Veðurstofa Íslands
Notes

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Seismic hazard at the Hvalfjörður tunnel

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SEISMIC HAZARD AT THE HVALFJÖRÐUR TUNNEL

SEISMICITY IN SOUTHERN AND WESTERN ICELAND

Several studies on historical earthquakes in Iceland have been published. The fundamental works on this subject are from Thoroddsen (1899, 1905, 1925). An overview of the seismicity in Iceland is given in Björnsson and Einarsson (1974), Einarsson and Björnsson (1979), Halldórsson and Stefánsson (1986, 1987) and Halldórsson (1991).

From the first decades of this century data from only few seismic stations in Europe are available (Kárník, 1969). These stations could detect earthquakes in Iceland down to magnitude 5.5. In the period 1909-1914 a seismometer of Mainka type was operated in Reykjavík. The data from this period are incomplete but the seismometer could detect most events down to magnitude 4.0. Since 1926 we have had continuous seismic measurements in Iceland. From 1926 to 1951 a single Mainka type seismometer was located in Reykjavík, but since then the number of stations has increased considerably. For this study only the southwestern part of the country is of interest. In Figure 1 earthquakes of magnitude 6 or more since 1700 are shown. Figure 2 shows earthquakes of magnitude 4 or greater since 1927.

Figure 3 shows the zones in southwestern Iceland where magnitude 5 or greater can be expected.

Eastern part of the South Iceland Lowland, zone 1.

The largest earthquakes in southern Iceland occur in zone 1. The biggest known earthquake in this area occurred on August 14, 1784, and had an estimated magnitude of 7.1 (Stefánsson, 1979). This is probably the largest quake in southern Iceland, at least since 1500. Since 1700, six earthquakes in zone 1 have an estimated magnitude greater than 6 and since 1900 six events have reached magnitude 5 or more on the Richter scale. In this study the maximum magnitude for earthquakes in the area is estimated 7.2.

Central part of the South Iceland Lowland, zone 2.

The oldest accounts of earthquakes in this area are from 1164. The largest known earthquake in zone 2 occurred in 1734 with an estimated magnitude of 6.8. Since 1700 at least four earthquakes have reached magnitude 6. In this century no quake in the area has reached magnitude 5. The maximum magnitude for earthquakes in zone 2 is estimated 6.9.

Western part of the South Iceland Lowland, zone 3.

Written accounts of earthquakes in this area date back to year 1370. The maximum magnitudes of earthquakes in zone 3 appear to be much smaller than in the eastern part of the South Iceland seismic zone. Since 1700 no earthquake exceeding magnitude 6 has occurred in zone 3 but four have reached magnitude 6. The maximum magnitude for earthquakes in zone 3 is estimated 6.1.

Hengill, zone 4.

The Hengill area is located in the southern part of the Western Volcanic Zone and between the earthquake areas of southern Iceland and the Reykjanes Peninsula. The largest seismic episode in zone 4 was in the summer of 1789. Estimation of the magnitude of the largest event in historic time is difficult but it is probably less than 6.0. The maximum magnitude for earthquakes in zone 4 is estimated 6.0.

Eastern part of the Reykjanes Peninsula, zone 5.
The earliest known earthquake with probable location in this area was in 1724. Its magnitude has been estimated 6.0 (Halldórsson and Stefánsson, 1987). The largest recorded event in zone 5 occurred on July 23, 1929 with M=6.3, based on registrations at 29 stations (Kárník, 1969). The maximum magnitude for earthquakes in zone 5 is estimated 6.4.

Krísuvík, zone 6.
Earthquake swarms are frequent in this area. Since 1926, six magnitude 5 earthquakes have occurred in zone 6. The biggest known quake was on June 10, 1933 with M=5.6. The maximum magnitude for earthquakes in zone 6 is estimated 5.7.

Reykjanes, zone 7.
Earthquake swarms are also common in this area but the events are generally smaller and more frequent than in zone 6. The largest event in Reykjanes was a M=5.3 quake that occurred on June 1, 1936. This is the only event greater than magnitude 5 since 1926. The maximum magnitude for earthquakes in zone 7 is estimated 5.5.

Langjökull-Skjaldbreið, zone 8.
This area covers the Western Volcanic Zone with its consistent microseismicity. The maximum magnitude for earthquakes in zone 8 is estimated 5.1.

Borgarfjörður, eastern part, zone 9.
The first known earthquake with probable location in this area occurred in November 1868. Several historical accounts of earthquakes in other parts of Iceland were written in Borgarfjörður. It is therefore considered unlikely that a catastrophic earthquake in the area would not have been noted in the annals. Seismicity in zone 9 is episodic with the largest known sequence in 1974. Its biggest quake was on June 12, with magnitude 5.6. Since 1926 five earthquakes in zone 9 have reached magnitude 5. The maximum magnitude for earthquakes in zone 9 is estimated 5.7.

Borgarfjörður, western part, zone 10.
There are no historical accounts of earthquakes in this area. The largest episode in zone 10 was in February 1938, including three M=5.0 events. The maximum magnitude for earthquakes in zone 10 is estimated 5.1.

AN INTENSITY-DISTANCE RELATION FOR ICELAND

To estimate the seismic hazard and to estimate magnitudes of historical earthquakes it is necessary to know the intensity-distance relation for Iceland.

To calculate the attenuation of intensities in Iceland isoseismal maps from 8 earthquakes have been analyzed. Their epicenters are distributed over all seismic zones in the country and their magnitudes range from 5.2 to 7.0. The method of Chandra et al. (1979) was used to estimate the average attenuation in Iceland. From these 8 earthquakes attenuations of 25 epicentral distances from 20 to 204 km were used for the analysis (Halldórsson et al., 1984). The result was:

$$I - I_o = 0.8767 - 0.0123R - 1.5691\log R$$

For these earthquakes the relation between I_o and magnitude was found to be:

$$I_o = 0.33 + 1.24M$$

R is the epicentral distance and I is the intensity at R. Here I_o stands for the calculated epicentral intensity which is usually much lower than the real intensity at the epicenter. The relation is valid for R > 20 km and the standard deviation is 0.2. The relation indicates a mean depth of about 5 km.

