On the calculation of the geometry of the diatreme pipe from a deposits of an "accidental lithic clast rich" maar, Tihany East Maar, (Hungary)

Terra Nostra (Potsdam, Germany) 2000/6, p.383-391

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Abstract

Tihany East Maar is a remnant of an unusual maar volcanic complex, and part of the Late Miocene alkaline basaltic Bakony- Balaton Highland Volcanic Field (BBHVF), in western Hungary. The deposits of the maar volcanic complex are generally extremely rich in accidental lithic clasts ("accidental lithic rich maar"). Lithic clast population of the individual stratigraphic units increases in deeper origin clasts in beds in up-section. Measuring and calculating the total volume of individual accidental lithic clasts derived from the same pre-volcanic strata allowed to calculate the simplified geometry of the conduit and its changes during eruption. A visual estimate in both microscopic and macroscopic scale neglecting large blocks or small ash in a total amount of the certain clast population has been used for the calculation. An error of 5-10 % in the calculation process has been accepted because also the possible distribution and the thickness of the ejecta blanket are assumed to extent in the same range. Beds in 5 stratigraphic levels have been measured, and used for the calculation of the vent widening in the different pre-volcanic strata through time. A cylinder conduit model was assumed to simplify the calculation. For the ejecta blanket a uniform layer of tephra is used in half thickness of their measured (near vent) thickness. According to the total of 35 m thickness of the measured sequence, **0.0333 km^3** tephrite magma was calculated to be involved in the phreatomagmatic explosions that generated these beds. In general, the shape of the vent was formed relatively early in the eruption with a wide upper part and a slowly widening deeper part. The minimum depth of the explosions and excavation zones may have reach around **987 m** using a uniform cylinder shaped conduit. A more realistic model using a cone shaped lower zone of the conduit resulted in a **1460 m** deep diatreme pipe.

Introduction/geological setting

The Tihany Maar Volcanic Complex (TMVC) is a combination of remnants of at least 3 maar craters and a scoria cone (Németh et al. 2000). TMVC belongs to the Late Miocene alkaline basaltic Bakony- Balaton Highland Volcanic Field (BBHVF) and its activity preceding the formations of other volcanoes in the BBHVF (Harangi et al. 1995). The East Maar of TMVC exhibit an extremely accidental lithic rich tuff breccia, lapilli tuff and tuff sequence in an average 35 m thick continuous unit (Fig. 1). The pyroclastic sequence of East Maar has been divided into three major lithofacies associations of different combination of beds of predominantly low to high concentration pyroclastic density currents (wet surges), co-surge fall out and syn-eruptive debris flows (Németh et al. 2000). In general, the initial pyroclastic deposits exhibit abundance in accidental lithic clasts with shallow seated origin. In contrast the middle part of the sequence is richer in deep seated origin accidental lithic clast. The top sequence is enriched in shallow seated origin accidental lithic clasts. The pre-volcanic stratigraphy consists of a deepest known unit, Silurian schist (SS) basement, covered by a ~700 m thick Permian Red Sandstone (PRS) beds, ~ 50 m thick Mesozoic carbonate (MF) beds, and ~ 200 m thick Neogene sandstones, sands and gravels (Pannonian Sandstone Formation) (Láng et al. 1970). For the calculations these thickness data have been used.

Calculation of the total ejecta volume

An approximately 1 km wide vent zone, filled with unsorted, accidental lithic rich tuff breccias and lapilli tuffs (lower diatreme) has been reconstructed at East Maar of TMVC (Németh et al. 2000). The inferred crater rim deposit can be traced along a few hundred metres distance from the marginal zone of the vent zone and assumed to extend not more then 1 km away from the former crater wall. This estimation is conform to geometrical parameters of recent maar craters (Lorenz 1986). For an easier calculation of the ejecta volume the ejecta blanket is taken as to be uniform around the maar. This assumption may be not perfect because the East Maar was very likely open to the south (Németh et al. 2000). However, the vent width was calculated with the ejecta volume data based on a uniform distribution, because the ratio between vent width is not effected by the total ejecta blanket volume. The possible error with this initial condition only effects the calculated of the total magma volume that has been involved forming the East Maar, thus that data will rather appear as maximum value. Total ejecta volume has been calculated according to the following formula:

(1) $V = (1500^2 - 500^2)\,\pi h/2 = \pi h\, 10^6$ [m^3]

with h as the thickness (in metre) of the certain, measured pyroclastic unit; π is approximately 3.14.

