**TABLE 1.1** Ground-water usage in the United States, 1985.

| Category | Ground-water Use (million gallons/day) | Percent of Total Use Supplied by Ground Water |
|---|---|---|
| Public water supply | 14,600 | 40.0 |
| Domestic, self-supplied | 3,250 | 97.9 |
| Commercial, self-supplied | 746 | 60.7 |
| Irrigation | 45,700 | 33.4 |
| Livestock | 3,020 | 67.6 |
| Industrial (fresh) | 3,930 | 17.6 |
| Industrial (saline) | 26 | 0.7 |
| Mining (fresh) | 1,410 | 52.8 |
| Mining (saline) | 626 | 81.9 |
| Power plant cooling | 608 | 0.5 |

Source: Solley, Merk, and Pierce, 1988.

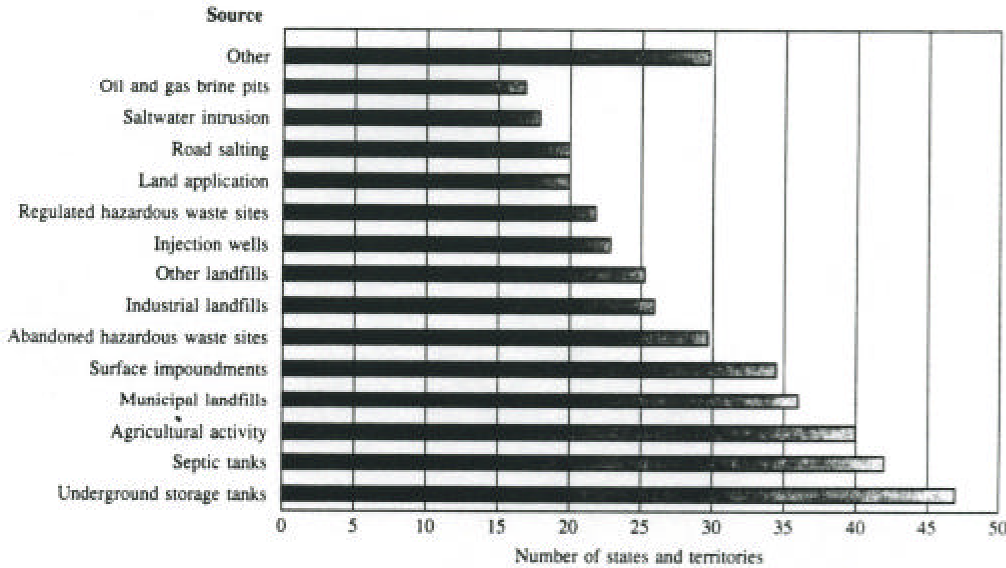



**FIGURE 1.2** Frequency of various contamination sources considered by states and territories of the United States to be major threats to ground-water quality. *Source:* National Water Quality Inventory, 1988 Report to Congress, Environmental Protection Agency, 1990.

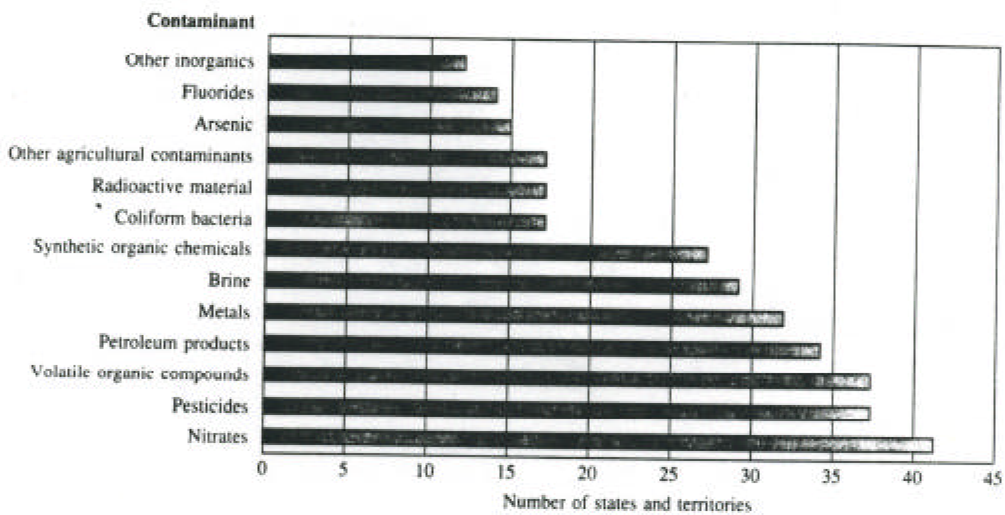
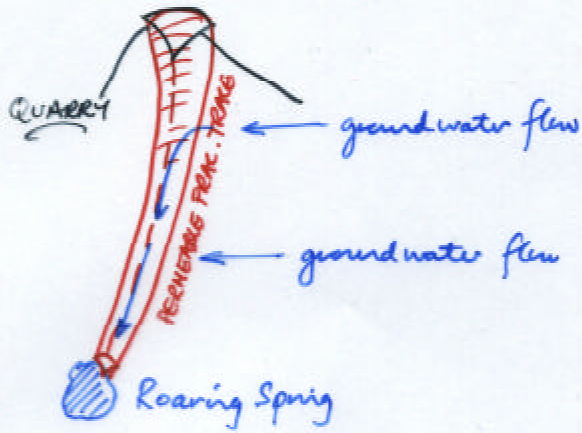



**FIGURE 1.5** Frequency of various contaminants considered by states and territories of the United States to be a major threat to ground-water quality. *Source:* National Water Quality Inventory, 1988 Report to Congress, Environmental Protection Agency, 1990.

## WATER RESOURCE PROTECTION

New Enterprise Stone & Lime (Huntingdon, PA).

- Expand quarry by deepening –
- What effect on g/w resources?




