2012 Saturday Morning Lectures Series at TRIUMF

THE ASCENT of KIMBERLITE: Taxicabs for Diamonds

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QUESTION:

What Allows for Ascent of Diamondiferous Kimberlite?

ORGANIZATION

Diamond Basics

Mantle Basics

Kimberlite Basics

THE ISSUE

Answer

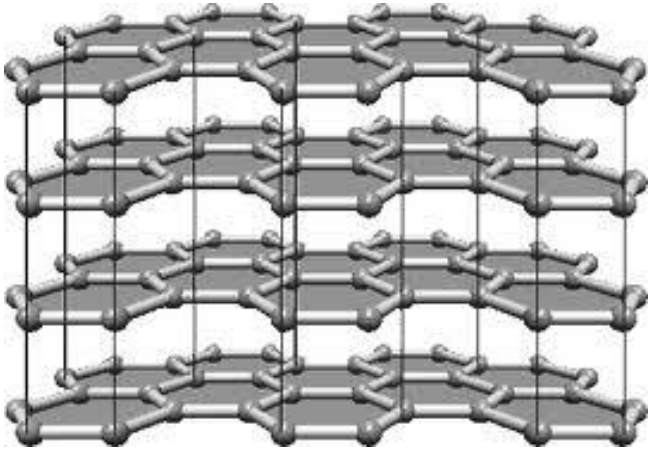
Proof of Concept

A NEW THEORY

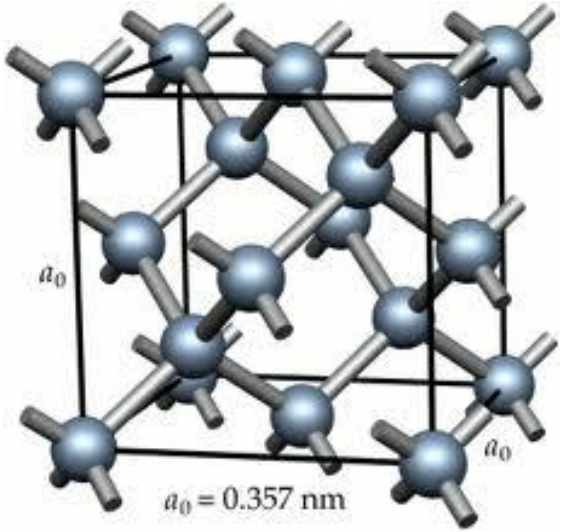
Diamond Basics

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)

$12 m

Diamond Basics

Diamond Size

29 carat

215 carat

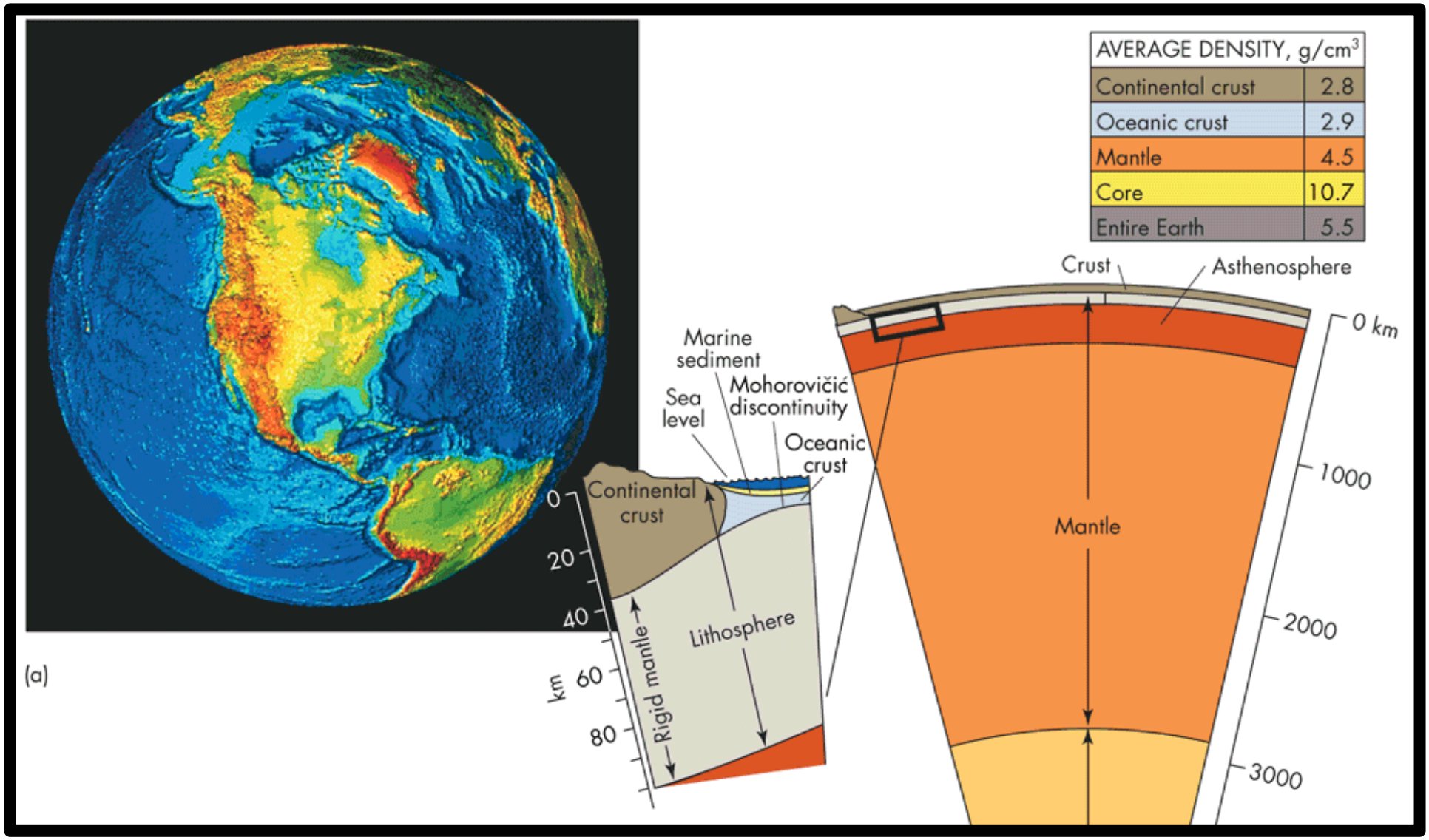
Diamond Basics

Stability of Carbon Polymorphs (C)

Courtesy Maya Kopylova (2011)

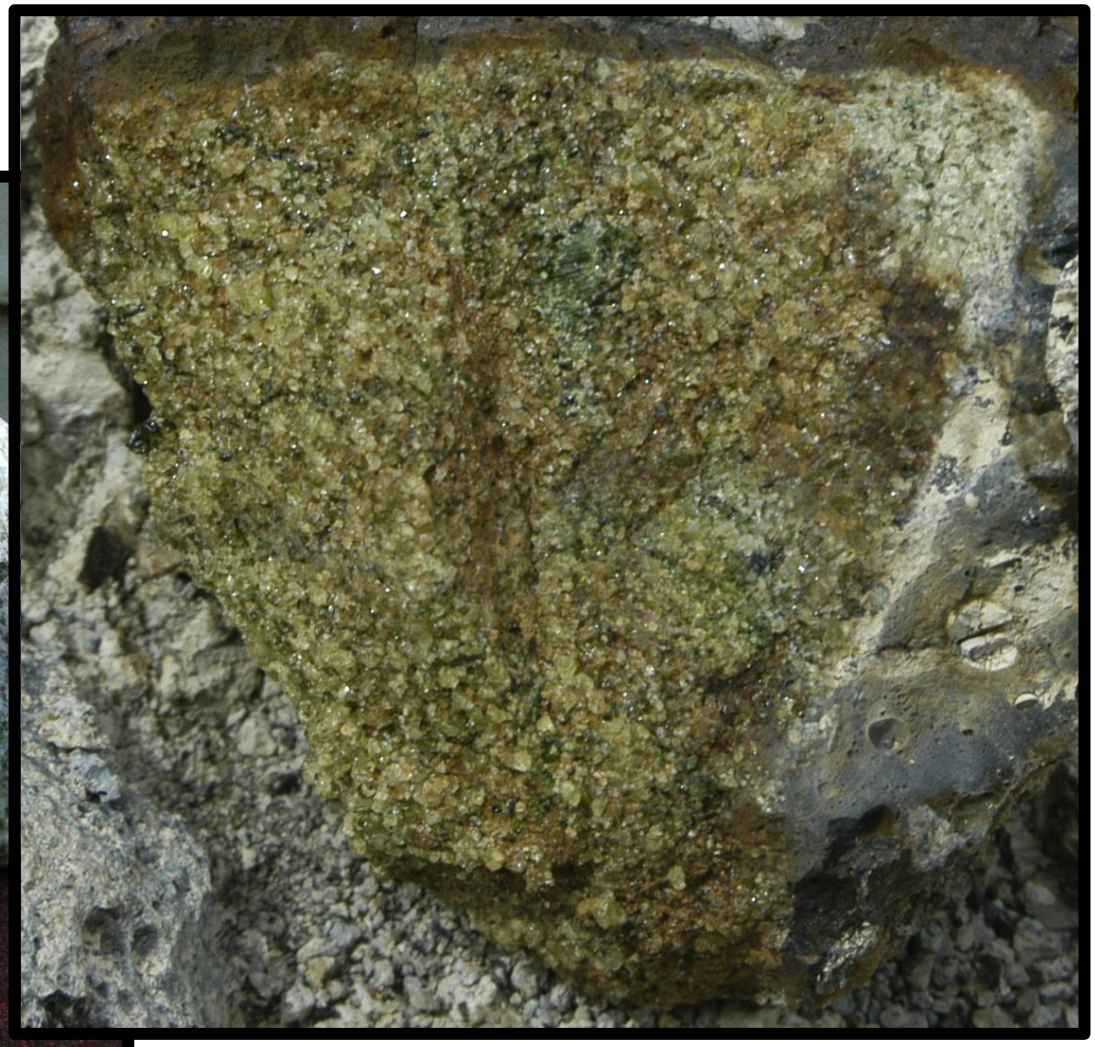
Mantle Basics

Where are the Carbon Polymorphs (C)



