Formation of Basaltic Tephra-Fall Deposits at Either Agglutinated or Fragmented Scoria Cones

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OBJECTIVE

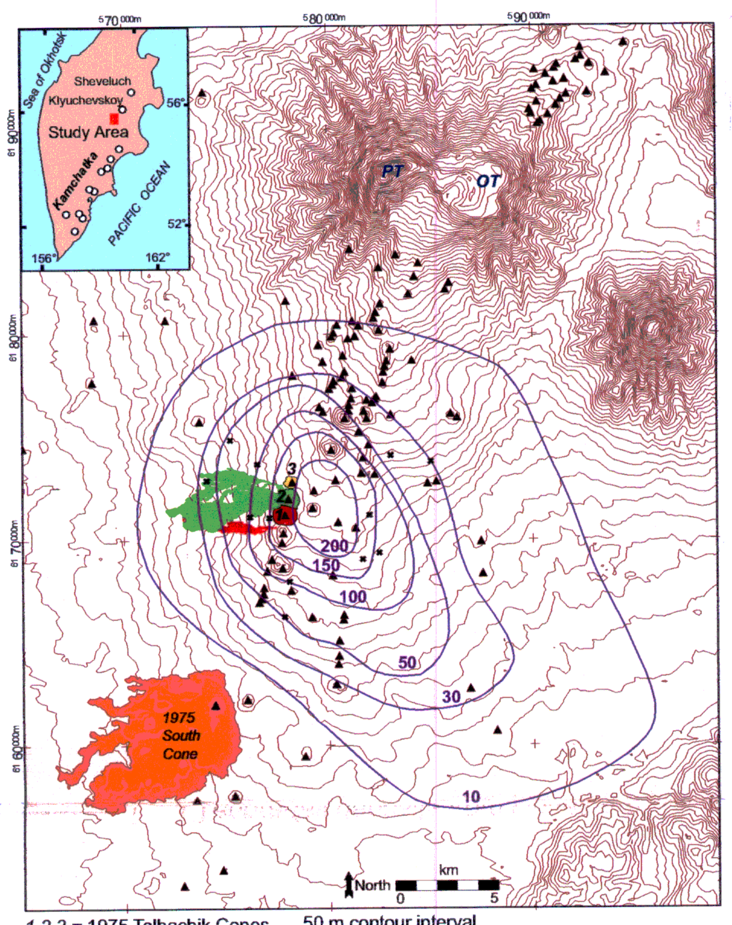
Some basaltic scoria-cone eruptions produce tephra-fall deposits that can create potential hazards. Risk assessments need to account for the likelihoods of potentially hazardous tephra falls. In the absence of preserved tephra-fall deposits, characteristics of eroded scoria cones often are used to interpret past eruption processes.

Observations from the 1975 Tolbachik eruption are used to evaluate the relationships between scoria-cone characteristics and the formation of extensive tephra-fall deposits.

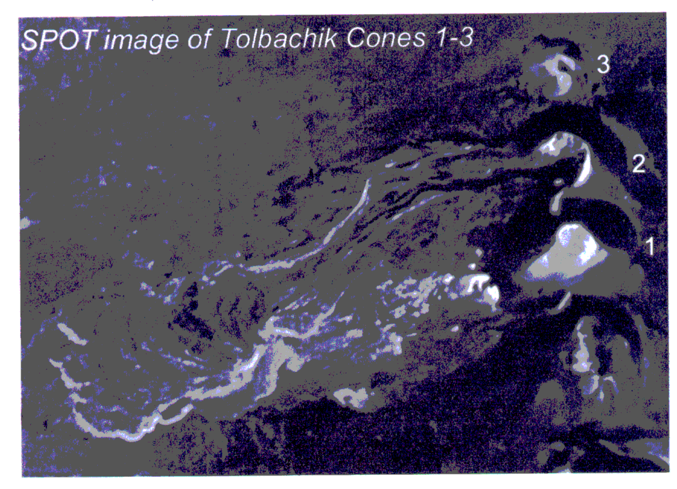
Early-formed Cone1 consists of nonagglutinated scoria with small volumes of lava effused from basal boccas. In contrast, later-formed Cone2 consists of agglutinated scoria and large volumes of lava effused from the central crater.

