# Some Rock Mechanics Aspects of Dike-Repository Interaction

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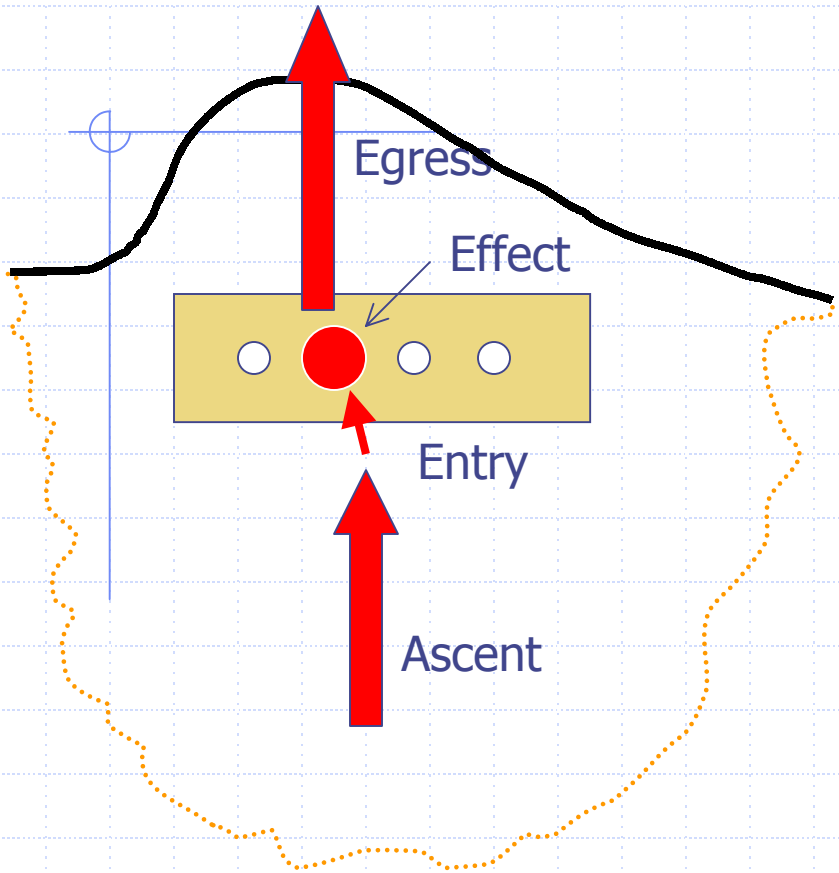
NWTRB Meeting
Thursday, November 8th, 2001
Arlington, VA.

*Comments and discussion on reference material – emphasis on magma-rock interactions*

- Ascent to repository level
- Entry into drifts
- Effect on drift(s)
- Egress from drift(s)

# Overview




**Egress from Drift(s)**

- Egress locations and form

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- Ingress location
- Anticipated magma overpressure
- Pressure wave
  - Dynamic effects and failure
  - Relaxation
- Magma ingress
- Effect of in-drift structures
- Maximum sustainable in-drift pressures

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- Control by local stress state
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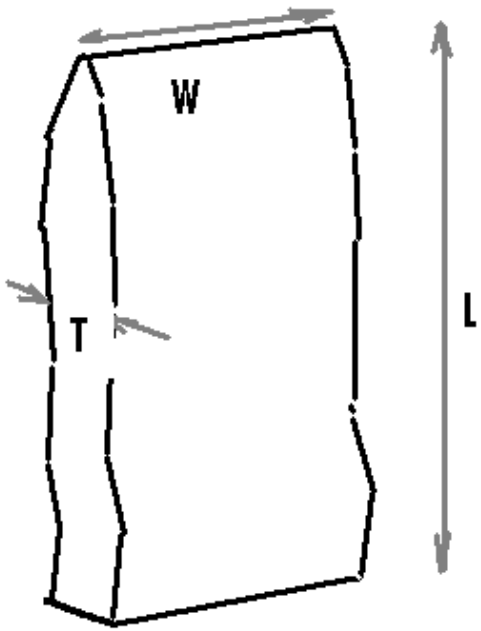
# Dike Ascent Mechanisms




**Ascent Conditions:**

$$p_m > s_h$$

$$T_{\min} = Thermal\ Freezing$$

$$T_{\max} = \frac{(p_m - s_h)}{G/(1-\nu)} W$$

$$K_{Icrit} > K_I = (p_m - s_h)\sqrt{L}$$

1. Driven by buoyancy contrast (Woods et al, 2001)

$$\left.\begin{cases} \rho_{magma} = 2600 kg/m^3 \\ \rho_{crust} = 2400 - 2940 kg/m^3 \end{cases}\right\} \Delta\rho = 70 kg/m^3 \ or\ 0.7\ MPa/km$$

