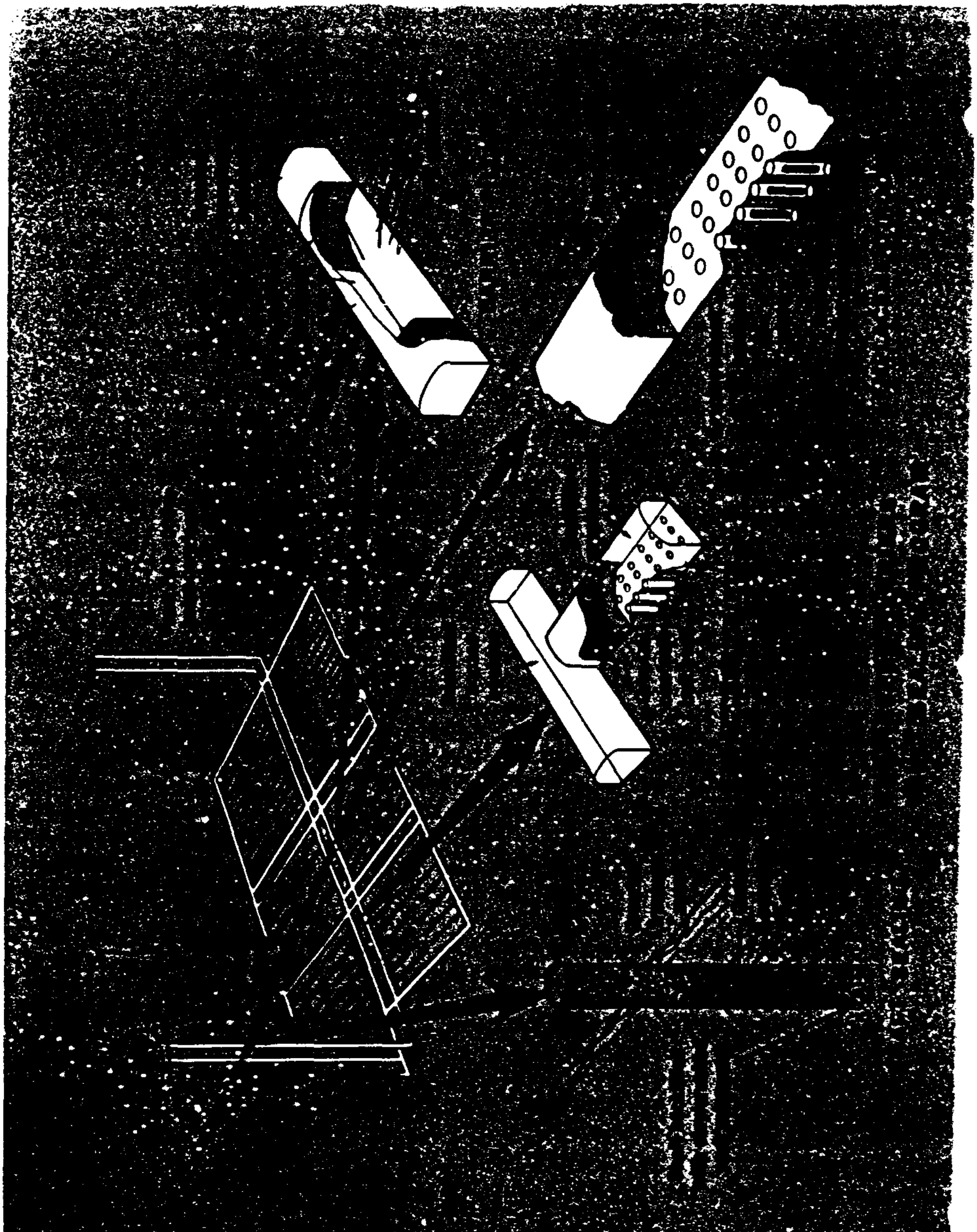
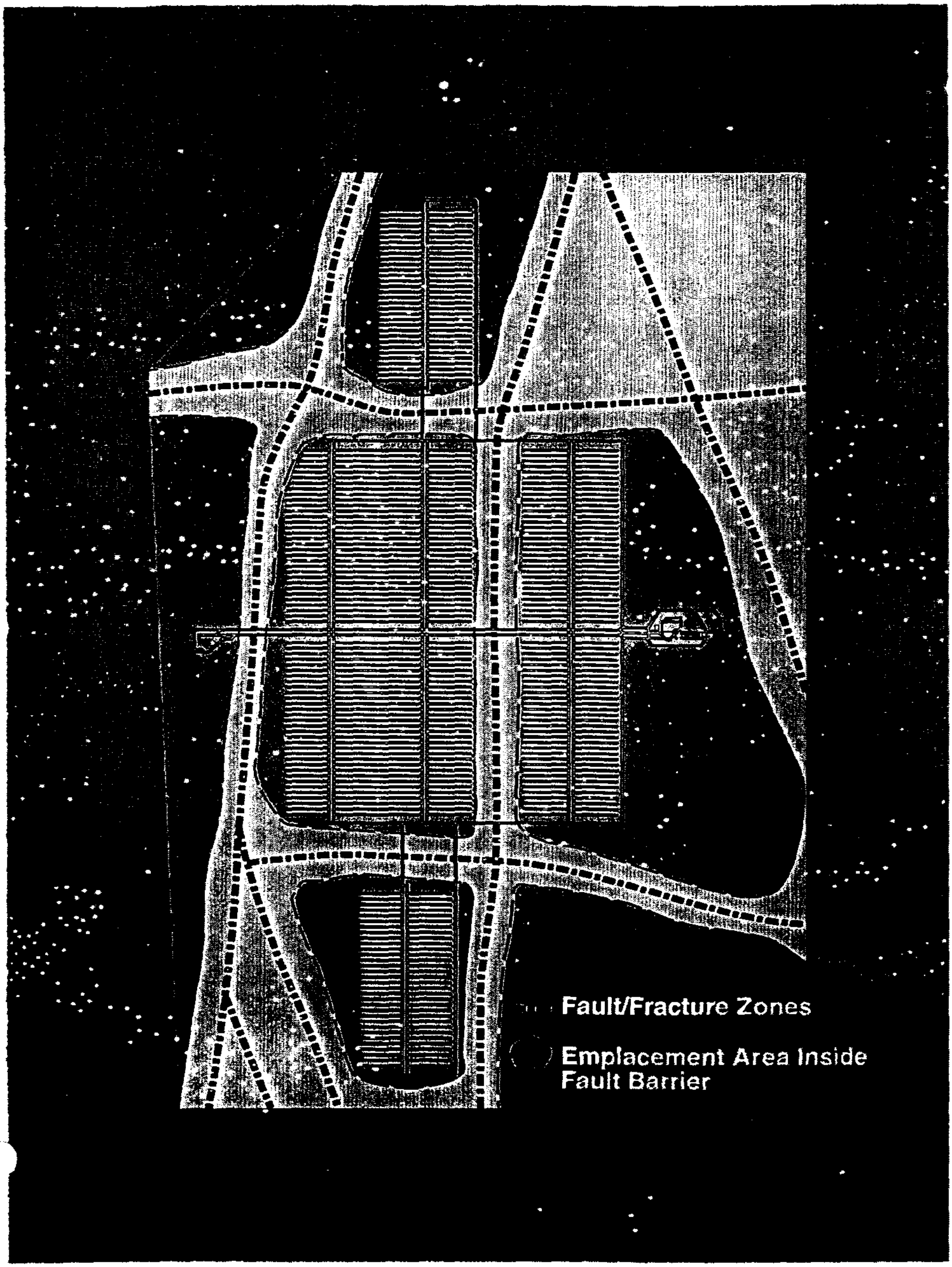
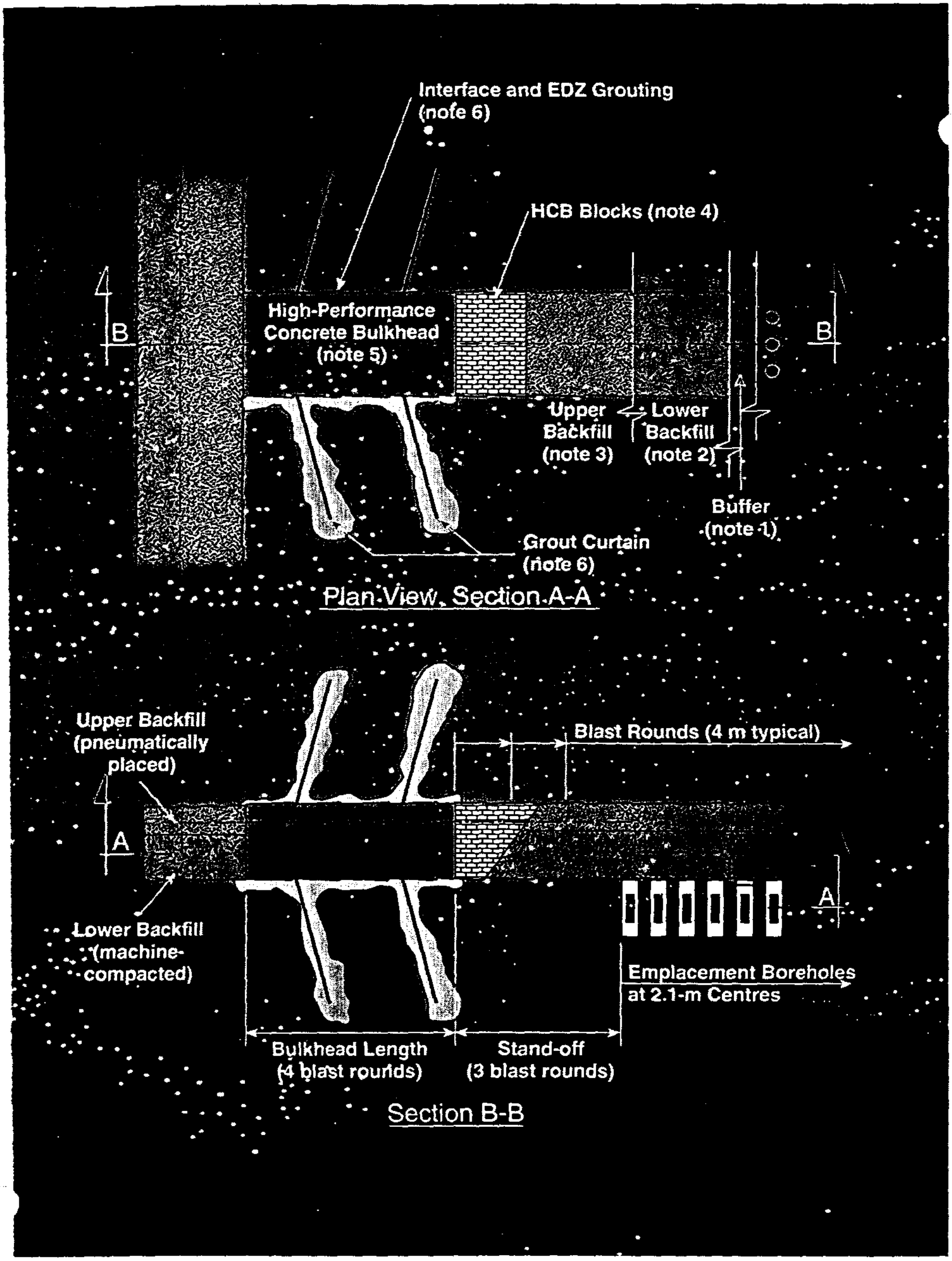
- **SEALING MATERIALS**
- **SEAL DESIGN**
- **SEAL PERFORMANCE**

