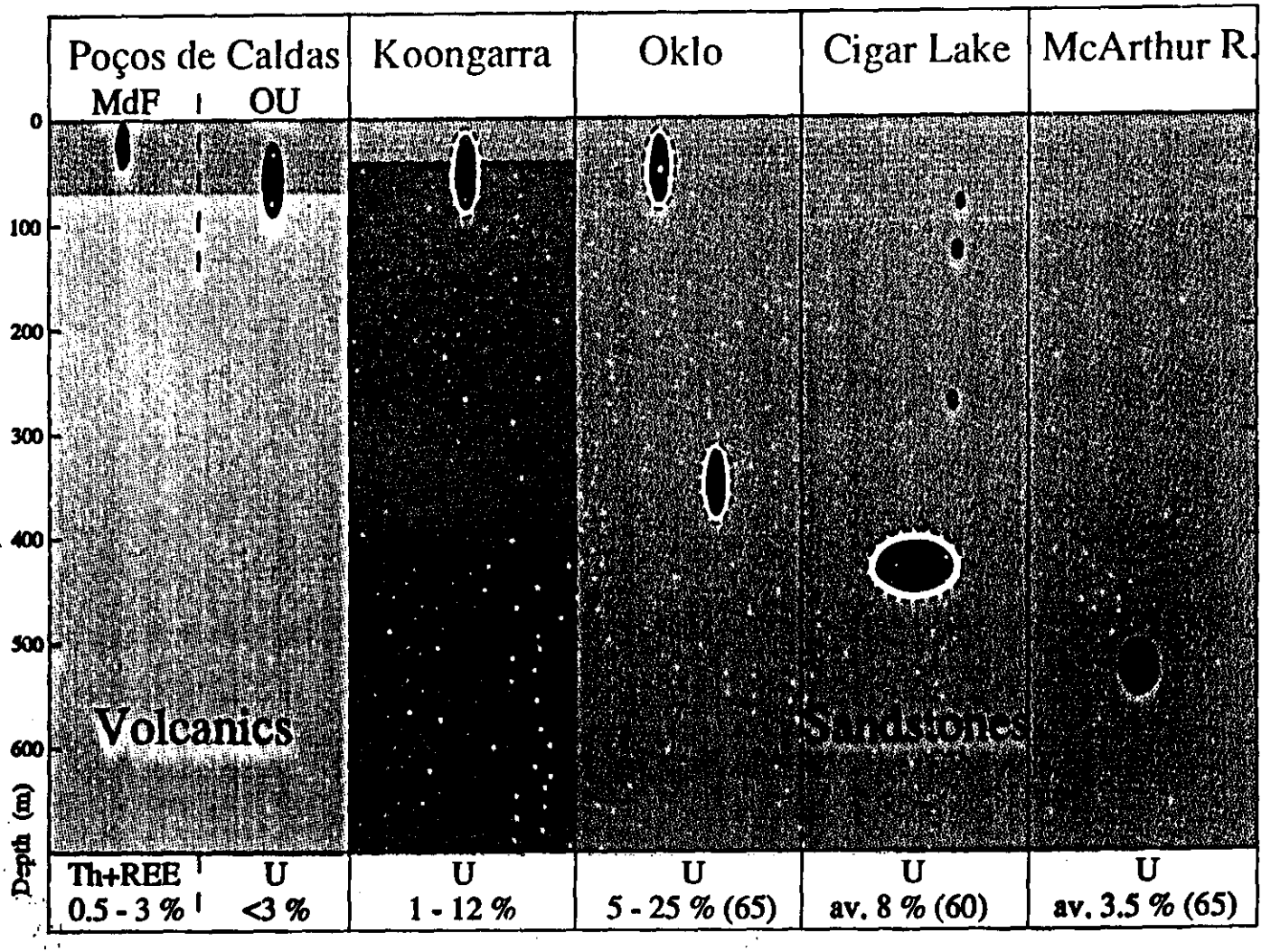
DISPOSAL SYSTEM ANALOG

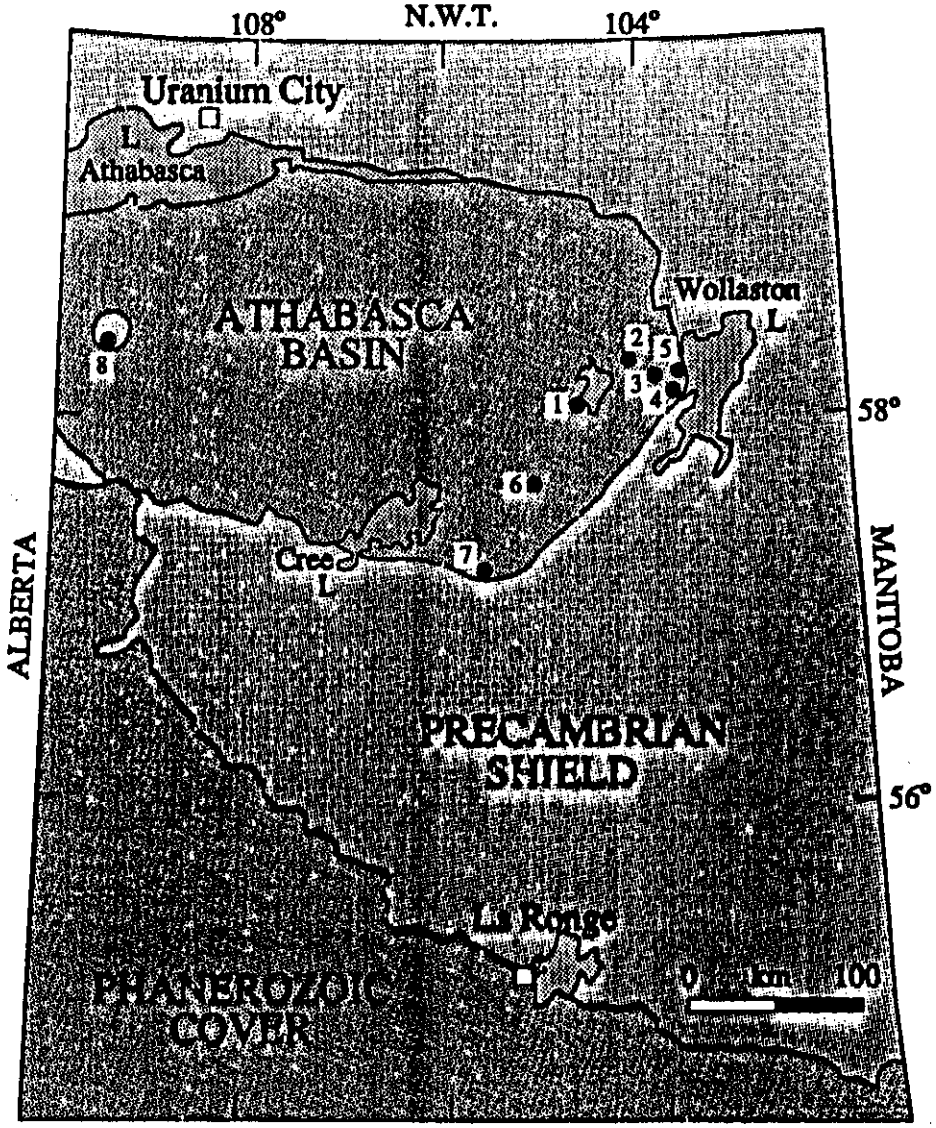
CIGAR LAKE URANIUM DEPOSIT

URANIUM DEPOSITS

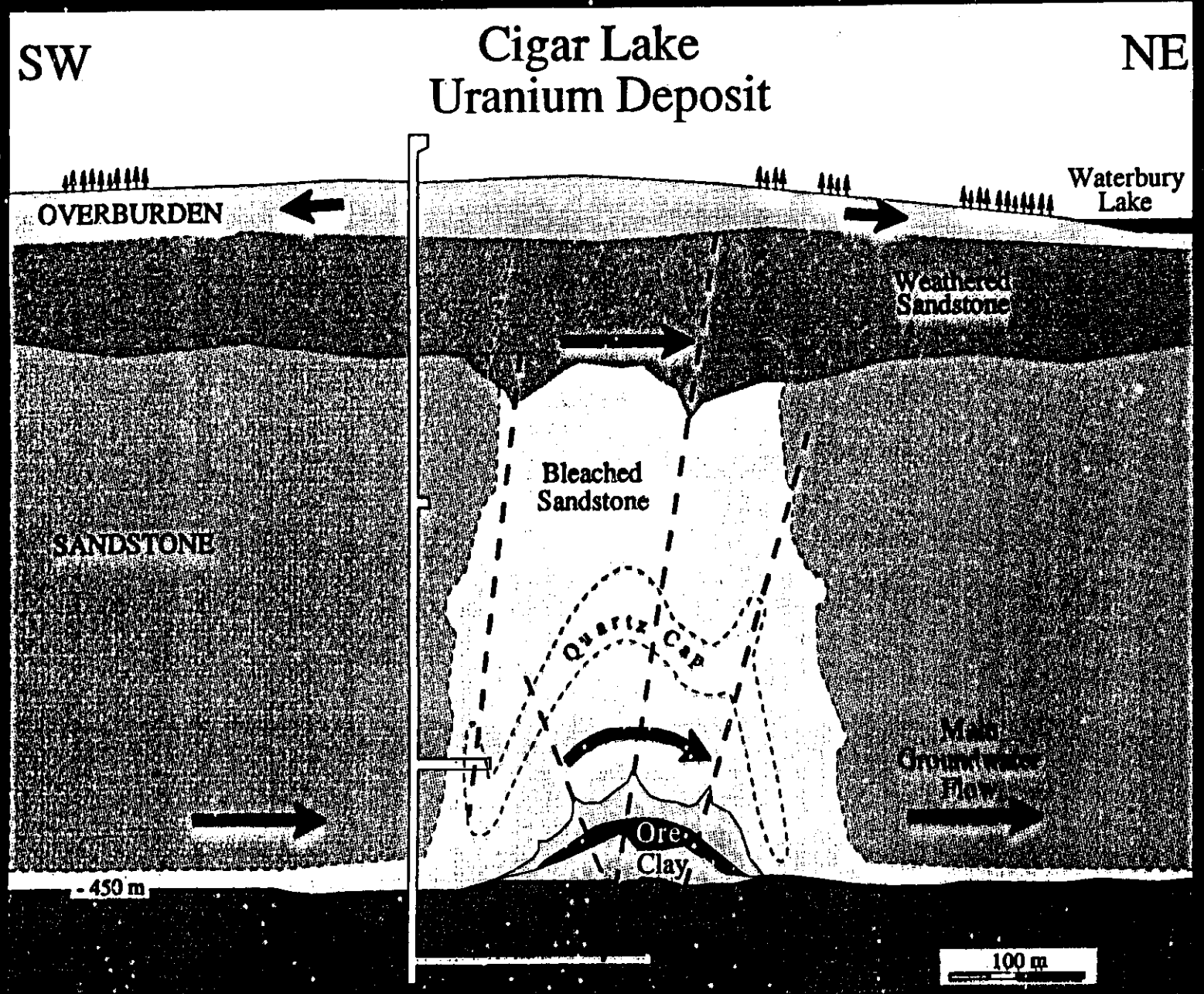


Uranium deposits

1 Cigar Lake
2 Midwest
3 McClean Lake
4 Rabbit Lake
5 Collins Bay
6 McArthur River
7 Key Lake
8 Cluff Lake

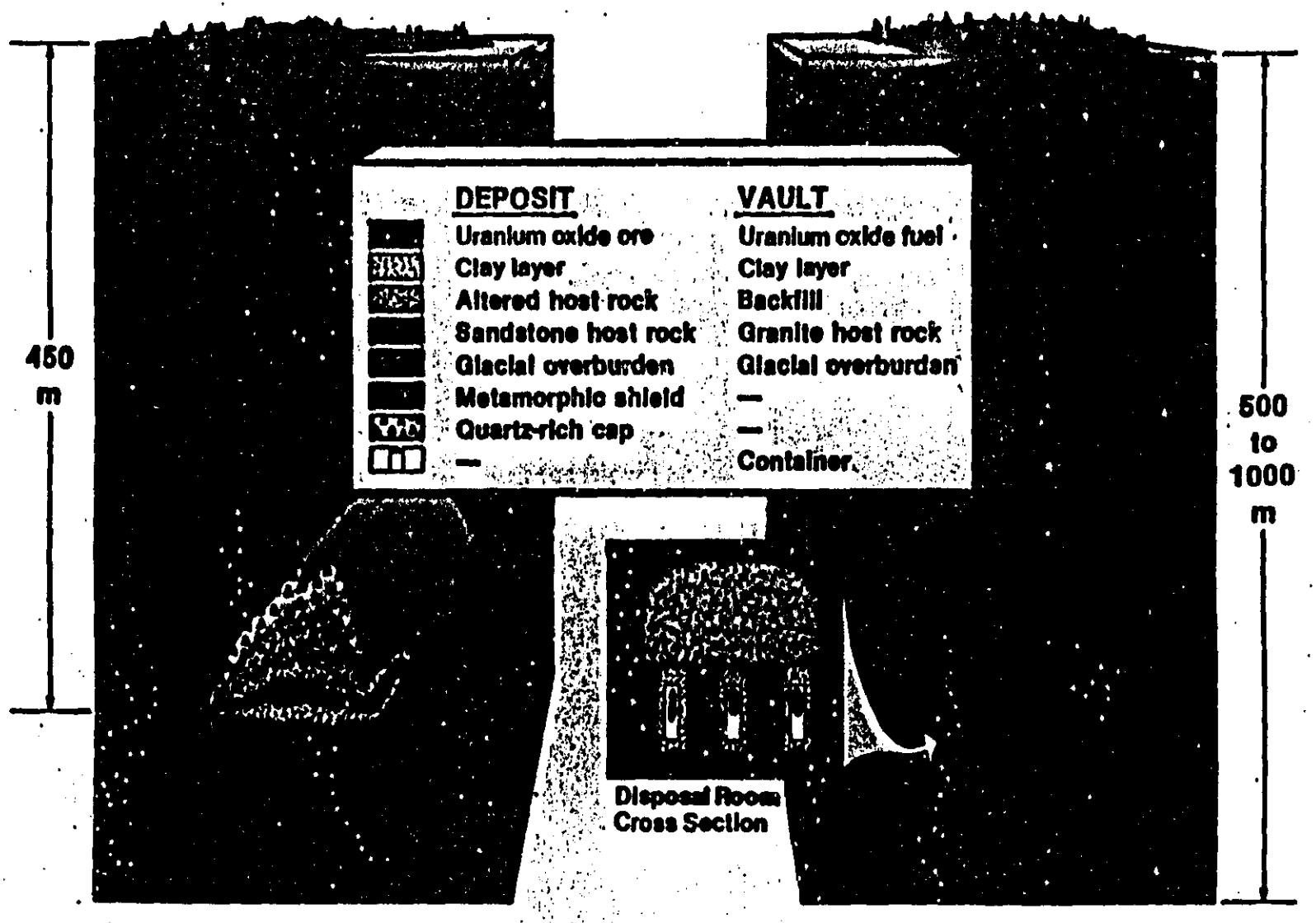


MULTIPLE BARRIER CONCEPT


SW
Cigar Lake
Uranium Deposit
NE
OVERBURDEN
Waterbury
Lake
Weathered
Sandstone
Bleached
Sandstone
SANDSTONE
Quartz Cap
Main
Groundwater
Flow
Ore
Clay
-450 m
100 m

FEATURES OF CIGAR LAKE

