IX. THE BEGINNINGS OF REVEGETATION IN KATMAI VALLEY.

ROBERT F. GRIGGS.

The effect of the great eruption of Mount Katmai in Alaska on plant life, and the remarkable recovery of vegetation around Kodiak have been discussed in previous papers of this series.[1] When it was observed with what rapidity the covering of ash at Kodiak was being removed by erosion, and that the new plant covering consisted almost entirely of old perennials which had survived and come up through the ash, it became evident that the main problem of revegetation must be worked out on the mainland, where the destruction of the antecedent vegetation was more complete, and the deposits in which the new plants must start very much deeper.

The present paper is published as a record of the first stages of the process in the valley of Katmai River, which, flowing under the Volcano in a narrow canyon, spreads out and for some twenty miles traverses a broad flat valley to the sea. (See map, page 319). These flats, in contrast to the steep mountains round about, contain considerable areas favorable to the study of revegetation.

METHODS OF WORK.

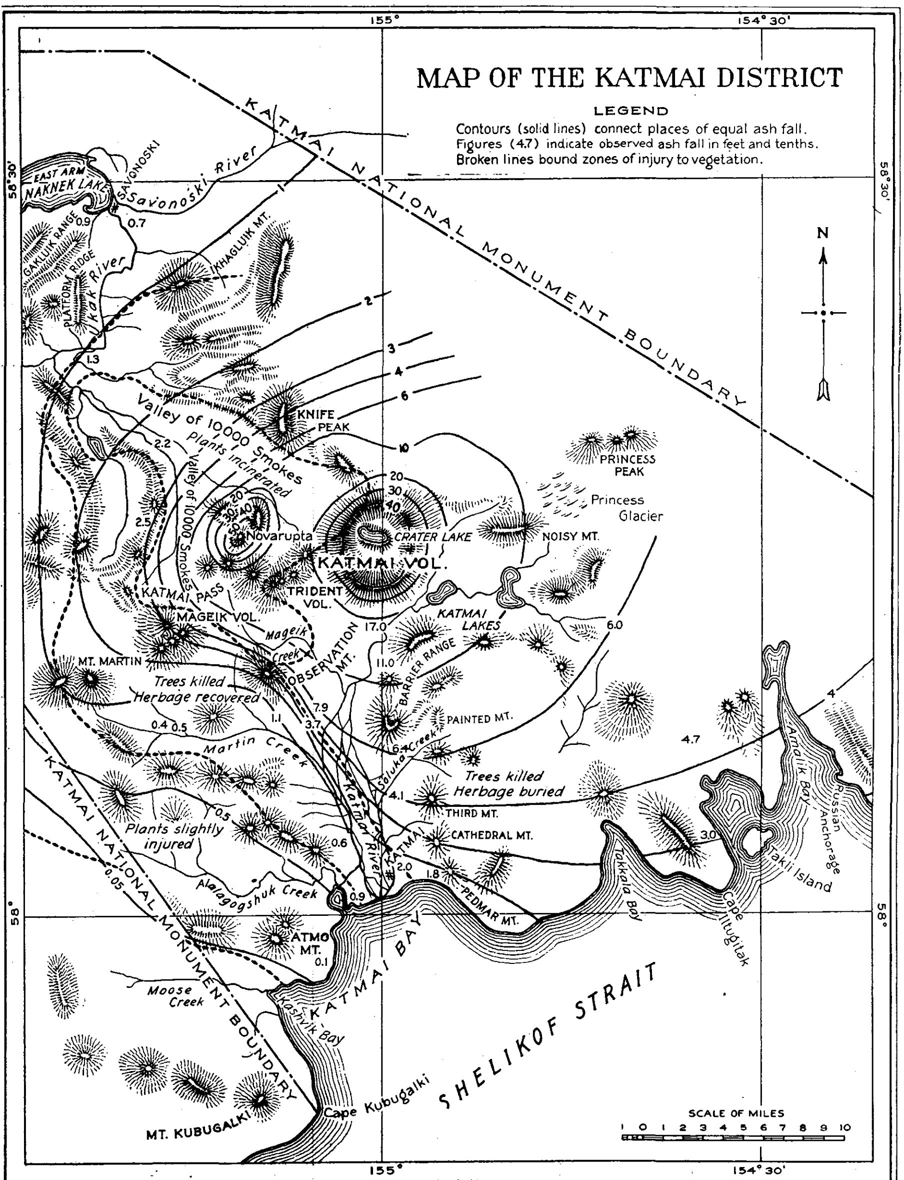
A considerable part of the work of the expeditions, which visited the country in 1915, 1916 and 1917, was the securing of records, both descriptive and photographic, of definite localities which may be visited at later dates and restudied for the purpose of recording the progress of returning vegetation.

[1]Griggs, R. F. Scientific Results of the Katmai Expeditions of the National Geographic Society.

I. The Recovery of Vegetation at Kodiak, Ohio Journal of Science 19: 1–57. 1918.

IV. The Character of the Eruption as Indicated by Its Effect on Nearby Vegetation. Ohio Journal of Science, 19: 173-209. 1919.

A full citation of literature is given in these papers, especially in I. General accounts of the expeditions have appeared in the National Geographic Magazine for January, 1917, and for February, 1918.


