RECORD

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Chuck Conner
5/1/93

CC

code output shown
on following graphs

```
for x = 2000 to 50000 step 2000

let prob1 = 1 - exp(-x*2e-6)
let prob2 =  1 - exp(-x*4e-6)
let prob3 =  1 - exp(-x*6e-6)
let prob4 =  1 - exp(-x*8e-6)
let prob5 =  1 - exp(-x*10e-6)

print prob1,prob2,prob3,prob4,prob5

next x

end
```


It's possible to estimate the prob. of volcanic eruption in the future in the YMR by using Poisson's equation:

$$\text{Prob}[N \geq 1, 10{,}000 \text{ yrs}] = 1 - \exp(-t \cdot \lambda)$$

where $t = 10{,}000$ and λ varies from 1e-6 to 15e-6.

This calculation indicates the probability of a new volcano forming anywhere in the region is 90% again.

The recurrence rate given is for anywhere from the lowest possible rate given by Crowe et al to a rate for the Cima volcanic field (also given by Crowe).

For late Quaternary rates, the Prob. of a volcano forming in this area in the next

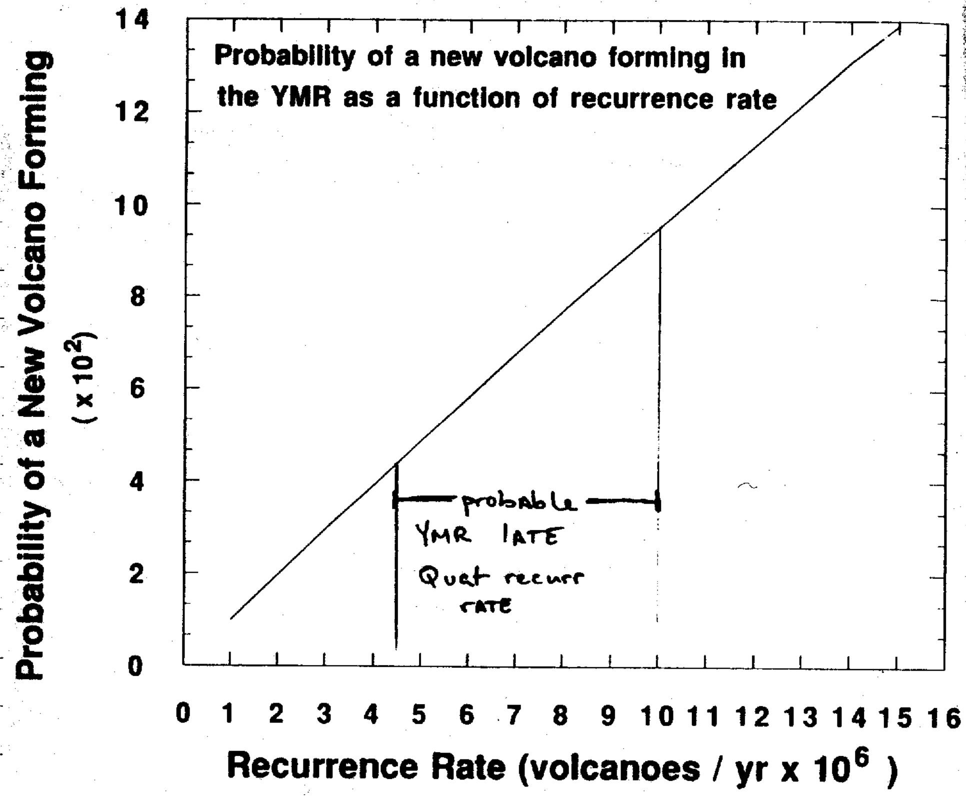
0.03 and 0.05.

Probability of a New Volcano Forming in 10ky.

$$P[N \geq 1, \lambda = 1e{-6}\ yr^{-1}] = 1 - e^{(-t\lambda)}$$

then the following graph represents change in risk of an eruption in the region w/ time, given the recurrence rate.

These calculations assume a Poisson model wrt time.

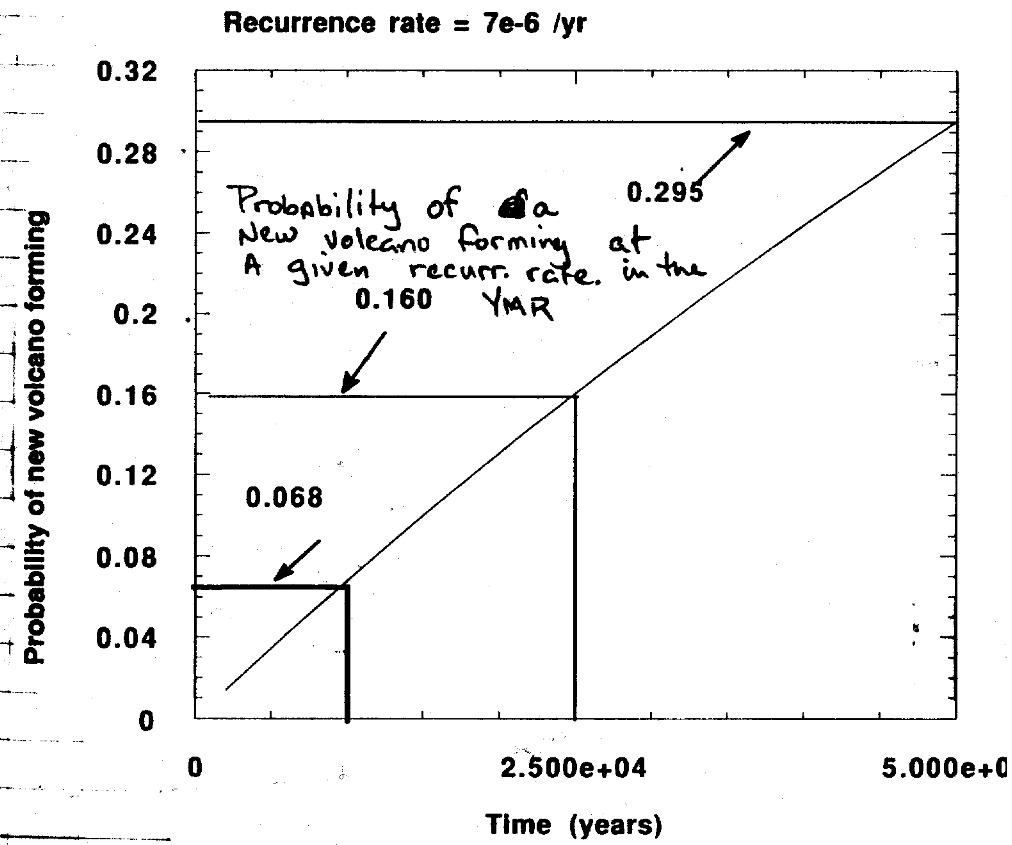


It is possible to use the same equation to consider the change in probability over different periods of time, keeping the recurrence rate constant.

For example, if $\lambda = 7e{-6}\ yr^{-1}$ and the calculation is done for various values of t

~~calculation is ...~~

various values of t



Time (years)

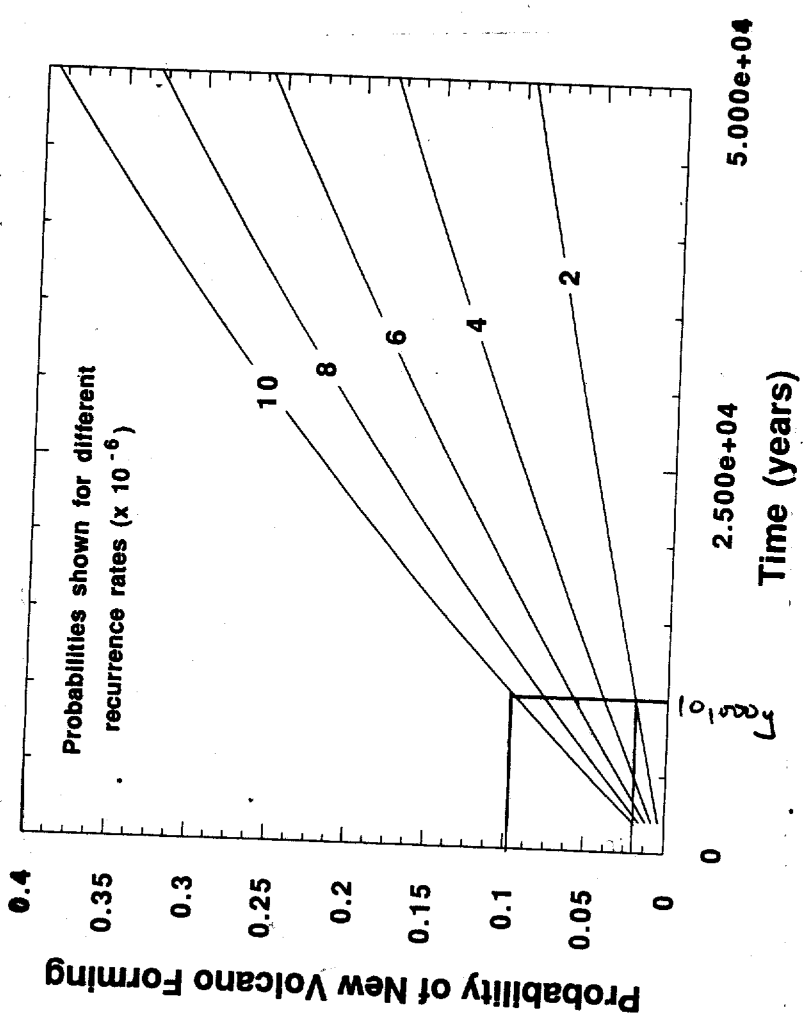
probability of a new volcano forming, given a range of recurrence rates, is shown at right ⟶ ▷

The probability of a new volcano forming in the Yucca Mtn Region during the next 10,000 yrs. varies from ~~[illegible]~~ ≈ 0.02 to 0.1 for different recurrence rates

For a 6×10^{-6} volcanoes/yr rate, the probability of volcanism occurring is about .05 or 5/100.

There is about a 1/4 chance of volcanism occurring in the region in the next 50,000 yrs. Assuming a rate of 6×10^{-6} v/yr and a homogeneous Poisson distribution wrt time

Probability of A New volcano forming at a given recurr. rate in the YMR



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working on the probability models using non homogeneous models.

- YMR → DATA used as input into the non-homogeneous models are given at right. These data are compiled from
Crowe, 1990
Crowe et al 1982; 1983
Vaniman and Crowe 1981
Crowe and Perry 1991

NonHomo. Poisson model used is based on the following assumptions:

(1) Recurrence rate in specific area is based on

CC 5/12 ~~$\hat{\lambda}_r = \sum_{i=1}^{m}$~~ (try again)

$$\hat{\lambda}_r = \frac{m}{\sum_{i=1}^{m} u_i t_i}$$

where m is the # nearest neighbor
$(u_i t_i)$ = min vents.
t_i is the age of the

Name	Age (Ma)	UTM easting	UTM northing	Name	Age (Ma)	UTM easting	UTM northing
Amargosa Valley SW	≈4.0	543376	4048820	Hidden Cone	0.3±0.2	523301	4113698
Amargosa Valley	≈4.0	544817	4050859	Timber Mountain	≈4.5	528129	4112249
Amargosa Valley NE	4.4	550306	4053139	Rocket Wash	8.0±0.2	535539	4109028
Lathrop Wells	0.13±0.05	543737	4060073	Buckboard Mesa	2.8±0.1	554946	4109111
Crater Flat S	3.7±0.2	541493	4066057	Pahute Mesa W	9.8±0.4	548758	4133489
Crater Flat E	3.7±0.2	543704	4067644	Pahute Mesa	8.8±0.1	554170	4134467
Crater Flat W	3.7±0.2	540584	4067787	Pahute Mesa E	≈9.8	561927	4132182
Crater Flat NW	3.7±0.2	539915	4070959	Paiute Ridge S	8.5±0.3	593698	4101888
Crater Flat W	3.7±0.2	536879	4068573	Paiute Ridge N	8.5±0.3	593611	4103166
Little Cone SW	1.2±0.4	534626	4069423	Scarp Canyon	8.7±0.3	595625	4103906
Little Cone NE	1.2±0.4	534825	4069884	Nye Canyon N	6.8±0.2	603210	4091744
Red Cone	1.2±0.4	537259	4071648	Nye Canyon	6.8±0.2	602370	4085671
Black Cone	1.2±0.4	538257	4074275	Nye Canyon SE	6.8±0.2	600999	4082470
Northern Cone	1.2±0.4	540088	4079455	Nye Canyon SW	6.8±0.2	599557	4083139
Little Black Peak	0.3±0.2	521298	4111346				

Table 1. Locations of volcanic centers and ages used for statistical models. Vent locations from Crowe (1990), and ages from Crowe et al. (1982; 1983), Vaniman and Crowe (1981), Crowe and Perry (1991), and Crowe, B.M., 1992, written communication. Vent coordinates in Universal Transverse Mercator, zone 11, Clarke 1866 spheroid.

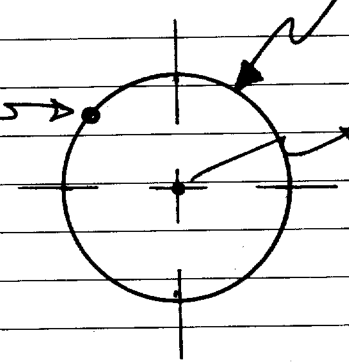
THIRSTY MESA

This is Thirsty Mesa, not Timber Mtn.

1st eruption (Age MA) in Table.

and U_i is the area of a circle swept out between the point and the near neighbor cone.

e.g.



The nearest m neighbors are determined by the minimum $U_i t_i$ product.

(2) The probability of repository disruption is given by

$$P[N \geq 1] = 1 - \exp\left[-t \iint_{XY} \lambda_r(x,y)\,dy\,dx\right]$$

$$P[N \geq 1] = 1 - \exp\left[-t \sum \lambda_{r_i} \Delta x \Delta y\right]$$

in these runs, $t = 10{,}000$ yrs.
Δx and Δy = 1 km each.

so in practice the $\lambda_r(x,y)$ recurrence rate is estimated for a 1 km^2 area.

These 1 km^2 area recurr. rates are summed:

e.g.: for a repository of 8 km^2 → eight estimates of the recurr rate are summed. [in this case the $\Delta y \Delta x$ multiplier = 1]

AND $P[N \geq 1]$ is calculated.

The value of $P[N \geq 1]$ will vary with the area and location chosen.

1 km^2 blocks give a fairly crude outline of repo.

also, need to consider areas slightly > than perimeter area because the area of the volcanic center is larger than a point, → based

on work by Smith et al (1990) → 500m is a reasonable estimate but this can prob. be improved on.

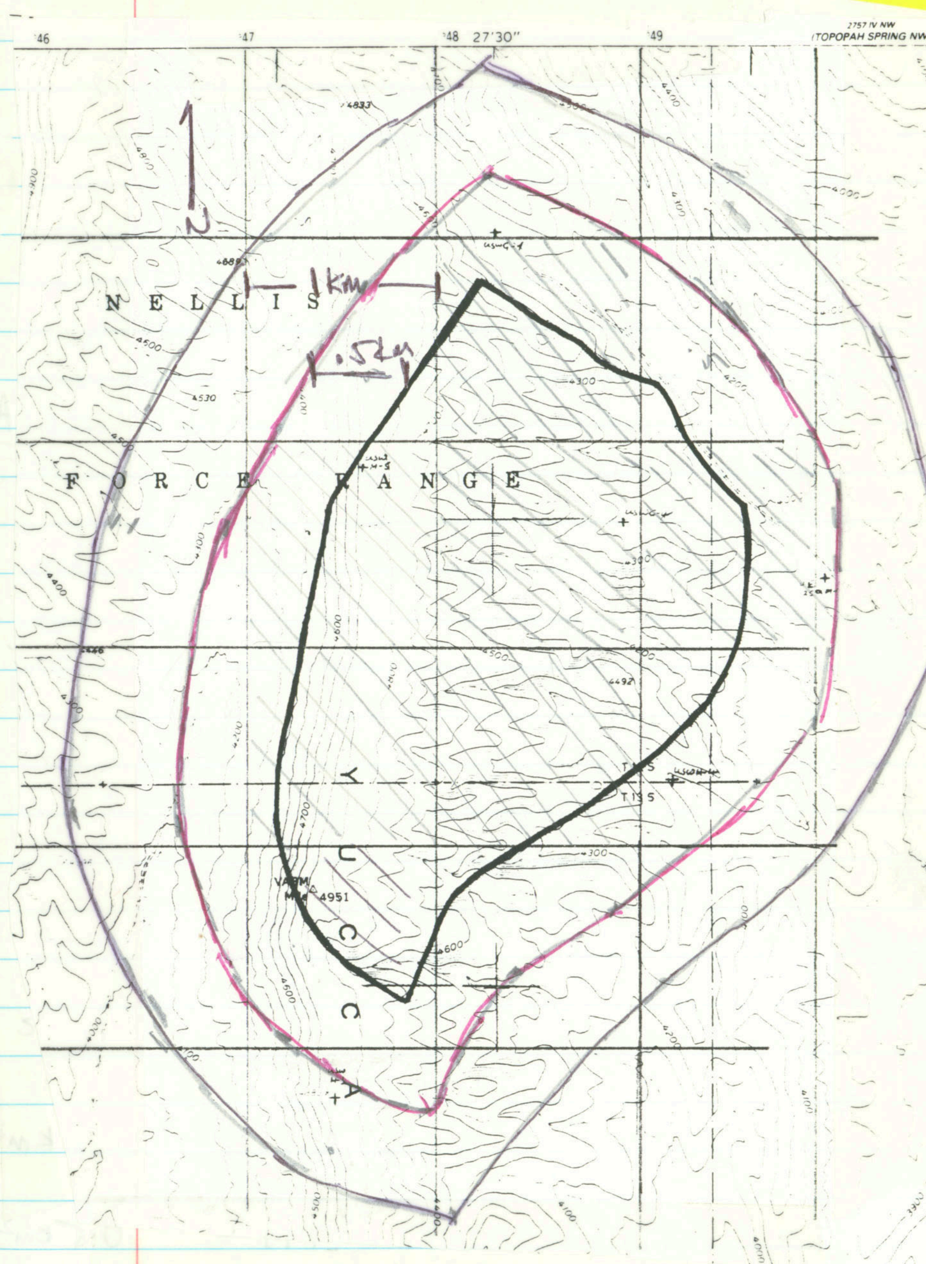
The Area of the repository, heavy line (at right) is about 5.2 km^2

The area enclosed in red line (extending about 500m beyond the repo. perimeter) is about 10.2 km^2

The area enclosed by pencil line (extending about 1km beyond the repo. perimeter) is about 16.7 km^2

Similarly → a "control area" of area 8km^2 would require a perimeter extending about 300m beyond the current repo ~~tim~~ boundry. 7km^2 "control area" is like extending the boundry about 200m, and 6km^2 control area is like extending the boundry about 100m.

This is likely also a probability density fn. How does the

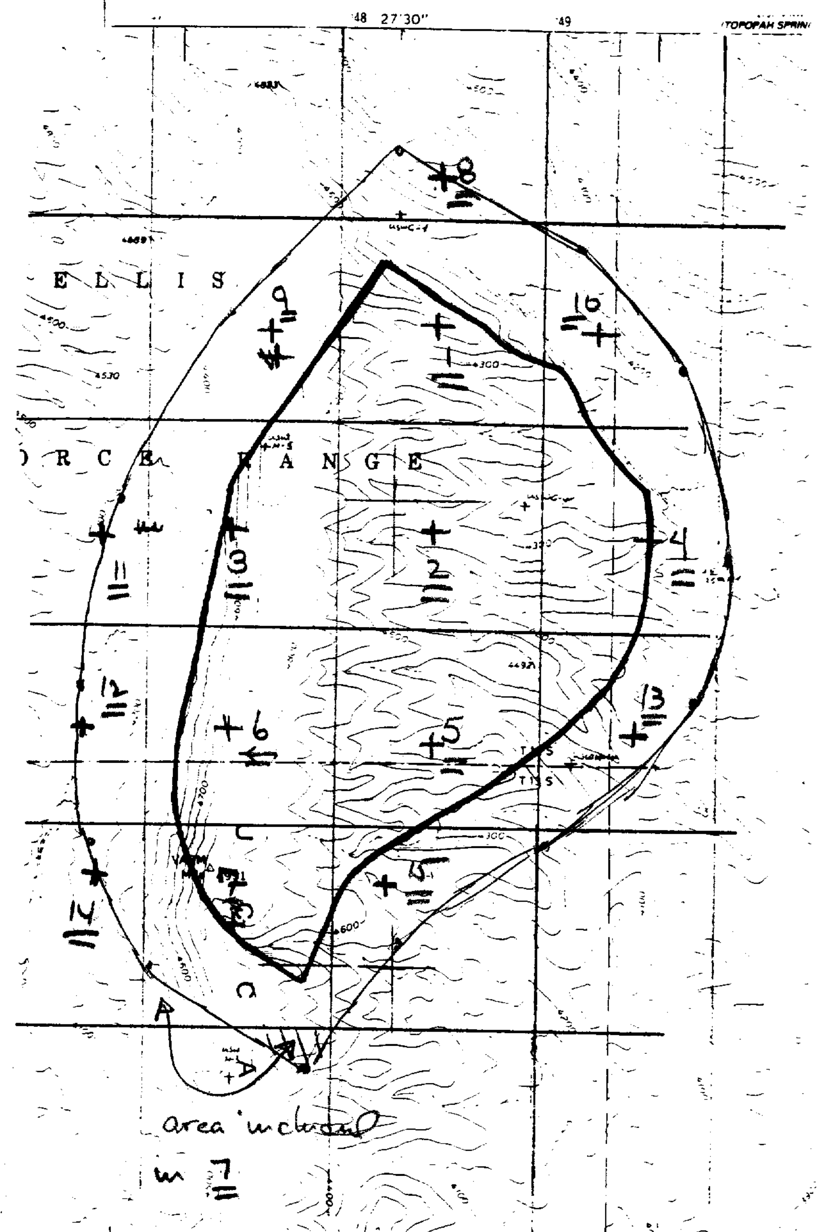


probability of direct disruption decrease with increasing distance from the perimeter.

for calculating recurrence rate over the repo. area (10 Km²), where boundary extends 500m from perimeter of actual repository

15 grid nodes are specified for the 10 Km² area.

