STATUS OF CNWRA VOLCANOLOGICAL PROBABILITY STUDIES

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PRESENTED AT THE
NWTRB MEETING ON PROBABILITY MODELS
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CNWRA VOLCANO PROBABILITY MODELS

OUTLINE OF THE PRESENTATION

- Overview of CNWRA Volcano Probability Models under development
- Spatial and temporal patterns in vent distribution
- The Near-Neighbor Nonhomogeneous Poisson model
- A spatio-temporal homogeneous Markov model
- Limitations of the current CNWRA models

CNWRA VOLCANO PROBABILITY MODELS

Models Under Development at CNWRA

- Near-Neighbor Nonhomogeneous Poisson
- Markov
- Cox (Cluster) Process

How are these models different from other probability models?

These Models:

- Are based on spatial and temporal patterns in volcanism (statistically significant spatio-temporal clustering)
- Avoid the need to define discrete areas in order to estimate probability
- Map probability surfaces (provides a sense of spatial variability)
- Can be expanded to capture geologic detail (easy to integrate into Iterative Performance Assessment and to work toward a geologic hazard map)

CNWRA VOLCANO PROBABILITY MODELS

Volcanoes form spatial clusters in the YMR (Hopkins F-test; Clark-Evans test, K-function) with 99% confidence. Differences in ages of near-neighbor cinder cones are less than expected (99% confidence, paired Student t-test).

- Recurrence rate must vary within the YMR

- Homogeneous Poisson models do not adequately describe volcano distribution

Homogeneous Poisson models will overestimate the probability of volcanism in some parts of the YMR, far from Quaternary volcanoes, and underestimate the probability of volcanism close to late Quaternary Crater Flat volcanoes.

NONHOMOGENEOUS POISSON MODEL

Estimating Recurrence Rate in a Nonhomogeneous Model

One approach is to use near neighbors: $\lambda_r(x,y) = \dfrac{m}{\sum_{i=1}^{m} u_i t_i}$

where: λ_r is the recurrence rate at a point, x,y

t_i is the time since the formation of volcano, i

u_i is the area of a circle whose radius is the distance from i to x,y

and $u_i t_i$ is minimum for the nearest m neighbors

The number of the near neighbors can be constrained by integrating the recurrence rate over the entire region. To estimate the recurrence rate in the YMR, λ_t:

$$\lambda_t = \sum_{i=0}^{m} \sum_{j=0}^{n} \lambda_r(i,j)\Delta x \Delta y$$

NONHOMOGENEOUS POISSON MODEL

Using a spatially varying recurrence rate, it is possible to estimate the probability of a new volcano forming within or near the repository block:

$$P\,[N \geq 1] = 1 - \exp\left[-t \int_x \int_y \lambda_r(x,y)\, dy\, dx\right]$$

