The thermal anomaly in Surtsey revisited

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On Sept. 5th 1975 an expedition was taken to Surtsey in the Coast Guard helicopter to map changes in the thermal anomaly formed in the tephra and lava after the eruption 1963—1967. Participants were, apart from the pilot, Karl Sæmundsson, a teacher going on behalf of the Surtsey Society to supervise the hut, Sveinn Jakobsson of the Museum of Natural History, Hörður Johnsen from the Vestmann Islands, Þórður Kristófersson, assistant, and the present author, both employed at the Science Institute, University of Iceland.

The expedition covered most of the island, taking temperature measurements at well over 100 points. The chief aim of the investigation was to map, as accurately as possible, the extent of thermal anomaly, to compare it with previous records, and to measure the temperature in previously investigated areas, noting changes in the heat flow with time. The earlier investigations were made in connection with plans to utilize geothermal heat from domestic heating in the town of Vestmann Islands.

Similar measurements were carried out by the present author in 1970 and the results published in the Surtsey Research Progress Report of 1972 (Vol.VI). Sveinn Jakobsson has also made similar measurements in Surtsey almost every year since the eruption came to an end in June 1967, and although there is a slight difference between his methods of measurement and those of the present author, causing minor divergences in their results, a fairly overall picture of thermal evolution in Surtsey from the very beginning has been obtained. The measurements carried out by the present author were made with a mercury thermometer, whereas those carried out by Sveinn Jakobsson were performed with a thermocouple at 20 cm depth. In the tephra, measurements made by the present author were, almost without exception, taken at a depth of 100 cm, and the limits of the thermal areas are therefore based on the 30°C isotherm at that depth.

The accompanying map of Surtsey (Fig. 1) shows thermal areas as well as the two main hot spots in the lava within the crater wall of Surtur II. Sveinn Jakobsson has kindly allowed me to use some of his results from the last few years, for which I am very grateful.

TEMPERATURE IN THE TEPHRA.

The thermal areas in the tephra have expanded greatly in later years (Surtsey Research Progress Report VI, 1972). All the thermal areas are enlargened to some extent and some of them considerably. In 1970 the tephra in the north-west part of the island was cold, but now the thermal anomaly extends almost to the rim of the tephra ring of Surtur II and new thermal areas have formed in the tephra wall on the NW-shore, reaching down to the beach and probably also up to the highest ridges. The heat has also ascended the northern slopes of the crater Surtur II, extending over the rim on the east side of Bunki, going in a sweep down to Svartagil, somewhat farther down than established in 1970.

On the east and southeast of Strompgígur the limits of the thermal anomaly stretch in a curve across the slope at 60—70 m above sea level, whereupon it slants down to the lava lying at the foot of a nearly vertical tephra wall at the easternmost corner of the tephra ring of Surtur II.

In the areas where heat was first discovered in the Surtsey tephra, hard móberg has long since been formed. Scarcely any surface heat can be detected there now and primitive measuring equipment cannot be forced through hard rock for