$builds\ to\ 20\ MPa\ over\ 30\ km$

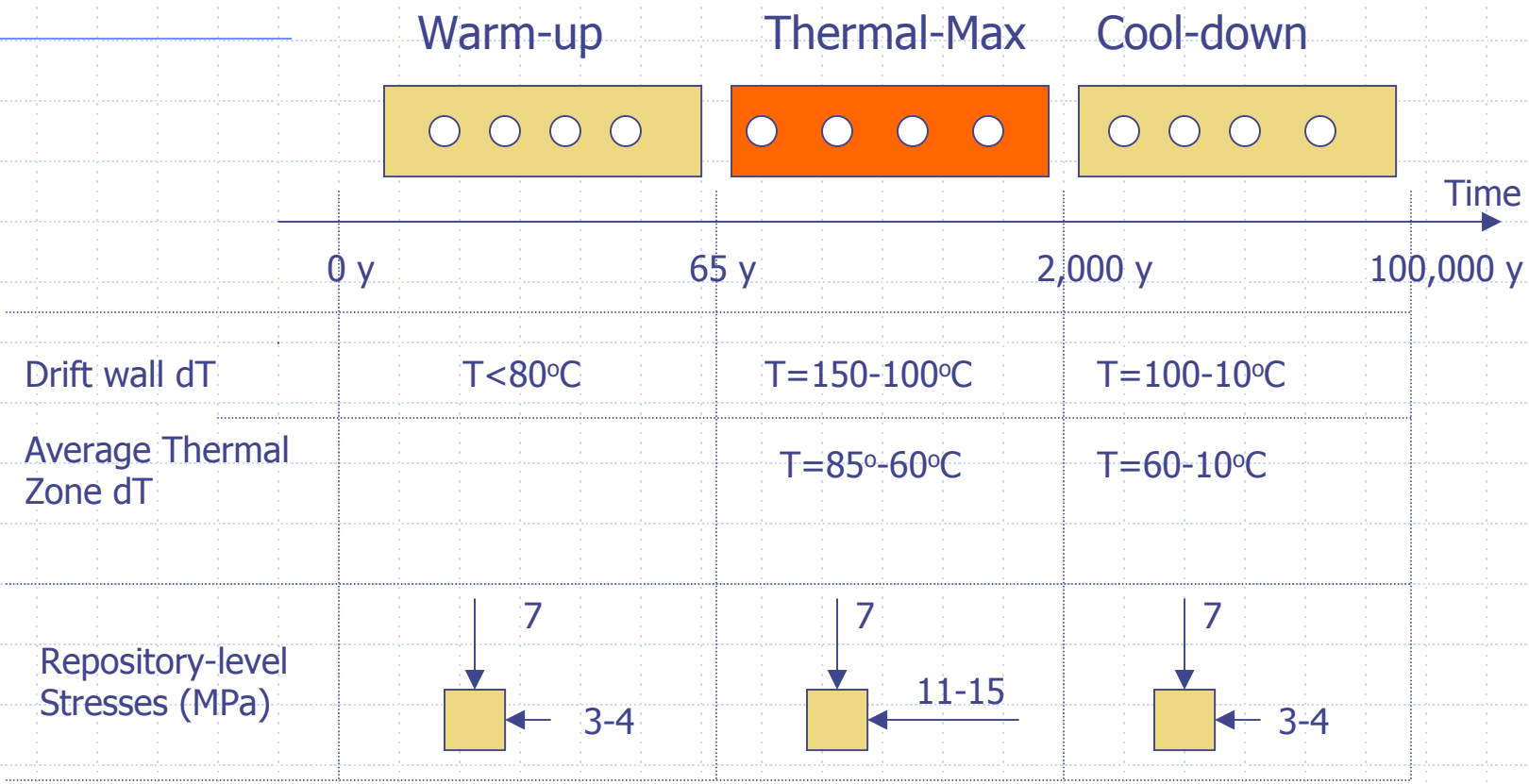
$Note\ \rho_{crust}\ of\ 2260 - 2940\ kg/m^3\ gives\ neutral\ buoyancy$

2. Will build to maximum magma pressure only as:
   1. Conduit losses diminish (static system)
      [1m dike at 1 m/s loses 0.1 MPa/km]
   2. Tip process-zone allows

For $K_{Icrit}$ =1 MPa $m^{1/2}$
(e.g. Rubin, 1995)

| L(km) | (Pm - Sh)(MPa) |
|---|---|
| 30 | 0.006 |
| 5 | 0.014 |
| 1 | 0.03 |

# Yucca Mountain – Schematic Thermal Rock Mechanics



# Thermal and Quasi-static Stresses

**Repository Zone Stresses**

$$\Delta Sh \approx \Delta SH \approx \frac{\alpha\,(ERm)\,\Delta Tav}{(1-v)} \left\{ \begin{array}{l} E = 10 - 40\ GPa \\ Rm = 0.15 \\ v = 0.25 \\ \alpha = 10^{-5}/^{\circ}C \end{array} \right\} \approx$$

**Drift-wall Hoop Stresses**

$$\Delta\sigma_{\theta} \approx \frac{\alpha\,(ER_m)}{1-v}(\Delta T_{drift} - \Delta T_{av}) \left\{ \begin{array}{l} E = 10 - 40\ GPa \\ Rm = 0.15 \\ \upsilon = 0.25 \\ \alpha = 10^{-5}/^{\circ}C \end{array} \right\} \approx$$

| | Thermal Maximum | Warm-up And Cool-down |
|---|---|---|
| Repository Zone Stresses | 11 – 8 MPa (150°) (100°) | 8 - 1 MPa |
| Drift-wall Hoop Stresses | 8 - 5 MPa (65°) (40°) | 8 – 1 MPa |

~0.1 MPa per °C

**Quasi-static pressurization**

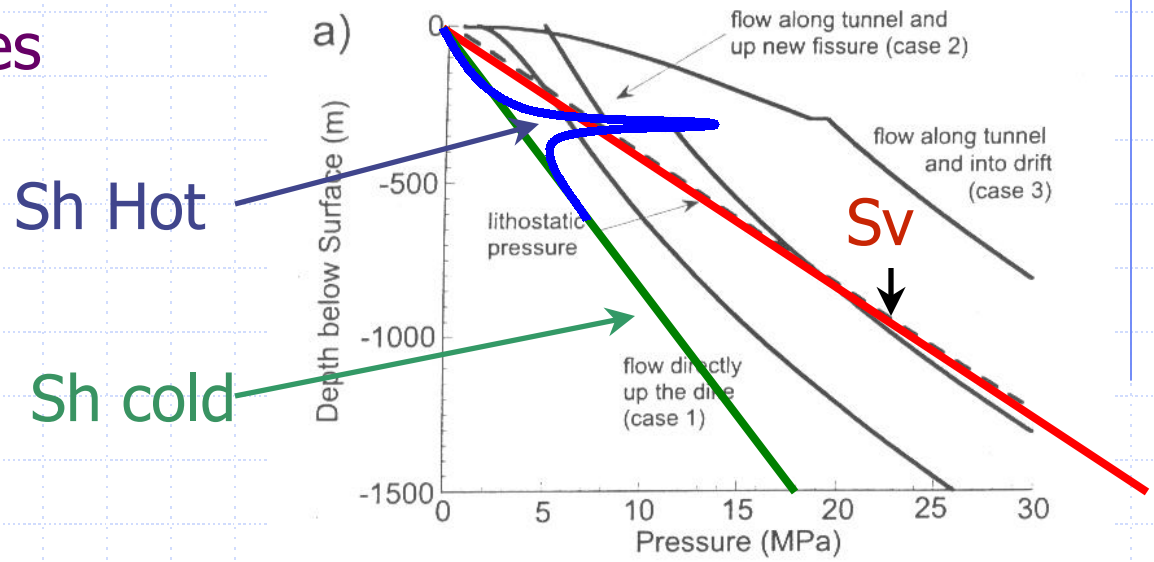
$$\Delta\sigma_{\theta} \approx -\Delta p \frac{a^2}{r^2} \approx -40MPa$$