MAP OF THE KATMAI DISTRICT
LEGEND
Contours (solid lines) connect places of equal ash fall.
Figures (4.7) indicate observed ash fall in feet and tenths.
Broken lines bound zones of injury to vegetation.
KATMAI NATIONAL MONUMENT BOUNDARY
Valley of 10000 Smokes
Plants incinerated
Novarupta
KATMAI VOL.
CRATER LAKE
TRIDENT VOL.
KATMAI PASS
MAGEIK VOL.
MT. MARTIN
KNIFE PEAK
PRINCESS PEAK
Princess Glacier
NOISY MT.
KATMAI LAKES
BARRIER RANGE
OBSERVATION MT.
PAINTED MT.
THIRD MT.
CATHEDRAL MT.
PEDMAR MT.
Trees killed
Herbage recovered
Trees killed
Herbage buried
Plants slightly injured
Martin Creek
Katmai River
Alalagogshuk Creek
ATMO MT.
Moose Creek
KATMAI BAY
Kashvik Bay
Cape Kubugalki
MT. KUBUGALKI
SHELIKOF STRAIT
Takkala Bay
Cape Ilugitak
Amalik Bay
Russian Anchorage
Takli Island
EAST ARM NAKNEK LAKE
Savonoski River
GAKLUIK RANGE
PLATFORM RIDGE
KHAGLUIK MT.
Ikak River
SCALE OF MILES
155°
154° 30'
58° 30'
58°
O. E. Williams

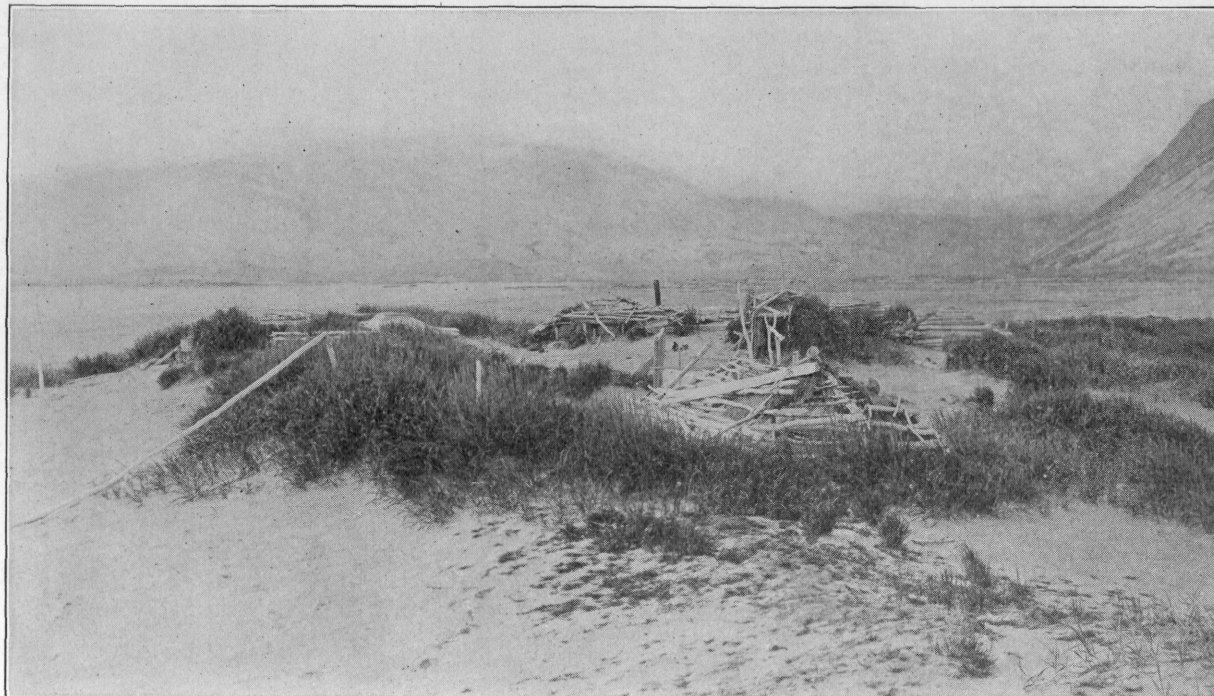
The effort has been to locate them in such a way that anyone can find them and carry on the study, if for any reason the writer should be prevented from continuing it.* Beside these formally established stations, there are many other localities, not susceptible of such precise location, which the writer expects to study repeatedly as opportunity presents. In the short time that has elapsed since the beginning of the work, changes at these stations for the most part have been small, so that the progress in revegetation here reported has been worked out from observation of the general conditions in the valley. But as time goes on, repeated records of conditions at the fixed stations and other localities photographed will furnish a more and more valuable record of progress, which finally will give us an understanding of the factors controlling the revegetation of volcanic deposits under the climatic conditions obtaining, and of the succession of plants in the process. Meanwhile, laboratory studies of plant growth in the ash have been made with samples brought back to the United States for the purpose. These, besides supplementing and aiding in the interpretation of the field observations, are of some interest in themselves.

CONDITION OF SURVIVALS.

The agents of revegetation consist of: (a) Surviving woody plants which protrude through the ash. (b) Herbage which has come up in places cleared of ash. (c) Seedlings starting in the deposits. The effects of the first two categories on the mainland may be dismissed with very brief discussion. The poplars, birches and alders have not recovered sufficiently to become of any consequence in revegetation, except as helping in places to maintain a windbreak under which new plants can start. None of them were found in fruit, although a few seedlings of poplar were observed in one place. But the larger willows, (*Salix alaxensis*, *Salix barclayi*, *Salix nuttallii*), have in places almost completely recovered and have begun to produce seed abundantly, which bids fair to become an important factor in revegetation.

The resurrected herbage, though of great interest as showing the possibilities possessed by plant life of surviving a violent eruption, is of minor importance in the revegetation of Katmai

*For a detailed discussion of the problems encountered in establishing the vegetation stations see the first paper of this series, pp. 24–31, on p. 174.



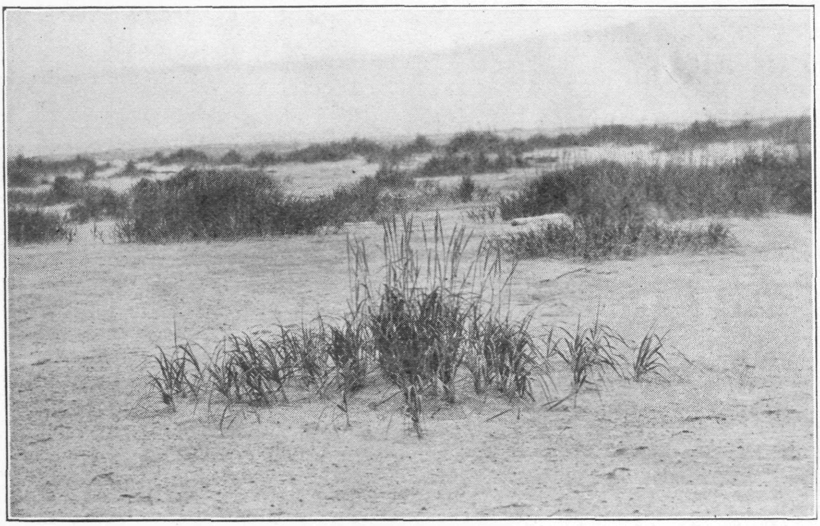
Photograph by D. B. Church

A PORTION OF KATMAI VILLAGE FOUR YEARS AFTER THE ERUPTION.