	EAST	North (UTM)	Ar.
(1)	5485⁰⁰	40795 ~~00~~	1 km²
(2)	5485⁰⁰	40785 ~~00~~	1 km²
(3)	~~5495~~ 5475⁰⁰	40785 ~~00~~	1 km²
(4)	5495⁰⁰	40785 ~~00~~	1 km²
(5)	5485⁰⁰	40775 ~~00~~	1 km²
(6)	5475⁰⁰	40775⁰⁰	1 km²
(7)	5475⁵⁰	40765⁰⁰	1 km²
(8)	5485⁰⁰	40802⁵⁰	0.2 km²
(9)	5477⁵⁰	40795⁰⁰	0.5 km²
(10)	549250	40795⁰⁰	~~0.2~~ 0.5 km²
(11)	546750	40785⁰⁰	0.15 km²
(12)	546750	40775⁰⁰	~~.25~~ 0.25 km²



	E	N	A
(13)	549500	40775⁰⁰	0.7 Km²
(14)	546750	40765⁰⁰	0.1 km²
(15)	548250	40765⁰⁰	0.5 km²

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TOTAL AREA is 10 km^2.

The repository recurrence rate is

$$\hat{\lambda}_r = \sum_{i=1}^{15} \hat{\lambda}_i \cdot A$$

Recurrence rate ~~(km^2)~~ (ce 5/14) in expected events / km^2 for each of the 15 grid nodes

$\hat{\lambda}_i$ reported for 1NN CASE

grid node	$\hat{\lambda}_i \times 10^{-8}$
1	1.22
2	1.35
3	1.38
4	1.31
5	1.50
6	1.54
7	1.72
8	1.13
9	1.24
10	1.20
11	1.40
12	1.57
13	1.45
14	1.76
15	1.68

Based on the i = 15 (10 km^2) area model: These are prob. of disruption:

# of Near Neighbors	Prob of disruption (in 10,000 yrs)
1	1.41×10^{-3}
2	7.4×10^{-4}
3	4.8
4	3.4
5	2.5
6	2.1
7	1.68
8	1.44
9	1.26
10	1.13
11	1.02
12	0.93
13	0.85

There are grid nodes used:

```
let grid(1,1)  = 548500
let grid(2,1)  = 548500
let grid(3,1)  = 547500
let grid(4,1)  = 549500
let grid(5,1)  = 548500
let grid(6,1)  = 547500
let grid(7,1)  = 547500
let grid(8,1)  = 548500
let grid(9,1)  = 547750 !
let grid(10,1)  = 549250
let grid(11,1)  = 546750
let grid(12,1)  = 546750
let grid(13,1)  = 549500
let grid(14,1)  = 546750
let grid(15,1)  = 548250
```

```
let grid(1,2)  = 4079500
let grid(2,2)  = 4078500
let grid(3,2)  = 4078500
let grid(4,2)  = 4078500
let grid (5,2)  =4077500
let grid(6,2)  = 4077500
let grid(7,2)  = 4076500
let grid(8,2)  = 4080250
let grid(9,2)  = 4079500
let grid(10,2)  = 4079500
let grid(11,2)  = 4078500
let grid(12,2)  = 4077500
let grid(13,2)  = 4077500
let grid(14,2)  = 4076500
let grid(15,2)  = 4076500
let gridpts = 15
```

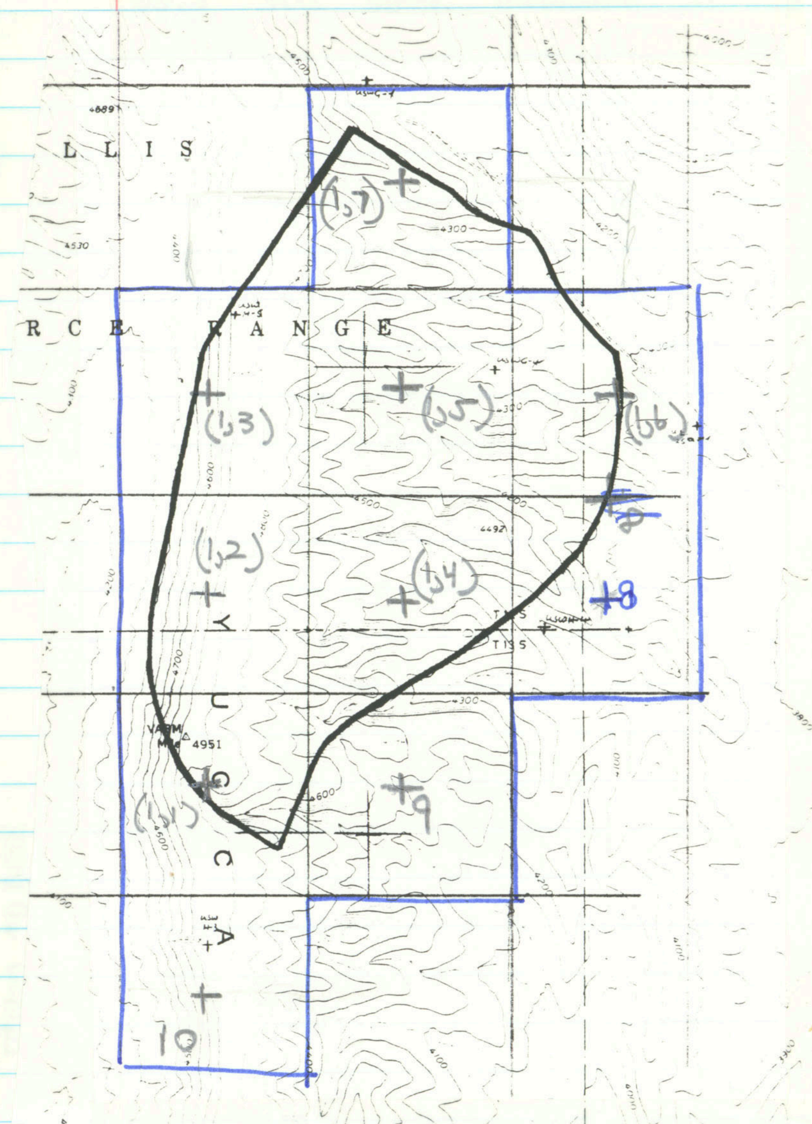
An alternative, easy method is to estimate the prob. of disruption using a more blocky (naive) approximation of the shape of the repository (right →)

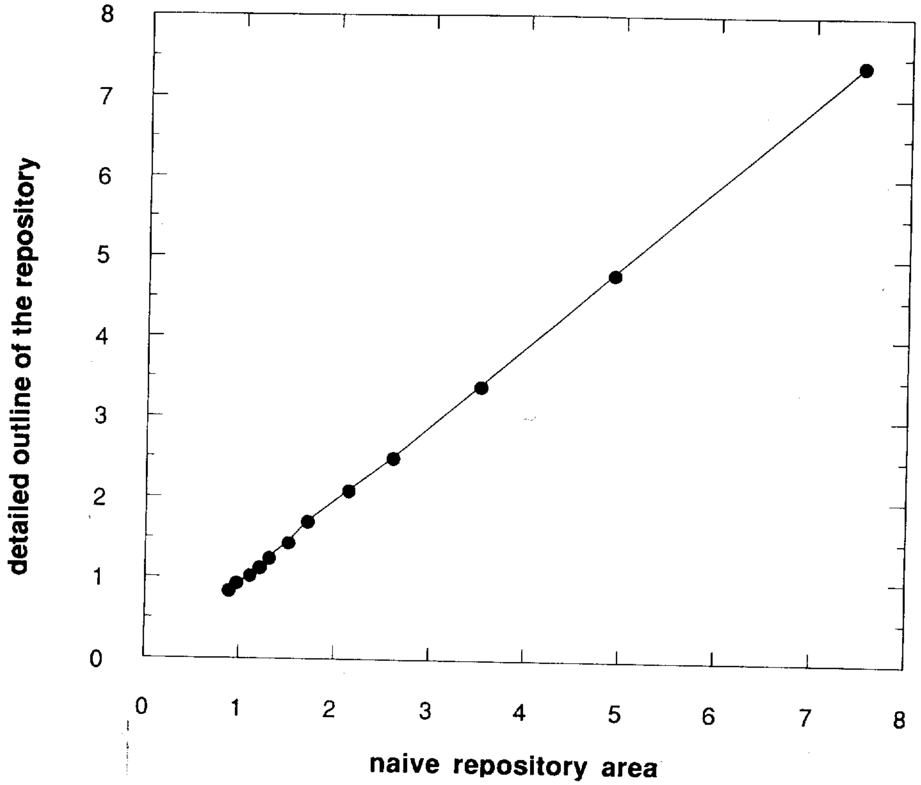
near neigh	Prob. Dis. (10^{-4}) in 10,000 yrs.
2.0000	7.5000
3.0000	4.9000
4.0000	3.5000
5.0000	2.6000
6.0000	2.1400
7.0000	1.7000
8.0000	1.5000
9.0000	1.3000
10.000	1.2000
11.000	1.1000
12.000	0.96000
13.000	0.87000

This blocky approach gives the same result as the more detailed approach.

So the variation in recurrence rate is small enough from place to place (on repository scale) to justify using a coarse approximation.

This is true regardless of the no. of near neighbors used.

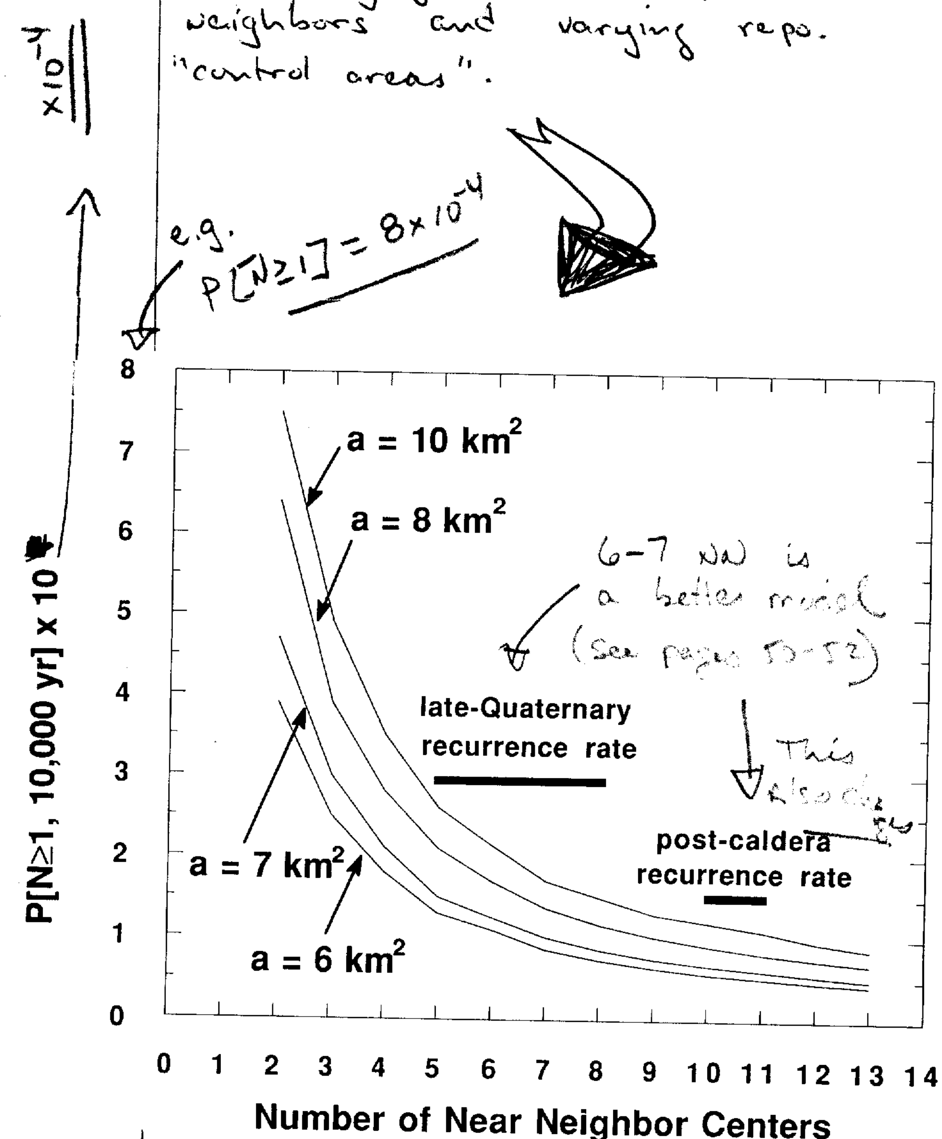




Graph of the relationship between detailed repository probability calculation (model using areas outlined on page 27) and simplified repository outline (model using area outlined on page 31). Trivial differences between these models.

Using the same approach, probabilities are calculated for varying numbers of near neighbors and varying repo. "control areas".

e.g. $P[N\geq1] = 8\times10^{-4}$



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It is Also possible to work through the calculations for a repository area at crater Flat.

Purpose: Calculate probability of disruption of one repo area in Crater Flat. This calculation is done to illustrate if:

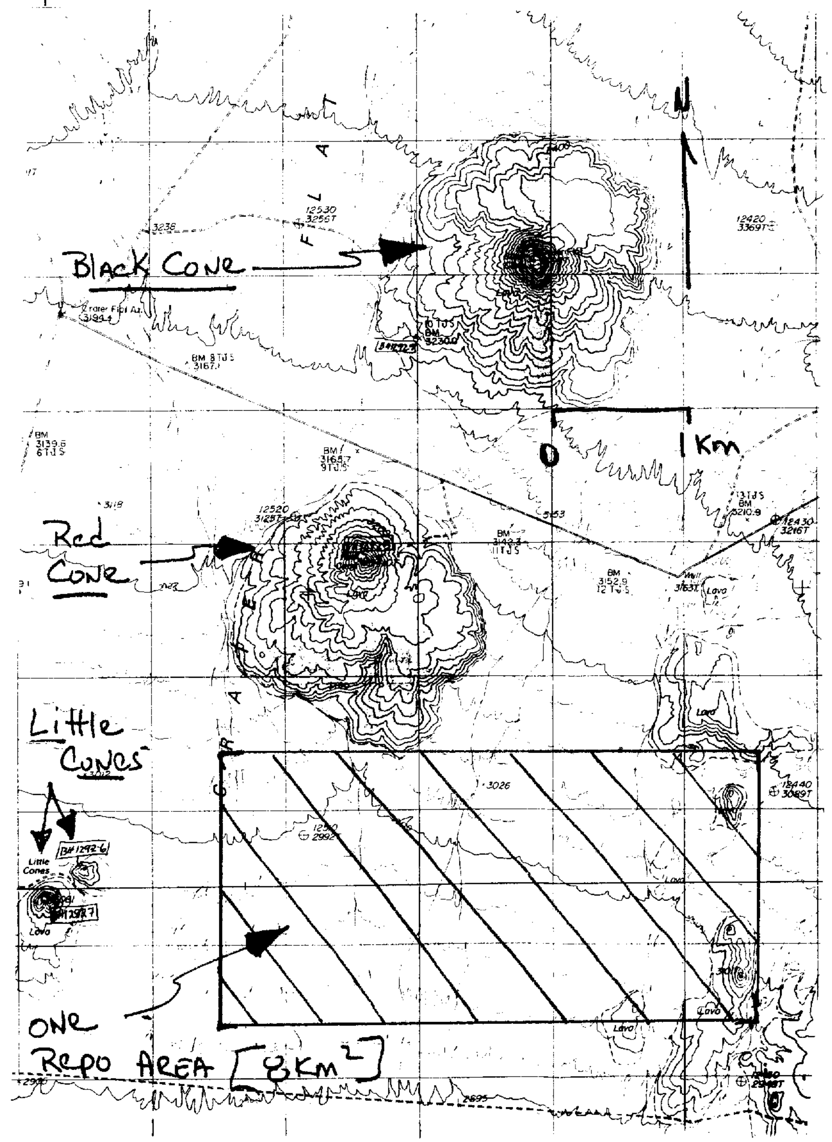
(1) a repository even in crater flat would be qualified / disqualified on the basis of volcanism

and to:

(2) calculate ~~max~~ approximate maximum risk for the area.

(3) illustrate the power of the nonhomogeneous Poisson and similar models.

The Area chosen was 8 km² shown at right →



MAp Above illustrates the location of one repo. Area in CRATER FlAt → for which probabilities Are calculated.

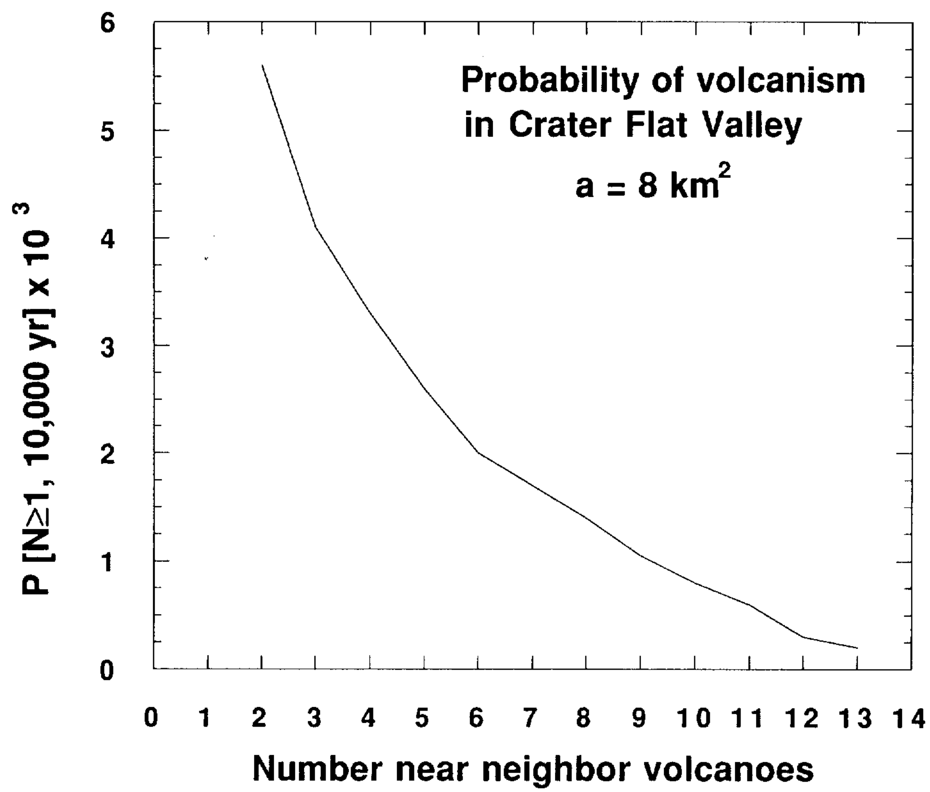
The centers of the 1 x 1 km grid cells used in calculation are:

```
let grid(1,1) = 540000      let grid(1,2) = 4070000
let grid(2,1) = 540000      let grid(2,2) = 4069000
let grid(3,1) = 539000      let grid(3,2) = 4070000
let grid(4,1) = 539000      let grid(4,2) = 4069500
let grid(5,1) = 538000      let grid (5,2) =4070000
let grid(6,1) = 538000      let grid(6,2) = 4069000
let grid(7,1) = 537000      let grid(7,2) = 4070000
let grid(8,1) = 537000      let grid(8,2) = 4069000
```

For these coordinates, the prob of disruption of 1, $8 km^2$ repository area is:

This calculation is for disrupt. of $8 km^2$ AREA in CRATER Flat

Near Neighbor	P[N≥1 event] 10,000 yrs
1	1.2×10^{-2}
2	5.6×10^{-3}
3	4.1×10^{-3}
4	3.3 "
5	2.6 "
6	2.0
7	1.7
8	1.4
9	1.05
10	0.8
11	0.6
12	0.3
13	0.2

