Conditions of Mélange Diapir Formation

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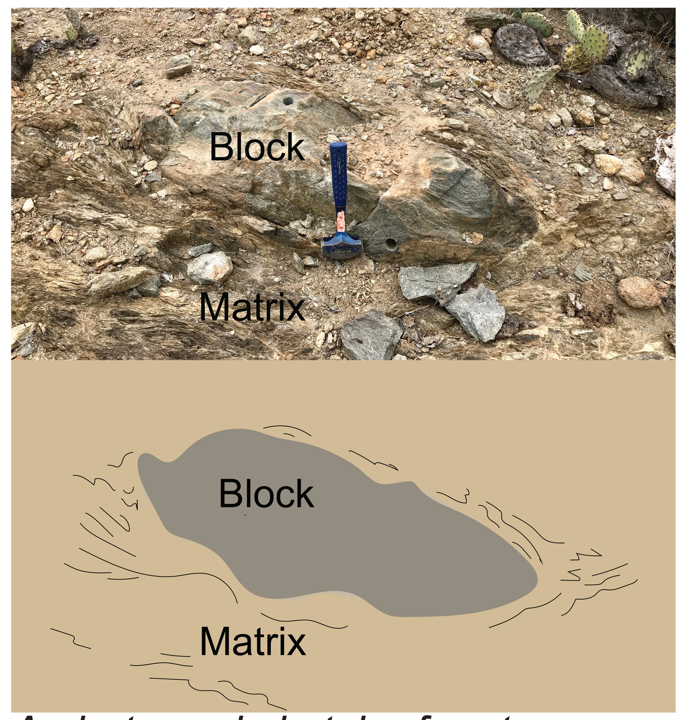
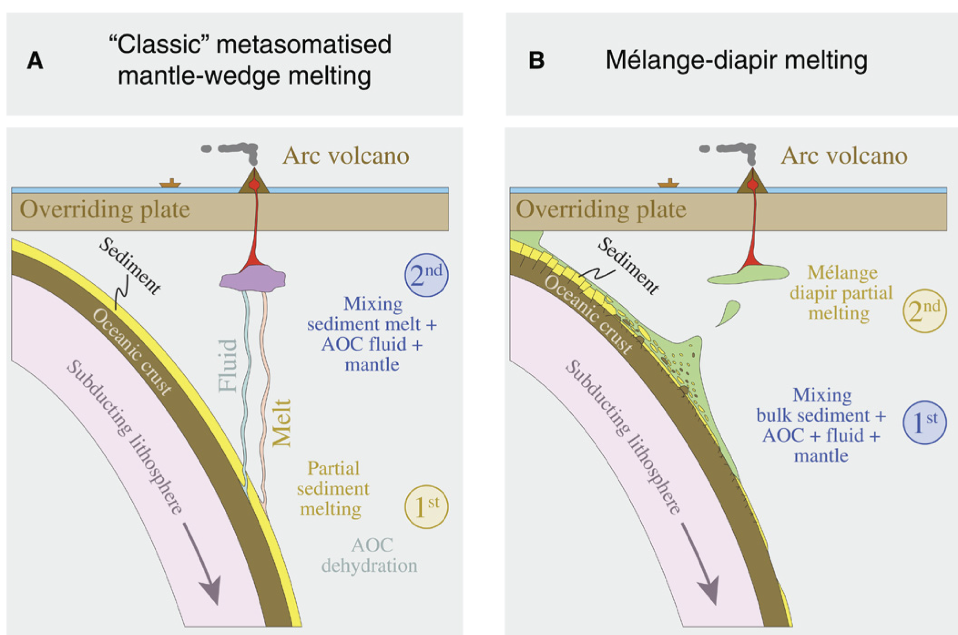
Introduction

- Sedimentary, mafic, and ultra-mafic rocks are thought to physically mix at the subduction slab interface to form mélange (Bebout and Barton, 2002).
- Exhumed terranes, such as those on Santa Catalina Island, CA, contain evidence that mélange exists at the subduction slab interface (Bebout and Penniston Dorland, 2016).
- It has been proposed that mélange materials detach from the subduction interface to form a diapir, which then rises through the overlying mantle wedge, providing a potential source of magma for volcanic arcs (Marschall and Schumacher, 2012).



