Environ. Sci. Hokkaido	5 (2)	197～209	Dec. 1982

Invasion and Recovery of Plants after the 1977–78 Eruption of Usu Volcano, Hokkaido, Japan: a preliminary note

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1977–78年噴火後の有珠山における植物の侵入と回復—予報

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I. Introduction

After 32 years of dormancy since the birth of Showashinzan lava dome, Usu volcano began to erupt from the summit on August 7, 1977. The 1977-78 eruption consisted of pumice and ash ejections and intense crustal deformation to form a new cryptodome, Usushinzan. Both activities together with the occurrence of mud-flows caused severe injuries to the plants. In particular, the summit caldera was considered a completely devastated area and thus, offered the possibility of carrying out investigations about the different kinds of damage caused by this type of eruption. The area provided also a good field to follow the recovery and invasion processes of the vegetation in new habitats.

II. The Study Area

1) Climate

The climate is classified as a humid cold temperate climate, with a mean annual temperature of 6-8°C and a mean annual precipitation of 1 200-1 400 mm. In contrast to Honshu and other southern regions of Japan, there is no marked rainy season but the rainy days tend to be concentrated in the three months, July to September.

Snow covers the land for five months, from mid-November to mid-April. The maximum snow depth sometimes exceeds 1.5 m on the slopes of the volcano. Less snow cover favours soil freezing with a maximum frozen depth up to 50 cm. While the minimum monthly temperature is as low as −7°C, the maximum monthly

Received 31 Aug. 1982
1982年8月31日受理

temperature reaches 21°C in August.

2) **Volcanic activity**

Use volcano (Fig. 1) is one of the most active volcanoes of Japan. However it is only classified in the B risk category by the Japan Meteorogical Agency because its eruption would never take away hundreds of lives like the monsterous volcanoes of Asama, Izu Oshima, Aso and Sakurajima. Extensive studies have been made on

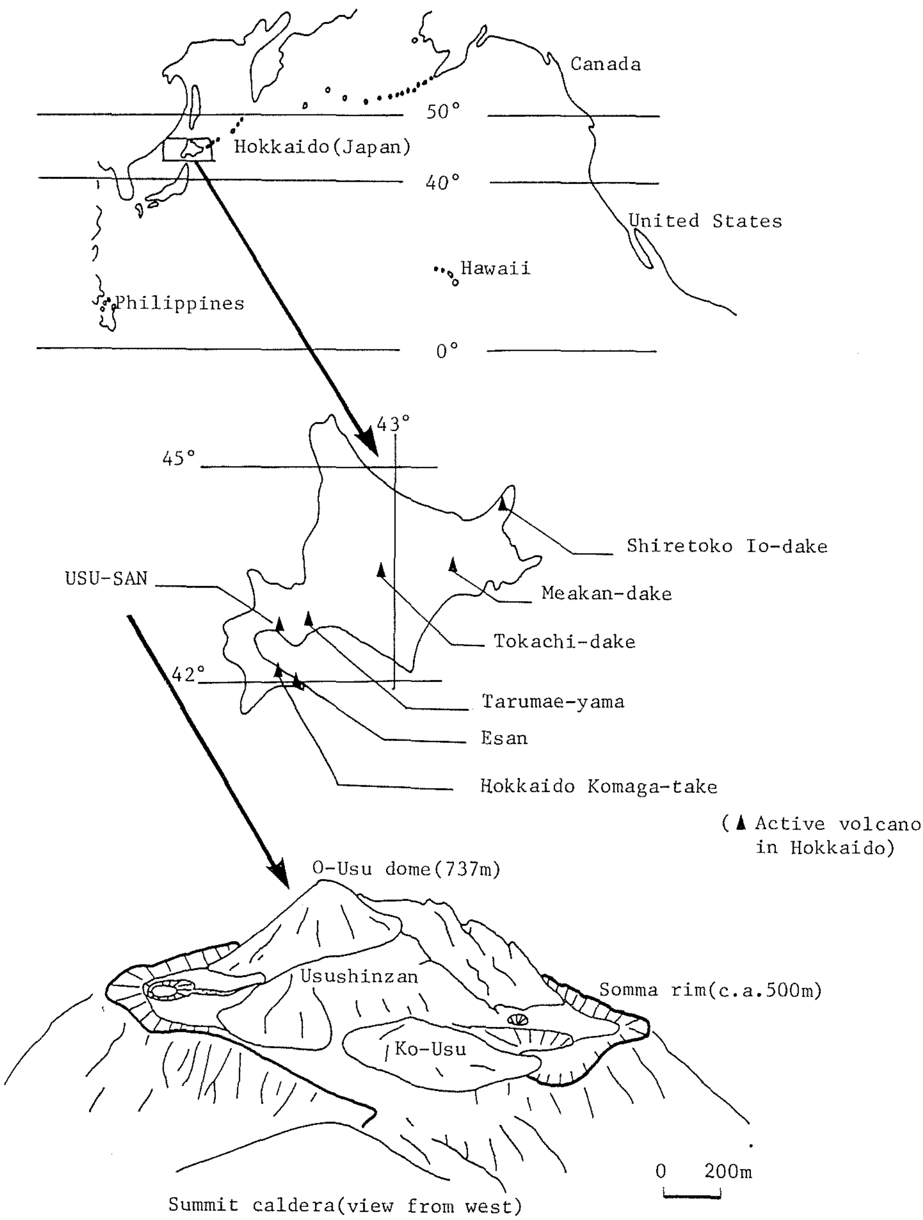

Fig. 1. Study area.

