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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: **ALTERATION HISTORY OF YUCCA MOUNTAIN DUE TO THERMAL EFFECTS: ANALOGUE FOR A HOT REPOSITORY?**

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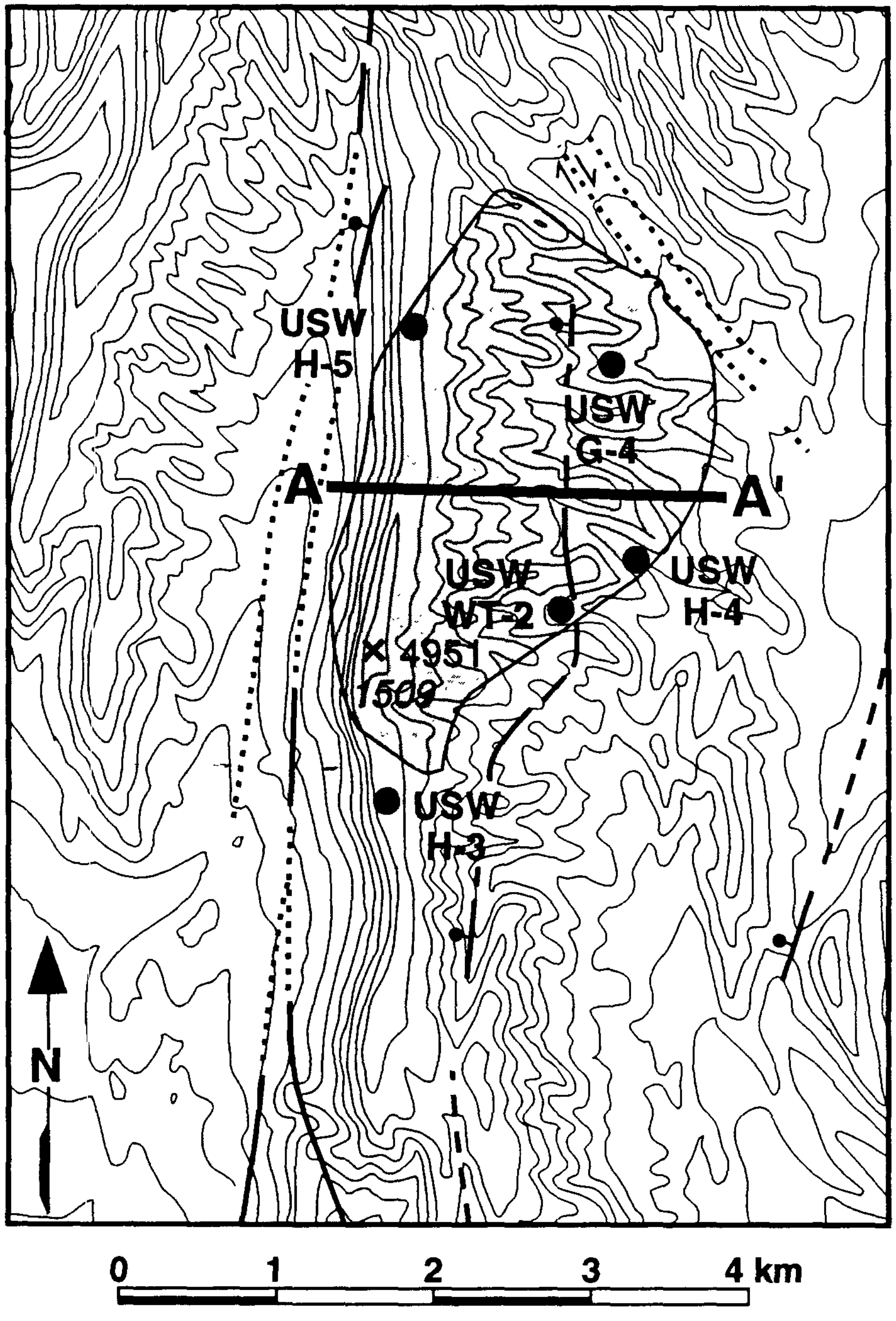
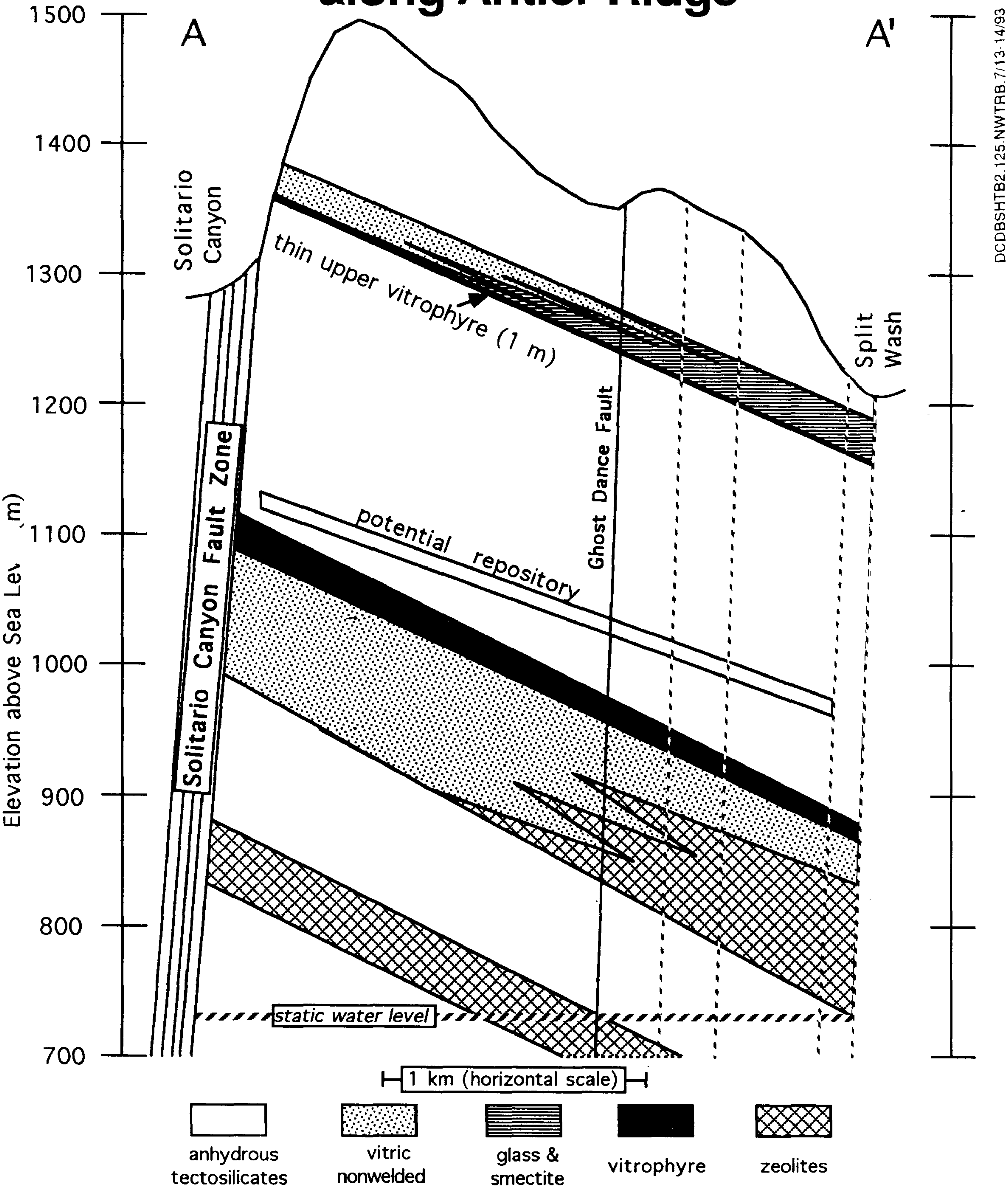
Cross-Section A-A' along Antler Ridge at Yucca Mountain, Nevada

