On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Institute of volcanology and seismology
Russian Academy of Science



June, 2015

On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

The example

The regime map

Experimental simulation analysis

The choice of FP system

Provocative questions

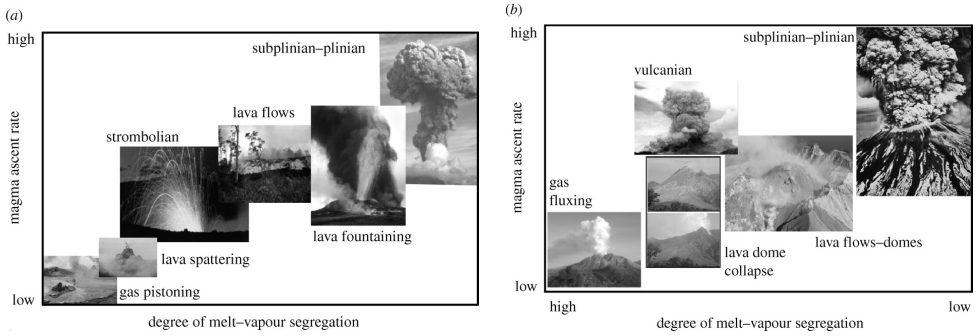
What is a “strombolian type” eruption? Which mass (volume) rates, viscosities, conduit size define this type?



Tolbachik, Kamchtka. A. Sokorenko, 2013

Provocative questions

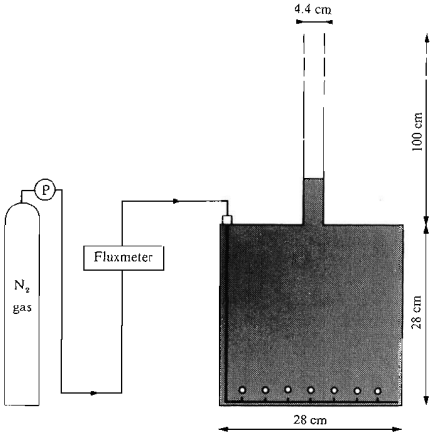
Is it possible in general to make a formal qualitative separation of different eruption types?



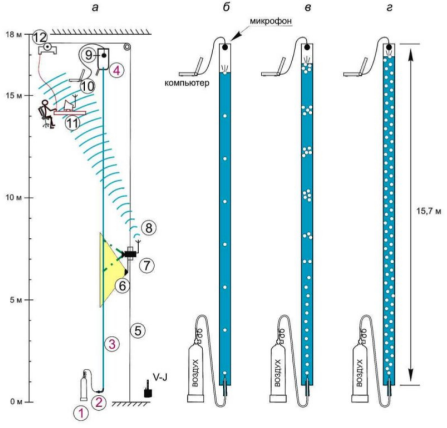
Marie Edmonds, New geochemical insights into volcanic degassing, 2008

Provocative questions

Is it possible to verify the model, if one is not able to get accurate eruption parameters?



Verniolle, Gaupart, 1986–1989



Ozerov, 2011

Provocative questions

Is it possible to verify the model, if one is not able to get accurate eruption parameters?



Tolbachik, Kamchatka. A. Sokorenko, 2013

Provocative questions

Is it possible to verify the model, if one is not able to get accurate eruption parameters?



Shiveluch, Kamchatka. Yu. Demyanchuk, 2007

Provocative questions

There are many effects, physical parameters vary in several orders, measurements are indirect and inaccurate — how can we ever build adequate models?



Tolbachik, Kamchatka. S. Samoylenko, 2012

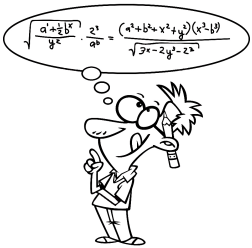
Provocative questions

When did you use modeling of the eruption last time?



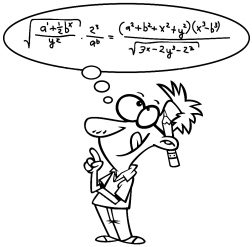
How to build a correct but useless model

equations

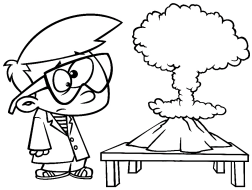


How to build a correct but useless model

equations

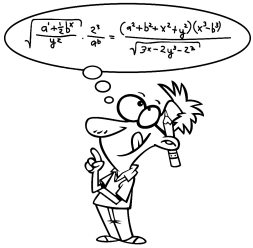


experiment



How to build a correct but useless model

equations



parameters, boundary and initial conditions

$\mu, \tau, \sigma, ...$

$\rho_m, \rho_g, T, ...$

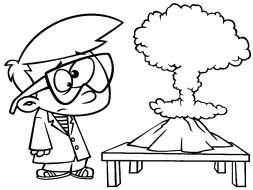
$\Lambda, D, ...$

$H, d(H), ...$

$\alpha, c_0, \beta, ...$

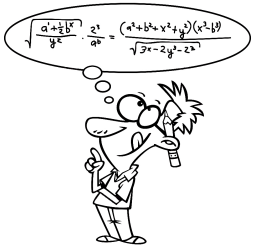
$\Delta P, ...$

experiment



How to build a correct but useless model

equations



parameters, boundary and initial conditions

$\mu, \tau, \sigma, ...$

$\rho_m, \rho_g, T, ...$

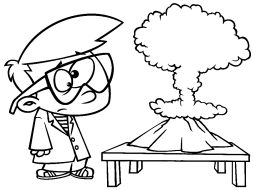
$\Lambda, D, ...$

$H, d(H), ...$

$\alpha, c_0, \beta, ...$

$\Delta P, ...$

experiment

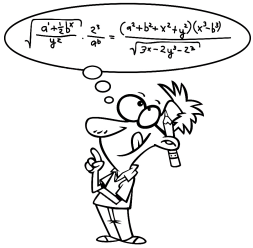


results

- space distribution of parameters;
- rates, velocities;
- regime and dynamic features.

How to build a correct but useless model

equations



parameters, boundary and initial conditions

$\mu, \tau, \sigma, ...$

$\rho_m, \rho_g, T, ...$

$\Lambda, D, ...$

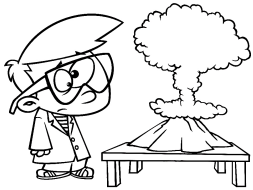
$H, d(H), ...$

$\alpha, c_0, \beta, ...$

$\Delta P, ...$

?

experiment

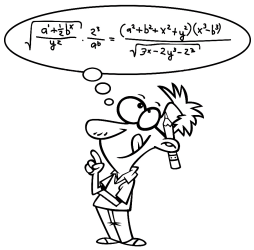


results

- space distribution of parameters;
- rates, velocities;
- regime and dynamic features.