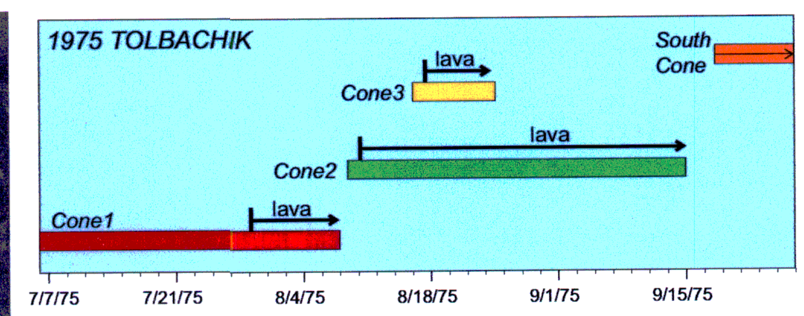
Both cones, however, produced sustained tephra plumes 2-12 km high that created extensive, nearly indistinguishable tephra-fall deposits.

This work evaluates the processes that may have led to the formation of such different cone deposits while simultaneously producing such similar fall deposits.



1,2,3 = 1975 Tolbachik Cones
PT = Plosky Tolbachik
OT = Ostry Tolbachik
50 m contour interval
▲ Basaltic vents
Fall isopachs in cm, from Budnikov et al. (1983)





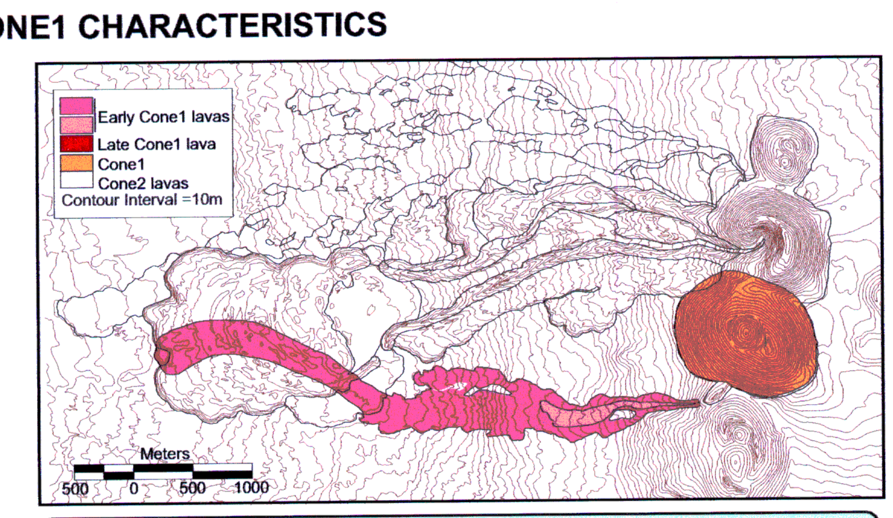
Timing of 1975 Tolbachik eruption. Note late effusion of lava at Cone1 relative to nearly continuous lava at Cones2&3. South Cone is high-aluminum basalt phase of eruption with different characteristics from high-magnesian Cones1-3.

ERUPTION SUMMARY

- The 1975 Tolbachik Northern eruption produced 2 primary cones (Cone1 and Cone2) and a small secondary cone (Cone3) on 6 July-15 September 1975.
- Sustained tephra columns 2–12 km high, produced 0.19 km³ dense rock equivalent (DRE) fall deposits, with total eruption volume of 0.6 km³ DRE.
- Violent Strombolian eruption characteristics:
  - Dispersivity >300 km² (Strombolian <10 km²)
  - Fragmentation >47% (Strombolian <10%)
- Cones and lavas are same high-MgO basalt (51% SiO_2, ~10% phenocrysts) until last days of eruption.
- Magmatic water contents of 2.2±0.4 wt% from several glass inclusion analyses.

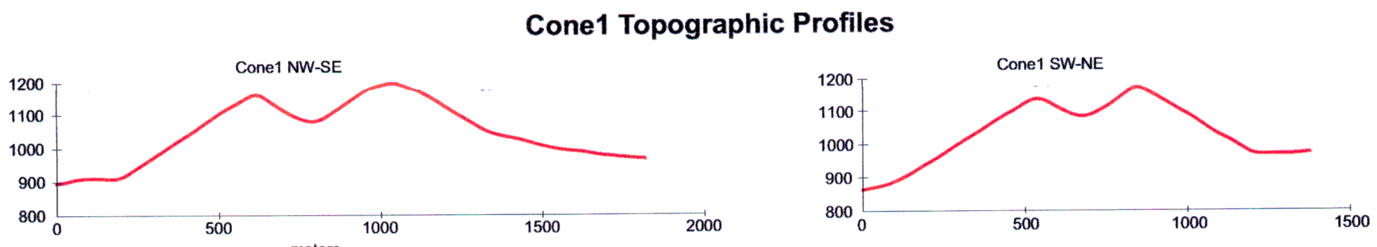
CONE1 CHARACTERISTICS

Cone1 around 10 July 1975. Sustained column around 8 km high, viewed from NW.