DCDBSHTB1.125.NWTRB.7/13-14/93



CONTOUR INTERVAL = 100 FT *(30.5M)*

Cross-Section of Yucca Mountain along Antler Ridge



(5x vertical exaggeration)

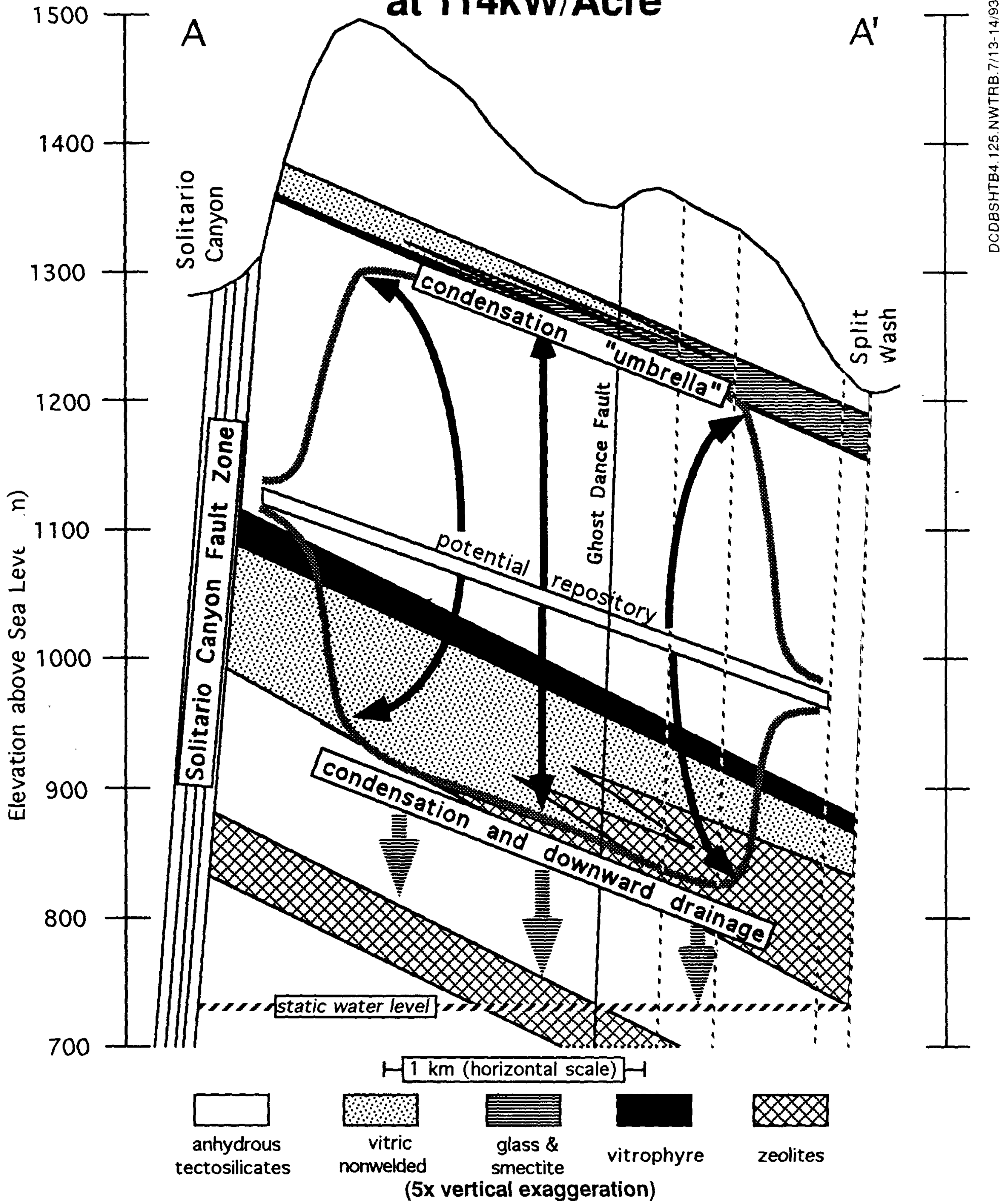
Mineralogical Alteration

- Goal is to predict the effects of repository-induced temperature and P(H_2O) changes on the current mineral assemblages

  - Potential alteration, dissolution-precipitation reactions:
    - -- Glass → zeolite/smectite/silica assemblage
    - -- Clinoptilolite → analcime, alkali feldspar
    - -- Mordenite → analcime
    - -- Silica dissolution/precipitation

  - Potential hydrologic effects:
    - -- Decrease in permeability in vitric, vitrophyre horizons
    - -- Increase in permeability in zeolitic horizons
    - -- Change in nature of water storage capacity

Cross-Section of Yucca Mountain along Antler Ridge Showing the Maximum Dry-out Zone at 114kW/Acre



Information Desired from a Natural Analogue

- Long-term behavior of rocks and minerals in a repository environment
  - Difficult to obtain in lab (low temperatures and long reaction times)

