Experimental Perspective on Sedimentation from Plumes

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Full Screen

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Introduction

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Works for volcanic plumes and umbrella clouds (Bursik et al., 1992)

Advection-Diffusion

Hazen's equation can be derived from the advection-diffusion equation

Assume that there is no relative diffusion

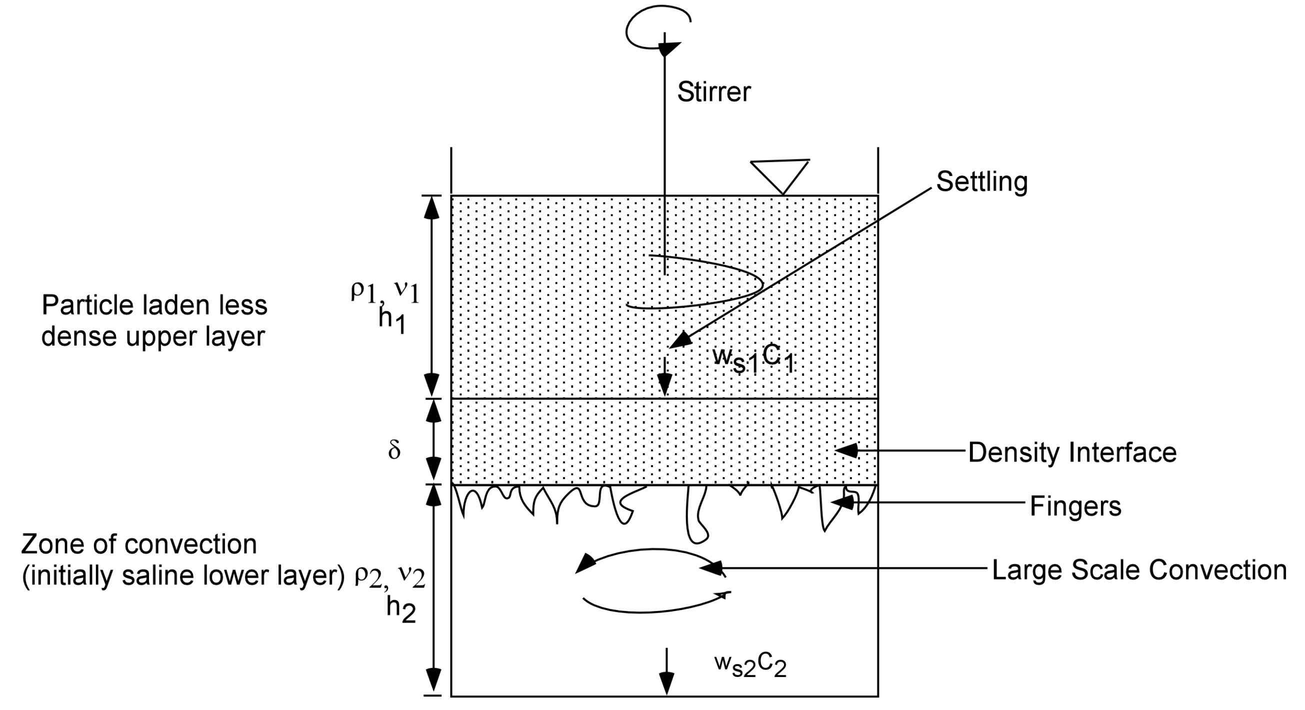
$$\partial_t C_i + \nabla \cdot \vec{u} C_i = \nabla^2 \kappa C_i + \Phi \tag{2}$$

