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## RESTUDY OF THE SCHOHARIE AND ESOPUS FORMATIONS IN NEW YORK STATE.

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**ABSTRACT.** Restudy of the Esopus and Schoharie formations involves regional tracing of the beds from Schoharie west to Springfield Center, then east to the Helderbergs and thence south to the Pennsylvania border. The Esopus formation is restricted, the beds formerly classed as upper Esopus being separated into the new Sharon Springs formation, which may be locally separated from overlying and underlying beds of glauconite bands. Instead of disappearing to the south, the Schoharie grit changes rapidly to a shaly and a cherty facies, here termed the Leeds facies, and thickens as it approaches the Pennsylvania border.

### INTRODUCTION.

**W**HILE mapping the Schoharie formation on the Cox-sackie quadrangle, the senior author again and again was impressed with the dissimilarity in character between the beds in this area and those of the Helderberg region. In addition, while working on the Hamilton beds with Dr. G. Arthur Cooper of the U. S. National Museum in the summer of 1938, she had opportunity to see the Schoharie and Esopus in a number of outcrops between Port Jervis and Kingston which only added to the conviction that it was necessary to trace the Schoharie from its type locality in the Schoharie valley through the Helderberg region and middle Hudson valley, and then southward. Dr. G. H. Chadwick of Catskill, New York, while rechecking the mapping of his Catskill quadrangle in the fall of 1938, found "grit bottoming the Onondaga at a point near Katsbaan plainly distinct from the so-called Schoharie beneath it" and asked the senior author (letter, Nov. 30) whether she "had any reason to suspect that it did not exactly correlate with the true Schoharie grit in the Helderbergs." Chadwick reports a break between the Esopus and the Schoharie, and between the latter and the Onondaga

in the Catskill region (1927, p. 160; personal communication). That there may be local breaks there is no question, but in the region of the Coxsackie quadrangle the senior author found the *Esopus* grading up into the "Schoharie" and found it difficult always to draw a boundary. There was some question whether the upper silicious beds of the *Esopus* belonged with the *Esopus* proper, constituted a new member of the *Esopus*, or should be considered as basal Schoharie. It was therefore apparent that it was necessary to combine with a restudy of the Schoharie throughout its extent in New York State a critical study of the *Esopus*, particularly with reference to the upper beds. This work was carried on jointly by the authors in the summer of 1940.

#### TYPE REGION OF THE SCHOHARIE.

The Schoharie formation or "grit" received its name from the type locality in Schoharie county at Schoharie (Vanuxem, 1840) where it is characterized by a great wealth of fossils quite in contrast to the *Esopus* shale. For the Schoharie-Helderberg area over 125 species of fossils have been listed, including 3 coral genera, 2 bryozoans, 33 brachiopods, 14 pel-ecypods, 12 gastropods, 2 pteropods, 45 cephalopods, and 16 trilobites (Grabau, 1906, p. 327). For this area the Schoharie is described (ref. cit. p. 180), as a "silicious limestone compact, mud-textured when fresh, and of a dark bluish-gray color. It effervesces readily with acid and weathers by solution of the lime into a brown, porous sandrock not affected by acid, in which the fossils remain as molds." Unfortunately exposures in the Schoharie region are rare and none is complete. According to Grabau, the best exposures occur on the north side of both West and East Hills, but it is quite evident that the large collections of Schoharie grit fossils from the Schoharie valley were made mainly from fragments and boulders scattered about on the *Esopus* slope. On the north side of East Hill the writers found no Schoharie in place, but a number of boulders which had slipped down the talus slope were studied. A two-foot boulder showed a tendency toward Onondaga lithology in the upper five inches. The remainder of the boulder was of a brownish gray color and resembled limestone when fresh; when weathered, it was buff to brown, spongy and gritty. Other boulders showed only the lower

portion, which was relatively barren. All were relatively thin bedded in comparison with the Schoharie of the Helderberg area. When freshly broken, the Schoharie was seen to be of a darker blue-gray color than the Onondaga and finer grained. Other loose pieces of the Schoharie were strongly cherty and weathered into a more rotted looking rock. In the boulders found here fossils were abundant, though apparently confined to pieces from the upper part of the Schoharie. An absence of corals, cephalopods and gastropods was noted, which is clearly atypical of the Schoharie, both as known from extensive collections made from the Schoharie valley and as observed in the Helderberg area. The junior author examined the north slope of West Hill for the Schoharie (1935 and 1936) but failed to find any exposures in place. As on East Hill, numerous loose fragments were encountered.

At East Cobleskill in the north slope of Sunset Hill just east of the road junction on the north side of the Schoharie-Cobleskill road, five inches of dark gray, cherty Schoharie with fossils are exposed under the Onondaga cliff. The fauna, though not abundant, appears to be quite typical, and corals are conspicuous. Above this layer are three to four inches of thin bedded limestone showing a tendency toward Onondaga lithology, but darker. This transition to the Onondaga is well shown just west of the falls of a small stream. Under the Onondaga here ten inches of massive dark blue-gray Schoharie limestone with brachiopods represents the Schoharie-Onondaga transition. There is no sharp contact. Beneath the transition zone are five inches of darker gray, rotting limestone, evidently a layer of typical silicious Schoharie grit. The thickness of the Schoharie for the Schoharie region has been estimated to be five or six feet.

