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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
PANEL ON STRUCTURAL GEOLOGY & GEOENGINEERING

SUBJECT: STATUS OF PROBABILITY STUDIES

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ALEXIS PARK HOTEL
SEPTEMBER 14 - 16, 1992

Probability Calculations
Discussion Topics

- Issue resolution: volcanism
  - First draft completed this month
  - First meeting with NRC: August 1992
    -- Productive meeting
  - Eruption scenario: not significant for Yucca Mountain

- Probability model (yet again)
  - Eruption scenario
  - Subsurface scenario

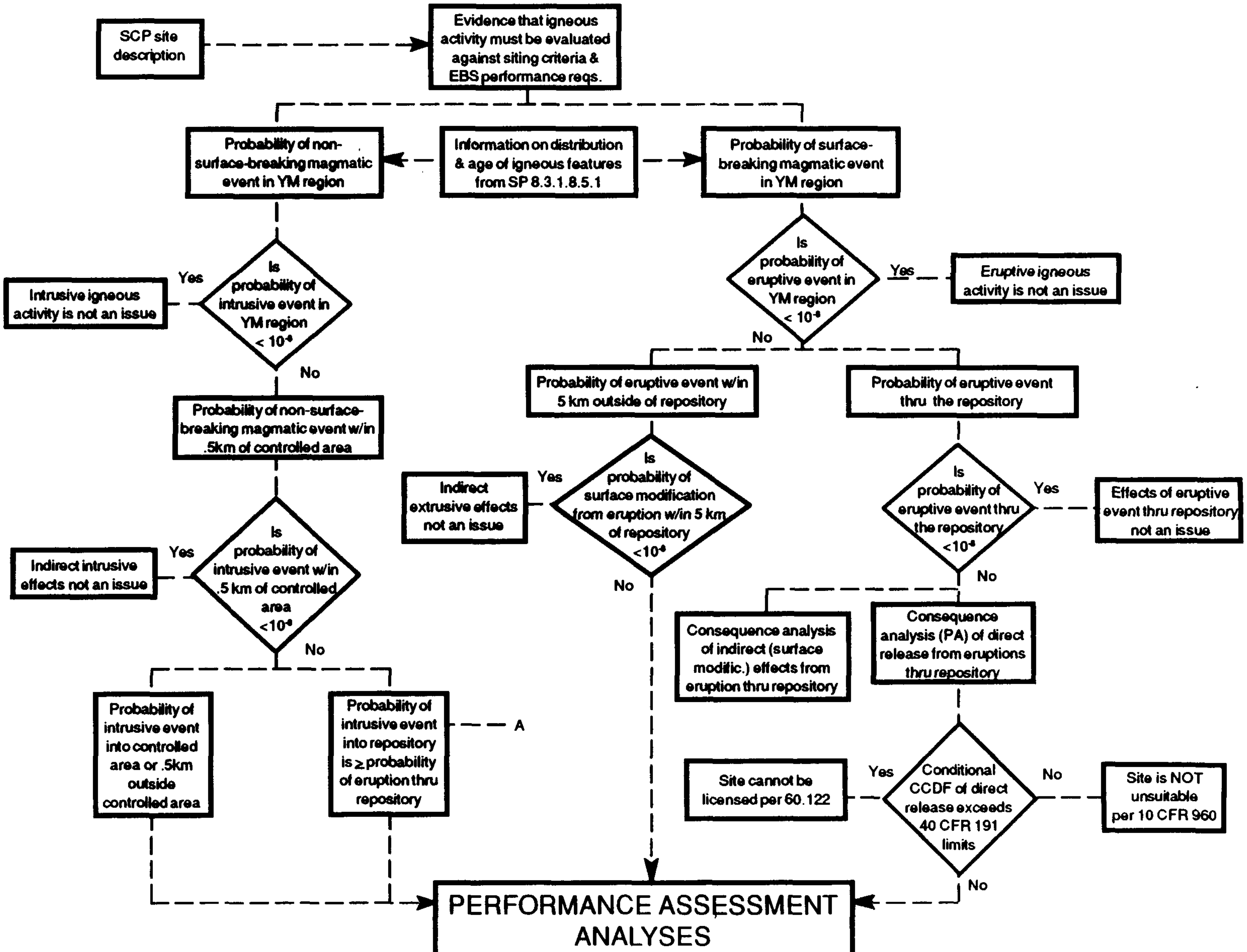
- Structural models for the Yucca Mountain region
  - Multiple tectonic models
  - Impact on volcanic risk
  - Discrimination of models

Probability Calculations
Discussion Topics
(Continued)

- Other probability models (State of Nevada, NRC)
  - Areas of agreement
  - Areas of disagreement
  - Request for recommendations: NWTRB
    -- Propagation of worst case
    -- Expert opinion
  - Latest tables: E1 and E2

- Subsurface magma: Yucca Mountain region
  - Strengths and weaknesses
    -- Teleseismic tomography
  - Alternative interpretations
  - Plans for resolution

Strategy for Resolution of Volcanism Issues



VOLCAN.129/9-14-92

Probability Calculations
Tripartite Probabilty

$$Pr = Pr(E3 \text{ given } E2 \text{ given } E1)Pr(E2 \text{ given } E1)Pr(E1)$$

where

E1 is the recurrence rate of volcanic events
E2 is the probability of repository disruption, given E1
E3 is the probability of exceeding regulatory limits, given repository disruption

Probability Model (Crowe, Johnson, and Beckman, 1982)

$$\text{Pr[no disruptive event in time } t\,] = \exp^{-\lambda prt}$$

where

λ is the recurrence rate
p is the probability of repository disruption
r is the probability of exceeding regulatory limits