Uses: Appleton Paper 500,000 gal/day

Roaring Spring Bottling: 30,000 gal/day

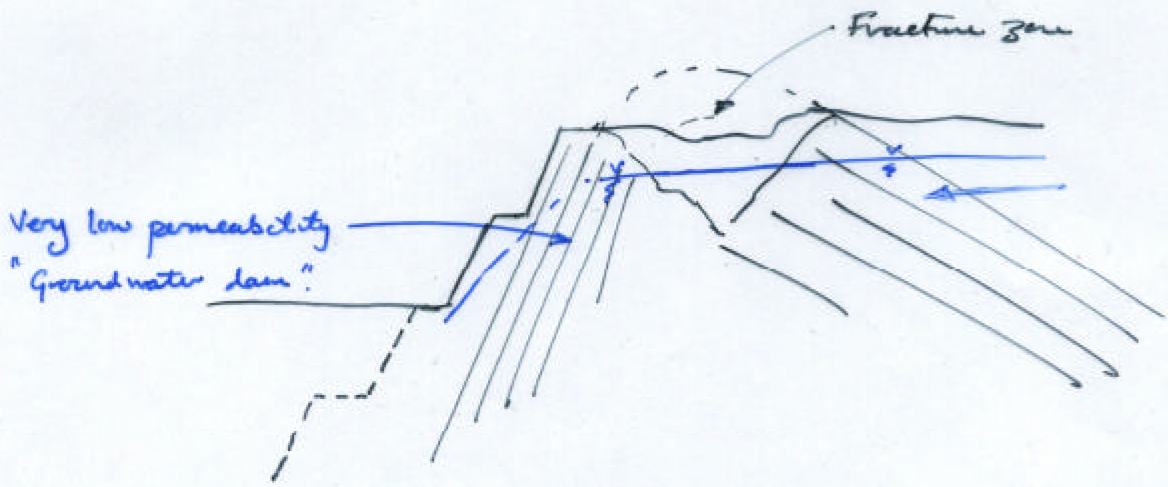


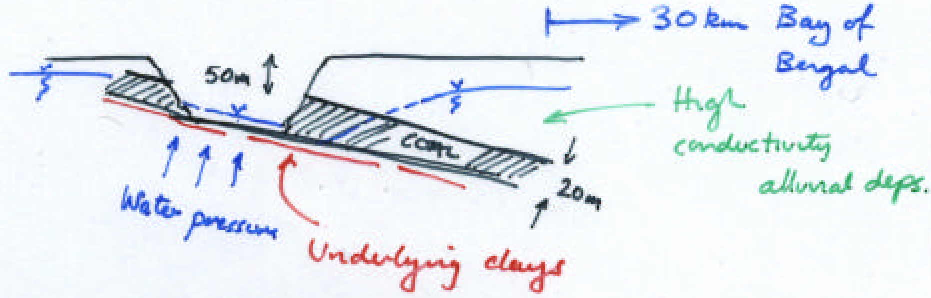

Figure 4-2
Regional Geologic Map
From: U.S.G.S. 7.5 min. Roaring Spring
and Martinsburg quads.
Scale: 1" - 5208.33'

**MEISER & EARL, INC. / Hydrogeologists**

1512 W. COLLEGE AVE.
STATE COLLEGE, PA 16801

# GROUNDWATER PROTECTION


Neyvelli, India.

