A Comparison of the Plant Succession on Hudson River Limestone with that on Niagara Limestone, Near Richmond, Indiana.

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The outcrops of bed-rock in the vicinity of Richmond, Ind., consist of two kinds of rock, namely, Niagara limestone and Hudson River limestone. The marked differences between these two kinds of rock make a study of the plant succession on the outcrops very interesting.

The principal outcrop of the Hudson River limestone is in the gorge of the Whitewater River, where it passes through the city of Richmond. This gorge is about three miles long, 200-300 feet wide and up to 100 feet or more in depth. This gorge is supposed to have been formed immedi ately after the ice age.

Outcrops of Niagara limestone occur only south of the city, the principal ones being in the gorges below the falls at Elliott's Mills and at Elkhorn Mills, two and three miles southeast of Richmond, respectively. The present report is the result of a study of the outcrops in the Whitewater gorge and the gorge at Elkhorn Mills.

The principal differences between the two kinds of rocks is in their physical character. The Hudson River limestone is composed of alternate layers of calcareous shale and rather soft limestone. These constituents vary greatly in amount, the rock consisting in some places almost entirely of shale and in others almost entirely of limestone. Generally, however, they are about equal in amount. The Niagara limestone is not accompanied by shale, but consists entirely of hard thick-bedded limestone.

On account of the physical character of the Hudson River limestone, the plant succession in the Whitewater Gorge is very rapid for a rock cliff. The stage of the succession of any part of the cliff is due to the length of time that has elapsed since the cessation of active undercutting by the river. All stages of succession from the plantless rock to the climax mesophytic forest are to be found. The earliest stage in the succession occurs where the cliff is being actively eroded by the river.

The walls are almost vertical. No plants exist, except those hanging from the top of the cliff. In most successions on bare rock, lichens are the pioneer plants, being found in the most xerophytic situations. No lichens are found anywhere on the Hudson River limestone, on account, no doubt, of the unstable nature of the substratum. This plantless stage persists until after active undercutting by the stream has ceased.

Then the cliff becomes less steep. The talus accumulates undisturbed by the stream, and bears a considerable vegetation. In this stage occur the pioneer cliff plants, occupying the shelves formed by projecting layers of limestone. The most of the plants are annuals and many of them are plants that have slipped down from the top of the cliff. The following plants are common in this pioneer association: Ambrosia artemisiaefolia, Poa compressa, Lactuca scariola, Nepeta cataria, Melilotus alba, Dipsacus sylvestris, Aster spp.

The shale layers of the cliff change readily to soil, which is washed down by rains. Layers of limestone thus left projecting break off of their own weight and fall. With the consequent reduction in slope, an increasingly larger number of plants gain a foothold. In addition to some of the pioneer plants mentioned above occur the following: Equisetum arvense, Aster nova-angliae, Daucus carota, Heracleum lanatum, Melilotus officinalis, Verbascum thapsus, Elymus canadensis, Cornus paniculata.

Up to this point, the succession has been controlled almost entirely by physiogenic factors. The stage in succession depends upon the slope of the cliff. When, however, the slope has become sufficiently gentle to permit the accumulation of a layer of soil, biogenic factors, those due to other organisms, come in. The plants, particularly the grasses, hold the soil and retard the further degradation of the cliff. The slope of a portion of the cliff occupied by a mesophytic forest is about the same as that of a portion occupied by the bush stage. Each plant association prepares the way for the succeeding one by holding the soil, accumulating humus and providing shade.

The herbs are soon partially displaced by a bush association. The most common species is Rhus aromatica, which often forms large colonies. Cornus paniculata, Salix longifolia, Rhus toxicodendron, Vitus vulpina, crataegus, Psedera, Ptelea trifoliata Rubus, Ribes and others are accompanying species.

The shrub stage is succeeded by a xerophytic tree stage, corresponding probably to the usual oak-hickory stage. Ulmus americana is the pioneer tree. With it occur Celtis occidentalis, Crataegus, Robinia pseudo-acacia, Cercis canadenses, Prunus americana, Gleditschia triacanthos, Juglans nigra and Sambucus canadensis.

The pioneer tree association gradually merges into the ultimate stage of the region, the mesophytic forest. Mesophytism is indicated by the following species: Fagus grandifolia, Acer saccharum, Coprinus caroliniana, Ostrya virginica, Asimina triloba, Impatiens pallida, I. biflora, Viola cucullata, Galium spp.