Probability Formula: Applications
Two Scenarios

1. **Eruptive Releases (eruption scenario)**

   Potential for release of radionuclides

   Magmatic disruption of the repository

   Surface eruptions

   ***E1* is the formation of a volcanic center**

   ***E2* is the probability of intersecting the repository**

   ***a*/*A* where *a* is the area of the repository or**

   ***a* is the area of the controlled area (C_a)**

   ***A* is the area of event definition**

   ***E3* is the probability of exceeding release limits from effects of surface eruption**

Important concepts:

linear dike model

as $a \Longrightarrow C_a$, $E3 \Longrightarrow 0$

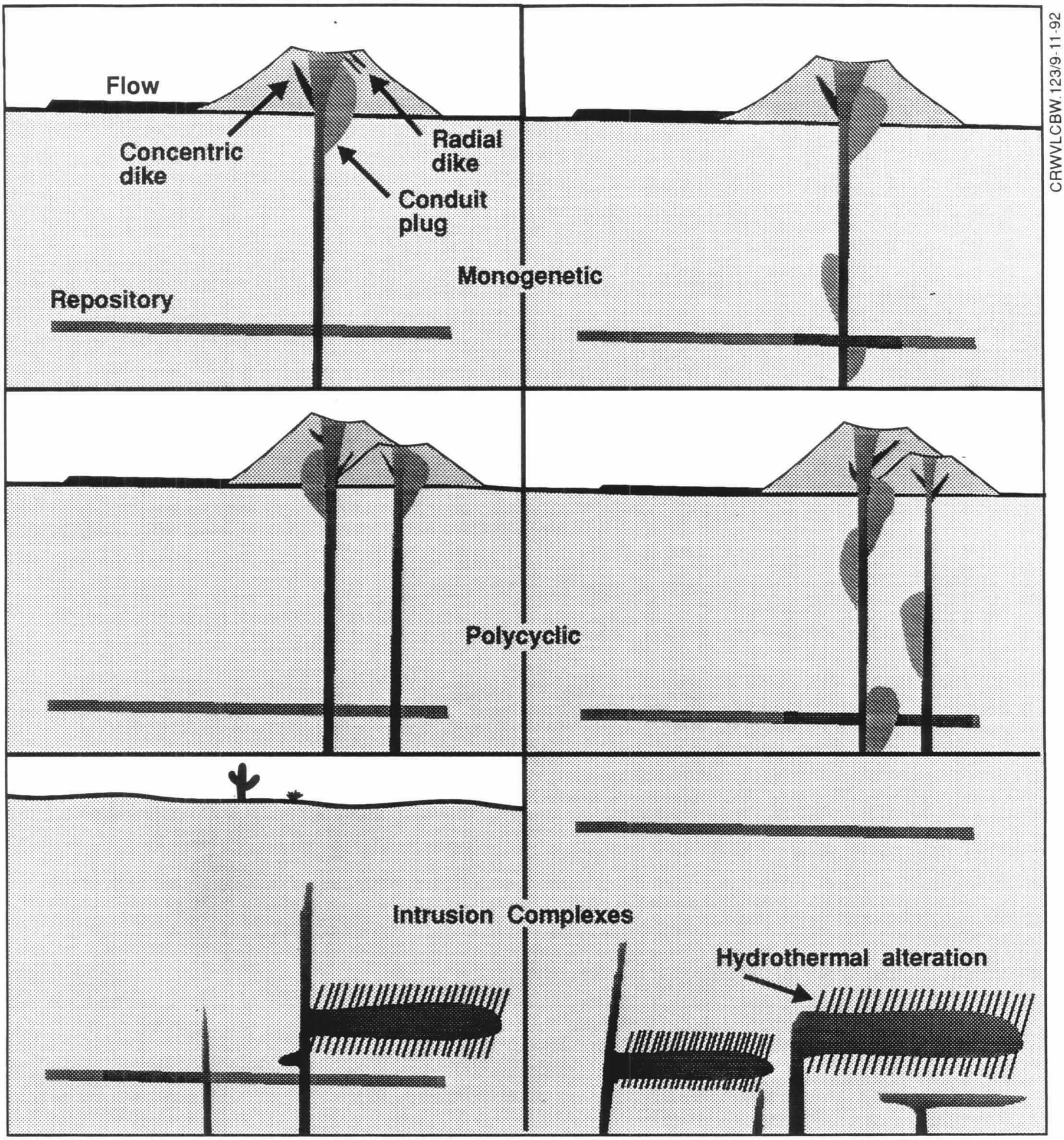
polycyclic versus monogenetic

Probability Formula: Applications
Two Scenarios
(Continued)

2. Subsurface effects (subsurface scenario)
   E1 is the intrusion of magma through or near the repository
   E2 is the probability of *affecting* the repository system
   E3 is the probability of exceeding release limits at the accessible environment from subsurface (coupled) effects

Important concepts:
- intrusion area
  - sills, lopoliths, conduits
- affected zone around intrusion
  - thermal, hydrothermal, volcanic gases

Eruption/Intrusion Scenarios



Areas of Agreement
(YMP, NRC, State of Nevada)

- **Probabilistic approach to volcanism**
  - Bound or test problem against regulations
  - Regulations: probabilistic
  - Standard volcanic hazard assessment: subjective
- **Number of volcanic events**
  - Lathrop Wells: one center, one cluster
  - Sleeping Butte: two centers, one cluster
  - Quaternary basalt of Crater Flat: four centers, three clusters
  - Buckboard Mesa: one center, one cluster
  - Pliocene basalt of SE Crater Flat: four or five centers, one cluster
    NRC: hidden intrusions (but unlikely)
- **Linear Dike Model**
  - Basalt centers are fed by linear dikes
  - Dimensions of feeder dikes
  - Intrusions may form under some conditions
    -- Conduits: probably above repository
    -- Intrusions: probably rare but somewhat unknown

Areas of Agreement (YMP, NRC, State of Nevada)

(Continued)

- Polycyclic Model
  - Needs to be considered carefully
    - -- Lathrop Wells
    - -- Red Cone/Black Cone
    - -- Hidden Cone ?
    - -- Cima ?
- Geochronology data: difficult
  - Quaternary basalt centers
  - Conventional K-Ar
    - -- Ages uncertain
    - -- Large errors

Probability Calculations
Common Areas of Disagreement

- **Polycyclic model**
  - **Effects λ but difficult to calculate**
    - **event dependency**
    - **λ of event recurrence at center: unknown**
  - **Assume center λ: conservative**

- **Volcanic Risk Assessment**
  - **Polycyclic model incorporated in E3: *composite* effects**
  - **Literature quote: incorrect (USGS)**
    - **assumed polycyclic model decreases risk**

- **E1 and E2 are independent but must be *consistent***
  - **Cannot vary E2 without examining E1**

Probability Calculations
Common Areas of Disagreement
(Continued)

