Result of Precision Levelling in Surtsey

by

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Introduction

On June 20 a levelling profile across the Surtsey lava was marked by 42 benchmarks consisting of small brass pins. These pins were inserted into the lava surface in a permanent position and a number (601 to 642) was stamped on each pin (Figure 1). This profile was levelled from east to west on June 21 to 22. A second levelling was made on August 9 to 10, also from east to west, and the third levelling on August 11-12 from west to east.

In addition, levellings from the east end of the profile (601) to the pond east of the research hut (Pálsbær) and to the doorstep of the hut were made on June 23 and again on August 12. Measurements of the surface elevation of a pond near the north shore of the island were made on August 9 to 12, and these were tied to the levelling profile.

Levelling across the Surtsey lava

The main result of the levelling is shown in Table 1 and Figure 2. In Table 1 all elevations are based on the elevation of benchmark 601 at the east end of the profile. As this work is primarily a study of the deformation of the Surtsey lava by comparing levellings made at different times, the accuracy of these levellings are of utmost importance.

The levelling of June 21-22 was less accurate than the later levellings due to limited time and experience. However, the probable error in relative elevation of the benchmarks is less than 0.5 millimeters over a distance of one kilometer. The levellings of August 9 to 12 are more accurate, with probable error about 0.25 millimeter per kilometer on profile. Thus the variation of observed elevation

(Table 1) is very much greater than the error of observation

The change in observed elevation of the benchmarks is shown in Table 1, and the average daily change is shown on Figures 3 and 4. The whole profile subsided relative to benchmark 601 with the possible exception of benchmark 642 on the west coast of Surtsey. Greatest subsidence between June 21-22 and August 9-10 was observed for benchmarks 619 (7.7 centimeters), 617 (5.6 centimeters), 625 (4.5 centimeters), 608 (3.4 centimeters), and 626 (3.3 centimeters). Other benchmarks subsided less than three centimeters. The probable error of the observed subsidence is about one millimeter on the western part of the profile and less on the eastern portion, making the probable error in the average daily rate of subsidence approximately 0.02 millimeters for the period June 21-22 to August 9-10 (Figure 3). Estimated errors in Figure 4 increase from left to right due to decreased time between levellings and are roughly 0.2 millimeters at benchmark 620 and 0.5 millimeters at 642. When Figures 3 and 4 are compared, it is clear that the rate of deformation is similar for the roughly 50 days period covered in Figure 3 and for the one to three day period covered in Figure 4. However, there are some significant changes. The movement of benchmarks 616, 617, 618, 619 and 620, relative to each other, is greater for the later period. The increase in average relative rate of movement in this area from the first to the second period amounts to about 20 percent. These benchmarks are in the area of the latest lava flows of Surtsey and the lava of this area was quite hot during the summer of 1967. The irregular movement of this area is probably caused by slow plastic flow of the still hot lava. Contraction due to cooling of the lava may account for a fraction of this subsidence.

The portion of the profile lying between benchmarks 621 and 640 was subsiding rapidly in August 1967 while a quite slow subsidence was observed over the much longer period between the first and second levelling. The rate of vertical movements of benchmarks 624 through 638, relative to each other, is,however, very similar for the two periods, while the whole area where the benchmarks are located, has started to subside rapidly in August of 1967.

The change in rate of deformation from the first to the second

period is shown on Figure 5. This graph shows very clearly the increased rate of subsidence in the western part of the island. A subsidence of benchmarks 624 to 638 at the rate observed in August 1967 would in one week account for the total subsidence of this area between June 22 and August 10.

Levelling near the north coast of Surtsey

On June 22 the surface of the pond east of the research hut was tied by levelling to benchmark 601 and to the doorstep of the hut. It was assumed that the surface elevation of this pond was very close to mean sea level. On August 13 levelling was performed from benchmark 601 to several points on northern Surtsey, including the average elevation of the pond near the coast north of the research hut. Table 2 shows the result of these levellings.

