University of Victoria

NSERC CRSNG

CO_2 transport in arc magmas: Evidence from unique orbicular dikes in the Jurassic Bonanza arc, Vancouver Island, Canada

Geoscience BC

Mineralogical Association of Canada
Association Minéralogique du Canada

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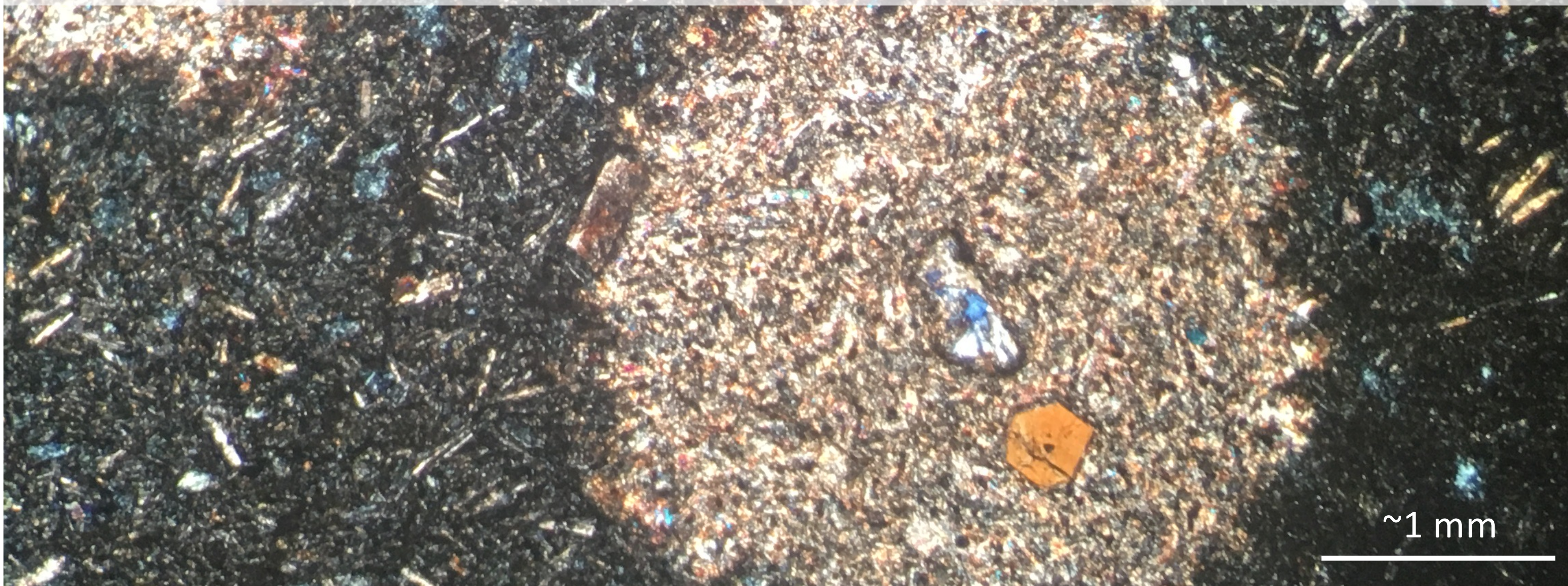
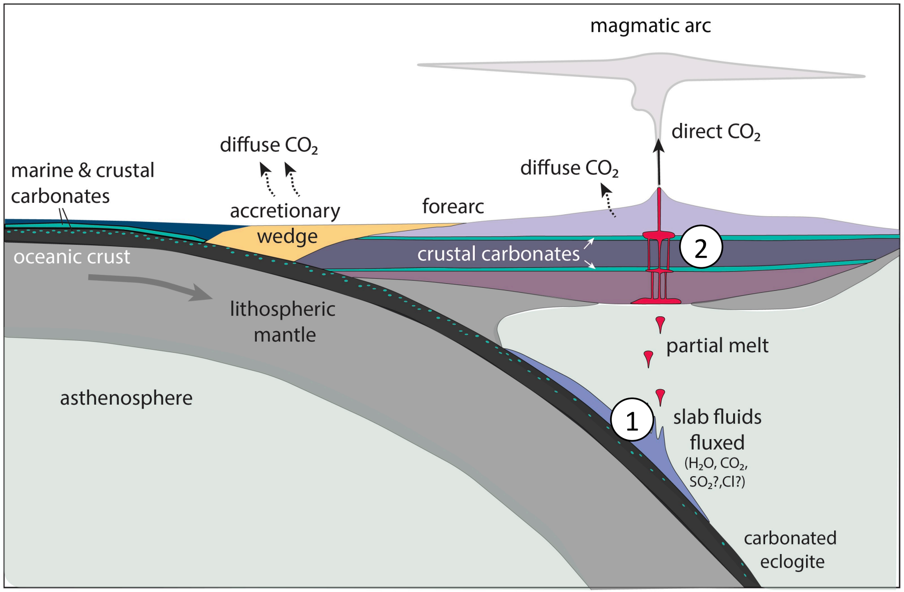
GSA Cordilleran Section Meeting 2021