- **Probability values are *Estimates***
  - **Paradox**

    small number of events: risk ⇓ uncertainty ⇑

    increased number of events: risk ⇑ uncertainty ⇓

Prefer Decreased Risk

- **Recurrence models**
  - **Range of permissive distribution models**
  - **Not based on data distribution**

    data limitations
  - **Prefer Poisson Model (Crowe et al. 1992)**

    most honest approach with limited data set

    error of Poisson assumption can be defined
  - **Cumulative magma volume versus time**

    test of distribution models

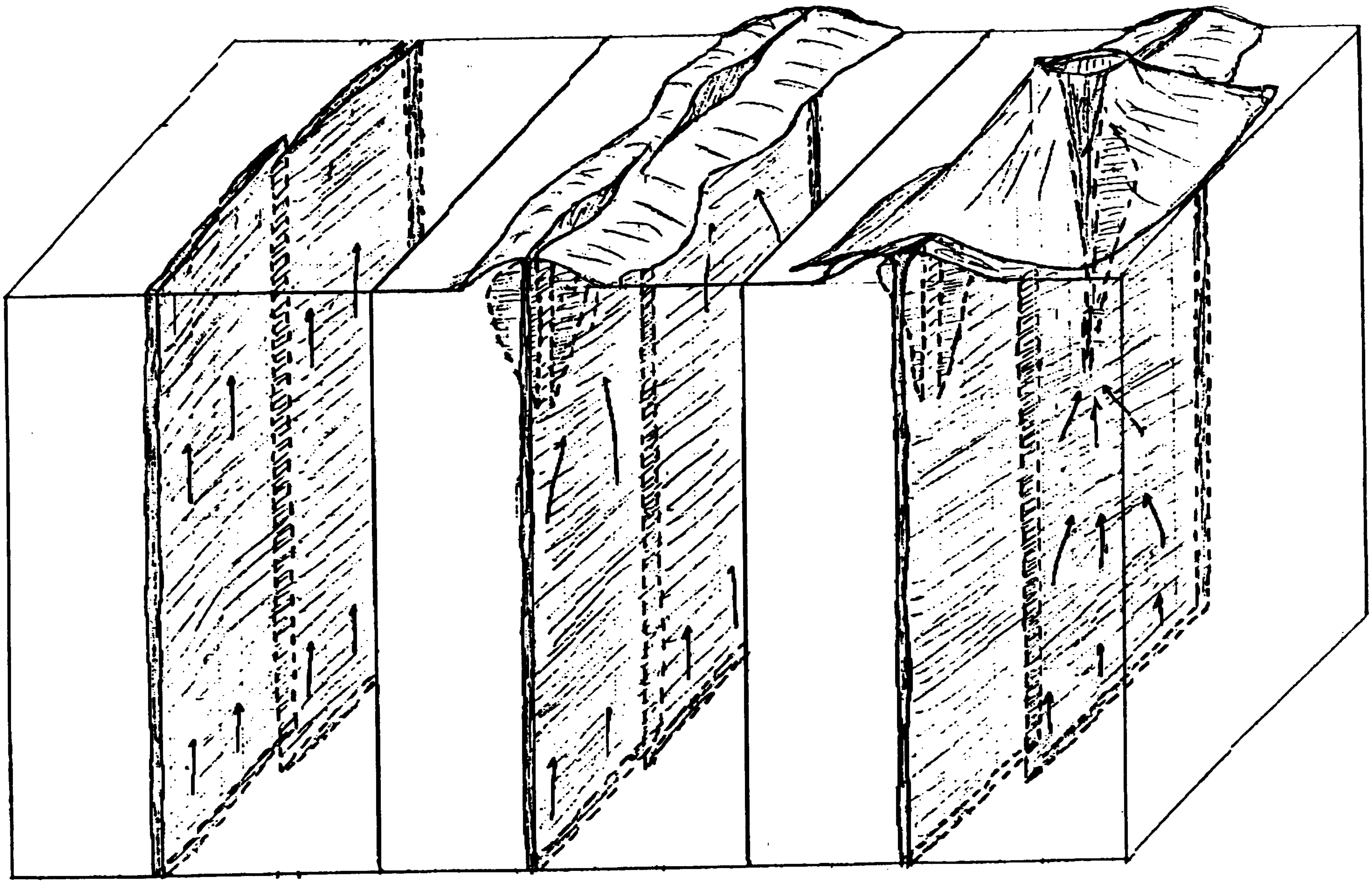
    waning volcanism

Probability Differences with Calculations by the State of Nevada

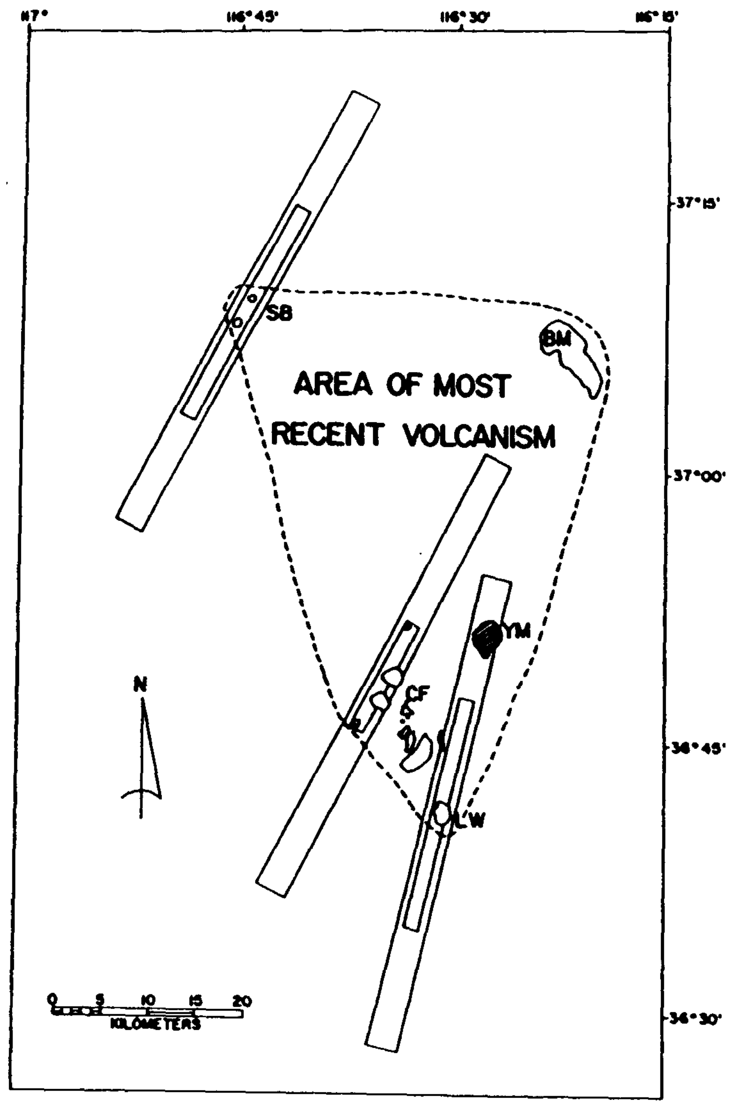
- **Definition of a volcanic event**
  - Factor of two to three in event counts
  - Resolved in recent publications (discussions with E. Smith)
- **E2 is partly defined by how E1 is structured**
  - Nevada's calculation: use AMRV for E1
    use 90% error bound for E1 for AMRV
  - Define E2 using Lathrop Wells center and "chain model"
  - Calculation uses E1 value for an approx. 3000 km^2
    applies it to an area of 75 km^2
  - Physically implausible calculation
    propagation of worst case (E1)
    application to area (E2) with only 1 Quaternary center
    equal to placing the repository in the middle of Lunar
    Crater Volcanic Center

