ISOTOPIC DATING OF GROUND WATER

AT YUCCA MOUNTAIN

Presented by

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PRESENTATION OUTLINE

- Objectives of isotopic studies (^{3}H, ^{14}C, ^{36}Cl)
- Sample collection
- Chloride concentrations of porewaters
- Isotopic results for borehole samples
  - Shallow profiles (upper 100 m)
  - Deep profiles (to water table at 500 m)
- Alternative interpretations of data
- Conclusions

OBJECTIVES OF ISOTOPIC STUDIES

- To estimate net infiltration
- To evaluate infiltration mechanisms
- To estimate spatial variability in ground-water travel times
- To identify evidence for fast paths in the unsaturated zone

GEOCHEMICAL TOOLS

- Radiometric tracers of ground-water travel time
- Other isotopic tracers (e.g., Sr and U isotopes)
- Porewater chloride concentrations
- Other porewater geochemical characteristics

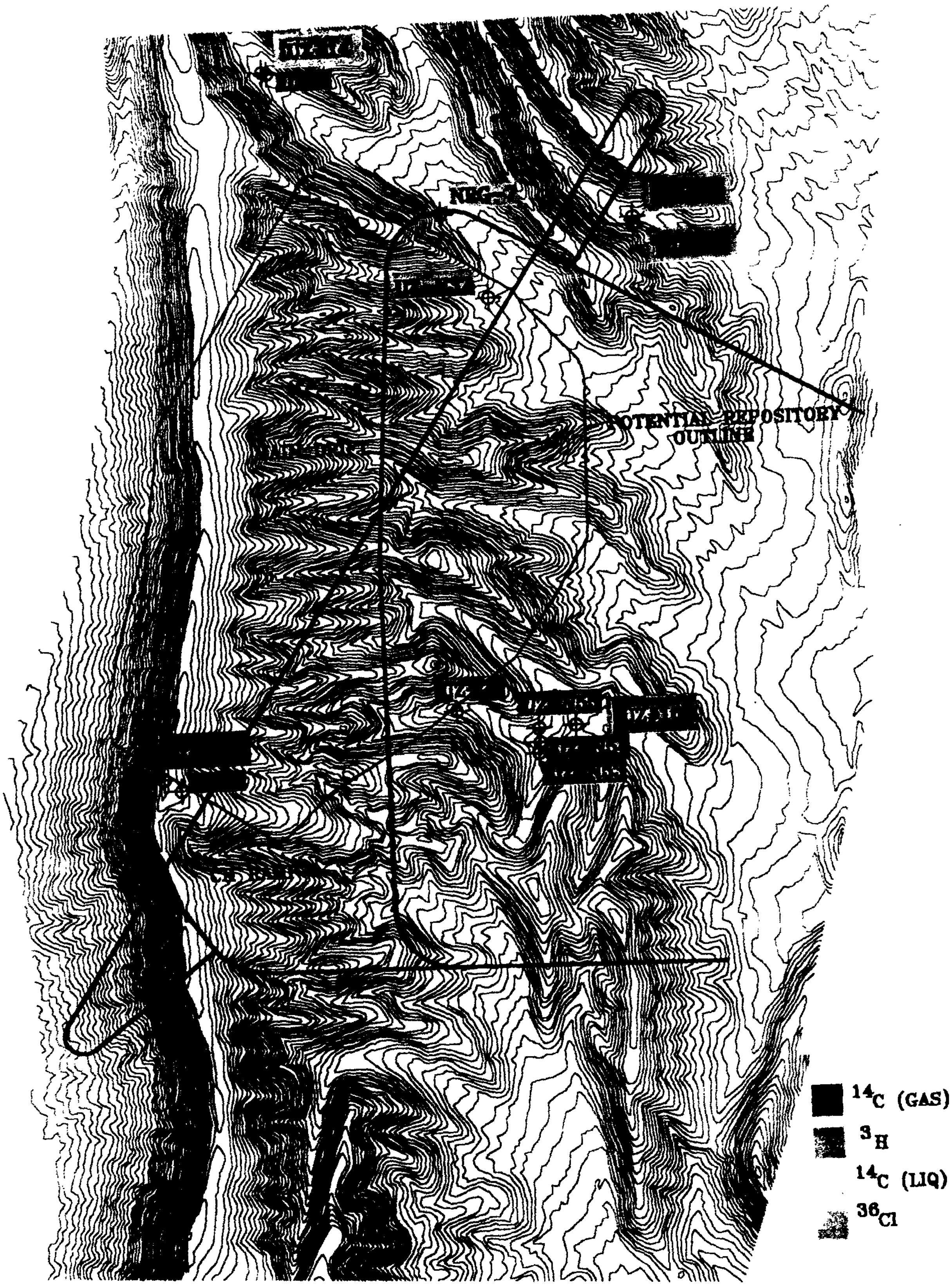
Radionuclide	**Half-life (yr)**	**Theoretical dating range**
Tritium	12.3	Bomb-pulse
Carbon-14	5730	Bomb-pulse 0.5 to 40 ky
Chlorine-36	301,000	Bomb-pulse 50 to 1000 ky