The increase in the vegetation is exclusively by vegetative extension. The present rate is about four feet per annum.

Valley. Although the oases, to be found in spots where conditions have permitted the recovery of the herbaceous plants, are conspicuous in the desert valley, their influence in the revegetation of the great bare areas is, from the nature of the case, quite limited. There are three ways in which they affect revegetation.

First, by direct extension out into the bare areas. Only two of the species present have sufficiently developed the power of sending out runners to be important in this respect.



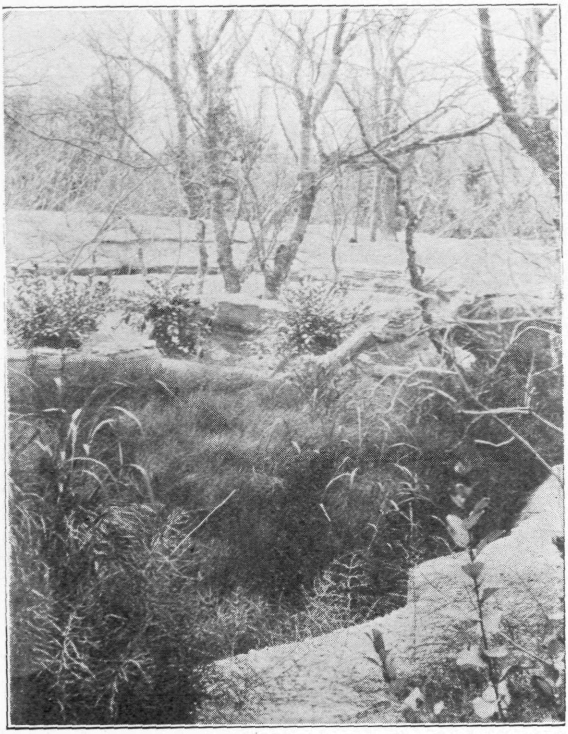
Photograph by Robert F. Griggs

BEACH GRASS SENDING RUNNERS INTO BARE ASH.

Runners of the current season (1916) are sterile, but the shoots that came through in 1915 have fruited. The rate of extension is about four feet per annum.

The beach grass, (*Elymus arenarius*), is especially adapted to cope with shifting sand, and in many places in the vicinity of the shore it has been locally of great importance in renewing the plant cover. (See page 321.) Comparison of photographs taken in successive years and observation of the plants shows that the rate of extension is about four feet per annum.

The horsetail, (*Equisetum arvense*), was able to penetrate deposits so thick that nothing else could come through. Its capacity for penetration is most strikingly shown in the bottoms of numerous gullies washed in the ash areas where it was so deep that nothing could come through on the level. Observation of such places shows that it can penetrate deposits up to about three feet in thickness. The horsetail is not, however, of anything like the importance in Katmai Valley that it is at Kodiak.* The deposits are for the most part so thick that it is only here and there that even the horse tail could grow through them. (See picture.).



Photograph by Robert F. Griggs

EQUISETUM COMING THROUGH IN THE BOTTOM OF A GULLEY WHERE THE DEPOSIT WAS TOO THICK FOR IT TO PENETRATE ELSEWHERE.

Second, the patches of surviving herbage serve as a wind break in the shelter of which new seedlings can start. This again is a function of considerable importance locally as will be seen from the discussion to follow.

Third, the oases of resurrected vegetation furnish the seed which may be the basis for starting new vegetation in the desert round about. This, however, is not a factor of great consequence in this case. The plants have come back on the steep mountains, from which the ash quickly slid off, so much more freely than in the deeply buried valley that they would furnish abundant seed, even if nothing had survived on the flats. Most of the plants of the district have seed adapted

*See the first paper of this series, p. 43.

for wind distribution, and the wind is so efficient a factor in this region, (see page 339), that seed in abundance is transported great distances.

SEEDLINGS BEGINNING TO START.

The seedlings starting up to 1915 were so few, and occurred so sporadically, that in my report of operations that year I stated that revegetation had not yet begun and that the observations of that year could furnish no basis for a prediction as to when it would begin, but a definite change was noticeable in 1916.

Photograph by Robert F. Griggs

A GENERAL VIEW OF THE PUMICE PLAIN ON WHICH LUPINES WERE STARTING.

The dark spots right and left are lupines, like that shown close up on the opposite page. Although far apart they have grown thriftily.

The landscape was, to be sure, as bare as ever, but the careful observer could not fail to see in many habitats the definite, though slight, beginnings of new vegetation. These were most marked in the lower valley, and diminished as one approached the Volcano, but even in the upper valley large areas which were absolutely barren in 1915 were coming up with occasional lupine seedlings which, though so sparse and widely scattered that one had to search for them, were nevertheless thriving with every prospect that some of them would survive. Farther down the valley a few areas were found where similar seedlings had started in 1915 and, having persisted even in deep pumice deposits, were flowering and seeding abundantly in 1916; while in 1917 considerable areas as far up stream as Martin Creek were sparsely occupied by fruiting lupines, furnishing the basis for an increasing rate of revegetation.

LUPINES THE MOST EFFECTIVE PIONEERS.

While the new vegetation in the lower valley consists of many species of plants, in the more exposed places lupines are the only pioneers. (See pages 324 and 335). For this role they are well adapted, because of their large heavy seeds

Photograph by Robert F. Griggs

A LUPINE ON THE PUMICE FLAT AT MARTIN CREEK.