or

$$P[N \geq 1] = 1 - \exp\left[-t \sum_a \lambda_r \Delta x \Delta y\right]$$

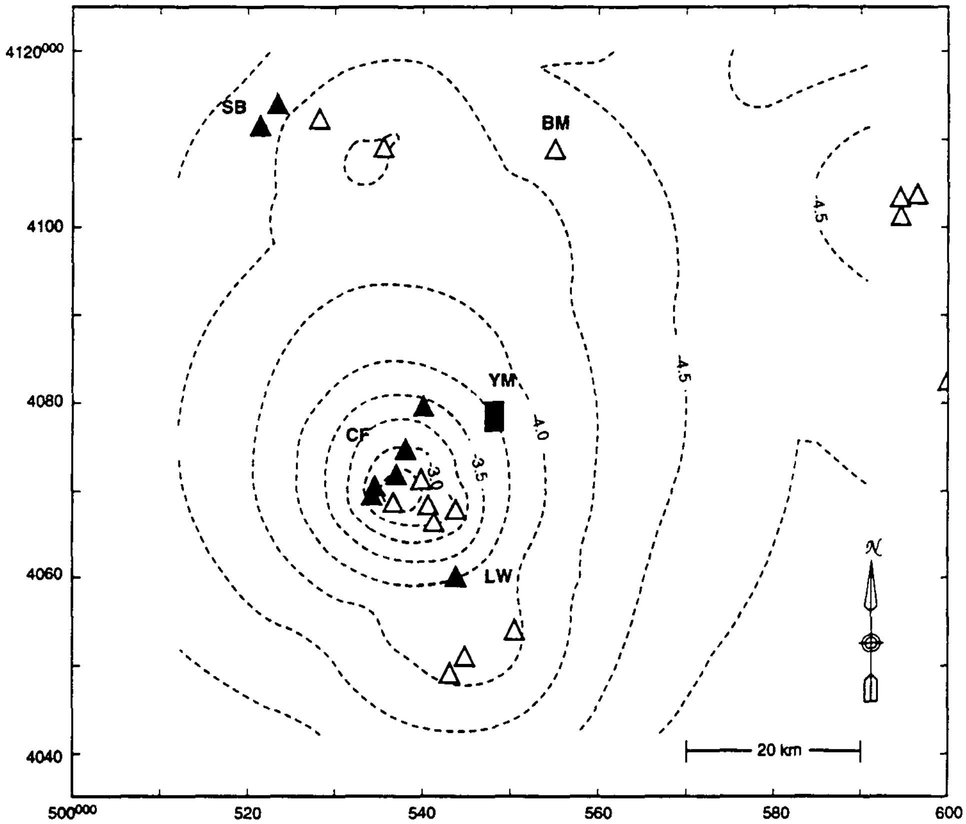
where

t = 10,000 years

λ_r is the expected recurrence rate at point x,y

a is the area of the repository

NEAR-NEIGHBOR NONHOMOGENEOUS POISSON MODEL



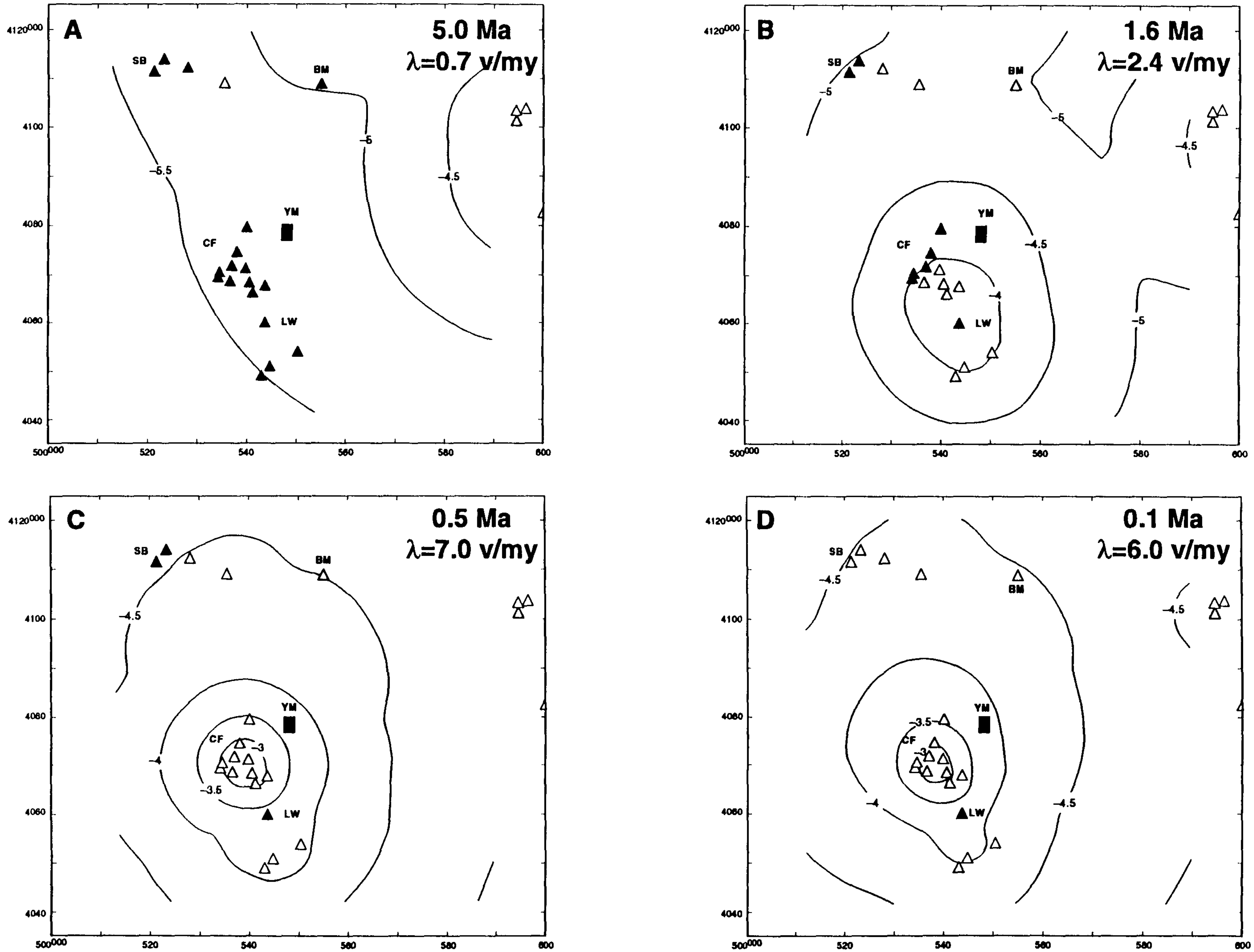
WHAT'S CONTOURED?