Must examine the physical reality of a calculation
Propagation of worst case values produces implausible probability calculations

Basalt Feeder Dike Model

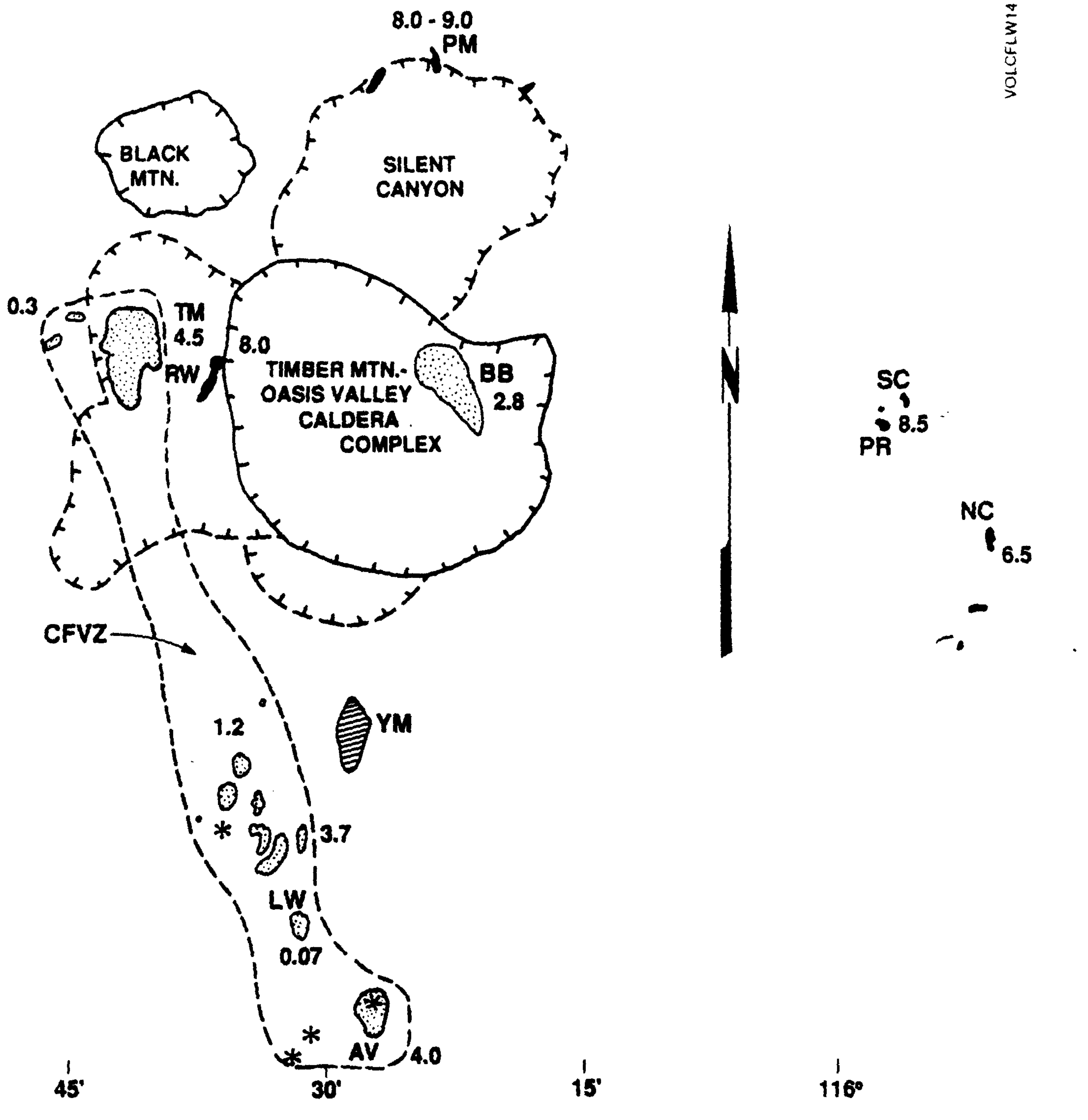


Silent Canyon Basalt
Basalt Feeder System



From Smith et al. 1990

Post Caldera Basalts



Two Areas of Needed Recommendations

- **Propagation of probability values**
  - Worst case leads to physically implausible values
  - Mean: best descriptor
  - Conservatism: Probability distribution function

Major Reason for Differences in Probability Calculations

- **Model weighting**
  - How do you accommodate bias?
  - Probability tables
  - Expert opinion

- **YMP approach: Issue Resolution**
  - Take reasonable position
  - Document basis for decisions
  - Proceed with calculations

- **NWTRB recommendations**
  - Worst case versus mean
  - Model bias

TABLE I: VOLCANIC RECURRENCE RATE (E1)