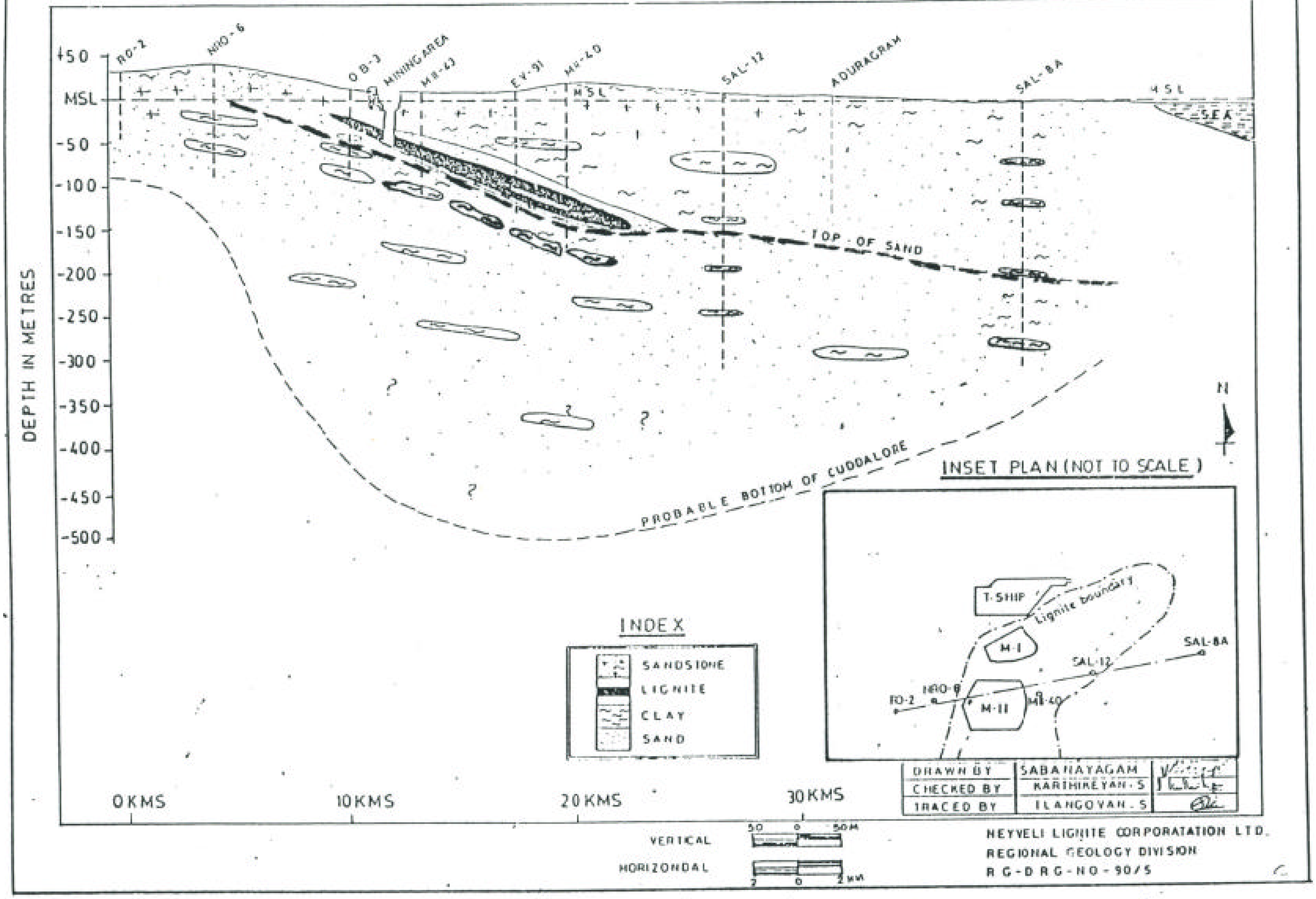



**Purpose:**
- Dewater coals prior to mining — not possible
- Depressurize coals to prevent uplift/rupture

**Problems:**
- 80 – 160 m below ground level
- Groundwater flow 450,000 tons/day
- Monsoons

**Benefits:** Excess water
- Consumed by power plants (600 MW).
- 30 M gallons/yr used for agriculture.

# WEST EAST CROSS SECTION ACROSS SECOND MINE



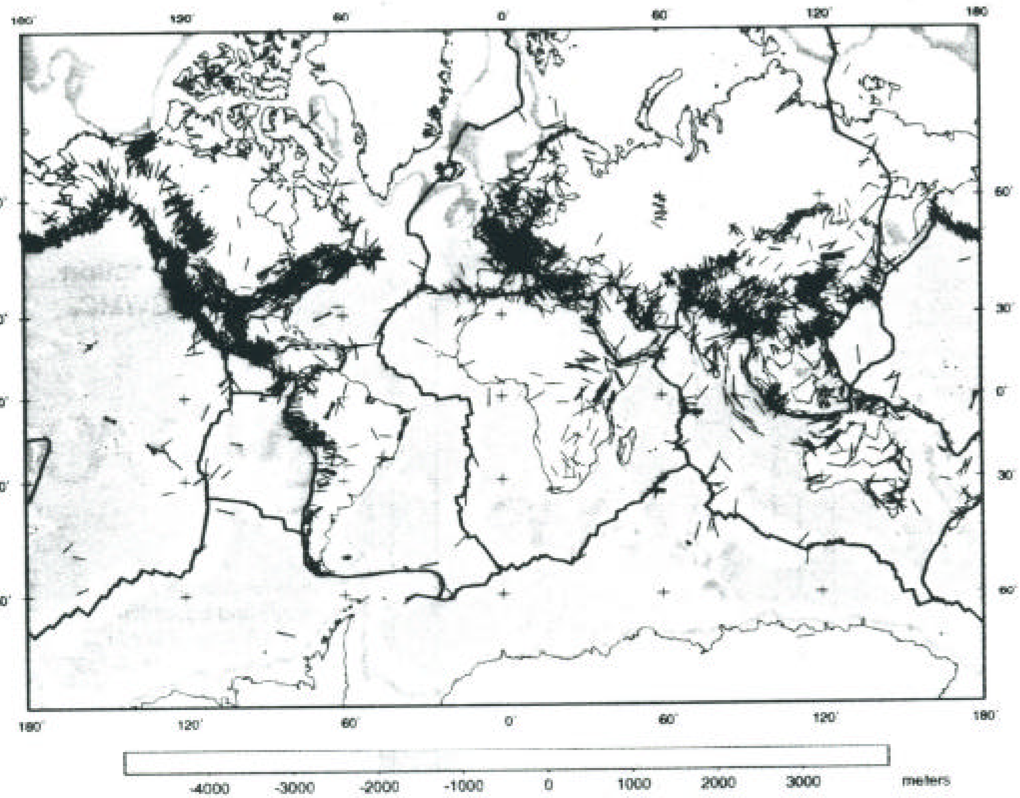



*Fig. 1.* *World stress map, with $S_{Hmax}$ orientations plotted on a base of average topography. Line lengths of data are proportional to quality. Red data indicate a normal faulting stress regime, green data indicate a strike-slip faulting stress regime, purple data indicate a thrust faulting stress regime, and black data indicate an unknown stress regime.*

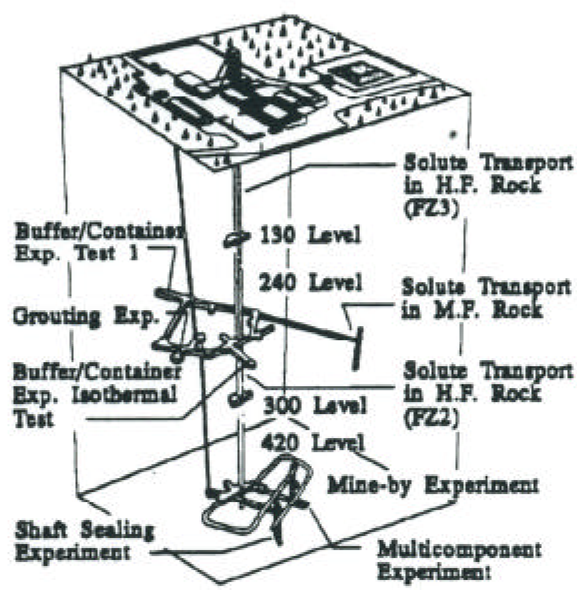
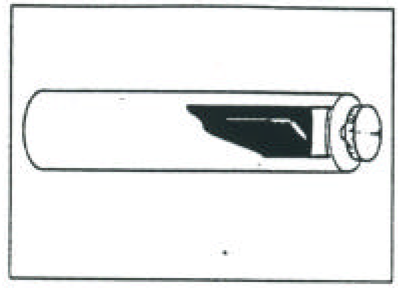



Figure 1 The location of AECL's experiments in the URL

## Safety barrier system for high-level waste

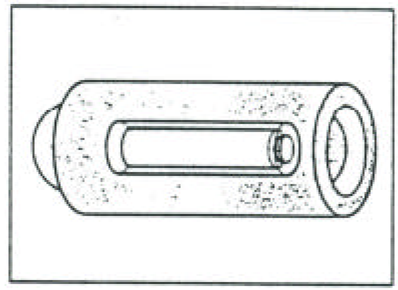
**Glass matrix (in steel mould)**

- Low corrosion rate of glass
- High resistance to radiation damage
- Homogeneous radionuclide distribution



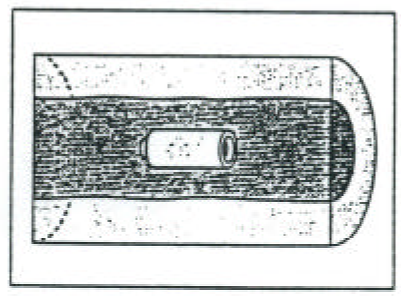
**Steel container**

- Completely isolates waste for > 1000 years
- Corrosion products act as a chemical buffer
- Corrosion products take up radionuclides



**Bentonite backfill**

- Long resaturation time
- Low solute transfer rates (Diffusion)
- Retardation of radionuclide transport (Sorption)
- Chemical buffer
- Low radionuclide solubility in leachate
- Colloid filter
- Plasticity (self-healing following physical disturbance)



**Geological barriers**

**Repository zone:**
- Low water flux
- Favourable hydrochemistry
- Mechanical stability

**Geosphere:**
- Retardation of radionuclides (sorption, matrix diffusion)
- Reduction of radionuclide concentration (dilution, radioactive decay)
- Physical protection of the engineered barriers (e.g. from glacial erosion)

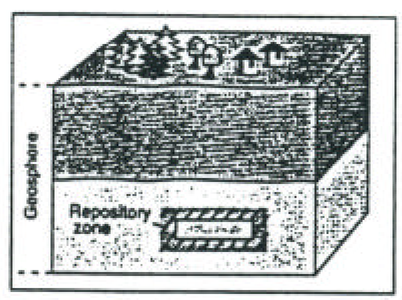



Fig. 2 The safety barrier system for disposal of high-level waste.