The modal composition was measured in 5 different levels of the pyroclastic sequence (Fig. 1) for fragments of juvenile, Silurian Schist (SS), Permian Red Sandstone (PRS), Mezozoic Formations (MF) and Neogene Sediment (NS) clasts. The calculated volume of the tephra blanket for each measured unit has been divided by the measured modal composition. The calculated total volume of disrupted individual accidental lithic fraction has been used for the calculation of the vent width, which is necessary for the calculated amount of the certain lithology. For the calculation of the vent width a fixed thickness value of pre-volcanic strata has been used (700 m for PRS, 50 m for MF, 200 m for NS). The calculation is based on a cylinder model to simplify the calculations. The vent radius (r) has been calculated as follows:

(2) $r = (V/\pi H)^{1/2}$ [m]

with V as the calculated volume (in cubic metre) of the certain lithology through which the conduit cut through; H is the “fixed” thickness (in metre) of the certain lithology.

From these calculated data of ejected volume of the deepest known lithology (SS) a possible depth of the explosion locus has been calculated. Since the value of thickness of that lithology is unknown it is not possible to calculate vent wideness. We therefore infer that the vent uniformly cut into the deepest lithology following the same wideness which was calculated for the overlying PRS strata. A rough estimation of the conduit depth using a uniform cylinder shape of the conduit and the assumption that that value plus the total thickness of pre-volcanic strata led to the result that these together represent a minimum depth of the explosion locus. The applied formula was the following:

(3) $H = V/ \pi r^2$

with H as the thickness of the excavated SS strata; r is the previously calculated vent wideness developed in the overlying PRS strata; π is approximately 3.14.

For a more realistic calculated value of the maximum depth of the pipe a cone model was used. The previously calculated data have been multiplied by 3, because the same amount of material excavated in a cylinder requires a 3 times higher cone if their base surface area is the same.

Vent development

The calculated values of vent wideness and a model is presented in Fig. 2. In the early stage (1) the eruption products of the East Maar were predominantly rich in shallow seated accidental lithics, a wide topside of the conduit is inferred to have been developed. The calculated excavated total volume of these pre-volcanic strata indicates a conduit radius of at least 130 m width at this stage (Fig. 2). The sudden increase of deeper seated accidental lithic clast in the overlying pyroclastic units indicates a progressive widening of the conduit in each deep, pre-volcanic strata (Fig. 2). It is noteworthy that the conduit width in the shallow (probably during eruptions) unconsolidated sand beds did not changed dramatically between the initial (1) and the final (4) period of the eruption (from ~130 m to ~175 m conduit radius). The conduit in the MF strata reached almost the value of the maximum conduit width in the NS unit (~202 m radius in NS, and ~165m in MF). It implies that it is very likely that the MF unit has been completely excavated. The resulting maar basin very likely exhibited the PRS and MF unit with its crater wall. It is therefore inferred that the maar basin of the East Maar may has reached 300 m depth, which is ideal for the formation of a maar lake and a subsequent lacustrine depositional environment . Since the MF unit functioned as the major karst water storage, it is very likely that the water from the disrupted karst water system “poured” into, and filled the deep maar relatively fast. The maximum depth of the disturbed (and partially disrupted) zone has been calculated to be in the range of 1000 to 1500 m. Accidental lithic clasts from other deeper (or even unknown regions) lithological units are lacking (or present in less than 1 vol%) in the pyroclastic beds. A maximum depth of 1500 m for the volcanic pipe is indicates that SS beds should occur even in that depth.

Conclusion

The calculation demonstrated above shows that a relatively good vent dynamic model can be introduced, even with a relatively few data set. Fortunately, the assumption of the total volume of the ejected tephra does not affect the ratio between conduit width in the different pre-volcanic lithologies. Its value affects only the absolute value of the calculated vent radius in different lithologies, and the absolute value of the magma involved in the eruption. Even though, it is very likely, that the presented absolute values will not change dramatically because even with an asymmetric distribution of the tephra rim just the shape of the blanketed are change their volume can be very close to the half thickness uniformly blanketed area (in other word, does not matter if we calculate a thick half rim, or a uniformly thin blanket as we make our assumption in this note).

The total volume of ejecta, calculated from the 35 m sequence, is ~110X10^6 m^3 which is in agreement of other calculations by e.g (Mertes 1983). After Mertes (1983), maar with a crater rim diameter of 1000 m would give 75 - 100X10^6 m^3 volume of total ejecta, which is in the same order then the calculation resulted from this note

The calculated volume of magma that has been involved in phreatomagmatic explosions generated “accidental lithic rich” maar (0.033 km^3) can be used to calculate the total magma involvement in volcanic processes in the BBHVF. At least 21 “accidental lithic rich maar” can be identified on the BBHVF with a possible similar geometry than East Maar of TMVC. A total of ~ **0.693 km^3** magma was involed in the process that led to the formation of “accidental lithic rich maars” in the BBHVF.