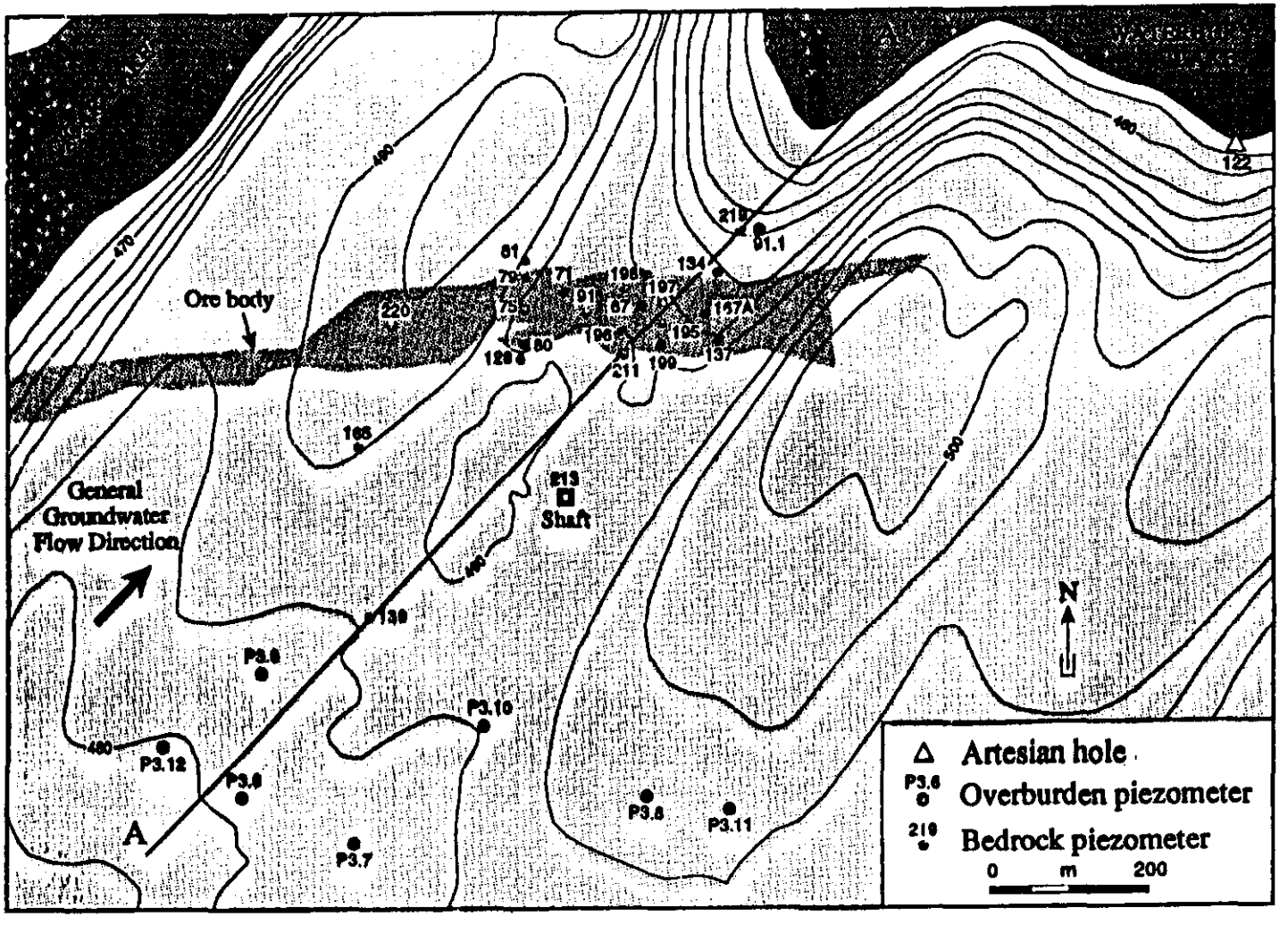
- ☆ High-grade UO_2 ore
- ☆ Multiple barriers
  - Clay matrix
  - 430 m Sandstone
- ☆ Water saturated
- ☆ Surrounded by aquifer
- ☆ No surface signature
- ☆ No environmental impact

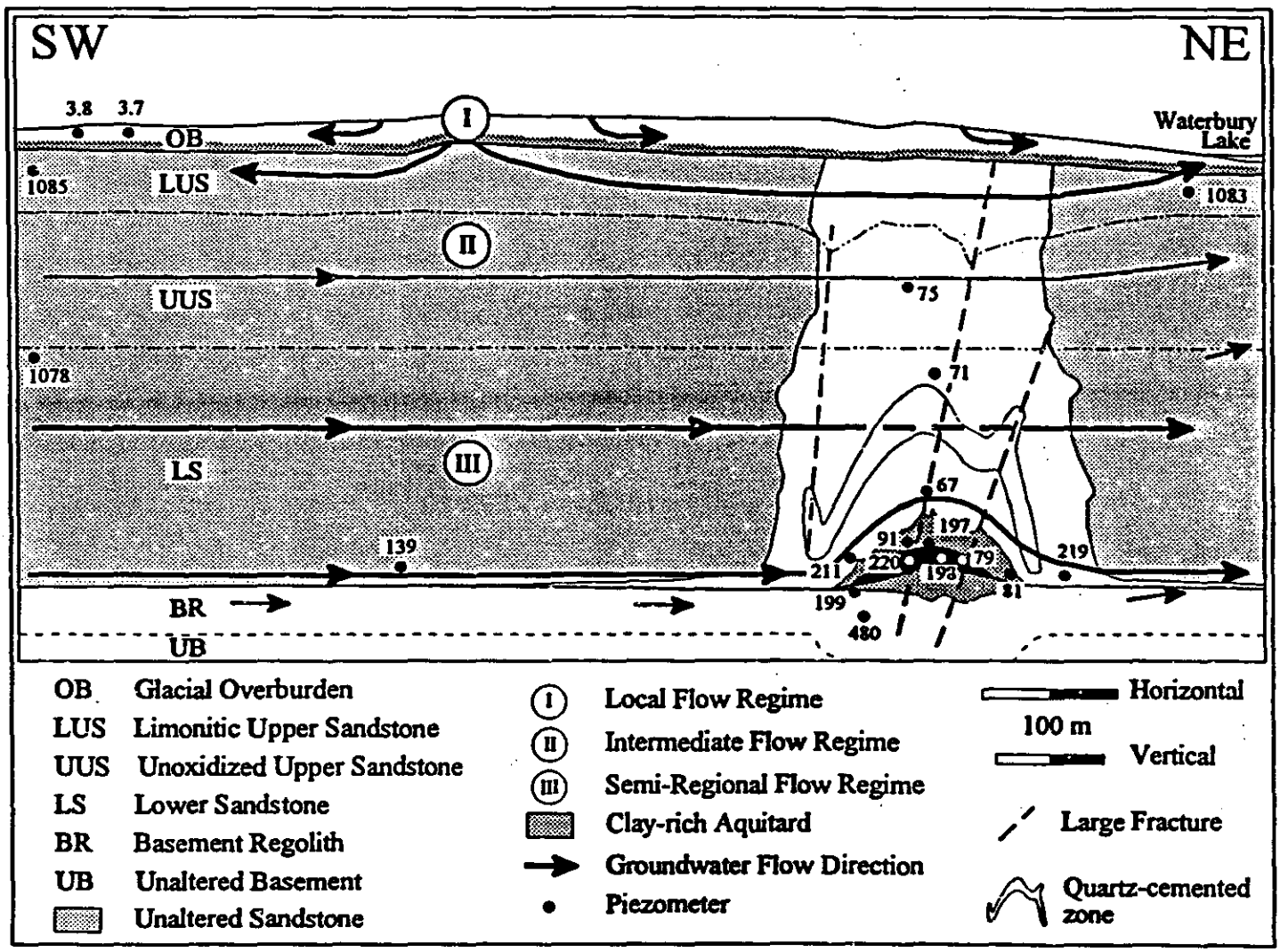

DEPOSIT
Uranium oxide ore
Clay layer
Altered host rock
Sandstone host rock
Glacial overburden
Metamorphic shield
Quartz-rich cap
—
VAULT
Uranium oxide fuel
Clay layer
Backfill
Granite host rock
Glacial overburden
—
—
Container
450 m
500 to 1000 m
Disposal Room Cross Section
CIGAR LAKE U DEPOSIT
USED FUEL DISPOSAL VAULT