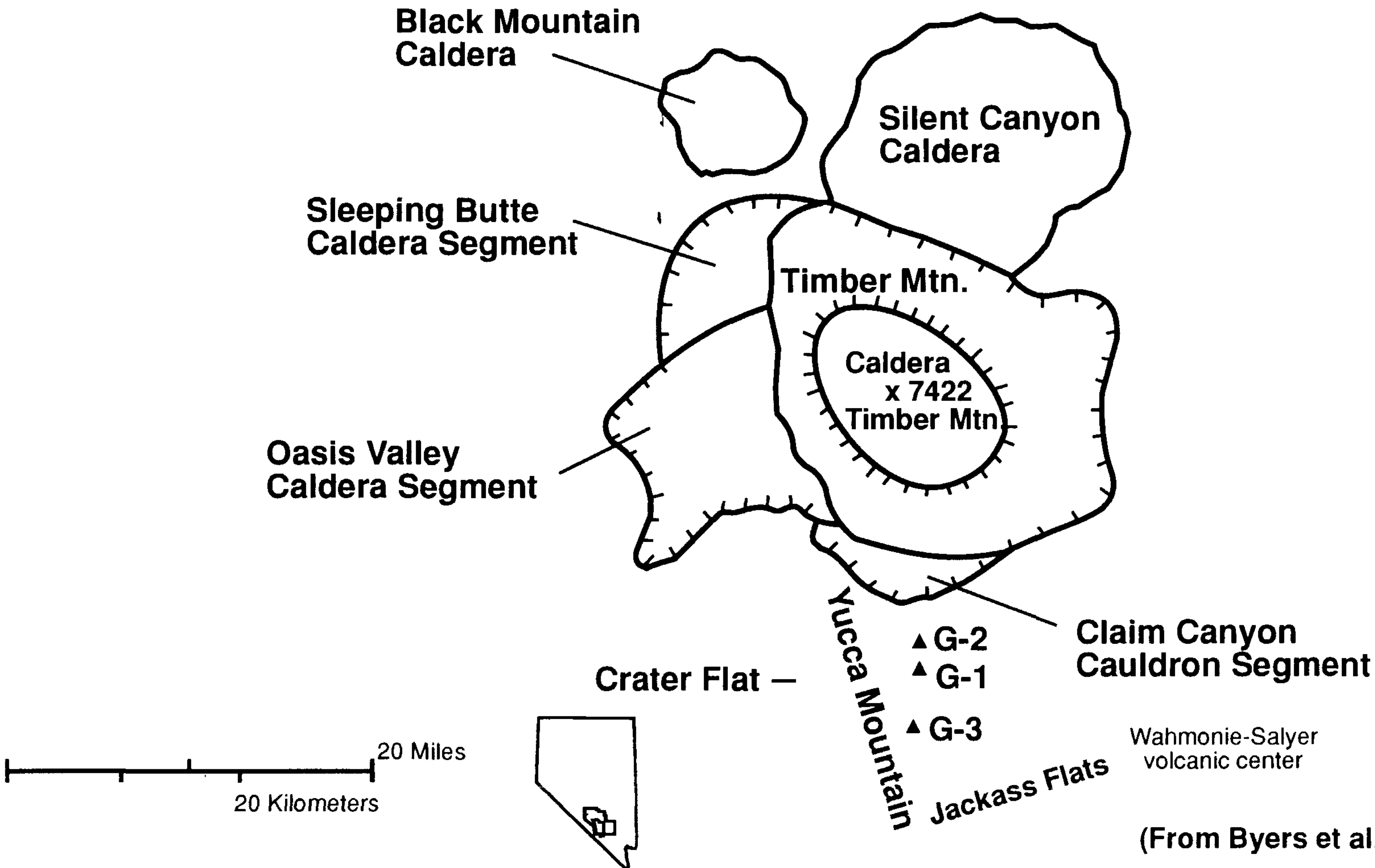
Difficulties with Natural Analogues

- Defining past conditions
- Locating representative conditions
- Identifying representative mineral assemblages
- Yucca Mountain not presently an active system; water amounts and concentrations during alteration unknown

Yucca Mountain as a Natural Analogue to Repository-Induced Alteration

1. Hydrothermal system in northern Yucca Mountain
   - Illite/smectite, fluid-inclusion geothermometers
   - Determine apparent long-term mineral stabilities
2. Topopah Spring vitrophyre alteration
   - Dynamic alteration, concentrated around fractures
   - State of saturation uncertain, spatially variable
3. Vitric-zeolitic transition in the Calico Hills Formation