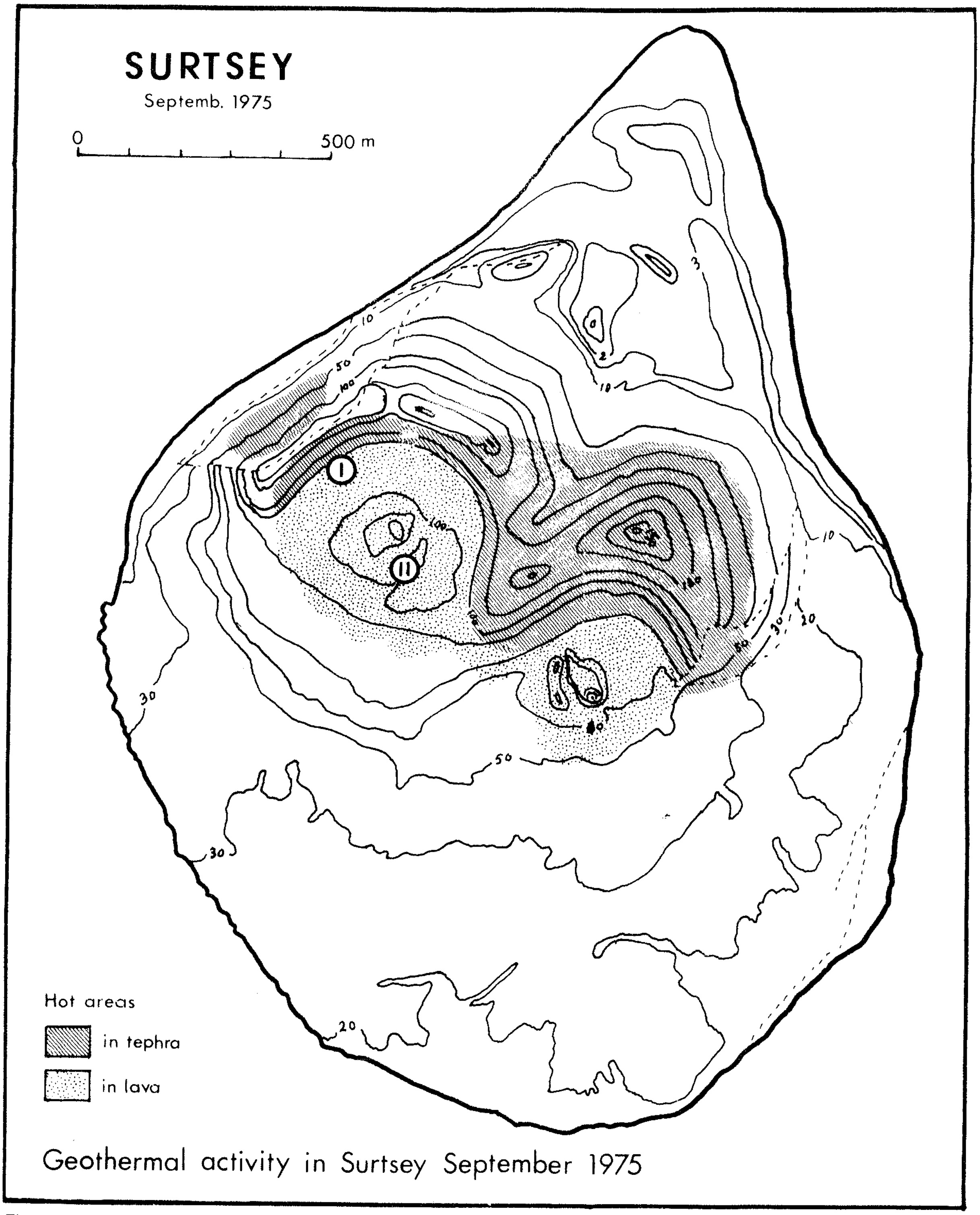

Fig. 1. A map of Surtsey showing thermal areas. Explanations in the text.

measurements at greater depth. According to a preliminary investigation the outflow of heat seems to slow down as the tephra hardens, probably owing to the decreasing permeability of the tephra. This heat is mostly carried in the form of steam, ascending through the un-solidified tephra. When the tephra solidifies the steam moves on laterally to easier outlets, and as those outlets successively close, the steam must go still farther sideways. Thus, the thermal areas in the tephra gradually increase in circumference while the temperature is lowered in the centre. This process will most likely continue as long as the heat ascends from below in the form of steam.

If this theory is correct, the thermal areas will continue to expand and most of the tephra will harden in the next few years. The theory is supported by the fact that most of the Vestmann Islands were built up in a manner similar to that of Surtsey and, like Surtsey, they consist largely of hardened tephra. These islands would not have been large enough in the beginning to withstand destruction by the sea, had the tephra not hardened comparatively quickly, as is the case in Surtsey. This indicates that post-eruptional heatflow through tephra is not an isolated phenomenon occurring only in Surtsey, but a link in a natural chain of events, and that the formation of móberg is often — if not always — due to such heating.

The measurements in 1970 showed heat up to 98°C at a depth of only a few cm. This time 60—70°C was the maximum at a depth of 100 cm. Closer investigations and more extensive measurements within the thermal anomaly might, however, reveal higher temperatures. Most of the measurements performed by the present author were restricted to defining the outlines of the thermal areas where the temperature is generally lower than near the centre. However, forcing measuring instruments into the tephra, when its hardening has reached a certain point, is very difficult and temperature values in such localities are therefore inadequately known. In steam vents within the crater of Surtur II 97—98°C were obtained, similar to the results in 1970. The same was the case in the crater Strompgígur.

TEMPERATURES IN THE LAVA.

Compared to 1970 the temperatures measured in the lava average considerably lower at all stations measured.