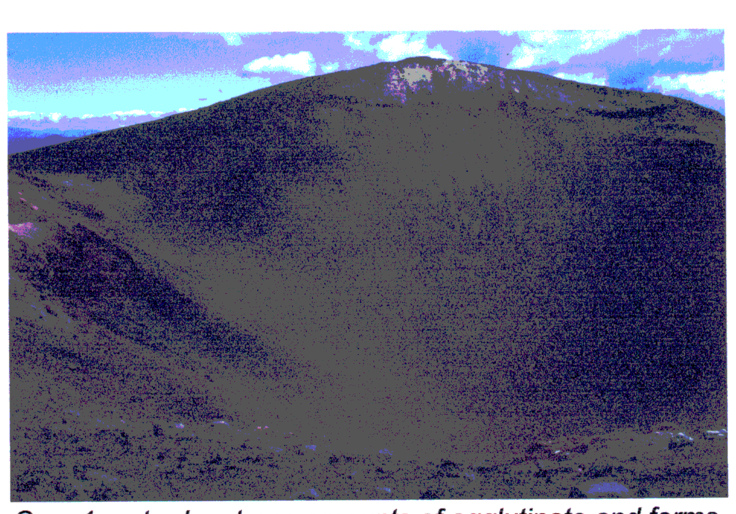


Cone1 produced:
- 0.02 km³ lavas (DRE) at 22 m³/s, from 2 basal boccas.
- 0.084 km³ scoria cone (DRE) at 29 m³/s.
- 0.11 km³ of tephra falls (DRE) at 36 m³/s, from central vent.
- Average column heights of 4.2 km for 34 day eruption.

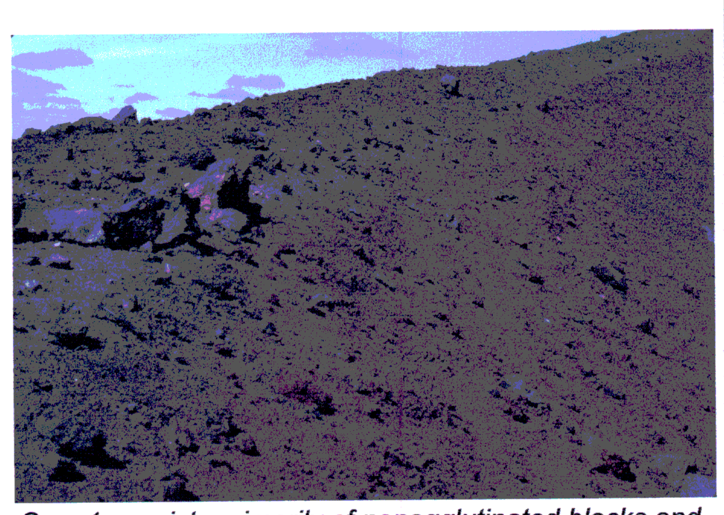
Cone1 Topographic Profiles



Cone1 has slopes of ≤ 33° for outer flanks and inner crater slopes, reflecting angle of repose for nonconsolidated blocky scoria.