The elevation of the northern pond was observed around high-and-low tide during a four day period, August 9 to 12, so the average elevation of this pond was obtained with an accuracy of roughly 5 centimeters. The amplitude of the tides in this pond was 1.52 meters on August 9 but decreased during the period of observation due to decreasing ocean tide (Table 3). The pond tide was delayed more than two hours relative to predicted ocean tide in Heimaey. The difference in time of ocean tide at Surtsey and Heimaey is not known but assumed to be insignificant. The average delay of the low tide is 2 hours 52 minutes, while the high tide is delayed an average of 2 hours 24 minutes. Furthermore, the delay is greater for large tidal amplitude than for small amplitude.

There is certainly some difference between the mean elevations in the pond and in the ocean, the pond being somewhat higher. How much this amounts to is not exactly known, but a mathematical solution of the problem seems possible and will be attempted. Preliminary study indicates that the average surface elevation of the pond may be about 10 centimeters above mean sea level.

The southern pond was about 12 centimeters lower on August 12 than on June 22, relative to 601 and the research hut. On August 12,

this pond was about 10 centimeters above the mean elevation of the northern pond and it is highly unlikely that the difference between the two ponds varies much. It is assumed that heavy rain may temporarily raise the level of the southern pond but the high permeability of the coarse sand between the pond and the ocean will allow a fast recovery of normal pond level. The elevation of the southern pond decreased about one centimeter per day during August 9-12, 1967. This was probably due to decreasing ocean tide during that period.

The water level in beach sand is normally somewhat higher than the mean sea level, the difference being proportional to the amplitude of the tide. The tidal amplitude of the northern pond decreased about 10 percent per day during August 9-12. Therefore, it may be assumed that the elevation of the southern pond above mean sea level has decreased about 10 percent per day during the same period. This reasoning places the elevation of the southern pond only 10 centimeters above mean sea level and the average elevation of the northern pond very close to mean sea level.

It is probable that the elevation of the southern pond is always nearly the same, relative to sea level except during periods of heavy rain and that the observed decrease in its elevation relative to the hut and 601 during the summer of 1967 is in fact due to an uplift of the northern part of Surtsey.

Conclusion

The Surtsey lava was deforming quite rapidly during the summer of 1967. Most of it subsided relative to benchmark 601 which is located near the northern edge of the lava, east of the tuff mountain formed during the first phase of the Surtsey eruption in 1963-64. Certain portions of the lava (benchmarks 608, 617, 619, 625) subsided more rapidly than other areas, probably due to slow plastic flow of the hot lava, and the subsidence rate of the lava was mostly higher in early August than earlier in the summer.

A large area in the western part of the lava where benchmarks 622 through 640 lie, appears to have started to subside as one block in early August 1967. These benchmarks are all within 500 meters

distance from the lava crater of 1964-65 while all other benchmarks on the levelling profile are farther away from this crater. This might indicate a beginning of the formation of a caldera-like depression of roughly 500 meters radius, centered near the crater.

Levelling on the northern part of Surtsey indicates that benchmark 601 was uplifted relative to sea level during the 50 days between the first and last levelling. This uplift may amount to about 10 centimeters.

Acknowledgements

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TABLE I

ELEVATION OF THE SURTSEY PROFILE AND CHANGES IN MEASURED ELEVATION

Benchmark	Elevation* meters	DH (1)** millimeters	DH (2)*** millimeters	Average daily rate of elevation changes in millimeters	
				A***	B***
601	0.0000	0.000	0 000	0.000	0.000
602	2 1116	-5.085	-0.076	-0.103	-0.026
603	3.7015	-7.103	-0.244	-0.144	-0.083
604	6 6902	-11.668	-0.525	-0.237	-0.180
605	9.9526	-14.248	-0.818	-0.289	-0.282
606	12 2598	-14.386	-0.844	-0.292	-0.291
607	14.9332	-24.443	-1.121	-0.497	-0.389
608	14.5701	-34.310	-1.398	-0.698	-0.488
609	15.5663	-22.545	-0.671	-0.459	-0.227
610	16.9093	-12.085	-0.397	-0.246	-0.128
611	19.8787	- 8.928	-0.380	-0.182	-0.122
612	22.1399	- 9.893	-0.155	-0.202	-0.039
613	24 4769	-18.145	-0.532	-0.370	-0.180
614	25.3169	-11.335	-0.276	-0.231	-0.084
615	26.3514	-11.138	-0.316	-0.277	-0.099
616	33.5863	-23.459	-0.827	-0.478	-0.293
617	35.1862	-55.622	-2 428	-1.134	-1 087
618	38.3812	-22.520	-0.872	-0.459	-0.307
619	40.0789	-77.015	-3.691	-1.571	-1.735
620	42.5310	- 8.921	-1.582	-0.197	-0.174
621	42.3529	-23.402	-2.198	-0.492	-0.646
622	43.4034	-17.345	-2.619	-0.368	-0.975
623	43.6928	-23.200	-3.138	-0.487	-1.389
624	44.8529	-29.603	-3.255	-0.618	-1.484
625	47.5836	-44.779	-3.811	-0.928	-1.944
626	46 3979	-33 215	-3.352	-0.692	-1.554
627	38.1017	-19.533	-3.051	-0.413	-1.282
628	30.1553	-11.671	-2.969	-0.253	-1.204
629	23.4799	- 7 434	-2.712	-0.167	-0.945