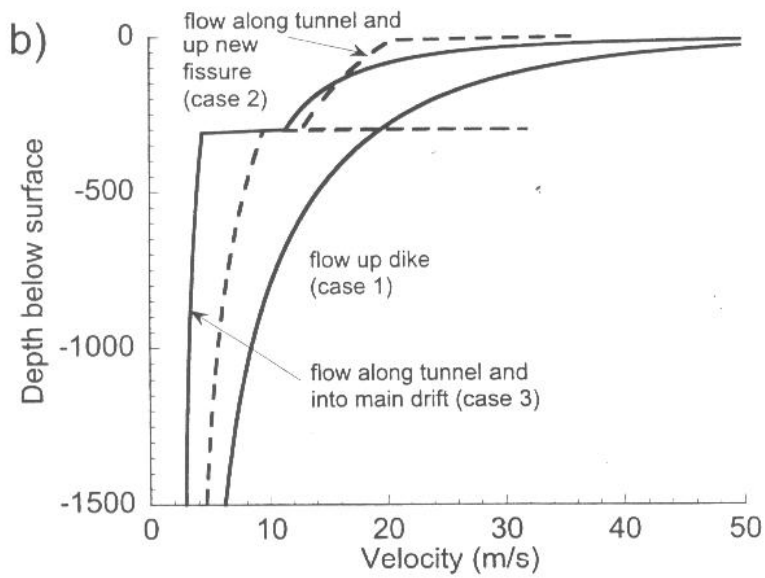
$$\Delta\sigma_{r} \approx \Delta p \frac{a^2}{r^2} \approx +40MPa$$

$$\Delta u_{r} \approx \frac{\Delta pa}{2G} \approx 10mm$$

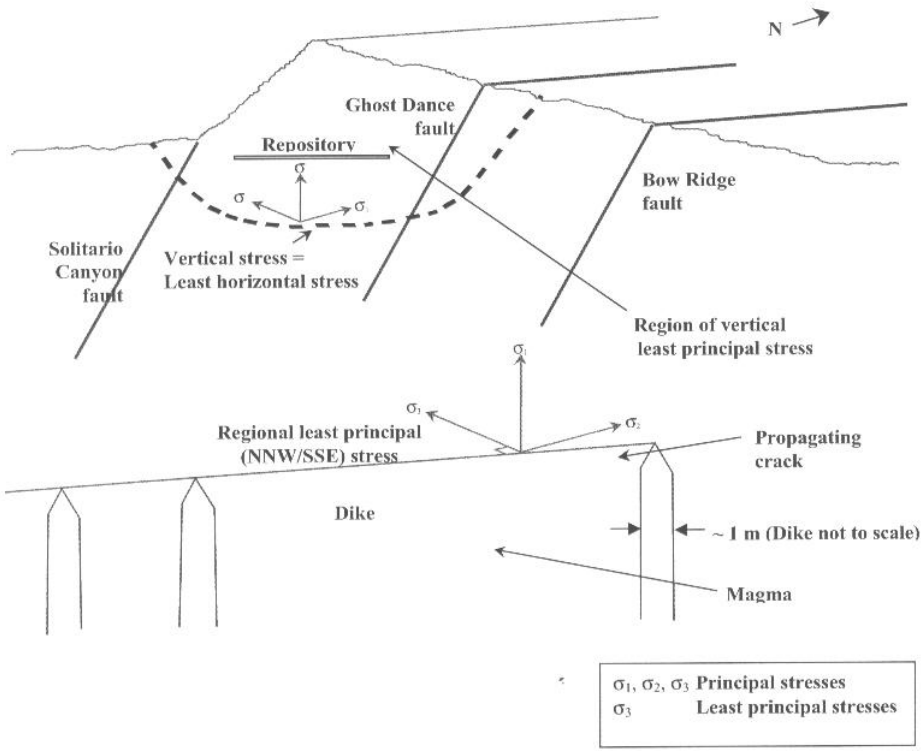
# In Situ Stress Profiles

- Mountain-scale vertical stress will change little with heating or cooling of repository
- High horizontal stresses develop at thermal maximum
- Magma pressures and over-pressures limited by rock strength at mountain-scale.



# Mountain-Scale Effects

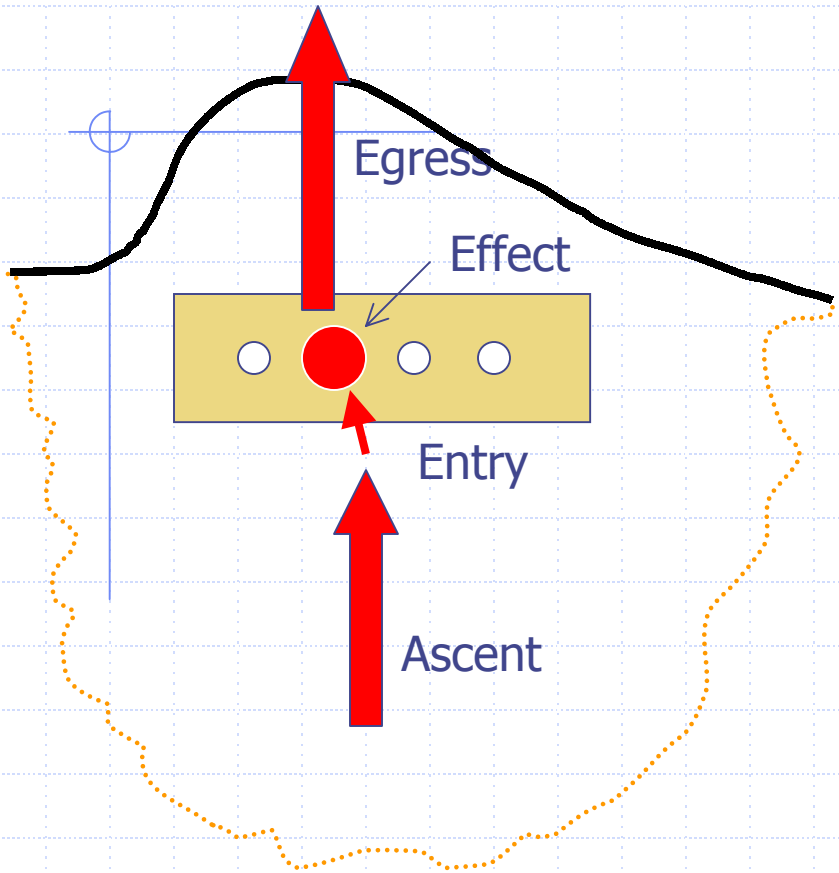



Source: Integrated Site Model-Disruptive Events Report

**Issues:**

1. Over-pressures limited by failure of the host rock.
2. Thermal stresses in repository horizon will be significant in the maximum thermal period
   - Vertical stress becomes minimum principal stress (65y – 2000y)
   - Barrier zone is thin. Order 40m
   - Weak extensional zone below repository
   - As $S_h$ and $S_H$ become closer structural controls (faults) may assume a larger role on intrusive processes
3. Topographic effects of adjacent Crater-Flats