PUBLICATION	EVENTS (yr^{-1})	QUATERNARY EVENTS*	RATE MODEL	TIME (Ma)
Crowe and Carr, 1980	4.0E-6	7.2	Poisson: Cone Count	1.8-2.8
Crowe, Johnson, and Beckman, 1982	6.0E-7 to 1.1E-6	1.1 to 19.8	Magma Output (210 m3 yr-1)	1.8-3.7
	9.4E-6	17.1	Poisson: Cone Count	1.8
	6.4E-6	11.5	Poisson: Cone Count	2.8
	8.0E-6	14.4	Poisson: Cone Count	3.7
Crowe et al., 1989	2.8E-5	73	Magma Output (133 m3 yr-1) (Lathrop=130 ka)	3.7
	7.0E-6	12.6	Magma Output (133 m3 yr-1) (Lathrop=20 ka)	3.7
	5.0E-6	9.0	Magma Output (66 m3 yr-1) (Lathrop=130 ka)	1.8
	3.2E-6	5.8	Magma Output (66 m3 yr-1) (Lathrop=20 ka)	1.8
Crowe and Perry, 1990	1.9E-6	3.4	Magma Output (33 m3 yr-1) (Lathrop=130 ka)	1.8
	1.6E-6	2.9	Magma Output (33 m3 yr-1) (Lathrop=20 ka)	1.8
Ho, 1991	2.3E-6	3.7	Weilbull: Episode	12
	5.0E-6	8.0	Weilbull: Cycle	3.7
	6.2E-6	9.9	Weilbull: Cone Count	6.0
	5.5E-6	8.8	Weilbull: Cone Count	1.6
Crowe et al., 1992	3.9E-6	7.2	Poisson Cone Count	1.8
	1.7E-6	3.6	Poisson Cluster Count	1.8
	3.5E-6	5.4	Poisson Cone Count	3.7
	1.3E-6	2.3	Poisson Cluster Count	3.7
	3.2E-6	5.0	Poisson Cone Count	5.0
	1.2E-6	2.2	Poisson Cluster Count	5.0
Ho 1992	5E-6	8.0	Weilbull:Episode	6.0
	5.5E-6	8.8	Weilbull:Episode	1.6
	1.8E-6	2.9	Weilbull:90% CI	1.6
	1.3E-5	21	Weilbull:90% CI	1.6

* Calculated number of volcanic events projecting the recurrence rate for the Quaternary Period. There were 3 to 7 volcanic events in the Yucca Mountain region in the Quaternary.

Table I: Disruption Parameter (E2)

Publication	a (repository area) km²	A (event area) km²	Model	Parameter E2
Crowe and Carr, 1980	10	1963	25 Km radius circle	5.1E-3
	10	7854	50 km radius circle	1.3E-3
Crowe, Johnson, and Beckman, 1982	8	2437	Min area circle	3.3E-3
	8	4419	Min area ellipse	1.8E-3
	8	2470	Min area circle (Buckboard)	3.2E-3
	8	1953	Min are ellipse (Buckboard)	4.1E-3
Crowe, Johnson, and Beckman, 1982 (Revised repository area)	6	2437	Min area circle	2.5E-3
	6	4419	Min area ellipse	1.4E-3
	6	2470	Min area circle (Buckboard)	2.4E-3
	6	1953	Min area ellipse (Buckboard)	3.1E-3
Smith et al.1990	6*	1953	AMRV	3.1E-3 1.6E-2
	6*	375	Lathrop Wells Chain	2.2E-3+
Naumann et al.1991	6*	1530*	NE Fault Zone	3.9E-3
Crowe et al.1992	6	1670	Cluster Length (3σ) Crater Flat Volcanic Zone	3.6E-3
Sheridan 1992	6		Mono Carlo Dike Propagation**	
			Model 1	6E-3
			Model 2	1.4E-2
			Model 3	1.7E-2
			Model 1a	1.1E-3
			Model 2a	1.0E-2
			Model 3a	5.3E-3
Ho 1992	6*		ARMV/Chain	8.0E-2

* Assigned to model.
\+ Assuming the CVFZ could produce clusters that are directed toward the Yucca Mountain Site over 14% of the length of the zone.
** Maximum probability values.

Structural Models
Yucca Mountain Region

- **Major structural models**
  - Detachment Models (Scott, 1990; Hamilton, 1988; M. Carr and Monsen, 1988; Fox and M. Carr, 1989)
  - Caldera Models (W.J. Carr et al. 1986)
  - Kawick-Greenwater Rift (W.J. Carr, 1990)
  - Amargosa Desert Rift Zone (Wright, 1988)
  - Strike-Slip Basin (Sweikert, 1989)
  - Pull-Apart Basin

- **Structural setting of Yucca Mountain**
  - North-trending normal faults (down to the west)
  - Oroflexural folding (paleomagnetic data)
  - Increase in deformation southward
  - Crater Flat Basin
  - North-Northeast trending left-slip faults

Basaltic Volcanism: Crater Flat Basin

Satellite Photograph
Yucca Mountain Region

Structural Models
Yucca Mountain Region
(Continued)