#### SECTIONS WEST OF SCHOHARIE.

The most western exposure of the Schoharie formation is found in an abandoned quarry one mile east-northeast of Cobleskill and about one quarter of a mile west of the road to Carlisle Center. Here the relationship of the Schoharie with overlying and underlying formations is clearly shown. The lowest part of the section exposed consists of thin-bedded, arenaceous sediments in which there is a prolific development of *Taonurus cauda-galli*. This is interrupted by a band of glauconite two and one-half to three inches thick, which has

been taken to represent the base of the Schoharie. The glauconite is followed by nine inches of soft, thin-bedded shale which is succeeded by about 35 inches of undoubted massive Schoharie, fine-grained, silicious limestone with chert, mud-textured, and of dark bluish gray color when fresh, but weathering buff colored. Fossils are present, but not nearly so abundant as in the typical Schoharie as developed in the Schoharie valley and the Helderbergs. Two massive beds are present. The lower yielded the characteristic gastropod *Platyceras dumosum* and some poorly preserved *Atrypa*, the upper yielded abundant corals, particularly species of *Favosites*, also numerous crinoid fragments, a *Meristella* sp., *Diaphorostoma* sp. and *Proetus* sp. Brachiopods are not nearly so abundant as in the typical Schoharie, and no cephalopods at all were found. Next in succession follows a series of relatively barren beds consisting of dark gray, fine-grained limestone transitional above the silicious fossiliferous bed to the typical Onondaga. In all, four to five feet of rock above the glauconite bed could be referred to the Schoharie, but the uppermost beds transitional above the silicious limestone could as readily be considered basal Onondaga. There is here no sharp contact between the Schoharie and the Onondaga.

The beds underlying the glauconite band in this quarry are exposed for a thickness of eight feet. The upper six feet and nine inches consist of thin bedded silicious platy and sandy shale, more heavily bedded at the top, which has weathered light gray to buff colored, and breaks in large platy pieces. Each bedding surface is packed with *Taonurus*, which continues through the glauconite band. A massive ten inch bed with typical *Taonurus* occurs below the thin-bedded silicious shale. The basal nine inches of soft shale of the Schoharie contain annelid trails, but they are less typical of *Taonurus* in form.

The relationship of the base of these shales below the glauconite is shown in a section three miles west of Sharon Springs in a road cut on the south side of Route 20 (Cherry Valley Turnpike). Here were found eleven feet of buff colored shales, similar to the eight feet seen in the quarry, and again *Taonurus* surfaces are prolific. Immediately beneath is a two inch bed of glauconite separating the upper beds from the drab colored typical Esopus beneath, which has broken down

into its characteristic gravel. The upper 22 inches of the Esopus beneath the glauconite are thinner bedded and more shaly than is typical, and break into small but not chunky pieces. *Taonurus* is not well developed in these beds, and is absent in the lower part of the section where typical Esopus lithology prevails.

Farther west along the same highway, in a road cut three-eighths of a mile east of East Springfield, twenty feet of the buff-weathering silicious shales with *Taonurus* were measured. In the nine miles between this and the preceding locality, the typical drab colored Esopus seems to have disappeared. The contact with the Oriskany is not visible. Farther west, about six miles north of Springfield Center, two and a half miles due east of Crains Corners, twenty feet of this rock are again exposed in a cut on the south side of the road. No glauconite is exposed at the base of the section, and there is no room for the Schoharie at the top, as shown by aneroid readings taken at the top of the shale bed along the road and at the base of the Onondaga along the road and in a small quarry in a field to the south. The contact is not exposed. For this twenty feet of silicious shale set off from the Esopus below and from the Schoharie above by comparatively thick beds of glauconite, the name *Sharon Springs formation* is here proposed. Although these beds have formerly been included in the Esopus, they are here regarded as a distinct formation, inasmuch as their relationship is no closer to the underlying Esopus shale, as here restricted, than to the overlying Schoharie. Both at the top and at the base of the Sharon Springs formation contact may be gradational, and the exact position of its boundaries is a matter of opinion for many sections in the Helderbergs and in the Hudson valley. However, in these areas the resistant Sharon Springs formation tends to form ridges, hogbacks in folded areas, and is distinct physiographically as well as lithologically from underlying and overlying beds. West of Schoharie, the Sharon Springs formation is clearly separated both at its top and at its base by glauconite bands, suggestive of diastemic breaks. On the basis of lithology alone, the Sharon Springs formation appears to be slightly more closely allied with the Schoharie grit than with the Esopus shales in this region. Near Cobleskill, the glauconite band at the top of the Sharon Springs is succeeded by a few

inches of soft shales at the base of the massive beds bearing the Schoharie fauna. At its type locality, however, the basal glauconite band marks a relatively abrupt change between the Esopus and the Sharon Springs lithology.

#### HELDERBERG AREA.

The best exposures of the typical Schoharie grit occur in the Helderberg area. The same lithology and the same fauna occur in the Schoharie valley, but no good exposures of the formation can be found there at the present time. Quite probably most of our knowledge of the Schoharie grit of the Schoharie valley has been derived from loose boulders collected from the Esopus talus slopes. Extensive collecting, extending over a period of nearly a hundred years, has proved a drain upon such material with which the agencies of supply, weathering, and creep have not been able to keep pace. Therefore our knowledge of sections of the typical Schoharie grit is dependent upon the several fine exposures of the formation in the Helderberg area. Grabau (1906, p. 325) has attempted to differentiate in his faunal lists of the Schoharie between species known from the Schoharie valley and those known from the Helderberg region. The junior author, who has collected in the Schoharie grit of the Helderberg over a period of some years, has found there a considerable number of the species which were formerly known only from the Schoharie region, together with a number of undescribed forms. This suggests that the faunal differences between the two regions, never very great, are due very largely to the chance preservation of the rarer elements, which actually constitute a considerable portion of the rather imposing faunal lists already on record. Many of the remaining species, which are still reported only from one region or the other, are known only from single specimens.