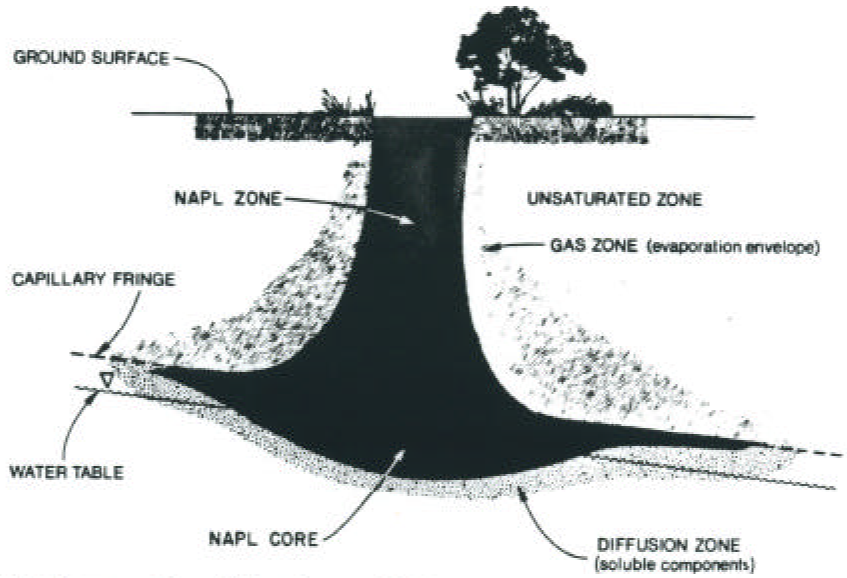



Fig. 1. Schematic representation of lighter than water NAPL movement through the unsaturated and into the saturated zone [after *Abriola and Pinder*, 1985*a*].

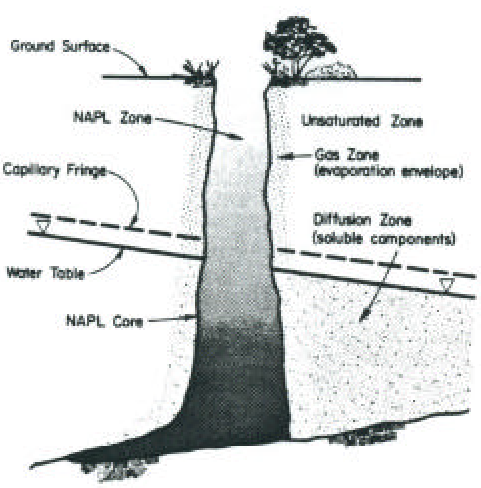



Fig. 2. Schematic representation of heavier than water NAPL movement through the saturated and unsaturated zones.

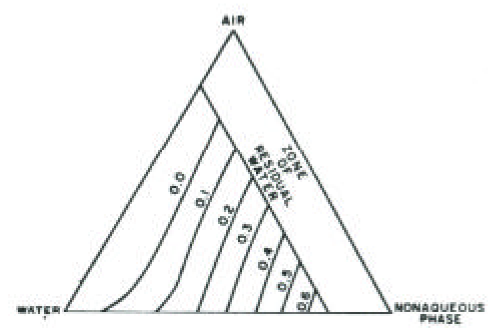
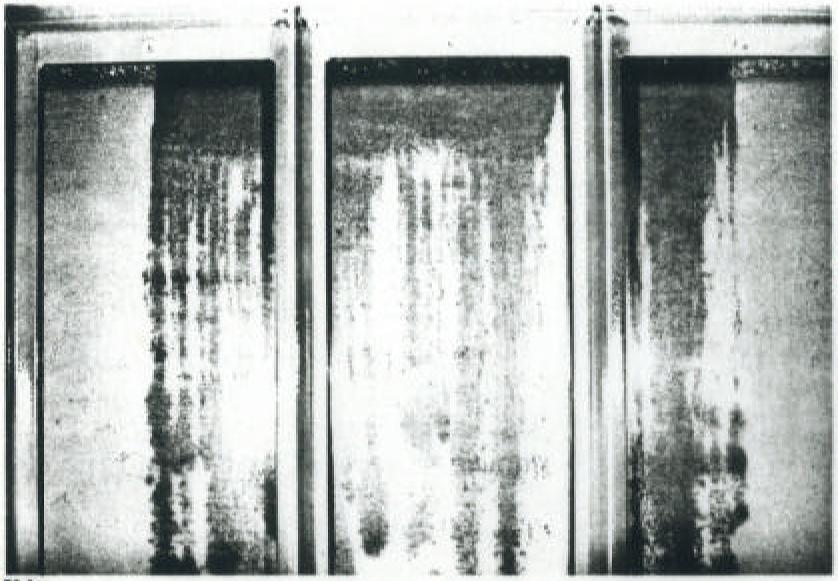



Fig. 3. Ternary diagram showing the relative permeability of the nonaqueous phase as a function of phase saturations [after *Faust*, 1985].

X.a.



X.b.