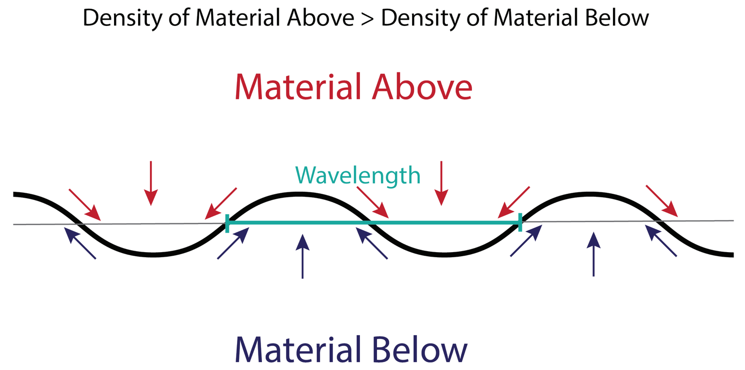
A photo and sketch of metamorphic mélange from Santa Catalina Island, California.



Two end-member models from Nielsen and Marschall (2017).

- There are two end-member models for how arc magma is generated in subduction zones (Nielsen and Marschall, 2017).
- This project is based on the mélange-diapir melting model.

- Diapirs form because of Rayleigh-Taylor instability, the tendency of less dense fluid to displace overlying denser fluid due to the influence of gravity (Turcotte and Schubert, 2014).
- Diapir formation requires a negative density contrast between materials at the slab interface.
- Diapir formation requires a diapir growth rate fast enough to overcome shearing forces at the slab interface caused by plate movement.
- Diapir formation depends on the interplay of density, viscosity, wavelength of perturbation, and slab velocity.



The movement of materials along an unstable interface caused by a negative density contrast.

Question

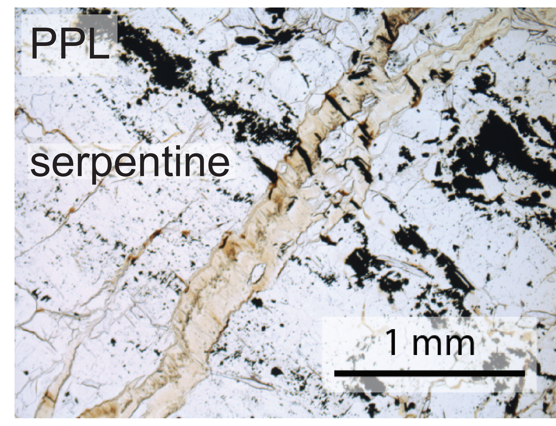
Under what conditions can diapirs form from mélange material located at the subduction slab interface?

Hypothesis

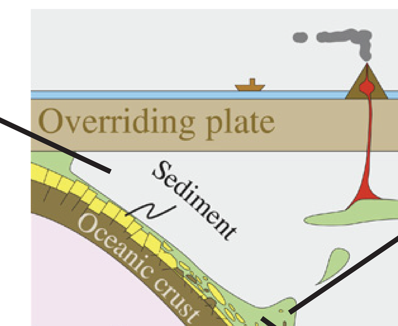
- The density contrast between subducted mélange and the overlying mantle is sufficient to generate a diapir.
- The rise of mélange at the subduction slab interface is fast enough to overcome entrainment by the mantle and detach as a diapir.

Representative Samples of the Catalina Schist

Serpentinite (represents mantle wedge)

