Uncertainty Underground: Yucca Mountain and the Nation's High-Level Nuclear Waste

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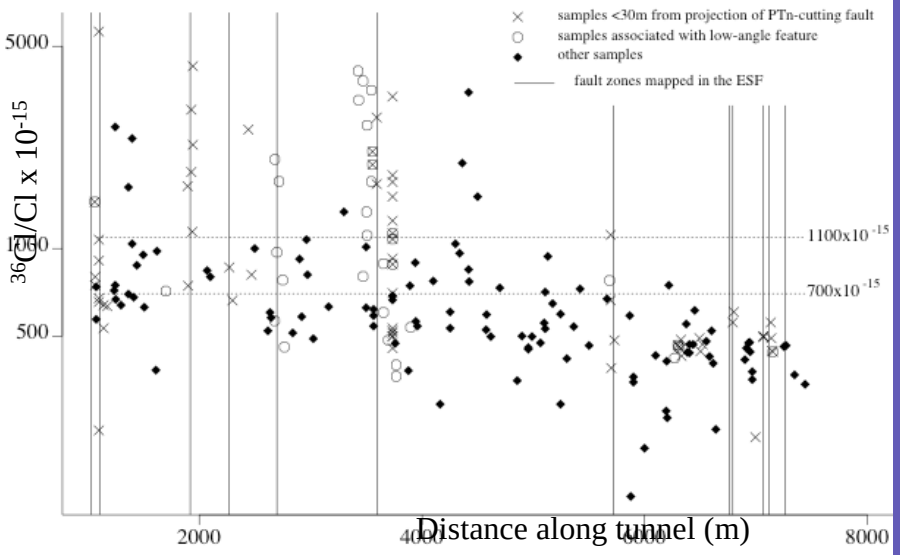
Uncertainty Underground

- Purpose of book
  - rectify lack of geologic input into nuclear waste policy decision-making
  - Shed light on uncertainties in technical issues at Yucca Mt
- Chapter authors
  - Wide variety of views
  - Wide variety of institutions

Surface Infiltration

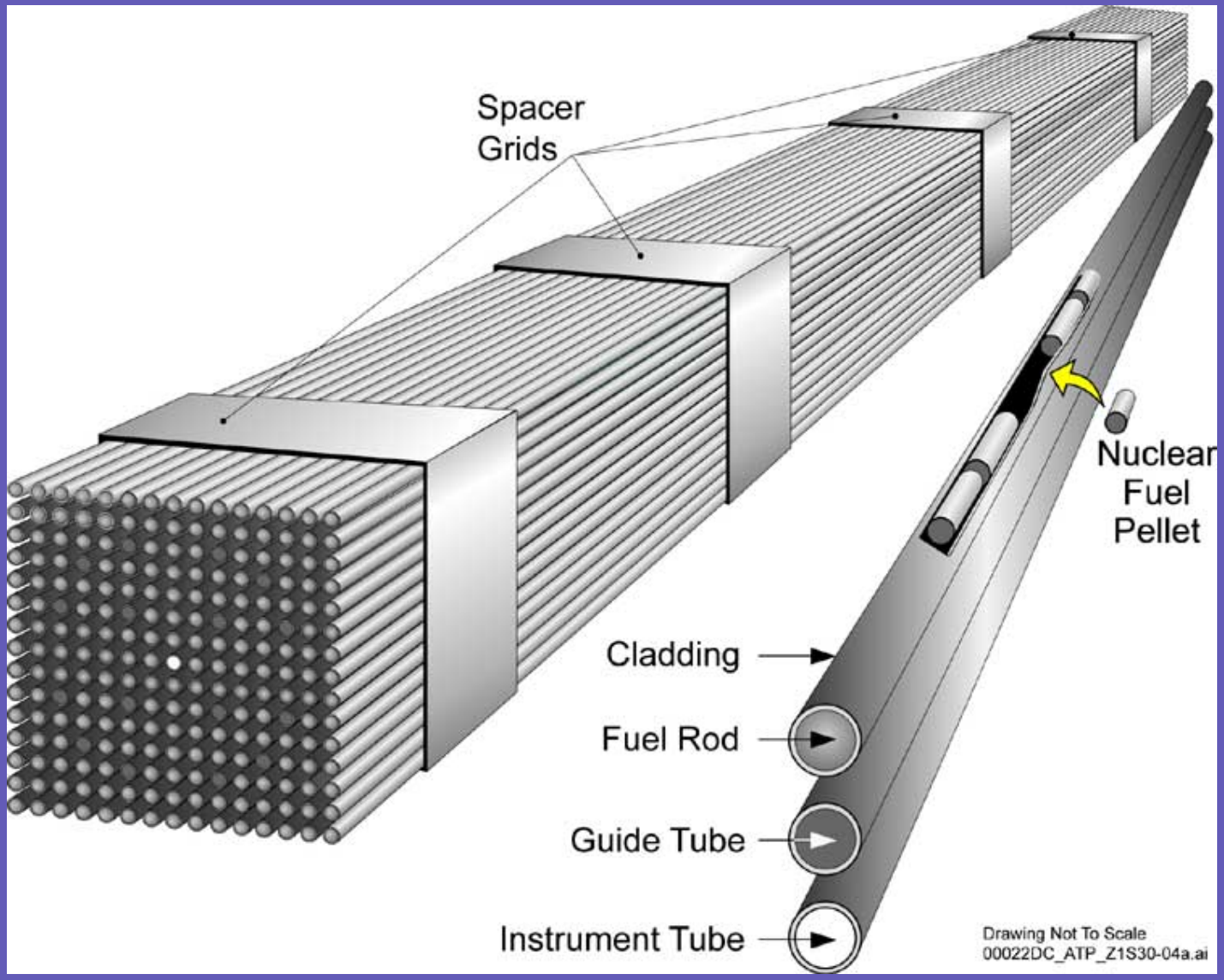
- Assumptions about future infiltration based on predicted climate change at YM
- Looked at last 400,000 years (last 4 interglacial-glacial cycles) to predict wettest conditions to be experienced over the next 10,000 years (up to 5-fold increase in infiltration)
- DOE may be underestimating climate effects:
  - Atmospheric CO_2 levels in Pleistocene: 200 ppm-280 ppm
  - Now: 380 ppm
  - 2100: 500 ppm - 1200 ppm
  - Last time CO2 levels in the 1000's of ppm: 50 Ma (Eocene)
  - Implies a greater than 5-fold increase in infiltration