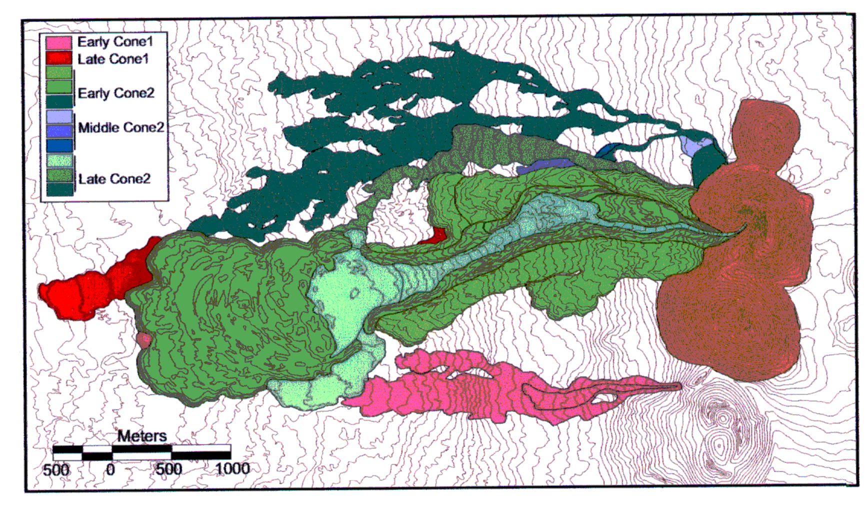


Cone1 crater has trace amounts of agglutinate and forms typical angle-of-repose slopes for nonconsolidated scoria.



Cone1 consists primarily of nonagglutinated blocks and scoria, with occasional bombs.

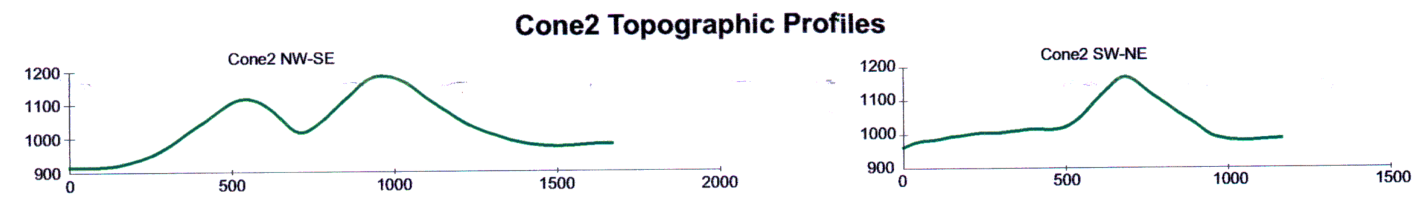
CONE2 CHARACTERISTICS



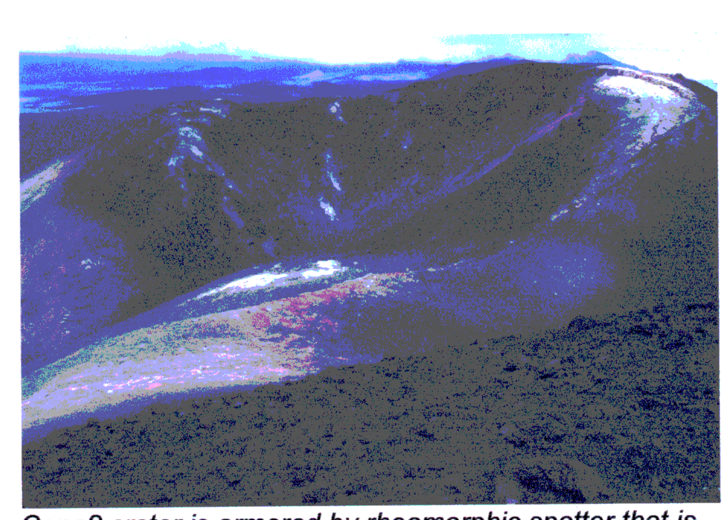
Cone2 produced:
- 0.22 km³ lavas (DRE) at 70 m³/s, from central vent & late boccas.
- 0.077 km³ scoria cone (DRE) at 24 m³/s.
- 0.09 km³ of tephra falls (DRE) at 27 m³/s, from central vent.
- Average column heights of 3.9 km for 37 day eruption.

Tephra plume from Cone2 on ~8/15/75 as lavas effuse from breached central crater. Photo from Gippenreiter (1979).