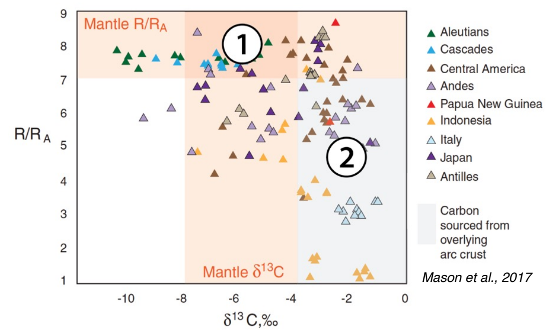


Orbicules within late—stage 197 Ma mafic dikes at Merry Widow Mtn, Vancouver Island, Canada

Do arc magmas liberate significant CO_2 from crustal carbonates?
Increasing evidence suggesting crustal carbonates play a larger role in CO_2 outgassed at arcs

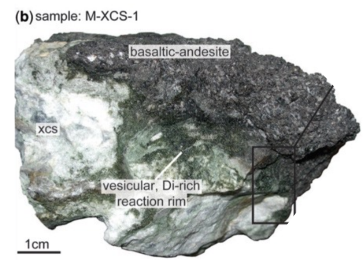


emitted gases (global arcs):



Mason et al., 2017

erupted xenoliths:



Merapi (from Deegan et al., 2010)

Carbonate assimilation and CO_2 transport in arc magmas

Complimentary perspectives

Field

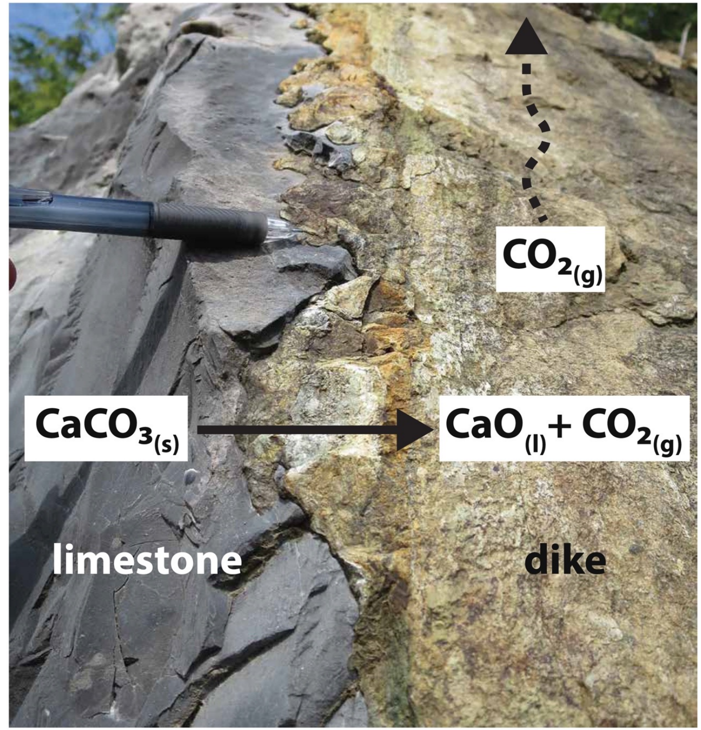
- focus on active arcs
- detailed studies on the country rock

Experiments

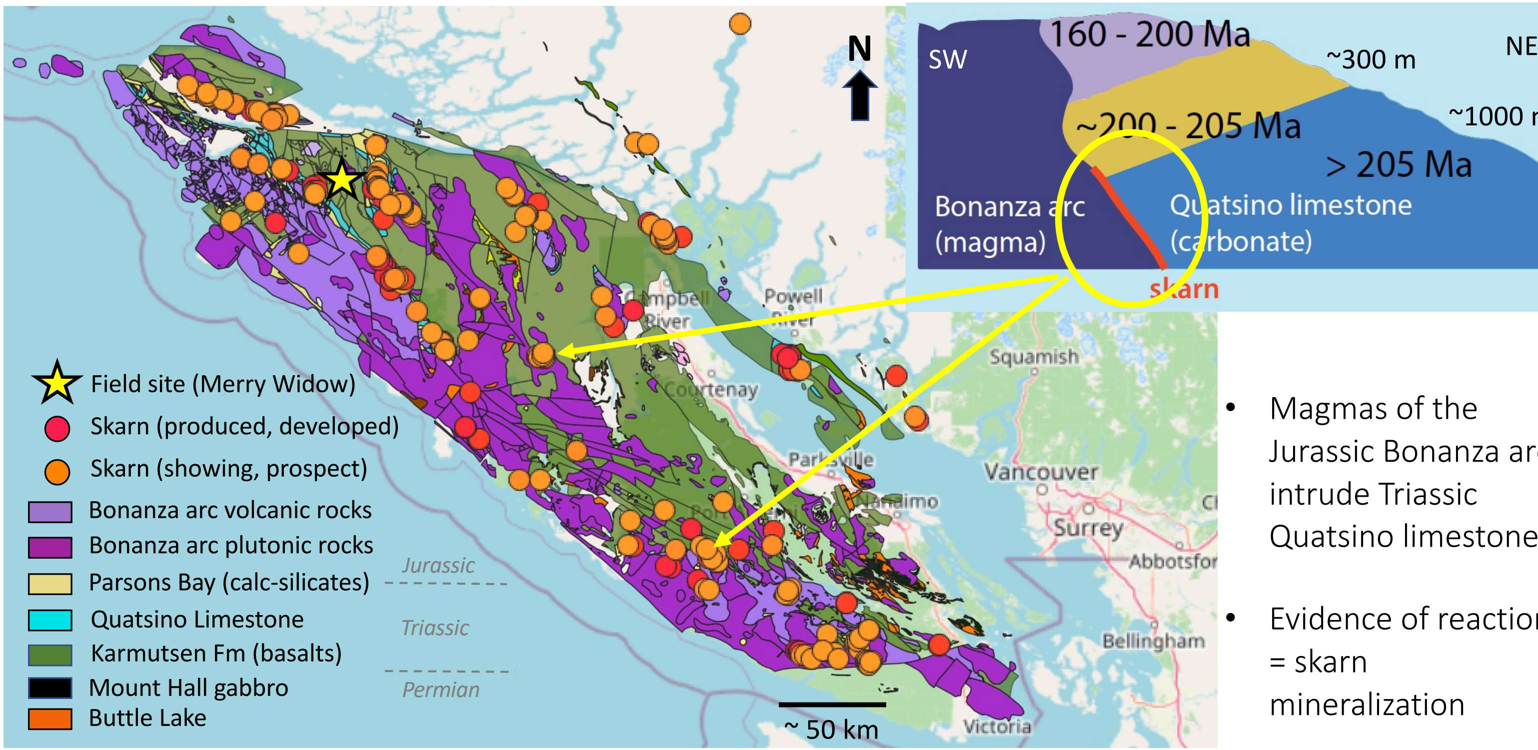
- focus on carbonate assimilation limits and fractionation products