(a) 36-Cl/Cl ratios and selected structural features



Transport in the Unsaturated Zone

- Initial conceptual model assumed water moved slowly: estimates of infiltration rates changed from <0.5 mm/yr to 4 mm/yr in 1980s
- Current model: mix of fast and slow pathways:
  - 5-10 mm/yr with some locations receiving up to 80 mm/yr
- Change in model largely a result of Cl-36 issue:
  - Normal levels of Cl-36/Cl at Yucca Mtn: 450×10^{-15} - 1200×10^{-15}
  - Around some fractures/faults - much higher levels detected
  - Bomb-pulse Cl-36 - evidence for fast water transport pathways
- Remaining unresolved technical issues:
  - Don’t know how much water is transported along fast pathways or which pathways transport water


Spacer
Grids
Nuclear
Fuel
Pellet
Cladding
Fuel Rod
Guide Tube
Instrument Tube
Drawing Not To Scale
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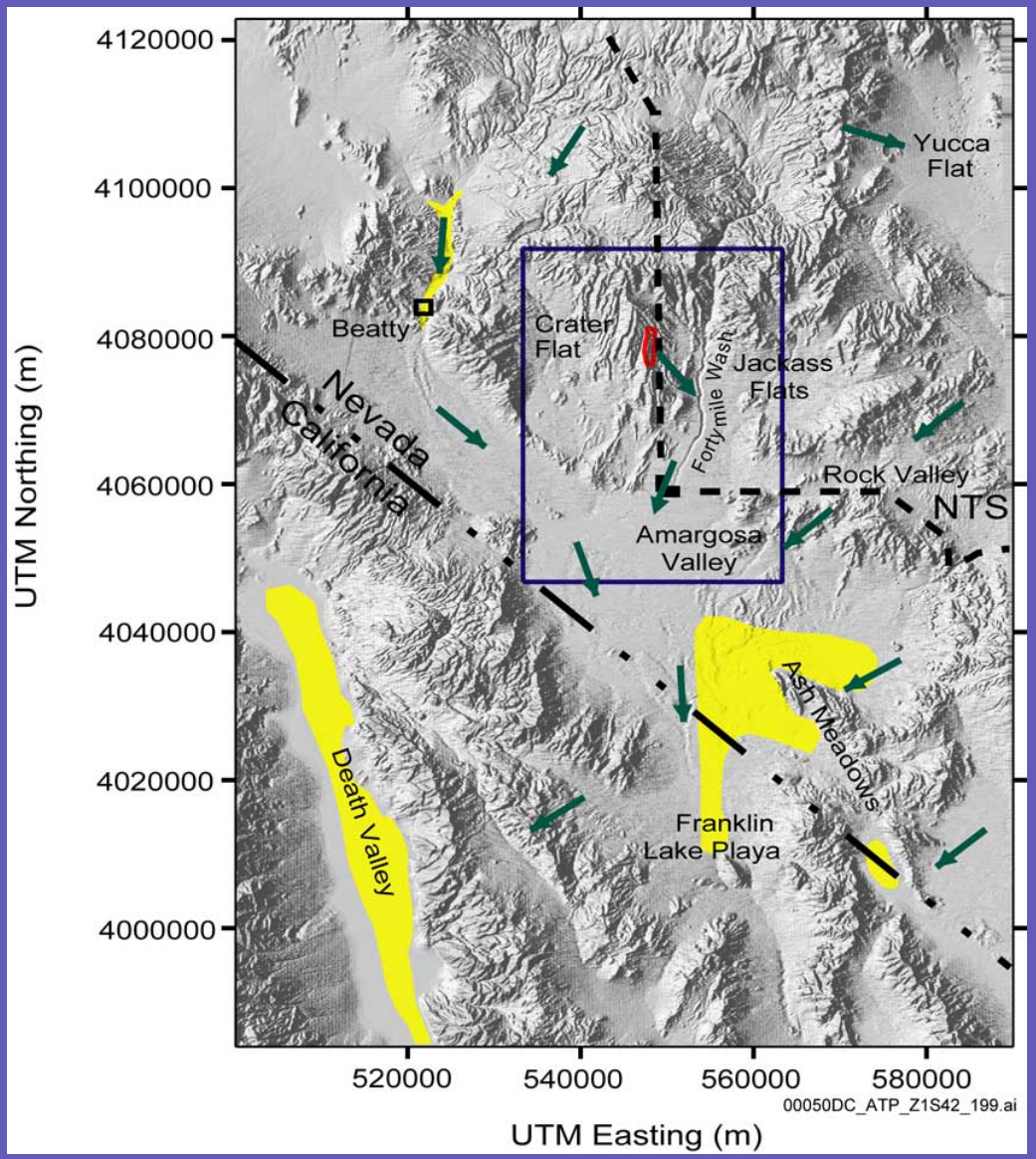
Engineered Barriers: Spent Fuel

- UO_2 not stable under oxidizing conditions + in presence of water
  - Forms UO_2^{6+} - complexes with CO_3^{6+}, HCO^{3-}, SO_3^{6-}, PO_4^{3-}
  - These phases are highly soluble
  - Alteration reactions will occur within 100-1000 years once spent fuel exposed to environment
  - Uncertainty: how alteration products will behave