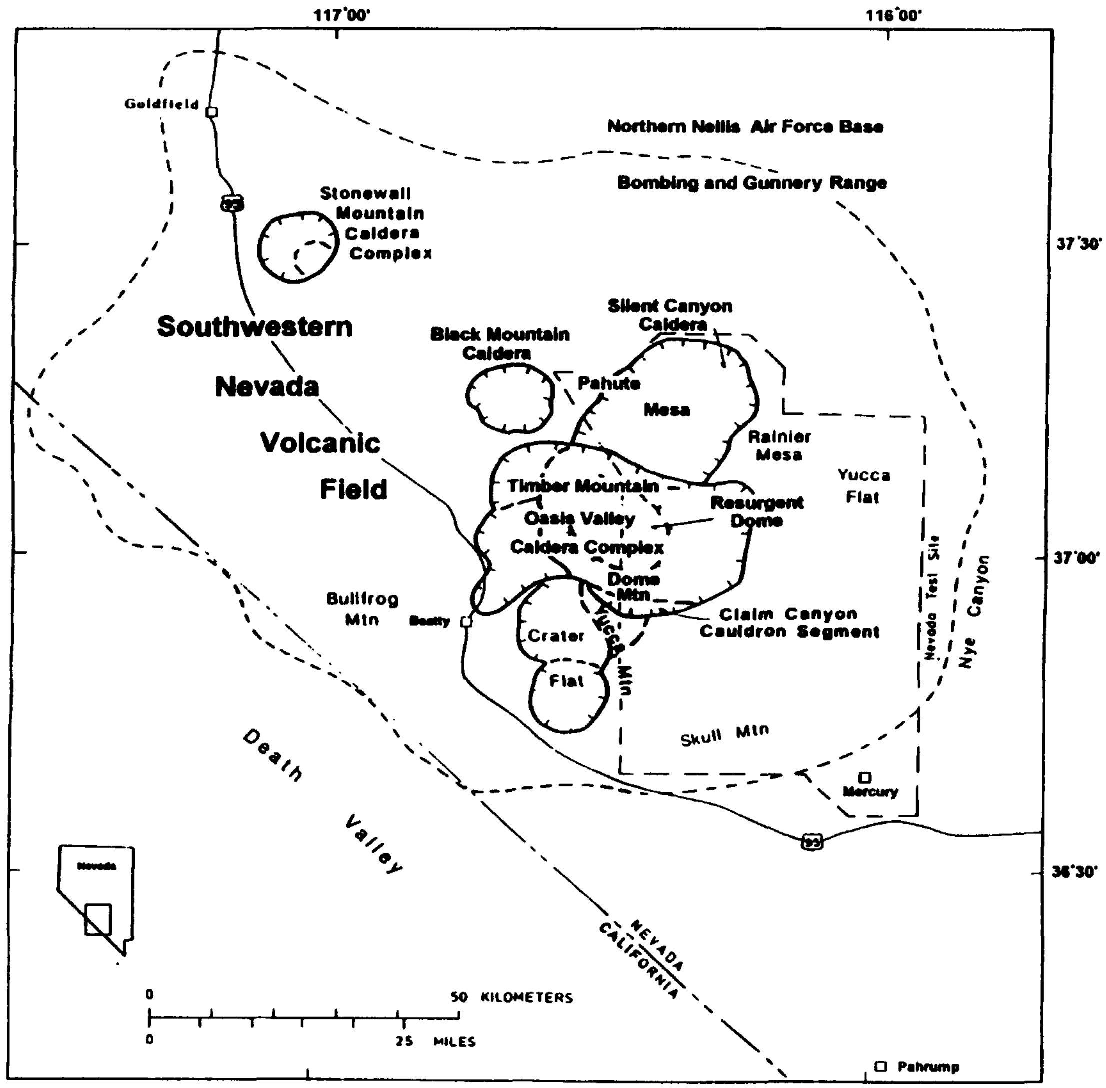
- **Event timing**
  - Mostly predates Timber Mountain Tuff (11.4 Ma)

Basaltic Volcanism postdates major extension

- **Effects on volcanic models**
  - Detachment faulting: not a pathway
  - Caldera models: along or through Yucca Mountain
  - Kawich-Greenwater Rift
  - Pull-Apart Basin
    Still active ?

- **Discriminate Northwest versus Northeast trending models**

Southwestern Nevada Volcanic Field



From Byers et al. (1989)

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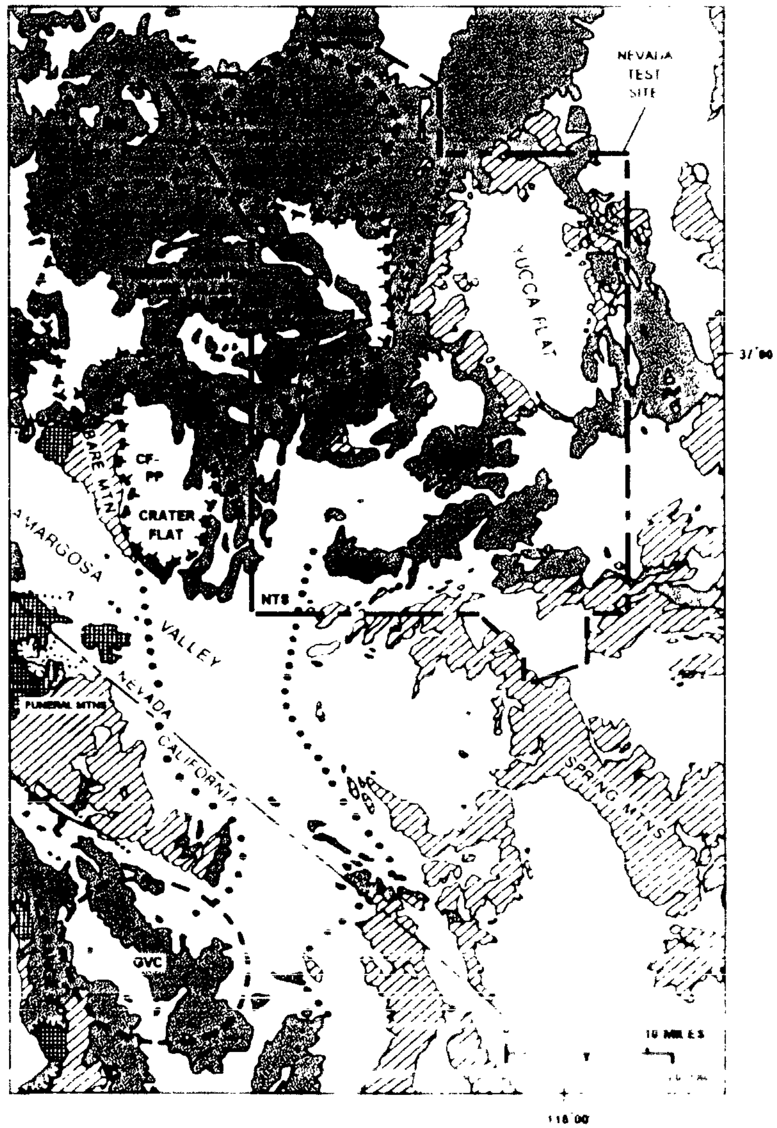
Kawich-Greenwater Rift



From W J Carr (1990)

Amargosa Desert Rift Zone

From Wright (1989)