DATA USERS

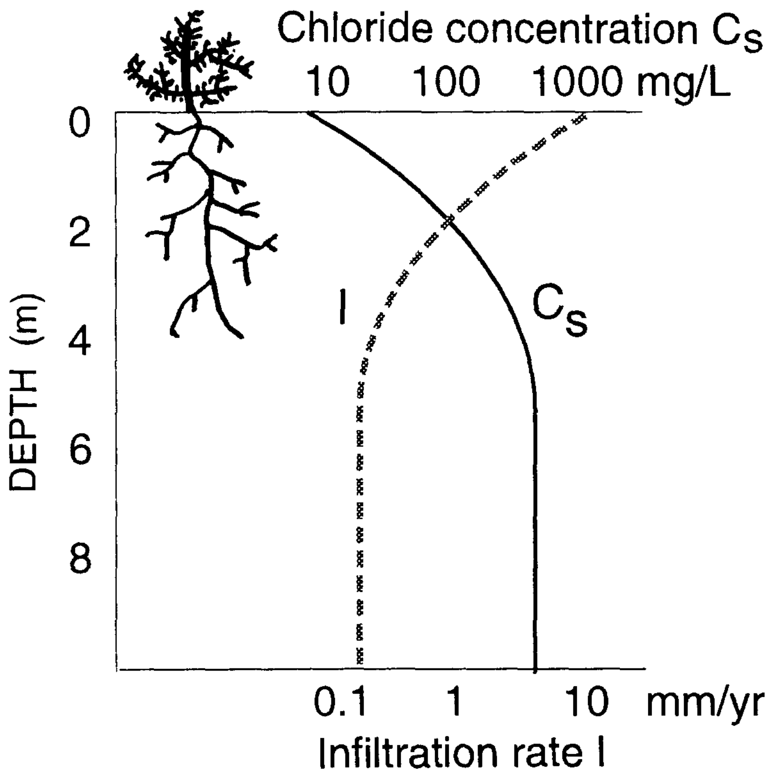
- Hydrologic flow modelers (LBL, SNL, USGS)
  - to validate or calibrate models
  - to evaluate boundary conditions
  - to provide corroborative information for calculations

- Solute transport modelers (LANL, SNL)

BOREHOLES WITH AVAILABLE ISOTOPIC DATA



FLUX ESTIMATES BASED ON CHLORIDE MASS BALANCE METHOD



$$I = \frac{P\ C_0}{C_s}$$

I = infiltration rate, mm/yr
P = average annual precipitation, 170 mm/yr
C_0 = average Cl concentration in precipitation (wet + dry fallout), 0.62 mg/L
C_s = average Cl concentration in porewater

ASSUMPTIONS

- 1-dimensional, downward piston flow (i.e., matrix flow)
- Constant annual precipitation rate
- No run-on or runoff
- Constant rate of chloride deposition
- No chloride source other than precipitation (e.g., no Cl release from rock weathering)
- No chloride sink