On a fissure NW of Surtur II, here called Area I, the maximum temperature measured in 1970 was 460°C, now it was only 50°C, cf. Fig. 2. In area II, SW of Surtur II, the highest temperature measured in 1970 was 220°C, now 160°C, cf. Fig. 2. In the so-called "Grill", SA of Surtur II, the temperature was now 73°C compared to 150°C in 1970. In steam vents elsewhere in the lava maximum temperature measured was 80—90°C, or less.

The areal extent and distribution of the thermal anomaly within the lava appeared similar to that of 1970, but the actual temperatures measured were considerably lower and the steam emission through fissures and holes has diminished.

Hlöðver Johnsen, who was in Surtsey in late August 1975, measured the temperatures in a few steam vents within the tephra ring of Surtur I. During the measurements the flow of steam from the holes increased greatly with a simultaneous rise in temperature, so that, whereas the recorded temperature was certainly over 200°C, it probably reached 400°C shortly afterwards. This occurrence was accompanied by a faintly whining sound. As mentioned above, the temperature in this locality measured only 98°C on September 5, 1975.

POSSIBLE EXPLANATION OF THE THERMAL ANOMALY IN SURTSEY

HEAT IN THE TEPHRA.

During the initial phase of eruptions of the Surtsey type, which originate in sub-aquatic or sub-marine vents, certain amounts of pillow lava can be expected to form and pile up around the vents before the eruption becomes visible at the surface of the sea. When the initial phase is powerful, as it may be assumed to have been in the Surtsey eruption, the speed of uprush is so great that the sea can only cool a thin film around each layer of pillow lava before the next layer is deposited on top of it, preventing further cooling. When the pile of pillow lava has grown to a height of a few tens of metres short of the surface the water pressure diminishes so far as to allow steam from the contact between lava and water to escape to the surface. This steam, in turn, tears away bits of the lava and blows them up to the surface, where the water cools the lava so fast that it pulverizes into fine-grained glass. The glass powder sinks down again to be deposited on top of the pillow lava, isolating it from the water. If the eruption continues, this glass, called tephra, will be piled up on top of the pillow lava in a layer tens of meters in thickness. The tephra is at first saturated with water, but through contact with the hot pillow lava its lowermost strata are quickly heated up to the boiling point of water at that depth. As a result