These plants first appeared in 1915. They were well provided with root tubercles and grew thriftily, fruiting freely in 1917. The soil is almost entirely without organic nitrogen.

which lodge where smaller seeds are blown away. On germination, moreover, their large supply of stored food enables them to grow into strong plants much more quickly than the other species present. But their capacity of utilizing atmospheric nitrogen through their root tubercles is probably the decisive factor, for the ash is almost devoid of nitrogenous compounds.[2] Lupines growing in pumice show an abundant development of root tubercles which must give their possessors enormous advantages over ordinary plants in the process of revegetation.

[2] Shipley, J. W. The Nitrogen Content of Katmai Ash. Paper No. V in this series, pages 213–223.

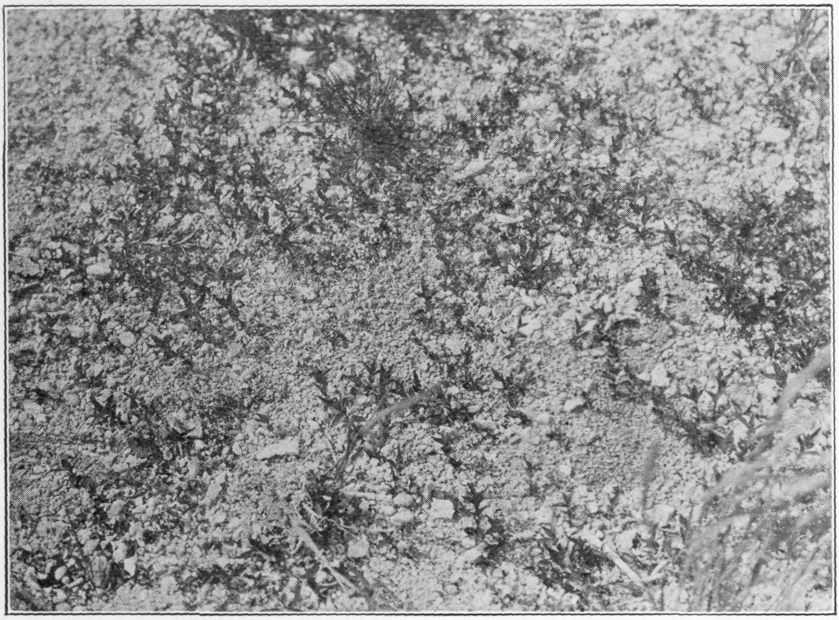
Photograph by D. B. Church

SEEDLINGS STARTING IN WATER-LAID ASH.

In outwash at the base of a hill where the ash was little contaminated with soil. Most of the abundant seedlings are

These lupines are, however, strictly confined to the valley and to situations that at one time or another have been overflowed by stream waters. On the surrounding hillsides and in other parts of the valley there are many areas that, to all appearance, offer quite as favorable habitats as those which are occupied by lupines, but not a single plant has ever been detected outside the flood plains except on oases of old soil.

The reason for this peculiarity of distribution is not clear at the present time. It may be that the seeds are water borne



Photograph by D. B. Church

SEEDLINGS OF EPILOBIUM ALASKÆ STARTING ON PUMICE IN A SPRINGY PLACE.

instead of wind disseminated. But the winds of the district are so extremely violent, (see below, page 339), as to make it appear unlikely that objects so slight as lupine seeds would resist their action. Legumes in general are known to be dependent on organisms in the soil for that innoculation with the tubercle bacteria upon which their success is dependent. It might well be that while these organisms were absent from the general mass of ash they were present in ash contaminated by flood waters.

Bacterial examinations of the soil in the neighborhood of the growing lupines, conducted by Jasper D. Sayre, have however failed to indicate the presence of the tubercle bacillus in the soil. The ash is extraordinarily poor in micro-organisms. Cultures from numerous collections made in 1917 remained altogether sterile, while in others a single organism developed consistently on some media. Otherwise no micro-organisms whatever were found, although the check samples of garden soil subjected to the same treatment fairly teemed with bacteria,

Photograph by Robert F. Griggs

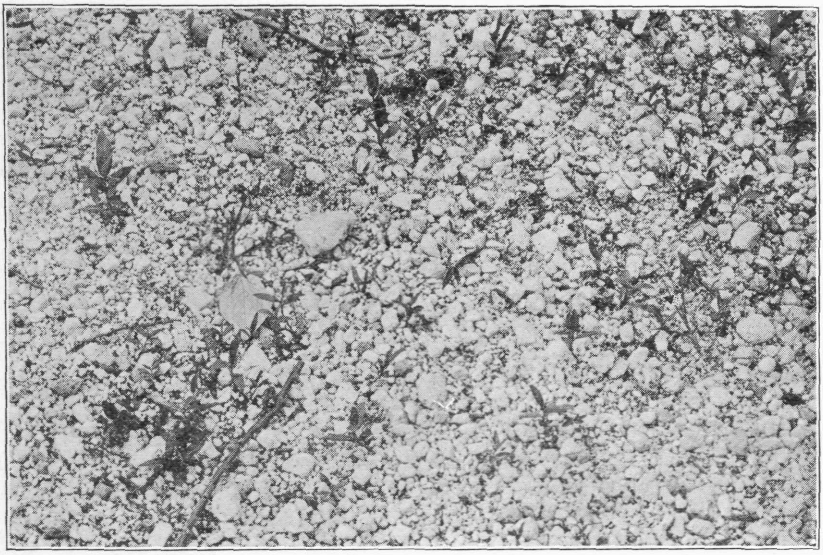
WILLOW SEEDLINGS COME UP IN FLOOD BORNE MUD IN KATMAI VALLEY. NATURAL SIZE.

indicating that there was nothing wrong with the methods of collecting and culturing the material.

The cultural work was interrupted at this stage by conditions incident to the war, but through the kindness of Dr. K. F. Kellerman, the Department of Agriculture undertook to investigate our suspicion that the one organism so consistently found was the tubercle bacillus. But when the report came it was negative. Our organism was pronounced not to be *Bacillus radicicola.* The matter must therefore be left in abeyance. But Mr. Sayre is continuing the bacterial work, having made further collections of soil for bacteriological study during the summer of 1918.

WILLOWS STARTING IN SOME PLACES.