Throughout the Helderberg area there is a definite succession of beds in the Schoharie grit which has not been previously recorded. The platy beds of the Sharon Springs formation are succeeded by more massive, rather concretionary, transition beds. These grade upward into massive beds of grit, typical of the Schoharie in lithology, and largely barren except for an occasional colony of *Favosites*. Overlying these beds there is a single massive layer about a foot in thickness

characterized by corals and two cephalopod species, *Michelinoceras pelops* (Hall) which is extremely abundant and occurs normally in an unflattened condition, and the rarer *Naedyceras (sensu lato) validum* (Hall), which the junior author has found only in this layer. *Atrypa* is occasionally present, as is the large *Pleurotomaria arata*. This bed is noteworthy as it has furnished the few cephalopods of the Schoharie grit which retain well preserved internal features. This layer is referred to below as the *pelops* bed.

This is succeeded by a series of beds, massive on the whole, and holding together well under weathering, but actually divided into relatively thin beds, with the fossils concentrated at the bedding planes. These layers have produced the greater part of the Schoharie fauna, and are packed with fossils. Brachiopods are abundant throughout. The lower two-thirds of the beds have yielded the greater number of the known cephalopods. Gyroceracones of the Ryticeratidae are largely confined to the basal beds, which are also particularly rich in orthoceracones, while the middle third is particularly characterized by the trochoceroid genera *Naedyceras* and *Sphyradoceras*. The upper third of the beds contains little besides myriads of brachiopods. The abundance of trilobites, gastropods and pelecypods is largely confined to the lower two-thirds of these beds. Brachiopods dominate the Schoharie grit in actual number of individuals, but they are overshadowed by the larger and more conspicuous corals and cephalopods.

The Schoharie exposures of the Helderberg area have been discussed in the bulletin on the Berne quadrangle (Goldring, 1935, pp. 136-139). Above New Salem along the Wolf Hill highway, one-quarter of a mile east of the New Scotland town quarry in the Onondaga limestone, the Schoharie is exposed in the woods above a road cut in the Esopus and Sharon Springs formations. Here only the upper part of the Schoharie grit is present, measuring two feet six inches, exposing the *pelops* bed, the upper layers and the Onondaga contact. Fossils are abundant. In the cut below the Sharon Springs formation is exposed, with a thickness of about 22 feet. The upper ten feet of the formation, just beneath the Schoharie, is characterized by concretionary lenses that pinch out shortly to the east and west of this region. In the Clarksville region five feet of typical Schoharie have been measured on the south side (near the top)

of the lower gorge of the Onesquethaw, where the fauna is typical and abundant. At this locality were observed the corals *Favosites* sp. and *Zaphrentis* sp. and brachiopods of the genera *Leptaena*, *Stropheondonta*, *Leptostrophia*, *Strophonella*, *Rhipidomella*, *Pentamerella*, *Meristella*, *Atrypa* and *Spirifer*. Pelecypods were represented by *Conocardium*, *Goniophora* and *Cypricardinia*, gastropods by *Pleurotomaria arata*, *Bellerophon* sp., *Platyceras dumosum*, *Platyceras* sp. and *Diaphorostoma* sp., cephalopods by *Ormoceras* cf. *luxum*, *Michelinoceras pelops*, *M. collatum*, *M. stylus*, *Spyroceras multincinctum*, *Ryticeras jason*, *R. eugenium*, and *Naedyceras* sp., trilobites by fragments of *Phacops* and *Proetus*. The selection represents many of the more common forms of the Helderberg area. The beds transitional to the Sharon Springs below retain the concretionary aspect noted at Wolf Hill.

One and one-half miles south-southeast of Tarrytown (Onesquethaw), Albany County, in the falls on the southern branch of the Onesquethaw Creek, this five feet of the Schoharie may be studied to good advantage and the exposure is more accessible. Here the upper 32 inches constitute a massive bed of dark blue-gray, fine-grained silicious rock that weathers to a spongy sand rock. As usual in the Helderberg area, numerous bedding planes are indicated, but boulders rarely separate along them, so that the Schoharie when viewed from exposures of loose boulders appears massive. The lower 30 inches retain much clearer bedding planes and are relatively barren. When fresh it appears as a dark blue-gray limestone, resembling somewhat the Schoharie as it thickens southward in the Hudson valley. Fossils are numerous in the upper part of the Schoharie here.

One half mile south of Callanans Corners in the woods on the west side of the road to Coeymans Hollow is the best exposure of Schoharie for collecting purposes. There is an estimated thickness of five feet here, 55 inches having been actually measured beneath the Onondaga. The basal beds of the Schoharie are, as is common, not well exposed. The upper beds are highly fossiliferous. The fauna is typical and abundant with a profusion of cephalopods, including *Ryticeras jason*, *R. aemulum*, *R. eugenium*\*, *R. spinosum*, *Sphyrado-*

\* *Ryticeras* is used here in a broad sense. Only *R. jason* and *R. spinosum* are typical. Other species are placed in a genus now in process of description.

*ceras discoideum*, *S. clio*, *Naedyceras pandion*, *N. n. sp. aff. eugenium*, *Ormoceras luxum*, *O. vastator*, *Michelinoceras pelops*, *M. zeus*, *M. collatum*, and "Orthoceras" *masculum*. Other fossils include the corals *Zaphrentis* and *Favosites*; fenestellid bryozoans; a brachiopod fauna essentially identical with the above list; the gastropods *Straparollus inops*, *S. clymenoides*, *Pleurotomaria arata*, *Diaphorostoma amplum*, *Bellerophon curvilineatus*, *Loxonema sp.*; the pelecypods *Actinopteria sp.*, *Cypricardinia*, *Goniophora*, *Modiomorpha*, and trilobites of the genera *Synphoria*, *Phacops* and *Terataspis*. In these last localities 22 to 25 feet of the Sharon Springs formation have been measured.

