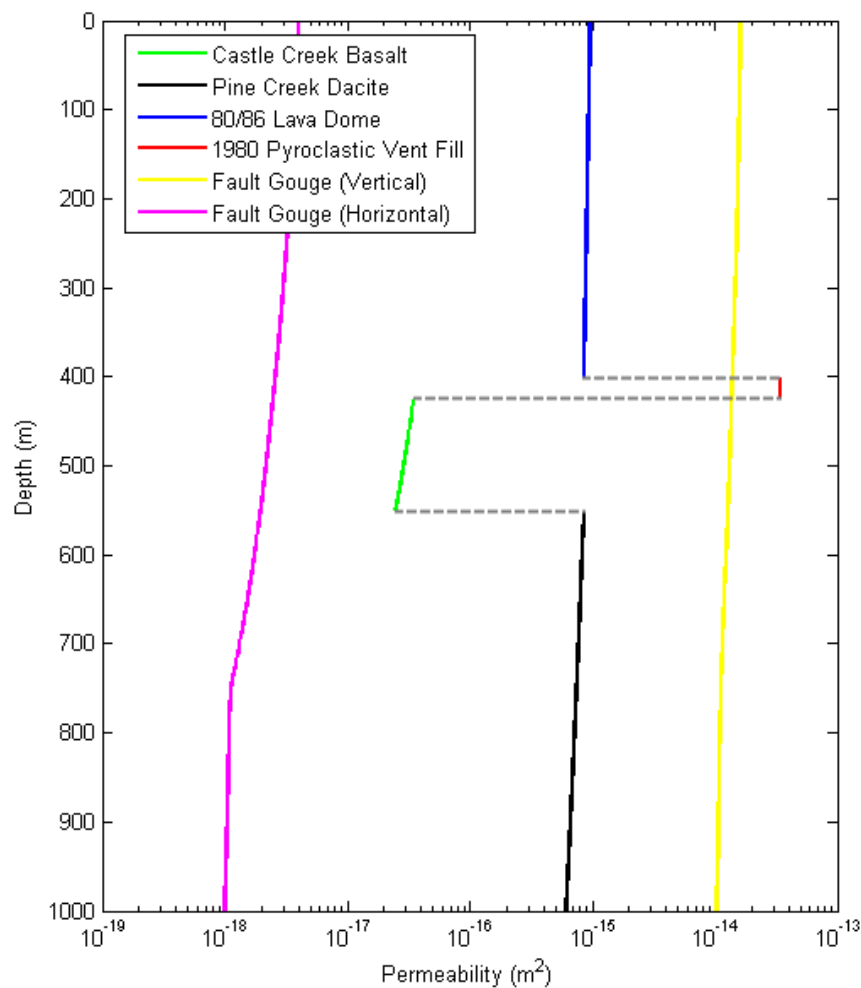
### Further permeability measurements at elevated effective pressures.

Measurements of permeability for the different lithofacies of Spine 4 plotted against distance from the spine margin at four different confining pressures from 5 to 30 MPa, which is equivalent to approximately 250 m to 1 km depth. Permeability measurements were made on samples oriented both parallel (sub-vertical, open symbols) and perpendicular (sub-horizontal, filled symbols) to the conduit wall. Note that the 5 MPa data is the same as that shown in fig. 2. Although permeability decreases slightly with increasing confining pressure (depth) the overall trends and degree of anisotropy remain very similar.

The response of the different rocks to increasing confining pressure can be explained by the different responses of micro- and macro-fractures to changes in confining pressure. Micro-fractures have higher aspect ratios than macro-fractures and are therefore concomitantly harder to close; they are therefore much less pressure sensitive than larger macro-fractures with lower aspect ratios (Nara et al., 2010). This explains the relatively small decreases observed in the permeability of the massive dacite with sparse, high aspect ratio micro-cracks, and the significantly larger decreases observed in the sheared dacite which contains macro-fractures. Similarly, the permeabilities of the samples of cataclastic breccia and fault gouge are also relatively insensitive to increases in confining pressure.

However, in this latter case this is because there are so many pathways available for fluid flow, the application of confining pressure and the closure of some of these pathways therefore has very little effect on the permeability. Similar observations were reported by Benson et al. (2006) for porous sandstones with multiple fluid flow pathways.