Approach

paleo-arc exposures of magma-carbonate interactions to understand assimilation and C transport

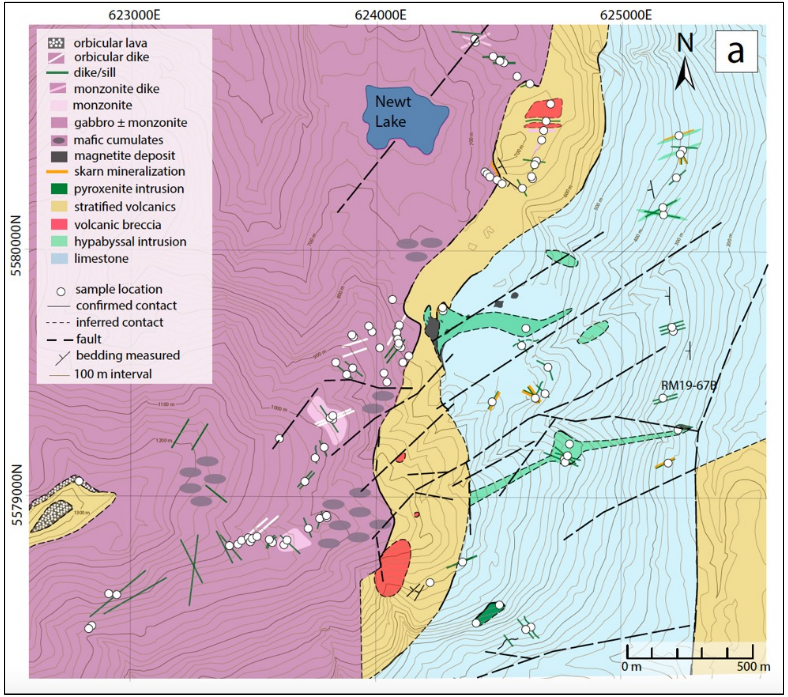


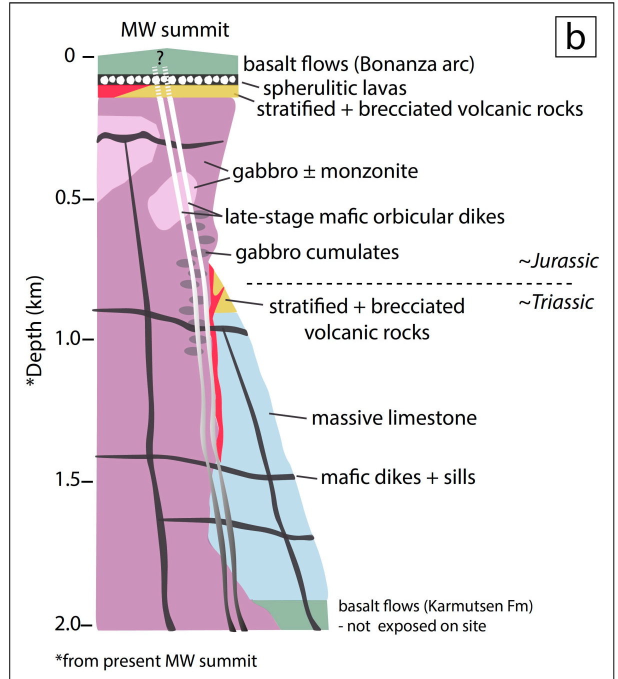
Jurassic Bonanza Arc, Vancouver Island, Canada:
Magma-carbonate interactions evident from abundant skarn occurrences



