U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: HYDROLOGIC FLOW PATHS AND RATES INFERRED FROM THE DISTRIBUTION OF CHLORINE-36 IN THE ESF

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OUTLINE

- Study Objectives and Approach
- Data and Interpretation
- Implications for UZ Conceptual Model
- Comparison with Transport Calculations
- Conclusions

OBJECTIVES OF ESF STUDY

- Evaluate the extent to which the PTn unit is an effective barrier to vertical flow
- Provide bounding estimates for the travel time of water in the matrix of the TSw unit at the repository horizon
- Evaluate frequency and distribution of preferential flow paths

CHLORINE-36
AS A HYDROLOGIC TRACER
(Half-life: 301,000 years)

Sources	Estimated Value at Yucca Mountain ($^{36}Cl/Cl \times 10^{-15}$)	Relative Importance at Yucca Mountain
ATMOSPHERIC SOURCES		
Anthropogenic sources ▸ Global fallout ▸ Local NTS activities	Up to 200,000 (peak global fallout)	Dominant in young waters
Natural atmospheric sources ▸ Reactions of cosmic rays with ^{40}Ar, ^{36}Ar, and ^{35}Cl	500 at present-day, but up to 1500 over past 0.5 My	Dominant in pre-bomb waters
IN-SITU PRODUCTION		
In Rocks and Minerals Near the Surface ▸ Reactions of cosmic rays with ^{39}K, ^{40}Ca and ^{35}Cl	Variable. Function of exposure age and elemental composition	Probably negligible relative to atmospheric sources
In Deep Subsurface Rocks and Waters ▸ Neutron capture by ^{35}Cl	20 - 30	Generally negligible