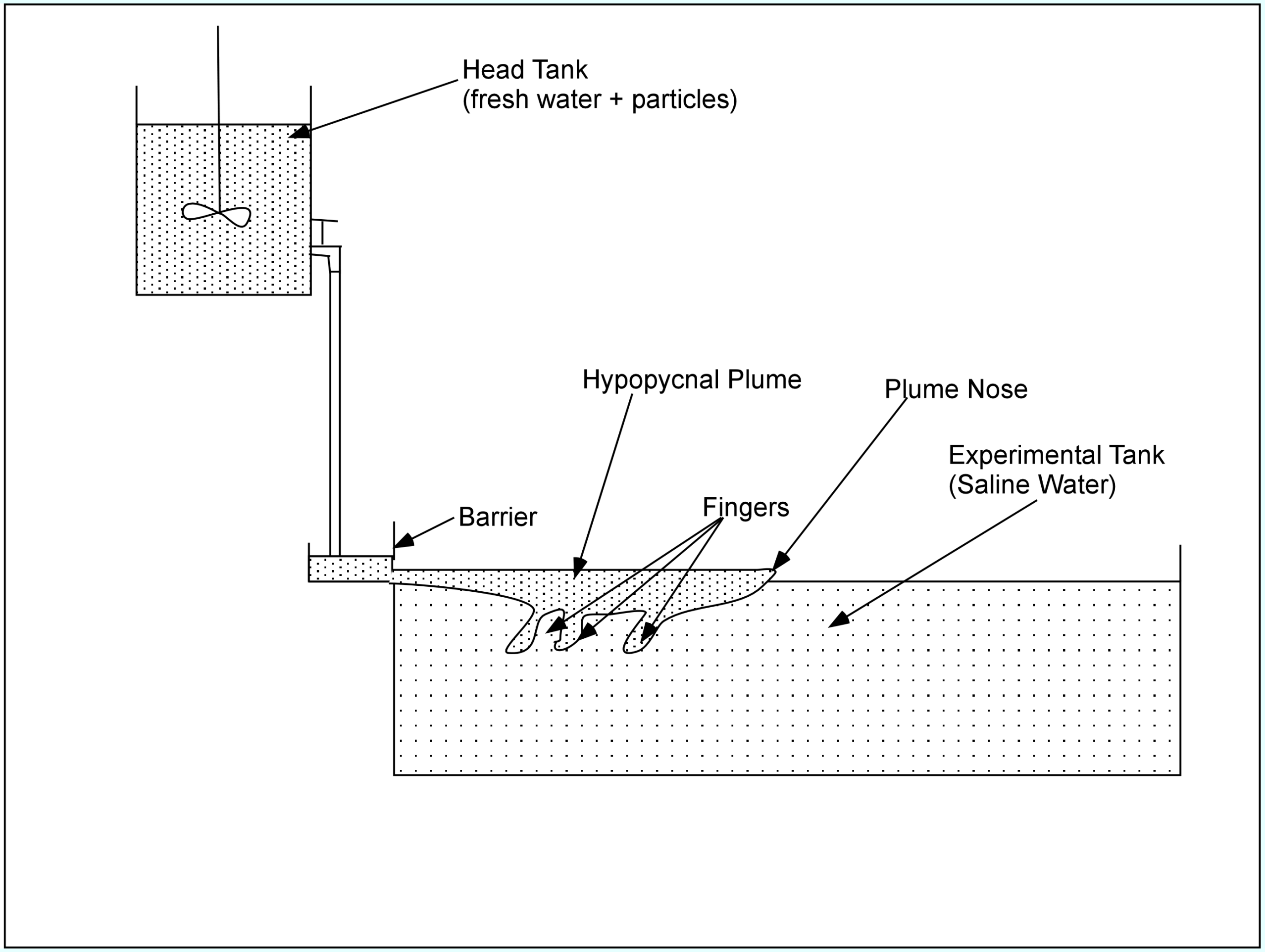
Layered Environment

Needed to test Hazen's validity for layered systems

Set up two main types of experimental systems

In the layered environment, a light, particle-bearing fluid lies atop a denser fluid with no particle


Stirrer
Settling
Particle laden less
dense upper layer
ρ_1, ν_1
h_1
$w_{s1}C_1$
δ
Density Interface
Fingers
Zone of convection
(initially saline lower layer) ρ_2, ν_2
h_2
Large Scale Convection
$w_{s2}C_2$


Head Tank
(fresh water + particles)
Hypopycnal Plume
Plume Nose
Experimental Tank
(Saline Water)
Fingers
Barrier