SEALING STRATEGIES

- Minimize Water Movement Around the Waste Container
- Decrease Hydraulic Conductivity in the Vault
- Seal Hydraulically Critical points in the Vault
- Enhance Sorption of Radionuclides and Chemically Condition the Groundwater

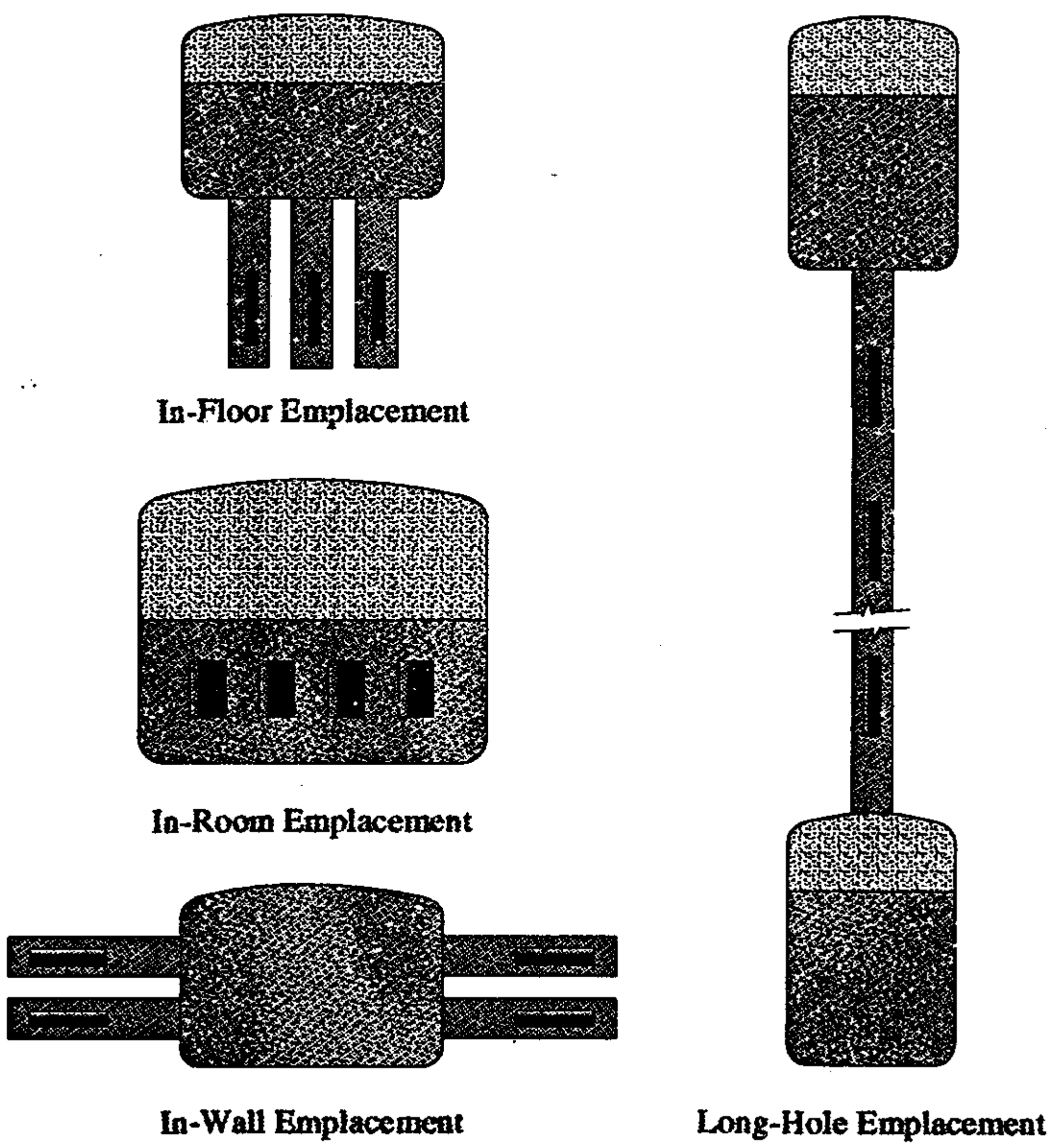



Fault/Fracture Zones
Emplacement Area Inside
Fault Barrier



Interface and EDZ Grouting (note 6)
HCB Blocks (note 4)
High-Performance Concrete Bulkhead (note 5)
B
B
Upper Backfill (note 3)
Lower Backfill (note 2)
Buffer (note 1)
Grout Curtain (note 6)
Plan View, Section A-A
Upper Backfill (pneumatically placed)
Blast Rounds (4 m typical)
A
A
Lower Backfill (machine-compacted)
Emplacement Boreholes at 2.1-m Centres
Bulkhead Length (4 blast rounds)
Stand-off (3 blast rounds)
Section B-B

Container Emplacement Alternatives



SEALING SYSTEM REQUIREMENTS

Seal	Engineering Objective	Performance Requirement	Approaches Used in EIS Vault Model
Buffer	Clay Dry Density >1.24 $Mg \cdot m^{-3}$ Hyd. Conductivity, (k) <10^{-11} $m \cdot s^{-1}$	No convection	No convection; always in transport path
Backfill	k < 10^{-10} $m \cdot s^{-1}$	No/minimal convection	In transport path, for rooms below FZ
Bulkheads, Shaft Seals - bentonite - concrete	Density >2 $Mg \cdot m^{-3}$ k < 10^{-11} $m \cdot s^{-1}$ Provide physical support to backfill	No convection Minimal alteration of buffer/backfill	Evaluated in detailed model, not in vault or geosphere model
EDZ - grouts - rock	Use where k > 10^{-7} $m \cdot s^{-1}$; reduction of k by 10 to 100 Optimize excavation to prevent connected permeability	EDZ should not be a flow path; e.g., keyed-in seals	Evaluated in detailed model, not in vault or geosphere model