Post Caldera Basalts

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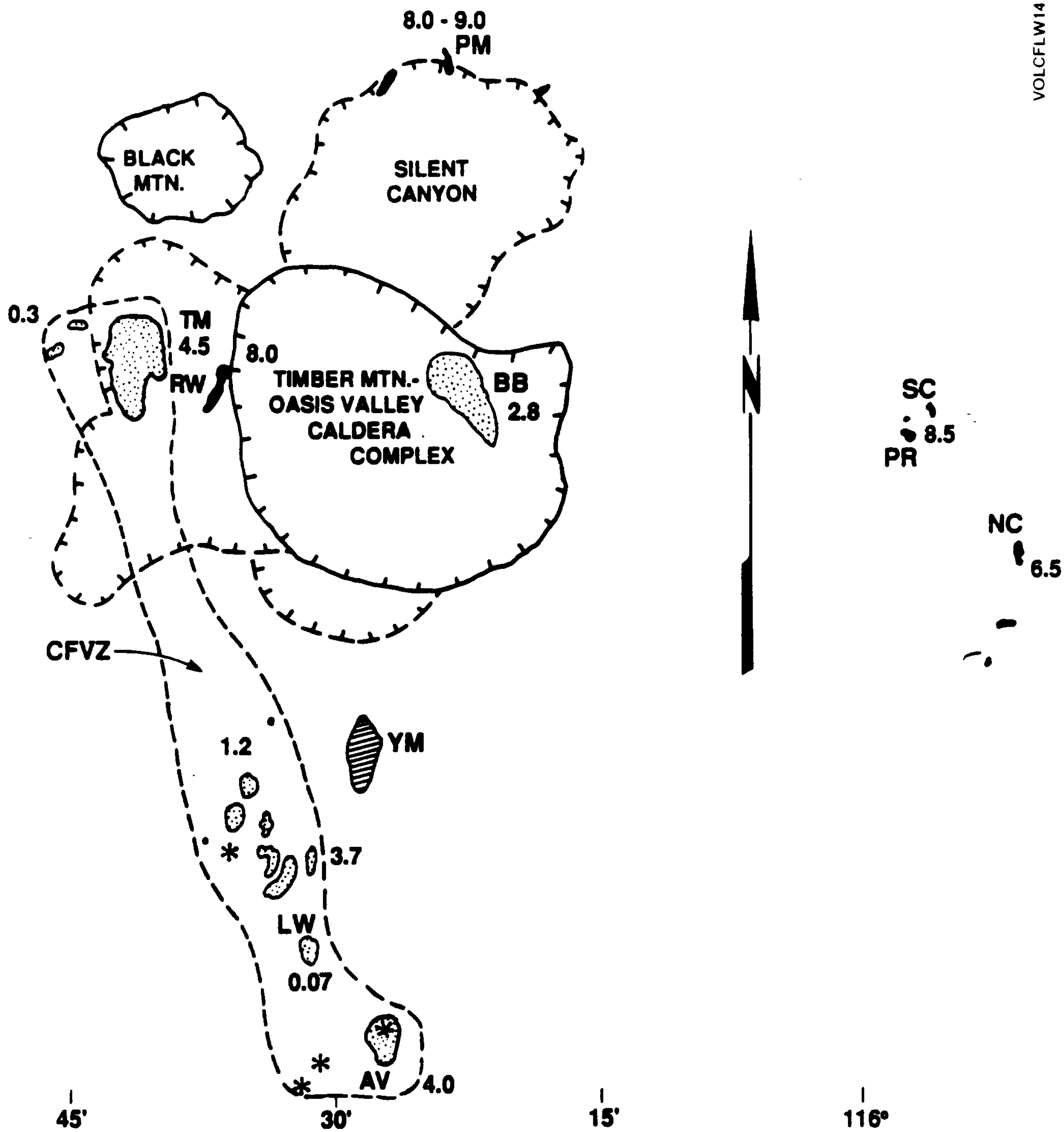


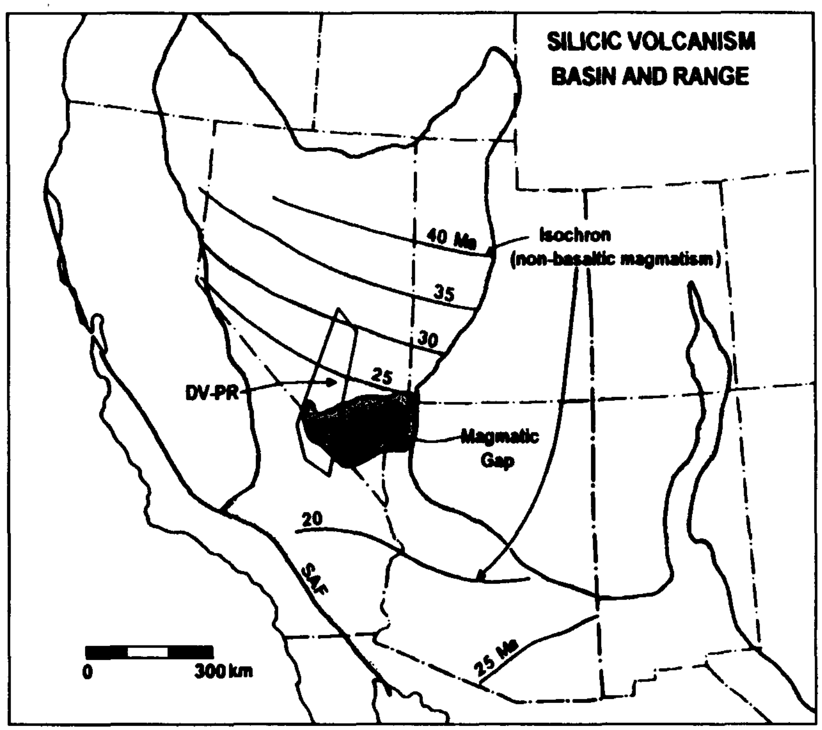
Magma Chambers
Yucca Mountain Region

- Evans and Smith (1992)
  - Low velocity teleseismic anomaly
  - Magma body
  - Northeast-trending plume trace
- Seismic Gap: Crater Flat/Yucca Mountain Region
  - Parsons and Thompson (1991)
  - Magmatic activity has accommodated strain
- Area of future investigations
- Examine existing geophysical data
  - Test for consistency/alternative interpretations
  - Magma not noted on seismic line