RESULTS OF CHLORIDE MASS BALANCE CALCULATIONS

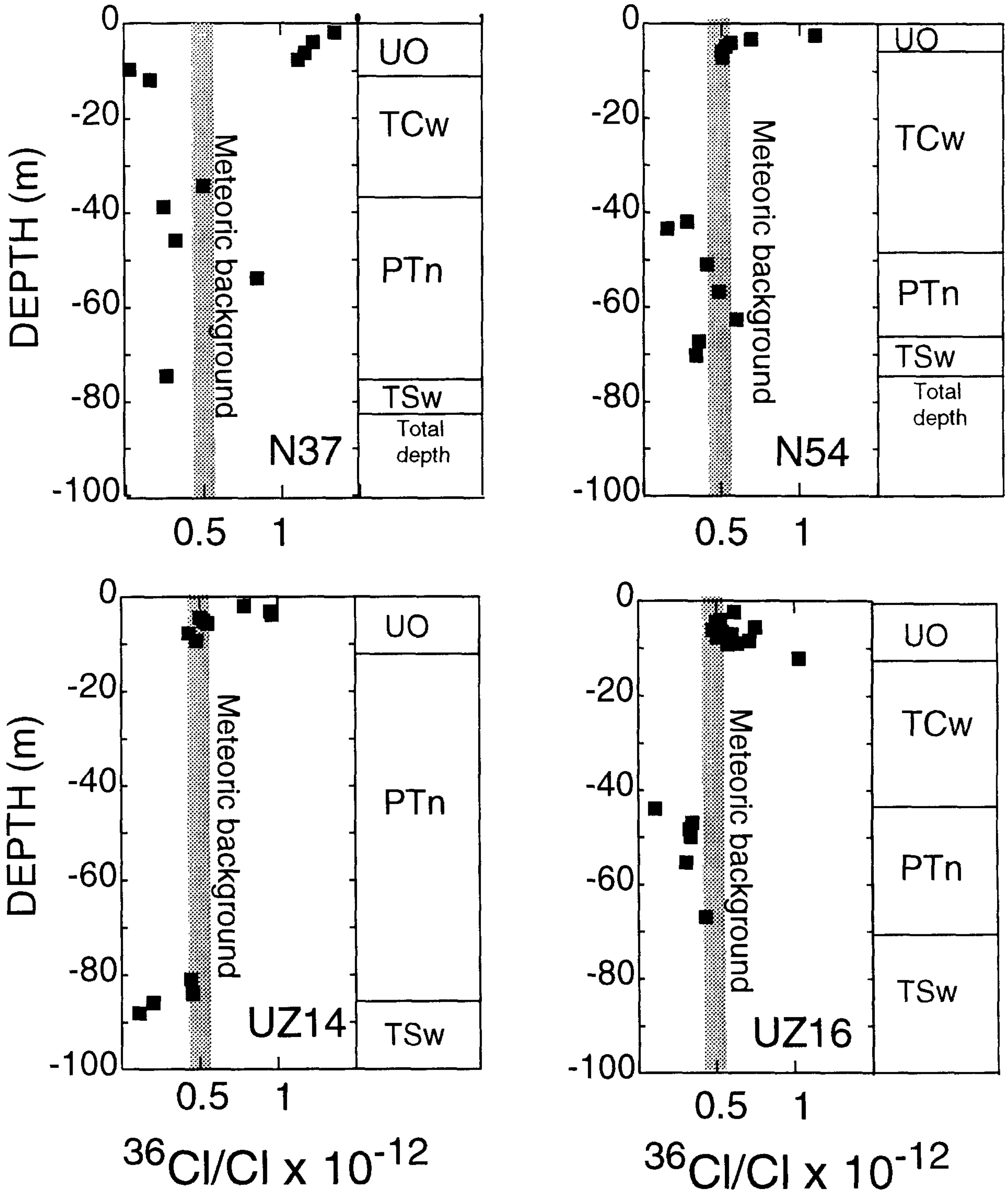
Unit	Borehole	Depth interval, m	Average porewater Cl, mg/L (Note 1)	# of samples	Apparent flux, mm/yr (Note 2)
Alluvium	UZ-N37	0 - 13	220	14	0.5
	UZ-N54	0 - 8	5700	6	0.02
	UZ-16	0 - 7	5150	14	0.02
PTn	UZ-16	50 - 55	35	2	3.0
	UZ-14	44 - 75	87	5	1.2
	UZ-4	91 - 96	94	6	1.1
	UZ-5	29 - 36	42	8	2.5
	UZ-5	94 - 97	76	3	1.4
CHn	UZ-16	368 - 440	30	9	3.5
	UZ-14	470 - 477	18	2	5.9

PTn - Paintbrush nonwelded unit; TSw - Topopah Spring welded tuff; CHn - Calico Hills nonwelded unit

Note 1: Cl concentrations for alluvial samples calculated from average moisture content (L. Flint, pers. commun.) and amount of leachable Cl in samples. Cl concentrations of porewaters extracted from tuff units reported by I.C. Yang (1988, 1990, pers. commun.)

Note 2: Compare fluxes to maximum possible matrix flux for overlying units: TCcr 3.4 mm/yr, TCmw 122 mm/yr, TCw 0.9 mm/yr, PTn 16 m/yr, TSw 1.9 mm/yr (Flint and Flint, 1994)