To convert the intensity to acceleration the relation from Murphy and O'Brien (1977) was used and then the relation between horizontal acceleration and an earthquake of magnitude M at distance R was found to be:

$$\log a_h = 0.911 + 0.396M - 0.00185R - 0.885\log R$$

The attenuation of intensities in Iceland appears to be higher than in Europe and N-America (Chandra 1979) and Iran (Chandra et al., 1979).

SEISMIC HAZARD AT THE TUNNEL

Using the maximum magnitudes estimated (Figure 3) the greatest acceleration expected at the tunnel site is listed in the following table:

Seismic zone	Maximum acceleration at the tunnel (%g)
Eastern part of the South Iceland Lowland, zone 1	10.5
Central part of the South Iceland Lowland, zone 2	12.5
Western part of the South Iceland Lowland, zone 3	6.5
Hengill, zone 4	7.5
Eastern part of the Reykjanes Peninsula, zone 5	10.9
Krísuvík, zone 6	5.7
Reykjanes, zone 7	2.9
Langjökull-Skjaldbreið, zone 8	2.8
Borgarfjörður, eastern part, zone 9	3.0
Borgarfjörður, western part, zone 10	1.9

The maximum acceleration at the tunnel is 12.5% g or122 cm/sec^2.

Distribution of acceleration at the tunnel.

The horizontal acceleration a_h at the tunnel has been calculated for each event ≥ 4.0 since 1926 (Figure 2) and ≥6.0 since 1700 (Figure 1). In this study an upper bound is assumed $a_{max}=122$ cm/sec^2. In Figure 4 the distribution of $U=\log_{10}a_h$ is shown.

To estimate the number of earthquakes causing horizontal acceleration a_h such that $\log a_h \geq U$ for a given value of U, a distribution proposed by Cornell og Vanmarcke (1969) is used:

$$N(U) = N(0)\frac{\exp(-\beta U) - \exp(-\beta\, U_{max})}{1 - \exp(-\beta\, U_{max})}$$

N(U) is the number of earthquakes where $\log_{10}a_h \geq U$ at the tunnel, N(0) is the number of earthquakes where $a_h \geq 1$, $U_{max} = \log_{10}a_{max}$ and β is a constant. If $U_{max} \rightarrow \infty$, $a = \log N(0)$ and $b = \beta/2.3$, we get the well-known Gutenberg-Richter relation:

$$\log N = a - bU$$

The highest probable horizontal acceleration and the probability of given acceleration.

In Figure 5 and in the following table the highest probable acceleration at the tunnel is shown for different time intervals.

Years	Highest probable acceleration (%g)
20	3.8
50	5.3
100	6.7
150	7.5
200	8.2
250	8.6
300	9.0
350	9.3
400	9.5
450	9.8
500	9.9

For comparison the highest probable horizontal acceleration in the southwestern part of Iceland for 50, 100 and 500 years is shown in Figures 7, 8 and 9.

The probability of a given acceleration in a given time interval is shown in Figure 6 and the following table:

Acceleration (%g)	Mean return period (Years)	The probability of a given acceleration in 20, 50, 100, 200, 400 and 500 years.					
		20	50	100	200	400	500
1	0.6	1.00	1.00	1.00	1.00	1.00	1.00
2	3.7	1.00	1.00	1.00	1.00	1.00	1.00
4	22.7	0.59	0.90	0.99	1.00	1.00	1.00
6	71.4	0.25	0.51	0.76	0.94	1.00	1.00
8	185.7	0.10	0.24	0.42	0.66	0.88	0.93
10	516.7	0.04	0.09	0.18	0.32	0.54	0.62
12	3784	0.01	0.01	0.03	0.05	0.10	0.12

CONCLUSION

According to the seismic activity in southwestern Iceland, i. e. both historical and measured data, we can not expect horizontal acceleration at the tunnel site above 122 cm/sek^2 or12.5% of g.

