Lecture 12 More on Layered Intrusions

Monday, February 28th, 2005

The Processes of Crystallization, Differentiation, and Layering in LMIs

- LMIs are the simplest possible case
- More complex than anticipated
- Still incompletely understood after a half century of intensive study

- Rhythmic modal layering most easily explained by crystal settling interrupted by periodic large-scale convective overturn of the entire cooling unit
- Reinjection of more primitive magma may explain major compositional shifts and cases of irregular cryptic variations

Problems with the crystal settling process.

- Many minerals found at a particular horizon are not hydraulically equivalent
- Size is more important than density in Stokes' Law, but size grading is rare in most LMIs
- Dense olivine in the Upper Border Series of the Skaergård
- Plagioclase is in the lower layers of the Skaergård

- Inverted cryptic variations in the Upper Border Series suggests that the early-formed minerals settled upward
- The Marginal Border Series shows vertical layering
- Basaltic magmas develop a high yield strength, slightly below liquidus temperatures

In-Situ Processes

- Nucleation and growth of minerals in a thin stagnant boundary layer along the margins of the chamber
  - Differential motion of crystals and liquid is still required for fractionation
  - Dominant motion = migration of depleted liquid from the growing crystals
  - Crystals settle (or float) a short distance within the boundary layer as the melt migrates away
    - Boundary layer interface inhibits material motion

- Systems with gradients in two or more properties (chemical or thermal) with different rates of diffusion
- Especially if have opposing effects on density in a vertical direction

Compositional Convection

- One gradient (in this case ρ_{temp}) is destabilizing (although the total density gradient is stable)
- The diffusivity of the destabilizing component (heat) is faster than the diffusivity of the salt

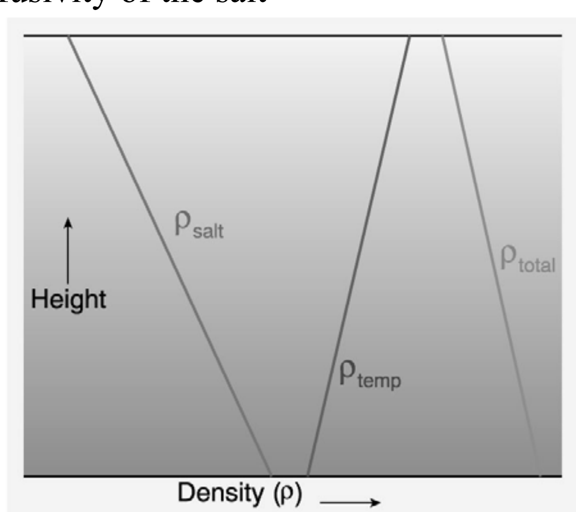

Figure 12-14. After Turner and Campbell (1986) Earth-Sci. Rev., 23, 255-352.

Double-diffusive convection situation

- A series of convecting layers

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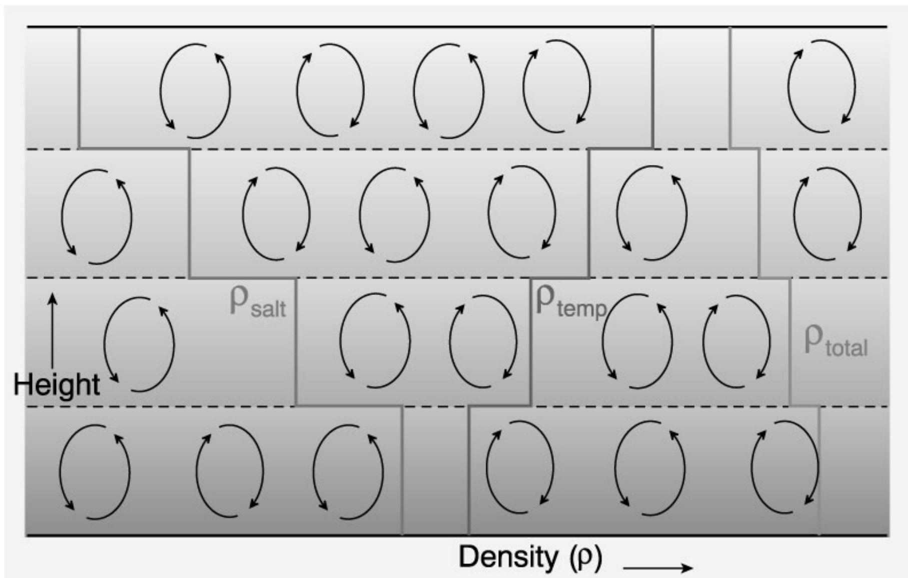