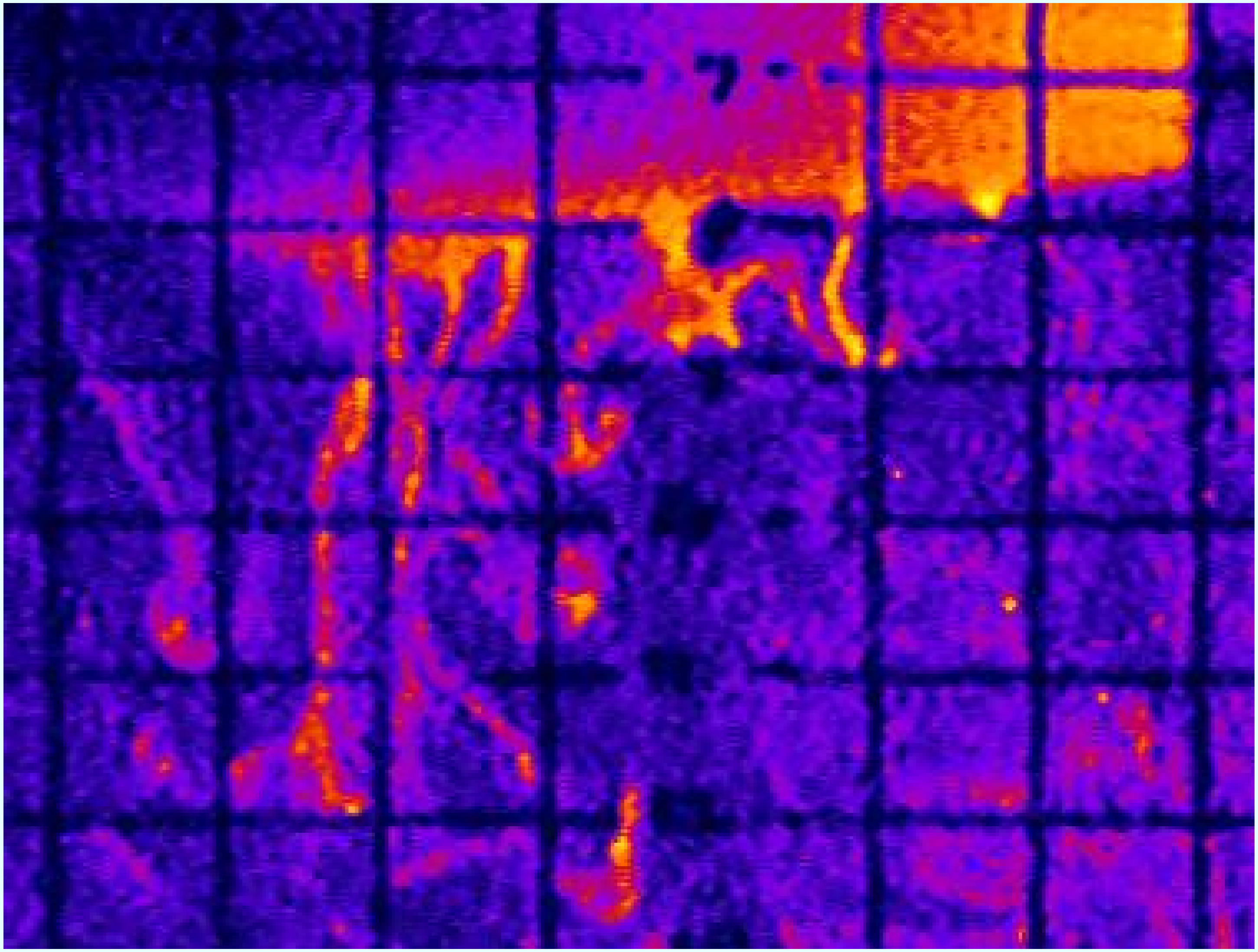
Settling Phenomenology

In experiments on layered systems, we found that. . .