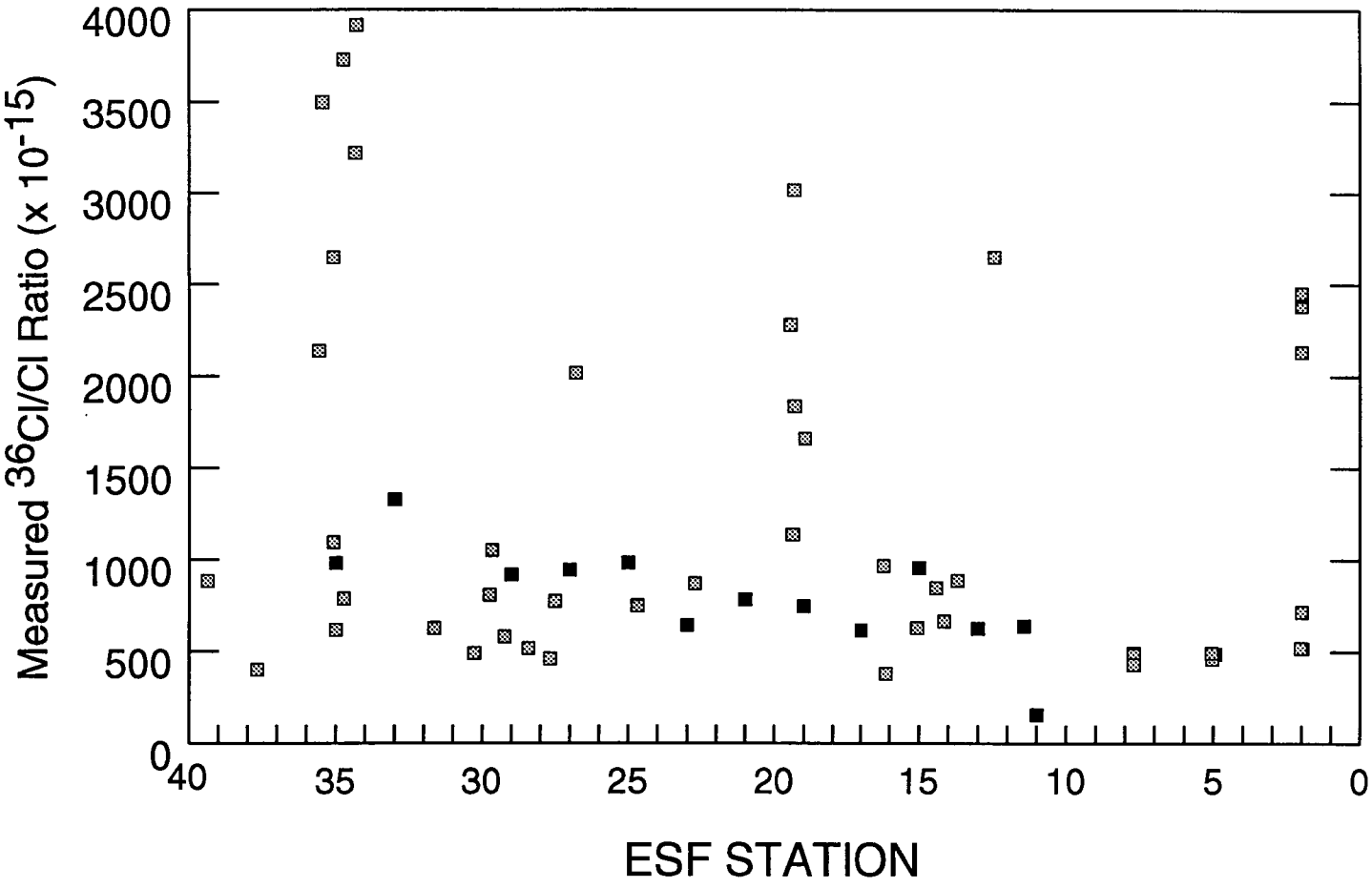
APPROACH

Comprehensive Sampling of ESF Rocks for Analysis of Chlorine-36, Chloride and Bromide

Sampling Category	Sample Inventory, Stations 2 to 55, as of 7/2/96		
	Collected	Analyzed	Submitted but not yet analyzed
Systematic sampling every 200 m	24	13	7
Feature-based sampling	107	41	24
Sampling of PTn subunit contacts (usually 3/contact)	22	3	15
Total	153	57	46

DISTRIBUTION OF $^{36}Cl/Cl$ IN ESF ROCKS

- Feature-based samples (fractures, faults, breccia, broken rock, lithophysal cavities)
- Systematic samples and intact bedrock



Preliminary data
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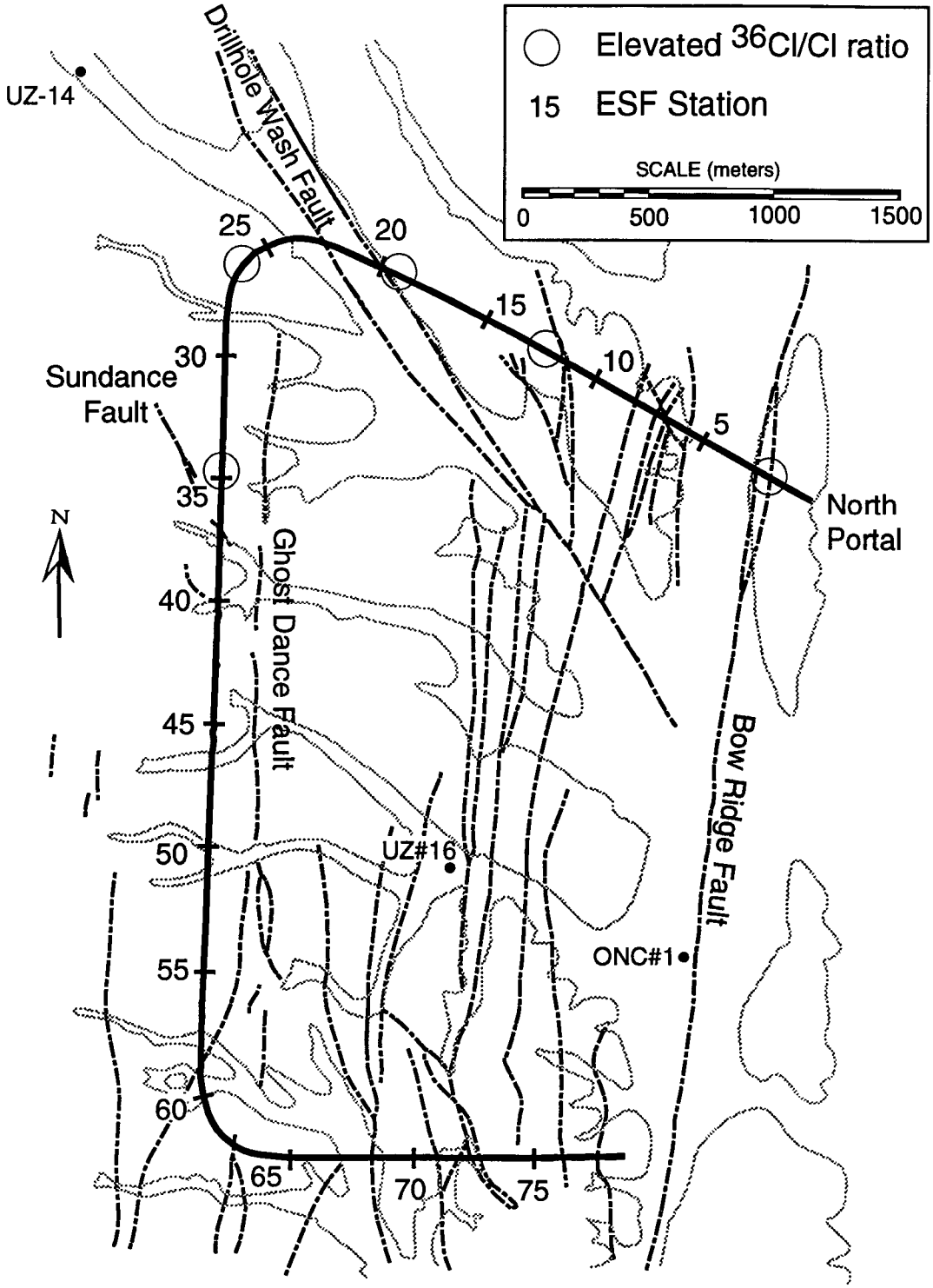
RELATIONSHIP OF ESF TUNNEL TO MAJOR STRUCTURAL FEATURES (mapped at surface)