the past and recent activities of the volcano. Among those published in English Ishikawa (1950), Oba (1966), Niida *et al.* (1980), Kadomura *et al.* (1980), Katsui *et al.* (1981) and the geological map of Soya *et al.* (1981) can be recommended. According to these authors, the activity of the volcano can be summarised as follows:

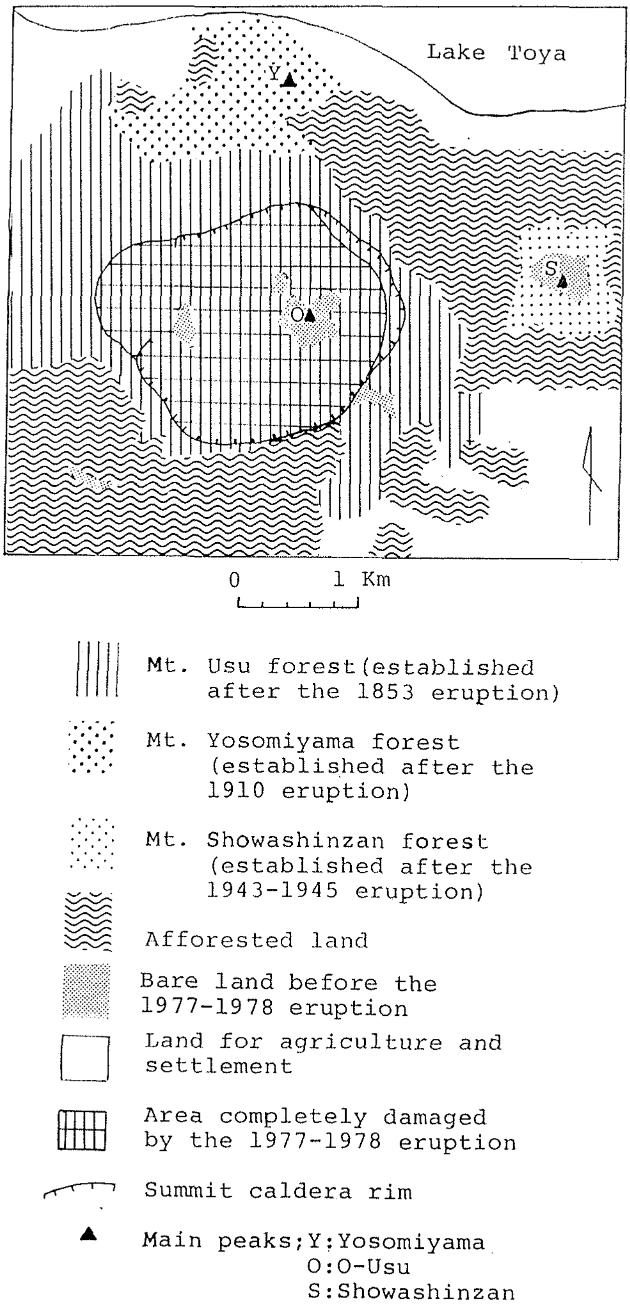

Fig. 2. Forest vegetation on Usu volcanic massif (Compiled from various sources).

Located on the northern coast of Funka wan (Volcano bay), in the southern part of Hokkaido, Usu started its activity on the southern rim of the Toya caldera, in the early Holocene age. The main cone, composed of olivine-pyroxene basalt and andesite lava flows and scoriaceous pyroclastics, was formerly a typical cone-shaped volcano. Explosive activities were recorded in 1663, 1769, 1822, 1853, 1910, 1943-45 and 1977-78. They have been either pumice eruptions or phreatomagmatic ones, sometimes accompanied by pyroclastic flows, base surge or volcanic mudflows. The occurrence of conspicuous crustal movements with earthquake swarms and the formation of 9 lava domes or cryptodomes are the characteristic features of the historic activity of Usu and may be interpreted as due to the high viscosity of the magma. In 1663, a great eruption of ryolithic pumice is thought to have formed the summit caldera, 500 m in elevation and about 2 km in diameter. The last eruption of 1977-78 occurred inside this summit caldera. Numerous craters opened from which an enormous quantity of ash and pumice (9×10^{13} cm^3) was blown out. Due to the prevailing wind direction during the fallout, the tephra was mostly distributed northwest and southeast. Near the craters, the deposit thickness surpassed 3 m but less tephra covered the caldera walls. The fallout was followed by an accelerated erosion of hillslopes and frequent mud and debris flows. Furthermore, the eruptive activities were accompanied by crustal deformation in the form of doming (formation of Usushinzan cryptodome), northeastward thrust and formation of faults.

3) Original vegetation

The natural forests of Usu volcanic massif (Fig. 2) belong to the cool temperate deciduous broad-leafed forest. Because of the frequent occurrence of eruptions, these forests are mostly composed of pioneer trees, like the poplar, *populus maximowiczii*, the birchs, *Betula ermanii* and *B. platyphylla* and the alders, *Alnus hirsuta* and *A. maximowiczii*. The domes issued from the recent eruptions of 1910 and 1943-45, Yosomiyama and Showashinzan, are covered almost exclusively by these species but the summit region of the volcano was previously occupied (before the last eruption of 1977-78) by Usu forest. Usu forest was also dominated by the same pioneer species but trees that can be qualified as "mesophytic" invaded progressively into the pioneer forest. Among the well represented species there were *Ulmus davidiana*, *Acer mono*, *Kalopanax pictus*, *Magnolia obovata*, *Sorbus alnifolia*, *Fraxinus mandshurica*, *Cercidiphyllum japonica* etc.. Usu forest originated after the catastrophic eruption of 1853.