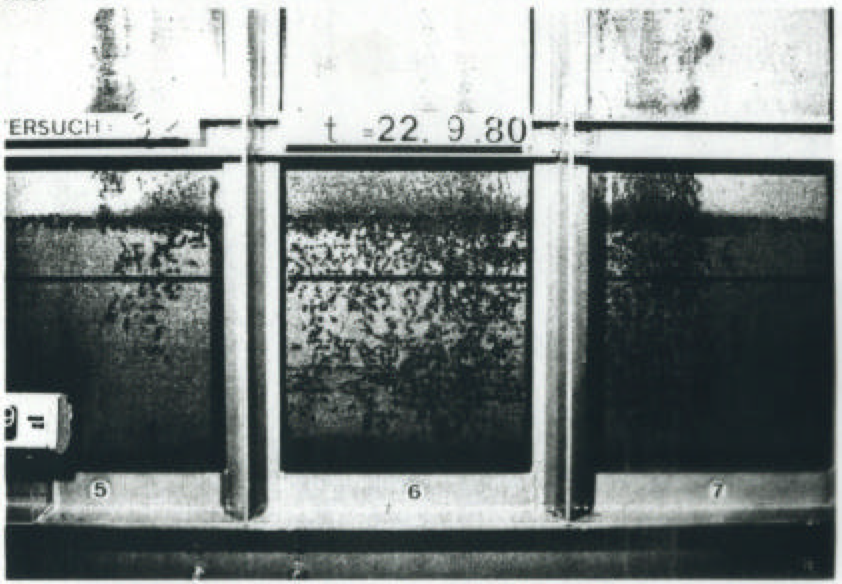
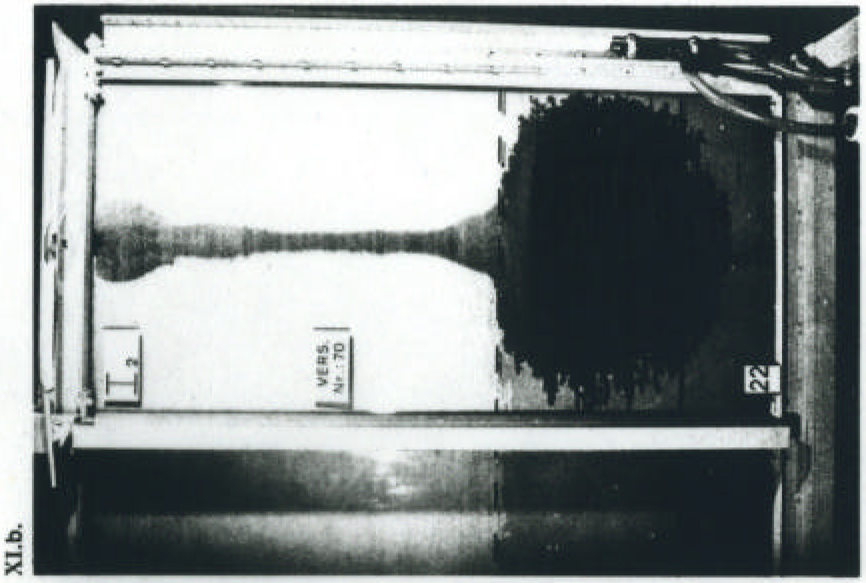


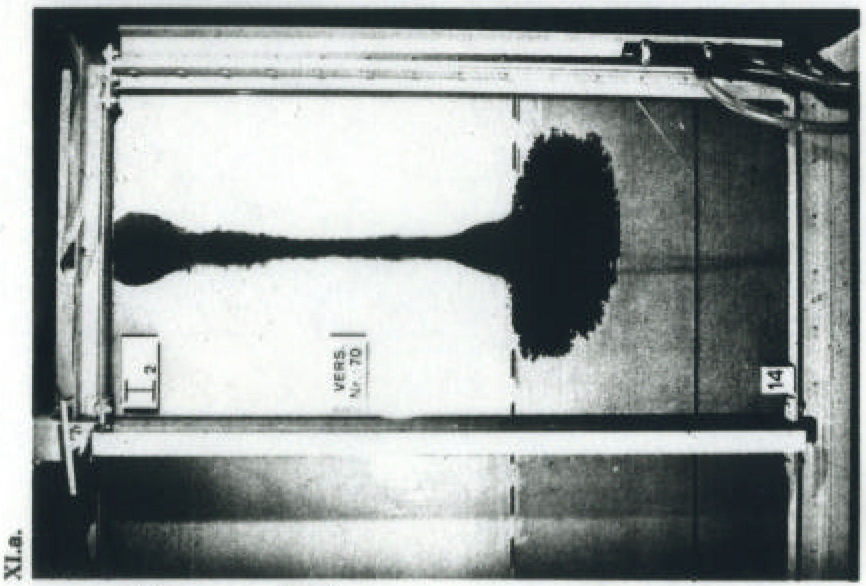

**Figure X.a.** Sheet-like spill of 36.3 L of PER. View of spill above the capillary fringe.

**Figure X.b.** Sheet-like spill of 36.3 L of PER. View of spill below the capillary fringe. Time = ~10 min.

XI.b.



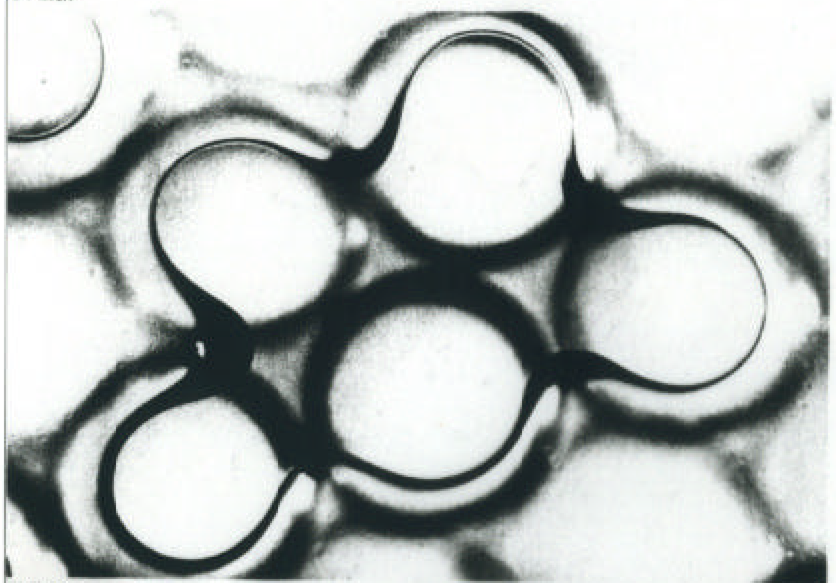

XI.a.




.I.a.
PER. Kinematic
= 0.54 mm²/s.
~1 h.

.I.b.
PER. Later
spill depicted in
.I.a. Kinematic
= 0.54 mm²/s.

XVI.a.



XVI.b.

XVII.a.

XVII.b.