# Overview

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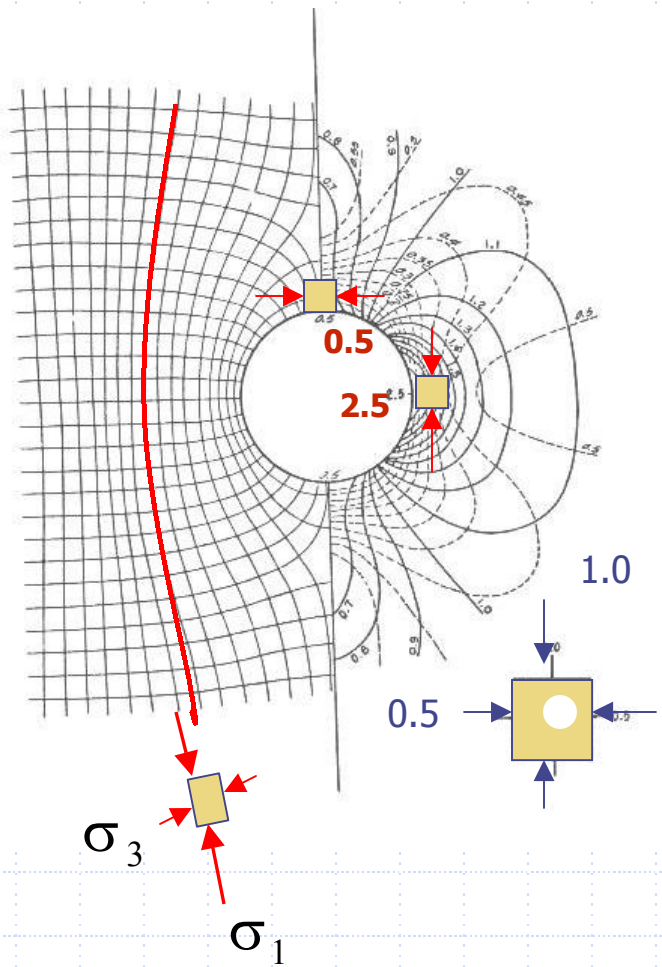
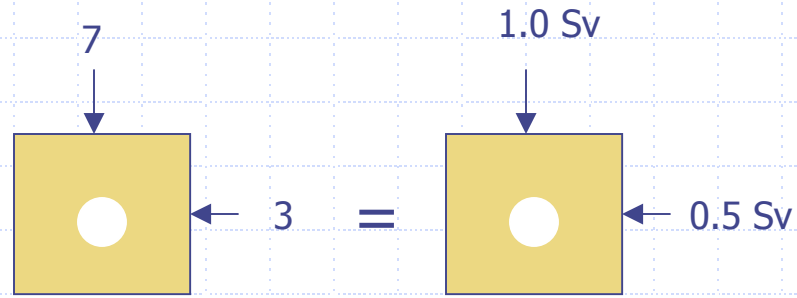
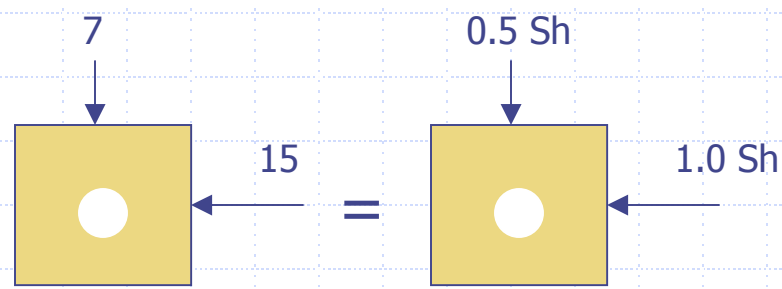
# Drift Stresses