APPEARANCE OF THE LEEDS FACIES.

From the above locality the Schoharie begins to thicken southward, with marked lithological changes which first become apparent in the lower beds. South-southwest of South Bethlehem in the woods on the east side of the road to Aquetuck, one and one quarter miles south of the four corners, eight to ten feet of this formation were measured. Five to six feet consist of silicious buff and spongy weathering, cherty limestones, the typical Schoharie of the Helderberg region down to and including the *pelops* bed. The lower 33 to 55 inches, well shown in huge boulders on the east side of the road for some distance south, are more massive in character, fine-grained and cherty, with the bedding planes practically lost. These beds are only sparingly fossiliferous, but *Atrypa*, *Pleurotomaria*, *Synphoria* and small corals were found. There is a strong resemblance of this bed to the Schoharie as seen in the Cobleskill quarry. About 16 feet of Schoharie are seen in road cuts and stream at the west along the same road three-eighths of a mile north of the junction with the Aquetuck-Coeymans Hollow road. Here the upper 33 inches immediately beneath the Onondaga are fairly typical, though becoming more massive, and there is an interfingering of more limy beds with the gritty and cherty beds. The limestone is finer grained and a light blue in color. Fossils are typical, but much less abundant than they are farther north. Cephalopods including *Michelinoceras cf. pelops*, *Ormoceras cf. luxum* and *Ryticeras eugenium* were found here, with species of *Favosites* and *Zaphrentis*, a few brachiopods and a *Synphoria*. A middle section of five feet ten inches in a nearby cut on the west side of the road

consists of fine-grained, massive limestone, resembling a mud-rock, drab colored when fresh, buff and gritty when weathered. Chert seams and chert nodules are present, particularly near the top, and fossils are scarce, consisting largely of *Atrypa*. Irregular shadowy worm markings can be seen, particularly in the lower portion of this section, and from this point southward seem to be characteristic of the Schoharie. Across the road in the stream bed are seven feet of underlying grit, weathering buff and spongy, but resembling a dark-blue, fine-grained limestone when fresh. Some of the surfaces show rather diffuse worm burrows. No fossils are present. Just to the south, on the east side of the road near the junction, was measured a thickness of ten feet six inches which corresponds to the middle section just described. These beds are cherty, particularly in the upper portion. Except along the road, the outcrop is weathered into a buff-colored, gritty rock in which the original drab color and mudrock appearance are lost. The top fossiliferous beds are not exposed here, nor are the basal grit beds, suggesting a total thickness of twenty feet or more for the Schoharie of this area. Fossils occur sparingly and are more apt to be found in the cherty portions, often in the chert nodules themselves. In this portion of the Schoharie have been noted such brachiopod genera as "*Spirifer*," *Lingula*, *Orbiculoidea*, *Meristella*, *Strophonella*, *Atrypa*, *Leptaena*; a small cup coral, probably a *Zaphrentis*, a *Ryticeras* and the trilobite *Synphoria* [*Dalmanites*]. Fish bones were also found.

As the Schoharie thickens southward from the valley of the Hannacrois in the vicinity of Aquetuck, it soon loses the typical lithology entirely, and finally becomes a shaly limestone with chert seams in the upper portion. Three and a half feet of the typical Schoharie were found under the Onondaga on the south side of the sharp bend in the Hannacrois one quarter of a mile south-southwest of Aquetuck. This phase of the Schoharie is found on the Cocksackie quadrangle as far south as the four corners south-southwest of Albrights (about four miles north from the West Cocksackie road junction). On the Catskill quadrangle the very thin representation of grit bottoming the Onondaga (Chadwick) at a locality near Katsbaan (three and one-half miles north-northwest of Saugerties), appears to be the most southern occurrence in the Hudson valley of the typical upper Schoharie developed so character-

istically in the Helderbergs and in the Schoharie valley. As far south as Mount Marion, however, beds of characteristic Schoharie lithology may occur, and seem to represent interfingering of the two facies. This occurrence is found at the east end of a road cut in the Schoharie about one-quarter of a mile east of the railroad crossing at Mount Marion. Here four to five feet of the basal beds weather into a gritty sand-rock, as does the Schoharie in the type region, and the presence of a small coral was noted in the basal portion. This may correlate with the seven feet of basal grit found in the section north of the Hannacrois valley on the Coxsackie quadrangle. On this quadrangle the best localities for the study of the Schoharie formation are found near the southern border in the Leeds gorge and on the south side of Greens Lake at the Casino, about two miles north-northeast of Leeds. In the fifteen miles between Leeds and the Hannacrois valley region the Schoharie has thickened from at least 20 feet to between 55 and 72 feet, (the latter measure including transition beds). At the Casino there is an estimated thickness of 55 feet of a silicious shaly limestone, buff weathering and with chert bands and nodules prominent in the upper portion, in which part of the section fossils occur sparingly. Besides trilobites and poorly preserved brachiopods a poorly preserved orthoceratic cephalopod was observed here indicating that the cephalopod content peculiar to the upper part of the Schoharie may carry through at least as far south as Leeds. This occurrence of cephalopods is of particular stratigraphic significance. Here, in a region where no typical Schoharie caps the cherty beds which dominate the Hudson Valley, and which are designated below as the Leeds facies, the uppermost beds of this facies carry cephalopods, particularly the Ryticeratidae, which are characteristic only of the upper beds of the Schoharie in the type region. This is significant as it indicates quite conclusively that the Leeds facies is, in this region, contemporaneous with the upper as well as the lower beds of the Schoharie of the Helderbergs. The Coxsackie sections alone might seem to indicate that the Leeds represents a lower member of the Schoharie, absent in the Helderbergs, but appearing and thickening rapidly while traced southward, while the upper beds, constituting the typical Schoharie, thin and finally disappear.