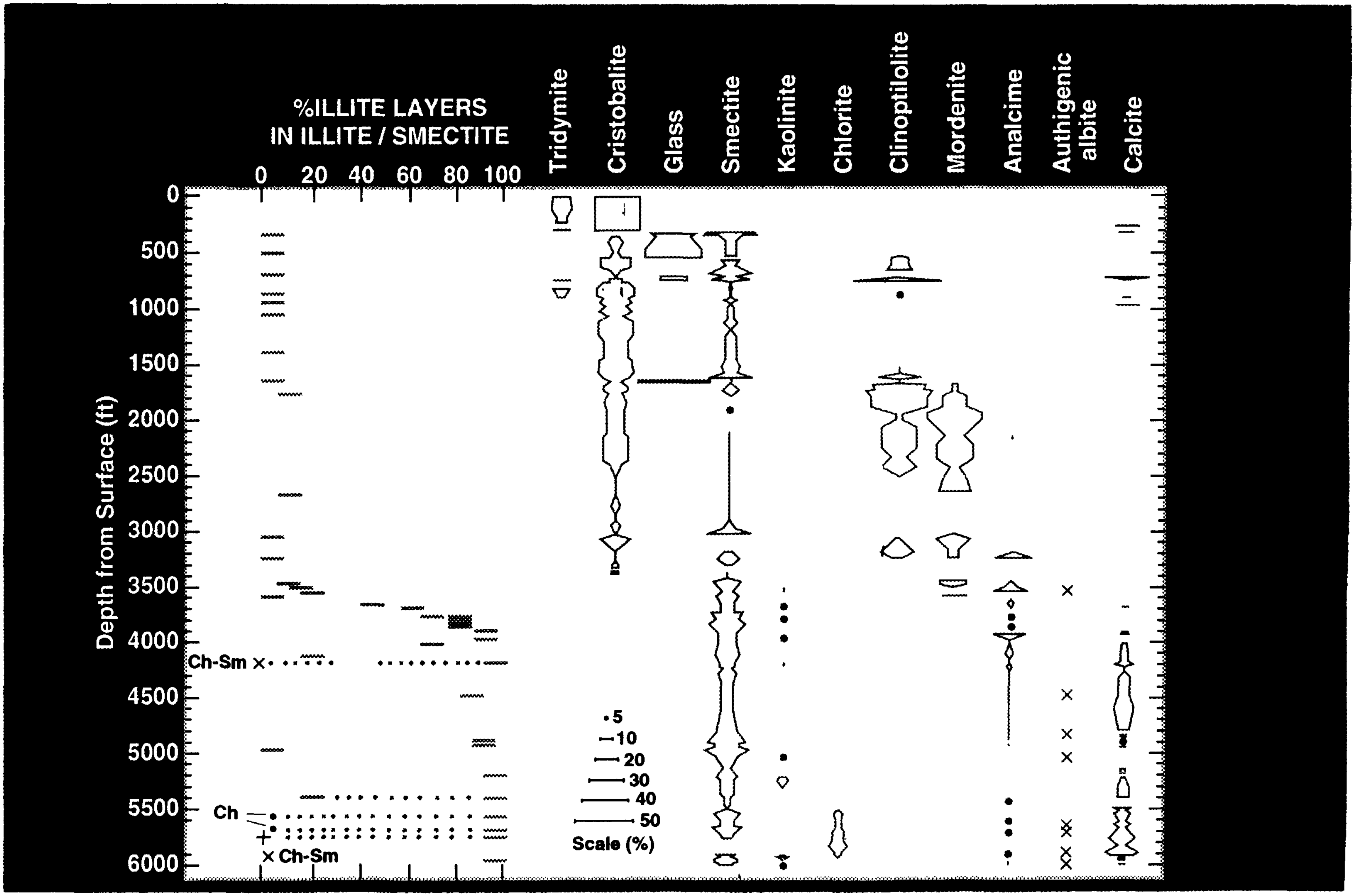
Southwestern Nevada Volcanic Field, Nye County, Nevada



(From Byers et al. 1976)

Note:
Heavy lines with hatchure marks to the inside represent the approximate outer limit of the Timber Mountain-Oasis Valley Caldera complex, including the Sleeping Butte and Claim Canyon segments (dashed where indefinite). Heavy lines with hatchure marks to the outside represent the periphery of the Timber Mountain resurgent dome. Drill cores USW G-1, G-2, G-3 are shown.