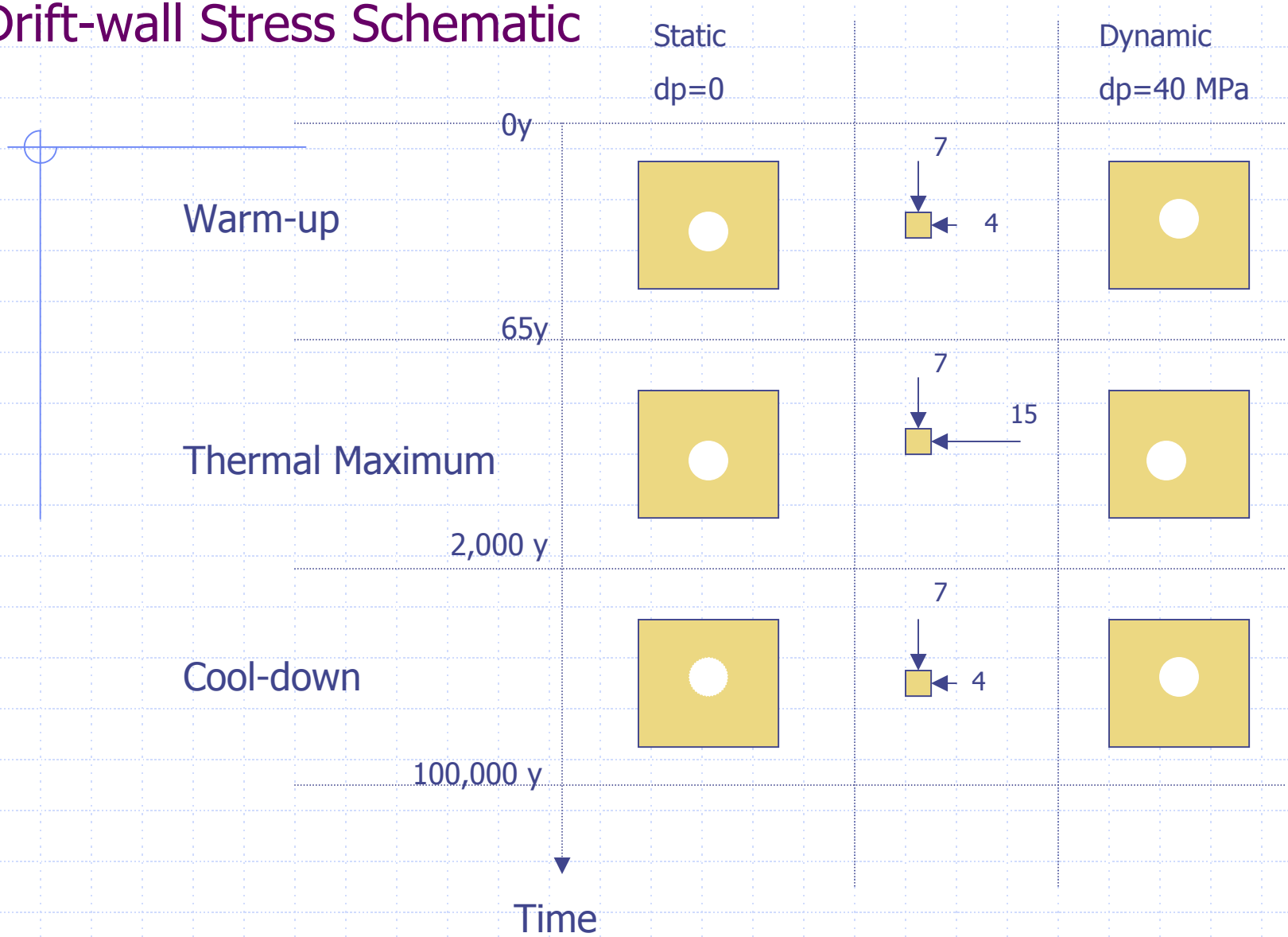

## Warm-up and Cool-down



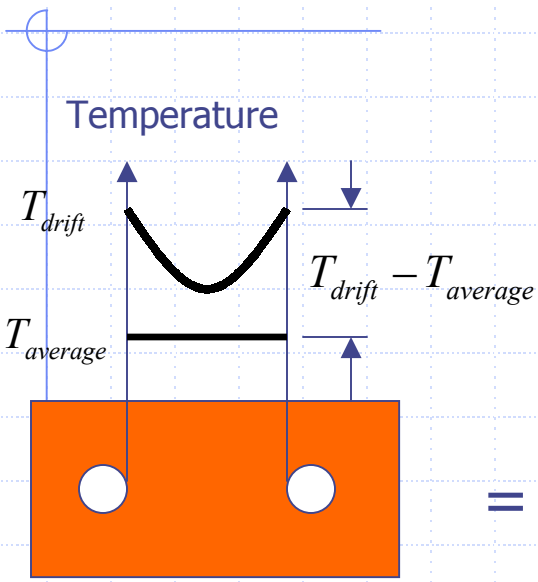

## Maximum Thermal



# Drift-wall Stress Schematic



# Drift-local Behavior

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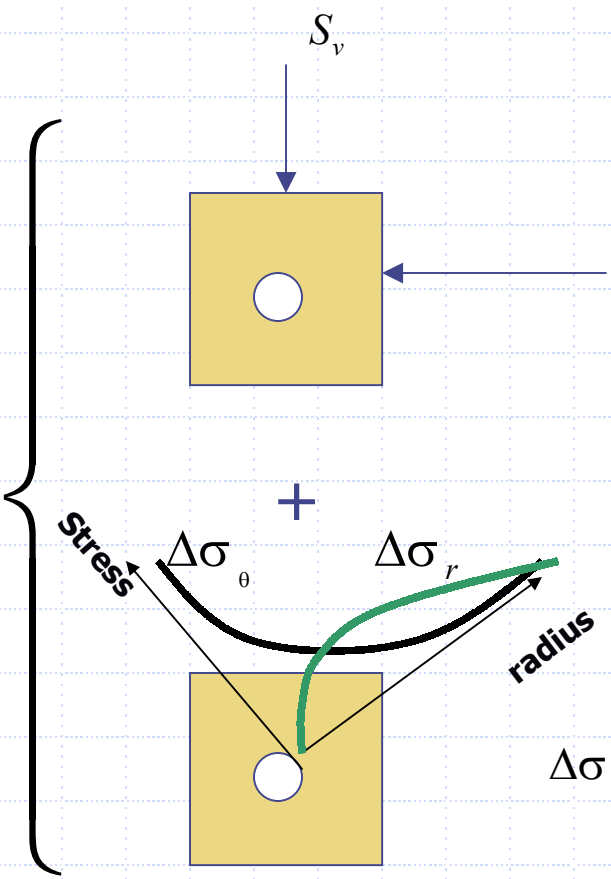
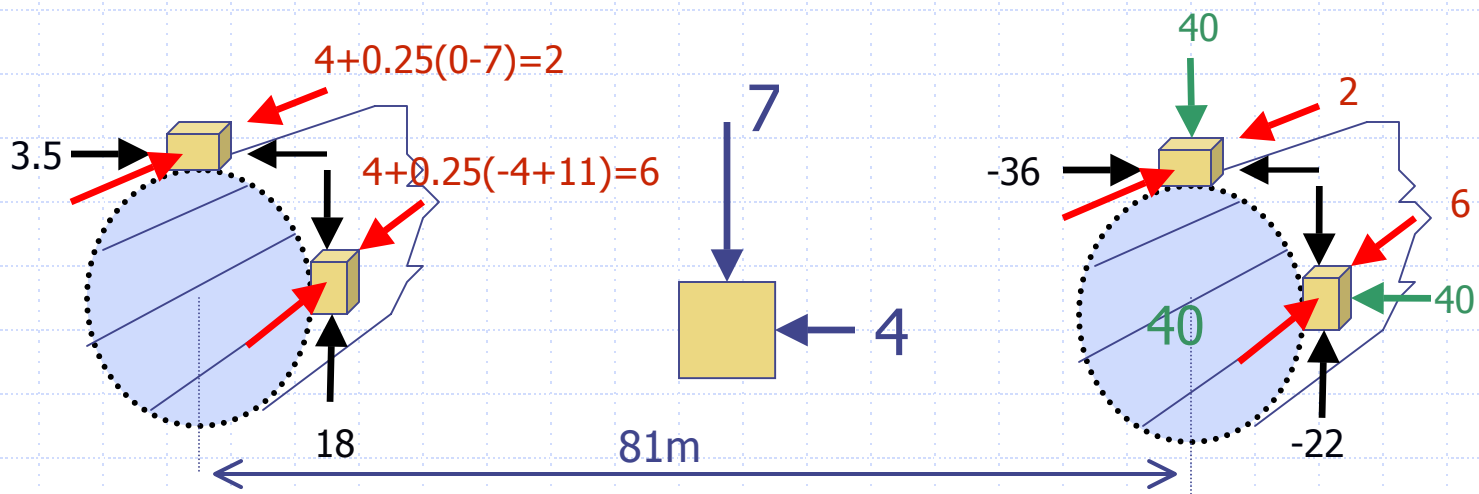



$$S_{h\,ambient} + \underbrace{\frac{\alpha(ERm)}{(1-v)}(T_{av} - T_{ambient})}_{Mountain-scale\ compression}$$

$$\Delta\sigma_{\theta\ \max} \approx \frac{\alpha(ERm)}{(1-v)}(T_{drift} - T_{av})$$

# Drift Stresses – Warm-up and Cool-down

**Static: dp = 0** **Dynamic: dp = 40 MPa**




**Implications:**

As drift-wall warms – additional compressive hoop stresses build at 0.1 MPa per °C. Acts to deter ingress.