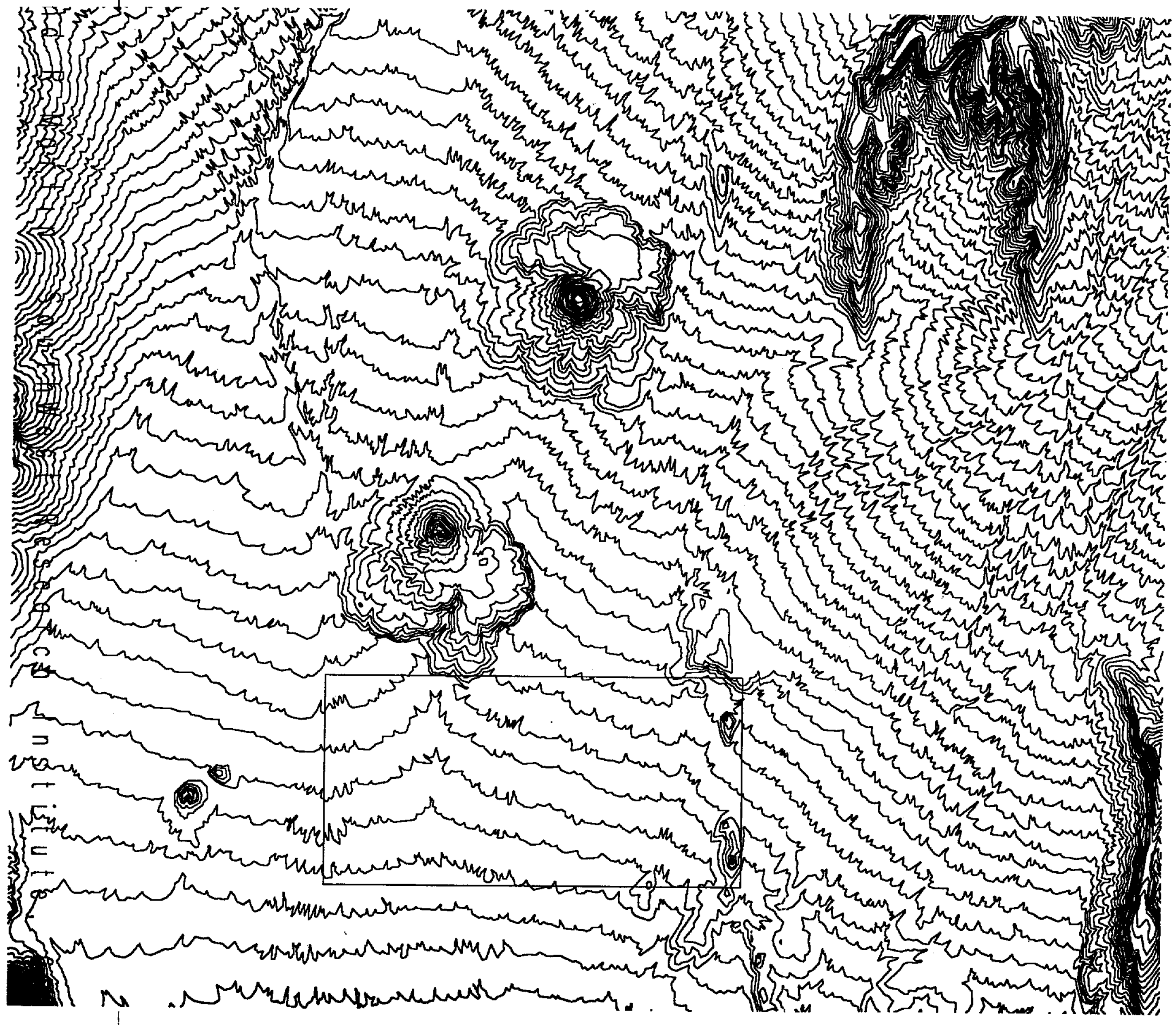


Five to 8 Near neighbors gives the range for the late Quaternary recurrence rate.

The box A right shows the Area used for probability calculations on previous pages.

The Area is $8\ km^2$

Topographic map at 1:60,000 of Crater Flat Valley



CONTOUR INTERVAL = 20 feet

N

To distinguish between nonhomogeneous probability models. The λ is estimated on a grid over the entire YMR.

As before:

$$\hat{\lambda}_r = \frac{M}{\sum_{i=1}^{M} u_i t_i} \quad ; \quad u_i > 1\,km^2$$

These $\hat{\lambda}_r$ values are calculated on a 40 x 40 grid over an entire region using a 2 km grid spacing.

Then the regional recurrence rate can be calculated using this grid of $\hat{\lambda}_r$.

$$\hat{\lambda}_t = \int_{\bar{X}} \int_{\bar{Y}} \lambda_r(x,y)\, dy\, dx$$

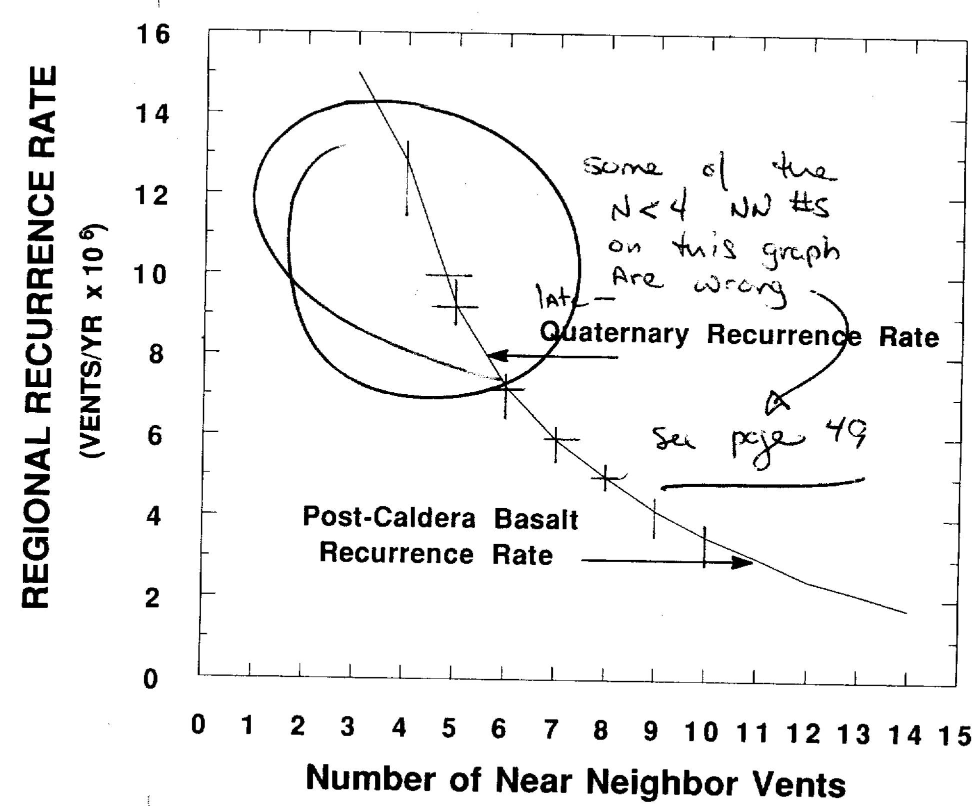
where $\bar{x}$ and $\bar{Y}$ are the regions of ~~interest~~ interest.
cc 5/17

$\bar{X}$ and $\bar{Y}$ must be big enough so $\lambda_r(x,y) \equiv 0$ at the boundary of the map.

The regional recurrence rate is calculated by summing over the whole region

$$\hat{\lambda}_t = \sum_{i=0}^{M} \sum_{j=0}^{N} \hat{\lambda}_r(i,j)\, \Delta x\, \Delta y$$

So, $\hat{\lambda}_t$ is calculated from $\hat{\lambda}_r$, which in turn can be calculated using different #'s of near neighbor volcanoes.



MAY 18 chuck C[illegible]

ESTIMATES OF The late-QUATERNARY recurrence rate vary quite a bit.

Ho et al. (1991) → 5.0 to 6.0 $\times 10^{-6}$/yr

but Ho et al (1991) do not consider error in the ages of young vents For example:

CRATER FLAT : 1.2 ± 0.4 my

So these vents could easily be as young as 0.8 my or as old as 1.6 m.y.

Sleeping buttes could be as old as .5 or as young as .1 → .3 ± .2 my

and Lathrop is as young as ~~[illegible]~~ 0.13 ± 0.05 for its formation.

using the youngest possible Ages:

5 CRATER FLAT VENTS AT 0.8 my
2 SLEEPING Buttes vents At 0.1 my
and LATHROP WELLS AT 0.08 my

This gives 8 vents in 800,000 yrs or ~~8×10^{-6}~~ 10×10^{-6} vents / yr

A point near the center of the repository Site is:

UTM:
NORTHING : 4077500 m
EASTING : 548500 m

Visit Report for whole Repo.

For 8 km^2 repository (approximated by blocky outline) I get the following results

For youngest ages:
CF = 0.8 my
LW = 0.08 my
SB = 0.1 my

6 Near Neighbors

Grid PT.	λ_i (MEAN Ages)	λ_i (youngest Ages)
1	2.53e-9	3.81e-9
2	2.38e-9	3.60e-9
3	2.23e-9	3.50e-9
4	2.09e-9	3.23e-9
5	1.97e-9	3.21e-9
6	2.06e-9	3.45e-9
7	1.84e-9	3.18e-9
8	1.79e-9	2.97e-9

For N=6 Near Neighbor and 8 km^2:
P[disruption using mean ages] = $\underline{1.69 \times 10^{-4}}$

P[disruption using youngest age] = $\underline{2.69} \times 10^{-4}$

using the oldest possible ages:

CF volcanoes = 1.8 my

SB " = 0.5 my

LW " = 0.18 my

For 6 NNs and 8 km^2

grid point	λ_i (oldest ages)
1	1.92 e-9
2	1.78 e-9
3	1.67
4	1.56
5	1.47
6	1.55
7	1.38
8	1.34

Probability of disruption given the oldest possible ages is

P[N≥1, oldest ages] = 1.27×10^{-4}

So there is a big uncertainty in the Probability of disruption of the repository introduced by uncertainty in the Ages of volcanoes

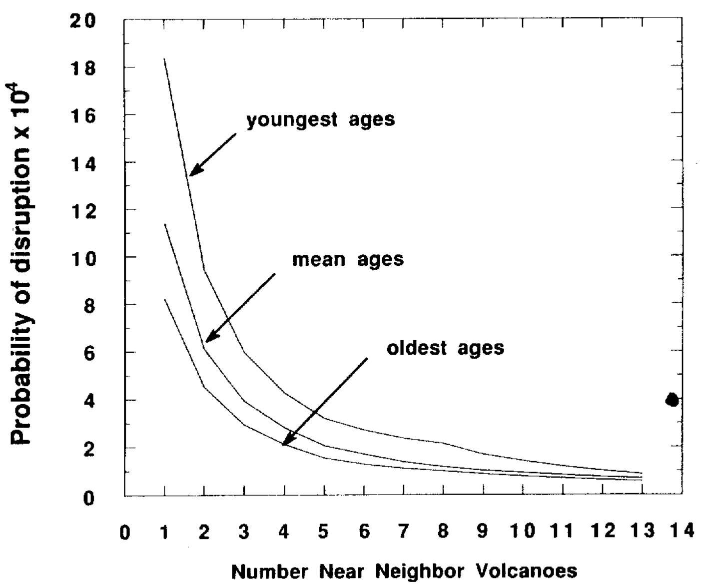
Bounding the probability Analysis using errors in Age [8 km^2 repo area]

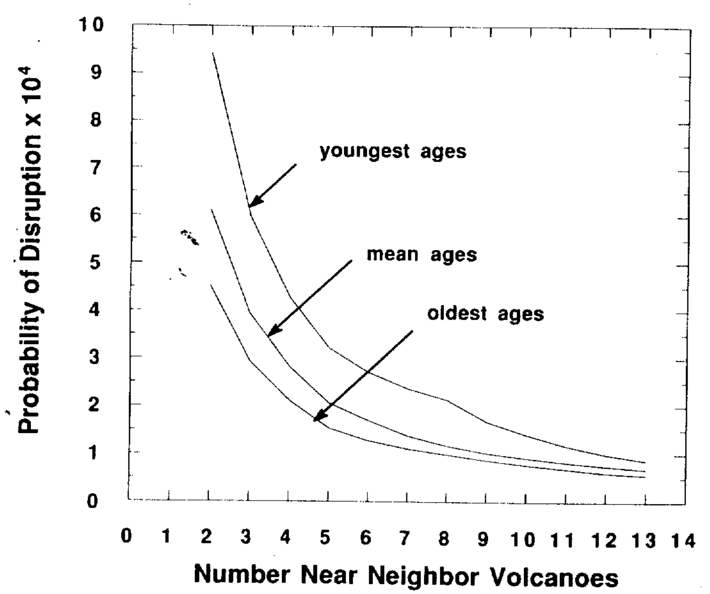
Near Neighbor	P[oldst]	P[mean]	P[youngest]
1	8.2×10^{-4}	1.14e-3	1.8e-3
2	4.52×10^{-4}	6.11e-4	9.43e-4
3	2.93 "	3.93 "	5.97e-4
4	2.11 "	2.82 "	4.27 "
5	1.53 "	2.05 "	3.20 "
6	1.27 "	1.69 "	2.70 "
7	1.10 "	1.37 "	2.36 "
8	0.987 "	1.17 "	2.13 "
9	0.87 "	1.02 "	1.68 "
10	0.77 "	0.915 "	1.41 "
11	0.69 "	0.828 "	1.18 "
12	0.61 "	0.752 "	1.00 "
13	0.56 "	0.685 "	0.87

CC 5/18 → if mean ages are used except Lathrop = 0.08 my

	P[disruption]
1	1.84e-3
2	~~7.1e-4~~ 7.1e-4
3	4.21e-4
4	2.94e-4
5	2.10
6	1.72
7	1.38
8	1.18
9	1.03
10	0.920
11	0.832
12	0.755
13	0.687

Probability of disruption in 10,000 yrs.





Area of repository is 8 Km^2

Calculations at left are for 8 Km^2 repository. The probability of disruption is calculated for various Near Neighbors and for a 10,000 yr period.

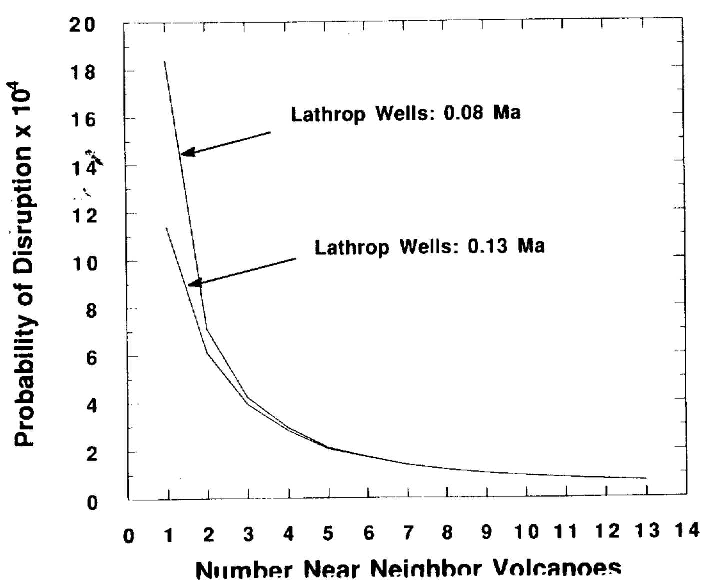
Three curves are shown. Mean curve uses current best estimates for mean Quaternary ~~vent~~ volcano ages. These are the mean values reported on page 21. Oldest age and Youngest age curves show the probabilities calculated using the Oldest possible ages and youngest possible ages for late Quaternary volcanoes.

The graph at top left shows the calculation for N = 1 to 13 near Neighbor volcanoes.

The graph at bottom left shows the ~~ca~~ calculation for N = 2 to 13 Near Neighbors. This change expands the scale because Lathrop Wells has a big effect on N = 1 Near neighbor calculations and changing the age of L.W. has an important influence on N=1 models.

Just looking at Lathrop wells Age and its effect on repository disruption:

Use mean Ages of All volcanoes AND a Mean age of Lathrop wells of 0.13 my for time of formation. Then use mean Ages of all volcanoes and use a young age for formation of Lathrop: 0.08 my. This has a big effect on N<4 Near neighbor models. But no effect on Near Neighbor models, N>4.



Recurr rate →

No. Near Neighbor	[Mean Ages]	[oldest]	[youngest]
1	4.95×10^{-4}	3.56×10^{-4}	8.8×10^{-4}
2	5.16×10^{-5}	3.64×10^{-5}	1.13×10^{-4}
3	2.02×10^{-5}	1.59×10^{-5}	3.28×10^{-5}
4	1.28×10^{-5}	1.00×10^{-5}	1.97×10^{-5}
5	9.2×10^{-6}	7.20×10^{-6}	1.40×10^{-5}
6	7.24×10^{-6}	5.68×10^{-6}	1.09×10^{-5}
7	5.89×10^{-6}	4.68×10^{-6}	8.8×10^{-6}
8	4.97×10^{-6}	3.97×10^{-6}	7.4×10^{-6}
9	4.16×10^{-6}	3.41×10^{-6}	5.89×10^{-6}
10	3.52×10^{-6}	2.95×10^{-6}	4.75×10^{-6}
11	3.02×10^{-6}	2.57×10^{-6}	3.97×10^{-6}
12	2.46×10^{-6}	2.06×10^{-6}	3.31×10^{-6}
13	2.13×10^{-6}	1.8×10^{-6}	2.84×10^{-6}

These regional recurrence rates are calculated using the program RECURMAP.TRV and using the methods described on pages 40-41.

IF the youngest regional recurr rate is used → 8 volcanoes ≤ 0.8 my Then 6 to 7 near neighbors is right.

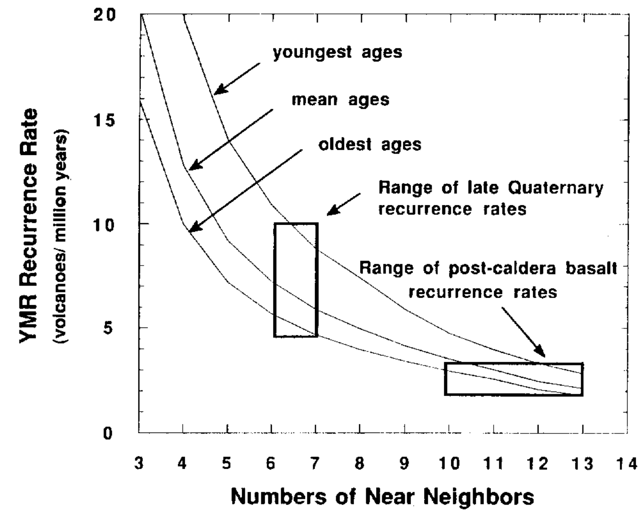
IF the mean ages are used then

there are 8 volcanoes ≤ 1.2 my old.
The recurrence rate is $6-7 \times 10^{-6}$ v/yr
and, again 6 to 7 near neighbors
is best.

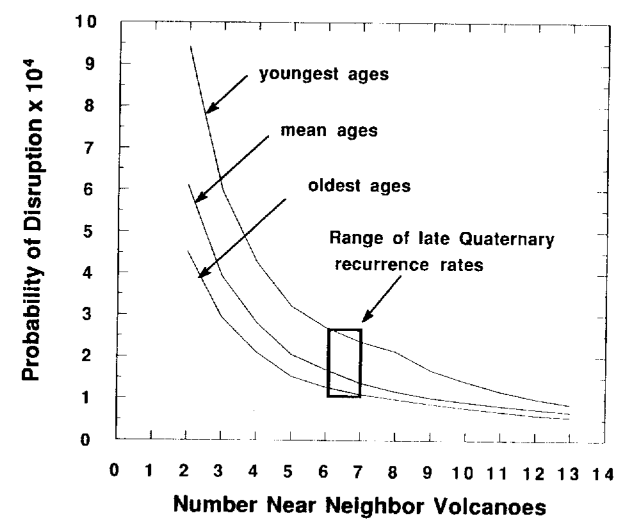
IF the oldest ages are assumed
8 volcanoes in the last 1.6 my.
The recurrence rate is about 5×10^{-6} v/yr
using the oldest rate → this, is
6-7 Near Neighbors.

So, regional recurrence rates estimated
using Averages over time since the
start of Quaternary activity are
5×10^{-6} to 1.0×10^{-5} v/yr, depending
on the Age of ~~3~~ Crater Flat Volcanoes.
Using the mean value from Geochron.
studies → $6-7 \times 10^{-6}$ v/yr.

Regional recurrence rate can also
be estimated by integrating
the Near Neighbor model over the
region. Models using 6-7 Near
Neighbors best Approximate the
regional YMR recurrence rate



10-13 near neighbors approximate
the post-caldera basalt rate.



using the six-seven near neighbor model, the probability of disruption of 8 km² by a new volcano forming is between 1.10×10^{-4} and 2.7×10^{-4} in 10,000 yrs., given the uncertainty in ages of late Quaternary volcanoes.