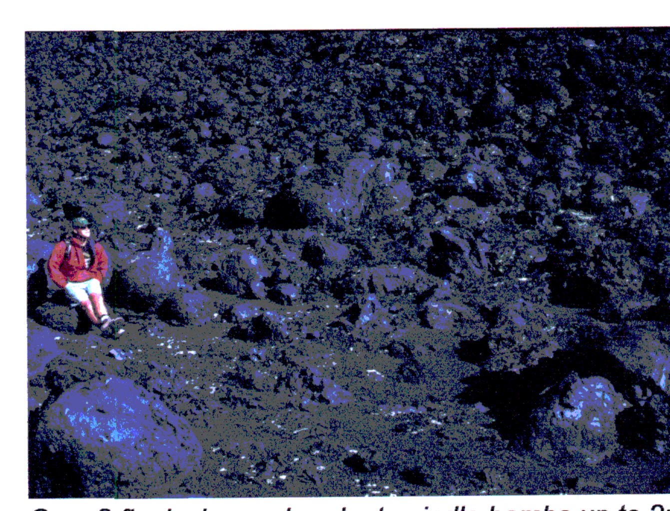
Cone2 Topographic Profiles



Cone2 has slopes up to 35-38° for outer flanks, with inner crater slopes up to 39-44°. Slope angles >33° are characteristic of agglutinated scoria cones. "Breached" cone morphology due to continuous effusion of lava from central vent during cone growth, not from flank collapse.

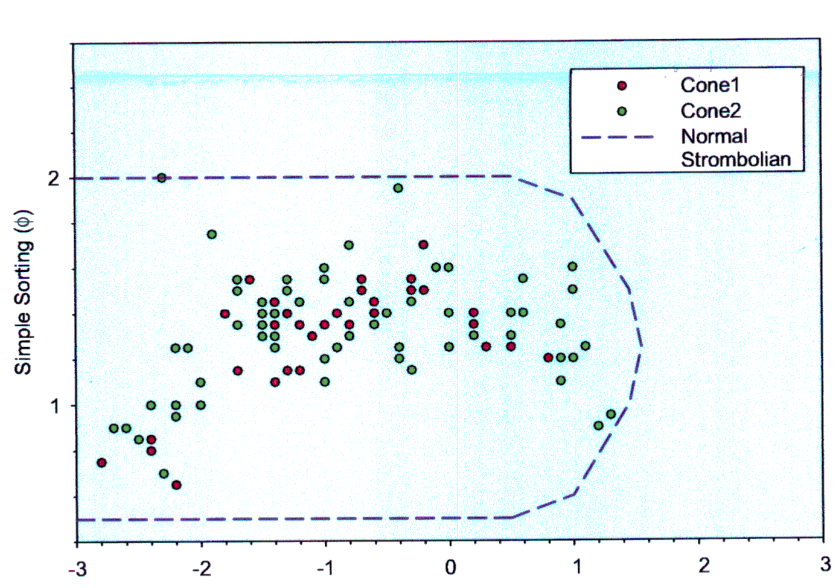


Cone2 crater is armored by rheomorphic spatter that is interbedded with beds of agglutinated scoria. Occasional tephra beds have angular, nonagglutinated scoria and blocks.