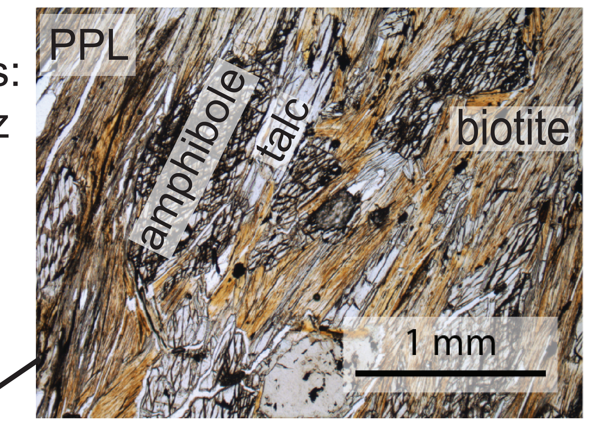


Other minerals: chlorite, sheet-silicate minerals in veins



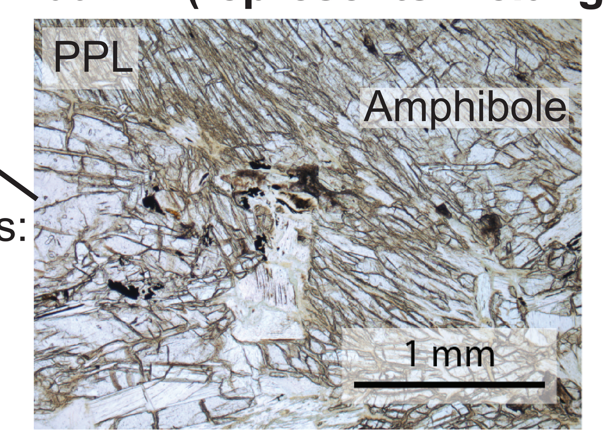
Matrix 1 (represents mélange)

Other minerals: chlorite, quartz



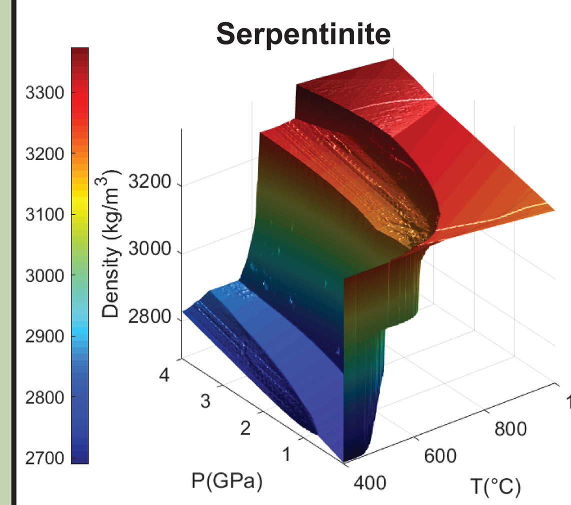
Matrix 2 (represents mélange)