Particles do not always settle from the upper layer singly

There are particle-laden, descending plumes

Settling Phenomenology



Theory

The development of descending plumes has been characterized by Hoyal et al. (1999a, b):

$$\text{Convective sedimentation}: \quad Gr = \frac{gC_0\delta^3}{\rho_1\nu^2}, \quad \delta = w_s t \tag{3}$$

$$\text{Double diffusion}: \quad Gr = \frac{gC_0\delta^2}{\rho_1\nu w_s} \tag{4}$$

$$\text{Criterion}: \quad Gr > 1000 \tag{5}$$

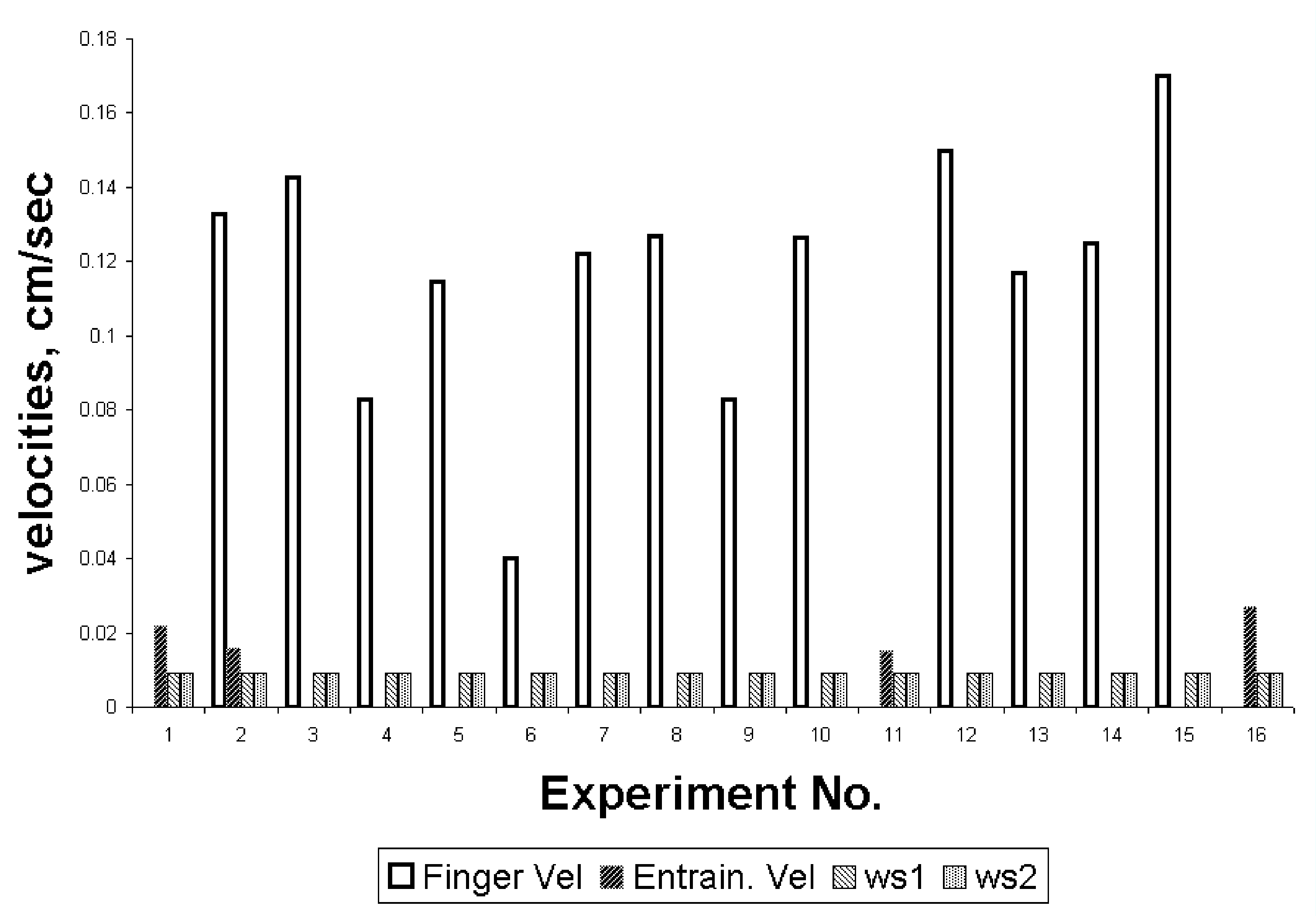
$$\tag{6}$$

Shear and Re-entrainment

Shear at the boundary between layers can destroy the convection, if the turbulence level in the upper layer is sufficiently vigorous (Gupta, 2002)

The result is. . .