III. Devastation by the Eruption

During the 1977-78 eruption, at one fell swoop, the summit caldera was transformed into a desert of ashes and the forest was completely destroyed except on the north-northeastern caldera wall where the trees, although strongly damaged, could nevertheless sprout again from the base. The damages caused to the plants can be classified into two categories: Those relative to the discharge of pyroclastic materials and those consecutive to the pursuit of the volcanic activity.

1) Discharge of pyroclastic materials

(a) Direct hits

During the major eruption of August 1977, the trees were directly lashed by the stones and pumices ejected out of new craters. The leaves, the branches and the tree tops sometimes, were blown out. So, only the tree trunks remained standing, with their barks laciniated or removed like sheets of paper.

(b) Burying under the ashes

Accompanying the flying rocks, a black cloud of ashes (hypersthene dacite) fell slowly, burying the plants with more than 3 m of deposit near the biggest crater but with only 10-30 cm in the north-northeastern area. The burying may explain why many trees did not fall down.

(c) Cementation by the rain water

The damage due to the ashfall was amplified by a strong rain shower which happened at the same time. The alkaline ashes (pH=8) turned to mortar and stuck to the leaves and branches. For some species like *Populus maximowiczii*, *Ulmus davidiana*, *Acer mono* etc.. young trunks and branches broke down under the weight. These wet ashes favoured also the decaying of the plants.

The first signs of plant regeneration were recognised by Ito (1978) and Higashi (1980) who searched for the surviving species a few weeks later. They observed that most of the trees had already emitted new foliar buds and were covered with leaves. Among the grass species, those with a strong rhizome had succeeded the performance of perforating 10-30 cm of ash deposit to reappear at the surface. These were: *Petasites japonicus*, *Rumex obtusifolius*, *Polygonum sachalinense*, *Dryopteris crassirhizoma* and *Matteucia struptiopteris*.

2) Pursuit of the volcanic activity

In 1978, a minor ash eruption deposited 2-5 cm of fine ashes. It is difficult to evaluate the extent of damage brought about. However, because the deposit hardened into an impermeable crust, the surviving species were almost certain to be cemented again.

During 1979-81, there was no further ash fallout and the disturbance resulted mainly from active geomorphic processes (formation of rills and gullies, mud and debris flows), emission of burning and noxious gases, exposure to the wind etc.. Under the combined effects, the plants were continuously uprooted, tossed away, buried and dried up.

IV. Processes of Recovery and Invasion in the New Volcanic Habitats

A vegetation map was made according to the interpretation of infrared photographs and field surveys carried out in 1981. Because the reestablishment of plant communities is just starting, only few habitats were recognised (Fig. 3).