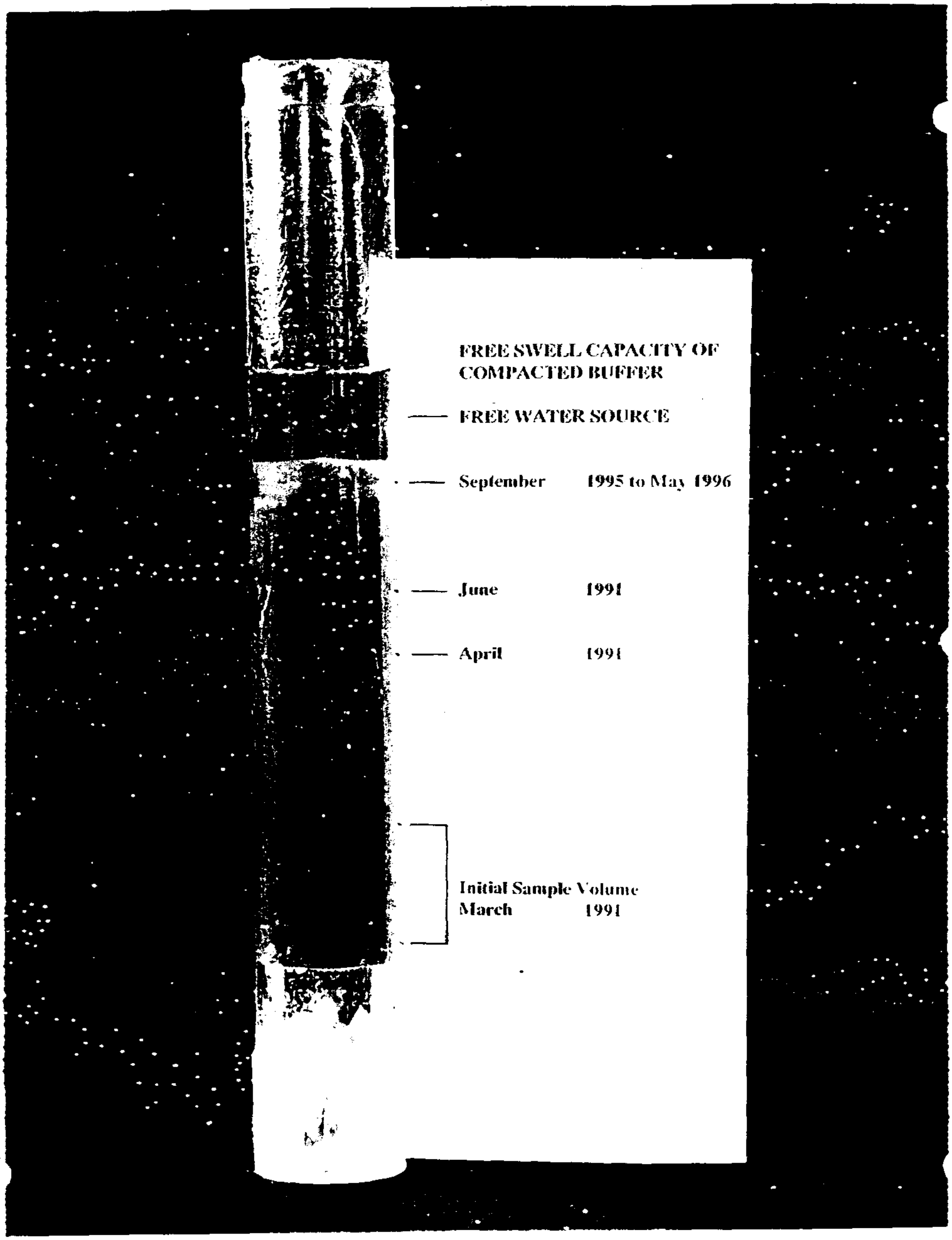
VAULT SEALING MATERIALS

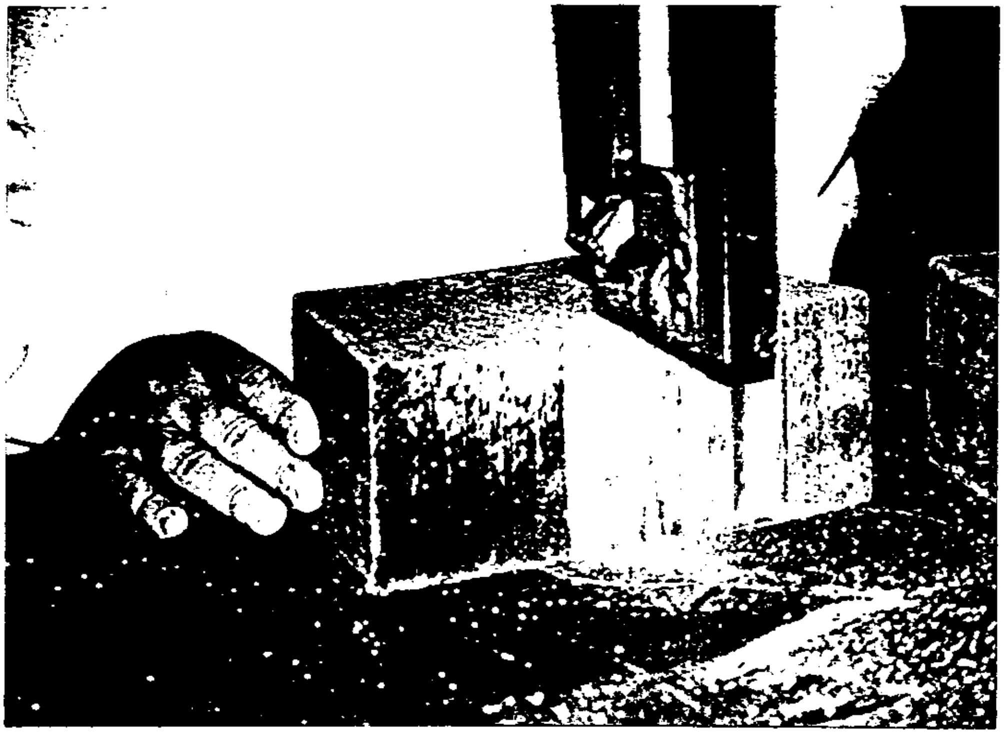
Clay-Based Materials

- Low Hydraulic Conductivity
- Swelling and Extrusion
- Sorption
- Neutral pH
- Emplacement Options
  - In-situ Compaction
  - Precompacted Blocks
  - Aggregate Addition
- Availability

Cement-Based Materials

- Low Hydraulic Conductivity
- High Strength
- Engineering Material - Many Options


FREE SWELL CAPACITY OF
COMPACTED BUFFER
FREE WATER SOURCE
September 1995 to May 1996
June 1991
April 1991
Initial Sample Volume
March 1991



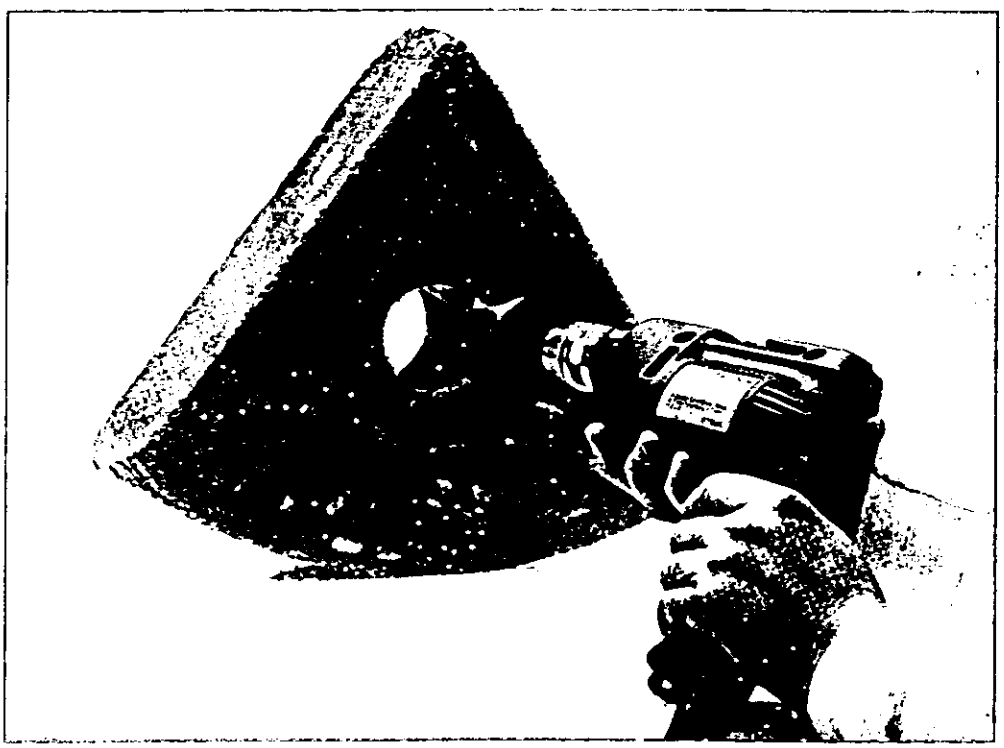


FIGURE 4-15: Large Precompacted Blocks of the Reference Buffer Material Being Sawn in a Band Saw (top) and Being Augered (bottom)

BUFFER AND BACKFILL PERFORMANCE

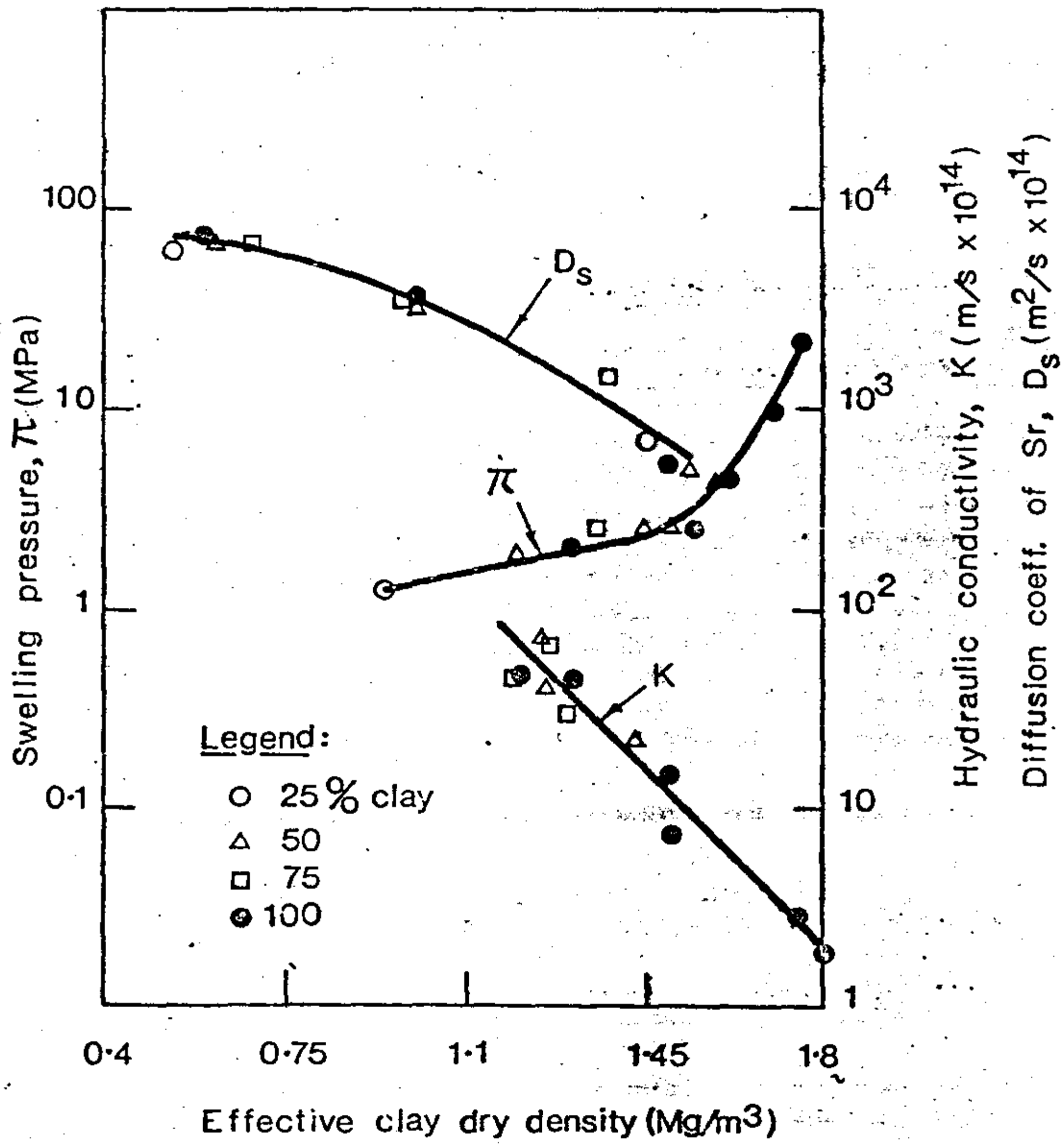
- Smectite $\rightarrow$ Illite
- Swelling
- Gas Generation and Transport
- Cements
- Radiation
- Microbial Activity
- Colloids