How to build a correct but useless model

equations



parameters, boundary and initial conditions

$\mu, \tau, \sigma, ...$

$\rho_m, \rho_g, T, ...$

$\Lambda, D, ...$

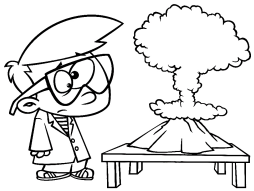
$H, d(H), ...$

$\alpha, c_0, \beta, ...$

$\Delta P, ...$

?

experiment

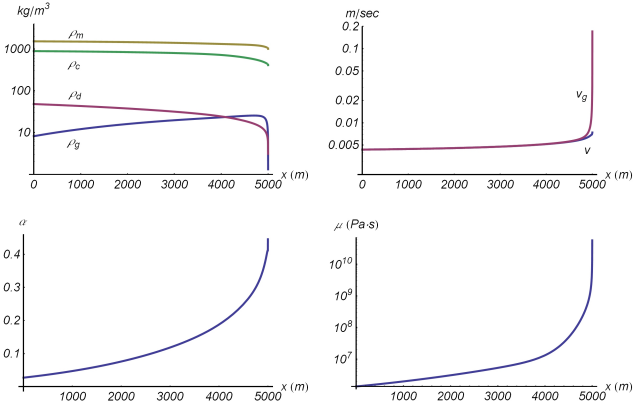


results

- space distribution of parameters;
- rates, velocities;
- regime and dynamic features.

?

Correct, but not really useful results



The sufficient number of experiments for 5 parameters

Linear model: $2^5 \sim 30$

Nonlinear model: $(3 \div 5)^5 \sim 300 - 3000$

In papers only $1 - 3$ successful examples are given.

On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

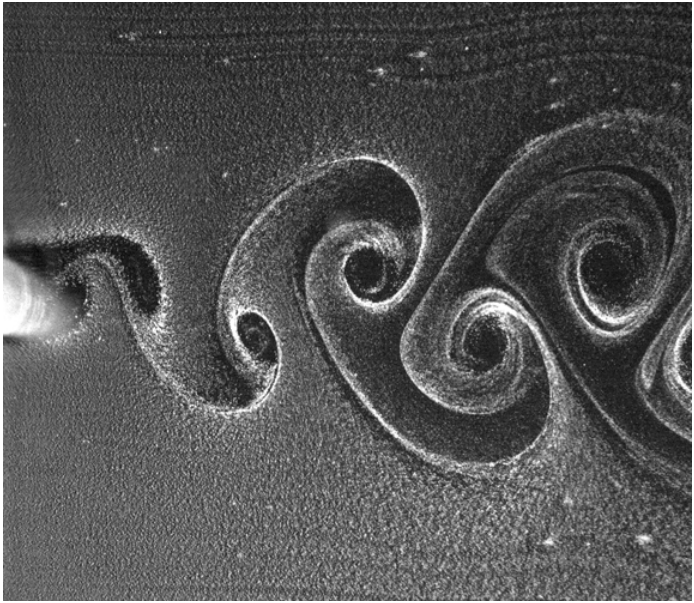
The example

The regime map

Experimental simulation analysis

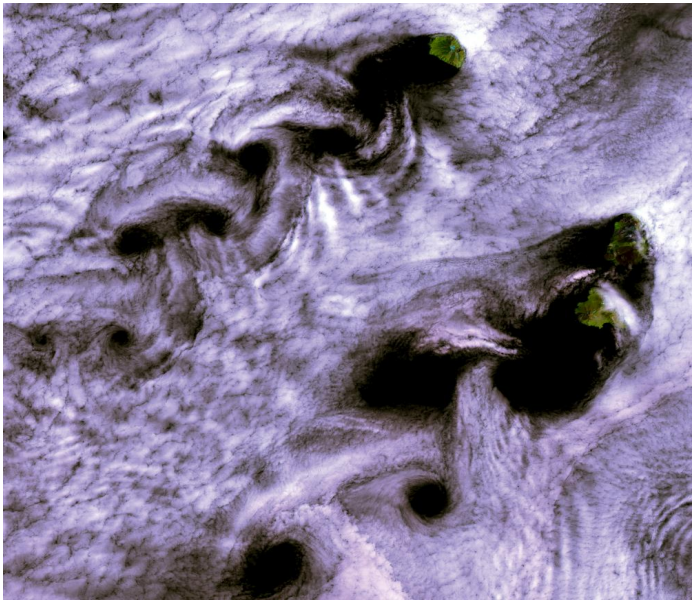
The choice of FP system

Example of physically similar flows



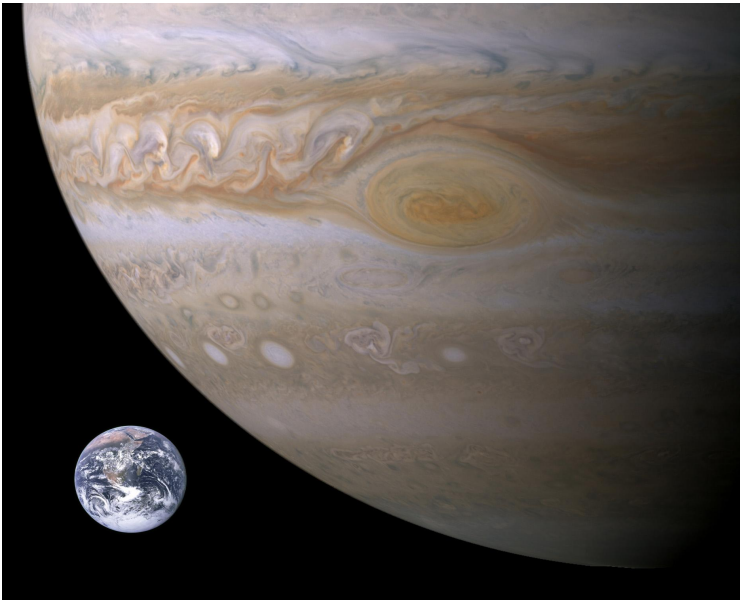
$d \sim 6mm$

Example of physically similar flows



$d \sim 600km$

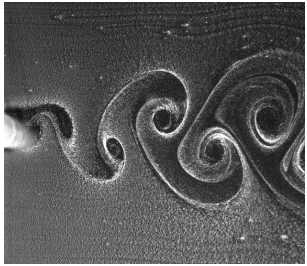
Example of physically similar flows



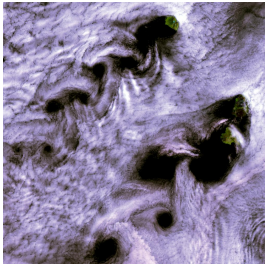
$d \sim 6000km$

The Reynolds number

$$Re = \frac{\rho v d}{\mu} = \frac{F_{in}}{F_{visc}}$$



$Re = 138$

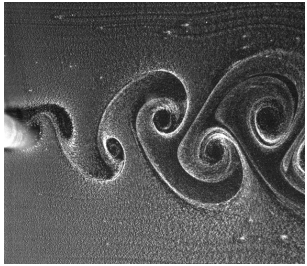


$Re = 100 - 200$

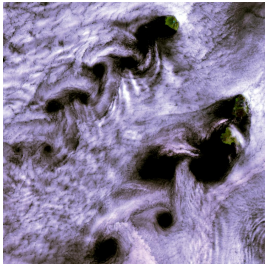


The Reynolds number

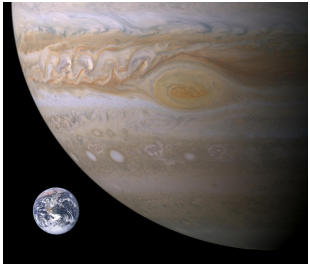
$$Re = \frac{\rho v d}{\mu} = \frac{F_{in}}{F_{visc}}$$