4120000
4100000
4080000
4060000
4040000
4020000
4000000
UTM Northing (m)
520000
540000
560000
580000
UTM Easting (m)
Yucca Flat
Beatty
Crater Flat
Jackass Flats
Fortymile Wash
Nevada
California
Rock Valley
NTS
Amargosa Valley
Ash Meadows
Death Valley
Franklin Lake Playa
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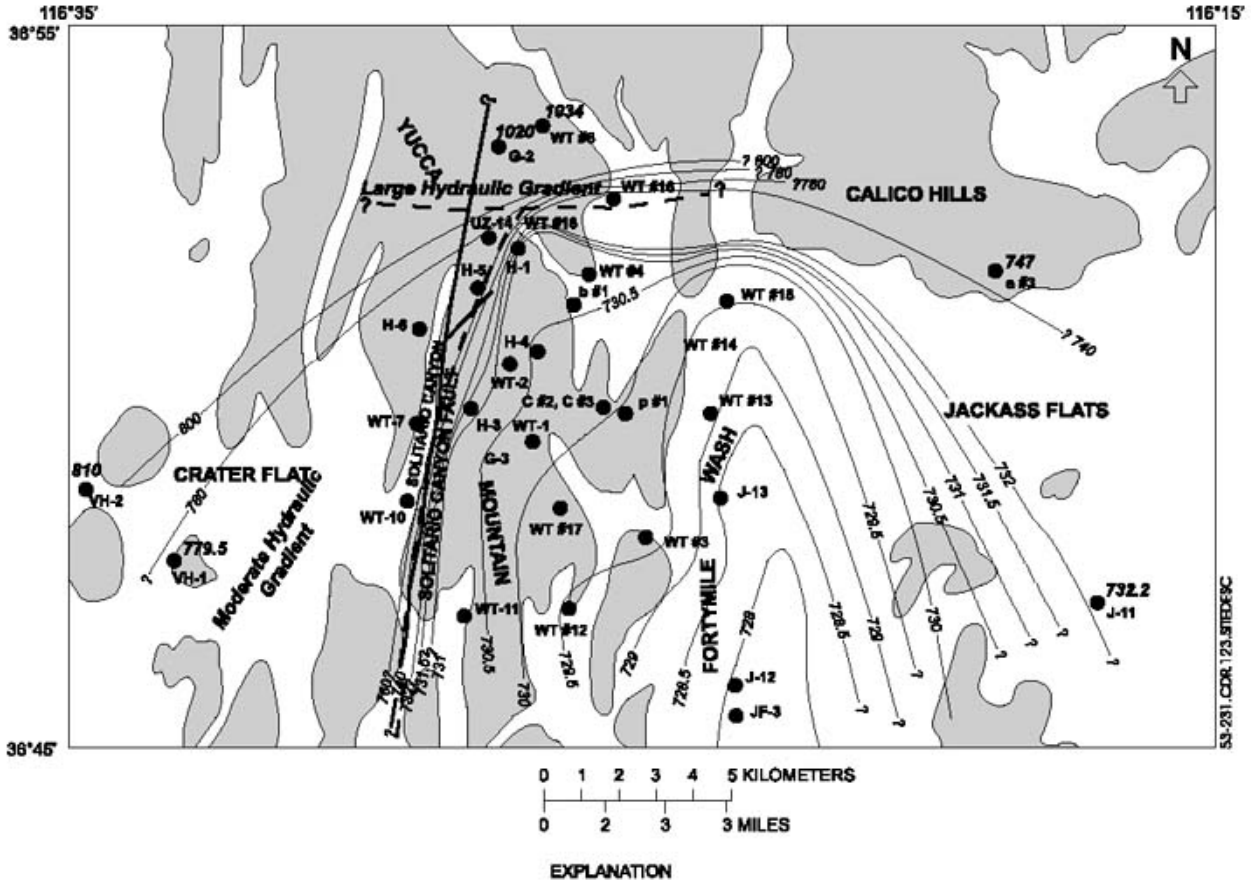
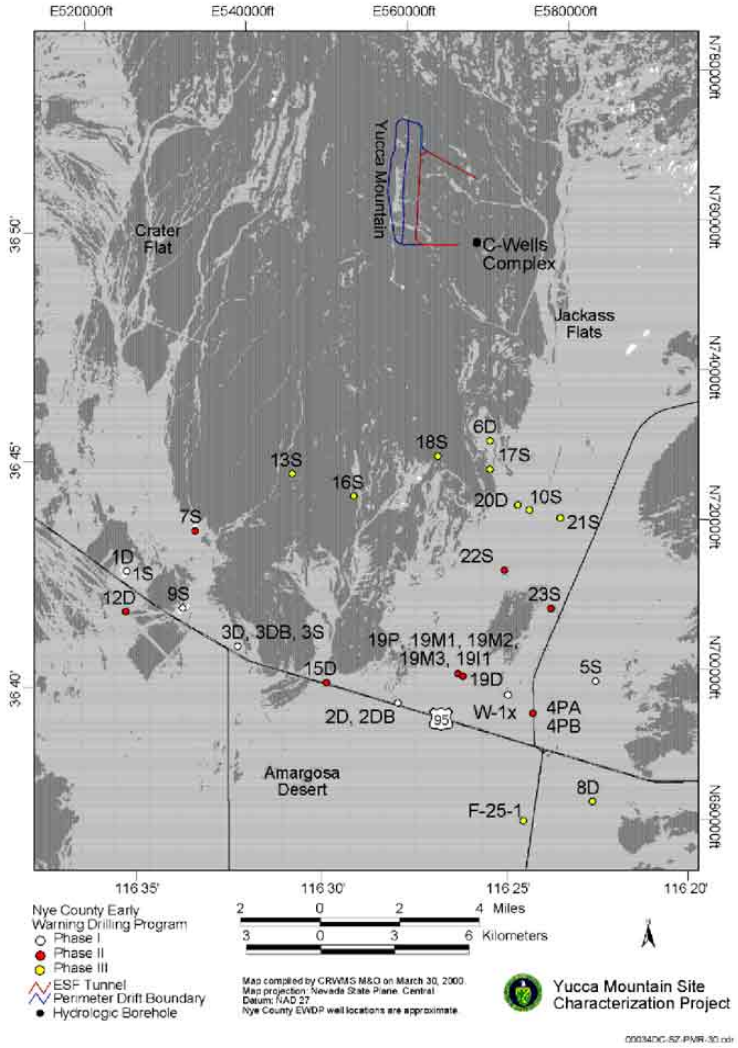
Saturated zone