Mineralogical composition and related chemistry of Avonlea bentonite

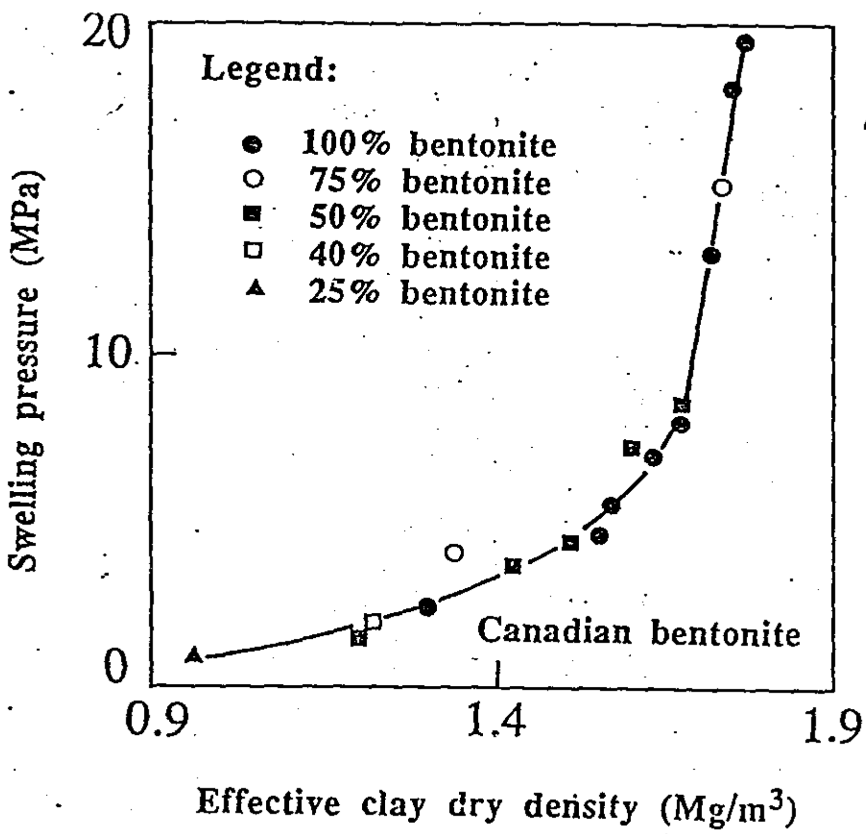
589-4

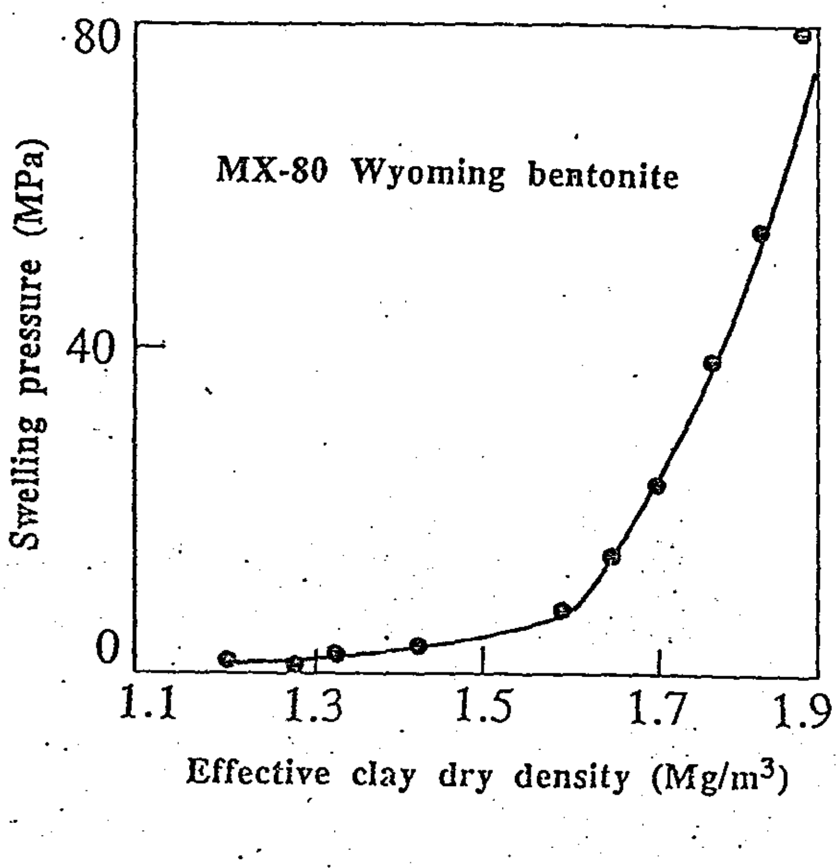
	%
Montmorillonite	79
Illite	10
Quartz	5
Feldspar	3
Gypsum	2
Carbonate	1
Organic Matter	0.3

SSA= 630 x $10^3 m^2/kg$; CEC= 82 $cmol_c/kg$; exchangeable cations in $cmol_c/kg$: Na^+= 47, Ca^{2+}= 40, Mg^{2+}= 7, K^+= 0.7.

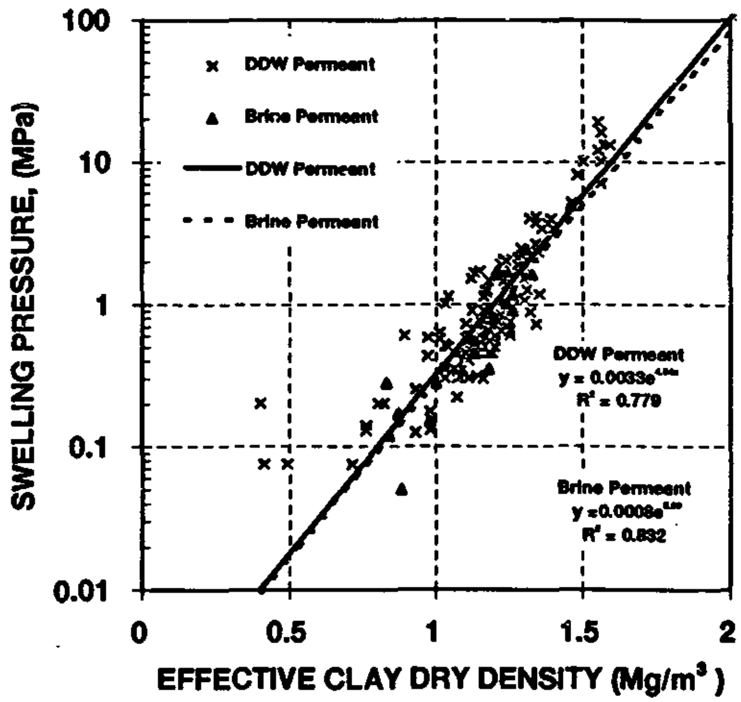


Swelling pressure, π (MPa)
100
10
1
0·1
Hydraulic conductivity, K (m/s x 10^14)
Diffusion coeff. of Sr, Ds (m²/s x 10^14)
10^4
10^3
10^2
10
1
Ds
π
K
Legend:
25 % clay
50
75
100
0·4
0·75
1·1
1·45
1·8
Effective clay dry density (Mg/m3)

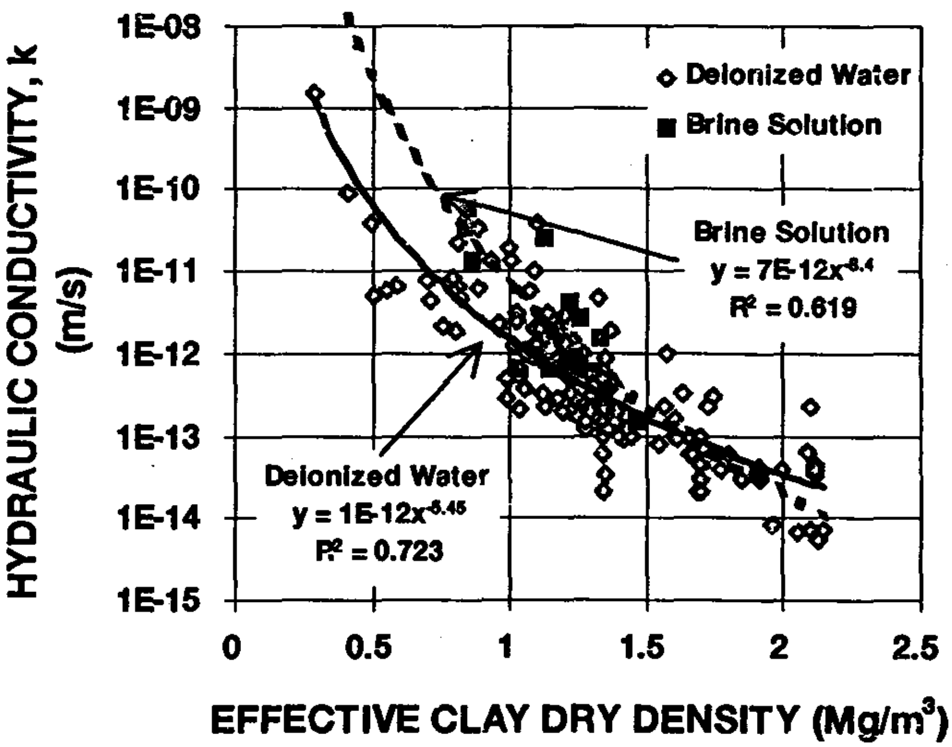

Legend:
100% bentonite
75% bentonite
50% bentonite
40% bentonite
25% bentonite
Canadian bentonite
Swelling pressure (MPa)
20
10
0
0.9
1.4
1.9
Effective clay dry density (Mg/m3)