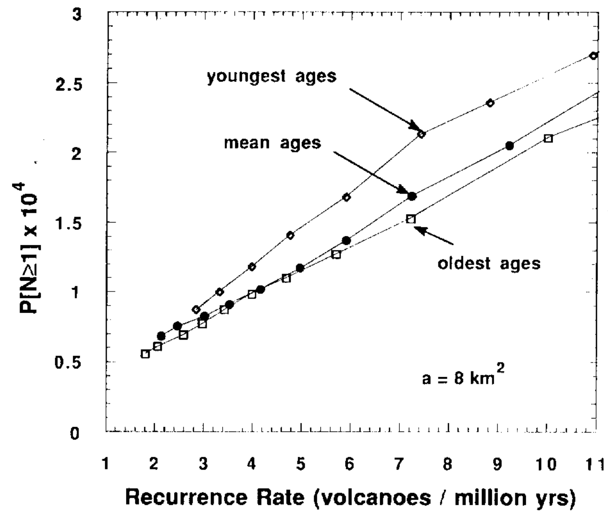
using A mean age the probability of disruption is between 1.4 and 1.7×10^{-4} in 10,000 yrs., given a recurrence rate of 5.9 to 7.2 volcanoes / m.y.

5/19 cc

~~Combing~~ Combining data sets on pages 45 and 49, the probability of disruption can be plotted as a fn of recurrence rate, using young, mean, and old ~~dates~~ ages. For an 8 km² repository there is a fairly linear relationship between the YMR recurrence rate and the probability of volcanic disruption.

For repositories of area 6 km² to 10 km²: [$\times 10^{-4}$]

	6 km²	7 km²	8 km²	10 km²
6 Near N	1.1	1.25	1.7	2.1
7 "	0.86	1.01	1.4	1.7



AS A WORST CASE senario:

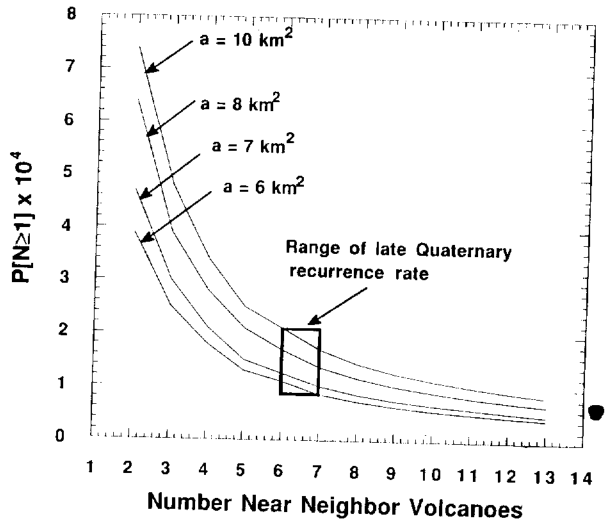
10 km² area
youngest rate
6 NN
} 3.4×10^{-4} in 10,000 yrs.

10.9 volcanoes / m.y.

AS A BEST CASE senario:

6 km² Area
oldest rate
7 NN
} 0.85×10^{-4} in 10,000 yrs.

4.7 volcanoes / m.y.



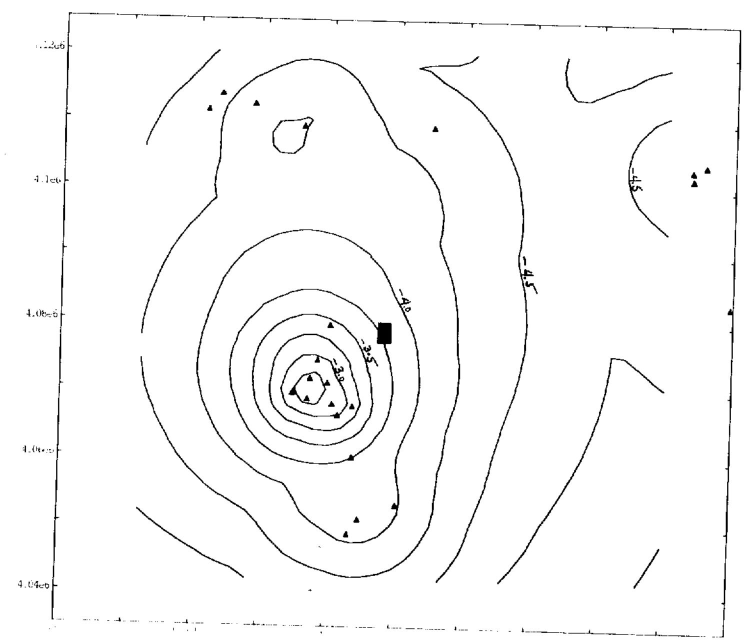
CC

May 20, 1993 Chuck Connor

5/20

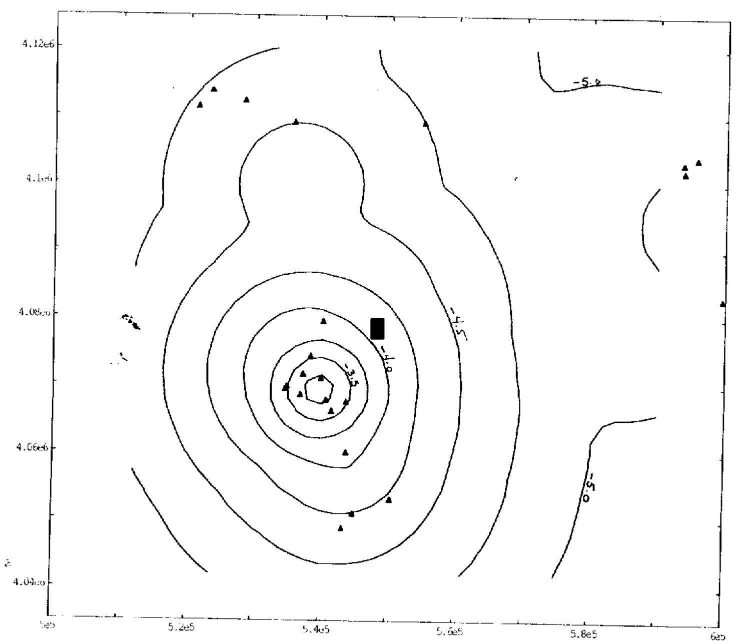
CC ~~DATA A~~ The probability of volcanism is contoured over the YMR. This is done by calculating the recurrence rate on a grid using near neighbor methods. Then probability is calculated over an 8 km^2 area for next 10ka years.

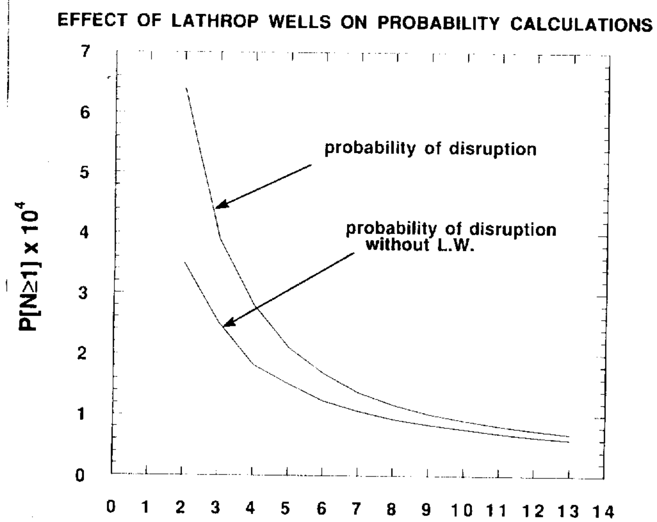
Map below is for 6 NN which is Quat. Recurrence rate. The log of probability is contoured.



Highest probability of disruption is in crater Flat → for six near neighbors have prob. of volcanism of more than 1/1000

Deleting Lathrop wells from calculation doesn't change the shape of the probability surface much but it does change the absolute





probability of repository disruption.

Prob. of disruption is greater than w/out Lathrop and the effect is more substantial than would be for a homogeneous Poisson model, in which recurrence rate would change only.

June 1, 1993 LCCJ

Cerro Negro. → This illustrates some preliminary calculations of erupt dynamics

data on eruption

Between 23:20 hrs on April 9 and 17:00 hours on April 10 → most ash fall

17:75 hours

7.5 km ash column height

~~.01 km³ DRE~~ .04 - .05 DRE

Average eruption rate of 450-650 m^3/sec

From Lionel Wilson 1978

$$Q = \rho V S (T_M - T_A) F$$

F = efficiency factor of heat transfer to the atmosphere ≈ 1

T magma - T atmos = 1100°C

Specific heat = 1.1×10^{3} J/kg°K

ρ = 2500 kg/m³

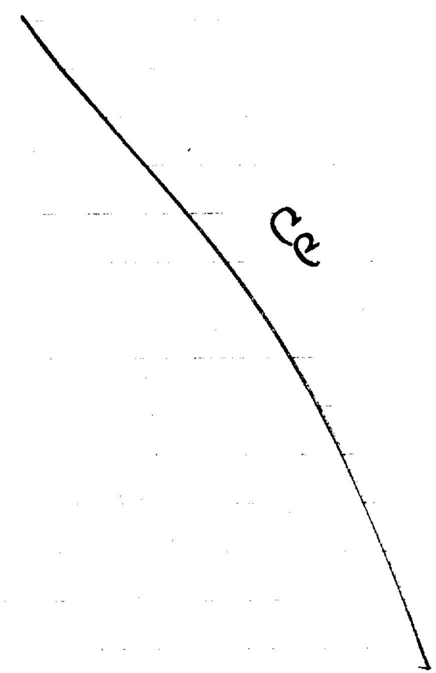
Q = 1,361,250 Watts - 1,361,250 watts

$H = 8.2\ Q^{1/4}$ for maintained column

$H = 1.37\ Q^{1/4}$ for instantaneous explosion

H = 307 m

H =



Ce

7/21/93

Notes from Noel Cressie's book:
stats. for spatial data (1991)

Any point process is

$\{z(s) : s \in D\}$ locations of the pts.
$D = \{s_1 \ldots s_n\}$
measures on the pts. (diameters)
$\{z(s_1) \ldots z(s_n)\}$

can also have a random point process that is a hybrid space-time process

$$\{z(s,t) : s \in D(t),\ t \in T\}$$

probability model that includes polycyclic volcanism is an example of a S-T process.

Using the K-function → best way to characterize spatial pattern at multiple scales [i.e. more robust than the Hopkin's F-test and Clarke-Evans]

$$\hat{K}_1(h) = \hat{\lambda}^{-1} \sum_{i=1}^{N} \sum_{\substack{j=1 \\ i \neq j}}^{N} I(\|s_i - s_j\| \le h)/N$$

where

$\hat{\lambda}^{-1} = |A|/N$ or the area / number of volcanoes

$\|s_i - s_j\|$ = the distance between the volcano s_i and volcano s_j

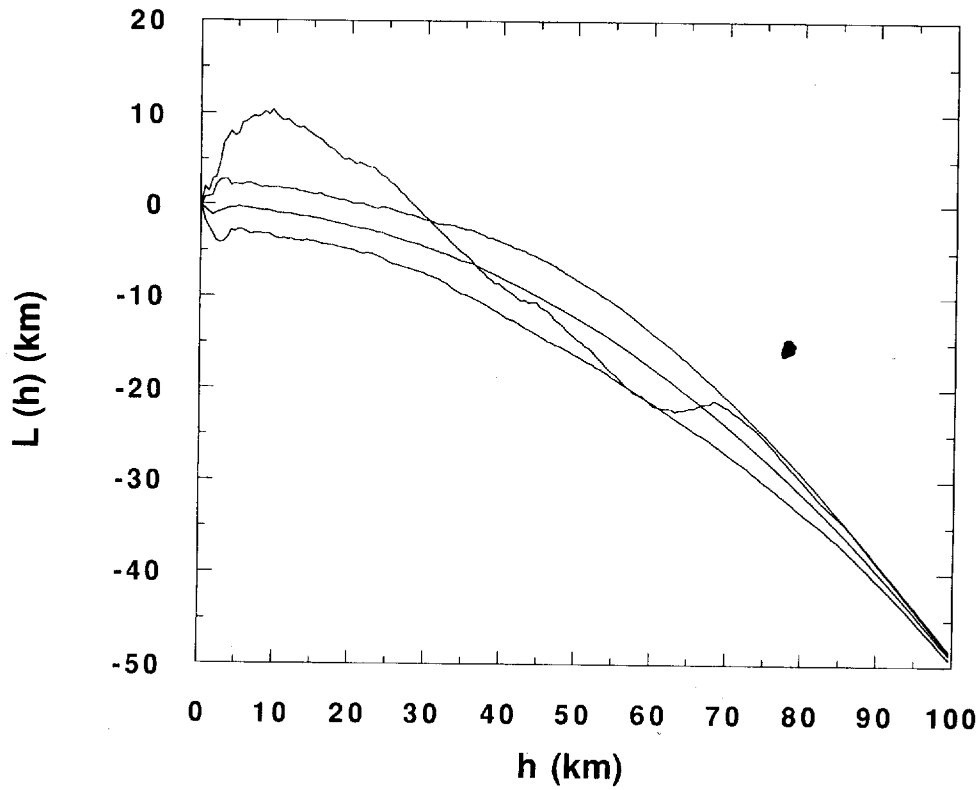
h is a variable and is some distance term
N is the total # of volcanoes

$I(\|s_i - s_j\| \le h)$ is an "indicator fn"

if the distance between s_i and s_j is less than h then $I(\|s_i - s_j\| \le h) = 1$
otherwise $I(\cdot) = 0$

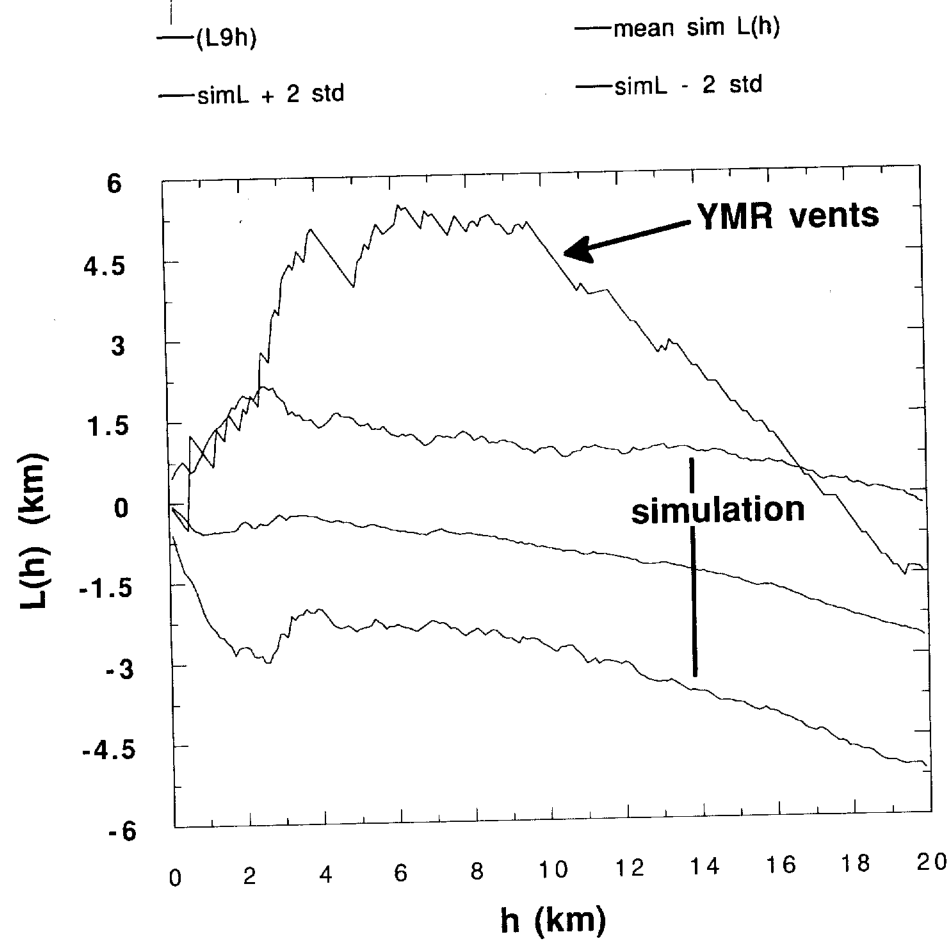
(see page 615-618, Noel Cressie).

L -Function Plot for YMR
with 95% CI for csr
(square study area)



This is done for all vents w/in the AMRV.

This uses the program – K-function



Clear from the plots that cinder cones cluster in the YMR at values of h(km) between 3 and 17 km, with ~ const. value of L(h) between 4 and 10 km
=> is this the cluster radius?

~~Tues~~ July 30

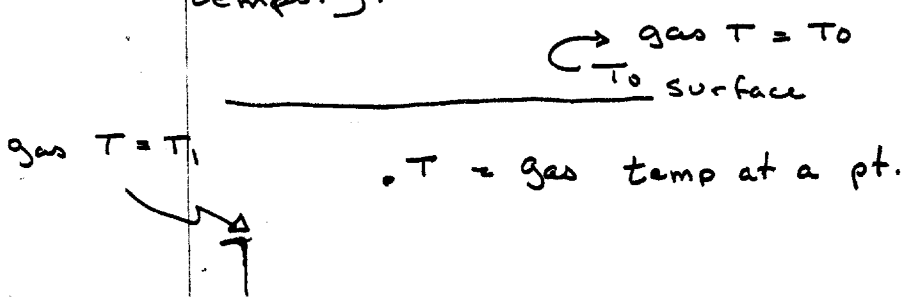
working on TASK 1 of field volcanism project. Problem is how to develop preliminary boundary-value models for degassing about a dike.

This is a coupled heat-mass transfer problem and needs to accomodate both forced and free convection.

The TOUGH code might be useful in solving this but initially it might be better to solve continuity, Darcy's law and energy equ. using a stream function. In this case:

$$\Theta = (T - T_0)/(T_1 - T_0)$$

where T is the temperature at a pt. To is the gas temperature at the surface (Far from heat source) and T_1 is the temperature of gas at the source (magmatic temps.).

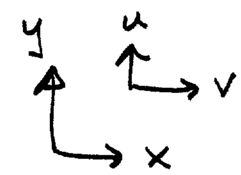


Θ is introduced as a similarity variable because it simplifies boundary value problem.

ψ is introduced as stream function where

$$u = -\partial\psi/\partial y$$

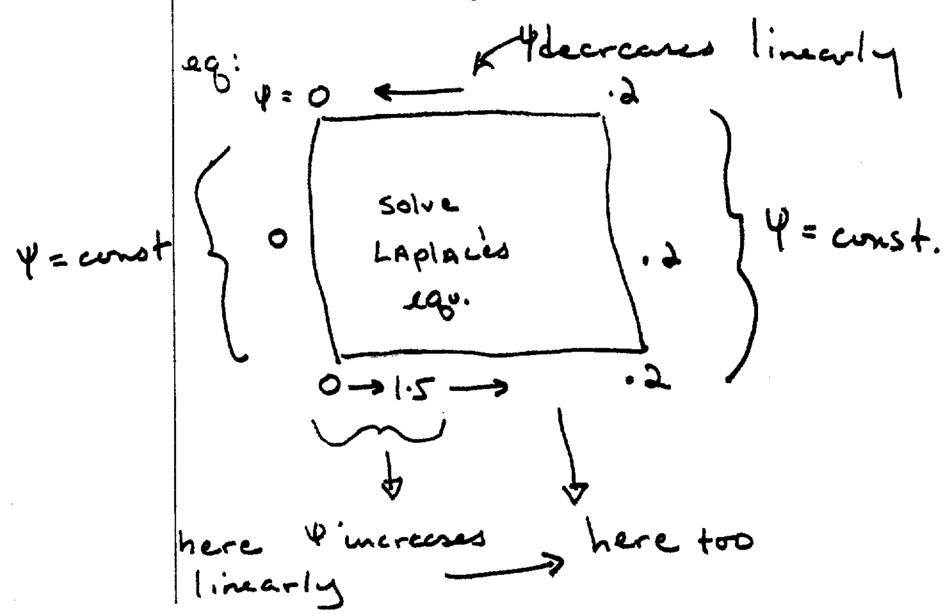
$$v = \partial\psi/\partial x$$



and u and v are components of the velocity field.