Based on Day et al. (preliminary draft of map, 4-26-96)



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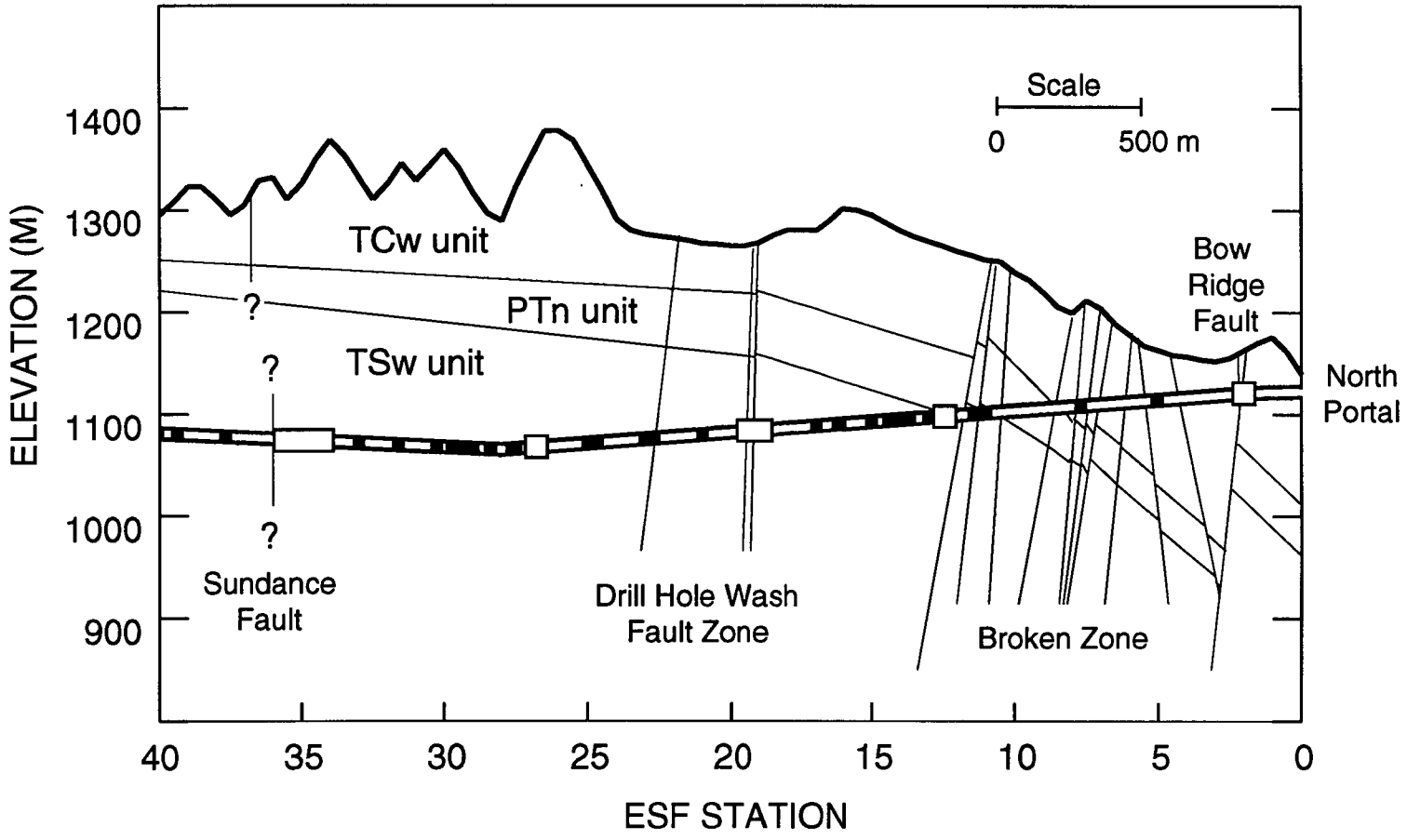
SCHEMATIC CROSS-SECTION OF ESF TUNNEL