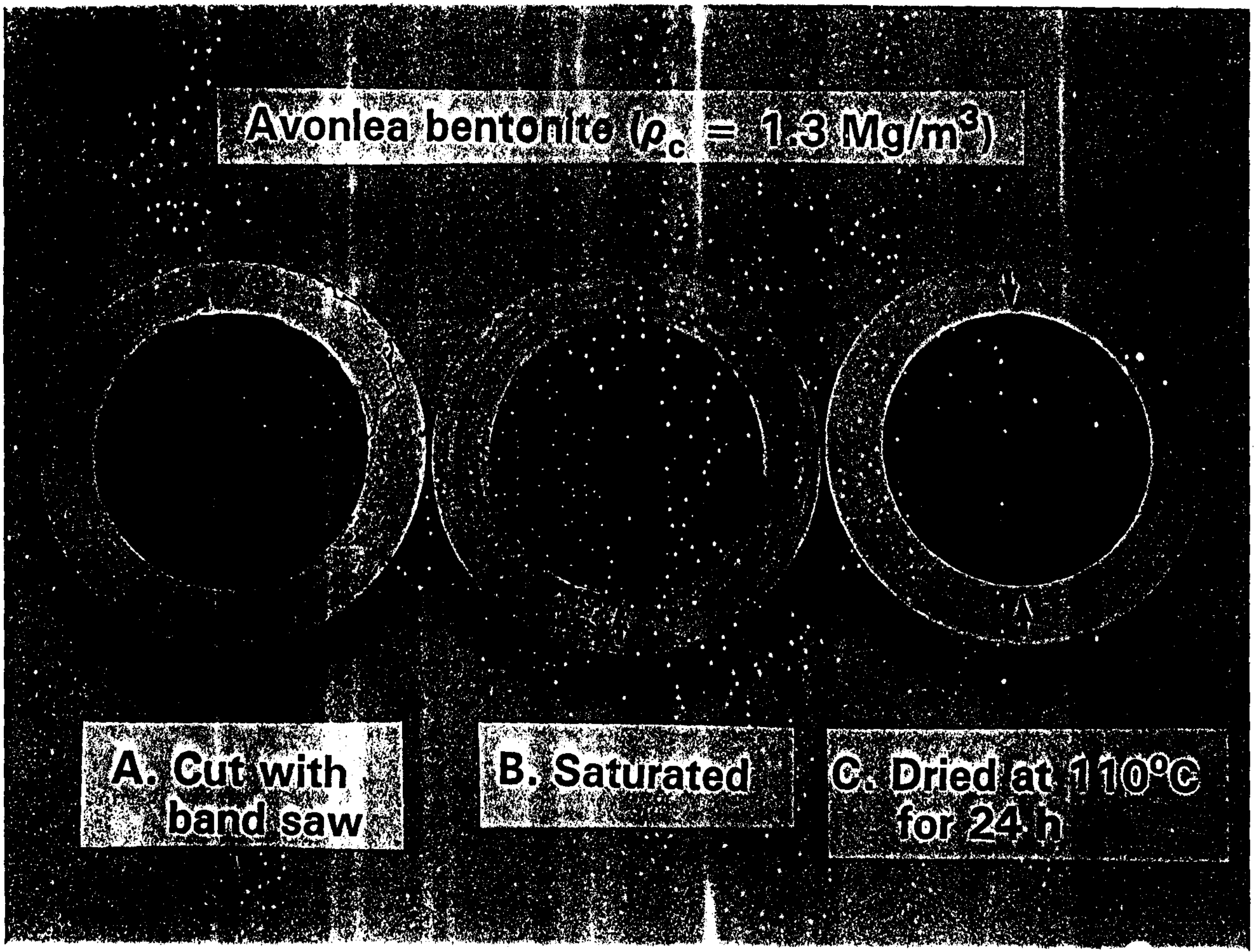

MX-80 Wyoming bentonite
Swelling pressure (MPa)
80
40
0
1.1
1.3
1.5
1.7
1.9
Effective clay dry density (Mg/m3)

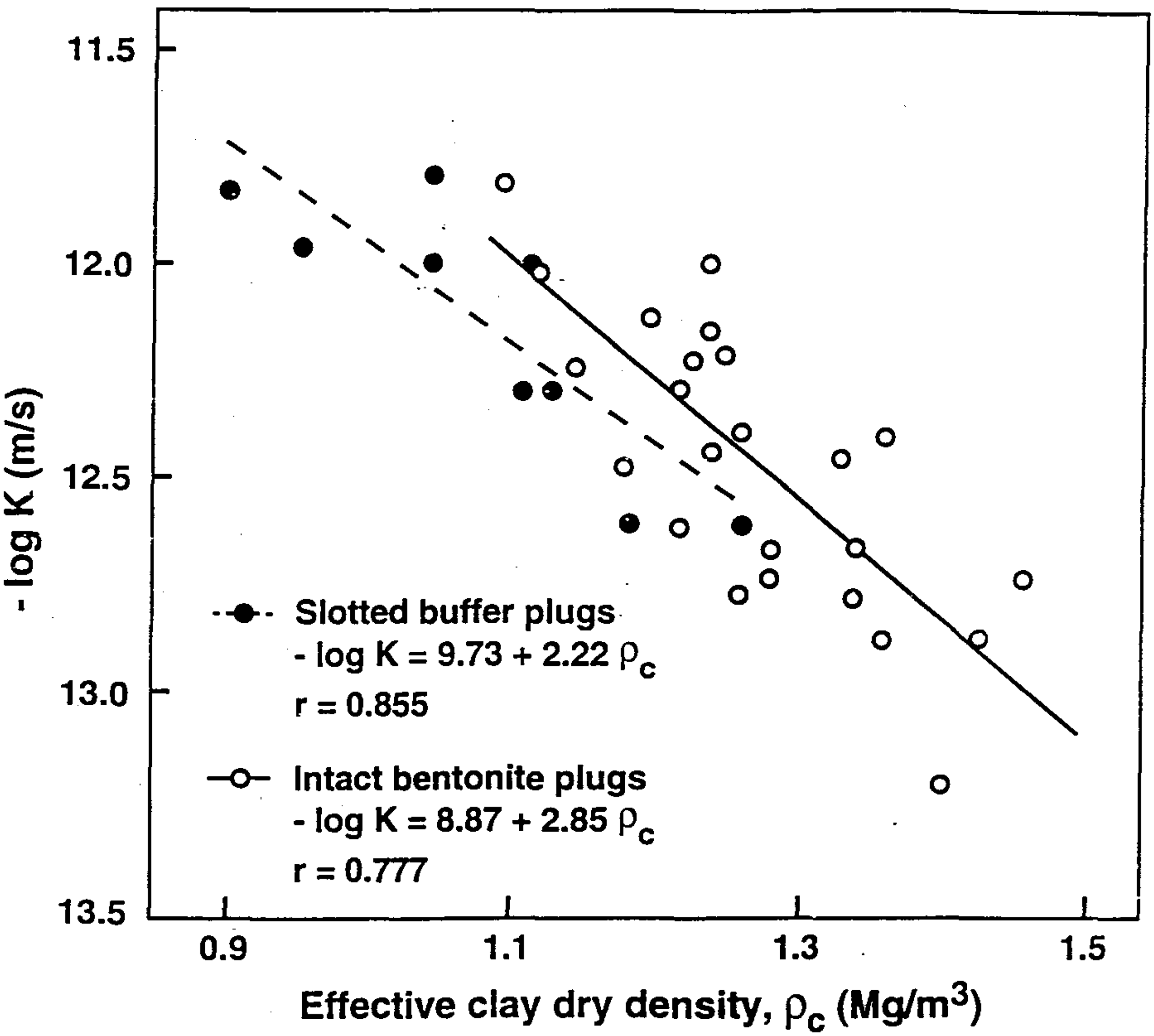
Influence of Pore Fluid Salinity on Swelling Pressure



Influence of Groundwater Salinity on Hydraulic Conductivity




Avonlea bentonite (ρ_c = 1.3 Mg/m^3)
A. Cut with band saw
B. Saturated
C. Dried at 110°C for 24 h



11.5
12.0
12.5
13.0
13.5
- log K (m/s)
0.9
1.1
1.3
1.5
Effective clay dry density, ρc (Mg/m3)
Slotted buffer plugs
- log K = 9.73 + 2.22 ρc
r = 0.855
Intact bentonite plugs
- log K = 8.87 + 2.85 ρc
r = 0.777

Gas Breakthrough Resistance in Bentonite

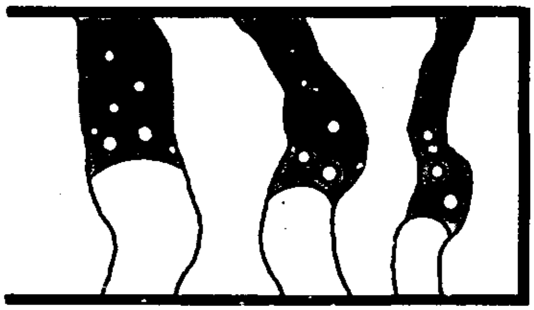
lechanisms that may create athways through porous media

- Diffusion
- Capillarity
- Pathway Dilatancy
- Tensile Fracturing

'ossible gas pressure conditions

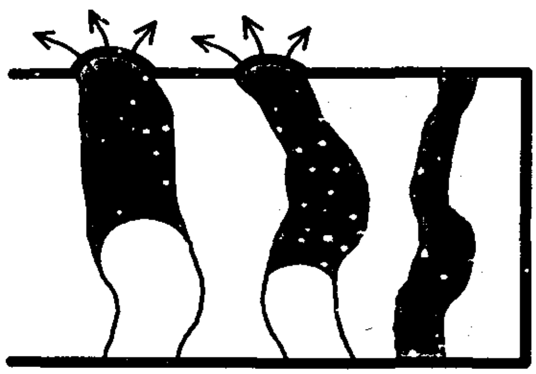
- gas pressure < pore water (PWP)
- gas pressure >PWP but < total soil pressure
- gas pressure > total soil pressure