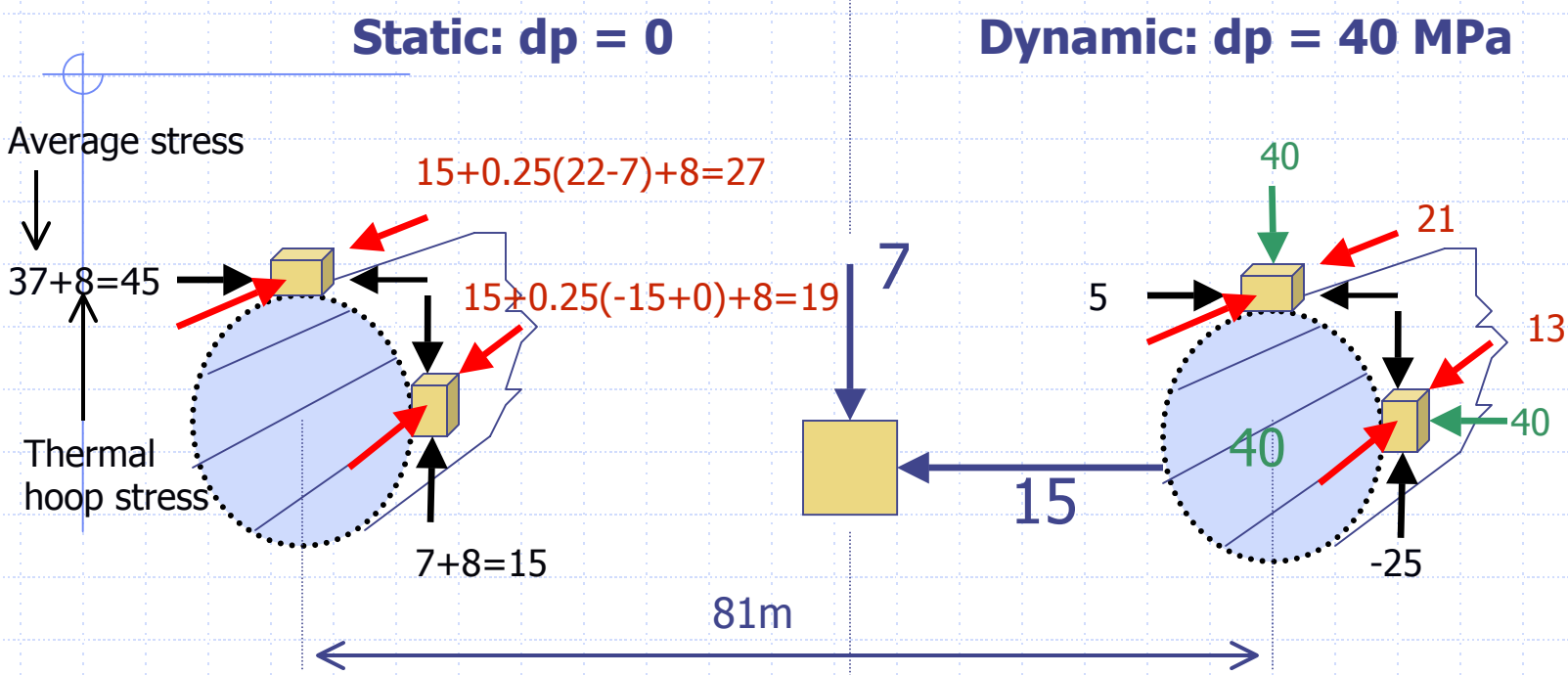
Dike ingress at invert (dp=0). Progressively more difficult as drift warms.

Gas or magma egress along drift crown (dp>0) and twist until normal to $S_h$

Fracture develops to bleed-off gas pressures

Limiting drift pressure ~ 4 MPa when cold or along favorably aligned pre-existing fractures

# Drift Thermal Stresses – Thermal Maximum




**Implications:**

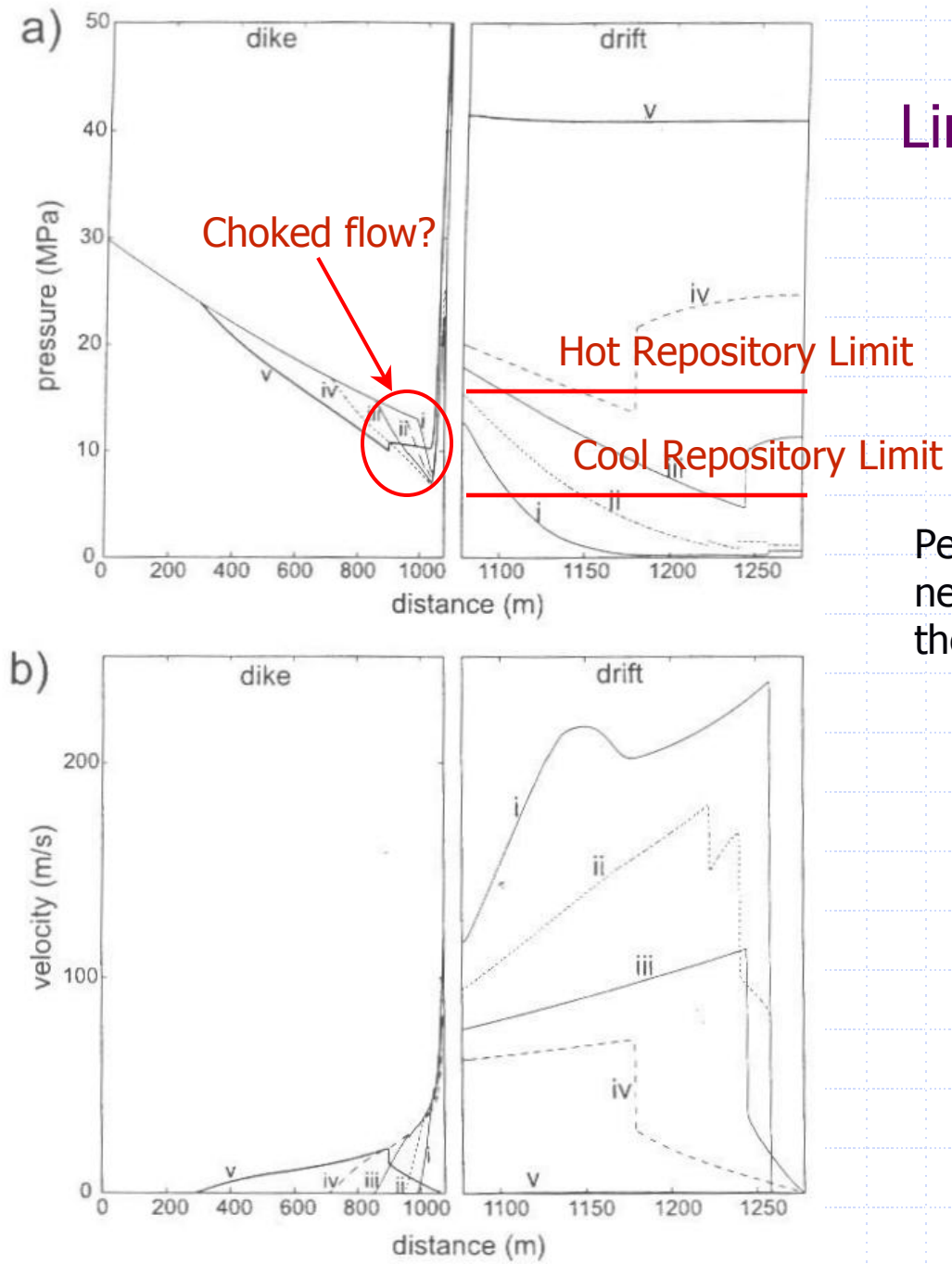
Ingress?