- Magmas of the Jurassic Bonanza arc intrude Triassic Quatsino limestone
- Evidence of reaction = skarn mineralization

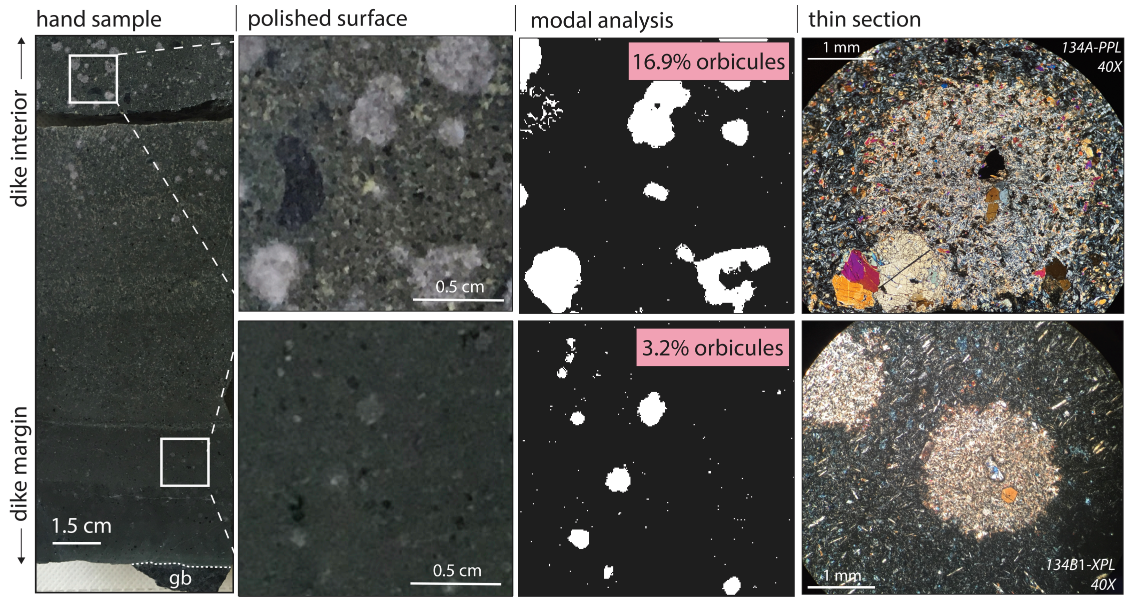
Merry Widow Mtn, Vancouver Island, Canada:
Variety of magma-limestone interactions (m-scale dikes, km-scale pluton)





Unique late-stage orbicular mafic dikes
Field textures, observations suggest liquid immiscibility

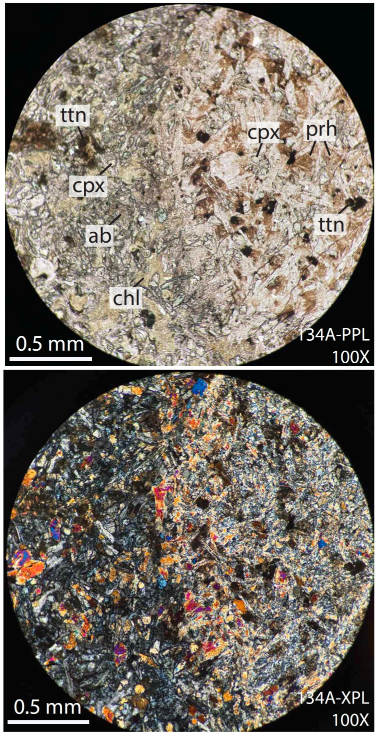
"foamy dikes"