TABLE I - Continued

ELEVATION OF THE SURTSEY PROFILE AND CHANGES IN MEASURED ELEVATION

Benchmark	Elevation* meters	DH (1)** millimeters	DH (2)** millimeters	Average daily rate of elevation changes in millimeters	
				A***	B***
630	22.1249	- 6.091	-2.716	-0.133	-0.949
631	21.8859	- 6.078	-2.952	-0.133	-1.231
632	23.3125	- 6.990	-2.528	-0.152	-0.763
633	24.6109	- 6.592	-2.842	-0.144	-1.118
634	24.4854	- 7.879	-2.715	-0.170	-0.971
635	28.4475	- 8.576	-3.019	-0.184	-1.334
636	24.4872	-10.444	-2.916	-0.222	-1.205
637	23.0009	-10.301	-3.006	-0.219	-1.321
638	21.5758	- 9.051	-2.919	-0.193	-1.206
639	17.9631	- 7.930	-2.563	-0.160	-0.716
640	13.5802	- 6.695	-2.317	-0.135	-0.367
641	11.8132	- 5.653	-2.164	-0.114	-0.135
642	7.0888	- 0.498	-1.834	-0.009	+0.376

* Elevation as measured June 21 to 22, 1967, above benchmark 601.

** DH (1) is the change of measured elevation from June 21 - 26 to August 9 - 10 assuming no movement of 601.
DH (2) is the change from August 9 - 10 to August 10 - 11.
Minus sign means subsidence relative to 601.

*** A covers the period June 21 - 22 to August 9 - 10
B covers period August 9 - 10 to August 11 - 12.

TABLE 2

DIFFERENCE IN ELEVATIONS ON NORTHERN SURTSEY

	June 23, 1967 cm	August 13, 1967 cm
H (601) - H(S - Pond)	878.42	890.63
H (Doorstep) - H (S - Pond)	728.42	740.32
H (S - Pond) - H (N - Pond)		9.73
H (000) - H (N - Pond)		406.21
H (Doorstep) - H (N - Pond)		750.06
H (601) - H (N - Pond)		900.36
H (Marker - 0) - H (N - Pond)		153.62
H (601) - H (Doorstep)	150.00	150.31
H (601) - H (Marker - 0)		746.74
H (Marker - 0) - H (S - Pond)		143.88
H (Doorstep) - H (Marker - 0)		596.44

H (601) is the elevation of benchmark numbered 601

H (S - Pond) is the surface elevation of the southern pond (Dropi)

H (N - Pond) is the average surface elevation of a tidal pond near the north coast of Surtsey

H (Doorstep) is the elevation of the doorstep of the research hut

H (000) is the elevation of top of galvanized pipe marking the zero point of triangulation grid in Surtsey

H (Marker - 0) is the elevation of a brass nail placed in lava about one meter east of north end of the southern pond

TABLE 3

TIDAL OBSERVATIONS IN THE NORTHERN POND ON SURTSEY

August 9 - 12, 1967

Time of high or low tide		Height of tide in pond	Delay of pond tide	
In pond	In Ocean			
d h m	d h m	cm	h	m
9-16-51	9-13-56	-69.9	2	55
9-22-39	9-20-09	80.6	2	30
(10-05-13)	10-02-27	(-67)	(2	46)
10-10-58	10-08-33	64.1	2	25
10-17-35	10-14-40	-64.8	2	55
10-23-19	10-20-52	74.9	2	27
11-06-11	11-03-10	-66.0	3	01
11-11-41	11-09-19	54.5	2	22
11-18-16	11-15-26	-63.4	2	50
11-23-58	11-21-40	61.1	2	18
12-06-45	12-03-56	-57.5	2	49
12-12-30	12-10-11	55.7	2	19
12-19-08	12-16-20	-41.5	2	48