Reykjavík, September 1, 1995,

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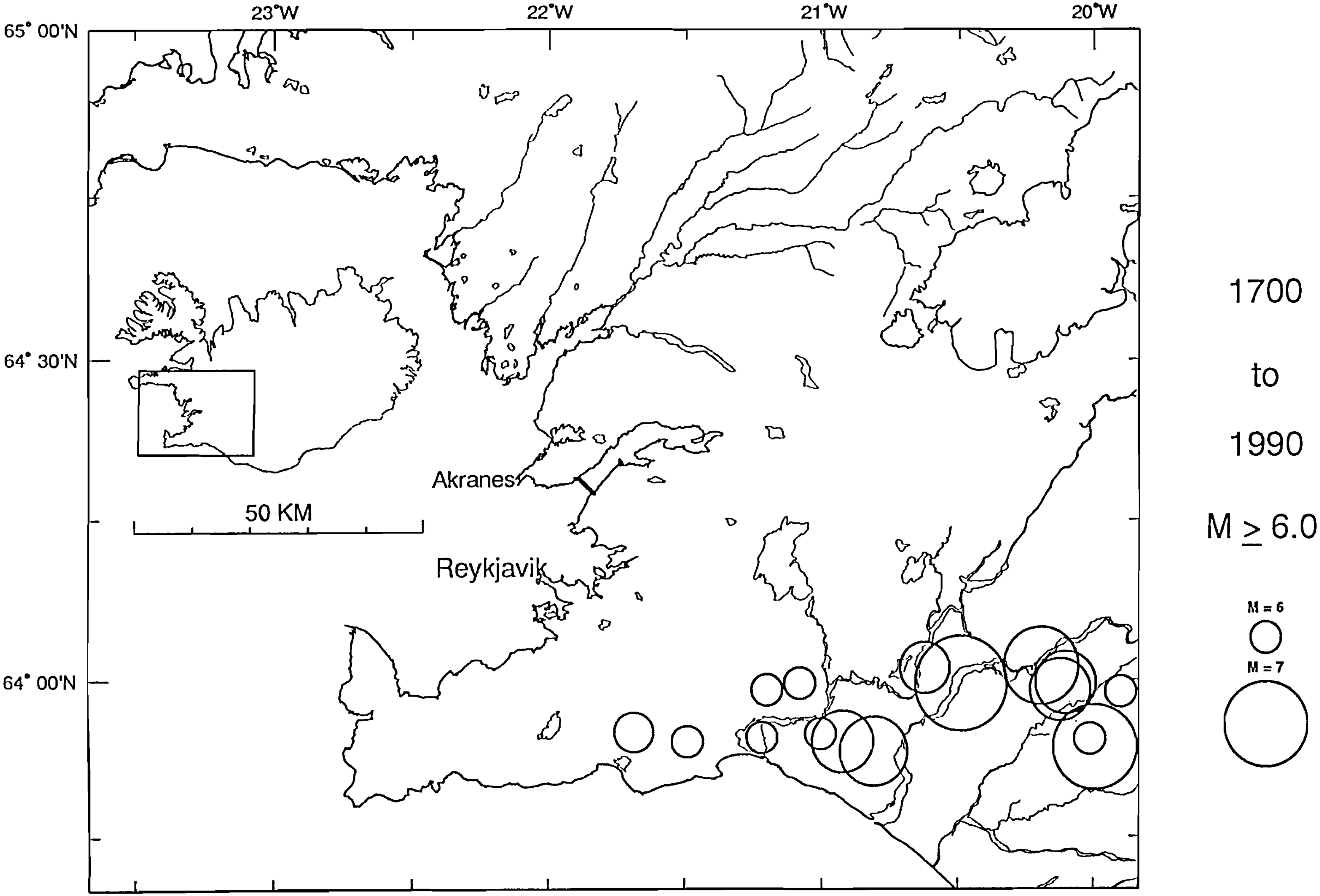
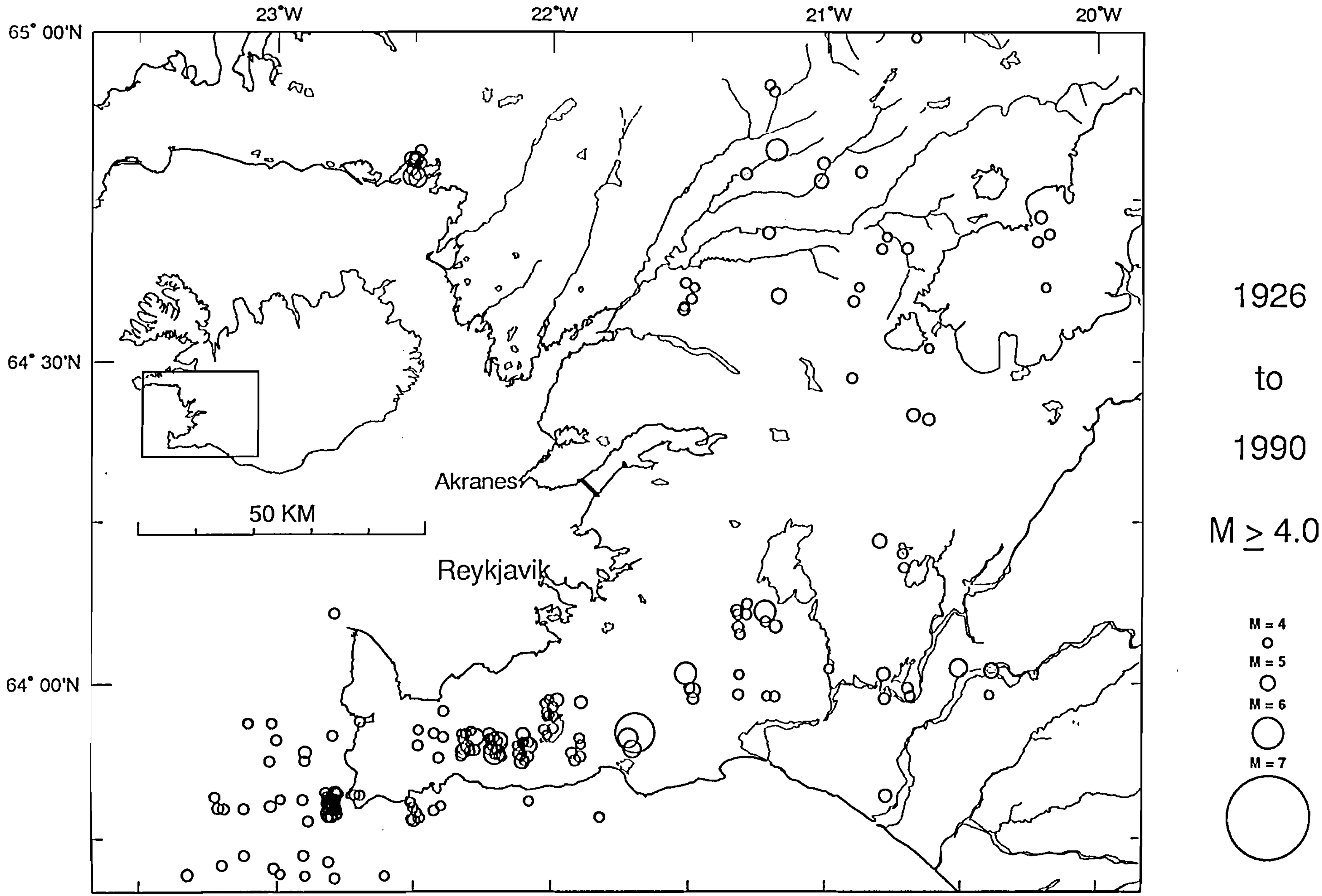