Mineral Distribution in Drill Hole USW G-2 from X-Ray Powder Diffraction Data



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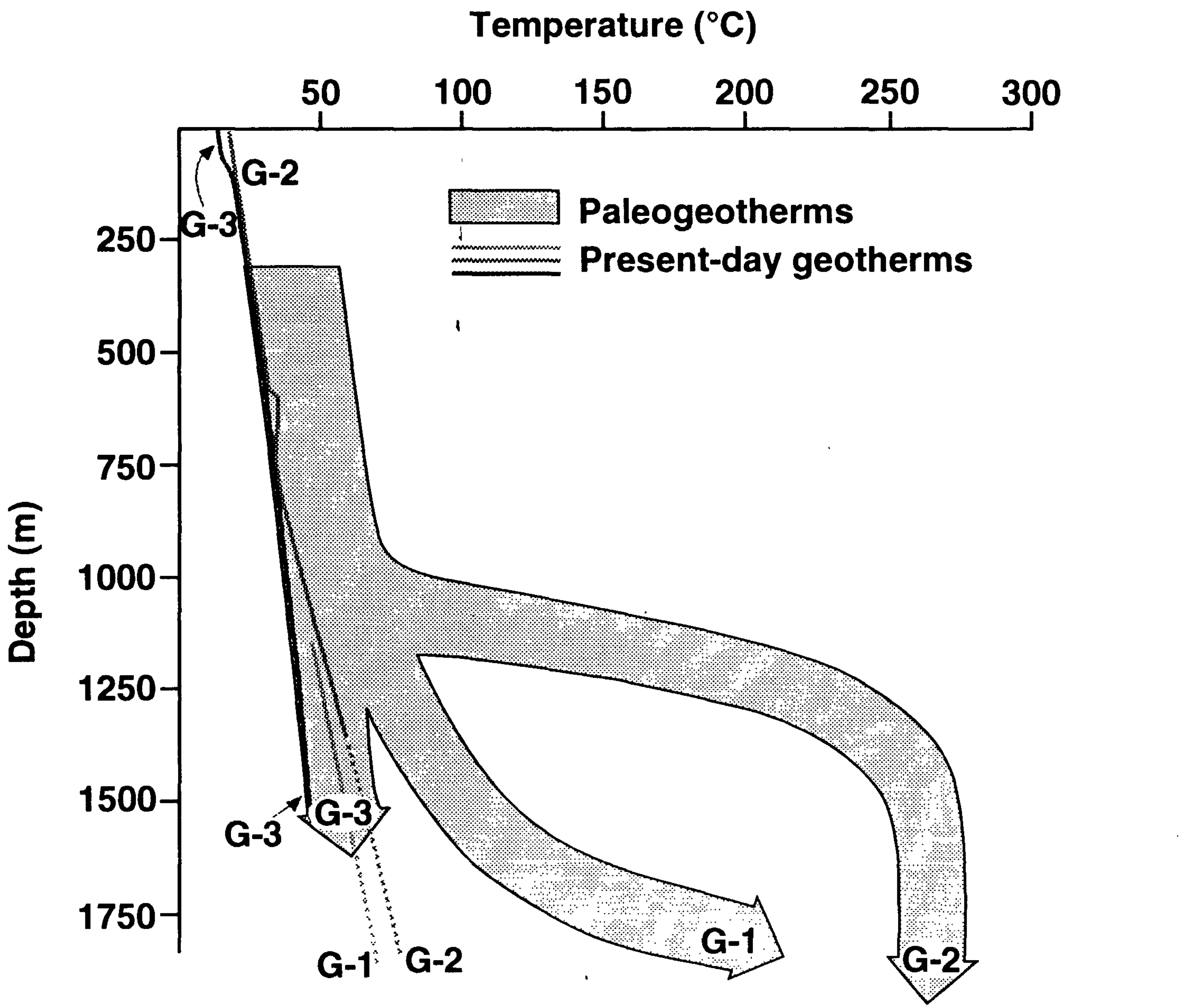
Geothermal Gradients in USW G-1, G-2, and G-3



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Northern Yucca Mountain Hydrothermal System

- **A hydrothermal system existed beneath the north end of Yucca Mountain ~10.7 Ma, £1Myr duration**

- **Paleogeothermal profiles are consistent with a change from a meteorically cooled zone to a convective zone, with depth**

- **Apparent long-term (saturated) thermal stabilities of minerals in Yucca Mountain tuffs:**
  - Clinoptilolite ~100°C
  - Mordenite ~130°C
  - Analcime 175-200°C
  - Cristobalite 90-100°C in G-2, lower in G-3
  - Reactions in G-3 appear to be water-chemistry dominated

Importance of Mineralogical Alteration

- **Transformation of clinoptilolite to analcime**
  - reaction times and temperatures?

2.67 clinoptilolite $\rightarrow$ 1 analcime + 1 quartz + $48H_2O$

Clinoptilolite: $Na_6Al_6Si_{30}O_{72} \bullet 24H_2O$ (V = 2100.0Å^3)

Analcime: $Na_{16}Al_{16}Si_{32}O_{96} \bullet 16H_2O$ (V = 2585.8Å^3)

Quartz: Si_3O_6 (V = 113.01Å^3)

Cristobalite: Si_4O_8 (V = 172.17Å^3)

Volume of reactants = 2.67(2100.0) = 5607.0Å^3

Volume of products = 2585.8 + 16(113.01) = 4393.96Å^3

Volume of products = 4651.8Å^3 w/cristobalite

ΔV = -21.5% (-16.9% w/cristobalite)

- Possible silica mobilization in the reflux zone
- Volume decrease
- H_2O generation
- Loss of sorptive phase