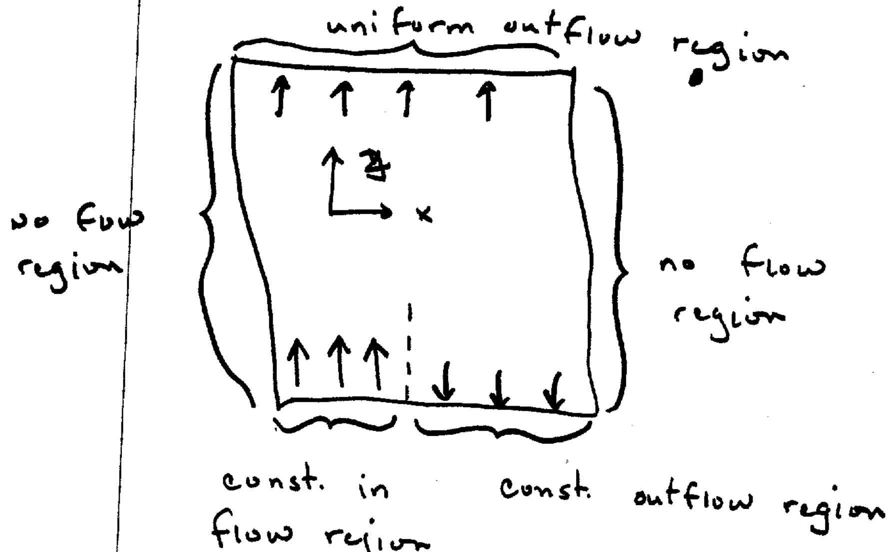
The velocity field can be solved for if the boundary conditions are specified using LaPlace's equation.

eg:

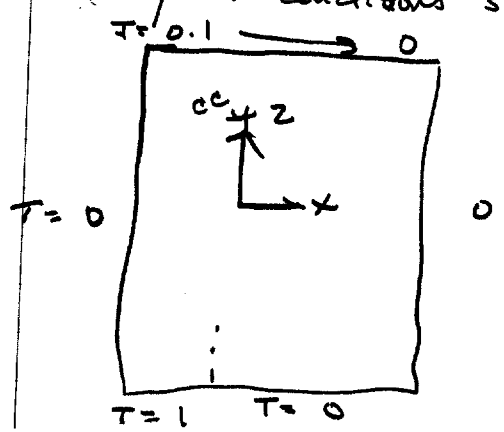


when ψ is increasing linearly then velocity is constant.; when ψ is constant then a no flow condition exists.

so boundary conditions on last page illustrate:



specify T conditions simultaneously



~~Bous~~ ce

Boussinesq approximation to mass, continuity, energy equations uses the stream fn.

$$\frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial z^2} = \frac{\partial \psi}{\partial x} \cdot \frac{\partial \theta}{\partial z} + \frac{\partial \psi}{\partial z} \cdot \frac{\partial \theta}{\partial x} \qquad (1)$$

ce

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial z^2} = n \frac{\partial \theta}{\partial x} \qquad (2)$$

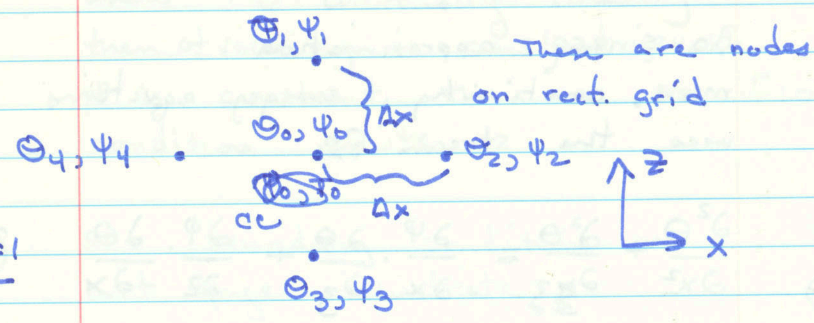
the only knew variable is n

n is Raliegh's number, as n increases the degree of convection increases

Solving (1) and (2) simultaneously by finite differences.

STEP 1: $\frac{\partial \psi}{\partial x}$, $\frac{\partial \psi}{\partial z}$, $\frac{\partial \theta}{\partial x}$ must be estimated. The easy way to do this is first solve the ψ and θ functions everywhere by specifying boundary conditions and using LaPlace's eqn.

STEP 2: solve ① using finite differences.



$\Delta x = 1$

solve for Θ_0

Ⓐ $\dfrac{\partial \Psi}{\partial x} \cdot \dfrac{\partial \Theta}{\partial z} = \dfrac{(\Psi_1 - \Psi_3)(\Theta_2 - \Theta_4)}{2}$

Ⓑ $\dfrac{\partial \Psi}{\partial z} \cdot \dfrac{\partial \Theta}{\partial x} = \dfrac{(\Psi_2 - \Psi_4)(\Theta_1 - \Theta_3)}{2}$

$\Theta_0 = [\Theta_1 + \Theta_2 + \Theta_3 + \Theta_4 + A + B] / 4$

→ let this converge and recalculate $\dfrac{\partial \Theta}{\partial x}$ everywhere

STEP 3: solve ② using finite differences

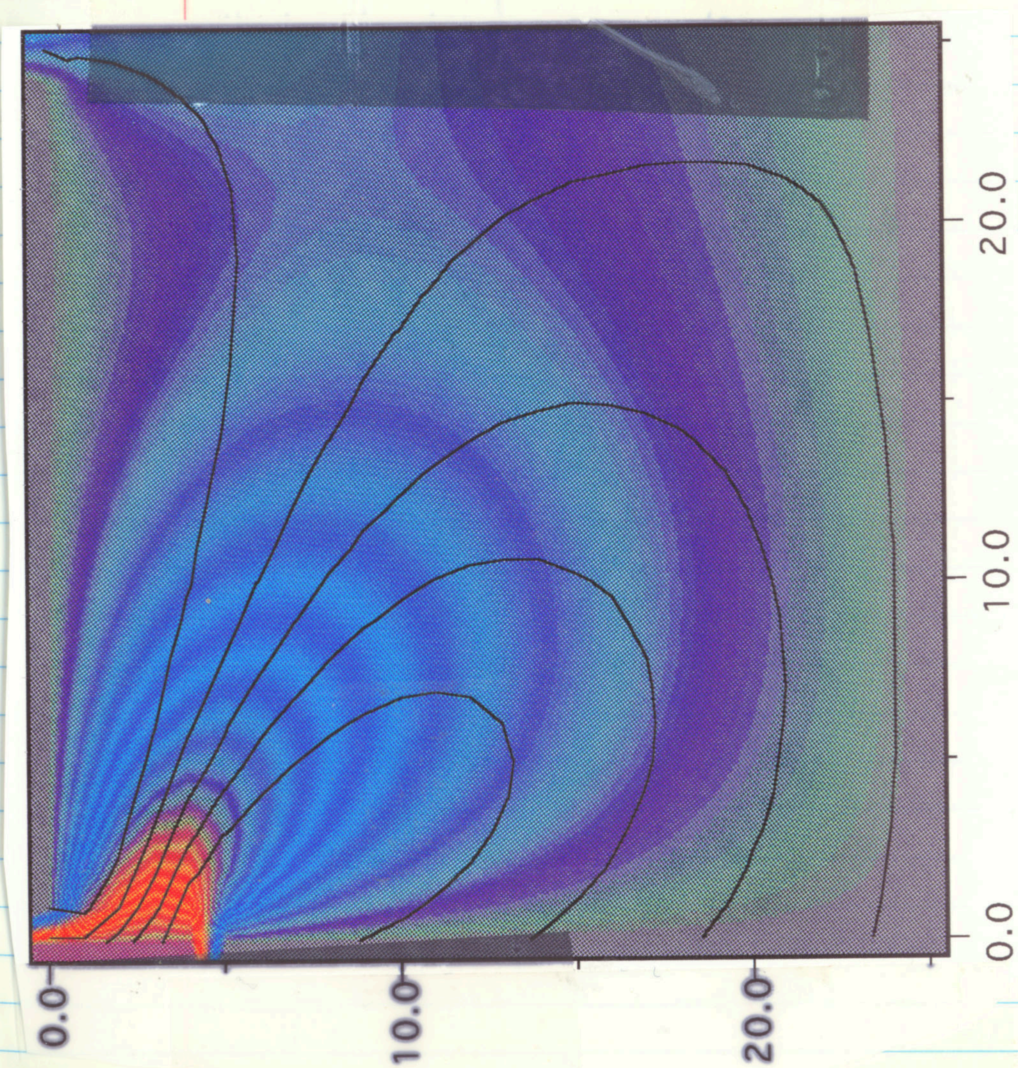
Ⓒ $n \cdot \dfrac{\partial \Theta}{\partial x} = n \cdot (T_2 - T_4) / 2$

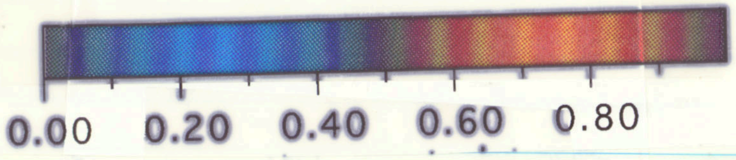
$\Psi_0 = [\Psi_1 + \Psi_2 + \Psi_3 + \Psi_4 - C] / 4$

let this converge.

④ repeat step 2-3 until there is no change in Θ, Ψ between successive iterations.

> Using the boundary conditions specified on pages 64-65, calculate H+M transfer:





This colorbar shows the variation in θ across the section. Stream lines are shown as solid black lines [previous page]

This solution closely mirrors the solution of Ballestracci [1982, Bulletin, Volcanologuie 45: 349-365].

The difference between this and Ballestracci's solution is that

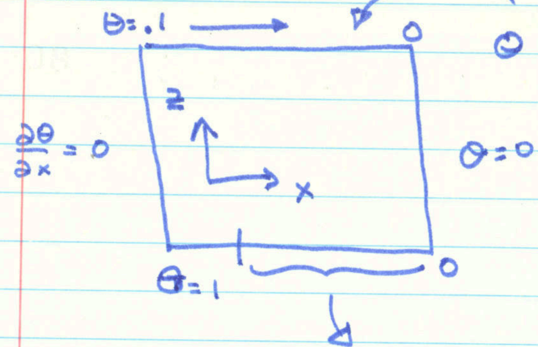
Ballestracci specified a ~~const~~ ~~heat~~ no heat flow condition on left-hand wall [$\partial\theta/\partial x = 0$] rather than $\theta = 0$

cc

Varying Boundary conditions:

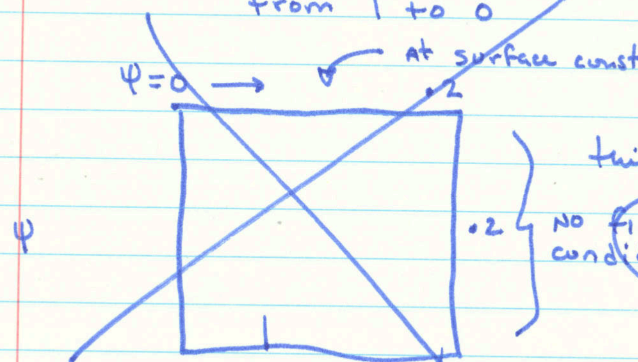
In the flowing diagrams the Boundary conditions are const, but different from the previous diagram.

The new boundary conditions are



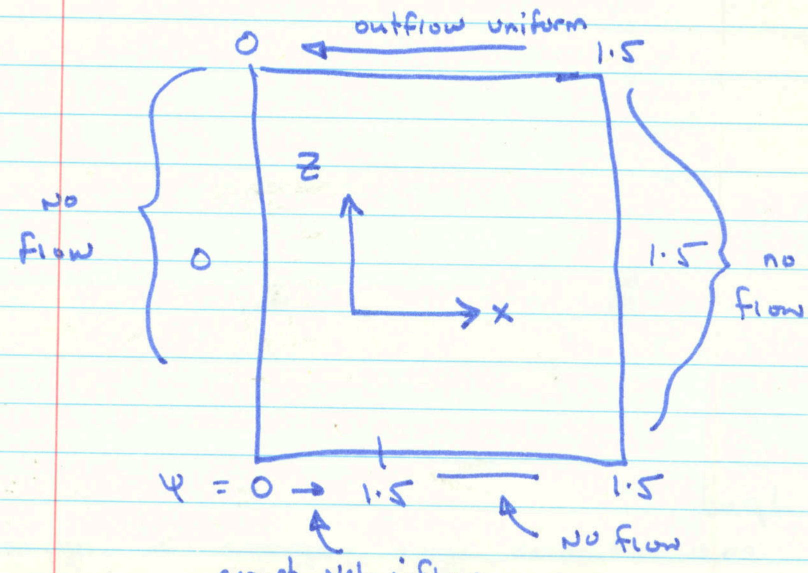
θ decreases linearly from 0.1 to 0

θ decreases linearly from 1 to 0

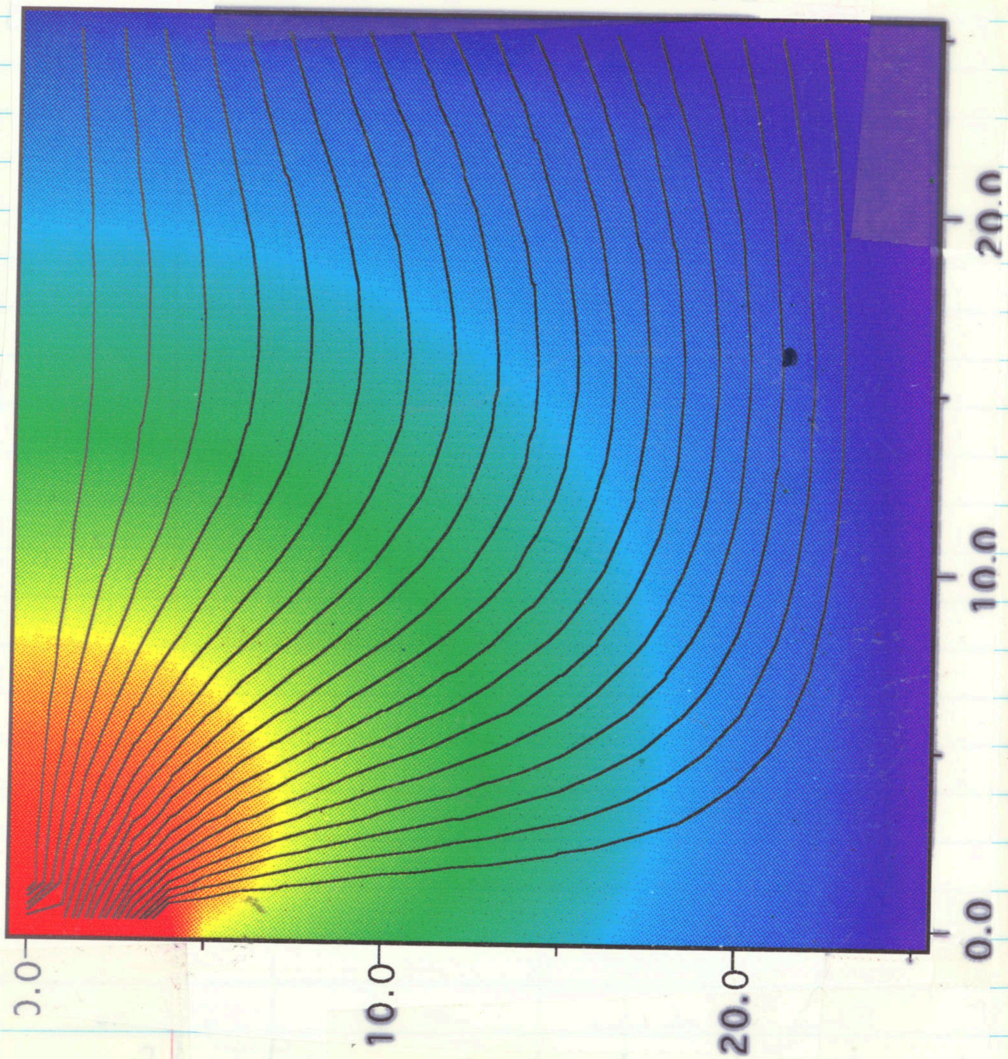


this is Wrong

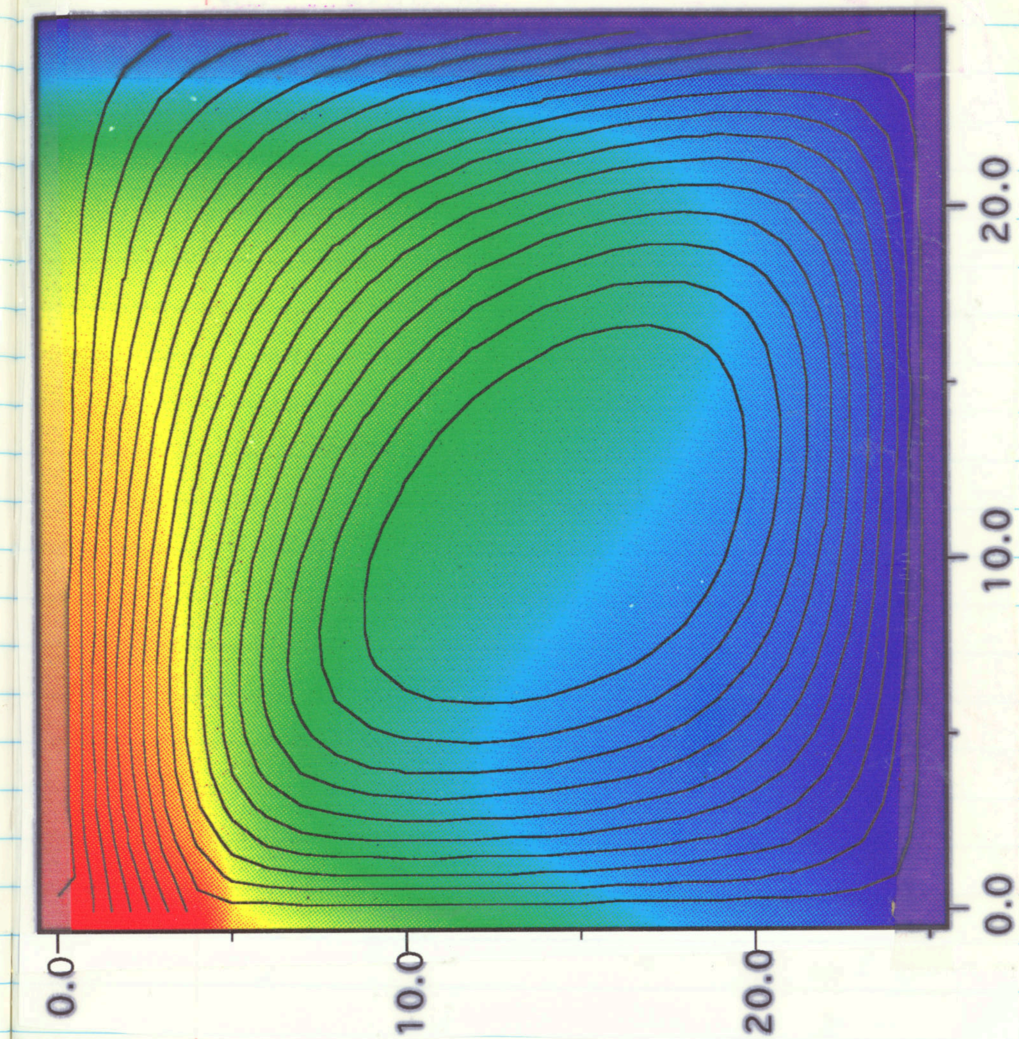
cc



N=0 [boundary conditions on pg. 71]



N=2 [boundary conditions on page 71]



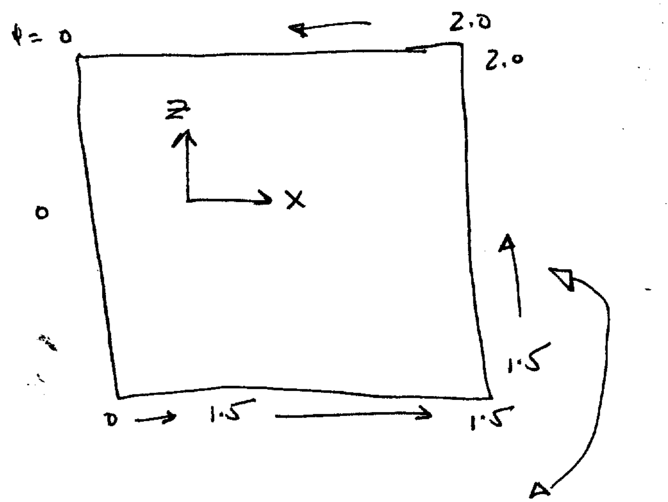
These solutions have the same boundary conditions. Only Rayleigh number is changed. Flow velocities are much higher for N=2.

August 9 Chuck [illegible]

Continuing w/ Bossinesq Approximation to solve for fumarole / dike gas transport.

In the previous solutions (i.e., pg 72-73) the only source of gas was the hot dike.

Now consider a small inflow of gas from the rt. wall. This gas is initially cold. The boundary conditions for the stream fn are



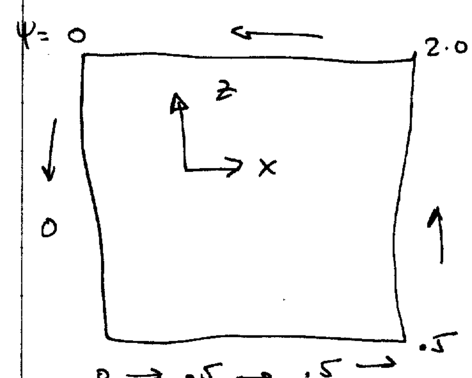
so the inflow on the rt. wall is low compared to inflow from the dike. Temperature boundary conditions are as before.