Egress along springline (dp > 0) as horizontal or vertical dike

Fractures develop to bleed off gas pressures

Limiting drift pressure ~ 15 MPa. Lower breakout pressures at cooler (and shallower?) edges of repository.

Analogs on NTS for dynamic wave?



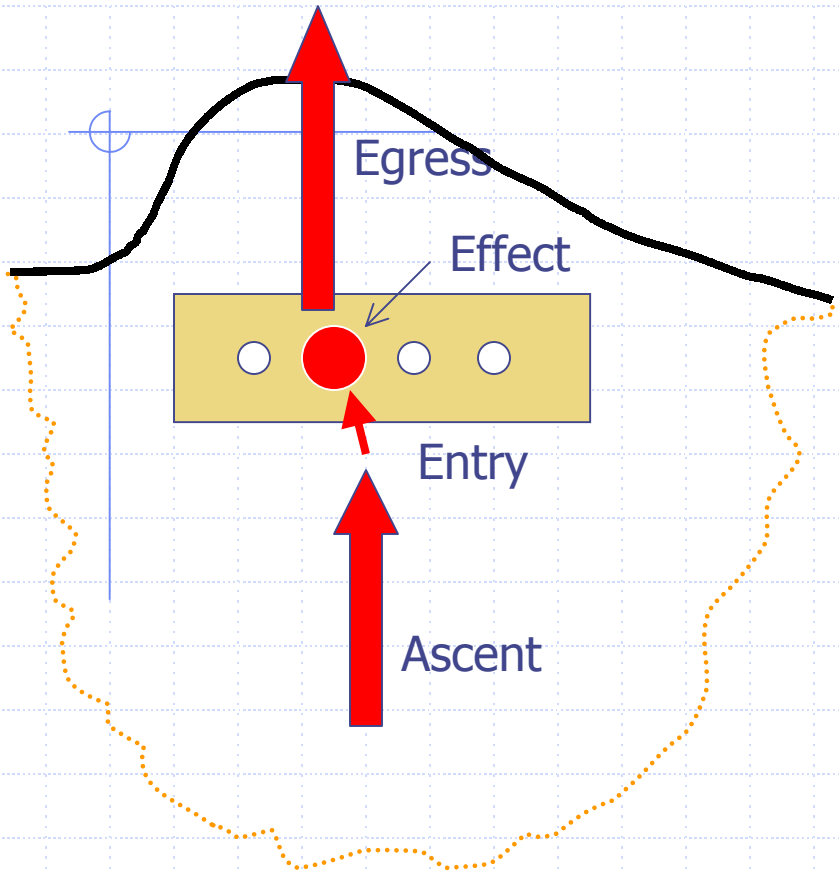

# Limiting drift pressures

Cold: ~2-4 MPa

Hot: 15 MPa?

Peak drift pressures controlled by near-drift stress regime and failure of the drift.

# Overview

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# In-Drift Obstructions

**Waste Packages and Drip Shields**

- Roof-falls following initial pressure pulse and after pressure release
- Large enough to rupture drip shields?
- Full length of drift affected?
- Some dynamic effects on adjacent drifts?

**Cross-section Partially Backfilled**

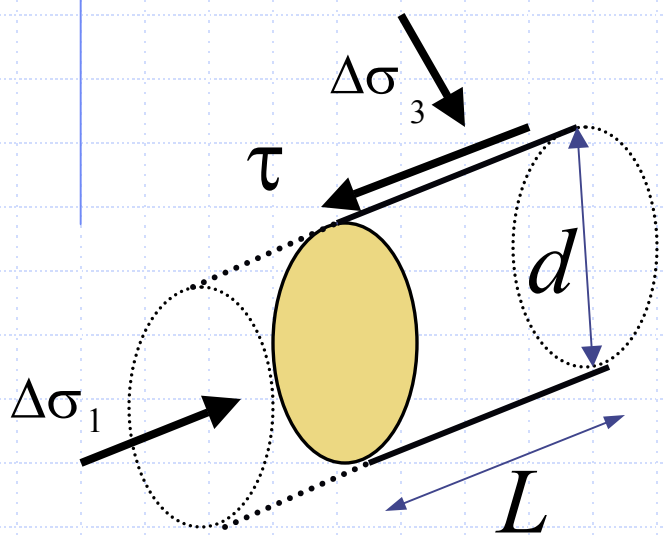
- Expansion volume reduced
    - Erosion of surface
    - Bulldozing extent of pulse
- Protection from roof-fall

**Cross-section Fully Backfilled – or bulkheads**

- Bulkheads separating packages (TSw2?)
- Stem dynamic expansion and force dike to continue
- Requirements
    - Low enough gas permeability to stem expansion
    - High enough strength to prevent displacement