Review by External Consultant
  - recommendations for future work

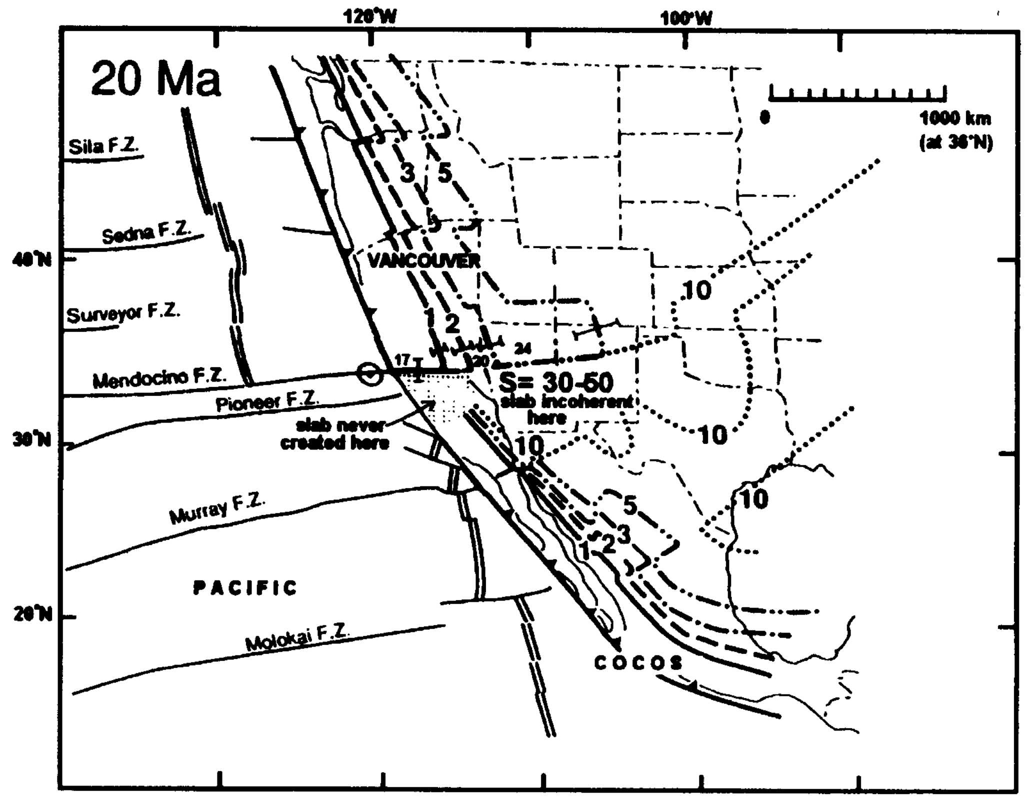
- Difficulties with the Magma Model
  - Magma gap
  - No driving mechanism
  - Lithospheric mantle preserved

Magma Gap



From Farmer et al. (1989)

20 Million Years
Reconstructed Plate Positions



From Severinghaus and Atwater (1990)

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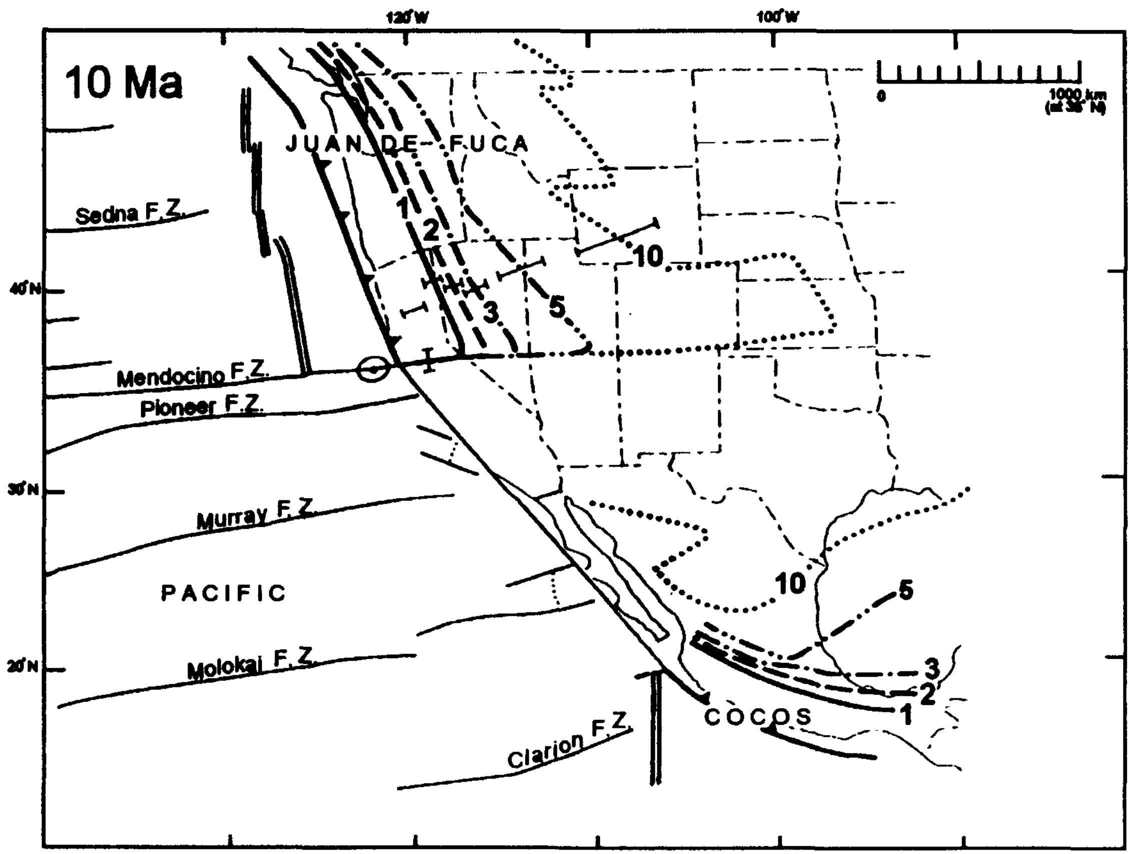
10 Million Years
Reconstructed Plate Position



From Severinghaus and Atwater (1990)

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