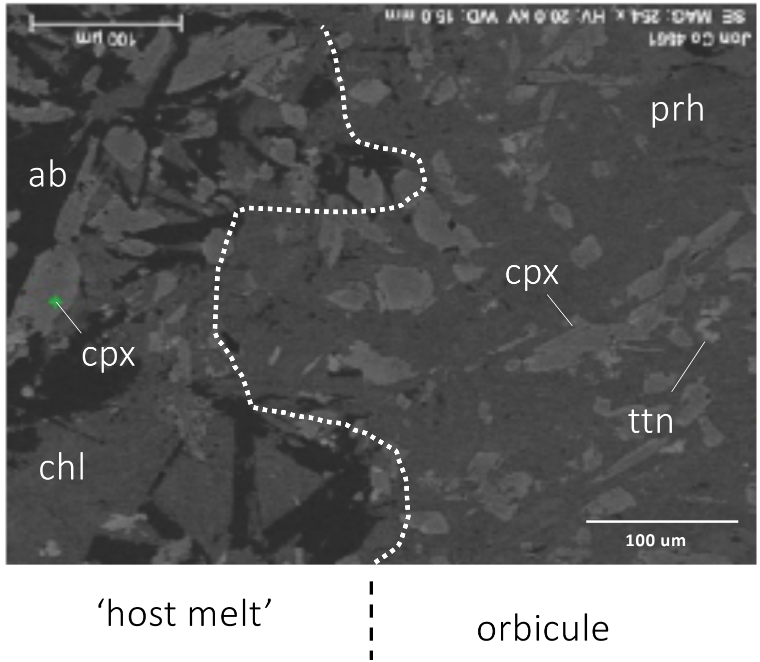


orbicules are microcrystalline

Textures and mineralogy of orbicules vs host melt

Identical intergranular textures, calcic phases within orbicules





<u>Host melt</u>

cpx: 20 – 40%

ab: 30 – 50%

chl: 20 – 35%

ep + ttn: <5%

<u>orbicules</u>

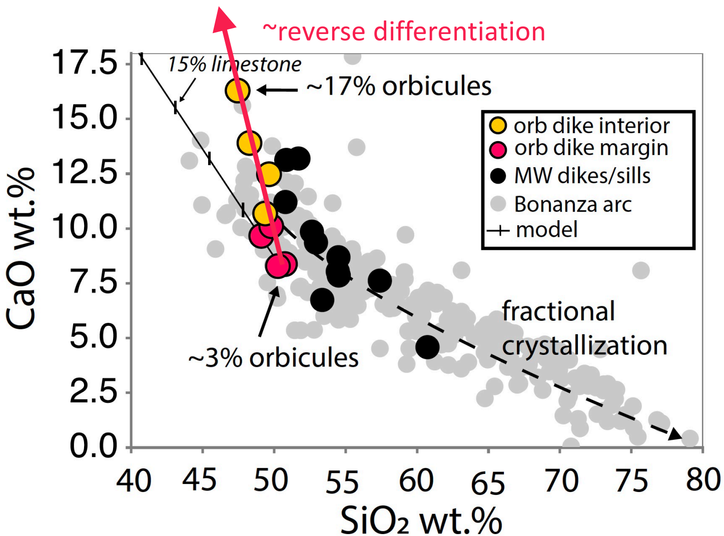
cpx: 20 – 60%

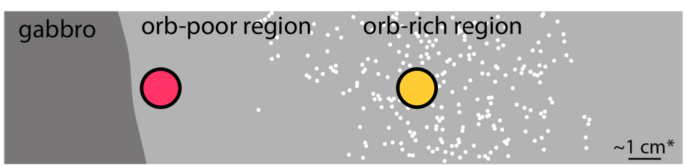
prh: 35 – 80%

ttn: <5%

Orbicular mafic dikes have unique geochemistry

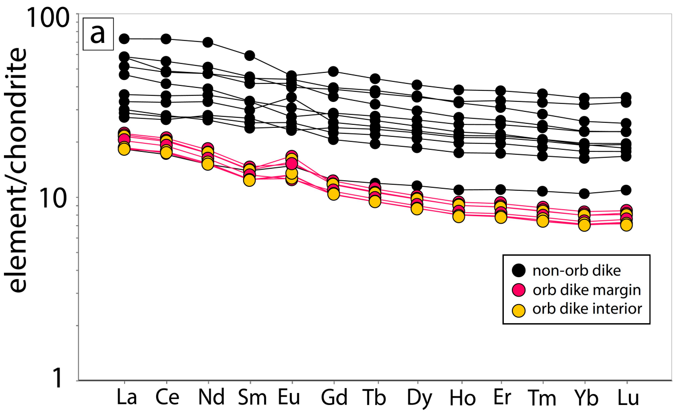
Chemical evidence of magmas interacting with limestone wallrock - majors





- orbicular dikes on a ~reverse differentiation trend: increasing Ca with decreasing Si, decreasing Mg, Fe with decreasing Si
- orbicule-poor dike margins are calc-alkaline
- orbicule-rich dike interiors are tholeiitic (Si-undersaturated, Fe-enriched)

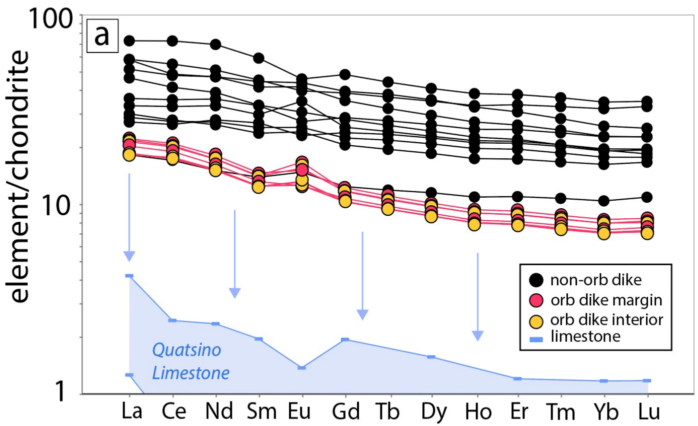
Orbicular mafic dikes have unique geochemistry
Chemical evidence of magmas interacting with limestone wallrock - trace