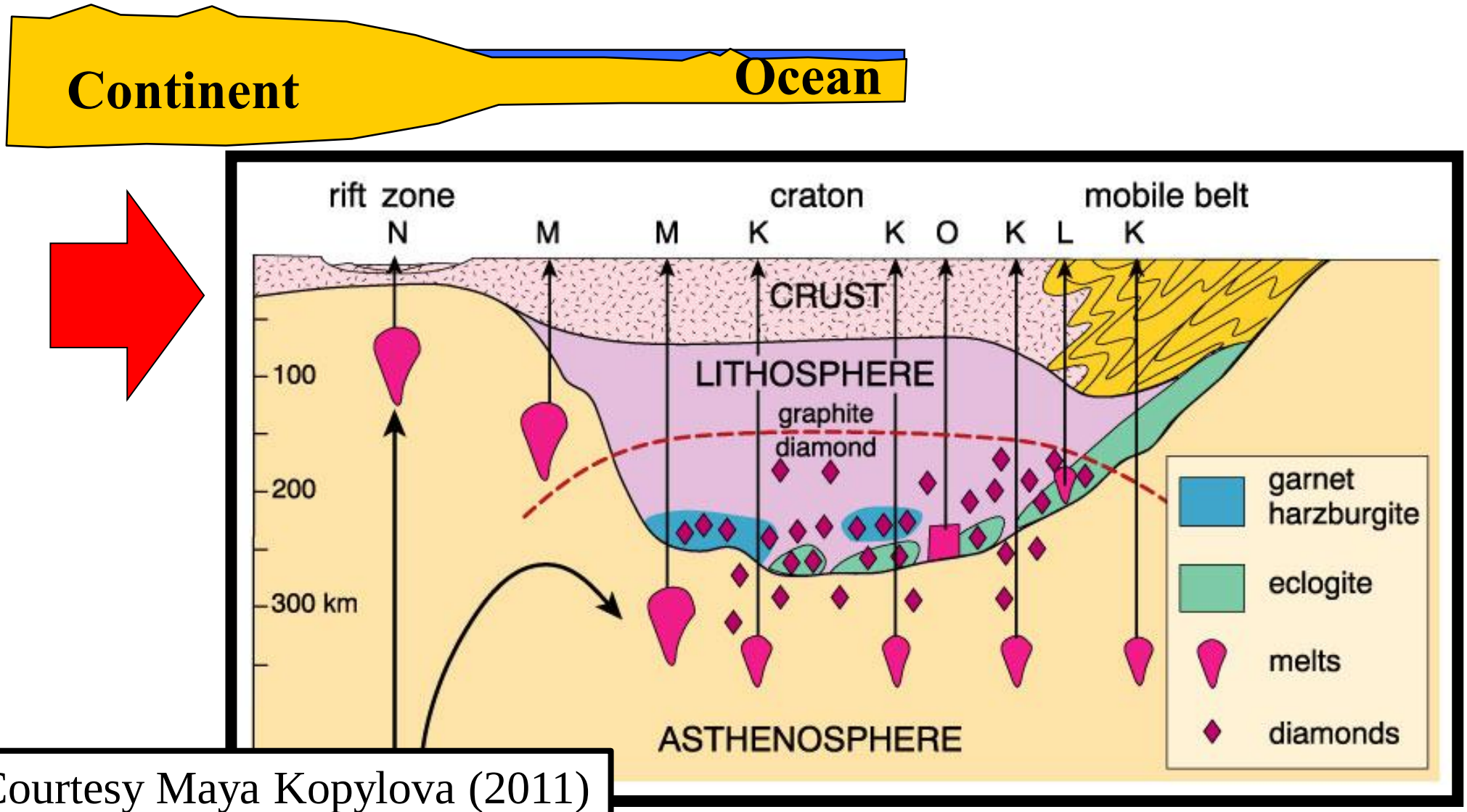
Mantle Basics

Where are the Carbon Polymorphs (C)



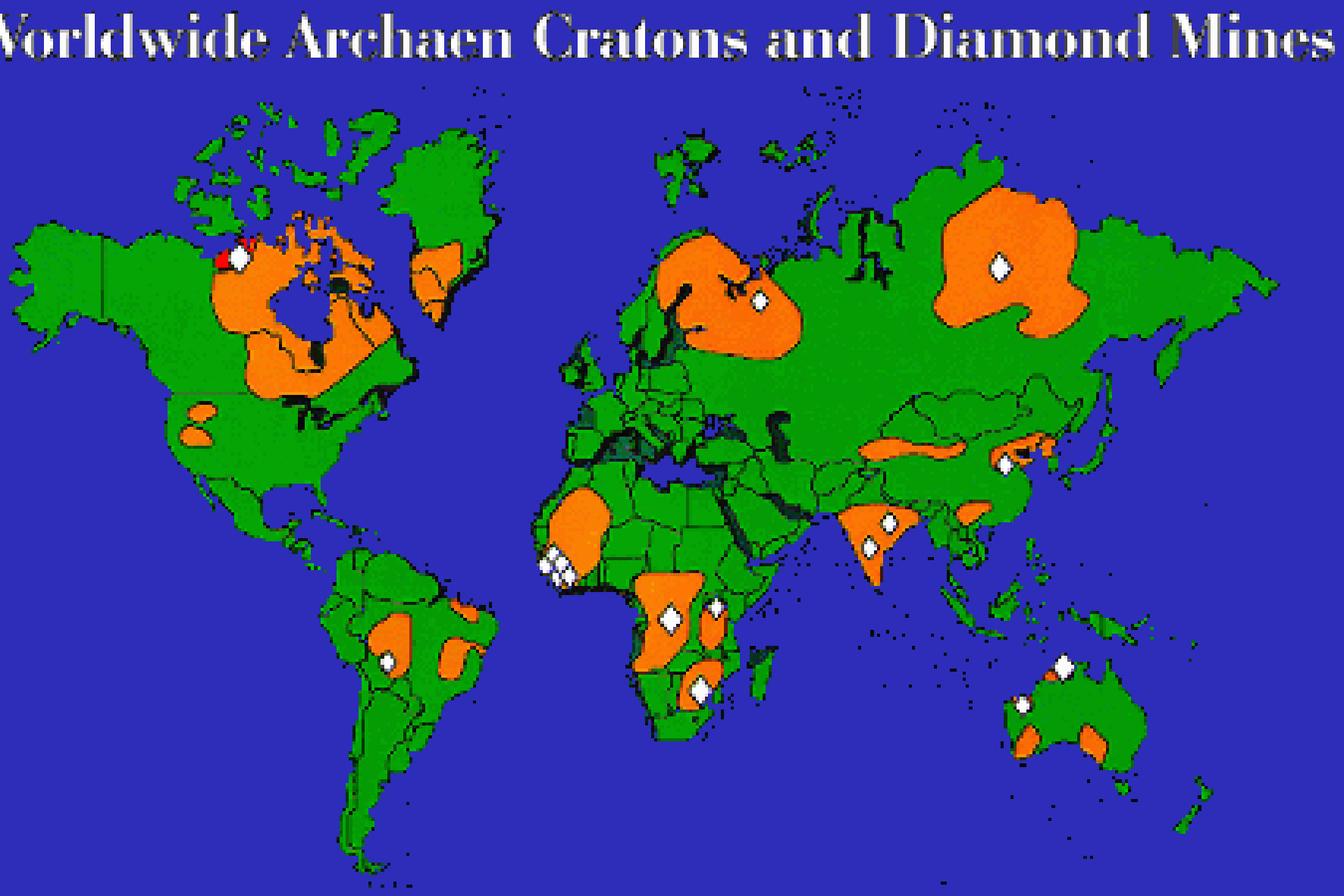
Mantle Basics

Where are the Carbon Polymorphs (C)



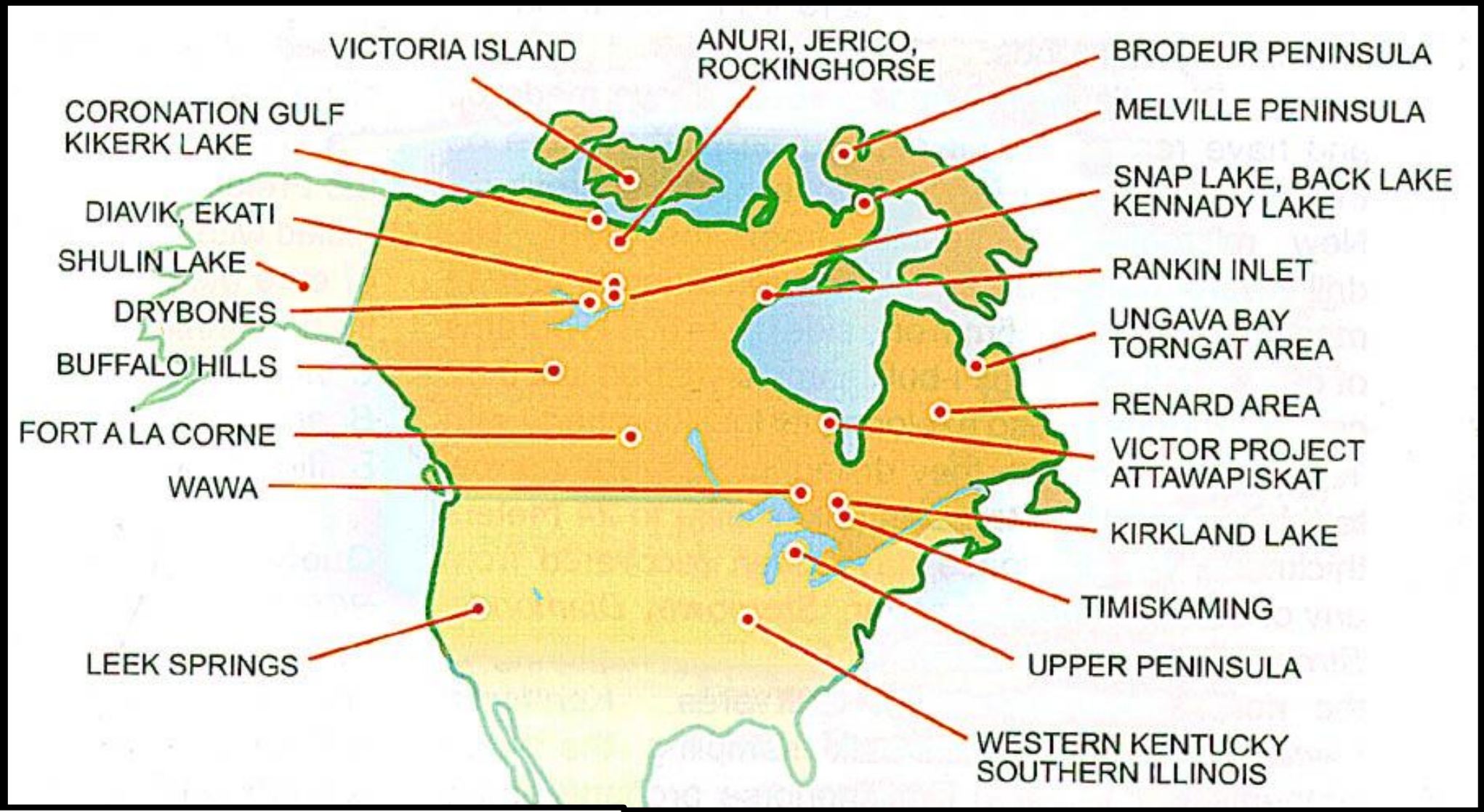
Courtesy Maya Kopylova (2011)

Kimberlite Basics



Courtesy Maya Kopylova (2011)