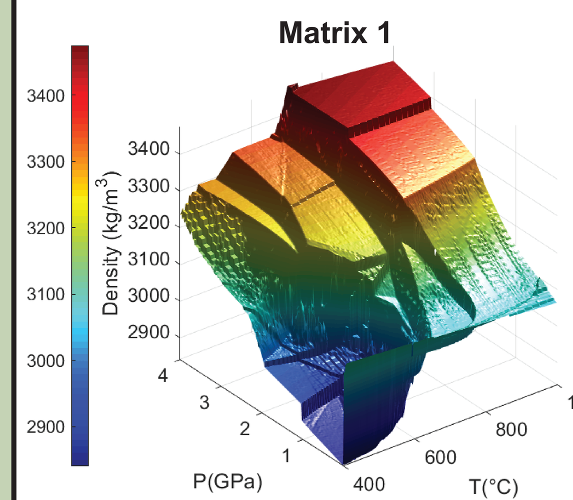
Other minerals: chlorite, talc, quartz

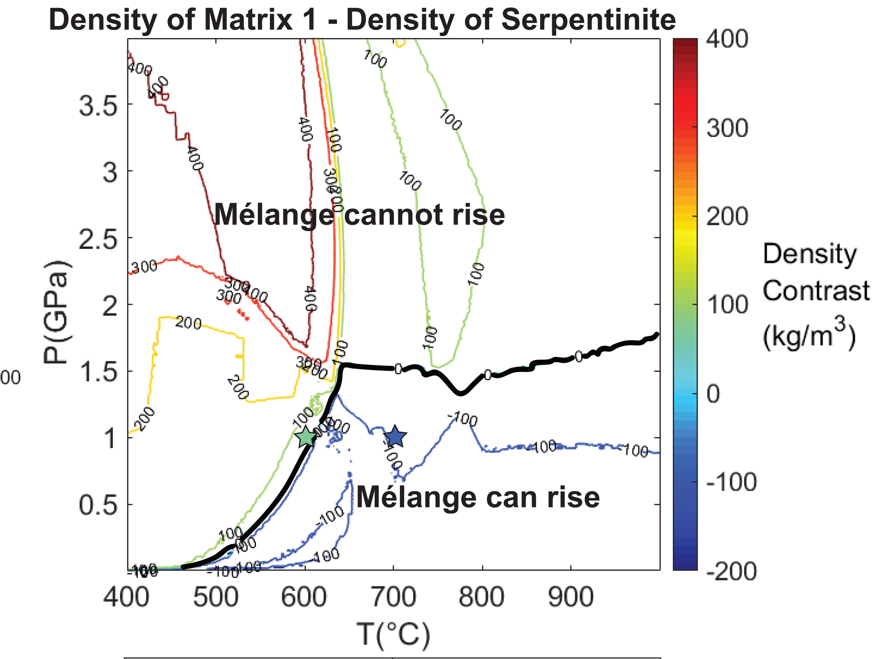


Photomicrographs of the three samples collected from Santa Catalina Island, CA for this project. Central image is from Nielsen and Marschall (2017).