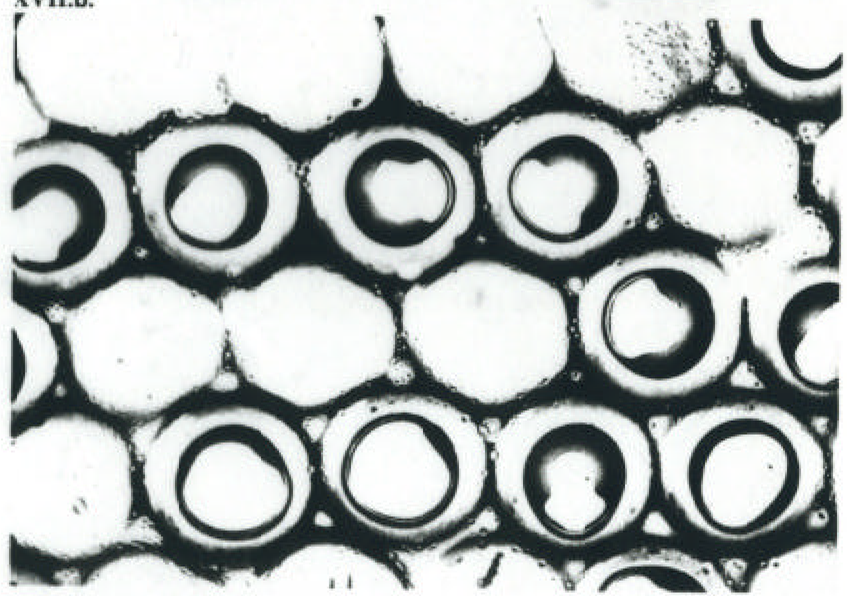


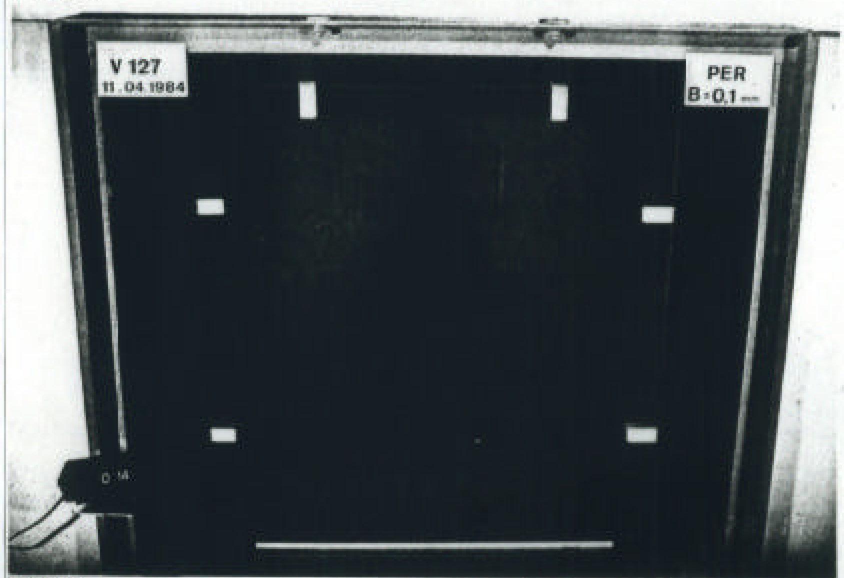
**Figure XVI.a.** Beads initially moist; diameter range = 0.85 - 1.23 mm. PER then dripped in from above. The PER accumulated as a sheath around a zone of high water content.

**Figure XVI.b.** Beads initially saturated with water; diameter range

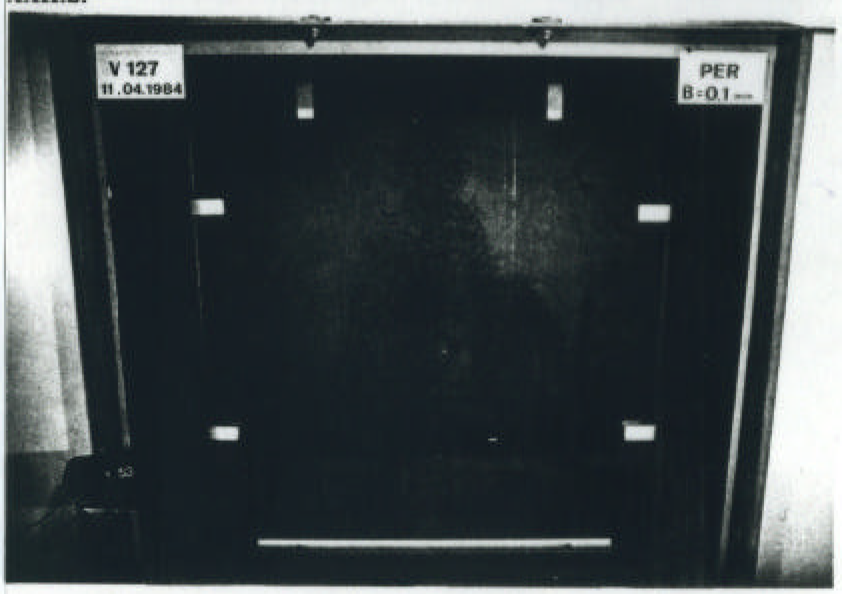
**Figure XVII.a.** Beads initially dry; diameter range = 0.85 - 1.23 mm. PER first applied from above. Water then applied from above. Infiltrating water drove PER from the bead surfaces.

**Figure XVII.b.** Later stage of process depicted in Figure XVII.a.

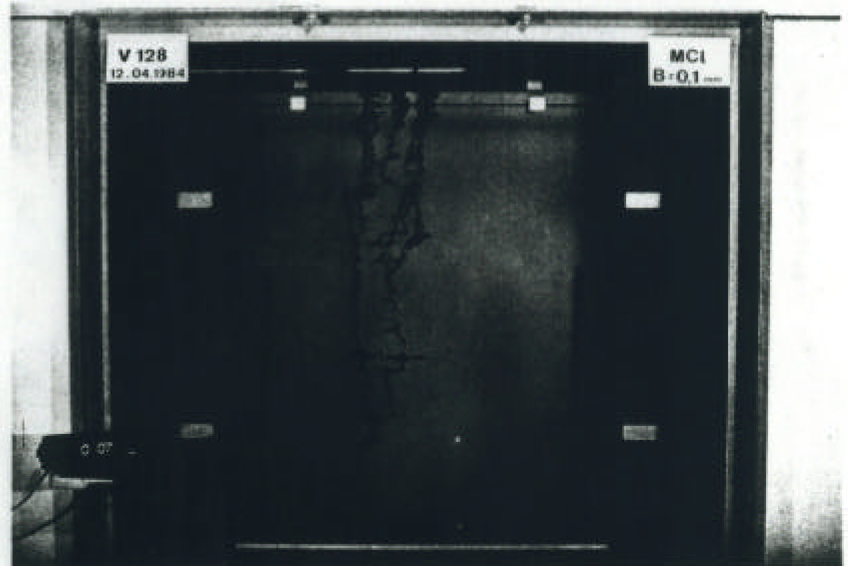
XXII.a.




XXII.b.




XXIII.a.




XXIII.b.