THE PROBABILITY OF A NEW VOLCANO FORMING WITHIN AN 8 KM^2 AREA WITHIN THE NEXT 10,000 YR IS CONTOURED. THE CONTOUR INTERVAL IS IN LOG PROBABILITY. FOR EXAMPLE, WITHIN THE -4 CONTOUR THE PROBABILITY OF A NEW VOLCANO FORMING IS GREATER THAN 1 IN 10,000 IN 10,000 YR, WITHIN THE -3 CONTOUR THE PROBABILITY OF A NEW VOLCANO FORMING WITHIN A GIVEN 8 KM^2 AREA IS GREATER THAN 1 IN 1,000 IN 10,000 YR.

ASSUMPTIONS IN THIS SOLUTION

- POSITION AND TIMING OF VOLCANISM ARE KNOWN
- PAST ACTIVITY IS A GOOD INDICATOR OF FUTURE ACTIVITY
- THE REGIONAL RECURRENCE RATE IS ABOUT 7 V/MY (SIX NEAR-NEIGHBORS)
- GEOLOGIC DETAILS (E.G., FAULT CONTROL) ARE NOT CONSIDERED

TESTING NONHOMOGENEOUS MODELS



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MARKOV MODEL

Used to predict the most probable location of future eruptions assuming volcanoes have the properties of Markov variables

- Location of most recent eruption most influences position of future eruptions [homogeneous Markov model]
- The position of future eruptions tends toward a Homogeneous Poisson model, described by the diffusion equation, with time since last eruption
- Parameters used in the model are estimated from positions of past volcanic eruptions in the YMR

MARKOV MODEL

The conditional probability density function is given by the Fokker-Planck equation:

$$\frac{\partial P}{\partial t} + (\eta P) - \frac{1}{2}\,\frac{\partial^2}{\partial x^2}\,(\sigma^2 P) = 0$$

Where η and σ^2 are time derivatives of mean and variance of volcano position, respectively.

$$a(x_o,t,t_o) = E\{x(t) \mid x(t_o) = x_o\}$$

$$= \int_{-\infty}^{\infty} x(t)\; P(x,t;\; x_o,t_o)dx$$

$$b(x_o,t,t_o) = E\{[x(t) - a(x_o,t,t_o)]^2 \mid x\,(t_o) = x_o\}$$

$$= \int_{-\infty}^{\infty} (x - a)^2\; P(x,t;\; x_o,t_o)dx$$

MARKOV MODEL

$$\eta(x_o,t_o) = \left.\frac{\partial a(x_o,t,t_o)}{\partial t}\right|_{t = t_o}$$