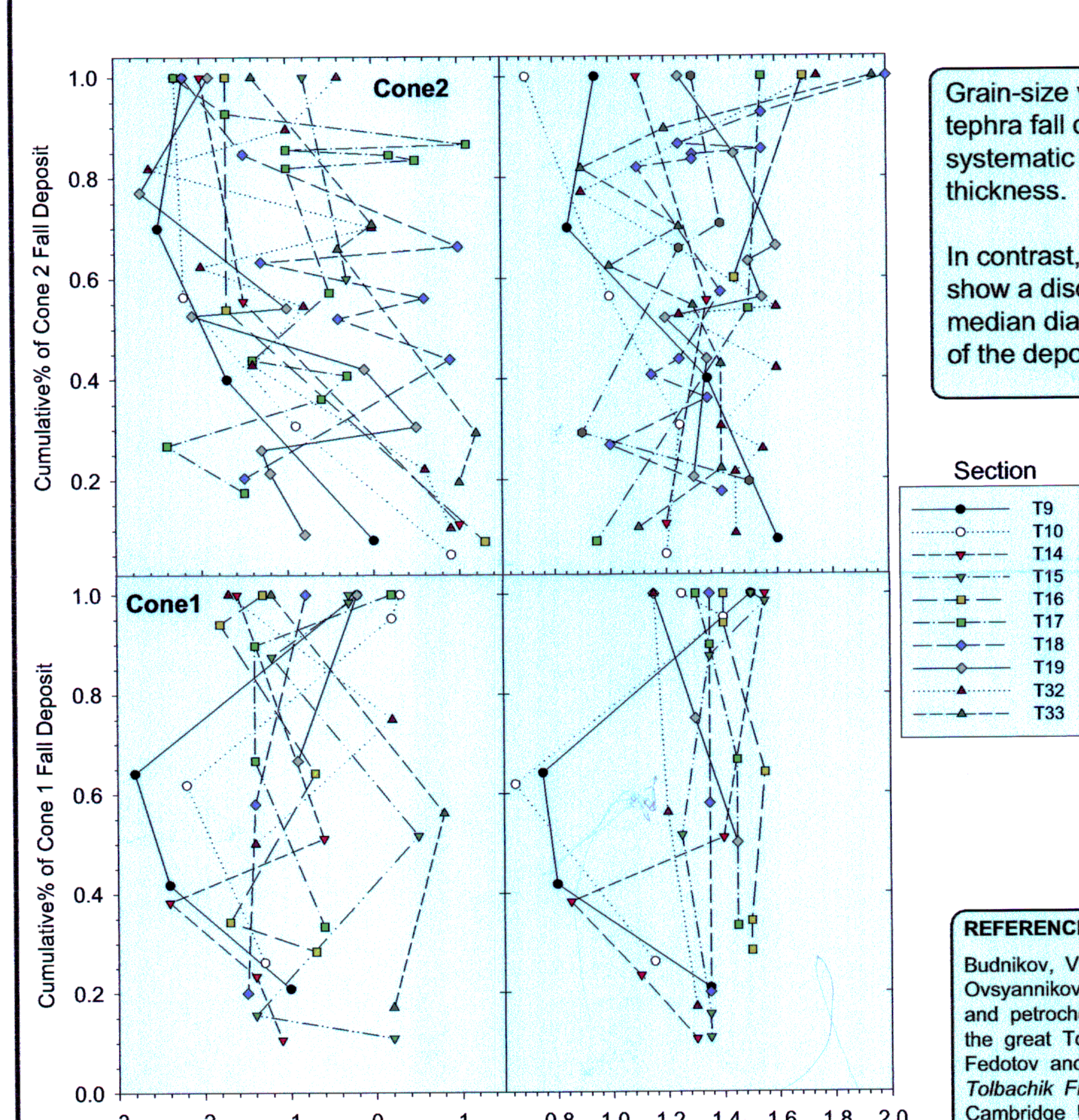
Cone2 flanks have abundant spindle bombs up to 2m long.

TEPHRA-FALL DEPOSIT GRANULOMETRY



Tephra-fall deposits from Cone1 are indistinguishable from Cone2.

Both deposits plot in the "Normal Strombolian" field of Walker & Croasdale (1972), although these deposits have fragmentation and dispersivity of Violent Strombolian eruptions.



Grain-size variations in the Cone1 tephra fall deposits do not show systematic changes with thickness.

In contrast, some Cone2 sections show a discernible increase in median diameter towards the top of the deposit.

REFERENCES

Budnikov, V.A., Ye.K. Markhinin, and A.A. Ovsyannikov. 1983. The quantity, distribution and petrochemical features of pyroclastics of the great Tolbachik fissure eruption. S.A. Fedotov and Ye.K. Markhinin, eds. *The Great Tolbachik Fissure Eruption*. New York, NY: Cambridge University Press: 41–56.

Gippenreiter, V. 1979. *Birth of a Volcano*. Moscow: Planeta.