GAS FLOW MECHANISMS



DIFFUSION

DISSOLUTION OF GASES IN
THE WATER PHASE



2-PHASE FLOW

WATER IS PUSHED THROUGH
SOME PORES BY INVADING GAS

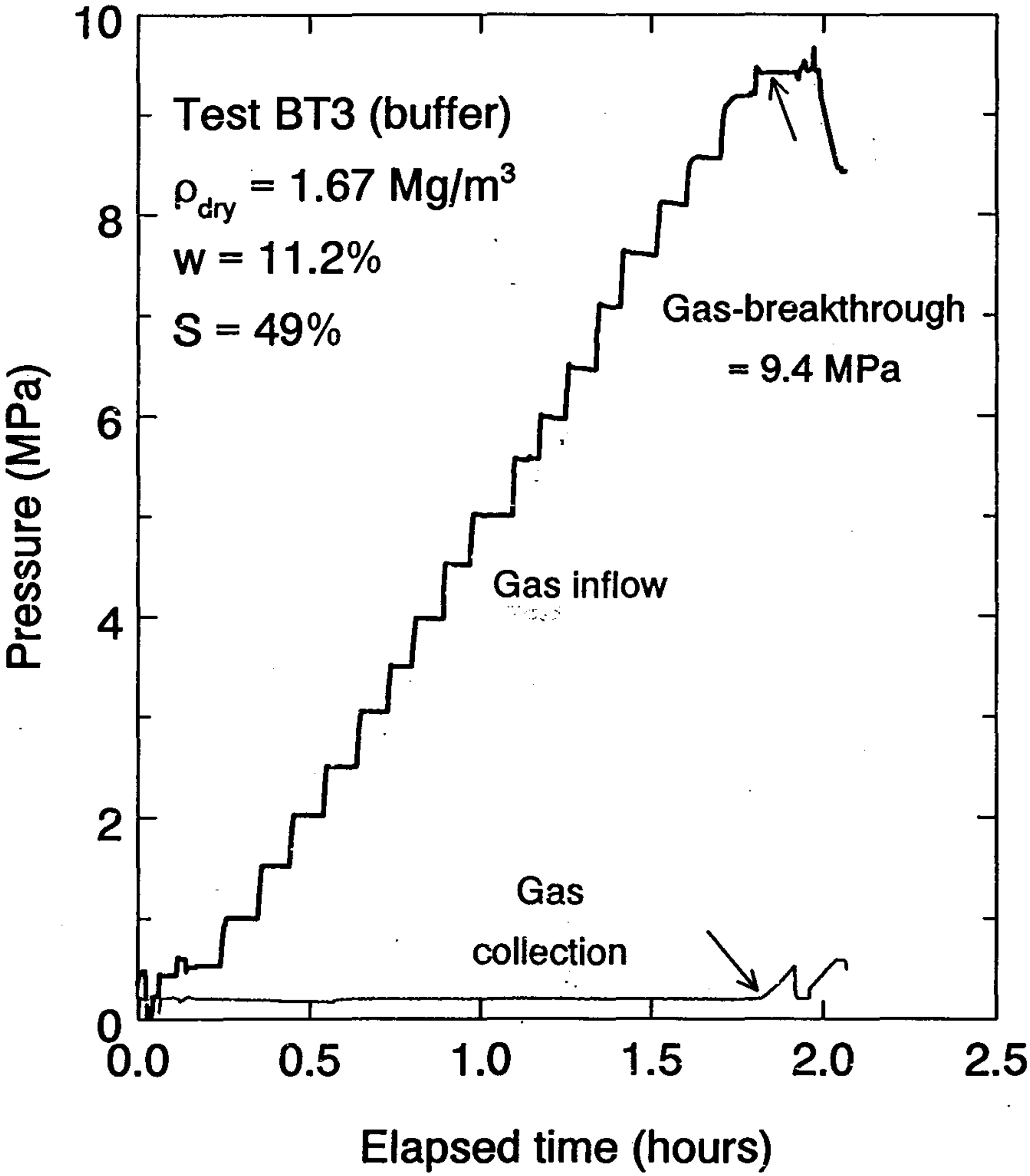
PORE DILATION

DEFORMATION OF SOIL FABRIC
CREATING LARGER PORES TO
ACCOMODATE GAS FLOW

FISSURING

CREATION OF NEW PORES
TO ACCOMODATE GAS FLOW

BUFFER GAS-BREAKTHROUGH
TEST RESULTS



Diffusion in Buffer and Backfill

$k < 10^{-10}$ m/s - diffusion dominant

D, Total Intrinsic Diffusion Coefficient from

$J = -D\ (\partial c / \partial x); \quad D = D_o \tau \varepsilon$

D_a, Apparent Diffusion Coefficient from

$$\frac{\partial c}{\partial t} = D_a \left(\frac{\partial^2 c}{\partial x^2} \right); \; D_a = \frac{D_o \tau \varepsilon}{\varepsilon + \rho K_d} = \frac{D}{r}$$

r = Capacity Factor $(\varepsilon + \rho K_d)$

D and r from
- Laboratory Experiments
- Literature
- Expert Judgement

Diffusion Coefficients, D_a, in Buffer

Diffusant	D_a ($\mu m^2/s$)	Breakthrough time* (years)
I^-	100	20
Cs^+	1	2000
Pu	0.01	200 000

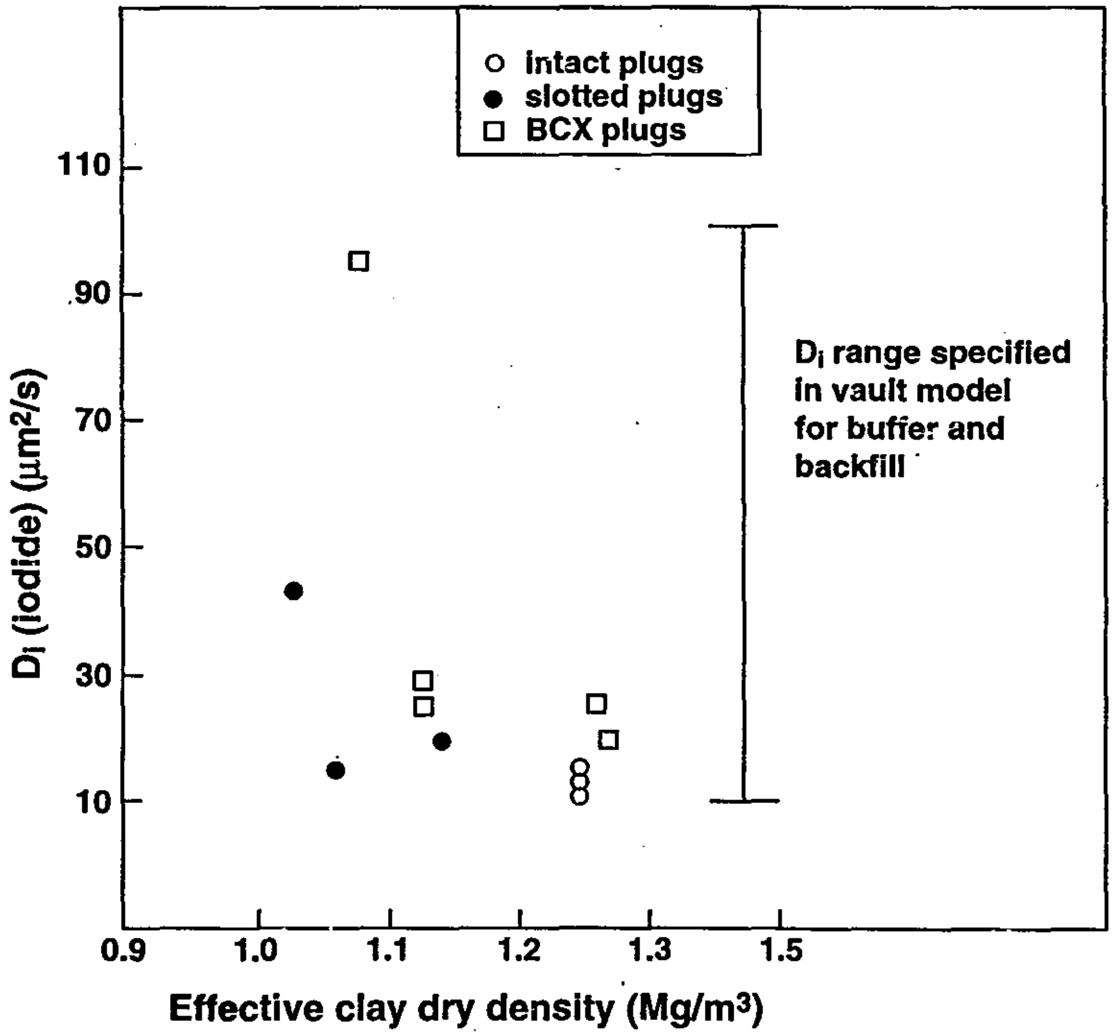
*Approximate time required for c/c_o = 0.5 at the buffer/rock interface; buffer thickness = 0.25 m

Diffusion Coefficients for Large Molecules
(MW 354 to 3000)

<0.001 $\mu m^2/s$

(Eriksen and Jacobsson, KBS TR-84-05)

Total intrinsic diffusion coefficients, D_i, for I^- in intact and defected bentonite plugs



AK-58-01

Cement-based Materials

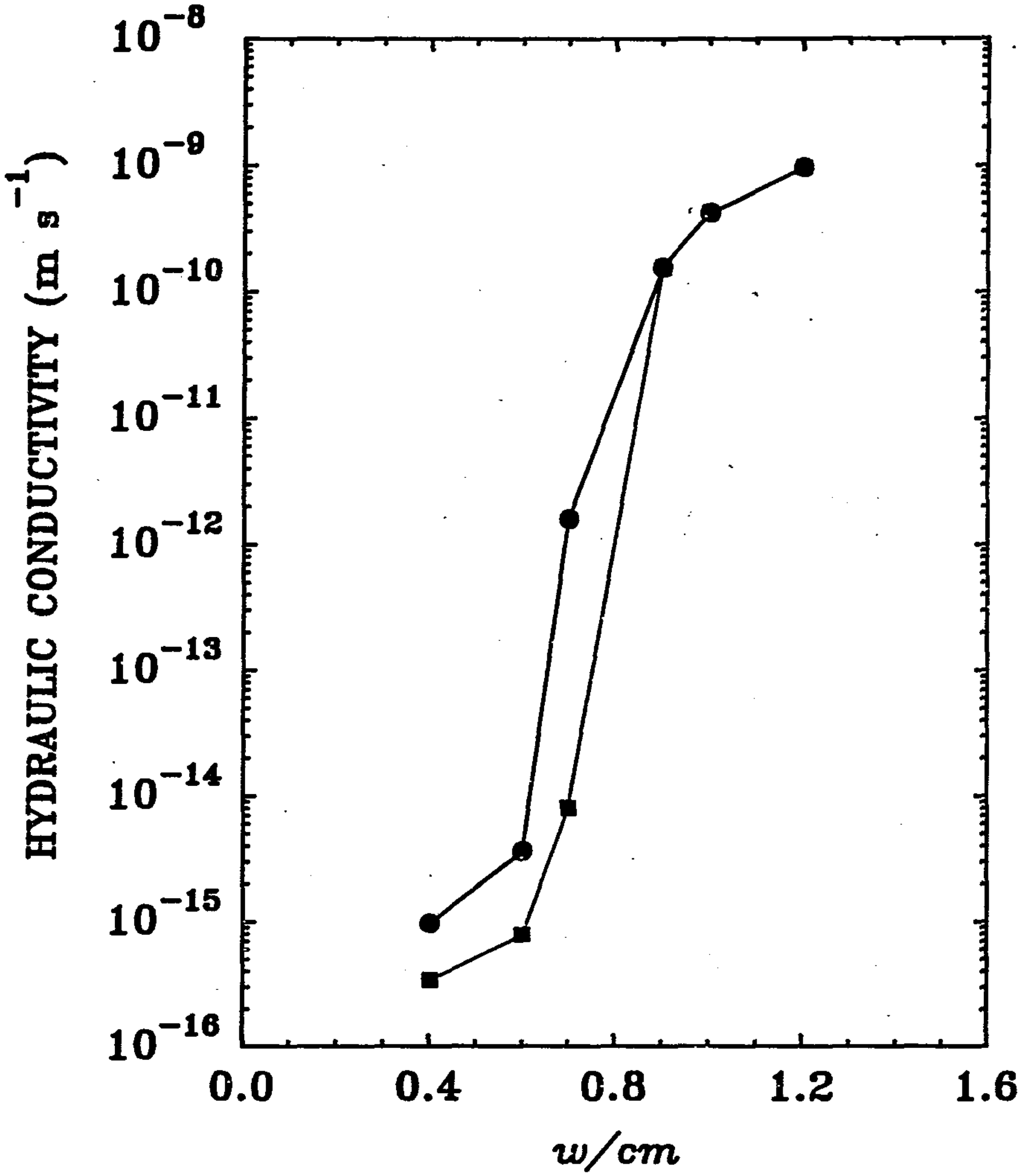
- For high-level waste disposal, generally restricted to grouting, shaft seal and construction applications (e.g., bulkheads, floors)

- Low pH concretes have been developed that are more compatible with clay buffers and backfills