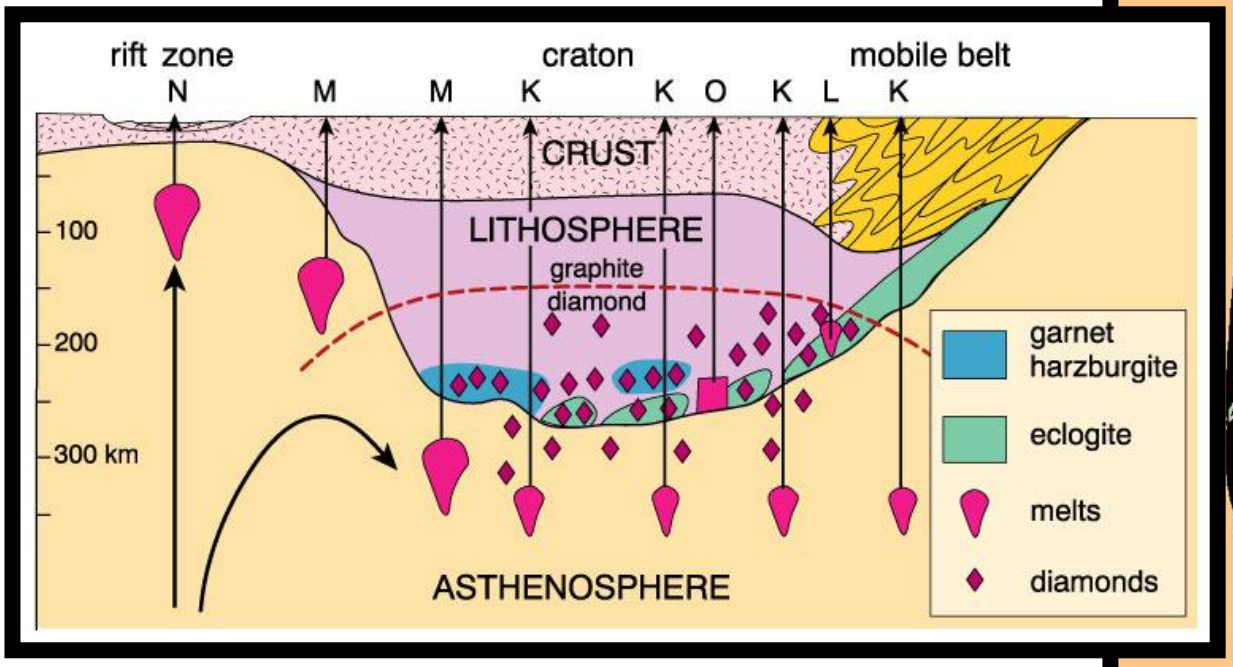
Canadian Kimberlite Bodies & Mines

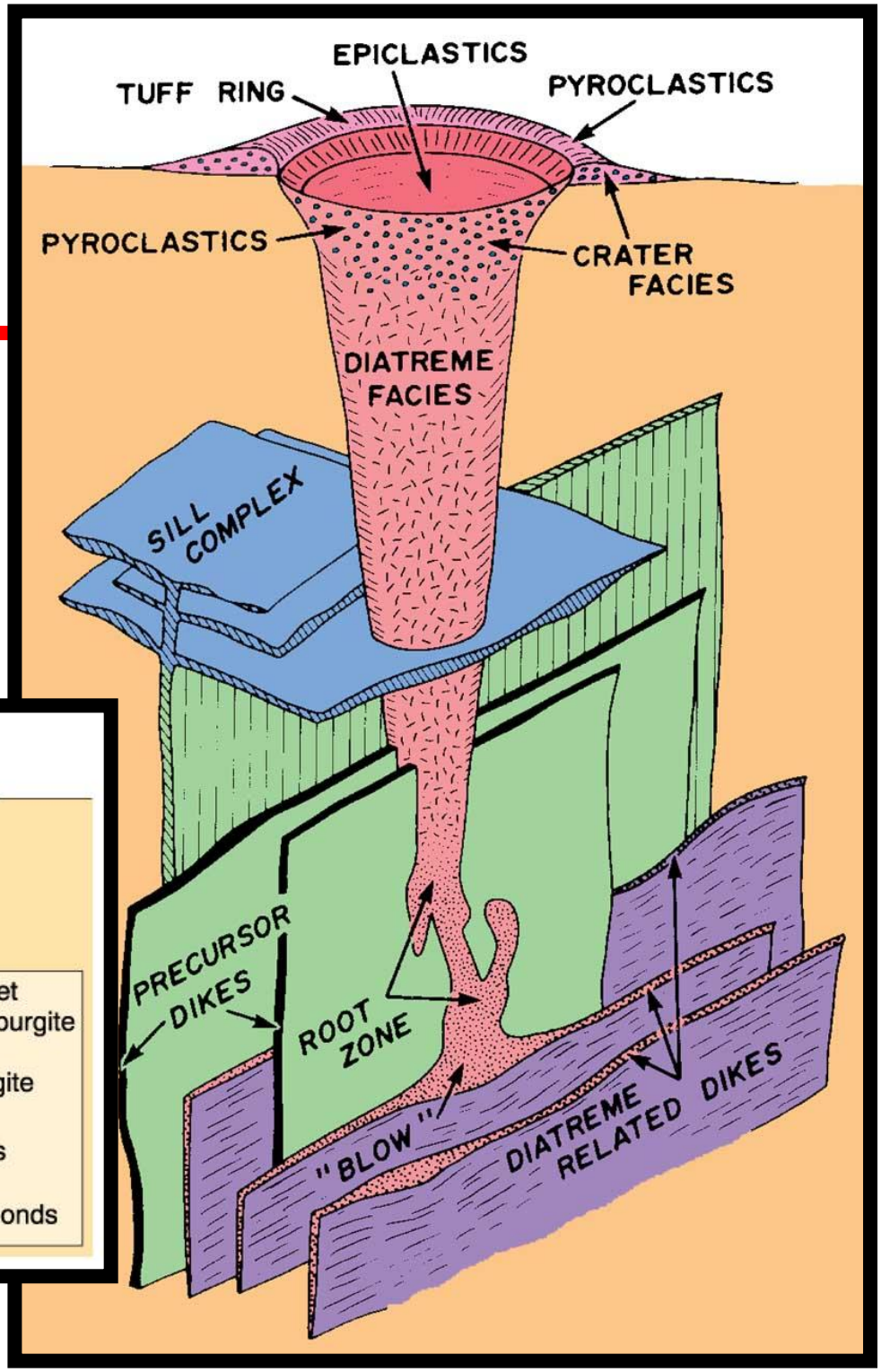


Courtesy Maya Kopylova (2011)