Files created for stream function and temperature using these boundary conditions as a fn of the Rayleigh #.

Rayleigh #	File Name
0	P1.dat , T1.dat
.25	P2.dat , T2.dat
.5	P3.dat , T3.dat
.75	P4.dat , P5.dat
1.0	

post-script files printed for
T1-P1
T3-P3
T5-P3

Change boundary conditions to increase outflow / inflow of cold gas and decrease inflow of hot gas



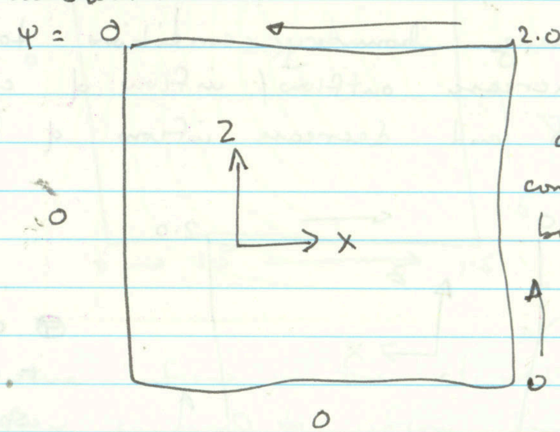
θ conditions remain the same.

For the new stream function boundary conditions

Rayleigh #	Files
0	p6 , T6
.25	p7 , T7
.5	p8 , T8
1.0	p9 , T9

These runs are saved as postscript files p6-T6, p7-T7, ~~p8~~ T8-p8 and T9-P9.

> final session with this type of model - no flow of mass from cooling dike, only flow from "groundwater"

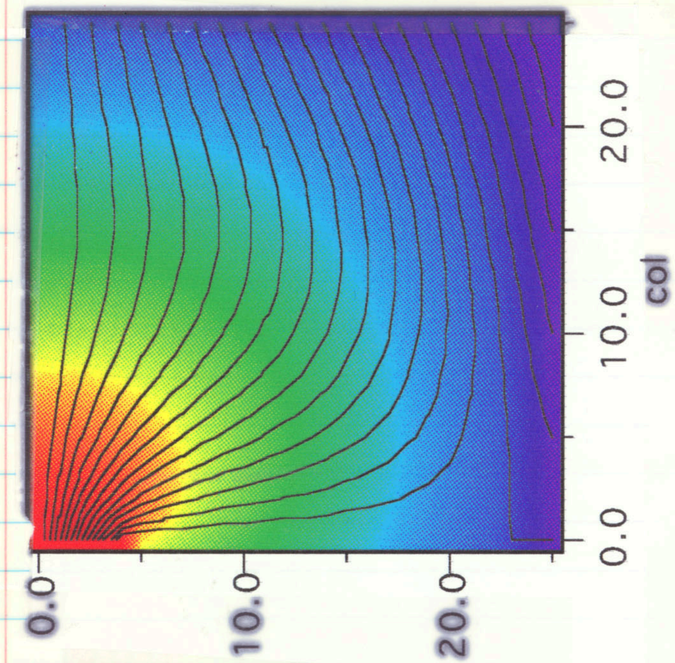


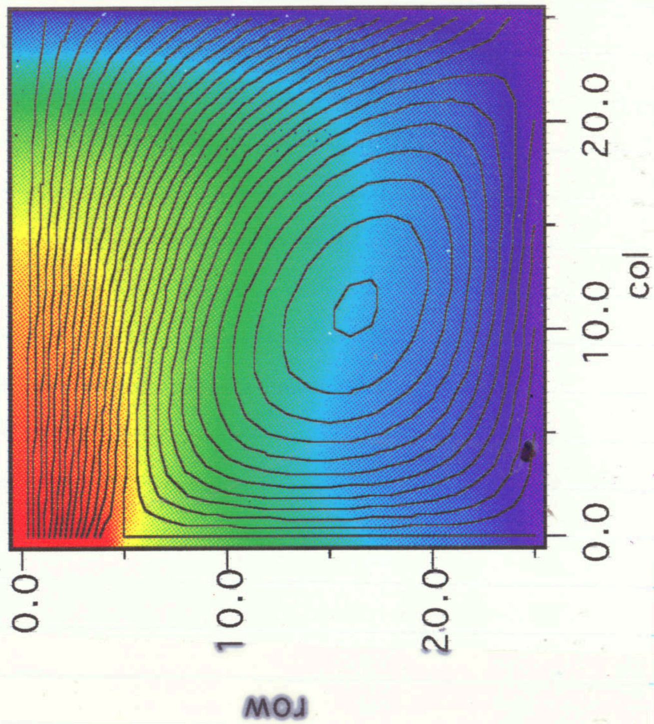
and T conditions as below

For the new stream fn. boundary conditions

Rayleigh #	Files
0	P10 , T10
.25	P11 , T11
.5	P12 , T12
1.0	P13 , T13

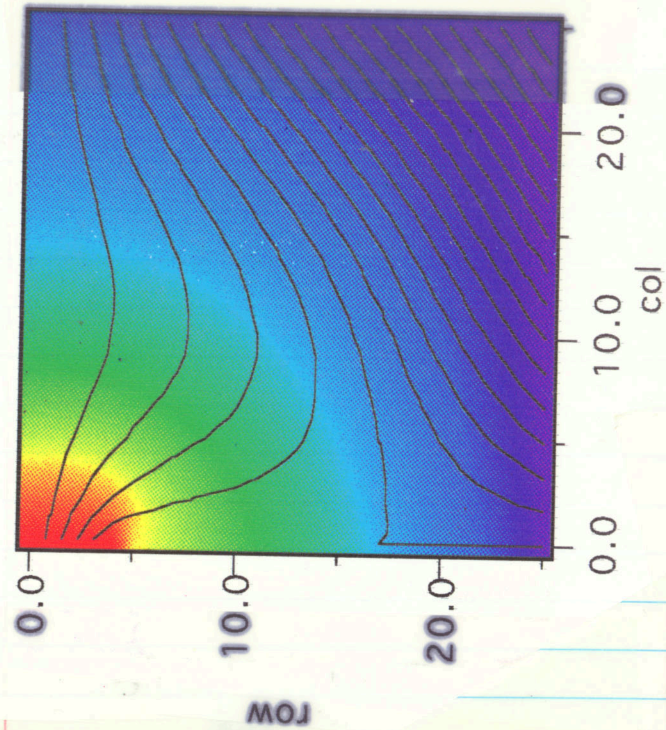
Print-out of T1-P1 [small inflow from sidewall, Ray # = 0



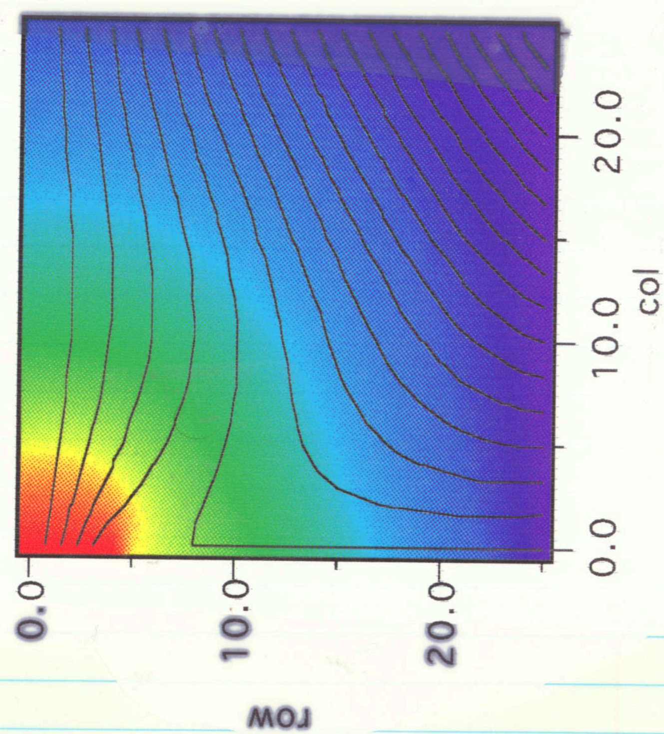


T5 - P5 · dat

Rayleigh # = 1

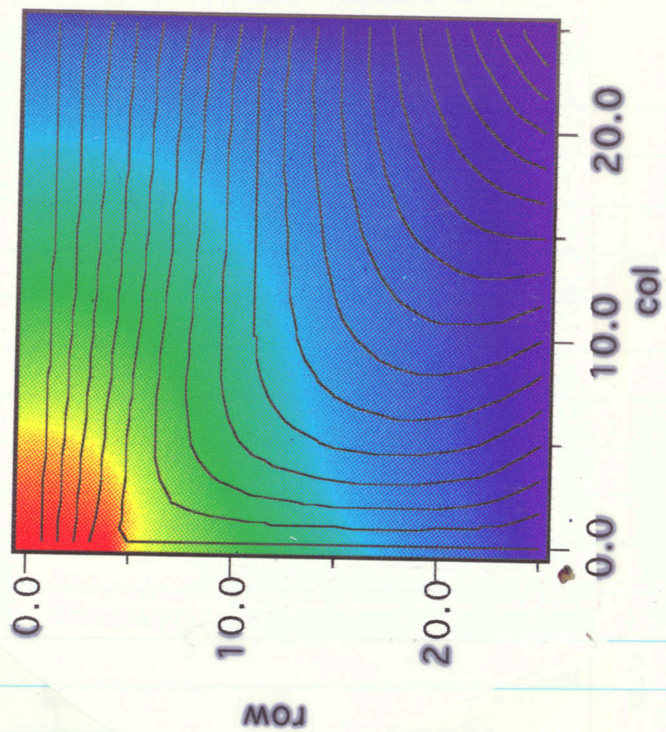


T6-P6

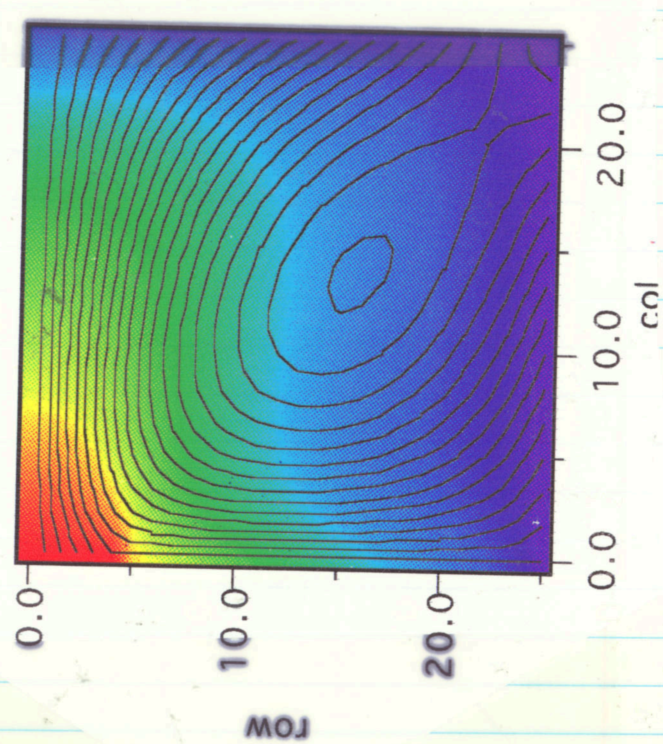


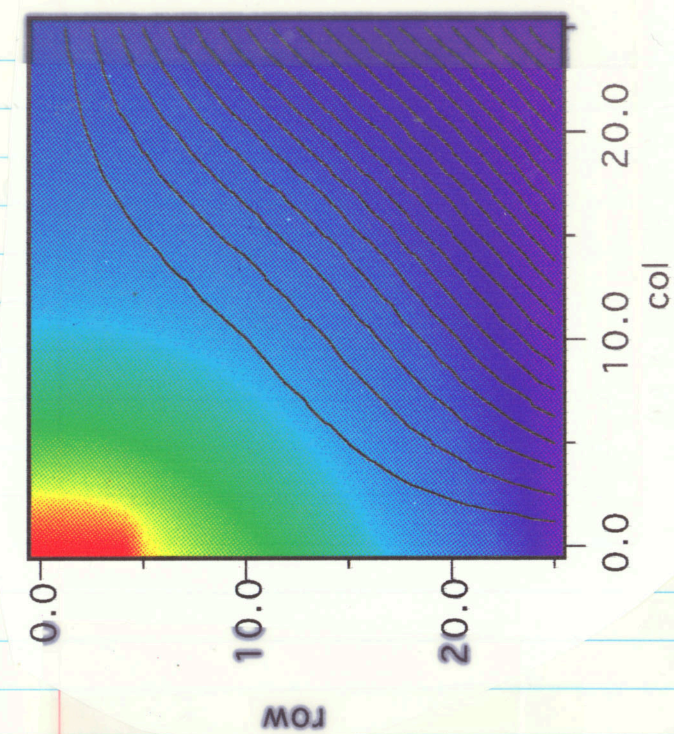
T7-P7

T-8
P-8

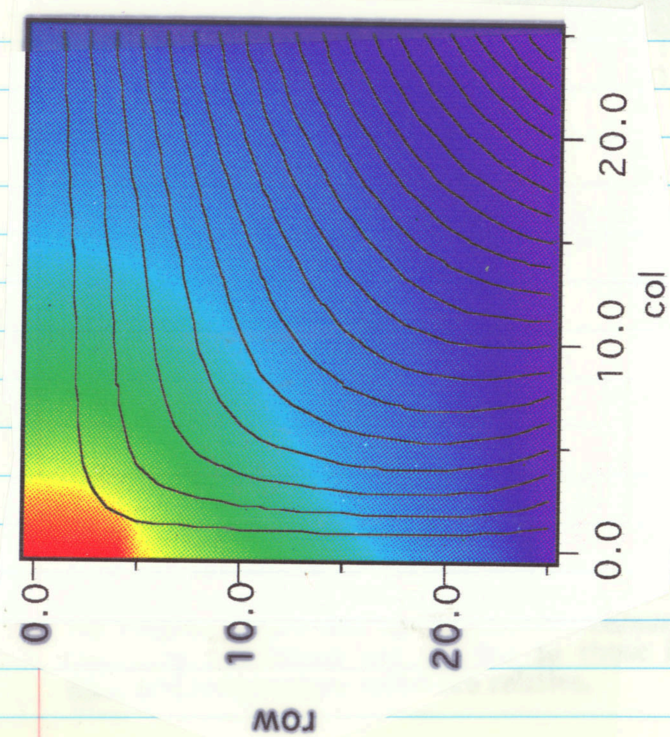


T-9
P-9



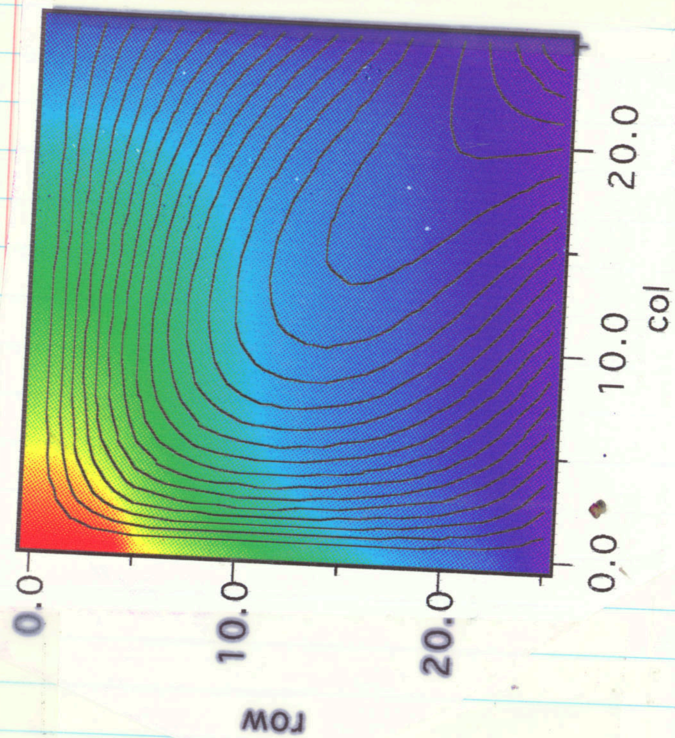


T=10
P-10



P-12
T-12

T-13
P-13



ce

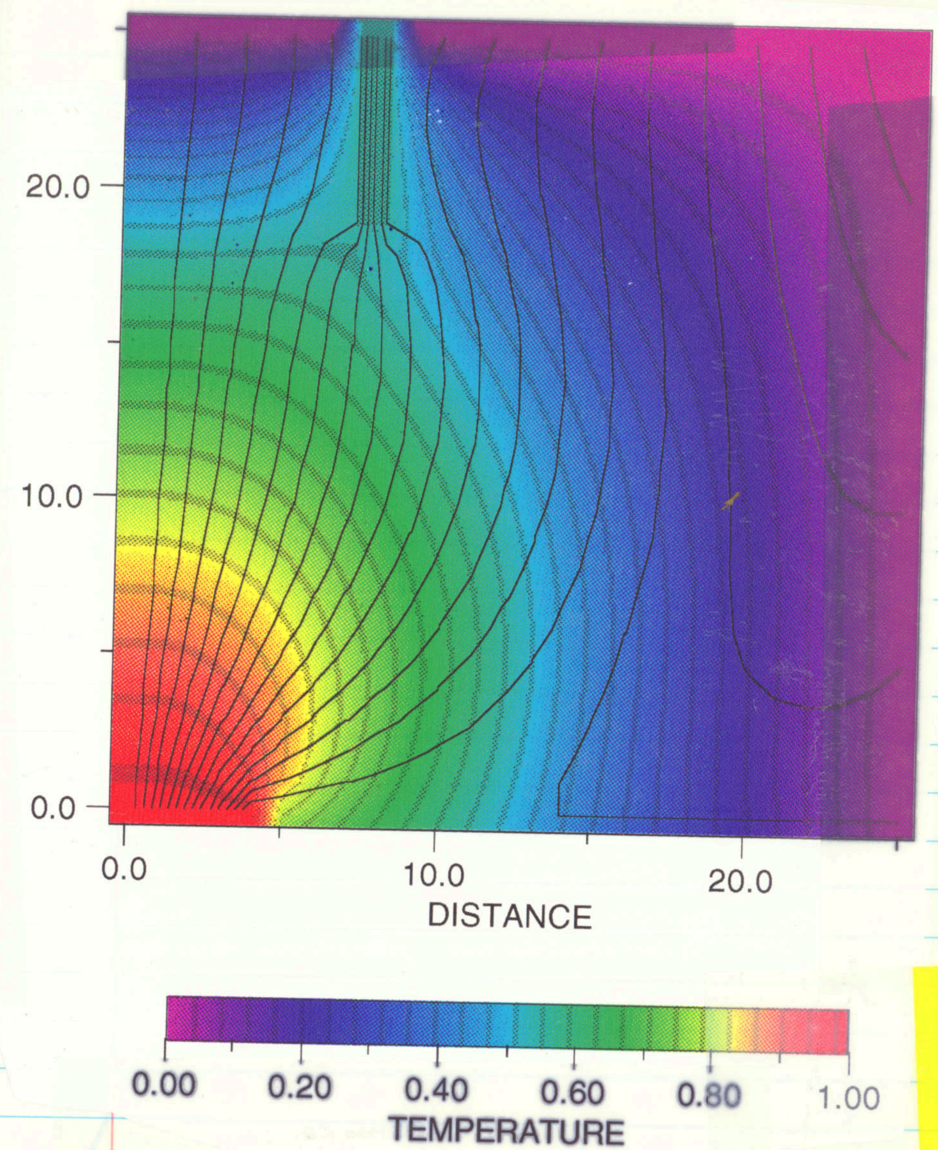


Figure 3-9. A boundary value heat and mass transfer problem solved using equations 3-3 to 3-5. Streamlines, Ψ, are indicated by solid lines. Temperature distribution, θ, is indicated by the color bar (cool, meteoric water vapor is shown in blue, hot magmatic gases in red). Gas escapes from a cooling and crystallizing magma (lower left corner) and rises by by free and forced convection to the surface, advecting heat along flow paths. A fracture extending part way to the magma (illustrated by increased streamline density) creates a thermal anomaly. Boundary conditions are similar to those illustrated schematically in Figure 3-8. Distance and temperature scales are relative.

CC

Sept 7, 1993 Chuck Connor

Doing calculations using the Poisson Weibull method of Ho (1991) to determine the effect of uncertainty in age data on calculations of recurrence rate $\lambda(t)$.