In more sheltered situations, seedlings of a number of species are starting in many places. The most important of these are probably the grasses, *Deschampsia caespitosa* and *Calamagrostis langsdorfii*, (see page 326). With these are other herbaceous



Photograph by Robert F. Griggs

YEARLING WILLOW PLANTS GROWING IN WATER-LAID PUMICE.
The appearance of these plants in August, 1915, is shown on page 328.
This picture was taken in August, 1916.

species, including *Artemesia tilesii*, *Campe barbarea*, (see page 331), *Polemonium acutiflorum*, *Epilobium alaskæ*, (see page 327), *Mimulus langsdorfii* and also the frutescent *Sambucus pubens*. There are also considerable areas where the ground is covered with seedlings of willow, (*Salix alaxensis*, *Salix barclayi*, *Salix nuttallii* and *Salix bebbiana*). (See page 328). Many of these latter survived the first winter and made vigorous growth in 1916. They have not, perhaps, established themselves well enough to justify the prediction that the pioneer growth over considerable areas will be a willow thicket, but present indications point in that direction. In 1915 seedlings of all sorts were scarce, though many were starting at the time of our arrival. But the following season it could be seen that, while great numbers of them had been winter killed, many had survived and were growing. Since the first winter would appear to be the most critical period in the life of seedlings, and especially since the winter of 1915-1916 was unusually severe in its effects on vegetation at Kodiak, it is to be supposed that these seedlings are the beginning of the new, permanent plant covering of the country.

SEEDLINGS ESPECIALLY IN WET PLACES.

These new plants, especially the herbs, show certain peculiarities of distribution which throw much light on the factors retarding revegetation. Except the lupines, which are always in well drained situations, the new seedlings show an evident preference for wet places, or more correctly, for places which bear evidence of water action. For they are not confined to springy places, the edges of ponds and the like, but also appear in numbers on some of the outwash deposits which are not especially wet habitats.

The readiest explanation of this preference would be that the ash in general has insufficient moisture to meet the water requirements of the plants. This might be expected, moreover, from the fact that the ash is purely mineral and altogether lacking in humus or similar water-holding substances, so that it dries out rapidly, giving up any water in its pores as readily as sand. Under ordinary climatic conditions this would probably be an important factor, but those who are familiar with this region will agree that it is difficult to imagine anything drying up here, so constant is the rainfall.

The season of 1915, in which occurred an unprecedented drought, gave an exceptional opportunity, however, to test the importance of this factor. Even at the close of the drought the ground was everywhere visibly moist immediately beneath the surface. To ascertain more definitely the exact situation, soil moisture determinations were made in the field. These were followed by determinations of the wilting coefficient, both by the centrifugal machine through the kindness of Dr. H. L. Shantz, and by tests of pot cultures under the writer's direction.

The results of these tests showed clearly that in all sorts of habitats there was a considerable margin of available moisture, even at the close of an unprecedented drought.

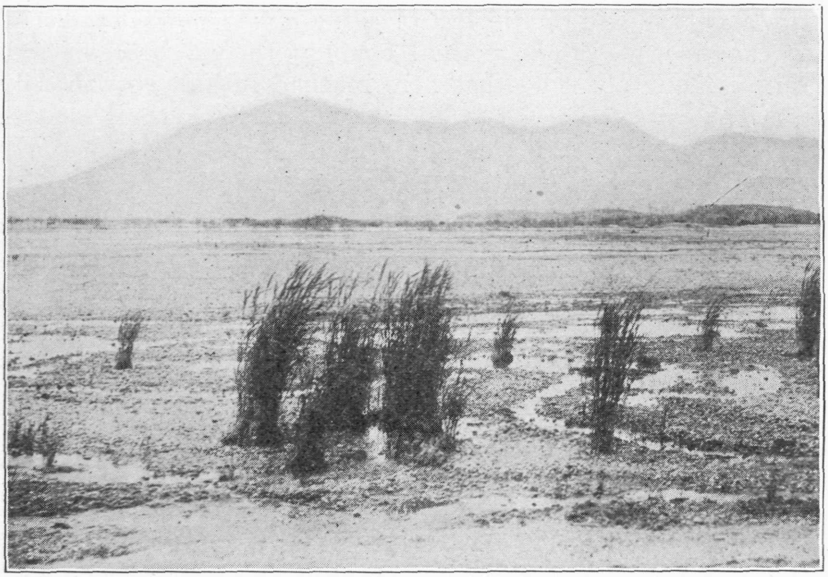
PREFERENCE FOR WET PLACES POSSIBLY DUE TO CONCENTRATION OF SALTS.

But in spite of this it could not be questioned that the rankest growth occurred in the wettest places. *Calamagrostis langsdorfii*, for example, which in normal country thrives best on well drained mountain sides, has here reached its full growth only

Photograph by Robert F. Griggs

SEEDLINGS, MOSTLY CAMPE BARBAREA, STARTING IN A WET PUMICE FLAT.

in springy places where the water is so abundant as to stand on the surface. (See page 332). For a long while it was very much of a puzzle why it did not spread onto the adjacent ground, whose soil-water content is more similar to that of the habitats it usually occupies. But finally an explanation suggested itself because of the similarity of conditions in these places to the alkali spots on the prairies. Everyone familiar with such a region as the Dakota prairies has noticed that such springy places become covered by a heavy crust of alkali salts, left behind from the evaporation of the seepage water. The places occupied by the plants in question present exactly similar conditions. Evaporation from the free water surface must similarly affect the concentration of salts. The ash contains such small amounts of the soluble salts necessary for plants that it may be supposed that only where concentrated by evaporation do they occur in amounts sufficient for vigorous growth.*



Photograph by Robert F. Griggs

CALAMAGROSTIS LANGSDORFII APPEARING IN AN AREA WHERE WATER, COMING TO THE SURFACE, MAY HAVE ITS SALTS CONCENTRATED BY EVAPORATION.

Surrounding pumice flats, where the surface is protected from evaporation, are bare.