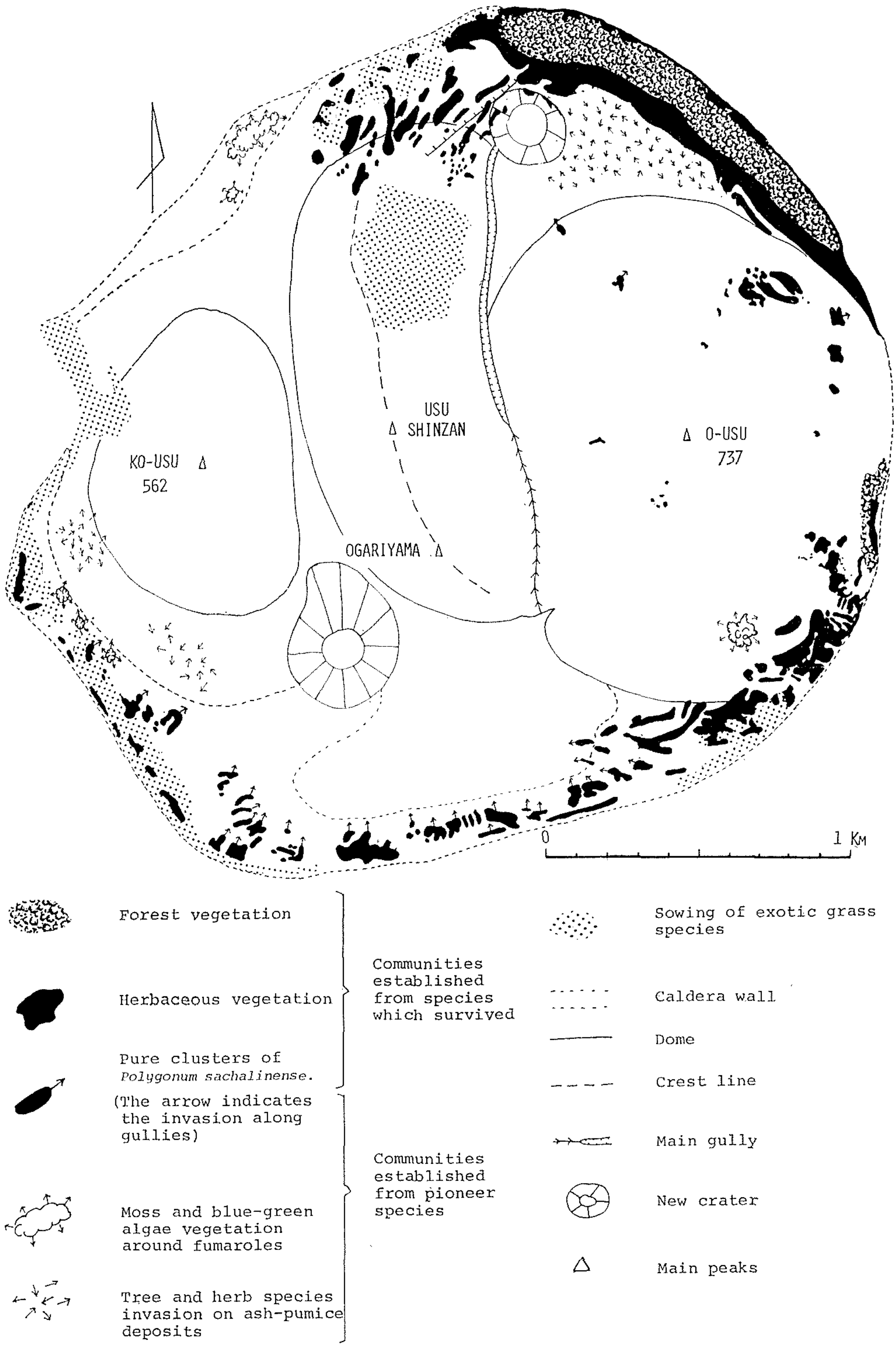

Fig. 3. Plant recovery and invasion in the summit caldera of Usu volcano, devastated during the 1977–1978 eruption, as of September 1981 (A. RIVIÈRE).

1) Zone of thin fallout with surviving tree and grass species

On the relatively steep slope of the northeastern wall of the caldera, numerous tree shoots can be observed (Table 1). For the majority of the species, these shoots are coming from the base of the trees, the trunks of which are still standing but dried up. However, the poplar and the willow shoots are also sprouting from branches which were thrown down during the eruption. Because this sprouting

Table 1. Number of surviving trees* in 13 plots (10×10 m) located on a transect. The species were listed in October 1981.

Tree species \ Plot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	Total number
Populus maximowiczii	2	34	21	2	1		5	5	19	1				90
Acer mono	5	3	18	14	13	8	8	2	2		1			74
Ulmus davidiana var. *japonica*	5	4		9	3	1	4	3	2	1	2			34
Rhus trichocarpa	1				5	2								8
Sorbus commixta	1	1			2	3								7
Magnolia obovata		2		2	2									6
Hydrangea paniculata						3		2						5
Viburnum wrightii		2								1				3
Alnus hirsuta	1						1							2
Fraxinus mandshurica var. *japonica*	1	1												2
Salix bakko					1	1								2
Sambucus sieboldiana var. *miquelii*							1						1	2
Elaeagnus umbellata			1											1
Aralia elata		1												1
Salix sachalinensis				1										1
Alnus maximowiczii					1									1
Lespedeza bicolor			1											1
*Salix integra***														—
*Kalopanax pictus***														—
*Morus bombycis***														—
*Prunus sargentii***														—
*Sorbus alnifolia***														—
Total number	16	47	42	28	27	18	19	13	23	3	3	0	1	240

* See in the text; For *Populus maximowiczii*, and *Salix* sp. the number of 'sprouting individuals' is recorded.

** Tree species abundantly represented in the surroundings of the transect.

from branches, the number indicated in the table does show what appears to be a sprouting individual. The height of the shoots varies with the species. The tallest are poplar and elm shoots which reach 2-3 m in height. On the same slope, dense communities of herbaceous species also survived. 50-60% of the ground is covered with species such as *Equisetum arvense, Petasites japonicus, Polygonum sachalinense, Angelica ursina, Aralia cordata, Aster ageratoides* and *Patrinia villosa.* As a whole, more than 50 phanerogam plants were recorded.

At the bottom of this northeastern slope, on the dome of O-Usu and on the somma rim of the caldera, very few trees survived. However, dense communities of herbaceous species thrived and are now in a stage of complementation in expanding themselves and welcoming new plants. The main species are *Petasites japonicus, Polygonum sachalinense* and *Equisetum arvense.*

2) Zone of thick fallout but ravined with surviving communities of *Polygonum sachalinense*

The south-southwestern wall of the caldera was covered with a thick blanket of ash but part of this layer moved down and was dug through by rills and gullies. That probably allowed the strong rhizome of *Polygonum sachalinense* to perforate the deposit. This species now form 2-3 m high clusters at mid-summer and is progressing towards the bottom of the slope by liberating seeds in the gullies. This plant seems to be the best adapted to the actual conditions of slope instability.

3) Fumarolic zones and moss invasion

The areas surrounding warm steam water spots are well colonised by blue algae and mosses. Among the moss species, *Funaria hygrometrica, Brechymenium exile* and *Ditricum* sp. were recognised. The lava blocks and the bare ash surface seem to have been invaded in a similar way.