(unit contacts and faults based on preliminary map provided by S. Beason, 6-28-96)

■ $^{36}Cl/Cl$ ratio less than 1500×10^{-15}

□ $^{36}Cl/Cl$ ratio exceeding 1500×10^{-15}



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INTERPRETATION

Approach to Corroborate Elevated $^{36}Cl/Cl$ Ratios as Indicators of Fast Paths

- Evaluation of sources of contamination
- Evaluation of surface calcite as additional source
- Reconstruction of past $^{36}Cl/Cl$ signal in atmosphere
- Examination of field relations and mineralogic features
- Correlation with net infiltration estimates
- Measurement of other bomb-pulse nuclides (^{3}H, ^{137}Cs, Pu, ^{99}Tc, ^{129}I)

TRITIUM IN ESF SAMPLES

Sample	Tritium (TU)	$^{36}Cl/Cl \times 10^{-15}$
ESF Main Tunnel		
Station 1+98	-6 ± 4	2440
Station 2+00	-1 ± 4	2440
Station 12+44	-2 ± 4	2580
Station 18+31	2 ± 4	2900, 1800
Station 34+71	-2 ± 4	3500
Alcove #3		
RBT#1, 32 feet	-3 ± 4	
RBT#4, 22 feet	12 ± 4	Not
RBT#4, 57 feet	8 ± 4	measured
RBT#4, 78 feet	6 ± 4	
RBT#4, 99 feet	7 ± 4	

Sample collection and analysis by USGS investigators:

- ESF samples collected by Alan Flint et al.
- Alcove #3 intersects the North Ramp at Station 7+54. RBT#1 and #4 are horizontal boreholes (Gary Patterson). Distances are measured from alcove wall.

INITIAL SCREENING OF OTHER BOMB-PULSE NUCLIDES AS POTENTIAL TRACERS OF RECENT WATER MOVEMENT

- Technetium-99 was present in two deep samples that also contained elevated chlorine-36
  - — ESF Station 2 (Bow Ridge Fault gouge), ~ 40 m below ground surface
  - — UZ-N55, cuttings from depth of 53 m

- Cesium-137 and plutonium were observed in surface soils but not in either of the above deeper samples

- These distributions are consistent with our understanding of the geochemical behavior of these nuclides.

IMPLICATIONS OF ELEVATED ^{36}CL RESULTS FOR CONCEPTUAL MODEL OF UNSATURATED ZONE HYDROLOGY

- The bimodal distribution of ^{36}Cl/Cl ratios demonstrates the existence of isolated fast paths from the surface to the ESF.

- Penetration of recent water into TSw unit is indicated by bomb-pulse ^{36}Cl in ESF fractures. However, bomb-pulse signals by themselves do not indicate magnitude of fluxes.

- Fast paths that carry water into the TSw may be associated with major fault zones that cut through the PTn.

- Transport calculations indicate that arrival of bomb-pulse ^{36}Cl at the ESF is consistent with increased fracture permeability in the PTn, as may be associated with faults.

