THE ASCENT of KIMBERLITE: Taxicabs for Diamonds

Professor Kelly Russell
Volcanology & Petrology Laboratory
University of British Columbia, Vancouver
QUESTION:

What Allows for Ascent of Diamondiferous Kimberlite?

ORGANIZATION

Diamond Basics
Mantle Basics
Kimberlite Basics
THE ISSUE
Answer
Proof of Concept
A NEW THEORY
Diamond Basics

Carbon Polymorphs (C)

Graphite (Hexagonal)
Planar layered structure
Soft Mineral 2/10

Diamond (Cubic)
Cubic structure
Hard Mineral 10/10
Diamond Basics

Diamond Size (Carat = 0.2 gm : Origin Carob seed)

- 39 ct.
- 119 ct.
- 603 ct.
- 83 ct.
- 100 ct.
- 13 ct.

$12 m

~120 gm

~2 gm
Diamond Basics

Diamond Size

29 carat

215 carat
Diamond Basics
Stability of Carbon Polymorphs (C)

Diamond!

Courtesy Maya Kopylova (2011)
Mantle Basics

Where are the Carbon Polymorphs (C)
Mantle Basics

Where are the Carbon Polymorphs (C)
Mantle Basics

Where are the Carbon Polymorphs (C)

 Courtesy Maya Kopylova (2011)
Kimberlite Basics

Worldwide Archaen Cratons and Diamond Mines

Courtesy Maya Kopylova (2011)
Canadian Kimberlite Bodies & Mines

Courtesy Maya Kopylova (2011)
Kimberlite Basics

Volcano & Pipe
Diavik Kimberlite Mine

- A154N: ~56.0+/−0.5 Ma
- A154S: ~55.5+/−0.5 Ma
- A418: ~55.2+/−0.5 Ma

- V: 6.2 MCM
- SA: 245882 m²
- D: 715 m

- V: 5.6 MCM
- SA: 214621 m²
- D: 600 m

- V: 5.9 MCM
- SA: 206327 m²
- D: 435 m
GOAL: A simple mechanism for kimberlite ascent

THE ISSUE

The Problem
Factoids
The Answer
Proof of Concept
A NEW THEORY

Helmstaedt & Gurney, 1995
BASIC FACTOIDS:

1) The primary composition of kimberlite melts especially volatile contents, remains unmeasured.

- Volatile enriched
- Low $\eta$
- Fragile (poor glass formers)
- High Reactivity

FOV = 7.8mm
BASIC FACTOIDS:

2) Olivine xenocrysts show early reduction in size and rounding; but later olivine crystallization is expressed as overgrowths.

*FOV = 1 mm*

*Macrocryst: Core and jacket*

*Brett & Russell (2009)*

*ROUND Core EUHEDRAL Jacket*
3) Kimberlite contains abundant xenocrysts of Ol, Cpx, Gar, ... BUT .. ORTHOPYROXENE is rare.

Peridotitic mantle: OL > OPX > Cpx > Gar (Sp)
4) Kimberlite magmas have high solids content (> 25%) and ascend through > 200 km of mantle lithosphere.

- Ascent is fast
- Ascent is continuous
- Buoyancy = Volatiles
- Deep seated Volatiles

![Diagram of Kimberlite ascent and melt](image)
BASIC FACTOIDS:

5) CO$_2$ (+ H$_2$O) solubility in silicic magmas is limited; precludes extraordinary sequestration of volatiles in melt.

- Volatiles for Buoyancy
- W & H 2007 Model
- Exsolution > 2 GPa
- Fluid-filled crack tips
- 120 km Cracks?

Silicic Melts to Kimberlite

COMPiled in Brooker et al. (2011)
Kimberlite - Ascent

• Volatile contents need to be HIGH (at depth)

• How HIGH?

• High enough to induce vesiculation within mantle at the greatest depths of sampling (see geotherms)

• High enough to support rapid ascent
  - preserves diamond
  - carries many & large xenoliths (ol +opx+cpx+gar)
  - mechanically mills xenoliths & megacrysts
  - no early crystallization (overgrowths & phenos?)
HOW?
ANOTHER FACTOID:

6) CO$_2$ solubility in carbonate melts is limited only by melt stoichiometry; Na-carbonate melt > 40% dissolved CO$_2$

Brooker et al. (2011)
THE INDUCTIVE IDEA

Assimilation-Induced Foaming
The Mechanism for Kimberlite Ascent

• ALL kimberlites start as carbonatic melts

• Carbonatic melts have stoichiometric CO$_2$ contents

• Melts enter and sample cratonic mantle lithosphere

• Peridotite disaggregates - OPX dissolves preferentially

• Carbonate melt + MgSiO$_3$ = EFFERVESCENCE
CO₂ Release
Chemically Driven Exsolution

Kimberlite Field

Olivine saturation

OPX Assimilation (rapid & preferential)

Solubility CO₂

30-20% SiO₂

0%
DEDUCTIVE TESTS OF IDEA
NEW HIGH-T WEIGHT LOSS EXPERIMENTS
Super-liquidus Conditions at T > 1050°C for > 1 hour

OPX [from xenoliths]
Finely Powdered (0-40% by Wt.)

NaCO3
$[T_f = 851°C]$
Experiments demonstrate:

1) long-term stability of dissolved CO$_2$ (~40 wt%) in Na-carbonate melt (i.e., no degassing)
2) Opx dissolves rapidly and promotes immediate effervescence of CO$_2$
3) Amount of Opx introduced dictates extent of decarbonation
4) Timescales $\ll$ Ascent rates
MECHANICAL MIXTURES

The diagram shows a graph with the x-axis labeled "Na–carbonate" and the y-axis labeled "Wt. % Oxides." The x-axis is further divided into "Wt. % SiO₂" and "Enstatite." The graph includes the following trends and markers:

- A line labeled "Na₂O" with a slope pointing downwards to the right.
- A line labeled "CO₂" with a slope pointing upwards to the right.
- A line labeled "MgO" with a slope pointing upwards to the right.
- A highlighted area labeled "K" with a vertical line pointing to the left labeled "Na₄SiO₄."
MECHANICAL MIXTURES

![Graph showing the relationship between Wt. % Oxide and Wt. Fraction of MgSiO₃ for different oxides: Na₂O, Na₄SiO₄, CO₂, SiO₂, and MgO.](image)
RESULTS: Transient Experiments

- $0\%$ Opx ($\Delta < 1.8\%$)
- $25\%$ Opx ($\Delta \sim 16\%$)
- $40\%$ Opx ($\Delta \sim 21\%$)
RESULTS: Decarbonation Experiments

![Graph showing decarbonation experiments results](image-url)
RESULTS: Melts from Chemical Mixtures

![Graph showing the relationship between Wt. % Oxide and Wt. Fraction of MgSiO₃]

- Na₂O
- SiO₂
- K
- MgO
- CO₂
- OI
1) Carbonate melts enter mantle lithosphere (OPX-rich)
2) Dissolve Opx preferentially \( (a_{\text{SiO}_2}) \) Opx >> Cpx, Gar, Ol
3) Causes spontaneous deep-seated effervescence
4) Exsolved fluid provides buoyancy

5) Melt is driven to higher \( \text{SiO}_2 \) contents (i.e., Kimberlite)
6) Allows for late saturation of melt with Olivine
7) Continued assimilation = more vesiculation = more cargo
8) \( \Delta P \) & expansion of fluid adds to (does not drive) buoyancy