Another approximately 10 maars can be classified as maars/tuff rings mostly related to shallow subsurface explosions and probably greater involvement of magma to their eruption (“juvenile rich maars”). With a ratio of approximately 50 vol% juvenile fragment in the pyroclastic blanket of those maars and with a similar bed thickness was calculated in the case of “accidental lithic rich maars” (35 m) the previously calculated 0.033 km^3 magma volume should approximately be duplicated to get the total volume of magma involved in forming one single “juvenile rich maar”. Thus a total of **0.66 km^3** magma can be assumed to be involved in the eruptions of “juvenile rich maars”.

A total of **1.353 km^3** (0.693 km^3 + 0.66 km^3) magma involvement can be assumed to form all the maar volcanoes on the BBHVF.

About 20 eruptive centres of the BBHVF have late magmatic infill (lava lake), that fill about 1000 m wide craters with an average thickness of 10 m. The total of magma stored in this way was not more than **0.2 km^3**.

Two large shield volcanic system which together cover an area of approximately 70 km^2 of 10 m thickness. These two shield volcano accommodate probably not more than **1 km^3** lava rock.

The most unsure data in this assumption is the calculation of the total amount of magma involved of forming scoria cones. An average (not too big) scoria cone has a size of ~500 m base diameter and 50 m highs and they predominantly build up by scoria (in simple assumption 100% of their volume are juvenile fragments). With these parameters a total volume of a single scoria cone is ~ 0.003 km^3. Unfortunately we have no good information of the total number of the scoria cones in the BBHVF, but in indirect way demonstrated that scoriaceous debris often deposited to maar lakes, thus they must have been common landforms in the BBHVF (Németh and Martin 1999;Németh 2000). With the assumption of minimum number based on that almost each eruptive complex (with maars and roots of scoria cones) developed at least one scoria cone with the previously described size, a total of around 50 scoria cone can be reconstructed for the BBHVF. With this number a total of **0.15 km^3** magma involvement can be assumed to produce the scoria cones in the BBHVF. The other problem with the estimation of size of scoria cones. With a 1000 m basal diameter and 100 m highs a single scoria cone can accommodate 0.0785 km^3 juvenile fragments which can be end up **3.925 km^3** in 50 scoria cone. This variation is the greatest in the entire estimation, but it is probably a good estimate that the real value is between these two extreme parameter and a possible contribution to the calculation of total volume of juvenile material derived from scoria cones could have been not more than 1 km^3. In total, at least 2.703 km^3 magma have been involved forming volcanic landforms in the BBHVF between 7.54 and 2.8 Ma (Table 1). In the maximum estimate assuming large scoria cones in an extended scoria cone field can increase the total volume of magma involvement up to 6.478 km^3. Very likely the **2.703 km^3** value is a lower estimate and the **6.478 km^3** well above the real value. We suggest that the real value of total volume of magma involvement forming the BBHVF is around **4 +/- 0.5 km^3**.