23°W
22°W
21°W
20°W
65° 00'N
64° 30'N
64° 00'N
50 KM
Akranes
Reykjavik
1700
to
1990
M ≥ 6.0
M = 6
M = 7

Fig. 1



23°W
22°W
21°W
20°W
65° 00'N
64° 30'N
64° 00'N
Akranes
50 KM
Reykjavik
1926
to
1990
M ≥ 4.0
M = 4
M = 5
M = 6
M = 7

Fig. 2

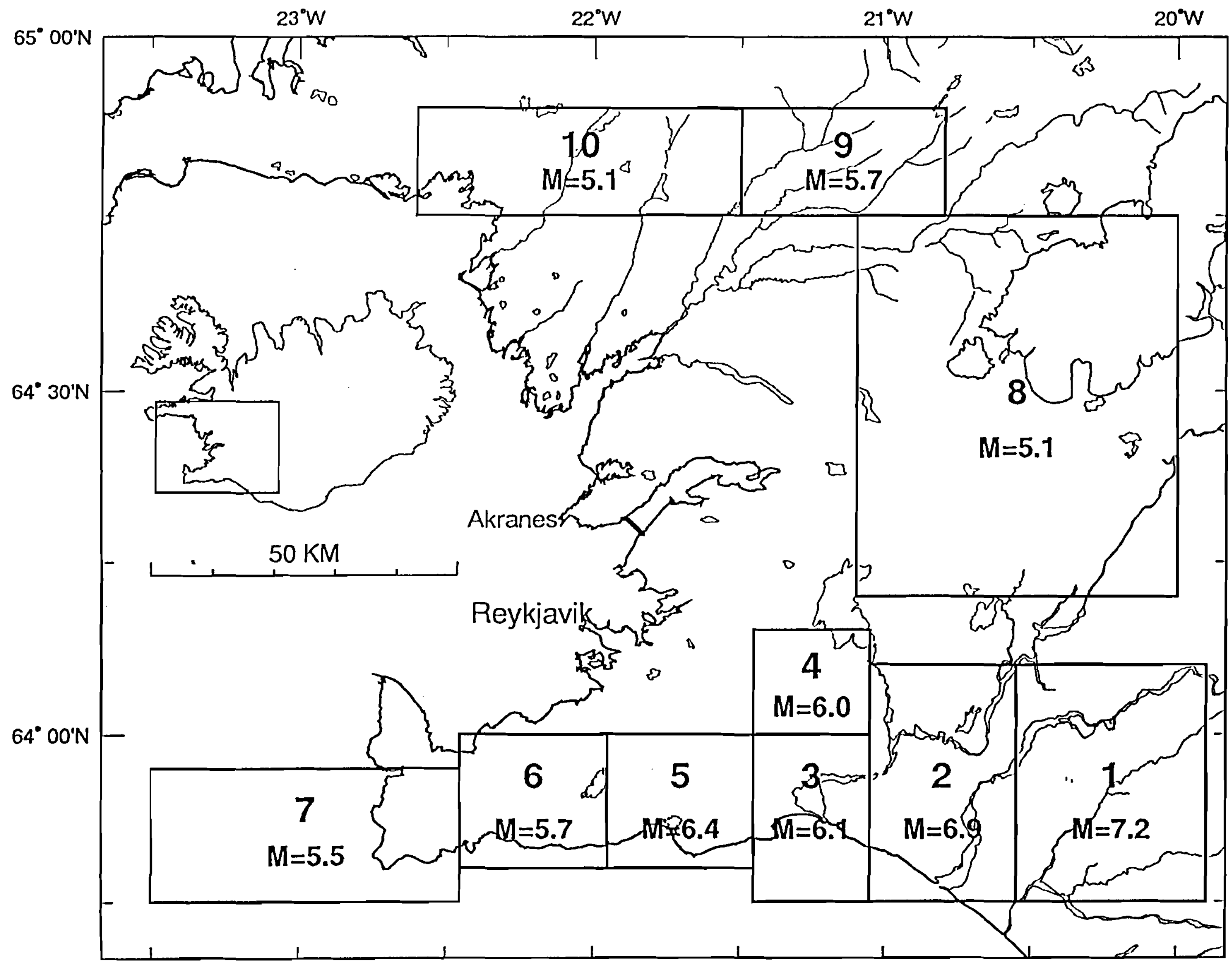
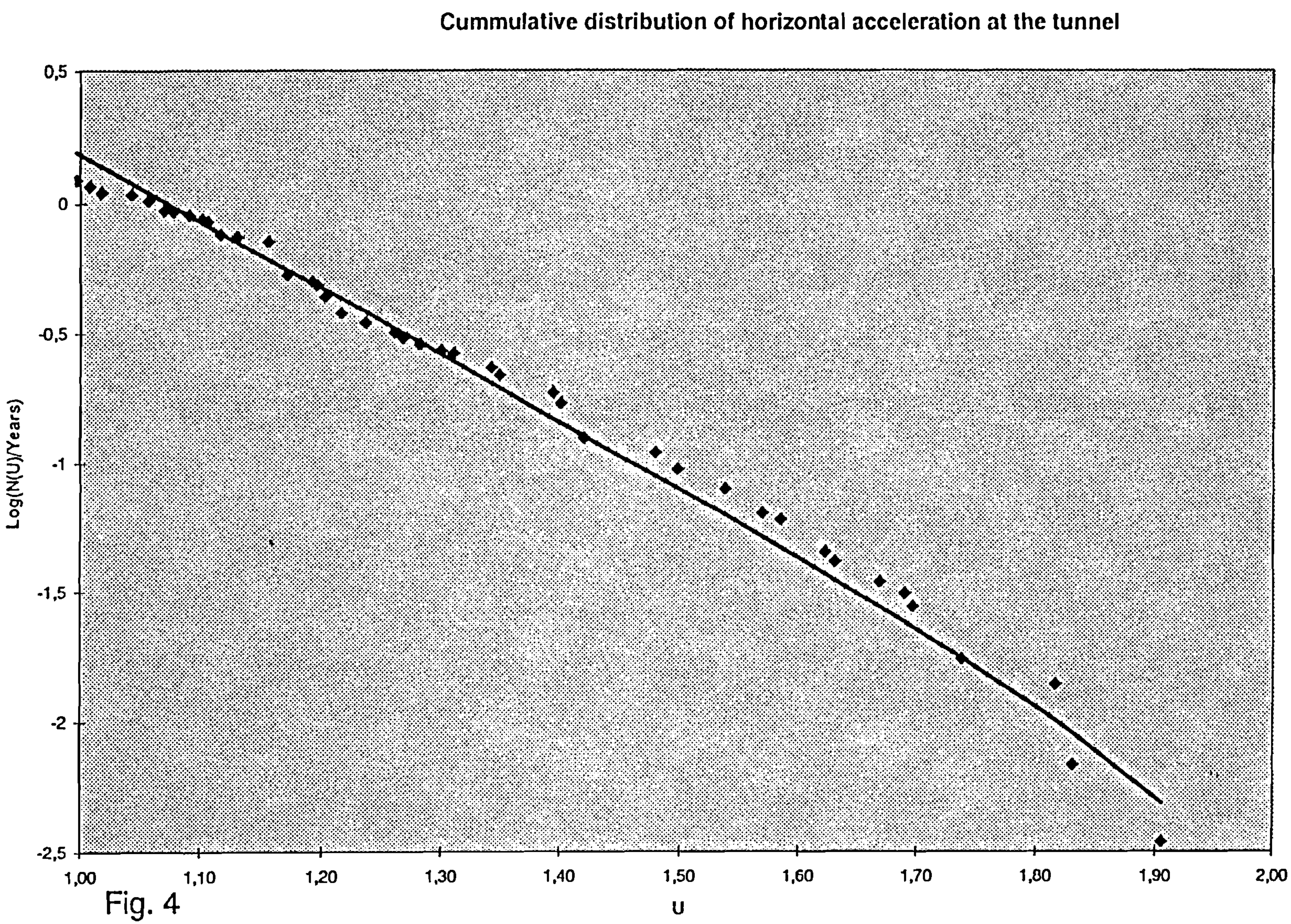
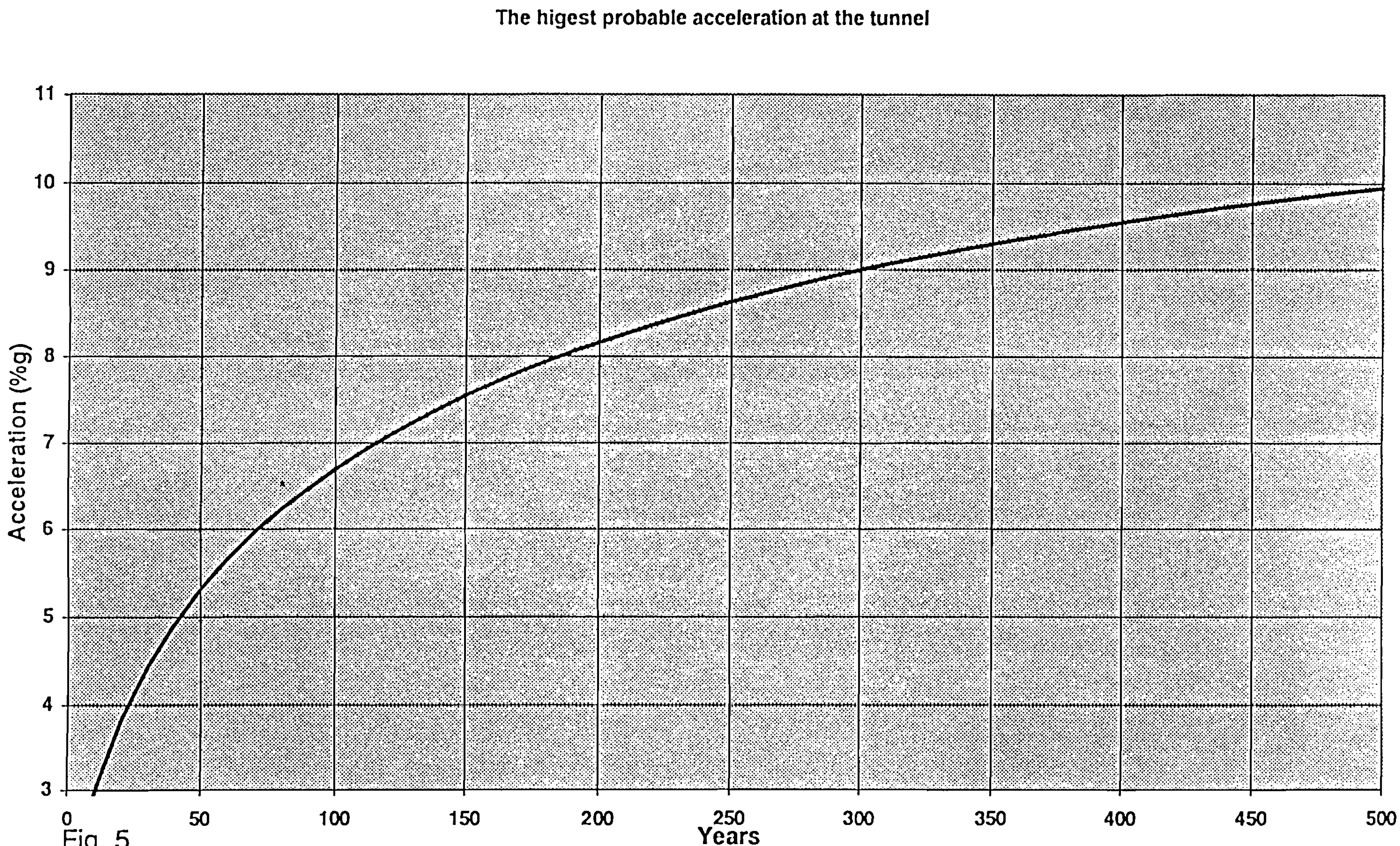