ANALOG STUDIES AT CIGAR LAKE

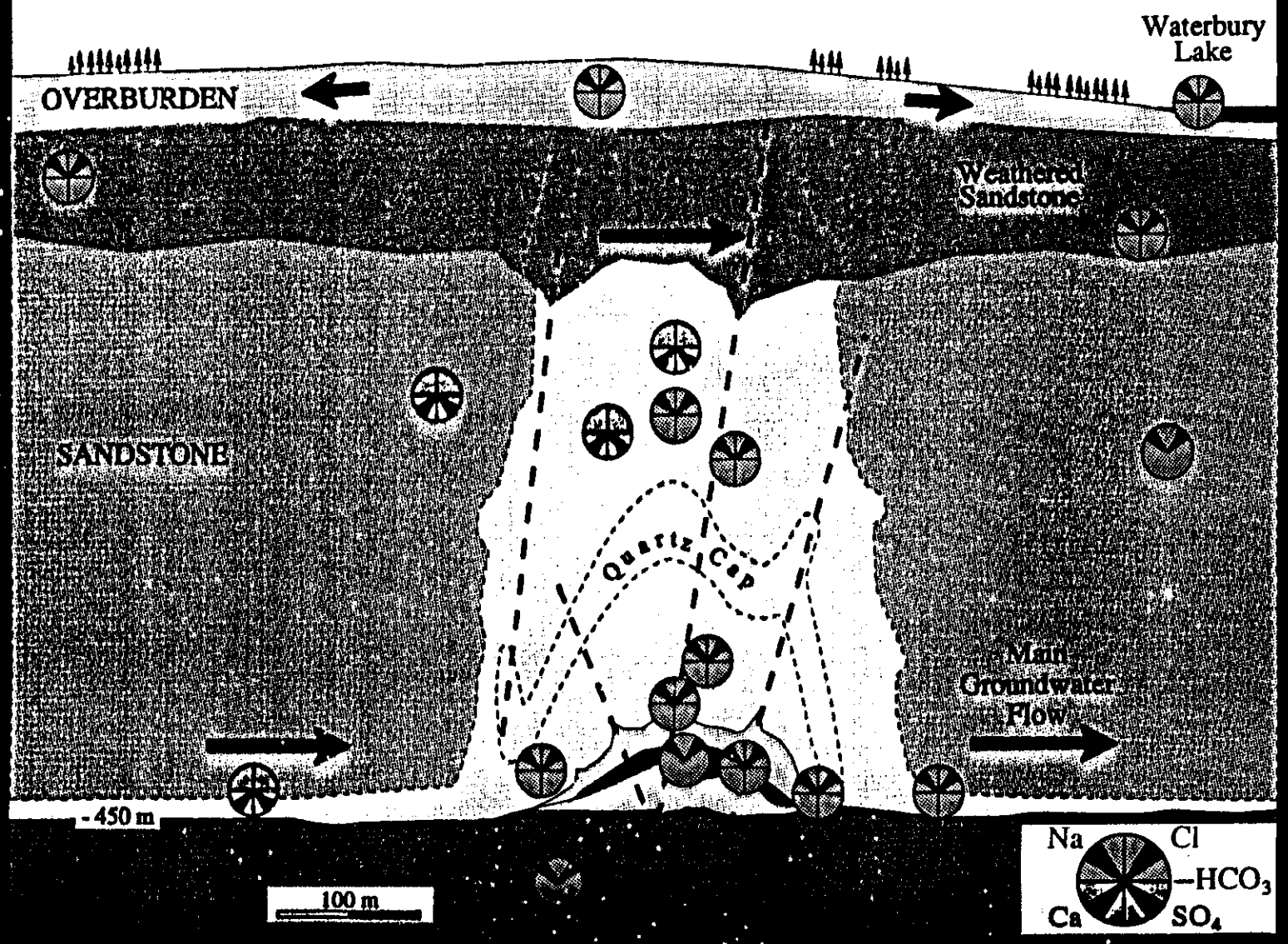
- UO_2 STABILITY AND DISSOLUTION
- RADIOLYSIS
- COLLOIDS
- CLAY SEALING
- GROUNDWATER CHEMISTRY
- ORGANICS AND MICROBES
- RADIONUCLIDE MIGRATION
- ^{36}Cl-^{99}Tc-^{129}I-^{239}Pu GEOCHEMISTRY