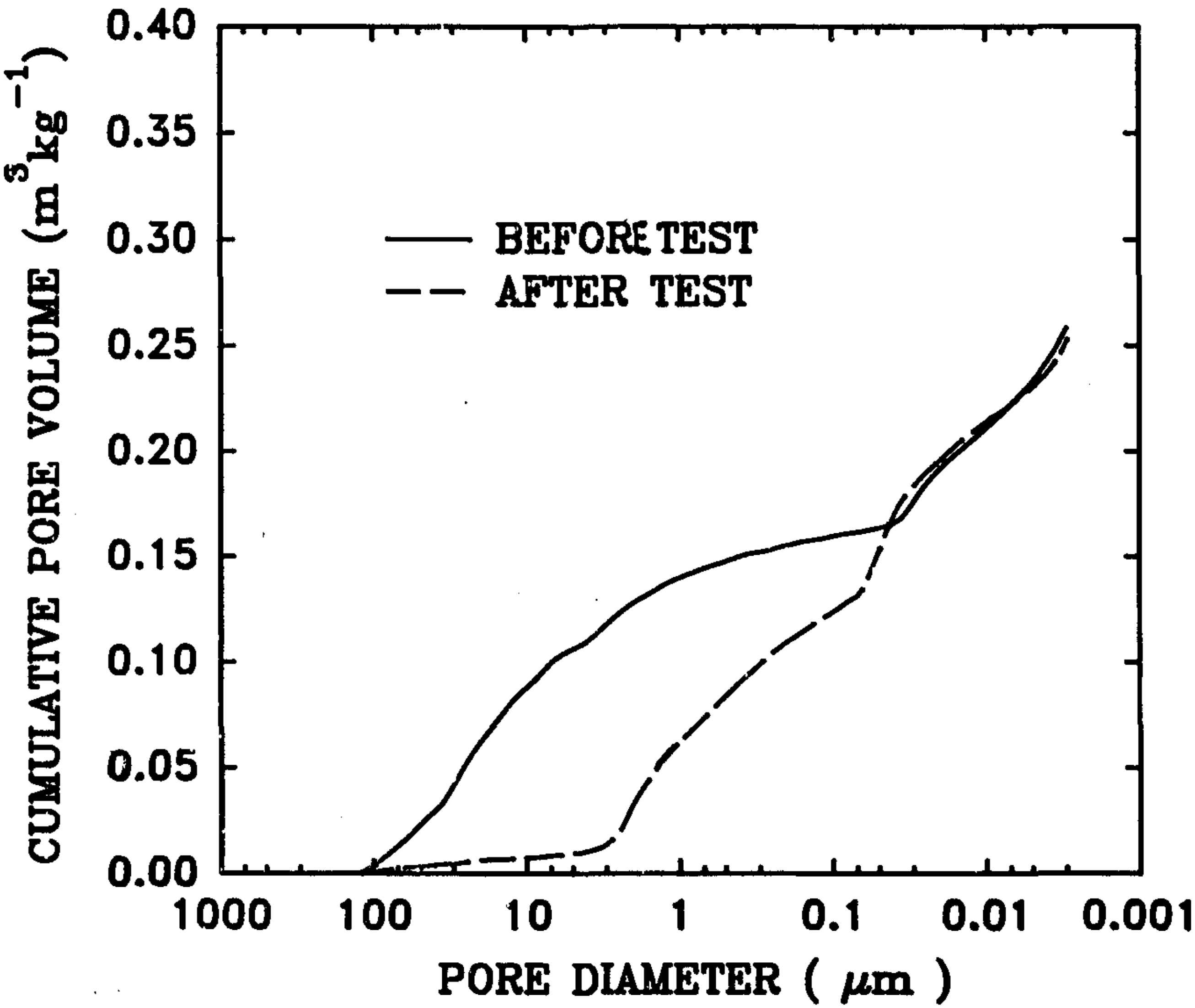
CNFWMP Reference Grout

Cement Type :	**Canadian Type 50 Reground to 600 m^2/Kg (Blaine)**
Pozzolan :	**Silica Fume (10% of total dry mass)**
Superplasticizer :	**Na-sulphonated naphthalene formaldehyde condensate (liquid)**
Mass ratio of water to (cement+pozzolan) :	**0.35 to 0.6**
Superplasticizer content :	**Varies with desired viscosity. Typical values 0.75 to 1.5 percent dry mass ratio superplasticizer to (cement+pozzolan)**

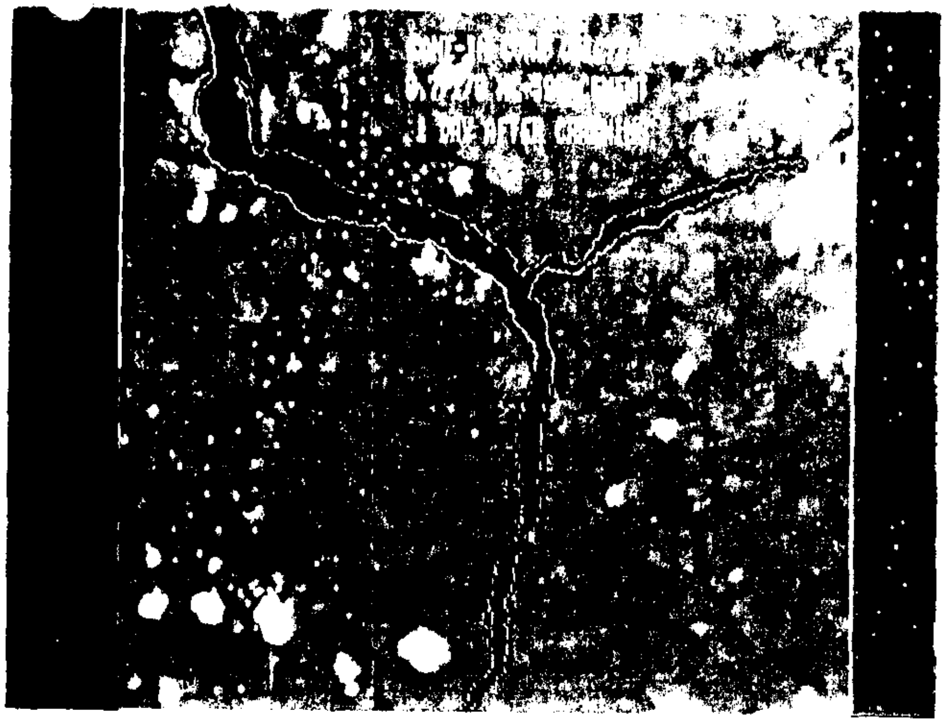
UP SUPERIEURE ⇧OBEN おもて

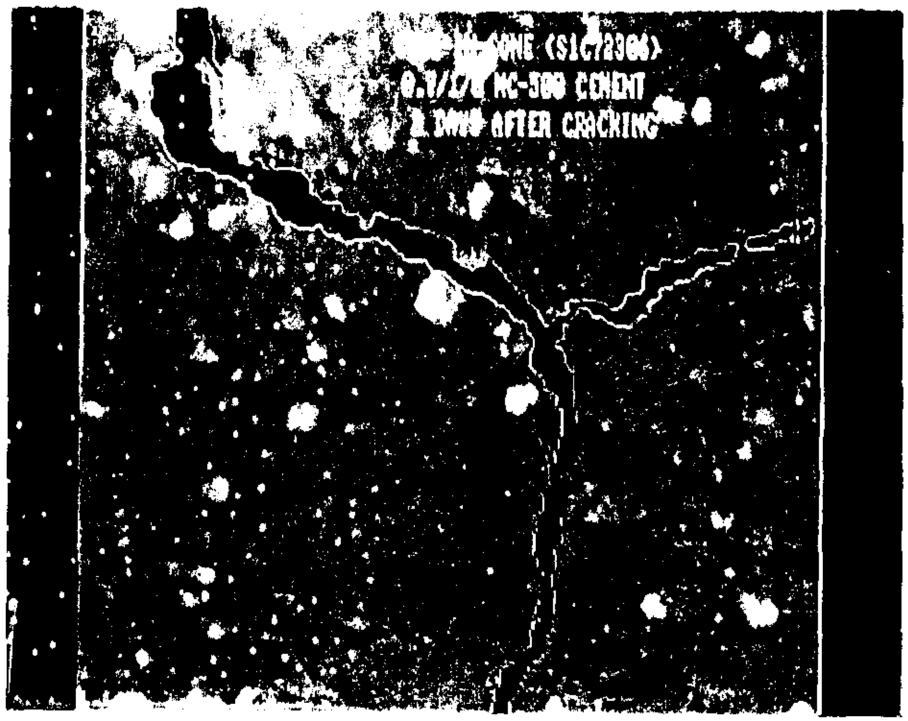


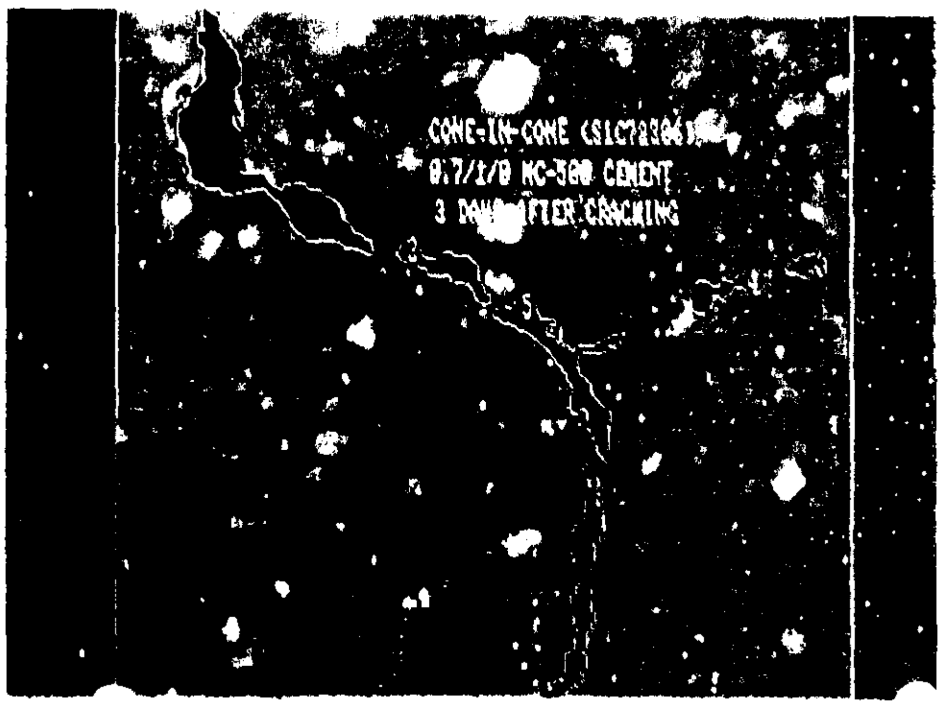
EFFECT OF WATER/CEMENTITIOUS MATERIAL RATIOS ON THE HYDRAULIC CONDUCTIVITY OF GROUTS