23°W
22°W
21°W
20°W
65° 00'N
64° 30'N
64° 00'N
10
M=5.1
9
M=5.7
8
M=5.1
Akranes
50 KM
Reykjavik
4
M=6.0
7
M=5.5
6
M=5.7
5
M=6.4
3
M=6.1
2
M=6.9
1
M=7.2

Fig. 3



Cummulative distribution of horizontal acceleration at the tunnel
Log(N(U)/Years)
0,5
0
-0,5
-1
-1,5
-2
-2,5
1,00
1,10
1,20
1,30
1,40
1,50
1,60
1,70
1,80
1,90
2,00
U

Fig. 4


The higest probable acceleration at the tunnel
Acceleration (%g)
11
10
9
8
7
6
5
4
3
0
50
100
150
200
250
300
350
400
450
500
Years
Fig. 5

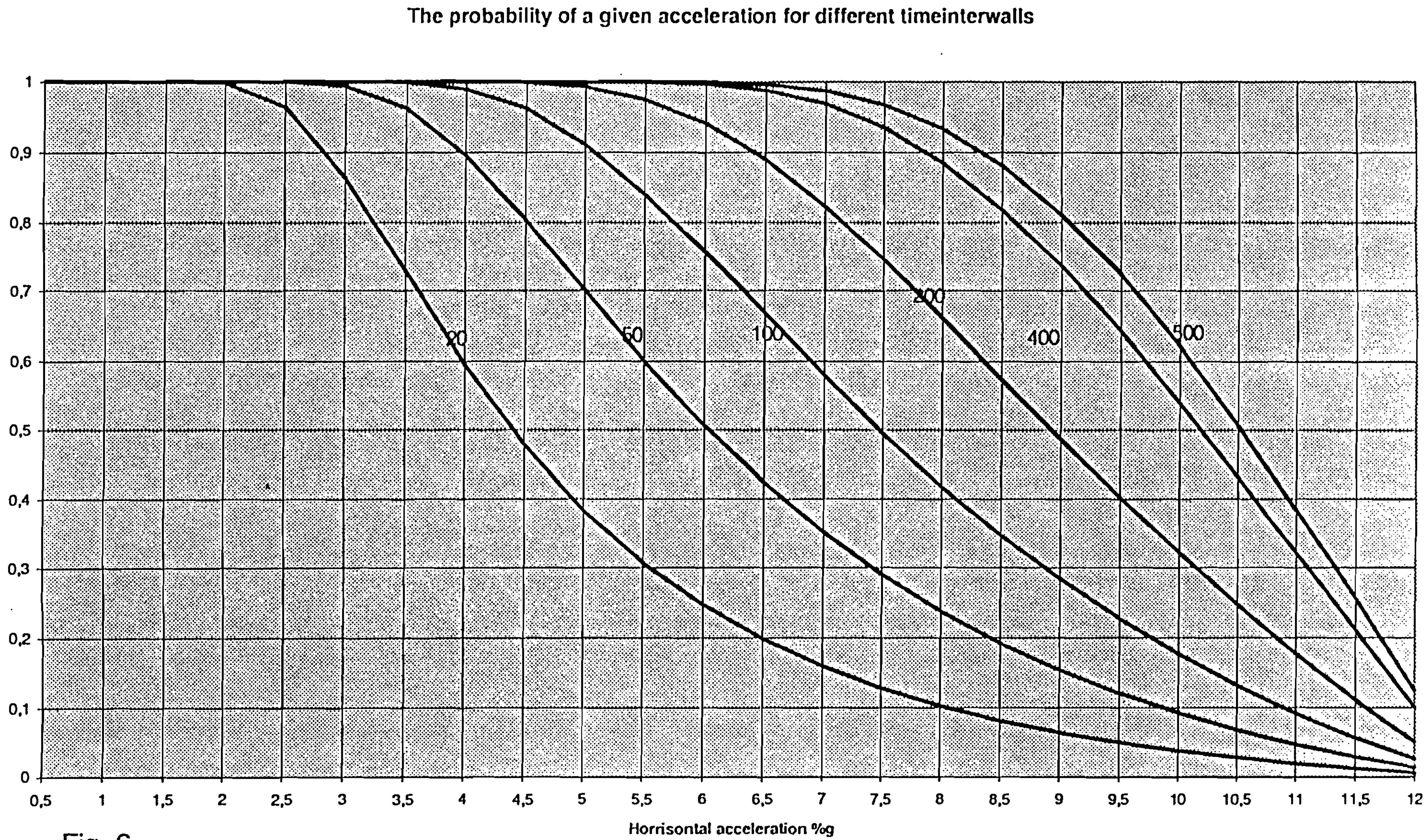

The probability of a given acceleration for different timeinterwalls
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10
10,5
11
11,5
12
20
50
100
200
400
500
Horrisontal acceleration %g