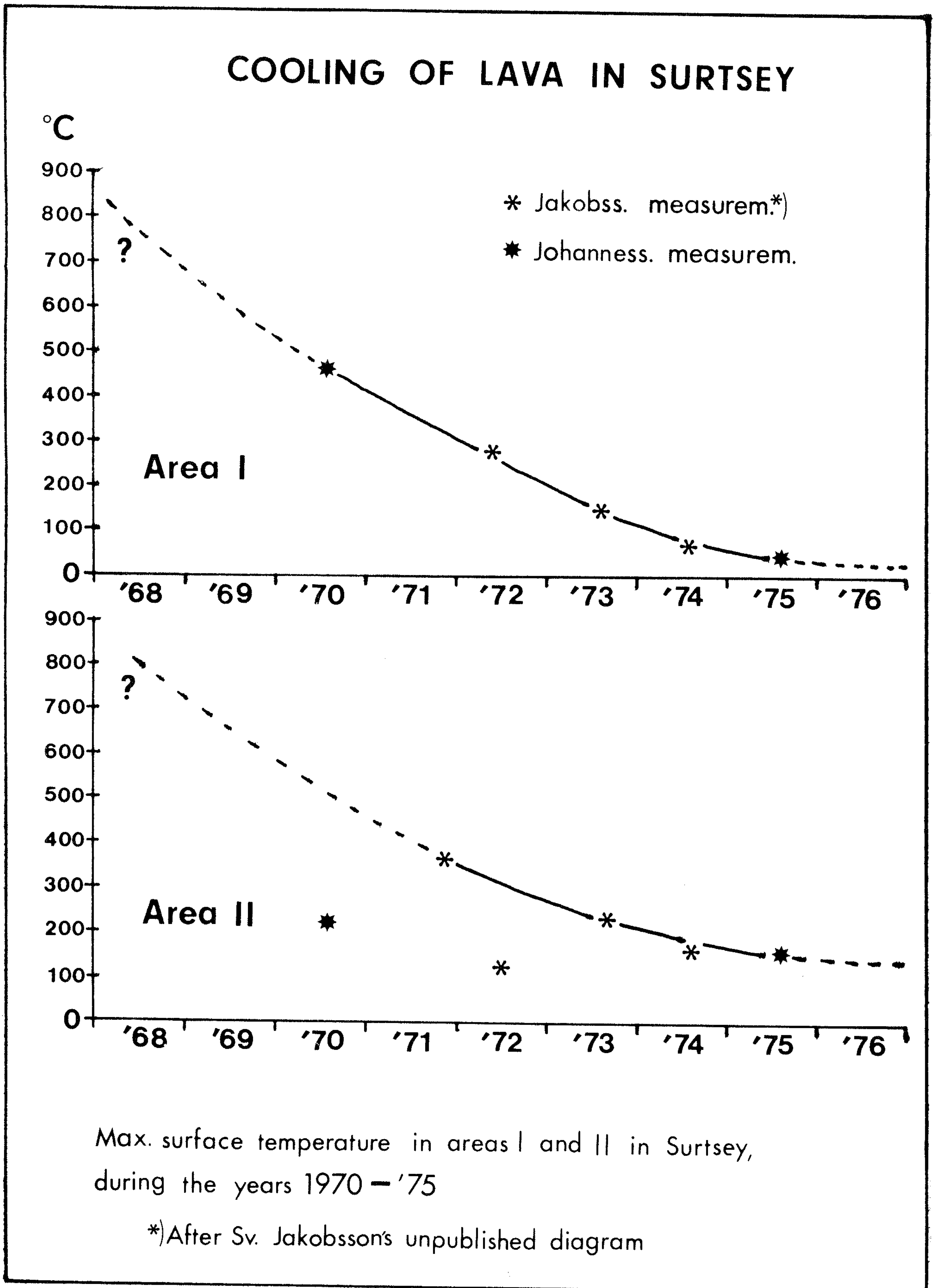

Fig. 2. Cooling of lava in Surtsey.