If this reasoning is correct, it would explain the decided advantage of the plants in the wettest places over those on the general surface of the ash where the loose top layer, acting as a

*Dr. Shipley, in the sixth paper of this series, has reported that the total soluble salt content of the ash is in general not especially low. But in analysis directed particularly toward the solution of this question, Professor C. W. Foulk, found that in the ash at Kodiak the amount of available (*i. e.*, water soluble) potash was only 0.05%, which is exactly the amount given by Hilgard as the minimum concentration requisite for plant growth. Phosphoric acid was present in an even smaller amount, which Professor Foulk described as slightly more than a trace, although it was so small that he made no attempt to give it a numerical value. The high salt content found by Shipley is probably made up, therefore, of salts not important to the growth of the plant.

mulch, prevents evaporation. It has not proved practicable as yet to submit this hypothesis to experimental test, but it has been found that it is impossible to obtain in pot cultures from small quantities of ash anything like such vigorous growth as occurs even in dry places in the field where the plants have unlimited possibilities of root extension with the consequent ability to draw upon wide areas for the necessary quantity of salts.

Photograph by Robert F. Griggs

SEEDS COMING UP WHERE COVERED UP BY THE OUTWASH OF A TEMPORARY STREAM.

General surface of the ash bare. Lower Katmai Valley.

SEEDLINGS IN DRY WATER-LAID DEPOSITS.

The distribution of only a portion of the new plants can, however, be accounted for on this hypothesis. Those coming up in outwash deposits are often so situated as to be kept better drained than the surrounding level. (See cut above.) At first I was inclined to suppose that such deposits were sufficiently contaminated by admixture of the original humus soil washed off the mountains along with the ash to present quite different and altogether more favorable conditions for the plants than the undisturbed ash deposits. But further study led me to doubt the correctness of this view, and this doubt was confirmed when it was found that pot cultures of this material were no more successful than those in which the undisturbed ash was used.

Meanwhile the field study was carried out on the hypothesis that the water content of the soil was inadequate. It was reasoned that numerous seedlings should have started in periods of wet weather, even in very unfavorable places. If this had happened many of these seedlings would have been caught in the drought and their dead and dying remains would have been easy to find. But, as a matter of fact, prolonged search failed to disclose any such, except in one solitary instance. This was considered remarkable, since, even under the conditions of the Central States, it would be easy to find numbers of seedlings which had perished in any considerable drought, even though mature plants had not suffered seriously. Moreover, since the bare ash surface is free from plant debris of any kind over considerable areas, seedlings if present could not have been overlooked. It became evident that there had never been any seedlings on the general surface.

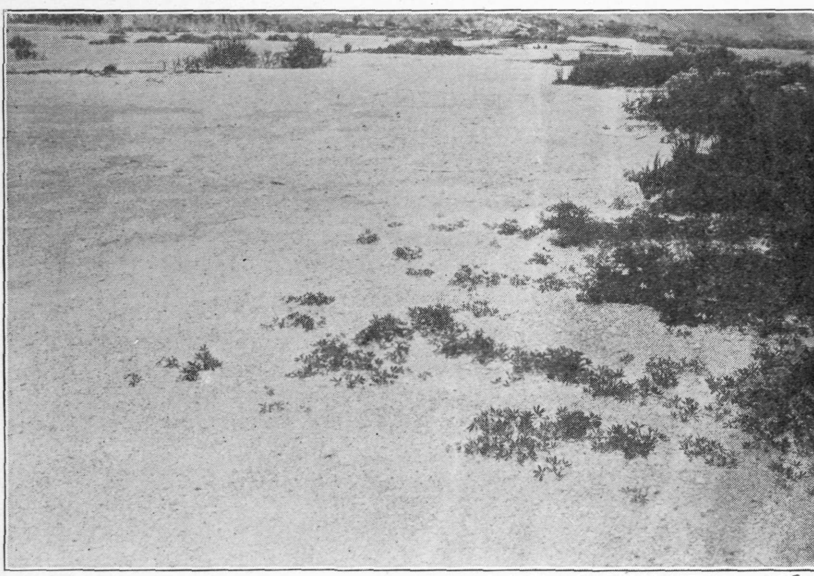
Here, then, was another significant fact which required interpretation. The most obvious explanation would be that the ash contained some substance deleterious to the germinating seeds. In the vicinity of the crater and in certain other special localities* some such chemical is evidently present, but it is certain that no such deleterious substance is generally present. It has been shown, both by chemical analysis and by the experience at Kodiak, that there is nothing injurious to plants in the ash deposited at that distance. The pot cultures made on the return to the States showed, except in special instances, that plants do not behave differently when grown in ash from the mainland than in that from Kodiak.

It was then suspected that the reason for the barrenness of the undisturbed ash might lie in the fact that its smooth surface afforded no lodgment for seeds which, distributed largely by the terrific gales that sweep the country, are carried across the smoother surfaces and dropped in situations better adapted to catch them.

*Dr. Shipley, in the sixth paper of this series, pages 224–229, has shown that in a few localities the ash bears so strong a concentration of ferrous sulphate as to be toxic to plants. But the occurrence of such deposits is limited to very special situations.

SEEDS PLANTED BY RUNNING WATER.

To test this hypothesis and at the same time to ascertain whether there was anything in the deposits which might prevent germination, buckwheat was sown in various habitats. At each planting the seeds were sown in two ways—by placing them in the ground and by scattering them on the surface of the ash. On our return to the Base Camp after the expedition up the valley, it was found that the seeds planted in the ground