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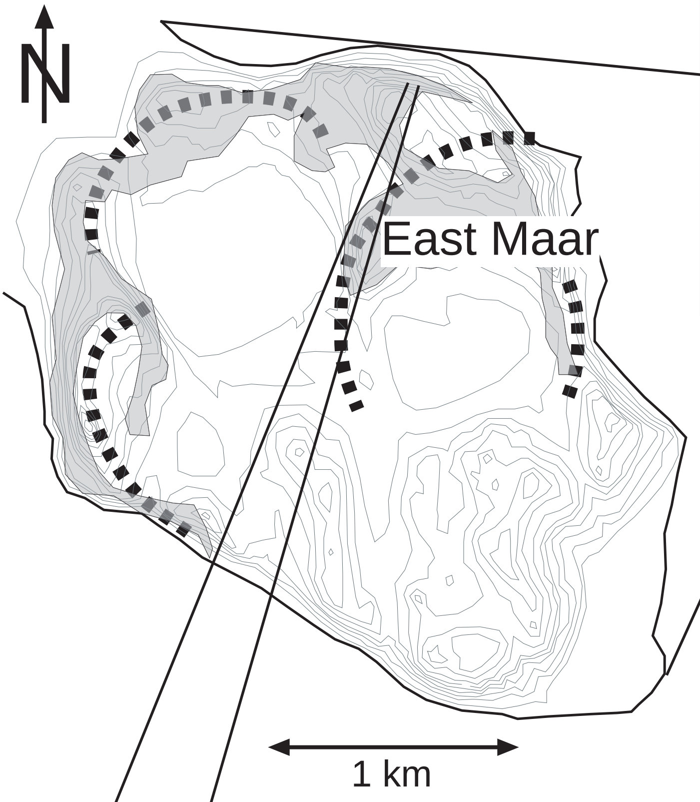
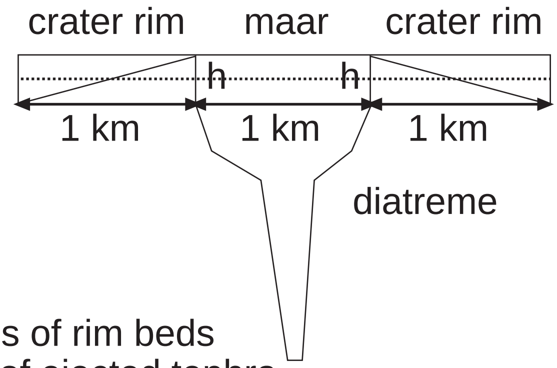
Figure 1 Location of study area and the calculation of total volume of individual ejected accidental lithic clasts and juvenile fragments

Figure 2 Development of the volcanic conduit of the Tihany East Maar, TMVC

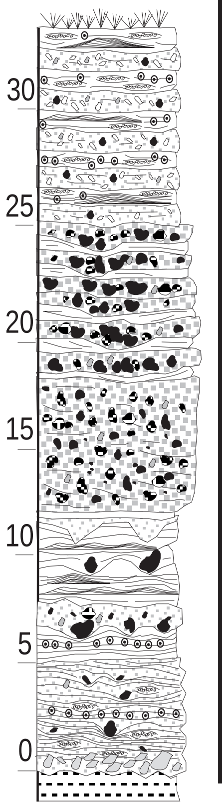
Table 1 Calculation of total magma volume have been involved forming volcanoes of the BBHVF. The total amount is most likely 4 +/- 0.5 km^3.