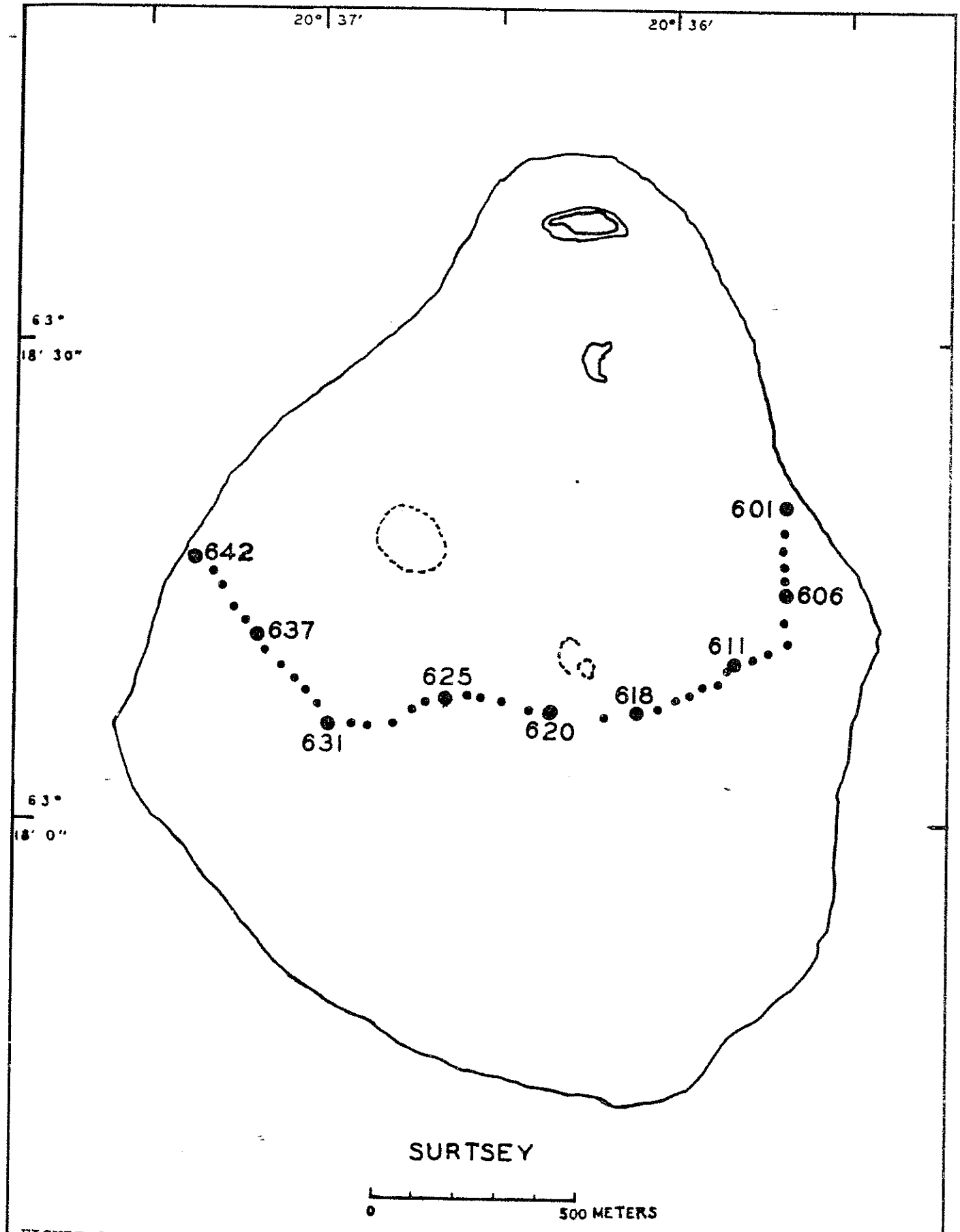

FIGURE 1. MAP SHOWING LOCATION OF BENCHMARKS ON THE LEVELLING PROFILE IN SURTSEY.