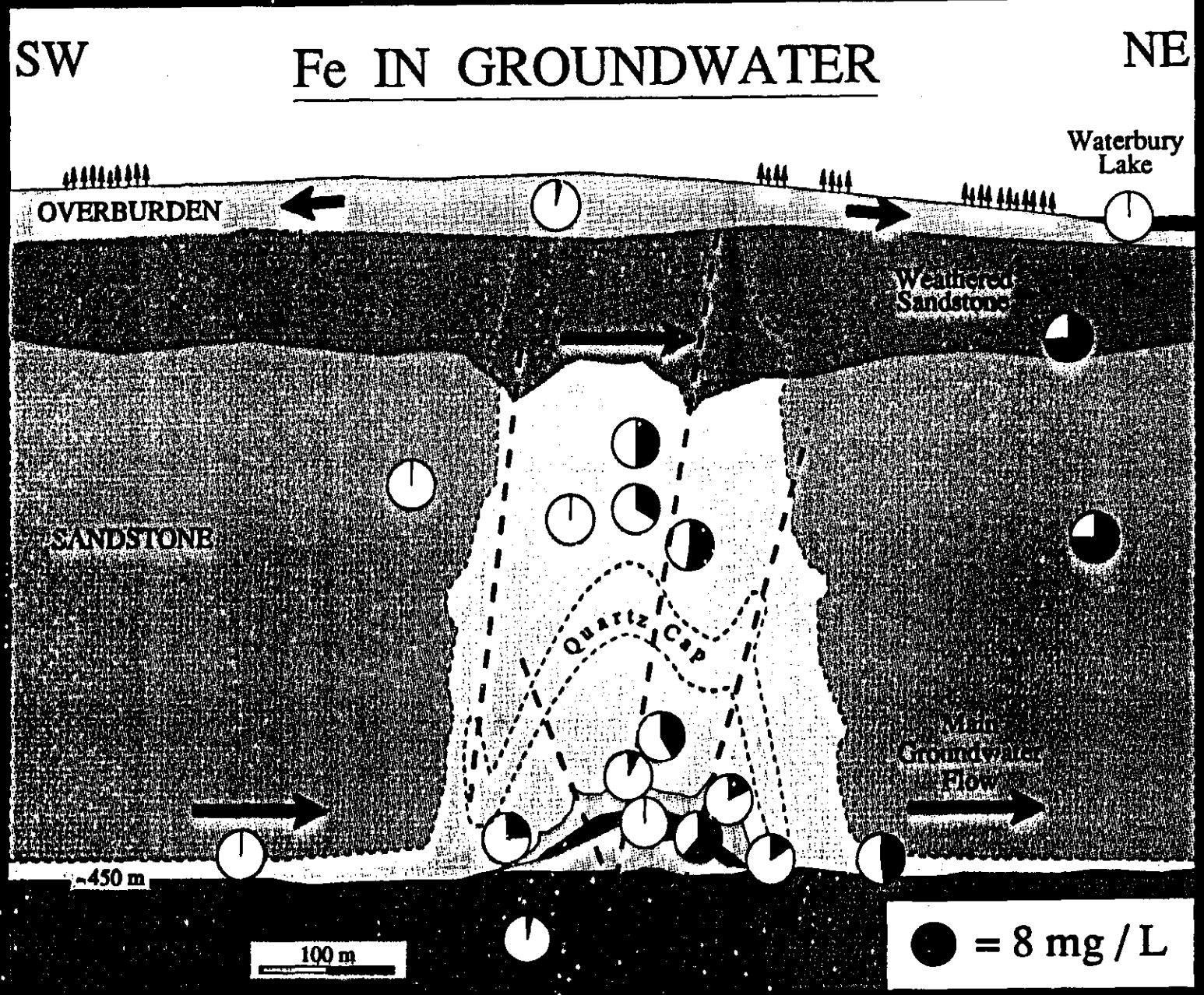
Piezometer locations at Cigar Lake



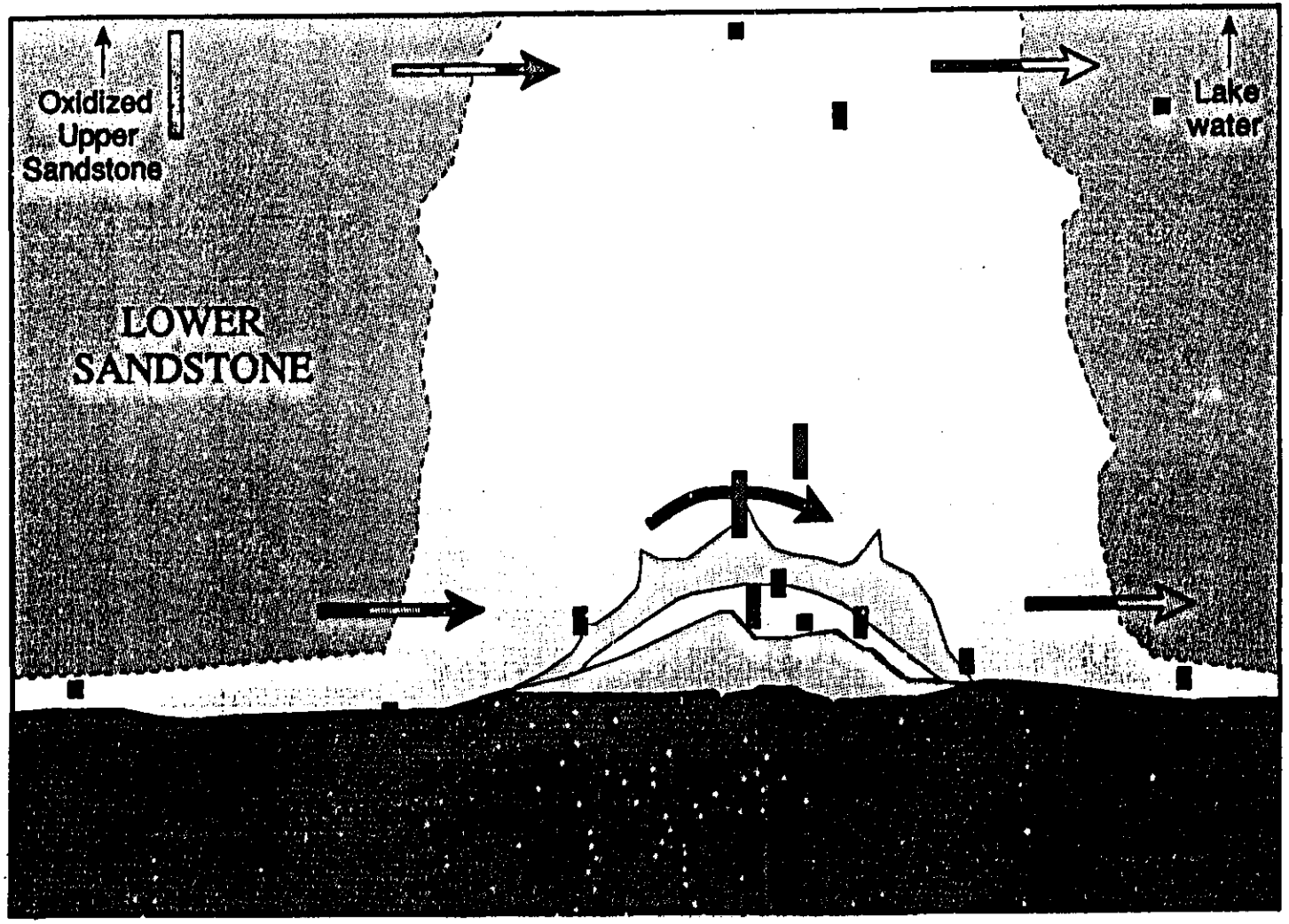

SW
NE
3.8
3.7
OB
I
Waterbury Lake
1085
LUS
1083
II
UUS
75
1078
71
LS
III
67
197
91
139
211
220
79
219
193
81
199
480
BR
UB
OB Glacial Overburden
LUS Limonitic Upper Sandstone
UUS Unoxidized Upper Sandstone
LS Lower Sandstone
BR Basement Regolith
UB Unaltered Basement
Unaltered Sandstone
I Local Flow Regime
II Intermediate Flow Regime
III Semi-Regional Flow Regime
Clay-rich Aquitard
Groundwater Flow Direction
Piezometer
Horizontal
100 m
Vertical
Large Fracture
Quartz-cemented zone

MAJOR IONS IN GROUNDWATER




SW
Fe IN GROUNDWATER
NE
Waterbury Lake
OVERBURDEN
Weathered Sandstone
SANDSTONE
Quartz Cap
Main Groundwater Flow
~450 m
100 m
= 8 mg / L

U IN GROUNDWATER

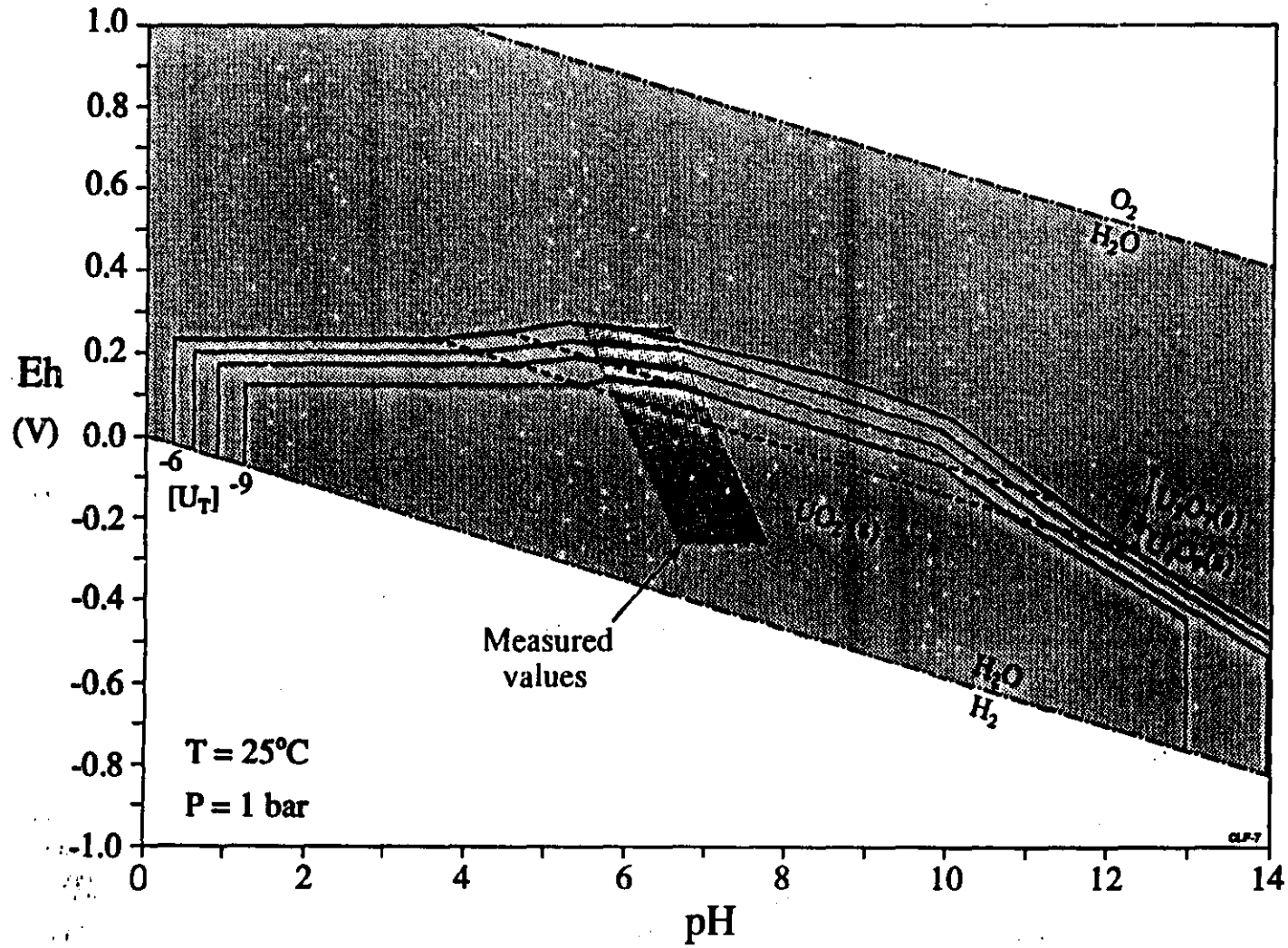


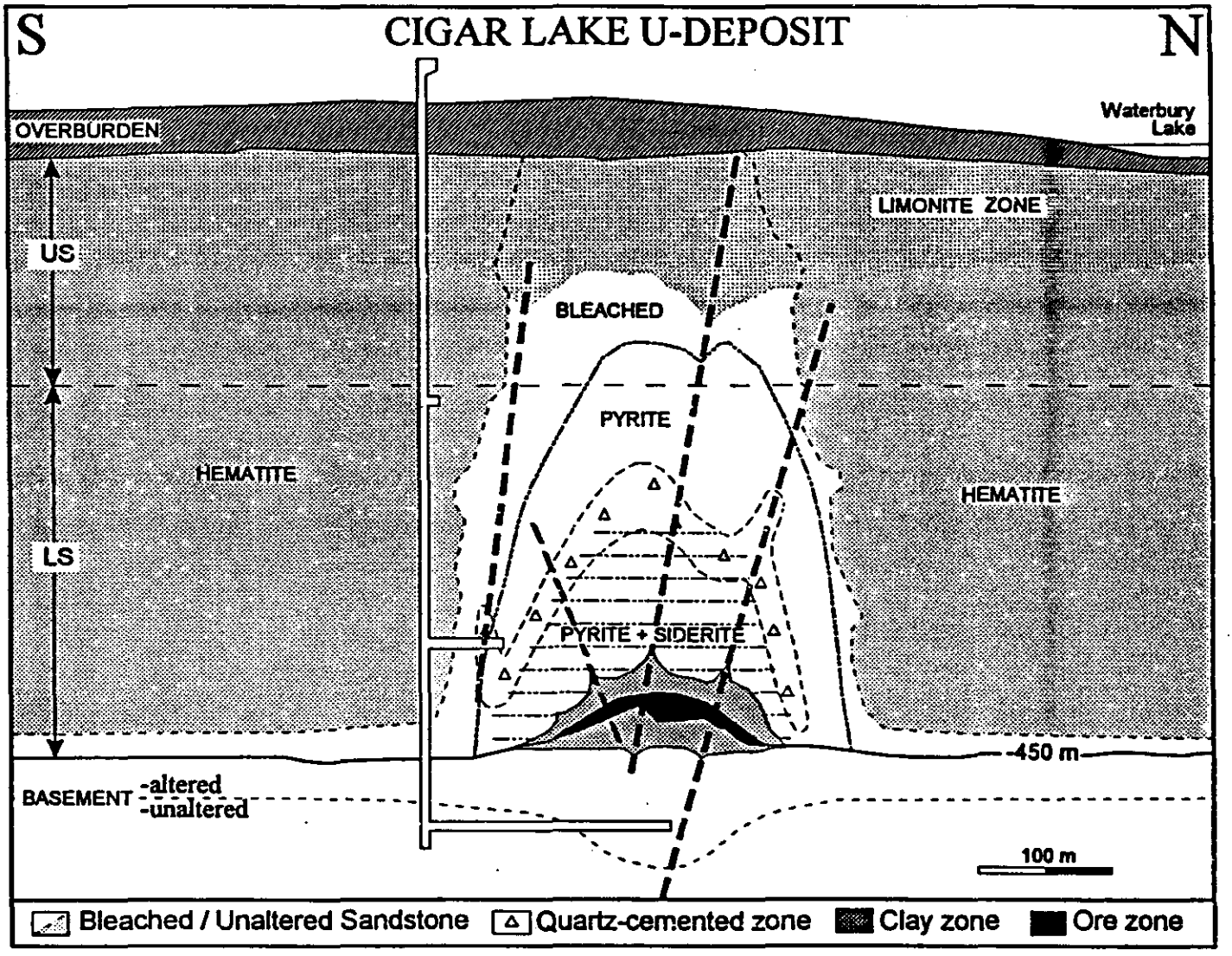
Oxid. ⟶ Reduc.