Kimberlite Basics

Volcano & Pipe

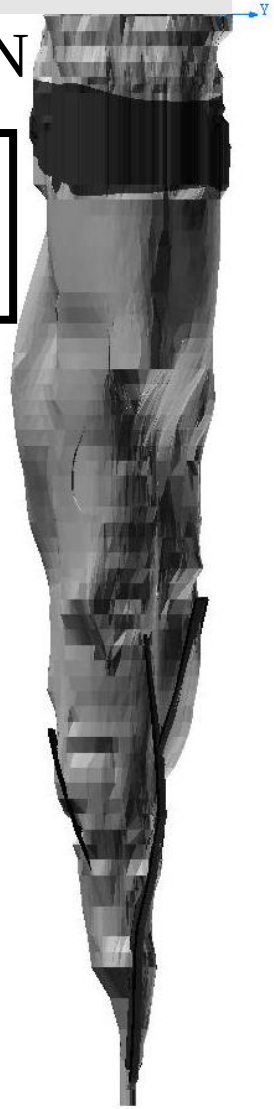




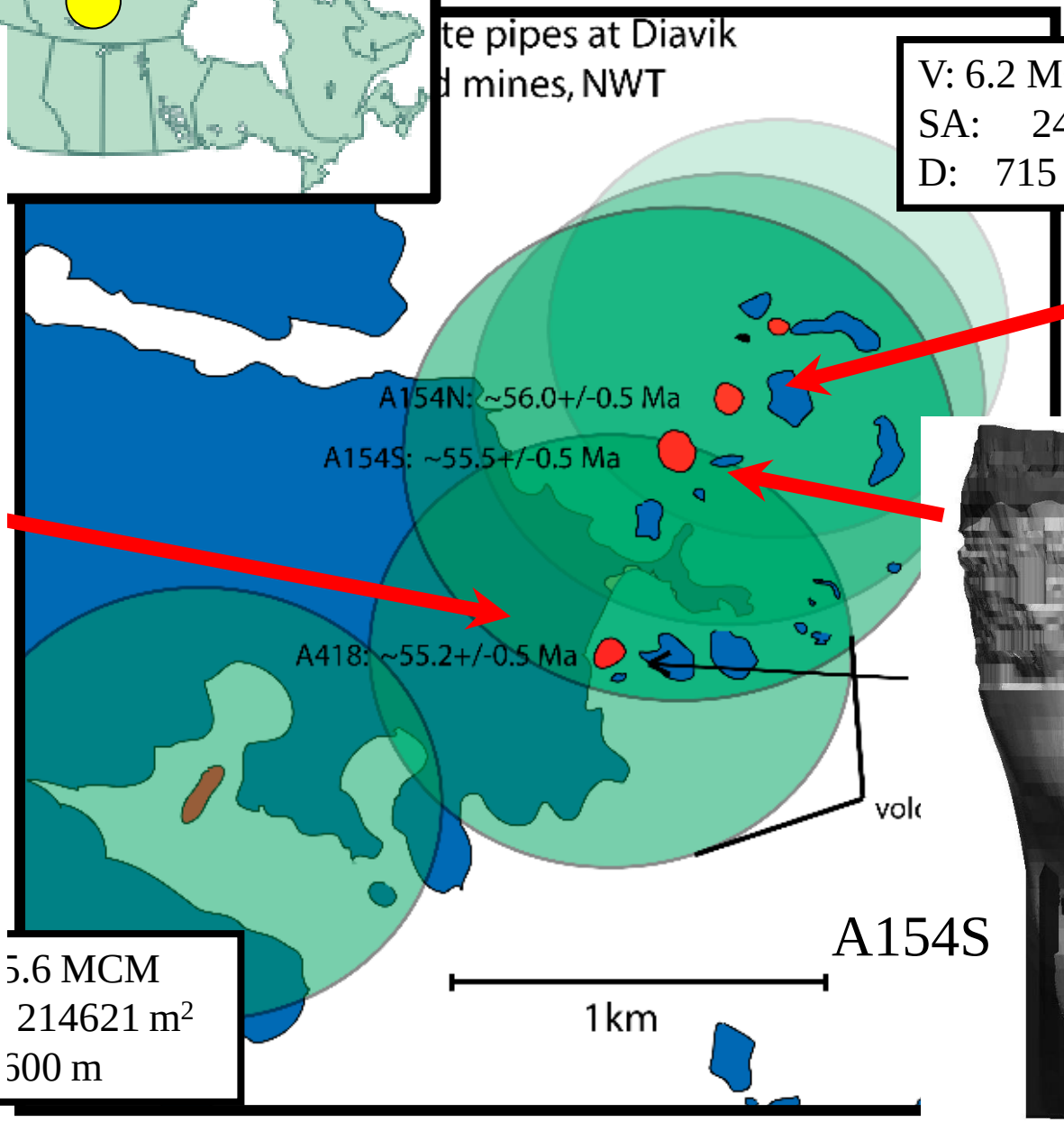
Diavik Kimberlite Mine

A418

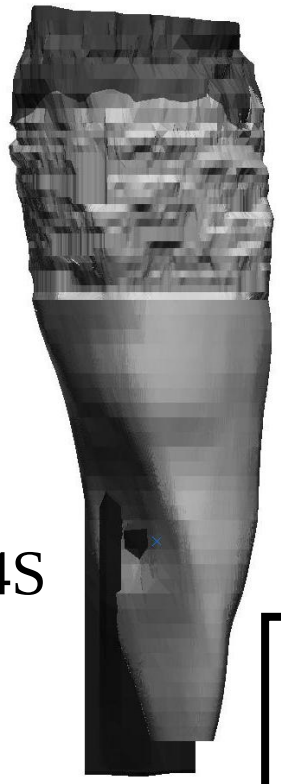
A154N



V: 6.2 MCM
SA: 245882 m^2
D: 715 m



A154S



5.6 MCM
214621 m^2
500 m

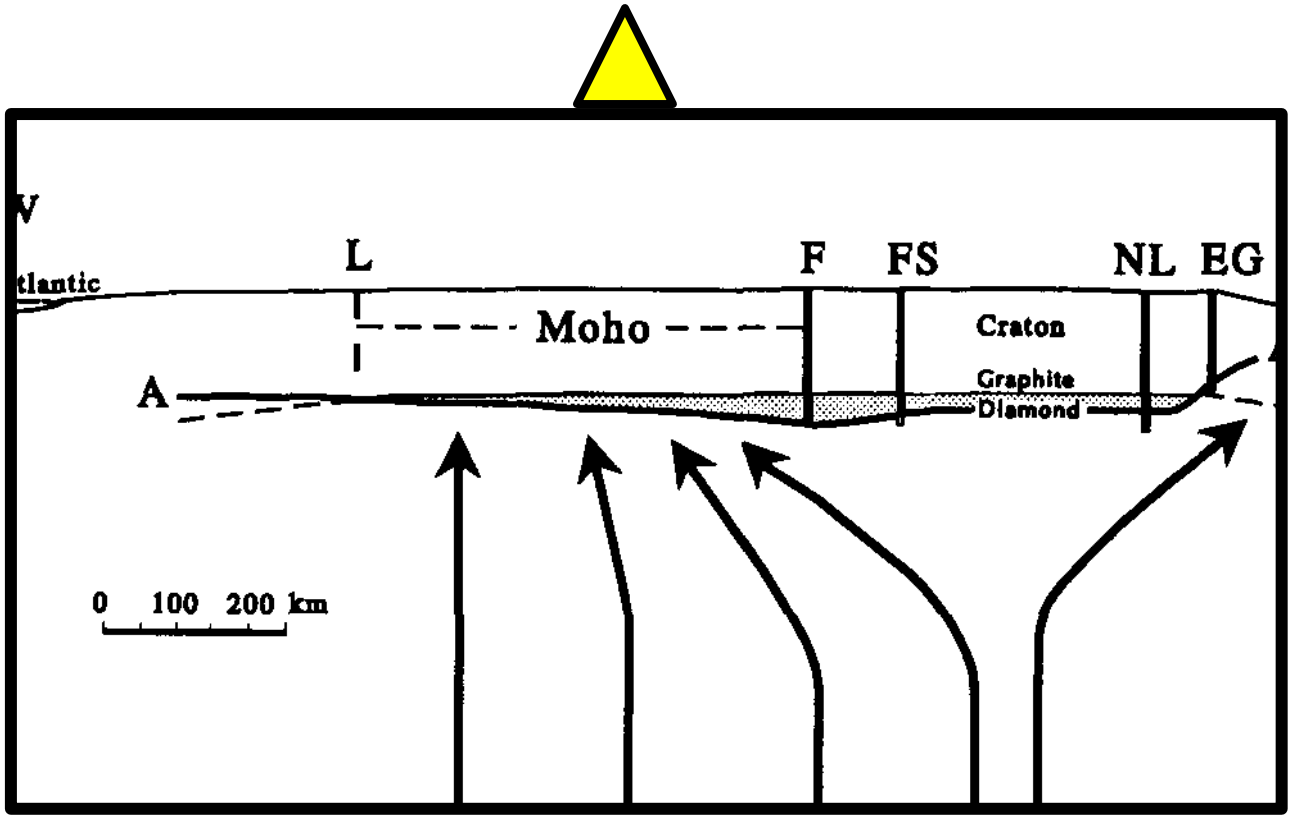
V: 5.9 MCM
SA: 206327 m^2
D: 435 m

Diavik: A154N/S

GOAL: A simple mechanism for kimberlite ascent

THE ISSUE

- The Problem
- Factoids
- The Answer
- Proof of Concept
- A NEW THEORY

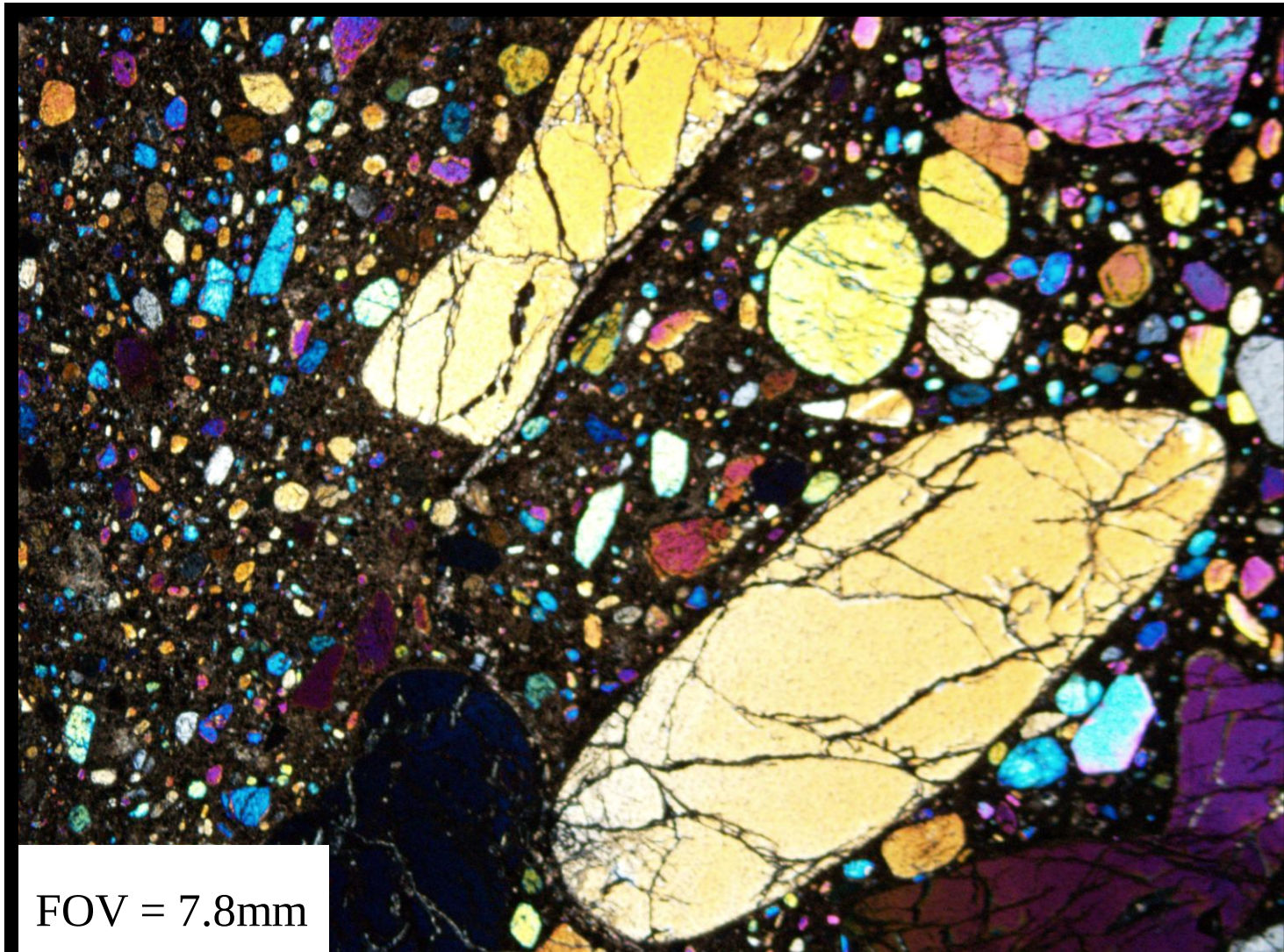


Helmstaedt & Gurney, 1995

BASIC FACTOIDS :

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

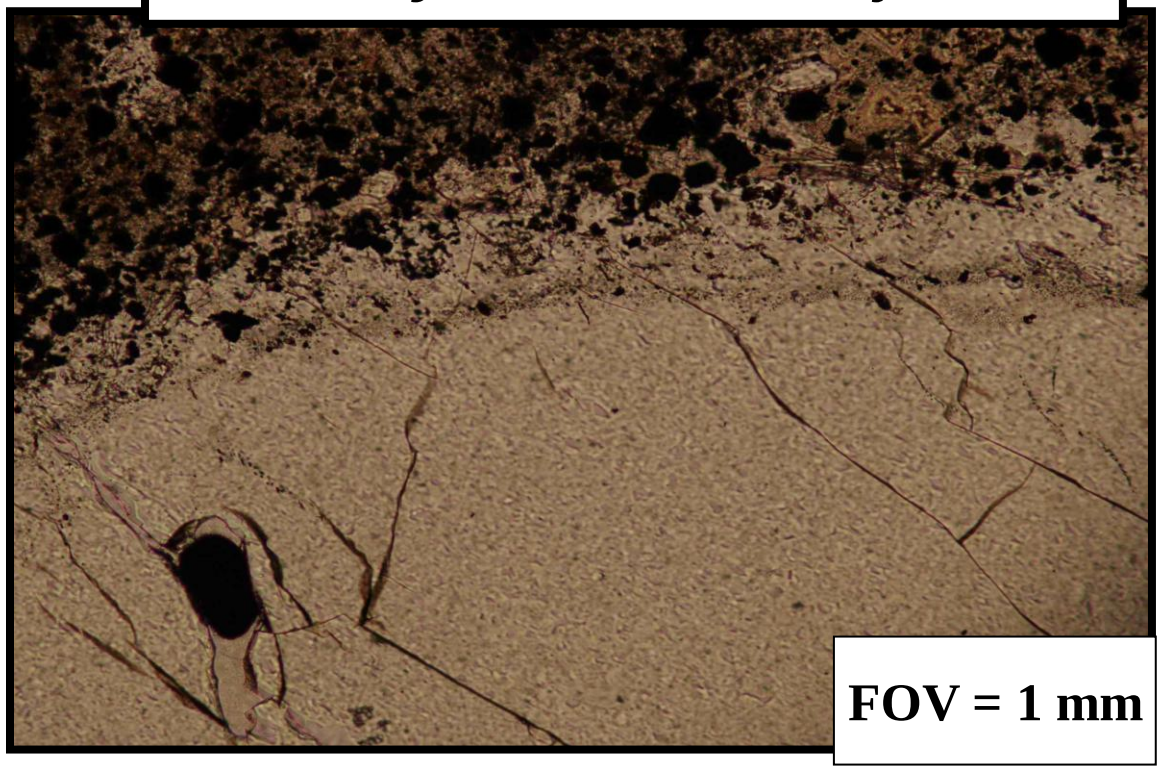
- ❑ Volatile enriched
- ❑ Low **η**
- ❑ Fragile
(poor glass formers)
- ❑ High Reactivity



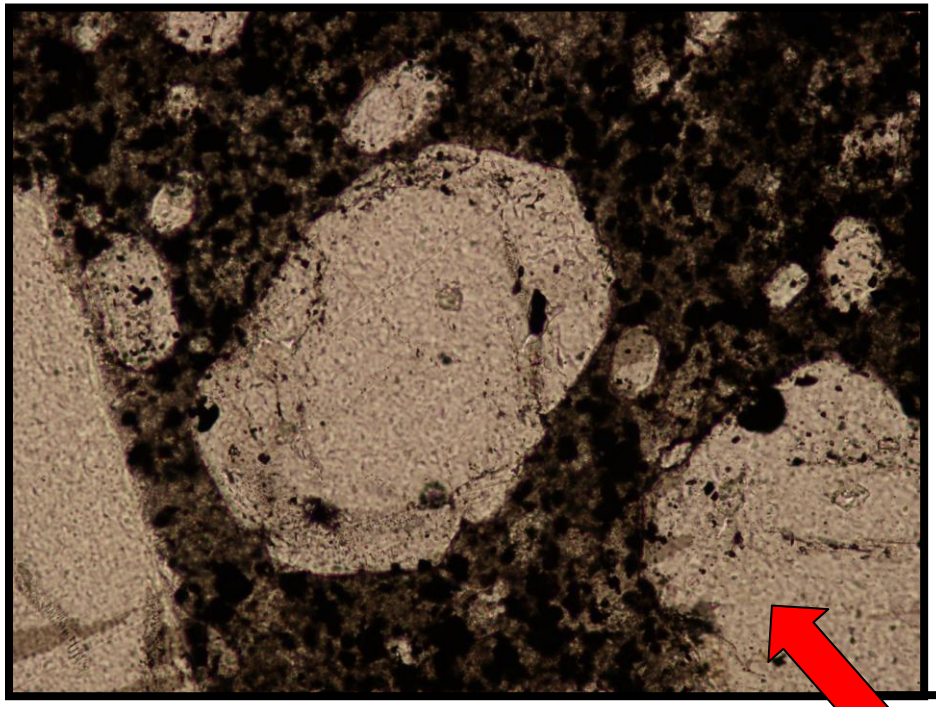
BASIC FACTOIDS:

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

Macrocryst: Core and jacket



FOV = 1 mm

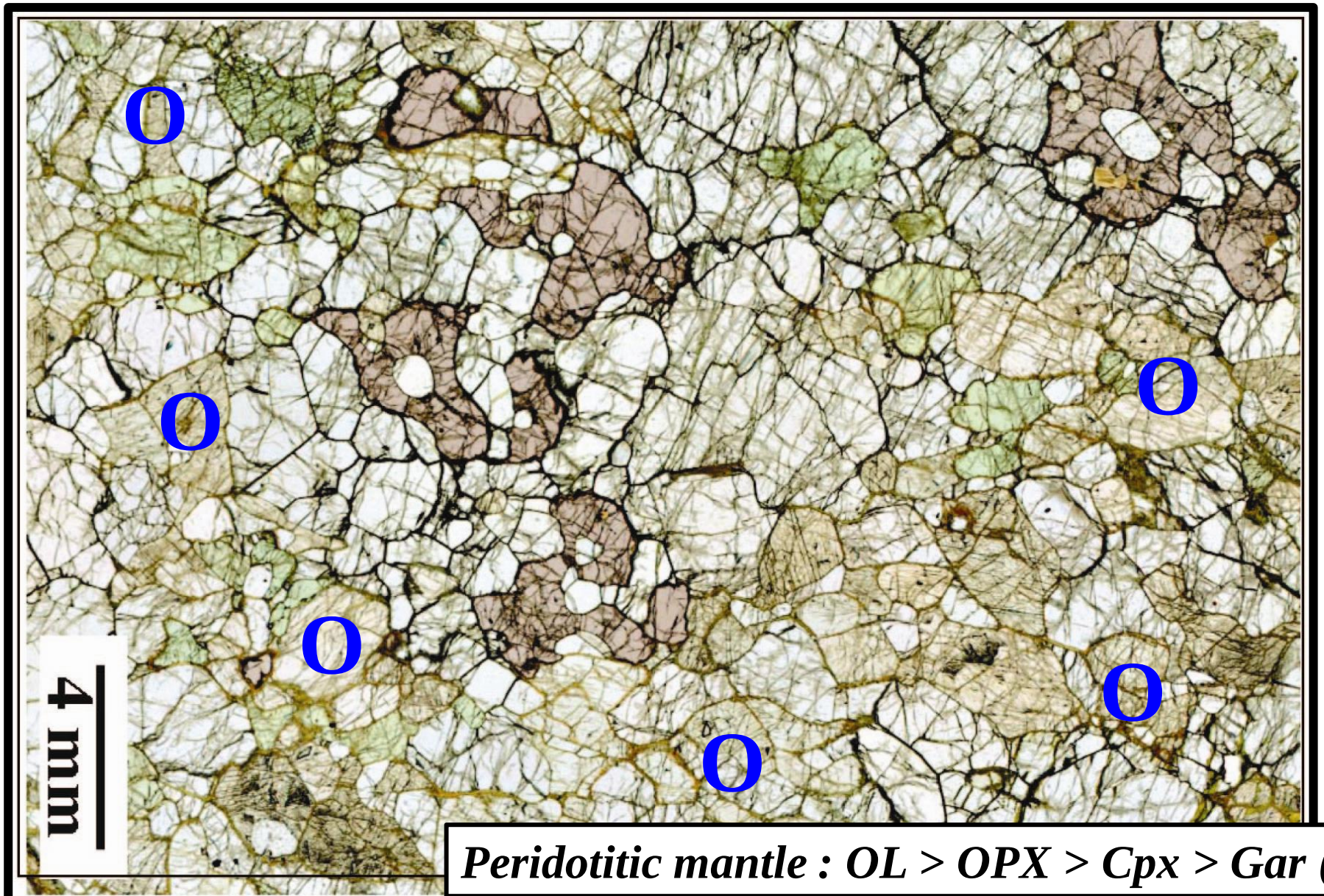


ROUND Core
EUHEDRAL Jacket

Brett & Russell (2009)

BASIC FACTOIDS:

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

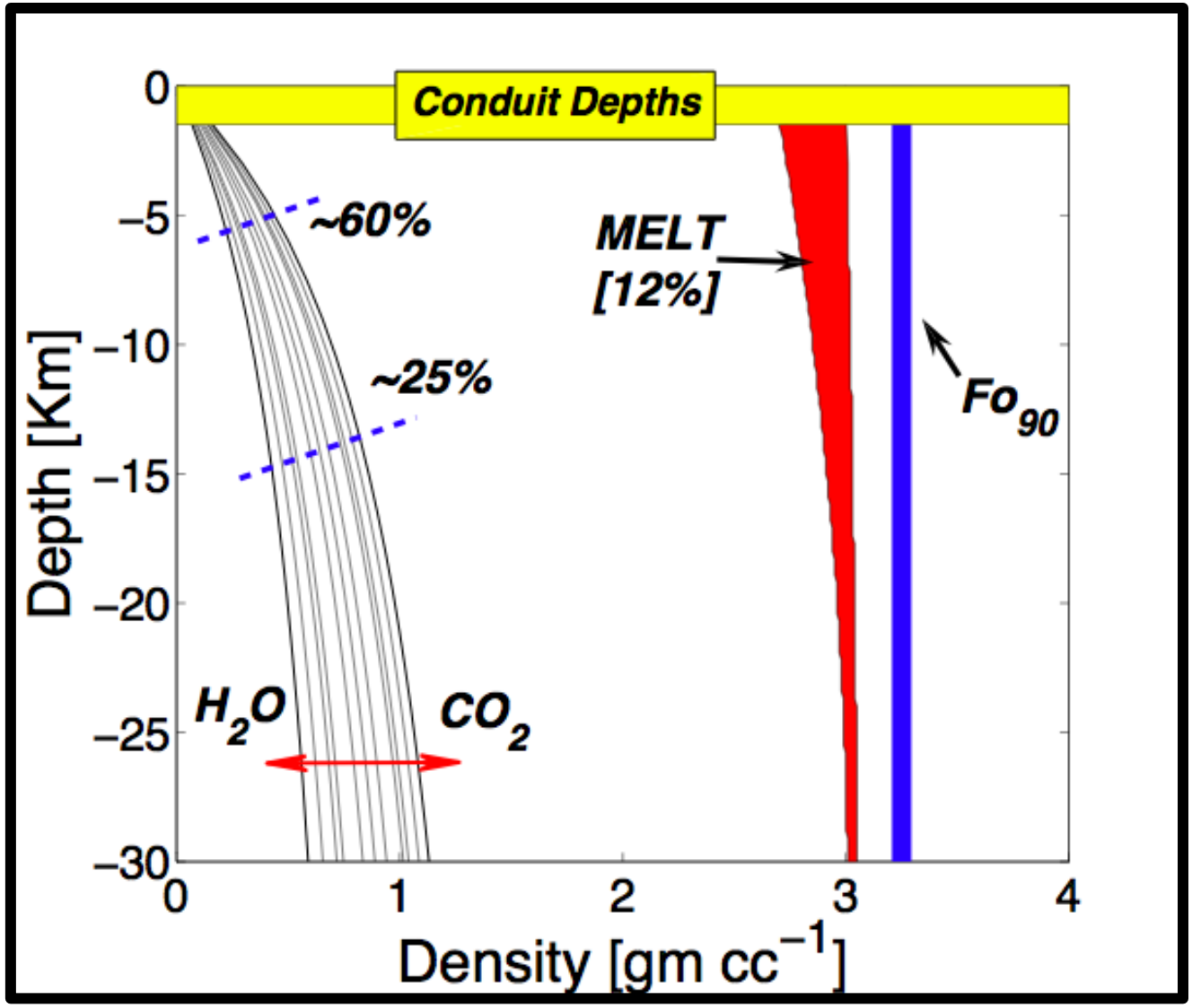


Peridotitic mantle : OL > OPX > Cpx > Gar (Sp)

BASIC FACTOIDS :

4) Kimberlite magmas have high solids content (> 25%) and ascend through > 200 km of mantle lithosphere.

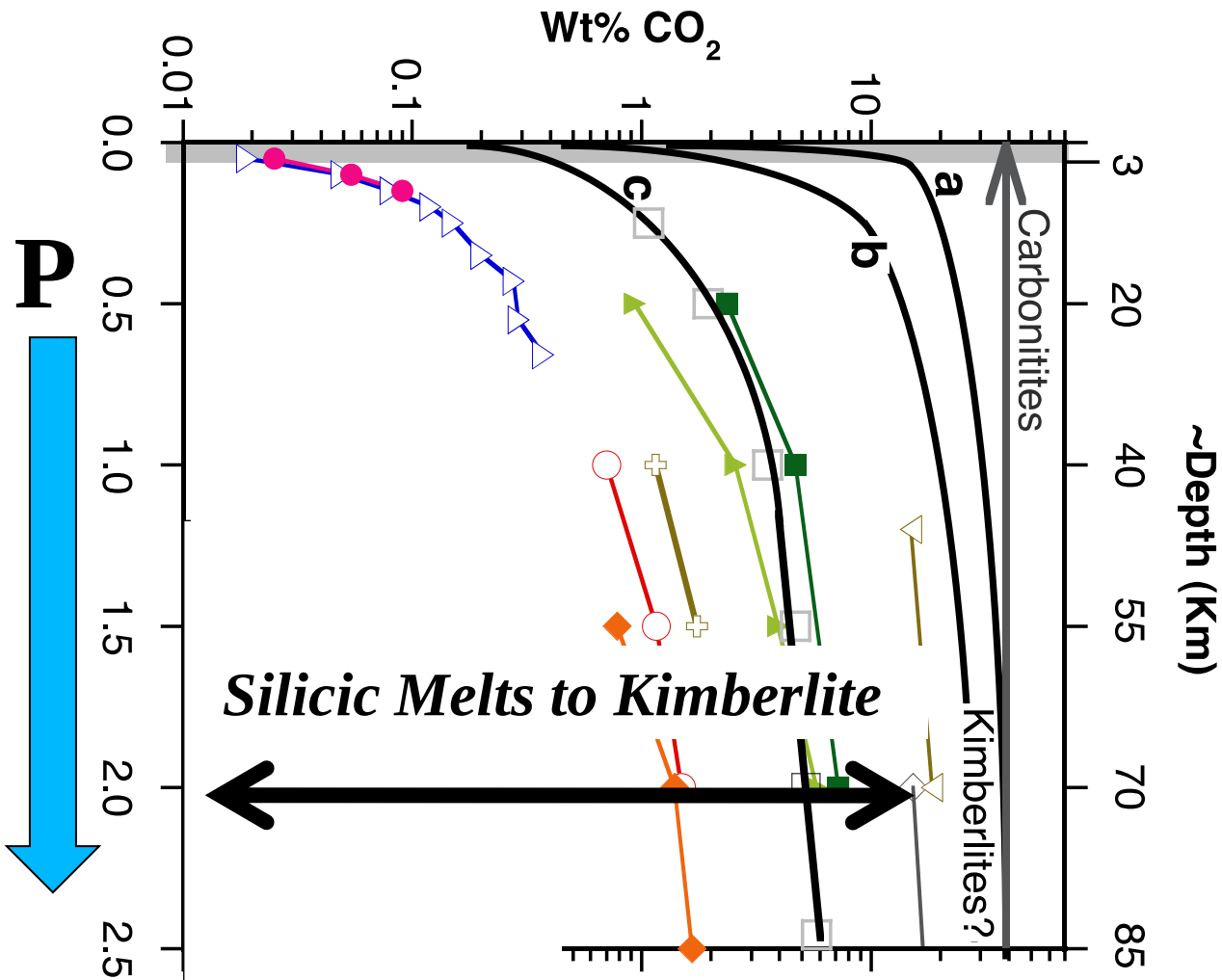
- ❑ Ascent is fast
- ❑ Ascent is continuous
- ❑ Buoyancy =Volatiles
- ❑ Deep seated Volatiles



BASIC FACTOIDS:

5) CO_2 (+ H_2O) 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?