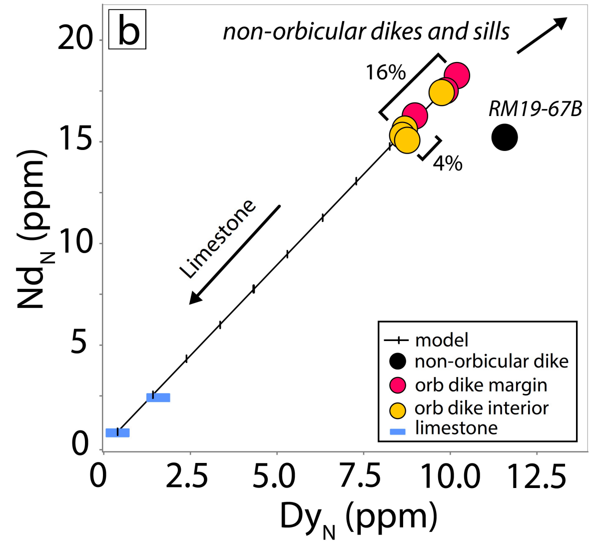


- orb dikes have low REE abundances
- orb dike interiors have lower abundances than margins
- decrease in REE abundances with increase orb %
- dikes appear to be on a mixing line with an REE-depleted source (i.e., limestone wallrock)
- can achieve interior compositions by adding 4-16% limestone

Orbicular mafic dikes have unique geochemistry

Chemical evidence of magmas interacting with limestone wallrock - trace





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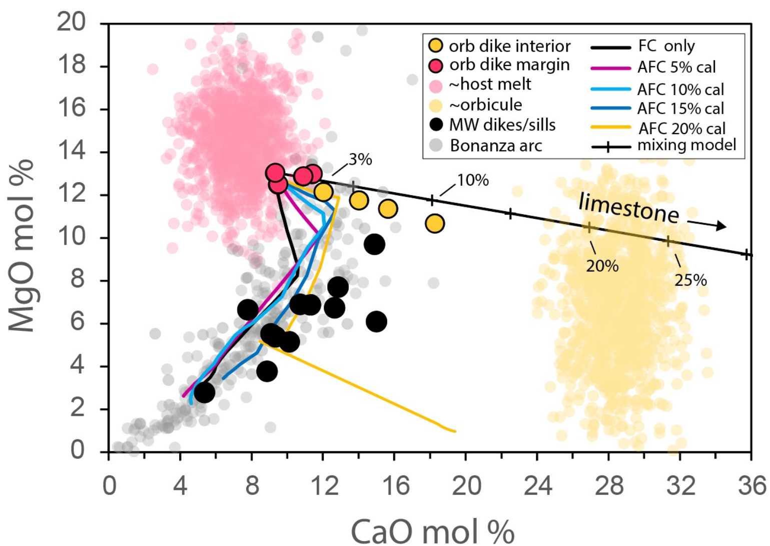
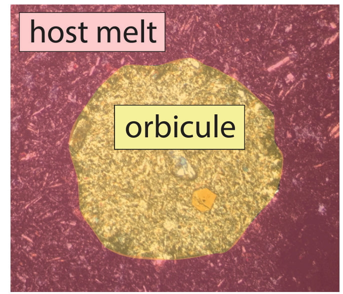
Are the orbicular dikes a result of magma-carbonate mixing or assimilation?

Test unique geochemical trends of orbicular dike with assimilation and mixing models



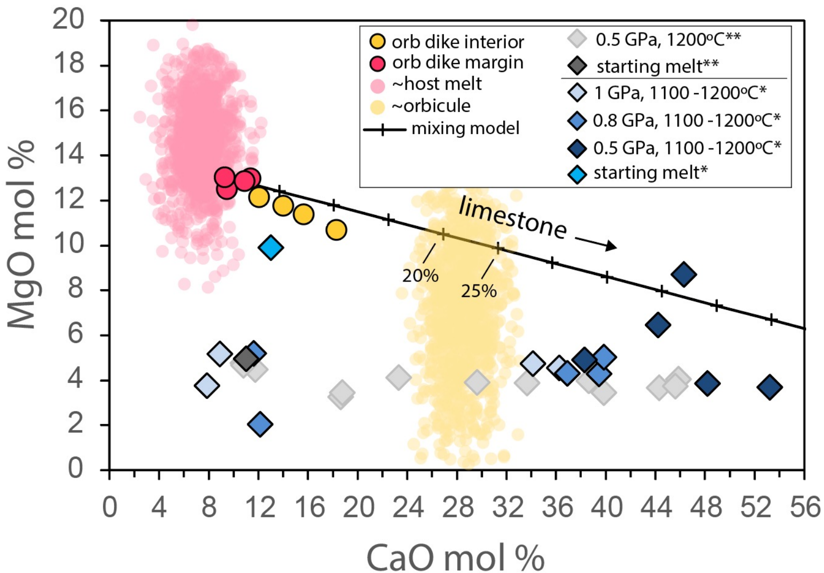
FC model conditions = hydrous (5 wt.% H_2O), fO_2 NNO+1, 2000 bars isobaric



- Thermodynamic models (MELTS – Gualda et al., 2012) cannot achieve orbicule dike interior compositions
- Mixing model indicates 3-11 % limestone addition can achieve orbicular interior compositions (**produce ~1.5 – 5 wt.% CO_2)**

How do the orbicular dikes compare to basalt-limestone experiments?