$Re = 138$



$Re = 100 - 200$

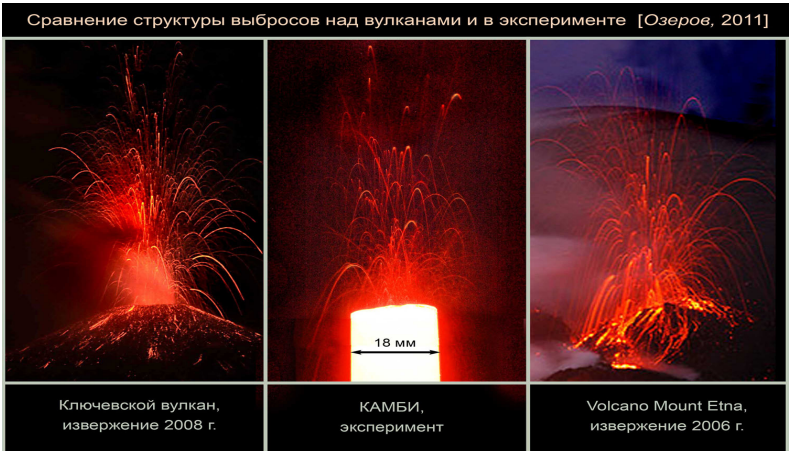


$Re = 20 - 200$

The Froude number



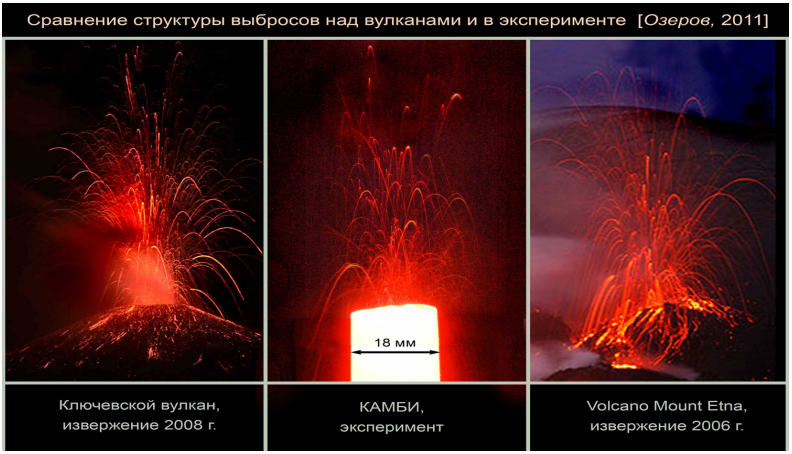
The Froude number



$$Fr = \frac{v^2}{gl} \qquad v \propto \sqrt{l}$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

The Froude number



$$Fr = \frac{v^2}{gl} \qquad v \propto \sqrt{l}$$

violation of the proportionality $\Longrightarrow$ model extension

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Some terminology

dimensional parameter — a value which depends on units.

Some terminology

dimensional parameter — a value which depends on units.

$$\mu_{\text{water}} = 8.9 \times 10^{-4}\text{Pa} \cdot \text{sec} = 5.9 \times 10^{-4} \frac{lb}{ft \cdot sec}$$

On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

The example

The regime map

Experimental simulation analysis

The choice of FP system

Some terminology

dimensional parameter — a value which depends on units.

$$\mu_{\text{water}} = 8.9 \times 10^{-4}\text{Pa} \cdot \text{sec} = 5.9 \times 10^{-4} \frac{lb}{ft \cdot sec}$$

dimensionless complex — a dimensionless value which includes several dimensional parameters with different dimensions

Some terminology

dimensional parameter — a value which depends on units.

$$\mu_{\text{water}} = 8.9 \times 10^{-4}\text{Pa} \cdot \text{sec} = 5.9 \times 10^{-4} \frac{lb}{ft \cdot sec}$$

dimensionless complex — a dimensionless value which includes several dimensional parameters with different dimensions

$$\text{Re} = \frac{vd\rho}{\mu}, \quad \text{Fr} = \frac{v^2}{gl}$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Some terminology

dimensional parameter — a value which depends on units.

$$\mu_{\text{water}} = 8.9 \times 10^{-4}\text{Pa} \cdot \text{sec} = 5.9 \times 10^{-4} \frac{lb}{ft \cdot sec}$$

dimensionless complex — a dimensionless value which includes several dimensional parameters with different dimensions

$$\text{Re} = \frac{vd\rho}{\mu}, \quad \text{Fr} = \frac{v^2}{gl}$$

formal parameter — a dimensionless complex, which is proportional to some dimensional parameter and which corresponds to the value of this parameter in a given context.

Some terminology

dimensional parameter — a value which depends on units.

$$\mu_{\text{water}} = 8.9 \times 10^{-4}\text{Pa} \cdot \text{sec} = 5.9 \times 10^{-4} \frac{lb}{ft \cdot sec}$$

dimensionless complex — a dimensionless value which includes several dimensional parameters with different dimensions

$$\text{Re} = \frac{vd\rho}{\mu}, \quad \text{Fr} = \frac{v^2}{gl}$$

formal parameter — a dimensionless complex, which is proportional to some dimensional parameter and which corresponds to the value of this parameter in a given context.

$$K_\mu = \frac{\mu}{vd\rho},$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Some terminology

dimensional parameter — a value which depends on units.

$$\mu_{\text{water}} = 8.9 \times 10^{-4}\text{Pa} \cdot \text{sec} = 5.9 \times 10^{-4}\frac{lb}{ft \cdot sec}$$

dimensionless complex — a dimensionless value which includes several dimensional parameters with different dimensions

$$\text{Re} = \frac{vd\rho}{\mu}, \quad \text{Fr} = \frac{v^2}{gl}$$

formal parameter — a dimensionless complex, which is proportional to some dimensional parameter and which corresponds to the value of this parameter in a given context.

$$K_\mu = \frac{\mu}{vd\rho}, \qquad \text{K}_v = \frac{v}{\sqrt{gl}},$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Some terminology

dimensional parameter — a value which depends on units.

$$\mu_{\text{water}} = 8.9 \times 10^{-4}\text{Pa} \cdot \text{sec} = 5.9 \times 10^{-4} \frac{lb}{ft \cdot sec}$$

dimensionless complex — a dimensionless value which includes several dimensional parameters with different dimensions

$$\text{Re} = \frac{vd\rho}{\mu}, \quad \text{Fr} = \frac{v^2}{gl}$$

formal parameter — a dimensionless complex, which is proportional to some dimensional parameter and which corresponds to the value of this parameter in a given context.

$$K_\mu = \frac{\mu}{vd\rho}, \qquad \text{K}_v = \frac{v}{\sqrt{gl}}, \qquad \text{K}_g = \frac{gl}{v^2}$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Formalization of physical values