The program I wrote to do this is listed below.

```
!Program weibull
!written by:
!       Chuck Connor
!       CNWRA
!       Southwest Research Inst.
!       San Antonio, TX
!       Sept., 1993
!Language: TrueBasic
!
!Description: This program calculates the recurrence rate
!of volcanism and probability of a new volcano forming within that
!region using the Poisson-Weibull method of Ho (1991).
!
!Reference: Ho, C.-H., 1991. Time trend analysis of basaltic
!volcanism for the Yucca Mountain Site. J. Volcanol. Geotherm.
!Research, 46: 61-72.
!
!t() in a matrix that contains the estimated ages of Quaternary
!volcanoes in millions of years
!n is the total number of volcanoes
!
!ttot is the total time period under consideration 1.6 m y
!
!The program calculates Beta.
!
!If Beta > 1 waxing magmatic system
!If Beta = 1 steady - state magmatic system
!If Beta < 1 waning magmatic system
!
!The program also calculates theta
```

```
!
!For a homogeneous Poisson distribution, theta = 1/recurrence rate
!the program also calculates the recurrence rate and probability
!of a new volcano forming in 10,000 years.
!
!varying t() and ttot strongly influences the results.

dim t(8)


let t(1) = 1.2
let t(2) = 1.2
let t(3) = 1.2
let t(4) = 1.2
let t(5) = 1.2
let t(6) = 0.3
let t(7) = 0.3
let t(8) = 0.1

let ttot = 1.6
let n = 8


    for i = 1 to n
    let t(i) = ttot - t(i)
    let sumt = sumt + log(ttot/t(i))
    next i

    let beta = n/sumt
    let theta = ttot/(n^(1/beta))

    let recur_rate = (beta/theta)*(ttot/theta)^(beta-1)
    let prob = 1- exp(-recur_rate*1e-6*10000)

    print "beta = ";beta
    print "theta = ";theta
    print "recurrence rate = ";recur_rate
    print "Prob in 10,000 yr = ";prob
    end
```


The matrix t() in the Weibull program contains the ages of the 8 Quat. volcanoes. This is known w/ varying precision.

Mean ages: $t(1) \rightarrow t(5) = 1.2$ Ma
$t(6) \rightarrow t(7) = .3$ Ma
$t(8) = .1$ Ma

CC 9/7

for the total time period ttot = 1.6 Ma

$\hat{\beta} = 1.1$

$\hat{\theta} = .2$

$\hat{\lambda}(t) = 5.4$

$P[10,000] = 5\%$

results.

These results agree exactly w/ those of Ho (1991) and ∴ I am sure the program is calculating correct results

oldest ages: $t(1) \rightarrow t(5) = 1.6$ Ma
$t(6) \rightarrow t(7) = 0.5$ Ma
$t(8) = 0.15$ Ma

for total time period = 1.61

$\hat{\beta} = 0.3$

$\hat{\theta} = .001$

$\hat{\lambda} = 1.5$

90% confidence interval $\rightarrow \hat{\lambda}_1, \hat{\lambda}_2$

where

$\langle \hat{\lambda}_1, \hat{\lambda}_2 \rangle = \langle 0.5, 3.44 \rangle$

$P[10{,}000] = 1.5\%$

The 90% confidence interval is calculated from P_1 & P_2 values given by L.H. Crow (1982) Technometrics Vol 24(1):67-71

For $n = 8$ samples

$\pi_1 = 0.436$

$\pi_2 = 2.981$

To calculate 90% confidence interval on $\hat{\lambda}(t)$

$$\hat{M}(t) = \hat{\lambda}^{-1}(t)$$

$$\langle \pi_1 \hat{M}(t), \pi_2 \hat{M}(t) \rangle$$

So... if oldest ages are assumed for the Quaternary, then the system appears to be waning and expected recurrence rate is less than ~3.5 v/my w/ 90% confidence

using youngest ages:

$t(1) \rightarrow t(5) = 0.8$
$t(6) \rightarrow t(7) = 0.1$
$t(8) = 0.05$

$t_{tot} = 1.6$ Ma

$\hat{\beta} = 2.2$, $\hat{\theta} = 0.6$, $\hat{\lambda} = 11$ v/my

$\langle \hat{\lambda}_1, \hat{\lambda}_2 \rangle = \langle 3.7, 25.3 \rangle$

$\hat{P}[10{,}000, \hat{\lambda} = 11] = 10\%$

in this scenario ... the magmatic system appears to be waxing

$\hat{\beta} > 1$ and the recurrence rate is quite high w/ a large degree of confidence. 90% [25 v/my].

So: depending on the ages of the volcanoes, given current uncertainty, the magmatic system could be waxing or waning. A lot of this depends on the relationship between t_{tot} and individual values of t_i. For example, if older values of t_i are considered to reflect reality, then the ages of the volcanoes

are close to the beginning of T_{tot}. Five volcanoes formed instantaneously at the beginning of the period of consideration. So of course the system appears to be waning. On the other hand, if the volcanoes are all 0.8 Ma or less, then all of the eruptions took place in the late Quaternary and if $t_{tot} = 1.6$ Ma then, naturally, the system appears to be waxing.

> This seems to be a problem w/ using arbitrary estimates of recurrence rate interval (t_{tot})

Crowe et al. (1993) point this out.

... us if mean ages are

$t(5) = 1.2$ Ma

$t(7) = 0.3$ Ma

0.1 Ma

Ma.

system expected

~ 3.5 ... 702 $\hat{\lambda} = 2.1$

4.8 >

The system appears to be waning and the recurrence rate is less than 5 v/my w/ 90% confidence.

However → what if Crater Flat volcanoes are not instantaneous, but erupt over a period of 100,000's of yrs.

$t(1) = 1.2$

$t(2) - t(3) = 1.0$

$t(4) - t(5) = .8$

$t(6) - t(7) = .3$

$t(8) = 0.1$

$t_{tot} = 1.21$

$\hat{\beta} = 0.71$

$\hat{\theta} = .06$

$\hat{\lambda} = 4.7$ v/my

system becomes closer to steady-state...

$\langle \hat{\lambda}_1, \hat{\lambda}_2 \rangle = \langle 1.6, 10.8 \rangle$

... and uncertainty in the value of $\hat{\lambda}(t)$ goes way up.

This indicates that uncertainty in the ages of individual volcanoes, particularly the 1.2 ma (?) Crater Flat volcanoes creates uncertainty in $\lambda(t)$, but some values of ti produce large confidence in $\lambda(t)$ regardless.

It makes a big difference whether or not Crater Flat volcanoes are all nearly the same age or if they formed over ~.5 my.

Question remains → how is the time period (t_{tot}) chosen in a non-arbitrary way.

CC

Sept 9, 1993 Chuck Connor

Need to calculate viscosities of basalts based on chemical composition, volatile content, and xstal size distribution.

Program adapted from McBirney and Murase (1984) Rheological properties of magmas Ann Rev Earth Planet Sci 12: 337-357.

Basic idea is that viscosity is an important parameter in volcano explosivity. To what extent is viscosity ~~cc~~ controlled by chemical composition compared w/ volatile content and xstal size distribution.

One idea is that basalts from Cerro Negro, Tolbachik, Paricutin, and the YMR ~~may~~ have different compositions but may have similar viscosities ~~but~~ because of xstal size, etc.

Following calculations made ~~used~~ using code modified from McBirney and Murase (1984).

	H_2O = 1%	H_2O = 1.5	2.0	2.5	3.0	Density liquid
cf 12-6-3	2.76	2.58				2.58
fb 78-1	2.95	2.76				2.49
cf 12-4-6	3.07	2.87				2.6
cf 12-4-13a	2.60					
cf 11-7-1	2.59					
cf 11-7-2	2.56					
fb 78-7	2.64					

CC

?/?

T = 1100°C XLS = 0 %

H_2O	1%	1.5	2.0	2.5	3.0	Density
cf 12-6-3	2.76	2.58				2.51
fb 78-1	3.33	3.32				2.49
cf 12-4-6	3.49	3.49				
cf 12-4-13a	2.98	2.98				
cf 11-7-1	2.54	2.97				
cf 11-7-2	2.93	2.93				
fb 78-7	3.02	3.02				2.53

CC

?/?

CC

?/?

Run viscosity calculations for samples from Crater Flat assuming various water contents

H_2O	1%	1.5	2.0	2.5	3.0
cf-12-6-3	2.76	2.58	2.42	2.26	2.11
fb 78-1	2.95	2.76	2.58	2.42	2.26
cf 12-4-6	3.07	2.87	2.69	2.52	2.36
cf 12-4-13a	2.6	2.43	2.27	2.12	1.97
cf 11-7-1	2.59	2.42	2.26	2.11	1.97
cf 11-7-2	2.56	2.39	2.23	2.08	1.94
fb 78-7	2.64	2.46	2.30	2.15	2.53

Paricutin samples (1943-1944) (McBirney et al. 1987)

Sam.	1%	1.5%	2	2.5	3
p51-W-18	3.38	3.18	2.98	2.80	2.63
p 108081	3.4	3.19	3.0	2.82	2.65
p 47-27	3.41	3.20	3.01	2.83	2.66

Cerro Negro Samples (Walker and Carr, 1986)

CN15e	2.98	2.8	2.62	2.46	2.31
CN 15c	2.92	2.74	2.57	2.41	2.25
CN 15b	2.95	2.77	2.59	2.43	2.28

Tolbachic samples from Northern Breakout Volynets (1983)
(Average of early phase chem 7 July - 10 Sept 1975)
(Intermediate 11-15 Sept 75)

early	2.33	2.17	2.03	1.89	1.76
mid	2.53	2.37	2.22	2.07	1.93

running at 1100°C with ol and 1% H_2O
for crater flat / Lathrop. ↳ .02 vol fract size = 1mm

cf 12-6-3	4.57
	4.76
	4.89
cf 12-4-13a	4.4
cf 11-7-1	4.39
cF 11-7-2	4.35
Fb78-7	4.44

running at 1050°C w/ .02 vol frac ol and .01 vol frac. plag. size = .5mm , 1% water

pSIw-18 :	4.15
p108081 :	4.17
pw47-27 :	4.19


```
! calculate the viscosity and density of a basalt
!given chemical composition and xstal size distributrion
DIM mtx(10,50), X(11)
PRINT "name of input file: ";
INPUT file$
OPEN #1: name file$

PRINT "name of output file"
INPUT file2$
OPEN #2: name file2$, create newold
ERASE #2

DO while more #1

   INPUT #1:id$, X(1),X(2),X(3),X(4),X(5),X(6),X(7),X(8),X(9),X(10),X(11)
   LET kount1 = kount1+1
   LET kount2 = 0

   FOR h = .5 to 3.5 step .5

       LET SI = X(1)
       LET TI = X(2)
       LET AL = X(3)
       LET F3 = X(4)
       LET F2 = X(5)
       LET MN = X(6)
       LET MG = X(7)
       LET CA = X(8)
       LET NA = X(9)
       LET K = X(10)
       LET P = X(11)

print si
print ti
print al
print f3
print f2
print mn
print mg
print ca
print na
print k
print p
get key dum
       LET sn = 0
       LET ss = 0
       LET sa = 0
       LET kf = 0
       LET nk = 0
       LET sf = 0
       LET sc = 0
```

This is the program used to calculate viscosities using the McBirney and Murase method

```
LET pf = 0
LET ol = 0
LET au = 0
LET hy = 0
LET mt = 0
LET qz = 0

LET kount2 = kount2 + 1

!calculate the density of the liquid
LET DL = 2.2 + 0.027 * (F3 + F2 + TI)     ! THIS IS THE APPROXIMATE

LET T = (SI + TI + AL + F3 + F2 + MN + MG + CA + NA + K + P)/(100-H)
LET SI = SI/T/60.0843
LET TI = TI/T/79.8988
LET AL = AL/T/50.9806
LET F3 = F3/T/79.8461
LET F2 = F2/T/71.8464
LET MN = MN/T/70.9374
LET MG = MG/T/40.3044
LET CA = CA/T/56.0794
LET NA = NA/T/30.9895
LET K = K/T/47.0980
LET H = H/T/18.0152
LET P = P/T/70.9753

LET FM = F3 + F2 + MN + MG
LET TN = SI + TI + AL + FM + CA + NA + K + P + H

LET te = 1100
LET PH = OL + PF + KF + AU + HY + MT + QZ

LET TE = TE + 273.15

IF OL <> 0 THEN
   LET MF = 3.33 * MG/F2   !MG/F2 OF CRYSTALS
   LET DO = 4.39 - 1.17 * MF/(1 + MF)
   LET QL = OL * TN * DO / DL
   LET SS = SS + OL * .333      !FIRST MENTION OF SS
   LET SF = OL * .667
END IF

IF HY <> 0 THEN
   LET MF = 4.15*MG/F2      !MG/F2 OF XLS
   LET DH = 3.96 - .75 * MF / (1 + MF)
   LET HY = HY * TN * DH / DL
   LET SS = SS + HY *0.5
   LET SF = SF + HY * 0.5
END IF

IF AU <> 0 THEN
```



```
   LET MF = 5.53 * MG/F2
   LET DA = 3.56 - 0.26*MF/(MF + 1)
   LET AU = AU * TN * DA/DL
   LET SS = SS + AU * 0.5
   LET SF = SF + AU * 0.25
   LET SC = SC + AU*0.25
END IF

IF QZ <> 0 THEN
   LET QZ = QZ * 2.65* TN/DL
   LET SS = SS + QZ
END IF

IF PF <> 0 THEN
   FOR Z = 0 TO PF STEP 0.001
       LET CN = 3.68 * (CA*AL)/(NA*SI)    !CA/NA FOR PLAG
       LET DP = 2.62 + 0.14*CN/ (1 + CN)
       LET PL = 0.001* TN * DP/DL
       LET SS = SS + PL * 0.6 - PL*.2*CN/(1 + CN)
       LET SA = SA +PL * 0.2 - PL*.2*CN/(1 + CN)
       LET SC = SC + PL*0.2* CN/(1 + CN)
       LET SN = SN + PL * .2/(1 + CN)
   NEXT Z
END IF

IF KF <> 0 THEN
   LET KF = KF * TN * 2.62/DL
   LET SS = SS + KF * 0.6 * TN
   LET SA = SA + KF * 0.2 * TN
   LET SK = KF * 0.2
END IF

IF MT <> 0 THEN
   LET FT = 0.92 * F3 * F3/(F2*TI)   !MAGNETITE/ULVOSPINEL
   LET MT = MT * TN * 5.18/DL
   LET ST = MT * 0.12/(1+FT)
   LET SF = SF + MT * .88
END IF

LET SI = SI - SS
LET TI = TI - ST
LET AL = AL - SA
LET FM = FM - SF
LET CA = CA - SC
LET NK = NA - SN + K - SK
LET H = H/(1-PH)
LET TV = SI + TI + AL + FM + CA + NK + P + H
LET TR = TN/TV
LET SI = SI * TR
LET TI = TI*TR
LET AL = AL*TR
```

```
        LET FM = FM*TR
        LET CA = CA*TR
        LET NK = NK*TR
        LET P = P*TR
        LET H = H*TR
        LET TC = SI+TI+AL+FM+CA+ (NK+P)/2 + H

        !CALCULATE THE VISCOSITY OF THE LIQUID FRACTION

        LET Q1 = AL*6.7
        LET Q2 = FM*3.4
        LET Q3 = (CA + TI)*4.5
        LET Q4 = NK*1.4
        LET Q5 = H * 2
        LET QT = (Q1 + Q2 + Q3 + Q4 + Q5) * SI/TC^2
        LET MU = (QT/(1-SI/TC)) * (1E4/TE - 1.5) - 6.4

        ! CALCULATE THE VISCOSITY OF THE LIQUID + XLS

        IF PH <> 0 AND DM <> 0 THEN
           LET PH = (1/PH) ^ 0.3333
           LET SH = 0.011 * DM/(PH-1) - 0.15
           LET NE = MU + SH
        ELSE

           LET NE = 0
        END IF

        LET MU = MU/2.3026
        LET NE = NE/2.3026

        LET LOG_GLASS = (INT(MU*100 +.5))/100
        LET LOG_VISC = (INT(NE*100 +.5))/100

        !clear
        !PRINT "LOG VISCOSITY OF THE GLASS: ";LOG_GLASS
        !PRINT "LOG VISCOSITY OF THE GLASS + XLS: ";LOG_VISC
        !PRINT "APPROXIMATE DENSITY OF THE LIQUID: ";DL

        LET mtx(kount1,kount2) = log_visc
        PRINT kount1,h,mtx(kount1,kount2), log_glass
    NEXT h
LOOP

FOR i = 1 to kount2
    FOR j = 1 to kount1
        PRINT #2: mtx(j,i);
    NEXT j
    PRINT
NEXT i
END
```


conclusion from these calculations is that viscosity is not strongly influenced by chemical composition of basaltic magma.

Rather, xstal fraction + volatile content play very important roles.

This is written up in semi-annual of August, 1993

CC

Chuck Connor

October 6, 1993 (See pages 60-63 for additional background)

working on the derivation of the k function for Neymann-Scott cluster distributions.

1st work it out following the example of Cressie (1991) page 665

Cressie (1991) indicates that Diggle (1983) pg. 55 has derived an expression for the K-function of N in $\mathbb{R}^d$

where N is a Neymann-Scott process and the Intensity of N is $\lambda = \rho E(K)$ where ρ is the intensity of cluster parents and $E(K)$ is the average # of volcanoes per cluster.

In all of this, assume that the parent process is homogeneous Poisson of intensity ρ

if there are two points in the same cluster, then
↳ $(\vec{s}, \vec{u})$

$$h = \|\vec{s} - \vec{u}\| = \|\vec{v}\|$$

the K-function of N in $\mathbb{R}^d$ is given by

$$K(h) = \frac{\pi^{d/2} h^d}{\Gamma(1+\frac{d}{2})} + \frac{E(K(K-1)) \cdot F_2(h)}{\rho m_K^2} \qquad (1)$$

where h is $\|\vec{s} - \vec{u}\|$
d is the dimension of the process
m_K is the mean # of offspring per parent, which has a poisson distribution.

if K is a poisson random variable then $E(K(K-1)) = m_K^2$

$f(\cdot)$ is the probability density function of the daughter process and is assumed to be radially symmetric

if $f(\cdot)$ is a circular bivariate Gaussian distribution with mean $\vec{0}$ (corresponding to the cluster centroid) and variance matrix $I\sigma^2$

the mean squared distance to a daughter from the parent is $2\sigma^2$

in this case

$$f_2(h) = \frac{h}{2\sigma^2} \exp\left(-h^2/4\sigma^2\right)$$

$F_2(h)$ is the cdf of $f_2(h)$, the pdf

$$F_2(h) = \int_{-\infty}^{h} f_2(t)\,dt$$

$$= \int_{-\infty}^{h} \frac{t}{2\theta^2} \exp\left(-\frac{t^2}{4\theta^2}\right) dt \qquad \text{but, } h > 0$$

$$= \int_0^h \sim \; dt$$

$$u = \frac{-t^2}{4\theta^2}$$

$$\boxed{\begin{aligned} du &= -2t/4\theta^2 \; dt \\ &= -t/4\theta^2 \; dt \end{aligned}}$$

$$-\int e^u\,du = -e^u + C$$

$$F_2(h) = -e^{-t^2/4\theta^2}\Big|_0^h$$

$$= 1 - e^{-\cancel{h}^2/4\theta^2}$$

going back to (1, page 103)

$$K(h) = \frac{\pi^{d/2} h^d}{\Gamma(1+\frac{d}{2})} + \frac{\cancel{E}(k-1))\; F_2(h)}{\rho\, m^2 k}$$

$\underline{d=2}$ in $\mathbb{R}^d = \mathbb{R}^2$

$$K(h) = \frac{\pi h^2}{\Gamma(2)} + \frac{\cancel{m^2 k} \cdot F_2(h)}{\rho\, \cancel{m^2 k}}$$

$$K(h) = \frac{\pi h^2}{\Gamma(2)} + \rho^{-1} F_2(h)$$

$$K(h) = \frac{\pi h^2}{\Gamma(2)} + \rho^{-1}\left(1 - \exp\left(-h^2/4\theta^2\right)\right)$$

cc

evaluating the Γ ~~\$~~ (gamma) distribution

$$\Gamma(r) = \int_0^\infty x^{r-1} e^{-x}\,dx$$

$\vdots$

$\Gamma(1) = 1$

$\Gamma(r+1) = r(\Gamma(r))$, for any positive r

$\Gamma(r+1) = r!$, for any positive integer

so... cc 10/6

$\Gamma(1) = 1$

$\Gamma(2) = 1$ $\quad d = 2$

$\Gamma(3) = 2$ $\quad d = 3$, $\mathbb{R}^d$

$$K(h) = \pi h^2 + \rho^{-1}\left(1 - \exp\left(-h^2/4\theta^2\right)\right)$$

10/6 cc

is the ~~K~~ K-function for a Neymann-Scott process w/ the

following assumptions.

(1) parent process is homogeneous poisson with intensity ρ

(2) daughter process is circular Gaussian about the parents with variance σ^2

both (1) and (2) can be tested with a variety of clusters in large fields.

