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WORKSHOP
GLOBAL GEOPHYSICAL INFORMATICS WITH APPLICATIONS TO RESEARCH IN EARTHQUAKE PREDICTIONS AND REDUCTION OF SEISMIC RISK

(15 November - 16 December 1988)

SPATIAL CHARACTERISTICS OF SIMILARITY FOR EARTHQUAKE SEQUENCES: FRACTALITY OF SEISMICITY

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Spatial characteristics of similarity for earthquake sequences: fractality of seismicity

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Gutenberg-Richter law:

$$\lg N(M) = a - b(M-5)$$

Question: What area ?

Let an earthquake flow be self-similar in space, and **N(M,L)** be average annual number of earthquakes with magnitude **M** in an area of linear size **L**.

$$N(M) = N(M,L)(L/l)^c$$

where **l** is characteristic size,

$$N(M) = N(M,l)$$

Generalized Gutenberg-Richter law

$$\lg N(M,L) = A + B\cdot(M-5) + C\cdot\lg L$$

A estimates the activity,

B characterizes the ratio between the numbers of earthquakes in different magnitude ranges,

C reflects spatial self-similarity, and may be treated as fractal dimension of earthquake prone areas

M.A.Sadovsky, L.G.Bolchovitinov, V.F.Pisarenko, 1982
M.A.Sadovsky et al, 1984

Algorithm of estimation of coefficients in

$$\lg N(M,L) = A + B\cdot(M-5) + C\cdot\lg L$$

1.Set of magnitude units ΔM

$$M_0+(j-1)\cdot\Delta M \le M < M_0+j\cdot\Delta M$$

$$M_j\ ,\ j=1, \dots ,m$$

2.Hierarchy of areas $\{ Q^i \}$:

$$L_{i+1} = 1/2 L_i\ ,\quad i = 0, 1, \dots ,h-1$$

3.Computation of

$$N_{ji} = \frac{\sum (n_j(Q^i))^2}{N_j}$$

N_j is the total number of earthquakes from j-th magnitude range,
$n_j(Q^i)$ counts those from area Q^i

4.Least squares for

$$\lg N_{ji} = A + B\cdot(M_j-5) + C\cdot\lg L_i$$

Calculations on :

Artificial catalogues
Catalogues of main shocks

Artificial catalogues:

Line

Three Sierpinsky gaskets
(cemetery, cross, carpet)