Topopah Spring Vitrophyre

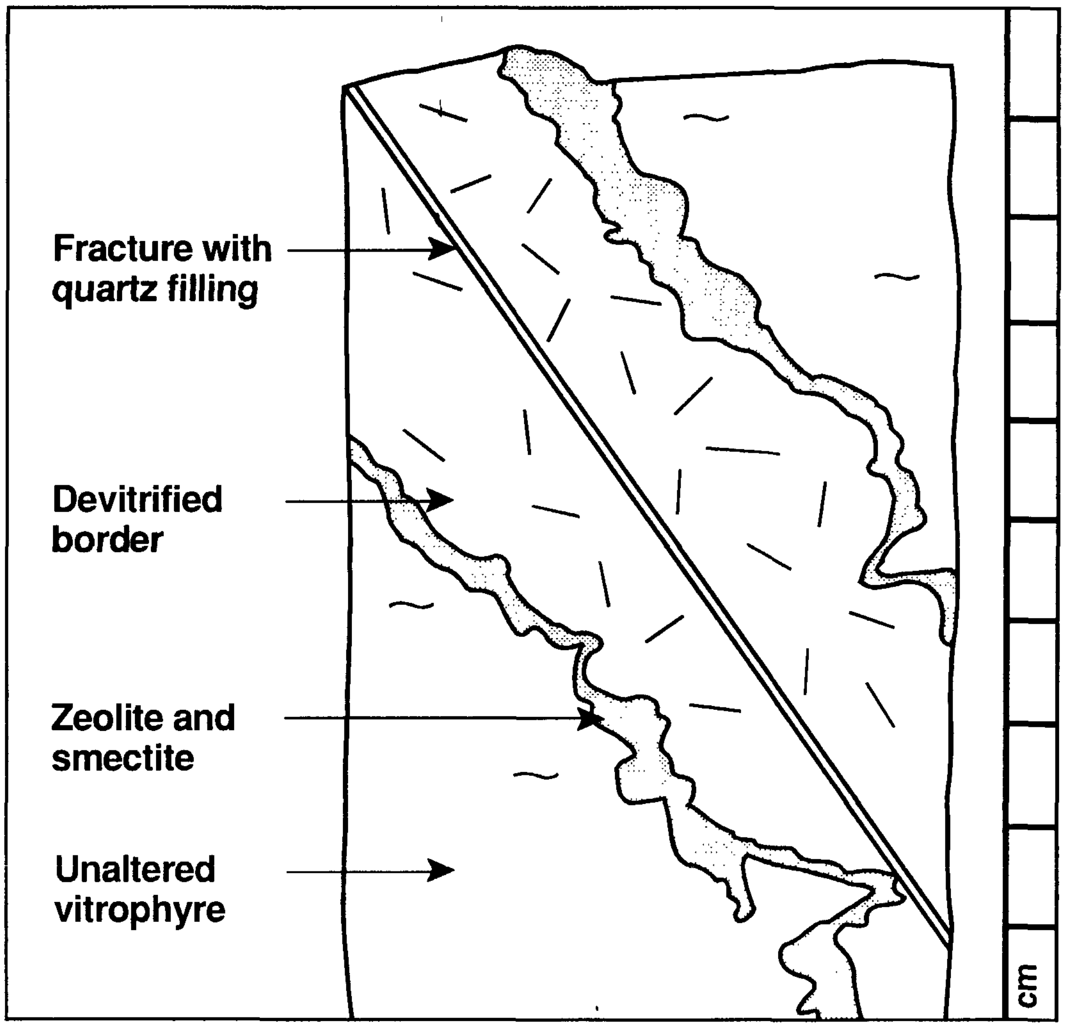
- Transition zone between Topopah Spring devitrified tuff and vitrophyre a potential natural analogue to repository-induced alteration
  - Uncertain saturation; spatially variable

- Alteration dynamic; concentrated around fractures

- Natural alteration assemblage suggests vitrophyre alteration to clinoptilolite, smectite, and silica phases (40-100°C, oxygen isotope geothermometry)