Fig. 6

Highest probable acceleration in 50 years

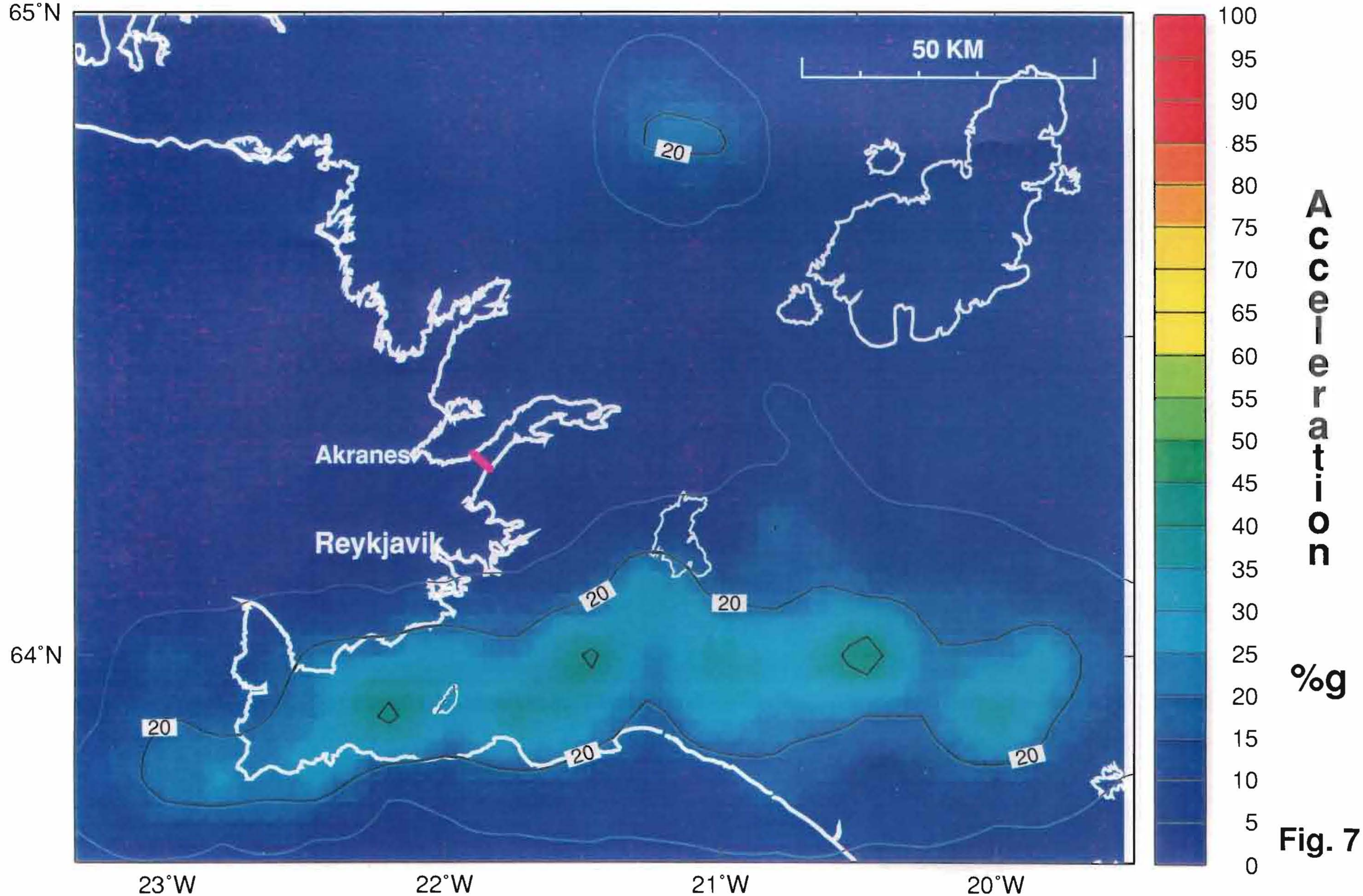


Fig. 7

Highest probable acceleration in 100 years