The cephalopods are of interest ecologically as well. Nautiloid cephalopods were largely benthonic shallow water organisms, though with some exceptions. Present investigations of the junior author are leading to the conclusion that they were relatively restricted in environmental range; in short, they were to a large extent, facies organisms. The occurrence of a few fragmentary shells in the upper part of the Leeds facies is probably to be interpreted as the transportation after death of floating shells, buoyed up by gas within the camerae, until breakage or solution of the shell allowed the gas to escape, and permitted the shell fragments to sink, become buried and preserved in the sediments of a foreign environment.

There is an excellent section of the Schoharie formation in the falls of the Catskill in the Leeds gorge. The lowest 20 feet are a dark blue, shaly limestone with intermittent and numerous chert bands, the basal 15 inches an almost solid chert bed because the individual chert bands are so close together. The next 25 feet constitute a more massive limestone. This portion consists of numerous chert bands alternating with limestone bands up to three and four inches in thickness, which weather whitish and in the upper 12 feet of this part of the section are very fossiliferous. The succeeding seven and one-half feet show limestone bands, up to eight inches in thickness, carrying an abundance of fossils: bryozoans, corals, brachiopods, gastropods and trilobites. The interbedded silicious shale bands are here thinner than the limestone bands. The next 27 inches consist of interbedded limestone bands and very silicious shale with a chert band at the top. On the underside of the basal bed shallow water markings are seen; *Taonurus* is present just above. The upper part of the bed contains corals. In the three feet above there is a large proportion of limestone. The chert bands pinch out and come in again. These sections have a total thickness of 54 feet 9 inches, and are regarded as undoubted Schoharie. Above this are 17 feet of transition beds which the authors would place with the Schoharie formation. At the base of this transition zone is an 18 inch massive limestone band followed by a zone of interbedded chert and limestone in which the chert lenses are so thick and numerous as to give the appearance of a massive chert bed. A three foot limestone bed follows and is succeeded by ten feet of interbedded limestone and chert bands, the latter again so numerous

as to give the effect of a thick chert bed. In this transition zone at the base of the uppermost three feet interference ripple marks are seen, clearly suggestive of shallow water conditions, and three inches of typical silicious shaly limestone show typical *Taonurus* markings. Certainly no break between the Schoharie and Onondaga is indicated here. Instead, the upper beds show a cyclic repetition of (1) a shallow water phase, (2) a phase reminiscent of the Sharon Springs, (3) typical Schoharie (Leeds) beds (4) beds very strongly suggestive of the lower cherty Onondaga, (5) a return to Schoharie lithology. This succession is repeated twice before the final phase, which is marked by the final recurrence of Onondaga lithology.

The fossils noted are those typical for the Schoharie of the Hudson valley. Head and cup corals, though small, are especially numerous here. A fair-sized fauna has been reported from the Hudson valley (Chadwick; Goldring; Clarke, 1900, p. 14), consisting of the following genera: two bryozoans ("*Fistulipora*," "*Monotrypa*"), three corals (*Favosites*, *Zaphrentis* and *Streptasma*), 13 brachiopods (*Atrypa*, *Coelospira*, *Chonetes*, *Elytha* [*Reticularia*], *Eodevonaria*, *Leptaena*, *Lingula*, *Meristella*, *Rhipidomella*, *Schuchertella*, "*Spirifer*," *Stropheodonta*, *Strophonella*), three gastropods (*Orthonychia*, *Platyceras*, *Straparollus*), three cephalopods ("*Cyrtoceras*," "*Gyroceras*," probably both *Ryticeras*, *sensu lato*, and "*Orthoceras*") and three trilobites (*Calymene*, *Phacops* and *Synphoria* [*Dalmanites*]). The radical change in the composition of the fauna of the Schoharie grit of the Hudson valley from that of the Helderberg-Schoharie region is at once apparent, and is recognized as due to the replacement of the conditions permitting deposition of the typical Schoharie grit by a very different set of environmental conditions which are reflected both in lithological and in faunal changes. The Schoharie grit in the type area is a distinct cephalopod facies, although, superimposed upon the typical association of such a facies in its purest form in which cephalopods, trilobites and gastropods dominate almost to the exclusion of all other forms, there is an admixture of corals, brachiopods and some bryozoans. Similar associations are known, however, in the Arctic Ordovician, in the Niagaran both as developed in the Arctic, and as developed in the reef associations of east-central North America.

The silicious shaly and often cherty limestones of the Schoharie in the Hudson valley contain a very different type of association, in spite of the fact that many of its species are apparently identical with those of the typical Schoharie. The organisms consist largely of brachiopods, small corals, bryozoans, trilobites and a few gastropods. The fauna is a sparse one and is made up of small forms in contrast to that of the typical Schoharie. For this facies the name *Leeds facies* is proposed from the locality described above at which a complete section can be seen. The name Saugerties formation suggested by Chadwick (letter 1938, also in mimeographed outlines for the Catskill meeting of the New York Geological Association, 1940), as a possible name for a new formation, if such it proved to be, is considered inadvisable. Chadwick's type section, a cut three-eighths of a mile west of the railroad underpass, on the western edge of Saugerties, exposes only 18 feet of the upper part of the Schoharie beneath the transition beds, and the more barren lower portion is not exposed. There is a strong resemblance in this exposure to the 35 inches of basal Schoharie seen in the Cobleskill quarry. Four bands of chert and cherty nodules are shown. When fresh, the rock appears as a fine-grained limestone of dark blue color, but it has weathered to a buff color with whitish-weathering chert bands. Fossils occur sparingly throughout the entire thickness here.