- Flow to the southeast/south
- Uppermost aquifer in volcanics extends 10-15 km S of Yucca Mtn, discharge in alluvial sediments in Amargosa Valley
- High permeability due to fractures, but not well quantified
- Significant lack of data:
  - Subsurface geology
  - Water table configuration
  - Hydraulic parameters
  - Division of flow between matrix and fractures
  - Magnitude of K_d values
- Lack of boreholes
  - many concentrated in alluvial aquifer
  - only one multi-well test site

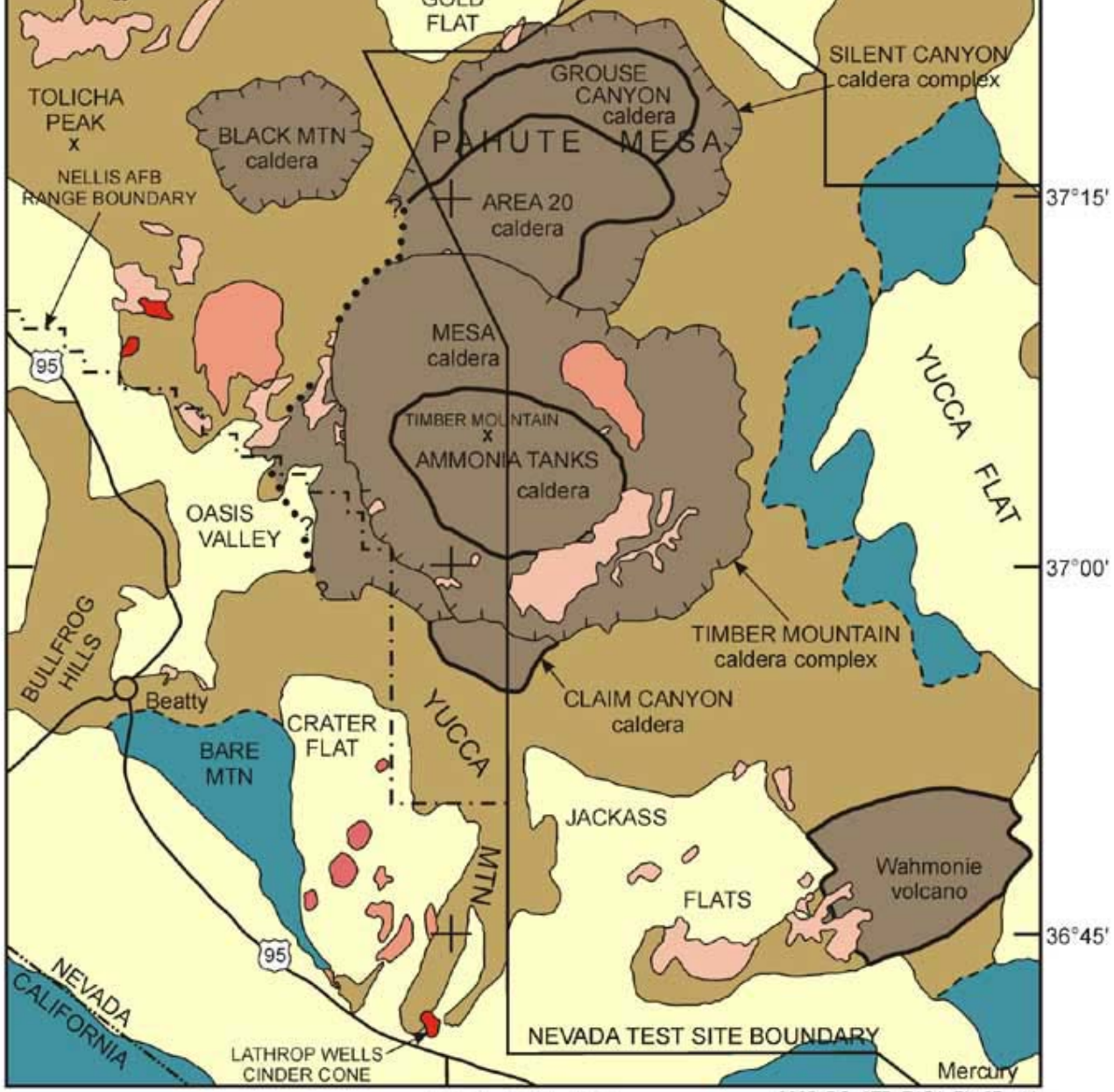


Source: CRWMS M&O (1998, Figures 5.3-222 and 5.3-231)



Source: Nye County Nuclear Waste Repository Project Office (2000)

Figure 2-3. Nye County Early Warning Drilling Program Boreholes and the C-Wells Complex



EXPLANATION

Caldera topographic walls

Caldera structural margins

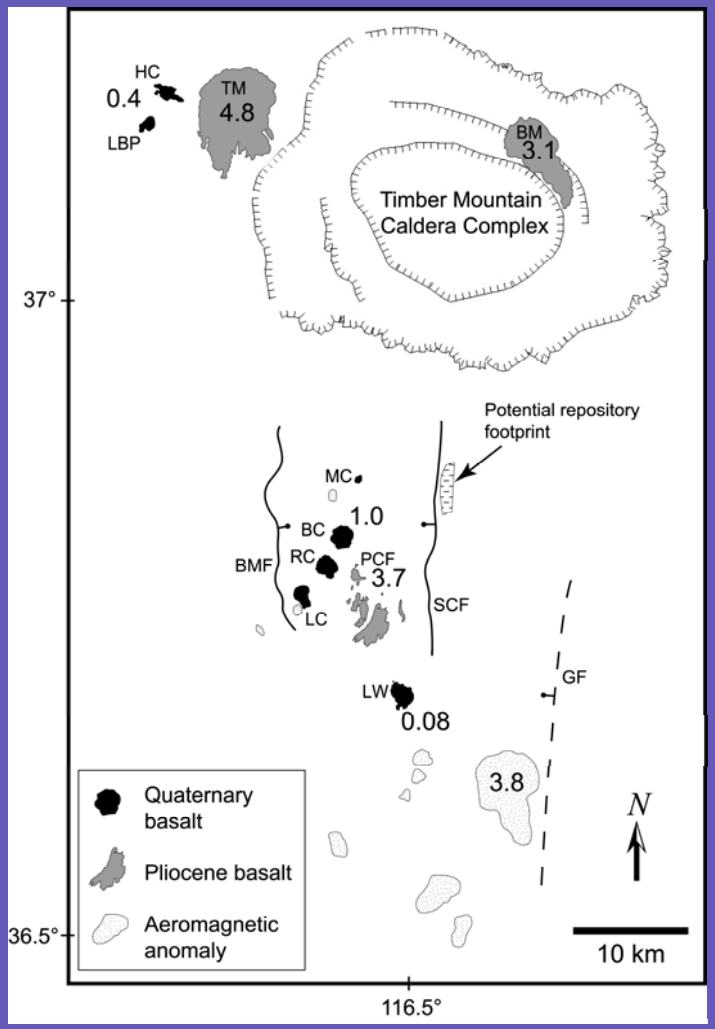
Inferred caldera margins

Typ — Late Tertiary (Pliocene) basaltic volcanic rocks, ranging from about 5.0 to 1.6 million years in age