Thermodynamic Modeling





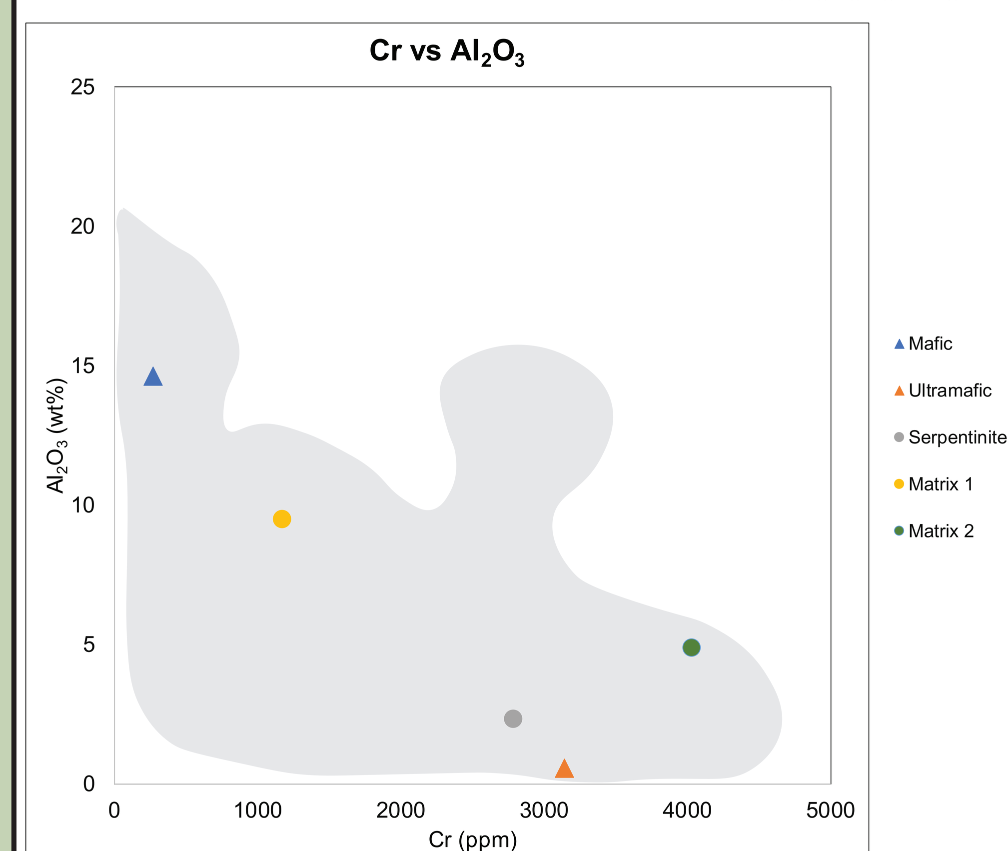


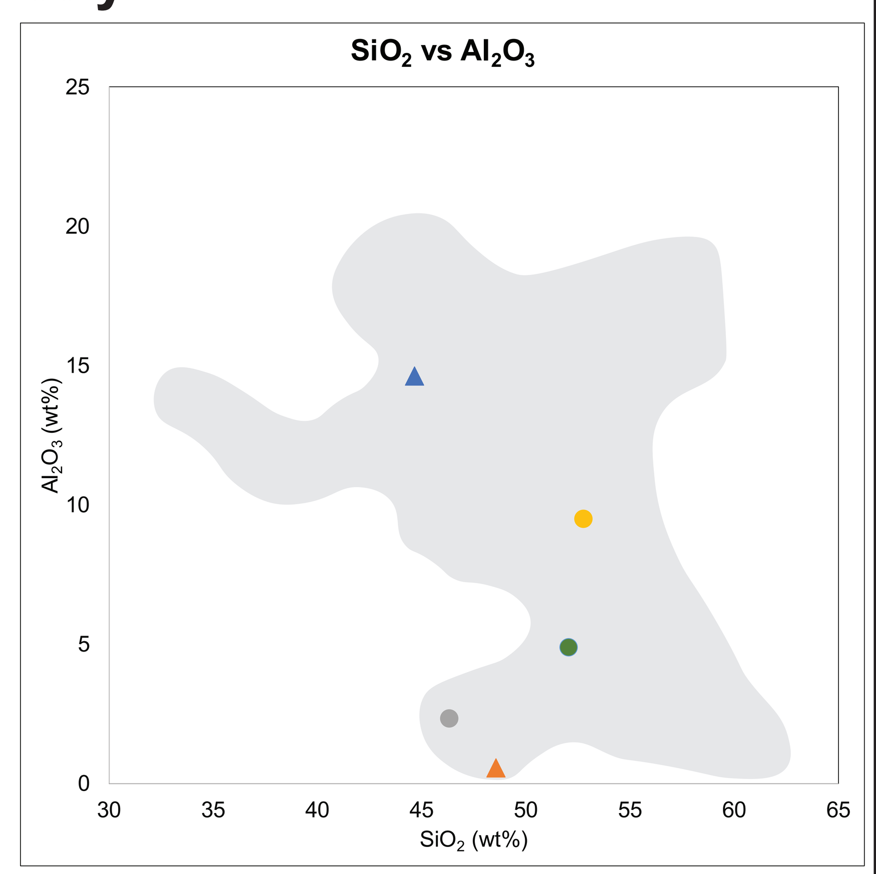
- A positive density contrast results in stability, so mélange cannot rise and form a diapir.
- A negative density contrast results in instability, so mélange can rise and form a diapir if the diapir can overcome shearing forces caused by the moving slab.

T = 600 °C ☆		T = 700 °C ★	
Mineral	wt%	Mineral	wt%
Talc	1.98	**Talc**	17.92
Biotite	6.91	**Biotite**	6.91
Garnet	0.48	**Garnet**	13.68
Clinoamphibole	39.06	**Clinoamphibole**	30.08
Feldspar	7.07	**Feldspar**	11.25
Quartz	10.46	**Quartz**	1.41
Rutile	0.74	**Rutile**	0.7
Zircon	0.06	**Zircon**	0.06
Chlorite	33.25	**Orthopyroxene**	17.99

Mineral assemblages of Matrix 1 predicted by Perple_X at peak metamorphic conditions of 600 °C and 700 °C, both at 1 GPa.

Geochemistry





- The mean composition of mafic and ulframafic rocks as well as the range in composition of mélange shown by the grey areas are based on Catalina Schist (Bebout and Barton 2002).
- Bulk rock composition of Matrix 1 and Matrix 2 are representative of mélange.
- The composition of mélange falls between that of mafic and ultramafic rocks.

Geodynamic Modeling

Equations from Turcotte and Schubert (2014):

$$\frac{\left(\frac{\lambda}{2\pi b}+\frac{1}{\sin\left(\frac{2\pi b}{\lambda}\right)\cosh\left(\frac{2\pi b}{\lambda}\right)}\right)}{\left(\frac{\lambda}{2\pi b}\right)^2\tanh\left(\frac{2\pi b}{\lambda}\right)-\frac{1}{\sin\left(\frac{2\pi b}{\lambda}\right)\cosh\left(\frac{2\pi b}{\lambda}\right)}}$$

Dimensionless growth time

$$\tau \rightarrow \frac{24\mu}{(\rho 1-\rho 2)gb}\left(\frac{\lambda}{2\pi b}\right)^2$$