Shear and Re-entrainment



Theory

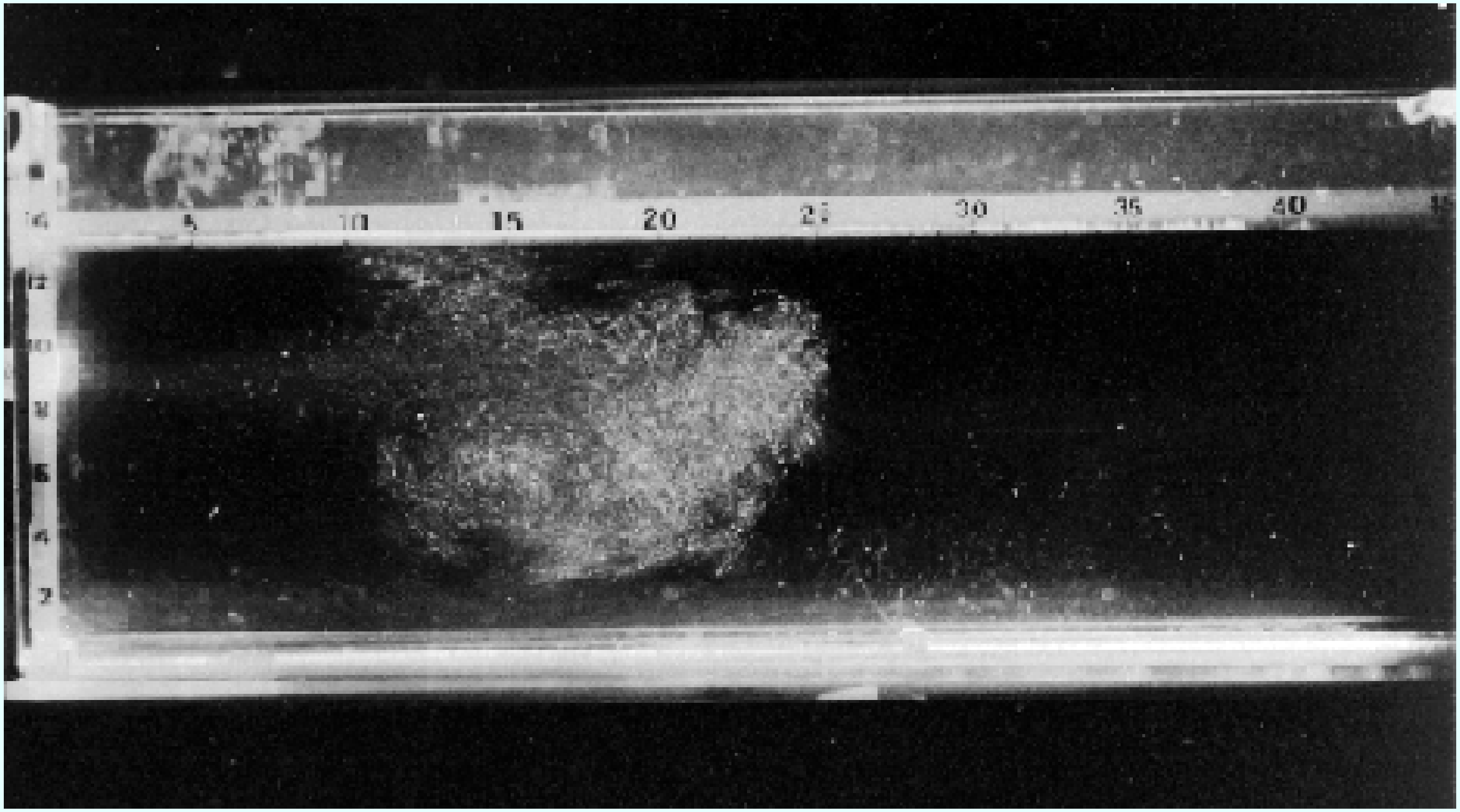
Because of inflow toward the plume caused by wind and atmospheric entrainment, particles can be re-entrained. In general, Eqn 1 takes on a form:

$$\frac{dM_i}{dt} = -f\left(w_s - w_\epsilon\right)\frac{M_i}{h} \tag{7}$$

where w_ϵ is a re-entrainment speed. The function, f, can be determined empirically.