Chlorine-36 Transport Simulation

Objective

Develop a quantitative conceptual model of chlorine-36 transport from ground surface to the ESF.

Method

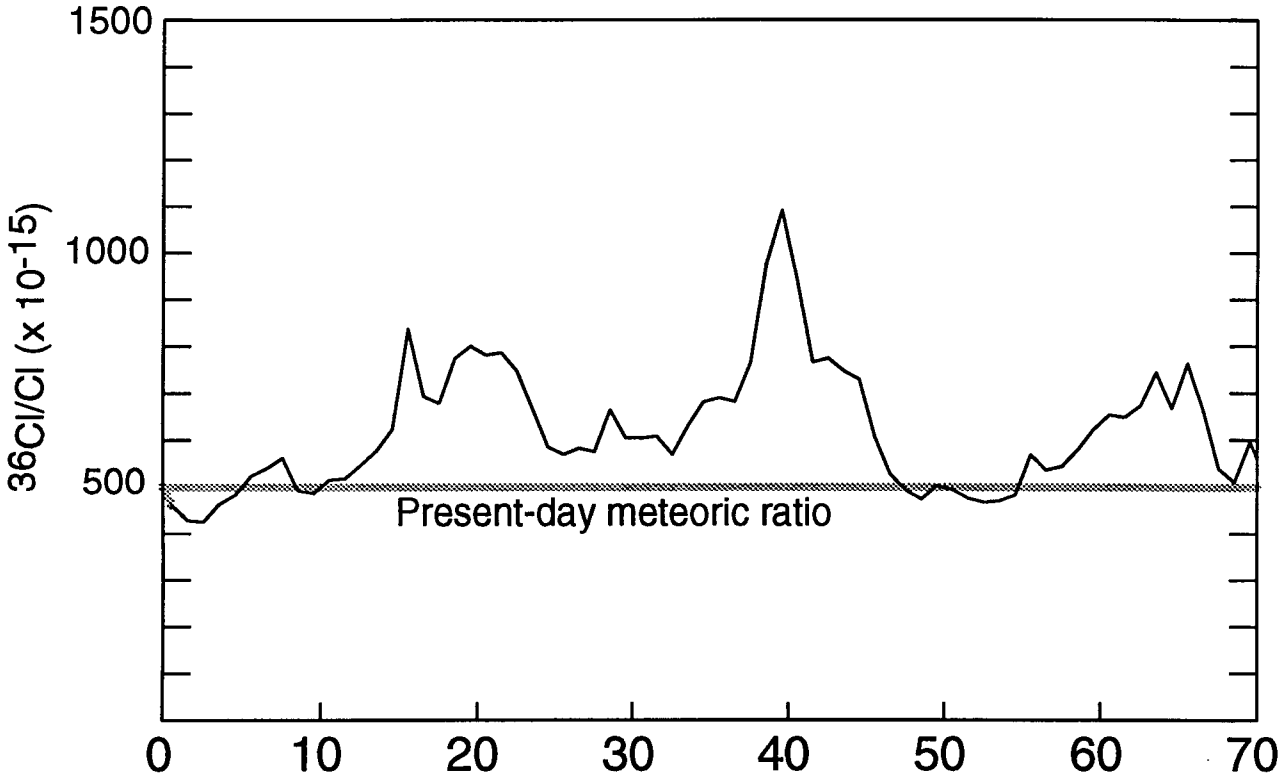
One-dimensional simulation study to examine:

- **Fracture/matrix interactions**
- **Differences between various locations (e.g. in or not in altered zones such as fault zones)**
- **Infiltration rate effects**
- **Transient infiltration**

Three-dimensional simulation study (not discussed) to examine:

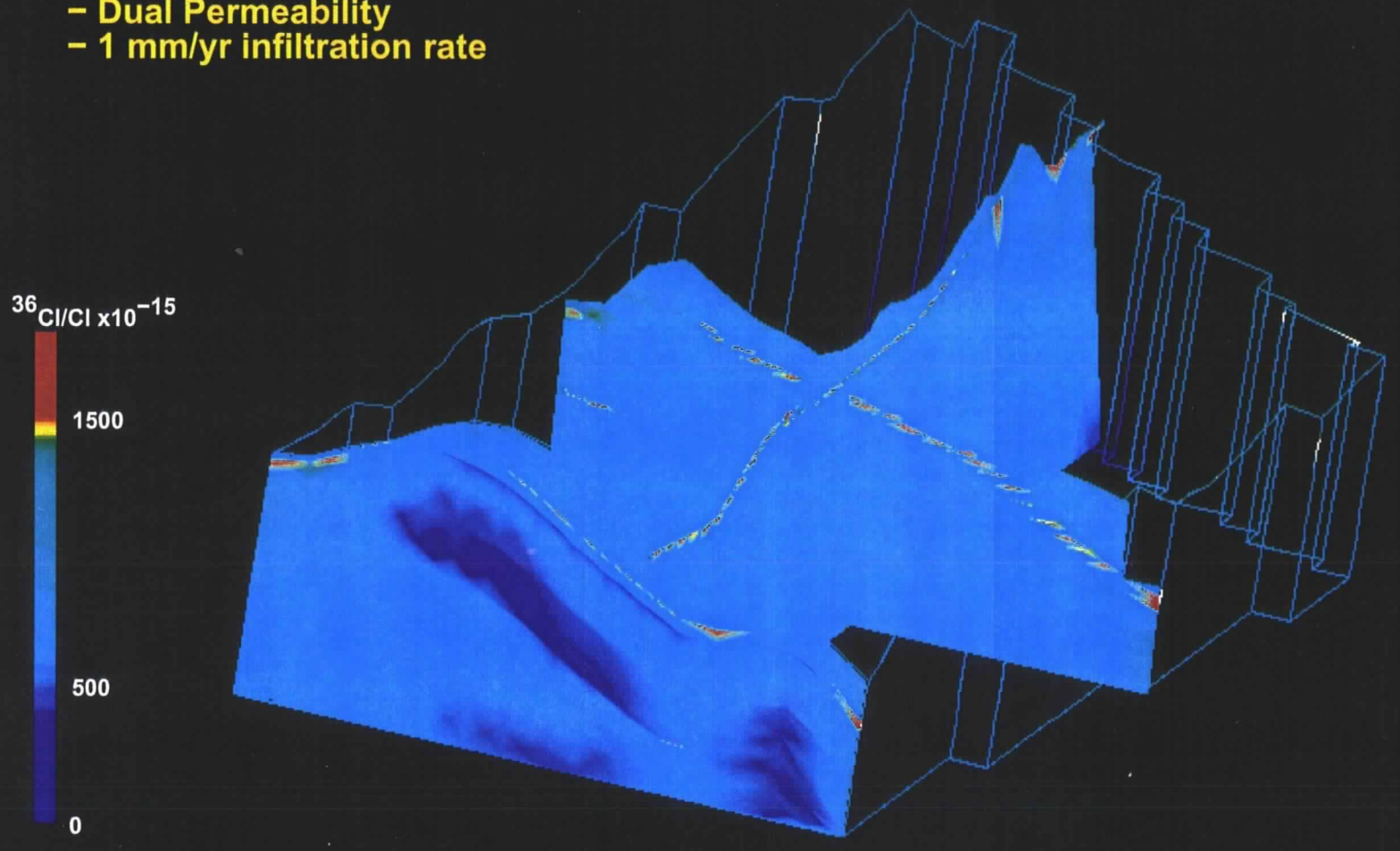
- **Lateral flow effects**
- **Spatially varying infiltration effects**
- **Effect of full fault system**

PREDICTED VARIATIONS IN ^{36}Cl PRODUCTION IN THE ATMOSPHERE



Site-scale Chlorine-36 Simulation

- Variable chlorine-36 source function includes bomb-pulse
- 52,000 Nodes
- Dual Permeability
- 1 mm/yr infiltration rate