^{36}Cl/Cl PROFILES FOR BOREHOLES IN CHANNELS AND TERRACES



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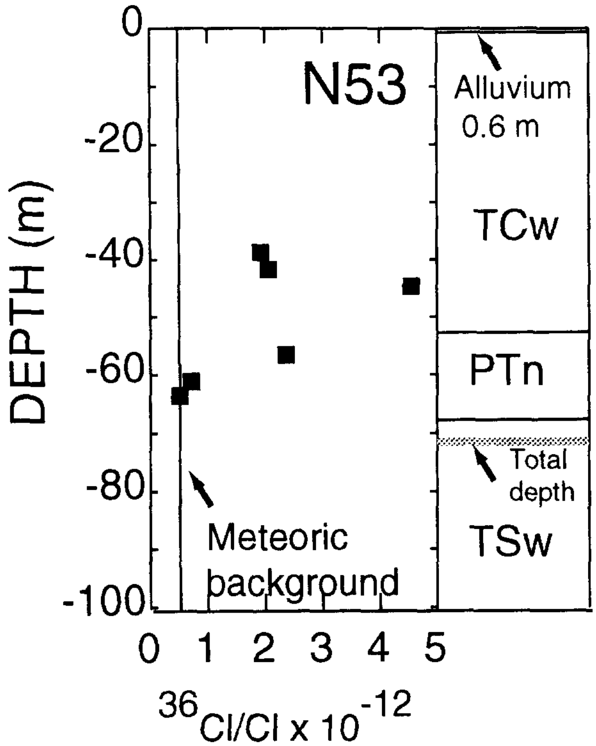
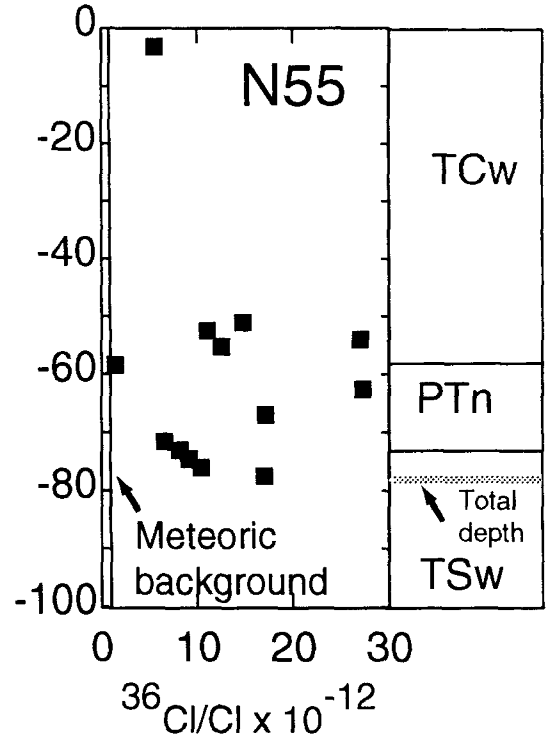
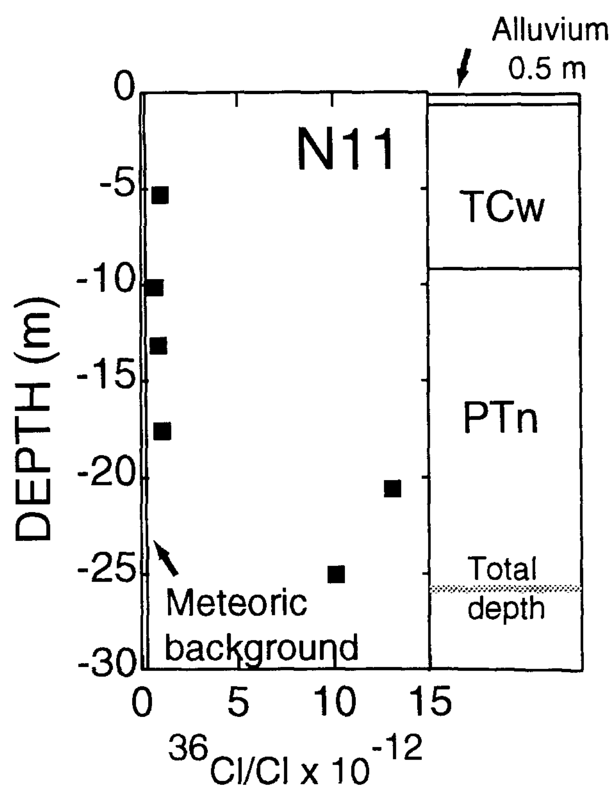
^{36}Cl/Cl PROFILES FOR BOREHOLES ON SIDESLOPES AND RIDGETOP







OBSERVATION:
Bomb-pulse 36Cl in PTn under sideslopes and ridgetop, but not under thick alluvium

CONCLUSION:
Initiation of fracture flow is most likely where alluvial cover is thin or absent