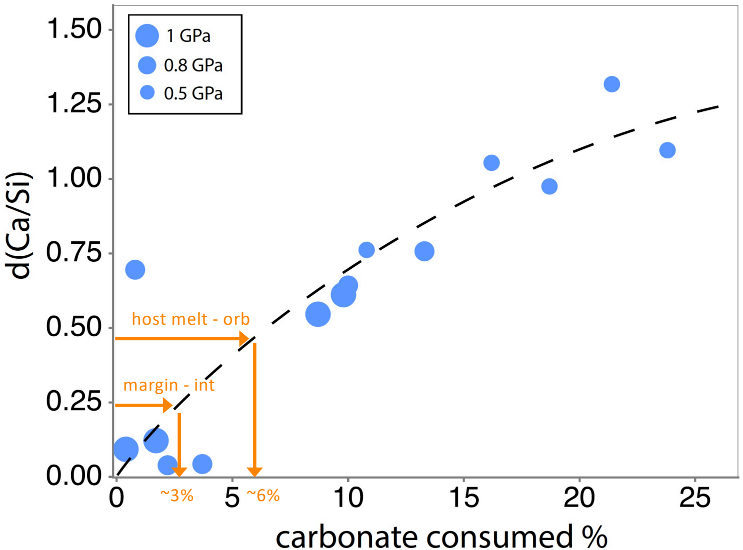
Orbicular dike and orbicules are geochemically similar to experimental melts



- orbicular dikes, orbicules, and hybrid melts fall on a mixing model trend with limestone
- orbicule compositions are similar to the experimental hybrid melts
- if the orbicules are a hybrid melt, they may be a results of 25% limestone addition (produces 11 wt.% CO_2)

Exp data:
Carter & Dasgupta, 2015
Deegan et al., 2010

High P experimental melts to estimate limestone consumed
High pressure (0.5 – 1 GPa) estimates ~ 3 – 6 % limestone consumed

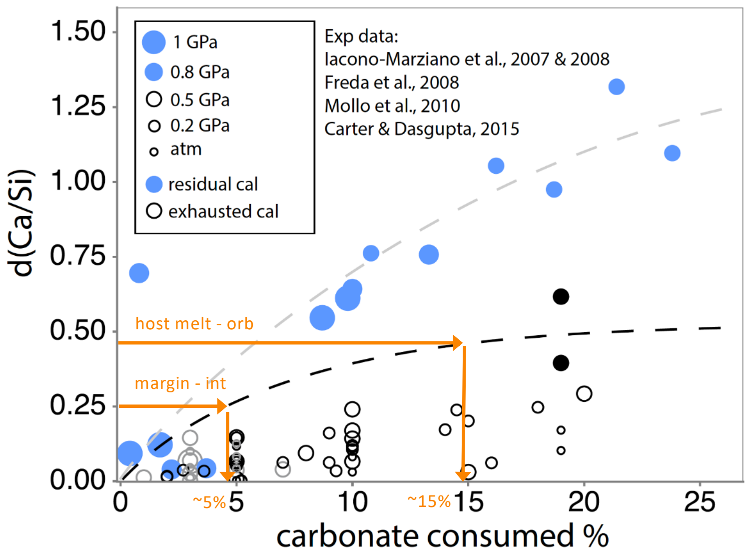


d(Ca/Si) = ABS(Ca/Si$_i$ - Ca/Si$_f$)
i = exps starting melts, orb margins, orb host melt
f = exps hybrid melts, orb interiors, orb compositions

Exp data:
Carter & Dasgupta, 2015

- comparisons to higher P (0.5 – 1 GPa) experiments indicate ~3 to 6% carbonate consumed (1.5 – 3 wt.% CO_2 produced)
- experiments conducted at pressures greater than our crustal setting (<2 kbar)

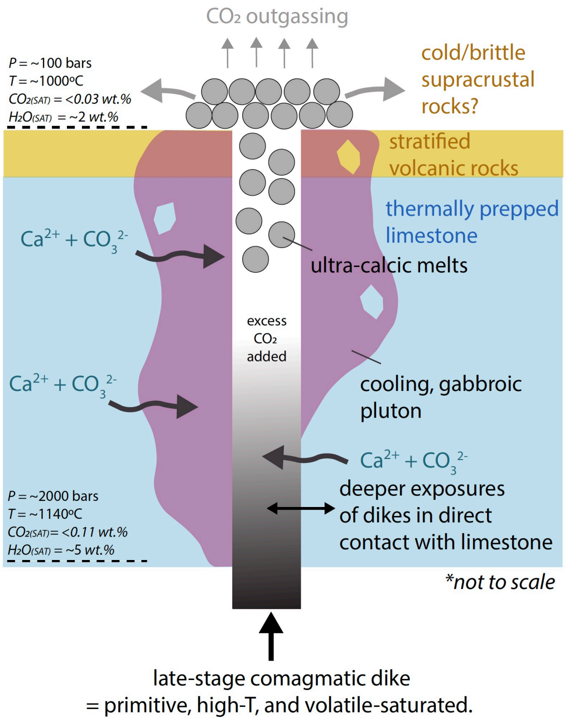
Low P experimental melts to estimate limestone consumed
Low pressure (<0.5 GPa) estimates ~ 5 – 15 % limestone consumed



d(Ca/Si) = ABS(Ca/Si_i - Ca/Si_f)
i = exps starting melts, orb margins, orb host melt
f = exps hybrid melts, orb interiors, orb compositions