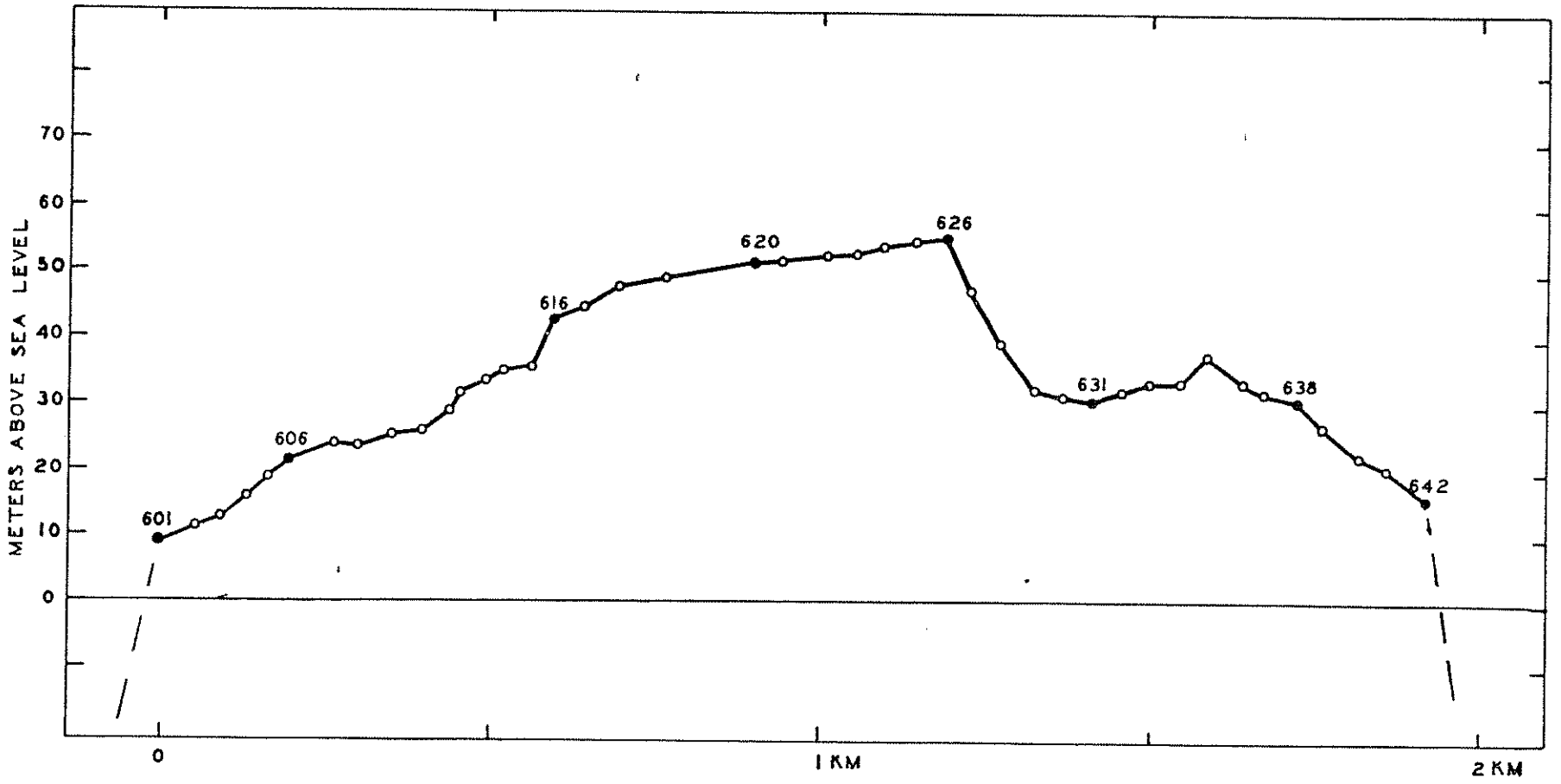

FIGURE 2. ELEVATION OF THE LEVELLING PROFILE IN SURTSEY IN JUNE 1967
VERSUS DISTANCE ALONG THE PROFILE

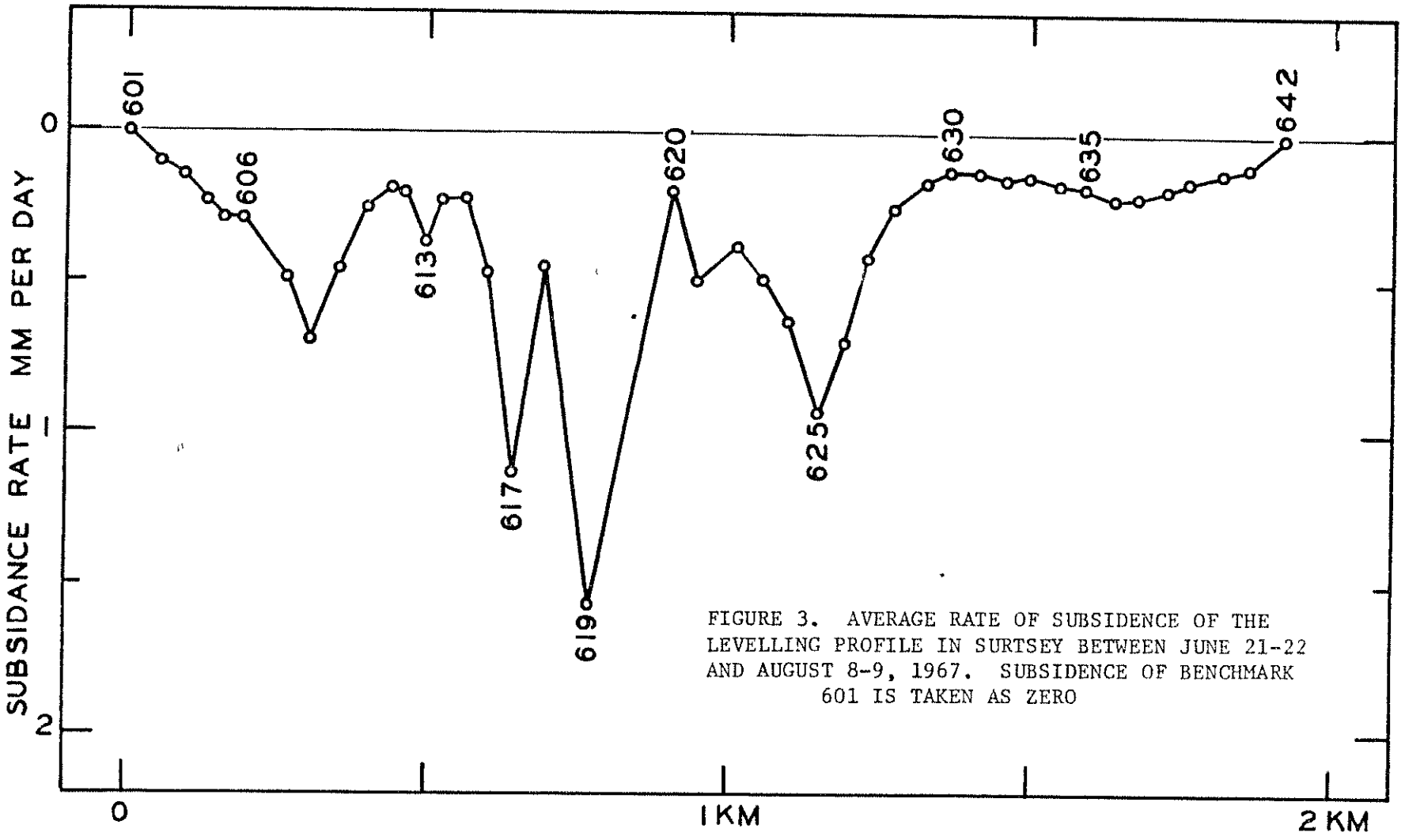

FIGURE 3. AVERAGE RATE OF SUBSIDENCE OF THE LEVELLING PROFILE IN SURTSEY BETWEEN JUNE 21-22 AND AUGUST 8-9, 1967. SUBSIDENCE OF BENCHMARK 601 IS TAKEN AS ZERO