Southward from Leeds the thickening of the Schoharie continues. At the Falls of the Esopus at Glenerie Falls, about six miles north of Kingston, a complete section exposes an estimated 80 to 90 feet of this formation. Here the upper 12 feet, forming the upper falls under the railroad bridge, show seams of heavy chert and limestone bands alternating with grit. Not far to the west and north is the exposure on the road to Mount Marion, cited above as containing lithology reminiscent of the typical Schoharie in the lower beds, suggestive of local interfingering. The extreme thickness of 200 feet assigned to the Schoharie of Becraft Mountain (Grabau, 1903, p. 1069), is erroneous. The thickness here has been found to be no greater than that for the Catskill region as a whole. The error may be due in part to difficulties in measuring disturbed and cleaved strata in a heavily wooded region, but largely from the inclusion of a considerable part, if not all, of the Sharon Springs formation with the Schoharie.

WARWARSING AREA.

In the vicinity of Warwarsing, about 25 miles south-southwest of Kingston on the north side of Rondout creek (route 209) a thickness of about 150 feet was estimated. A nearly complete section is exposed in the woods near an old Onondaga quarry on the Wiese property one-quarter of a mile north of route 209 at the end of a lane that crosses the main road about a mile northeast of Warwarsing. As elsewhere the uppermost beds show interfingering limestones and limy shales with some chert. The basal 21 feet of Onondaga exposed in the quarry is finer-grained than is typical. The lowest ten feet of Schoharie exposed, probably the basal beds, are capped by an eight inch band of a dark-blue, fine-grained limestone. Beneath is a thin-bedded, silicious, limy rock, of a dark blue color when fresh. The rock breaks chunky, weathers buff-colored and shows the shadowy worm burrows characteristic of the Schoharie. Only in this lower portion has it been possible to collect fossils and here a small fauna was found consisting of *Atrypa*, a small "*Spirifer*" of the *sculptilis* type, *Dalmanella*, *Orbiculoidea*, *Leptocoelia* and *Leptostrophia* a fauna similar to that found in the Hudson valley exposures. About one-half mile southwest of the lane junction, on the north side of the main road behind an old lime kiln, about 35 feet of Schoharie are exposed beneath the Onondaga in the old quarry. Here the 15 feet of basal Onondaga is knotty with shaly seams and, as was found in the quarry at the previous locality, though light-gray in color, it is finer-grained than typical for the Onondaga. The Schoharie in its upper portion is thin-bedded and has a knotty appearance. Near the top is an eight-inch grit band.

PORT JERVIS AREA.

The section for "Trilobite Mountain" in the Port Jervis region, immediately northeast of Tristate on the east side of the Neversink river, has been carefully measured by Shimer (1905). In the section measured across the hill where the lane turns up on the east side, Shimer measured (op. cit., pp. 222-231) 235 feet of rock between the tracks of the Erie railroad and the road (old Newburg turnpike) along the west side of the hill, which he assigned to the Onondaga limestone. In his "Onondaga" section he found a basal 30 feet of arena-

ceous shale, with fossils, becoming calcareous toward the top; above this about 130 feet of fossiliferous calcareous shales, with "the occurrence of thin bands of limestone more and more frequently toward the top." In the "next 40 or 50 feet the limestone and calcareous shale beds are about equal in number and thickness" (op. cit. p. 192). The next 15 feet of shaly strata are followed by a ten-foot, rather massive-bedded, gray limestone capped by seven feet of a "cherty, exceedingly closely grained limestone, in beds three to six inches thick. The chert is more abundant in two to six inch bands parallel to the bedding but is found also scattered irregularly throughout all the beds. The chert does not occupy a bed to the exclusion of the limestone . . . , but occurs in very irregular masses through it; this gives the rock when weathered an exceedingly rough appearance and at times it is pitted and amygdaloidal like" (op. cit. p. 231). These cherty beds are exposed along the northeast side of the road for a distance of a mile and a quarter northeast of Tristate, but particularly between the north and south junctions with the old road over the hill.

Shimer reports (op. cit.) *Coelospira acutiplicata* (Conrad) as the only fossil found in the basal 30 feet. The 18 feet of dark-gray, light-gray weathering, calcareous shale immediately above carry *Zaphrentis*?, *Chonetes hemisphericus*? Hall, *C. yandellanus* Hall, *Coelospira acutiplicata* (Conrad) and *C. grabau* Shimer (these last two the most abundant species), *Dalmanella subcarinata*? Hall, *Eatonia medialis* (Vanuxem) and *Loxonema* sp.