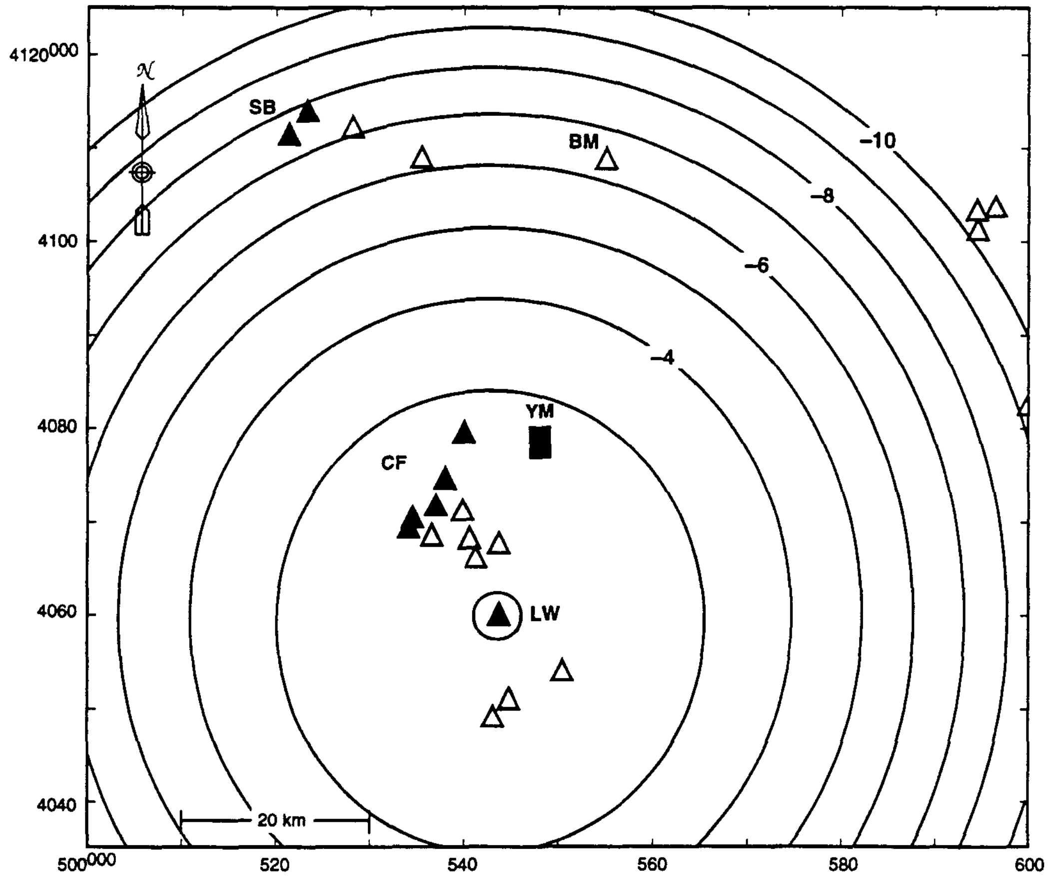
$$\sigma^2(x_o,t_o) = \left.\frac{\partial b(x_o,t,t_o)}{\partial t}\right|_{t = t_o}$$

In two dimensions the conditional probability density function becomes:

$$P = \frac{1}{2\pi(t - t_o)\sqrt{\sigma_x^2 \ \sigma_y^2}} \exp\left\{ - \frac{[x(t) - x_o - \eta_x(t - t_o)]^2}{2\sigma_x^2(t - t_o)} - \frac{[y(t) - y_o - \eta_y(t - t_o)]^2}{2\sigma_y^2(t - t_o)} \right\}$$

with parameters estimated from the volcano distribution.