1. The transition from the dimensional parameters to formal.

dimensional parameters		formal parameters
$\mu, \tau, \sigma, ...$		$K_\mu, K_\tau, K_\sigma, ...$
$\Delta P, Q, v, ...$	$\longrightarrow$	$K_Q, K_P,$
$H, d(H), ...$		$\Phi,$
$\alpha, c_0, \beta, ...$		$\alpha, c_0, \beta, ...$

Formalization of physical values

1. The transition from the dimensional parameters to formal.

dimensional parameters		formal parameters
$\mu, \tau, \sigma, ...$		$K_\mu, K_\tau, K_\sigma, ...$
$\Delta P, Q, v, ...$	$\longrightarrow$	$K_Q, K_P,$
$H, d(H), ...$		$\Phi,$
$\alpha, c_0, \beta, ...$		$\alpha, c_0, \beta, ...$

2. Dimensionless equations

Formalization of physical values

1. The transition from the dimensional parameters to formal.

dimensional parameters		formal parameters
$\mu, \tau, \sigma, ...$		$K_\mu, K_\tau, K_\sigma, ...$
$\Delta P, Q, v, ...$	$\longrightarrow$	$K_Q, K_P,$
$H, d(H), ...$		$\Phi,$
$\alpha, c_0, \beta, ...$		$\alpha, c_0, \beta, ...$

2. Dimensionless equations

$$\rho v \frac{dv}{dh} = -\frac{dP}{dh} - \rho g - C_f \frac{\mu v}{d^2},$$

Formalization of physical values

1. The transition from the dimensional parameters to formal.

dimensional parameters		formal parameters
$\mu, \tau, \sigma, ...$		$K_\mu, K_\tau, K_\sigma, ...$
$\Delta P, Q, v, ...$	$\longrightarrow$	$K_Q, K_P,$
$H, d(H), ...$		$\Phi,$
$\alpha, c_0, \beta, ...$		$\alpha, c_0, \beta, ...$

2. Dimensionless equations

$$\rho v \frac{dv}{dh} = -\frac{dP}{dh} - \rho g - C_f \frac{\mu v}{d^2},$$
$$u \frac{du}{dz} = -\mathrm{Eu} \frac{dp}{dz} - \frac{1}{\mathrm{Fr}} - \frac{C_f}{\mathrm{Re}} u.$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Formalization of physical values

1. The transition from the dimensional parameters to formal.

dimensional parameters		formal parameters
$\mu, \tau, \sigma, ...$		$K_\mu, K_\tau, K_\sigma, ...$
$\Delta P, Q, v, ...$	$\longrightarrow$	$K_Q, K_P,$
$H, d(H), ...$		$\Phi,$
$\alpha, c_0, \beta, ...$		$\alpha, c_0, \beta, ...$

2. Dimensionless equations

$$\rho v \frac{dv}{dh} = -\frac{dP}{dh} - \rho g - C_f \frac{\mu v}{d^2},$$
$$u \frac{du}{dz} = -\mathrm{Eu} \frac{dp}{dz} - \frac{1}{\mathrm{Fr}} - \frac{C_f}{\mathrm{Re}} u.$$
$$u \frac{du}{dz} = -\mathrm{K}_P \frac{dp}{dz} - \mathrm{K}_g - C_f \mathrm{K}_\mu u.$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Dimensional paremeters vs. formal parameter

dimensional parameter	formal parameter
▶ Linked to the standards.	

Dimensional paremeters vs. formal parameter

dimensional parameter

- Linked to the standards.
- The values is relative and not informative.

formal parameter

Dimensional paremeters vs. formal parameter

dimensional parameter

- Linked to the standards.
- The values is relative and not informative.
- The accurate value is needed but unavailable.

formal parameter

Dimensional paremeters vs. formal parameter

dimensional parameter

- Linked to the standards.
- The values is relative and not informative.
- The accurate value is needed but unavailable.
- There is a big number of them.

formal parameter

Dimensional paremeters vs. formal parameter

dimensional parameter

- Linked to the standards.
- The values is relative and not informative.
- The accurate value is needed but unavailable.
- There is a big number of them.
  - Many experiments.

formal parameter

Dimensional paremeters vs. formal parameter

dimensional parameter

- Linked to the standards.
- The values is relative and not informative.
- The accurate value is needed but unavailable.
- There is a big number of them.
  - Many experiments.
  - Many diagrams with pure information.

formal parameter

Dimensional paremeters vs. formal parameter

dimensional parameter

- Linked to the standards.
- The values is relative and not informative.
- The accurate value is needed but unavailable.
- There is a big number of them.
  - Many experiments.
  - Many diagrams with pure information.

formal parameter

- Linked to the phenomenon an to the scale.

Dimensional paremeters vs. formal parameter

dimensional parameter

- Linked to the standards.
- The values is relative and not informative.
- The accurate value is needed but unavailable.
- There is a big number of them.
  - Many experiments.
  - Many diagrams with pure information.

formal parameter

- Linked to the phenomenon an to the scale.
- The value defines global behavior of the system.

Dimensional paremeters vs. formal parameter

dimensional parameter

- Linked to the standards.
- The values is relative and not informative.
- The accurate value is needed but unavailable.
- There is a big number of them.
  - Many experiments.
  - Many diagrams with pure information.

formal parameter

- Linked to the phenomenon an to the scale.
- The value defines global behavior of the system.
- The value could be estimated according to observed behavior of the system.

Dimensional paremeters vs. formal parameter

dimensional parameter

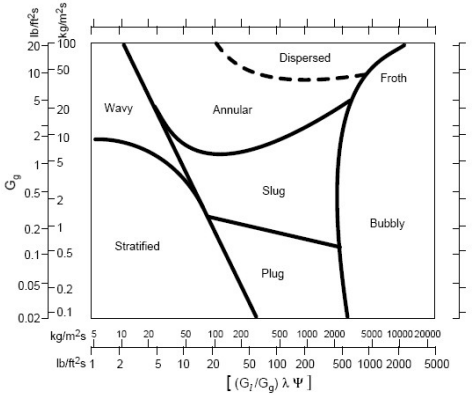
- Linked to the standards.
- The values is relative and not informative.
- The accurate value is needed but unavailable.
- There is a big number of them.
  - Many experiments.
  - Many diagrams with pure information.

formal parameter

- Linked to the phenomenon an to the scale.
- The value defines global behavior of the system.
- The value could be estimated according to observed behavior of the system.
- The number of them is not so big. (Π-theorem).