COMPILED IN Brooker et al. (2011)

Kimberlite - Ascent

- **Volatile contents need to be HIGH (at depth)**

- **How HIGH?**

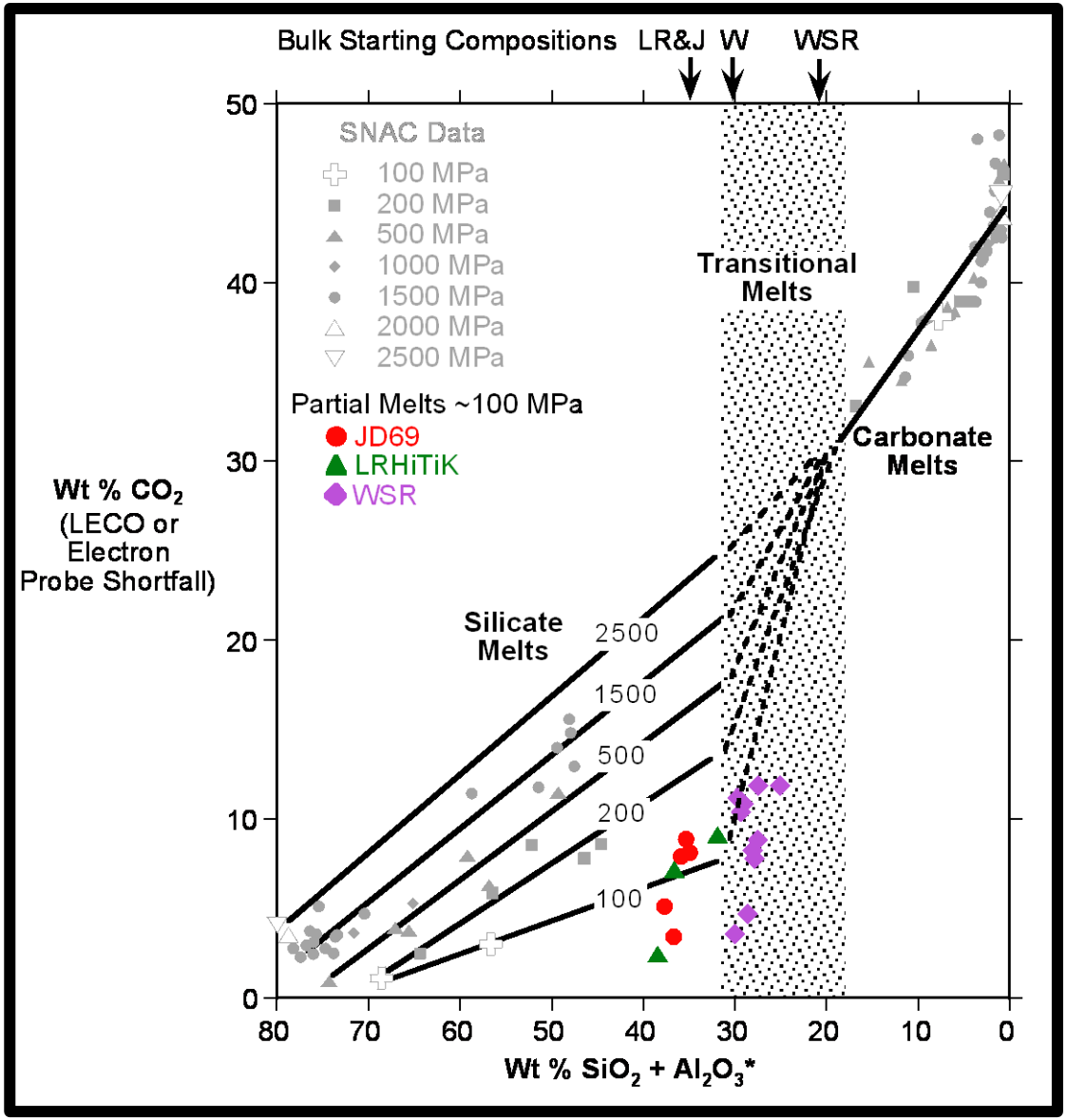
- **High enough to induce vesiculation within mantle at the greatest depths of sampling (see geotherms)**

- **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

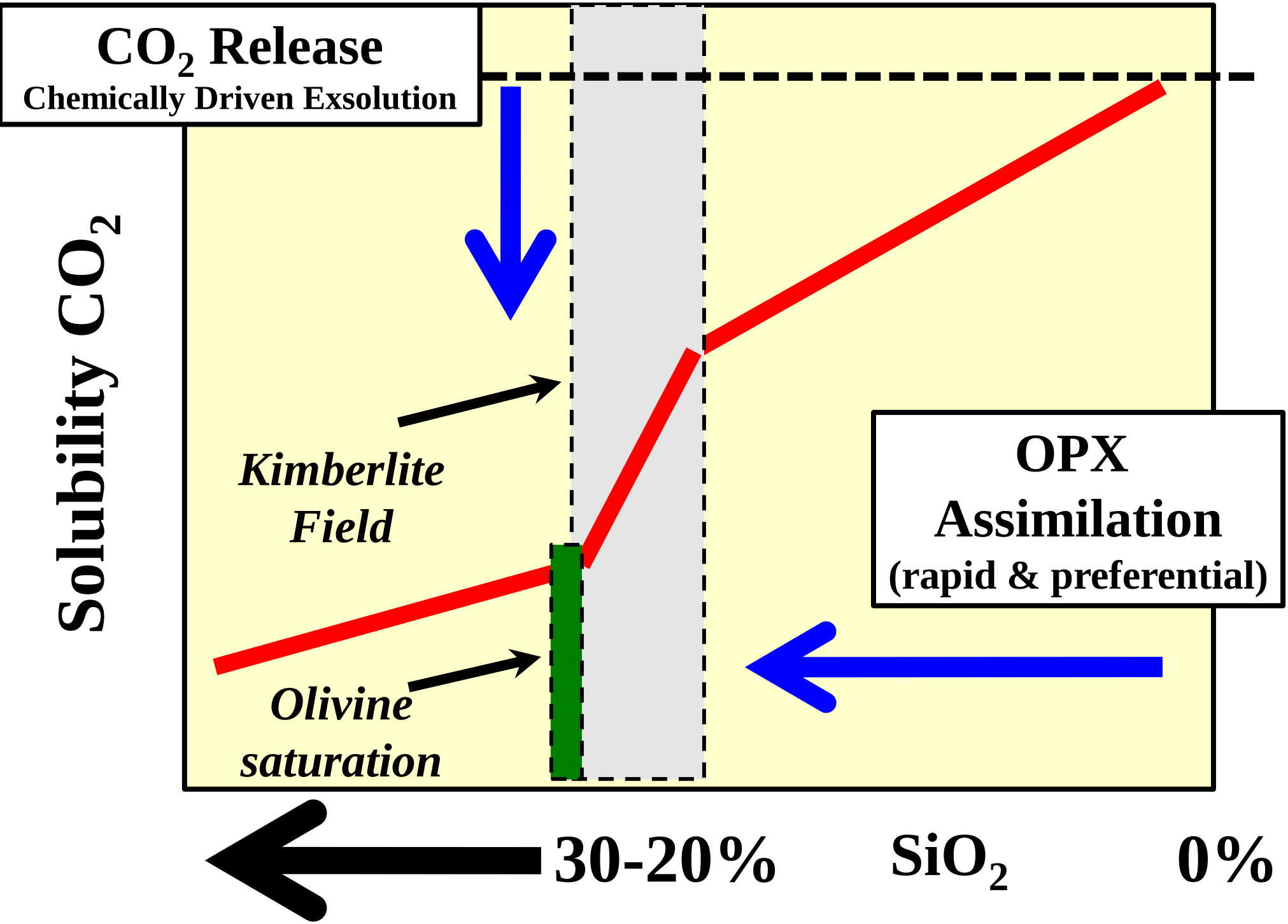


Brooker et al. (2011)

THE INDUCTIVE IDEA

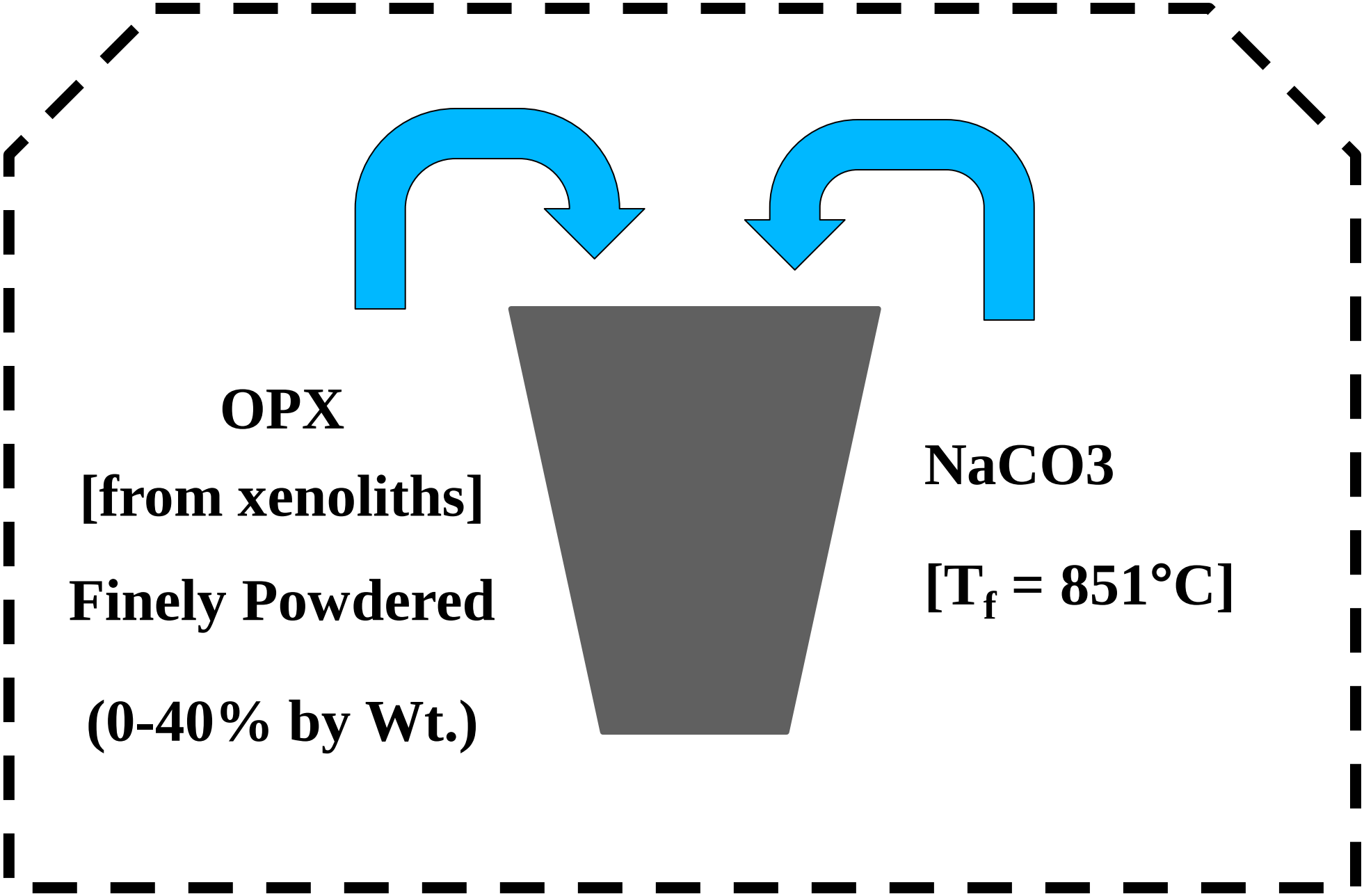
Assimilation-Induced Foaming
The Mechanism for Kimberlite Ascent

- **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**


CO_2 Release
Chemically Driven Exsolution
Solubility CO_2
Kimberlite Field
Olivine saturation
OPX Assimilation
(rapid & preferential)
30-20%
SiO_2
0%