4) Gullies and local grass species invasion

The upper rills and gullies of the caldera walls are colonised by local species : *Polygonum sachalinense* (mainly) and *Petasites japonicus.* The seeds from neighbouring mother plants are transported by the water running down the gullies. The gullies offer a favorable microhabitat to the seed germination and to the seedling survival by providing humidity and protection against the wind. At spring season, more than 100 seedlings can be counted on a surface of 10 cm^2 along some gullies. Mosses, especially *Ceratodon purpureus,* also abundantly cover the gully sides and bottom.

5) Ash-pumice desert and invasion of pioneer trees

On relatively undisturbed gentle slopes covered with ash-pumice, the primary invasion of pioneer trees can be observed along with the colonisation of other plants. On a 10 m^2 plot located in the northeastern area, the following plants were recorded in October 1981 :

Trees		Herbs		Ferns and mosses	
Salix sp.	28	*Petasites japonicus*	25	*Matteucia struthiopteris*	1
Popvlus maximowiczii	12	*Polygonum sachalinense*	30		
Betula sp.	9	*Rumex obtusifolius*	1	*Ceratodon purpureus*	$2\times10\ cm^2$
Alnus sp.	4	*Gramineae* sp.	12	*Polytrichum communis*	$2\times5\ cm^2$
		Artemisia vulgaris	5		

Two thirds of the young trees are about 10-15 cm in height above the ground surface. They probably invaded 3-4 years ago, just after the eruption. All these trees come from anemochorus seeds. The trees invaded directly on the ash-pumice field without searching for microhabitats such as cracks or accumulated debris.

6) Artificially sown areas and their invasion by local herbs

In order to prevent an accelerated erosion, the somma rim of the caldera and the upper and lower slopes of the new cryptodome, Usushinzan, were sown with exotic species such as *Festuca elatior, Festuca rubra, Poa compressa, Trifolium* sp. and *Artemisia vulgaris.* Among these grasses there are no trees invading but many local herbaceous species.

V. Discussion and Conclusion

The observations after the eruption seem to indicate that plant survival is related to the degree of destruction and species life characteristic. An obvious cause of non-recovery was the thick ash and pumice fallout. A probable cause of regressing recovery was the pursuing disturbance by active erosion processes. It appears that the trees showed less adaptability to the burying than the herbs which recovered on a wider area. When lashed but not buried too thickly, most of the trees could recover very quickly by emitting new shoots form a basal remnant or root system. Thus showing an adaptation to this kind of damage. *Populus maximowiczii, Ulmus davidiana* and *Acer mono* are among the best survivors. Most of the herbs which survived are plants with underground storage organs : *Petasites japonicus, Polygonum sachalinense* and *Equisetum arvense.* These plants can be recognised as geophytes.

The characteristic features of the invasion phenomenon can be summarised as follows :

(1) The mosses were not the first to invade the bare ash-pumice fields but shared the pioneering with herbaceous and woody species. Inside gullies, mosses and herbs are invading together. Around fumaroles, only blue-green algae and mosses are found.

(2) The main factor preventing the plant invasion on the ash-pumice deposits is the instability of the land surface. In order to check that the invasion was not limited by the disseminule supply, an experiment of seed catching with traps displayed on the bare surface was carried out and showed that numerous anemochorous seeds of *Salicaceae* sp. and *Betula* sp. can reach easily the devastated zones. The seeds can develop easily into seedling but these cannot

survive where slope-wash occurs.

(3) No analysis of nitrogen contained in the bare fields of ashes and pumices was made but it is supposed to be low and that does not prevent the establishment of pioneer plants when the surface is relatively stable.

In some habitats such as the bare lava on the top of the domes, the broken lava on some steep slopes, the temporary ponds and the hot sulfurous fumarolic areas, the inhospitable nature of the substrat prevented until now the plant invasion.

Acknowledgments

Firstly, I would like to give special recognition to Prof. H. Kadomura, Laboratory of Fundamental Research, Hokkaido University, for his helpful suggestions. I also wish to express my gratitude to Prof. I. Yokoyama, Department of Geophysics, Hokkaido University, for allowing the use of the facilities provided at Usu Volcano Observatory. I owe heartfelt thanks to Prof. S. Higashi, Sabo Engineering, Hokkaido University, for his valuable advice and to Mr. S. Yanai, Hokkaido Forest Experiment Station, Bibai, for his kind help and constructive suggestions during the survey. I am also particulary indebted to all the members of the Laboratory of Fundamental Research, Hokkaido University, for their generous assistance in the field work.

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Summary

The summit caldera of Usu volcano was completely devastated by the volcanic eruption of 1977–78. Projections of stones, ashfalls, tremors and ground deformations are among the factors which caused a great deal of damage to the plants. The following remarks are issued of surveys carried in 1980–82.

It was found that in areas where the burying was not too significant, herbaceous species with

underground storage organs and most of the trees survived ; The grasses, *Polygonum sachalinense, Petasites japonicus* and *Equisetum arvense* and the trees, *Populus maximowiczii, Acer mono* and *Ulmus davidiana* appeared to be the best survivors.

In some of the areas thickly covered with ash and pumice, the Primary Invasion started quickly (probably in 1979–80). The herbaceous pioneer plants originated mostly from proximate surviving mother-plants. The seeds were transported by the wind and also, to a large extent, by the water along the rills and gullies. The pioneer trees originated almost exclusively from light anemochorous seeds coming from relatively undisturbed forest outside the caldera. The Salicaceae species are the best represented among the pioneer trees. The mosses invaded the ash-pumice desert along with the phanerogams.