Main Groundwater Flow

10^{-6} 10^{-7} 10^{-8} 10^{-9} mol/L U

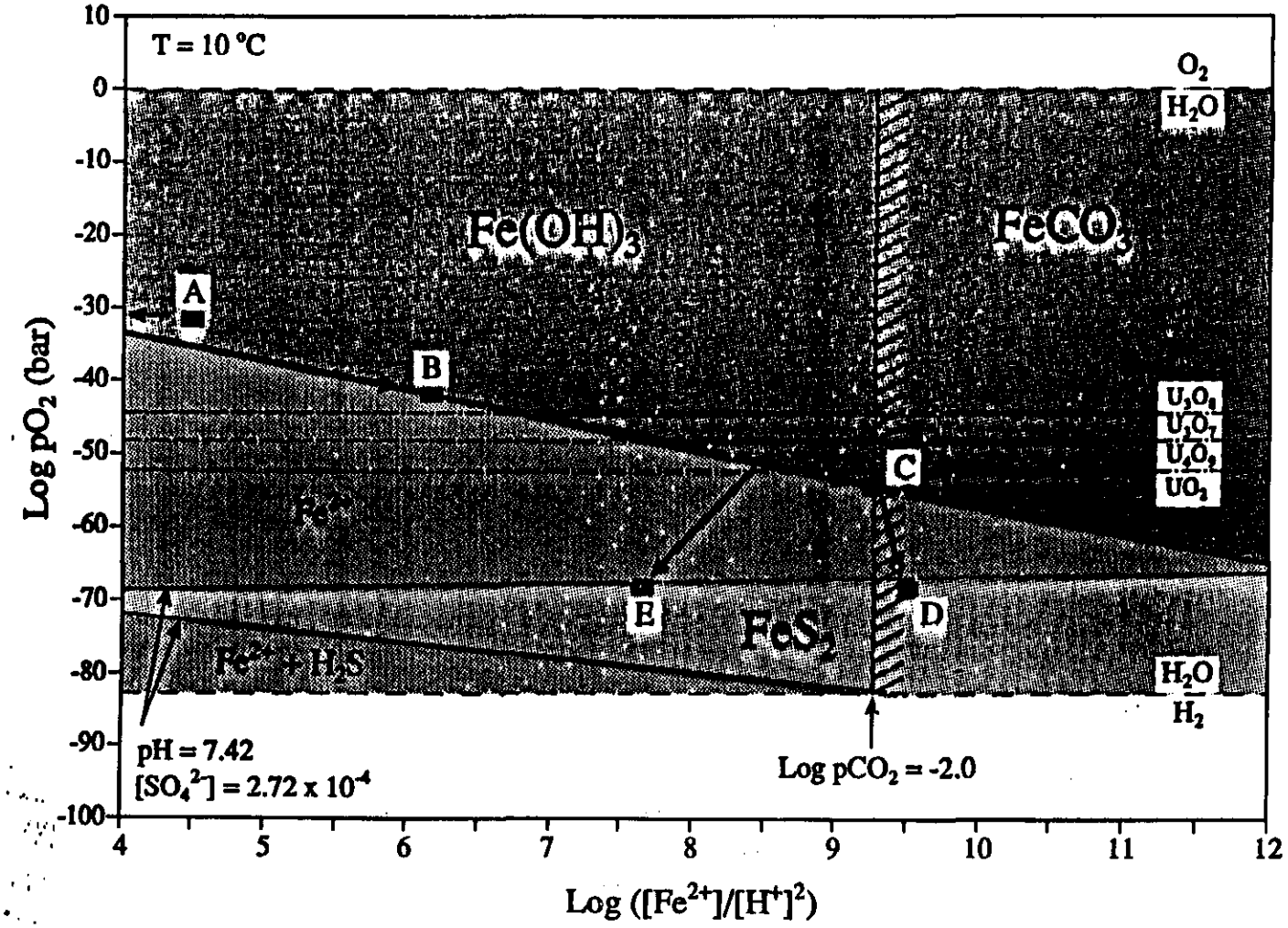
CIGAR LAKE GROUNDWATERS

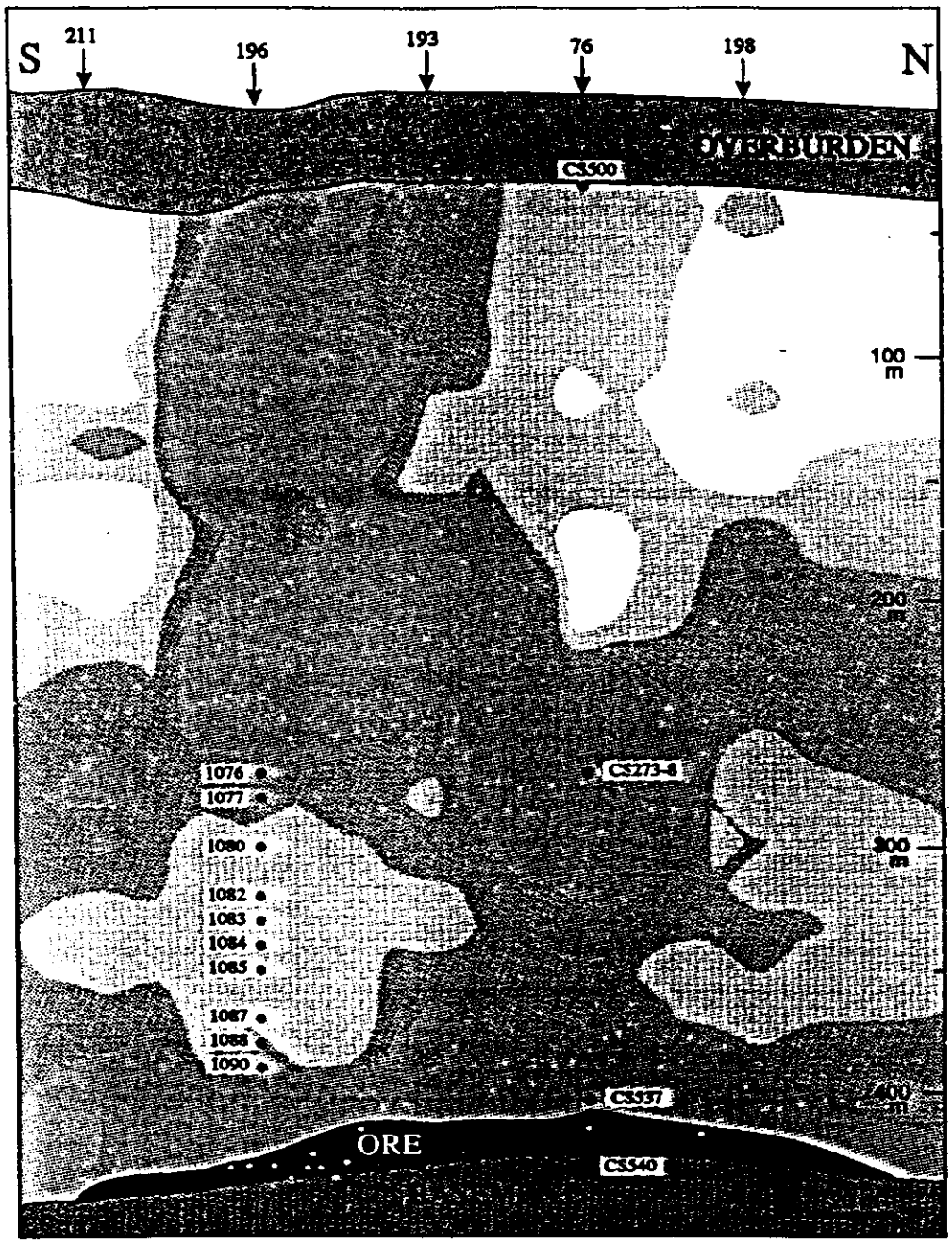



S
CIGAR LAKE U-DEPOSIT
N
OVERBURDEN
Waterbury Lake
LIMONITE ZONE
US
BLEACHED
PYRITE
HEMATITE
HEMATITE
LS
PYRITE + SIDERITE
450 m
BASEMENT
-altered
-unaltered
100 m
Bleached / Unaltered Sandstone
Quartz-cemented zone
Clay zone
Ore zone

Evolution of Cigar Lake Groundwaters

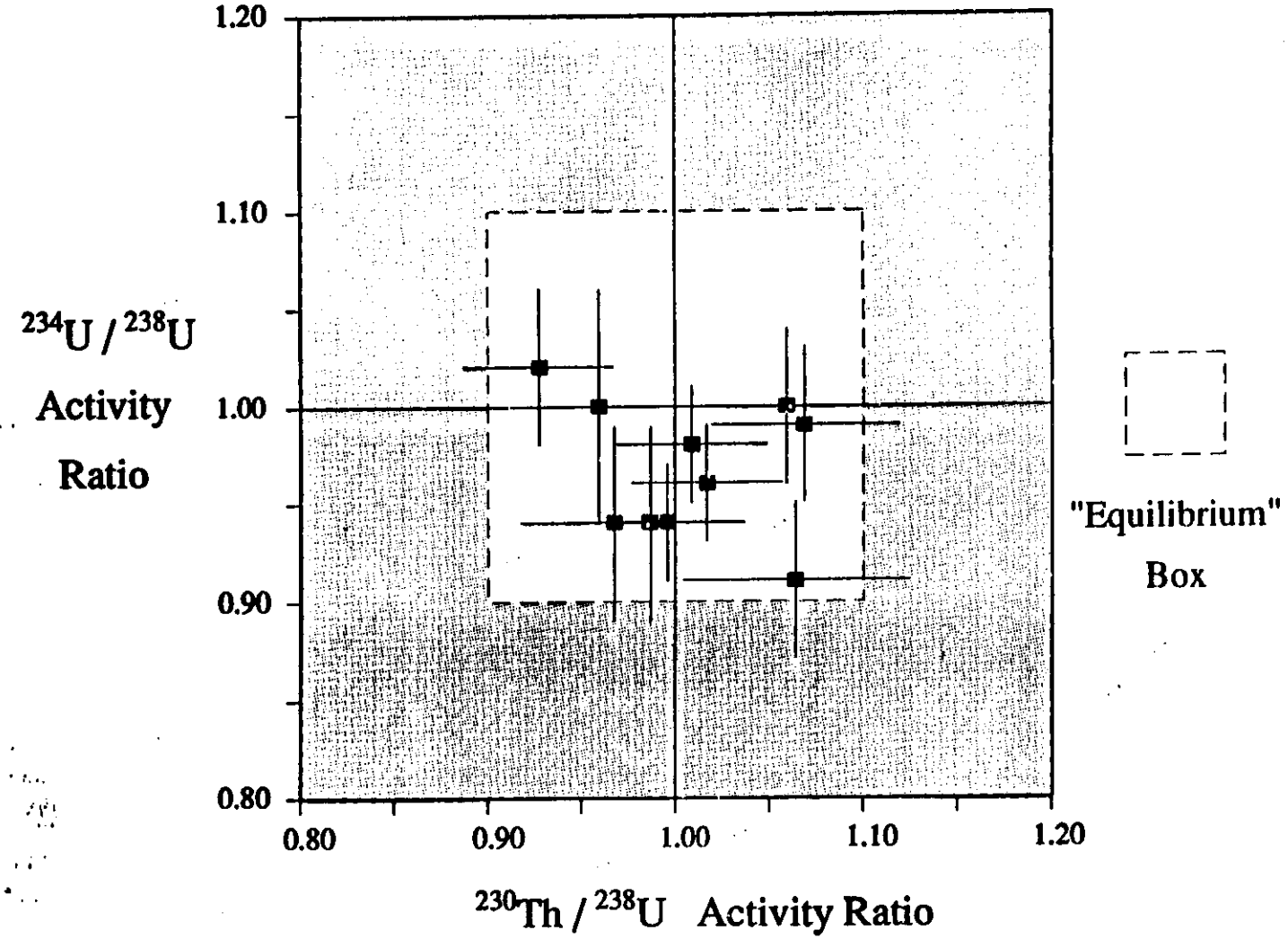
A = Overburden
B = Sandstone Upstream
C = Altered Sandstone
D & E = Mineralization