# Bulkhead "Strength" Constraints

- Radial displacements small. Order of 10mm for 40 MPa overpressure. Therefore rigid plug also feasible.
- Plug sizing




$$Elastic: \quad \sigma_3 \approx \frac{v}{1-v}\sigma_1 \approx \frac{1}{3}\sigma_1$$

$$Plastic: \quad \sigma_3 \approx \frac{1-\sin\phi}{1+\sin\phi}\sigma_1 \approx 0.3\sigma_1$$

$$\sigma_1 \frac{\pi}{4} d^2 = \pi\, d\, L\, \sigma_3 \tan\phi$$

$$\frac{L}{d} \approx \frac{3}{4}\frac{1}{\tan\phi} \approx 1$$

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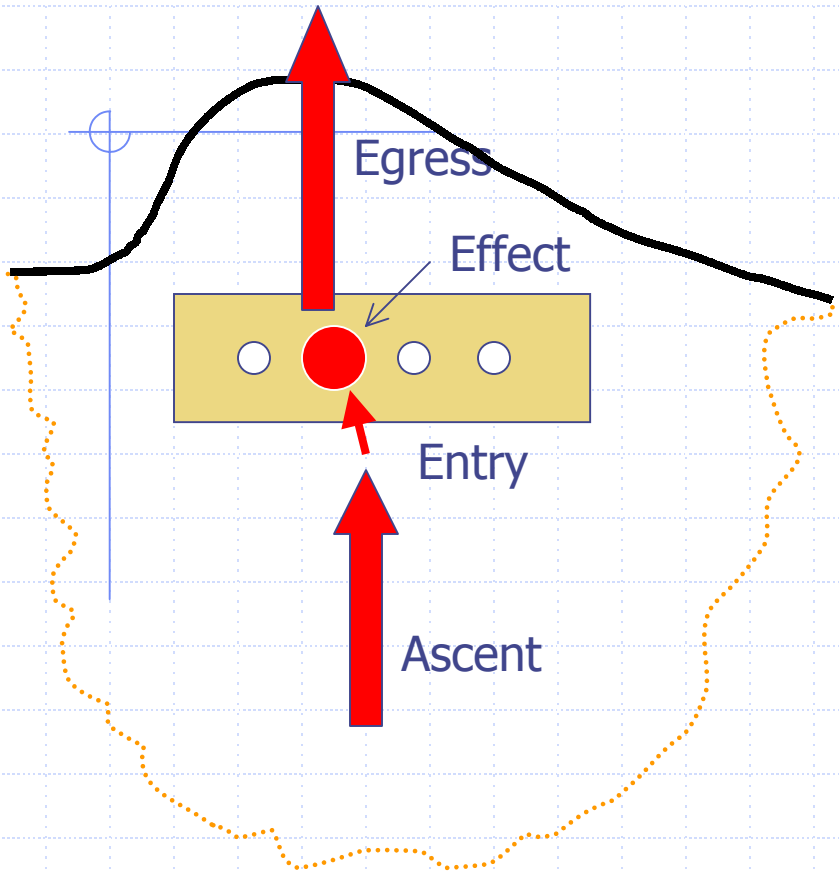


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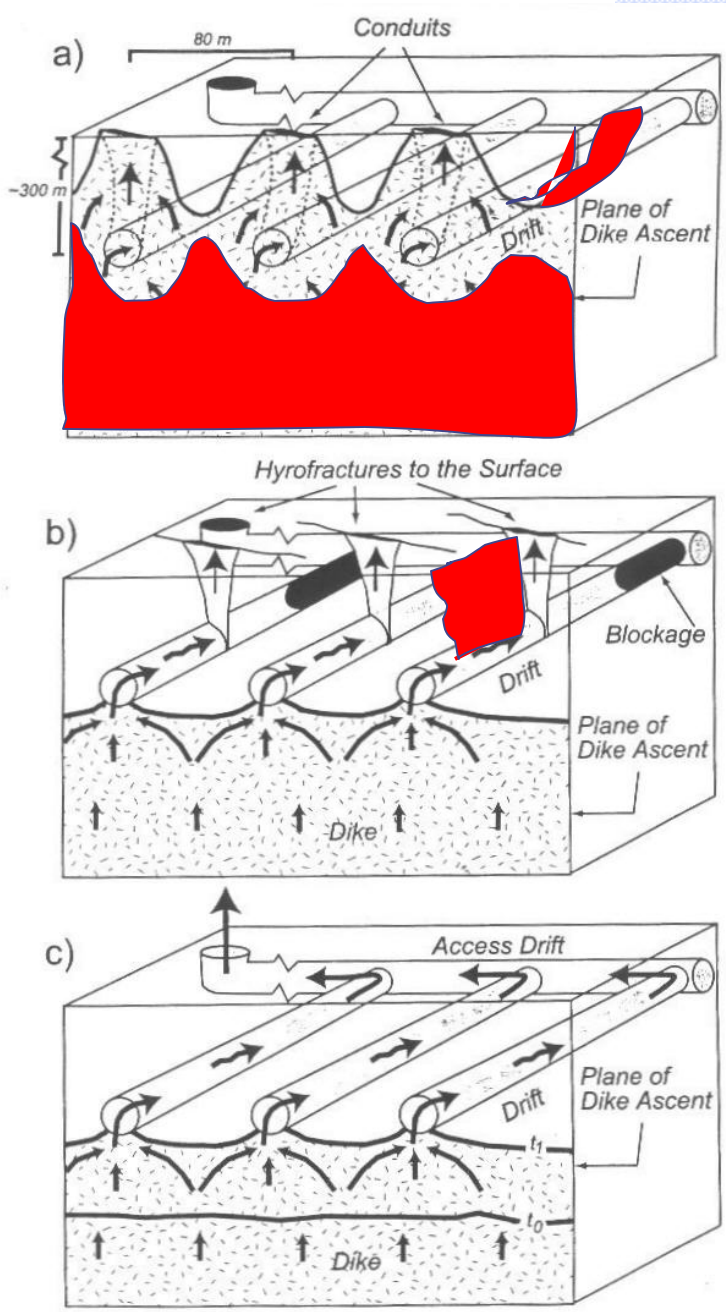
# Egress from Drift




**Hot Repository**

Ingress easiest at repository periphery

Stress regime around drifts deters ingress

Egress easiest along original dike intersection

**Cold Repository**

Dike develops most readily perpendicular to minimum field stress

Pressurized drift fails first at crown and escape feature rotates until perpendicular to field stress.

# Summarized Observations

- Maximum dike overpressures above $S_{min}$ expected to be moderated by rock strength. Likely of the order of less than ~1 MPa
- Cold repository (80% of 10,000 y)
  - Entry at total magma pressure of 2-5 MPa
  - Drifts fail at pressure of the order of ~4 MPa
- Hot repository (20% of 10,000 y)
  - Significantly higher entry pressures and exit pressures than for cold drifts
  - Can ingress occur?
- Backfill or backfill bulkheads could reduce the effects of in-drift decompression and magma ingress.