## Supplementary Information 2



### Wall rock and fault gouge permeability measurements as a function of depth.

Magma rising in the conduit at Mount St. Helens (MSH) intersects four different types of wall rock at different depths. At around 1 km depth, where the magma is thought to have solidified, shattered dacites of the Pine Creek lava domes form the conduit walls for around 450m (Pallister et al., 2013). A series of basalt lava flows (Castle Creek basalt) lie on top of the Pine Creek dacite and extend for around a further 125m. On top of the Castle Creek basalts are pyroclastic products from the 1980 cataclysmic eruption and dacite lava domes that grew thereafter. All but the 1980 pyroclastic vent fill unit have a lower permeability than the sub-vertical fault gouge and a higher permeability than the sub-horizontal fault gouge. By contrast, the 1980 pyroclastic vent fill has a higher permeability than the sub-vertical fault gouge.

The permeability of the wall rocks at MSH, especially the 1980 pyroclastic and lava dome units in the shallow conduit would be sufficient to allow degassing on eruptive timescales. However, the low horizontal permeability of the fault gouge, due to the presence of vertical ultracataclasite bands, will most likely result in channelled vertical flow in the fault gouge. As a result, the permeability of the conduit walls is potentially of little consequence during eruptions for which strong cataclastic margins develop.

## Supplementary Information 3

### Gas flux calculations

Estimated volumes of water vapour lost from the dacite as it was extruded can be used to evaluate the measured values of permeability from the laboratory. These estimates can be used to calculate the theoretical permeability required to lose the estimated volumes of water vapour over the eruption time scale. This provides us with a good idea of whether our measured permeabilities are sufficient to facilitate the gas escape during the eruption.

Water vapour volume estimation:

The single glassy sample dredged (from spine 3) had about 2.3 wt% water in its matrix glass. In contrast, the residual matrix glass in the largely crystalline samples of spine dacite have only about 0.1 wt. % H<sub>2</sub>O (Pallister et al., 2008 USGS Professional Paper 1750). So, estimates of water loss would call for ~2 wt. % in ascent from a depths between 1.5 to 2 km to the surface (Pallister et al., 2008 USGS Professional Paper 1750 p. 675).

For a 120m-diameter (60 m radius) conduit rising at a linear rate of 6 m/day (Major et al., 2008, USGS Professional Paper 1750), the volume of dacite extruded per day (v) is given by:  $v = h \times \pi \times r^2 = 6 \times 3.14 \times 60^2 \text{ m}^3 = 67,824 \text{ m}^3$  (which we have rounded to 68,000 m<sup>3</sup>).

Then, using a dacite density of ~ 2600 kg/m<sup>3</sup>, this yields a value of 176,800,000 kg per day of extruded dacite (which we have rounded to 175 x 10<sup>6</sup> kg/day). For a loss of 2 wt. % water, that results in a total water loss of 2% x 175 million kg = 3.5 million kg H<sub>2</sub>O/day.

We then consider the expansion of the water phase, starting with a water phase at ~850 °C (Fe-Ti oxide temperature of glassy sample SH-305). Then, dividing the 3.5 million kg H<sub>2</sub>O/day by the density of H<sub>2</sub>O at different pressures (obtained from steam tables), we obtain an estimate of the potential flux of water vapour through the rocks (see table below).

Finally, we can then solve Darcy's law ( $K = (\eta \times \Delta X \times Q) / (A \times \Delta P)$ ) using estimates for the water vapour flux from the table below, the known area of the damage zone ( $A = 2100 \text{ m}^2$ ), a hydrostatic pressure gradient of 10 kPa/m and the viscosity of steam at 850°C (approx.  $\eta = 4.0 \times 10^{-5} \text{ Pa.s}$ ) to provide an estimate of permeability required to facilitate the gas flux. The results of these calculations are also shown in the table below.

Pressure (MPa)	H <sub>2</sub> O Density (kg/m <sup>3</sup> )	Flux (m <sup>3</sup> /s)	Permeability (m <sup>2</sup> )
15	28.1	1.4	1.80E-15
10	18.6	2.1	1.80E-15
5	9.2	4	1.50E-15
1	1.8	20	1.50E-15

It can be seen that the permeability values obtained from these calculations are around an order of magnitude lower than the vertical permeability of the fault core and damage zone rocks. They are also between one and three orders of magnitude higher than the horizontal permeability values of the damage zone rocks. This suggests that the vertical permeability of the marginal shear zone rocks is easily high enough to facilitate the estimated gas fluxes, even at pressures as low as 1MPa. The estimates also show that the horizontal permeability is far too low to facilitate this volume of gas escape over the timescale of the eruption.