This K-function model requires estimate of ρ and σ^2

This prog. is called P-C. model

```
DIM K(150), L(150)

OPEN #1: NAME "P-C.OUT", CREATE NEWOLD
ERASE #1

LET INVRHO = 5500/15      ρ^-1 estimate
LET SIG2 = 9              σ^2 estimate

FOR H = 1 TO 15 STEP .1

LET KOUNT = KOUNT + 1
LET K(KOUNT) = PI*H^2 + INVRHO*(1- EXP(-H^2/(4*SIG2)))
LET L(KOUNT) = (K(KOUNT)/PI)^0.5 - H
PRINT #1: H, K(KOUNT), L(KOUNT)
NEXT H

END
```


October 11. Chuck Connor

Summary of S. McDuffie's paper on fracture prop. and faults / Dikes interaction.

- Dikes as a hydrofracture process

In order to propagate, dike must

(1) overcome in situ stress due to overburden and tectonics

(2) must be sufficient fluid pressure to deform the host rock. → this depends on material properties of the host rock. [shear modulus, Poisson's ratio]

- the fluid P required to maintain a given aperture depends on dike length

- the longer the dike the less P required to open a given aperture

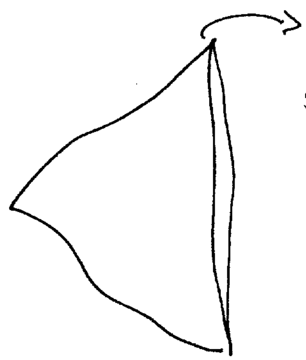
dike width is $\propto$ to pressure * length

Aspect ratio of dike $\approx \dfrac{\text{driving P}}{\text{host rock stiffness}}$

where driving P = Fluid P − σ_3
the driving P is the pressure available to deform the host rock.
Pollard (1987): Driving P for dike 1-10m in width and aspect ratio of 1:10^3 and rock μ of 10^3 MPa is 1-4 MPa

↳ but this seems low?

(3) Stress at fracture tip must overcome fracture toughness



K = magnitude of stress at fracture tip = stress intensity factor.

Kc = fracture toughness [rock property]

if K ≥ Kc → propagate

$K \propto \sqrt{\text{fracture length}}$ (like driving P)

→ if conditions 1-3 are met, dike propagates until it
(A) solidifies
(B) reaches LNB
(C) erupts

Fluid P is probably most important factor in dike arrest because

Kc and σ_1 ↓ with shallowing depths.

Fluid pressure drops ~~when~~ due to
(1) viscous dissipation
(2) reaches or passes LNB

in this case vis. dis means magma cools and becomes more viscous – Delaney and Pollard (1987)
Bruce and Huppert (1990)

Springerville results.

run e-E test on 366 dated vents in SVF

Near neighbor stat : 0.88
expected error : 3.4
Z - stat : -4.187
mean distance to nearest neighbor : 0.0112
expected distance 0.012
total area : .235944
→ total pts : 366

CC

Cluster five in Springerville field

total # of pts. 68
min age : 0.308
max age : 1.745

start of time 1.845

stop time : 1.645
# events : 2
beta = 2.56
theta = 0.153
RR = 25.93 Vols/my. f(β)
P[10,000] = .228

start always 1.845

stop time	# events	B	θ	RR	P[10,000]
1.645	2	2.56	.153	25.93	.228
1.545	5	2.33	.150	38.84	.321
1.454	10	2.52	.16	63.0	.467
1.345	14	2.12	.144	59.3	.44
1.245	24	2.32	.152	92.8	.605
1.145	31	2.13	.14	94.6	.611
1.045	42	2.16	.14	113	.67
0.945	49	1.97	.125	107	.659
.845	60	1.98	.126	118.6	.694
.745	68	1.78	.105	105.2	.651
.645	65	1.54	.08	83.5	.566
.545	67	1.41	.066	72.75	.51
.4$5	67	1.28	.05	62	.46
.345	67	1.17	.041	52	.40

.245	68	1.11	.035	42.0	.375
.145	68	1.03	.029	41.5	.339
.045	68	.97	.02	37.00	.309
0	68	.95	.022	35.2	.297

cluster 3
start at 1.8 my

1.6	2	1.9	.139	19.0	.173
1.5	4	1.76	.136	23.5	.209
1.4	5	1.38	.124	17.27	.15
1.3	15	2.60	.174	78.0	.541
1.2	21	2.4	.169	84.0	.569
1.1	25	2.02	.143	72.0	.51
1.0	28	1.76	.12	61.6	.46
.9	32	1.64	.109	58.5	.44
.8	45	1.91	.136	86.0	.577
.7	48	1.71	.115	75.0	.527
.6	53	1.63	.106	72.0	.515
.5	53	1.449	.08	59.09	.44
.4	53	1.30	.067	49.55	.39
.3	53	1.2	.054	42.4	.34
.2	53	1.11	.043	36.9	.308
.1	53	1.04	.037	32.5	.277
0	53	.98	.031	29.0	.251

cluster 2
start 2.095

M yr	# wnb	β	⊕	λ RR	P[10,000]
1.8	7	1.72	.15	40.91	.335
1.7	18	2.43	.12	110.8	.669
1.6	24	1.98	.100	96.3	.618
1.5	44	2.27	.112	168.3	.814
1.4	45	1.70	.074	110.7	.669
1.3	56	1.68	.073	118.8	.695
1.2	65	1.60	.066	116.4	.687
1.1	75	1.55	.0619	117.2	.690
1.0	87	1.558	.0623	123.7	.710
.9	92	1.44	.052	111.0	.67
.8	96	1.34	.043	99.8	.63
.7	96	1.22	.033	84.2	.569
.6	99	1.16	.028	76.9	.536
.5	99	1.08	.026	67.0	.488
.4	100	1.02	.0188	60.3	.453
.3	100 →	.966	.015	53.8	.416
.2	100	.918	.0126	48.48	.38
.1	100	.877	.010	43.97	.355
0	100	.841	.0081	40.15	.33

cluster 1

start at 2.01

my	# events	β	θ	RR	P[10,000]
1.81	1	1.44	.2	7.21	.069
1.71	4	2.34	.166	31.3	.268
1.61	8	2.196	.155	43.9	.355
1.51	9	1.626	.129	29.28	.255
1.41	13	1.66	.128	36.0	.3023
1.31	16	1.56	.119	35.88	.301
1.21	20	1.58	.121	39.69	.328
1.11	20	1.33	.096	29.72	.257
.91	26	1.30	.091	30.89	.266
.81	26	1.17	.074	25.4	.22
.71	26	1.07	.062	21.5	.193
.61	26	.99	.052	18.45	.168
.51	26	.93	.045	16.12	.148
.41	26	.877	.039	14.25	.132
.31	26	.833	.034	12.74	.119
.21	26	.795	.0299	11.48	.108
.11	26	.762	.026	10.43	.099
.01	26	.733	.023	9.53	.091
0	26	.731	.023	9.45	.090

cluster 4

start time @ 2.18

my	#events	β	θ	RR	Prob[10,000]
1.~~88~~8	1	2.46	.3	8.22	.078
1.78	1	1.44	.4	3.606	.035
1.68	1	1.09	.5	2.182	.0215
1.58	1	.910	.6	1.51	.015
1.48	3	2.08	.413	8.92	.085
1.38	10	4.24	.464	53.02	.411
1.28	17	4.11	.452	77.8	.540
1.18	26	4.04	.446	105.06	.65
1.08	29	3.21	.386	84.85	.571
.98	31	2.66	.33	68.79	.497
.88	34	2.39	.298	62.7	.466
.78	37	2.19	.270	58.1	.440
.68	38	1.96	.234	49.63	.391
.58	38	1.73	.197	41.3	.338
.48	40	1.65	.1822	38.8	.322
.38	40	1.50	.156	33.54	.285
.28	42	1.46	.147	32.28	.275
.18	42	1.36	.127	28.53	.248
.08	42	1.27	.111	25.48	.225
0	42	1.21	.100	23.43	.209

cc

cc

cluster 6
start time 2.07

my	# event	β	θ	RR	Prob[10,000]
1.87	6	2.94	.108	88.41	.586
1.77	12	2.40	.106	96.05	.617
1.67	13	1.48	.071	48.35	.383
1.57	15	1.24	.056	37.23	.310
1.47	15	1.01	.041	25.35	.22
1.37	17	.983	.040	23.89	.212
1.27	19	.963	.037	22.88	.204
1.17	21	.953	.037	22.2	.199
1.07	24	.981	.039	23.5	.209
.97	24	.897	.0318	19.5	.177
.87	24	.832	.026	16.65	.153
.77	24	.780	.022	14.4	.134
.67	24	.737	.018	12.6	.118
.57	27	.788	.022	14.18	.132
.47	27	.750	.019	12.65	.118
.37	27	.717	.017	11.39	.107
.27	27	.689	.015	10.33	.098
.17	27	.66	.013	9.44	.090
.07	27	.64	.011	8.67	.083
0	27	.62	.010	8.20	.078

cluster 7
start time 1.88

my	# event	β	θ	RR	Prob[10,000]
1.68	1	1.44	.2	7.21	.069
1.58.	1	.91	.3	3.03	.029
1.48	3	2.08	.235	15.6	.144
1.38	5	2.11	.233	21.08	.190
1.28	20	4.75	.319	158.68	.795
1.18	25	3.20	.256	114.5	.681
1.08	31	2.649	.218	102.6	.642
.98	35	2.24	.184	87.32	.582
.88	43	2.18	.178	93.82	.609
.78	48	1.99	.158	87.09	.581
.68	49	1.73	.126	70.66	.506
.58	50	1.54	.103	59.52	.448
.48	50	1.38	.083	49.58	.390
.38	50	1.27	.068	42.23	.344
.28	50	1.17	.056	36.67	.307
.18	50	1.09	.047	32.16	.270
.08	50	1.03	.042	28.59	.249
.0	50	.985	.035	26.2	.230

Dec 1 Chuck Connor

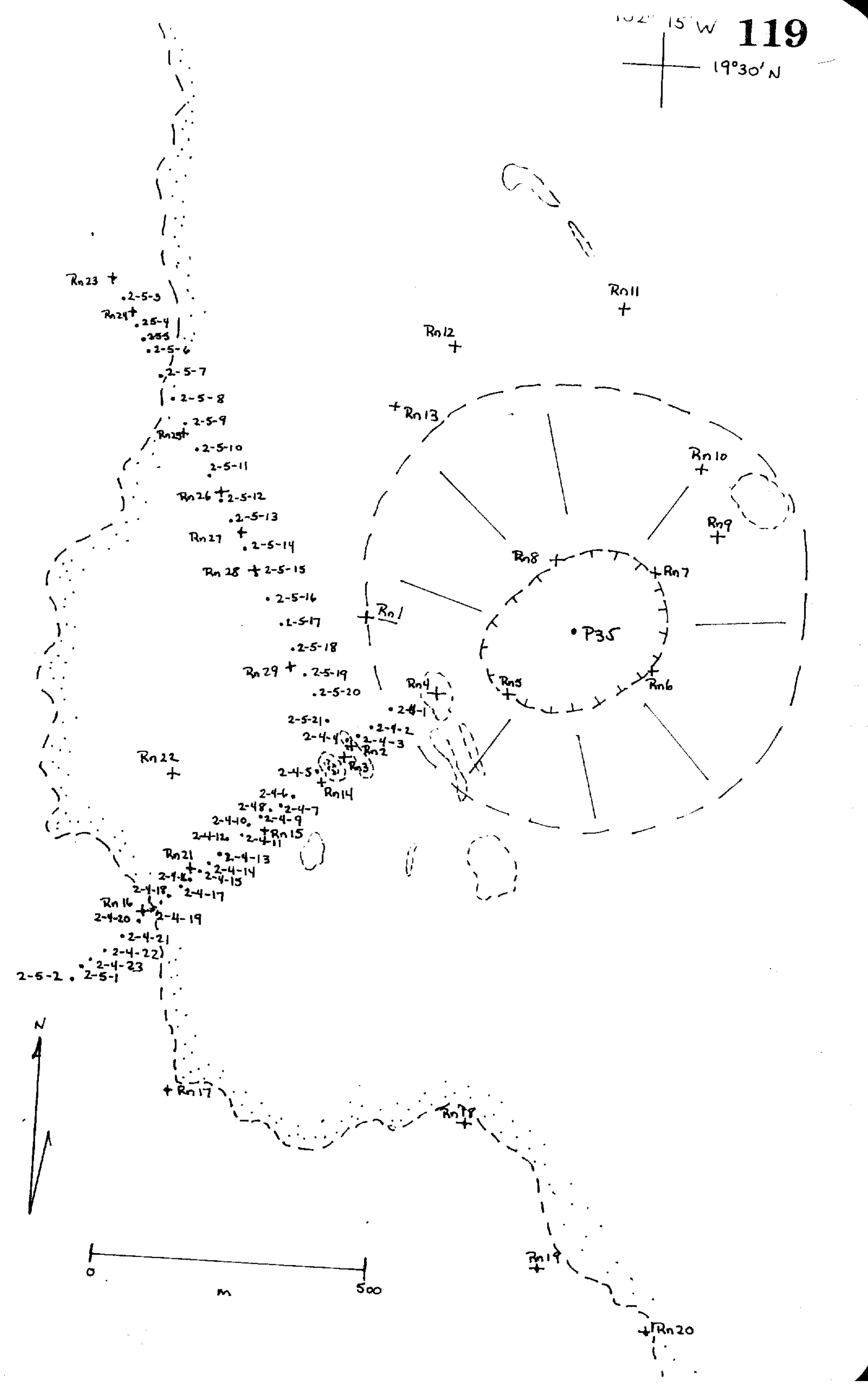
Summary of sample locations at Paricutín volcano, Mexico.

Samples were collected at Paricutin on Jany 29 – Feb 7, 1994.

Purpose was to collect soil gases using various techniques.

Stations

Rn StA	Hg Stat	CO_2 stA	He Stat
1	rn 1	P-42	
2	rn 2	P1 + P31	#282 + #171
3	rn 3	P11 + P12	#410 + #283
4	rn 4	P-43	#135
5	rn 5	P-32	
6	rn 6	P-33	
7	rn 7	P-34	
8	rn 8	P-36	
9	rn 9	P-37	
10	rn 10	P-38	
11	rn 11	P-39	
12	rn 12	P-40	
13	rn 13	P-41	
14	rn 14	P-47	203
15	rn 15	P-20	
16	rn 16	P-61	147
17	rn 17	P-15	259 10/15
18	rn 18	P-16	390 ~~259 259~~ cc
19	rn 19	P-17	~~390 259~~
20	rn 20	P-18	



Rn	Hg	CO_2	He
21	rn 21	P-21	
22	rn 22	P-22	
23	rn 23	P-24	
24	rn 24	P-25	
25	rn 25	P-26	
26	rn 26	P-27	
27	rn 27	P-28	
28	rn 28	P-29	
29	rn 29	P-30	
30	rn 30	P-23	
—	2-4-1	P-44	
—	2-4-2	P-45	#359
—	2-4-3	P-46	
—	2-4-4	—	
—	2-4-5	P-48	
—	2-4-6	—	
—	2-4-7	P-49	#595
—	2-4-8	P-50	
—	2-4-9	P-51	
—	2-4-10	—	
—	2-4-11	P-52	#204
—	2-4-12	P-53	
—	2-4-13	P-54	
—	2-4-14	P-55	
—	2-4-15	P-56	
—	2-4-16	P-57	
—	2-4-17	P-58	
—	2-4-18	P-59	
—	2-4-R	P-60	
—	2-4-20	P-62	

Rn	Hg	CO_2	He
—	2-4-21	P-63	
—	2-4-22	P-64	#589
—	2-4-23	P-65	
—	cc ~~2-4-24~~		
—	2-5-1	P-66	
—	2-5-2	P-67	
—	2-5-3	P-68	
—	2-5-4	P-69	
—	2-5-5	P-70	
—	2-5-6	P-71	#156
—	2-5-7	P-72	
—	2-5-8	P-73	
—	2-5-9	P-74	
—	2-5-10	P-75	
—	2-5-11	P-76	
—	2-5-R	P-77	
—	2-5-13	P-78	
—	2-5-14	P-79	
—	2-5-15	P-80	
—	2-5-16	P-81	
—	2-5-17	P-82	
—	2-5-18	P-83	
—	2-5-19	P-84	
—	2-5-20	P-85	
—	2-5-21	P-86	

— He sample #432 is atmospheric —

He ~~results~~ from samples collected at Parícutin + Jorrullo, Jan-Feb, 1994

Sample #	He ppb absolute
147	5376
156	5386
432	5303
203	5442
589	5466
197	5358
259	5421
282	5571
283	5406
359	cc ~~5302~~ 5342
595	5440 → 5440
171	cc ~~5570~~ 5573
135	cc ~~5444~~ 5570
204	5444
390	5385
410	5406
111	5388
370	5316
196	5439

These samples were run blind by Mike Reimer at the USGS in Denver.

Samples collected at Jorullo Volcano #197, 111, 196, 370

#197: At the fumaroles on SW crater wall

#111: Flanks of satellite vent furthest SW

#196: bottom of the main Jorullo crater

#370: 15 m up inner crater wall, main crater of Jorullo.

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Ma						
0	0.92×10^{-4} v/y	.73	3.35	~~0.0~~ 0.41 ✓	.52	.60
.25	1.18	1.02	4.2	0.52	.72	✓ .84
.5	1.97	1.56	7.4	0.84	1.08	✓ 1.27
.65	3.37		12.6	1.14		
.75	3.13	2.52	10.9	1.41	1.82	✓ 2.12
.85	6.09	~~5.1~~	27.3	2.58		
1	6.26	5.10	22.1	2.95	~~3.36~~ 3.69	✓ 4.29
1.15	5.77		20.3	2.53		
1.25	6.77	5.38	23.4	2.84	3.73	✓ 4.4
1.40	4.07		12.2	1.72		
1.50	3.83	2.94	13.7	1.46	✓ 1.97	✓ 2.36
1.65	2.80		15.1	1.06		
1.75	2.83	2.19	10.7	0.97	1.43	✓ 1.79
1.85	1.02		4.6	0.22		
1.9	0.69	.47	4.28	0.14	✓ 0.24	16.30

de 10/20

de 10/1/20

Using mean ages:

inclusive age range	number of vents
1.9 - 2.15	10
1.85 - 2.10	15
1.75 - 2.0	31
1.65 - 1.9	41
1.5 - 1.75	62
1.4 - 1.65	62
1.25 - 1.5	103
1.15 - 1.4	119
1.0 - 1.25	97
0.85 - 1.10	80
0.75 - 1.0	69
.65 - .9	55
.5 - .75	19

.65 - .9 55
.5 - .75 19

inclusive age range	Number vents formed in that interval
2 - 1.9 Ma	10
1.9 - 1.8	9
1.7 - 1.8	24
1.6 - 1.7	27
1.5 - 1.6	34
1.4 - 1.5	29
1.3 - 1.4	60
1.2 - 1.3	49
1.1 - 1.2	42
1.0 - 1.1	38
0.9 - 1.0	25
0.8 - 0.9	43
0.7 - 0.8	6
0.6 - 0.7	15
0.5 - 0.6	4
0.4 - 0.5	1
0.3 - 0.4	3
0.2 - 0.3	0
.2 - .45	3
.0 - .25	0
~~1.8~~ -	
1.85 - 1.95	10
1.75 - 1.85	16
1.65 - 1.75	26
1.25 - 1.35	59
~~1.15~~ 1.15 - 1.25	43
~~.8~~ .85 - .95	31

~~1.15~~ 1.15 - 1.25 70
~~.8~~ .85 - .95 31

Using mean ages

Inclusive age range	# vents formed
.75 - .85	28
.65 - .75	10

7NN volcanoes

	λ ($\times 10^{-4}$)	# vents in .25 Ma
1.75 - ~~1.50~~ 1.50	2.22	
1.50 - 1.25	4.05	
1.25 - ~~1.5~~ 1.0	3.63	
~~1.5~~ 1.0 - .75	1.31	
.75 - .5	.30	
.5 - .25	0	
.25 - 0	0	
2 - 1.75	1.79	

ce 10/31

2.25 - 1.75		1.79
2 - 1.5		2.36
1.75 - 1.25	✓	4.3
1.5 - 1.0	✓	4.1
1.25 - .75	✓	1.74
1 - .5		.69
.75 - .25		.17
.5 - 0		0

8 NN

2.25 - 1.75	1.43
2.0 - 1.5	1.97
1.75 - 1.25	3.7
1.5 - 1.0	3.5
1.25 - 0.75	1.5
1.0 - .5	.59
.75 - .25	.14
.5 - 0	0

Pages 1 through 131 of this Scientific Notebook were reviewed for compliance with QAP-001 in response to Corrective Action Request 94-02. Corrections and clarifications were made as appropriate. In some cases, the date of a change will reflect the date of this review rather than the date of the original Scientific Notebook entry.

Randy Folck
SwRI-QA
12/6/94

ah = complex(mtr, mtx)

I have reviewed this scientific notebook and find it in compliance with QAP-001. There is sufficient information regarding procedures used for conducting tests, acquiring, and analyzing data so that another qualified individual could repeat the activity.

H. L. McKague
GLGP Element Manager

06/14/00
Date

06/14/00

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EFFECTIVE 10/2/00

H. Lawrence McKague

HLMcK
10/2/00