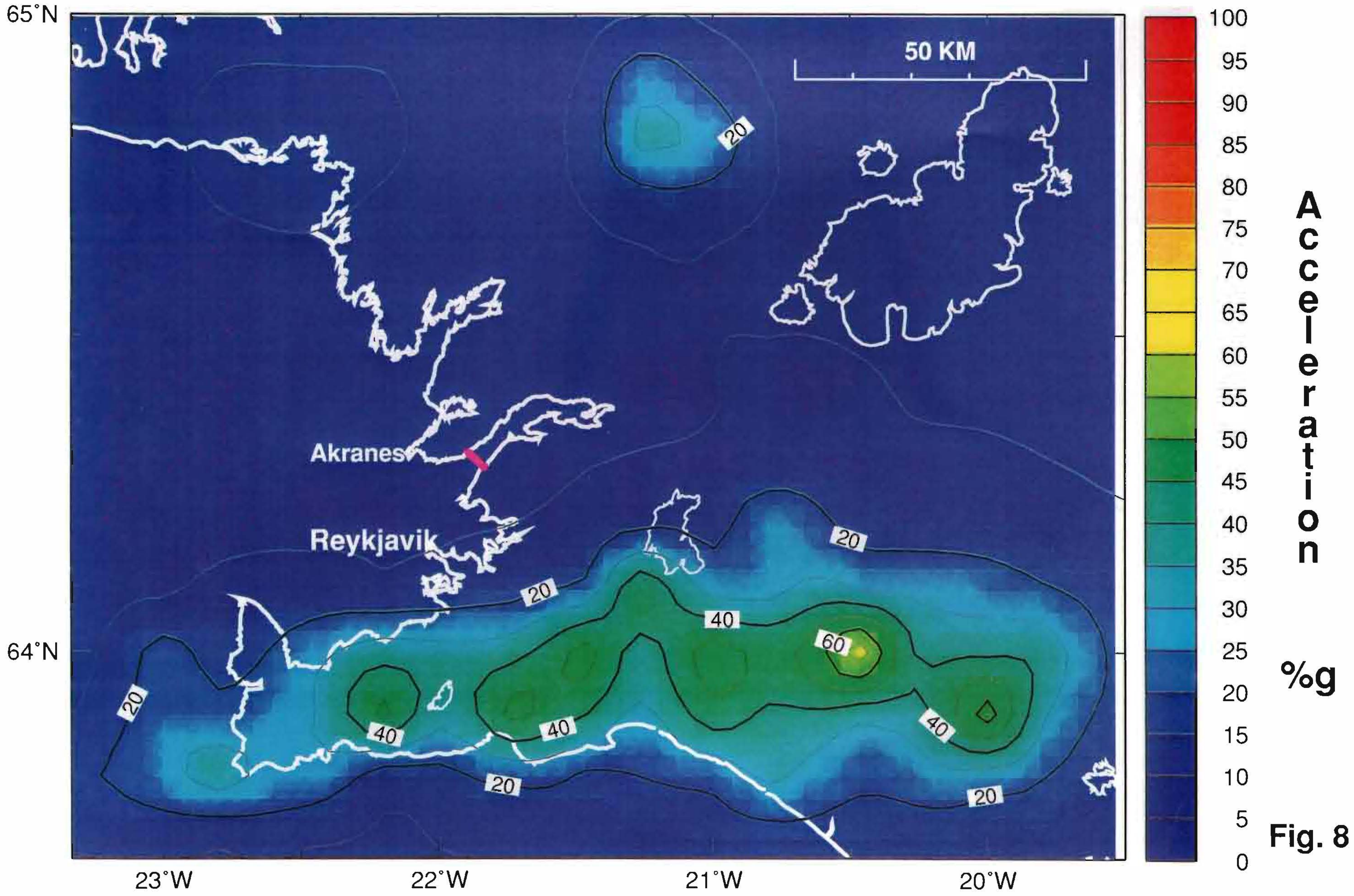


Fig. 8

Highest probable acceleration in 500 years

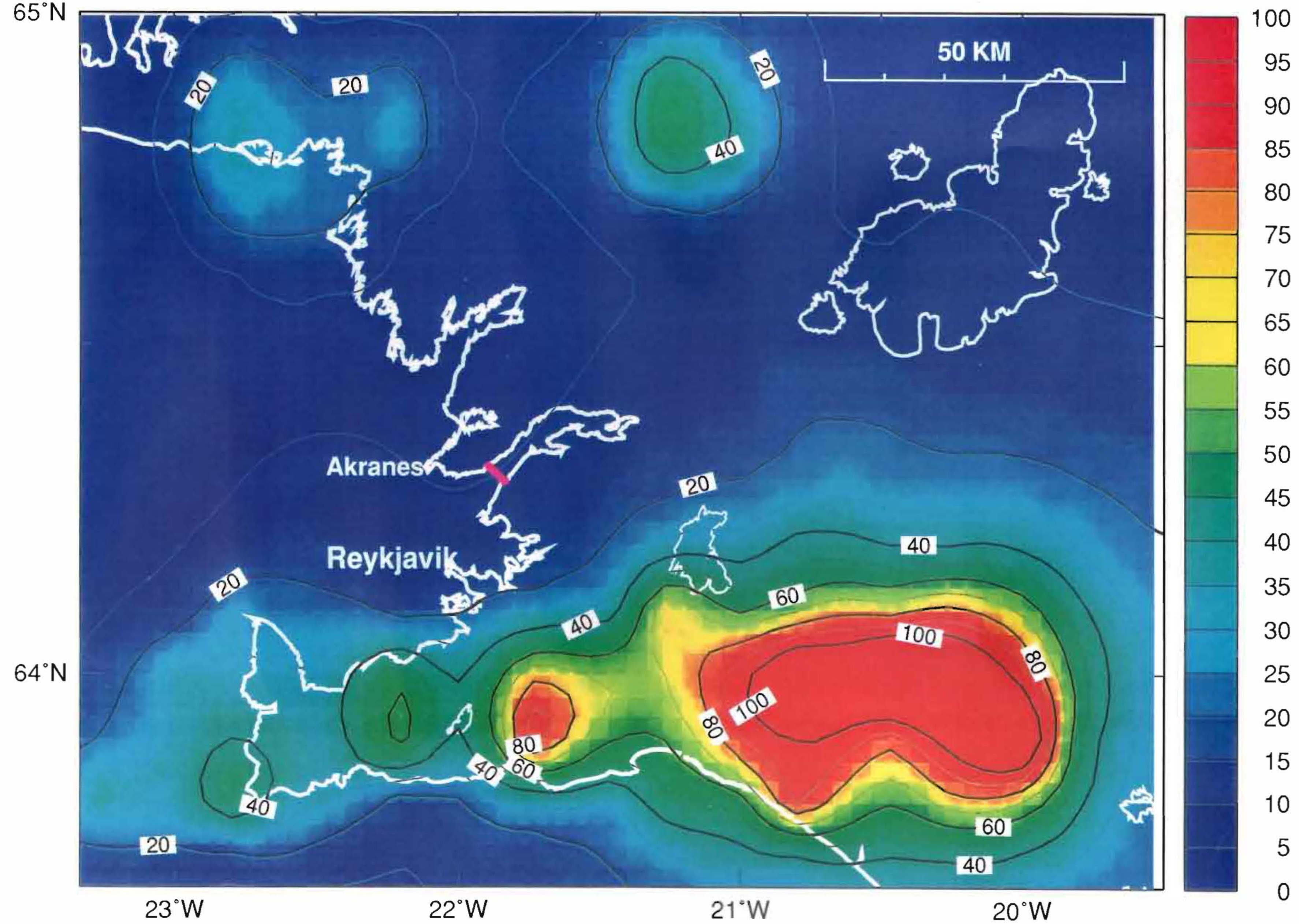


Fig. 9