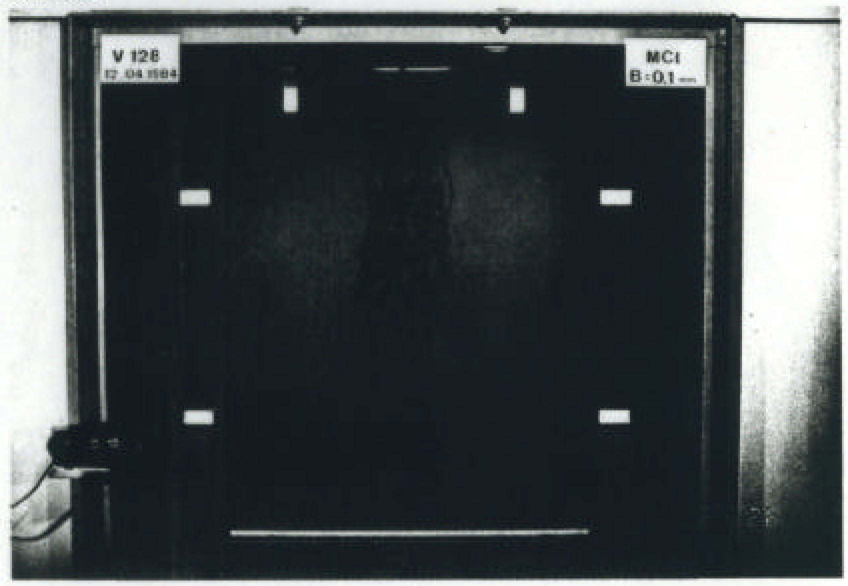


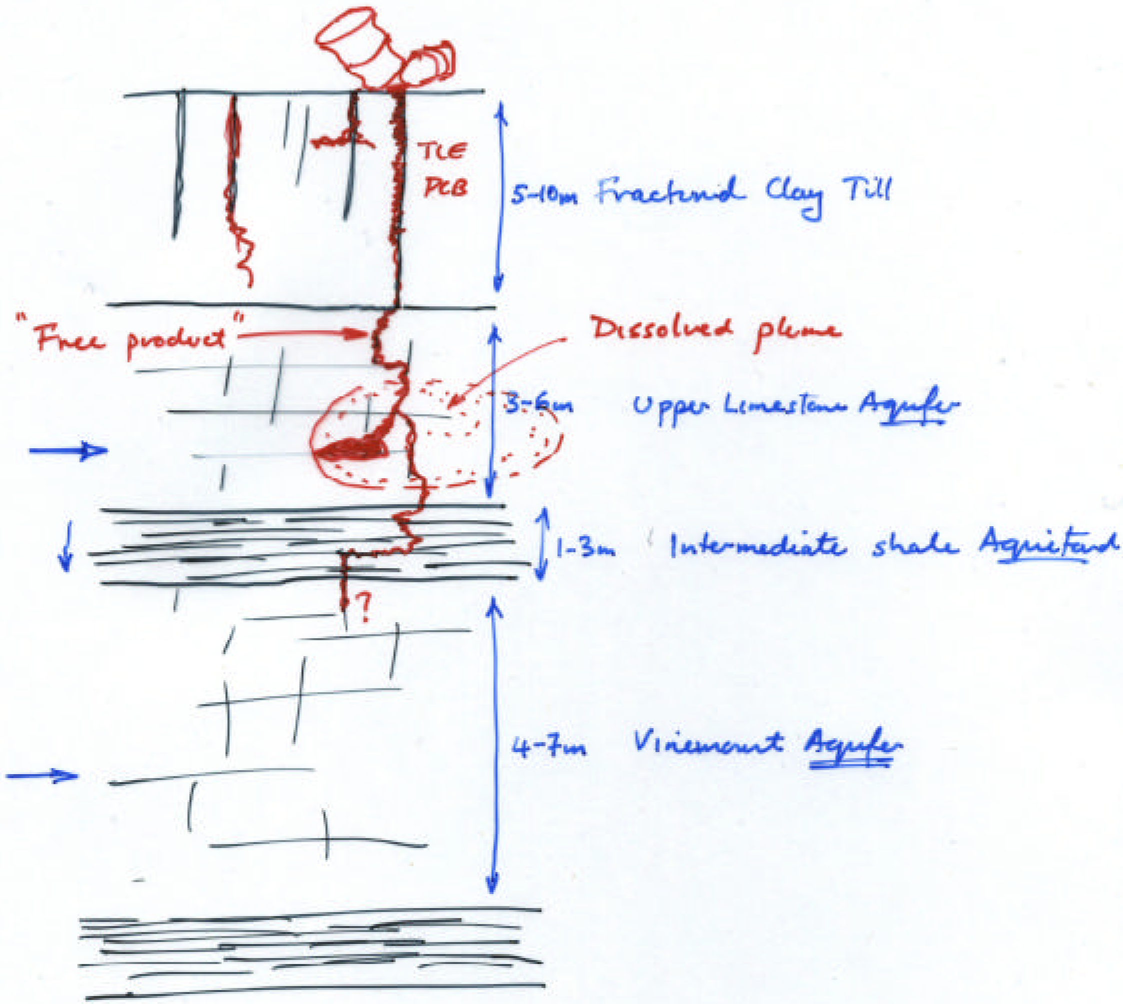

**Figure XXII.a.** Fracture with an aperture of 0.1 mm, and rough walls initially saturated with water. Water level then lowered. PER then applied at 1.3 mL/min. Water remaining on fracture walls affected distribution of PER.