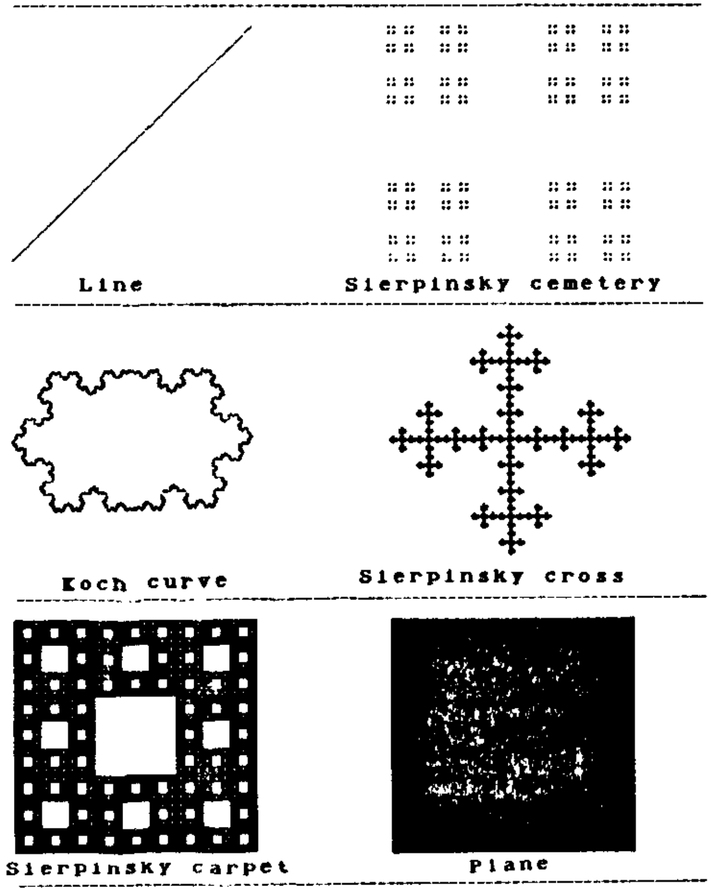
Koch curve

Plane

Line on plane

"Morphostructural Lineaments" of Pamirs and Tien Shan

Catalogues of main shocks for
Caucasus, Turkmenia, Pamirs and Tien Shan, Baikal lake, N.California, Mendocino, S.California, E. and W. Hemispheres



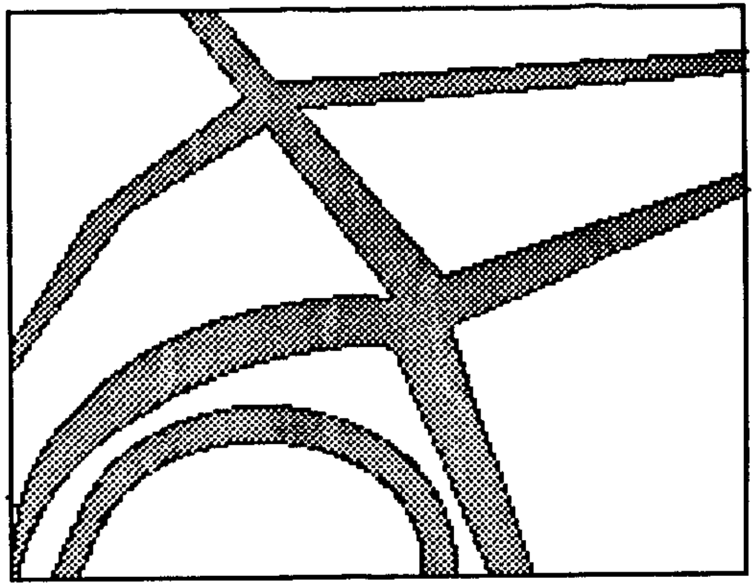


Table 1. Artificial catalogues.

Catalog	$dim^T X$	$dim^F X$	$\lg N(M) = a + b \cdot M$
Line	1	1	7.91 - 1.00 M
Sierpinsky cemetery	0	1,26..	8.41 - 1.00 M
Koch curve	1	1,26..	8.41 - 1.00 M
Sierpinsky cross	1	1,46..	8.60 - 1.00 M
Sierpinsky carpet	1	1,89..	9.61 - 1.00 M
Plane	2	2	9.82 - 1.00 M
"Morphostructural lineaments" of Central Asia	2	2	
1)			8.65 - 1.00 M
2)			5.60 - 1.00 M
3)			5.63 - .71 M ±.12 ±.03

Note: $dim^T X$ and $dim^F X$ are topological and fractal dimension of a set X.

Table 2. Estimates of coefficients in
$\lg N(M,L) = A + B \cdot M + C \cdot \lg L$ for artificial catalogs