Large wavelengths

$$\tau \rightarrow \frac{4\mu}{(\rho 1-\rho 2)gb}\left(\frac{2\pi b}{\lambda}\right)$$

Small wavelengths

Dimensionless wavenumber = $\frac{2\pi b}{\lambda}$

Mélange thickness = b

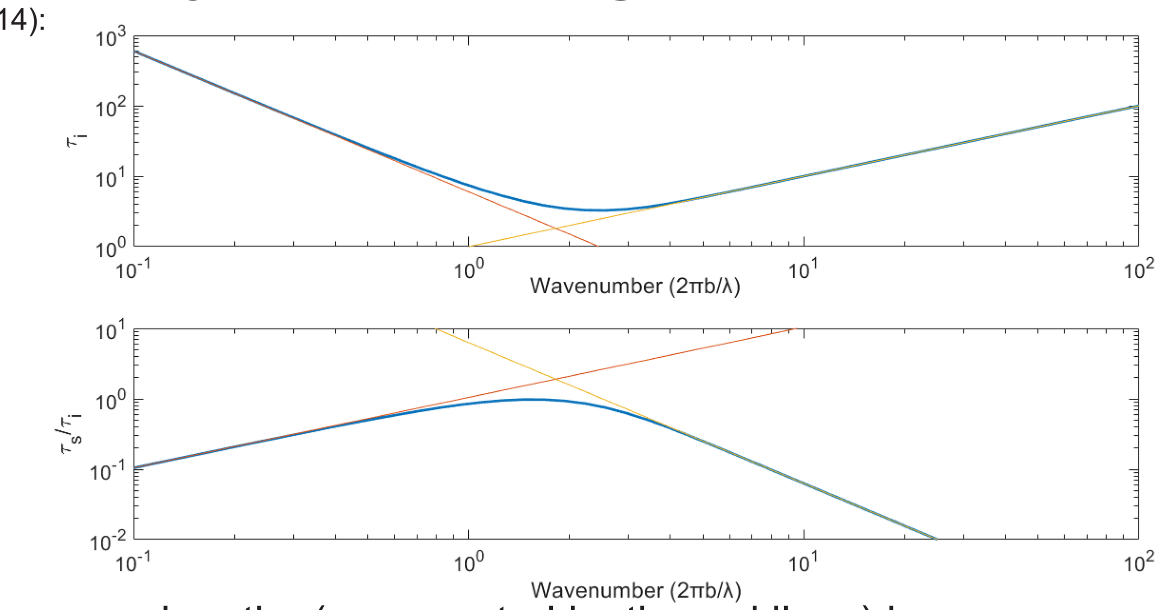
Wavelength = λ

Viscosity = μ

Density of material 1 = ρ1

Density of material 2 = ρ2

Gravitational acceleration = g



- Large wavelengths (represented by the red lines) increases growth time because it requires a greater amount of material to move.
- Small wavelengths (represented by the yellow lines) increases growth time because of large shear forces.
- A smaller τ_i (growth time) means a faster growth rate and a larger ratio of τ_s (slab time) to τ_i means that slab velocity is slower in relation to diapir growth rate.
- Diapir formation is most likely to occur at the smallest τ_i and at the largest ratio of τ_s to τ_i.

Conclusion

- Density contrast between serpentinite and Matrix 1 was calculated using Perple_X.
- Predicted mineral assemblages were compared to minerals present in rock.
- Preliminary thermodynamic models provide range of P (< 1 GPa) and T (> 600 °C) for mélange to rise.
- Based on preliminary geodyamic models, diapir formation is most likely to occur at a wavenumber of ~2.6 when diapir growth rate is the greatest.

Future Work for GEOL394

- Thermodynamic models will be improved to better represent mineralogical compositions observed in the samples.
- The density contrast between the serpentinite and Matrix 2 will be calculated.
- The growth rate curve will be modified to account for different values of density contrast, viscosity and mélange thickness.
- The calculated growth time will be compared to values of subduction time to evaluate the likelihood of diapir formation.

References

Bebout, G. E., & Barton, M. D. (2002). Tectonic and metasomatic mixing in a high-T, subduction-zone mélange—insights into the geochemical evolution of the slab–mantle interface. Chemical Geology, 187(1-2), 79-106.

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