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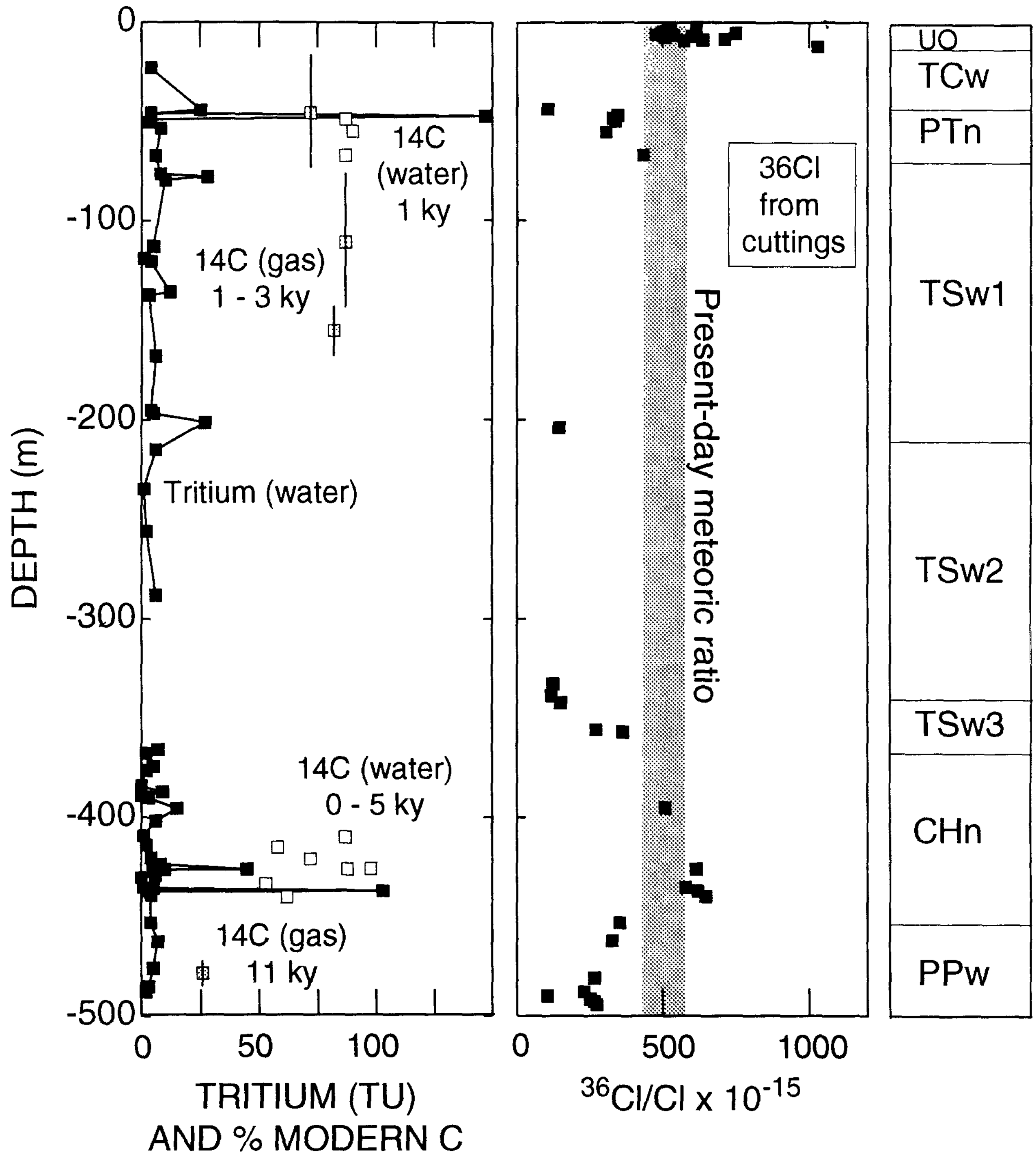
PROFILES OF ^{3}H, ^{14}C, AND ^{36}Cl IN UZ-16



Detection limits: 4 TU, 1 % modern C, $^{36}Cl/Cl$ ratio 1 x 10^{-15}

Data source: 3H, 14C (USGS/Yang); 36Cl (LANL/Fabryka-Martin)