Tyb — Tertiary (Miocene) basaltic volcanic rocks, greater

Volcanism

- 5 Quaternary basaltic volcanoes within 20 km of Yucca Mtn
  - Youngest volcanism Lathrop Wells: 80,000 years
- Could a new volcanic center form under YM? 2 possibilities
  - Explosive eruption
  - Magma doesn't vent but fills drifts - corrosive gases, thermal effects
- Current probability estimates (controversy between NRC and DOE)
  - DOE: 5.4×10^{-9} to 4.9×10^{-8} events/yr
  - NRC: 10^{-7} to 10^{-8} events/yr
- Remaining Uncertainties
  - "buried" basalts (from magnetic anomaly data) suggest the number of young events in the area could be larger than initially thought
  - DOE has convened a new Volcanic Hazards Assessment expert elicitation
    - DOE wants to eliminate from consideration rocks that are older than 1.8 million years (allows them to hide volcanism btwn 1.8-5.3 my)
  - Predicting out to 1 million years introduces more uncertainties


HC
0.4
LBP
TM
4.8
BM
3.1
Timber Mountain
Caldera Complex
37°
Potential repository
footprint
MC
1.0
BC
BMF
RC
PCF
3.7
LC
SCF
GF
LW
0.08
3.8
N
Quaternary
basalt
Pliocene basalt
Aeromagnetic
anomaly
36.5°
10 km
116.5°

How to Decide Whether Yucca Mt is Suitable?

- DOE/NRC using “Total System Performance Assessment”
- “Probabilistic analysis identifies all the features, events, and processes that affect repository performance”

Performance Assessment

- Ewing analysis
- Vaucanson's duck - how much can we learn about real ducks by studying a mechanical one?
  - Analogy for performance assessment
- Problems with PPA
  - Models in PPA are simplified
    - Do not include low probability events
    - Models that omit low-probability events produce overly optimistic results

Performance Assessment (con't)

- Models in PPA may not be scaled in time and space
  - Space: models are based on lab- and small field-scale
  - Time: models extrapolated from short times
- Boundary conditions change over time
  - May get changes in climate, volcanism, seismicity
- Conceptual models may be wrong
  - "unknown unkowns"

Models and Predictions

- Uncertainty may be a result of a lack of coherence among scientific subdisciplines
  - IAEA scholars found that among 6 performance assessment models of the same phenomenon, there were large differences
    - Resulted from differences in “problem formation, model implementation, and parameter selection”
    - Implications for YM: if a different group created the model, would the results be different?

But, Earth System Models Cannot Be Validated or Verified

- These models simulate open systems
  - in an open system, there's no way to know all input parameters, processes, or assess the boundary conditions that might affect the system over geologic times
- Models of open systems require modeler to know all input parameters for all processes that will occur over period modeled
  - For geologic systems, can't do this because our current datasets are incomplete
  - Field geology based on observations of natural world - investigate the past; learn that equilibrium is rarely reached, so it's almost impossible to decipher the detailed history of a rock, let alone predict its future

How should siting decisions be made then?

- Use Technical Judgment
  - Includes use of multibarriers, multiple techniques to analyze site, with weighting as judged reasonable by experience
- Compare site to others (1982 NWPA)
  - Right now, with one site being evaluated against itself, it's difficult to grasp the important issues that will affect safety
  - Compare site to other sites about which there's a substantial set of data:
    - Swedish sites, Olkilouto, French clay site, WIPP

If Yucca Mt Is Not Suitable, Then What?

- Even if Yucca okay, capacity there is limited by the geology
- If the US experiences an expansion in nuclear power, there will likely be a need for additional repositories

Other Sites for a Repository

- Many decent sites in US, including East
  - Fit the IAEA criteria
  - BUT - Nuclear Waste Policy Act Amendments of 1987 forbid study of crystalline rock - which underlies much of the eastern half of the US
- Process for selecting future repository sites must be perceived to be fair

Conclusions

- Solution to high-level waste not an easy problem technically or politically
- Geologic repositories are needed no matter what path is followed
- Should be working on them now
- Siting must be perceived as fair

IAEA Siting Criteria

- Long-term (millions of years) geologic stability - no seismicity or volcanism
- Low groundwater content and flow at repository depths - stable for tens of thousands of years
- Stable geochemical or hydrochemical conditions at depth, mainly described by a reducing environment
- Good engineering properties that readily allow construction of a repository
- Yucca Mt violates 2, maybe 3 of above criteria