For a more complete account of the succession in the Whitewater Gorge, see a paper by the writer in the proceedings of the Indiana Academy of Science for 1910.

The rock exposed in the gorge at Elkhorn Falls is Niagara limestone. The falls are occasioned by the presence underneath the hard Niagara limestone of a softer layer, which is probably Hudson River limestone. Below the falls is a gorge about one-half mile in length and 150 to 350 feet in width. On the walls of this gorge, various stages in plant succession may be observed.

In general, the earliest stages in the succession are to be found nearest the falls, though they may be found wherever a rejuvenescence of the succession has occurred. The pioneer association consists almost entirely of lichens, a large, gray, leathery species of Umbillicaria being the most prominent. This lichen covers the rock in all exposed situations, sometimes growing to a diameter of three inches.

The lichen association is followed by another, made up of a small black moss, probably a species of Grimmia, and such seed plants as Poa compressa, Nepeta cataria, Verbascum thapsus, Aster and Solidago.

These are succeeded, after further weathering of the rock and the accumulation of humus in the widening cracks, by an association dominated by Hydrangea arborescens and Aquilegia canadensis. These may be accompanied by Psedera quinquefolia.

The falls overhang a distance of 10 to 20 feet, on account of the weathering away of the softer lower stratum. For the same reason, the cliff soon becomes overhanging. This condition is more marked where stream action is prominent. Under these overhanging cliffs a very mesophytic association develops. Here occur Conocephalus, Cystopteris bul-

bifera, Camptosorus rhizophyllus, Pilea pumila, Aquilegia canadensis and Hydrangea arborescens. Psedera quinquefolia hangs in long streamers from the top of the cliff. On the edge of the cliff or on the talus beneath, where stream action is absent, occur Ulmus americana, Ostrya virginica, Prunus serotina, Celastrus scandens and Vitis. Under the cliff flourish such herbaceous plants as Sedum ternatum, Pilea pumila, Impatiens, Equisetum arvense, Eupatorium perfoliatum, Ambrosia trifida, Stellaria media, Galium, Carex and various mesophytic mosses. The mesophytic condition is due largely to the constant shade.

The vegetation becomes more and more mesophytic as the cliff becomes more overhanging. On account of the stability of the limestone, this may continue until the cliff overhangs to a surprising extent, but eventually overhanging portions of the cliff fall in large masses. This process is aided by the presence of prominent cleavage planes in two series at right angles to one another, but neither parallel to the edge of the cliff. The breaking off of the large masses gives the cliff a jagged appearance. The immediate result of the breaking off of a portion of the cliff is a rejuvenation of the succession. The mesophytic vegetation beneath the overhanging cliff is destroyed, both by being covered by the fallen fragments and by exposure. Stream action on the base of the cliff is hindered or rendered impossible by the covering of the soft underlying stratum. The stream is too weak to remove or wear away the fallen fragments. The fallen portions of the cliff eventually become covered with vegetation. The new, vertical faces of the cliff after a longer period are clothed with plants. Soil and humus accumulate more readily than before the interstices of the fragments, giving better conditions for the growth of trees. With the increase of shade, more mesophytic conditions prevail.

Slowly the edge of the cliff and the fallen masses of rock are crumbled by action of the weather. The result is finally a gentle slope with occasional remnants of the cliff projecting through the soil. The climax mesophytic forest does not occur here, though conditions approaching it are found at the lower end of the gorge. Tilia americana, Robinia pseudo-acacia, Morius rubra and Fraxinus americana are the principal trees, with an undergrowth of Sambucus canadensis and such herbs as Galium, Poa pratense, and Sedum ternatum.

On the whole, it would be difficult to find two rock-cliff successions

more different than the two just described. The differences become more striking when it is considered that the two successions are both on limestone, in the same region and on cliffs extending in the same general direction. The principal differences are as follows: (1) The succession on Hudson River limestone is more rapid than that on Niagara limestone. (2) There is a striking contrast in the pioneer stages. The pioneer association on Hudson River limestone is characterized by the complete absence of lichens, liverworts, xerophytic mosses and ferns, all of which are prominent on Niagara limestone. (3) In the Whitewater Gorge, the degradation of the cliffs of Hudson River limestone is accomplished by the crumbling of the rock into small fragments, while at Elkhorn Falls the fragments of Niagara limestone are of many tons' weight. (4) On account of the overhanging character of the cliff at Elkhorn Falls, an intermediate mesophytic stage is introduced into the succession.