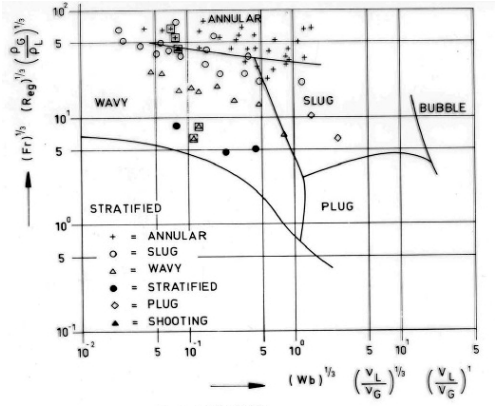
Two-phase flow regimes plot

Baker's plot



O. Baker. Simultaneous flow of oil and gas. The Oil and Gas Journal 1954

Martin van der Jagt

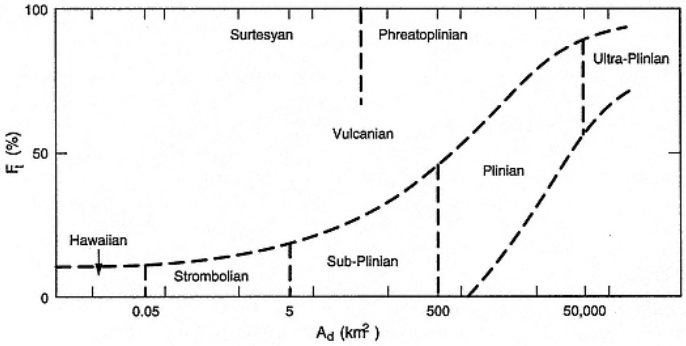


New Diagram for Prediction of Two Phase Flow, International Congress of Refregiration, Moscow, 1975, 2010

Two-phase flow regimes plot

Walker's chart

F_t is the weight percent of tephra finer than 1 mm found along the dispersal axis where the deposit thickness is 10% of its maximum. A_d is the area of the deposit where it's thickness is at least 1% of its maximum.



Walker, 1972

Dimensional analysis in volcanology

Slyozin, 1972-1998	Di
Verniolle, Gaupart, 1986-1989	Re, Eu, Mo, E, N_1, N_2
Barmin, Melnik, 2001-2005	Eu, Ar, C_a
Manga, 1998	Re, Ca, μ_{rel}

- In most of papers only dimensional parameters or simplexes are used.

Dimensional analysis in volcanology

Slyozin, 1972-1998	Di
Verniolle, Gaupart, 1986-1989	Re, Eu, Mo, E, N_1, N_2
Barmin, Melnik, 2001-2005	Eu, Ar, C_a
Manga, 1998	Re, Ca, μ_{rel}

- In most of papers only dimensional parameters or simplexes are used.
- There is no uniform formal parameter system, specific for volcanology.

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Dimensional analysis in volcanology

Slyozin, 1972-1998	Di
Verniolle, Gaupart, 1986-1989	Re, Eu, Mo, E, N_1, N_2
Barmin, Melnik, 2001-2005	Eu, Ar, C_a
Manga, 1998	Re, Ca, μ_{rel}

- In most of papers only dimensional parameters or simplexes are used.
- There is no uniform formal parameter system, specific for volcanology.
- There is no regime maps, given in terms of dimensionless parameters or similarity criteria!

The motivating example

The forces acting on the fluid in a vertical channel:

- driving force F_P;
- inertia F_i;
- gravity F_g;
- viscosity F_v.

The motivating example

The forces acting on the fluid in a vertical channel:

- driving force F_P;
- inertia F_i;
- gravity F_g;
- viscosity F_v.

Physical parameters:

ΔP — overpressure in the chamber,

ρ — liquid density,

Q — mass rate,

g — gravity acceleration,

μ — liquid viscosity,

l — the distance along the conduit,

d — the average conduit size (diameter).

The motivating example

The forces acting on the fluid in a vertical channel:

- driving force F_P;
- inertia F_i;
- gravity F_g;
- viscosity F_v.

Physical parameters:

ΔP — overpressure in the chamber,

ρ — liquid density,

Q — mass rate,

g — gravity acceleration,

μ — liquid viscosity,

l — the distance along the conduit,

d — the average conduit size (diameter).

Traditional dimensionless complexes:

$$\mathrm{Eu} = \frac{F_P}{F_i}, \quad \mathrm{Fr} = \frac{F_g}{F_i}, \quad \mathrm{Re} = \frac{F_v}{F_i}$$

On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

The example

The regime map

Experimental simulation analysis

The choice of FP system

Derivation of the formal parameter system

1. The set of dimensional parameters:

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions:

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters:

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2
4. The choice of parameters to be formalized:

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2
4. The choice of parameters to be formalized: μ, Q

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2
4. The choice of parameters to be formalized: μ, Q
5. The basis of formal parameters:

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2
4. The choice of parameters to be formalized: μ, Q
5. The basis of formal parameters:

$$\left\{ \frac{\mu\sqrt{l}}{\rho d^2\sqrt{g}}, \frac{Q}{\rho d^2\sqrt{gl}} \right\} = \{\mathrm{K}_\mu, \mathrm{K}_Q\}.$$

On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

The example

The regime map

Experimental simulation analysis

The choice of FP system

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2
4. The choice of parameters to be formalized: μ, Q
5. The basis of formal parameters:

$$\left\{ \frac{\mu\sqrt{l}}{\rho d^2\sqrt{g}}, \frac{Q}{\rho d^2\sqrt{gl}} \right\} = \{\mathrm{K}_\mu, \mathrm{K}_Q\}.$$

6. The formal parameter space analysis:

On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

The example

The regime map

Experimental simulation analysis

The choice of FP system

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2
4. The choice of parameters to be formalized: μ, Q
5. The basis of formal parameters:

$$\left\{ \frac{\mu\sqrt{l}}{\rho d^2\sqrt{g}}, \frac{Q}{\rho d^2\sqrt{gl}} \right\} = \{\mathrm{K}_\mu, \mathrm{K}_Q\}.$$

6. The formal parameter space analysis:

$$\left\{ \frac{Q}{l\mu}, \frac{Q\mu}{d^4 g\rho^2} \right\} = \left\{ \frac{\mathrm{K}_\mu}{\mathrm{K}_Q}, \mathrm{K}_\mu \mathrm{K}_Q \right\}.$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2
4. The choice of parameters to be formalized: μ, Q
5. The basis of formal parameters:

$$\left\{ \frac{\mu\sqrt{l}}{\rho d^2\sqrt{g}}, \frac{Q}{\rho d^2\sqrt{gl}} \right\} = \{\mathrm{K}_\mu, \mathrm{K}_Q\}.$$

6. The formal parameter space analysis:

$$\left\{ \frac{Q}{l\mu}, \frac{Q\mu}{d^4 g\rho^2} \right\} = \left\{ \frac{\mathrm{K}_\mu}{\mathrm{K}_Q}, \mathrm{K}_\mu\mathrm{K}_Q \right\}. \qquad Div = 0.7, \quad Or = 1$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2
4. The choice of parameters to be formalized: μ, Q
5. The basis of formal parameters:

$$\left\{ \frac{\mu\sqrt{l}}{\rho d^2\sqrt{g}}, \frac{Q}{\rho d^2\sqrt{gl}} \right\} = \{\mathrm{K}_\mu, \mathrm{K}_Q\}. \qquad Div = 0.7, \quad Or = 0.6$$

6. The formal parameter space analysis:

$$\left\{ \frac{Q}{l\mu}, \frac{Q\mu}{d^4 g\rho^2} \right\} = \left\{ \frac{\mathrm{K}_\mu}{\mathrm{K}_Q}, \mathrm{K}_\mu\mathrm{K}_Q \right\}. \qquad Div = 0.7, \quad Or = 1$$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