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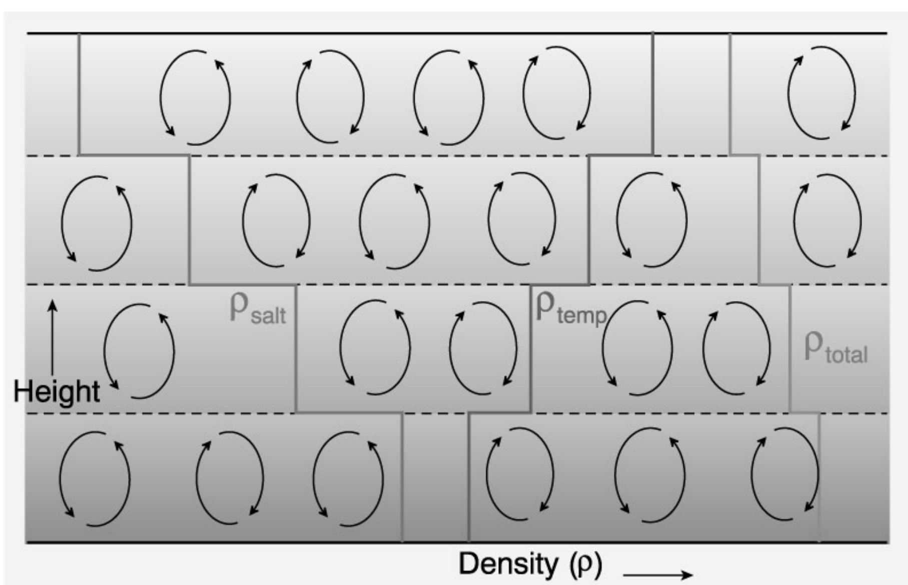
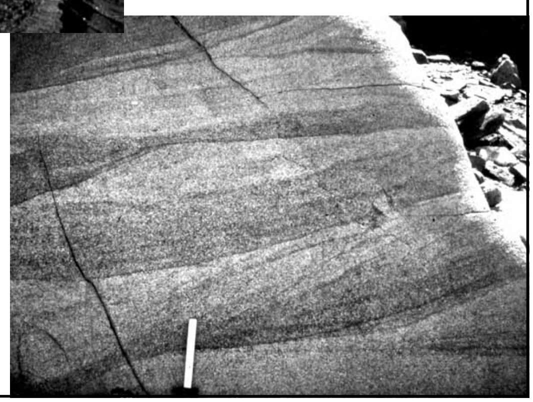


Density currents

- Cooler, heavy-element-enriched, and/or crystal-laden liquid descends and moves across the floor of a magma chamber
  - Dense crystals held in suspension by agitation
  - Light crystals like plagioclase also trapped and carried downward

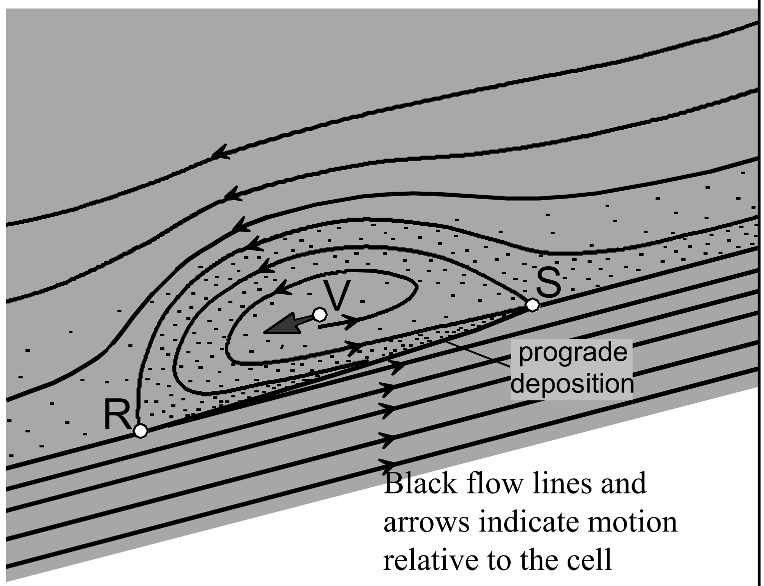
Figure 12-15a. Cross-bedding in cumulate layers. Duke Island, Alaska. Note also the layering caused by different size and proportion of olivine and pyroxene. From McBirney (1993) Igneous Petrology. Jones and Bartlett

Figure 12-15b. Cross-bedding in cumulate layers. Skaergård Intrusion, E. Greenland. Layering caused by different proportions of mafics and plagioclase. From McBirney and Noyes (1979) J. Petrol., 20, 487-554.



- Neil Irving's Vortex model

Figure 12-16. After Irvine et al. (1998) Geol. Soc. Amer. Bull., 110, 1398-1447.