In particular habitats such as the fumarollic zones, only mosses and blue algae are found.

The plant Recovery and Invasion do not seem to be limited by the disseminule supply or the low nutrient value of the new volcanic deposit, but by intensive geomorphic processes such as slope-wash mud and debris flows. These started almost immediately after the ash fallout and were still active in 1982.

Résumé

L'éruption de 1977–78 dévasta complètement la caldéra sommitale du volcan Usu. Les projections de pierres, les retombées de cendres, les secousses et les déformations de terrain sont parmi les facteurs qui endommagèrent le plus la végétation. Les remarques suivantes sont issues d'études effectuées en 1980–82.

Dans les zones où l'enfouissement ne fut pas trop important, les plantes herbacées à organes de réserve souterrains et la plupart des arbres survécurent ; les espèces herbacées : *Polygonum sachalinense, Petasites japonicus* et *Equisetum arvense* et les arbres : *Populus maximowiczii, Acer mono* et *Ulmus davidiana* étant les mieux rescapés.

Dans certaines des zones recouvertes de façon épaisse par les cendres et les pumices, l'invasion primaire débuta rapidement (probablement en 1979–80). Les espèces herbacées pionnières furent surtout issues de plante-mères proches ; les graines étant transportées par le vent et aussi, dans une large mesure, par l'eau le long des ravineaux et ravins. Les arbres pionniers s'établirent de façon presque exclusive à partir de légères graines anémochores provenant de forêts relativement peu touchées, situées à l'extérieur de la caldera. Parmi les arbres pionniers, les espèces salicacées sont les mieux représentées. Les mousses envahirent le désert de cendres et de pumices en même temps que les plantes phanérogames.

Dans des habitats particuliers comme les zones de fumerolles, on ne trouva que des mousses et des algues bleues.

La régénération et l'invasion des plantes ne semblent pas être limitées par l'apport en disséminules ou par la faible valeur nutritive du nouveau dépot volcanique mais par d'intenses processus géomorphiques comme le lessivement des pentes et les coulées de boue et de débris ; ces phénomènes commencèrent just après les chûtes de cendres et étaient encore actifs en 1982.

Explanation of Photos

Photo 1. Usu-san is a stratovolcano crowned with a small caldera, 1.8 km in diameter. The last eruption of 1977–78 occurred inside the summit caldera: An ash cloud rose up to a maximum height of 12 km. Ash and pumice were transported to the southeast by a westerly wind.
(August 7, 1977, 09:12 JST.)

Photo 2. The summit caldera was transformed into a desert of ash and pumice. The summital broad-leafed forest was destroyed by stone projections and deeply buried with ash.
(October 3.)

Photo 3. The trees, stripped of their leaves, branches and barks sometimes, are still standing due to the deep burying. Because of the oblique doming of the magma body underneath, the dead trunks of the northern half of the summit caldera lost their uprightness.
(October 4, 1980. Photo by Anne RIVIÈRE)

Photo 4. The accelerated erosion, due to rainfall and the shock of repeated earthquakes ravages mostly the steep slopes, preventing the plant establishment.
(August 12, 1981. Photo by Anne RIVIÈRE)

Photo 5. Clusters of *Polygonum sachalinense.* A: General view, B: Close up. The plant survived the burying in the upper part of the slopes. It is now progressing toward the desert by rhizome elongation and liberation of thousand of highly viable seeds which are transported downward by the water along the gullies. This plant species seems to be the best adapted to the actual conditions of erosion.
(August 8, 1982. Photo by Anne RIVIÈRE)

Photo 6. The forest of the north-northeastern caldera wall was lashed with stones but not deeply buried. There, most of the trees could sprout again from basal remnants or branch fragments. The new shoots measure about 2–3 m.
(October 12, 1981. Photo by Anne RIVIÈRE)

Photo 7. Shrub of *Sambucus sieboldiana* which survived at the foot of the northern caldera wall. The shrub measures 3 m and was bearing seeds in August 1982. The herb layer is almost solely composed of *Equisetum arvense* and *Petasites japonicus.*
(June 5, 1982. Photo by Anne RIVIÈRE)

Photo 8. Community of *Equisetum arvense* and *Petasites japonicus.* These species survived first the burying by perforating the ash deposit with their rhizome. Then, they invaded the proximate gentle slopes by means of vegetative growth and liberation at spring season of large amounts of seeds and spores.
(August 10, 1981. Photo by Anne RIVIÈRE)

Photo 9. Pioneer trees invading directly the desert of ash and pumice in places where the slope-wash is not too active. The seedlings are from anemochorous seeds coming from undisturbed forests at a distance of about 1–3 km from the summit caldera. Seedlings of the genus *Salix, populus, Betula* and *Alnus* are commonly found. A: Seedling in situ; B: Seedlings of *Alnus* (left) and *Salix* (right).
(August 8, 1982. Photo by Anne RIVIÈRE)

Photo 10. Many pioneer tree seedlings of *Salix* sp. can be found inside the herbaceous community of *Equisetum arvense*. The fact is notable because ordinary grass communities strictly prevent the invasion of pioneer trees.
(August 10, 1981. Photo by Anne RIVIÈRE)