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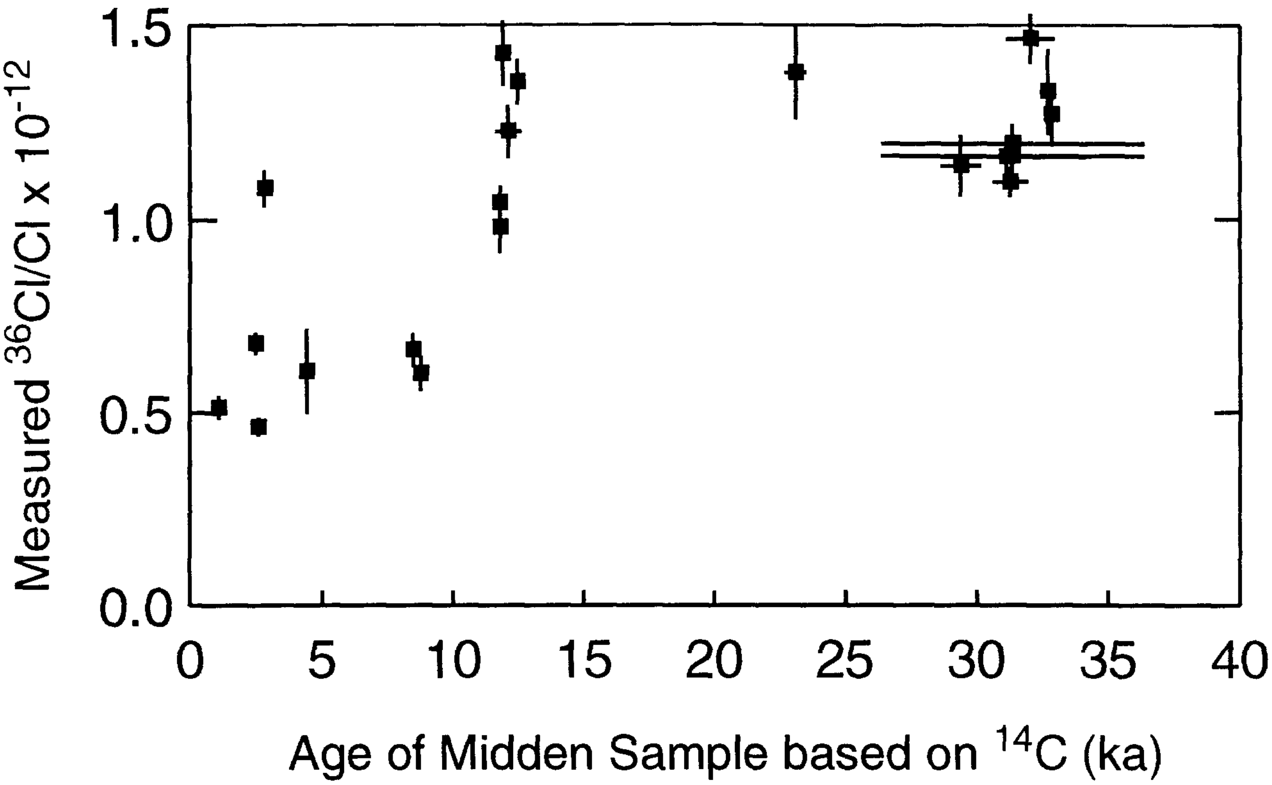
EVIDENCE FOR VARIATIONS IN THE METEORIC $^{36}Cl/Cl$ RATIO

Packrat midden samples from Pyramid Lake, Nevada



Source: Mitch Plummer, M.S. thesis (in preparation), New Mexico Tech, Socorro NM

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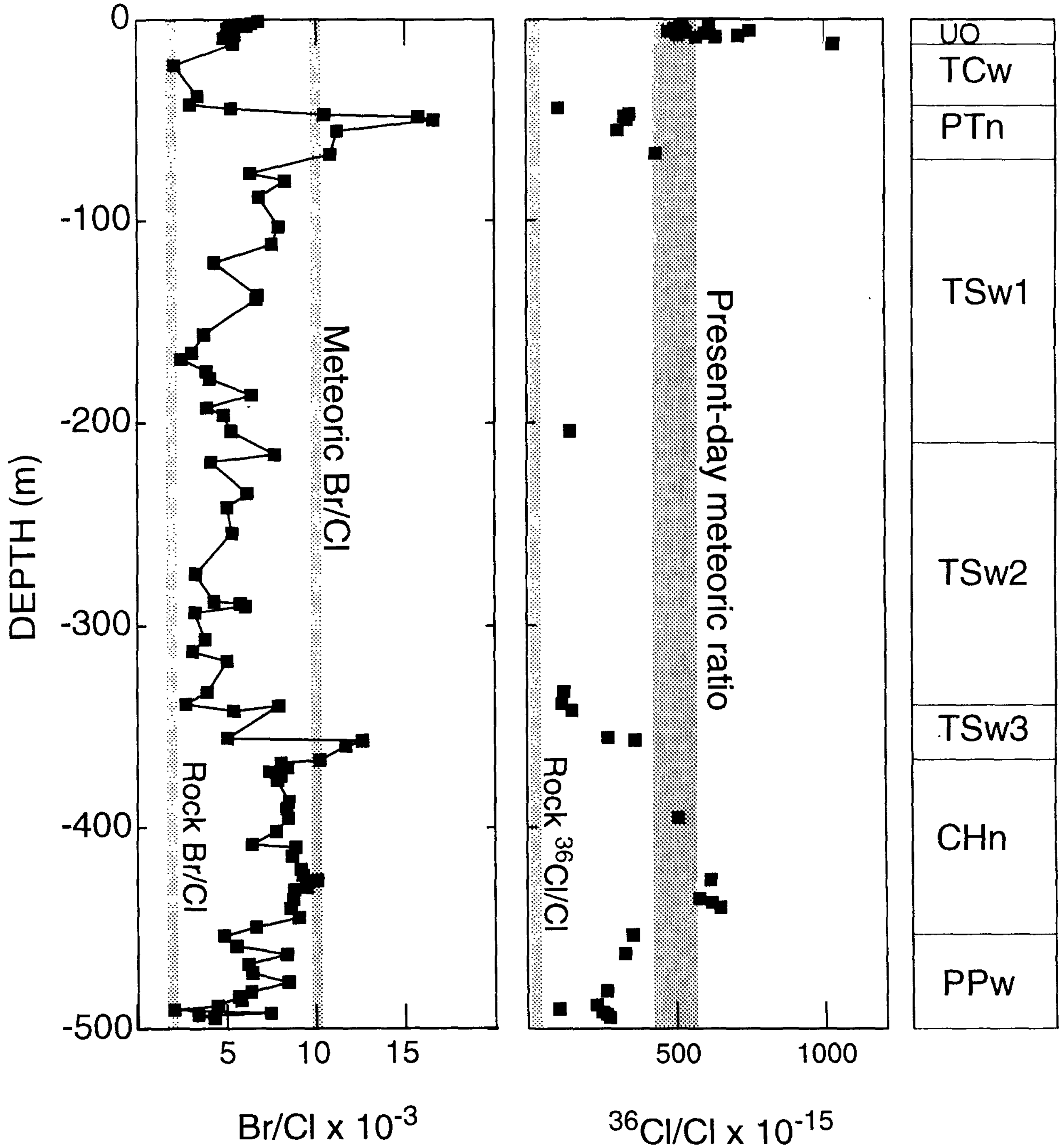
$^{36}Cl/Cl$ and Br/Cl ratios for halides leached from UZ-16 cuttings