*Atrypa reticularis* (Linn.) and a "*Spirifer*" of the *duodenarius* type were found by the writer in the calcareous shales above. For the 40 to 50 feet of interbedded calcareous shale and limestone bands Shimer cites *Atrypa reticularis* (Linn.), the most common form, *Chonetes hemisphericus* Hall, *Coelospira acutiplicata* (Conrad), *Leptaena rhomboidalis* (Wilckens), *Meristella* sp., *Elytha* [*Reticularia*] *fimbriata* (Conrad), "*Spirifer*" *macrus* Hall, *Synphoria* [*Dalmanites*] cf. *anchiops* (Green), *Phacops rana* (Green). The ten feet of massive-bedded gray limestone have yielded *Ceratopora* sp., *Favosites* sp., *Atrypa reticularis* (Linn.), again the most common form, *Coelospira concava* (Hall) and *Phacops rana* (Green). In the uppermost cherty beds the authors noted *Ceratopora* sp., *Favosites* sp., *Zaphrentis* sp., *Atrypa reticularis* (Linn.),

*Rhipidomella*, "*Spirifer*" sp. and *Phacops rana* (Green). One recognizes at once the resemblance in composition between this fauna and that of the Hudson valley. Of this section of his "Onondaga" in Trilobite mountain Shimer writes: "There are thus over 200 feet of the Onondaga laid down before the formation becomes the typical heavy bedded limestone usually associated with this formation" (op. cit., p. 193). Of the 235 feet measured here all but the uppermost 17 feet, that is 218 feet, are considered by the authors as unquestioned Schoharie. The upper 17 feet exposed might be considered transition beds, but the writers would place them also in the Schoharie formation. When fresh, they resemble the typical upper beds of the Leeds facies of the Hudson valley seen to good advantage in the fairly fresh cut just west of the city of Saugerties. The true Onondaga, with an estimated thickness of 250 to 300 feet, lies in the valley of the Neversink to the west. A good outcrop may be studied along the Delaware in the cemetery west of Tristate and south-southeast of Port Jervis.

The "Schoharie" of Shimer, included in the maximum thickness of 550 feet measured for the combined Schoharie and Esopus formations of Trilobite mountain, represents the Sharon Springs formation of the authors which constitutes a prominent feature in the topography through the Hudson valley and south-westward and, like the Schoharie formation, thickens in this direction. On the north side of the road one-quarter of a mile west-northwest of the Aquetuck road junction (Coxsackie quadrangle) about 35 feet of the Sharon Springs formation is exposed in its typical aspect in a series of hogbacks. The rock has weathered a rufous-buff color and shows the thin-bedding with an abundance of strongly-developed *Taonurus* on all surfaces. In the Leeds gorge east of the falls about 75 feet of this formation were measured. Here there is a transition to the Schoharie formation. The upper 15 feet are full of thin chert seams in all but the uppermost two feet which are free from chert. Glauconite was found by Chadwick (personal communication) between these beds and the Schoharie formation along the Rip Van Winkle Trail (route 23A) when the cuts were fresh, but the writer has seen no indication of it at Leeds or elsewhere in the Hudson valley. In the falls of the Esopus under the railroad bridge at Glenerie Mills a thickness of between 105 and 115 feet have been estimated for

the Sharon Springs. At least ten feet at the top are regarded as transition beds. South-southwest of Kingston on the east side of route 209 near the junction with the road to High Falls an estimated thickness of 135 feet of this formation is found. Here the Schoharie has a thickness of 115 to 120 feet. On the outskirts of Warwarsing, three-eighths of a mile northeast of the Onondaga quarry and lime kiln the uppermost beds are characteristically exposed as a prominent cliff just beneath the Schoharie, in a barn yard on the north side of the road. No measurement of thickness was obtained in this region where the Schoharie has thickened to about 150 feet. In the Port Jervis region the Sharon Springs formation has reached an estimated thickness of 200 to 225 feet and, because of its more resistant character, accounts for the hog backs developed on the northwest slope of Trilobite mountain, southeast of the tracks of the Erie railroad.

#### PALEOECOLOGICAL AND PALEO GEOGRAPHICAL INTERPRETATIONS.

The close relationship which has been found between the Esopus, Sharon Springs and Schoharie formations is indicative of a period of fairly continuous deposition in which changes of lithology and faunas which are diagnostic of the formations are to be interpreted in terms of changing environments. Certainly the gradational contacts in the Hudson valley are such as to preclude the application of the much worn explanation of distinct marine embayments. Unfortunately our knowledge of paleoecology is not as yet sufficiently precise to permit a very detailed reconstruction of the conditions under which these sediments were accumulated. However, some facts of importance are evident which permit interpretation. The Esopus, as restricted, is uniform in lithology over its entire area. The silty muds record a meagre fauna consisting of very small shells found only in a few localities. The dominant sign of life is a small, irregular, more or less vertical scolithid tube. *Taonurus* is present only in the extreme basal beds, and in the Schoharie region appears to be confined to a single bedding plane at the top of the Oriskany. The conditions suggest deposition in shallow water mud flats. The Sharon Springs formation records the accumulation of somewhat coarser grained sediments which were evidently an ideal environment for the organism which produced the markings known

as *Taonurus cauda-galli*, for these beds contain no other fossils. Analogy with recent day marine conditions would suggest that the makers of Sharon Springs *Taonurus* lived in exceedingly shallow water, perhaps a widespread tidal flat, in which sandy sediments were subject to constant reworking by organisms during their extremely slow accumulation.

In Schoharie time deposition showed regional variation both in lithology and faunas. The appearance of the Leeds facies at its most northward occurrence on the Coxsackie quadrangle might, in the absence of biotic data, be interpreted as a distinct and an older formation, which thickens rapidly southward as the Schoharie itself thins and disappears. Several facts show conclusively that this interpretation must be rejected and that instead the Leeds represents only a different facies, contemporaneous with the entire Schoharie, which happened to extend farther northward at the beginning than at the end of Schoharie time. Perhaps the most striking evidence is supplied by the upward gradation of both phases into the Onondaga, a change which is so gradational that the exact position of the Onondaga-Schoharie boundary cannot be placed precisely. Admitting that gradational contacts may be due to the reworking of unconsolidated sediments, it is particularly significant that in the Leeds area cephalopods have been found in the upper part of the Leeds facies which are known only from the upper beds of the Schoharie in its type region. Not only do these shells suggest that in the Leeds area the upper beds of the Leeds facies were strictly contemporaneous with the upper beds of the Schoharie of the Helderbergs, but, as noted above, they suggest strongly that we are dealing here with the chance preservation of shells which were floated from their normal Schoharie environment after the death of the organism by virtue of gas within the camerae.