MARKOV MODEL



WHAT'S CONTOURED?

CONTOURED IS THE LOG PROBABILITY OF A NEW VOLCANO FORMING WITHIN AN 8 KM^2 AREA AT THE PRESENT TIME, IF A VOLCANO WERE TO FORM NOW. HENCE, INTEGRATING ACROSS THE ENTIRE REGION, THE PROBABILITY IS UNITY.

ASSUMPTIONS IN THIS SOLUTION

- POSITION AND TIMING OF VOLCANISM ARE KNOWN (LW = 0.13 Ma)
- PAST ACTIVITY IS A GOOD INDICATOR OF FUTURE ACTIVITY. MODEL PARAMETERS ARE ESTIMATED FROM PAST ACTIVITY
- CINDER CONES IN THE YMR BEHAVE AS HOMOGENEOUS MARKOV VARIABLES
- GEOLOGIC DETAILS (E.G., FAULT CONTROL) ARE NOT CONSIDERED

CNWRA VOLCANO PROBABILITY MODELS

Probability of disruption in 10,000 yr using near-neighbor nonhomogeneous Poisson Model

Quaternary YMR recurrence rate (7 ± 3 v/my):

8.0×10^{-5} to 3.5×10^{-4}

with most estimates between 1×10^{-4} and 3×10^{-4}

Based on the preliminary results of the homogeneous Markov model and a 0.05 to 0.15 Ma age for Lathrop Wells, the probability that a new volcano will form within the repository boundaries, should volcanism occur:

1.5×10^{-3} to 3×10^{-3}

CNWRA VOLCANO PROBABILITY MODELS

THESE NUMBERS ARE LIKELY TO CHANGE

Current CNWRA models treat volcanoes as points. Using areal terms, for example PDF'S for dikes or accounting for satellite vents, will increase the probability of disruption

No probability model currently incorporates geologic and geophysical information to a sufficient (convincing) degree

- Indirect effect of volcanism
  - Change in the hydrologic setting
  - Change in geochemical transport rates

- Role of fault control and/or tectonic control
  - Scale of structural control on magma ascent
  - Deformation rates and magmatism
  - Change in magma supply

CNWRA VOLCANO PROBABILITY MODELS

THESE NUMBERS ARE LIKELY TO CHANGE (Cont'd)

- Impact of uncertainty
  - Shallow intrusion to extrusion ratio
  - Geochronology

- Range of explosivity of small-volume basaltic eruptions
  - PDF for explosivity
  - Impact of the repository itself on magma ascent
  - Ash and waste dispersion models

CNWRA VOLCANO PROBABILITY MODELS

Current probability models for direct magmatic disruption of the candidate repository suggest that:

$$P\,[N \geq 1,\ 10{,}000\ YR] = 5 \times 10^{-5} \text{ To } 6 \times 10^{-3}$$

Where N is the number of small-volume basaltic volcanoes. These are based on widely varying assumptions and solution strategies.

- All probability models indicate that volcanism is a PA concern
- A probability model that does not include geologic detail does not fully address the volcanism issue
- Range in current models strongly impacts PA

SUMMARY

RESULTS OF THE CNWRA ANALYSIS TO DATE:

- Vents cluster in time and space in the YMR
- Probability of eruptions has been highest near Crater Flat since at least the beginning of the Quaternary
- Probability of a new volcano forming within the candidate repository site, based on the nonhomogeneous model, is on the order of 1×10^{-4} to 3×10^{-4} in 10,000 years
- Markov models support the idea that volcanism is most likely to occur in the Crater Flat region in the future

CNWRA PROBABILITY MODELS WILL NOT BE COMPLETE UNTIL GEOLOGIC DATA ARE INCORPORATED TO A SUFFICIENT DEGREE, INCLUDING:

- Indirect effects
- Explosivity
- Structural and tectonic control

IT IS WORTH EXPLORING A FULL RANGE OF MODELS

- The effort that goes into model development is small compared to the effort that goes into data collection
- Test models using other volcanic fields will reveal strengths and limitations