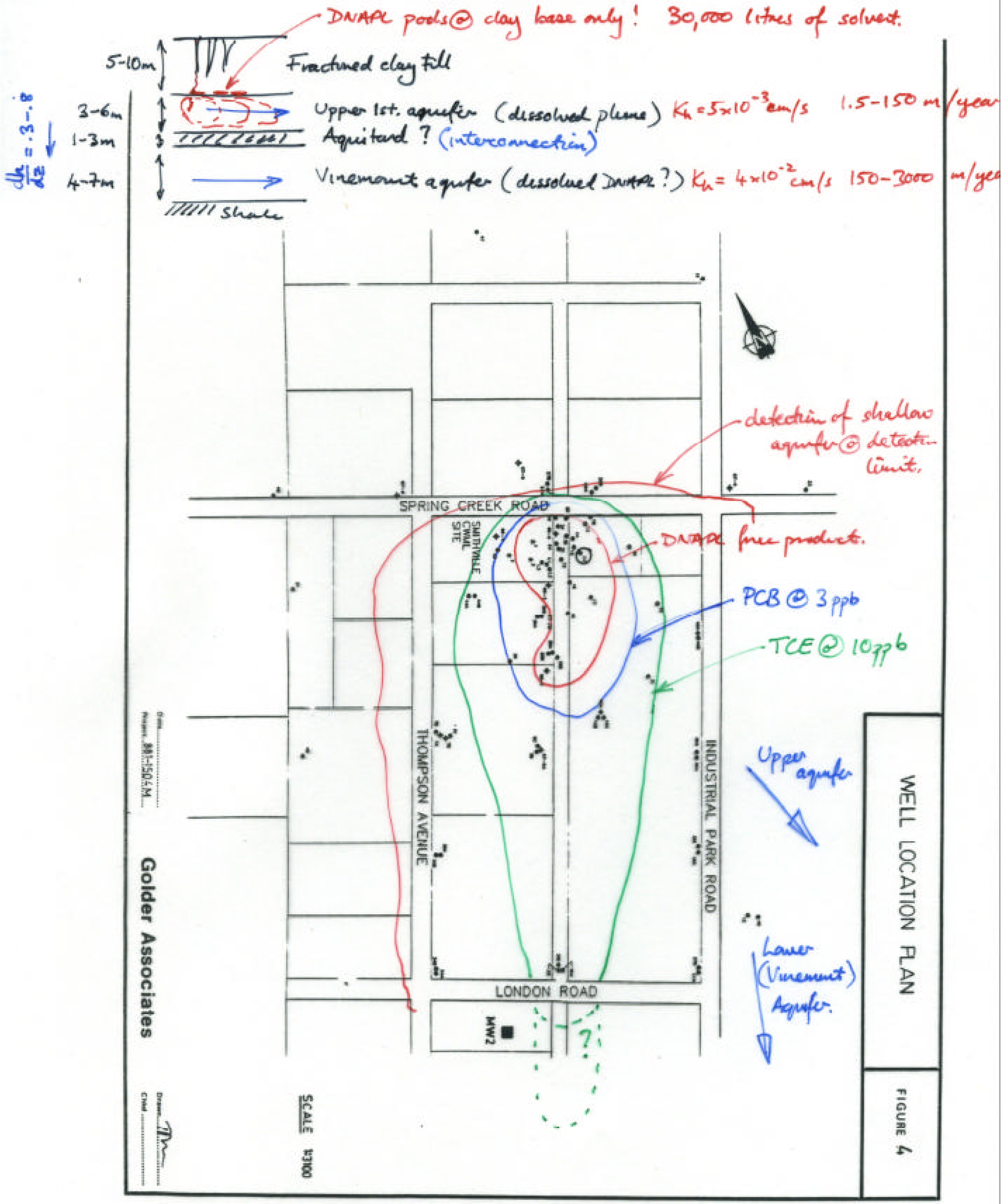
**Figure XXII.b.** Same system as in Figure XXII.a., but at 1.5 h after discontinuation of the application of PER. All PER shown is in a stable state

**Figure XXIII.a.** Infiltration of DCM into a fully saturated fracture with an aperture of 0.1 mm, and rough walls. DCM appled at 1.4 mL/min. Results similar to those for PER in Figure XXI.b.

**Figure XXIII.b.** Continuation of Figure XXIII.a. experiment. 45 min after ending the DCM application, the water level was lowered. Little DCM

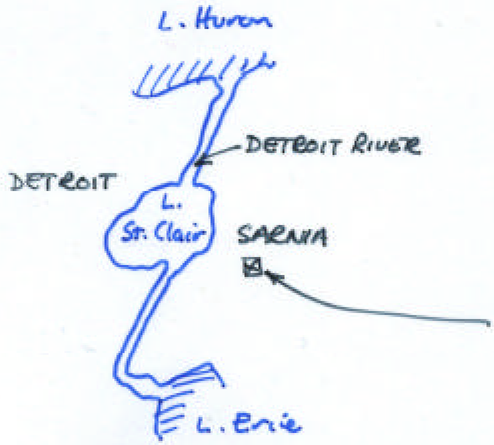
SMITHVILLE SITE

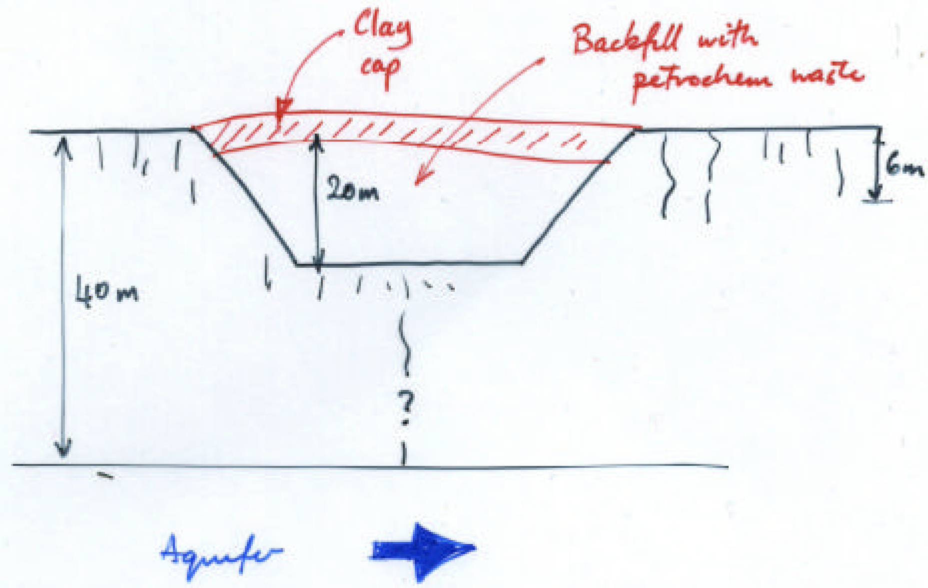




DNAPL pools @ clay base only! 30,000 litres of solvent.
5-10m
Fractured clay till
3-6m
Upper 1st. aquifer (dissolved plume) $K_h = 5 \times 10^{-3}$ cm/s 1.5-150 m/year
1-3m
Aquitard ? (interconnection)
4-7m
Vinemount aquifer (dissolved DNAPL ?) $K_h = 4 \times 10^{-2}$ cm/s 150-3000 m/year
Shale
detection of shallow aquifer @ detection limit.
SPRING CREEK ROAD
SMITHVILLE CWML SITE
DNAPL free product.
PCB @ 3 ppb
TCE @ 10 ppb
THOMPSON AVENUE
INDUSTRIAL PARK ROAD
Upper aquifer
Lower (Vinemount) Aquifer.
LONDON ROAD
MW2
WELL LOCATION PLAN
FIGURE 4
Golder Associates
SCALE

# HYDROLOGY OF AQUICLUDES



## SCIENTIFIC ISSUES

Most insidious/penetrative contaminants are NAPLs.

1. How to determine location of free product:
   - what hydrologic controls (multiphase flow)
   - how far will it migrate
     - influence of unsaturated zone; fractures; g/w flow
   - once arrested, will it remobilize? can it?

2. Characterization of travel/retardation times:
   - what are the dissolution rates
   - How quickly and at what concentration will the plume develop?
   - How long will it endure?

3. Methods of removal/isolation: (Economics)
   - What methods will work?
   - How much will each method cost?
   - Do we need to isolate/remediate?