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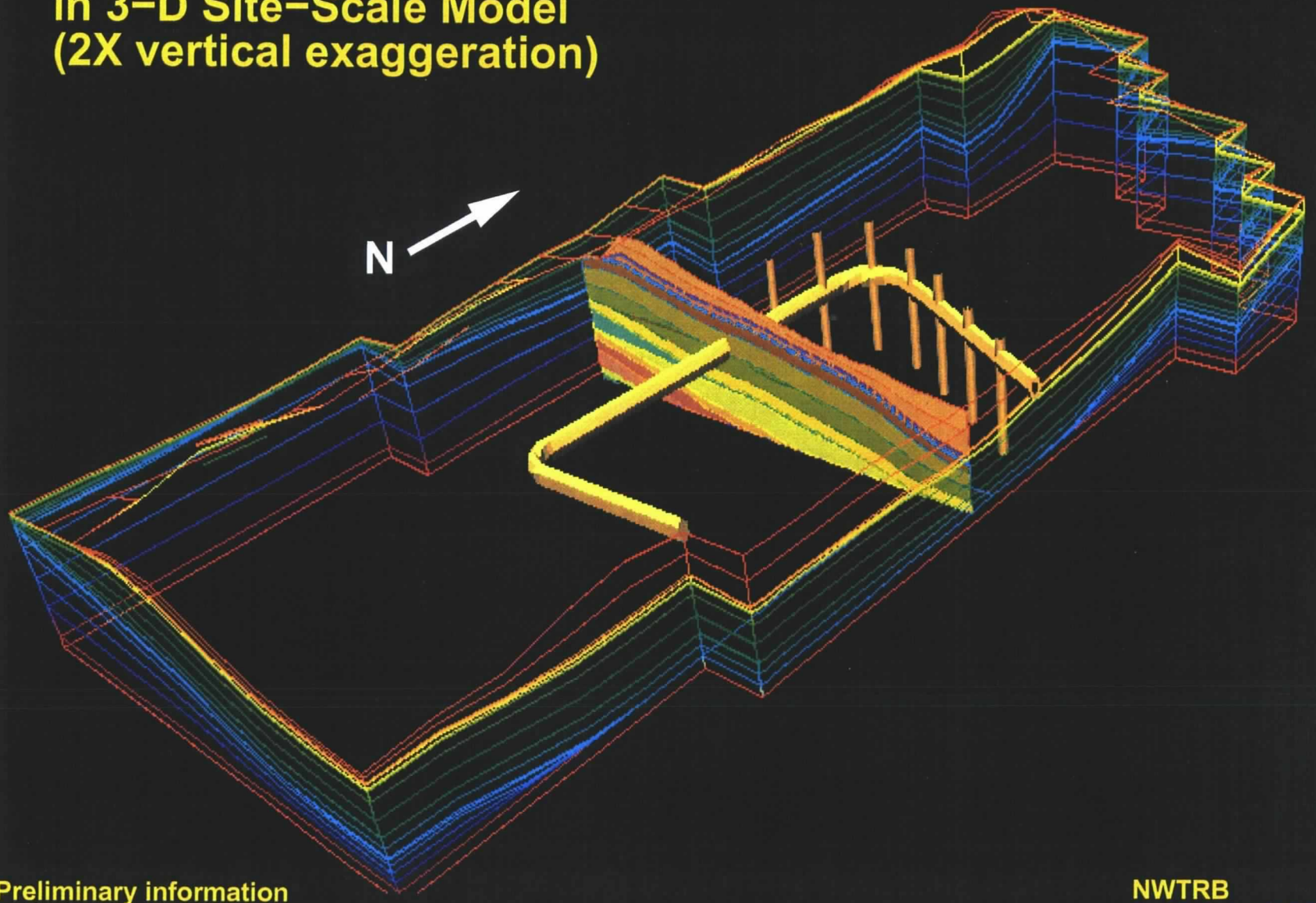
Locations of 36Cl 1-D Column Studies in 3-D Site-Scale Model (2X vertical exaggeration)