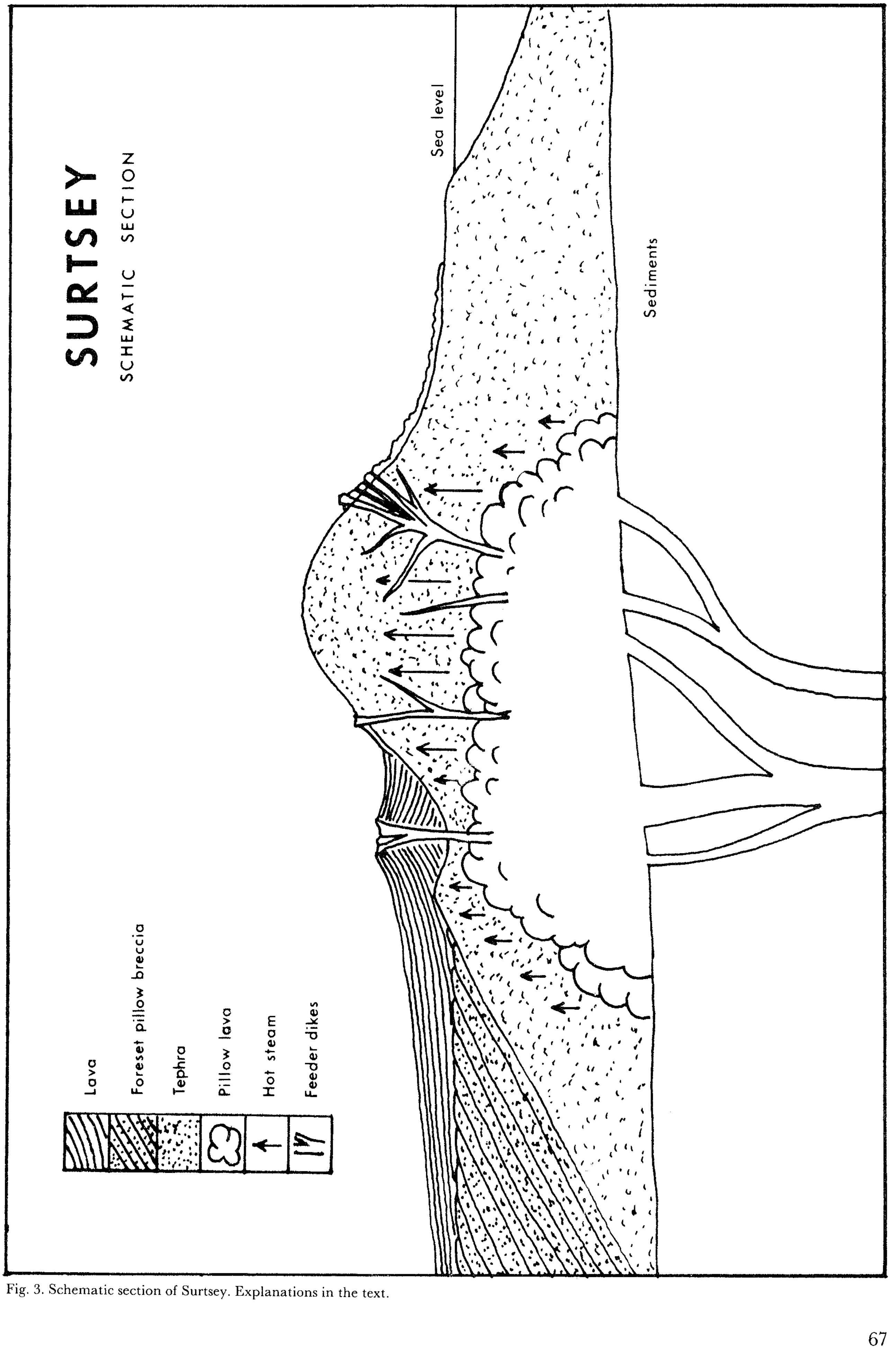

Fig. 3. Schematic section of Surtsey. Explanations in the text.

the water-content is distilled out of the lowermost layers and the steam presses its way upwards through the tephra pile. As the tephra gets drier its isolation increases and the uprush of heat from the pillow lava through the tephra pile slows down. The boiling point isotherm in the tephra pile gradually moves farther from the heat source until equilibrium is obtained through surface cooling of the tephra at a boiling point of water at that particular depth. Outside this area the temperature keeps below the boiling point of water and the tephra remains saturated with water, whereas farther down the tephra is dry and the temperature at, or above, the boiling point. In an eruption of long duration the tephra piles up far above sea level, and the thickness of the pile may amount to hundreds of metres. For some years the equilibrium area will expand outwards and upwards through the tephra pile and where 100°C steam passes through the cooler layers of tephra it must heat it up before it can eventually be detected at the surface. This may take a few years, as has been the case in Surtsey. The first detectable increase in temperature can be expected in areas where the tephra cover on the pillow lava is thinnest. From there the outflow will gradually expand in all directions.

This idea assumes a mean temperature of 600—900°C in the pillow lava during the initial phase of phreatic activity. The estimate is, admittedly, uncertain, but probably not far from the mark, at least not in Surtsey. It seems probable that in an eruption of the Surtsey type minor intrusions will be formed within the pile of pillow lava. These intrusions increase the main temperature in the pile. Minor eruptions occurring outside the tephra crater of Surtur II in late December 1966 and early January 1967 probably derived from such intrusions beneath the tephra ring, so that the material erupted may have been "reactivated" magma from the first weeks of the Surtsey eruption. This might possibly be tested by chemical analysis.

The volume of pillow lava in Surtsey is roughly estimated about 0,1 km^3. Thermal energy of 0,1 km^3 of pillow lava at 600—900°C would be sufficient to heat all the tephra deposited above sea level in Surtsey up to 100°C. There may be some additional thermal processes in the tephra caused by oxidation of iron, although this would be of minor consequence compared with the heat from the pillow lava.

It seems, therefore, safe to conclude, that the thermal areas in Surtsey will continue to expand, changing most of the tephra to móberg before the sea can break it down. The future of the island seems therefore to be comparatively secure as far as destruction by the sea is concerned.

HEAT IN THE LAVA.

As mentioned above, the temperature in the lava is at all stations lower than in 1970. The decrease has, however, been least in the area around Surtur II. The lava layer is thicker there than elsewhere on the island, and will therefore take longer time to cool. In areas where hot air blows out of the lava, this seems to be fresh, atmospheric air, heated by the passing through the lava. Probably this air has entered cracks further down and, when heated, has forced its way up through crevices, helped by its lower weight, as up a chimney, finding outlets at the top of the pile. All these areas have cooled down considerably during the last years, most of them appear to be approaching complete cooling. This is in harmony with the above explanation.

In the hot areas at Surtur II fairly high temperatures still prevail, but will presumably decrease slowly in the coming years. It may take a number of years, or even some decades, before the state is reached when the thermal anomaly has completely disappeared.

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