The Leeds facies represents a return to the Hudson valley of ecological conditions which had been twice experienced before, first in the New Scotland limestone of the Helderbergian, and again in the Alsen limestone. Lithologically all three beds in this area consist of rather dense, muddy limestones separated by shaly partings and containing a quantity of chert. Sometimes the chert is in isolated concretions, but frequently the concretions are closely bedded together forming seams. The faunas of the three formations are strikingly

similar in aspect, though differing in species, the difference being most striking between the Alsen and the Leeds. Fossils are rather sparsely distributed. Brachiopods consist dominantly of *Atrypa*, broadly-plicated *Spirifer*, stropheodontids and a few meristellids. Corals are fairly common though uniformly small and are associated with bryozoans,—fenestellids and fistuliporids. Fragments of *Dalmanites* are fairly common, and likewise *Platyceras*, though other gastropods are very rare. Cephalopods and pelecypods are extremely rare or completely absent.\* Quite evidently three times similar ecological conditions have brought together similar faunas, though closer scrutiny will show that the species are quite different.

In the Leeds gorge the upper beds of the Schoharie repeat twice in a relatively short thickness an orderly sequence of (1) shallow water markings with interference ripples, (2) *Taonurus* markings in beds strongly reminiscent of the Sharon Springs formation (3) typical Leeds lithology and faunas, and (4) cherty light weathering limestone of Onondaga aspect. Though such a succession is a local one, it suggests strongly that here minor oscillations have caused a recapitulation of a sedimentary cycle involving the physical factors of varying depth and supply of sediment which in a broader sense are characteristic of the formations in this part of the section.

The Leeds facies, by its relatively great thickness in contrast to the typical Schoharie, suggests that it was deposited in the center of a subsiding trough, which was the major structural feature in eastern New York throughout the Lower Devonian, and is here an active factor in the preservation of sediments for the last time. In contrast to the Sharon Springs formation, supply of sediments was evidently more rapid. There is enough similarity of the shadowy, loose, worm markings of the Leeds facies to typical *Taonurus* to suggest that both may have been made by the same organisms, but that the typical *Taonurus* trails, which involve thorough reworking of slowly accumulating sediments by organisms, were modified when deposition became too rapid for the activity of the animals to keep pace.

\* This association is not typically developed in the New Scotland limestone of the Helderbergs, but rather of that formation in its more southern expression. It is most strikingly expressed in the lower beds of the New Scotland, the Kalkberg limestone. The upper more shaly beds contain a more prolific fauna.

It would presumably follow that the typical Schoharie of the Helderbergs represents a deposit formed in shallower water near the western edge of the trough. There are, however, other factors complicating the picture. The supply of sand and the fauna are local developments, confined to the Schoharie and Helderberg regions. The muddy phase of the Schoharie farther west is strikingly similar to the Leeds facies in its most northern expression. Both the fauna and the lithology of the Schoharie are exceedingly restricted geographically. The abundance of arenaceous material suggests a local source of supply; perhaps it represents the edge of a minor delta which supplied coarse sediments into the Schoharie sea, probably from the Adirondack region. The abundance of the fauna might be correlated with such a phenomenon, as our richest molluscan faunas today are concentrated beyond the mouths of some of the larger rivers; and studies of recent marine faunas are leading to the conclusion that such concentrations are biochemical in their nature, having to do with the necessity for copper and other substances supplied by streams. Some current action is evident in the typical Schoharie. Beds containing abundant large orthoceracones commonly show these fossils arranged in a prevailing parallel direction. This is shown particularly clearly in large slabs at the Wolf Hill exposures discussed above. Such current arrangement of cephalopod shells has commonly been interpreted in the past in terms of transportation of the shells after death. While it is certainly indicative of current action upon dead shells, it does not necessarily imply that the cephalopods had been assembled here as thanatocoenos, though such explanations have been applied, inadvisably perhaps, to somewhat similar associations elsewhere. The abundance of cephalopods, gastropods, and trilobites which characterizes the Schoharie is an association to be found as far back as these three types of organisms existed, and one which persisted until the regression and later the extinction of the trilobites made it no longer possible. Instead there are here criteria which indicate that the typical Schoharie fauna is a natural one, little if any affected by mechanical sorting of the shells, for young and adults are found together, and the association as a whole is not unlike that found in the shallow water bioherms of the Silurian.

Among the more curious results brought out by this study is

the close relationship between the Esopus shales, formerly classed as Lower Devonian, and the Schoharie, classed as Middle Devonian. There is no natural break in deposition which can be regarded as of major diastemic importance. Minor oscillations of the sea are evident at the western edge of the trough; the Esopus proper is regressive in contrast to the Oriskany. The Sharon Springs shows slight progressive overlap, followed by a regression of the Schoharie sea, and finally by a widespread submergence in Onondaga time. If the bands of glauconite are indicative of diastemic breaks, these stages were separated by local uplift and weathering, but it is by no means certain that this interpretation of the glauconite is the true one. In the Hudson valley, however, there is no indication of such breaks, but only of changes indicative of variations in depth, possible variations in erosional history of the continents supplying the sediments, and the invasion of a Middle Devonian fauna.

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