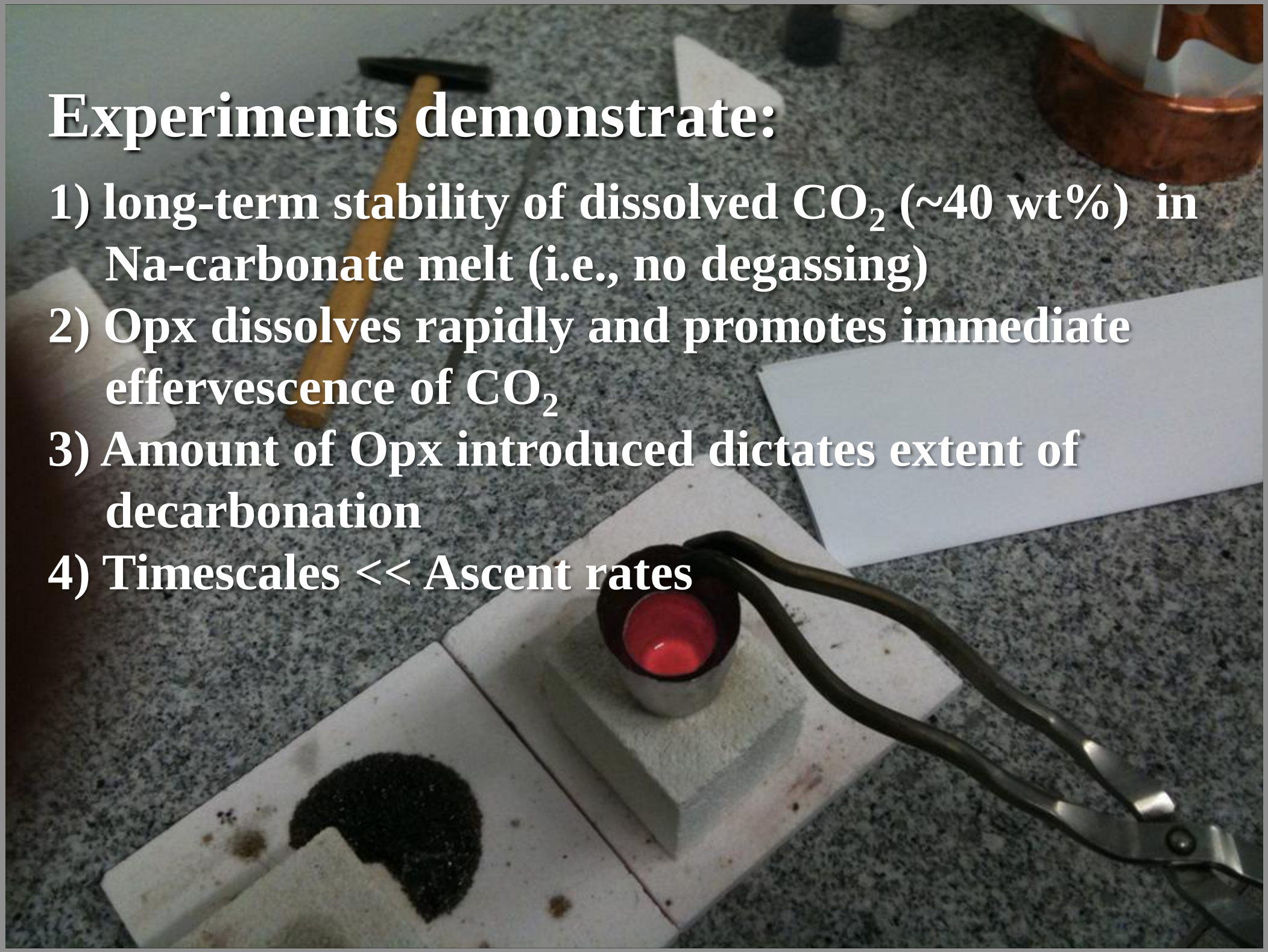
DEDUCTIVE TESTS OF IDEA

NEW HIGH-T WEIGHT LOSS EXPERIMENTS
Super-liquidus Conditions at T>1050°C for > 1hour

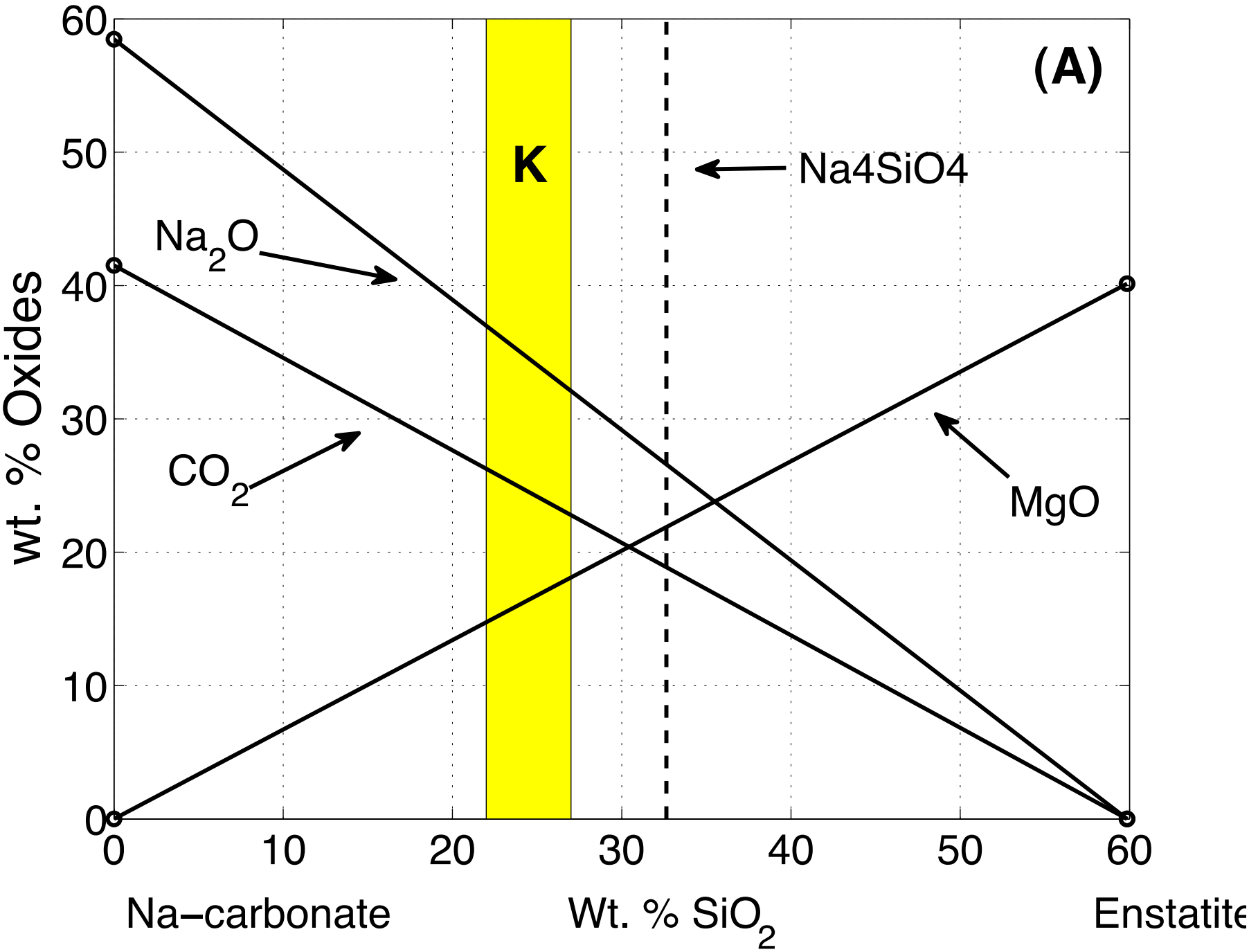


Experiments demonstrate:

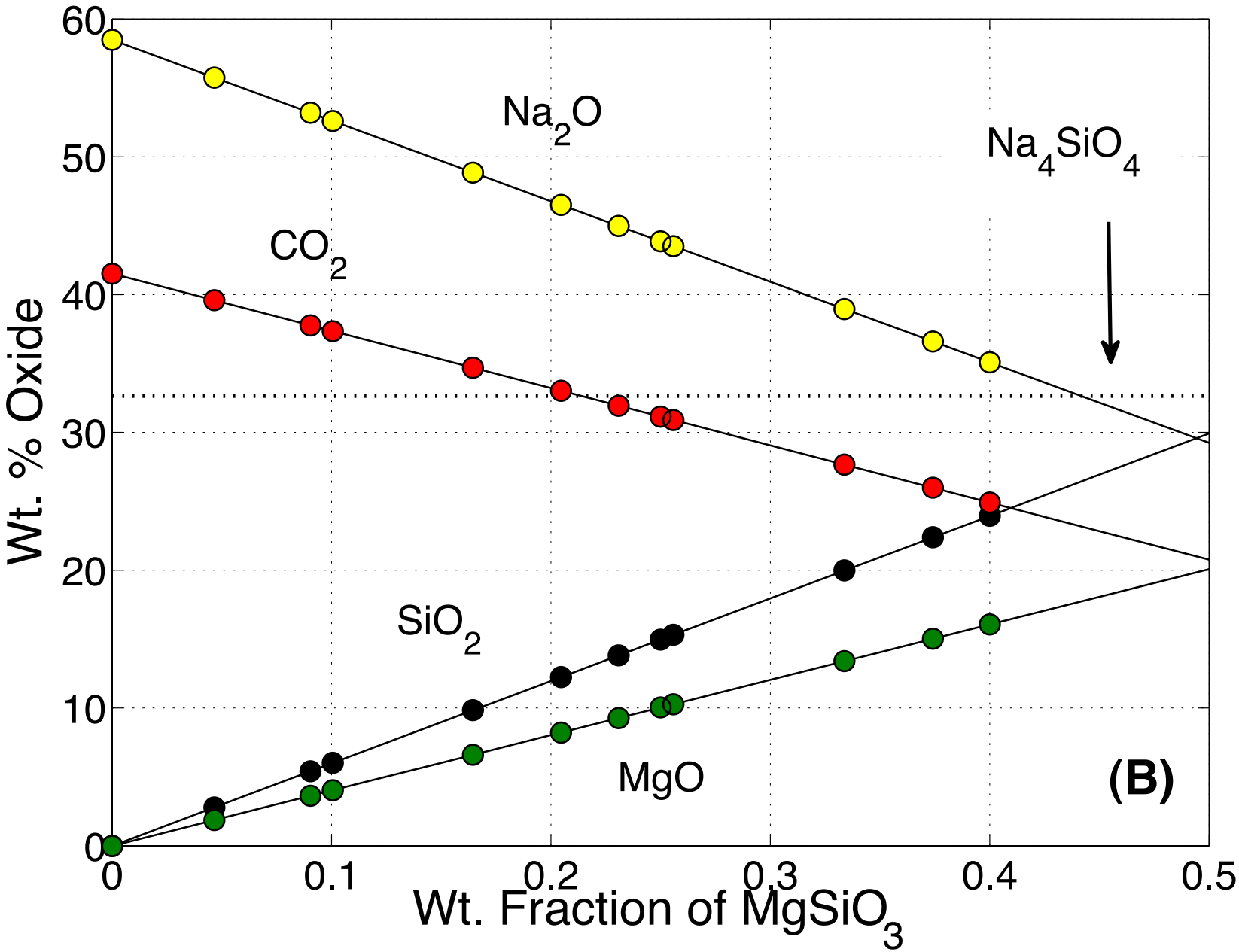
1) long-term stability of dissolved CO_2 (~40 wt%) in Na-carbonate melt (i.e., no degassing)
2) Opx dissolves rapidly and promotes immediate effervescence of CO_2
3) Amount of Opx introduced dictates extent of decarbonation
4) Timescales << Ascent rates