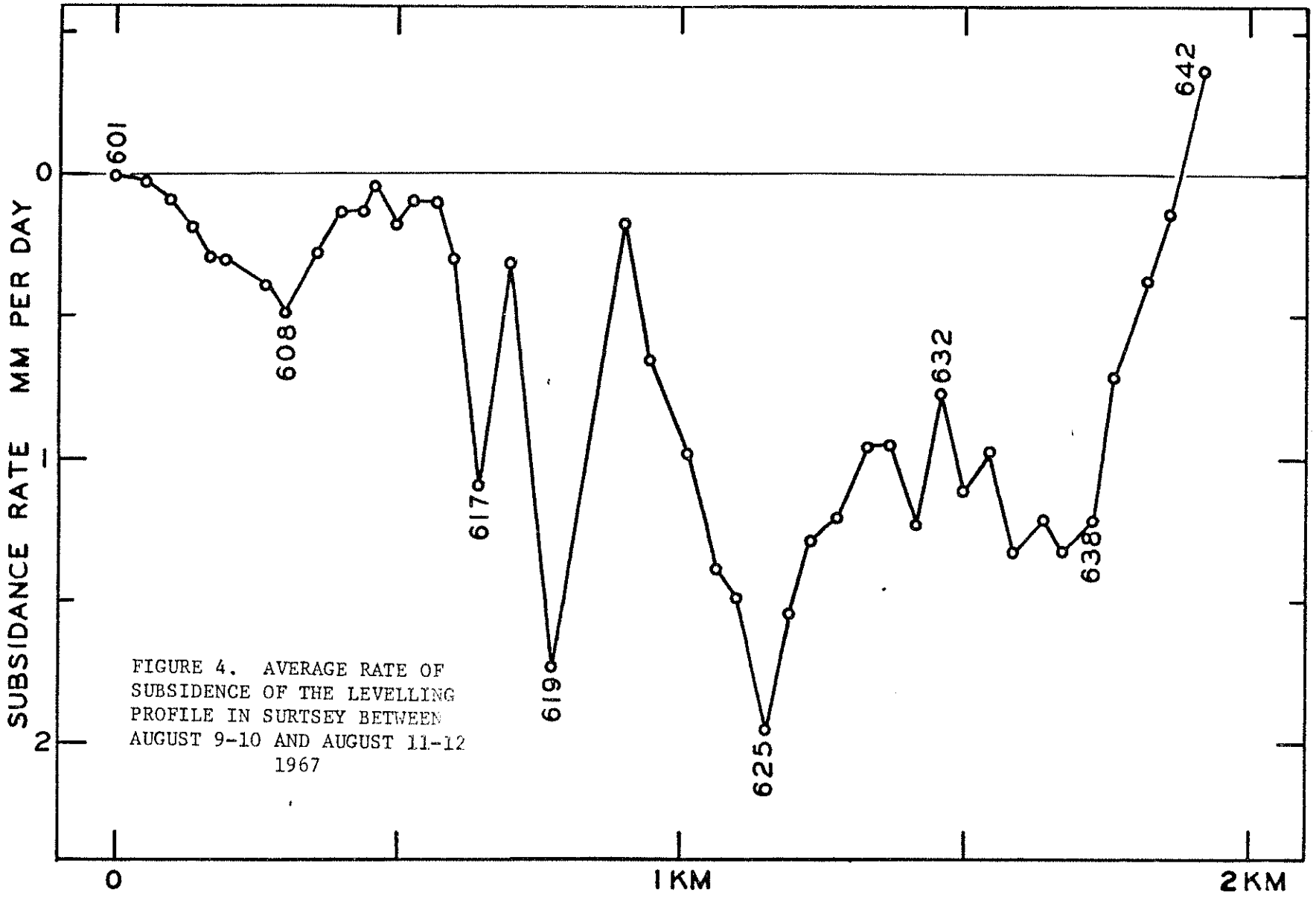

FIGURE 4. AVERAGE RATE OF SUBSIDENCE OF THE LEVELLING PROFILE IN SURTSEY BETWEEN AUGUST 9-10 AND AUGUST 11-12 1967

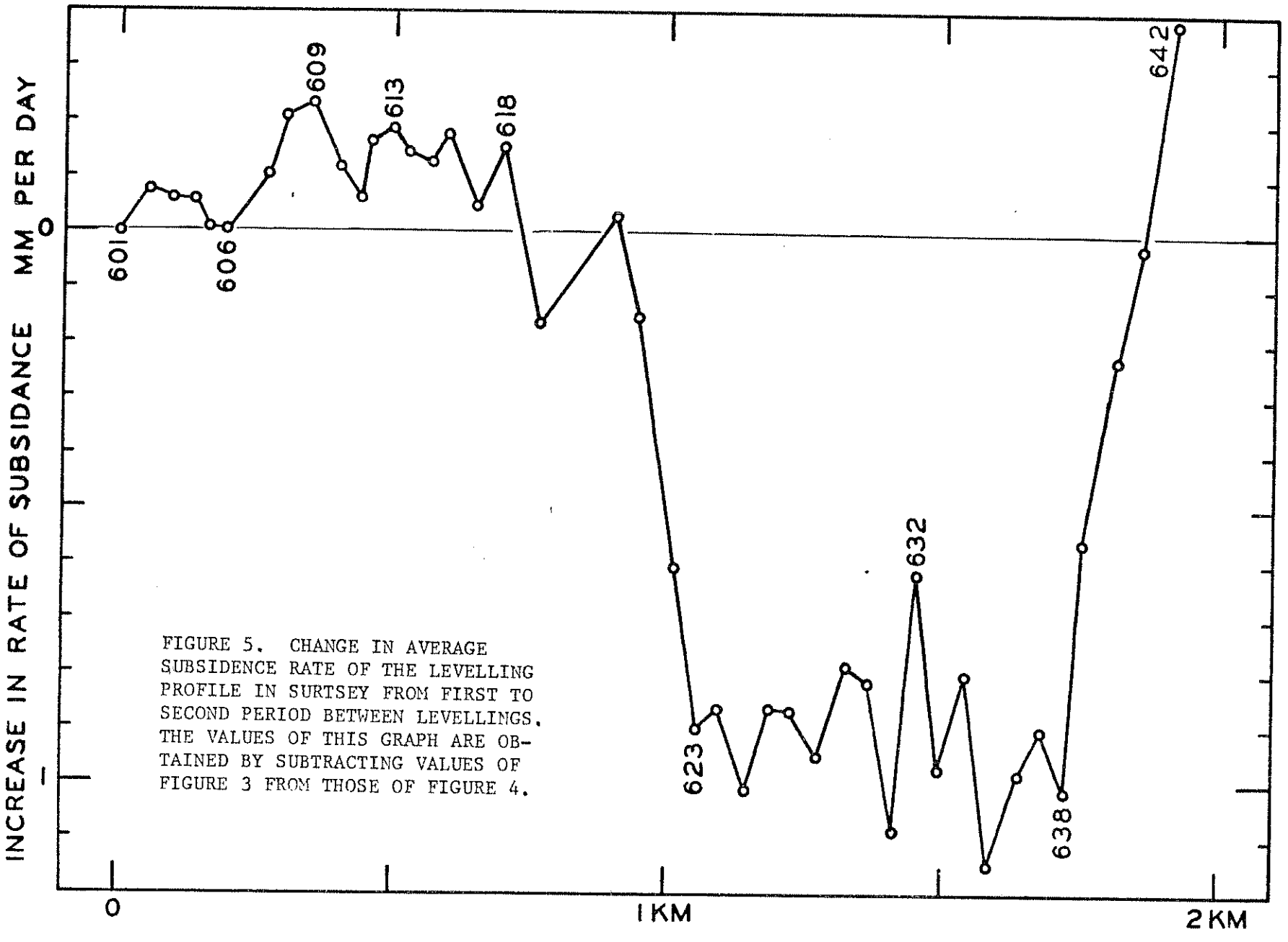

FIGURE 5. CHANGE IN AVERAGE SUBSIDENCE RATE OF THE LEVELLING PROFILE IN SURTSEY FROM FIRST TO SECOND PERIOD BETWEEN LEVELLINGS. THE VALUES OF THIS GRAPH ARE OBTAINED BY SUBTRACTING VALUES OF FIGURE 3 FROM THOSE OF FIGURE 4.