- Suggests that mineral sealing of fractures in vitrophyre may occur

Devitrified Fracture Detail from GU-3, 1195-Ft. (364.2m) Depth



Isotopic Compositions and Temperatures of Secondary Quartz Formation

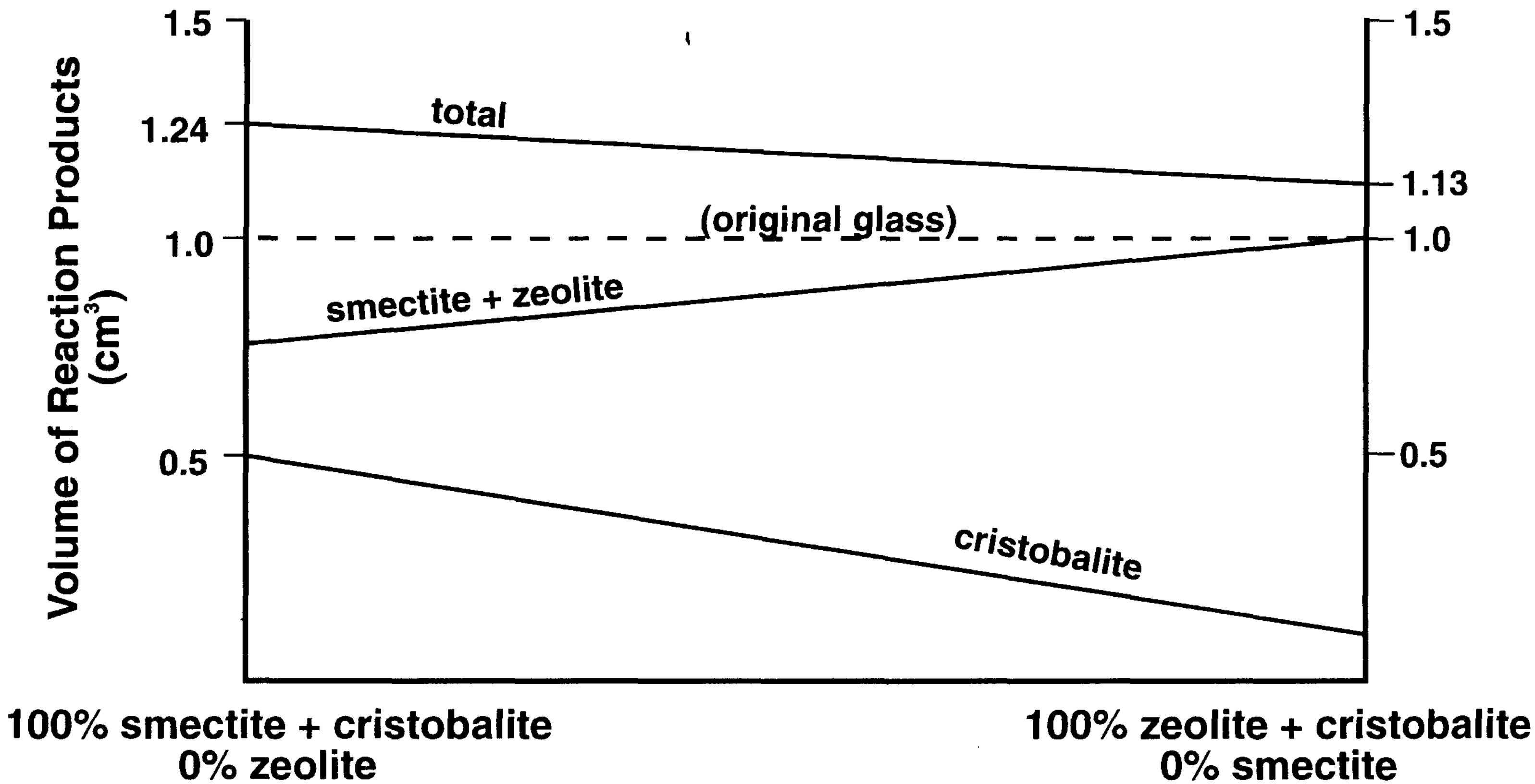
Sample	$\delta^{18}O$ (‰, SMOW)	T_A (°C)	T_B (°C)
VH2-3545-q	13.0	65	95
VH2-3565a	11.9	70	100
YF-4-q	17.8	40	70

T_A Calculated from Clayton & others (1972)
T_B Calculated from Bottinga & Javoy(1973)
$\delta^{18}O$ of -13.5‰ assumed for the water
Analyses reproducible to ±0.1‰
SMOW = standard mean ocean water

Alteration of Vitrophyre Glass

Moles Cation/cm^3

	Glass	Smectite	Heul-Clinopt.	Cristobalite
Si	0.029	0.014	0.024	0.038
Al	0.006	0.008	0.006	0



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Vitric-Zeolitic Transition

- Saturated hydraulic conductivity decreases by 10^2-10^4 going from vitric to zeolitic
- Porosity decreases from ~37% to ~29%
- Water reservoirs:
  - Clinoptilolite tuff
    -- 0.29 g/cm^3 in pores
    -- 0.26 g/cm^3 in clinoptilolite (strongly held)
  - Vitric, nonwelded tuff
    -- 0.37 g/cm^3 in pores
- Vitric tuff in contact with warm condensate may react quickly, depending on degree of saturation

Conclusions

- **Deep alteration system represents a saturated end member**
  - Information on stability of zeolites and silica phases
- **Vitric to zeolitic transition in nonwelded tuffs**
  - Porosity decreases little; storage significantly different
  - Saturated hydraulic conductivity decreased by 10^2-10^4
- **Topopah Spring alteration may be appropriate analogue**
  - Unsaturated zone (?)
  - Geologically short duration
  - Fracture dominated and spatially variable
  - Evidence of glass dissolution and mineral sealing
  - Channeling and concentration of fluids
- **Alteration of fractured, welded rock**
  - Little alteration, but potential silica redistribution in reflux zone
  - Potential changes in permeability and porosity

Future Work

- Kinetics of dissolution/precipitation of silica polymorphs, including opal-CT
- Kinetics of dissolution/precipitation of clinoptilolite, mordenite, and analcime
- Performing coupled transport/chemical reaction modeling
- Reaction of existing phases under partially saturated or steam conditions