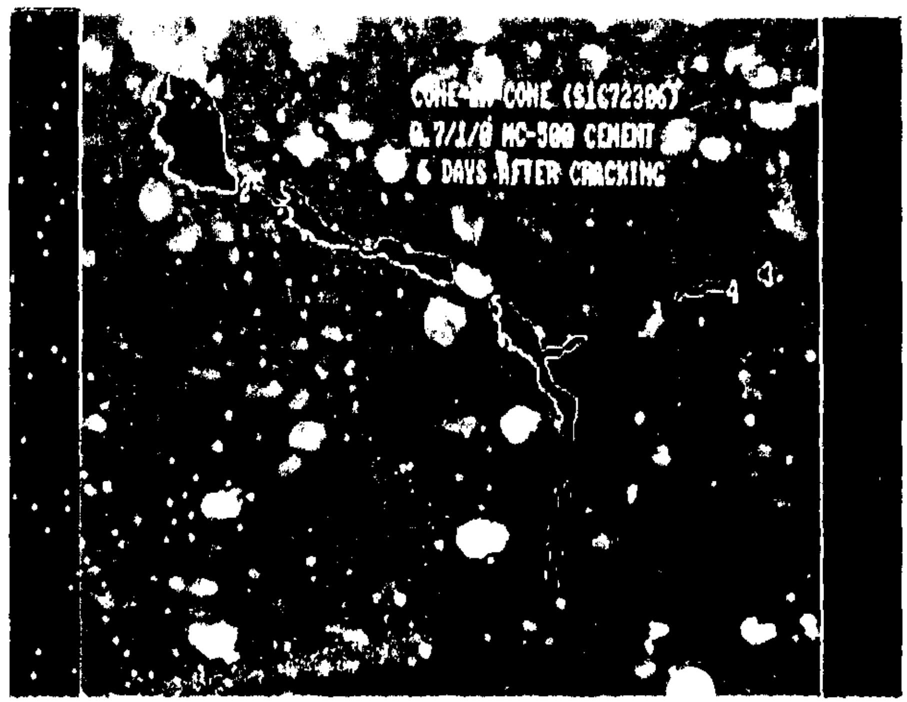


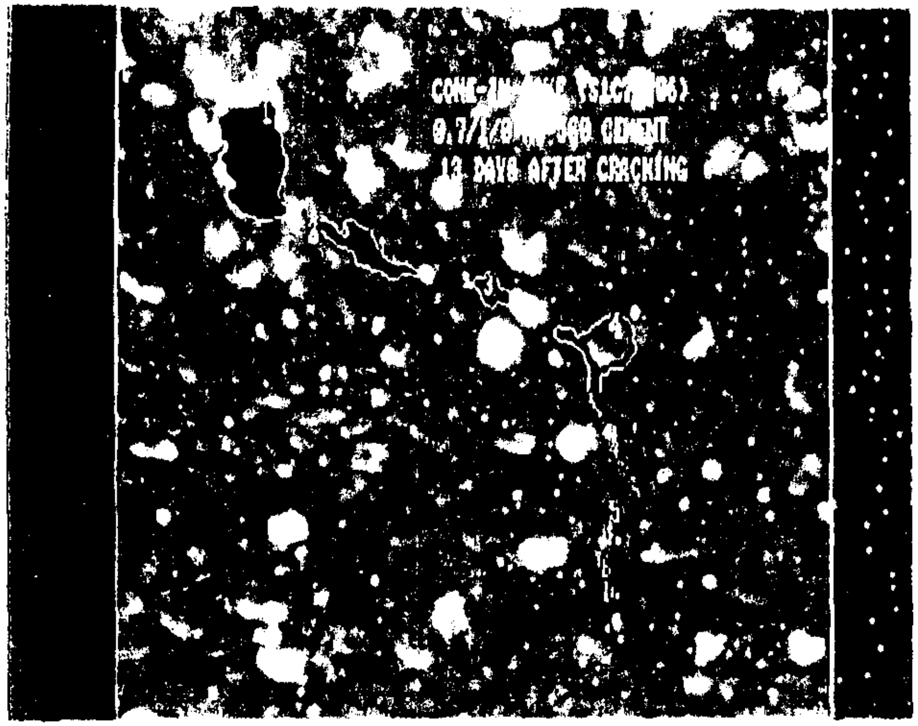
CHANGE IN PORE–SIZE DISTRIBUTION OF CEMENT–BASED GROUT (*W/CM=0.4*, TWO PARTICLE SIZES : Φ = 1.18 mm AND Φ = 0.30 mm) COMPACTED AT ρ = 1.6 Mg m^{-3}.

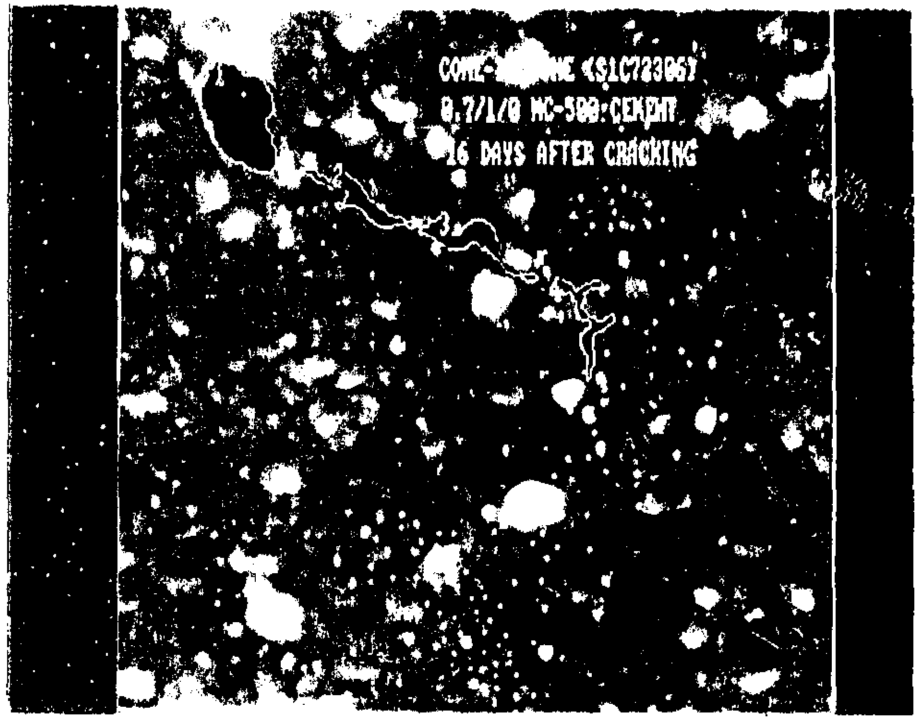

CONE-IN-CONE
1 DAY AFTER CRACKING

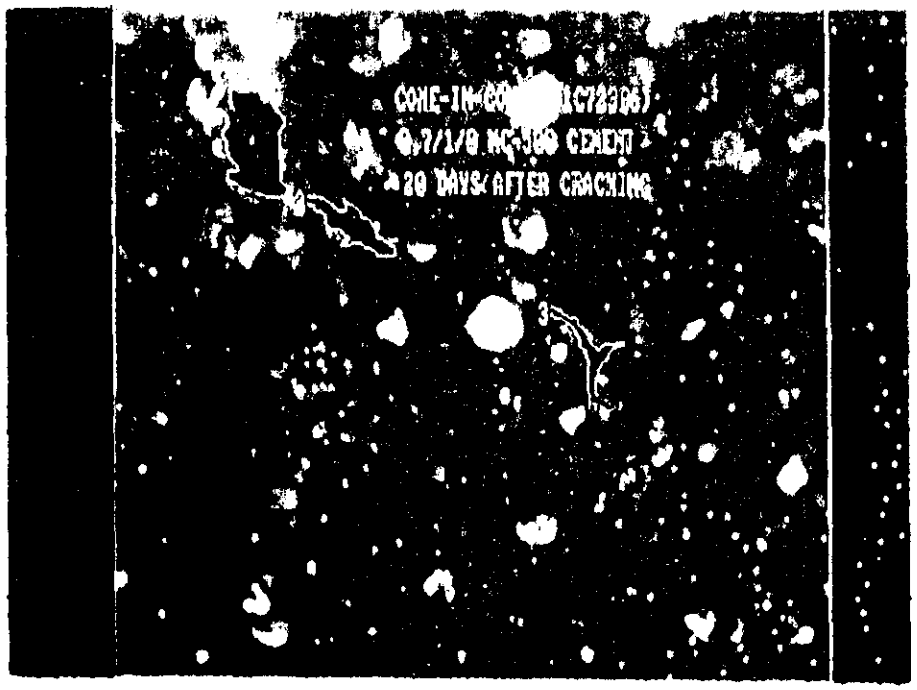

CONE (S1C72306)
0.7/1/0 MC-500 CEMENT
DAYS AFTER CRACKING


CONE-IN-CONE (S1C72306)
0.7/1/0 MC-500 CEMENT
3 DAYS AFTER CRACKING


CONE-IN-CONE (S1C72306)
0.7/1/0 MC-500 CEMENT
6 DAYS AFTER CRACKING


0.7/1/0 MC-500 CEMENT
13 DAYS AFTER CRACKING


(S1C72306)
0.7/1/0 MC-500 CEMENT
16 DAYS AFTER CRACKING


0.7/1/0 MC-500 CEMENT
20 DAYS AFTER CRACKING


MC-500 CEMENT
AFTER CRACKING

Properties of fresh and hardened LHHPC and normal concrete.

Properties	LHHPC (w/cm 0.47)	Normal (w/cm 0.56)
Fresh concrete		
Slump (mm)	160	170
Air Content (%)	2.75	2.75
Maximum temperature rise during hydration (°C)	15	~ 45
Maximum temperature during hydration (°C)	37	~ 65
Hardened concrete		
Density (kg/m^3)	2424	2168
Hydraulic conductivity (m/s)	10^{-13} to 10^{-12}	10^{-11} to 10^{-12}
pH	9.65	~ 12.5
Total porosity - MIP technique (ml/g)	0.0580	n/a
Drying shrinkage - 90 days in air (με)	863	n/a
Drying shrinkage - 7 days in water and 83 days in air (με)	348	n/a
Drying shrinkage - 21 days in water and 69 days in air (με)	171	n/a
Drying shrinkage - 90 days in water (με)	-50	n/a
Compressive strength - 28 days, 23°C (MPa)	86	29
Young's modulus - 28 days, at 40% of ultimate stress (GPa)	36.26	21.89
Poisson's ratio - 28 days, at 40% of ultimate stress	0.114	0.087