Photo 11. In order to estimate the natural seed invasion on the denuded ground, traps containing water have been set. The anemochorous seeds are caught in the traps.
(May 9, 1982. Photo by Anne RIVIÈRE)

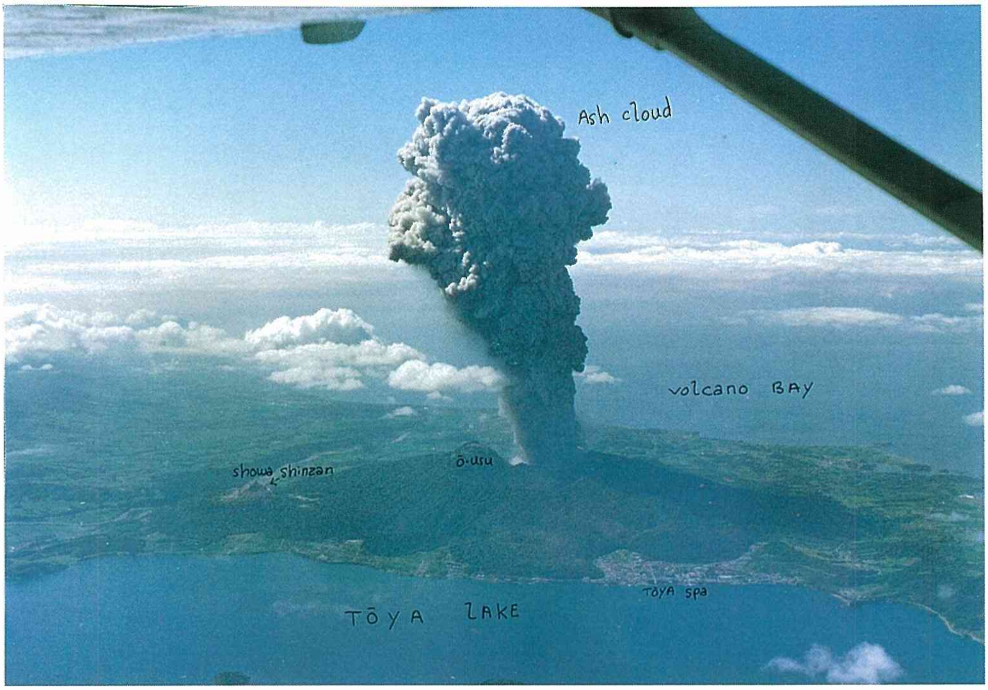
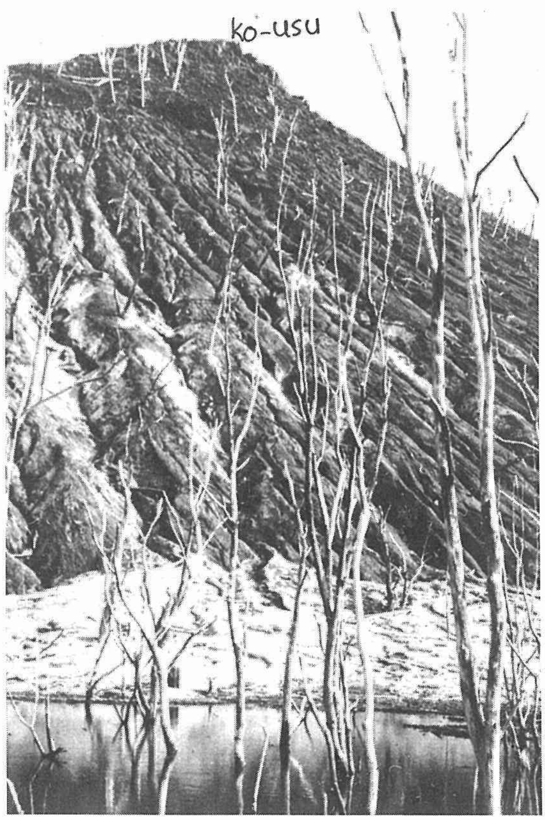


Photo 1.

Photo 2.

Photo 3.



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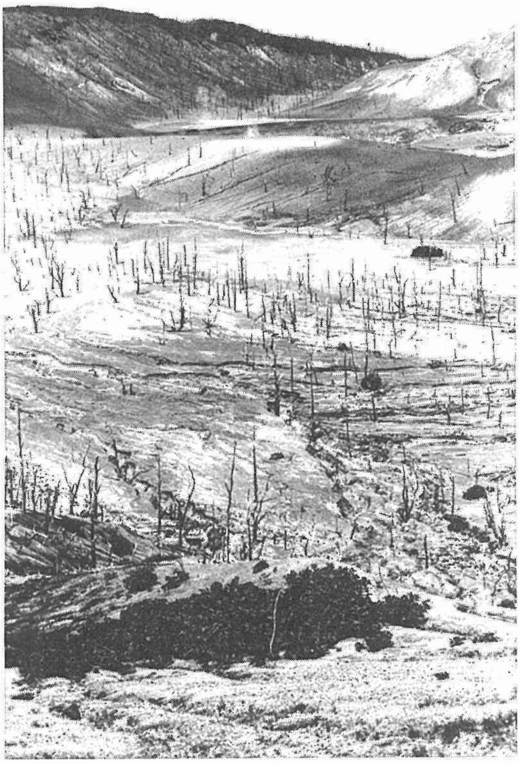