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UZ ISOTOPIC DATA : INTERPRETATION #1

Hypothesis:

- Fracture flow transmits bomb-pulse nuclides below Paintbrush nonwelded (PTn) unit under some conditions
- Young water ($\leq$ 11 ky) throughout unsaturated zone
- Calico Hills nonwelded (CHn) unit contains a significant component of bomb-pulse water

Arguments in favor:

Accounts for elevated 3H, 14C and 36Cl in CHn

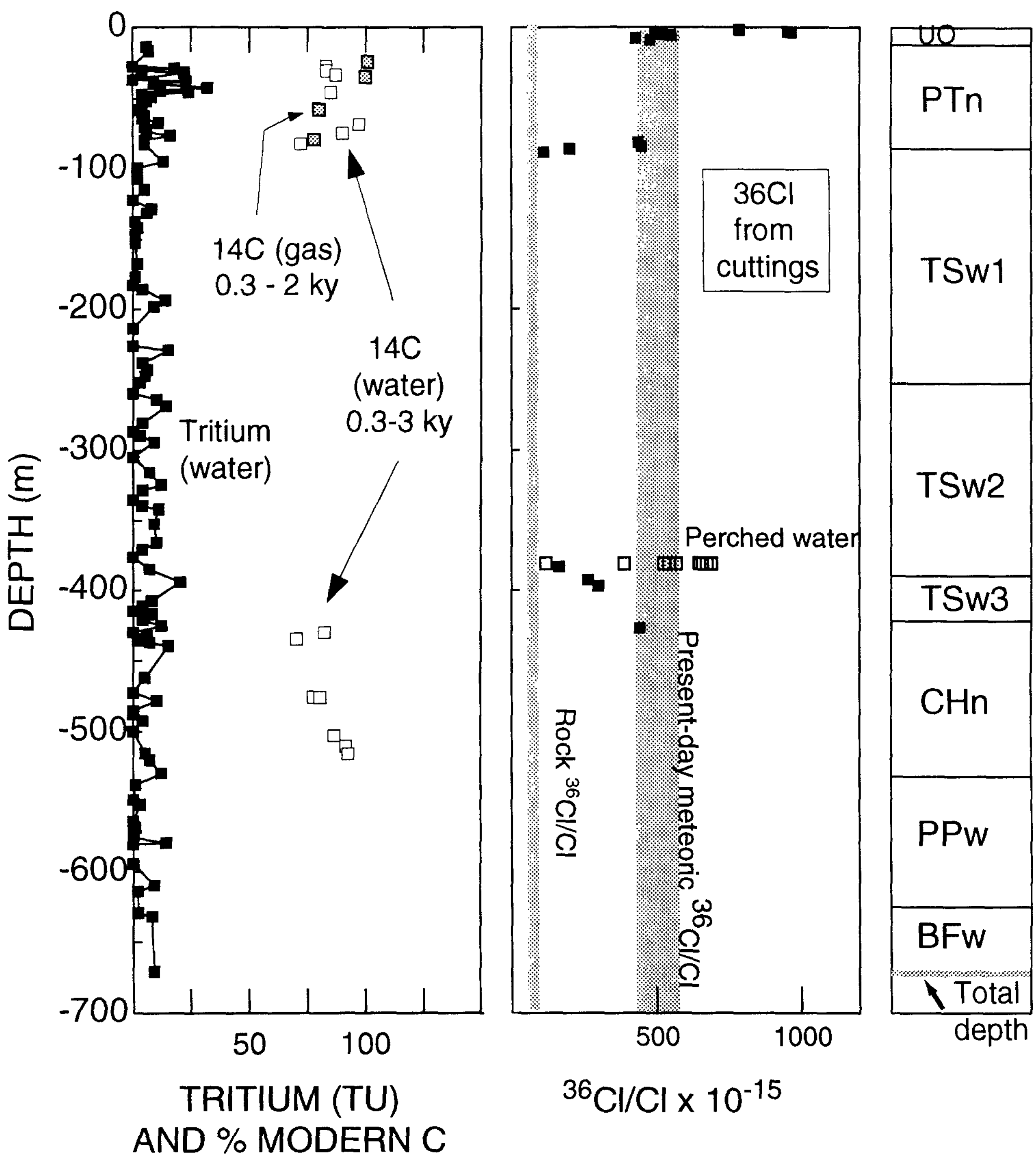
Arguments against:

Unlikely to have a continuous pathway from surface extending to Calico Hills unit because Paintbrush nonwelded unit has low fracture density

Requires precipitation capable of initiating fracture flow during peak years for global fallout. However, these years were drier than average.

Implies negligible interaction between fracture and matrix fluids

PROFILES OF ^{3}H, ^{14}C, AND ^{36}Cl IN UZ-14



Detection limits: 4 TU, 1 % modern C, $^{36}Cl/Cl$ ratio 1×10^{-15}

Data source: 3H, 14C (USGS/Yang); 36Cl (LANL/Fabryka-Martin)

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UZ ISOTOPIC DATA : INTERPRETATION #2

Hypothesis:

- Bomb-pulse water reaches Paintbrush nonwelded (PTn) unit in some locations, but PTn is a barrier to additional downward fracture flow
- Water in Topopah Spring welded (TSw) unit may be > 50 ky
- High vapor flux through fractures driven by temperature and pressure gradients in the unsaturated zone
- Water in Calico Hills (CHn) unit is younger than that in overlying TSw, but does not contain any bomb pulse
- Elevated radionuclide concentrations are due to:
  - higher meteoric 36Cl/Cl values in the past
  - isotopic exchange of porewater CO2 with CO2 in the gas phase
- 14C in gas and liquid phases above the water table are maintained in equilibrium with 14C in the saturated zone

CONCLUSIONS

FLOW PROCESS	PRIMARY EVIDENCE
Low infiltration fluxes through thick alluvium and soil cover	High Cl concentrations and limited depth of 36Cl bomb pulse in alluvium, neutron logging
Fracture flow into PTn through TCw occurs under some conditions	Bomb 36Cl and 3H, low Cl concentrations, Br/Cl ratios, neutron logging, field observations
Fast flow path into CHn at UZ-16 (fracture or lateral flow)	Bomb 3H, elevated 36Cl, young 14C, low Cl concentrations
Age reversals: Younger water in nonwelded units underlying older water in welded units	36Cl in UZ-16
Complex flow system, with multiple flow paths	Highly variable radiometric and geochemical signals

UZ ISOTOPIC DATA : INTERPRETATION #2
(continued)

Arguments in favor:
Accounts for elevated 14C and 36Cl in CHn
Consistent with expectations about gas/liquid isotopic exchange
Does not require continuous fracture pathway from surface
Qualitatively consistent with predictions of flow models

Arguments against:
Does not account for high 3H value in CHn
No strong field evidence supporting C isotopic equilibrium for gas and liquid phases in unsaturated zone at Yucca Mountain

LESSONS LEARNED

1. Disconcordances among travel times indicated by ^{36}Cl, ^{14}C and tritium are inevitable.

2. Multiple radionuclides, in combination with porewater geochemistry, are needed for constraining conceptual flow hypotheses for the site.

3. For application of radiometric age indicators in model validation, one cannot separate hydrologic flow and solute transport aspects. Physical and geochemical processes control the transport rate of even conservative tracers.

4. No site model will be able to reconstruct all radiometric signals, if for no other reason than differences in spatial scales for modeling and measurements.