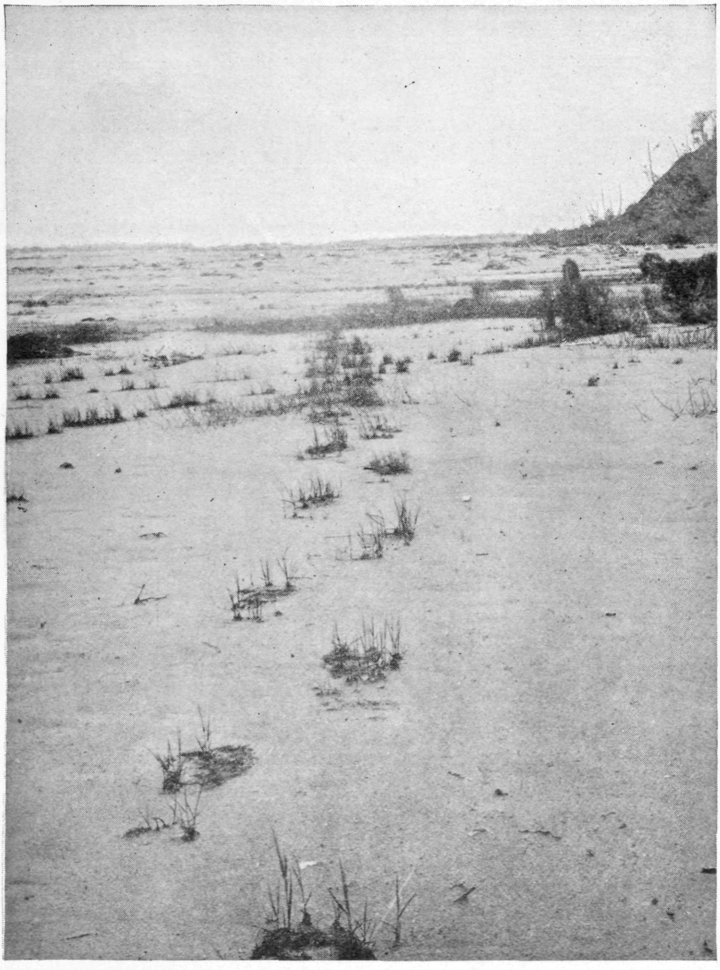


Photograph by Robert F. Griggs

LUPINE SEEDLINGS SPREADING OUT INTO BARE ASH.

Under the protection of the old vegetation along a dune ridge, they have started in deep ash beyond the ridge. When mature they will widen the strip of protecting vegetation and facilitate further the spread of vegetation. Katmai beach, August, 1916.

had in every case come up well and showed normal growth, which continued as long as we stayed. But of those scattered on the surface of the ash not a single individual was found. Since the vicinity of the Base Camp abounds in birds, it was thought that perhaps the seeds scattered on the surface might all have been picked up by the birds, and we awaited with interest opportunity to examine similar plantings made at Katmai Village where there are no birds and the wind sweep is greater. When examined, all of these with a single exception, were found in the same condition as the others—the planted seeds had all come up, while those strewn on the surface had blown away. In one of the sowings, however, though almost all had blown away, there was one small spot where a number of seeds had come up. This was found to be in a heel mark made



Photograph by Robert F. Griggs

A BEAR TRAIL THAT SPROUTED.

The depressions in the tracks of the heavy animal caught wind-borne seeds, which drifted across the smooth surface round about without finding any place of lodgment.

by someone who had walked across the area and pressed a few seeds down into the soil with his foot! For nearly two weeks after these seeds were planted, moreover, there had been no hard blows, but considerable rain and mist, so that they may be said to have had as favorable an opportunity for catching hold as could have been given them under the climatic conditions of the region.

The same conditions are held responsible for the fringe of seedlings found along the outwash deposited by temporary streams. (See page 333). Seeds buried in the outwash

Photograph by Jasper D. Sayre

THE SAME BEAR TRAIL A YEAR LATER.

From a somewhat different position. The grasses in the track have made notable growth, but no new plants have started in the general surface of the ash, although the horsetail in the background, probably a survival, has considerably extended its runners.

deposits were protected from the wind and given favorable conditions for germination in situations where none had caught hold on the ground surface of the ash. Similar conditions, but less striking, were found at Kodiak. (See the first paper of this series, page 51).

In 1917 further striking natural demonstration of the inability of seeds to lodge in the general surface of the ash was supplied by the discovery of several bear trails that had "sprouted." The depressions made by the animal's tracks in the soft mud had served to arrest numerous wind blown seeds which otherwise would have drifted clear across the barren flats without finding any lodgment. The seeds thus caught had sprouted and grown well, proving that in that particular place, at least, the principal deterrent to revegetation was the inability of seeds to catch hold. When examined a year later, the plants growing up in the tracks had made a notable growth, as may be seen by comparing pictures taken in the two years. (See pages 336 and 337).

WIND EROSION A GREAT DETERRENT TO REVEGETATION.

But the effect of the wind on vegetation is not to be measured merely by its influence as a seed disseminator. Much more important is its effect on the soil itself. It is so violent that it keeps the surface of the ground over large areas always in an unstable shifting condition, so that plants have little opportunity to start.

The wind is, indeed, one of the most important factors retarding the revegetation of the devastated district. In another place I have shown how important it is in the vicinity of Kodiak.* Near the Volcano the total devastation and the Conformation of Katmai Valley give it a clear sweep so as to greatly intensify its effects and augment its importance.

Here the snowdrifts which accumulate during the winter are buried under a mantle of wind blown sand which is often more than half a meter thick. Our observations on such drifts in 1916 showed uniformly that the sand had all accumulated after the snow fell, for it lay as a sharply distinct layer on top of the snow and the two were not interbedded. This indicates that it was all accumulated during a short period in the spring. (See page 339). Such sand-blanketed snow is very slow in melting and in places shows little wastage even as late as the first of August, which of itself is a factor of considerable moment in retarding the renewal of vegetation on the snow covered areas.

The abrasive power of this shifting sand, as it is carried by the wind, is very considerable. There are large tracts in the upper valley in which the sandblast has cut away the bark and even abraded the wood on the northwest side of the dead trees, leaving them uninjured on the lee side. A forest of such trees is most striking testimony of what the wind can do.