- comparisons to lower P (<0.5 GPa) experiments indicate ~5 to 15% carbonate consumed (2 – 7 wt.% CO_2 produced)

Conceptual model for orbicule dike formation



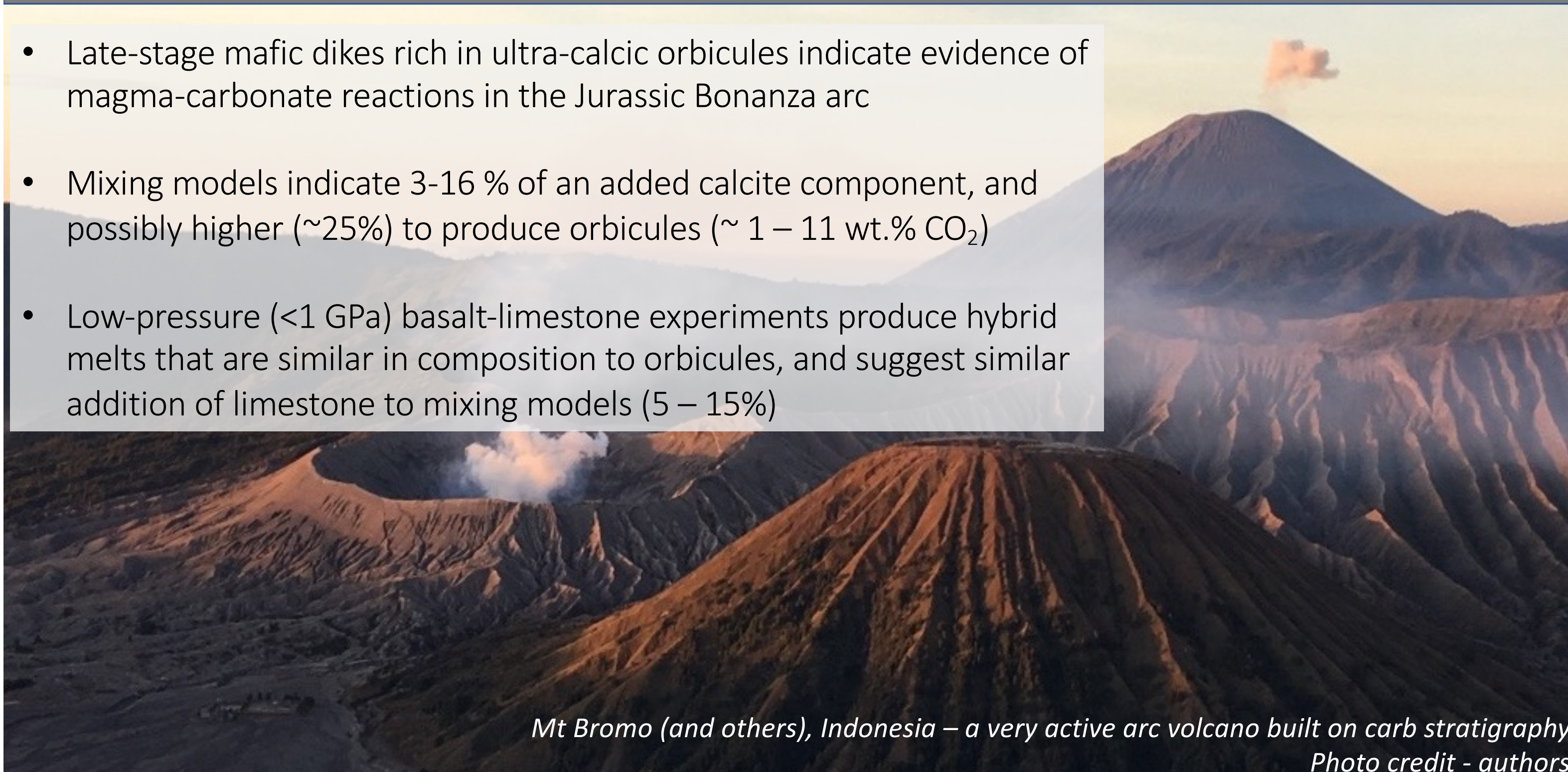
- extensive primitive mafic diking generates partial melts from the limestone wallrock
- partial melt of limestone wallrock enters the dikes directly (dike-limestone contact) or indirectly (via pluton in contact with the limestone)
- excess CO_2 produced from generating partial melts is immediately offgassed, leaving behind a residual and more viscous ultra-calcic melt in the form of a segregated orbicule

Summary

- Late-stage mafic dikes rich in ultra-calcic orbicules indicate evidence of magma-carbonate reactions in the Jurassic Bonanza arc

- Mixing models indicate 3-16 % of an added calcite component, and possibly higher (~25%) to produce orbicules (~ 1 – 11 wt.% CO_2)

- Low-pressure (<1 GPa) basalt-limestone experiments produce hybrid melts that are similar in composition to orbicules, and suggest similar addition of limestone to mixing models (5 – 15%)



Mt Bromo (and others), Indonesia – a very active arc volcano built on carb stratigraphy
Photo credit - authors