>20 | 14-20 | 8-14 | <8 ppm URANIUM

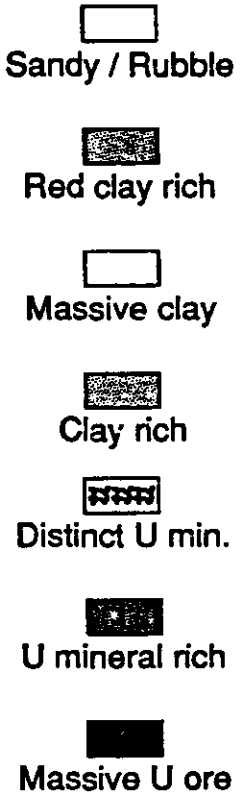
SANDSTONE PROFILE HOLE 196

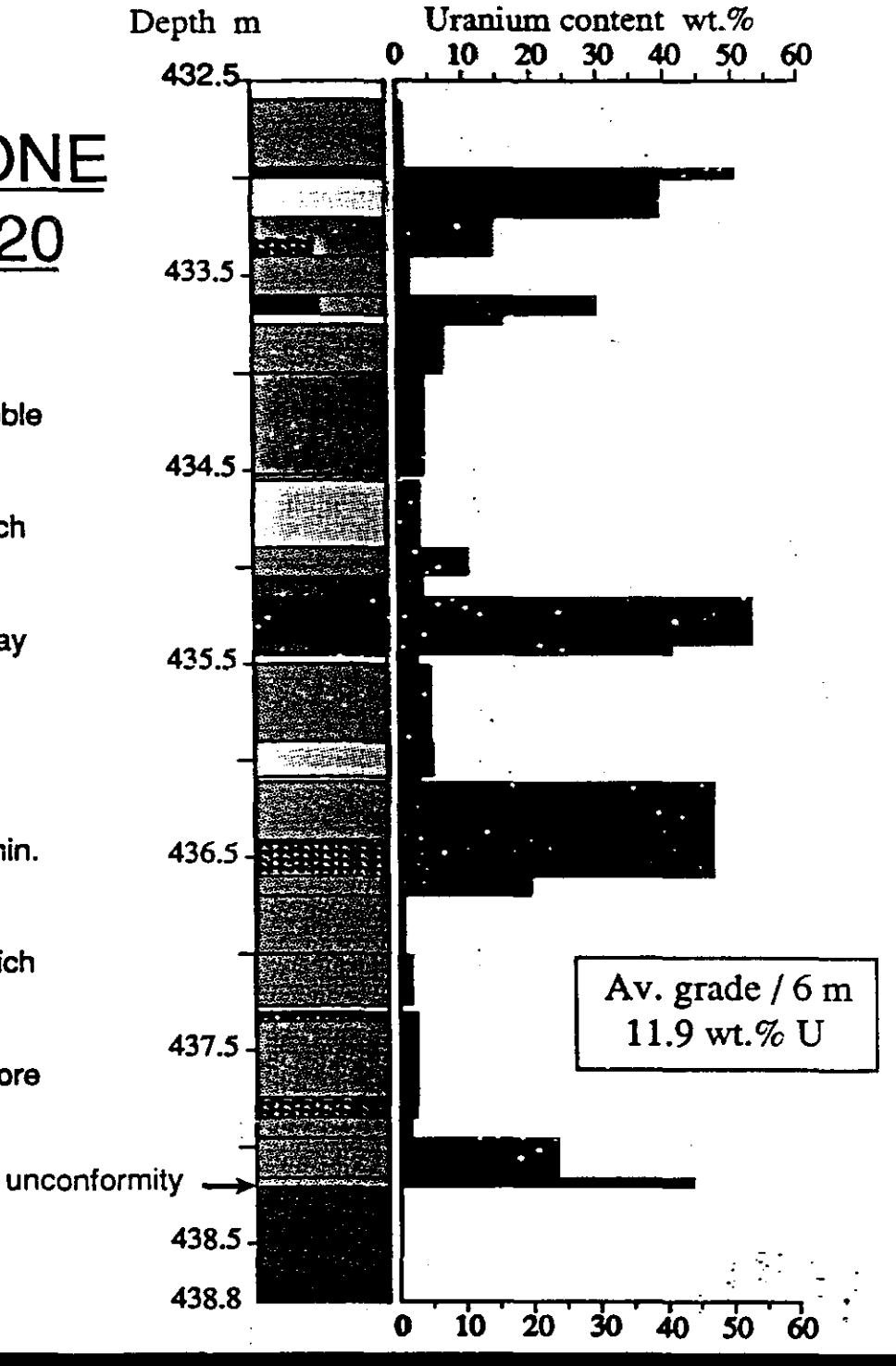


USED FUEL DISSOLUTION

- Rapid release of fission products in fuel-cladding gaps (Cs, I)
- Slower release of fission products at fuel grain boundaries (Cs, I, Tc)
- Very slow release of actinides and majority of fission products controlled by rate of dissolution of UO_2 matrix