Lee Wave, Separation, Coanda Effect. . .

For plumes in a highspeed crossflow, topography can have an effect



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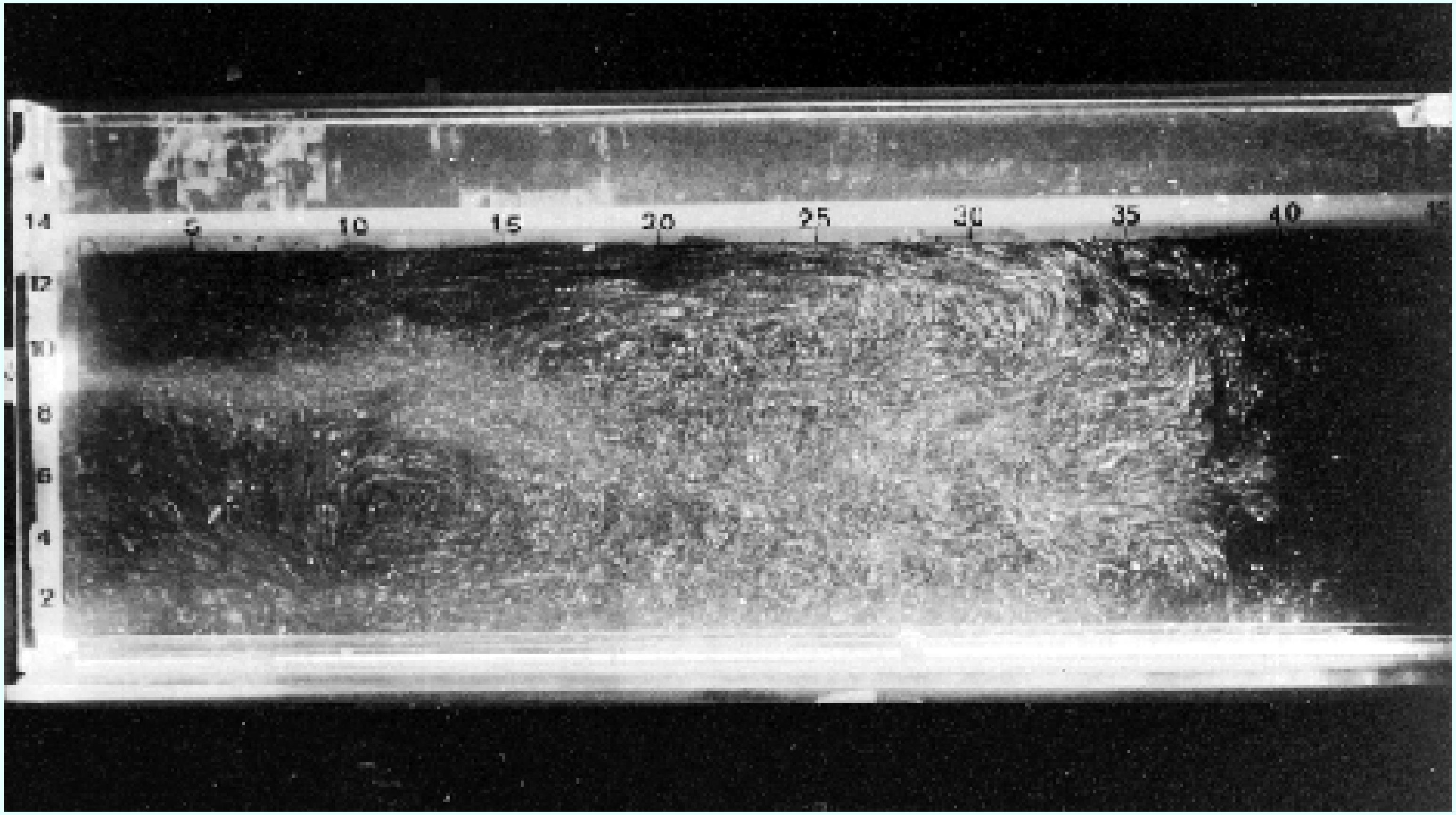
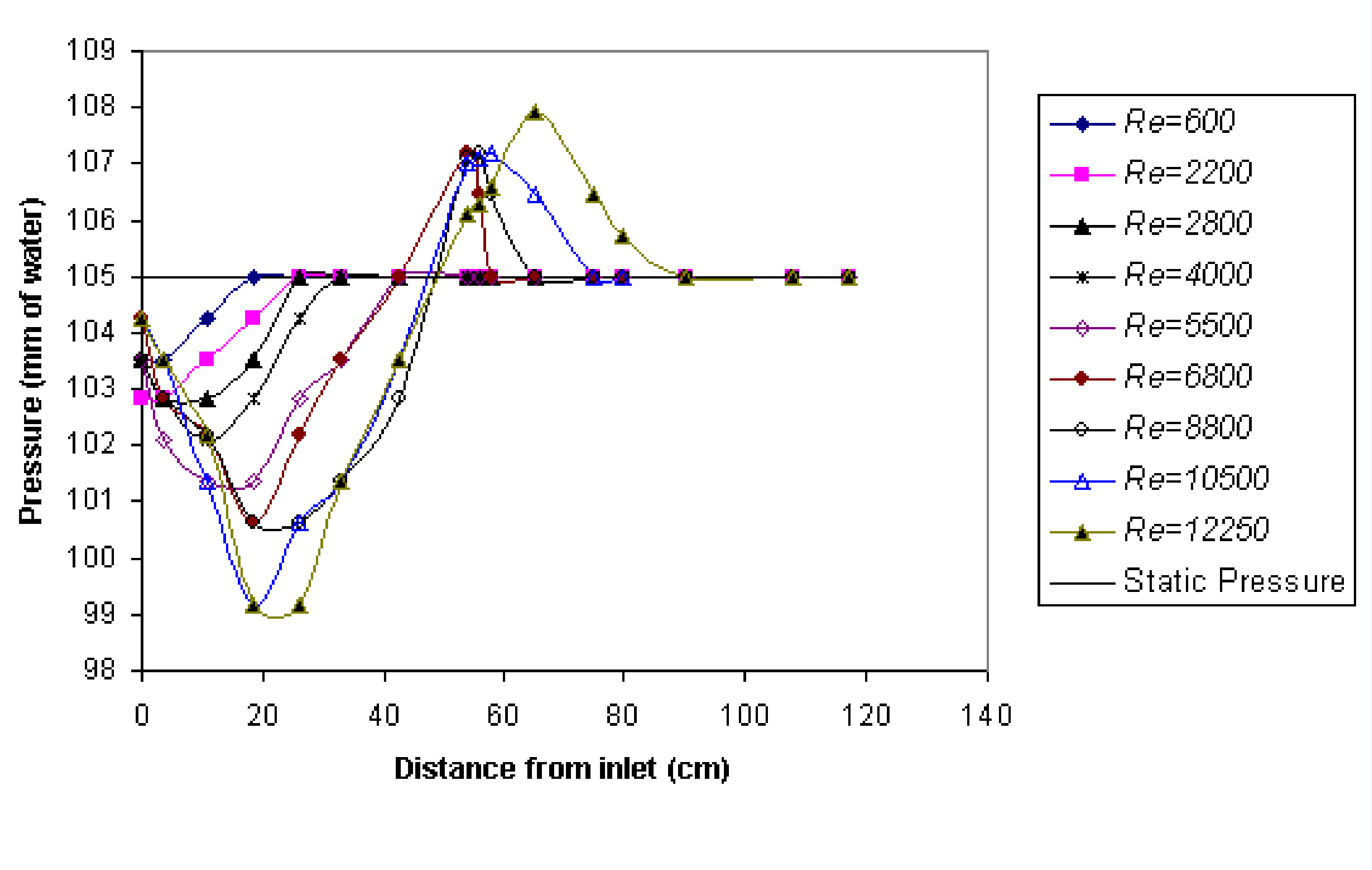


But is this the case even when the plume is less dense than underlying layers?