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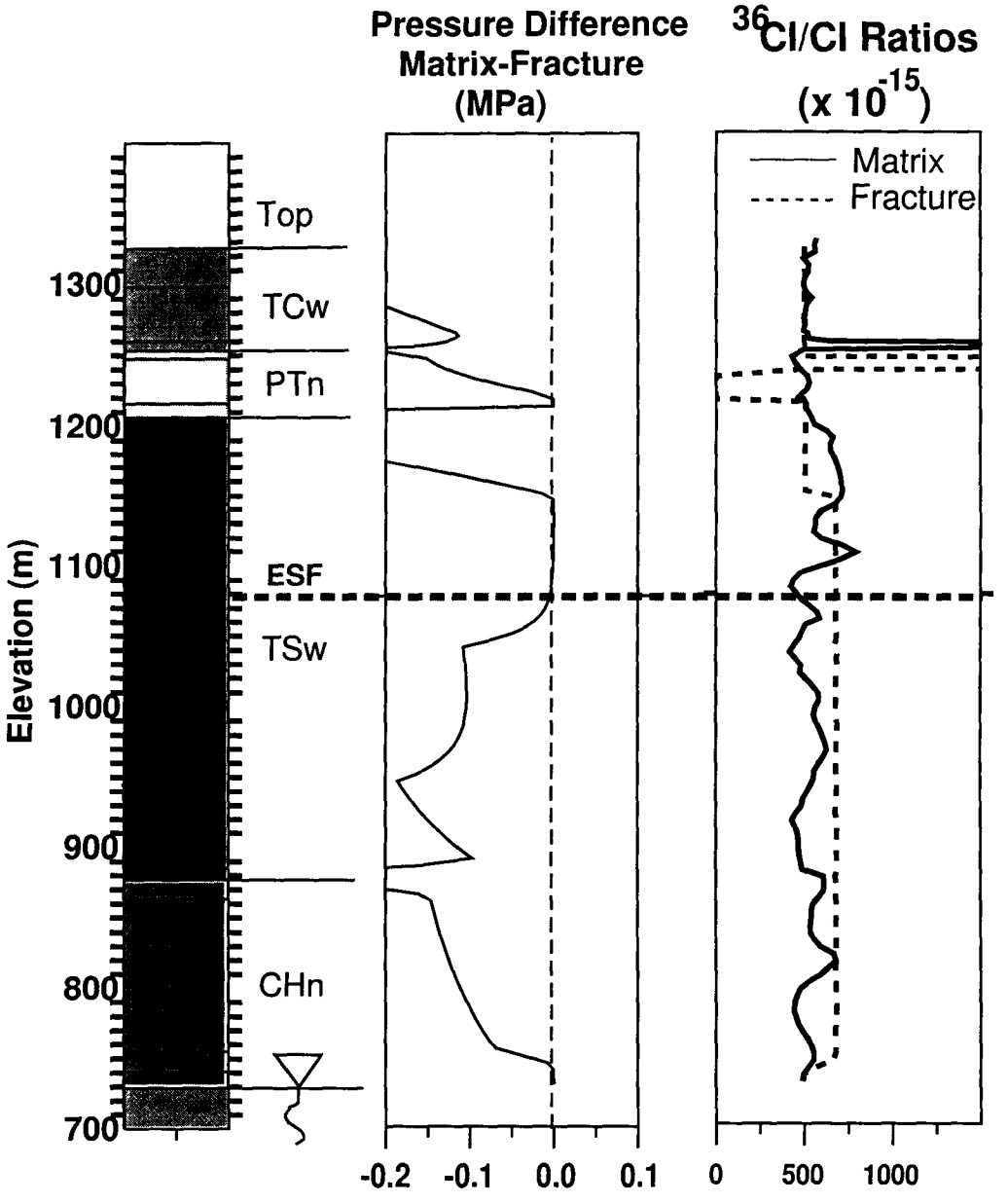
Station 35 Description and Simulation Results for Base-Case Properties and 1 mm/yr Infiltration



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SIMULATED TRANSPORT OF BOMB-PULSE 36Cl TO THE ESF

	CASE	PTn Fracture Properties (normalized to base-case value)				Infiltration Rate (mm/yr)				
		Assumed		Calculated		0.1	1	5	10	50
		Density	Aperture	Permeability	α_{frac} (m^{-1})					
Non Fault Zone Properties	Base	1	1	1	1	No	No	No	No	No
Modified PTn Fault Zone Fracture Properties	A	2	1	2	1			No	No	
	B	1	2	8	2		No	Yes		
	C	1	2.5	16	2.5		No	Yes		
	D	2	2	16	2			No	Yes	
	E	1	1	1	0.1		No	Yes		
	F	2	2	16	0.1	No	Yes			

No - Bomb-pulse signal does not reach ESF

Yes - Bomb-pulse signal arrives ESF

α_{frac} (m^{-1}) assumed equal to 0.1 for cases E and F

Implications of Chlorine-36 Transport Simulation Results For Conceptual Model of Unsaturated Zone Hydrology

- **Transport calculations indicate that arrival of bomb-pulse ^{36}Cl at the ESF is consistent with increased fracture permeability in the PTn, as may be associated with faults.**
  - **With base-case properties in PTn, bomb-pulse ^{36}Cl does not reach ESF in any transport simulations.**
  - **Increasing PTn fracture permeability (e.g. in fault zones) leads to bomb-pulse arrivals at ESF in transport simulations.**