ORE ZONE
Hole 220





CIGAR LAKE MINERAL PARAGENESIS

STAGE

I

<u>Uraninite</u>

Ni-Co-Fe Arsenides/Sulphides

Illite

II

<u>Uraninite + Pitchblende</u>

Poly-metallic Arsenides/Sulphides

Sudoite

Siderite

III

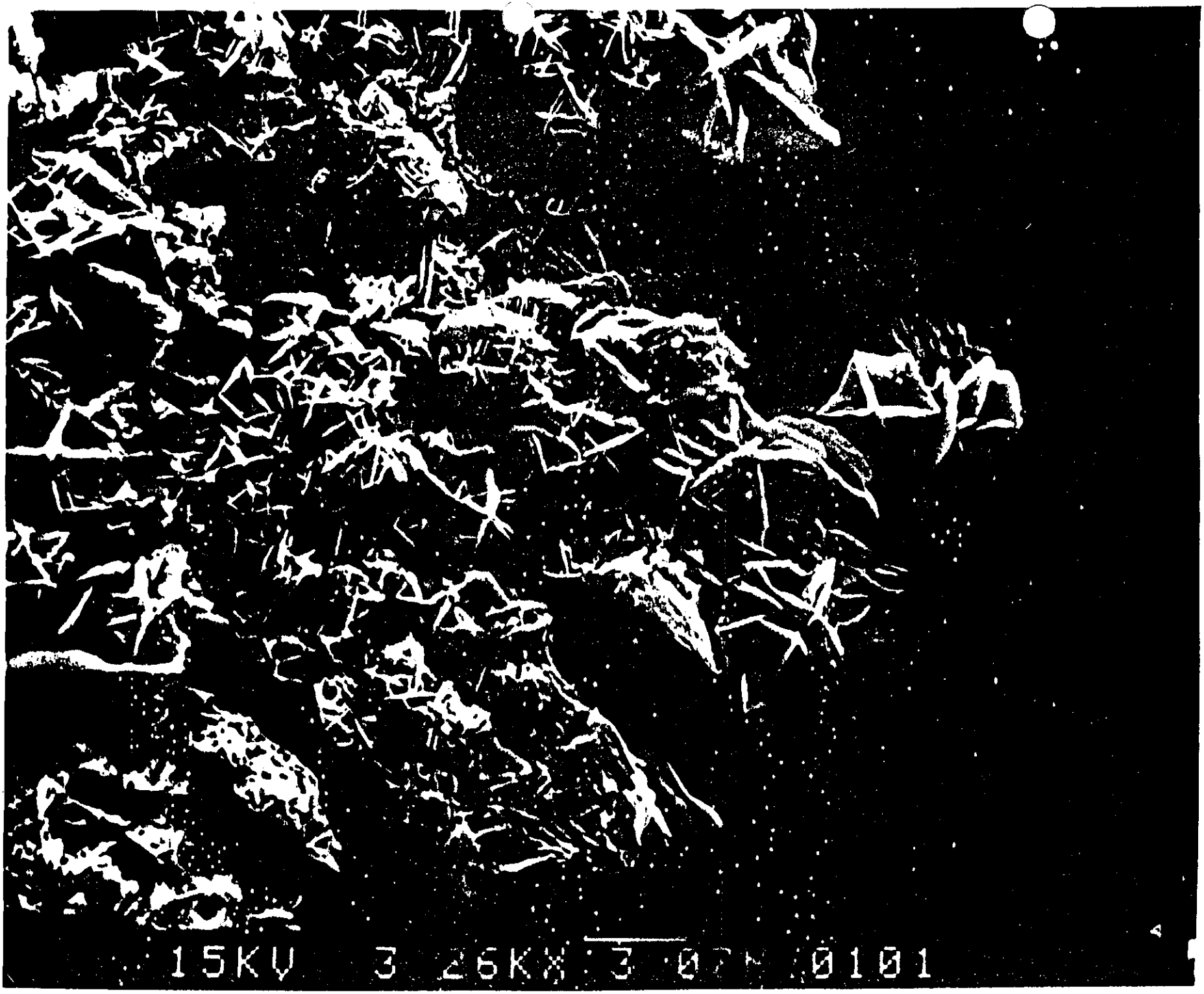
<u>Pitchblende + Coffinite</u>

Fe-Pb Sulphides

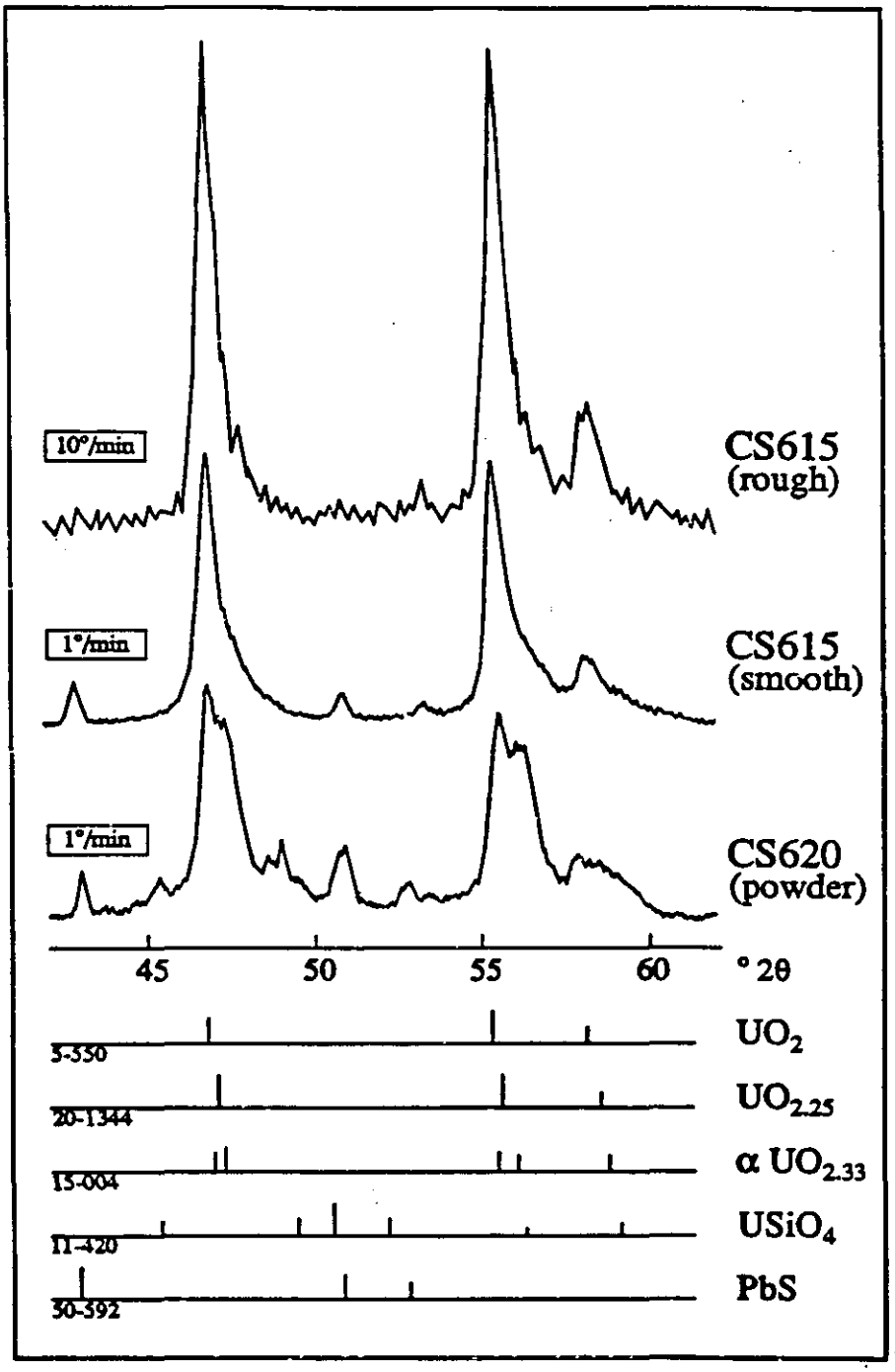
Hematite

TIME

1362 - 1287 | 1100 - 1000 | 320 - 293 | Ma


15KV 3.26KX 3.07N 0101

15KV 4 22KX 2 0104

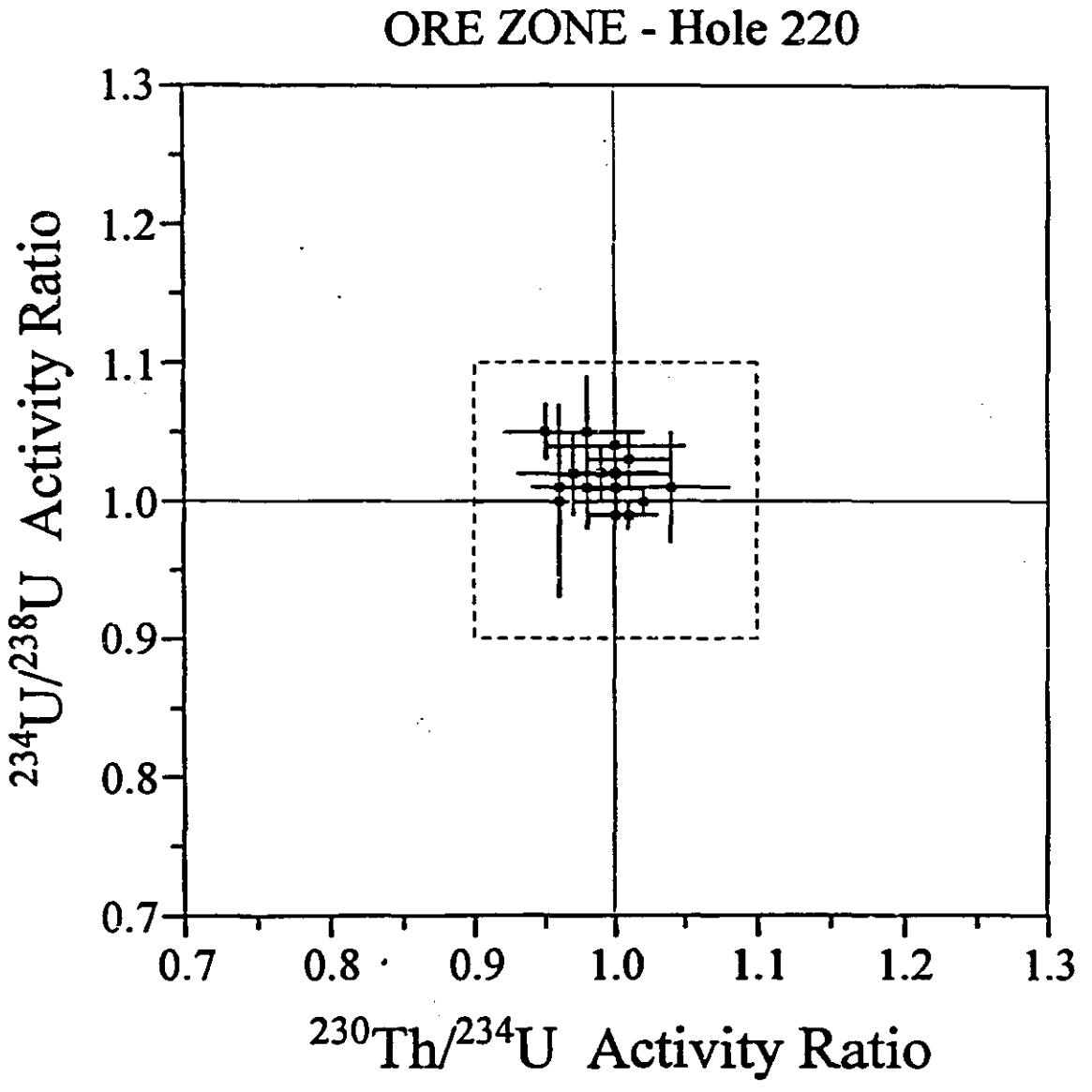

10°/min
CS615
(rough)
1°/min
CS615
(smooth)
1°/min
CS620
(powder)
45
50
55
60
° 2θ
5-550
UO2
20-1344
UO2.25
15-004
α UO2.33
11-420
USiO4
30-592
PbS

COMPOSITION OF CIGAR LAKE U-ORE

XPS : U^{6+} / U^{4+} up to 0.57 ($\sim U_3O_7$)

XRD : UO_2 - U_4O_9 - U_3O_7

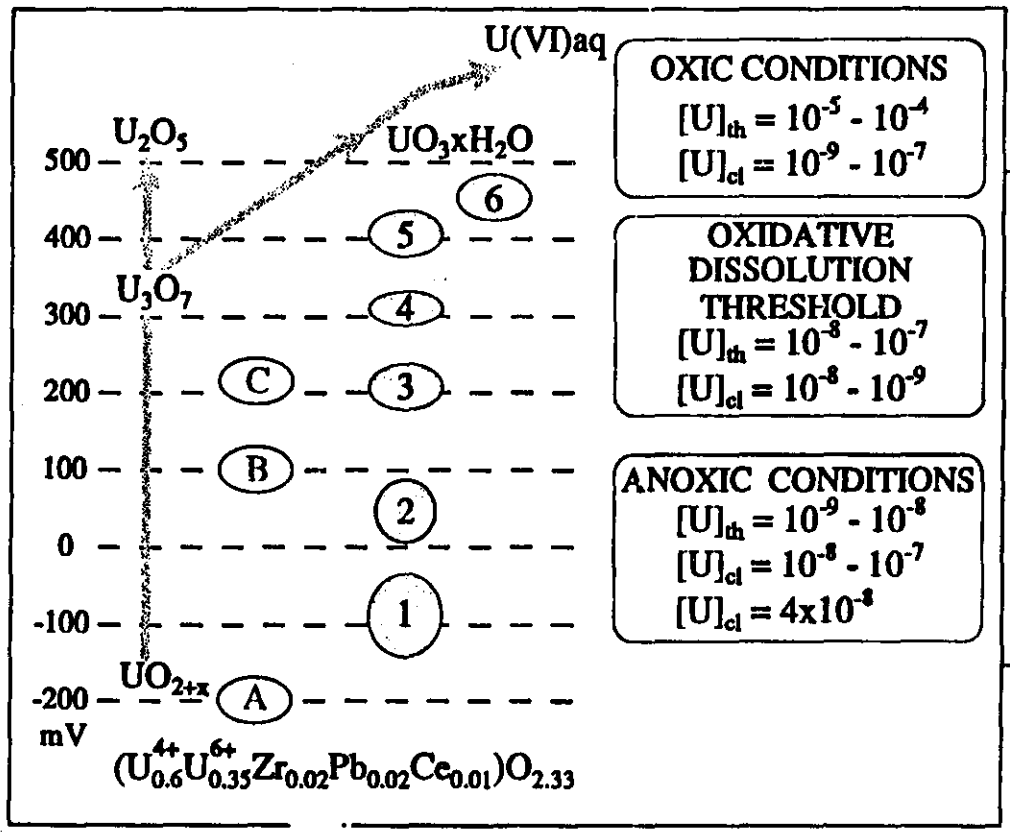
☞ Uranium oxidation has not proceeded beyond $UO_{2.33}$ (U_3O_7)


ORE ZONE - Hole 220
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.7
0.8
0.9
1.0
1.1
1.2
1.3
$^{234}U/^{238}U$ Activity Ratio
$^{230}Th/^{234}U$ Activity Ratio

ANALOGS FOR USED FUEL DISSOLUTION

	UO_2 in α-field H_2-sat. DW 100°C 100 h	Used Fuel Reducing GW 100°C 500 d	Cigar Lake Ore Reducing GW 8-10°C $>10^4$ a
UO_2 surface oxidation (U^{6+} / U^{4+})	0.21 - 0.34	0.12 - 0.27	0.16 - 0.47
U concentration in aqueous phase (mol U/L)	5×10^{-8}	$10^{-6} - 10^{-8}$	5×10^{-8}