Photo 5. A

Photo 5. B

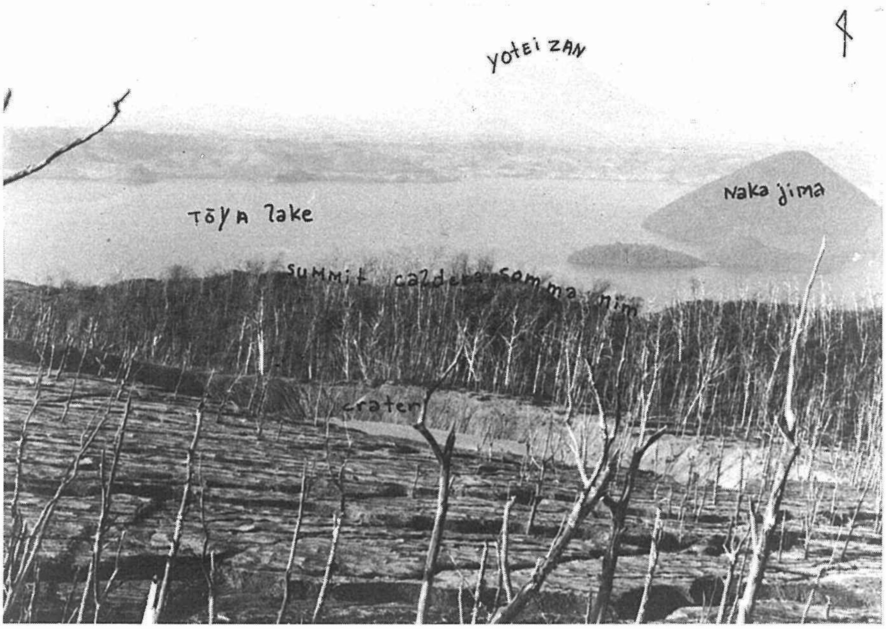

Photo 6.

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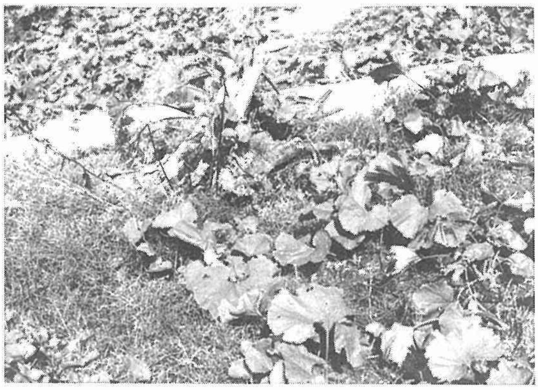

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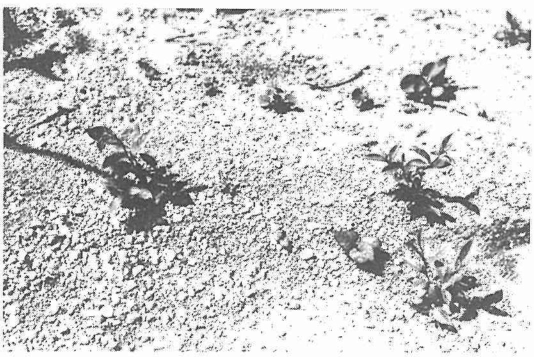

Photo 9. A

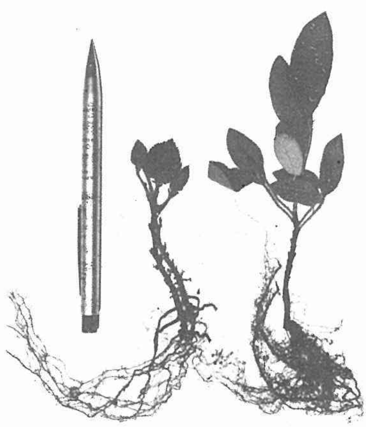

Photo 9. B

Photo 10.

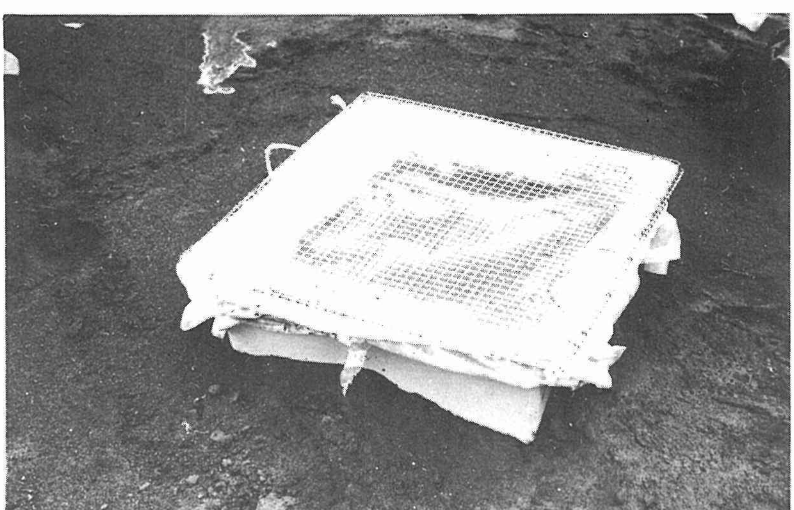

Photo 11.