Over a range of Re, for the buoyant jet with ambient water density above plume density, there is reattachment

The result is that particles that would otherwise settle through atmosphere are deposited from a ground-hugging current

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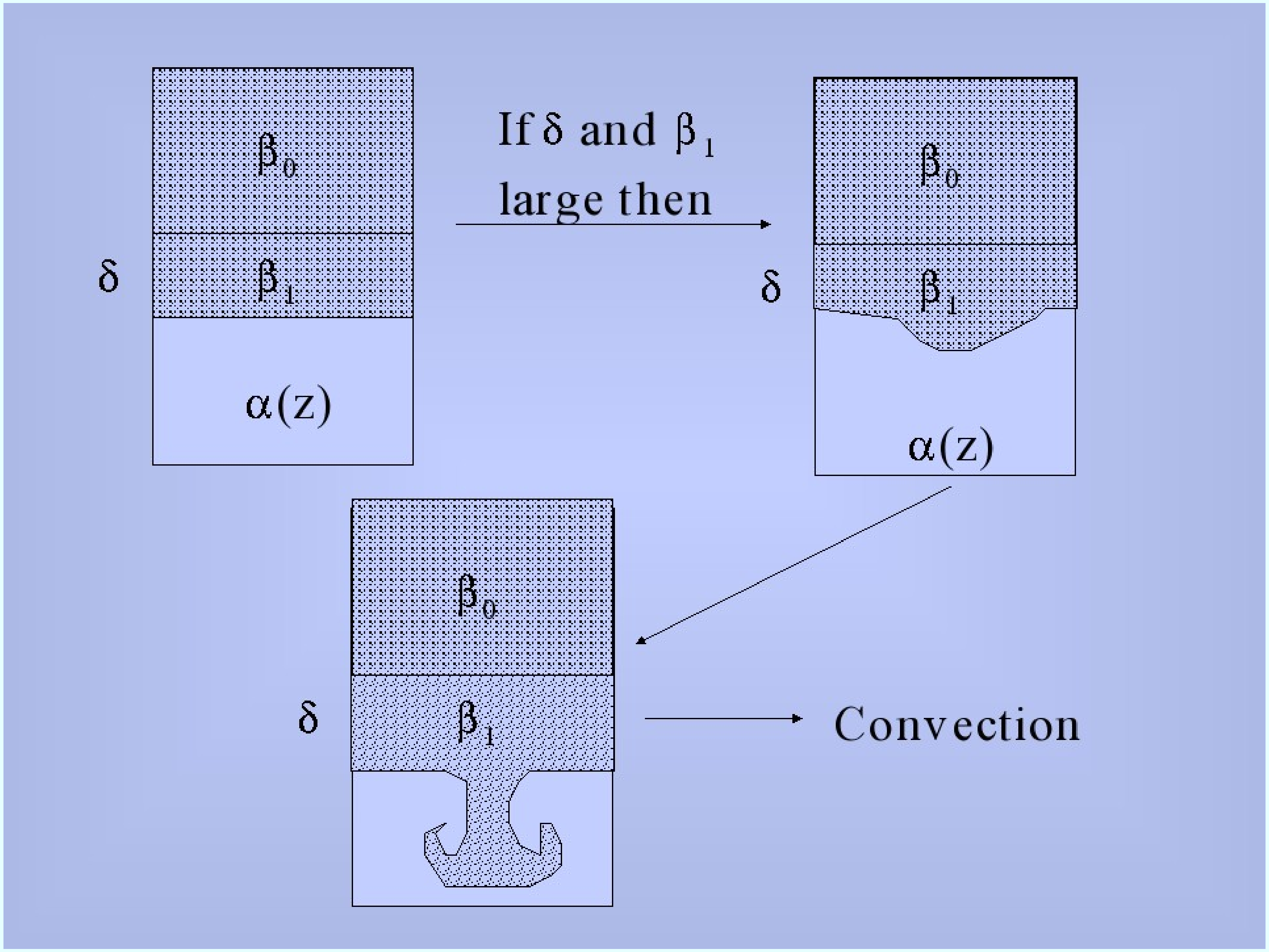
Volcanic Plume Convection



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