Tihany Maar Volcanic Complex

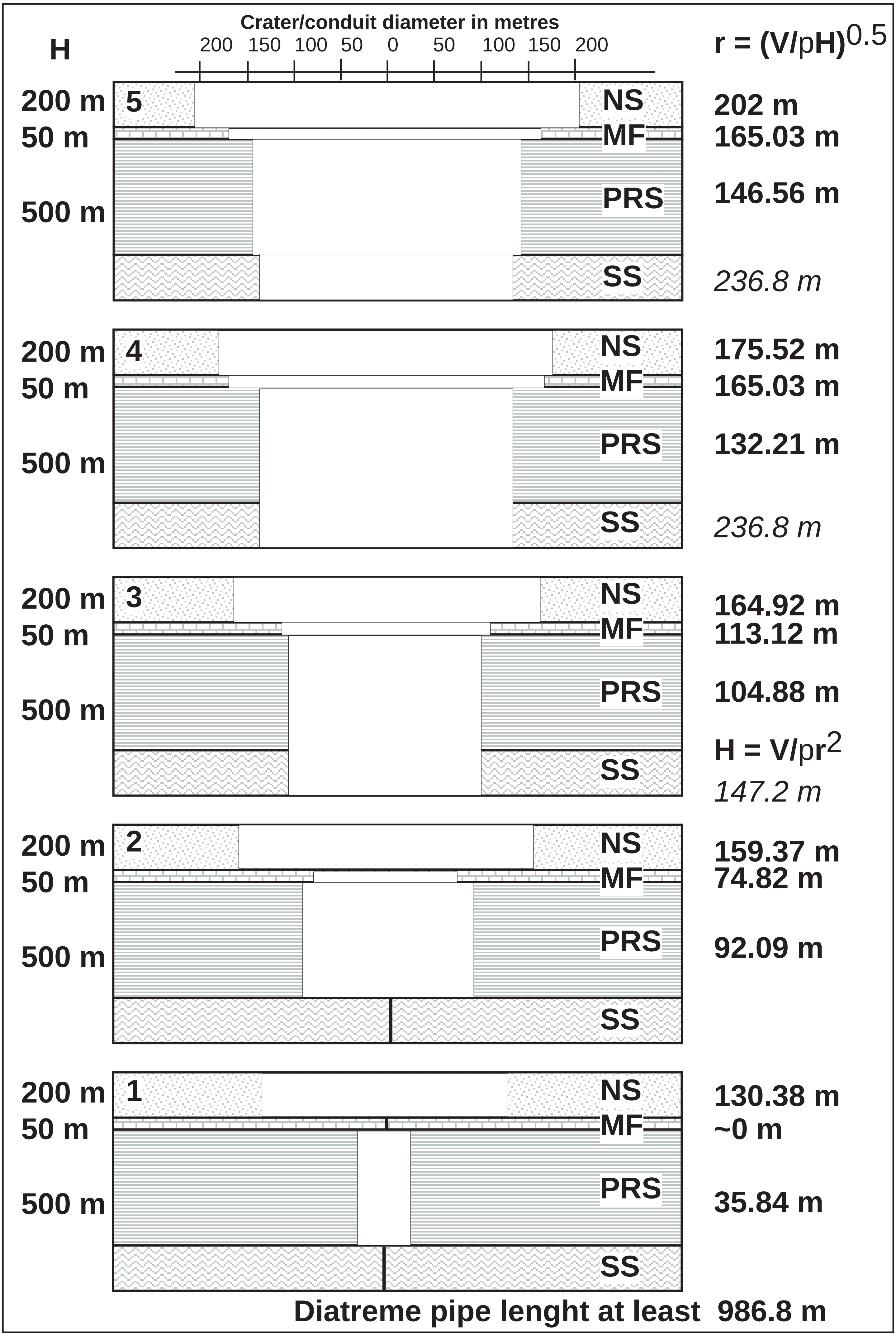




h - thickness of rim beds
V - volume of ejected tephra
$V = p\ 1500^2\ h/2 - p\ 500^2\ h/2 = p\ h\ 10^6\ [m^3]$



h	Total volume of tephra	Total volume of juvenile	Total volume of SS	Total volume of PRS	Total volume of MF	Total volume of NS
8 m	25.12	50% 12.56	0% 0	25% 6.28	0% 0	25% 6.28
9 m	28.26	20% 5.652	28% 7.913	36% 10.174	8% 2.267	8% 2.267
6 m	18.84	40% 7.536	27% 5.087	21% 3.956	6% 1.13	6% 1.13
7 m	21.98	20% 4.396	0% 0	52% 11.43	4% 0.879	24% 5.275
5 m	15.70	20% 3.14	0% 0	12% 1.884	0% 0	68% 10.676
total volume of ejecta:		33.284	13	33.724	4.276	25.628


Crater/conduit diameter in metres
200 150 100 50 0 50 100 150 200
H
r = (V/pH)^0.5
5
200 m
50 m
500 m
NS
MF
PRS
SS
202 m
165.03 m
146.56 m
236.8 m
4
200 m
50 m
500 m
NS
MF
PRS
SS
175.52 m
165.03 m
132.21 m
236.8 m
3
200 m
50 m
500 m
NS
MF
PRS
SS
164.92 m
113.12 m
104.88 m
H = V/pr^2
147.2 m
2
200 m
50 m
500 m
NS
MF
PRS
SS
159.37 m
74.82 m
92.09 m
1
200 m
50 m
500 m
NS
MF
PRS
SS
130.38 m
~0 m
35.84 m
Diatreme pipe lenght at least 986.8 m

Type of eruptive centers	Common composition of this type of volcanoes	Volume of magma involved producing 1 volcano	Total number of this type of volcano	Total volume of magma involved to form this type of volcanoes
Accidental lithic rich maars (1 km wide maar, 35 m thick deposit)	tephrite/phono- tephrite (volcanic glass analyses by electrone microprobe)	~0.033 km^3	~21	~0.693 km^3
Juvenile rich maars (1 km wide maar, 35 m thick deposit)	tephrite/phono- tephrite, hawaiite (trachy basalt) (volcanic glass analyses by electrone microprobe)	~0.066 km^3	~10	~0.66 km^3
Lava lakes, plugs (1000m wide, 10m thick)	basanite, hawaiite (lava rock analyses by XRF)	(0.00785 km^3) ~0.01 km^3	~20	~0.2 km^3
Scoria cones (500m base diameter, 50m highs)	basanite, hawaiite (lava rock analyses by XRF)	~0.003 km^3	~50	~0.15 km^3
(1000 m base diameter, 100m highs)		~0.0785 km^3		~3.925 km^3
Shield volcanoes (covered 70 km2 are in 10 m thickness)	basanite, hawaiite (lava rock analyses by XRF)		~2	~1 km^3

Total volume of magma involved forming the BBHVF volcanoes ~2.703 - 6.478 km^3