URANINITE STABILITY IN U-DEPOSIT ANALOG SITES



OXIC CONDITIONS
$[U]_{th} = 10^{-5} - 10^{-4}$
$[U]_{cl} = 10^{-9} - 10^{-7}$

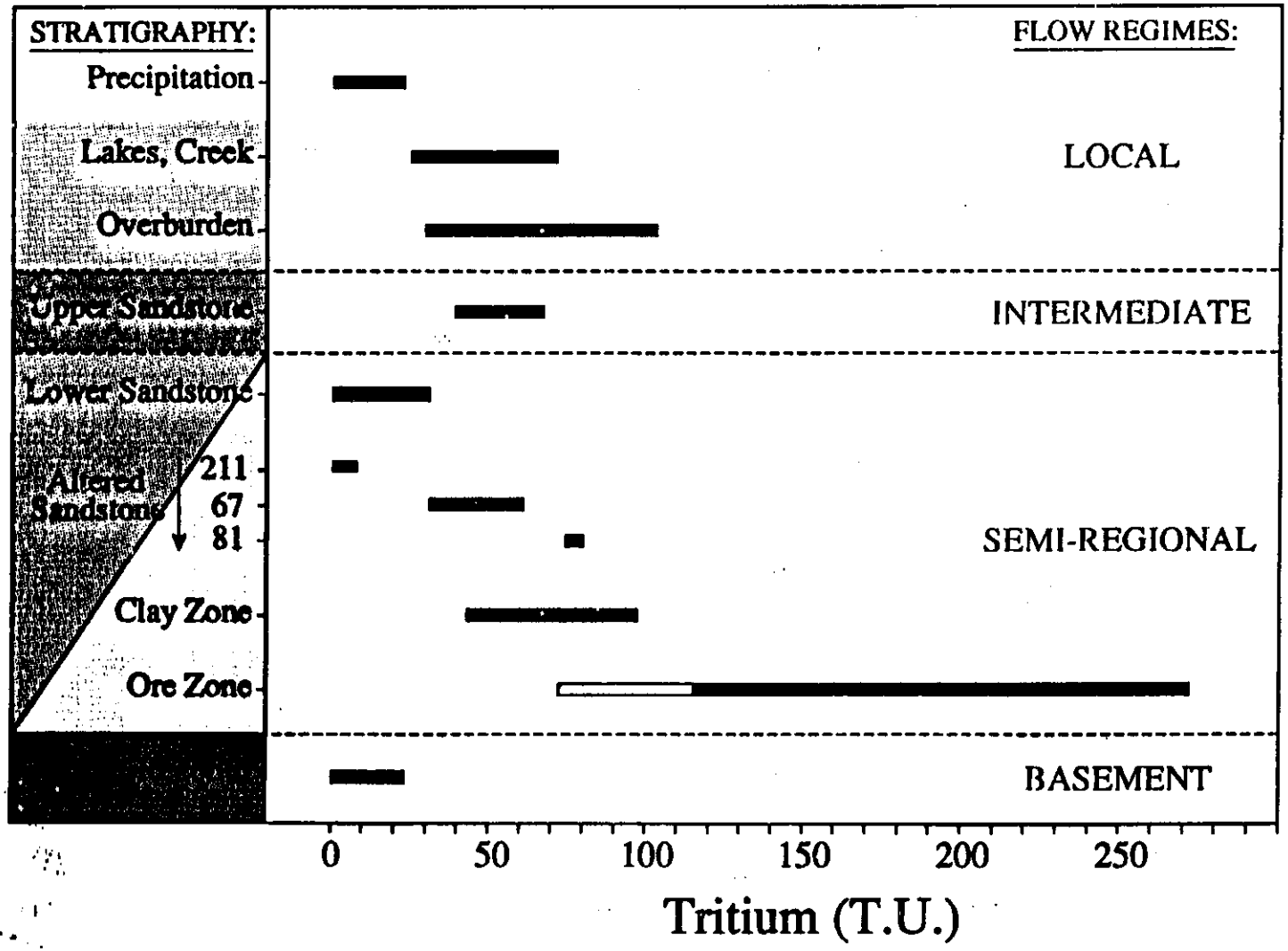
OXIDATIVE DISSOLUTION THRESHOLD
$[U]_{th} = 10^{-8} - 10^{-7}$
$[U]_{cl} = 10^{-8} - 10^{-9}$

ANOXIC CONDITIONS
$[U]_{th} = 10^{-9} - 10^{-8}$
$[U]_{cl} = 10^{-8} - 10^{-7}$
$[U]_{cl} = 4x10^{-8}$

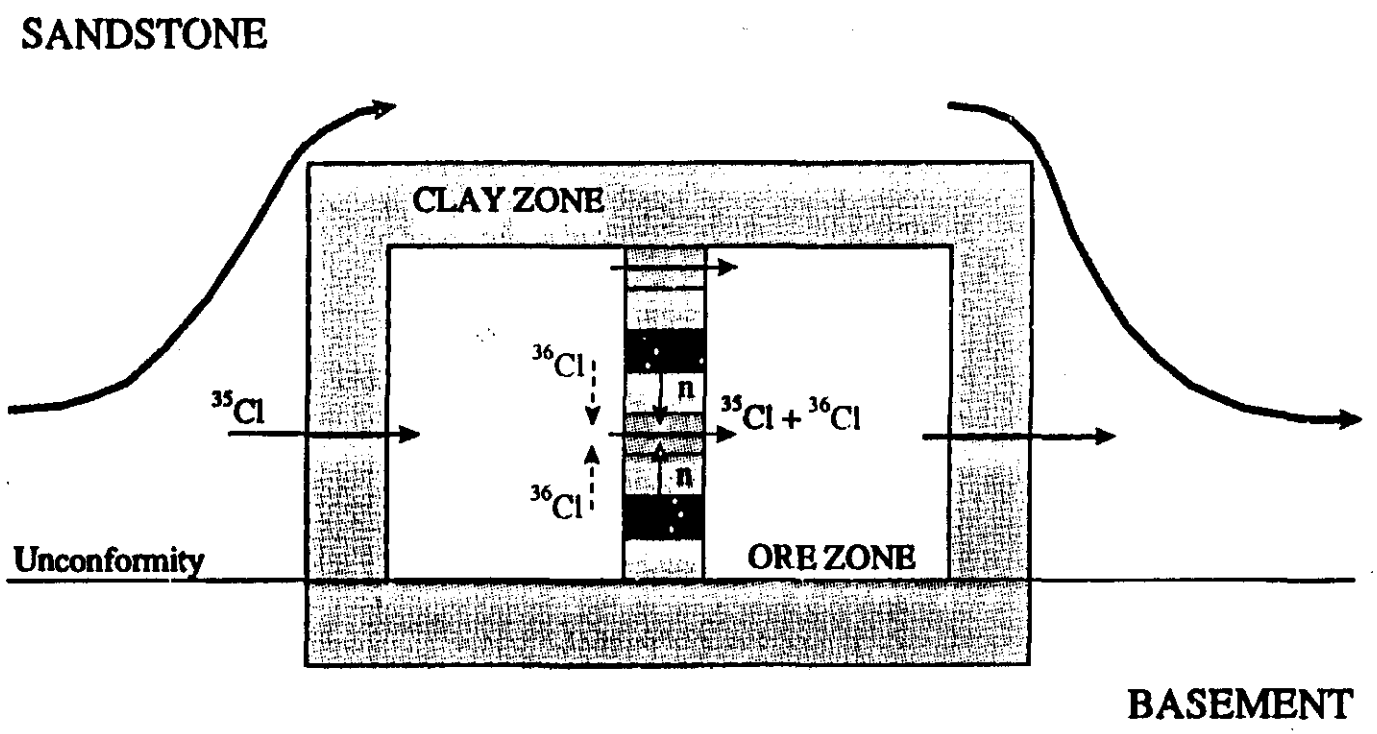
Cigar Lake:
A = mineralization
B = basement and sandstone
C = clay halo

1 = Oklo
2 = Palmottu
3 = ARAP
4 = Poços de Caldas
5 = Peña Blanca
6 = Shimkolobwe

CIGAR LAKE GROUNDWATERS



CIGAR LAKE U-DEPOSIT

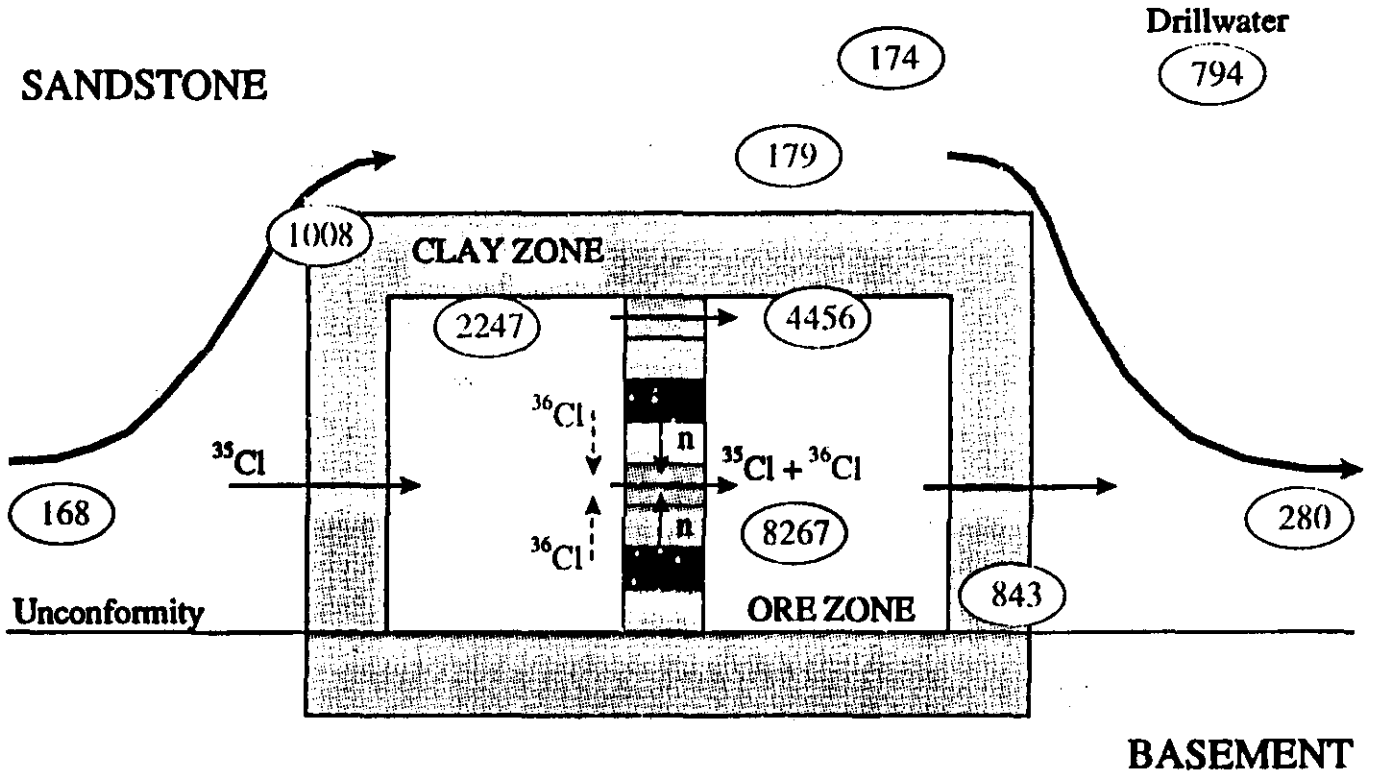


$$^{35}Cl + n \longrightarrow {}^{36}Cl$$

$$(t_{1/2}^{^{36}Cl} = 3.01 \times 10^5 \text{ y})$$

U mineralization | Low-permeable clay | Permeable zone

CIGAR LAKE U-DEPOSIT



$$^{35}Cl + n \longrightarrow {}^{36}Cl$$

$$794 = {}^{36}Cl/Cl \times 10^{15}$$

U mineralization | Low-permeable clay | Permeable zone

LOW FLUX OF WATER THROUGH ORE ZONE

- direct observations from underground drilling
- low measured hydraulic conductivity $\leq 10^{-9}$ m/s
  $\rightarrow$ residence time for groundwater 2-8 $\times 10^{4}$ a
- no kaolinite in ore zone $\rightarrow$ low mass transport
  (i.e. no illite alteration)
- effective redox buffering
- ^{36}Cl-residence time for groundwater $> 10^{5}$ a
- ^{14}C-age of dissolved humic fraction $> 1.5 \times 10^{4}$ a
- U-series dating of suspended particles $\sim 8 \times 10^{3}$ a