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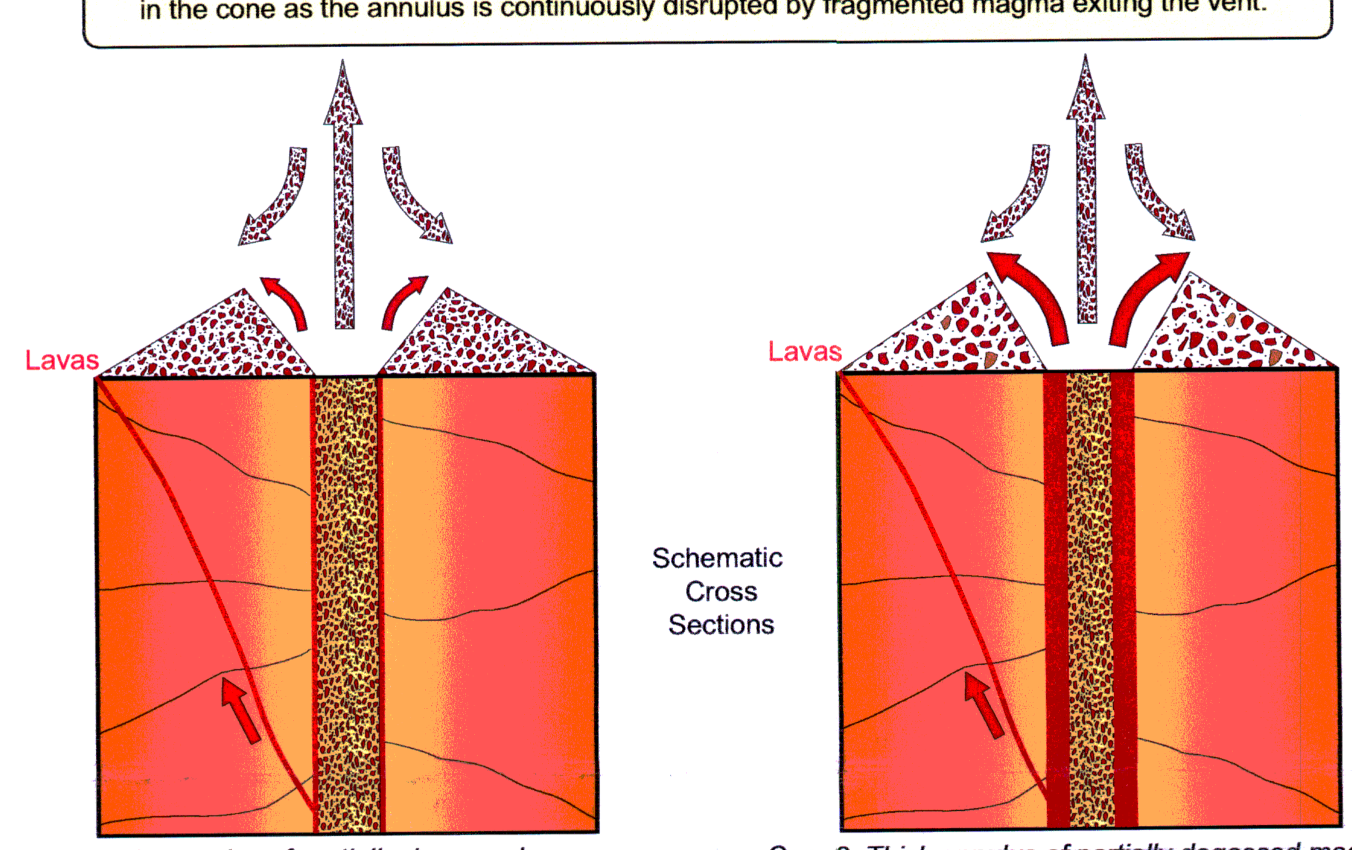
INTERPRETATION & CONCLUSIONS

Interpretation of Data

1) Tephra-fall deposits have same granulometric and dispersal characteristics
   - Fragmentation processes must be comparable in Cone1 and Cone2 conduits
2) Pyroclastic mass-flow rates at Cone2 are only 25% lower than at Cone1.
   - Small variations in average column height did not affect tephra dispersal significantly.
3) Lava mass-flow rates at Cone2 are 300% higher than at Cone1.
   - Same compositions, and simultaneous eruption with tephra.
4) Cone1 effused lavas from basal boccas, but most Cone2 lavas issued from the central vent.
   - Relatively large amounts of lava in Cone2 conduit is main difference between eruptions.

Conceptual Model

Thick annulus of partially degassed magma in the shallow conduit can create abundant agglutinate in the cone as the annulus is continuously disrupted by fragmented magma exiting the vent.



Cone1: Thin annulus of partially degassed magma is mostly removed by bocca lavas. Cone formed primarily from cooled tephra falling out of eruption column, with minor amounts of hot ballistic ejecta.

Cone2: Thick annulus of partially degassed magma exceeds mass removal rate by boccas and thus effuses from central conduit. Hot ballistic ejecta from disrupted annulus dominates cone facies, but does not affect fragmented flow of tephra.

CONCLUSIONS

Basaltic scoria cone morphology may not be a robust indicator of tephra-fall occurrence for ancient eruptions.

Steep sided scoria cones with abundant agglutinate can form during violent strombolian eruptions with widely dispersed tephra falls.

Shallow conduit conditions appear to significantly affect scoria cone morphology for annular or fragmented flow regimes.

ACKNOWLEDGEMENTS

Discussions with Phil Doubik, Chuck Connor, Andy Woods, and Don Hooper improved and focused these investigations. This work was performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the Nuclear Regulatory Commission (NRC) under Contract NRC-02-02-012. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of High-Level Waste Repository Safety. This paper is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC.

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