Derivation of the formal parameter system

1. The set of dimensional parameters: ρ, μ, Q, l, d, g
2. The set of basic dimensions: M, L_z, L_d, T
3. The number of possible formal parameters: 2
4. The choice of parameters to be formalized: μ, Q
5. The basis of formal parameters:

$$\left\{ \frac{\mu\sqrt{l}}{\rho d^2\sqrt{g}}, \frac{Q}{\rho d^2\sqrt{gl}} \right\} = \{\mathrm{K}_\mu, \mathrm{K}_Q\}. \qquad Div = 0.7, \quad Or = 0.6$$

6. The formal parameter space analysis:

$$\left\{ \frac{Q}{l\mu}, \frac{Q\mu}{d^4 g\rho^2} \right\} = \left\{ \frac{\mathrm{K}_\mu}{\mathrm{K}_Q}, \mathrm{K}_\mu\mathrm{K}_Q \right\}. \qquad Div = 0.7, \quad Or = 1$$

$$\left\{ \frac{Q}{l\mu}, \frac{Q^2}{d^4 gl\rho^2} \right\} = \{\mathrm{Re}, \mathrm{Fr}\}. \qquad Div = 0.5, \quad Or = -0.4$$

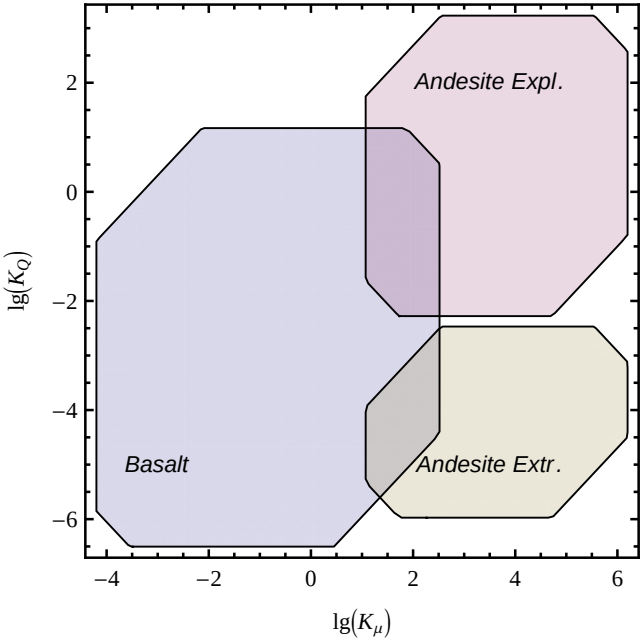
On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

The regime map

The ranges of different physical values:

		Basalts	Andesites
ρ	$\mathrm{kg/m^3}$	$2500 - 2800$	$2200 - 2500$
μ	Pa·sec	$10^1 - 10^5$	$10^6 - 10^7$
Q	kg/sec	$10^2 - 10^6$	$10^3 - 10^4$ (extrusive)
			$10^6 - 10^8$ (explosive)
g	$\mathrm{m/sec^2}$	10	10
l	m	$500 - 10000$	$500 - 10000$
d	m	$1 - 10$	$10 - 50$

The regime map



On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

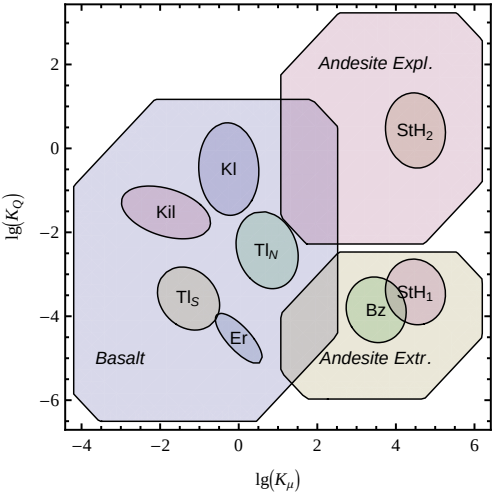
An example of regime map detailing

Parameters of some eruptions.

	Volcano	μ Pa·sec	Q kg/sec	d m	Source
TolN	Tolbachik NV	10^5	$(2-4)\cdot 10^4$	10	(Slyozin, 1998), (GTFE, 1984)
TolS	Tolbachik SV	10^3	$(3-5)\cdot 10^3$	10	(Slyozin, 1998), (GTFE, 1984)
Kl	Klyuchevskoy	$5\cdot 10^3$	$5\cdot 10^5 - 5\cdot 10^6$	$5-10$	(Ozerov, 2011)
Er	Erebus	$1.6\cdot 10^3$	$10^1 - 10^2$	2	(Calkins, 2008)
Kil	Kilauea	10^2	10^5	$4-5$	(Mastin, 2001)
StH_1	St. Helens	10^9	10^4	50	CVO
StH_2	St. Helens	10^9	10^7	50	CVO, (Mastin, 2001)
Bz	Besymyanny	10^8	$7\cdot 10^3$	$10-20$	(Slyozin, 1998)