	Main variant	Shift	Rotation
1. Line	5.07 -1.01M+0.99lg L ±.020 ±.004 ±.004	5.23 -1.01M+0.87lg L ±.233 ±.048 ±.041	4.89 -1.02M+1.02lg L ±.038 ±.008 ±.007
2. Sierpinsky cemetery	4.03 -0.98M+1.43lg L ±.258 ±.054 ±.044	4.27 -0.95M+1.22lg L ±.326 ±.068 ±.056	4.32 -0.95M+1.14lg L ±.104 ±.022 ±.018
3. Koch curve	3.97 -0.98M+1.31lg L ±.200 ±.041 ±.034	4.08 -0.99M+1.27lg L ±.168 ±.034 ±.028	3.98 -1.98M+1.32lg L ±.199 ±.040 ±.034
4. Sierpinsky cross	4.34 -0.99M+1.49lg L ±.161 ±.033 ±.028	3.98 -0.99M+1.44lg L ±.073 ±.015 ±.013	4.03 -1.01M+1.45lg L ±.145 ±.030 ±.025
5. Sierpinsky carpet	4.01 -1.00M+1.91lg L ±.042 ±.009 ±.007	3.59 -0.98M+1.85lg L ±.080 ±.017 ±.014	3.58 -0.99M+1.86lg L ±.051 ±.011 ±.009
6. Plane	4.00 -1.00M+1.99lg L ±.015 ±.003 ±.003	——	——

Table 3. Estimation of coefficients in
$\lg N(M,L) = A + B \cdot M + C \cdot \lg L$ for "Morphostructural Lineaments"

	Main variant	Shift	Rotation
variant A	4.66 -1.00M+1.34lg L ±.16 ±.03 ±.03	4.55 -1.00M+1.40lg L ±.12 ±.03 ±.02	4.68 -1.00M+1.33lg L ±.16 ±.03 ±.03
variant B	1.71 -0.69M+1.29lg L ±.10 ±.02 ±.04	1.59 -0.69M+1.36lg L ±.08 ±.02 ±.03	1.76 -0.71M+1.30lg L ±.09 ±.02 ±.04

Table 4. Estimation of coefficients in $\lg N(M,L) = A + B \cdot M + C \cdot \lg L$

for a line on a plane

K	Gutenberg-Richter law	$\lg N(M,L) = A + BM + C\lg L$
1/40	9.21 - 1.00 M	4.02 - .99 M + 1.99 lg L ±.02 ±.004 ±.004
1/4	9.30 - 1.00 M	4.63 - 1.00 M + 1.77 lg L ±.14 ±.03 ±.03
1	9.51 - 1.00 M	5.86 - 1.00 M + 1.37 lg L ±.16 ±.04 ±.04
2	9.68 - 1.00 M	6.46 - 1.00 M + 1.21 lg L ±.13 ±.03 ±.03
4	9.90 - 1.00 M	6.96 - 1.00 M + 1.12 lg L ±.08 ±.02 ±.02
8	10.16 - 1.00 M	7.37 - 1.00 M + 1.06 lg L ±.05 ±.01 ±.01

Table 5. Catalogues of some seismic regions.

Catalogue of earthquakes	Period of time	M_0	Center of region		Gutenberg-Richter law	Mean sq.
			φ	λ		
1. Caucasus	1962-1983	2,7	43,0	45,0	-.03 - .85(M-5) ±.02 ±.02	±.03
2. Turkmenia	1962-1983	2,7	39,5	56,0	-.05 - .80(M-5) ±.10 ±.07	±.11
3. Pamirs and Tien Shan	1962-1985	2,7	41,0	74,5	-.53 - .77(M-6) ±.03 ±.03	±.05
4. Baikal lake	1962-1983	2,7	56,0	110,0	-.22 - .96(M-5) ±.01 ±.01	±.01
5. Northern California	1980-1987	1,5	38,0	-121,0	-.08 - .80(M-5) ±.06 ±.03	±.10
6. Mendocino	1974-1983	2,5	40,8	-125,0	-.14 - .63(M-5) ±.02 ±.01	±.02
7. Southern California	1949-1965	3,0	35,0	-118,0	.16 - .82(M-5) ±.03 ±.02	±.04
8. Southern California	1980-1987	2,0	35,0	-118,0	.05 - .87(M-5) ±.02 ±.01	±.03
9. Eastern hemisphere	1964-1985	5,0	0	90,0	2.43 - .82(M-5) ±.04 ±.03	±.06
10. Northern hemisphere	1964-1985	5,0	0	-90,0	2.19 - .86(M-5) ±.04 ±.03	±.05