Black flow lines and arrows indicate motion relative to the cell

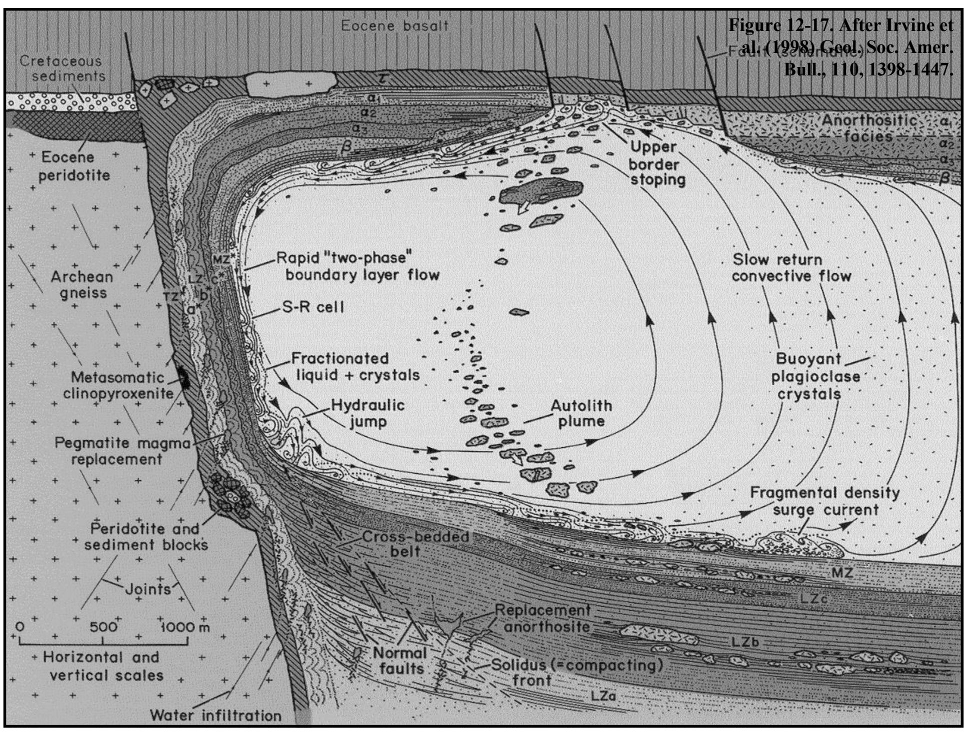


Figure 12-17. After Irvine et al. (1998) Geol. Soc. Amer. Bull., 110, 1398-1447.

Figure 12-18. Cold plumes descending from a cooled upper boundary layer in a tank of silicone oil. Photo courtesy Claude Jaupart.

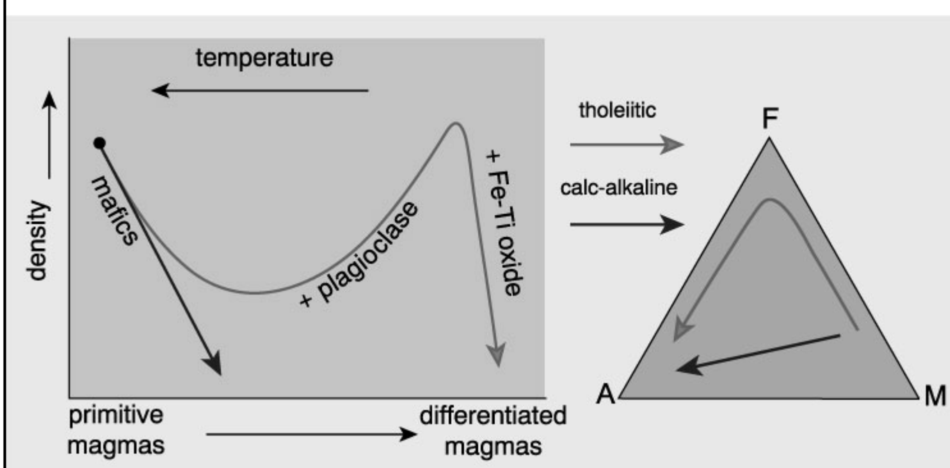


Figure 12-19. Schematic illustration of the density variation in tholeiitic and calc-alkaline magma series (after Sparks et al., 1984) Phil. Trans. R. Soc. Lond., A310, 511-534.

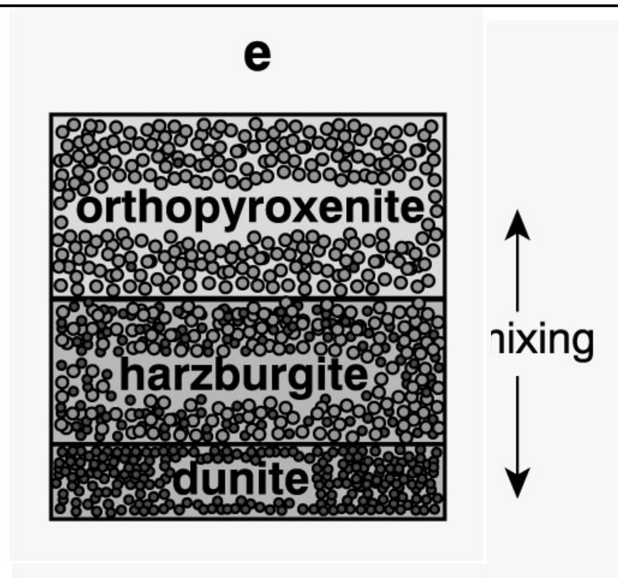


Figure 12-20. Schematic illustration of a model for the development of a cyclic unit in the Ultramafic Zone of the Stillwater Complex by influx of hot primitive magma into cooler, more evolved magma. From Raedeke and McCallum (1984) J. Petrol., 25, 395-420.