The regime map detalization

Areas of specific eruptions



On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

The example

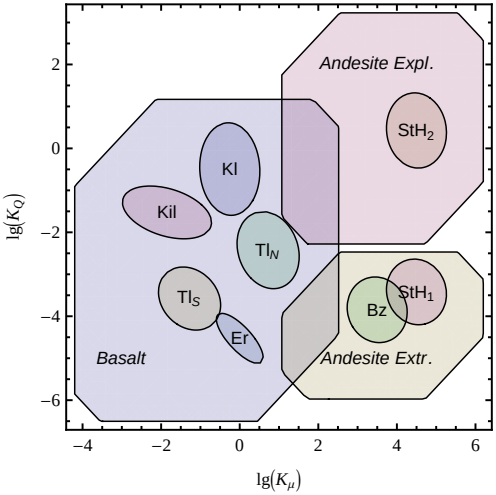
The regime map

Experimental simulation analysis

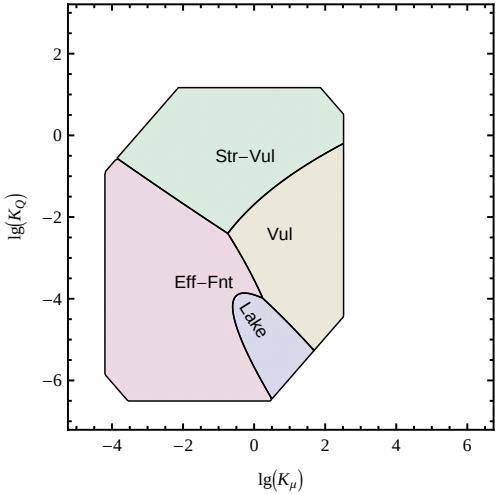
The choice of FP system

The regime map detalization

Areas of specific eruptions



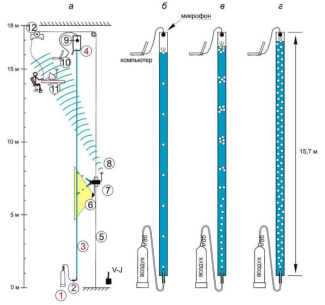
Areas of basaltic magmas eruptions

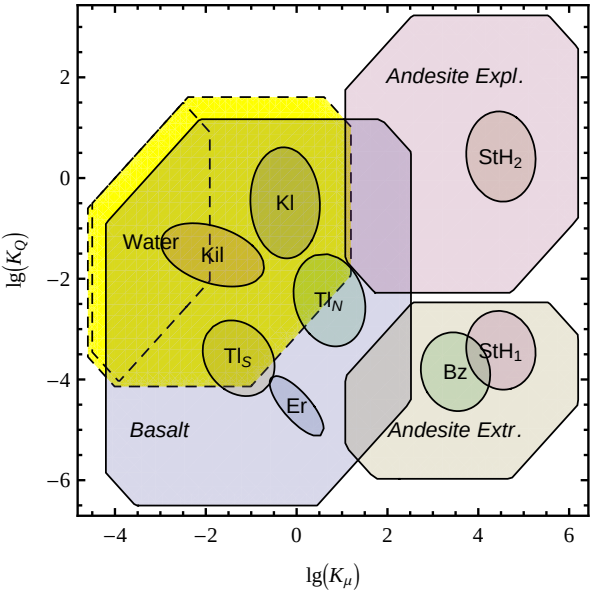


Experimental simulation analysis

Experimental setup
(Ozerov, 2007–2012)

ρ	$0.8 - 1.26$	g/cm^3
μ	$10^{-3} - 1$	Pa·sec
Q	$10^{-2} - 1$	kg/sec
l	$1 - 15$	m
d	$1 - 10$	cm



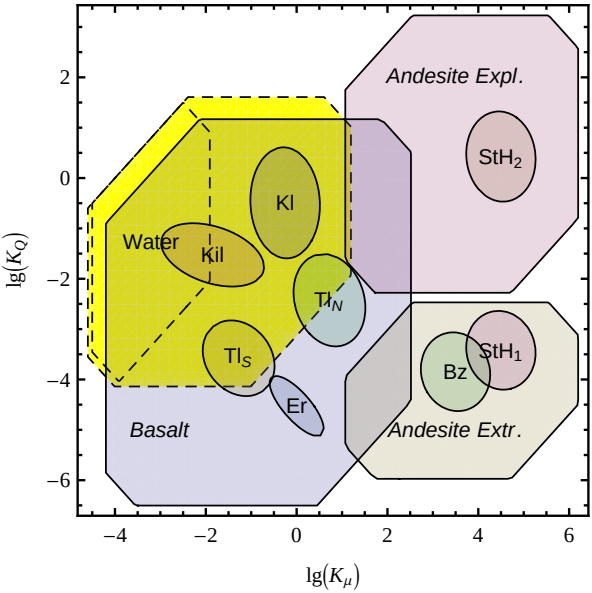


Experimental simulation analysis

Experimental setup
(Ozerov, 2007–2012)

ρ	$0.8 - 1.26$	g/cm^3
μ	$10^{-3} - 1$	Pa·sec
Q	$10^{-2} - 1$	kg/sec
l	$1 - 15$	m
d	$1 - 10$	cm

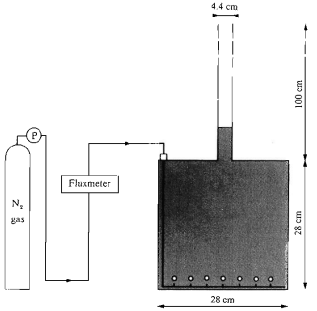
By setting parameters' values accurately we can build detailed regime map.

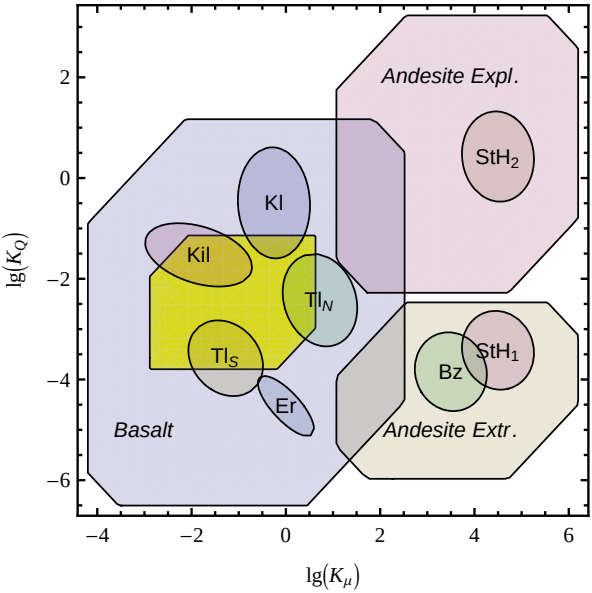


Experimental simulation analysis

Experimental setup of Verniolle (Verniolle, Gaupart, 1986–1999)

ρ	$0.93 - 0.97$	g/cm^3
μ	$10^{-2} - 5$	Pa·sec
Q	$10^{-4} - 10^{-2}$	kg/sec
l	1	m
d	$2 - 5$	cm

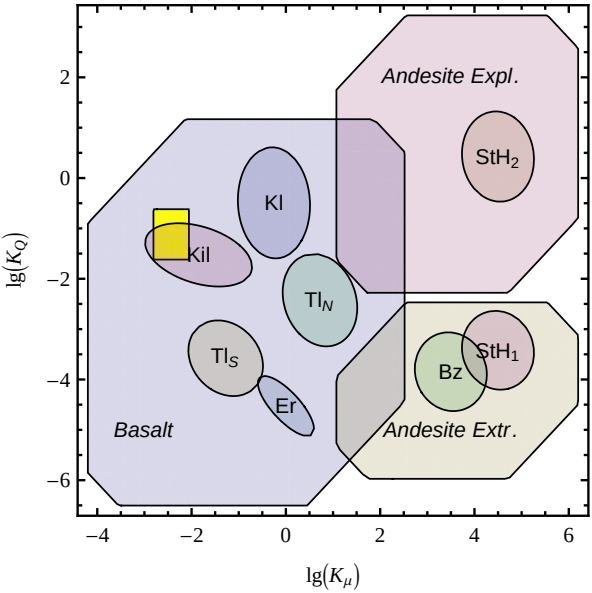




Experimental simulation analysis

A champaign vine bottle

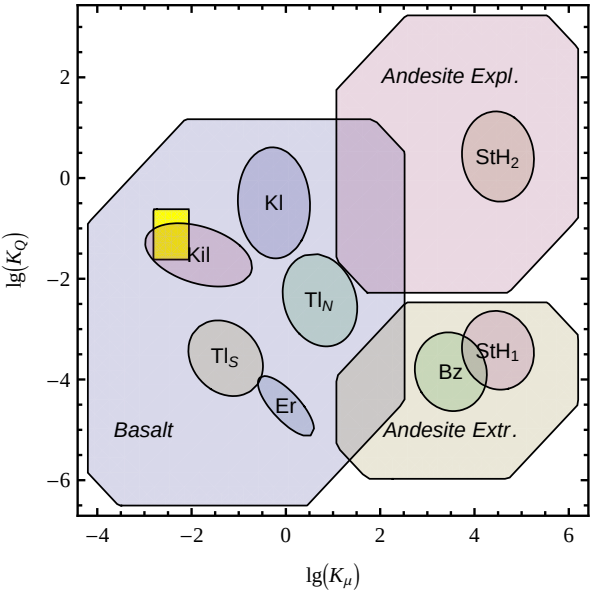
ρ	1	kg/m^3
μ	10^{-3}	Pa·sec
Q	$10 - 100$	g/sec
l	40	cm
d	2	cm