Table 7. Estimation of coefficients in lg N(M,L) = A + B·M + C·lg L for regions of Northern California

Region	Center		lgN(M,L) = A + B·M + C·lgL	Mean sq.
	φ	λ		
San Andreas (North)	40	-123	-3.11 - .81(M-5) + .94lg L ±.20 ±.05 ±.06	±.15
San Andreas (center)	38	-122	-3.24 - .82(M-5) + 1.00lg L ±.20 ±.04 ±.06	±.15
San Andreas (South)	36	-121	-3.96 - .82(M-5) + 1.27lg L ±.17 ±.04 ±.05	±.10
Sierra Nevada (North)	40	-120.5	-4.81 - .84(M-5) + 1.54lg L ±.19 ±.03 ±.06	±.08
Sierra Nevada (South)	39	-119	-3.78 - .57(M-5) + 1.43lg L ±.20 ±.03 ±.07	±.12

Table 6. Estimations of coefficients in lg N(M,L) = A + B·M + C·lg L for seismic regions

Region	Period of time	Magnitude range	L (km)	lg N(M,L) = A + B(M-5) + Clg L	Mean sq.
1. Caucasus	1962-1983	2,7 - 4,7	1200	-4.73 - 0.86(M-5) + 1.52 lg L ±.08 ±.01 ±.02	±.03
2. Turkmenia	1962-1983	2,7 - 4,7	1000	-4.04 - 0.78(M-5) + 1.34 lg L ±.22 ±.04 ±.07	±.08
3. Pamirs and Tien Shan	1962-1985	2,7 - 5,2	1700	-3.88 - 0.72(M-5) + 1.39 lg L ±.15 ±.02 ±.05	±.08
4. Baikal lake	1962-1983	2,7 - 4,7	2000	-4.36 - 0.96(M-5) + 1.26 lg L ±.09 ±.02 ±.03	±.04
5. Northern California	1980-1987	1,5 - 5,0	800	-3.86 - 0.79(M-5) + 1.20 lg L ±.16 ±.03 ±.05	±.13
6. Southern California	1980-1987	2,5 - 5,0	800	-3.80 - 0.79(M-5) + 1.26 lg L ±.25 ±.05 ±.08	±.12
7. Mendocino	1974-1983	2,5 - 4,5	400	-3.34 - 0.63(M-5) + 1.22 lg L ±.13 ±.02 ±.05	±.05
8. Southern California	1949-1985	3,0 - 5,0	600	-4.52 - 0.82(M-5) + 1.52 lg L ±.12 ±.02 ±.04	±.04
9. Southern California	1980-1987	2,0 - 5,0	800	-4.32 - 0.89(M-5) + 1.50 lg L ±.05 ±.01 ±.02	±.04
10. Southern California	1980-1987	3,0 - 5,0	800	-4.39 - 0.89(M-5) + 1.52 lg L ±.09 ±.02 ±.03	±.04
11. Eastern hemisphere	1964-1986	5,0 - 7,5	18000	-2.77 - 0.77(M-5) + 1.20 lg L ±.06 ±.01 ±.02	±.07
12. Western hemisphere	1964-1986	5,0 - 7,5	18000	-2.26 - 0.83(M-5) + 1.01 lg L ±.11 ±.03 ±.03	±.12

Conclusions:

1. $\lg N(M,L) = A + B\cdot(M-5) + C\cdot\lg L$
is applicable in wide ranges of magnitudes and sizes

2. Coefficient **C** in different regions varies from **1.** to **1.5**.
It is adequate to fractal dimension d_2.
C correlates with geometry of tectonic structures.

3. Coefficients can be used as averaged estimates

4. Time scaling in characteristic area is the same for earthquakes of different strength:

for Pamirs and Tien Shan

$$\lg N(M,L(M)) = -3.88 - .72(M - 5) + 1.39(.54M - 2.0) = -3.06 + .03M$$