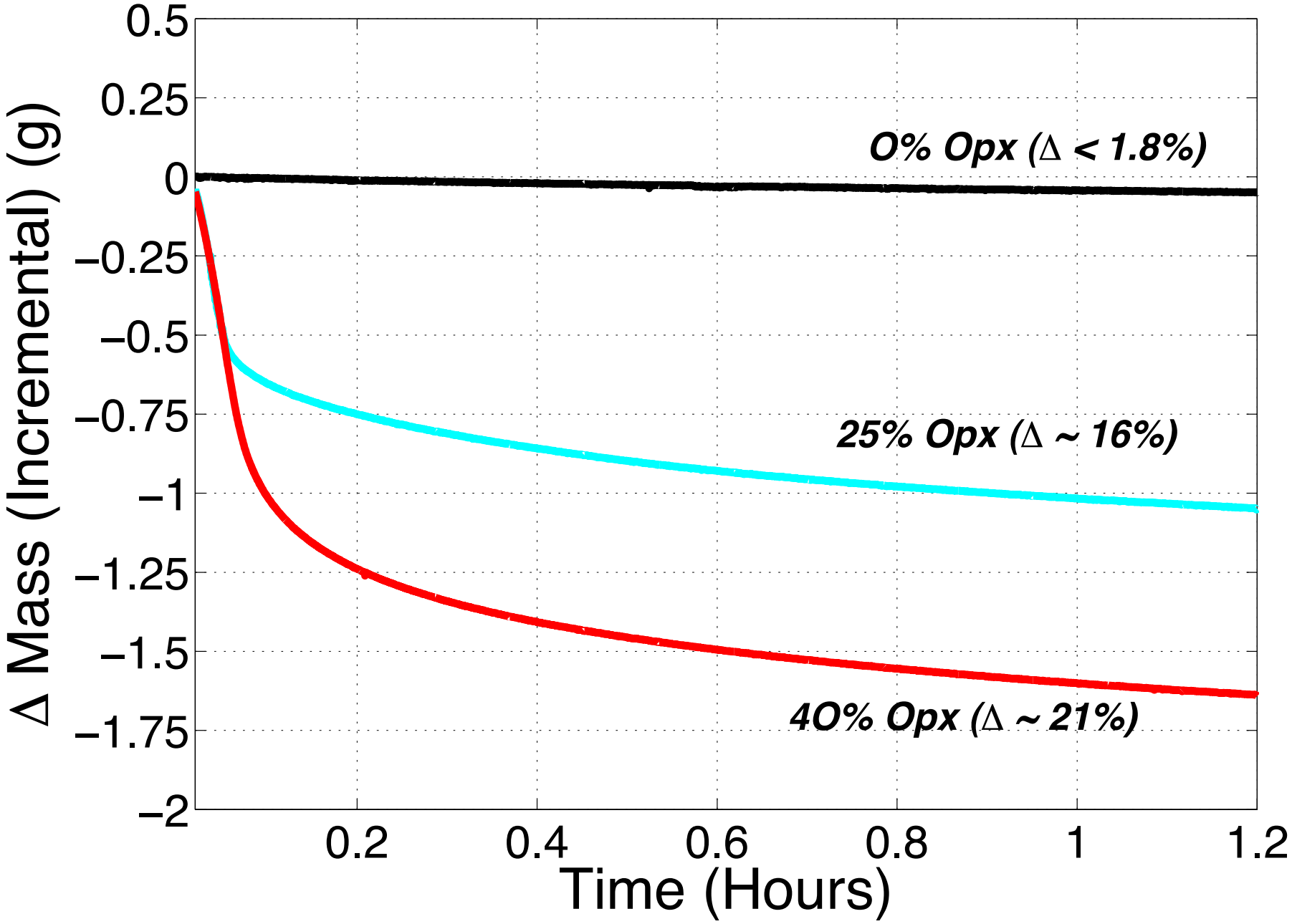
MECHANICAL MIXTURES



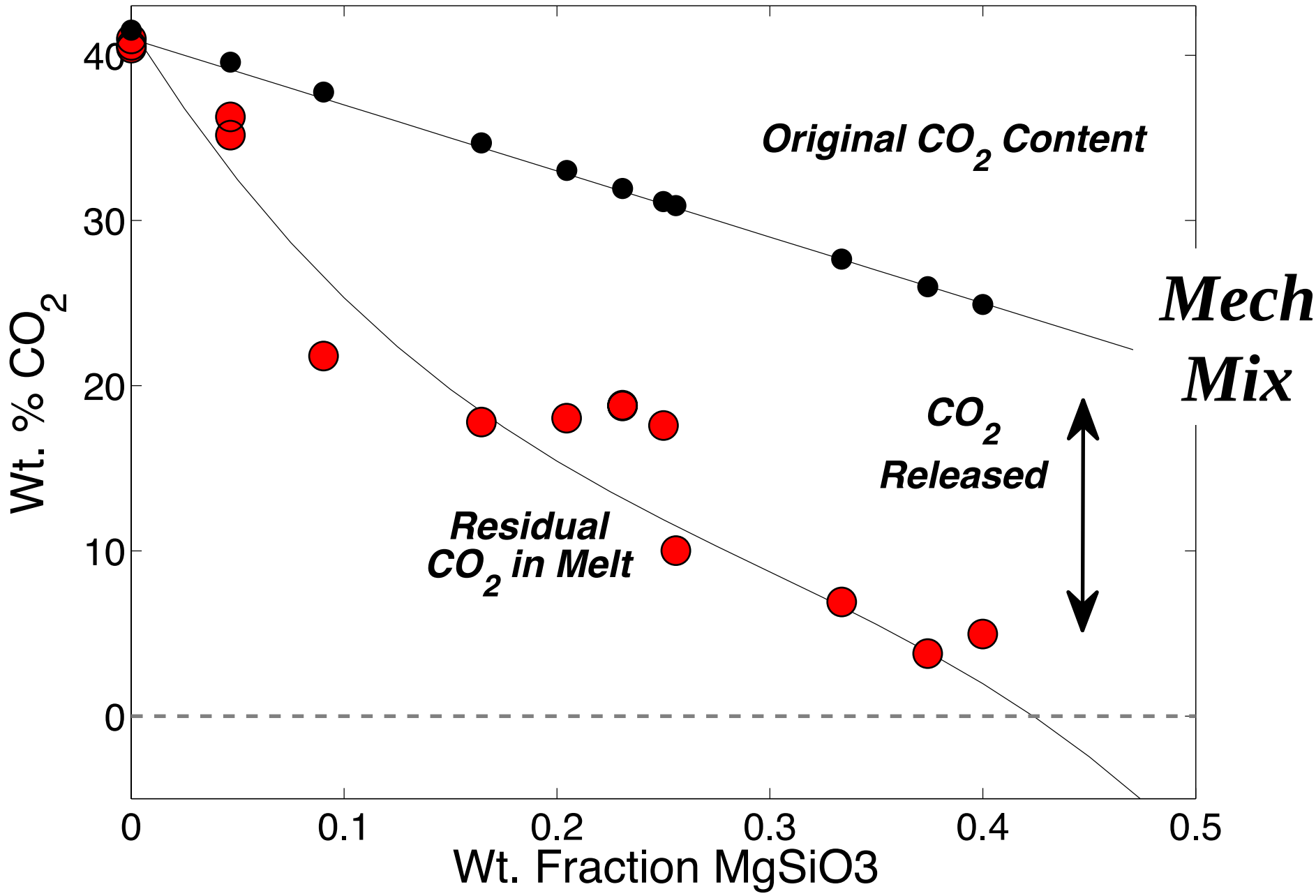
MECHANICAL MIXTURES



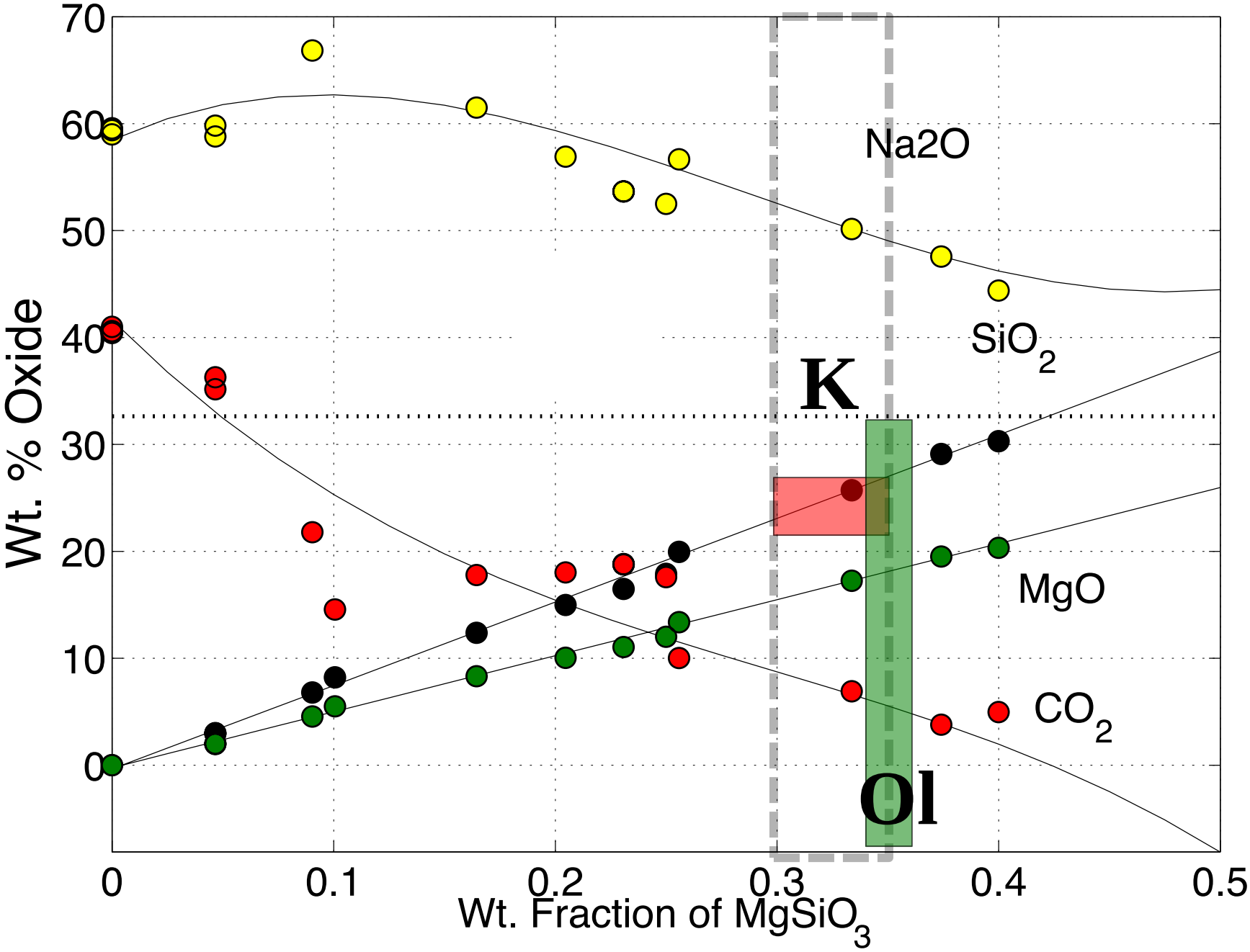
RESULTS: Transient Experiments



RESULTS: Decarbonation Experiments



RESULTS: Melts from Chemical Mixtures



Kimberlite Ascent
(THE ANSWER – FINALLY)

Kimberlite: Assimilation-Fueled Ascent of Carbonatite

1) Carbonate melts enter mantle lithosphere (OPX-rich)
2) Dissolve Opx preferentially (a_SiO_2) Opx>>Cpx, Gar, Ol
3) Causes spontaneous deep-seated effervescence
4) Exsolved fluid provides buoyancy

5) Melt is driven to higher SiO_2 contents (i.e., Kimberlite)
6) Allows for late saturation of melt with Olivine
7) Continued assimilation = more vesiculation = more cargo
8) ΔP & expansion of fluid adds to (does not drive) buoyancy