Experimental simulation analysis

A champaign vine bottle





On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

The example

The regime map

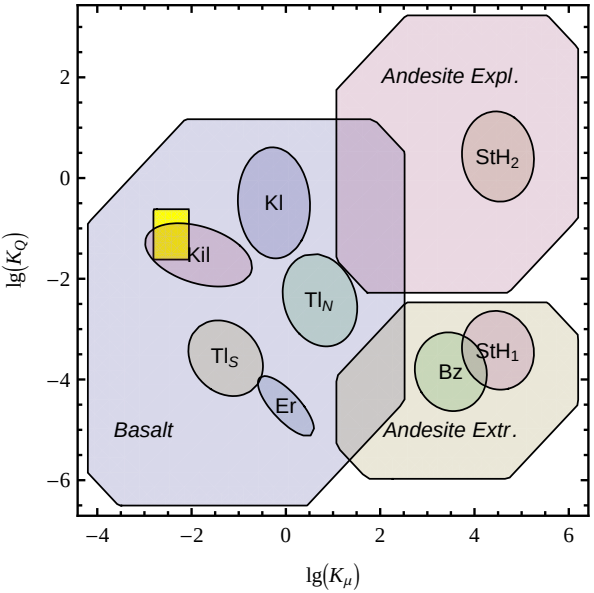
Experimental simulation analysis

The choice of FP system

Experimental simulation analysis

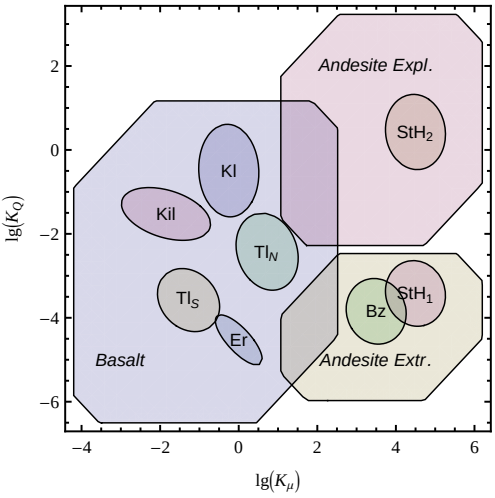
A champaign vine bottle





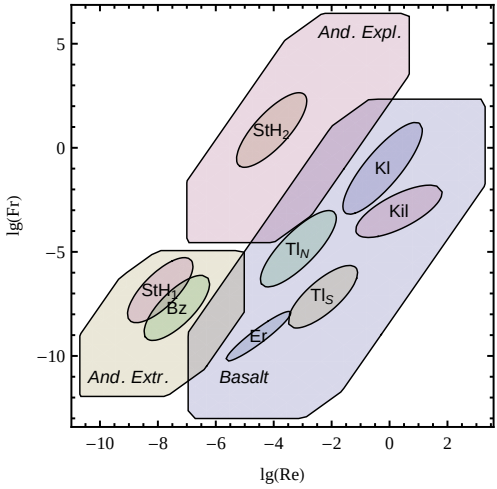
The choice of basis in formal parameter space

basis $\{K_\mu, K_Q\}$



$Div = 0.7, \quad Or = 0.6$

basis $\{\mathrm{Re}, \mathrm{Fr}\}$

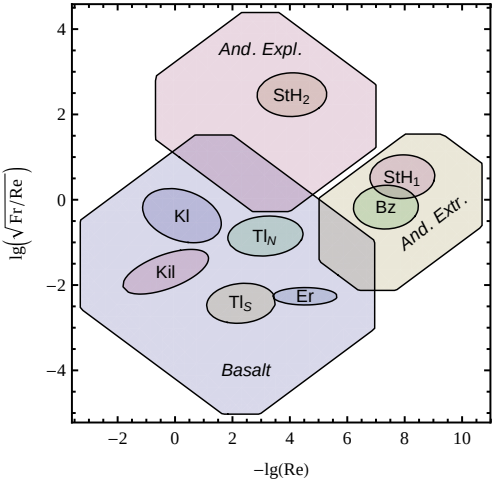


$Div = 0.5, \quad Or = -0.4$

On formal classification of volcanic eruption types and regimes based on the similarity theory
S.B. Samoylenko
Problem statement
Physical similarity
Formalization of physical values
The example
The regime map
Experimental simulation analysis
The choice of FP system

The choice of basis in formal parameter space

$$\text{basis } \left\{ \frac{\mathrm{K}_\mu}{\mathrm{K}_Q}, \mathrm{K}_\mu \mathrm{K}_Q \right\}$$



$$Div = 0.7, \quad Or = 1$$

On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

The example

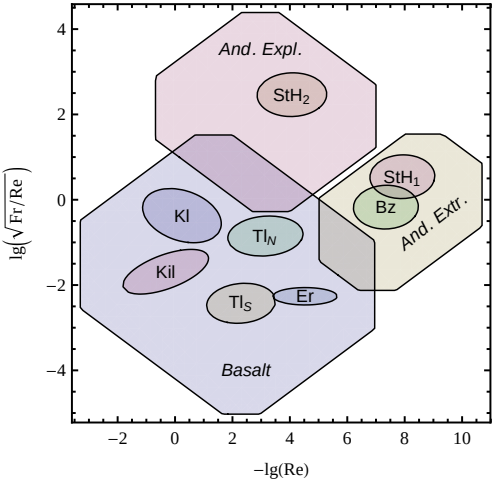
The regime map

Experimental simulation analysis

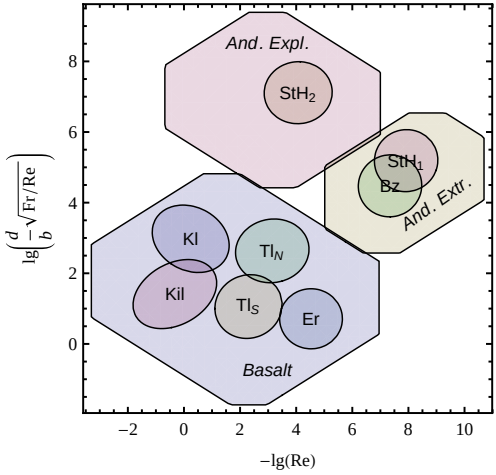
The choice of FP system

The choice of basis in formal parameter space

basis $\left\{\dfrac{\mathrm{K}_\mu}{\mathrm{K}_Q}, \mathrm{K}_\mu\mathrm{K}_Q\right\}$



basis $\left\{\dfrac{\mathrm{K}_\mu}{\mathrm{K}_Q}, \dfrac{d}{b}\mathrm{K}_\mu\mathrm{K}_Q\right\}$



$Div = 0.7, \quad Or = 1$

On formal classification of volcanic eruption types and regimes based on the similarity theory

S.B. Samoylenko

Problem statement

Physical similarity

Formalization of physical values

The example

The regime map

Experimental simulation analysis

The choice of FP system



A. Sokorenko