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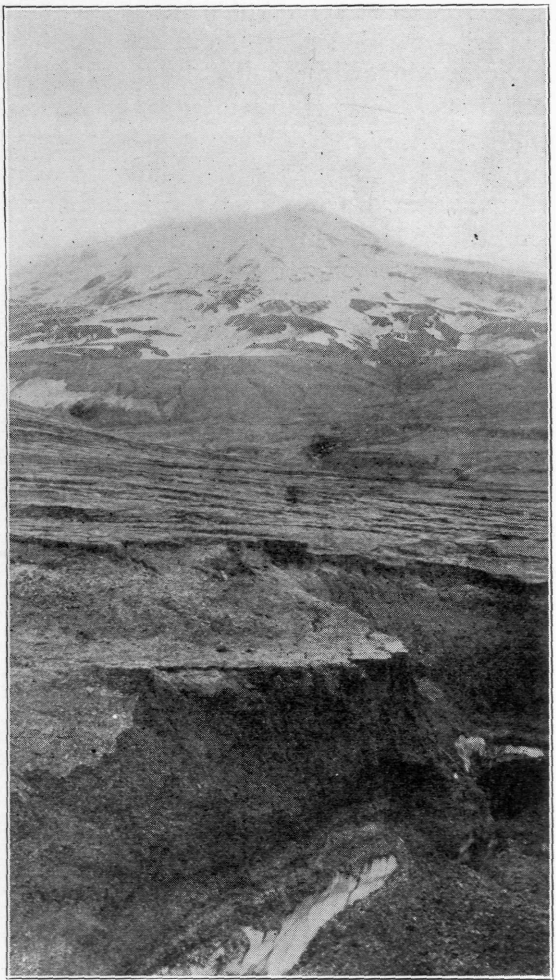
*The first paper of this series, pages 37-39.

KATMAI A VERY WINDY COUNTRY.

Unfortunately the weather records taken by the Government do not include measurements of wind velocity, so that there are no data for giving exact statements concerning the winds. The best that one can do therefore is to report some



Photograph by Robert F. Griggs

A SNOWDRIFT COVERED BY TWO FEET OF WIND-BLOWN ASH, NEAR KATMAI VILLAGE, AT SEA-LEVEL, JULY 15.

Thus protected from the sun, melting of the snow is so retarded that in many places formerly uncovered early in the season the snow now fails to melt away and is accumulating year by year.

of the effects of wind action, in order to enable the reader to form some conception of its violence. In this region the regular westerly gales approach in velocity the tornadoes which occasionally sweep our middle western states. Spurr[3] states that the natives cannot be induced to cross Katmai Pass except in fine weather, because the wind picks up stones and carries them with such force as to have killed many men. In Kodiak, a heavy dory was once picked up from the beach and carried up hill for a hundred yards, finally smashing in the front of a house before it stopped. Winds of only less violence are of common occurrence.

At our camp in the upper valley we have measured, with a weather bureau standard anemometer, winds blowing steadily 60 miles per hour, and much higher in the gusts. But the camp was in an especially sheltered situation, chosen especially with reference to avoiding such winds. Up on the mountains it was much worse, for there it picked up pieces of sharp pumice up to an inch in diameter and carried them with such force as to inflict painful blows where they struck one's flesh. Pieces even twice as large, though too heavy to be carried aloft, went scurrying over the slopes almost like dry leaves before the gale.

REVEGETATION GREATLY RETARDED BY SHIFTING STREAMS.

Another factor retarding vegetation, whose importance is almost as great as that of the wind, is introduced by shifting water currents. The streams were completely choked with ash and pumice by the eruption, and have not yet recovered from that condition. They are so overloaded with detritus that they have built up fans and flood plains many feet above the former levels of their beds. Over these great deposits of loose material they wander helplessly in many shifting channels, now here, now there, now cutting away, now building up. It is evident that no plants can obtain a foothold in such places until the streams settle down enough to give them a chance at the soil.

[3] 20th Ann. Rept. U. S. G. S., pt. 7., p. 91.

FICKLE CREEK SHIFTS ITS COURSE ONE THOUSAND FEET IN A YEAR.

Perhaps the most astonishing instance of the instability of the country was encountered when we traveled up toward Soluka Creek in 1916. Here, as elsewhere, the country looked perfectly familiar, but when we tried to find our last year's camp our memories seemed to fail us, for we could not locate it. How we could have missed it was a mystery, for it was conveniently located on the bank of a tumultuous torrent which supplied us with water. Curious to check up our unusual lapse of memory, we hunted and hunted through the dead forest in search of the old camp.

Finally we found the tent pins and the coals of the fire, just as we had left them, but the creek was nowhere in the vicinity. It had moved a thousand feet away.

Not only was the stream gone, its very bed was missing as well. The year before it had flowed in a steep sided trench, six feet below the general level, but now the ground was all smoothed off so perfectly that we could not detect the position of the former bank after the most careful search.

That some plants can start in such places, when the surface remains undisturbed, was shown by an examination of the area beyond the migrations of the stream. In 1915 this was absolutely sterile, but the next year we found in a space of about ten acres one seedling of Carex, two of *Calamagrostis langsdorfii*, two of another grass, a solitary specimen of *Chamaenerium augustifolium* and one patch of moss. Such feeble beginnings of plant life may strike the reader, familiar only with regions of luxuriant vegetation, as altogether too insignificant to deserve notice. But such is not the case, for these scattered plants, few and humble as they were, demonstrated the possibility of new plants starting in deep and pure ash deposits. Whether they were able to survive or not is questionable, but even if they succumbed they attained a size and weight far in excess of the seeds from which they originated, and their decaying bodies will furnish material for other plants to carry along the revegetation—that is, if the stream does not shift and wash them out.

HUMUS FORMATION THE REAL PROBLEM.

To the field worker the instability of the ground produced by the operation of these factors appears so important as to overshadow all else in the problem of revegetation. But experience with areas of high wind and loose soils outside the Katmai district clearly indicates that the shifting sands would be quickly caught and stabilized by the advancing vegetation if it were not for the lack of sufficient "plant food" in the ash. If such plants as start were able to grow thriftily, it would be only a relatively short time until the whole valley was again covered with luxuriant vegetation.

The real problem of revegetation is, therefore, the *nitrogen supply*. When the ash was thrown out from the Volcano in a fused condition, it was of course completely free of organic nitrogen. Dr. Shipley's work, reported in the fifth paper of this series, page 213, shows that the ash soil still remains extraordinarily poor in nitrogen compounds.

The task before us is, therefore, to follow the process by which a supply of combined nitrogen is built up in these soils as vegetation gradually returns, supplementing field observations on the plants with chemical and bacteriological examinations of the substratum. If this process of humification can be followed successfully, the knowledge so obtained will throw much light on many problems concerning the relations of plants to the soil, of great importance from both a theoretical and a practical point of view.